2008

WINSTON-SALEM STORMWATER MANAGEMENT

Winston-Salem, North Carolina

$Q_{pre}* = (P-0.2S_{pre})^2 / (P+0.8S_{pre}) = 1.0856$ inches

$Volume_{pre} = 1.0865$ inch x 1 ft/12 inch x 3.10 ac x 43,560 ft^2/ac = 12,226 ft^3

$Q_{post}* = (P-0.2S_{post})^2 / (P+0.8S_{post}) = 3.156$ inches

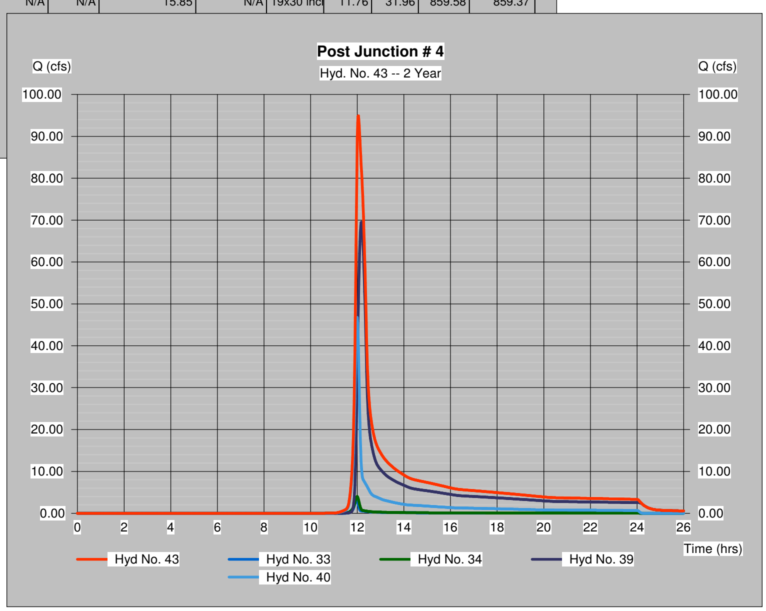
$Volume_{post} = 3.156$ inch x 1ft/12 inch x 4.83 ac x 43,560 ft^2/ac = 55,337 ft^3

se in volume for 25-yr storm, 6-hr event is the difference between the pre and p

26 ft^3 = 43,111 ft^3

Combined Pipe\Node Report

Label	Upstream Node	Downstream Node	Length (ft)	Upstream Inlet Area (acres)	Upstream Inlet Rational Coefficient	Upstream Inlet CA (acres)	Upstream Calculated System CA (acres)	Upstream Inlet Rational Flow (cfs)	Section Size	Full Capacity (cfs)	Average Velocity (ft/s)	Upstream Invert Elevation (ft)	Downstream Invert Elevation (ft)
P-M3	In-M2	In-N1	74.00	4.30	0.21	0.92	17.85	6.99	30 inch	50.01	24.01	857.10	856.00
P-N1	In-N1	J-n1	103.00	0.61	0.27	0.17	18.01	1.36	30 inch	65.91	24.19	856.00	853.34
P-M1	In-M1	J-m1	57.00	3.79	0.28	1.07	1.07	8.66	12 inch	9.23	13.37	868.28	864.45
P-M2	J-m1	In-M2	97.00	N/A	N/A	N/A	1.07	N/A	12 inch	9.19	10.99	864.45	858.00
P-N2	J-n1	O-N1	270.00	N/A	N/A	N/A	18.59	N/A	24 inch	20.00	38.94	853.34	846.15
P-K1	In-K1	J-k1	75.00	0.82	0.19	0.16	15.85	1.30	24 inch	14.54	33.62	859.90	859.59
P-K2	J-k1	In-L1	96.00	N/A	N/A	N/A	15.85	N/A	19x30 inch	11.76	31.96	859.58	859.37
P-L1	In-L1	J-l1	202.00	0.00									
P-L2	J-l1	In-M2	177.00	N/A									
P-O1	In-O1	J-n1	183.00	1.85									
P-J1	In-J1	J-j1	62.00	6.75									
P-J2	J-j1	In-J2	28.00	N/A									
P-G5	J-g4	J-h2	191.00	N/A									
P-H3	J-h2	J-i1	118.00	N/A									
P-F1	In-F1	J-f1	64.00	4.11									



DESIGN EXAMPLES

CONTENTS

INTRODUCTION

Stormwater management is an important aspect of a site-development project and many communities recognize the value in managing additional stormwater runoff due to the increase in impervious cover. When stormwater is not managed properly, it often results in stormwater problems downstream. The City of Winston-Salem, like many communities is being required to respond to Federal Phase II rules and regulations mandated by the "Clean Water Act". These issues combined have resulted in the City of Winston-Salem adopting the 2008 Stormwater Ordinance. This document has been prepared to provide guidance to those preparing site-development documents that require stormwater management under the City of Winston-Salem Stormwater Ordinance. Water quality design measures are to adhere to the NC Division of Water Quality Stormwater Best Management Practices Manual (BMP), latest edition. Water quantity design measures must adhere to the latest stormwater ordinance. This guide illustrates designing water quantity control measures and only refers the designer to water quality measures which are explained and detailed in the BMP manual.

The **Stormwater Management Review** process that will be followed by the City of Winston-Salem, Stormwater Division is divided into the following components:

1. **Stormwater Management Concept Meeting:** This meeting between City Staff and the Development Team (Developer and/or Engineer) is needed for the Development Team to convey to the City its conceptual intentions for compliance with the quality and quantity stormwater management regulations, and for the City to identify potential issues and limitations that must be addressed in order to qualify for a Stormwater Permit. The Development Team must bring to this meeting sufficient site information so that at least a conceptual picture of the issues can be reviewed. Since this meeting is not a formal submittal or review, no binding commitments, approvals, or directions will be made.
2. **Adverse Off-Site Impact Review:** If the Development Team anticipates that the proposed project will not cause adverse off-site impacts, it may submit an analysis to support this condition. This submittal must include sufficient hydrologic and hydraulic analysis and site information for the City to review and determine if this condition exists. If it is determined that in fact, no adverse off-site impacts will result from the project, then the City will issue a Stormwater Management Permit and no further stormwater submittals will be required. On the other hand, if it is determined that off-site impacts will result from the project, then the Development Team must proceed through Phase 1 and Phase 2 submittals to design and implement a stormwater management system to obtain a Stormwater Permit.
3. **Phase 1 – Hydrologic Analysis and Review:** Proceeding with Phases 1 and 2 submittals will occur if no Adverse Off-Site Impact Submittal/Review was performed or if one has been performed and it was found that Adverse Impacts are anticipated. If the Development Team chooses to apply for a finding of No Adverse Off-site Impacts, then a preliminary hydrologic analysis will have already been prepared and this Phase 1 will be a refinement and possible expansion of that earlier effort, otherwise a formal and complete hydrologic analysis will be performed in this Phase. In general, the hydrologic analysis must cover all aspects of the pre- and post-development conditions. The City will review in detail these analyses to ensure accuracy and completeness. The checklists and guidance documents provide a more complete listing of submittal requirements. It is recommended that detailed design of site stormwater management components not proceed until Phase 1 is complete and approved.
4. **Phase 2 – Detailed Design of Site Stormwater Management Components:** Following approval of Phase 1 analyses, the Development Team will perform hydraulic analyses and designs to prepare a detailed Stormwater Management Plan for the site that will mitigate

stormwater impacts caused by the proposed development in order to meet quantity and quality stormwater management requirements. The City will review in detail these analyses to ensure accuracy and completeness. The checklists and guidance documents provide a more complete listing of submittal requirements. Once Phase 2 is complete and approved, a Stormwater Permit for the site will be issued.

Design Examples: Two design example solutions based on the latest Stormwater Ordinance are contained in this document. The ordinance contains stormwater runoff water quality (similar to 2007 State Standards) and water quantity controls. This manual is presented in three (3) parts. The first part considers some general guidelines for any proposed site development. The second part offers suggested design guidelines for a 22.44 acre residential site and the third part similarly addresses a 4.83 acre commercial site. The solutions presented herein are not to be construed as the single solution for the particular site being designed. For instance, the residential design example covers details for the design of a wet detention pond which manages a large part of the site, but due to topography the pond alone does not provide the entire water quality and quantity controls needed for the total site. Multiple watershed basins on this site result in a more complex solution. Additional controls must be utilized to provide total stormwater management at the example sites, but the additional details for every component are not included in this Design Manual. It is up to the designer as to what methods will be used for compliance. Supporting documentation should be included in the submittal to the City. The designer is assumed to be familiar with the ordinance and competent to design and prepare the stormwater management submittal package required as part of the stormwater permit approval process. This Manual is not intended to teach hydraulic and hydrologic principles, but merely to assist the designer in submittal preparation for approval.

PART 1. GENERAL STORMWATER SUBMITTAL GUIDELINES

This document contains stormwater management design examples that provide direction for proposed site-development submittals and describes the typical information that should be included in a stormwater submittal to the City of Winston-Salem for review. An often overlooked but very necessary part of the typical stormwater submittal is the narrative. This should include descriptions of the proposed project site, existing hydrologic and geographic conditions, issues that need to be resolved and how they will be handled. Everything that is proposed to manage the stormwater on site should be discussed in the narrative. Descriptions of why certain structures are used and how they will provide the appropriate solution for stormwater management on the site should be included in the narrative, which should be placed at the beginning of the stormwater report.

Another item that must be included in the stormwater report is the completed checklist (see Appendix I). Each item on the checklist should be reviewed and checked indicating that each item has been included in the submittal for review or at least reviewed and found not applicable (NA) for this particular project.

The general guidelines for preparing a proposed development site plan for stormwater submittal should include these basic items:

<u>Phase 1 submittal portion</u>

- Include a narrative.
- Provide the completed checklist.
- Perform a hydrologic analysis of the existing conditions. Locate the downstream outlet for the site and the overall watershed that will be affected by the site development at a point downsteam where the site represents 10% of the watershed. Delineate all the watershed basins of concern.
- Provide a drainage map showing all the existing drainage and sub drainage basins in the watershed. Add labels, sizes, etc. for each basin on an existing topographic map of the region. Any downstream existing drainage structures and systems should be noted as to size, inverts, slope and capacities. All information should be shown clearly and to an accurate scale. A bar scale and north arrow must be included on the map.
- Provide a map showing proposed drainage conditions, developed in a manner similar to the existing conditions map.
- Include precipitation data information from National Oceanic and Aeronautical Administration (NOAA) website for the proposed site location. Print out a copy and include in the stormwater submittal report.
- Determine the soil types and the current and proposed land uses. Use the TR-55 method for calculating pre and post-development peak flows based on the NOAA precipitation data.
- Include the CN's, Tc's, proposed and existing land uses and all hydrological information necessary to design a stormwater management solution for the proposed site.

<u>Phase 2 submittal portion</u>

- Check for existing FEMA floodplain information if any on or near the proposed project site.
- Determine if any regulatory streams (blue line streams as found on a USGS map) are on the proposed site or nearby that may be impacted by the development.
- Check to see if any downstream or upstream properties will be impacted by stormwater runoff from the proposed site development and include the analysis in the stormwater report.

- Locate all utilities on the site and determine if there are any conflicts with proposed stormwater management systems.
- Perform and include all supporting calculations for proposed stormwater systems including proposed BMP's, with details of outlets, inverts, time of concentration, composite CN values, capacity, storage, flows, etc in the stormwater submittal.
- Incomplete submittals will not be accepted for review.

The following two (2) examples indicate suggested steps to follow for two different types of proposed development sites in order to meet the requirements of the Stormwater Management Ordinance. The first example is based on a proposed residential site-development project and the second is a proposed commercial site-development project within the jurisdiction of the City. Development of various sites, with similar or different topography, size, complexity and location, etc., may be managed differently from the examples, but still fulfill the ordinance. The following information is provided as a general guide for compliance with the ordinance for proposed residential and commercial site developments in Winston-Salem, NC. The SCS method (SCS, 1985; NRCS, 1986) using Technical Release TR-55, which utilizes land use based curve numbers (CN's) for calculating the hydrology of watersheds, is allowed when designing stormwater management solutions for all proposed site-developments in Winston-Salem, NC. That method is used for the two design examples. Referenced notes in the text may be found at the end of the summary section.

PART 2. RESIDENTIAL DESIGN EXAMPLE

Narrative:
A 62-lot residential subdivision site-development project is proposed to be developed on gently rolling terrain (shown in App. II, Exh. 2.1). The proposed zoning will be RS-9 with each lot being approximately 0.36 acres on the average or 2.76 houses per acre. This a high-density residential development which will require stormwater management for both quality and quantity. Since the site is 22.44 acres, the outlet for the overall basin is represented at a point downstream where the proposed site is 10% of an overall 220 acre basin. That watershed drainage basin consists of 12 defined sub-basin areas which drain to Muddy Creek. Seven of those sub-watershed basins are directly affected by the site development. A stormwater management plan showing stormwater quantity and quality control will be required for this proposed site. Water quality for Basin 7 will be managed in a wet-detention pond located within Basin 7, but other BMP's will also be needed for water quality management in Basins 3, 4, 5, 6 and 11. The onsite portions of these drainage basins are noted as A, C, D, E and F on the drainage map (see Appendix III). BMPs for water quality management may consist of vegetated swales, bio-retention structures or other approved treatment measures.

Stormwater quantity control for the 25-yr, 6-hr event will be managed in a single wet-detention pond located in Basin 7. Post-peak flow control as well as extended detention time for the 25-yr, 6-hr event are managed in the Basin 7 wet detention pond. The wet-detention basin also provides peak flow reduction for the 100-yr storm. Post-peak flow control for the 2-yr and 10-yr, 6-hr events are minimized through the wet detention pond in Basin 7, but do not provide peak flow control for the entire site. Additional quantity control for those two storm events will have to be managed in additional BMP's used elsewhere on the proposed 22.44 acre site.

There is an existing downstream offsite 7-foot diameter CMP. Hydraulic analysis indicates that it provides a small amount of detention during larger storm events. If the existing structure were to be removed or replaced sometime in the future, the hydrology of the drainage through that system could be affected and may adversely impact existing downstream structures. Due to this situation the City may require the site-developer to obtain an agreement with the owner of the private property where the 7-foot diameter pipe is located to prevent possible adverse future impacts to downstream residents (see Note 2). The designer should contact the City Stormwater Dept. for comments.

The downstream location where the site represents 10% of the watershed is noted on the drainage map. The site drains to a tributary that flows into the floodplain of Muddy Creek. With the proposed detention structure, no impacts were found to any habitable structures where the site represents 10% of the watershed.

Detailed Steps for Development of the Stormwater Plan:

Table 1. Residential Example Site Data

Existing Conditions	Proposed Conditions
Zoning: RS-9	Zoning: Residential RS-9
Size: 22.44 acres, mostly wooded, undeveloped site	High Density: 62 homesites/22.44 ac = 2.8 homes/acre
Land use: RS-9, with large portions of the proposed site consisting of mature woods, meadows & streams	Residential home sites with new access roads to connect home sites to Robinhood Road
Watershed: 220 acres with 12 sub-basins	Wet detention pond for water quality and quantity control w/additional BMP's on site
Watershed drainage over proposed 22.44 acre site includes/affects six (6) sub-watersheds	BMP's required for each watershed for water quality management
Site discharges to an un-named tributary of Muddy Creek	Additional water quality control management separate from Basin 7 wet detention pond
Un-named tributary crosses site (USGS blue line regulated stream)	New drive with culvert for tributary stream crossing
Offsite 7-foot diameter culvert	Offsite 7-foot diameter culvert

Determine what portions of the ordinance apply to the site for quality and quantity control. High density proposed development requires both quality and quantity controls. Quality control consists of using an approved BMP or BMP's designed in accordance with the NC Division of Water Quality Stormwater Best Management Practices Manual, latest edition.

Existing (pre-development) Conditions

1. Delineate existing watershed drainage areas pertinent to the proposed site. Prepare delineated areas on a topographical drawing as an exhibit for including in stormwater report (see Appendix III, Exh. 3.1)
2. Locate the downstream point where the site represents 10 percent of the watershed For this example, stop at confluence with Muddy Creek. (see Appendix III)
3. Determine hydrologic soil types within the watersheds (see Appendix IV). Include a map with the soil survey geographic database information labeled appropriately or a copy of applicable map page(s) from the County soil survey report in the stormwater submittal.
4. Delineate existing land use areas within the watershed drainage areas of interest.

5. Overlay land use with hydrologic soil types to determine curve number (CN) values. Composite CN values should be calculated and the calculations included in the Stormwater Report (see Appendix VIII).
6. Determine time of concentration (Tc) from the hydrologic information. Using the Kirpich equation to determine Tc, requires finding the slope and the hydrologic length of the watershed basin. This is determined by measuring the hydraulically most distant point in the basin to the drainage outlet for that basin. Basin 7 is where the wet detention pond will be placed to manage the bulk of water quality and quantity for the proposed site. Stormwater management will also be needed in other drainage basins impacted by this residential site development. Similar calculations must be performed for all drainage basins and included in the submittal.

   Eq. 1. $Tc = 0.0078 \times L^{0.77} \times S^{-0.385}$

   L = length of the channelized flow reach, feet
   S = slope of the channelized flow reach, dimensionless
   Tc = time of channelized flow, minutes

   Tc calculated for Basin 7 is 6.9 minutes, for L = 1778 ft and S = 7.1%

7. Examine existing USGS maps (see Appendix VII) to see if any of the drainage channels in the area of the proposed site development are noted as blue lines indicating perennial streams regulated by the US Army Corp of Engineers (USACE) or NC Department of Water Quality (DWQ). Note that absence of a blue line does not mean that perennial streams do not exist. Check with the USACE for a determination. Streams and wetlands regulated by the USACE and DWQ (see Note 5) must be shown on drawings. The proposed new road and culvert stream crossing associated with this project will impact the un-named tributary, which appears to be a regulated water. Also the proposed pond location may be within wetland or stream areas that could be regulated . All necessary permits must be obtained and approved by the regulatory authorities where applicable. Include an exhibit of the USGS map in the stormwater report. Provide a copy of the 401/404 permit or a statement that no 401/404 permit is needed.
8. Calculate pre-development existing flows (2-yr, 6-hr, 10-yr, 6-hr & 25-yr, 6-hr) per the ordinance for peak flow quantity control requirements (see Hydrology Summary Table at end of example).
9. Calculate pre-development 100-yr flows (peak and volume) at downstream location as defined by Step 2 (see summary table at end of example)..
10. Calculate an existing surface runoff volume for the proposed site based on the 25-yr, 6-hr storm (see Volume Calculation Example 1).
11. The Residential design example includes an existing offsite 7-foot diameter pipe where runoff drains through it from the majority of the proposed site. This condition should be analyzed to see if detention is occurring at the pipe. Analysis of the pipe reveals that it is acting as detention when large events such as the 25-yr storm event occur. In this case, special conditions may be indicated (see Note 2.).
12. Assemble all pre-development exhibits and calculations for inclusion in the Stormwater Report. If calculations and hydrographs are performed by software,

include a schematic of model or a diagram of all modeling components along with file output in the stormwater report.

13. Check the location of any FEMA floodplain zones per the FIRM map for the proposed site. The floodplain may be viewed online at the City of Winston-Salem website where the Geo-Data Explorer site may be accessed (http://www.co.forsyth.nc.us/tax/geodata.aspx). Include a copy of this information in the Stormwater Report (where applicable). The residential example development drains downstream to the floodplain of Muddy Creek (see Appendix VI).

Proposed (post-development) Conditions

14. Revise the CN values based on the proposed impervious cover in order to model post development conditions (show calculations and include in Stormwater Report).
15. Delineate post-development drainage areas with descriptions on either a separate map or on the existing overall drainage map (must be readable) and submit in the stormwater report.
16. Calculate the post-development 2-yr, 10-yr and 25-yr, 6hr flows (include in the stormwater report and see Hydrology Summary Table at end of example).
17. Calculate post-development 100-year flows at a location where the site represents 10 percent of the watershed for comparison with pre-development flows (peak and volume). The location where the proposed site development is 10% of the watershed is downstream at Muddy Creek. This is the area to check adverse flooding impacts to habitable structures.
18. Determine if any impacts occur to downstream structures or development as defined by the ordinance. Examine cross section(s) where downstream structures may be impacted to find the change in water surface depth between pre and post development peak flows.
19. Based on the results of Steps 17 through 18, go to A or B.
    A. **No adverse impacts** to habitable, permanent structures downstream. Post-development peak flow and water surface depth less than or equal to pre-development peak flow and depth. Analysis is complete. Proceed to step 20.
    B. **Adverse impacts** to habitable, permanent structures downstream. Post-development water surface depth is higher than pre-development analysis. Continue with analyses. Development of a water surface profile is required to determine the increase in water surface depth near permanent downstream structures.

    For this example, the downstream location joins the Muddy Creek floodplain. While the total volume of runoff is increased due to the site development, the peak flow is reduced. No adverse flooding impacts are anticipated to downstream structures.
20. Make adjustments to proposed site design where necessary and re-calculate stormwater controls to meet ordinance requirements. Compare results. Further analysis may have to be followed per Stormwater Ordinance Section 75-302 (F) to comply with a "no adverse impacts" condition.
21. Find the volume difference between pre and post-development for the 25-yr, 6-hr event (the increase of volume will be the required minimum storage to be held on site and released slowly). In this example, the volume required for the entire residential site will be contained in the wet detention pond. See Volume Calculation Example One, which follows.

Volume Calculation Example One.

Find S and Q* (inches depth) per the TR-55 method.

$Area_{pre}$ = 22.44 acres for proposed development
4.92 acres are 'C' class soils
17.52 acres are 'B' class soils

Find composite CN values for pre and post-development conditions

CN_{pre} = 55 (B soils, wooded, good cond.), 70 (C soils, wooded, good cond.)
CN_{post} =72 (B soils, residential, 1/3 ac sites), 81 (C soils, residential, 1/3 ac sites)

$CN_{pre\text{-}composite}$ = [4.92 ac (70) + 17.52 ac (55)]/22.44 ac = 58.28
$CN_{post\text{-}composite}$ = [4.92 ac (81) + 17.52 ac (72)]/22.44 ac = 73.97

P = 4.07 inch (NOAA ATLAS 14, for 25-yr, 6hr event, (Winston-Salem, NC, 36.119N, 80.3617W) Solve for pre and post S values

$S_{pre} = 1000/CN_{pre} - 10$, $S_{pre} = 7.16$
$S_{pre} = 1000/CN_{post} - 10$, $S_{post} = 3.52$

Inserting the calculated S values, find the increase in depth Q* (inches). Convert the depth, Q*, inches into volume (ft^3) as follows:

$$Q_{pre}^* = (P-0.2S_{pre})^2/(P+0.8S_{pre}) = 0.71 \text{ inches}$$

$Volume_{pre}$ = 0.71 inch x 1 ft/12 inch x 22.44 ac x 43,560 ft^2/ac = **57,875 ft^3**

$$Q_{post}^* = (P-0.2S_{post})^2/(P+0.8S_{post}) = 1.65 \text{ inches}$$

$Volume_{post}$ = 1.65 inch x 1ft/12 inch x 22.44 ac x 43,560 ft^2/ac = **134,058 ft^3**

The increase in volume for 25-yr storm, 6-hr event is the difference between the pre and post-development volume:

$Volume_{post} - Volume_{pre}$ = 134,058 ft^3 - 57,875 ft^3 = 76,182ft^3

Increased volume at site to manage for 25-yr, 6-hr event = 76,182 ft^3

The increased volume is to be detained and released in not less than 48 hours or more than 120 hours.

22. Design stormwater management structures to control post-development 2-yr, 10-yr and 25-yr peak to pre-development peak flows. Each event is to be examined individually and the results compared to see which event requires the largest volume to be detained. The 25-yr event produces the largest volume in this example.
23. Compare the required 25-yr event volume of 76,182 cu ft with the volumes required to control the peak flows from the other events. The 25-yr volume is the largest, so this will be the minimum design volume amount needed in the detention basin above the permanent pool (see Appendix III, Exh.3.2). If more than one quantity control structure is used at the proposed site, the total required volume storage will be distributed between them.
24. Determine land use and curve numbers for the area actually draining to the wet pond per the guidelines contained in the NC Division of Water Quality Stormwater Best Management Practices Manual, latest edition. This area will determine the minimum volume for the first one-inch of rainfall runoff (State

Standards). Calculate the rainfall runoff volume required to meet the water quality requirements in the wet detention pond per the Stormwater Ordinance. Design the stormwater treatment (water quality) discharge outlet to comply with Stormwater Ordinance 75-302 (B) for water quality standards based on post-development conditions (volume from 1 inch rainfall) and drawdown times per the NCDENR BMP Manual (see Note 1).

25. Determine the permanent pool volume required for water quality management. Note that this pond will be managing both the water quality for the drainage basin it is located within and the 25-yr volume water quantity requirements (if water quantity only, it would not have a NCDENR regulated "permanent pool" for example). Use the NCDENR Stormwater BMP Manual to determine the minimum required area, depth, forebay, litoral shelf, etc for this wet detention pond. The water quality permanent pool volume portion of the pond requires approximately 29,194 ft^3 of pond volume. Adding the 76,182 ft^3 required for water quantity volume and the majority of peak detention for the entire site, the wet detention pond including the permanent pool will require approximately 105,400 ft^3 plus appropriate freeboard and an emergency spillway. Include calculations in the Stormwater Report.
26. Check to make sure the proposed structure discharging the 25-yr, 6-hr storm volume does not discharge the required volume in less than 48 hours or more than 120 hours. The orifice used to meet that requirement for this particular pond will be a 2.75 inch orifice constructed as recommended in the NCDENR BMP Manual. It should be protected by a wire screen cage (see Note 1). The pond will drain down to the permanent pool in approximately 89 hours for the 25-yr, 6-hr event and 77 hours for a 1-yr, 24-hr event.

The orifice equation is:

Eq. 2 $Q = Cd \times A \times \sqrt{(2 \times g \times h)}$

Q = flow (cfs)
Cd = 0.6 (dimensionless), typical value used with the orifice equation
A = area (sq. ft.)
G = 32.2
H = head above the center of the orifice when the level of the water is above the top of the orifice opening in the pipe (ft)

There is also a weir at the top of the riser to allow additional discharge for larger events which requires use of the weir equation (see Eq. 3).

27. Design orifice inlet and pipe outlet discharge protection. The constructed design for the orifice will need to be adequate to allow discharge through the orifice without clogging. Also, maintenance will be required to ensure that the outlet remains un-obstructed. Additional orifices or weirs may be used to manage the peak flow requirements. Include calculations and designs in the stormwater report and indicate on the site plan.
28. The emergency spillway should be designed using the weir equation.

The weir equation is:

Eq. 3 $Q = Cw \times L \times H^{1.5}$

Q = discharge flow over the weir (cfs)
Cw = weir coefficient (dimensionless, not to be confused with the orifice coefficient)
L = Length of the weir (feet)
H = height of the water over the weir spillway (feet)

The water quantity storage above the permanent pool to manage the 25-yr water quantity requirement for the site has been contained within the wet detention pond in Basin 7, area B on the Drainage Map (see Exh. 3.1). In this particular case, because the pond is sized to manage the additional volume for the entire site, the pond also manages the 100-yr peak flow from Basin 7. The emergency spillway is not activated during the 100-yr event in this pond. It is recommended that a 100-yr event water surface elevation at emergency spillways should have a minimum 1-foot freeboard to the top of the dam above the 100-yr event water surface elevation.

29. Each drainage basin area within the 22.44 acre residential site must have water quality management within each basin (see Appendix III). The wet detention pond with a permanent pool and multiple discharge outlets to manage peak flows and volumes will provide water quality treatment only for the watershed basin within which it is placed (the proposed wet detention pond is located in area B). Design water quality treatment BMP's for locations A, C, D, E and F. Those individual BMP's will collectively provide the required water quality control for the total site to meet the first 1 inch of rainfall runoff water quality treatment control as required by 75-320 (B) of the Stormwater Ordinance.
30. Pond and dam design must comply with NC Dam Safety standards and if required, submit the design for approval by the NC Dam Safety engineer. Any submittals to the Dam Safety unit may be concurrent with this stormwater submittal. Submit proof of having met this requirement per 75-303 in the Stormwater Report (see Note 3. below).
31. Design discharge outlet protection. Include design and supporting calculations in Stormwater Report and indicate on site plan.
32. To check for degradation in the receiving channel downstream, evaluate downstream (at or below 10% point) post-development runoff volume. Compare with pre-development volume to determine if the post-development volume is 10% greater than pre-development volume for the 2-yr, 1-hour rainfall event. Suggested example calculations for this can be found in Technical Release 55: Urban Hydrology for Small Watersheds, Chapter 2, Estimating Runoff. The post-development volume calculations should include details for all BMP's: A of Basin 11, B of Basin 7, C of Basin 3, D of Basin 5, E in Basin 4, and F in Basin 6. Since the wet detention pond in Basin 7 designed for this proposed residential site contains the required difference in volume for the 25-yr storm, no additional mitigation is required for Basin 7 to comply with this ordinance. The SCS method for calculating direct runoff, Q (in inches), can be utilized to determine the change in depth. Converting the inches to a volume for the location in question, the volume difference can be determined to see whether it is more or less than a 10% change in volume. The pre and post development volume calculations and solutions are to be included in the Stormwater Report. The following outcomes follow from this volume comparison:
    A. **Less than or equal to 10% difference.** Finished with analyses.
    B. **Greater than 10% difference-**mitigation required per 75-303 (F) of the Stormwater Ordinance, Protection of Receiving Channels and Water Bodies.

    Downstream channel velocities check follows from volume comparison for the residential example site. Both pre and post-development velocities are within the recommended velocity flows per DENR recommendations shown in Table 8.05d of the NC Erosion Control Manual for channel stability (see Appendix V).
33. Submit analysis for the downstream, offsite, existing 7-foot diameter pipe culvert and submit documentation as to how this proposed site development will impact

that culvert. Prepare an agreement with the current owner for the offsite downstream 7-foot diameter culvert if necessary (see Note 2 below).

34. Combine all pre-development exhibits and calculations along with post-development calculations and exhibits for inclusion in Stormwater Report.
35. Prepare a narrative describing how the proposed stormwater management at the site complies with the Winston-Salem Stormwater Ordinance requirements and include in the stormwater report.
36. This 22.44 site encompasses a stream which means there is a 50 ft buffer on both sides of that stream. Structures must not be placed within the stream buffer area on either side of the stream. Buffer boundaries should be defined and shown on the plans.
37. Submit the stormwater management study with analyses, narrative and all documentation (i.e. maps, proposed site improvement and stormwater control drawings, ref. materials and spreadsheets, etc).

Following is the hydrology data developed from the pre-developed conditions to the post developed conditions utilizing the single wet detention pond. Peak flows and other hydrologic data was found using the Hydraflow Hydrographs Extension program. The pond is able to manage a large portion of the site both for water quantity and quality, but additional measures will be needed in the other basins on the site for complete water quantity and quality management for this proposed residential development.

Table 1. Hydrology Summary for Residential Site

	Condition	Hydrograph Volume 25-yr (ft^3) Downstream	$Q_{1\text{-YR, 24-hr}}$ (cfs) Basin 7 to Pond	$Q_{2\text{-yr, 6-hr}}$ (cfs) Site outflow	$Q_{10\text{-yr, 6-hr}}$ (cfs) Site outflow	$Q_{25\text{-yr, 6-hr}}$ (cfs) Site outflow	$Q_{100\text{-yr, 6-hr}}$ (cfs) Site outflow
Drainage from site	Pre-dev.	586,678	1.40	12.18	52.18	84.57	144.6
With wet detention pond in Basin 7	Post-dev.	642,240	0.33 WQ outflow for Basin 7	13.87	52.41	81.68	134.8

Note: These numbers do not reflect total site BMP controls. In this example only the single wet detention pond was analyzed. The numbers shown are the results downstream from the site due to the wet detention pond placed in Basin 7 to manage as much runoff on site as is feasible. The pond manages water quality only for Basin 7, while managing water quantity volume for the total site as shown in Volume Calculation One. Additional BMP's must be designed for water quality and peak flow (2-yr & 10-yr) controls in the remaining drainage basins impacted by the proposed design to manage stormwater runoff for the entire site per the Stormwater Ordinance.

PART 3. COMMERCIAL DESIGN EXAMPLE

Narrative:
A commercial site-development is proposed at the intersection of two (2) roads, Waughtown Street and Reynolds Park Road. The proposed site layout is shown in Appendix II, Exh.2.2. This proposed commercial site contains 4.83 acres and is composed of three (3) existing watersheds draining in different directions (see App. III, Exh.3.3). Two of the sub-basins drain to Salem Lake which is a water supply watershed (see App. VII, Exh.7.3). The final grading design revises the three existing sub-basins into one sub-basin in order to allow treatment of the whole site in a single basin. This proposed design requires a diversion of a small portion of the runoff from one watershed to another. The additional stormwater runoff diverted to the Salem Lake Watershed will be treated by the BMP's proposed for this site. To minimize the actual storage volume required at the site, and with approval from the City, calculations are made using 4.83 acres both before and after development for calculating the amount of difference in volume required for storage.

The commercial site-development project will contain 2 separate commercial buildings with over 190 proposed parking stalls and new sidewalks along the entire property line adjoining the rights-of-way for both roads (see App.III, Exh.3.4). To manage stormwater draining off the parking lots, several designed bioretention areas will be placed in the area where streetyard landscaping is required. The plants which will be used can withstand a varied environment in the bioretention area and will also comply with streetyard landscaping requirements. The overflow from those several bioretention areas will be piped to underground detention to handle the 2-yr, 10-yr and 25-yr, 6-hr events for peak flow and volume controls as required per the ordinance. Rooftop runoff from both buildings will be piped directly to the underground detention basin. A small wet detention pond will be placed at the northwest corner of the property to manage the first inch of runoff for water quality control for the stormwater drainage from the asphalt drive and portions of parking areas draining toward that pond. Offsite runoff to the west property line is captured and piped around the pond toward Reynolds Park Road to the existing drainage system in order to prevent offsite runoff from draining into the pond.

Stormwater discharge from this site drains through an existing pipe system which discharges into a downstream open channel flowing to a culvert consisting of 2-48 inch pipes under Salem Gardens Drive. This culvert is the location where the proposed site-development represents 10% of the watershed. The 2 - 48 inch diameter pipes have sufficient capacity to handle the 100-yr event with underground detention on the proposed commercial development site. In the event that the stormwater runoff cannot be handled by that culvert, and subsequently overtops the road at that location, the overtopping elevation would be several feet below finished floor elevations of nearby homes.

The downstream offsite receiving drainage channel currently has visible scouring. The underground detention structure controlling the 25-yr, 6-hr event controls much of the discharge from this site and so the post-development discharge will not significantly add to scouring of the existing drainage channel. Additional armoring is recommended to be applied to the existing channel banks to stabilize the channel.

Note that a different designer could have utilized other types and locations of BMPs and have also successfully complied with the Stormwater Ordinance. The commercial design example that follows contains a portion of the solution. Other design solutions may include any of several combinations of BMP's to control and manage stormwater runoff to meet the requirements of the ordinance.

Detailed Steps for Development of the Stormwater Plan:

Table 2. Commercial Example Site Data

Existing Conditions	Proposed Conditions
Site: 4.83 acres	Site: 4.83 acres
Current Zoning: RS-9 and IP	Proposed Zoning: PB-S, Office and Retail General Merchandise (two separate businesses w/190 parking stalls)
Three (3) Watersheds = approximately 3.1 acres, 0.4 ac and 1.3 ac (see Appendix III, Exh.3.3)	Watershed = 4.83 acres (see Appendix III, Exh.3.4)
Portion of Salem Lake Watershed and other (non-water supply) watershed	Salem Lake Watershed (transfer additional 1.7 acres)
Impacted watershed (site represents 10%) 47.4 acres, located at (2) – 48 inch concrete culvert pipes under Salem Gardens Drive	Impacted watershed (site represents 10%), 49.1 acres at (2) – 48 inch concrete culvert pipes under Salem Gardens Drive
Site Drainage to 15 inch RCP under Reynolds Park Road	Replace 15 inch RCP with 18 inch under road
No existing stormwater management currently located on proposed site	Underground detention, bioretention and wet detention pond BMP's for water quantity and quality management drain to 18 inch RCP

Determine what portions of the ordinance apply to the site for quality and quantity control. Commercial development requires both quality and quantity controls which consist of approved BMP's in accordance with the NC Division of Water Quality Stormwater Best Management Practices Manual, latest edition.

Existing (pre-development) Conditions

1. Delineate and determine watershed drainage areas pertinent to the proposed site. Prepare exhibit for inclusion in the Stormwater Report (see Appendix III)
2. Determine hydrologic soil types (see Appendix IV)
3. Determine existing impervious areas for the site.
4. Estimate existing CN values based on the information found in steps 2 and 3 for the watersheds covering the proposed site.
5. Determine locations, sizes and inverts for existing storm drainage receiving structures downstream of site (include on appropriate exhibit).
6. Determine the time of concentration (Tc) from the hydrologic information. Use the Kirpich equation to determine Tc, which requires finding the slope and the hydrologic length of the watershed basin. This is determined by measuring the hydraulically most distant point in the basin to the drainage outlet for that basin. Similar calculations must be performed for all drainage basins when multiple basins drain on the site and all the data should be included in the submittal.

   Eq. 1. $Tc = 0.0078 \times L^{0.77} \times S^{-0.385}$

   L = length of the channelized flow reach, feet
   S = slope of the channelized flow reach, dimensionless
   Tc = time of channelized flow, minutes

7. Analyze existing site conditions to determine pre-development stormwater runoff peak flows and volume of discharge as required per the ordinance for water quality and volume control requirements (1-inch rainfall event and 2-yr, 10-yr & 25-yr, 6-hr events-see Hydrology Summary Table at end of example).
8. Calculate existing runoff volume for the proposed development from the 25-yr, 6-hr event (see Volume Calculation Example 2 below).
9. Locate watershed point or outlet downstream where the site represents 10 % of the drainage area (see Appendix III, Exh.3.3).

Proposed (post-development) Conditions

10. Determine new proposed impervious surface area.
11. Revise the CN values based on the proposed conditions.
12. Determine and identify post-development watershed boundaries on a topographical map and include the drainage map in the stormwater report (see Appendix III, Exhibits 3.2 & 3.3).
13. Determine if any existing perennial streams are on the property or if any blue lines are recorded on the USGS map. Note that absence of a blue line does not mean that perennial streams do not exist. Existing USGS defined water channels must be taken in to consideration when developing the site. Include an exhibit in the submittal.
14. Check the FEMA map of the site for existing flood boundaries and include an exhibit of one of these maps with the site location properly indicated. For this commercial design example, no regulated flood plains are found on site or within the watershed basin of concern (where the site represents 10% of the basin).
15. Calculate the post-development runoff volume. From step 7 above, find the difference in pre and post site runoff volume based on the 25-yr, 6-hr storm. The increase (difference) in volume will be stored on site. This calculated volume increase is the required amount to be used for the underground storage system.

The emergency spillway should be designed using the weir equation (see Volume Calculation Example 2 below).

The weir equation is:

Eq. 3 $Q = Cw \times L \times H^{1.5}$

Q = discharge flow over the weir (cfs)

Cw = weir coefficient (dimensionless, not to be confused with the orifice coefficient)

L = Length of the weir (feet)

H = height of the water over the weir spillway (feet)

There is no water quality storage contained in the underground detention system. The water quality management at this site consists of an additional small wet detention pond at the northwest corner of the site and five (5) bioretention cells. The overflow from the bioretention cells is directed to the underground detention for the capture of the 2-yr, 10-yr and 25-yr events.

Volume Calculation Example 2.

<u>Find S and Q* (inches) per the TR-55 method.</u>
$Area_{pre}$ = 4.83 acres for pre-development
$Area_{post}$ = 4.83 acres for post-development site (original + transferred basin runoff area)
Hydrologic Soils classification = Type "B" soils
P = 4.04 inch (NOAA ATLAS 14, for 25-yr, 6hr event, Winston-Salem, NC, 36.0772N, 80.1831W)

$CN_{pre\text{-}composite}$ = [98(1.095 ac) + 61(3.73 ac)]/4.83 ac = 69.3
CN_{post} =92 (B soils, commercial & business, TR-55)
$S_{pre} = 1000/CN_{pre} - 10$ $S_{pre} = 1000/69.3 - 10$, $S_{pre} = 4.43$
$S_{post} = 1000/CN_{post} - 10$ $S_{post} = 1000/92 - 10$, $S_{post} = 0.8696$

<u>Find the increase in depth Q* (inches) and convert to volume (ft^3) as follows:</u>
$Q_{pre}^* = (P-0.2S_{pre})^2/(P+0.8S_{pre}) = 0.109$ inches

$Volume_{pre}$ = 0.109 inch x 1 ft/12 inch x 4.83 ac x 43,560 ft^2/ac = **22,997 ft^3**

$Q_{post}^* = (P-0.2S_{post})^2/(P+0.8S_{post}) = 3.156$ inches

$Volume_{post}$ = 3.156 inch x 1ft/12 inch x 4.83 ac x 43,560 ft^2/ac = **55,337 ft^3**

The increase in volume for 25-yr storm, 6-hr event is the difference between the pre and post-development volume:
$Volume_{post} - Volume_{pre}$ = 55,337 ft^3 - 22,997 ft^3 = 32,340 ft^3 (Volume Storage Required)

Increased volume at the Commercial site for a 25-yr, 6-hr event = 32,340 ft^3

Increased volume is to be detained and released in not less than 48 hours or more than 120 hours.

16. Design BMP structures to manage peak flows so that discharges will not exceed pre-development peak flows (2-yr, 10-yr and 25-yr).
17. Design the proposed structure(s) to manage/contain the 25-yr, 6-hr volume increase so that it does not discharge in less than 48 hours or more than 120 hours (See Appendix III, Exh.3.4).
18. Underground detention will be utilized to handle the 2, 10 and 25 year peak and volume control requirements for the majority of the site. It will be centrally located near the east property line. All roof drainage is directed to the underground detention structure. The underground structure solution consists of multiple outlets with a 2.25 inch orifice and a 1 foot x 0.25 feet weir opening at different elevations. The underground storage system will be composed of 11 - 72 inch diameter pipes, each 78 feet long. This system will release the required volume in approximately 48 hours which complies with the 48 hour minimum discharge time required.
19. Check to make sure the proposed structure discharging the 25-yr, 6-hr storm volume does not discharge the required volume in less than 48 hours or more than 120 hours. The orifice used to meet that requirement for this particular pond

will be a 2.25 inch orifice in the underground detention device. It should be protected by a wire screen cage (see Note 1).

The orifice equation is:

Eq. 2. $Q = Cd \times A \times \sqrt{(2 \times g \times h)}$

Q = flow (cfs)

Cd = 0.6 (dimensionless), typical value used with the orifice equation

A = area (sq. ft.)

G = 32.2

H = head above the center of the orifice when the level of the water is above the center of the pipe(ft)

There is also a weir at the top of the riser to allow additional discharge for larger events which requires use of the weir equation (see Eq. 3).

20. Design water quality BMP's to address the water quality requirements of the Stormwater Ordinance for the proposed development. Water quality cannot be managed in an underground detention facility. Five (5) individual bioretention BMP's will be used at several locations (see Appendix III, Exh.3.4) on the property to receive sheet flow from the parking lots and will be sized to handle the water quality requirements. Bioretention overflow drainage will be discharged to the underground detention structure for the 2-yr, 10-yr and 25-yr peak and volume control requirements. Design should follow the NCDENR Stormwater BMP Manual. Surface areas required for the Bioretention BMP's can be calculated using information from the Biological and Agricultural Engineering (BAE) Stormwater education, publication web site developed by Bill Hunt, PE, North Carolina State University. Include BMP design calculations in the stormwater report.
21. Runoff discharge from this site drains toward the existing 15 inch pipe under Reynolds Park Road. A new 18 inch concrete pipe installed at a lower invert will replace the 15 inch existing pipe in order to provide adequate drainage from the underground detention structure and other areas of the site.
22. A culvert with two drainage pipes under Salem Gardens Drive represents the location where the proposed commercial development site is equal to 10 percent of the watershed. This location is to be checked for impacts to structures for the 100-year event. From the result of this analysis, go to A or B.
    A. **No adverse impacts** to habitable, permanent structures downstream. Post-development peak flow and water surface depth less than or equal to pre-development peak flow and depth. Analysis is complete. Proceed to step 21.
    B. **Adverse impacts** to habitable, permanent structures downstream. Post-development water surface depth is higher than pre-development analysis. Continue with analyses. Development of a water surface profile is required to determine the increase in water surface depth near permanent downstream structures.

    In this example, the downstream location where the site represents 10% of the watershed is checked at two (2) existing 48 inch pipes under Salem Gardens Drive. They are found to have adequate capacity to handle post-development flows associated with the commercial site design. Also, the road surface elevation is approximately four (4) feet lower than nearby homes allowing water to overtop the road before impacting existing habitable structures at that location. Therefore, no adverse impacts are anticipated.
23. The downstream receiving channel is to be checked for scour protection at the offsite outlet of the pipe drainage system due to volume increase for the 2-yr, 1-

hr event. The SCS method for calculating direct runoff, Q (in inches), can be utilized to determine the change in depth. Converting the inches to a volume for the location in question and then comparing the pre and post difference will indicate whether there is a 10% increase in volume which would require mitigation. The pre and post development calculations and solutions are to be prepared and included in the Stormwater Report. The pre and post development volume calculations and solutions are to be included in the Stormwater Report. The following outcomes follow from this volume comparison:

A. **Less than or equal to 10% difference.** Analysis complete.

B. **Greater than 10% difference** Mitigation required per 75-303 (F) of the Stormwater Ordinance, Protection of Receiving Channels and Water Bodies. The west pond is designed for water quality control discharge rates, based on the post-development 1-yr, 24 hr peak flows, to be equal to or less than the pre-development 1-yr, 24 hr flows. The channel protection requirement of the Stormwater Ordinance is also met where runoff is managed by a detention/retention structure. If a water quality structure is not required to comply with 71-302 B of the Stormwater Ordinance, then some type of mitigation to control channel degradation will be required, such as stormwater retention or channel stabilization/armoring method.

24. Prepare a narrative describing how the proposed stormwater management at the site complies with the Winston-Salem Stormwater Ordinance requirements. Include in the stormwater report.
25. Prepare and submit documentation and exhibits to support all calculations and watershed boundaries, soil classifications and other data used to determine the solutions used for this site.

Table 2. Hydrology Summary for Commercial Site

	Condition	Hydrograph Volume 25-yr (ft^3) Downstream at 15” pipe	$Q_{1\text{-YR, 24-hr}}$ (cfs)	$Q_{2\text{-yr, 6-hr}}$ (cfs)	$Q_{10\text{-yr, 6-hr}}$ (cfs)	$Q_{25\text{-yr, 6-hr}}$ (cfs)	$Q_{100\text{-yr, 6-hr}}$ (cfs)
Drainage from site	Pre-dev.	24,765	4.77	1.5	3.97	5.74	8.89
	Post-dev.	66,811	3.91	1.5	2.80	3.68	13.10

PART 4. SUMMARY AND NOTES

Summary:

The design examples and their solutions herein have been provided for general guidance in preparation of a stormwater submittal for proposed site development in the City of Winston-Salem to be compliant with the City's Stormwater Management Ordinance. The steps which accompany the examples and the illustrations shown are to assist in designing stormwater management systems for a wide variety of site-development projects consisting of various sizes and complexity. Following these guideline steps will assist the designer in preparing stormwater management designs that will be compliant with ordinance requirements for proposed site development projects.

There may be multiple solutions for providing post-development stormwater peak and volume controls to comply with stormwater quality and quantity standards as defined in this ordinance. The residential design example illustrates a single pond within one of the defined drainage basins as part of the overall solution. The pond was designed to manage the 25-yr difference in runoff quantity for the entire site. This was accomplished by designing the pond to over capture the runoff within the basin it was placed. However, this technique was not capable of managing the 2-yr and 10-yr peak flow controls required for the entire site. Total peak flows from the proposed site would have to be managed on additional areas of the site to allow the entire site to have post-peak 2-yr, 10-yr and 25-yr flows equal to or less than pre-peak flows. An additional detention pond on another area of the site may be utilized to reduce the size of the large pond as shown in this example or the use of other stormwater control measures in conjunction with the pond to manage the overall site stormwater when such a combination is more efficient. The final solution could include multiple BMP controls to comply with post-development runoff water quantity and quality requirements under Stormwater Ordinance Standards 75-302 and 75-303. Those BMP's would be strategically placed on the residential site for compliance of the overall site stormwater management requirements.

Hydraflow Hydrographs Extension for AutoCad Civil 3D, 2008 by Autodesk, Inc. v6.052 (Hydrographs) computer software was utilized for analyses in these two design examples. Utilizing a time step of one minute produced reasonable results at these sites, which are comprised of relatively small watersheds and sub-basins. Stormwater quality management requires discharge drawdown times to be between 48 hours and 120 hours. When using one-minute time steps, the current software version will only indicate the hydrograph drawdown time up to 48 hours, since Hydrographs only computes 2880 time steps. Thus, the one-minute time step may not produce and adequate check of drawdown time. The solution for reading the resulting drawdown time in Hydrographs for the pond after it is designed is to adjust the input for the basin that is being routed through the pond to 3 minute time steps. This will allow the designer to see the drawdown time up to 144 hours. Drawdown should not discharge in less than 48 hours or exceed 120 hours. The residential pond discharges the 1-yr, 24-hr storm in approximately 77 hours and the 25-yr, 6-hr storm in approximately 89 hours. The commercial site with underground detention discharges the 25-yr, 6-hr event in 48 hours to meet the water quantity discharge time requirement. The water quality requirement is handled by the bioretention cells and the small pond, while the underground detention stormwater system manages water quantity.

The residential design example contains an existing, off-site privately owned 7-foot diameter culvert, which receives the discharge from the area where the proposed site-development will be placed. The existing culvert influences stormwater runoff depths by detaining water in larger storm events. At the downstream point where the site represents 10% of the drainage area, residential structures are found. Those structures may be affected by the removal, relocation or replacement of the existing culvert. The city may require an agreement between the developer and the current or future owner in case of needed or wanted replacement of removal to the culvert. A deteriorated culvert at the point of failure could result in downstream stormwater impacts. The existing culvert should remain hydraulically constant. A future permit would be required to make any changes to that culvert (see Note 2 below). Any proposed development or re-development that will discharge to downstream stormwater structures will have to be reviewed on a case-by-case basis.

The commercial design example illustrates the significance of diverting stormwater from existing sub-watershed basins to other watershed basins. That process is generally not encouraged or allowed at most proposed site-development projects. The watershed revision for this site increases the difference between pre-development and post-development peak flows. Increased volume increases the potential for downstream impacts. In order to prevent oversized underground detention system, pre and post-development volume was based on using the same drainage area in the pre and post calculations. This is shown in the Volume Calculation Example 2 where pre and post drainage areas remain the same.

The commercial site solution includes utilizing multiple BMP's: bioretention, underground detention and a wet detention pond. The increase in impervious areas on the site will produce a large increase in runoff which could be addressed by many different solutions. This example illustrates the use of multiple BMP's to meet different requirements for storm water management. The multiple bioretention areas used on the commercial site also qualify to satisfy the buffer requirements and streetyard landscaping requirements, making an efficient use of these BMPs.

Notes:

1. The orifice opening for the Residential Example pond design is 2.75 inches. The solution uses a clogging preventive design with a trash guard at the orifice as shown in Figure 10-4 of the NC DENR Stormwater BMP Manual, July 2007 edition..
2. The downstream existing 7-foot diameter pipe in the Residential Example was analyzed as a detention device. During the 25-yr and greater storms, runoff rates become reduced at this pipe and runoff storage begins in the area upstream of the pipe. Those storage volumes increase in significance when calculating or analyzing impacts downstream for the 100-yr event. Therefore, an agreement is required to be held with the current property owner to maintain the 7-foot culvert. A copy of this agreement is to be submitted to the City of Winston-Salem prior to a Certificate of Occupancy being issued for the proposed residential development site. Another option could be to detain the total runoff (100-yr event) from the proposed residential site to pre-development runoff rates at a point upstream of the existing 7-foot diameter pipe. In that case no agreement would be necessary. If any downstream structure is publicly owned, a maintenance easement by the City may require additional calculations to prove that the existing public structure has adequate capacity to handle any increase in flows. Contact the City Storm Water Department.
3. Any proposed pond detention structure must be reviewed with the Dam Safety Division of NC DENR. A letter is to be submitted that includes the case number and dates of submittal to the Dam Safety Division of DENR for review. This may be submitted at the beginning of the project with review occurring throughout the planning and construction stages. The review and any subsequent permits must be completed/approved before a Certificate of Occupancy will be issued.
4. For the Commercial Design Example, other stormwater control solutions may be used. For instance, parking could be reduced (must comply with building usage parking requirements) on this site opening additional surface area for different types of BMP's to be utilized such as larger bioretention, sand filters or other structures as defined and outlined in the latest edition of the Stormwater Best Management Practices Manual that would allow the site to be compliant with the

Stormwater Ordinance. Any approved stormwater control structure could be utilized to comply with the ordinance

5. Any activity performed on perennial and intermittent streams will require 404 and 401 permits issued by the US Army Corp of Engineers (USACE) and/or NC Department of Water Quality (DWQ) as applicable. Check with the governing authorities to determine which permits, if any, are required and submit proof of the determination in the stormwater report.

References:

1. Technical Release 55: Urban Hydrology for Small Watersheds, 2nd Edition (TR-55), Soil Conservation Service, USDA, Washington, DC, June 1986.
2. SCS National Engineering Handbook, Section 4, Hydrology, August, 1972
3. North Carolina Division of Water Quality Stormwater Best Management Practices Manual, NC Department of Environment and Natural Resources, (DENR), July 2, 2007 or latest ed.,
4. Hydraflow Hydrographs Extension for AutoCad Civil 3D, 2008 by Autodesk, Inc. v6.052.
5. Biological & Agricultural Engineering (BAE), NC State University, Cooperative Extension Department, NC State University, Raleigh, NC, http://www.bae.ncsu.edu/stormwater/downloads.htm
6. Open Channel Hydraulics, Richard H. French, McGraw-Hill, 1985.
7. Hydrology & Hydraulic Systems, Ram S. Gupta, Waveland Press, 1995