# Integrating Stormwater Runoff Quantity and Quality Requirements in a Coastal County

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## ABSTRACT

Beaufort County, in coastal South Carolina, is proud of its water resources and efforts to protect them through water quality control. The county adopted water quality control requirements in its Best Management Practices (BMP) Manual in 1998, and realized a 30 percent increase in population without any additional water quality impairments through 2009. Further control requirements were considered in 2009 when the state restricted shellfish harvesting in a section of the May River. Specifically, the BMP Manual and development regulations have been modified to add stormwater runoff quantity control requirements. The approach taken by Beaufort County provides a relatively simple and scientifically based approach for evaluating runoff volume for new development. The threshold of the runoff control is an "equivalent" imperviousness of 10 percent, which will not necessarily reduce runoff to pre-development levels, but will limit runoff to a level of uncontrolled imperviousness that has been associated with limited receiving water impacts. The county has also modified the development requirements to control the runoff volume from undeveloped lots that are located in developments that had a BMP plan approved prior to runoff volume control requirements. For these "Step 2" controls, the county has developed a spreadsheet to evaluate runoff volume control under the post-development lot condition, and also allows for an engineering analysis to assess whether a development will meet the equivalent impervious goal without additional on-lot controls. The county has also explored the benefits of the runoff volume controls in meeting existing peak flow attenuation for extreme storm events.

## KEYWORDS

Best Management Practice (BMP), runoff volume control, equivalent impervious cover (EIC), low impact development (LID)

## INTRODUCTION

Beaufort County, South Carolina is located in the southeast corner of South Carolina between Charleston, South Carolina and Savannah, Georgia. Due to the coastal location, the county has been an attractive location for resorts and other types of development. Many of the tidal receiving waters in the county are designated as shellfish harvesting waters and, in some cases, outstanding resource waters. Protection of water quality in the county is a priority for its citizens.

The *Beaufort County Manual for Stormwater Best Management Practices* was produced in 1998 to provide developers and county engineers with guidance regarding the selection and design of BMPs necessary to protect the high quality waters within the county. The manual includes the consideration of site features (e.g., soil type, tributary area, imperviousness of development) as part of BMP selection and includes design guidelines for many of the more common BMP types (e.g., wet detention ponds).

From 1998 to 2010, the focus of the manual was a water quality worksheet designed to evaluate whether a proposed BMP plan would meet the recommended antidegradation water quality goal. This goal was defined as the pollutant loading characteristic of a low-density development with imperviousness of 10 percent or less – in other words, an "equivalent" impervious cover (EIC) of 10 percent with respect to pollutant loads. Schueler (1994) suggests that a relatively low percentage of impervious cover (10 – 15 percent) can induce adverse and irreversible changes in stream water quality.

Following a shellfish harvesting closure in the May River in 2009, the county investigated possible causes, and the volume of stormwater runoff (rather than pollutant load) was considered. Increased stormwater runoff volume from development projects can lead to salinity changes in tidal streams, increased discharges into wetlands with observed increases in fecal coliform bacteria concentration at wetland outlets, and adverse impacts to fisheries.

With direction from the County Council, the County Stormwater Utility developed a volume-based stormwater management criterion that requires capture and retention of runoff from rainfall events up to the 95$^{th}$ percentile storm event (derived from the federal facilities standard in the 2007 Energy Independence and Security Act). This storm in Beaufort County is 1.95 inches of rainfall in 24 hours.

The new criterion prompted two specific actions by the county:

1. Update the BMP Manual to include stormwater runoff volume control requirements for new development, and
2. Update the stormwater ordinance to require on-lot volume reduction BMPs for individual new homes and modifications

The updated BMP Manual documents the analysis of expected runoff volume reduction and associated EIC credits for six stormwater practices that infiltrate, evapotranspire, and/or reuse runoff. These include:

1. Rooftop practices such as green roofs, evaporative cooling on flat roofs,
2. Pervious pavement,
3. Runoff capture and use for irrigation,
4. Disconnection of impervious areas,
5. Rain gardens and other devices, and
6. Swales for runoff from highways and roadways.

The new ordinance changes require on-lot volume reduction BMPs for individual new homes and modifications of existing homes that are more than 50 percent of assessed value of the existing home, unless the volume control requirement is achieved through a development plan or other method. This allows the subdivisions and Planned Urban Developments (PUDs) to opt for a neighborhood retrofit in lieu of only on-lot controls.

The implementation of the new runoff volume control requirements are expected to provide benefits for both water quality and water quantity control. Beaufort County has evaluated the benefits of the runoff volume control in the peak flow attenuation for extreme design storm events. Findings suggest that the new controls will offer a higher level of extreme storm control and/or will reduce the size of facilities required to meet current peak flow attenuation requirements.

**BMP MANUAL EVALUATION OF RUNOFF VOLUME CONTROL**

To evaluate a BMP plan for runoff volume reduction, the manual presents analysis findings from long-term computer simulation of the stormwater practices, which are tabulated based on the EIC associated with the volume reduction controls. If a volume control reduces impervious area runoff so that it is exactly equal to pervious runoff, the EIC of the impervious area is zero. If there is no runoff volume control, the impervious area has 100 percent EIC. When the runoff volume control for impervious area does not reduce the runoff to the level of a pervious surface, the EIC of the impervious area must be determined.

To assess the EIC for a new development, a worksheet was developed. The worksheet requires that the development is broken down into specific pervious and impervious land elements, and volume controls applied to the impervious areas are identified. Based on the values selected from tables in the BMP Manual for the design criteria applied, the breakdown of traditional impervious area into EIC and "developed pervious area" can be calculated. For example, if a volume control reduces parking lot effective imperviousness to 40 percent, then 40 percent of the parking lot area would be assigned to EIC and 60 percent of the parking lot area would be assigned to "pervious developed area."

The established criterion for volume control is a threshold of 10 percent EIC. The threshold target will require significant reduction in runoff volume. Achieving the threshold should be protective of the county's tidal receiving waters, which generally experience a tidal range of 6 to 10 feet and therefore have significant tidal flushing. One advantage of the selected target is that it remains consistent with the overall framework of the BMP reviews for water quality, which allow loads from new development up to the uncontrolled load expected from a 10 percent impervious development.

If Beaufort County interprets the maximum extent technically feasible (METF) requirement in the same way as the federal technical guidance on implementing Section 438 requirements (USEPA, 2009), measures designed to meet the threshold effective imperviousness goal are expected to satisfy the new county ordinance. The US Environmental Protection Agency guidance assumes that storage (e.g., cistern volume or rain garden surface ponding plus planting media pore space) is fully available before the storm event. If the same assumption regarding initial storage is applied in Beaufort County, the EIC goal will satisfy the new ordinance. Several example calculations presented in the manual show storage of about 2 inches or more over the impervious area would be required to meet the EIC goal.

**Rooftop Practices**

Rooftop practices that were evaluated include green roofs and roof evaporation for structures with flat roofs. The green roof includes a depth of planting media on the roof, which will capture rainwater and experience water loss through evapotranspiration, whereas the roof evaporation includes a depth of water allowed to pond on the roof and evaporate. In both cases, the rooftop practice can be supplemented with a cistern to collect roof runoff and re-circulate that collected water back to the rooftop.

In this paper, cistern volumes will be expressed as inches over the impervious roof surface. One inch of cistern volume is equivalent to 0.62 gallons per square foot of impervious surface (e.g., a 2000 square foot roof would require a 1,240 gallon cistern to provide a 1-inch cistern volume).

The EPA Stormwater Management Model (SWMM) was used to evaluate long-term average reduction in runoff from a green roof based on planting media depth and cistern volume. Results of the analysis are presented in Figure 1, which shows results for various combinations of media depth and cistern volumes. According to the model results, the roof runoff reduction can range from 30 to 75 percent depending on the design characteristics.

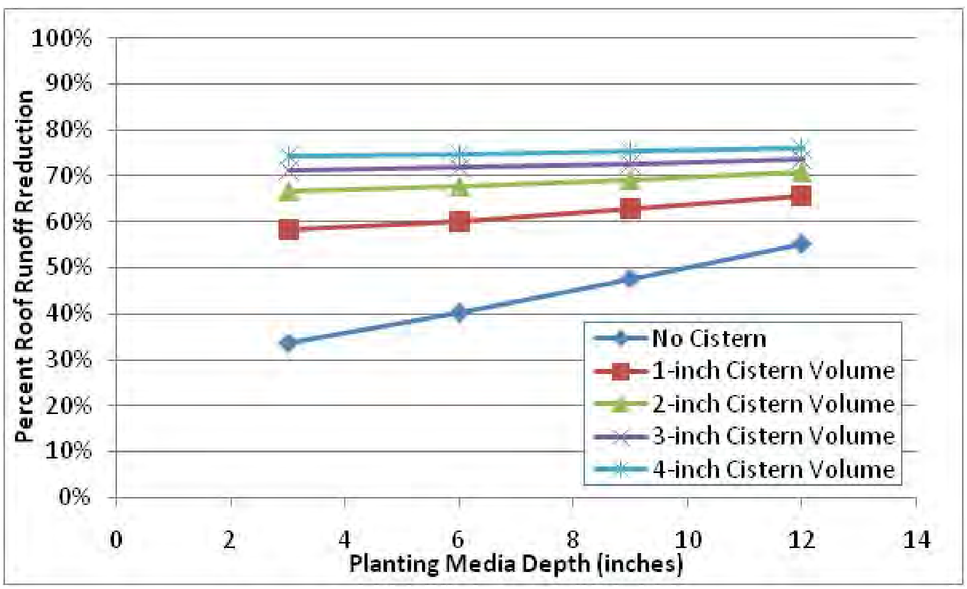


Figure 1. Runoff Reduction for Green Roofs.

Roof evaporation calculations were conducted using spreadsheet calculations. Spreadsheet inputs included long-term meteorological data such as daily rainfall and pan evaporation data, plus user inputs such as the maximum ponding depth on the roof, roof area, and cistern volume. Results displayed in Figure 2 show that roof runoff reduction can be 70 percent or more depending on the design characteristics, and generally has greater runoff reduction potential than a green roof.

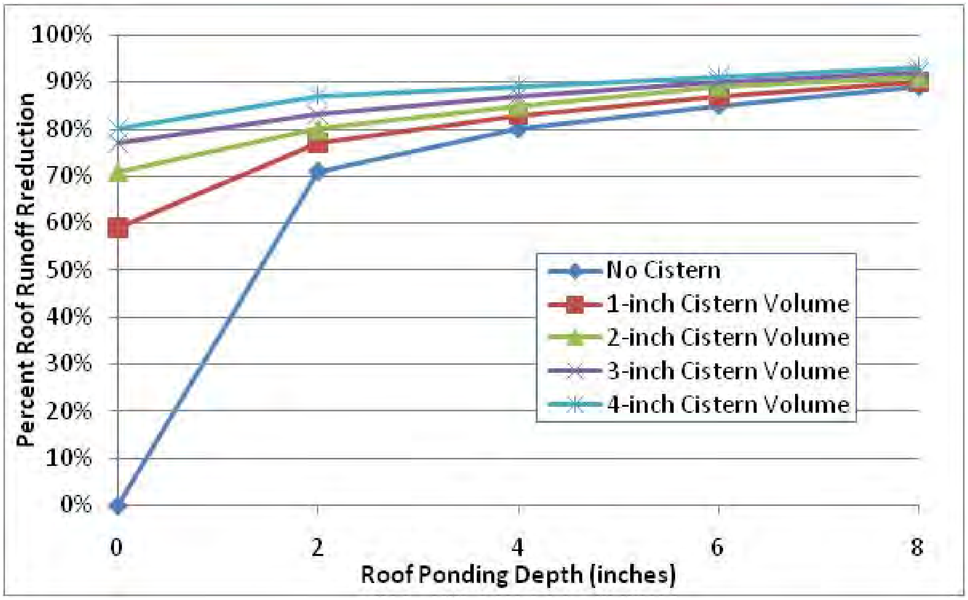


Figure 2. Runoff Reduction for Roof Ponding and Evaporation.

**Runoff Capture and Use for Irrigation**

Roof runoff capture and use for irrigation was evaluated using spreadsheet calculations. Spreadsheet inputs included long-term meteorological data such as daily rainfall and pan evaporation data, plus other inputs such as irrigated area, roof area, cistern volume, and desired irrigation water depth. The spreadsheet was developed assuming that irrigation would occur once per week, at the desired irrigation water depth, if the preceding 7-day period did not provide the desired irrigation water depth. The irrigation water calculation took water from the cistern if available, and supplemented that with an external source. Values used in the analysis were 1 inch of irrigation for months of April through September and 0.75 inches per week for the other months.

Calculation results for runoff capture and irrigation are displayed in Figure 3. These results show that roof runoff reduction can vary widely depending on the design characteristics. As the ratio of irrigated area to rooftop area goes beyond a value of 3, there is little additional benefit in terms of runoff reduction.

**Disconnection of Impervious Area**

SWMM was applied to the soil groups A, B, C, and D to assess the impervious area runoff reduction that would occur if the runoff was routed on to adjacent pervious area. In the analysis, the ‘run on’ feature of SWMM was used to route the runoff generated by the impervious area onto the pervious area. By comparing the amount of runoff that would be generated separately by the pervious and impervious areas to the runoff generated by the combination of impervious area discharging to pervious area, the ‘effective imperviousness’ of the impervious area was calculated.

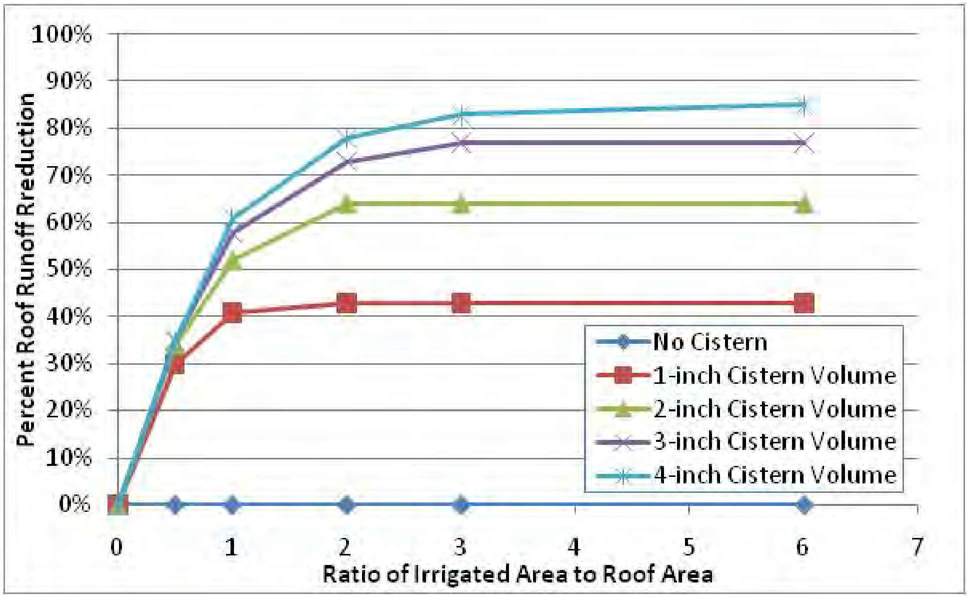


Figure 3. Runoff Reduction for Runoff Capture and Use for Irrigation

Calculation results are displayed in Figure 4, which shows that the effective imperviousness decreases with decreasing ratio of impervious area to adjacent pervious area. As expected, Soil Group A (sandy soil with the greatest infiltration capacity) has the lowest effective imperviousness values and Soil Group D (clay soils with the lowest infiltration capacity) has the highest effective imperviousness values.

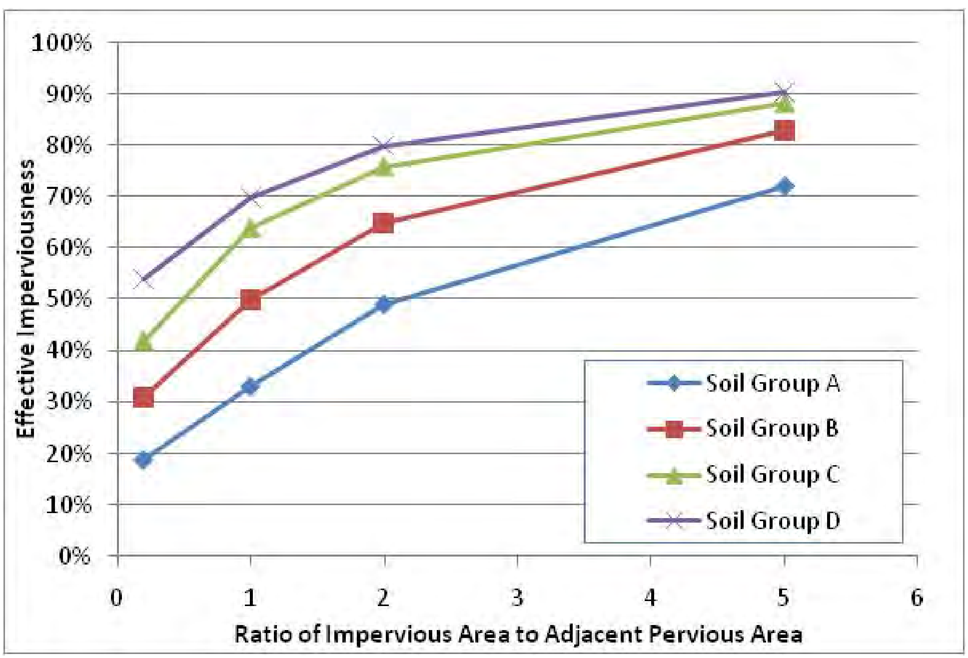


Figure 4. Effective Imperviousness of Impervious Area Discharging to Adjacent Pervious Area

### Rain Gardens

SWMM was used to evaluate developed area runoff routed to a rain garden area. Again, the "run-on" feature of SWMM was used to route the developed area runoff to the rain garden, which was modeled as a separate pervious subbasin. The subbasin was assigned depression storage equivalent to the maximum ponding volume, plus the total water storage capacity in the planting media, and unlimited soil water storage (infiltrating water from the rain garden is assumed to be conveyed away from the rain garden to surficial aquifer groundwater).

SWMM results suggested that rain gardens sized in accordance with the county BMP Manual will limit runoff to levels at, or near, undeveloped conditions, provided that the assumptions listed above are valid. This is particularly true for Soil Groups C and D, as the current manual does not recommend rain garden applications on these soils with limited infiltration capacity. Use of underdrains was not evaluated as part of this study.

### Swales

Evaluation of SWMM results for swales was similar to model results for disconnected impervious area. Thus, the results for disconnected impervious area can be used to determine the volume reduction benefit of swales. In calculating the ratio of impervious runoff area to adjacent pervious area, half of the swale top-width should be used as the basis for the pervious area receiving runoff from the impervious roadway.

## EVALUATION OF ON-LOT RUNOFF VOLUME CONTROL

Along with the adoption of new development volume control requirements in the BMP Manual, questions were raised about developments that had been approved before runoff volume control requirements, but had not been built out. Analysis conducted by the county indicated that over 22,000 residential lots of record could be developed without volume controls, with 15,000 of these in previously approved subdivisions and Planned Urban Developments (PUD). Considering that the current total number of improved single family residential structures is 39,000 units, it was determined that the additional stormwater runoff from the 22,000 permitted future building lots could make the runoff volume problems worse and could lead to further water use impairments.

Consequently, ordinance changes were developed to require on-lot volume reduction BMPs for individual new homes and existing homes for which modifications will be more than 50 percent of assessed value. This was required only if the runoff volume of the lot was not being treated by a development plan or other method. This allowed the voluntary option of subdivisions and PUDs to opt for a neighborhood retrofit in lieu of only on-lot controls. These controls were adopted in June 2011 after some workshops with a new stakeholder in the stormwater control arena, the local home builders.

**Analysis of Individual Lots**

As part of this process, the county developed a web-based program to assist in the determination of compliance with these on-lot controls. This web-based program allowed homebuilders and homeowners to develop solutions without resorting to technical support. Over 50 homes have already received permits using the web-based approach.

The program includes the following steps as part of the analysis:

1. **Lot Information:** Data are provided that will be used in subsequent calculations. These include lot size, added impervious cover after development, soil conditions (sand vs. clay), and pervious area that will be irrigated.
2. **Post Construction Stormwater Calculations**: Using data from Step 1, the excess runoff (i.e., increase in runoff from undeveloped to developed condition) is calculated
3. **Application of BMPs**: Credit for runoff volume control is calculated in the following order:
    a. Storage and Reuse Credit: Accounts for runoff capture and irrigation use for implementation of rain barrels and/or cisterns; and,
    b. Disconnected Impervious Area: Accounts for impervious area runoff reduction as a function of soil type and ratio of impervious area to pervious sheet flow area receiving the runoff.
4. **Rain Garden Credit**: Calculates the footprint (surface area) of a bioretention facility (rain garden) required to meet the remaining runoff volume control requirement after considering the volume controls in Step 3

One comment received from the initial rollout of the web-based program was that other alternatives to the rain garden should be considered in Step 4. Consequently, several other alternatives to the rain garden have been considered and will be incorporated into the program. These include:

- Retention swale/depressed pervious area,
- Exfiltration trench,
- Green roof,
- Pervious pavement, and
- Planters.

For each of these alternatives, calculations were performed to determine the ratio of appropriate surface area between the alternative and the rain garden (output from the current program). The results are tabulated in a “help sheet” for applying the web-based program. For example, if the help sheet table states that the ratio for an exfiltration trench is 3, then the trench surface area should be 3 times the required rain garden area that was calculated by the program.

**Development-Wide Analysis**

Additionally a number of developments have analyzed their existing controls and have documented their compliance with the new volume control requirements on a development-wide basis. In general, compliance has been achieved in these cases as a result of one or more of the following site characteristics:

- Limited imperviousness and/or significant dedicated open space built into the development design,
- Use of unpaved alleys and parking areas,
- Roadside swales,
- Disconnected impervious area, and
- Irrigation of golf course and common areas from stormwater ponds.

The analyses have raised interesting issues with respect to the evaluation of the stormwater control features documented in the BMP Manual. For example, one development using irrigation from stormwater ponds as a volume control measure is also receiving some reuse water from the Beaufort-Jasper Water & Sewer Authority (BJWSA). In addition, the development had actual data on stormwater pond irrigation use which differed significantly from the results tabulated in the BMP Manual based on a hypothetical set of rules for irrigation discussed earlier in the section Runoff Capture and Use for Irrigation. In the end, calculations were performed to determine the amount of stormwater reuse required to meet the 10 percent EIC requirement, and the acceptance of the analysis (eliminating the requirement of on-lot controls for undeveloped lots in the development) was contingent upon that stormwater reuse quantity requirement.

**INTEGRATING STORMWATER RUNOFF QUANTITY AND QUALITY**

Traditional stormwater approaches have typically kept stormwater quantity and quality decisions in separate “silos” such that the mutual benefits of stormwater control practices were not recognized. The computational methods for evaluating runoff quantity and quality control were further partitioned by state and regulatory programs. Quantity controls are primarily designed for control of one or more extreme design storm events, whereas water quality controls are designed to provide a long-term level of treatment focusing more on small and medium events.

The one thing driving both quantity and quality control has been impervious surface. Development in Beaufort County has increased impervious surfaces, to which researchers have linked decreases in stream health and increased water use impairments. Increased impervious surface causes three impacts:

- Increase in rate of runoff (peak flow controls),
- Increased loads of pollutants to receiving waters (water quality controls), and
- Increase in total volume of runoff (runoff volume controls).

When the county adopted controls for the third impact in 2009, many questions were being raised regarding the benefits of volume controls with respect to peak flow attenuation for extreme storm events and reduction in runoff pollution loads.

**Volume Control and Water Quality Treatment**

The county discovered that the EIC concept historically used for water quality compliance could be adapted for the new volume control criterion. Analysis showed that the LID features designed to meet the 95th percentile storm (1.95 inch) control requirement would also reduce long-term runoff to a level that would be expected from a site with 10 percent equivalent impervious cover. This was consistent with the goals set for two of the targeted pollutants in the county (total phosphorus and total nitrogen). Additional water quality control would still be required for fecal coliform bacteria, for which the loading target is the equivalent of an uncontrolled development with 5 percent imperviousness. This additional control could be provided by traditional BMPs such as wet detention ponds.

Based on these findings, the BMP Manual was redone to recognize the water quality control benefits of the runoff volume control. In the updated manual, the development is reviewed for runoff volume control and the EIC for the development is established. Then, the established EIC value (rather than the actual imperviousness of the development) is used in the water quality worksheet calculations. This BMP Manual change was finalized in 2012 after seeking additional formatting input from local stakeholders and users.

**Volume Control and Peak Flow Attenuation**

Implementation of runoff volume controls are expected to provide some benefit for water quantity control as well as water quality control. Though the runoff volume controls are typically designed to capture and retain runoff from small and medium sized storms up to the $95^{th}$ percentile storm event, the same controls are expected to provide a higher level of control for extreme events, or to require smaller peak flow attenuation facilities to achieve the same level of control relative to the development without volume controls.

Current requirements in Beaufort County specify that a detention pond with a positive outfall must be designed for the 25-year/24-hour design storm. The detention pond outlet configuration is established so that the peak post-development flow for the 25-year design storm is less than or equal to the peak pre-development flow for the same design storm. A detention pond without a positive outfall needs to be designed for the 100-year/24-hour design storm. The local 25-year/24-hour and 100-year/24-hour design storm depths are 8.0 and 10.0 inches, respectively, based on the Beaufort County Stormwater Management Plan (T&H and CDM Smith, 2006).

Acceptable hydrologic models for design storm analyses include the rational method and the TR-55 model. The rational method may only be used for developments up to 50 acres. The TR-55 model may be used for developments of any size. Other models may also be applied if approved by the county engineer.

An analysis was conducted to evaluate the potential benefits of runoff volume controls for peak flow attenuation. The Interconnected Channel and Pond Routing (ICPR) model was used as the basis for the analysis. ICPR is often used in the county for stormwater analyses of developments, and was used in the master plan study. ICPR hydrologic simulation options include the "curve number" approach that is consistent with TR-55, and that is the method that was used in the analysis.

The Georgia Coastal Stormwater Supplement (CSS) webpage includes a spreadsheet that allows the user to consider the runoff volume reduction and peak flood flow reduction associated with LID site practices. The spreadsheet is located at:

http://www.gaepd.org/Files_PDF/techguide/wpb/CoastalStormwater/Coastal_Stormwater_Supplement_Site_Planning_Design_Worksheet_June_2010.xls

The technique used to determine the peak flow reduction impact was evaluated for the analysis and is described below.

Using the basic TR-55 methodology, the quantity of runoff R (inches) generated from a 24-hour design storm is calculated using the following equation:

$$R = (P - 0.2*S)^2 / (P + 0.8*S); \quad (1)$$

Where P is the rainfall depth in inches and S is calculated as a function of the curve number (CN). This equation is

$$S = 1000/CN - 10. \quad (2)$$

The CSS approach accounts for the flood control benefit of LID features based on the runoff volume control (in inches) by determining a modified value of S and then applying that modified value to get a modified CN.

Consider an example with a site CN of 80, rainfall depth of 8 inches, and volume control storage of 1 inch over the site. From equation 2, the calculated value of S is 2.5. Substituting S = 2.5 and P = 8 in equation 1, the resulting runoff R = 5.63 inches. If the site provides 1 inch of volume control storage over the site, the adjusted runoff R = 4.63 inches (5.63 – 1 inch of storage). Applying R = 4.63 and P = 8 in equation 1, the corresponding adjusted S value would be 4.00 inches. Applying the adjusted S value of 4.00 in equation 2, the adjusted CN value is 71.

Analyses were conducted for a pre-development condition and for post-development with imperviousness of 25% and 50%. The pre-development condition was run for the 25-year and 100-year design storms, to establish the peak runoff rate that would be acceptable for the post-development condition. The post-development condition with no volume control was run for the 25-year design storm, and runoff was routed through a hypothetical detention pond to determine the storage volume required to meet the current peak shaving requirement for the 25-year event. The post-development condition with volume control (and associated adjusted CN) was run for the 100-year design storm, and again runoff was routed through a hypothetical detention pond to determine the required storage volume to limit 100-year post-development peak flow to the 100-year pre-development level.

Analysis indicated that by applying runoff volume controls, peak flow attenuation to pre-development levels for the 100-year design storm could be achieved with roughly the same required detention volume as control of the 25-year design storm without the runoff volume controls. Consequently, if developers designed the runoff peak flow attenuation facilities for the 25-year design storm independent of the volume control, it is believed that the facilities would actually control design storms up to the 100-year event when required volume controls were included.

While there was some benefit to going to the higher level of peak flow attenuation control, it was decided to maintain the current attenuation requirement. Discussion with local engineers revealed that they were already incorporating the runoff volume control features into their flow attenuation calculations.

## CONCLUSION

Beaufort County has committed to stormwater runoff volume control as well as runoff water quality treatment to protect the high-quality receiving waters in the county. The county has developed calculation methods based on modeled performance of runoff volume control features and a reasonable "equivalent" imperviousness target. These tools provide developers and reviewers with the means of determining the adequacy of runoff volume control for new development.

Beaufort County found in addressing a runoff volume requirement that runoff volume quantity and quality requirements can be integrated by use of EIC. Quantity requirements such as peak flow attenuation, computed on an event basis, can be related to runoff volume controls sizes and evaluation of the EIC percentage. This percentage can then be related to water quality requirements that have historically been developed on an annual average pollutant load basis. Using EIC allows for a systematic linkage of all three impacts of impervious surface increase and links well to research that has related biological and hydraulic health of streams to the impervious surface in the watershed.

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