Volume Based Hydrology Design
Is It Time?

Richard Karkowski, PE, PH, CPSWQ
Water Resources Group Leader; Thomas & Hutton, Charleston, SC

Daniel Ahern
Stormwater Manager; Beaufort County, South Carolina

Robert Klink, PE
County Engineer; Beaufort County, South Carolina

ABSTRACT

Beaufort County, South Carolina and its local cities and towns have been working together to protect the natural resources unique to the Low country including the system of salt water marshes, tidal creeks, and rivers. Realizing that state and federal regulations and requirements for new development may not be enough to protect the natural systems in the County, the County government and many local jurisdictions enacted additional stormwater management requirements and explored options to retrofit previously developed areas. Despite these efforts, monitoring of water quality, fisheries, and other parameters has continued to indicate degradation in some of these systems.

The County, along with other local jurisdictions, has or are considering new regulations for development that would require volume based hydrology (VBH) design for stormwater management. The VBH approach to stormwater management is to reduce post-development runoff volumes to pre-development conditions. Low impact design (LID) and "green" development may approach the necessary reduction in the volume of runoff, but it may not be enough. This paper serves to emphasize the national dialogue surrounding VBH design, discuss how other communities are addressing VBH design, explore the science and engineering that will be required to implement VBH design, and finally discuss Beaufort County's approach to VBH design.

NATIONAL DIALOGUE

National Research Council. In October 2008, the Water Science and Technology Board of the National Research Council (NRC) published its authoritative report *Urban Stormwater Management in the United States* (http://books.nap.edu/catalog/12465.html). The Water Science and Technology Board is the National Research Council's focal point for studies related to water resources. The Board's studies are accomplished under the aegis of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. For this report, the Board formed the Committee on Reducing Stormwater Discharge Contributions to Water Pollution by bringing together leading scientist, engineers, economists, and others from government, academia and business.

The study documented in the report was conducted in response to a request by the United States Environmental Protection Agency (USEPA). The USEPA requested the advice of the NRC on the federal stormwater program. The USEPA essentially asked the Board to assess the current stormwater regulatory program, identify and describe the issues and challenges related to non-point source pollution, and finally provide recommendations for the stormwater program under the Clean Water Act (CWA).

The report framed the problem of urban stormwater management fairly simply by stating:

> *Urbanization causes change to natural systems that tends to occur in the following sequence. First, land use and land cover are altered as vegetation and topsoil are removed to make way for agriculture, or subsequently buildings, roads, and other urban infrastructure. These changes, and the introduction of a constructed drainage network, alter the hydrology of the local area, such that receiving waters in the affected watershed experience radically different flow regimes than prior to urbanization. Nearly all of the associated problems result from one underlying cause: loss of the water-retaining and evapotranspirating functions of the soil and vegetation in the urban landscape.*

The report went on to present several finding, including:

- *There is a direct relationship between land cover and the biological condition of downstream receiving waters.*
- *The protection of aquatic life in urban streams requires an approach that incorporates all stressors (even without noticeably elevated pollutant concentrations in receiving waters, alterations in their hydrologic regimes are associated with impaired biological condition.).*
- *The full distribution and sequence of flows (i.e., the flow regime) should be taken into consideration when assessing the impacts of stormwater on streams.*
- *Roads and parking lots can be the most significant type of land cover with respect to stormwater.*

The report made the following recommendations:

> ***Flow and related parameters like impervious cover should be considered for use as proxies for stormwater pollutant loading.*** *Without these more easily measured parameters for evaluating the contribution of various stormwater sources, regulators will continue to struggle with enormously expensive and potentially technically impossible attempts to determine the pollutant loading from individual dischargers or will rely too heavily on unaudited and largely ineffective self-reporting, self policing, and paperwork enforcement.*
>
> ***Individual controls on stormwater discharges are inadequate as the sole solution to stormwater in urban watersheds****. Stormwater cannot be adequately*

managed on a piecemeal basis due to the complexity of both the hydrologic and pollutant processes and their effect on habitat and stream quality.

Nonstructural SCMs (stormwater control measures, also known as, best management practices) such as product substitution, better site design, downspout disconnection, conservation of natural areas, and watershed and land-use planning can dramatically reduce the volume of runoff and pollutant load from a new development. *Such SCMs should be considered first before structural practices. Not creating impervious surfaces or removing a contaminant from the runoff stream simplifies and reduces the reliance on structural SCMs.*

SCMs that harvest, infiltrate, and evapotranspirate stormwater are critical to reducing the volume and pollutant loading of small storms.

Congress and Executive Branch. The United States Congress waded into the VBH design dialogue at about the same time that NRC was studying urban stormwater management for its report. In January 2007, the 110th Congress passed a law entitled the "Energy Independence and Security Act of 2007". The law was geared towards greater energy independence and security, but also included environmental provisions related to renewable fuels, green house gases, and the development and operations of the Federal facilities.

The law included requirements for stormwater runoff management from Federal development projects. Under Title IV, Subtitle C, Section 438 (Storm Water Runoff Requirements for Federal Development Projects), the law required that *the sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow.* This law apparently had no implementation time table associated with it, since no substantive Federal action was taken related to the new law.

But on October 5, 2009, President Obama issued an Executive Order entitled "Federal Leadership in Environmental, Energy, and Economic Performance". Section 14 (Stormwater Guidance for Federal Facilities) of this order instructed that …*within 60 days of the date of this order, the Environmental Protection Agency, in coordination with other Federal agencies as appropriate, shall issue guidance on the implementation of Section 438 of the Energy Independence and Security Act of 2007(42 U.S.C. 17094).*

United States Environmental Protection Agency. In December 2009, the USEPA issued the document entitled *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act* (http://www.epa.gov/owow/nps/lid/section438/). In addition to introduction and background material, the document provided interpretations and technical guidance for meeting the requirements of Section 438 of the Energy Independence and Security Act.

The USEPA guidance provides two options to demonstrate a design meeting the requirements of Section 438 of the Energy Independence and Security Act. The options are:

- Option 1 – Retain the 95th Percentile Rainfall Event
- Option 2 – Site Specific Hydrologic Analysis

Option 1 – Retain the 95th Percentile Rainfall Event. This approach of establishing the performance design objective of Section 438 is to *design, construct, and maintain stormwater management practices that manage rainfall onsite, and prevent the off-site discharge of the precipitation from all rainfall events less than or equal to the 95th percentile rainfall event to the maximum extent technically feasible (METF).* The USEPA identified the 95th percentile rainfall amount as the design event because it appeared to best represent the volume that is fully infiltrated in a natural condition and thus should be managed onsite to restore and maintain pre-development hydrology. The goal is to capture, retain, infiltrate, evaporate, or otherwise "dispose" of the volume of runoff from all rainfall events equal to, or less than, the 95th percentile rainfall event on-site.

Option 2 – Site Specific Hydrologic Analysis. The USEPA offers a second and more involved process to demonstrate compliance with the requirements of Section 438. This option *allows the designer to conduct a site-specific hydrologic analysis to determine the pre-development runoff conditions instead of using the estimated volume approach of Option 1*. Under this option, the pre-development hydrology is determined based on site-specific conditions and local meteorology by using continuous simulation modeling techniques, published data, studies, or other established tools. Defensible and consistent hydrological assessment tools should be used and documented. The technical guidance emphasized that the *approach in Option 1 is intended to be a surrogate for determining the pre-development reference condition and this standard (Site Specific Hydrologic Analysis) is intended to be used in cases where it is more practical, cost effective, and/or expeditious than Option 1, or where it is difficult or infeasible to identify the relevant reference conditions for the site.*

Maximum Extent Technically Feasible. The USEPA guidance also defines Maximum Extent Technically Feasible (METF) by actually defining "technically infeasibility". In general, a qualitative analysis is undertaken to document conditions that make attaining the goals of Section 438 (pre-development hydrology) as "technically infeasible". The conditions that may make a site technically infeasible to meet the requirements include:

- *The conditions on the site preclude the use of infiltration practices due to the presence of shallow bedrock, contaminated soils, near surface ground water or other factors such as underground facilities or utilities.*
- *The design of the site precludes the use of soil amendments, plantings of vegetation or other designs that can be used to infiltrate and evapotranspirate runoff.*
- *Water harvesting and use are not practical or possible because the volume of water used for irrigation, toilet flushing, industrial make-up water, wash-waters, etc. is not significant enough to warrant the design and use of water harvesting and use systems.*

- *Modifications to an existing building to manage stormwater are not feasible due to structural or plumbing constraints or other factors as identified by the facility owner/operator.*
- *Small project sites where the lot is too small to accommodate infiltration practices adequately sized to infiltrate the volume of runoff from impervious surfaces or soils that cannot be sufficiently amended to provide for the requisite infiltration rates*
- *Situations where site use is inconsistent with the capture and use of stormwater or other physical conditions on site that preclude the use of plants for evapotranspiration or bioinfiltration.*
- *Retention and/or use of stormwater onsite or discharge of stormwater onsite via infiltration has a significant adverse effect on the site or the down gradient water balance of surface waters, ground waters or receiving watershed ecological processes.*
- *State and local requirements or permit requirements that prohibit water collection or make it technically infeasible to use certain GI/LID techniques.*
- *Compliance with the Section 438 requirements would result in the retention and/or use of stormwater on the site such that an adverse water balance impact may occur to the receiving surface waterbody or ground water.*

It was stressed that more than one condition would be needed to demonstrate technical infeasibility. Even if a site had challenging conditions, *the facility should still install stormwater practices to infiltrate, evapotranspire and/or harvest and use onsite the maximum amount of stormwater technically feasible.*

OTHER JURISDICTIONS

Various local jurisdictions around the United States have enacted stormwater volume control regulations. The approaches taken by Philadelphia, PA, Spokane, WA, Phoenix, AZ, Portland, OR and coastal Georgia (refer to Figure 1) are presented below.

Philadelphia, PA requires the management of the first one inch of runoff from all Directly Connected Impervious Areas (DCIA) within the limits of earth disturbance. The requirement was established to: (1) recharge the groundwater table and increase stream base flows; (2) restore more natural site hydrology; (3) reduce pollution in runoff; and (4) reduce combined sewer overflows (CSO) from the City's combined sewer systems.

The requirement must be met by infiltrating the water quality volume unless infiltration is determined to be infeasible (due to contamination, high groundwater table, shallow bed rock, poor infiltration rates, etc.) or where it can be demonstrated that infiltration would cause property or environmental damage. When infiltration is not feasible for all or a portion of the water quality volume, the remaining portion must be treated by an approved stormwater management practice (SMP). Treatment and release requirements differ for separate and combined sewer areas, but all areas must route a minimum of 20 percent of the water quality volume through an approved SMP that provides volume reduction.

FIGURE 1
Stormwater Runoff Volume Control Jurisdictions

Spokane, WA requires that the peak rate and volume of stormwater runoff from any proposed land development to any natural or constructed point of discharge downstream shall not exceed the pre-development peak rate or volume of runoff. If the requirement cannot be met, a down-gradient analysis demonstrating that there will be no expected adverse impacts on down gradient properties will be required. Exceptions with regard to rate and volume control may be made if regional facilities are planned. In general, the requirement is enforced by development projects incorporating properly sized detention and evaporation/infiltration facilities that store the increase in stormwater runoff volume and evaporate and/or infiltrate the excess volume. During design, a water budget analysis is conducted to demonstrate that the volume of runoff leaving the site over a 2-year cycle is less than or equal to the pre-developed volume for the cycle.

Phoenix, AZ requires on-site retention of stormwater for all developments equal to or exceeding one-half acre in size. All new developments must retain the stormwater runoff from a 100-year, 2-hour duration storm falling within its boundaries. The 100-year, 2-hour rainfall depth is approximately 3 to 3.5 inches. In some special case in which a detention facility is allowed, the requirement to retain the 100-year, 2-hour runoff volume may be waived. However, post-development peak discharges shall not exceed pre-development peak discharges for the 2-, 10-, and 100-year storm events. If detention is allowed, first flush water quality criteria must be met.

The design of all storm water storage facilities shall be such that the stored runoff is emptied completely from the facility within 36 hours after the runoff event has ended by infiltration, controlled bleed-off, dry well, or discharge pump to an approved facility. Where bleed-off pipes are to be used the 100-year (design) storm water storage volume shall be recovered within 36 hours, but not less than 24 hours. The maximum bleed-off rate into a City storm drain system is limited to 1 cubic foot per second (cfs).

Portland, OR requires that the quantity and flow rate of stormwater leaving the site after development shall be equal to, or less than, the quantity and flow rate of stormwater leaving the site before development, as much as is practicable. The City's design target for on-site retention and infiltration is the 10-year, 24-hour storm event (3.4 inches). Several stipulations are included in Portland's regulations for the feasibility to infiltrate the captured excess post-development stormwater volume. If infeasible, provisions for off-site discharge of excess volumes are provided. However, peak flows are managed up to and including the 25-year, 24-hour event. In addition, provisions are made for off-site control of post-development volumes.

Georgia published its Coastal Stormwater Supplement to the Georgia Stormwater Management Manual in April 2009. The supplement is a guide to be used by local jurisdictions in the development of new and more protective stormwater regulations. The supplement provides for several post-constructions stormwater management criteria including:

- <u>Stormwater Runoff Reduction</u> - Reduce the stormwater runoff volume generated by the 85^{th} percentile storm event (and the "first flush" of the stormwater runoff volume generated by all larger storm events) on a development site through the use of appropriate green infrastructure practices to pre-development levels. In coastal Georgia, this equates to managing the stormwater runoff volume generated by the 1.2 inch rainfall event. The supplement includes various caveats to the requirement that include a lower standard is site constraints are prohibitive and a higher standard (90^{th} percentile or 1.5 inch rainfall event for shellfish waters.
- <u>Stormwater Quality Protection</u> - Adequately treat post-construction stormwater runoff before it is discharged from a development site. If the stormwater runoff volume reduction measure cannot be met, the runoff from these events shall be *intercepted and treated* in one or more stormwater management practices that: (1) provide for at least an 80 percent reduction in TSS loads; and (2) reduce nitrogen and bacteria loads to the m*aximum extent practical*.

Other provisions call for the control of post-development stormwater peak flows to that of pre-development rates for the 25-year and 100-year events to address overbank and extreme flood protection.

RUNOFF VOLUME CALCULATION CASE STUDY

To better understand the hydrologic effect of a typical Beaufort County development on the volume of stormwater released to surrounding creeks and rivers, a case study of an actual Beaufort County development was undertaken. The Eagle's Pointe development was selected for the case study due to the relatively limited size, access to historical design data, and the amount of available water quality/flow monitoring data. The Eagle's Pointe Planned Unit Development (PUD) is located in west-central Beaufort County (see Figure 2) and includes a

Davis Love III designed 18-hole golf course and 245 single-family homes located on a 370 acre tract.

FIGURE 2
Eagle's Pointe Location Map

Pre-development and post-development runoff volume conditions were analyzed using the widely used USDA Soil Conservation Service (SCS) method outlined in Technical Release 55 (June 1986). The SCS equations used in estimating the depth runoff for a particular area are:

$$I_a = 0.2\,S$$

$$Q = \frac{(P - 0.2\,S)^2}{(P + 0.8\,S)}$$

$$S = \frac{1000}{CN} - 10$$

Where:

Q = runoff depth (in)
P = rainfall depth (in)
I_a = initial abstraction (in)
S = potential maximum retention after runoff begins (in)
CN = curve number

The SCS method of calculating runoff assumes that runoff does not occur until initial abstraction is exceeded. Thus for this analysis, runoff for a particular CN is assumed zero, unless the total runoff exceeds the initial abstraction for that particular CN. The runoff curve number (CN) represents runoff potential – higher curve numbers produce more runoff, lower curve numbers produce less runoff. Major factors in estimating CNs are the hydrologic soil group (HSG), land cover type (i.e. land use), and antecedent moisture condition (AMC).

Hydrologic soils group data is available from the USDA Natural Resource Conservation Service (NRCS, formerly known as SCS) soil survey geodatabase (SSURGO). A project specific land cover classification scheme was developed for the Eagle's Pointe study area. Pre-development (1994) and post-development (2006) land cover conditions were generated. The land cover classifications selected for the classification included: impervious surface, forest, water, grassland/herbaceous, non-forested wetland, forested wetland, scrub/shrub and bare land. These land uses are similar to those employed by NOAA for their Coastal Change Analysis Program (C-CAP).

Figures 3 and 4 illustrate the pre-development and post-development conditions for the Eagle's Pointe development, respectively. Figures 5 and 6 illustrate the pre-development and post-development land uses, respectively. For this case study, only the developed portion of the Eagle's Pointe tract was considered, assuming that hydrologic (and thus runoff) conditions in the undeveloped areas would remain constant. Table 1 is a summary of the pre-development and post-development conditions (for the developed area only) for the Eagle's Pointe PUD.

Antecedent moisture condition (AMC) heavily affects runoff volume. AMC is generally described as dry (AMC I), normal (AMC II), or wet (AMC III). Most CN's listed in available literature are for normal, or AMC II, conditions. The National Engineering Handbook (USDA NRCS, 1971) suggests a method to account for varying moisture conditions. The CN is adjusted up or down (from the average or AMC II CN) based on the amount of rainfall in the previous 5 days. The method accounts for a dormant and growing season. The NEH method was used in this study to account for the variability of moisture conditions for various rainfall events.

FIGURE 3
Eagle's Pointe Pre-development

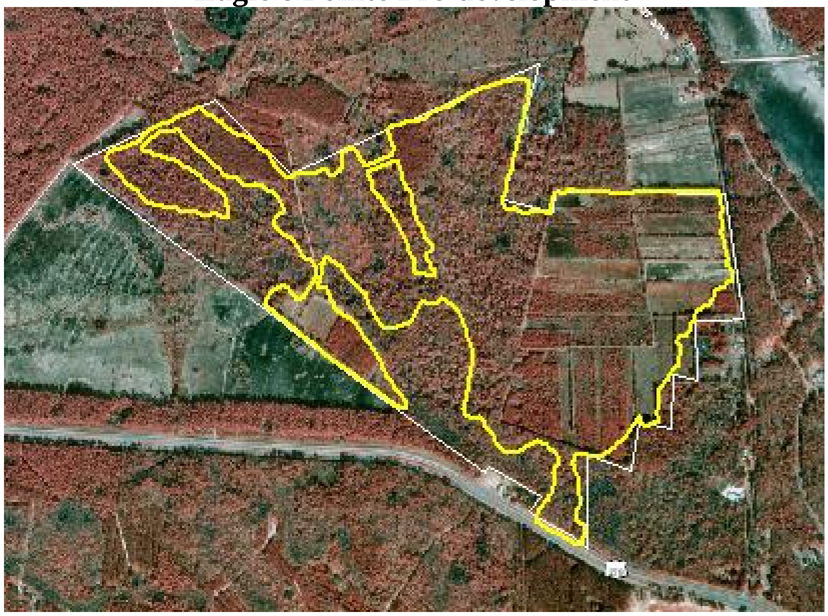


FIGURE 4
Eagle's Pointe Post-Development

FIGURE 5
Eagle's Point Pre-development Land Cover

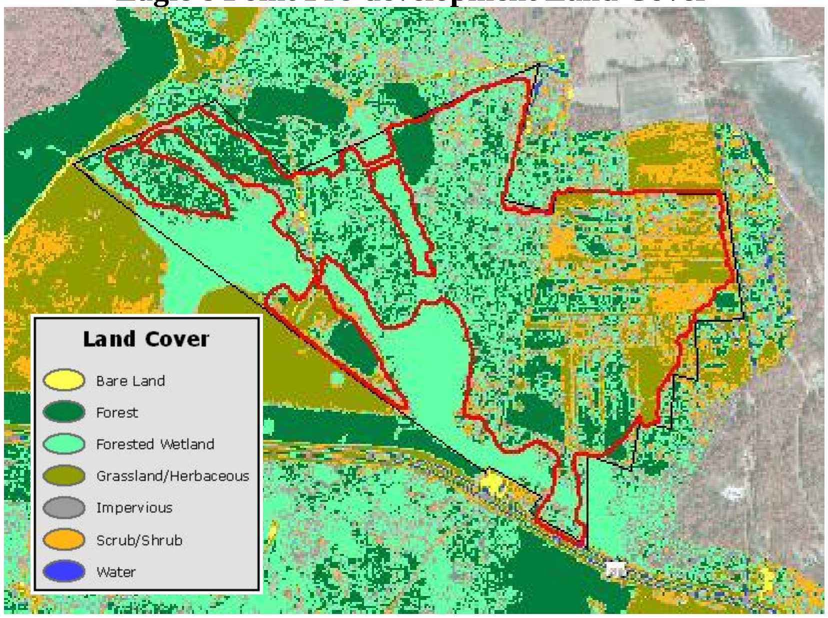


FIGURE 6
Eagle's Pointe Post-Development Land Cover

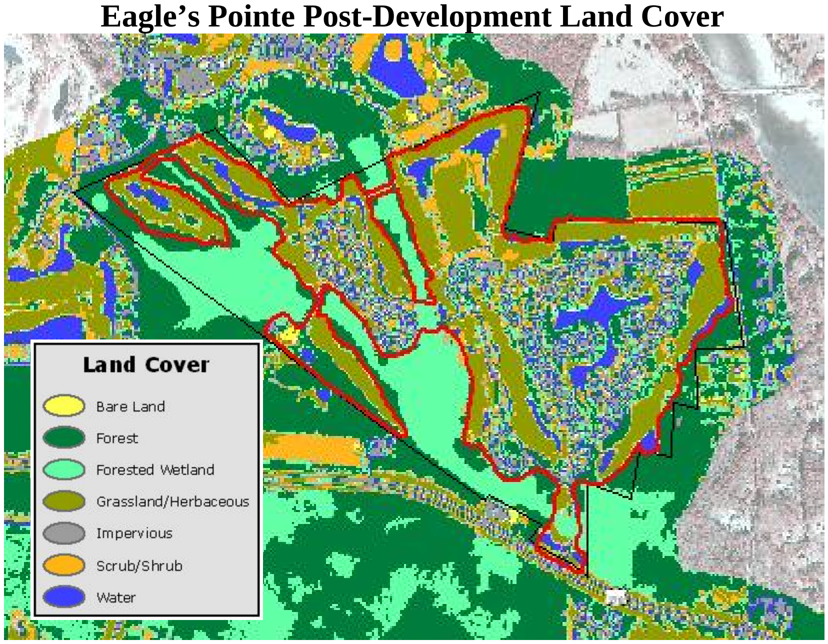


TABLE 1
Eagle's Pointe Development Area Summary

Land Cover	Pre-Development		Post-Development		Percent Change
	Area (ac)	%	Area (ac)	%	
Bare Land	0.7	0.3%	0.5	0.2%	-0.1%
Forest	161.4	60.9%	49.2	18.6%	-42.3%
Forested Wetland	7.8	3.0%	3.8	1.4%	-1.5%
Grassland	38.5	14.5%	128.1	48.3%	33.8%
Impervious	0.0	0.0%	47.1	17.8%	17.8%
Scrub/Shrub	56.6	21.3%	12.9	4.9%	-16.5%
Water	0.0	0.0%	23.5	8.9%	8.9%
TOTAL	265.1	100.0%	265.2	100.0%	
Curve Number (*CN*)	78.1		85.5		

For each condition (pre-development and post-development), daily runoff volumes were calculated of the 60-year period of record for rainfall at the nearby Savannah Airport (approximately 22,000 daily calculations). A spreadsheet analysis was used and the general order of calculation for each day was:

1. Determine daily rainfall (from National Weather Service for the Savannah Airport)
2. Determine the season (growing / dormant)
3. Determine the previous 5-day rainfall amount
4. Determine AMC condition based on 5-day rainfall amount
5. Adjust *CN* based on AMC condition
6. Calculate S (potential maximum retention after runoff begins)
7. Calculate I_a (initial abstraction)
8. Calculate Q (runoff depth)

Figure 7 illustrates typical results of the runoff analysis for pre-development and post-development conditions.

The results of the calcualtions were analyzed in various way, including comparing annual rainfall and runoff depths. Figure 8 illustates this comparison. The amount of runoff as a percentage of rainfall is highly variable from year to year. Over the 60-year period of record, pre-develolpment runoff as a percentage of rainfall varied from 7 percent to 33 percent with an average of 17 percent. For the same period, post-development runoff varied from 13 percent to 44 percent with an average of 26 percent. The change in runoff volume (as a percentage of rainfall) was much less variable. Over the same period the change (increase) in annual runoff varied from 6 percent to 11 percent with an average of 9 percent.

FIGURE 7
Typical Rainfall and Pre-development/Post-development Runoff Depths

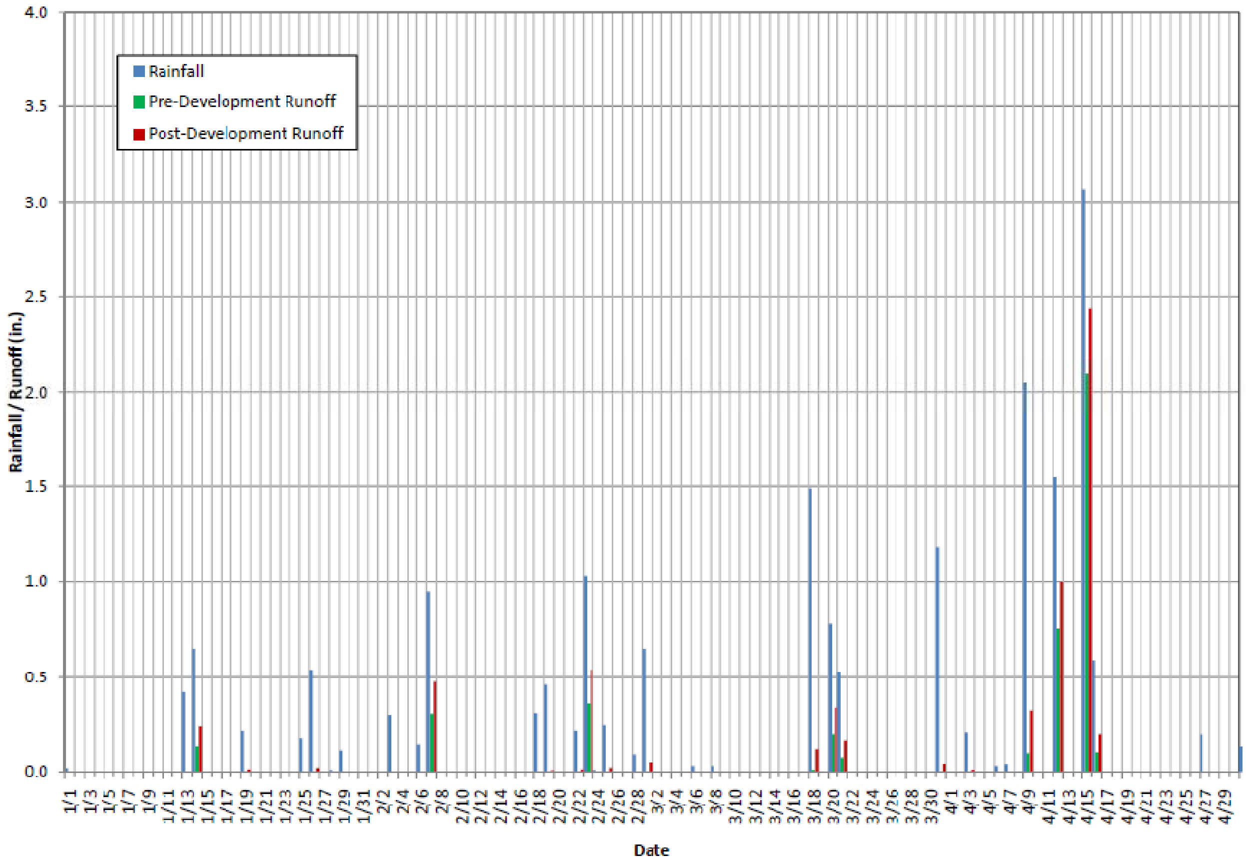
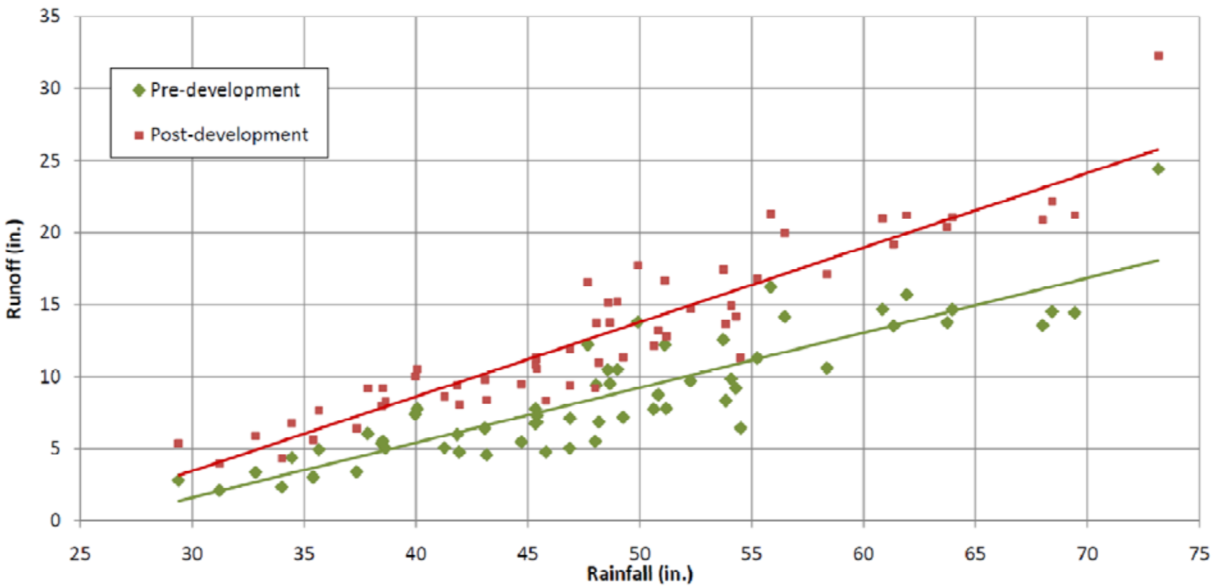
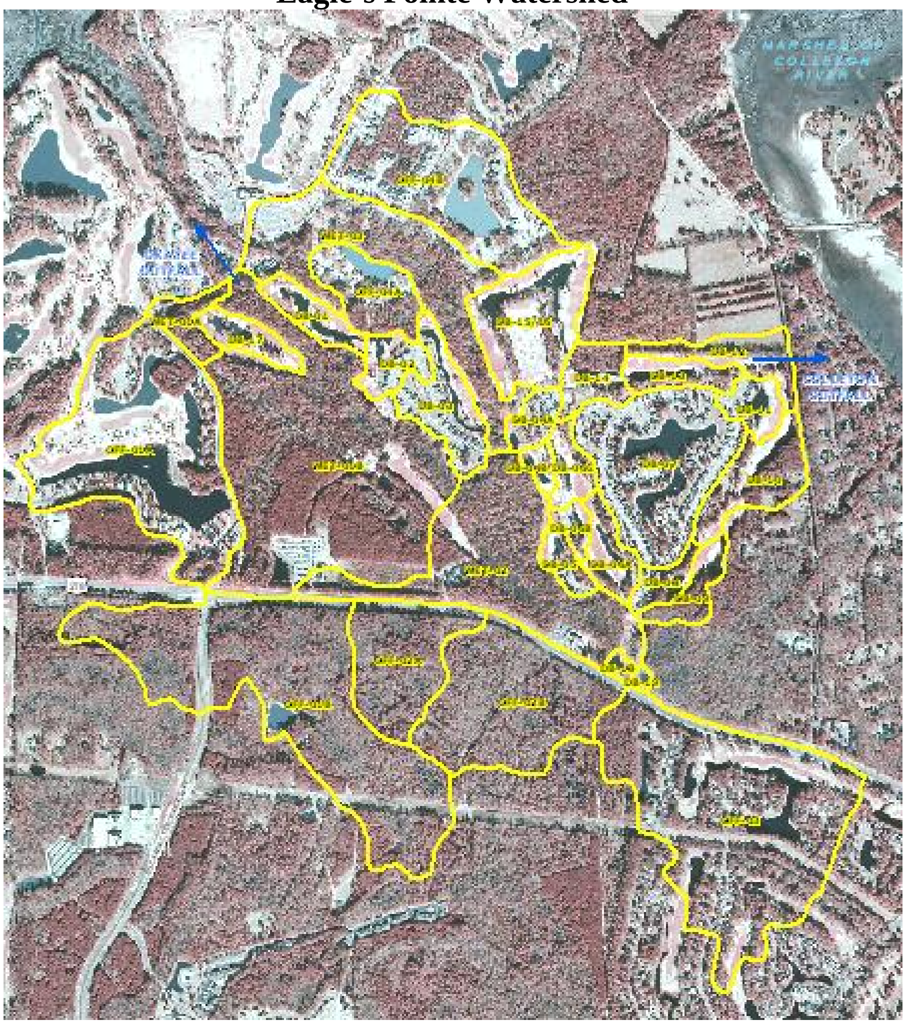


FIGURE 8
Eagle's Pointe Annual Rainfall / Runoff Relationship



Using the method outlined above, an attempt to validate the predicted runoff volumes from the Eagles Pointe PUD was made. A monthly water budget was calcualted using local rainfall data and flow monitoring data from the Colletion River outfall (see Figure 9). The water budget considered monthly values of rainfall, runoff, pond augmentation by well water, irrigation withdrawal, and evaporation. Since the lagoon system at Eagle's Pointe is used as the irrigatioin source of the golf course, irrigation water is withdrawn from the lakes and well water is used to augment the lakes. The water withdrawals (both from the well and from the lakes) is recored as a monthly total for reporting to the South Carolina Deparment of Health and Environmental Control (SCDHEC). The water budget calculations considered the larger watershed area (rather than just the development area) as illustrated in Figure 9.

FIGURE 9
Eagle's Pointe Watershed

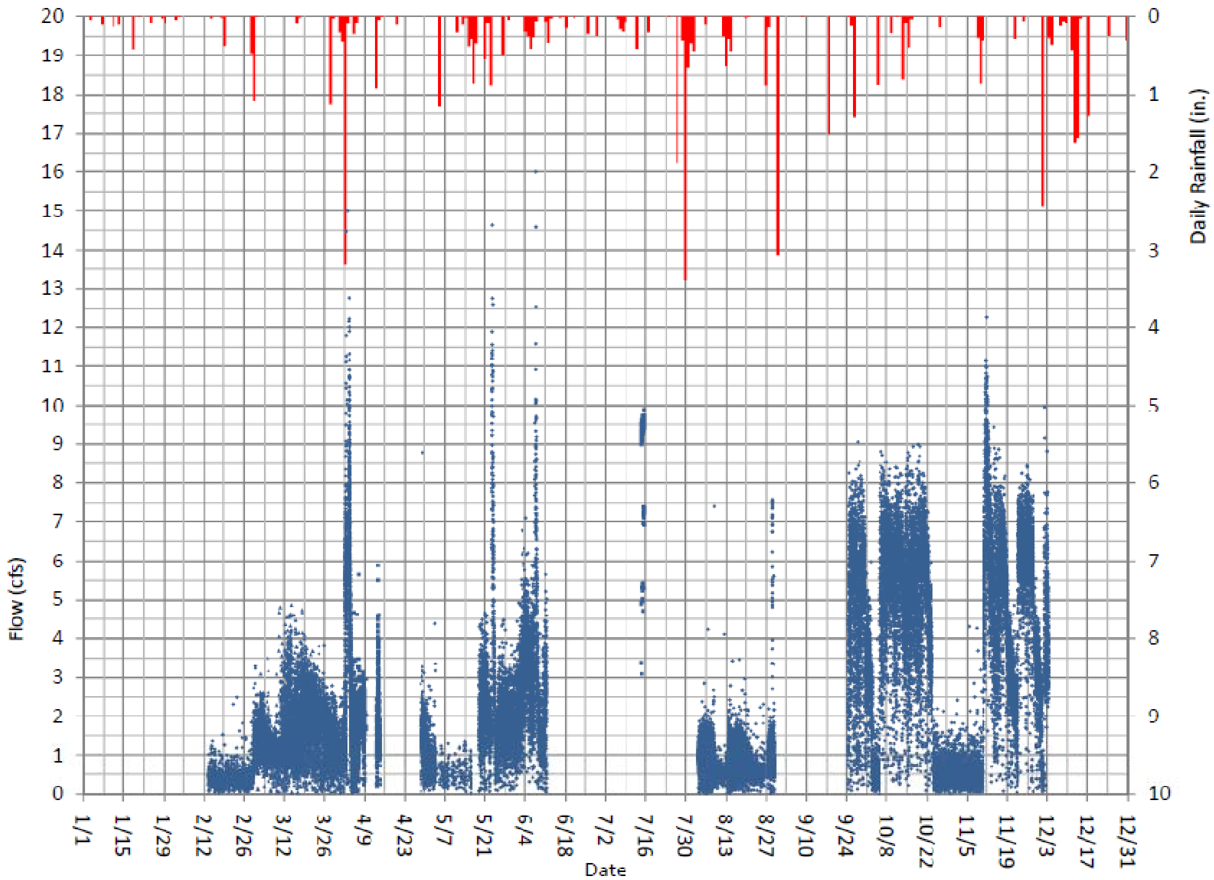


Unfortunantly, the validation results where not successful and thus were not used. Possible reasons for this include:

1. Limited flow monitoring data - due to numerous equipment failures only a handful of months have continuous flow data (see Figure 10).
2. Lack of monitoring of the second oufall from the system (Okatie Outfall, see Figure 9).
3. Lack of local and time coincident evaporation data.
4. Potential impacts of groundwater on the water budget could not be accounted for.

Future studies using long-term computer simulation of the system (with the Colleton River outflow as the calibration) may be able to provide validation of the runoff flow volume estimate method provided here.

FIGURE 10
Eagle's Pointe Rainfall and Flow Monitoring



However, research conducted by the USDA Forestry Service (Amatya, et. al., 2006) for two forested watersheds (similar to the Eagle's Pointe pre-development condition) in the Santee Experiemntal Forest near Huger, SC (Berkeley County) have indicated similar (if not higher) runoff percentages. In general, the measured annual runoff (as a percentage of rainfall) varied greatly from 12 percent to as much as 43 percent, with a long term average of approxiamtely 25 percent. This is higher than the long-term average predicted by this study for the pre-development conditon. The higher runoff volumes predicted by the Forestry Service may be attribted to the limited period of record of the Forestry Service data (20 years) and the inclusion of wetland areas in the Forestry Service study area. The Forestry Service study area include both wetland and upland areas where as the Eagle's Pointe study only considered the develolpable upland area.

BEAUFORT COUNTY'S APPROACH TO VOLUME CONTROL

Beaufort County has recently amended its Zoning and Development Standards Ordinance (ZDSO) for Stormwater Management Standards to address stormwater runoff volume. This amendment represents a major shift in the way that the County regulates development (and redevelopment) with regards to stormwater management. The amendments to this section of the ZDSO include the stated purpose of "*…no development or redevelopment shall cause the post development stormwater rates, quality or volume to increase above pre development levels…*" Beaufort County also adopted the Federal definition of "maximum extent technically feasible" in the ordinance.

The County, along with other local, regional, and state governmental entities, has long regulated stormwater management associated with development by limiting the post-development peak runoff rate to that of the pre-development peak runoff rate (for certain design storms) from a site. This generally meant that detention ponds were required to temporarily hold the stormwater runoff and slowly release it over time at a rate less than, or equal to, the pre-development peak runoff rate.

Beaufort County has also required design considerations and calculations for addressing targeted pollutants and adopted an anti-degradation goal of 10% "effective" imperviousness (5% for bacteria). The County's manual for the implementation of stormwater best management practices (BMPs) establishes a targeted percent removal for pollutants of concern – namely phosphorous, nitrogen and bacteria (i.e. fecal coliform) based on the constructed impervious surface to reach the goal "effective" imperviousness. However, the amended stormwater standards will now require new developments (and redevelopments) to first design and implement additional BMPs (structural or non-structural) or change development elements (i.e. less impervious area) to control the volume of runoff that leaves a site.

Beaufort County recently released a draft of Appendix C (Stormwater Volume Control) to the BMP Manual. The appendix addressed candidate volume control BMPs such as:

- Rooftop practices (e.g., green roofs, flat roof rainfall collection/evaporation)
- Pervious pavement
- Runoff capture and reuse for irrigation
- Disconnection of impervious area (e.g., routing rooftop runoff onto adjacent lawn surface)
- Rain gardens (and other devices designed to capture runoff and promote infiltration)
- Swales to capture runoff from highways and other roadways.

The appendix also provides the metrix for which compliance with the volume control regulation is met. The metric chosen is again "effective impervious area". Noting that when runoff from a impervious area is routed through a properly designed BMP that promotes infiltration or evaporation, the effective "imperviousness" of the area is reduced (or possibly eliminated). Based on research and long-term computer simulations, the effect on "imperviousness" of the candidate BMPs were determined. Using a combination of design practices and implementation of volume control BMPs, a designer must demonstrate a sites "effective impervious area" is less than 10 percent to be in compliance with County's regulation. Meeting volume controls may reduce or eliminate the necessity for water quality BMPs The County and its consultant are currently revising the appendix after receiving input and comments on the draft.

CONCLUSION

The question posed at the beginning of this paper was: Is it time for volume based hydrology design requirements in our local stormwater regulations? This paper has shown that there is a national shift towards controling stormwater runoff volume for varied and numerous reasons. This paper has also shown that the science and engineering tools that are necessary to address this issue are also available, but may require a fundamental shift in how stormwater from developed areas is managed. Each community must decide if VBH design requirements is right for them. Beaufort County has descided yes.

REFERENCES

Amatya, et. al., 2006. Amatya, D.M.; Miwa, M.; Harrison, C.A.; Trettin, C.C.; and Sun, G.; *Hydrology and Water Quality of Two First Order Forested Watersheds in Coastal South Carolina*. ASABE Paper No. 062182. St. Joseph, Mich.: ASABE.

NRCS, 1986. *Urban Hydrology for Small Watersheds*. USDA Natural Resources Conservation Services. Technical Release 55. June 1986.

National Research Council. 2008. *Urban Stormwater Management in the United States*, The National Academies Press, Washington, DC.

Thomas & Hutton, 2009a. *Freshwater Flow Study for Eagle's Pointe Watershed.* Prepared for Beaufort County, SC. September 10, 2009.

Thomas & Hutton, 2009b. *Opinion of Probable Cost for Stormwater Runoff Volume Control.* Prepared for Beaufort County, SC. November 6, 2009.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2007. *National Engineering Handbook*, title 210–VI. Part 630, chapter 7. Washington, DC. http://directives.sc.egov.usda.gov/.

U.S. Environmental Protection Agency, 2009. *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act,* EPA 841-B-09-001; December 2009. www.epa.gov/owow/nps/lid/section438