CONSIDERATION OF LOW IMPACT DEVELOPMENT BENEFITS IN BEAUFORT COUNTY

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ABSTRACT

The Beaufort County (County) Stormwater Best Management Practices (BMP) Manual provides guidance regarding the selection and design of BMPs necessary to treat stormwater runoff and thereby protect the high quality waters within the County. Worksheets are completed by the developer to demonstrate that the proposed BMP plan will meet the designated water quality goals.

Recent updates to the manual have focused on benefits of both runoff volume and load reduction attributed to Low Impact Development (LID) site features. Initially, the update included consideration of disconnected impervious area and onsite retention storage. Further concern regarding the freshwater runoff volume discharged to the tidal rivers led to additional evaluation of LID features. Considerations included runoff capture and reuse for lawn/landscape irrigation, recycling of “flat roof” runoff to enhance rooftop evaporation, “green roofs”, pervious pavement, and rain gardens.

This paper demonstrates how the benefits of the LID features were addressed in the worksheet calculations by an adjustment to the “effective” impervious area data entered in the worksheet. Computer modeling results were used to determine runoff volume reduction and to develop charts that reflect the reduction in effective impervious area resulting from LID implementation.

KEYWORDS

Low impact development (LID), best management practices (BMPs), effective imperviousness, runoff volume control

INTRODUCTION

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 Best Management Practices (BMPs) necessary to protect the high quality waters within the County. The manual included the consideration of site features (e.g., soil type, tributary area, imperviousness of development) as part of BMP selection and included design guidelines for many of the more common BMP types (e.g., wet detention ponds).

One of the key elements of the manual was a water quality worksheet designed to evaluate whether a proposed BMP plan would meet the recommended antidegradation goal. This antidegradation goal was established based on a pollutant loading characteristic of a low-density development with imperviousness of 10 percent. Schueler (1996) suggests that a relatively low percentage of impervious cover (10 – 15 percent) can induce adverse and irreversible changes in stream water quality. Total phosphorus (total P) was selected as the "indicator pollutant" for consideration in the worksheet. Thus, completion of the worksheet demonstrates whether or not the proposed development with selected BMPs will adequately limit total P runoff loads.

Subsequently, the manual was been updated in 2003 and 2008. The 2003 update added fecal coliform bacteria as a second indicator pollutant and included additional BMP types including bioretention ("rain gardens") and commercially-manufactured stormwater treatment technologies. The 2008 update added total nitrogen (total N) as a third indicator pollutant, and also factored the implementations of several low impact development (LID) features, such as diverting impervious area runoff onto pervious areas or providing onsite storage to reduce impervious area runoff.

The current proposed update in 2010 takes a more comprehensive approach to considering stormwater runoff volume control. In addition to reducing the stormwater runoff pollution loads to receiving waters, these controls will limit the quantities of freshwater runoff pulses to tidal receiving waters, which can cause adverse impacts to aquatic life.

Practices that were evaluated for the manual update include:

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

For each of these practices, the analysis evaluated the expected long-term runoff volume reduction, and results were compiled to support completion of a volume control worksheet.

STORMWATER RUNOFF FOR UNDEVELOPED AND IMPERVIOUS AREA

The EPA Stormwater Management Model (SWMM) was used to determine the expected long-term stormwater runoff (percent of rainfall converted to stormwater runoff) for various soil types. In this case, separate model runs were done for the NRCS soil groups A, B, C, and D, and for an impervious land area. Runs were done using a long-term rainfall record using hydrologic parameter values that have been established based on model calibration as well as literature values. Key input parameters for the simulations include the Horton infiltration rates, maximum soil storage volume, and rate of soil storage recovery after rainfall events. The results of the analysis for long-term conversion of rainfall to stormwater runoff were as follows:

- Soil group A: 4%
- Soil group B: 8%
- Soil group C: 14%
- Soil group D: 21%
- Impervious: 83%

These values were used as the basis for comparison for other practices, to determine the extent to which a developed area can control the ‘excess runoff’ (i.e., runoff beyond what would be generated by the natural undeveloped land).

EVALUATION TECHNIQUES FOR LID PRACTICES

In general, either the EPA Stormwater Management Model (SWMM) or other spreadsheet-based tools were used to determine the expected long-term stormwater runoff (percent of rainfall converted to stormwater runoff) for various soil types. Detailed results are presented elsewhere (Wagner, 2010). The general methods of evaluation and summary of the results are presented below.

Rooftop Practices

Rooftop practices that were evaluated included green roofs and roof evaporation for structures with flat roofs. The green roof includes some depth of planting media on the roof, which will capture rainwater and experience water loss through evapotranspiration, whereas the roof evaporation includes some depth of water that is allowed to accumulate 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. Review of literature suggests that the typical planting media depth for green roofs is in the range of 3 to 12 inches. SWMM was used to evaluate the expected runoff from the green roof for each of those media depths, assuming that the media would behave similarly to soil group B. Simulations were done with and without considering use of a cistern to collect excess stormwater and recirculate it back to the green roof later. Rather than explicitly modeling the capture and recirculation of water through the cistern, cistern storage volume was evaluated by providing additional surface depression storage to the green roof. Values of 1 inch, 2 inches, 3 inches and 4 inches of additional storage were evaluated.

Roof evaporation calculations were conducted using a spreadsheet tool. 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, coefficient for orifice flow from roof to cistern, roof area, and cistern volume.

The results tend to show that the roof evaporation has greater runoff reduction for equal depths of planting media (green roof) versus roof ponding depth (roof evaporation). One reason is that for an equivalent depth, the planting media provides less water storage in the voids of the media than the open water storage for roof evaporation. Another is that the roof evaporation in most cases will occur more rapidly than the evapotranspiration of the plants and planting media on the green roof.

Pervious Pavement

The current BMP Manual suggests that pervious pavement should be treated as ‘pervious developed area’ for the purposes of water quality BMP plan evaluation. This is in part based on the fact that properly designed, installed, and maintained pervious pavement should have an infiltration rate through the pavement that is greater than or equal to the infiltration rate of the underlying soil – in other words, the rate of infiltration through the pavement surface is not the limiting factor in the facility’s capability to infiltrate rainfall. However, products such as pavers may be considered pervious pavement as well, and these systems may not reduce post-development runoff to pre-development conditions. The *Chesapeake Stormwater Network Technical Bulletin No. 4* (Chesapeake Stormwater Network, 2009) shows studies that measured 70-100 percent volumetric reduction. A value of 75 percent runoff volume reduction is recommended in the Technical Bulletin. Consideration should be given to distinguishing between pavement and pavers in determining how to assess porous pavement as part of the BMP plan review process.

Runoff Capture and Use for Irrigation

Roof runoff capture and use for irrigation was evaluated using a spreadsheet tool. Spreadsheet inputs included long-term meteorological data such as daily rainfall and pan evaporation data, plus user 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.

Disconnection of Impervious Area

The 2008 BMP manual update included consideration of disconnected impervious area (i.e., routing flow from impervious area onto adjacent pervious area where it has an opportunity to infiltrate. Figure 3-6 of the manual shows the relationship between the ratio of impervious runoff source area to adjacent pervious area receiving the impervious area runoff, and the appropriate ‘effective’ imperviousness value for the impervious area. For example, if the ratio is equal to 2, the graph shows an effective imperviousness of 75 percent. This means that in the BMP plan evaluation, the impervious area should be treated as 75 percent impervious and 25 percent developed pervious area, to reflect the runoff reduction (and associated load reduction) benefit of disconnecting the impervious area.

The graph was based on model runs for an ‘average’ soil condition in Beaufort County. For the current analysis, SWMM was run for the soil groups A, B, C, and D to assess the variability by soil group and consider revising the figure to reflect that variability. 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.

Rain Gardens

In the 2003 BMP manual update, the bioretention (or rain garden) BMP was added as one of the BMPs featured with design and maintenance information. This BMP functions by capturing stormwater runoff, which can pond on the rain garden surface and infiltrate into the planting media below the rain garden surface. Runoff volume reduction is achieved by evapotranspiration of the water at the surface and in the planting media, and by infiltration from the rain garden to the subsurface around and below the rain garden. SWMM was used to evaluate the expected runoff from a combination of a developed area routing its runoff to a rain garden area. Again, the “run-on” feature of SWMM was used to route the developed area runoff to the rain garden area, which was modeled as a pervious area with depression area equivalent to the maximum ponding area, 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).

Design criteria outlined in the manual was used to determine model input. These criteria included the following:

- Water quality storage volume of 1.5 inches per impervious acre or 0.5 inch per acre, whichever is greater
- Planting media depth of 3 feet (minimum recommended value)
- Ponding depth of 6 inches (maximum allowable value)

The model was run for a medium density residential case (assumed 25 percent imperviousness) and a high intensity commercial case (assumed 85 percent imperviousness) to test both of the water quality storage volume requirements. As discussed in the manual, the surface area of the rain garden was calculated based on accommodating the water quality volume considering the ponding volume above the rain garden (6 inches in this case), plus available water storage in the planting media below the surface for average antecedent conditions. The manual suggest using a factor of 0.2 to establish the soil storage volume in the planting media, so in this case, 3 feet (36 inches) of planting media provides 7.2 inches of water storage.

Swales

Initial model runs were conducted to evaluate the potential for roadside swales to reduce runoff volumes from roadway runoff. The ‘run-on’ feature of SWMM was again used to evaluate reductions in runoff occurring when impervious area runoff (from roadway) is routed onto pervious area (swale). Evaluation of the initial results indicated that the results were 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. It is recommended that half of the swale top-width be used as the basis for the pervious area receiving runoff from the impervious roadway.

EVALUATION OF VOLUME CONTROL IN BMP PLANS

To evaluate a BMP plan for runoff volume reduction, all of the analysis findings were compiled based on the “effective” impervious area with the volume reduction controls. If a volume control reduces impervious area runoff so that it is exactly equal to pervious runoff, the “effective” imperviousness of the impervious area is zero. If there is no runoff volume control, the impervious area has 100 percent “effective” imperviousness. In cases where the runoff volume control for impervious area does not reduce the runoff to the level of a pervious surface, the “effective” imperviousness of the impervious area is determined.

Table 1 shows an example of the “effective” imperviousness based on a hypothetical impervious area with volume control. In the example, the uncontrolled impervious area has a runoff of 50 inches per year, and with the volume control BMP, the impervious area runoff is limited to 25 inches per year. For soil group A, the expected runoff from pervious area is 2 inches per year. Consequently, the uncontrolled increase in runoff in going from pervious to uncontrolled impervious condition (i.e., 100 percent effective) is 48 inches per year. With the volume control BMP, the increase in runoff is 23 inches per year. In this case, the effective imperviousness of the impervious area is calculated as the ratio of controlled runoff increase to uncontrolled runoff increase, which equals 23/48, or 48 percent.

Tables for use in the determination of effective imperviousness are included in the BMP manual for the following practices:

- Green Roof
- Flat Roof Evaporation
- Stormwater Capture and Irrigation Use
- Rain Garden

- Disconnected Impervious Area and Roadside Swale

Each of these tables shows the estimated effective imperviousness based on the four soil groups (A, B, C, and D) and various design criteria.

Table 1. Example of Effective Imperviousness Calculation

Runoff Parameter	Soil Group			
	A	B	C	D
Uncontrolled Impervious Runoff (inches)	50	50	50	50
Pervious Runoff (inches)	2	4	7	11
Controlled Impervious Runoff (inches)	25	25	25	25
Uncontrolled Increase (inches)	48	46	43	39
Controlled Increase (inches)	23	21	18	14
Effective Imperviousness	48%	46%	42%	36%

A summary of the effective imperviousness values in the tables is presented in Table 2. For each practice, the table lists the ranges of design parameters analyzed, and then the range in effective imperviousness values for each soil type.

As illustrated in the table, the effectiveness of the LID practices in reducing the effective imperviousness varies depending upon the practice and the design criteria that are applied and the soil group. In general, the flat roof evaporation, runoff capture and irrigation, and rain garden practices are the most effective at reducing effective imperviousness. In some cases, these practices can actually reduce the impervious runoff to a value less than would be expected from an undeveloped pervious area (and are represented by a negative effective imperviousness value). For the rooftop practices and runoff capture and irrigation, the effective imperviousness values tend to be lower for the more poorly drained soils (groups C and D) because these soils are expected to produce more runoff in an undeveloped state, whereas the post-development impervious runoff is not affected by the soil group. In contrast, the rain garden and disconnected impervious area practices have lower effective imperviousness values for the more well-drained soils (groups A and B), because the effectiveness of these practices is affected by the drainage characteristics of the soil for the post-development condition.

Table 2. Summary of Effective Imperviousness

LID Practice	Design Criteria	Evaluated Range	Range of Effective Imperviousness Values by Soil Group			
			A	B	C	D
Green Roof	Planting media depth (inches)	3 to 12	21 to 65%	17 to 63%	12 to 61%	4 to 57%
	Cistern volume (inches)	0 to 4				
Flat Roof Evaporation	Planting media depth (inches)	0 to 8	3 to 100%	-1 to 100%	-8 to 100%	-18 to 100%
	Cistern volume (inches)	0 to 4				
Runoff Capture and Irrigation	Ratio of irrigated area to impervious runoff area	0 to 6	11 to 100%	7 to 100%	1 to 100%	-8 to 100%
	Capture volume (inches)	0 to 4				
Rain Gardens	Planting media depth (feet)	3 to 12	-2 to 1%	-1 to 5%	-1 to 7%	-2 to 12%
	Surface ponding depth (inches)	3 to 6				
Disconnected Impervious Area	Ratio of pervious run-on area to impervious runoff area	0.2 to 5	19 to 54%	31 to 85%	42 to 90%	54 to 93%

NOTE: Cistern or capture volume of 1 inch is equivalent to 0.62 gallon per square foot of impervious runoff area.

To assess the effective impervious area for a new development, a worksheet has been developed and is presented here as **Figure 1**. The worksheet requires that the development is broken down into specific pervious and impervious land elements, and volumes 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 “effective impervious area” 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 “effective impervious area” and 60 percent of the parking lot area would be assigned to “pervious developed area.”

Figure 1. Worksheet for Determining Effective Impervious Area

Site Element	Area (acres)	Volume Control BMP	Effective Imperviousness (%)	Impervious Developed Area (acres)	Pervious Developed Area (acres)	Dedicated Open Space (acres)
TOTAL AREA (acres)		---	---			
% of Total Area	---	---	---			

Predominant Soil Group:	

An example worksheet application for a hypothetical residential development is presented in **Figure 2**. For this example, the total site area is 120 acres, with 40 acres of what would traditionally be considered impervious area. This would include rooftops, paved driveways, and paved streets. Soil group D is predominant on the site.

As shown in Figure 2, the proposed volume control BMPs would include rain gardens to treat rooftop runoff, porous pavement for all driveway areas, and swales along all of the streets. For the rain gardens, a value of 12 percent effective imperviousness is read from the manual table assuming soil group D, ponding depth of 6 inches, and planting media depth of 3 feet. The porous pavement is treated as 0 percent effective imperviousness (100 percent developed pervious area) as is the case in the most recent version of the BMP Manual. For the street runoff to swales, the value of 90 percent effective imperviousness is interpolated from values in the manual table for soil group D and ratio of street impervious area to adjoining pervious area (one-half of total swale surface area as discussed earlier) equal to 4.3. Note that the rain garden and swale entries include notes suggesting how the rain garden and swale areas were established. Overall, the volume control BMPs take the development from a 33 percent uncontrolled imperviousness to an effective imperviousness (Impervious Developed Area in the figure) of 10 percent.

The methodology for assessing the volume control BMPs has been based on evaluating individual BMPs and the runoff volume reduction benefits of each BMP. This leads to a question of what the volume reduction benefits on BMPs in series will be, and how this can be incorporated into the proposed assessment methodology. In some cases, the interaction of upstream and downstream BMPs in series can be complex.

In the absence of more detailed analysis and generation of numerous additional tables to account for all potential combinations of BMP types, it is suggested to estimate a suggested approach using the tables for the individual BMPs. In most cases, it may be appropriate to assume that the highest maximum effective imperviousness would be equal to the minimum value of effective imperviousness for each individual BMP (i.e., no additional benefit for any other BMP in the series). The lowest conceivable value of effective imperviousness would be the product of the effective imperviousness values for the BMPs in series. The suggested effective imperviousness value is the average of those two calculated values. For example, if one BMP had an individual effective imperviousness of 40 percent and another had an individual effective imperviousness of 60 percent, the effective imperviousness of the BMPs in series would be expected to be somewhere between 40 percent (minimum value of individual BMPs) and 24 percent (= 40% * 60%). The suggested effective imperviousness value would then be the average of 40 percent and 24 percent, which is 32 percent.

Figure 2. Example of Worksheet Calculations for Hypothetical Residential Development with Volume Control BMPs

Site Element	Area (acres)	Volume Control BMP	Effective Imperviousness (%)	Impervious Developed Area (acres)	Pervious Developed Area (acres)	Dedicated Open Space (acres)
Rooftop	25	Rain Garden Ponding depth = 6 inches Media depth = 3 ft	12%	3	22	0
Driveway	5	Porous pavement	0%	0	5	0
Streets	10	Swale Ratio of impervious to pervious area = 4.3 (based on 1/2 swale topwidth)	90%	9	1	0
Urban Pervious Area (e.g., lawns)	56	---	---	0	56	0
Rain Garden	5	(Rain garden area is 20% of tributary impervious area)	---	0	0	5
Dedicated open space	8.3	---	---	0	0	8.3
Swales	4.7	(Ratio of street impervious area to full swale surface area = 2.15)	---	0	0	4.7
Wet detention pond	6	---	---	0	0	6
TOTAL AREA (acres)	**120.0**	**---**	**---**	**12.0**	**84.0**	**24.0**
% of Total Area	**---**	**---**	**---**	**10%**	**70%**	**20%**

Predominant Soil Group: D

DISCUSSION OF APPROPRIATE VOLUME CONTROL TARGET

The initial recommendation on an appropriate volume control target is a threshold of 10 percent effective impervious area. One advantage of this target is that it remains consistent with the overall framework of the BMP reviews for water quality, which allow loads of total phosphorus (total P) and total nitrogen (total N) from new development up to the uncontrolled load expected from a 10 percent impervious development. Based on the example presented earlier, it appears that the goal can be met with one or more volume control BMPs in a typical development.

In general, it appears that the recommended target would be consistent with the new County stormwater ordinance that requires post-development stormwater volume to be controlled to the “maximum extent technically feasible (METF). In this case, the County considers this to be control of storm events up to the 95^{th} percentile event, which was established as a daily rainfall of 1.95 inches.

Given this rainfall amount over a 24-hour period and average antecedent moisture conditions, the SCS methodology would predict the following runoff from an undeveloped area:

- Soil type A: 0.00 inch
- Soil type B: 0.06 inch
- Soil type C: 0.33 inch
- Soil type D: 0.53 inch

So the quantity of runoff that would need to be captured from the impervious developed site would range from 1.46 inches (soil type D) to 1.95 inches (soil type A) to be consistent with the updated stormwater ordinance. For the green roof, flat roof evaporation and stormwater capture and irrigation use, the storage associated with captured/cistern storage plus rooftop storage for rooftop practices would need to be 2 inches or more to achieve a 10 percent effective imperviousness. The rain garden designs are based on a storage volume of 1.5 inches or more over the impervious area, and rain gardens on type A and B soils would capture even more volume because of the relatively rapid infiltration rates of those soil types.

IMPACT OF VOLUME CONTROL BMPS ON WATER QUALITY ASSESSMENT OF BMP PLANS AND PEAK SHAVING REQUIREMENTS

The preceding evaluations dealt strictly with the hydrologic consideration of runoff reduction. There will also be an impact on load reductions for the indicator pollutants (total N, total P and fecal coliform bacteria) that are the basis for the water quality worksheets in Section 3 of the BMP Manual, as well as peak shaving requirements for extreme storm events.

For the water quality worksheets, it will be appropriate to revise the worksheets so as not to “double count” the effectiveness of these BMPs (e.g., accounting for runoff volume reduction and then also assigning a percent load removal that already considers the runoff volume reduction). Of the evaluated volume reduction BMPs featured in the proposed update to the manual, it appears that the rooftop practice, pervious pavement, runoff capture and irrigation use, and disconnected area could be handled directly by adjusting the “developed impervious” area in the worksheets. This is how the current BMP manual does account for pervious pavement (treated as 100 percent “developed pervious” area) and disconnected area (using Figure 3-6 in the manual). For these practices, the appropriate “developed impervious” area would be the same as the “effective impervious” area calculated in the volume control worksheet (Figure 1). For the rain garden and swale BMPs, however, additional consideration must be given, as the swales and rain gardens (bioretention) are specifically identified BMPs in the worksheets with specific percent removal values. It may be appropriate to eliminate the load reduction currently built into the water quality worksheet, accounting for the BMP load reduction benefit strictly by considering runoff volume reduction.

The additions of LID practices for runoff volume control may also provide some benefit in controlling peak flows from extreme storm events. County regulations generally require that extreme events up to the 25-year return period design storm must be controlled so that the post-development peak flow does not exceed the pre-development peak flow. Though LID features are not likely to control peak runoff from extreme events to the point that the county requirements for peak shaving are met, they may lead to a reduction in required size of the peak flow attenuation facility (e.g., detention ponds).

SUMMARY

The most recent proposed update to the Beaufort County BMP Manual focuses on the runoff volume control benefits of several different volume control BMPs. For each BMP, the volume control benefit is addressed by defining an “effective impervious” value for impervious area tributary to the BMP, based on the practice design features and soil type. A worksheet has been developed to determine the effective impervious value for a given development based on the results of the BMP analyses presented in the proposed updates, and example calculations are also presented. Based on the findings, the preliminary recommendation for volume control is an effective imperviousness of 10 percent. With the additional consideration of volume control, the water quality BMP worksheet calculation methods will need to be reviewed and refined as appropriate to provide consistency. Further study of impacts on peak shaving calculations for extreme storm events, and benefits of BMPs in series is also warranted.

REFERENCES

CDM, 1998 (updated 2003, 2008). *Beaufort County Manual for Stormwater Best Management Practices.*

Cheaspeake Bay Network, 2009. *CSN Technical Bulletin No. 4, Technical Support for the Bay-Wide Runoff Reduction Method, Version 2.0*.

Schueler, T, 1994. “The Importance of Imperviousness.” *Watershed Protection Techniques*, Volume 1, Number 3, pp. 100-111.

Wagner, R.A., 2010. “Calculation of LID Benefits in Meeting New Development Standards.” *Proceedings of the ASCE 2010 International Low Impact Development Conference* (available April 2010).

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