ENHANCING LAND DEVELOPMENT DECISION-MAKING TO REDUCE WATER QUALITY IMPACTS

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Abstract. As upstate South Carolina continues to develop, stormwater runoff must be managed for its quantity and quality. Therefore, an incentive-based program to encourage developers to use low impact development (LID) designs is being developed for Greenville County. To achieve this goal, various best management practices (BMPs) were researched for their effectiveness and feasibility, and a post construction index (SITE SCALE) was developed to rate development. The SITE SCALE helps address questions about the benefit of small structures scattered around a development as compared to larger structures located near the outlet point and also considers economics of BMPs. The SITE SCALE is related to available parameters to scientifically anchor the SITE SCALE and make it directly related to stormwater runoff and water quality characteristics that reflect benefits of structural, non-structural, management and maintenance practices. The SITE SCALE is a function of nine (9) defined sub-factors with each having a range from zero to a maximum score of 5, 10, 15 or 20. Total scores for all sub-factors are used to differentiate between the water quality impacts of legacy, conventional, and innovative housing developments/LID designs.

Once the SITE SCALE was developed, it was tested for consistency using current developments and the IDEAL model. The SITE SCALE was determined an effective tool overall, however, more specific criteria for nitrogen, phosphorus, and bacteria levels were needed to accurately portray water quality parameters in these areas. Traditional developments received scores between 30 to 50 out of 100, and LID developments received scores between 50 and 80, though the LID goal was to achieve a score above 70. These low LID scores may be attributed to the fact that LID developments must continue to improve in order to achieve desired water quality.

Keywords. Low impact development, BMP, best management practice, post construction, water quality, LID

INTRODUCTION

Currently, no incentive-based programs exist for the use of low impact development (LID) strategies for stormwater in South Carolina's Saluda-Reedy watershed. The goal of this project is to develop and refine a spreadsheet that can be used to yield a post construction index (SITE SCALE) to identify and define whether residential developments qualify for a density bonus based on water quality objectives.

This goal was achieved by completing several objectives as listed below.

- Based on available literature review, a spreadsheet based SITE SCALE was developed to quantitatively relate best management practice (BMP) efficiencies, advantages, and disadvantages with their possible water quality benefits.
- Various traditional and LID subdivisions were scored using the SITE SCALE to allow revisions and modifications to be made. Such will ensure fair, accurate, representative scores for developments. All modifications must be made considering the goal that the SITE SCALE must be user friendly.
- Select developments were modeled in the Integrated Design and Evaluation Assessment of Loadings (IDEAL) stormwater modeling program, and loadings compared to SITE SCALE scores in order to better modify the SITE SCALE.

This paper focuses on the first and second objectives. Ultimately, the scores received by the developments from this spreadsheet will be used to evaluate economic solutions for managing stormwater quality. The developer may choose from several economic, acceptable combinations for stormwater management techniques. These solutions have the potential to improve developers' margins, and provide funds for retrofit of stormwater BMPs in older developments, as well as improve water quality in current and future development.

Emphasis is being placed on reducing the amount of impervious surfaces—surfaces that do not allow water to penetrate, such as pavement and rooftops create increased stormwater volume. This increased volume causes flooding in areas downstream if not handled properly. Traditionally, stormwater detention ponds have been used to control this increased flow. However, these ponds may not provide removal for contaminants such as nitrogen, phosphorus, bacteria, and sediment that alternative BMPs are able to provide. Other BMPs seek to increase infiltration and return the runoff to a more natural system.

Low impact development includes many of these alternative BMPs in their designs. These BMPs include infiltration trenches, green roofs, sand filters, cisterns, stormwater wetlands, bioretention cells, bioswales, and pervious pavement.

SITE SCALE SCORING SYSTEM DEVELOPMENT

Seven traditional developments and five LID subdivisions were analyzed using the SITE SCALE. This SITE SCALE was evaluated using nine criteria shown below. These criteria included a runoff factor, soil factor, detention factor, infiltration factor, sediment factor, nitrogen factor, phosphorus factor, bacteria factor, and maintenance factor. These factors encouraged natural processes such as overland flow, minimal fertilizer usage, and BMP use. Each factor allowed a score from 0 to 10, 10 being the highest score. A brief description of each factor follows:

Runoff Factor. Primarily a function of surface cover. Reflects relative amount of rainfall that becomes surface runoff and considers degree to which the normal pervious surfaces maintain an undeveloped runoff condition as well as whether surfaces become impervious.

Soil Factor. Reflects soil texture, permeability, organic matter and degree to which soil is maintained in undisturbed condition as well as whether surfaces become impervious.

Detention Factor. Reflects influence of timing parameters in slowing runoff. Primarily varies in response to extent to which impervious areas are directly connected to drainage system, i.e., whether rooftops and driveways drain directly to a storm sewer or whether runoff flows across well established lawn.

Infiltration Factor. Highly dependent on LID practices and will consider addition of practices that are installed specifically to aid infiltration like enhanced bioswales and bioretention cells. Will consider practices that go beyond getting infiltration back to the undeveloped level, and should actually increase local infiltration.

Sediment Factor. Evaluates whether site is fully stabilized. This is critical because sediment potentially settles in LID practices and reduces their effectiveness because of clogging. It also carries nutrients, bacteria, and other materials.

Nitrogen Factor. Reflects whether measures have been included that reduce likelihood of nitrogen entering runoff such as use of native vegetation that does not require large applications of fertilizer, as well as measures that provide infiltration and nutrient uptake by plants.

Phosphorus Factor. Reflects whether measures have been included that reduce the likelihood of phosphorus from entering runoff such as use of native vegetation that does not require large applications of fertilizer, as well as measures that provide settling of particulate phosphorus and nutrient uptake by plants.

Bacteria Factor. Reflects whether measures have been included that reduce likelihood of bacteria from entering runoff such as reduction in attractive nuisances for Canada geese, control of pets, and houses on sanitary sewers.

Maintenance Factor. Considers whether installed practices require maintenance and whether they are expected to be maintained over the long term. It considers whether maintenance of practices is the responsibility of individual homeowners, a homeowner association or similar group, or community/county.

These nine factors were given various weights based on their importance and allowed a possible score of 100 points. These weights were varied to view the effect that each performance criteria had on the overall score. The SITE SCALE was designed to score traditional developments between 30 and 50, whereas LID developments were intended to receive a score above 70. This method of scoring allowed a distinct separation to be made between traditional and LID scores while still leaving room for higher scores as stormwater technology improves. From this SITE SCALE score, users may easily determine whether or not the development of interest has potential to meet the requirements for a density bonus, i.e., an increase in the number of housing units placed on a parcel. No questioning as to whether or not the development can be considered LID results.

RESULTS AND DISCUSSION

Literature review provided limited insight on the effectiveness of each BMP and allowed for quantitative performance data to be collected. Additionally, other advantages and disadvantages for each BMP were noted. Total nitrogen and total suspended solids removal were best achieved with the use of pervious pavement. Total phosphorus was best removed with the use of a bioretention cell. Many sources did not include bacteria data, but the bioretention cell also provided the most bacteria removal from the sources given than the infiltration trench. The cost of each BMP varied due to differing vegetation and media costs.

Social benefits to adding BMPs such as bioretention cells, bioswales, or stormwater wetlands were found to be the increased aesthetic values and increased property values. Many of these BMPs were able to be disguised in the landscape so that they were unnoticed or even preferred over a wet pond.

An added advantage to green roofs includes lowered heating and cooling costs as they provide added insulation. Other advantages to the various BMPs studied include water conservation. Increased infiltration recharges groundwater. Cisterns also minimize potable water usage for activities such as irrigation, where water does not have to meet drinking standards.

Disadvantages to BMPs with sand media included raised nutrient and bacteria levels as well as flooding due to clogging. Sand filters and pervious pavement had high maintenance costs and risked clogging as sediment and other debris entered the BMPs. Also, BMPs that do not allow as much infiltration were subject to problems such as increased bacteria levels and vectors. Cisterns allowing collected water to stagnate over long periods promoted bacteria growth. Additionally, stormwater wetlands were found to promote vectors, a problem for residential areas.

The SITE SCALE is a spreadsheet-based system that was developed so that there is a weighting factor for each of the nine factors. This system allows each factor to have a score ranging from 0 to 10. A weighting factor adjusts each factor based on its importance and can be modified if a given region has a TMDL that is of critical concern. The SITE SCALE score for Greenville County, South Carolina will be used to set density bonuses for developers as a way to promote LID and better water quality. It ties the economics associated with development and the cost of LID and is designed to determine whether a proposed development will be allowed a density bonus.

Site Scale System Evaluation

Table 1 shows an example scoring sheet for LID development 1. It shows the preliminary score on a scale of 0 to 10 for each factor, weighting factors that are multiplied by the preliminary score to yield the factor weighted score in the last column. The sum of the factor weighted scores is the SITE SCALE. Several different weights were considered for each factor in the SITE SCALE scoring guide. The weighting factors listed in Table 1 were considered the most representative and are the weights currently being used.

Sediment, runoff, and detention were given higher weights due to the importance of reducing peak flows, and minimizing sediment—the largest culprit of water quality impairment in South Carolina. Because bacteria is difficult to accurately measure and results fluctuate, it was given smaller weight than other parameters.

The site scale results for the traditional developments analyzed may be viewed in Table 2. In order for each development to remain anonymous, their names were substituted with numbers. Table 2 also gives the weighted scores for each factor for the traditional developments 1-7.

The runoff, detention, and sediment factors were considered to affect water quality more than the others, so they were given greater weights than the other factors. Also, because bacteria levels are difficult to define due to rapid growth and death rates, this factor was given less weight than the remaining factors. From these weighted values, a total score for each development was attained. These scores may be found at the bottom of Table 2. The average score was approximately 41. These results are expected since traditional developments were projected to receive between 30 and 50 points on the SITE SCALE.

The post construction index results for the LID developments analyzed may be viewed in Table 3 which gives the weighted scores for LID developments 1-5.

The LID developments did not score as high on the SITE SCALE as originally expected. The average score for the LID developments was 67.2. Several reasons give validity to these lower scores. First, the developments contained commercial space. Therefore, increased impervious area contributed to poor runoff and soil scores. Additionally, because the use of LID practices is a somewhat new concept, developments are gradually implementing these practices and must continue to enforce these techniques to become truly LID. Detention and infiltration scores were improved, however, due to BMP usage.

Table 1. Example Development Scoring Report.

Factor	Preliminary Score	Reason for Determining Factor Score	Weighting Factor	Factor Weighted
Runoff	2	<30% natural cover	1.5	3
Soil	6	Cecil soil, ~70% impervious.	1	6
Detention	10	Runoff is routed to rain garden.	1.5	15
Infiltration	10	Rain gardens included in design.	1	10
Sediment	10	Good ground cover established, tree plan specified.	1.5	15
Nitrogen	6	Fertilizer plan established.	1	6
Phosphorous	6	Fertilizer plan established.	1	6
Bacteria	8	Sanitary sewers used and no ponds included in design.	0.5	4
Maintenance	8	County is responsible for maintenance.	1	8

Table 2. Weighted Scores for Traditional Developments 1-7.

SITE SCALE FACTOR	1	2	3	4	5	6	7	Potential Score
	Factor Weighted Score							
Runoff	12	6	12	9	9	12	6	15
Soil	8	6	8	6	6	6	8	10
Detention	9	12	15	12	9	0	6	15
Infiltration	0	0	0	0	0	0	10	10
Sediment	3	6	6	6	6	3	3	15
Nitrogen	2	0	0	2	0	2	2	10
Phosphorous	2	0	0	2	0	2	2	10
Bacteria	4	5	4	4	5	4	5	5
Maintenance	4	4	2	4	0	4	4	10
Total Score	44	39	47	45	35	33	46	100

Table 3. Weighted Scores for LID Developments 1-5.

SITE SCALE FACTOR	1	2	3	4	5	Potential Score
	Factor Weighted Score					
Runoff	3	9	3	3	3	15
Soil	6	6	2	2	6	10
Detention	15	15	12	12	12	15
Infiltration	10	10	10	10	10	10
Sediment	15	15	15	15	12	15
Nitrogen	6	6	6	4	2	10
Phosphorous	6	6	6	4	2	10
Bacteria	4	5	5	4	4	5
Maintenance	8	8	6	6	4	10
Total Score	73	80	65	60	58	100

IDEAL Modeling

In order to validate SITE SCALE scores, several developments were modeled in IDEAL. Results of this modeling were related to their corresponding SITE SCALE scores. As expected, the nitrogen factor score increases with decreased nitrogen loading. Because the SITE SCALE scores nitrogen factors by considering scheduling policies and general fertilizing limits, a tight correlation could not be achieved. More specific factors effecting nitrogen uptake such as plant types, soil types, and specific loading rates may produce a better correlation. Similar to nitrogen, phosphorus loading also decreased with increased SITE SCALE score. Bacteria loading results did not show any correlation with the SITE SCALE score. Because bacteria are difficult to model, the SITE SCALE criterion was not able to precisely represent bacteria levels in the development discharge. Like the bacteria results, sediment loading did not show a correlation between SITE SCALE score and IDEAL loadings.

The largest sediment loading values, 566 lb and 916 lb, were from large developments. These numbers nevertheless reveals a poor correlation between sediment loading and SITE SCALE sediment factor score. Sediment loadings per unit area rather than sediment loading may be more appropriate for comparison among developments in order to eliminate land area differences. The sediment score normalized to land area gives a negative correlation which is more reasonable than the positive correlation. However, more specific sediment criteria may be needed in order to achieve a tighter correlation among these values.

CONCLUSIONS

In order to refine a SITE SCALE scoring guide that accurately represents water quality parameters for development, a literature review was conducted, various developments were tested using the SITE SCALE, and the developments were modeled in IDEAL.

The results of the literature review allowed BMP performance to be evaluated using quantitative data. The changing nature of biological systems did not allow constant removal rates to be found, but a range of removal rate values for nitrogen, phosphorus, total suspended solids, and fecal coliform suggested that bioretention cells were the most consistent, effective BMPs for LID, especially for small areas. Stormwater wetlands were more effective than the traditional retention ponds, but their tendency to attract wildlife and vectors make them a less popular choice for residential BMPs.

The SITE SCALE was determined to be a sufficient tool for the scoring of development. Traditional developments scored within 30 to 50—the expected range, while current LID developments scored between 50 and 80—lower than expected. While the SITE SCALE could be further modified to raise these scores, these low scores also reveal that LID designers must become more aware of BMP selection, fertilizer usage, and maintenance procedures.

The SITE SCALE should be further modified as advances in bacteria modeling develop in order to better calculate bacteria removal efficiencies in BMPs. Additionally, in order to better reflect fertilizer application rates, the SITE SCALE fertilizer section can be modified to give specific amounts. The SITE SCALE will ultimately provide developers with a user friendly tool to help improve low impact, cost effective designs.