Water Quality Planning Services for Northwest Cary Area Plan - Example On-Site BMP Evaluation

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Introduction

This Technical Memorandum summarizes the analysis conducted by CH2M HILL to compare several BMP approaches for two development types, both under existing rules and under the approach proposed for the Northwest Cary Area Plan (NWCAP). The development types evaluated include:

1) A typical single-family subdivision, with a density of approximately 6 units/acre covering 50 acres, and
2) A typical shopping center, floor-area ratio (FAR)=0.18, 70% impervious surface, occupying 12 acres

The analysis was conducted for two targets defined by the following assumptions:

Target A — The sites need to achieve a maximum loading for Total Nitrogen (TN) of 3.6 lb/ac-yr, meet 85% TSS removal, and include peak runoff control so that the post-development peak flow does not exceed the pre-development peak for the 1-year, 24-hour rainfall event.

Target B — The sites need to achieve TN loading of 6 lb/ac-yr maximum that seems possible under the NWCAP with the wider buffers and open space, meet 85% TSS removal, and control the 1-year, 24-hour rainfall event.

For each of the two development types, CH2M HILL identified several stormwater management scenarios consisting of combination of various Best Management Practices (BMPs). These scenarios were analyzed to determine whether they achieve the performance targets. CH2M HILL estimated land requirements to deploy the BMPs and planning level capital costs.

Methodology and Assumptions

This is a planning level analysis on hypothetical sites and consequently, a number of simplifying assumptions were made. In the absence of specific site drawings, the computations and quantities estimated apply to the sites only in general terms. The following are specific factors considered in the analysis:

- The Simple Method was applied to compute pollutant loadings based on available Event Mean Concentrations (EMCs). Land use data were taken from input data to existing PLOAD model runs.
- The TR-55 methodology was applied to estimate runoff volumes and required detention storage (SCS, 1986).
- The predevelopment condition is assumed to correspond to woods in good condition with hydrologic soil type D. Times of concentration were assumed based on observations for similar situations.
- Prince George's County's publication *Low Impact Development Hydrologic Analysis* was used to estimate bioretention requirements.
- Pollutant removal efficiencies were taken from sources published by the North Carolina Department of Environment and Natural Resources (NCDENR, 2001) and supplemented with other literature sources.
- Planning-level costs were estimated from a variety of sources including NCDENR (2001).
- BMPs were assigned to the sites as fractions of the total area.

Residential Site

Hydrology

Table 1 summarizes the application of the TR-55 methodology to estimate detention requirements for this land use for the 1-year, 24-hour storm, which has a depth of 3 inches. CN values were based on Hydrologic Group D soils as a worst case scenario. Group C and D soils are typical in the NWCAP portions of Wake County.

Table 2 shows the summary of computations to determine the volume of bioretention to control both peak flow and runoff volume for the 1-year, 24-hour storm, according to methods used by Prince George's County (Maryland) (2000).

Table 1. Summary of hydrologic modeling for residential land use.

Before Development	
CN	77
Runoff (in)	1.07
Time of concentration (h)	1.00
Peak flow (cfs)	27
After Development	
CN	90
Runoff (in)	1.98
Time of concentration (h)	0.25
Peak flow (cfs)	113
Detention Volume Needed (ac-ft)	3.5
Fraction of the site area	2.3%

Table 2. Bioretention requirements for residential land use.

Existing CN	77
Proposed CN[1]	85
Bioretention storage needed (ac-ft)[2]	2.58
Area needed (ac)	5.17
Fraction of site	11%

[1] with impervious area disconnection
[2] assuming 6-inch storage per facility

Pollutant Loading

Table 3 shows the BMPs considered to control stormwater on site and their removal efficiencies for total nitrogen (TN) and total suspended solids (TSS).

Table 3. BMPs and removal efficiencies used for residential land use.

BMP Type	***Removal Efficiency***	
	TN	*TSS*
Extended Wet Detention Pond	25%	85%
Stormwater wetlands	40%	85%
Bioretention	25%	85%
Infiltration trench	30%	85%
Vegetated filter strip	30%	25%
Grass swales	20%	35%

The overall efficiency E of a combination of BMPs in series is computed as

$$E = 1 - \sum_i (1 - E_i) \qquad (1)$$

where E_i is the efficiency of each individual BMP.

Table 4 summarizes the stormwater treatment scenarios analyzed. Table 5 shows the results of the pollutant loading resulting from each of these scenarios.

Table 4. Summary of stormwater management scenarios for residential land use.

Scenario	Description[1]
0	No treatment
1	Drainage over filter strip[2] to closed conduit storm drains and conveyed to extended detention pond.
2	Drainage over filter strip[2] to grass swales and conveyed to extended detention pond.
3	Drainage over filter strip[2] to bioretention facilities to grass swales to stream
4	Drainage over filter strip[2] to bioretention facilities to grass swales to extended detention pond
5	Drainage over filter strip[2] to bioretention facilities to grass swales to stormwater wetlands
6	Drainage over filter strip[2] to infiltration trenches[3] to grass swales to extended detention pond
7	50% of the site drains according to Scenario 3 and the remainder according to Scenario 2

[1] Unless noted the BMPs are applied in series in the sequence indicated by the description.
[2] It is assumed that lawns and backyards act as filter strips.
[3] Because of the low infiltration capacity of D soils, these are infiltration trenches modified with a slow release drain (Argue, 2002)

Table 5. Results of BMP modeling for residential land use.

Scenario	TSS Removal	TN Export (lb/ac-yr)
0	0.0%	9.1
1	88.8%	4.8
2	92.7%	3.8
3	92.7%	3.8
4	98.9%	2.9
5	98.9%	2.3
6	97.9%	2.7
7	91.8%	3.9

Cost and Space Requirements

The cost estimates by no means include all of the components and are limited to the main BMPs. For example, the cost of installing an extended detention wet pond is included but not that of laying the storm drain system to convey the stormwater to the pond. Bioretention costs include the facilities themselves but not the grass swales receiving the effluent from them. In general, design, permitting, and the cost of the land are not included.

For all scenarios that involve bioretention, the cost reflects the fact that the facilities can be built as part of site landscaping.

The analysis assumes 300 houses for all scenarios. Therefore, BMP space requirements do not reduce the number of units that can be built; instead, the density increases. The space requirement is the total fraction of the site that provides the main stormwater management treatment. For example, it includes the area for a pond but does not include easements for conveyances. This fraction is not totally unusable as part of the development; for instance, bioretention facilities can be deployed in front and backyards.

Subject to the conditions above, Table 6 summarizes the costs and space requirements of the various treatment scenarios.

Table 6. Summary of cost and space requirements for residential land use.

Scenarios 1 and 2 – Extended Detention Pond	
Capital cost (NCDENR, 2001)	$ 102,000
Fraction of site required	2%
Scenario 3 — Bioretention	
Capital cost ($\$3/\text{ft}^2$)	$ 720,000
Fraction of site required	11%
Scenario 4 — Bioretention and pond in series	
Assume that the effluent from the bioretention facilities discharges into the pond	
Capital cost	$ 581,000
Fraction of site required	11%
Scenario 5 — Bioretention and stormwater wetlands in series	
Assume that the effluent from the bioretention facilities discharges into the wetlands	
Capital cost	$ 569,000
Fraction of site required	11%
Scenario 6 — Infiltration and pond in series	
Assume that the effluent from the infiltration trenches discharges into the pond	
Capital cost	$ 274,000
Fraction of site required	5%
Scenario 7 — 50% Bioretention and 50% pond	
Assume that half of the storage requirement is provided by the pond and the remainder by bioretention facilities	
Capital cost	$ 423,000
Fraction of site required	11%

Analysis

Table 7 summarizes the variation of removals and cost. Table 8 shows which scenarios meet the performance standards.

Table 7. Range of stormwater control variables and cost for residential land use.

Variable	Minimum	Maximum	Average
TN export (lb/ac-yr)	2.3	4.8	3.5
TSS removal	88.8%	98.9%	94.5%
Site area requirement	2%	11%	5%
Cost	$102,000	$720,000	$396,000

Table 8. Compliance with performance standards for residential land use.

Scenario	85% TSS Removal	3.6 lb/ac-yr TN Export	6 lb/ac-yr TN Export
0			
1	✓		✓
2	✓		✓
3	✓		✓
4	✓	✓	✓
5	✓	✓	✓
6	✓	✓	✓
7	✓		✓

Table 8 indicates that all of the scenarios meet the TSS removal criterion and the TN criterion at the 6 lb/ac-yr threshold. Only scenarios 4, 5, and 6 meet the 3.6 lb/ac-yr criterion. These scenarios involve drainage through swales and treatment with bioretention facilities or infiltration trenches followed by a extended detention pond or stormwater wetlands.

A comparison of the costs would appear to indicate that a more stringent TN standard does not necessarily imply higher capital costs. However, this observation needs to be qualified with the effectiveness of the treatment system and the comprehensiveness of the cost estimates. For example, in Scenario 3, bioretention alone does not have the removal efficiency to attain 3.6 lb/ac-yr; therefore, regardless of the relative high cost, the BMP's performance is the limiting factor. Second, the cost estimates are not comprehensive. As stated elsewhere, the costs only include the main treatment components because the cost of others, such as length of grass swales, depends on site-specific features. In addition, operation and maintenance (O&M) costs are not considered and some of the BMPs analyzed have higher O&M costs than others. For example, bioretention has a higher capital cost than a conventional stormdrain/pond system, but it requires less maintenance over the life of the project. Straightforward cost comparisons can only be performed if a real-life site is analyzed. The cost estimates presented are still useful in evaluating the BMPs in that they provide an order of magnitude of the expenditure.

A third consideration for comparing alternatives is the effect of the various BMPs on site usage. For example, a pond requires a dedicated portion of the site that is not available for other uses. For the same number of houses, bioretention would allow larger lots than a pond because bioretention facilities can be built in front and back yards. It is possible that a developer may be able to obtain better profit for larger lots thereby offsetting the greater bioretention capital cost. This consideration may be important but at the same time more difficult to quantify for a generic site.

In conclusion, straightforward cost comparisons of alternatives can only be performed if a real-life site is analyzed. However, the cost estimates presented are still useful in evaluating the BMPs in that they provide an order of magnitude of the expenditure.

Commercial Site

Hydrology

Table 9 shows the land breakdown for the commercial site.

Table 9. Distribution of site area for commercial land use.

Lot Breakdown	Area (ac)	Fraction
Building area	2.16	18%
Non-building impervious area	6.24	52%
Non-building pervious area	3.60	30%

Table 10 summarizes the application of the TR-55 methodology to estimate detention requirements for this land use for the 1-year, 24-hour storm, which has a depth of 3 inches. CN values were based on Hydrologic Group D soils as a worst case scenario. Group C and D soils are typical in the NWCAP portions of Wake County.

Table 10. Summary of hydrologic modeling for commercial land use.

Before Development	
CN	77
Runoff (in)	1.07
Time of concentration (h)	0.67
Peak flow (cfs)	8.3
After Development	
CN	93
Runoff (in)	2.25
Time of concentration (h)	0.10
Peak flow (cfs)	42.7
Detention volume needed (ac-ft)	1.0
Fraction of total site area	2.9%
Fraction of non-building area	3.1%

Table 11 shows the results of computations to determine the volume of bioretention to control both peak flow and runoff volume for the 1-year, 24-hour storm, according methods used by Prince George's County (MD) (2000).

Table 11. Bioretention requirements for commercial land use.

Existing CN	77
Proposed CN	93
Bioretention storage needed (ac-ft) [1]	1.40
Area needed (ac)	2.80
Fraction of total site area	23.3%
Fraction of non-building area	28.5%

[1] assuming 6-inch storage per facility

The approach was modified to take into account BMPs in series. For instance, the green roof was modeled by assuming that it controls 40% of the rainfall on it (NCDENR, 2001). The excess becomes the inflow to receiving bioretention. The remainder of the site is treated by bioretention facilities. The combined effluent discharges to stormwater wetlands.

When two or more BMPs operate in series, the total peak attenuation was distributed equally among them.

Pollutant Loading

Table 12 shows the BMPs considered to control stormwater on site and their removal efficiencies for TN and TSS.

Table 12. BMPs and removal efficiencies used for commercial land use.

BMP Type	**Removal Efficiency**	
	TN	*TSS*
Extended Wet Detention Pond	25%	85%
Stormwater wetlands	40%	85%
Green roof	25%	85%
Bioretention	25%	85%
Infiltration trench	30%	85%
Vegetated filter strip	30%	25%
Grass swales	20%	35%

The overall efficiency of a combination of BMPs in series is computed according to Equation 1, presented earlier. Table 13 shows the stormwater treatment scenarios analyzed.

Table 13. Summary of stormwater management scenarios for commercial land use.

Scenario	Description[1]
0	No treatment
1	Drainage to closed conduit storm drains and conveyed to extended detention pond.
2	Drainage to grass swales and conveyed to extended detention pond.
3	Drainage to grass swales and conveyed to stormwater wetlands, with 25% of site pre-treated with bioretention
4	Drainage over filter strip to bioretention facilities to grass swales and then to stream
5	Drainage through filter strips to infiltration trenches[2] to grass swales and then to stormwater wetlands
6	Roof drainage treated by green roof and discharged to bioretention facilities to swales and then to stormwater wetlands. Remainder of site drains through filter strips to bioretention facilities to grass swales and then to the wetlands.

[1] Unless noted the BMPs are applied in series in the sequence indicated by the description.
[2] Because of the low infiltration capacity of D soils, these are infiltration trenches modified with a slow release drain (Argue, 2002)

Table 14 summarizes the results of the pollutant loading resulting from each of these scenarios.

Table 14. Results of BMP modeling for commercial land use.

Scenario	TSS Removal	TN Export (lb./ac-y)
0	0.0%	13.8
1	85.0%	10.4
2	90.3%	8.3
3	92.4%	5.9
4	92.7%	5.8
5	98.9%	3.3
6	99.1%	3.5

Cost and Space Requirements

The cost estimates and space requirements for the commercial land use shown in Table 15 are derived using the same assumptions as for the residential site.

Table 15. Summary of cost and space requirements for commercial land use.

Scenarios 1 and 2 – Extended Detention Pond[1]	
Capital cost[2]	$ 44,000
Fraction of non-building area required	4%
Scenario 3 — Stormwater wetlands[3]**, 25% of site pretreated with bioretention** Assume that the effluent from the bioretention facilities discharges into the wetlands	
Capital cost	$ 133,000
Fraction of non-building area required	12%
Scenario 4 — Bioretention	
Capital cost	$ 401,000
Fraction of non-building area required	28%
Scenario 5 — Infiltration trench[4] **- stormwater wetlands in series** Assume that the effluent from the infiltration trenches discharges into the wetlands	
Capital cost	$ 135,000
Fraction of non-building area required	7%
Scenario 6 — Greenroof and bioretention- stormwater wetlands in series	
Capital cost	$ 629,000
Fraction of non-building area required	17%

[1] The ED pond is assumed to be 3 feet deep on average

[2] Source: NCDENR (2001)

[3] The stormwater wetlands is assumed to be 2 feet deep on average

[4] Infiltration trenches assumed to be 4 feet deep with a porosity of 0.32.

Analysis

Table 16 summarizes the variation of removals and cost. Table 17 shows which scenarios meet the performance standards.

Table 16. Range of stormwater control variables and cost for commercial land use.

Variable	Minimum	Maximum	Average
TN export (lb/ac-yr)	3.3	10.4	6.2
TSS removal	85.0%	99.1%	93.1%
Non-building area requirement	4%	22%	10%
Cost	$44,000	$629,000	$231,000

Table 17. Compliance with performance standards for commercial land use.

Scenario	85% TSS Removal	3.6 lb/ac-yr TN Export	6 lb/ac-yr TN Export
0			
1	✓		
2	✓		
3	✓		✓
4	✓		✓
5	✓	✓	✓
6	✓	✓	✓

Table 17 indicates that all of the scenarios meet the TSS removal criterion. Scenarios 3, 4, 5, and 6 meet the TN criterion at the 6 lb / ac-yr threshold, and scenarios 5 and 6 meet it at the 3.6 lb / ac-yr level.

As with the residential case, a more stringent TN standard does not necessarily require higher capital costs. The reasons are the same as stated earlier: effectiveness of the BMPs and the comprehensiveness in the cost estimates. The site usage factor is exemplified by Scenario 6, which takes better advantage of space by using a green roof and freeing up a portion of the non-building area for other uses. For a particular developer, this feature may be extremely valuable. As with the residential case, straightforward cost comparisons can only be done for a real-life site but that the cost estimates presented are nonetheless still useful in evaluating the order of magnitude of the capital expenditure.

It is also important to note that while technically, the BMPs in Scenarios 5 and 6 can be shown to comply with the TN standard at 3.6 lb / ac-yr, they may be difficult to permit. These BMPs are either somewhat innovative, as is the case for the green roof, or are not widely accepted in Wake County and North Carolina Piedmont, as is the case of infiltration trenches. Therefore, while technically feasible, designs showing these technologies to comply with the more stringent TN standard may not be approved by Town staff.

Conclusions

For the example residential land use, BMP combinations exist that control the 1-year, 24-hour storm and meet the 3.6 lb/ac-yr TN and 85% TSS removal targets at a cost ranging approximately between $274,000 and $581,000. Less expensive alternatives can meet the 6 lb/ac-yr target.

The commercial site can be designed to meet the runoff peak flow criterion and there are BMP alternatives that achieve the 6 lb/ac-yr or 3.6 lb/ac-yr limits. For all of these, the cost ranges approximately between $133,000 and $629,000. For the 6 lb/ac-yr, the control options require a portion of the non-building area from 7% to 28% dedicated to stormwater management. For 3.6 lb/ac-yr, the space requirement is between 7% and 17% of the non-building area. One of the least costly options involves infiltration trenches, but these devices historically have a high failure rate and are not well accepted in the Piedmont region of North Carolina.

The most expensive option involves a green roof over the building combined with bioretention and stormwater wetlands. The green roof adds considerably to the cost but has the advantage of reducing the portion of the non-building area. For a site with 30% perviousness, the estimates indicate that the majority of the pervious areas must be used for stormwater management. Green roofs would be an innovative technology in the area because there are no known applications in North Carolina.

Straightforward cost comparisons cannot be made unless a complete economic analysis is conducted to take into account the opportunity cost of the various scenarios. The costs given correspond to the main components of the BMP treatment but do not include savings that can be realized in other aspects of the development. For example, these figures do not include the savings if swales are installed instead of storm sewers.

References

Argue, J R., ed. (2002), *Water-Sensitive Urban Design: Basic Procedures for 'Source Control' of Stormwater (Handbook for Australian Practice)*, Stormwater Industry Association, Sydney, Australia.

North Carolina Department of Environment and Natural Resources (2001), *Stormwater Best Management Practices*, *Division of Water Quality*, Raleigh, North Carolina.

Prince George's County (2000), *Low-Impact Development Hydrologic Analysis*, Department of Environmental Resources, Largo, Maryland.

Soil Conservation Service (1986), *Urban Hydrology for Small Watersheds*, US Department of Agriculture, Technical Release 55, Washington, DC.