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Technical Memo

To: Keith Huff	
From: Patrick Blandford	Project: Salem Creek Watershed Master Plans
CC: Ron Geiger	
Date: June 14, 2013	Job No: 153206-018

RE: EPA SUSTAIN Modeling for Salem Creek Watersheds

DRAFT

PURPOSE

The City of Winston-Salem (City) is faced with an evolving assembly of NPDES Permit requirements stemming from its initial Phase I permit back in 1995 through the present, where the City's Phase I permit has been renewed with additional guidance. With each evolution, the permit language is expanded to include more program enhancements that address the quality of storm water discharges from the City's MS4. The City has responded to these requirements by incorporating water quality analysis into its watershed master planning process and performing non-point source reduction services within its MS4 program. In addition, the surface waters in the region have not improved, resulting in 303(d) listings and development of TMDLs. As a result, new permit language is being further refined to require the City to address MS4 wasteload contributions to waters with an approved TMDL. A historical summary of actions taken by the City to address these requirements is presented below:

1. Event Based Monitoring to Develop Loading Rates
2. Modeling or Estimation of Loads from Watersheds
3. Ambient and Synoptic Water Quality Modeling
4. Identification and Evaluation of Structural Storm Water Management Measures
5. Identification and Evaluation of MS4 Wasteload Pollution Controls

This technical memorandum summarizes activities taken to identify structural storm water management measures (i.e., structural best management practices or BMPs) within the Salem Creek watershed. The primary purpose of these measures is to reduce MS4 loads that are contributing to the fecal coliform impairment in Salem Creek. The current MS4 wasteload is 4.22×10^{12} colony forming units per day (cfu/day) and the new allocation is 2.95×10^{11} (cfu/day) for a 93% reduction. The City's proposed permit recognizes that a greater collection of pollution controls are needed and that structural BMPs may play an important role in that collection. This technical memorandum frames the purpose, approach, and results of the structural BMP assessment and supporting water quality analysis in context for both the past watershed master planning efforts and emerging TMDL MS4 wasteload reduction efforts.

BACKGROUND

HDR Engineering, Inc. of the Carolinas (HDR) has assisted the City in producing watershed master plans for the 15 basins within City municipal limits. The origins of these master plans included the estimation of non-point source loads from various land uses utilizing the results of the event based storm water sampling that HDR performed in the early 1990's. The estimation of these annual loads and resulting concentrations was performed in the RUNOFF block of XP-SWMM, coincidentally the same model used to perform hydrologic and hydraulic analysis. As the water quality portion of the City's Program grows, there is a need for more flexibility than currently provided in the XP-SWMM software. Since the early 1990's, a number of land use load estimation tools and models have been developed that provide far more flexibility, support, and integration than XP-SWMM. One of these tools, EPA's SUSTAIN, satisfies this need and provides other added value to the City's program and planning efforts. In particular, EPA SUSTAIN combines a number of

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Benefits of SUSTAIN

popular, tested models into a GIS framework for not only the estimation of non-point source loads but also the water quality routing of fate and transport processes, performance evaluation of common structural BMPs, and cost-benefit optimization of said BMPs and other low impact development practices. HDR recognized the opportunity to transition existing efforts in XP-SWMM for non-point source load estimation to EPA SUSTAIN and to leverage the structural BMP performance evaluation and cost estimation features.

Since 2007, the Phase I permits have included a requirement to address urban runoff in TMDL approved waters. The original language focused on the development and implementation of the Water Quality Recovery Plan which included planning for structural BMPs. However, this language has evolved to not be inclusive of structural BMPs only and more direct about reducing MS4 waste load contributions rather attainment of water quality standards. In either case, the City recognizes a need to identify structural BMPs and evaluate their potential for implementation as part of an overall MS4 waste load reduction strategy. The SUSTAIN model is adept at performing this analysis. Traditional structural BMPs, such as wet ponds, wetlands, and bioretention areas, can be input into the hydraulic network of the model so that they receive and treat sub-basin runoff. These structural BMPs, when evaluated with a continuous long-term simulation, can be assessed for their performance against a variety of storm volumes, durations, and intensities, providing an overall picture of performance. Furthermore, the SUSTAIN framework provides an associative cost for the structural BMP simply based on cost indices of excavated/fill material or in a more complex manner based on cost indices for distinct construction elements. Lastly, optimizations can be performed to size the structural BMPs for the hydrologic response of the contributing drainage area or as part of a larger overall strategy to meet load reduction values, percentages, or concentrations. It should be noted that, without extensive calibration and monitoring, predicting structural BMP performance is limited to a relative evaluation amongst equivalent structural BMPs; however, there is value in this understanding when making decisions about projects in light of construction constraints. As such, HDR used this model as an evaluation framework to assess a subset of structural BMPs that were screened from a larger subset of opportunities for their individual performance and their collective performance.

BMP SELECTION AND MODEL DEVELOPMENT

HDR performed a screening analysis of potential BMP opportunities from the retrofit reconnaissance field investigations performed in the five Salem Creek watersheds. Through the use of simple feasibility metrics, the screening analysis identified the top candidate sites that provided the most treatment potential for available area and least amount of implementation constraints. The eleven highest ranking sites regardless of basin location were then configured into SUSTAIN. The following table highlights the screening metrics.

Table 1. Screening Criteria for Structural BMPs

Evaluation Criteria	Basis of Metric
Ownership Type	Public Private Commercial Private Residential
Acceptance of Significant Drainage	Drainage Area
Future Growth Impact	Present Imperviousness Future Imperviousness
Pollutant Loading Impact	Pollutant Load Relative Ranking
Ability to Treat First Flush	Water Quality Volume Preferred BMP Design Depth
Treatability of Pollutant of Concern	BMP Efficiency
Permitting Involvement	Dam Permit Required Wetland Permit Required Stream Impacts Permit Required

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Q: When designing BMPs, what vertical depth were used for BMP-type

Contributing drainage areas were delineated from the Watershed Master Plan sub-basins and structural BMP parameters were derived or estimated based on available information. These parameters typically included surface area and depth of the structural BMP, outlet control configuration, infiltrative capacity, first order decay rates, and cost indices for excavated/fill material. The cost indices were based on HDR's recent experiences with structural BMP construction costs and included a $1.50 per cubic foot of excavated storage material for a wet pond and $2.50 per cubic foot of excavated material for a bioretention. The bioretention cost per cubic foot is greater due the added cost of filter media and planting. The conceptual design of the structural BMPs adhered to the standards of the North Carolina DENR Storm Water BMP Manual to the extent practicable for retrofit sites. Test structural BMPs for bioretention and wet ponds were performed separate from the Salem Creek work to approximate first order decay rates for fecal coliform removal efficiencies for an ideal first flush loading event. The continuous simulation was performed for an average year of rainfall production. The following table summarizes the structural BMP sites identified for SUSTAIN evaluation (additional information on each structural BMP is provided in a table at the end of this memo). The infiltration BMP types were entered as bioretention and the detention BMP type were entered as wet ponds. Figure 1 displays the location of these structural BMPs and their contributing drainage areas.

was

What decay rate?

Any consideration for geese/vectors to pond? by SUSTAIN

Table 2. BMPs Screened for Modeling in SUSTAIN

ID	Location	BMP Type	Location	Status
BR-3	Winston Lake Park	Infiltration	Public	Retrofit (pond)
BR-5	Lower Skyland Park	Detention	Public	New (floodplain)
PE-4	Upper Bloom-Blanding Park	Infiltration	Public	New (open space)
PE-5	Lower Bloom-Blanding Park	Infiltration	Public	New (open space)
SAU-3	Happy Hill Park	Detention	Public	New (floodplain)
SAU-5	84 Lumber (Lowery Street)	Detention	Commercial	Retrofit (pond)
SAU-9A	Washington Park	Detention	Public	New (floodplain)
SAU-10	Marketplace Mall/Washington Park	Infiltration	Public	New (floodplain)
SAM-2B	Douglas Battery Manufacturing Park	Infiltration	Commercial	New (open space)
SAM-3B	Konnoak Elementary (Renon Street)	Detention	Public	New (open space)
SAM-8A	Miller Park	Detention	Public	New (floodplain)

The transition to SUSTAIN was manageable, given the existing foundation of base data from the watershed master planning efforts and the similarity of simulation routines between XP-SWMM and SUSTAIN. However, a number of deviations were made to create efficiency in the analysis and maximize capabilities of SUSTAIN.

- First, all five Salem Creek basins (Peter's Creek, Brushy Fork, Upper, Middle, and Lower) were aggregated to create a comprehensive watershed model in order to perform whole system evaluation. Sub-basins were aggregated to the contributing tributary in order to reduce the number of modeling elements and improve computational efficiency. Typically, the number of sub-basins was aggregated to 10-15 percent of their original total. Because long-term continuous simulations are performed, the reduction in number and increase in size of sub-basins is not a concern.
- SUSTAIN is not limited in the categorization of land uses like XP-SWMM is, so the land use categories for hydrologic parameterization were used verbatim but were grouped in some instances where it made sense, such as grouping all roadway land uses regardless of their edge of pavement treatment (e.g., with gutters, without gutters, ditched-lined, etc.).
- The loading rates used in XP-SWMM were replicated in SUSTAIN but regional event mean concentrations (cfu/100 mL) were added for fecal coliform because none previously existed.

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How achieved? Q x concentration x 2.447x10^9 cf/mt / day = cfu

However, fecal coliform is not a mass based constituent, so post processing of the results (e.g., pounds, mg/L) had to be converted to common units for fecal coliform (colony forming units).

- For simplicity, the hydraulic network of pipes and open channels in the watershed were modeled as zero length elements with no travel time, which results in mass balancing occurring at the next downstream node per each time step with no lag or decay of the mass.
- Lastly, SUSTAIN relies on more physical based runoff simulations, such as Green-Ampt or Horton's equation as opposed to NRCS method. Green-Ampt was used. Both these changes are appropriate for water quality modeling where departure of hydrologic and hydraulic performance over a long-term continuous simulation is less significant than event based modeling. This represents the full transition of the modeling environment necessary to support the historical land use load estimation efforts of the watershed master plan.

information needed to show difference in influent vs. effluent concentrations

Q = 43% of rain/year (365 days) / day = Q/day

A = 5Ac x 0.118" / day

.18" / day rain

hydrological function

cumulative concentration thru watershed - land use, decay rates, etc.

cfu/day = Q(Flow) x concentration x 2.47x10^9 constant

MODELING RESULTS

The total existing condition annual daily fecal coliform loading produced by the SUSTAIN model was 5.0 x 10^{12} cfu/day which is higher than the total load identified in the City's TMDL (4.22 x 10^{12} cfu/day). The model results are considered reasonable because there are many factors not included in the model that may increase or decrease this daily load. These factors include the fate and transport fecal coliform through the watershed, variations in local event mean concentrations, as well as other contributing non-point sources not accounted for (i.e. sanitary overflows and leaks). The model produced is sufficient for the relative comparison of the proposed BMP performance and generalized assessment of the MS4 impacts to the overall fecal coliform loading.

The model was first set up to perform an analysis of a single set of BMPs with fixed dimensions; these simulations are known in the model framework as the "current scenario". The fixed dimensions were the maximum BMP dimensions supported by each site based on a limited visual assessment. "Current scenario" simulations were run initially to establish rankings based on individual site development potential. The "current scenario" simulations allow for multiple assessment points within a watershed, meaning all results can be mutually exclusive to each other. This scenario resulted in a daily fecal coliform reduction of approximately 1.9 percent. The potential construction cost for these structural BMPs is on the order of $7-8 million based on excavation cost indices.

SUSTAIN's highlighted feature is an optimization routine that uses genetic or scatter algorithms to evaluate initial simulations for the purpose of directing and optimizing potential solution sets of various sized structural BMPs. After performing the "current scenario," optimization simulations were performed to establish a range of pollutant reduction versus cost (i.e. cost curve). Optimization simulations are limited to a single assessment point, which typically is the pour point of the watershed, but can be intermittently adjusted throughout the watershed for other objectives. These simulations were performed to optimize the pollutant reductions across all sites by allowing the model to adjust mainly the size of the surface area of the structural BMPs within 75 to 125 percent of the proposed surface area. From the cost curve, a single cost-effective solution for all structural BMPs was identified and then separately evaluated. In addition, the cost indices were evaluated further for sensitivity during results post-processing, especially where a pond retrofit may only require some embankment and outlet control construction. This scenario resulted in identifying a solution that resulted in a daily fecal coliform reduction of approximately 1.9 percent. The potential construction cost for these structural BMPs is on the order of $7-8 million based on excavation cost indices.

The following two tables summarize the top five structural BMPs of these two scenarios when they are ranked by their cost-effectiveness (counts of cfu removed). Because structural BMP performance is typically measured for a period of representative hydrology, the load removed is reported as cfu/year. The performance of all structural BMPs evaluated in SUSTAIN is provided in a table at the end of this memo.

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Q: How is load removed calculated?

Table 3. Rank, As Part of Current Scenario

Rank	ID	Location	Approximate Size (acres)	Removal Efficiency (%)	Load Removed (cfu/year)*
1	PE-5	Lower Bloom-Blanding Park Bioretention	0.4	63.8	6.8×10^{12}
2	SAU-5	84 Lumber (Lowery Street) Wetpond	1.1	70.3	2.3×10^{12}
3	BR-5	Lower Skyland Park Wetpond	3.2	72.4	1.5×10^{13}
4	SAM-3B	Konnoak Elementary (Renon Street) Wetpond	0.8	71.4	1.0×10^{12}
5	SAU-9A	Washington Park Wetpond	1.1	70.0	2.6×10^{12} converted to 7.12×10^{9} cfu/day

Table 4. Rank, As Part of the Optimal Solution Set

Rank	ID	Location	Approximate Size (acres)	Removal Efficiency (%)	Load Removed (cfu/year)*
1	PE-5	Lower Bloom-Blanding Park Bioretent	0.5 (+)	68.9 (+)	7.3 x 1012 (+)
2	BR-5	Lower Skyland Park Wetpond	2.6 (-)	67.1 (-)	1.3 x 1013 (-)
3	SAU-5	84 Lumber (Lowery Street) Wet pond	1.3 (+)	75.4 (+)	2.4 x 1012 (+)
4	SAM-3B	Konnoak Elementary (Renon Street) Wet Pond	0.7 (-)	66.6 (-)	9.6 x 1011 (-)
5	BR-3	Winston Lake Park Bioretention	0.6 (-)	77.2 (-)	1.2 x 1012 (-)

what does (-) or (+) mean?

This type of modeling and evaluation provided a number of conclusions and observations. Some of the key observations and conclusions from this study with its contributing assumptions are summarized below.

- The 11 structural BMPs modeled in SUSTAIN demonstrated around 1.9 percent reduction in fecal coliform loading for the modeled portion of the Salem Creek watershed for the period of record treating 3 percent of the total watershed. This underlines that structural BMP development has a limited cost-effective role in fecal coliform reduction.
- The optimized solution does not demonstrate significantly more fecal coliform reduction over the "current scenario" for the cost provided. This may be because of a number of reasons including the limitations established on optimization of parameters, the model compilation of a solution set, and the relatively small solution set of structural BMPs input into the model.
- The top ranking structural BMPs provide 1.4 to 1.5 percent of the 1.9 percent reduction at less than half the proposed cost of the 11 structural BMPs.
- On average, of the 11 structural BMPs evaluated, wet ponds were more cost effective than bioretention. The Winston Lake Park bioretention site was the best performing bioretention site and had the largest drainage area of the three proposed bioretention sites. What if influent more polluted?
- Despite a higher assumed removal efficiency for bioretention (85 percent) versus wet ponds (70 percent), the assumed cost index for bioretention made these structural BMPs less cost-effective for this study. The sensitivity of the cost index was evaluated during results post-processing, but lowering the cost did not make a substantial difference in the ranking until the value was comparable with wet ponds, which is likely not the case. Retrofitting existing ponds for water quality controls is a cost-effective strategy.

seems correct, seems high for removal

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- Even when evaluating the sensitivity of the cost indices for retrofitting in results post-processing, these same six structural BMPs were ranked highest but in different orders.

FUTURE MODEL CAPABILITIES

There are a number of incremental steps the City can take to improve the overall accuracy and function of the SUSTAIN model. With each possible improvement, HDR can assist the City in evaluating the cost for instituting the improvement with respect to the model simulation and prediction reliability. This discussion should occur within the context of how the City will be using the model to make decisions or record performance. A short list of improvements to consider includes:

1. Detailed watershed monitoring to support calibration of various hydrologic and water quality parameters.
2. Detailed structural BMP monitoring to support calibration of BMP performance.
3. Incorporation of existing BMPs and ponds to reflect the existing reduction in loading. It is recommended these be included either as an adjusted land use loading rate or as multiple composite BMPs in lieu of each structure being individually modeled.
4. The incorporation of hydraulic elements, such as channels and pipes, to improve dynamic routing as well as provide travel duration for water quality fate and transport processes to occur.
5. Adaption of land use loading rates to reflect the influence of non-structural practices on source reduction or remediation.
6. Ultimately use the model to represent the estimated fecal coliform loading or other pollutant loading associated with MS4 runoff within reasonable tolerances and demonstrate the need for identification of other pollutant sources.
7. Detailed cost accounting of structural BMP construction to establish a database of cost parameters.

RECOMMENDED NEXT STEP

HDR recommends a number of steps the City can take to process the findings from this analysis.

- Initially, use the ranking as a starting point for the structural BMP development as part of an overall strategy for reducing fecal coliform wasteload from the MS4.
- Begin to vet more fully the prioritized list of structural BMPs for development with public funds or seek grants using the results of the SUSTAIN modeling as part of the decision basis. This may include siting the other structural BMPs from the screening effort as perspectives on working on non-public evolve with possibility of P3 funding options.
- Incorporate other watershed water quality objectives and goals into the decision making for Salem Creek, such as addressing impairments for copper and zinc and potential nutrients in the future.
- Continue to enhance the model's capability to more accurately predict and track pollution control measures for both structural BMPs and select non-structural BMPs as a tool for MS4 wasteload compliance by implementing the aforementioned model improvements.
- Formulate the procedure by which the SUSTAIN model and its capabilities will be used in other basin planning efforts throughout the City

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Table 5. BMPs Screened for Modeling in SUSTAIN

				Site Characteristics			
ID	Location	Ownership	BMP Type	Status	Drainage Area (ac)	Impervious (%)	Load (cfu/year)
BR-03	Winston Lake Park	Public	Bioretention	Retrofit (pond)	18	41.9	1.5E+12
BR-05	Lower Skyland Park	Public	Wet Pond	New (floodplain)	388	19.4	2.0E+13
PE-04	Upper Bloom-Blanding Park	Public	Bioretention	New (open space)	5	43.5	3.7E+11
PE-05	Lower Bloom-Blanding Park	Public	Wet Pond	New (open space)	135	34.5	1.1E+13
SAU-03	Happy Hill Park	Public	Wet Pond	New (open space)	108	15.7	5.0E+12
SAU-05	84 Lumber (Lowery Street)	Commercial	Wet Pond	Retrofit (pond)	50	24.2	3.2E+12
SAU-09A	Washington Park	Public	Wet Pond	New (floodplain)	64	24.5	3.7E+12
SAU-10	Marketplace Mall/Washington Park	Public	Wet Pond	New (floodplain)	15	8.4	4.6E+11
SAM-02B	Douglas Battery Manufacturing Park	Commercial	Bioretention	New (open space)	9	66.9	7.5E+11
SAM-03B	Konnoak Elementary (Renon Street)	Public	Wet Pond	New (open space)	29	16.7	1.4E+12
SAM-08A	Miller Park	Public	Wet Pond	New (floodplain)	23	26.7	1.5E+12

influent ?

Table 6. BMPs Screened for Modeling in SUSTAIN

ID	Proposed BMP Performance					Optimal Solution BMP Performance				
	Approximate Size (acres)	Removal Efficiency (%)	Load Removed (cfu/year)	Cost ($)	Cost Effectiveness ($/cfu x 10^6 removed)	Approximate Size (acres)	Removal Efficiency (%)	Load Removed (cfu/year)	Cost ($)	Cost Effectiveness ($/cfu x 10^6 removed)
BR-03	0.7	79.7	1.2E+12	$317,036	$0.26	0.6	77.2	9.3E+11	$263,623	$0.22
BR-05	3.2	72.4	1.5E+13	$1,732,271	$0.12	2.6	67.1	9.8E+12	$1,411,845	$0.10
Bioretention PE-04	2.7	85.9	3.2E+11	$1,190,665	$588,060	$3.75 $1.84	3.1	86.0	2.7E+11	$1,342,503	$4.22
	(117,612 ft²) ≈ 4 ft depth for bioretention cell									
PE-05	0.4	63.8	6.8E+12	$432,501	$0.06	0.5	68.9	4.7E+12	$522,184	$0.07
SAU-03	4.9	82.8	4.2E+12	$2,049,180	$0.49	4.4	80.5	3.4E+12	$1,827,420	$0.45
SAU-05	1.1	70.3	2.2E+12	$243,922	$0.11	1.3	75.4	1.7E+12	$295,202	$0.12
SAU-09A	1.1	70.0	2.6E+12	$549,543	$0.21	1.3	73.2	1.9E+12	$620,675	$0.23
SAU-10	1.1	65.7	3.0E+11	$438,961	$1.47	1.0	64.3	1.9E+11	$408,903	$1.40
SAM-02B	0.7	82.9	6.2E+11	$290,890	$0.47	0.7	82.7	5.1E+11	$287,469	$0.46
SAM-03B	0.8	71.4	1.0E+12	$182,536	$0.18	0.7	66.6	6.9E+11	$151,172	$0.16
SAM-08A	0.6	69.2	1.0E+12	$268,917	$0.26	0.6	70.7	7.4E+11	$285,717	$0.27

7,696,422

$7,416,713

$\boxed{\Sigma_{x} = \$15,113,135}$