Final Technical Report

Anacostia Wetland Study Demonstration

Anacostia LID Project Phase V

U. S. Environmental Protection Agency
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PRINCE GEORGE'S COUNTY
Department of Environmental Resources

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Overview

The Anacostia River flowing through the backyard of the U.S. Congress and the White House is a national treasure. Unfortunately, it has been severely compromised by urban decay, misuse, polluted runoff, and benign neglect. This freshwater tidal wetland system, draining an urban area encompassing 176 square miles in the District of Columbia and Prince George's and Montgomery Counties, Maryland, comprises the Anacostia Watershed. One of the key water pollution problems in the Anacostia watershed is storm water runoff. EPA and Prince George's County Government (PGCG) has worked together for several years to help control polluted runoff. These efforts have resulted in over 20 Low Impact Development (LID) projects and the development of a Green Highways Program, and improved water quality. LID projects are Best Management Practices (BMPs) focusing on low maintenance landscaping and other techniques that can easily be maintained to control storm water runoff.

Implementing LID projects provides the County with an opportunity to demonstrate how LID techniques can be used to maintain pre-development watershed conditions for new development projects, to retrofit existing urban areas, and to control polluted runoff. These actions improve the ecosystem.

This EPA /PGCG joint project consists of three (3) components:

I. BMP-DSS Model Enhancement: To enhance the Model to include more BMPs and improve the software so that it can more efficiently and accurately identify and place appropriate pollution control techniques at any selected project sites;

II. Anacostia Off-Line Tidal Wetland Study: To conduct a detailed monitoring, modeling, and analysis of the performance of this newly created wetland; and

III. Porous Concrete/Porous Asphalt Experiment and Research: To ascertain the differences between pervious concrete and porous asphalt in regards to durability, maintenance requirements, and the ability to transmit or filter key contaminants such as hydrocarbons.

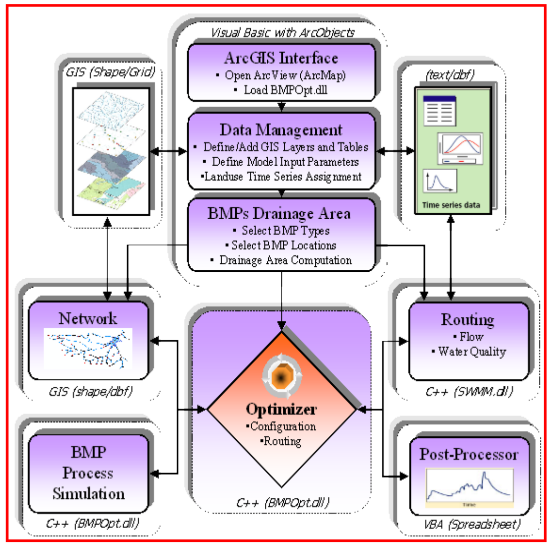
The detailed description of the above three project components is presented in detail in the following sections. This Final Technical Report is posted on the following County website:

http://www.princegeorgescountymd.gov/Government/AgencyIndex/DER/index.asp

I. BMP-DSS Enhancement

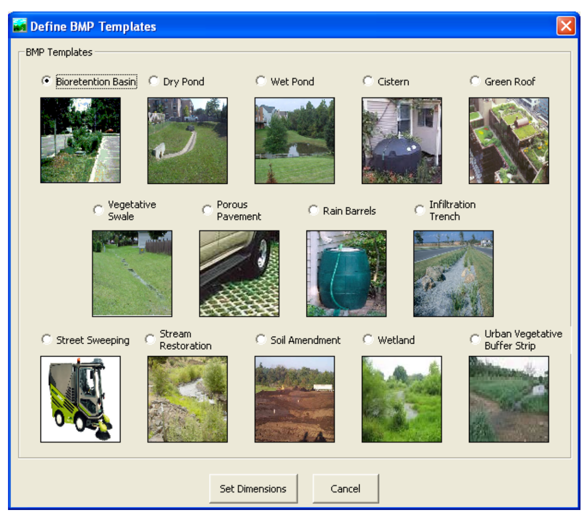
The BMPDSS model was developed and applied to evaluate and optimize BMPs for achieving various stormwater management objectives. Recently developed version, version 3.0, has eleven new enhancements to the previous version. This report summarizes the new enhancements included in version 3.0. For more details on the capabilities and instructions on how to use the model, please refer the user's guide (Tetra Tech, 2010a) and the step-by-step application guide (Tetra Tech, 2010b).

1. Background and Progress



Best management practices (BMPs) are measures for mitigating NPS pollution caused mainly by stormwater runoff. The BMPDSS program is a watershed-level model that supports analysis and decision-making for stormwater management planning and design. This system supports watershed hydrologic and water quality analysis, simulation of various innovative BMPs, and selection/placement optimization. The system helps planners to determine which solution alternatives provide the greatest benefit while balancing costs associated with selecting certain other alternatives. Even though the previous version of BMPDSS system served as an efficient tool for BMP evaluation and optimization, the need for further enhancements had arisen due to the need to include more BMPs and to expand the current model capabilities. Subsequently, the County contracted Tetra Tech to develop the new version with several enhancements.

On November 11, 2008 an expert panel meeting was held at Tetra Tech, Inc, Fairfax, VA to evaluate potential enhancements to the PGBMPDSS program. Tetra Tech submitted a memo documenting the design of new enhancements. Following approved design and recommendations received during the progress meetings held on 7/8/2009, 2/2/2010, 4/13/2010, and 6/10/2010, Tetra Tech developed the system. A demonstration session was held on 7/27/2010 and the beta version, except WinVAST capabilities, was submitted on 8/31/2010. Following the review comments, a final version was submitted on 1/7/2011.



2. Enhancements to the PGBMPDSS Program

A total number of eleven updates were implemented for the BMPDSS model enhancement. The eleven updates can be grouped into three categories specified as follows.

- **Category 1 - New and Enhanced BMP Simulation Modules**
  - Stream Restoration
  - Street Sweeping
  - Porous Pavement
  - Soil Amendment
  - Wetland
  - Vegetative Buffer

- **Category 2 - New Simulation Capabilities**
  - Green-Ampt Infiltration
  - Irregular cross-section representation

- **Category 3 - New Utility Tools**
  - Automatic BMP Calibration Tool
  - WinVAST BMP Location Optimizer
  - Subwatershed Prioritization Module

2.1 Stream Restoration Module

The Stream Restoration Module in BMPDSS v3.0 was developed to evaluate the impact of stream restoration on sediment loadings from the stream. On the basis of the user input of streambank and bed conditions, the module prepares input files to run the QualHymo model (Rowney 2009), which evaluates sediment loadings from pre- and post-restoration conditions.

Key Features of Stream Restoration Module

- BMPDSS runoff time series applied to stream cross-section and slope, and QualHYMO generates velocity and depth; then computes cumulative shear stress at each increment of the bank cross-section.
- Bank critical shear stress is subtracted from cumulative shear stress to obtain section impulse as excess shear stress.
- Water quality benefits to be predicated in terms of reductions in impulse miles due to BMPs.
- BMPs can be either:
  - Distributed BMPs that improve the cumulative shear stress through improved FDF regimes.
  - Or bank stabilization BMPs that increase critical shear stress.
- Benefits to be based upon total and average impulse mile computations-
  - Pre-restoration
  - Post-restoration

2.2 Street Sweeping Module

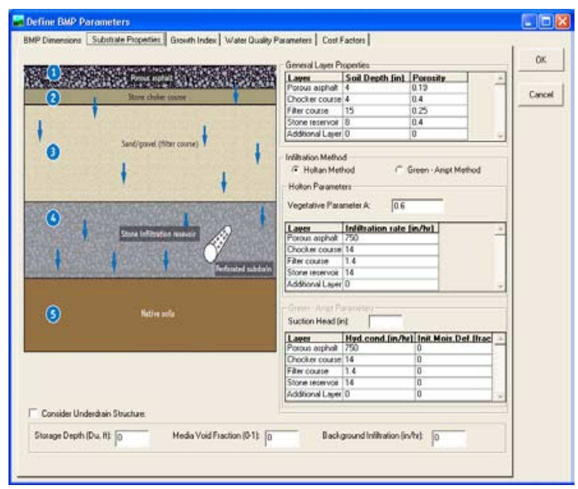
The Street Sweeping Module was develop to understand and quantify the water quality benefit of the most common non-structural BMP, street sweeping. It has the flexibility to select the percentage of area being swept, sweeper type, sweeper efficiency to various pollutants, and sweeping frequency. Here the percentage of area being swept and the sweeping frequency can be built as decision variables for the optimization process.

Key Features of Street Sweeping Module

- Accommodate different sweeper types
  - Mechanical
  - Vacuum
- Accommodate different sweeping schemes
  - Area swept
  - Sweeping frequency
  - Sweeping efficiency
- Optimize on sweeping schemes

2.3 Porous Pavement Module

The Porous Pavement Module was developed to accommodate the recent development and enhancements in this stormwater BMP. The module can simulate a multi-layer design or a simple design of Porous Pavement.



Key Features of Porous Pavement Module

- Allow for flexible representations of vertical profile
  - Depth
  - Porosity
  - Hydraulic conductivity
- Optimize on area of porous pavement

2.4 Soil Amendment

The Soil Amendment Module was developed to quantify the water quality and hydrological benefit of another commonly applied non-structural BMP, soil amendment. Soil amendment refers to practices of improving compacted soil through mechanical improvement, and/or the addition amendments (e.g., compost, mulch, organic material, fungi, worms, topsoil, lime and gypsum) to restore their water absorption and filtering capacity and chemical characteristics.

Key Features of Soil Amendment Module

- Allow for flexible representations of varies amendments through
  - Infiltration model (Green-Ampt or Holtan)
  - Soil property and infiltration parameters
  - Applied area of soil amendment
  - Water quality parameters
- Optimization on area of soil amendment

2.5 Wetland Module

The Wetland Module was developed to quantify the water quality and hydrological benefit of constructed wetlands, shallow marsh areas containing emergent vegetation to treat stormwater runoff. The major processes in wetlands that remove pollutants from stormwater runoff include settling, adsorption, plant uptake and microbial breakdown of pollutants. Suspended solids are removed from water through settling as the velocity and depth of water reduce in wetlands. Adsorption occurs on vegetative surface and in sediment as dissolved pollutants pass through constructed wetlands. Bacteria attached to plant stems and the humic deposits of wetlands play major roles in removing BOD5. Plant uptake removes nutrients during the growing season, although nutrients may be released by plants in the fall. Hydraulic characteristics of constructed wetland also affect the pollutant removal efficiencies through mixing and detention

Key Features of Wetland Module

- Hydrology simulation
  - Water balance
  - Modified puls routine
- Water quality simulation
  - k-C* model (Kadlec and Knight, 1996)
- Multi-configuration capabilities

2.6 Vegetative Buffer

The Vegetative Buffer Module was developed to quantify the water quality and hydrology of vegetative buffer or filter strips, land areas of either planted or indigenous vegetation, situated between a potential pollutant-source area such as along roads, parking lots, etc. In urban environments, vegetative riparian zones along rivers or streams are often referred to as “Greenways or Greenbelts” and are protected and managed under conservation easements or open space designations, e.g. linear parks.

Key Features of Vegetative Buffer Module

- Flow mainly by infiltration
- Pollutant removal by:
  - Deposition
  - Infiltration
  - Biological and chemical processes such as volatilization, degradation, adsorption and absorption of pesticides, nitrogen and phosphorus transformations, vegetative uptake, etc.

2.7 Green-Ampt Infiltration Method

In the previous version of BMPDSS program, the stream segments can only be represented by rectangular, trapezoidal, and circular cross-section. This enhancement brings the representation of irregular cross-sections, similar to those represented in the U.S. EPA's SWMM model, into BMPDSS program.

Key Features of Green-Ampt Simulation

- A three-layer scheme
  - root zone
  - a soil layer
  - gravel under-drain layer
- Required user input
  - Depth of each layer
  - G-A parameters for each layer

2.8 Irregular cross-section for stream segment representation

In the previous version of the BMPDSS program, the infiltration through the soil profile is simulated using the Holtan Equation. The Green-Ampt method was added to BMPDSS as an alternative for infiltration simulation. Because the Green-Ampt method is physically based, it is presumably more accurate, especially at smaller simulation time steps. The disadvantages of this method, comparing to Holton's method, is that it required more parameters and is more computationally expensive. The users have an option to select whether to use the Holtan or the Green-Ampt method depending on the application and data availability.

2.9 Automatic Calibration Tool

The automatic calibration was added to the BMPDSS program as a new module, and to save the user from the tedious manual calibration of BMPs. With the automatic calibration module, BMPDSS will be able to calibrate BMP parameters, including ET (evapotranspiration) rate, infiltration rate, pollutants first order decay rates and underdrain percent removal percentages, using the observed performance data, hourly monitoring flow and pollutant load, data supplied by the user.

Key Features of Automatic Calibration Tool

- Run optimization for best solutions:
  - Scatter Search method
  - Compare modeled and observed data using root mean square error (RMSE) statistical method

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(Observed_i - Modeled_i\right)^2}{N}}$$

- Evaluate the best solutions:
  - Compare best solutions through post processing exercise in MS Excel

2.10 WinVAST BMP Location Optimizer

The WinVAST BMP Location Optimizer is completely independent of the BMPDSS main system. It requires a separate activation of the BMP Location Optimizer extension, and has its own data management form. It is a screening level utility for helping the user identify the cost-effective placement of infiltration (bioretention) and detention (detention pond) BMPs at the user specified subwatershed scale. The Location Optimizer employs WinVAST to perform storm event based hydrology and water quality simulation of each subwatershed, and rout runoff through receiving BMPs to evaluate the BMP performance. The advantage of this tool is that it does not require land use time series, and it performs event based simulation and consumes much less computation time.

The tool has two components, i.e., a GIS interface and WinVAST model. The GIS interface prepares the WinVAST input file based upon the GIS data, including landuse, soil, and optional DEM, stream layer, and subwatershed delineation. Once the WinVAST input file is created, the user can launch the WinVAST model, and add infiltration and detention BMPs for each subwatershed. The sizes of the BMPs are automatically determined using the Maryland BMP Design Manual standard. Then based on the user specified optimization objective, the tool identifies the suitable subwatersheds for the pre-defined BMPs.

Key Features of WinVAST BMP Location Optimizer

- Automatically size BMPs for each subbasin based on Maryland BMP Design Manual
- Optimize the location and type of BMPs based on the user's defined management objective(s)

- Evaluate BMP performance using user defined rainfall data

2.11 Subwatershed Prioritization Module

The Subwatershed Prioritization Module is a tool designed to help decision makers strategize the implementation of BMPs in a staged manner when budget constraints do not warrant the immediate full implementation of BMPs for meeting TMDL goals. The module is intended to identify a staged BMP implementation plan that maximizes the benefit at the earliest stage within a given budget. In other words, it ensures that at each stage, the combination of subwatershed with most pollutant reductions is selected.

The tool first assigns generic infiltration (bioretention) and detention (dry pond) BMPs to each subbasin, and then generates optimal BMP sizes for each subbasin through the round-one optimization process for meeting the target objectives (e.g., TMDL pollutant reduction goals). Then, on the basis of the round-one optimization results and the user specification of BMP implementation scheme (i.e., number of phases and number of subwatersheds in each phase), the module identifies the optimal combination of subwatersheds for BMP implementation in each phase through a round-two optimization process.

- User-specified goal of evaluation target:
    - The number of priority subbasins, or
    - Total amount of budget
- Routing is included during the optimization process

The BMPDSS model is a very powerful tool to evaluate and optimize BMPs for achieving various stormwater management objectives. However, the above described enhancements are needed in order to significantly improve the usefulness of the tool. Data was collected and used to fully calibrate a computer model to simulate hydrodynamics and water quality conditions and show results. Ultimately, the study results will be used by the county and other jurisdictions in developing best management practices for achieving water quality improvements in similar highly-urbanized watersheds.

3. References

Kadlec, R.H., and Knight, R.L., 1996. *Treatment Wetlands, Lewis Publishers,* Boca Raton, NY.

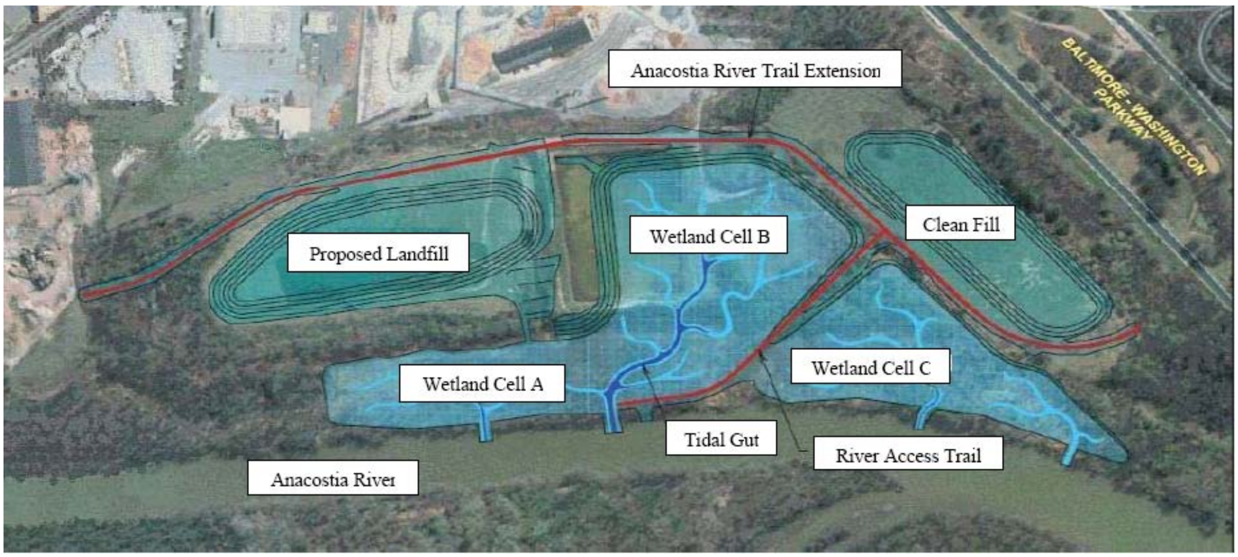
Rowney, C. 2009. *QualHymo User Manual and Documentation*.

Tetra Tech, 2010a, *Prince George's County Best Management Practices Decision Support System User's Guide,* Fairfax, VA

Tetra Tech, 2010b, *Prince George's County Best Management Practices Decision Support System Step-by-Step Application Guide,* Fairfax, VA

II. Study of the Anacostia Off-Line Tidal Wetland project

The Anacostia tidal wetland was constructed in 2008 at the site of a former sanitary landfill along the Anacostia River in Prince George's County (the County), Maryland. The river water does not flow directly into the wetland and hence the wetland is considered "off-line." However, a portion of the river water is routed through the wetland during the tidal flux. The wetland is composed of four cells: Wetland A, Wetland B, Wetland C1, and Wetland C2 (see Figure below). An active gravel yard and railroad track are located east of the wetlands and several stormwater outfalls from these land uses drain directly into the wetlands.



Wetland site map

The County, through a grant administered by the U.S. Environmental Protection Agency (EPA), initiated a 2-year study of the wetland to evaluate the wetland's effects on the water quality and biological condition of the Anacostia River. The first year of the study (Task 1) was completed by EA Engineering, Science, and Technology, Inc. (EA) in 2010. The study included physical, water quality, and biological monitoring programs that encompassed a range of tidal, weather, and seasonal conditions. Monitoring activities were completed in accordance with an EPA-approved Quality Assurance Project Plan (QAPP) developed by EA in 2010, before the start of the project. The second year of the study (Task 2), completed in 2011, includes construction of a Low Impact Development (LID) facility at one of the outfalls draining into the wetland from the industrial area to the east. The LID facility is designed to treat a portion of the contributing off-site runoff. It is suspected that this off-site runoff may be reducing the overall long-term functionality of the tidal wetland system.

The objective of the physical monitoring program was to develop and calibrate a tidal prism model (TPM) which describes the relationships between stage and volume in the Anacostia River and within the off-line tidal wetland. As part of the physical monitoring, velocity measurements were conducted in the river and at the wetland entrance channels to verify the original design stage-volume relationships. Stage or tide elevations were also measured using tide gauges at two locations in the river and one location in the wetland to identify the ebb and flood periods of the tidal cycle. The data sets developed during the physical monitoring were incorporated into the TPM for use in the water quality monitoring program and the water quality modeling.

Stands of cardinal flower in bloom on the wetland.

Water quality monitoring was conducted to determine the pollutant loads entering and leaving the wetland from the Anacostia River during both dry and wet weather conditions. Samples were collected during 12 monitoring events (six dry and six wet) from May 2010 through June 2011. Hourly sample aliquots were collected with ISCO samplers at one location in the river and three locations at the wetland entrance channels. Two of the events (one wet and one dry) were limited sampling events where only certain parameters were tested at two of the four sites. The aliquots were combined together into flow-weighted ebb and flood tide composites based on the output of the TPM, which used built-in stage-volume relationships and stage elevations recorded by the tide gauges to identify the ebb and flood tides and calculate the volume of the sample aliquots needed to construct the composite samples. The water quality parameters evaluated were based on pollutants of concern identified in Maryland's Total Maximum Daily Loads list, and included:

- Toxic metals (arsenic, copper, lead, and zinc),
- Nitrate-Nitrite (NO3-NO2),
- Total Kjeldahl Nitrogen (TKN),
- Total Nitrogen (calculated as TKN + NO3-NO2),
- Total Phosphorus,
- 5-day Biochemical Oxygen Demand,
- Total Suspended Solids, and
- Fecal Bacteria assessed as *Enterococci*.

Wetland Creation Site

Results from the water quality monitoring program were analyzed with two approaches. The first was a statistical approach that compared pollutant concentrations entering and leaving the wetland. The second was a modeling approach that evaluated the pollutant removal efficiency of the wetland (i.e., the percentage of pollutants removed by the wetland) based on a mass balance water quality model (WQM). The statistical comparison was used as a screening tool to identify which parameters should be retained for further analysis in the WQM.

Wetland View

The biological monitoring program included evaluations of the wetland vegetation, physical habitat, and the benthic community. Wetland vegetation was assessed during the spring and fall of 2010 to capture seasonal changes in plant growth at Wetlands A, B, C1, and C2 using the Mid-Atlantic Tidal Wetland Rapid Assessment Method (MidTRAM) designed for Mid-Atlantic tidal wetlands. Benthic samples were also collected seasonally at the same four wetlands and in the Anacostia River during the spring, summer, and fall of 2010. Sampling was conducted at two locations in the Anacostia River using a Ponar grab sampler and at four locations within the wetland entrance channels using the 20-Jab Dip Net Method. Each method was appropriate for the locations given the conditions of the site. The Chesapeake Bay benthic index of biotic integrity (B-IBI) for tidal freshwater rivers was calculated for the benthic samples collected at the river locations for the summer data only; samples collected in the spring and fall do not fall within the time window specified by the method. However, several community metrics, including total abundance, taxa richness, and the Shannon-Wiener species diversity index were computed for all seasonal data. Physical habitat was also assessed using U.S. EPA Rapid Bioassessment Protocol Physical Characterization data sheets to determine the quantity and quality of habitat available for benthic communities.

The results of the biological monitoring suggest that the wetland vegetation is in fairly good condition overall despite some low MidTRAM scores in the Buffer/Landscape Attribute category. The MidTRAM method accounts for development in the surrounding landscape and, since the wetland is located near a developed industrial area, the scores were somewhat low in this category. However, the wetland itself provides high value ecological habitat, and is dominated by native plants such as volunteer broad-leaved cattail (*Typha latifolia*). Some invasive species, including common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*), were also observed at low levels and should be monitored closely.

Sampling Equipment

The physical habitat assessment showed that the habitat available for benthic communities was primarily soft-bottom substrates typical of freshwater rivers and wetlands in this region. At the wetland entrance channels, some woody debris, emergent and aquatic vegetation, root wads, algae mats, and rip-rap were also observed. Water quality measurements indicated adequate conditions to support a benthic community and all parameters were within expected ranges for an urbanized area. At all six sample locations, the benthic community was generally characterized by low taxa richness, low species diversity, and relatively high abundance of a few taxa which is typical of soft-bottom tidal freshwater systems in this area. Habitat conditions at the two river locations were similar. The difference may potentially be the result of a localized physical disturbance such as scouring or sedimentation associated with flooding events.

The results of the statistical comparison of wetland inflow and outflow pollutant concentrations showed that *Enterococci* bacteria (ENT) and zinc showed a significant difference. All other parameters were either not significantly different or were not included in the statistical comparison analysis because of quality control issues (see Table 1).

Table 1. Statistical Comparison of Anacostia Inflow and Wetland Outflow Concentrations of Selected Water Quality Constituents

Sample	Station	No. of Events (N)	BOD5 (mg/L)	TSS (mg/L)	Total Phos. (mg/L)	Arsenic (µg/L)	Copper (µg/L)	Lead (µg/L)	Zinc (µg/L)	Bacteria (MPN/100 mL)	NO3-NO2 (mg/L)
						Mean	Concentration				
Dry	Anacostia Inflow	4	1.67	3.60	0.0458	2.80	6.04	1.65	10.0	14	0.66
	Wetland Outflow	4	2.17	5.61	0.0456	2.70	4.75	1.70	9.26	64	0.52
Wet	Anacostia Inflow	4	3.26	11.9	0.0653	2.70	6.21	2.90	21.1	1,782	0.45
	Wetland Outflow	4	2.92	12.0	0.0503	2.70	4.22	2.61	17.0	350	0.36

The wetland was most likely not affecting these parameters because of the insufficient hydraulic residence time, which was calculated to be approximately 2 hours. As a result of these findings, only ENT was selected for further analysis with the WQM. A model simulation of ENT over a tide cycle showed a large degree of variability, especially during dry weather when concentrations varied by almost a factor of 10. According to the model simulations, the wetland releases ENT during dry weather and removes ENT during wet weather. A possible explanation of this trend is that, during wet weather, the bacteria are transported into the wetland during a flood tide, where they are deposited onto the wetland banks, resulting in net removal of bacteria. During dry weather, the bacteria are subsequently re-mobilized due to tidal action and released from the wetland back into the Anacostia River. *In situ* sources of bacteria in the wetland such as base-flow and/or wildlife waste may also be contributing to the dry weather releases of ENT. The pollutant removal efficiency during wet weather was approximately 20 percent. The initial statistical comparison results of the zinc inflow and outflow concentrations did not indicate a significant difference (see Table 2). The zinc data and monitoring data collected from the LID monitoring study are incorporated into the model updates for submittal of the final technical report. This table indicates that the pollutant removal efficiencies are not significant at all.

Table 2. Comparison between influent and effluent Concentrations

Constituent	UNITS	N	Avg. Concentration Inlet	Avg. Concentration Outlet		Does BMP Significantly Reduce Concentration?
As	UG/L	5	0.64	2.80	**	*No, BMP is a source*
Cu	UG/L	5	1.47	3.18	*	*No, BMP is a source*
Pb	UG/L	5	1.37	0.31		*No*
Zn	UG/L	5	6.32	9.94	*	*No, BMP is a source*
BOD5	MG/L	5	2.58	1.25		*No*
NO3-NO2	MG/L	5	0.61	0.09	**	*Yes*
TKN	MG/L	5	1.02	0.76		*No*
TSS	MG/L	5	21.68	5.04		*No*
TP	MG/L	5	0.11	0.05	*	*Yes*
ENT	MPN/100 ml	5	651.38(a)	25.95(a)	**	*Yes*

a = Concentration for ENT are geo-means
** = significant at 95% level
* = significant at 90% level

The pollutant removal efficiency during wet weather was approximately 20 percent and shows an improvement of water quality.

III. Comparison of Pervious Concrete and Porous Asphalt

This project included funding for Villanova University to support the BMP monitoring of the Pervious Concrete and Porous Asphalt (PCPA) Comparison Study. Flow conditions, hydrocarbons, dissolved and particulate metals, total Nitrogen and Phosphorus, and temperatures were monitored. The monitoring results were used to support additional calibration of the County's BMP-DSS Model.

This project applied the BMP-DSS model to assess and determine the optimal selection of a suite of BMP practices for reducing pollutant runoff. Close coordination with EPA took place throughout the project. Quarterly progress reports and a final technical report have been provided to EPA. This report will be provided to key stakeholders in the Anacostia Watershed for their consideration in future work, and also will be posted on web site. The entire project was completed in April 2009 as scheduled. The final results of this demonstration will not only benefit the people living in the Anacostia Watershed but the model can be used in other watersheds.

The study commenced in the fall of 2007 when construction of the site was completed. For approximately one year, the water in the stone beds beneath the pavements drained too quickly. After several failed attempts, the leak was isolated, and the leaking pipe was grouted. Although this leak hampered the ability to collect all of the data, some interesting and valuable results were found.

The major goals of this project were:

1. Design the BMP
2. Construct the BMP
3. Instrument the site and keep equipment calibrated
4. Objectively and subjectively summarize the installation process
5. Develop inspection methodology to document the performance of the pavements over time and inspect the site quarterly
6. Sample and test for all rain events over 0.25 inch within an 8 hour period, specifically:
    a. Inflow and outflow
    b. Infiltration rates
    c. Temperature
    d. pH
    e. Total Suspended Solids (surface samples only)
    f. Total Dissolved Solids (surface and subsurface)
    g. Chlorides
    h. Total N and total P
    i. Particulate metals: Pb, Cu, Cd, Zn
    j. PAHs
7. Perform a bench top, side-by-side comparison of the pavement types focusing only on hydrocarbons.
8. Mathematically model the temperature reduction caused by the BMPs
9. Conduct a survey of those parking in the area to ascertain public perception of the pavements
10. Disseminate the results of the work via the website, seminars, etc.

All the goals were reached and the major conclusions of this work are:

- Both pavements are wearing well, however, the asphalt side is showing slightly more spalling and signs of wear.
- The pavements respond well to vacuum-street sweeping with a noticeable increase in permeability after cleaning.
- A survey revealed that the pavements are viewed favorably amongst the people that park there.
- Since the grouting of the outflow pipes, none of the rain events exceeded the capacity of the stone beds.
- The variability of the water quality of the inflow is larger than anticipated considering that the two pavements types are adjacent to one another.
- From a water quality standpoint, both pavement types are performing well, with no real difference observed between the two pavements.
- The BMP is effective at mitigating high temperature inflows.

One of the most significant research results is a comparison of mean Total Suspended Solids between pervious concrete and pervious asphalt. This research result is shown in Figure 1.

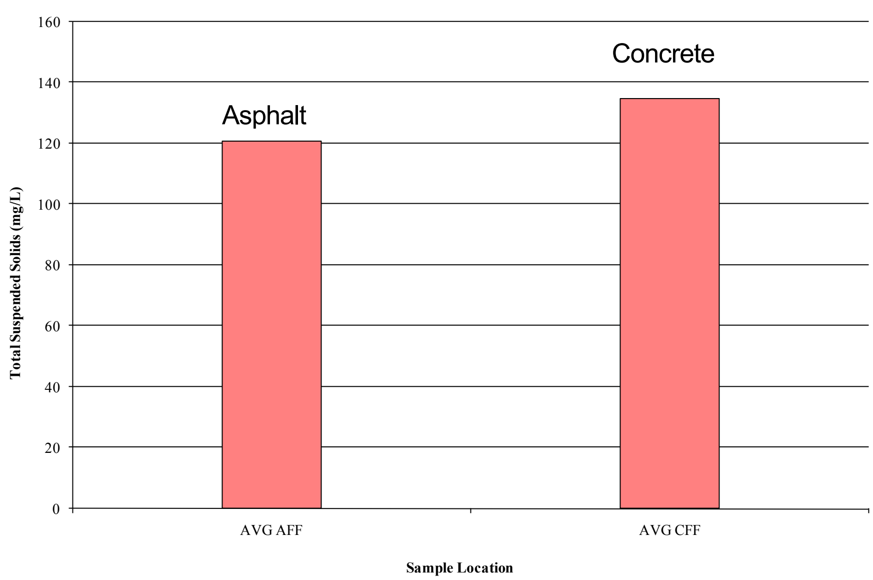


Figure 1. Comparison of Mean Total Suspended Solids between Pervious Concrete and Asphalt

The study concludes that, from a water quality standpoint, both pavement types are performing well with no real difference observed between the two pavements and the BMP is extremely effective at mitigating high temperature inflows.