1.0 Introduction

1.1 Background

Surface water quality degradation due to non-point source (NPS) pollution has risen to the forefront of environmental concerns over the last twenty years. The advent of the National Pollutant Discharge Elimination System (NPDES) permitting program for municipal separate storm sewer systems (MS4s) and the implementation of Total Maximum Daily Loads (TMDLs) that include load allocations for NPS runoff has community leaders scrambling to determine how to reduce contributions to specific impairments. Although simple efforts such as public education programs can reduce NPS pollution, the reduction of many forms of pollutants requires the use of some type of structural best management practice (BMP).

Design techniques for pollutant-specific structural controls other than sediment are still in their infancy, with limited computer models and/or design tools currently available to the engineering community. Those that are available are empirically based with questionable accuracy and applicability from one location to another, requiring difficult and costly storm water monitoring to truly evaluate the effectiveness of the designed BMP. However, the newly developed Integrated Design and Evaluation of Assessed Loadings (IDEAL) computer model created by Dr. Billy J. Barfield, Oklahoma State University and Dr. John C. Hayes, Clemson University, in partnership with Woolpert LLP, takes site specific and regional hydrologic data and uses physics-based techniques to evaluate BMP performance. The program quantifies expected mass loadings and provides trapping efficiencies of total suspended solids (TSS), total nitrogen and phosphorus, and bacteria for numerous selected BMPs. IDEAL is the only known physics-based model for determining pollutant trapping efficiencies of these parameters in the country, but prior to this point has not been validated with actual field measured analytical data.

1.2 Objectives

Funded by Greenville County, the intent of this project was to determine if IDEAL could accurately predict BMP performance within the County based on measured results. Although model output generally showed favorable results compared to many national data sets and empirical rules-of-thumb, the purpose of the project was to provide the County with an assessment of the model. The assessment would focus on a comparison of modeled results versus measured analytical data, but would include an evaluation of strengths and weaknesses of the program, with recommendations for future model improvements or further investigation. The objectives of the project were to:

1) Perform a sensitivity analysis in order to re-design and retrofit the outlet structure of the chosen BMP in an attempt to maximize potential benefits in water quantity and water quality.
2) Collect field samples and flow data at the inlet and outlet of the BMP using automated storm water monitoring equipment for seven significant storm events.
3) Model the BMP in IDEAL to determine predicted mass loadings and trapping efficiencies, for comparison with calculated mass loadings and trapping efficiencies based on field measured analytical data.

2.0 IDEAL Model

2.1 Summary

Dr. Bill Barfield, Oklahoma State University, and Dr. John Hayes, Clemson University, in partnership with Woolpert LLP developed an innovative approach to calculate pollutant removal efficiencies for nutrients, sediment, and bacteria within various types of structural post development BMPs. The design approach was developed for two post construction permitting authorities in South Carolina, Greenville County an NPDES Phase I community, and the SCDHEC Office of Ocean and Coastal Resource Management (OCRM), the primary regulatory agency for the coast of South Carolina (IDEAL abstract). The process-based approach has been programmed into a user-friendly computer model called IDEAL.

Based on historical rainfall data, the program uses a probabilistic approach to approximate individual storm events over an average year. Traditional design methodologies are used for calculating runoff, peak flowrates, and sediment yield from each discrete storm. The program then uses expected eroded particle size distributions to determine the mass loadings of each particle class contained in storm water runoff that is discharged to the BMP from each storm. Using settling theory and the partitioning concept, the program then predicts the effectiveness of the BMP based on the portion of the pollutants sorbed to settlable particles versus those that are discharged or remained suspended within the effluent from the BMP. Calculated output from the program includes expected pollutant mass loadings from the one-year recurrence interval storm (approximately 4 inches for Greenville) and a total annual loading to the downstream receiving water.

2.2 Rainfall Data

Rather than the use of a single synthetic design storm like many BMP models, the IDEAL model uses a very unique approach for application of rainfall data. The model uses historical gaged rainfall data to perform a probability distribution of individual event rainfall depths, antecedent moisture conditions

(AMC) during each of those events, and whether the given event occurred during the growing (April-October) or dormant season during an average one year period. Rainfall depths are assigned to one of twelve rainfall bins or grouping of similar rainfall depths for calculation of expected probabilities.

The models for both Greenville County and for the OCRM allow the user to select from various rainfall gaged data sites based on the location of the proposed development. For example, Woodruff rain gage data in the IDEAL model customized for Greenville County calculates the probability of the depth of rainfall in a given storm event of between 0.00-0.50 inches as 60.3%. Within this rainfall bin, there is a x% chance associated with the probability of a given storm occurring during each of the SCS antecedent moisture conditions and a x% chance that the event occurs during either the growing or dormant season. Therefore, there are six different scenarios or conditions under which a storm event of 0.00-0.50 inches could occur and six different scenarios under which a storm event could take place for each of the other 11 rainfall depth groupings for a total of 72 different categories.

It is important to note that the historical rainfall data must be pre-programmed into the model for the respective geographic area. The model cannot be applied to other geographic regions without adding local historical rainfall data and soils information.

2.3 Hydrology

Hydrologic data is calculated for each of these 72 given storm scenarios, under each of these antecedent moisture and growing/dormant conditions. The program calculates runoff and peak flow rates with widely used methods developed by the National Resource Conservation Service (NRCS), formerly known as the Soil Conservation Service (SCS). The program uses the Curve Number method for calculating runoff and the Graphical Peak Discharge Method for approximating peak flows. The peak rate factor is currently hard coded with the SCS Graphical Peak Discharge Method recommended default value of 484 and cannot be modified by the user.

2.4 Sedimentology

After calculation of peak flows the model must calculate sediment yield or mass loadings based on user specified pervious and impervious areas. IDEAL uses the Modified Universal Soil Loss Equation (MUSLE) to determine sediment yield for pervious areas. For impervious areas, the program uses EMCs for TSS developed in the NURP study (and other sources discovered during a detailed literature review), multiplied by the calculated runoff to approximate sediment yield. However, the user can and is encouraged to input local or regional approximations if available. Like the hydrologic calculations, sediment yield from both pervious and impervious areas is calculated for all 72 possible event scenarios.

The next step in the model calculations is to determine the total mass of each particle size class contained in the influent runoff. For pervious areas, the model calculates the mass loadings using the Chemicals Runoff Erosion in Agricultural Management Systems (CREAMS) equation. The CREAMS equation utilizes the user-input sand, silt, and clay percentages for the respective soil type to determine an expected eroded particle size distribution. These values can commonly be found for any soil type in the County using SCS Soils handbooks. The particle size distribution used for impervious areas is that calculated during the NURP study.

2.5 Isotherms

An isotherm (also referred to as the partitioning concept) is the ratio of a given pollutant in a soil solution sorbed "on the solid phase (ug/gram sediment) versus concentration in the dissolved phase (mg/l)" (IDEAL Model User's Manual). The ratio is determined experimentally in a laboratory by adding known, varying concentrations of a given pollutant to soil samples and mixing in a tumbler or shaker for periods of up to 24 hours. This provides ample time for the pollutant to sorb to the sediments or dissolve and to reach an equilibrium state. Subsequent analytical testing provides quantitative ratios of this partitioning for each applied pollutant concentration and are plotted, generally providing a curvilinear relationship.

Linear approximations of the data provide an average partitioning ratio or isothermic relationship of the pollutant within the given soil type. The use of this relationship is what makes IDEAL truly unique. Using the previously calculated mass loading of clay particles from the CREAMS equation and settling theory in the respective BMP, the isotherm allows the model to approximate the pollutant mass loading sorbed to the cationic portion of the clay fraction which is trapped in the respective BMP. However, it should be noted that trapping efficiencies for bacteria include calculations for removal due to natural mortality and mortality due to light penetration.

For each version of the model, isotherms were developed for the most predominant soil in that respective area only, due to the resources required to develop these parameters. The isotherms used in the model developed for Greenville County were for the Cecil soil series.

3.0 Means and Methods

3.1 BMP Selection

The first step for the validation was to identify what type of potential BMP (ie. detention pond, retention pond, or VFS) to study and subsequently which individual BMP to use for the analysis. The most common type of BMP group in use around the state and more specifically in Greenville County, are detention ponds. In addition, a detention pond inventory was completed in 2002 for the entire County due to NPDES permitting requirements. The inventory included cataloging various physical attributes, such as condition and approximate size, into a GIS database for approximately 850 detention ponds. More importantly however, each structure was located using GPS technology. Therefore, it was decided to utilize the inventory and complete the research on an appropriate detention pond.

Since the IDEAL model and its predicted trapping efficiencies are based on isothermic relationships for Cecil soil (the predominant soil type in Greenville County), it was imperative to select a pond with a contributing watershed that drained areas located within this soil series. The detention pond inventory was therefore overlain with a digital coverage of Greenville County soils as delineated by the National Resource Conservation Service (NRCS). Although the contributing watershed for each pond was unknown at this stage, this created a means to quickly identify potential ponds that were located within the correct soil series. Since most detention ponds are site specific with small drainage areas, it was likely that these ponds drained areas made up of Cecil soils. In addition to finding suitable soils, there were numerous other items deemed important for the chosen pond that primarily involved the conditions at the point of inflow.

Due to fairly common malfunctions with automated storm water monitoring equipment, it was desired to find a pond with only one discrete inflow point. This would require the use of only two total monitoring stations, one each at the point of inflow and outflow and reduce overall operation and maintenance burdens. Second, it was important that the pond experienced minimal to no overland flow. Surface flow into the pond could not be metered/measured and would cause the actual measured hydrographs to under estimate true inflow rates and flow volumes. Third, it was desired to find a pond with a pipe/culvert point of inflow, rather than a natural channel or curb cut. This would greatly simplify the development of the relationship between flow depth and flow rate. The installation of flow measuring devices would also be much less complicated within a pipe or box culvert. The last major qualification for the selected pond was to find one with a functional outlet structure or riser that detained as designed.

Although there were many ponds constructed within Cecil soils, selection of a pond that met each of the previous criteria proved to be much more difficult than originally anticipated. It was suspected that finding a pond that did not experience any overland flow would be the most difficult and that finding a pond with a functional outlet structure would be the least demanding. However, each of the four criteria proved to be equally difficult. Many developers have chosen to use curb cuts at points of inflow and have multiple inflow points to each site-specific detention pond. It is suspected that these measures save significant money due to reduced materials and costs of installation.

The most surprising development during the field reconnaissance was that many of the potential ponds that were visited obviously did not detain due to an improperly designed and/or constructed outlet structure. In some instances, ponds did not have a riser or standpipe, but rather an outflow pipe only. It was evident that these ponds did not detain as intended, and were not appropriate for attempts to validate detention pond trapping efficiencies. However, after visiting over fifty ponds throughout the County, a suitable detention pond was selected for the project.

3.2 Pelzer Pond

Although proximity to downtown Greenville was desired, the pond chosen for the analysis is located just east of the Town of Pelzer, near the Greenville/Anderson County line. The contributing watershed for the pond includes an approximately 7.3 acre drainage basin with mixed commercial and open space landuse. The site includes a Bargain Foods grocery store constructed in 2001 and an abandoned warehouse with accompanying parking lots located off SC Hwy 8. Per the NRCS soil survey, both the pond itself and all pervious area within the watershed are located within Cecil soil. The pond has 1-24 inch concrete inflow pipe with a flared and beveled inlet section. The pond features a somewhat functional concrete outlet structure, and experiences virtually no overland flow due to a small berm around the north side of the pond.

The outlet structure of the pond is a 3-foot square concrete riser (knockout box) with two vertically stacked orifice holes and a 24-inch concrete outlet pipe. Although structurally sound, silt lines on the outside of the riser indicated that the orifice holes were too large and that the pond was not experiencing significant detention. It was evident based on the non-uniformity of both orifice holes that they were likely roughed in using a sledgehammer and chisel, rather than with any finishing tool capable of meeting design tolerances. Therefore, it was desired to obtain a copy of the construction plans to evaluate whether the pond was constructed as designed. After obtaining the construction plans, it was surprising to discover that the upper orifice was fairly close to the design diameter of 12 inches, while the lower 15-inch designed orifice was approximately 13.8 inches or actually 1.2 inches too small. Before proceeding with the analysis, it was decided to re-design the pond outlet structure to ensure that the pond would detain properly and make minor structural adjustments if needed.

3.3 Outlet Structure Improvements

In order to re-design the outlet structure, the pond and portions of the watershed were surveyed obtaining invert elevations where needed. This was especially important for determining available storage volumes since the pond appeared to have experienced some sedimentation since the original construction. Applicable County GIS data was then overlain with the surveyed data to approximate various hydrologic inputs such as curve number and time of concentration required to determine peak runoff from the site.

Both peak runoff and routed flows within the pond were calculated using a spreadsheet-based design program developed by Dr. Michael Meadows within the Civil and Environmental Engineering Department at the University of South Carolina. Since detention pond design in Greenville County is based solely on water quantity rather water quality, the revised outlet structure was primarily designed to attenuate peak flows only. The analysis showed that 1-6 inch orifice could safely pass the 2, 10, 25, and 100-year design storms as required per the County ordinances.

Prior to finalizing the design, a sensitivity analysis was performed in IDEAL to determine if minor changes to the water quantity-based design could provide beneficial results in water quality. Since the outlet structure could be retrofitted only due to financial constraints, the iterative changes were limited to those that could feasibly be changed for the project only. In addition, the current version of IDEAL provides an option for one orifice only, so no iterations were performed with multiple orifice openings. The changes included varying the orifice diameter and invert elevation (to provide a small amount of wet storage) for numerous total rainfall depths. As expected, design changes that would typically provide greater sediment trapping efficiency also provided slightly better pollutant trapping since IDEAL is based on the partitioning of pollutants to sediments. The sensitivity analysis demonstrated that these minor changes provided little benefit to overall pollutant trapping efficiencies.

The revised outlet structure was constructed by attaching two aluminum plates to the concrete riser over the existing orifice holes. Since the upper orifice was not needed for the revised design, the upper plate completely covered the existing opening. The bottom plate was drawn in AutoCAD and was fabricated with a 6-inch opening/orifice by a local sheet metal manufacturer. In order to continue to function as a dry pond between rainfall events, small bleeder holes were drilled below the orifice to gradually drain the pond after a storm (flow rates through the perforations were extremely minimal and were not included in the design calculations). After installation of the aluminum plates, both monitoring stations were setup to begin the sampling analysis.

3.4 Monitoring Equipment

Each monitoring station at the inlet and outlet of the pond consisted of an American Sigma 950 Max flow meter and 900 series storm water sampler. Both stations also included a modem and a 20-watt solar panel. The solar panel and accompanying regulator were connected to a deep cycle marine battery to provide power for each of the station peripherals. A landline drop was installed by the local phone carrier to provide phone service and remote modem access to both the inlet and outlet stations. Both the solar panel and modem greatly reduce the need for site visits to monitor the power supply and other equipment trouble shooting issues. One tipping bucket rainfall gauge was utilized for the project, at the station monitoring inflow to the pond. This was especially important for the initiation of a sampling sequence due to the timing considerations of each sample taken during the event.

3.5 Sampling Protocol

Rogers and Callcott Engineers were retained to perform the laboratory analysis after each storm. Prior to an anticipated storm event, the laboratory placed ice and recently autoclaved bottles within the samplers to preserve the samples. The automated storm water monitoring equipment took each sample after meeting pre-programmed rainfall and/or flow depths. The modem at each setup placed a call upon initiating a sampling sequence to inform the laboratory that samples were being taken. Since each of the tested constituents are relatively stable with long holding times, the laboratory collected the samples within approximately 24 hours, at their convenience.

The influent and effluent samples were tested for total nitrogen, total phosphorus, and TSS. For total nitrogen and total phosphorus, the laboratory provided analytical data for every phase that each constituent naturally exists in including total nitrogen, total kheldahl nitrogen, nitrate, nitrite, ammonia, total organic nitrogen, dissolved phosphorus, and total phosphorus. This allowed the County to compare the laboratory-tested isotherms for Cecil soil to the partitioning of the pollutants as measured in the field.

In addition, event mean concentrations (EMCs) for each of these parameters were calculated for comparison to the default EMCs for these values as provided in IDEAL. Due to the location of the pond and their short respective small holding times, bacteria were not included as part of the analysis.

3.6 Validation

The IDEAL model was setup specifically for this analysis by entering data from various resources including the construction plans, Greenville County GIS data, survey data, and information compiled during a detailed reconnaissance of the contributing watershed. However, additional Visual Basic (VB) code was written to import and export data to and from a separate Excel sheet in order to isolate the interactions within the pond itself. Although the program is capable of calculating the hydrology using the SCS methods discussed previously, it was decided that the focus of this project should center on validation of the use of isotherms to approximate pollutant trapping. Otherwise, the results of the validation could be greatly influenced by limitations of the SCS methodology of determining peak runoff, rather than the actual component of the model that differentiates it from other empirical-based BMP models.

Measured peak inflow, total runoff volume, and calculated event mean concentrations were therefore used for the calculation of the measured results (see Section 4.3) and to override those respective (normally calculated) values within the software to produce the modeled results (see Section 4.2). Note that the measured EMCs were used in place of the individual default EMCs for both pervious and impervious areas as setup in IDEAL, since the samples included runoff contribution from both types of landuse. Upon setting up these inputs for each of the seven measured storms, the VB programming provided the capability to model all of the storm events at once.

4.0 Results

4.1 Shared Results

The following table outlines the field-measured rainfall and peak inflow, as well as the calculated runoff volume and pollutant EMCs based on sampling and subsequent analytical data for each storm event. As discussed in Section 3.6, this information was used to override model inputs for each storm event.

	Storm Events						
Date ('04)	02/02	02/12	03/30	04/14	06/09	06/15	08/02
Rainfall (in)	0.79	0.63	0.59	1.15	0.46	0.31	1.07
Runoff, Q (in)	0.51	0.37	0.14	0.49	0.10	0.04	0.30
Peak Flow, Q_p (cfs)	1.50	1.20	0.75	1.81	1.33	0.83	1.80
TSS EMC (mg/l)	252	51	76	217	136	73	96
Nitrogen EMC (mg/l)	0.97	0.68	1.07	0.83	0.97	0.94	0.79
Phosphorus EMC (mg/l)	0.31	0.13	0.14	0.26	0.27	0.21	0.15

The peak inflow for each storm was measured with a flow meter using area-velocity approximation techniques, while runoff was calculated working backwards from the measured peak inflow. The measured storm events varied from 0.31 - 1.15 inches of rainfall. Per the statistical analysis of historical rainfall data in IDEAL, a given rainfall event in Greenville County has an 81% probability of being less than 1 inch in total depth. Therefore, the storm data set is very representative of typical storm events in Greenville County. The data also spanned from the winter months through the summer, which appears to have had significant affects on the measured results due to routine, seasonal variations in rainfall intensity and vegetation.

Although there were numerous smaller rainfall events (<0.25 inches) in between those listed above, these events could not be used for the analysis because there was insufficient runoff to fill the permanent (dead) storage below the orifice invert elevation and produce effluent. The revised outlet structure was designed to prevent smaller storms from short-circuiting or passing directly through the pond with virtually no retention time and subsequently no treatment. It is also important to note that since a detention pond by definition is a dry pond, each of the sampled storm events followed at least a four day period with no rainfall (excluding a small 0.11 inch storm that preceded the 04/14 storm event by one day).

As shown above, the calculated EMCs were fairly variable as expected. However, the average EMC for TN of 0.89 mg/l and EMC for TP of 0.21 were much lower than expected since the IDEAL model default EMCs are 1.88 mg/l for TN and 0.40 mg/l for TP. The default EMC for TSS in the IDEAL model is 117 mg/l compared to a measured average of 129 mg/l. The variability between events appears to be primarily a function of rainfall intensity, total runoff volume, the thickness of or dormancy of vegetation in the inflow ditch, and the interarrival time (or antecedent moisture) between storm events. In order to draw conclusions from the table above considering these variables, the following discussion primarily focuses on the outliers of the data set.

The TSS measured during the 02/02 storm event appears to have been greatly influenced by the preceding event, an 8-inch snowfall. It is suspected that sand and salt used in the Bargain Foods parking lot and driveway likely caused this spike in concentration. Although 0.11 inches of rainfall were measured one day prior to the 04/14 storm, it is suspected that there was not enough rainfall to thoroughly washoff or dislodge any potential pollutants and that much of this rainfall likely infiltrated into the soil. Prior to this minor event, the preceding storm was the event collected on 03/30. The combination of this two week pollutant build-up and the volume of rainfall of over an inch, likely caused a significant pollutant washoff as well as erosion of the upstream ditch. Pictures document that the vegetation in April was still in a fairly dormant state, compared to pictures during the summer months making the ditch much more susceptible to erosion.

It is also believed that the thick vegetation in the ditch during the summer caused much lower TSS concentrations during the highly intense 08/02 storm, even though the event exceeded 1-inch of rainfall. The rainfall data showed one logged 3-minute interval during this event that recorded 0.16 inches, while no other recorded event had a peak 3-minute logging interval of over 0.10 inches. It is unknown what caused the peak in the concentration of nitrogen during the 03/30 storm event.

4.2 Modeled Results

4.2.1 Total Suspended Solids

Using the measured values (grayed out in the table below) to override the hydrologic inputs to the proposed pond, the following table outlines the modeled results for total suspended solids for each storm:

	Storm Event						
Date	02/02	02/12	03/30	04/14	06/09	06/15	08/02
Runoff, Q (in)	0.51	0.37	0.14	0.49	0.10	0.04	0.30
Peak Inflow, Q_p (cfs)	1.50	1.20	0.75	1.81	1.33	0.83	1.80
TSS Inflow EMC (mg/l)	252	51	76	217	136	73	96
Total Suspended Solids (TSS)							
Into Pond (lbs)	274.5	202.4	90.3	298.2	103.1	47.4	225.9
From Pond (lbs)	20.1	13.8	4.9	22.3	5.9	2.1	16.0
Trapped in Pond (lbs)	254.4	188.6	85.4	275.9	97.1	45.2	209.9
Trapping Efficiency (%)	93%	93%	95%	93%	94%	95%	93%

With the model inputs above, IDEAL did not need the actual recorded rainfall depth since the peak inflow is a function of rainfall depth. The rainfall depth still had much direct influence on the data, but the intensity or distribution of the rainfall event could not be taken into account using this methodology. It is important to note that even though a given storm may produce a higher peak inflow than another storm, the runoff depth may still be greater due to the duration of the event (see 06/09 storm compared to the 02/12 event).

The controlled or "predicted" TSS values into the pond are simply a function of the two measured inputs. The predicted trapping efficiencies were slightly higher than expected, since 80% trapping efficiency is deemed sufficient to meet the state sediment and erosion control requirements. It was also unexpected that each modeled storm event would produce such similar trapping efficiencies.

4.2.2 Nutrients

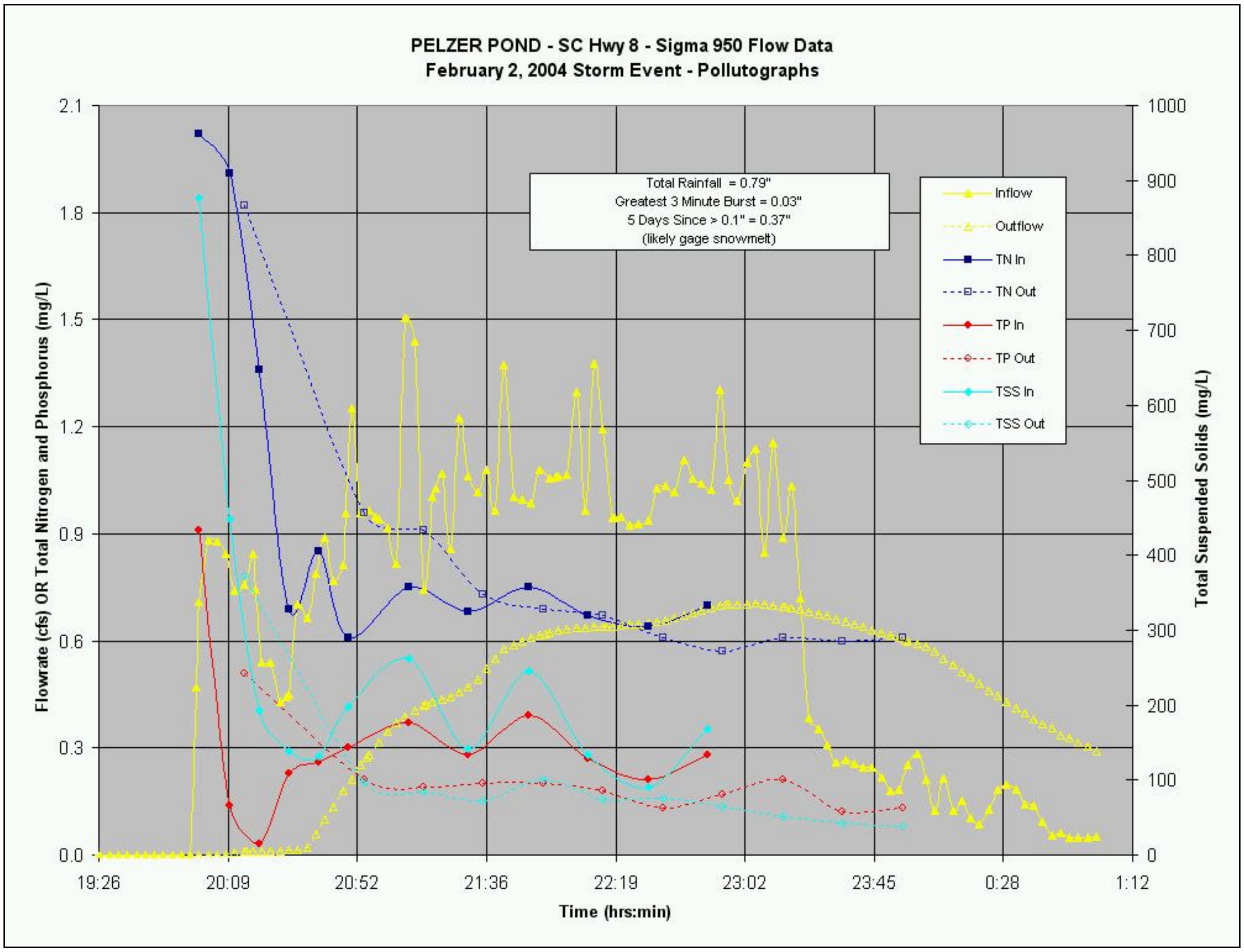
The IDEAL model takes into account nutrients in three different physical forms; dissolved, sorbed, and as a discrete individual particle itself. The following table shows the predicted results from the IDEAL model for nitrogen and phosphorus in each of these forms:

	Storm Event						
Date	02/02	02/12	03/30	04/14	06/09	06/15	08/02
Runoff, Q (in)	0.51	0.37	0.14	0.49	0.10	0.04	0.30
Peak Inflow, Q_p (cfs)	1.50	1.20	0.75	1.81	1.33	0.83	1.80
Nitrogen EMC	0.97	0.68	1.07	0.83	0.97	0.94	0.79
Phosphorus EMC	0.31	0.13	0.14	0.26	0.27	0.21	0.15
Nitrogen (TN)							
Total Inflow to Pond (lbs)							
Dissolved and Sorbed	1.093	0.788	0.278	0.998	0.140	0.047	0.546
Dissolved	1.092	0.787	0.277	0.997	0.140	0.047	0.545
Sorbed on Clays	0.001	0.001	0.000	0.001	0.000	0.000	0.001
Primary Settleable	0.413	0.305	0.136	0.449	0.155	0.071	0.340
Total	1.506	1.092	0.413	1.447	0.295	0.118	0.886
Outflow from Pond (lbs)							
Dissolved and Sorbed	1.092	0.787	0.277	0.997	0.140	0.047	0.545
Dissolved	1.092	0.787	0.277	0.997	0.140	0.047	0.545
Sorbed on Clays	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Primary Settleable	0.130	0.094	0.040	0.142	0.046	0.020	0.106
Total	1.222	0.881	0.317	1.139	0.186	0.067	0.651
Phosphorus (TP)							
Total Inflow to Pond (lbs)							
Dissolved and Sorbed	0.132	0.095	0.034	0.121	0.017	0.006	0.066
Dissolved	0.132	0.095	0.033	0.120	0.017	0.006	0.066
Sorbed on Clays	0.001	0.001	0.000	0.001	0.000	0.000	0.001
Primary Settleable	0.050	0.037	0.016	0.054	0.019	0.009	0.041
Total	0.182	0.132	0.050	0.175	0.036	0.014	0.107
Outflow from Pond (lbs)							
Dissolved and Sorbed	0.132	0.095	0.033	0.120	0.017	0.006	0.066
Dissolved	0.132	0.095	0.033	0.120	0.017	0.006	0.066
Sorbed on Clays	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Primary Settleable	0.016	0.011	0.005	0.017	0.006	0.002	0.013
Total	0.147	0.106	0.038	0.137	0.022	0.008	0.079
Trapping Efficiency							
Nitrogen	19%	19%	23%	21%	37%	43%	26%
Phosphorus	19%	20%	24%	22%	37%	44%	27%

The mass loading of TN had to be higher than the mass loading of TP since the measured EMC for TN was significantly higher than the EMC for TP. However, the predicted distribution of each pollutant in each form was not hypothesized. Since the primary focus of IDEAL was for determining the partitioning of each pollutant between the solid and dissolved phase, it was expected that significant mass loadings of both nitrogen and phosphorus would have been sorbed to clays. The predicted output in the table above indicates that the portion of each pollutant sorbed to clays was negligible. Excluding the small storm event on 06/15, 47-73% of the inflow mass loading of nitrogen and phosphorus was dissolved for every measured storm event. Therefore, the only pollutant removal that occurred within the structure was from trapping of the primary settleable particles. Without this physical form of the pollutant loading, the model would have predicted that no portion of the mass loading was contained in the pond. Like the TSS, it was also surprising that the predicted trapping efficiency for the two different nutrients was so similar for each storm event.

4.3 Measured Results

Field readings were logged on the two flow meters every 3-minutes for rainfall, flow depth, velocity where applicable, and flowrate. Each flow meter was programmed to initiate a sampling sequence upon reaching a given flow depth. Although the inflow flow meter used a flow area and velocity readings to calculated flow, a stage versus flow relationship was developed and programmed for the flow meter at the pond outlet. Each flow meter was also pre-programmed with a given sampling interval to fill each of the twelve bottles in each sampler. Due to extreme variations in rainfall intensity and duration in each storm event, it was difficult to anticipate and obtain samples distributed evenly throughout the given event. Since some pollutant concentrations were expected to peak at different times during a storm event, the sampling interval was vital for providing a representative estimate of concentrations for the duration of storm water runoff. The following graph for the first storm on 02/02 shows the typical data which was collected for each storm event:



After downloading this data above from each flow meter after each measured storm event, numerous calculations were completed in Excel to determine the total flow volume at both the inlet and outlet. Using these volumes and the analytical data from the laboratory (usually received three weeks after the event), mass loadings could be calculated to determine actual loadings during each storm event. In the event that the sampler reached capacity prior to the end of runoff at the inlet or prior to the pond fully draining at the outlet, exponential decay functions were fit to the available data sets in order to extrapolate expected pollutant concentrations. These functions generally fit the measured pollutant concentrations quite well. The following data table shows the real, measured field data for each event:

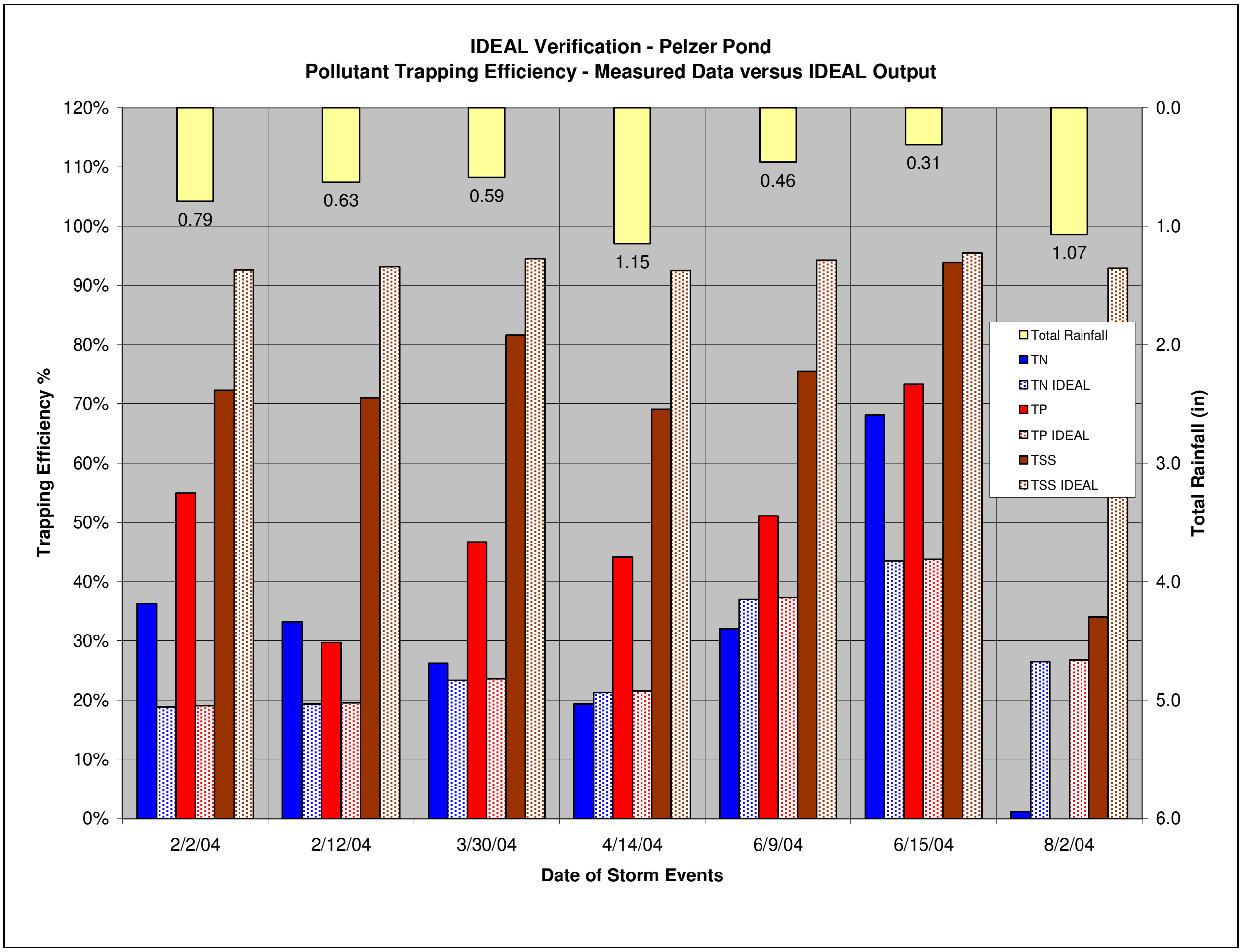
	Storm Event						
Date	02/02	02/12	03/30	04/14	06/09	06/15	08/02
Total Suspended Solids (lbs)							
Into Pond	149.6	23.8	12.5	161.3	22.4	6.5	35.0
From Pond	41.4	6.9	2.3	49.9	5.5	0.4	23.1
Trapped in Pond	108.2	16.9	10.2	111.4	16.9	6.1	11.9
Trapping Efficiency	72%	71%	82%	69%	75%	94%	34%
Nitrogen (lbs)							
Into Pond	0.634	0.283	0.221	0.449	0.153	0.069	0.345
From Pond	0.404	0.189	0.163	0.362	0.104	0.022	0.341
Trapped in Pond	0.230	0.094	0.058	0.087	0.049	0.047	0.004
Trapping Efficiency	36%	33%	26%	19%	32%	68%	1%
Phosphorus (lbs)							
Into Pond	0.233	0.064	0.030	0.195	0.045	0.015	0.070
From Pond	0.105	0.045	0.016	0.109	0.022	0.004	0.070
Trapped in Pond	0.128	0.019	0.014	0.086	0.023	0.011	0.000
Trapping Efficiency	55%	30%	47%	44%	51%	73%	0%

The trapping efficiencies for each pollutant were much more erratic than was originally expected. The trapping efficiencies for phosphorus were somewhat higher than expected, while the trapping efficiencies for nitrogen and TSS were near expected values. The storm data for 06/15 is misleading, since there was not enough runoff to produce effluent through the orifice. Discharge from the pond during this storm was through smaller bleeder holes in the outlet structure only (provided to maintain dry pond only). This explains the abnormally high trapping efficiencies for each pollutant.

The unusually low trapping efficiencies for the 08/02 storm appears to be due to seasonal vegetation. Although this was the second largest measured storm in terms of rainfall depth, the table above shows that only 35 pounds of sediment were present in the inflow. Pictures show extremely dense vegetation in both the upstream ditch and within the pond itself during August. It is suspected that the vegetation in the upstream channel caused the larger sized sediment particles to settle and that the inflow sediment loading were made up of extremely small particles only. Due to the fact that these inflow particles were so small, they would have remained suspended within the pond providing minimal trapping. Any nutrient sorption would have been to the small active fraction of clay, or the smaller particles which passed directly through the structure. In addition, one low, depressed corner of the pond maintained some standing water after periods of rainfall during the summer months and began to grow thick, dark green vegetation that appeared similar to vegetation found in some wetland areas. It is possible that this vegetation may have been an actual source of nitrogen and/or phosphorus during the summer.

4.4 Discussion/Recommendations

The following graph shows a comparison of the modeled versus measured trapping efficiencies at the pond. The IDEAL model consistently over-predicted the trapping of TSS. Since the final storm event on 08/02 should probably be excluded from the data set due to the potential for the generation of nitrogen and/or phosphorus, it can also be concluded that IDEAL consistently under-predicted the trapping of total phosphorus. It is much more difficult to draw conclusions concerning trends in the predicted versus measured values of total nitrogen due to variability above and below the field measured values from storm to storm. However, the predicted trapping efficiencies for nitrogen were much closer to the actual measured values than the phosphorus. The average measured trapping efficiency for nitrogen for the first six storms was 36%, while the modeled trapping efficiency was 27%. For phosphorus, the measured trapping efficiency was 50%, while the modeled trapping efficiency was only 28%.



The following bulleted items are the suggested recommendations for further analysis and/or consideration by the County:

- Verify that algorithms in the model for the determination of pollutants which are sorbed to clays are linked properly, due to the extremely low model estimates.
- Per Dr. Bill Barfield, perform iterations with the particulate phosphorus estimates. He suspects that the particulate phosphorus from impervious areas is higher than anticipated due to traffic on the parking lot and the subsequent break-up of phosphorus in aggregate form.
- Perform a particle size analysis of the inflow, possibly one during the summer and one during the winter months to determine if summer vegetation does influence the TSS loading as suspected. The

upstream ditch and the pond itself may benefit from the application of winter rye to stabilize the channel banks.

- Compare the measured versus predicted outflow volumes to determine if this is a potential source of the discrepancy between the mass loading estimates. This would further isolate the processes within the pond.
- Utilize the measured inflow concentrations, and monitoring data from other County wet weather monitoring efforts to revise the IDEAL default EMCs for total nitrogen and total phosphorus.
- The County should investigate retrofitting other detention ponds, which do not detain as intended. Prior to installing the orifice plates on the outlet structure, the Pelzer pond did not show signs of providing detention. This retrofit was inexpensive and provides signicant benefits in water quantity and water quality downstream.
- The County should require permanent or dead storage in all detention ponds, to keep small storms from passing unchecked, without treatment through a given outlet structure. The results above indicate significant trapping for the small 0.31 inch storm on 06/15.
- Perform a subsequent validation on other types of BMPs in the County to look for trends from various BMPs. This may help to further determine both strong and weak points of the model, which may require additional research.