

## **Stormwater Infiltration in Clay Soils**

**A case study in the North Carolina Piedmont**

*by Christopher J. Estes*

### **INTRODUCTION**

Storm water runoff from impervious surfaces is causing devastating effects on the landscape of our developing watersheds. We are disrupting the natural hydrological cycle that supports our potable water supplies and natural fauna. Intentional storm water infiltration can restore that cycle. However, the lack of awareness and the perceived lack of data are currently limiting its use. This paper will present monitoring data for three sites in the North Carolina Piedmont that demonstrate the success of storm water infiltration in clay soils.

Negative consequences of increased impervious area within developing watersheds have been quantified and documented worldwide. The lack of success in mitigating impervious area has also been verified and documented. Runoff from an acre of pavement is approximately ten to twenty-five times greater than the runoff from an acre of grass. In urban areas, thirty to forty percent of the rainfall runs directly into the nearest stream. In heavily urbanized areas, such as central business districts, precipitation run-off can be more than fifty percent. Compare this to the amount of runoff from woodlands, which is often less than five percent \* *Center for Watershed protection, Ferguson*

Lost ecological functions due to impervious pavements include retention and infiltration. Storm water infiltration is a critical ecological function within the hydrologic cycle. Infiltration reduces flooding, recharges our ground water and generates stream base flows during periods of limited precipitation. Infiltration is a quantifiable process that follows the basic laws of physics. Infiltration is not a new concept. In fact the basic principle governing flow in homogeneous porous media, Darcy's Law, was formulated in 1856. The model typically used today in quantifying infiltration, the Green-Ampt equation, was formulated in 1911.

Targeting the composition of the pavements themselves to mitigate lost retention and infiltration function makes the most environmental sense, and in many cases, also the most economic sense. The degree of retention and infiltration that naturally existed prior to development can be matched, and in many cases easily exceeded, utilizing the readily available tested technology of infiltration and porous pavements. Porous pavements vary in infiltration rates, aesthetic values, materials and cost. Porous pavements typically require a higher degree of technical consideration for bearing capacities and longevity, while having a more limited level of maintenance that consists primarily of vacuum cleaning.

When impervious pavements must be utilized, careful design of other infiltration techniques can mitigate the lost retention and infiltration function. Each infiltration technique, including bio-infiltration basins/swales and porous pavements, has its own unique advantages and caveats. Vegetated BMP applications such as bio-infiltration may include diverse vegetation types that can tolerate a variety of environmental conditions, can project different landscape

aesthetics, and can be discreetly adept in removing specific pollutants. Vegetated BMPs can require a higher degree of aesthetic design and varying levels of maintenance, including vegetation replacement, soil amendment and vegetation management.

Regardless of the infiltration technique utilized, the common design constant is the infiltration rate of the native soils that underlie the system.

Within the geologic region of the “Charlotte Belt” in Mecklenburg County, N.C., soils are typically high in clay. The two project sites presented in this paper are underlain by typical clay soils for this region, the Cecil series, classified by the NRCS as well drained, moderately permeable soils. The phrase “clay soil” is broadly used among the design industry, typically in negative context, when referring to drainage or infiltration.

According to the Natural Resource Conservation Service (formally the Soil Conservation Service), 64% of Mecklenburg County’s land area is composed of soils in hydrologic group B. These soils vary in composition of clay, silt and sand. They have NRCS-reported infiltration rates that vary from 0.6”/hr to 2.0”/hr. The soils observed on the sites of the two case studies presented here are in the Cecil and Cecil-Urban series, which compose approximately 59% of the Mecklenburg County land area.

The first project, Wilmore Walk is two years old and presents monitoring data of retention and infiltration rates over a period of one year. The second project, Jetton Street Condominiums, presents monitoring data for a project that was planned, designed and modeled as a low impact development. Also included in this presentation is monitoring data from an undeveloped site adjacent to Six mile Creek that contains high clay soils in the hydrologic soil groups C and D, to illustrate natural infiltration rates in difficult soils.

### **WILMORE WALK: Infiltration in Porous Pavement**

The data from Wilmore Walk demonstrates the infiltration performance of a basin located under a pervious concrete parking lot as well as the infiltration potential of bio-retention rain gardens in a high-density residential project. This example provides validation of the concept of a low impact storm water project in the urban landscape, demonstrates the successful use of pervious concrete, and quantifies design criteria for clay soil infiltration.

Located in Charlotte, Wilmore Walk is a 2.84-acre condominium development that was constructed in the summer of 2005. This project was an urban redevelopment project where an existing apartment building was removed. No regulated detention was required for the site. However, due to sensitive watershed and environmental impacts associated with culverting an existing stream, water quality management techniques were required. The site design was analyzed for opportunities to incorporate various storm water best management practices (BMPs). The analysis indicated that the water quality requirements could be met by installing eight (8) bio-retention gardens. The analysis further identified the opportunity for storm water infiltration in the form of a 0.14-acre porous concrete parking lot. The resulting project treated 93% of the impervious surface runoff.

The existing soils are Cecil sandy clay substrate. According to the NRCS Soil Survey, the site was mapped as soil unit CuB and CuD. This soil unit is composed of approximately 49% clay, 25% silt and 30% sand.

The bio-retention areas were incorporated to fit a very tight site design, and are almost indistinguishable from typical landscaped areas.



**Figure 1. A bio-retention garden at Wilmore Walk**

As required by the regulatory authorities at the time, the bio-retention gardens all have subdrains that connect to the conventional storm water drainage infrastructure and have minimal infiltration function. It is important to note that although these bio-retention gardens do not infiltrate to their maximum capacity they can be easily retrofitted to do so.



**Figure 2. Installation of a bio-retention sub-drain system, Wilmore Walk**

Pervious concrete was chosen as the material for the porous parking lot due to its high infiltration rate and for its durability and ease of maintenance. The infiltration efficiency of pervious concrete depends on the consistency of the mix and installation quality, but typically exceeds that of other manufactured paving systems. Properly installed pervious concrete contains 15%-30% void space throughout the entire volume of the application. The voids increase in size from top to bottom of its cross section, greatly reducing the chance of clogging. Flow rates through pervious concrete range from 140 to over 1,000 in/hr.

Six inches (6 in) of pervious concrete can detain and store 1.5 in of rainfall. A reservoir base course composed of single-size aggregate with approximately 30-40% voids and underlain with non-woven filter fabric was added to the design to retain the 2-year recurrence storm event for the parking lot and adjacent roof top drainage area. The base reservoir was excavated into existing soil as a closed basin; there is no primary drainage outlet except infiltration into the soil. The base's aggregate material was placed on the soil without further compaction. For post construction monitoring purposes, three PVC monitoring wells were incorporated to house water level data loggers.

Pre-construction infiltration testing was conducted for the proposed pervious concrete parking lot, utilizing a double ring infiltrometer. Test results yielded a range of 0.23-3.1 in/hr with an average infiltration rate of 0.90 in/hr for the existing unmodified sandy clay subgrade. The lowest rate of 0.23 in/hr was measured in an area of light compaction caused by a bobcat with rubber tracks. The highest infiltration rate, 3.1 in/hr, was measured in an area that was cut raked, with no compaction.



**Figure 3. Native soil infiltration rate testing at Wilmore Walk.**

Post construction infiltration monitoring data was collected using an Infinetes USA pressure water level data logger. The monitoring period was one year. The data presented here was for a six-month period from August 2006 through February of 2007.



**Figure 4. Monitoring well in porous concrete parking lot**

During the post-construction monitoring period, several months of data had to be disregarded due to malfunction of the pressure sensor. The problem was apparently due to sediment that was present in an installed conduit directly above the sensor. However, results of the monitoring data from August through September 2006 included eleven rain events, five of which ranged from .98 in to 2.97 in per day. The maximum rate that the reservoir raised during any single event was 3.4 in/hr ( $\pm 1$  inch water level equivalent). The reservoir water level reflects the available void space in the stone and additional catchments surrounding the porous concrete lot. Infiltration rates into the existing subgrade varied, depending on the depth or head of the water in the reservoir, which is consistent with Darcy's Law.

The maximum recorded water depth within the reservoir was 13.28 inches ( $\pm 4$  inches water equivalent). During this event, the soil infiltration rate at maximum head was 0.29 in/hr. During the following 6.3 day period between storm events, the water level in the reservoir dropped 13.24 inches. As the water level declined with time, the infiltration rate also declined, which is consistent with the role of head in Darcy's law. The average rate of infiltration was 0.09 in/hr, or 2.1 in/day. During the majority of the recorded events, infiltration was occurring in saturated soil conditions.

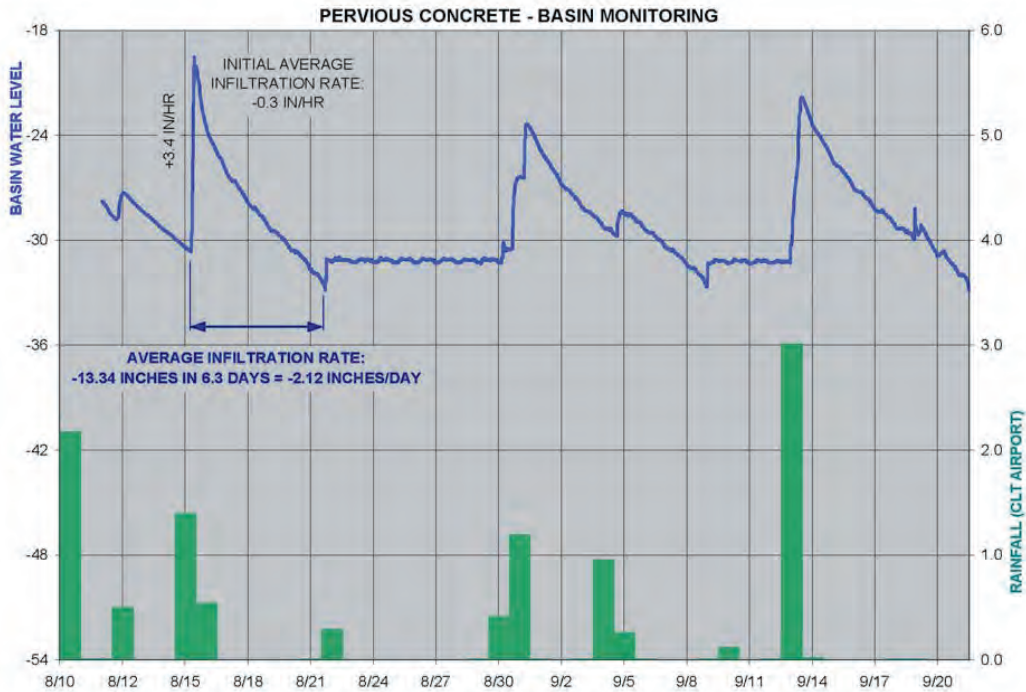


Figure 5. Wilmore Walk Reservoir Monitoring Data for rain events August - September 2006

In February 2007 the reservoir was artificially filled utilizing a water truck. Prior to filling the reservoir, the water level was measured at 2.28 in ( $\pm 0.7''$  water equivalent). The final water level depth after filling was 13.74 in. From the time the reservoir was artificially filled and the next rain event 5.57 days later, the average infiltration rate into the subgrade was 0.06 in/hr, or 1.34 in/day, with a total water level drop of 7.42 inches.

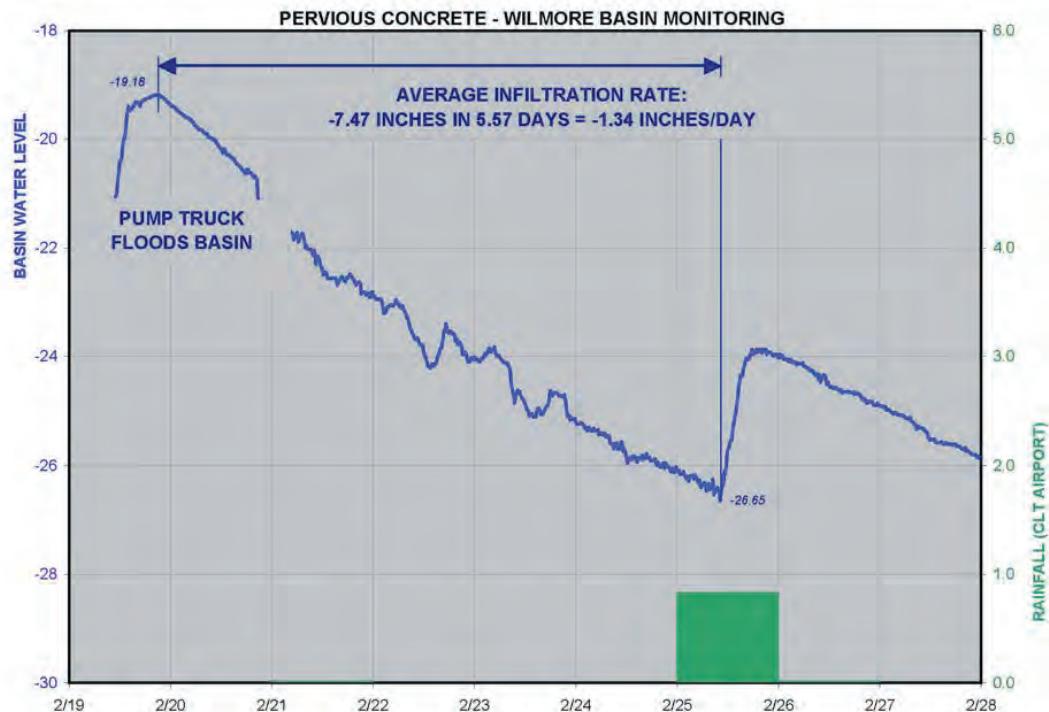


Figure 6. Wilmore Walk Reservoir Monitoring Data of filling by watering truck



**Figure 7. Wilmore Walk Reservoir filling by watering truck.**



**Figure 8. Wilmore Walk finished porous concrete parking lot**

Reduction in soil infiltration rate of approximately one order of magnitude was observed between pre-construction and post-construction infiltration rates. Possible reasons for this variation include the introduction of the non-woven filter fabric, inadvertent compaction during construction such as from the introduction of the reservoir aggregate material, seasonally higher water table and extended saturated soil conditions due to consecutive storms, and subsurface flow from an adjacent uphill property.

Another observation worth mentioning was during the winter of 2005, when Charlotte experienced several freezing rain and snow events. On January 29 and February 28, 2005, the project site received 0.44 in. and 0.56 in. of snow, respectively. Although snow accumulated on the pervious concrete surface, there were no puddles once the snow began melting. This is a significant secondary benefit to typical vehicular applications, as well as pedestrian applications that require non-slip surfaces.

### **JETTON STREET: Infiltration in Rain Gardens**

A detailed hydrological model was performed during the design phase of Jetton Street Condominiums that illustrates the effectiveness of planned bio-retention and infiltration BMPs to reduce the required detention volume. This presentation will focus on the monitoring data collected for two infiltration BMP's in clay soils. Monitoring data presented for this project spans a period of 4.5 months from February 8, 2008 to June 25, 2008.

The site is a 5.75 acre condominium project developed within the protected water supply watershed of Lake Norman. The project site is underlain with sandy clay soils of the Cecil series. This project was not a retrofit design and incorporated the proposed BMPs into the storm water infrastructure planning phase.

This site was a new development and did require regulated detention. Since there was an opportunity for preliminary planning, the proposed BMPs were incorporated into a hydrological model utilizing HydroCAD software. The modeling allowed for an accounting of the proposed hydraulic mechanisms within the BMP structures and quantified the reduction in required detention volume. This project treats 83% of the 5.75 acre parcel, of which 31% is impervious.



**Figure 9. Jetton St. bio-retention gardens**



According to the NRCS Soil Survey the site was mapped as Cecil soil unit CeB2. This soil unit is composed of approximately 37% clay, 27% silt and 24% sand. Additional soil borings were conducted during the geotechnical site investigation. Pre-construction infiltration testing utilizing a double ring infiltrometer was conducted on the site. Infiltration rates for the existing soils at two proposed BMP locations and grades varied from 1.13 in/hr to 1.5 in/hr with an average of 1.3 in/hr.

This project incorporates three bio-retention gardens with sub-drains and two bio-infiltration gardens that rely entirely on exfiltration into the native soil for drainage. The two bio-infiltration gardens are designed to retain and infiltrate the 2-yr recurrence design volume (3.12" per the Charlotte-Mecklenburg Storm Water Design Manual). Two other bio-retention gardens with subdrains detain the 2-yr recurrence design storm. A remaining bio-retention garden is the smallest and is designed to detain the 1" storm event, which is then routed to the first bio-infiltration garden.

The model predicted a 45% reduction in required detention volume for the 10-yr recurrence storm event utilizing the gardens.

The monitoring devices for this project site differ from the previous Wilmore Walk project site in that the monitoring devices are capacitance water level probes placed in 6.5 foot deep wells that extend from the surface of the installed soil mix to approximately 1.5 feet to 3.3 feet below the bottom of the constructed infiltration gardens. These monitoring wells are perforated pipe and also act as infiltration wells.



**Figure 10 Jetton St. 15" diameter monitoring well**

The monitoring period is from February 8, 2008 to June 25, 2008. The data for thirty-seven precipitation events ranging from a trace to 1.5 inches per day and their corresponding infiltration rates were recorded.

For infiltration garden 1, the maximum rate the well water level rose during this period was 46.24 in/hr ( $\pm 15$  in/hr water equivalent?). The maximum water level recorded during this period was 74.06 inches above the bottom of the well. Consistent with Darcy's Law, infiltration rates through the installed soil mix varied with depth or head of the water. Once the water level infiltrated past the bottom of the installed soil mix and filter fabric the infiltration rate increased by a factor of 3.7. The average rate increased from 0.26 in/hr through the installed soil mix to 0.97 in/hr into the native soil matrix.



Figure 11. Jetton St. Bio-infiltration Garden

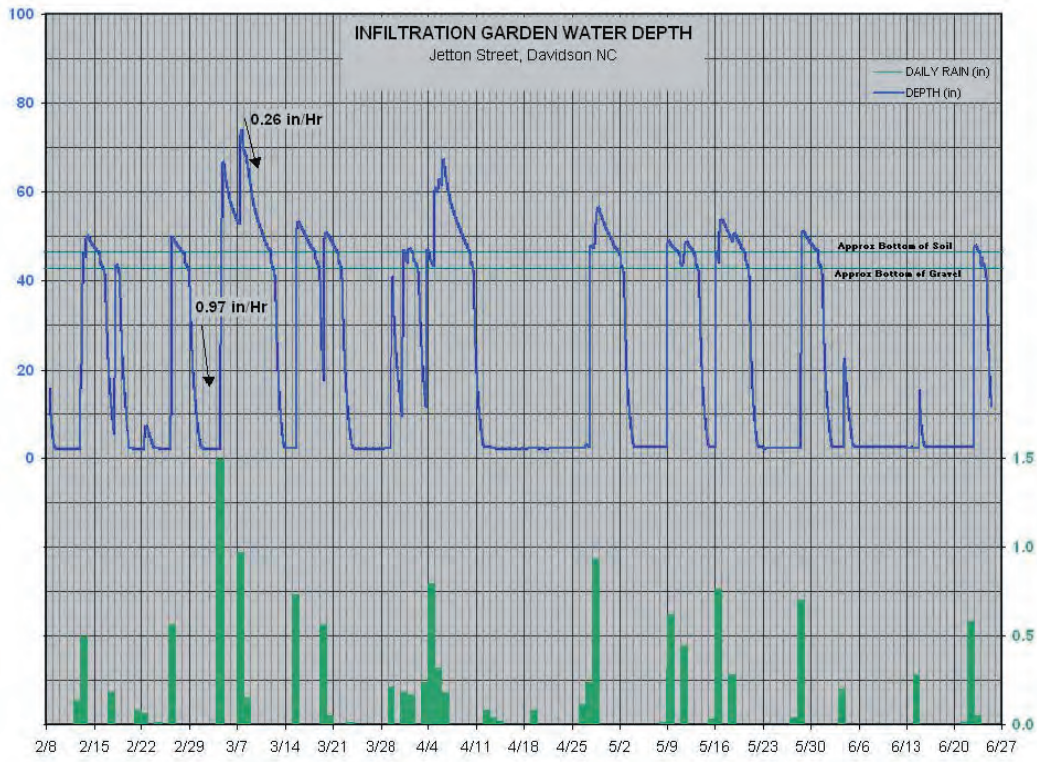
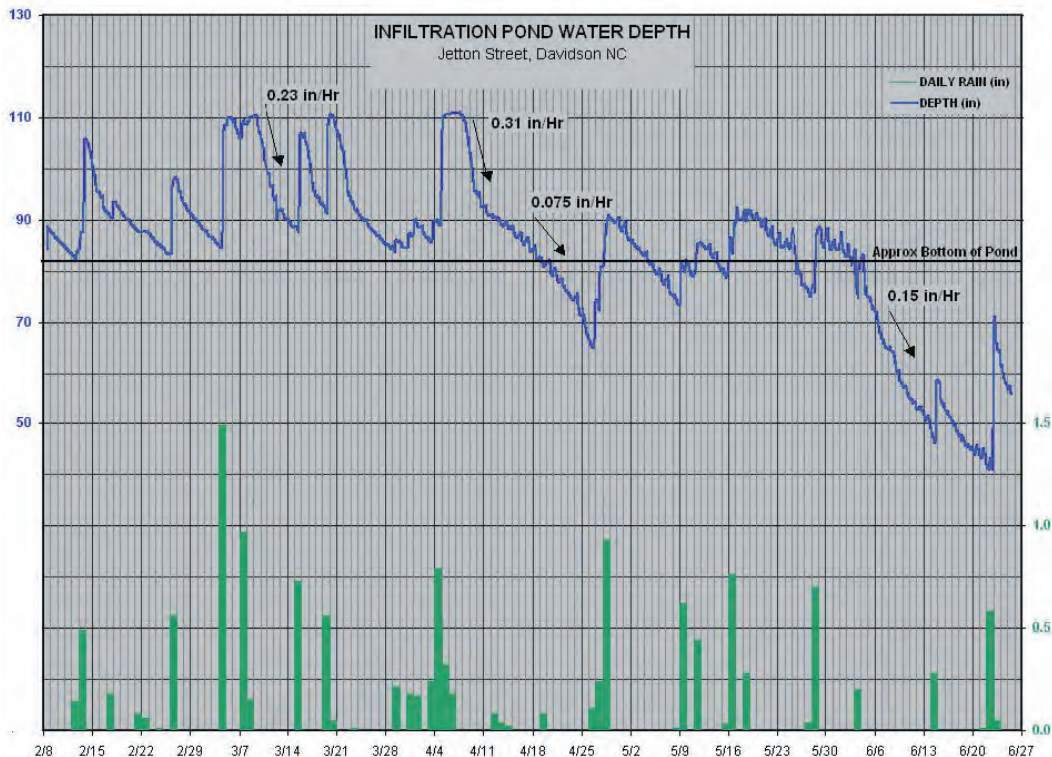


Figure 12. Jetton St. Bio-infiltration Garden monitoring data

For infiltration garden 2, noted as “infiltration pond” on the data sheets, the maximum rate the reservoir water level rose during the period was 5.6 in/hr. The maximum water level measured in the field during this period was 111 inches (33 inches above the top of the well). Again, consistent with Darcy’s Law, infiltration rates through the installed soil mix varied with depth or head of the water from 0.15 to 0.31 in/hr. A consistent and distinct rate increase was recorded once the water level reached native soils below the geotextile fabric. This is visually apparent in Figure 11.



**Figure 13. Jetton St. Bio-infiltration Garden 2 (infiltration pond)**



**Figure 14. Jetton St. Bio-infiltration Garden 2 monitoring data.**

The reasons for variation in infiltration rates between the infiltration gardens may be the elevation differences affecting proximity to the existing water table and the introduction of irrigation run off. Infiltration garden 2 is lower in elevation and maintains a shallow vadose zone. Irrigation water is introduced to infiltration garden 2 through the storm system.

### **SIXMILE CREEK: Infiltration in Natural Preserve**

The data collected for the Sixmile Creek project provides an example of natural infiltration in difficult clay soils at an undeveloped site. The intent of this data is to illustrate natural infiltration conditions in a worst-case scenario.

The site is located within 36.2 acres of formerly agricultural floodplain adjacent to Sixmile Creek in southwest Mecklenburg County. The site was previously used as cattle pasture and is dominated by fescue turf. The Mecklenburg County Soil Survey indicates that soil series at the site are Monacan (MO) and Iredell (IrA) fine sandy loams, with 0 to 1 percent slopes. MO soils (Hydrologic Soil Group C) are somewhat poorly drained, nearly level soils found on flood plains along streams and drainage ways. IrA soils (Hydrological Soils Group D) are moderately well drained soils found on broad flat areas on the uplands.



**Figure 15. Sixmile Creek Site monitoring well.**

Monacan soils are classified as fine loamy, mixed thermic Fluvaquentic Eutrochrepts. The Monacan series consists of somewhat poorly drained, moderately permeable soils that formed from recent alluvium. The organic content is low in the surface layer of this Lignum soil. The permeability is slow and runoff is medium. The water table is below 5 feet with the exception of a perched water table at 1 to 2.5 feet during wet seasons (apparent water table November-May). The depth to bedrock ranges from 48 to 72 inches (soils survey of Mecklenburg County, 1980). This Monacan series is listed on the Hydric Soils of North Carolina list (NRCS, 1995).

Iredell is classified as a fine, montmorillonitic, thermic Typic Hapludalfs. The Iredell series consists of moderately well drained slowly permeable soils that formed in residuum from basic crystalline rock. The organic matter content is low in the surface layer. A seasonally perched water table is only 1 to 2 feet below the surface. Depth to bedrock is greater than 60 inches. This Iredell series is listed on the Hydric Soils of North Carolina list (NRCS, 1995).

The monitoring period was from March 2006 to March 2007. Two Infinetes USA pressure water level data loggers were installed 41.5" below the ground surface to document the existing hydrology prior to restoration activities. The monitoring data was compared to rainfall data to gage infiltration rates into the existing subgrade.

The twelve months of data were analyzed and the wettest months were used as the sampling average. From January 1, 2007 to March 7, 2007 there were nineteen precipitation events, ranging from 0.01 in to 2.17 in, with a total rainfall of 9.58 in for the period.

The measured infiltration rates ranged from 0.354 in to 0.439 in, with an average infiltration rate of 0.42 in/hr.

## **CONCLUSION**

With the number of proven BMP methods available to designers, storm water runoff can be reduced and managed effectively with a great range of benefits both economically and environmentally. Correctly implemented storm water infiltration can be the most effective and important of all the storm water strategies available.

## **BIOGRAPHY**

Christopher J. Estes, RLA, ASLA is president of Estes Design Inc. an environmental design and consulting company specializing in low impact storm water design and stream restoration design. Mr. Estes graduated the University of Georgia, College of Environmental Design in 1988 with a bachelor's degree in Landscape Architecture. Mr. Estes has worked in the Charlotte area for over 18 years. His work experience includes 8 years spent working for one the country's first storm water utilities.

## **ACKNOWLEDGEMENTS**

Thanks to Mr. Jim Guyton of Design Resource Group for helping coordinate the many design adjustments required to make the Wilmore Walk project successful.

Special thanks go to Dr. Craig Allan of the University of North Carolina Charlotte for his tireless advice and his instruction on the intricacies of setting up the monitoring hardware / software.