Storm Water Infiltration in Clay Soils:
A Case Study of Storm water Retention and Infiltration Techniques in the North Carolina Piedmont

Christopher J. Estes[i]
Estes Design Inc.[ii] P.O. Box 79133, Charlotte, NC 28271

Abstract

As developers and regulators alike struggle with increasing pressure to protect our streams and water quality, the perceived lack of sufficient data supporting the merits of the concept of storm water infiltration in sandy clay substrate is currently limiting its use.

According to the nonprofit Center for Watershed Protection, as much as sixty-five percent of the total impervious cover over America's landscape consists of streets, parking lots, and driveways. The estimated growth of paved areas nationally is 250 square miles per year. 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.

Mitigating environmental damage caused by impervious pavements can be successful and economical. The function that is lost when impervious pavement is installed is the natural process of retention and infiltration. This loss causes devastating effects on the landscape. Targeting the composition of the pavements themselves to mitigate this 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 the installation of pavements can be matched, and in many cases easily exceeded, utilizing the readily-available tested technology of porous pavements.

When, for various reasons, impervious pavements must be utilized, careful design of other infiltration techniques can mitigate the lost retention and infiltration function. Each infiltration technique, including bio-retention, infiltration basins/swales and porous pavements, has its own unique advantages and caveats.

Vegetated BMP bio-retention applications may consist of different vegetation types that can tolerate different environmental conditions, can project varying landscape aesthetics, and can be especially adept in removing specific pollutants. Vegetated BMPs can require a higher degree of aesthetic design consideration and varying levels of maintenance, including cleaning, soil amendment and vegetation management.

Porous pavements vary in materials, infiltration rates, aesthetic values and cost. Porous pavements typically require a higher degree of technical design for bearing

capacities and longevity, while having a more limited level of maintenance that consists primarily of vacuum cleaning.

Regardless of the infiltration technique utilized, the one design constant is the infiltration rate of the native soils that underlie these systems.

Introduction

Two case studies will be presented, showcasing design and implementation of two projects in Mecklenburg County. One project, Wilmore Walk is two years old and presents preliminary monitoring data of retention and infiltration rates over a period of one year. The second project, Jetton Street Condominiums, presents design, modeling and installation issues associated with planning a low impact storm water solution. 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.

All projects presented here are within Mecklenburg County. Mecklenburg County is located in the Piedmont Geographic Region and the Charlotte Belt Geologic Region of North Carolina. 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 infiltration rates that vary from 1.5 cm/hr to 5 cm/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.

Background, Wilmore Walk

The first case study, Wilmore Walk, located in Charlotte is a 1.15 hectare (2.84 acre) condominium development. 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. A conventional preliminary design had already been completed. The existing 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 porous concrete parking lot. The resulting project treats 93% of the impervious surface runoff.

This study looks at the design and construction of BMPs retrofitted into an existing site plan, and provides a preliminary quantitative analysis of retention and infiltration rates of a 567 square meter (0.14 acre) porous concrete parking lot and its underlying Cecil sandy clay substrate. According to the NRCS Soil Survey, the site was mapped as soil unit CuB and CuD. These soil units are composed of approximately 49% clay, 25% silt and 30% sand.

Procedure

The bio-retention areas were incorporated to fit a very tight site design, and are almost indistinguishable from typical landscaped areas. The bio-retention gardens all have subdrains that connect to the conventional storm water drainage infrastructure and have minimal infiltration function.

Pervious concrete was chosen as the preferred material for the porous parking lot due to its high permeability and for its durability and ease of maintenance. The permeability 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 a consistent 15%-30% void space throughout the entire volume of the application. The voids in pervious concrete also increase in size from top to bottom of its cross section, greatly reducing the chance of clogging. Flow rates through pervious concrete range from 1536 to 4,570 cm/hr (600-1,800 in/hr). The median flow rate for pervious concrete is 4,064 cm/hr (1,600 in/hr) (E. Bean, 2005). Fifteen centimeters (6 in) of porous concrete can detain and store 5.7 cm (1.5 in) of rainfall. A reservoir composed of gravel 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 of the associated parking lot and adjacent roof top drainage area. For post construction monitoring purposes, three PVC monitoring wells were incorporated to house water level pressure transducers.

Pre-construction infiltration testing was conducted for the proposed pervious concrete parking lot, utilizing a double ring infiltrometer. Test results yielded a range of 0.61-8.0 cm/hr (0.24-3.15 in/hr) with an average infiltration rate of 2.3 cm/hr (0.90 in/hr) for the existing unmodified sandy clay subgrade. The lowest rate of 0.61 cm/hr was measured in an area of light compaction caused by a bobcat with rubber tracks. The highest infiltration rate, 8.0 cm/hr, was measured in an area that was cut raked, with no compaction.

Post construction infiltration monitoring data was also collected using an *Infinites USA* pressure water level data logger. The monitoring period was six months from August 2006 through February of 2007.

Results

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 2.5 cm to 7.6 cm. The maximum rate that the reservoir level rose during any single event was 8.7 cm/hr. Infiltration rates into the existing subgrade varied, depending on the depth or head of the water in the reservoir.

The maximum recorded water depth within the reservoir was 34 cm. The infiltration rate at maximum head was 0.75 cm/hr. During a 6.3 day period between storm events, 33.9 cm of water was infiltrated into the subgrade. The average rate of infiltration was 0.224 cm/hr, or 5.4 cm/day (2.1 in/day). During the majority of the recorded events, infiltration was occurring in saturated soil conditions.

In February 2007 the reservoir was artificially filled utilizing a water truck. Prior to filling the reservoir, the existing water level was measured at 5.8 cm. The final water level depth after filling was 34.87 cm. 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 0.14 cm/hr, or 3.4 cm/day (1.3 in/day), with a total of 19.0 cm infiltrated.

Variation of approximately one order of magnitude was observed between pre-construction and post-construction infiltration rates. The post-construction conditions had the lesser infiltration rate. Possible reasons for this variation include the introduction of the non-woven filter fabric, inadvertent compaction during construction, and extended saturated soil conditions due to consecutive storms and subsurface flow from the adjacent uphill property. Charts illustrating the recorded rates are included at the end of this document.

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 1.10 cm (0.44 in.) and 1.42 cm (0.56 in) of snow, respectively. Although snow accumulated on the adjacent impervious asphalt, there was no accumulation on the pervious concrete surface. This is a significant secondary benefit to typical vehicular applications, as well as pedestrian applications that require non-slip surfaces.

Background, Jetton Street Condominiums

The second case study is a 2.3 hectare (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 which required 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 a more accurate 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.

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 also conducted on the pre-developed site.

This study looks at the preliminary analysis, modeling, implementation and monitoring of five BMPS. Two are bio-infiltration gardens that have no subdrains and rely entirely on exfiltration. One of these infiltration gardens is also modeled and designed to retain and infiltrate the 2-yr recurrence design volume (3.12” per the Charlotte-Mecklenburg Storm Water Design Manual). The second infiltration garden retains and infiltrates the 1” storm event. Two other bio-retention gardens with subdrains detain the 2-yr recurrence design storm. The remaining bio-retention garden is the smallest and is designed to detain the 1” storm event, which then drains to largest infiltration garden.

Procedure

The preliminary design incorporated significant open-space as required by local ordinance. Draft locations of proposed BMPs and detention were mapped based on a preliminary site layout and the existing topography. During the geotechnical investigation phase, additional borings were taken at BMP locations and the report details were analyzed. The preliminary locations of the two infiltration gardens were found in the field utilizing sub-meter GPS. These locations were excavated to the proposed grade at the bottom of the infiltration gardens and tested for infiltration rates utilizing a double ring infiltrometer. Average infiltration rates varied between the two locations producing results of 2.9 cm/hr (1.13 in/hr) and 3.81 cm/hr (1.5 in/hr). Charts illustrating the infiltration results are included at the end of this document.

During the preliminary design phase and upon completion of the soils and infiltration analysis, a hydrological model was prepared to study the pre-existing and post-development hydrology relative to retention and detention volume. The model incorporated all of the proposed bio-retention and infiltration gardens. The preliminary model predicted significant reductions in required detention volumes.

The final design incorporated various changes, including road realignments and storm water infrastructure revisions. The revisions were incorporated into the model, resulting in a predicted storage volume reduction of slightly over 45% for the 10-yr recurrence storm event using the infiltration gardens, compared to traditional detention BMPs. Construction was completed by the end of 2007.

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. The monitoring wells are perforated polyethylene pipe.

The recorded monitoring period is from February 8, 2008 to September 18, 2008. The data for sixty precipitation events ranging from a trace to 3.85 inches per day, including a consecutive 3 day rain event totaling 7.39 inches, and their corresponding infiltration rates were recorded.

Results

For infiltration garden 1, the maximum rate the well water level rose during this period was 46.24 in/hr. 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 level of 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.

Background, Six Mile Creek

The site is located within 36.2 acres of formerly agricultural floodplain adjacent to Six Mile 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.

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).

Procedure

Two Infinites USA pressure water level data loggers were installed 105.4 cm (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 0.02 cm (0.01 in) to 5.50 cm (2.17 in), with a total rainfall of 14.21 cm (9.58 in) for the period.

Results

The measured permeability rates ranged from 0.90 cm/hr (0.354) in to 1.11 cm/hr (0.439 in), with an average infiltration rate of 1.07 cm/hr (0.42 in/hr).

Conclusions

In the Carolina Piedmont, the concept of designing storm water BMPs that rely on infiltration is often met with skepticism. The projects presented here provide data that demonstrates the feasibility of the concept.

The advantages of storm water infiltration include reduction in the regulated detention volume, reduction in the scale of storm water infrastructure, reduction in polluted surface water, and increased ground water recharge.

The advantages of pervious concrete include all the advantages of storm water infiltration mentioned above, plus allowing the beneficial use of the affected land area. That, is, pervious concrete can be substituted for conventional hard surface areas while still maintaining conventional functions. Another advantage observed on the pervious concrete parking area is the non-slip surface and immunity to ice and snow accumulation.

The data from the Wilmore Walk study demonstrates the performance of the infiltration BMP at the site, as well as the applicability 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 the design criteria for clay soil infiltration.

The detailed hydrological model performed for the Jetton Street Condominiums illustrates the effectiveness of the bio-retention and infiltration BMPs to reduce the required detention volume. This project effectively incorporates storm water quality management into the planted landscape while reducing the area required for dry detention.

The data collected for the Six Mile Creek project provides an example of native permeability in difficult clay soils on an undeveloped site. The intent of this data is to illustrate that even the most difficult soils have a capacity for infiltration.

Storm water infiltration is a valid and important tool for land development in the Carolina Piedmont. Sandy clay soils can be predictable if assessed correctly. With the number of proven BMP methods available to designers, storm water runoff can be reduced and managed effectively with a greater range of benefits both economically and environmentally. Correctly implemented storm water infiltration can be the most effective and important of all the storm water management strategies available.

Acknowledgement

Special thanks goes to Mr. Jim Guyton of Design Resource Group for getting me involved in both of the featured development projects and for coordinating the many design adjustments required to make the Wilmore Walk project successful.

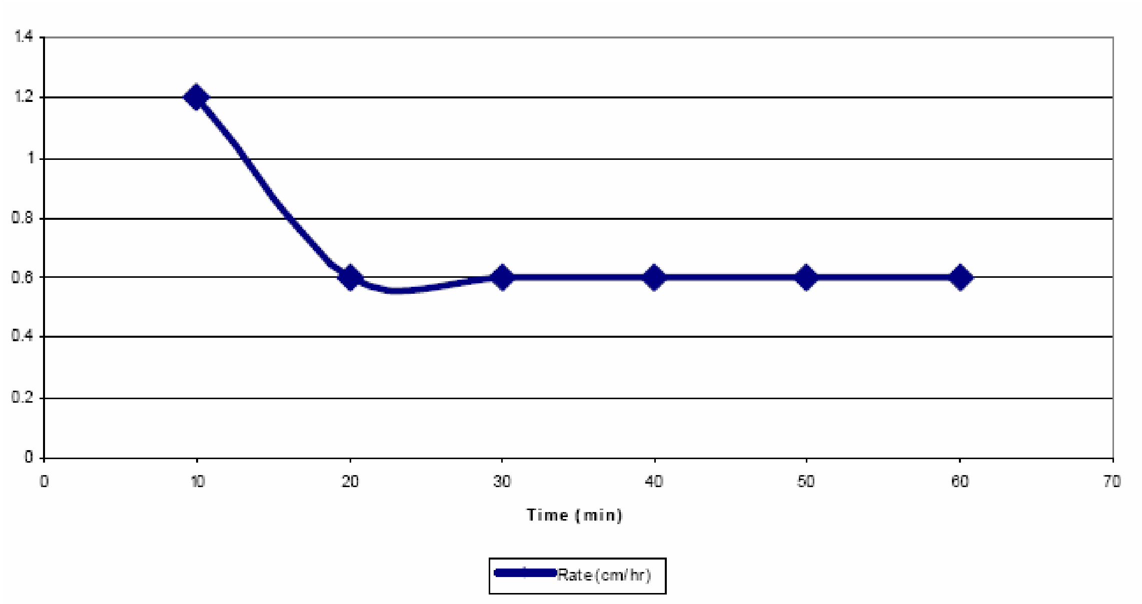

Figure 1. Wilmore Walk Infiltration Basin Pre-construction (Infiltration Rate, Area A 2nd Run) Source: Manual measurement, double ring infiltrometer

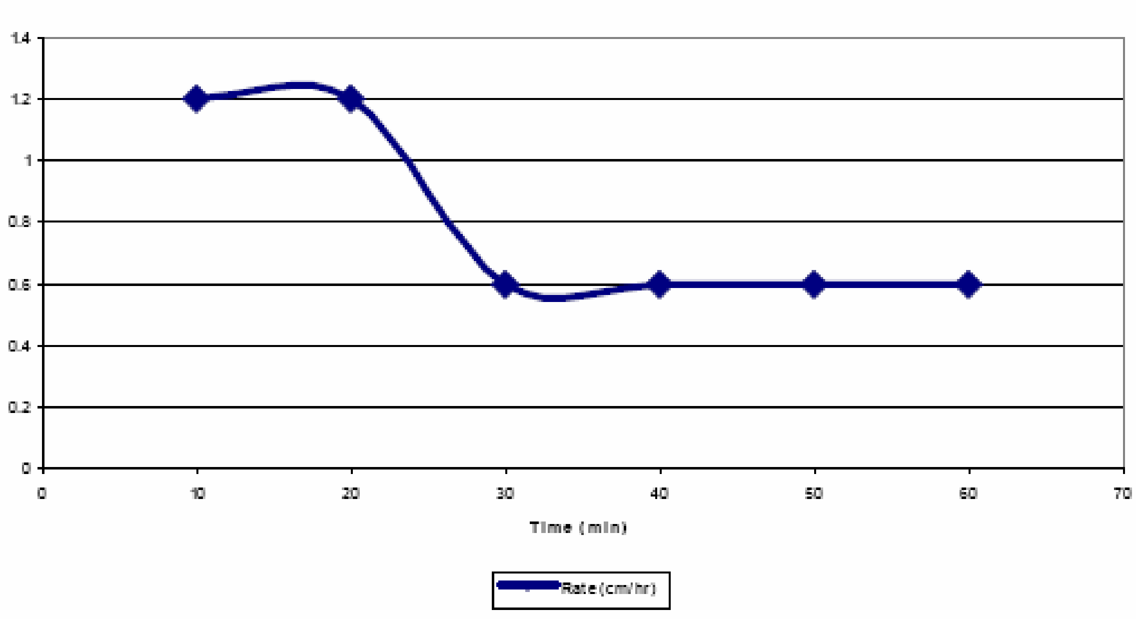

Figure 2. Willmore Walk Infiltration Basin Pre-construction (Infiltration Rate, Area B 2nd Run) Source: Manual measurement, double ring infiltrometer

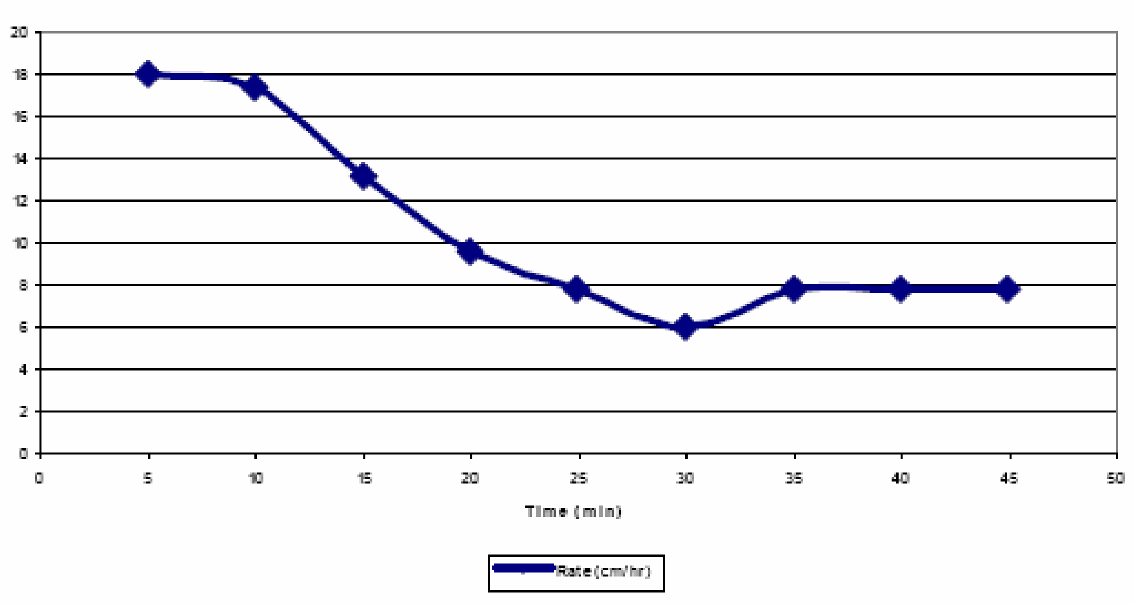

Figure 3. Wilmore Walk Infiltration Basin Pre-construction (Infiltration Rate, Area C 2nd Run) Source: Manual measurement, double ring infiltrometer

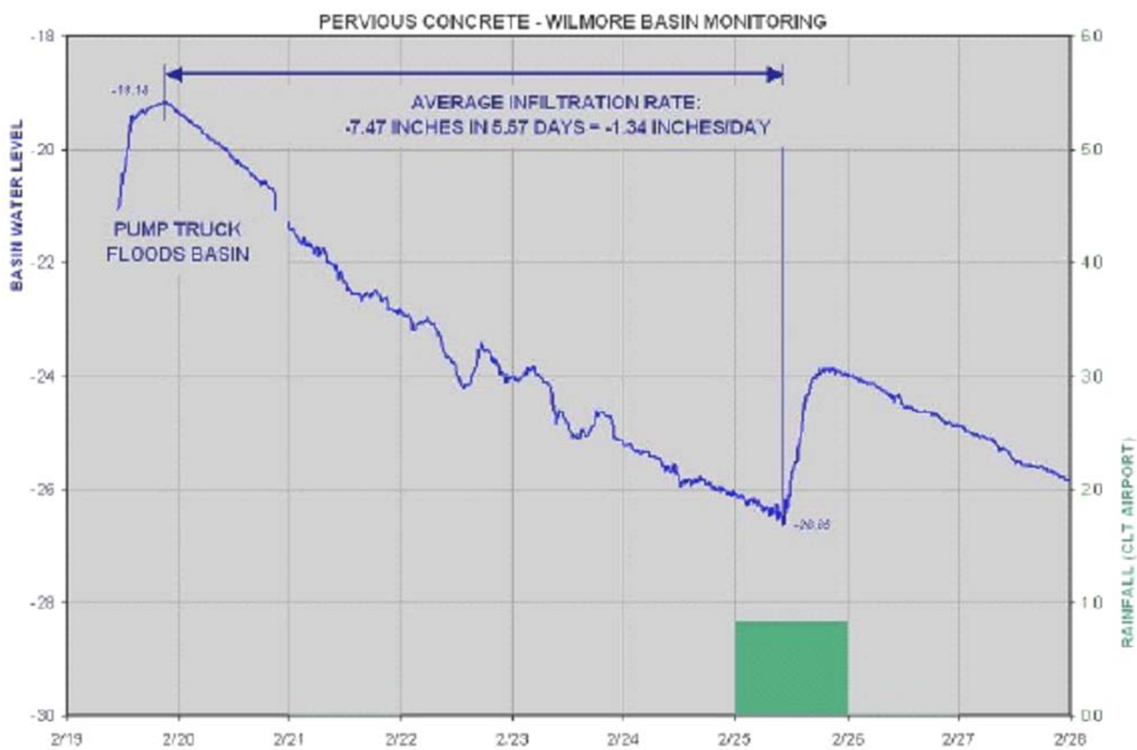

Figure 4. Wilmore Walk Pervious Concrete Post Construction (Artificial filling)

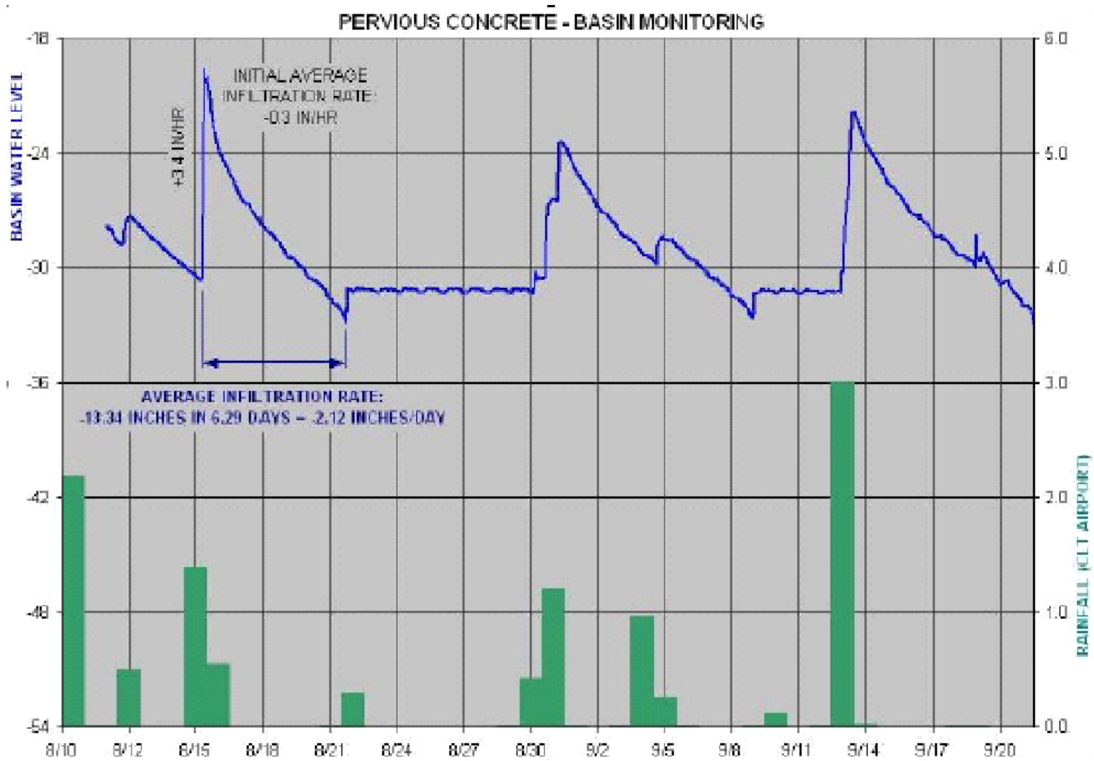

Figure 5. **Wilmore Walk Pervious Concrete Post Construction –** Basin Monitoring

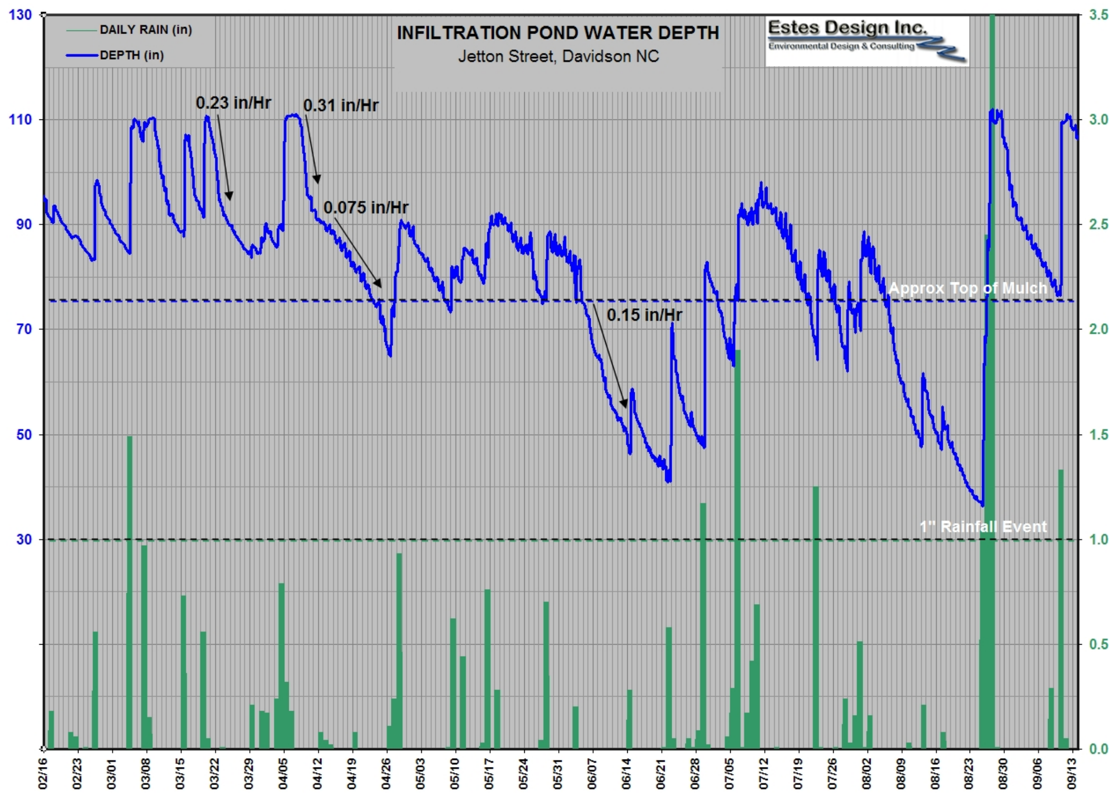

Figure 6. Jetton Street Condominiums – Basin Monitoring

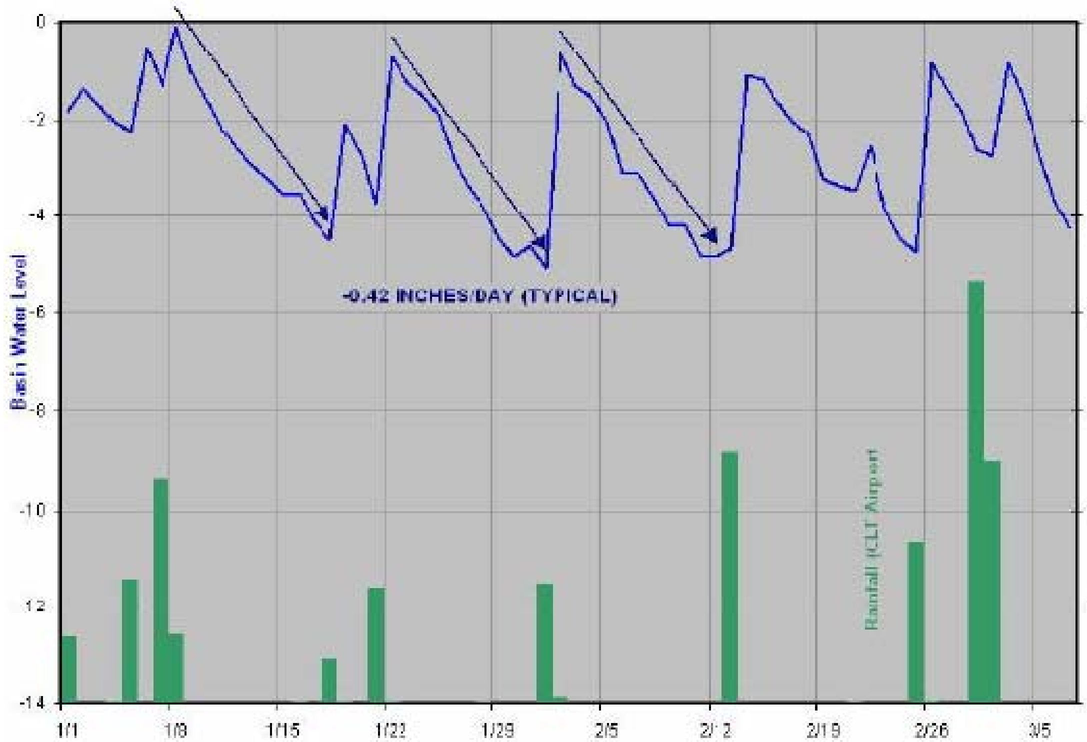

Figure 7. Six Mile Creek Monitoring

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[i] Mr. Estes is a licensed Landscape Architect and owner of Estes Design Inc. Mr. Estes worked for the City of Charlotte Engineering department for over 10 years. Mr. Estes initiated and managed the City's stream restoration, enhancement & bioengineering program. In 8 years, over 60 stream projects and 5 miles of urban stream restoration & enhancement were completed. Associated with his work Mr. Estes has been a speaker at more than 35 conferences on the local, state, national and international levels. He has traveled nationally and internationally to areas including Canada, England and Denmark to observe and learn about different environmental projects and programs including Danish Stream Restoration Practices, West Jutland, Denmark; River Black Water, Norfolk, England and Hutchinson's Tip Hazardous Waste Site Reclamation, Manchester England. Mr. Estes currently conducts research and training in storm water quality including storm water infiltration and porous pavements.

[ii] Estes Design Inc. is a private consulting firm specializing in the design & research of water resource protection and restoration.