EFFECT OF A PERMEABLE PAVEMENT PARKING LOT ON RUNOFF FROM THE IRWIN CREEK WATERSHED IN CHARLOTTE, NC.

A Capstone Research Project Presented

by

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Abstract

Investigators from UNC Charlotte's Department of Geography and Earth Sciences were hired by The City of Charlotte Stormwater Services to monitor the performance of a permeable concrete stormwater Best Management Practice (BMP) from March 2007 - June 2009. The study had three major objectives: 1. Quantify the water table response in the storage reservoir underlying the permeable concrete to various precipitation inputs; 2. Evaluate the long term performance of the structure for changes in percolation and infiltration; and 3. Characterize water quality constituents and their concentrations in infiltrating stormwater beneath the structure. The study was designed to provide the City's stormwater management engineers with a comprehensive long term analysis to assess the utility of permeable pavement (PP) as a Stormwater BMP in an urbanized Piedmont setting. In addition to the monitoring study for Charlotte Stormwater Services, three other aspects are included in this research study: 4. Evaluate the utility applying Green Ampt approach to model the infiltration response within the storage reservoir; 5. Model and evaluate the potential effectiveness of multiple, spatially distributed PP installations on stormwater runoff at the watershed scale using ArcGIS and HydroCAD, modeling software for four scenarios (Scenario 1: Present Conditions, 2: PP parking lots, driveways, sidewalks, 3: PP secondary roads, 4: PP parking lots, driveways, sidewalks, and secondary roads); and 6. Compare the cost effectiveness of PP as a water quality and stormwater BMP to other commonly employed stormwater control measures.

The study of the permeable concrete structure at Wilmore Walk indicated no significant change in the infiltration capacity of the structure itself; however there may be a slight decline in the infiltration performance of the subsoil below the structure. The estimated porosity (η) of the crushed rock reservoir is 38.5% ± 10.5% and the average measured corrected infiltration rate IR_c at 0.041 inches/hour ± 0.032 inches/hour would take approximately 61 hours to infiltrate a 1" rain event. The treatment of water quality is minimal at this site because it is treating only the precipitation that hits the pavement surface. In addition there does not appear to be an accumulation of infiltrated nutrients (N or P) within the structure itself. The application of the Green Ampt model to the Wilmore Walk precipitation and well response data shows that the predicted well responses did emulate actual infiltration data for 7 of 10 events when applying the Sand texture parameters of porosity (ϕ) at 0.34, and wetting front tension (ψ_f) at 3.75. In applying the SCS Runoff Curve Number model application to the Wilmore Walk sub-watershed it was found that if impervious surfaces were converted to PP successfully over time, it has the potential to significantly reduce and delay stormwater runoff within the urban watershed. The most cost effective BMP to meet the water volume requirements required in the Charlotte-Mecklenburg Stormwater BMP Design Manual according to the findings of this study is PC. The most cost effective BMP for pollutant removal are retention ponds (for areas larger than 10 acres) and bioretention areas (less than 5 acres).

Acknowledgements

I wish to express my gratitude to the individuals who have helped to guide, support, and advise me as I took on this endeavor. I would like to first thank my advisor, Dr. Craig Allan, who was instrumental in pointing me in the direction of this research project. His support, advice and patience were critical in my completion of the project. I am grateful to have been able to research something that may have a future impact on stormwater regulations in NC. A big thank you goes to the City of Charlotte Stormwater Services for their support of this project. I would also like to thank my committee members Dr. Ross Meentemeyer, and Dr. Sandra Clinton for their time, ideas, input, and feedback on this project. Others I am grateful to are; Dr. John Chadwick, Claire Chadwick, Dr. Eric Delmelle, Douglas Shoemaker, Adam Lagrow, and Kunwar Singh. I would also like thank Stephen Bowman for making sure that everything was in order in regards to paperwork and deadlines. A big thank you to Chris Estes of Estes Design, Inc. who opened his office to me in order to ask questions of his staff and allowed me the use of the hydrology software needed in order to complete this study.

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Chapter 1: Literature Review

Impervious surfaces with an area of one city block can generate up to five times more runoff than a wooded lot of equal size (USEPA 2003). Such surfaces divert stormwater that normally recharge the groundwater to storm sewers and channels. Diverting stormwater alters the natural hydrologic cycle and impedes the infiltration of water into the soil surface during storm events, causing higher volumes of stormwater to enter streams and channels quickly. The differences between normal stream flow (Pre-development) and impervious cover (IC) runoff stream flow (Post development) is shown in Figure 1 (CWP 2003). Higher peak flows within a shorter time period are associated with the Post-development condition, this increases the amount of bank erosion and channel incision, increases the transportation of sediment, and degrades the biotic integrity of the stream system (Brattebo, et al. 2003, Dreelin, et al. 2006, NCDENR 2006, USEPA 2003).

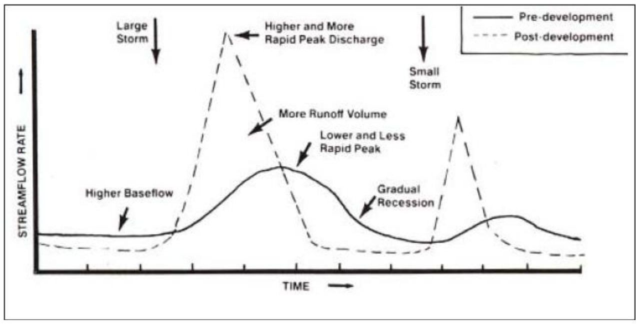


Figure 1: A large storm event hydrograph of stream flow rate conditions over time for Pre-development and Post-development scenarios (CWP 2003).

Runoff from IC in urban zones also mobilizes various pollutants such as nutrients (e.g. N & P), metals and hydrocarbons, pesticides, and chloride (CWP 2003). Urban runoff carrying these pollutants often bypasses the natural filtration system of the soil, thus directly degrading the surface water quality of our waterways (Brattebo et al 2003, CWP 2003, Dreelin et al 2006, Gilbert 2006). To help retain and infiltrate stormwater, and improve water quality, a variety of best management practices (BMP's) have been created to delay the delivery of runoff through a variety of structural installations such as: bioretention areas (rain gardens), retention ponds, and permeable pavement (USEPA 2003). In urban areas, where space is limited, the natural soil infiltration process of an urban wooded or grassy lot can be somewhat replicated by a permeable pavement (PP) structure in the ability to remove water from the surface, temporarily storing it within the crushed rock reservoir below the pavement surface, thus allowing the stormwater runoff time to infiltrate into the subsoil.

Roadways' and parking lots' stormwater runoff is of particular concern. During storm events, one out of five automobile accidents is caused by water lying on impermeable roadways (Edwards 2002). A porous surface's ability to allow water to pass through the surface quickly facilitates infiltration resulting in little or no standing water on roadways and creates a better surface for driving during rain events. For highways and high traffic roadways – state transportation agencies are increasingly using a PP overlay on conventional surfaces called Permeable Friction Course (PFC). A PFC surface is an open-graded asphalt surface that is formulated with less binder and fine aggregates as compared to conventional pavement surfaces. A PFC surface is typically about 50mm thick, has void spaces of 18 to 22%, and has a lifespan of 10 to 12 years (Barrett 2008, Asphalt Pavement Alliance 2003). PP surfaces are being used to reduce splash and spray (as shown in Figure 2), increase visibility and road traction, reduce incidences of hydroplaning, reduce the amount of pollutants going into storm drains, and are less noisy than conventional surfaces (Ferguson 2005, Barrett 2008). Permeable pavement structures that are not overlay applications like a PFC surface are not recommended for high traffic Interstates and highways with significant truck volumes as PP surfaces are quicker to degrade due to their lower weight bearing capacity and incidences of clogging. PP surfaces have to be regularly maintained by vacuuming to clear debris from the surface pores and therefore are more suitable for more ***light to medium traffic settings*** - like secondary roads and parking lots (Dreelin 2006, Hunt 2008, Edwards 2002, Ferguson 2005, NPDES 2006). Full PP structures are advantageous for their ability to infiltrate water from the pavement surface immediately and for their ability to handle stormwater *in situ* rather than rely on storm drainage systems (Edwards 2002).

Figure 2: (Left) Image of the lack of spray, on a section of Loop 360 in Austin Texas, while on a PFC overlay application VS. (Right) the lack of visibility while driving on a conventional surface on the same highway (Right) (Barrett 2008).

The performance of PP as an alternative road surface and for the ability to have on-site stormwater control and treatment is being evaluated under various types of soil conditions and scenarios to determine its ability to delay storm runoff and improve water quality within watersheds (USEPA 1999, NCDENR 2006).

In North Carolina, the Legislature passed Bill H1473 in July 2007 stating that any uncovered vehicle parking areas shall not have more than eighty percent (80%) of the parking surface as impervious, and the remaining area shall consist of PP or other pervious BMPs (e.g. grass swales, rain gardens, etc). Bill H1473 was later replaced in 2008 with Senate bill 845, listing that after August 8, 2008, no more than eighty percent of a new parking area of an acre or more may be impervious AND that statute applies only to areas of the State that does not have a preemptive Stormwater Management program (e.g. NPDES Phase II Stormwater Management) (SL2007-323, SL-2008-0198, Hunt et al 2008).

The new bill would apply to new properties that are being built and properties larger than one acre. Shopping centers and mall parking lots are prime candidates for PP applications because they usually cover more than one acre and the IC is 90% (including building structures) or more of the land they occupy. Impervious pavements on these sites occupy up to 65 to 70 percent of the land surface area. A large portion of a typical parking lot have areas that have little to moderate loads of traffic use (e.g.

parking stalls, and outer lanes further from the mall) making them suitable sites for PP applications (Ferguson 2005).

Under a controlled laboratory test, researchers Andersen et al. (1999) determined that 55% of a 15mm/hr (0.049 feet) storm event was stored within the permeable pavement structure under laboratory conditions. Subsequently when a second synthetic rain event was applied to the installation the initially wet PP structure was able to store 30% of the same volume of water (Anderson 1999). If this 15mm/hr scenario was applied to a three acre (130,680 ft^2) shopping center, 6,403 ft^3 (47,900 gallons) of stormwater runoff would be generated. If 70% of the 3 acre plot is used for parking (91,476 ft^2), and 20% of the parking lot (18,295 ft^2) was designed under the new statute using PP; **896 ft^3** of stormwater would impact the PP structure itself. According to the study – 55% of stormwater that hits the surface of the initially dry PP structure would infiltrate into the structure and ultimately into the subsoil, which is approximately 7.7 % of total stormwater runoff for the whole site.

If developers installed a rain garden instead of a PP structure for the same scenario, they would have to purchase an additional **0.013 acres** based on a 15mm rain event and a 9 in depth of runoff. The acreage is derived by using the equations provided by United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) for designing Bioretention areas, as shown in Table 1 – (Hunt 2001, NRCS 1986).

Table 1: Calculations to determine size of Rain Garden		
Eq. 1: SCS TR-55 Runoff Model		
Q =	$(P - 0.2S)^2$ / $(P + 0.8S)$	
Eq. 2: Curve Number Value to Calculate Land-use Values		
CN =	[% Land Coverage x (Land-use vs. Soil type CN)] [(90% impervious x 98) + (10% pervious x 79)]	
Eq. 3: Runoff volume (ft^3) =		Area × Q
426.89 ft^3 =		18295.20 ft^2 x (0.28 in x (1 ft/12 in))
Eq.4: Rain garden surface area =		Runoff Volume (ft^3) ÷ Average depth of water (ft)
569.19 ft^2 =		426.89 ft^3 ÷ (9 in x (1ft/12

Legend & Summary for Eq. 1 - 4		Values
CN =	Overall Curve Number Value of Land	**96.1**
S =	(1000/CN) - 10	**0.41**
P =	Precipitation Depth (Inches)	**0.59 in or 15 mm***
Q =	Runoff Depth (Inches)	**0.28in**
A =	Area (ft^2) equal to 3 acres	**18295.20 ft^2***
Average Depth of Water designed for in Rain Gardens is 9 inches		**0.75 ft or 9 in***
Runoff Volume (ft^3) =		**426.89 ft^3**
Rain Garden Surface Area (ft^2) =		**569.19 ft^2**

Given numbers are *

Table 1: Calculations to determine size of Rain Garden example for Wilmore Walk in Charlotte, NC using equations provided by USDA NRCS for designing Bioretention areas. (NRCS 1986)

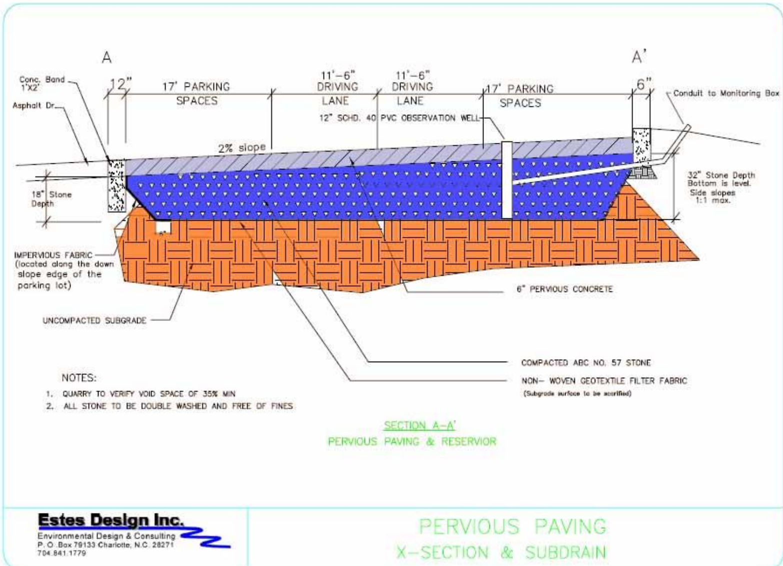


Figure 3: A cross-section view of the Permeable Concrete Structure at Wilmore Walk in Charlotte, NC. The basic construction of a PC structure is made up of the porous surface, crushed rock reservoir, and filter fabric on top of in situ soils (Estes Design 2008).

It is important to consider the following issues that can reduce the effectiveness of a PP structure before installing one; areas with consistent high winds, sites characterized by clay subsoils, and/or those locations subject to high vehicular traffic. High winds can cause significant soil erosion that can be deposited onto the surface of the pavement structure and clog the surface. Subsoils with high clay content have a low permeability rates and are seen by many stormwater professionals as not being suitable for BMPs dependent on filtration (Hunt 2008, USEPA 1999). Areas with steep slopes are not desirable because the bottom of the reservoir must be flat and it cannot be placed in bedrock which would be effectively impermeable to infiltration. Permeable pavement also must be maintained regularly by vacuuming and/or sweeping to preserve the infiltration capacities that they were designed for (Ferguson 2005). As new installation techniques, technologies, and studies arise that demonstrate the long term performance and cost effectiveness of PP as a stormwater BMP, these installations will become more commonplace.

A permeable structure called permeable concrete (PC) will be the primary PP structure examined in this study. A PC structure, as shown in cross-sectional view in Figure 3, allows precipitation to infiltrate through the surface layer of permeable bound ASTM # 69 course aggregate and stores water below in an open-graded ASTM # 57 crushed rock reservoir until the water can infiltrate into the subsoil through a filter fabric installed beneath the crushed rock reservoir (Estes 2008, NPDES 2006, USEPA 2003).

Where a PP structure is installed on clay subsoils, it is essential that compaction of the soil is minimized to prevent reduction of the already low infiltration capacities of the subsoil (Estes 2008, NPDES 2006). If the storage reservoir reaches capacity during an extreme precipitation event, stormwater will overflow the structure and enter the stormwater system via storm drains (USEPA 1999, Dreelin et al. 2006).

In focusing on areas with clayey subsoils many studies have found variable infiltration rates for the permeable structure and subsoil. According to a study conducted with a Grassy Paver™ structure, shown in Figure 4, installed over a 35-60% clay subsoil in Athens, Georgia, a 93% reduction in runoff with storms less than 20mm was measured as compared to an impervious lot nearby (Dreelin 2006). Sixty-six percent of forty permeable pavement sites monitored by North Carolina State University within the Piedmont and Coastal Plains of North Carolina were found to have an infiltration rate greater than grass (6.4 cm/hr) (Hunt & Collins 2008). Gilbert and Clausen found that runoff rates from PP structure driveways were reduced by up to 72% of the rainfall volume that impacted the surface compared to asphalt surfaces (Gilbert & Clausen 2006). Hunt & Collins found that the median value for discharge volume for four types of PP reduced runoff by 36 to 67% for storms less than 50mm. A study conducted by Tyner, Wright and Dobbs found that using additional methods of infiltration underneath the PP, (such as boreholes, ripping, or trenches) help improve the infiltration capacity of clay subsoils from 1,700% to 4,400% when compared to the control (Tyner et al 2009).

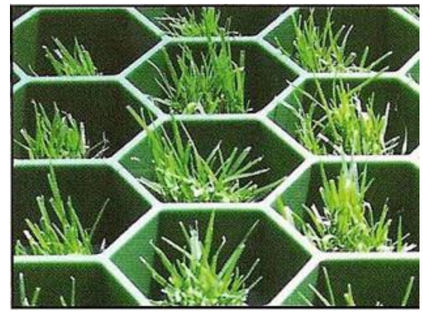


Figure 4: Close up of plastic Grassy PaverTM grid with grass seedlings. (EFS, Inc. 2009).

Beyond storing and infiltrating all or part of a runoff event, simply delaying the onset of runoff relative to rainfall can significantly reduce the deleterious impacts of urban stormwater runoff. According to Fassman's study in New Zealand which examined the effectiveness of a PP installed over clay subsoils, the median delay of runoff for the PP structure was 48 minutes, compared to 12 minutes for a conventional asphalt surface. The PP structure also expanded the duration of runoff by 3 to 6 hours for 7 to 50mm storms compared to the conventional surface (Fassman et al 2009).

Permeable Pavement has a higher initial installation cost when compared to traditional asphalt parking surfaces. The structure requires more aggregate material and its installation is more labor intensive due to the use of the crushed rock reservoir and the need to preserve the porosity of the structure and subsoil. This precludes the contractor from driving equipment over the structure during the installation of the crushed rock reservoir. Ideally, the higher initial costs of the PP structure is offset because there is no need to buy additional land for bioretention installations, and the PP structure serves a dual purpose, road surface and as a stormwater control measure.

With advancements in computer technology and model development, storm water runoff for a single rainfall event can be determined for a watershed through computational models employing detailed spatial landcover and topographic data from satellite imagery and geographical information system (GIS) software. Modern hydrological models are capable of simulating the hydrologic impact of multiple, spatially distributed permeable pavement installations watershed runoff within an urbanized setting.

Chapter 2: Project Overview

STUDY SITE

The City of Charlotte Stormwater Services worked with a contractor and installed PC storm water BMP structure a few miles from uptown Charlotte, NC, in March 2006 (Figure 5). The study site is located within a sub-division called Wilmore Walk within the Irwin Creek Watershed (ICW) which covers 30 square miles in the west-central part of Charlotte, NC. The prevalent surface soil type within the area of Wilmore Walk is a clay rich urban Cecil soil. Cecil soils here have a slope between 2 and 15 percent, but much of the area has been re-developed and the slopes and soil properties have been changed through excavation and compaction through construction (USDA, 2013). The subdivision site's soils were excavated up 8 feet as the eastern side of the site is approximately five feet above the PC structure. The soil underneath the PC structure itself was excavated to about 3 feet deep at the deepest point. According to the Mecklenburg Soil survey, the soil at a depth of 53 to 65 inches is red and yellow saprolite (McCachren, 1980). Red and yellow saprolite is a chemically weathered rock.

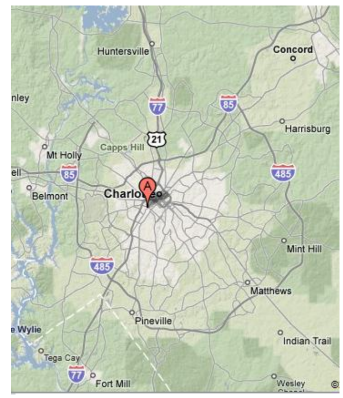


Figure 5: Google Map of Charlotte, NC. Point "A" indicates the location of Wilmore Walk.

The contractor installed a 38 by 19m PC parking lot within Wilmore Walk and figures Figure 6 and Figure 7 show a close up aerial view of the study site as well as a site schematic of the original plans (Google 2010, Estes Design, Inc. 2008). Three shallow, 0.75 to 0.90m deep wells were installed within the parking lot, and lockable-boxes outside the lot provided access to monitoring instruments and sampling lines. Three pressure transducer style water level loggers and later three capacitance water level loggers were installed in the wells to continuously record water levels within the crushed rock storage reservoir underlying the pavement surface. Precipitation gauges were mounted on two poles fifteen feet above the surface of the parking lot (Allan and Gray 2008). All loggers and gauges were downloaded at least biweekly, and precipitation samples were collected after each storm event.

Figure 6: Satellite image from Google Map (2010) of Wilmore Walk Condominiums. The parking lot in light grey is the porous concrete structure designed by Estes Design, Inc.

Figure 7: Site schematic of Wilmore Walk drawn in 2005 by Estes Design, Inc. The Permeable Concrete (PC) structure is shown in gray in top left of drawing.

Project Objectives and Study Hypotheses

Investigators from UNC Charlotte's Department of Geography and Earth Sciences were hired by The City of Charlotte Stormwater Services to monitor the performance of a porous pavement stormwater Best Management Practice (BMP) beginning in March 2007 and ending June 2009. The monitoring study had three major objectives: 1. Quantify the water table response in the storage reservoir underlying the permeable concrete to precipitation inputs of different magnitude; 2. Evaluate the long term (2 year) performance of the structure with regard to changes in percolation (clogging) and drainage (infiltration); and 3. Characterize water quality constituents and their concentrations in infiltrating stormwater beneath the structure. The study was designed to provide the City's stormwater management engineers and planners with a comprehensive long term performance database with which to assess the utility of permeable pavement as a Stormwater BMP in an urbanized Piedmont setting.

In addition to the monitoring study for Charlotte Stormwater Services three other aspects are included in this research study: 4. Evaluate the utility of utilizing the commonly applied Green Ampt approach to model the infiltration response within the storage reservoir after precipitation events; 5. Model and evaluate the potential effectiveness of multiple, spatially distributed PP installations on stormwater runoff at the watershed scale using ArcGIS and HydroCAD, modeling software; and 6. Compare the cost effectiveness of PP as a water quality and stormwater BMP to other commonly employed stormwater control measures.

Hypothesis

H_1 There ***will be*** a significant change in the performance of the PP systems ability to infiltrate water through to the subsoil over the two year monitoring period.

H_0 There *will* ***not*** *be* a significant change in the performance of the PP systems ability to infiltrate water through to the subsoil over time.

H_2 The Green and Ampt model ***can be parameterized*** to effectively model the infiltration of the percolating storm water within the crushed rock storage reservoir underlying the PP surface.

H_0 The Green and Ampt model ***is not an appropriate approach*** to effectively model the infiltration behavior of the percolating storm water within the crushed rock storage reservoir underlying the PP surface..

H_3 The installation of multiple spatially distributed PP installations can significantly impact the overall stormwater runoff at the watershed scale in a highly urbanized setting when compared to conventional pavement surfaces.

H_0 The installation of multiple spatially distributed PP installations does not significantly impact the overall stormwater runoff at the watershed scale in highly urbanized settings when compared to conventional pavement surfaces.

H_4 PP ***is a*** cost-effective stormwater BMP when compared to other BMPs.

H_0 PP *is* ***not*** *a* cost-effective stormwater BMP when compared to other BMPs.

Methods

Hydrologic

The water table response below and within the structure was determined via measurements taken from monitoring wells on site, and is the result of a storm event that exceeds the infiltration rate of the percolating water through the subsoil which ponds within the reservoir. Three Global Water Instrumentation Inc. (GW) pressure transducers were installed into three access wells situated in the PC structure at the initiation of the field study. The access wells were installed during the initial construction of the BMP by the contractor and City of Charlotte in 2006. The GW devices measure changes in pressure (water level) above the sensor every five minutes and the data is stored on an internal data logger. Data was retrieved from the GW devices, residing in the access boxes, on an event or monthly basis with a laptop computer. Owing to noisy output from the GW devices (see appendix 1) three Odyssey Capacitance type water level recorders were installed alongside the GW recorders in the September 2007. The Odyssey Capacitance Loggers had to be converted into water levels with units of inches from recorded voltages using individual regression relationships shown in Figure 8. The water levels for all six loggers were recorded every five minutes.

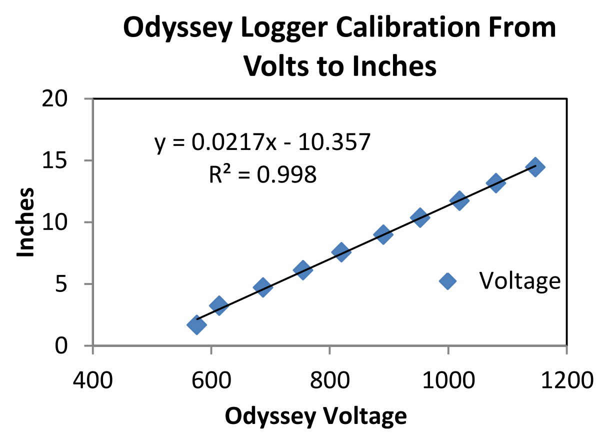


Figure 8: Results of Odyssey Capacitance Logger calibration from volts to mm at known volumes and depths.

Precipitation inputs to the PP structure were measured and recorded with a HOBO RG3 recording rain gauge. Three periods of missing precipitation records (March-April, December 2007, and July-August 2008) occurred during the monitoring period and data from the National Weather Service Data (NWS) recorded at Charlotte Douglas Airport was used in these instances. Precipitation input was also recorded manually after every rain event with a standard metric Tenite rain gauge. Air temperature and relative humidity were also recorded at the monitoring location with a HOBO combination temperature/RH logger (data not presented).

Water Quality

Water samples were obtained with a hand operated peristaltic pump from each of the three monitoring wells after each rain event where a sufficient water table response permitted sampling. Samples were withdrawn from fixed sampling lines installed in each well. An aquarium type "air stone" attached to the well end of each sampling line served as a pre-filter for the well samples. Atmospheric dry and wet deposition is sampled with a bulk collector suspended from a pole above the pavement surface. The collector consists of a five gallon plastic pail with a plastic bag liner that is exchanged after each precipitation event. Bulk precipitation and well samples were poured off into acid washed Nalgene bottles and transported to the UNC Charlotte Hydrology and Biogeochemistry Laboratory. Samples were immediately analyzed for pH, conductivity and filtered within 24 hours of collection. After initial sample analyses all samples were frozen for later analysis for major ions and nutrients.

All observation well water samples are filtered with glass fiber filter papers (nominal pore size 0.45μm) before analyses. Bulk precipitation samples are passed through an inert nytex prefilter when particulates were prevalent in a sample. Temperature corrected specific conductance and pH determinations were made with suitable meters standardized to appropriate buffers or standard solutions. Major cations (NH_4^+-N) and anions (PO_4^{-3}, NO_3-N and Cl^-) were measured by ion chromatography with a Dionex DX-500 IC system. Total Dissolved Nitrogen (TDN) was measured with a Shimadzu TOC/TN analyzer. Total phosphorus determinations were made colormetrically on acid/persulphate digested samples reacted with pre prepared HACH TP kits. Random quintuplet samples were analyzed during each run to assess the analytical variability for each method.

Infiltration

One of the main objectives of this research is to determine if the infiltration rate (IR) into the underlying clay subsoil below the crushed rock reservoir changes over time. The actual porosity (η) is unknown for the crushed rock reservoir but an estimated (η) was determined by dividing the maximum water level response by the depth of precipitation recorded for each event, (1). The IR is determined by dividing the highest point of water level response (in mm) from a storm by the elapsed time in hours until the water level reaches zero or another rain event interrupts the drainage of the crushed rock reservoir. This method does not account for the porosity of the crushed rock reservoir and is considered the uncorrected infiltration rate, (2). It is assumed that precipitation abstractions are relatively minor and can be neglected, particularly for those events that are sufficiently large to produce a water table response in the subsurface reservoir. The porosity of the reservoir is determined as the average of the estimate from multiple rain events. Finally, to account for the porosity of the reservoir, the corrected IR rate is given in Equation 3.

Equation 1 Porosity (η) The porosity of the crushed rock reservoir was estimated from the rainfall/water level response in the following manner:

$$\eta = \text{Precipitation depth (inches)/Maximum Water Level Increase (inches)}$$

Equation 2 Infiltration Rate Uncorrected (IR_u) The uncorrected infiltration rate for each rain event was calculated by:

IR_u= Maximum Water Level Increase (Inches)/Drainage Duration (hours)

Note the period selected for the drainage duration was either the time until complete recovery to the initial water level prior to the precipitation event for solitary events, or the maximum drainage duration until interruption by a subsequent precipitation event.

Equation 3 Infiltration Rate Corrected (IR_c) The corrected infiltration rate for each rain event was calculated by:

IR_c = Maximum Water Level Increase (Inches)* η /Drainage Duration (hours)

As above the period selected for the drainage duration was either the time until complete recovery to the initial water level prior to the precipitation event for solitary events or the maximum drainage duration until interruption by a subsequent precipitation event.

Green and Ampt Model

The Green Ampt model (GA), shown in Equation 4, will be applied to emulate the water table response data. F(t) in the model is the depth of the infiltrated water in mm, $F(t_p)$ is the cumulative infiltration of water in mm, K_h* is the saturated hydraulic conductivity, $|\Psi_f|$ is the effective tension of the wetting front, ϕ is porosity, Θ_O is the water content. The model describes the infiltration capacity of the crushed rock reservoir by applying Darcy's Law, which describes the flow of water through subsoil (Dingman 2002). Ideally the time of infiltration and depth of water infiltrated of the site should resemble the GA model's calculation - an example of this is shown in Figure 9.

Equation 4: Green Ampt Equation

$$t = \frac{F(t) - F(t_p)}{K_h^*} + \left[\frac{|\psi_f| \bullet (\phi - \theta_0)}{K_h^*}\right] \bullet \ln\left[\frac{F(t_p) + |\psi_f| \bullet (\phi - \theta_0)}{F(t) + |\psi_f| \bullet (\phi - \theta_0)}\right] + t_p$$

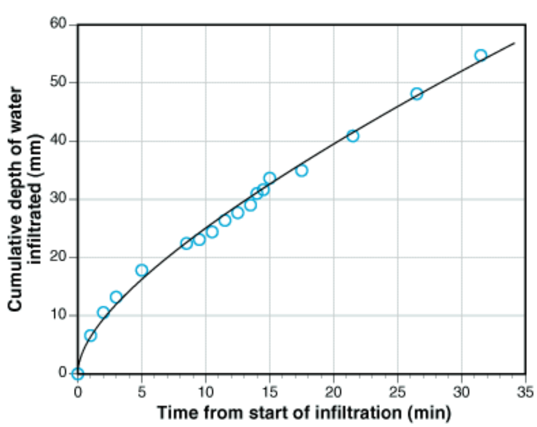


Figure 9: "Cumulative infiltration measured for a loamy soil in central Virginia (blue circles) and calculated using the Green-Ampt equation (black line) (Hornberger et al 1998)."

If it does effectively model the infiltration rate of stored water, then it can be used to predict the infiltration rates of different or a series of storm events. If the Wilmore Walk infiltration rates are found to not be predictable with the GA model then a more complete mathematical treatment utilizing the Richards equation may be more applicable Reference?. If the GA model is found to be suitable, it could be used to help Stormwater management determine how deep the storage reservoir for a new installation would need to be, based on how long the water takes to infiltrate into the subsoil under different rainfall scenarios, different ponding durations, etc.

The GA model estimates the rate of water entering the crushed rock reservoir, the time it takes for saturation to occur, how long it takes for the water to discharge, and if saturation does occur how much runoff has occurred at the projected precipitation rate. When the water input is greater than the saturated hydraulic conductivity, the water will overwhelm the soils ability to infiltrate and ponding, t_p, within the reservoir will occur. When ponding occurs, the wetting front begins to move downward and the water content equals total porosity of the soils saturated layer. The GA model should predict what the duration of ponding would be according to the determined infiltration rate. Actual data is collected by studying the water table rise at Wilmore Walk and is calculated with Equation 5, where b is the pore size distribution index and $|\Psi_{ae}|$ is the air entry tension. Saturated hydraulic conductivity, porosity, air entry tension, and pore size distribution parameters will be specified from literature values for known soil textures (Dingman, 2002). The model can be used to consider different input rates and storm event durations to emulate measured data from Wilmore Walk (Dingman, 2002).

The first variable that must be determined using the GA methodology is the wetting front effective tension, $|\psi_f|$, in Equation 5. The calculated wetting front would then be applied within Equation 6, to determine the time of ponding (t_p) and the depth of t_p. In Equation 6, ω is the precipitation input rate. Equation 7, F(t), is used to calculate the overall infiltration rate of water, in inches. $F(t_p)$ in shown in Equation 8, represents the total precipitation that resides in the soil between the surface and depth at t_p, and is used to determine what the total infiltrated water would be for the duration of the rain event.

Equation 5	Wetting Front Effective Tension:	$|\psi_f| = \dfrac{2 \bullet b + 3}{2 \bullet b + 6} \bullet |\psi_{ae}|$
Equation 6	Time of Ponding:	$t_p = \dfrac{K_h^* \bullet |\psi_f| \bullet (\phi - \theta_0)}{\omega \bullet (\omega - K_h^*)}$
Equation 7	Cumulative Infiltration:	F(t) [Infiltration Rate] $= Z_f'(t) \bullet (\phi - \theta_0)$
Equation 8	Cumulative Infiltration:	$F(t_p)$ [Infiltration Rate] $= Zf'(t_p) \bullet (\phi - \theta_0)$
Equation 9	Depth of Ponding:	$Z_f'(t_p) = \dfrac{K_h^* \bullet |\psi_f|}{\omega - K_h^*}$

The model must be applied to a series of F(t) values to determine how much water has infiltrated into the ground for a specific precipitation input and duration. Once the infiltration rate, F(t), is determined in inches hr^{-1}, it can then be applied to the corresponding depth of ponding, $Z_f'(t_p)$ in

Equation 9, to calculate how long it would take for the water to leave the reservoir within the permeable pavement.

Variable ranges in the GA model specified in literature include hydraulic conductivity, pore-size distribution, and porosity for each basic soil type. The initial water content in the soil is assumed to be 0.1. The precipitation input rate is derived from measured precipitation data. All other variables are calculated through Equation 4 through Equation 9. Ideally, the GA model should not have significant differences from actual infiltration rates. However due to some unknown factors within the system (soil type, depth to bedrock, etc.) the GA model may fail to correctly or consistently model the water table response due to changes in the system over time. The Richard's equation may be more suitable for modeling the infiltration rates at Wilmore Walk owing to the complexity of urban soil conditions.

Dingman (2002), Table 2 lists eleven standard soil textures, ranging from sand with the biggest pore size distribution to clay with the smallest pore size distribution index. A summary of the given results and the calculated wetting front suction is shown in Table 2**Error! Reference source not found.**. For this application of the Green Ampt Model, three soil textures were tested to determine the texture with the best fit of the model for the Wilmore Walk Study. The soil textures Clay, Sandy Clay Loam, and Sand, highlighted in blue below in Table 2, were the three initial textures that were applied.

Summary of Soil Texture Results applied in Green Ampt Model

	ϕ	st dev	Kh* (in)	$\lvert\Psi_{ae}\rvert$ (in)	st dev(in)	b	st dev	$\lvert\Psi_f\rvert$ (in)	st dev
Clay	0.48	0.050	0.000050	15.94	15.63	11.40	3.70	14.28	14.67
Silty Clay	0.49	0.064	0.000041	19.29	24.45	10.40	4.45	17.13	22.93
Sandy Clay	0.43	0.057	0.000085	6.02	6.81	10.40	1.64	5.35	6.20
Clay Loam	0.48	0.053	0.000096	24.80	20.08	8.52	3.44	21.57	18.81
Silty Clay Loam	0.48	0.057	0.000067	14.02	14.88	7.75	2.77	12.06	13.63
Sandy clay loam	0.42	0.059	0.00025	11.77	14.88	7.12	2.43	10.03	2.47
Loam	0.45	0.078	0.00027	18.82	20.16	5.39	1.87	15.45	17.82
Silt Loam	0.49	0.059	0.00028	30.94	20.16	5.30	1.96	25.35	18.28
Sandy Loam	0.44	0.086	0.0014	8.58	12.20	4.90	1.75	6.95	10.60
Loamy Sand	0.41	0.068	0.0061	3.54	4.88	4.38	1.47	2.82	4.17
Sand	0.40	0.056	0.0069	4.76	5.63	4.05	1.78	3.75	4.87

Table 2: Summary of applied Soil Texture values applied in Green Ampt Model to determine which soil texture is best fit for Wilmore Walk Study in Charlotte, NC (Dingman 2002).

Stormwater Modeling: SCS Runoff Curve Number Method

Today there is a growing understanding of how well permeable pavement performs as a stormwater BMP at the site scale, but the question remains about its potential to affect stormwater runoff volume and timing at the watershed scale. The SCS Runoff Curve Number (CN) method, shown below (NRCS, 1986), has been chosen to help illustrate the potential of permeable pavement to reduce stormwater runoff volumes and peak flow rates. The SCS method is utilized because it is a widely recognized and common runoff model used by professionals. The method considers the interactions between precipitation, infiltration, surface retention volume, antecedent moisture, soil type, and land-use (USDA-SCS 1972, NRCS 1986). The CN Method was developed by what is now the USDA Natural Resources Conservation Service (NRCS) to approximate the volume of surface runoff (Q) for a single rain event within a watershed and infiltration losses to groundwater (NRCS 1986). CN values are assigned numeric values that represent the land use and soil type of the study area. A higher CN value means lower infiltration rates, and increased stormwater runoff (Q) (NRCS 1986). The CN is applied to equation 11 below) to determine the S variable of the Runoff CN method (NRCS 1986).

Equation 10 SCS Runoff Curve Number Method Equation: $Q = (P - 0.2S)2/(P + 0.8S)$

Equation 11 S Variable Equation for SCS Runoff Curve Number Method: $S = (1000/CN) - 10$

Where P represents the precipitation event of the design rainfall for the purposes of the study and is converted from inches into feet. Q is stormwater runoff in feet, S is in inches and converted into feet, and CN is the curve number for the study watershed and is dimensionless. P is modified to account for elevational differences in the watershed by:

Equation 12 Precipitation Equation applied to SCS Runoff Curve Number Method:

P = 1” of rain/1000ft of elevation x DEM in feet + Rain of Storm Interval (e.g. 1.25 yr event)

SCS Runoff CN in Application

For the purposes of this study, four different scenarios were created to investigate what impact permeable pavement might have on runoff volumes draining from the Wilmore Walk watershed. The four scenarios investigated were: 1) Present Conditions, 2) Parking lots, Driveways, & Sidewalks are considered pervious, 3) Secondary roads are considered pervious, and 4) Parking Lots, Driveways, Sidewalks, and Secondary roads are considered pervious.

In this study - two different methods of modeling the SCS Runoff CN method were used. The first method utilized ArcGIS® to create spatial maps that displayed the total runoff values of each scenario in visual form. The second method employed the hydrologic runoff modeling software HydroCAD®, which utilizes the curve number data of the watershed in order to create hydrographs of accumulated runoff for each scenario and specified rain event.

ArcGIS® Spatial Mapping

A digital elevation model (DEM) of Irwin Creek Watershed, a landuse map, and a SSURGO soil map of the area were used as the basic variables to execute the SCS Runoff Model in ArcGIS®. These three basic variables were applied to ArcGIS to create new maps that provided the necessary spatial data to employ the SCS Runoff Model. Figure 11 summarizes the ArcGIS© method from beginning to end. The spatial data included the generation of watershed precipitation maps, curve number maps, S variable maps, Q maps, and finally accumulated Q (AQ) maps.

The first step of the ArcGIS process was to correct the DEM, a National Elevation Dataset DEM 1/9 arc raster (approximately 3m cell size) shown in Figure 10, by “filling” in any sinks within the data. The original corrected Digital Elevation Model of the Irwin Creek Watershed area covered nearly 30 square miles. Due to the extensive computer processing time associated with computing runoff from the entire watershed the Irwin Creek DEM was used to delineate and define the watershed containing the Wilmore Walk Subbasin. The Wilmore Walk Subbasin (WWS), outlined in turquoise in Figure 10, is approximately 0.14 mi^2.

The next step was to create Rain Maps that represent the “P” variable in the SCS Runoff Equation (10). To create the “P” variable, as shown in Figure 12, Equation 12 was applied to the ‘raster calculator’ in ArcGIS to create a precipitation map for each of six rainfall scenarios using ArcGIS. Each Precipitation map represents six rainfall scenarios - 2.93, 3.36, 4.22, 4.89, 5.81, 6.54, 7.28 inches of precipitation with the respective storm return intervals of 1.25, 2, 5, 10, 25, 50, and 100 year storms for the Charlotte region (PFDS 2012).

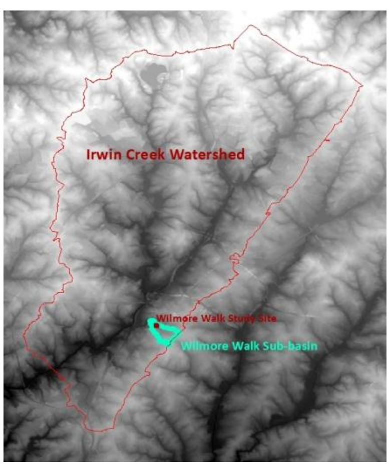


Figure 10: Digital Elevation Model of Irwin Creek Watershed in Charlotte, NC covering 30 square miles. Highlighted in turquoise within Irwin Creek is the Wilmore Walk Sub-basin and covers 0.14 mi^2.

The aerial orthophoto of the study area was analyzed using a geospatial remote sensing software called ENVI (ENvironment for Visualizing Images by Exelis Visual Information Solutions), in order to identify the spectral signatures within the multi-band image to distinguish between land-use types. The spectral signatures are specific characteristics of an object within an image that has multiple color bands, each color reflects a specific color within the image that defines its own signature. The high spatial resolution orthophoto (within 1 foot) used in this study had only 3 bands – Red, Green, and Blue. The orthophoto is not a traditional spectral image as it is not an image intended for remote sensing, and contains very basic information in regards to color (e.g. 4 bands of Red, Blue, Green, and Infrared). As a result, after processing the orthophoto it was extremely difficult to distinguish between different impervious structures clearly. However, the method was able to successfully identify the majority of tree covered areas within the study area. The tree layer, derived from the ENVI software, was then applied to the land-use map.

The land-use map created and used for this study represents buildings, primary roads, secondary roads, parking lots, driveways and sidewalks, gravel, barren ground, trees, and grassy areas. Four of the nine land-use layers were compiled using existing data-layers of roadways, parking lots, and buildings from the City, County, and State GIS Data Centers, and then the data layers were modified or updated according to the 2007 Aerial Orthophoto of Mecklenburg County. The presence or absence of driveways/sidewalks, barren ground, gravels, and vegetation layers were determined by what was visually seen within the orthophoto. Ground truth observations were used to verify land-use types since the study area was easily accessible.

The Land-use map of the Wilmore Walk Study Area was combined with a Soil Survey Geographic Database (SSURGO) map. The combined SSURGO and Land-use map was reclassified into a Curve Number (CN) map based on the soil type and land-use of a given cell (or pixel). A CN map represents the different areas of hydrologic soil groups and land-use types by assigning a number value that is used to indicate the ability of water to infiltrate through the ground surface. For the purposes of this study – four reclassified CN map scenarios were created to represent:1) Present conditions; 2) Parking Lots; driveways, and sidewalks as a pervious surface; 3) Secondary roads as a pervious surface: and 4) Parking lots, driveways, sidewalks, and secondary roads as a pervious surface. According to the scenarios where a normally impermeable service is considered pervious, the now pervious surface is assigned the equivalent CN of grass in good condition over a sandy-loam soil (Hunt 2008, NRCS 1986). The CN value of 61 over is to represent the hypothetical application of permeable concrete to each of the scenarios (NRCS 1986, Meentemeyer 2008*).*

Each CN map was applied to the Raster Calculator Model of ArcGIS to generate the value of the "S" variable in the SCS Runoff Equation (Equation 12). Once all variable maps have been created the Precipitation Map, and S maps for each scenario was then applied to the raster calculator again to create the runoff grid to serve as the *"Q"* value (Equation 11). The ArcGIS method requires an additional step as the GIS generated Q results only show runoff values for an individual cell. The Q map is applied as a weight to the 'flow direction' model to create the "Accumulated Runoff" (AQ) map which outputs the data as meters accumulated over a 24 hour period, which is then converted into acre-foot or cubic feet per second. An AQ map was created for each of the four scenarios of each storm interval, generating a total of 28 AQ maps.

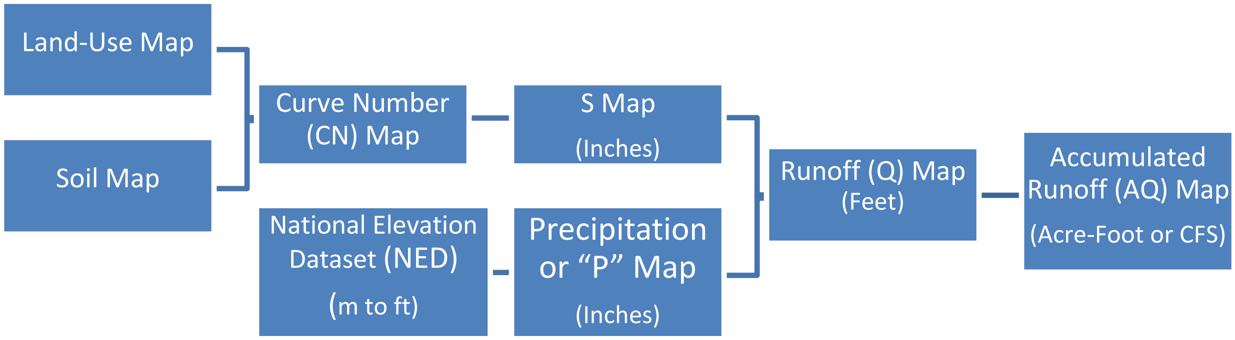


Figure 11: Basic Breakdown of ArcGIS Map Variables applied to SCS Runoff Curve Number Model. First, local land-use map was combined with area soil map to create a Curve Number (CN) map of watershed. The CN map is then used in equation to find S of SCS Curve Number Equation. Meanwhile, the National Elevation Dataset (NED) after being converted from meters to feet is applied to create Precipitation maps for each of the Storm Return Intervals applied in the Wilmore Walk Study. The P and S Maps are applied to SCS CN Equation to find the Q map for each of four permeable pavement scenarios and each rain event. The Q map is then converted to an Accumulated Runoff map to determine the volume of runoff for each scenario and storm event.

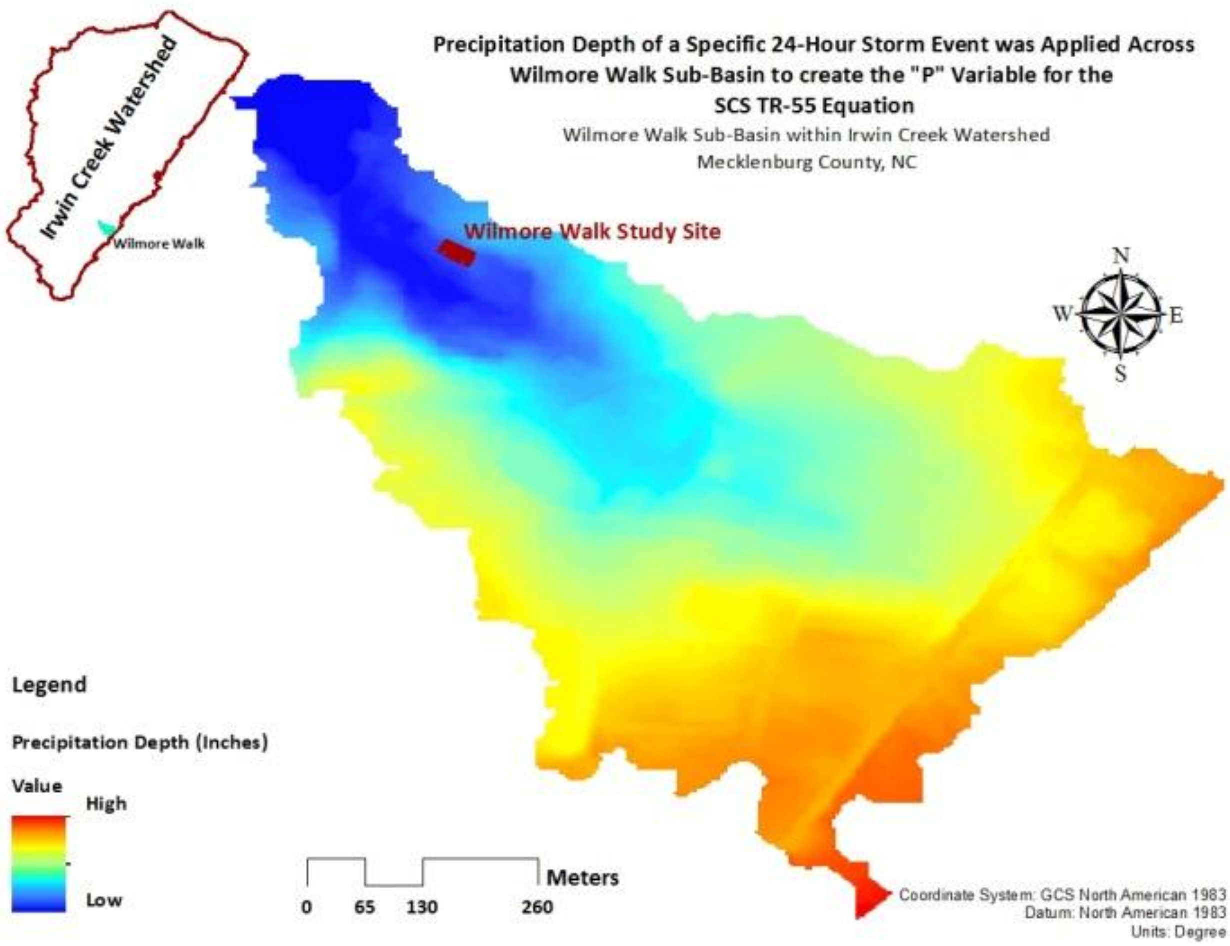


Figure 12: Example of a Precipitation Map used in Wilmore Walk Study in Charlotte, NC using ArcGIS©.

HydroCAD Stormwater Modeling

The HydroCAD© software was used in this study in a side-by side comparison with the ArcGIS® results of the SCS Curve Number runoff model. In the case of this study, the acreage of each Curve Number (CN) value within the watershed was created by the ArcGIS software and applied to the HydroCAD software. The same four CN scenarios used in the ArcGIS model were applied to the HydroCAD model.

For this study the objective is to compare similarly applied methods of computing the SCS Curve Number Method. Even though HydroCAD can be modified to include detailed stream cross-sections it was deemed important to keep the variables similar in order to be able to directly compare results with the ArcGIS method. In HydroCAD© only one subcatchment node was created which encompasses the Curve Number and time of concentration data (T_c) data of the watershed. Time of Concentration is the time it takes a drop of water to travel from the most distant part of the contributing watershed to the outlet point, and the time will vary according to each landuse type that the droplet will run across (Dingman 2002). For example runoff will be much higher for an asphalt surface than for grass. The percentage in acres of Curve Number values applied in the HydroCAD© procedure was derived from the ArcGIS® data. Since there is no stream or elevation data in the HydroCAD© application to indicate direction of flow it was important to be as accurate as possible with the T_c data. Meanwhile the acreage of each CN value within the watershed created by the ArcGIS® software was utilized by the HydroCAD software to generate the runoff response for each land cover simulation.

Cost Benefit Analysis and Comparative Analysis Between Select BMPs

A simple cost-benefit analysis was performed to compare permeable pavement to other commonly used stormwater BMPs. The cost of permeable concrete, porous asphalt, and permeable interlocking concrete pavement (PICP) are compared to the costs of installing and maintaining retention and detention ponds, infiltration trenches/basins, and bioretention areas. This analysis involved determining the costs of materials from various reports and documents such as :NPDES BMP Summary fact sheets, EPA Stormwater Technology facts sheets, a 2013 study on “The Costs of LID” by Mark Grey et al., a 2007 study by Montalto et al., and the 1997 report on “The Economics of Stormwater BMPs…” by Brown & Schueler. The first step was to determine the size of each BMP recommended for the study site. The Charlotte Stormwater Hydrology BMP Design Standards Manual for each BMP type was used to determine the size of each BMP type for either the entire Wilmore Walk Subdivision (3.53 acres), which includes the permeable concrete study site, or the overall Wilmore Walk Sub-basin (88.01 acres). BMPs such as bioretention areas and infiltration trenches are applicable to a small watershed of 5 acres or less, while other BMPs like retention or detention ponds are more suitable to treat runoff from watersheds that are 10 acres or more.

The Charlotte-Mecklenburg Stormwater Services requires certain BMPs to be used for either water quality control or water quantity control for a particular design storm, depending on the attributes of a particular BMP. Each BMP is designed to handle a pre-determined Water Quality Volume (WQ_v), meaning the volume of water from a 1”, 6 hour storm, or the Channel Protection Volume (CP_v), the runoff volume from a 1-Year, 24 Hour Storm (2.58” for Mecklenburg County). Certain BMPs are used alternatively, to act as the peak flow detention of a 10 year, 6 hour storm of 3.72”, or a 25 year, 6 Hour storm of 4.38”. Some stormwater BMP’s are best suited for water quantity control, others for water quality treatment (removal of TSS and TP from water column using settling or infiltration into the subsoil), or in some instances a mixture of the two.

The next step in the process was to determine the cost of land, if additional land was needed to accommodate the BMP installation. This involved compiling the land parcel data within the boundaries of the Wilmore Walk Sub-basin through the Mecklenburg County Polaris GIS website. Parcel data was then organized into four categories; Commercial, Residential, Other, and Vacant properties. Once categorized, each parcel category was calculated to determine the overall unit area cost.

Construction and design costs (shown in Table 3) were calculated for each BMP type according to design equations developed for the mid-Atlantic region (Brown and Schueler’s 1997). Maintenance costs were determined according to the NPDES fact sheets for each BMP (US EPA, 2012). The operating and maintenance (O & M) costs noted in Table 3 were determined by the reported percentage of total construction values attributed to O & M costs for retention, detention, and infiltration basins. These percentages were retrieved from the NPDES fact sheets for each respective BMP with the exception of bioretention areas, which was pulled from the U.S. EPA’s 1999 preliminary study on “Cost and Benefits of Storm Water BMPs.”

Table 3: Summary of Total Cost Equations from Brown and Schueler’s 1997 ‘Economics of Stormwater BMPs’ report that was utilized to determine the design and construction costs for this study.

Total Construction and Design Cost Equations – Brown and Schueler, 1997		Operating and Maintenance (O&M) (U.S. EPA 1999; U.S. EPA 2012)
Equation 13: Retention Ponds	$TC = 23.07\ V^{0.705}$	3% - 5% of TC
Equation 14: Detention Ponds	$TC = 11.72\ V^{0.760}$	3% - 5% of TC
Equation 15: Bioretention Areas	$TC = 6.88\ WQ_V^{0.991}$	5% - 7% of TC
Equation 16: Infiltration Trench/Basin	$C = 2.80\ V$ (does not include design costs)	5% - 20% of C

TC = Total Construction per Ft^3 (1997 Values), V = Total Storm Volume (Ft^3), C = Construction costs only per Ft^3 (1997 values), WQv = Water Quality Volume (Ft^3)

Results

Hydrologic Data

The hydrologic data summarizing each precipitation event monitored at Wilmore Walk from March 27, 2007 to June 1, 2009 are shown in Appendix 1. Bulk precipitation data for events or periods where insufficient precipitation occurred to produce a water level response in the porous pavement storage reservoir are also presented in Appendix 1. A summary of the precipitation events that occurred during the study and the water table response, estimated η, and average corrected and uncorrected infiltration rates for each event are presented in Table 4. The water level response to precipitation inputs for each monitoring well are presented in Figure 13, 14, and 15.

Table 4: Summary of Precipitation Events, Water Table Response, Estimated η and corrected and uncorrected infiltration rates from March 25, 2007 to June 1, 2009 for Wilmore Walk, in Charlotte, NC.

Date	Rainfall Total (in)	Duration (hours)	Average Intensity (in/hour)	Peak 5 Minutes Intensity	Water Table Response (Inches)	Porosity (η)	Uncorrected Infiltration Rate (Inches/Hour)	Corrected Infiltration Rate (Inches/Hour)
4/1/2007	0.17	---	---	---	NA	NA	NA	NA
4/11/2007	**0.91**	**---**	**---**	**---**	**1.66**	**0.58**	**0.10**	**0.06**
4/14/2007	**1.29**	**---**	**---**	**---**	**3.30**	**0.39**	**0.10**	**0.04**
4/15/2007	0.11	---	---	---	NA	NA	NA	NA
4/19/2007	**0.53**	**---**	**---**	**---**	**1.33**	**0.42**	**0.12**	**0.05**
4/27/2007	0.33	---	---	---	NA	NA	NA	NA
5/4/2007	0.06	---	---	---	NA	NA	NA	NA
5/5/2007	0.20	---	---	---	NA	NA	NA	NA
5/12/2007	0.12	---	---	---	NA	NA	NA	NA
6/4/2007	0.09	0.75	0.12	0.02	NA	NA	NA	NA
6/11/2007	0.26	5.12	0.05	0.03	NA	NA	NA	NA
6/12/2007	**0.69**	**6.82**	**0.10**	**0.03**	**1.50**	**0.46**	**0.32**	**0.15**
6/13/2007	0.23	4.83	0.05	0.01	NA	NA	NA	NA
6/14/2007	0.27	4.20	0.06	0.01	NA	NA	NA	NA
6/24/2007	0.72	7.30	0.18	0.06	NA	NA	NA	NA
6/25/2007	0.10	18.98	0.01	0.00	NA	NA	NA	NA
6/30/2007	0.20	1.42	0.14	0.01	NA	NA	NA	NA
7/2/2007	0.17	2.62	0.06	0.01	NA	NA	NA	NA
7/9/2007	0.83	1.18	0.71	0.04	NA	NA	NA	NA
7/11/2007	0.16	0.25	0.63	0.02	NA	NA	NA	NA
7/15/2007	0.43	4.52	0.10	0.02	NA	NA	NA	NA
7/17/2007	0.35	3.00	0.12	0.02	NA	NA	NA	NA
7/27/2007	**1.98**	**2.20**	**0.90**	**0.11**	**6.03**	**0.34**	**0.12**	**0.04**
7/30/2007	0.13	0.42	0.30	0.01	NA	NA	NA	NA
8/22/2007	0.34	0.78	0.43	0.02	NA	NA	NA	NA
8/23/2007	0.07	0.32	0.22	0.00	NA	NA	NA	NA
8/26/2007	0.05	1.28	0.04	0.00	NA	NA	NA	NA
8/30/2007	0.20	3.67	0.06	0.01	NA	NA	NA	NA
8/31/2007	0.23	0.08	2.74	0.00	NA	NA	NA	NA
9/10/2007	0.06	0.10	0.55	0.01	NA	NA	NA	NA
9/14/2007	**1.60**	**18.97**	**0.08**	**0.04**	**3.09**	**0.46**	**0.11**	**0.04**
10/4/2007	0.20	2.40	0.09	0.02	NA	NA	NA	NA
10/19/2007	0.36	0.98	0.37	0.02	NA	NA	NA	NA
10/24/2007	0.62	2.40	0.26	0.02	NA	NA	NA	NA

Storm events which produce a water level response are highlighted in **bold** and underline

--- = No Data   NA = Not Applicable

Table 4: Continued Summary of Precipitation Events, Water Table Response, etc. - October 25, 2007 to April 5, 2008

Date	Rainfall Total (in)	Duration (hours)	Average Intensity (in/hour)	Peak 5 Minutes Intensity	Water Table Response (Inches)	Porosity (η)	Uncorrected Infiltration Rate (Inches/Hour)	Corrected Infiltration Rate (Inches/Hour)
10/25/2007	0.67	22.82	0.03	0.01	NA	NA	NA	NA
10/26/2007	**0.54**	**4.75**	**0.11**	**0.00**	**3.18**	**0.59**	**0.06**	**0.04**
11/15/2007	0.23	---	---	---	NA	NA	NA	NA
11/22/2007	0.11	---	---	---	NA	NA	NA	NA
11/25/2007	0.12	---	---	---	NA	NA	NA	NA
11/26/2007	0.09	---	---	---	NA	NA	NA	NA
12/15/2007	0.97	---	---	---	3.00	0.38	0.07	0.02
12/16/2007	0.15	---	---	---	NA	NA	NA	NA
12/21/2007	0.30	6.93	0.04	0.00	NA	NA	NA	NA
12/23/2007	0.22	4.25	0.05	0.01	NA	NA	NA	NA
12/26/2007	0.48	9.00	0.05	0.00	0.00	0.40	0.06	0.00
12/28/2007	0.60	10.38	0.06	0.02	0.00	0.35	0.15	0.00
12/29/2007	0.06	0.13	0.41	0.01	NA	NA	NA	NA
12/30/2007	**0.93**	**13.18**	**0.07**	**0.01**	**2.08**	**0.35**	**0.05**	**0.01**
1/10/2008	0.17	2.35	0.07	0.02	NA	NA	NA	NA
1/11/2008	0.10	2.18	0.05	0.00	NA	NA	NA	NA
1/17/2008	0.90	13.72	0.07	0.01	NA	NA	NA	NA
1/19/2008	0.29	8.48	0.03	0.00	NA	NA	NA	NA
1/23/2008	0.11	8.62	0.01	0.00	NA	NA	NA	NA
1/30/2008	0.09	3.98	0.02	0.00	NA	NA	NA	NA
2/1/2008	**1.15**	**12.07**	**0.10**	**0.02**	**2.63**	**0.45**	**0.04**	**0.02**
2/6/2008	0.11	6.60	0.02	0.01	NA	NA	NA	NA
2/12/2008	0.08	12.07	0.01	0.01	NA	NA	NA	NA
2/13/2008	0.51	19.93	0.03	0.04	NA	NA	NA	NA
2/17/2008	0.08	1.30	0.06	0.00	NA	NA	NA	NA
2/22/2008	0.39	16.23	0.02	0.00	NA	NA	NA	NA
2/26/2008	0.39	1.87	0.21	0.03	NA	NA	NA	NA
3/4/2008	**1.36**	**7.45**	**0.18**	**0.02**	**3.19**	**0.46**	**0.07**	**0.03**
3/8/2008	0.50	24.82	0.02	0.01	NA	NA	NA	NA
3/15/2008	1.24	13.67	0.09	0.03	NA	NA	NA	NA
3/19/2008	**0.66**	**2.18**	**0.30**	**0.03**	**2.39**	**0.28**	**0.05**	**0.01**
3/31/2008	0.17	20.35	0.01	0.00	NA	NA	NA	NA
4/1/2008	0.06	4.30	0.01	0.00	NA	NA	NA	NA
4/3/2008	0.35	9.13	0.04	0.01	NA	NA	NA	NA
4/4/2008	0.44	15.28	0.03	0.04	NA	NA	NA	NA
4/5/2008	0.20	14.37	0.01	0.00	NA	NA	NA	NA

Storm events which produce a water level response are highlighted in **bold** and underline

--- = No Data NA = Not Applicable

Table 4: Continued Summary of Precipitation Events, Water Table Response, etc. – April 12, 2008 to October 18, 2008

Date	Rainfall Total (in)	Duration (hours)	Average Intensity (in/hour)	Peak 5 Minutes Intensity	Water Table Response (Inches)	Porosity (n)	Uncorrected Infiltration Rate (Inches/Hour)	Corrected Infiltration Rate (Inches/Hour)
4/12/2008	0.20	12.88	0.02	0.01	NA	NA	NA	NA
4/14/2008	0.06	5.78	0.01	0.00	NA	NA	NA	NA
4/26/2008	0.41	3.70	0.11	0.02	NA	NA	NA	NA
4/27/2008	0.36	7.23	0.05	0.05	NA	NA	NA	NA
<u>4/28/2008</u>	**<u>0.85</u>**	**<u>13.58</u>**	**<u>0.06</u>**	**<u>0.03</u>**	**<u>2.24</u>**	**<u>0.38</u>**	**<u>0.08</u>**	**<u>0.03</u>**
5/9/2008	0.07	11.00	0.01	0.00	NA	NA	NA	NA
5/11/2008	0.33	8.13	0.04	0.00	NA	NA	NA	NA
5/16/2008	0.28	10.30	0.03	0.00	NA	NA	NA	NA
5/18/2008	0.09	11.32	0.01	0.01	NA	NA	NA	NA
5/20/2008	0.07	0.52	0.14	0.00	NA	NA	NA	NA
5/28/2008	1.06	19.70	0.05	0.04	NA	NA	NA	NA
6/2/2008	0.06	0.27	0.21	0.01	NA	NA	NA	NA
6/5/2008	0.14	1.03	0.14	0.02	NA	NA	NA	NA
6/20/2008	0.12	0.33	0.35	0.01	NA	NA	NA	NA
6/21/2008	0.62	0.62	1.01	0.03	NA	NA	NA	NA
<u>6/22/2008</u>	**<u>1.19</u>**	**<u>3.90</u>**	**<u>0.30</u>**	**<u>0.05</u>**	**<u>2.65</u>**	**<u>0.45</u>**	**<u>0.08</u>**	**<u>0.04</u>**
6/26/2008	0.65	1.63	0.40	0.05	NA	NA	NA	NA
7/4/2008	0.31	2.18	0.14	0.02	NA	NA	NA	NA
7/5/2008	0.11	12.73	0.01	0.01	NA	NA	NA	NA
<u>7/8/2008</u>	**<u>1.53</u>**	**<u>2.32</u>**	**<u>0.66</u>**	**<u>0.07</u>**	**<u>3.98</u>**	**<u>0.39</u>**	**<u>0.08</u>**	**<u>0.03</u>**
8/16/2008	0.57	3.28	0.18	0.04	NA	NA	NA	NA
8/17/2008	0.28	4.33	0.07	0.01	NA	NA	NA	NA
8/25/2008	0.43	5.80	0.07	0.03	NA	NA	NA	NA
<u>8/26/2008</u>	**<u>3.69</u>**	**<u>22.60</u>**	**<u>0.16</u>**	**<u>0.02</u>**	**<u>14.33</u>**	**<u>0.48</u>**	**<u>0.18</u>**	**<u>0.10</u>**
8/27/2008	2.01	20.97	0.10	0.07	NA	NA	NA	NA
<u>8/30/2008</u>	**<u>0.54</u>**	**<u>0.37</u>**	**<u>1.46</u>**	**<u>0.06</u>**	**<u>1.28</u>**	**<u>0.45</u>**	**<u>0.07</u>**	**<u>0.03</u>**
9/8/2008	0.12	0.30	0.39	0.02	NA	NA	NA	NA
9/10/2008	0.80	9.03	0.09	0.03	NA	NA	NA	NA
9/12/2008	0.06	4.67	0.01	0.00	NA	NA	NA	NA
9/16/2008	0.70	15.62	0.04	0.01	NA	NA	NA	NA
9/17/2008	0.09	7.58	0.01	0.00	NA	NA	NA	NA
<u>9/26/2008</u>	**<u>1.54</u>**	**<u>22.08</u>**	**<u>0.07</u>**	**<u>0.01</u>**	**<u>3.34</u>**	**<u>0.46</u>**	**<u>0.08</u>**	**<u>0.04</u>**
9/27/2008	0.24	8.23	0.03	0.00	NA	NA	NA	NA
10/8/2008	0.77	11.12	0.07	0.01	NA	NA	NA	NA
10/17/2008	0.44	9.45	0.05	0.01	NA	NA	NA	NA
10/18/2008	0.06	2.00	0.03	0.00	NA	NA	NA	NA
Storm events which produce a water level response are highlighted in **bold** and <u>underline</u>								
--- = No Data					NA = Not Applicable			

Table 4: Continued Summary of Precipitation Events, Water Table Response, etc. - October 25, 2008 to March 16, 2009

Date	Rainfall Total (in)	Duration (hours)	Average Intensity (in/hour)	Peak 5 Minutes Intensity	Water Table Response (Inches)	Porosity (η)	Uncorrected Infiltration Rate (Inches/Hour)	Corrected Infiltration Rate (Inches/Hour)
10/25/2008	0.17	6.43	0.03	0.00	NA	NA	NA	NA
11/3/2008	0.21	21.52	0.01	0.00	NA	NA	NA	NA
11/13/2008	0.08	12.12	0.01	0.00	NA	NA	NA	NA
11/14/2008	0.59	17.02	0.03	0.00	NA	NA	NA	NA
11/15/2008	0.20	4.67	0.04	0.00	NA	NA	NA	NA
11/24/2008	0.07	5.37	0.01	0.00	NA	NA	NA	NA
11/25/2008	0.11	2.77	0.04	0.00	NA	NA	NA	NA
11/29/2008	0.15	18.07	0.01	0.00	NA	NA	NA	NA
<u>11/30/2008</u>	**<u>0.98</u>**	**<u>17.08</u>**	**<u>0.06</u>**	**<u>0.01</u>**	**<u>2.77</u>**	**<u>0.38</u>**	**<u>0.06</u>**	**<u>0.02</u>**
12/10/2008	0.59	10.65	0.06	0.01	NA	NA	NA	NA
<u>12/11/2008</u>	**<u>1.07</u>**	**<u>23.92</u>**	**<u>0.04</u>**	**<u>0.01</u>**	**<u>4.52</u>**	**<u>0.32</u>**	**<u>0.08</u>**	**<u>0.02</u>**
12/12/2008	0.30	2.92	0.10	0.01	NA	NA	NA	NA
12/14/2008	0.17	2.75	0.06	0.00	NA	NA	NA	NA
12/20/2008	0.21	6.98	0.03	0.01	NA	NA	NA	NA
12/21/2008	0.13	9.08	0.01	0.01	NA	NA	NA	NA
12/25/2008	0.06	6.88	0.01	0.00	NA	NA	NA	NA
12/27/2008	0.05	5.57	0.01	0.00	NA	NA	NA	NA
12/28/2008	0.08	10.50	0.01	0.00	NA	NA	NA	NA
1/4/2009	0.53	5.47	0.10	0.01		0.40	0.30	0.00
<u>1/6/2009</u>	**<u>1.33</u>**	**<u>20.75</u>**	**<u>0.06</u>**	**<u>0.02</u>**	**<u>3.71</u>**	**<u>0.37</u>**	**<u>0.06</u>**	**<u>0.02</u>**
1/7/2009	0.29	2.37	0.12	0.03	NA	NA	NA	NA
1/11/2009	0.09	5.78	0.01	0.01	NA	NA	NA	NA
1/29/2009	0.24	10.70	0.02	0.01	NA	NA	NA	NA
2/2/2009	0.29	15.00	0.02	0.00	NA	NA	NA	NA
2/11/2009	0.15	0.27	0.56	0.02	NA	NA	NA	NA
2/14/2009	0.08	2.57	0.03	0.00	NA	NA	NA	NA
2/16/2009	0.23	3.08	0.07	0.00	NA	NA	NA	NA
2/18/2009	0.50	17.48	0.03	0.02	NA	NA	NA	NA
2/27/2009	0.15	3.23	0.05	0.00	NA	NA	NA	NA
2/28/2009	0.86	15.07	0.06	0.00	NA	NA	NA	NA
<u>3/1/2009</u>	**<u>1.39</u>**	**<u>14.03</u>**	**<u>0.10</u>**	**<u>0.01</u>**	**<u>6.23</u>**	**<u>0.38</u>**	**<u>0.07</u>**	**<u>0.03</u>**
3/2/2009	0.56	2.50	0.22	0.01	NA	NA	NA	NA
3/13/2009	0.13	6.50	0.02	0.00	NA	NA	NA	NA
3/14/2009	0.38	15.67	0.02	0.00	NA	NA	NA	NA
<u>3/15/2009</u>	**<u>0.53</u>**	**<u>17.38</u>**	**<u>0.03</u>**	**<u>0.00</u>**	**<u>1.99</u>**	**<u>0.29</u>**	**<u>0.09</u>**	**<u>0.02</u>**
3/16/2009	0.10	10.93	0.01	0.00	NA	NA	NA	NA

Storm events which produce a water level response are highlighted in **bold** and <u>underline</u>

--- = No Data NA = Not Applicable

Table 4: Continued Summary of Precipitation Events, Water Table Response, etc. – March 19, 2009 to May 28, 2009

Date	Rainfall Total (in)	Duration (hours)	Average Intensity (in/hour)	Peak 5 Minutes Intensity	Water Table Response (Inches)	Porosity (η)	Uncorrected Infiltration Rate (Inches/Hour)	Corrected Infiltration Rate (Inches/Hour)
3/19/2009	0.20	3.48	0.06	0.00	NA	NA	NA	NA
3/25/2009	0.21	13.92	0.02	0.00	NA	NA	NA	NA
3/26/2009	0.14	14.37	0.01	0.01	NA	NA	NA	NA
3/27/2009	0.23	10.55	0.02	0.01	NA	NA	NA	NA
<u>3/28/2009</u>	**<u>0.94</u>**	**<u>8.03</u>**	**<u>0.12</u>**	**<u>0.01</u>**	**<u>2.75</u>**	**<u>0.35</u>**	**<u>0.06</u>**	**<u>0.02</u>**
4/2/2009	0.10	12.88	0.01	0.00	NA	NA	NA	NA
4/6/2009	0.05	3.17	0.01	0.00	NA	NA	NA	NA
<u>4/11/2009</u>	**<u>0.80</u>**	**<u>19.22</u>**	**<u>0.04</u>**	**<u>0.03</u>**	**<u>1.94</u>**	**<u>0.41</u>**	**<u>0.05</u>**	**<u>0.02</u>**
4/13/2009	0.24	3.43	0.07	0.01	NA	NA	NA	NA
4/14/2009	0.23	13.33	0.02	0.01	NA	NA	NA	NA
4/20/2009	0.57	6.85	0.08	0.02	NA	NA	NA	NA
5/2/2009	0.43	2.37	0.18	0.02	NA	NA	NA	NA
<u>5/4/2009</u>	**<u>0.34</u>**	**<u>4.98</u>**	**<u>0.07</u>**	**<u>0.02</u>**	**<u>9.58</u>**	**<u>0.28</u>**	**<u>0.12</u>**	**<u>0.03</u>**
5/5/2009	2.61	18.67	0.14	0.06	NA	NA	NA	NA
5/6/2009	0.13	5.67	0.02	0.01	NA	NA	NA	NA
5/7/2009	0.08	1.52	0.05	0.00	NA	NA	NA	NA
5/8/2009	0.06	0.85	0.06	0.00	NA	NA	NA	NA
5/11/2009	0.15	11.95	0.01	0.01	NA	NA	NA	NA
5/18/2009	0.33	14.95	0.02	0.00	NA	NA	NA	NA
5/23/2009	0.05	0.05	0.94	0.01	NA	NA	NA	NA
<u>5/24/2009</u>	**<u>0.70</u>**	**<u>12.43</u>**	**<u>0.06</u>**	**<u>0.02</u>**	**<u>0.52</u>**	**<u>0.29</u>**	**<u>0.02</u>**	**<u>0.00</u>**
5/25/2009	0.24	2.43	0.10	0.01	NA	NA	NA	NA
5/28/2009	0.34	6.18	0.05	0.02	NA	NA	NA	NA

Storm events which produce a water level response are highlighted in **bold** and <u>underline</u>

--- = No Data NA = Not Applicable

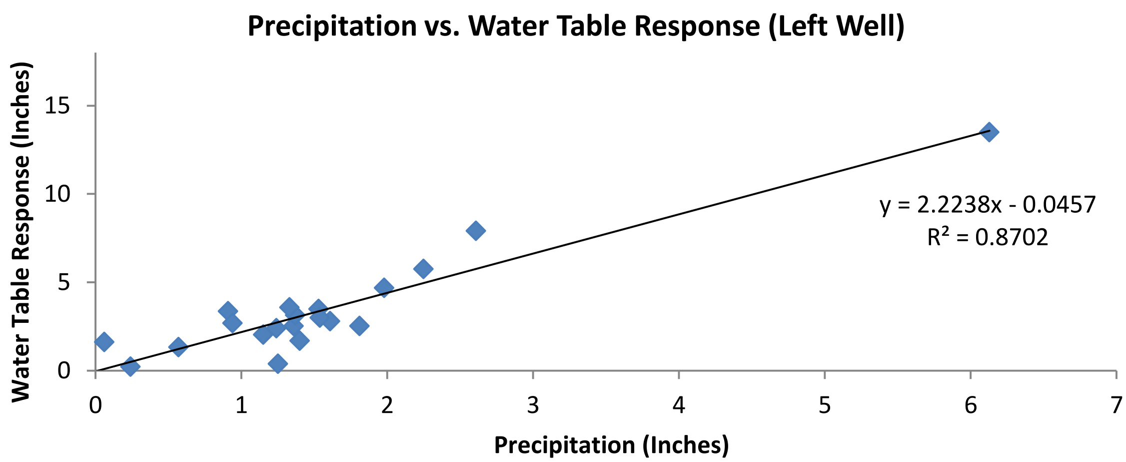


Figure 13: Precipitation versus the water table response within the Left Well of Permeable Concrete Structure at Wilmore Walk in Charlotte, NC.

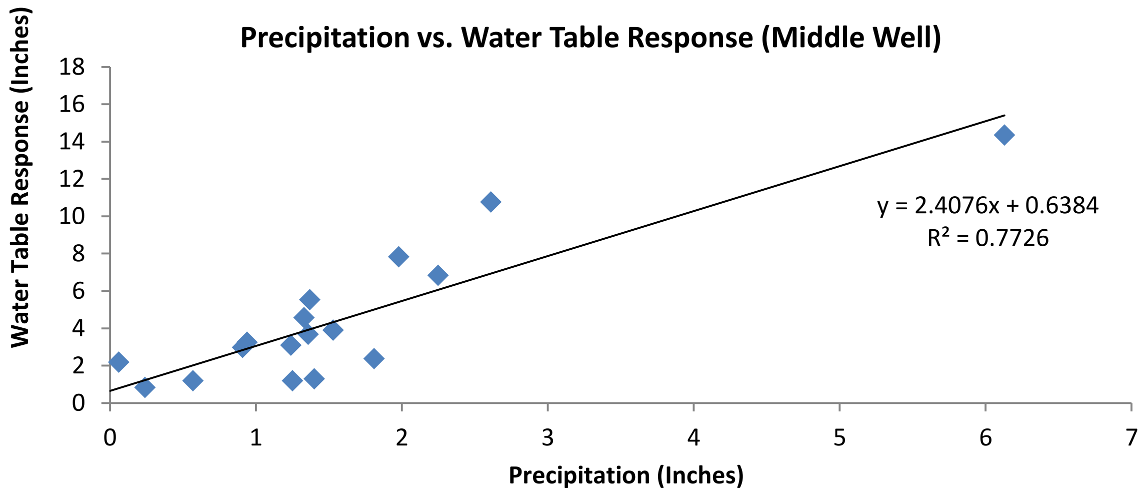


Figure 14: Precipitation versus the water table response within the Middle Well of Permeable Concrete Structure at Wilmore Walk in Charlotte, NC.

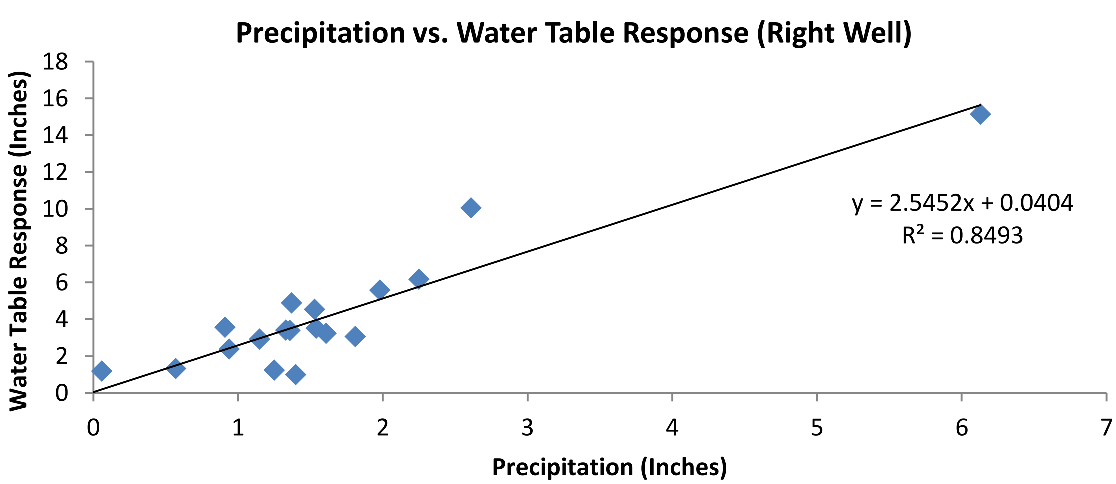


Figure 15: Precipitation versus the water table response within the Right Well of Permeable Concrete Structure at Wilmore Walk in Charlotte, NC.

Figure 16: Google Image of Wilmore Walk Site showing locations of 3 monitoring wells (labeled in red letters) within permeable

The locations of the three monitoring wells are oriented from left, middle, and right while facing the upslope end of the permeable pavement structure as shown left in Figure 16. While all three GW level recorders did respond adequately to the majority of stormwater events for the duration of this study, there were periods where a considerable amount of noise was recorded. Some of this uncertainty may be related from the use of rain data from the airport for March, April, December 2007, and July, August of 2008 when the HOBO precipitation logger failed. Meanwhile, several events were found to have an erratic output from one or two of the GW pressure transducers (see Appendix 1). This is likely due to trapped air bubbles within the pressure transducer of the GW data-logger as the wells re-fill after a period where the well became completely dry. These bubbles likely affected the pressure response of the logger until the bubbles were either dislodged or dissolved. Three additional loggers, called Odyssey capacitance water level recorders, were installed in September 2007 alongside each GW device to ensure the accuracy of the water level data records.

Over the duration of the study, thirty one precipitation events were monitored, these precipitation events produced water level responses within the permeable concrete reservoir ranging from 0.05" to 14.63". The largest water level response of 14.63" occurred on August 26, 2008. The recorded water level responses to precipitation was used to calculate the approximate porosity (η) for the crushed rock reservoir which averages 38.5% ± 10.5% n= 64. Data from each of the three wells generated a slightly different porosity result: 40.2% ± 10.1% n= 23 (Left Well), 36.8% ± 8.2% n= 5 (Center Well) and 38.2% ± 12.6% n=22 (Right Well). The average measured uncorrected infiltration rate (IR_u) for the data set is 0.112 inches/hour ± 0.110 inches/hour, with the exception of one extreme event (5.70" of rainfall) that has an (IR_u) rate of 0.937 inches/hr. This study's IR_u results have a range of 0.02-0.59 inches/hour, whereas the results reported by C. Estes (Year) ranges from 0.06-0.09 inches/hour under semi dry and wet conditions (Estes, 2008). With the exception of the 5.70" event, the average corrected infiltration rate (IR_c) for the subsoil is 0.041 inches/hour ± 0.032 inches/hour. This study's highest measured IR_c was 0.15 inches/hour whereas the minimum was 0.01 inches/hour. The average IR_c of 0.041 inches/hour was used to in the calculation to determine that it takes approximately 61.0 hours for a 1" rainstorm to infiltrate through the PP system and into the subsoil. A summary of the estimated water table responses and drainage times for 1.25, 2, 5, 10, 25, 50, and 100 year, 24 hour rainfall events is shown in

Table 5. The water level responses were determined by dividing the storm event depth by the lower (0.38) and upper (0.40) estimates of the porosity (η) values. The estimated drainage times were calculated by applying the average uncorrected infiltration rate (IR_u) (0.112 inches/hour) to the estimated water level response for each design precipitation event. According to the estimated water level responses, an 18" crushed rock reservoir would contain nearly all storm event volumes with the exception of a 100 year storm where overflow drainage would be expected.

The primary objective of this aspect of the study was to measure the medium term performance of this permeable concrete BMP and to determine if the infiltration capacity of the subsoil will change over time. As of 2009, there was no significant change in the rainfall-water table responses, which indicates the infiltration capacity of the permeable concrete surface is not changing (i.e. not clogging). In the fall of 2007 however, it was noticed in several places that the upper surface of the permeable concrete surface was beginning to show signs of "raveling." It appears to have been limited to just the surface of the pavement and only to a small portion of the total surface area of the site. In regards to the infiltration capacity of the subsoil, the regression relationships shown in Figure 17 display slightly negative slopes suggests that infiltration rates may be declining over time. There is however, still extensive scatter in the estimated infiltration rates and the ranges show an overlap of infiltration rates over the duration of the study.

Estimated water table responses and drainage times

Return Interval	Depth	Water Level Response	Drainage Time (Hours)
1.25 year	2.93"	7.3" - 7.7"	65.4 - 68.8
2 year	3.36"	8.4" - 8.8"	75.0 - 79.0
5 year	4.22"	10.6" - 11.1"	94.2 - 99.2
10 year	4.89"	12.2" - 12.9"	109.2 - 114.9
25 year	5.81"	14.5" - 15.3"	129.7 - 136.5
50 year	6.54"	16.4" - 17.2"	146.0 - 153.7
100 year	7.28"	18.2" - 19.2"	162.5 - 171.1

Table 5: The estimated water table responses and drainage times to 1.25, 2, 5, 10, 25, 50, and 100 year 24 hr rainfall events using the calculated porosity of 0.38 and 0.40 (38.5% ± 10.5) and average IR_u to determine the water level response and drainage time of the Wilmore Walk permeable concrete storage reservoir in Charlotte, NC (2007-2009 values).

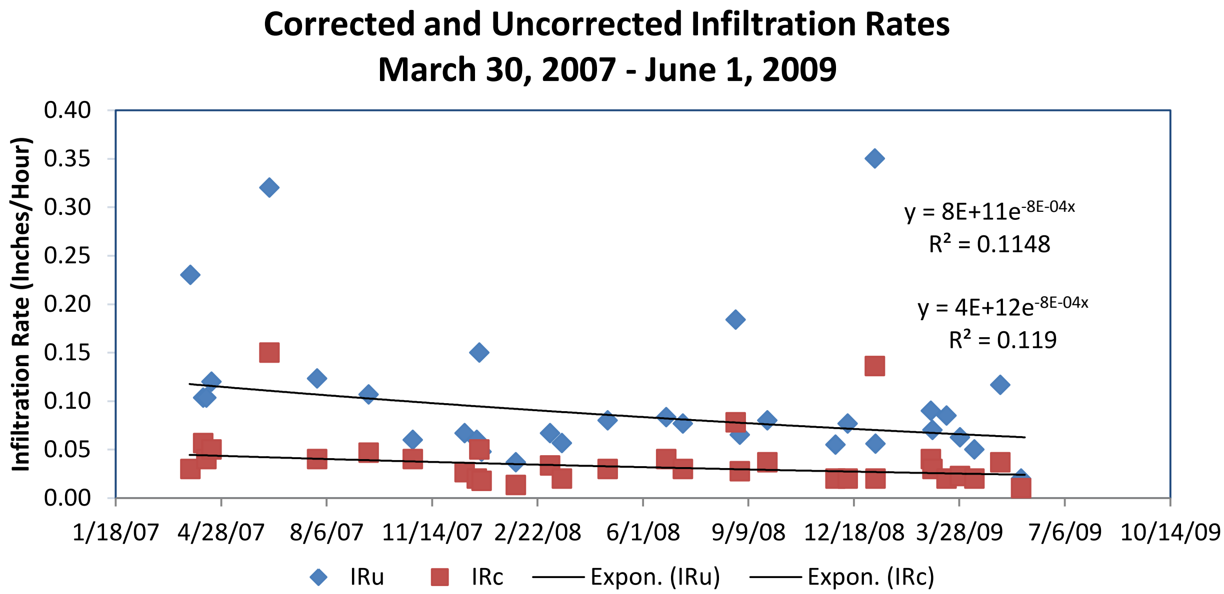


Figure 17: The Corrected and Uncorrected Infiltration Rates for rain events occurring from March 30th, 2007 through June 1st, 2009 at Wilmore Walk in Charlotte, NC.

A few outliers contribute significantly to the scatter displayed in the data in Figure 17. The first outlier shown represents a 0.06" event that occurred on 3/30/07 where the IR_u was calculated to be 0.23 inches/hour, which caused a half inch response within the reservoir. A second outlier occurred on 6/12/07 where a 0.69" event caused a well response of 1.50" with a total drain time of two hours. The high infiltration rate is attributed to the short duration of infiltration of the stormwater into the subsoil. The third outlier represents the largest storm event of the study starting 8/26/08, where a total 5.70" of rainfall was recorded on site within two days' time. Between all three wells, the 8/26/08 event caused an average well response of 14.63." The combination of increased pressure head and possibly a portion of the stormwater leaving the system via overflow pipes, may have contributed to a higher infiltration rate observed for this event. A fourth outlier is of a 1.33" event that occurred on 1/6/09, and there was a reservoir response of 3.44." The infiltration of the 1/6/09 event however was interrupted by a 0.29" event that occurred on 1/7/09, which shortened the assessed amount of time that was used to determine the IR. In summary, the PC structure investigated in this study, does not generate runoff until approximately 7.20" of rainfall occurs within a 24 hour period (Nearly a 100 year storm event).

Water Quality Data

Water quality samples for bulk precipitation and monitoring well (Left, Middle, and Right Wells) are summarized in Table 6 - Table 9. Bulk Precipitation samples from 81 events were collected and an average of 47 monitoring well samples were collected for each well location. The atmospheric deposition overall loading to the PP was calculated by multiplying the concentrations determined for each Bulk Precipitation sample by the depth of precipitation recorded for each event and the area of the PP. The bulk precipitation and the reservoir load concentrations in kg/m^3 are summarized in Table 10 and Table 11. The percent difference in concentrations between the bulk precipitation and the reservoir is summarized in Table 12. Box-whisker plots depicting the range and distribution of bulk precipitation and monitoring well chemical composition are shown in Table 13.

The monitoring well samples indicate a significant increase in conductivity compared to the bulk precipitation for each event. A likely source of ionic compounds that may contribute to the increased conductivity is the dissolution or washing away of atmospheric deposition and fecal matter (by pets or wildlife) from vehicles, and from the pavement surface. The stormwater entering in the reservoir can also mobilize dissolved ions from within the crushed rock storage reservoir. A review of the data indicates increased levels Ca^{2+}, Mg^{2+}, Na^{+} suggest there is a pavement or reservoir source of these major cations. As the stormwater passes through the reservoir, the pH level also becomes less acidic. The reduction in acidity is most likely due to the reaction between precipitation and the lime that was used within the Portland cement of the pavement surface, or it can also be neutralized from within the mineral surfaces of the reservoir materials. Ammonium, (NH_4^+), is one chemical species that shows a consistent decline between the bulk precipitation and monitoring well samples for each event, and appears to be oxidizing after it passes through the reservoir and is converting into Nitrate, NO_3-N. The other chemical compounds do not indicate significant dissimilarities between the bulk precipitation and reservoir samples. The percent change for each precipitation event is summarized in Table 11, with the reservoir conductivity, pH, Cl^-, and NO_3-N tending to increase compared to the precipitation concentrations for each event. However, there does not however seem to be an accumulation of the compounds within the reservoir over time.

According to the data, there appears to be nominal contributions of additional nutrients beyond what has been introduced to the permeable concrete structure from wet and dry deposition. The chemical compounds studied suggest that there were minimal contributions of additional nutrients from the pavement surface itself which suggests the PP structure’s role in improving water quality in this installation was negligible. It is likely however that if other water quality components were measured that were associated with human and vehicular activity (e.g. metals, oil, and grease) then it would be likely that these compounds would be identified within the storage reservoir. One essential finding from the water quality data is that there is no indication of an accumulation of compounds within the reservoir signifying that nutrients are infiltrated into the subsoil.

Table 6: Bulk Precipitation Water Quality Results for Samples Taken from Wilmore Walk between April 16, 2007 and May 7, 2009 in Charlotte, NC.

Date	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
4/16/2007	17.0	5.11	0.49	0.48	0.12	1.44	0.03	0.68
4/19/2007	17.0	5.11	0.49	0.48	0.12	1.44	0.03	0.68
5/17/2007	38.9	5.73	1.60	0.72	0.84	9.85	0.22	1.31
6/4/2007	15.7	4.91	0.67	0.28	0.26	0.17	0.04	0.29
6/12/2007	23.8	3.12	0.33	1.58	0.26	0.87	0.05	0.36
7/12/2007	46.1	4.10	---	3.80	---	2.44	---	3.65
8/31/2007	45.5	5.00	1.09	0.55	0.01	0.01	0.05	0.57
9/15/2007	0.0	5.23	1.14	0.66	0.16	0.23	0.01	0.25
10/21/2007	15.6	5.62	1.55	0.53	0.15	0.08	0.00	1.62
10/24/2007	11.3	4.98	16.47	1.08	1.36	0.15	0.21	0.17
10/26/2007	8.3	5.52	0.21	0.41	0.13	0.21	0.00	0.15
11/27/2007	35.7	5.23	3.25	4.02	0.60	0.80	0.31	1.81
12/16/2007	6.3	5.03	0.30	0.47	0.15	0.19	0.01	0.14
12/26/2007	4.9	4.56	0.12	0.24	0.08	0.06	0.01	0.12
12/31/2007	7.4	5.18	0.47	0.32	0.11	0.15	<DL	0.12
1/12/2008	14.6	6.12	0.48	0.92	0.24	0.48	0.01	0.17
1/23/2008	32.1	4.62	8.76	0.97	0.38	0.50	0.04	0.19
1/30/2008	24.3	5.73	0.77	0.82	0.30	0.40	0.00	0.19
2/1/2008	12.9	5.63	0.87	0.51	0.47	0.30	0.00	0.13
2/7/2008	31.9	5.40	0.94	0.94	0.42	0.37	0.01	0.25
2/14/2008	12.8	6.25	0.39	0.59	0.24	0.31	<DL	0.16
2/19/2008	56.5	5.75	1.74	4.74	0.54	2.19	0.87	3.64
2/24/2008	40.3	5.62	0.94	1.30	0.27	0.15	0.01	0.34
2/27/2008	16	5.46	0.29	0.75	0.30	0.38	<DL	0.21
3/5/2008	11.7	5.62	0.63	1.42	0.08	0.34	0.23	1.14
3/9/2008	13.8	5.66	0.26	0.81	0.28	0.43	<DL	0.18
3/16/2008	19.5	6.85	0.11	0.72	0.17	0.53	0.02	0.21
3/20/2008	27.5	7.09	1.00	0.62	0.14	0.32	<DL	0.33
4/2/2008	25.3	6.26	0.99	1.46	0.36	0.68	<DL	0.32
4/4/2008	19.8	6.15	0.27	1.75	0.37	0.61	<DL	0.87
4/6/2008	14.6	6.31	0.39	0.57	0.16	0.22	<DL	0.25
4/14/2008	68.5	6.22	1.36	5.78	0.34	3.19	0.48	3.64
4/28/2008	---	6.26	0.30	0.35	0.14	<DL	0.06	0.29
4/29/2008	200	6.69	1.18	0.67	0.28	<DL	0.05	0.54
5/9/2008	92.3	5.68	2.88	4.92	3.41	0.41	<DL	1.28
5/12/2008	17.8	5.79	0.09	0.60	0.20	0.13	<DL	0.28
5/19/2008	31.1	5.99	0.78	1.26	0.57	0.79	0.02	0.19

--- = No Data <DL = Below Detectable Levels

Date	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
5/22/2008	21.8	5.74	0.42	1.60	0.54	0.93	0.06	0.47
5/30/2008	23.5	5.81	2.38	1.03	0.52	0.03	0.03	0.60
6/12/2008	43.4	6.40	0.56	3.00	1.21	1.26	0.12	1.25
6/23/2008	17.4	4.10	0.20	0.93	0.38	0.56	0.01	0.10
7/9/2008	19.3	5.93	0.16	1.87	0.24	1.06	0.14	0.63
7/11/2008	32.5	5.63	1.46	1.72	0.66	0.00	0.04	0.27
7/14/2008	13.7	3.97	0.11	0.67	0.19	0.53	0.00	0.16
7/23/2008	17.4	4.60	0.19	1.23	0.43	0.36	0.03	0.38
7/30/2008	19.3	5.74	0.32	1.02	0.38	0.10	0.00	0.18
8/1/2008	27.7	6.00	0.42	1.20	0.52	0.19	0.00	0.27
8/13/2008	83.1	5.73	2.27	10.12	0.51	4.32	1.34	---
8/16/2008	1.5	4.59	1.15	3.13	0.68	0.88	0.11	0.74
8/17/2008	13.6	4.11	0.09	0.85	0.35	0.33	0.00	0.02
8/26/2008	11.3	4.79	0.20	1.00	0.09	0.00	0.07	0.44
8/28/2008	66.5	4.79	0.13	0.43	0.08	0.04	0.01	0.12
9/2/2008	18.5	5.49	0.15	1.86	0.41	1.50	0.08	0.44
9/11/2008	9.1	5.68	0.22	0.52	0.19	0.27	0.04	0.21
9/14/2008	38.8	5.71	---	---	---	---	---	1.25
9/19/2008	13.5	4.61	0.29	0.94	0.38	0.67	0.00	0.29
10/8/2008	15.2	3.97	0.28	1.21	0.54	0.87	0.03	0.15
10/11/2008	11.5	5.72	1.08	0.97	0.24	0.81	0.06	0.51
10/26/2008	17.4	5.03	2.45	0.74	0.15	0.14	0.01	0.18
11/15/2008	8.4	4.46	0.53	0.41	0.15	0.20	0.00	0.11
11/25/2008	26.7	4.52	0.60	0.94	0.42	0.49	0.00	0.19
12/1/2008	6.2	4.25	0.11	0.33	0.12	0.12	0.00	-0.02
12/12/2008	6.5	4.38	0.52	0.25	0.09	0.08	0.00	0.00
12/19/2008	62	3.94	0.85	1.87	0.93	0.97	0.05	0.35
12/25/2008	14.7	4.95	1.33	0.81	0.34	0.50	0.00	0.04
12/27/2008	1.5	5.48	0.99	1.42	0.43	1.34	0.00	0.09
12/30/2008	2.5	5.96	3.34	1.55	0.47	1.63	0.02	0.26
1/7/2009	11.9	6.29	0.29	0.31	0.09	0.27	0.00	0.02
1/11/2009	27.3	6.15	0.75	1.05	0.37	0.86	0.00	0.12
1/30/2009	34.2	5.46	3.32	2.54	1.02	2.48	0.01	0.24
2/4/2009	87.2	5.83	2.14	1.20	0.00	0.17	0.00	1.14
2/13/2009	18.1	5.74	1.62	0.99	0.34	0.77	0.00	0.27
2/17/2009	27.5	5.73	0.29	1.44	0.54	1.08	0.01	0.19
2/20/2009	11.2	5.74	8.45	0.54	0.38	0.19	0.04	0.13
3/2/2009	5.5	6.13	0.45	0.29	0.23	0.23	0.01	0.04
3/17/2009	22.2	5.13	0.85	2.14	0.44	1.43	0.20	1.10

--- = No Data <DL = Below Detectable Levels

Date	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
3/26/2009	21.8	4.74	0.31	1.93	0.89	1.26	0.03	0.24
3/30/2009	13.5	5.41	0.90	0.91	0.31	0.58	0.07	0.37
4/5/2009	1.1	4.78	0.64	3.95	0.37	4.15	0.41	3.04
4/11/2009	26.7	4.88	0.68	1.88	0.30	1.71	0.15	0.71
4/23/2009	56.9	4.93	3.16	6.39	0.60	0.14	0.31	3.76
5/7/2009	7.3	4.44	0.01	0.14	1.02	0.19	0.00	0.23

--- = No Data   <DL = Below Detectable Levels

Table 7: Left Well Reservoir Water Quality Results for Wilmore Walk in Charlotte, NC from December 31, 2007 to May 7, 2009.

Date	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)	Volume (m^3)
12/31/2007	141	6.81	0.53	0.57	0.33	0.00	0.03	0.45	29.09
2/1/2008	194.5	6.43	16.66	1.51	1.31	0.11	0.21	0.80	23.47
3/5/2008	129	6.69	0.84	1.23	0.42	<DL	0.07	0.56	24.91
3/16/2008	185.7	6.94	0.96	1.04	0.63	<DL	0.02	0.35	22.61
6/23/2008	191	6.25	2.03	2.71	2.46	0.00	0.09	0.28	35.28
7/9/2008	139.1	6.32	1.08	1.50	1.26	0.08	0.06	0.33	27.94
8/28/2008	93.8	6.03	0.56	0.52	0.29	0.02	0.04	0.20	112.03
9/27/2008	1.2	6.32	0.64	1.16	0.98	0.00	0.06	0.33	32.69
12/12/2008	115.6	6.20	0.76	0.54	0.40	0.00	0.04	0.22	36.29
1/7/2009	105.6	6.10	3.13	1.53	1.00	0.00	0.17	0.61	39.46
3/2/2009	90.2	6.30	0.20	0.20	0.13	0.00	0.01	0.19	51.26
5/7/2009	3.2	5.71	0.03	0.24	15.63	1.58	4.87	0.09	65.81
<DL = Below Detectable Levels									

Table 8: Middle Well Reservoir Water Quality Results for Wilmore Walk in Charlotte, NC from April 16, 2007 to January 1st, 2009.

Date	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)	Volume (m^3)
4/16/2007	159.2	6.83	0.44	0.42	0.16	0.31	<DL	0.17	2.02
9/15/2007	0.4	6.27	1.07	1.15	0.58	0.15	<DL	0.18	29.38
10/26/2007	218	6.64	0.77	1.05	0.64	0.00	<DL	0.05	22.18
12/31/2007	108.8	6.44	0.44	0.27	0.17	0.00	0.01	0.18	29.09
1/20/2008	128.2	6.48	0.50	0.43	0.22	0.00	<DL	0.08	21.74
2/1/2008	147.4	6.23	3.43	0.52	0.33	<DL	<DL	0.14	23.47
3/5/2008	162.5	6.76	0.61	1.15	0.25	<DL	<DL	0.18	24.91
3/16/2008	122.7	6.81	0.42	0.49	0.29	<DL	<DL	0.14	22.61
3/20/2008	172	7.02	0.50	0.66	0.37	<DL	<DL	0.12	12.10
4/6/2008	152.2	6.76	0.84	0.86	0.57	<DL	<DL	0.20	20.02
4/29/2008	92.9	6.15	0.96	0.82	0.49	<DL	0.03	0.27	29.66
6/23/2008	206	6.50	0.53	0.85	0.68	0.00	0.00	0.06	35.28
7/9/2008	175.2	6.90	0.43	0.63	0.47	0.00	0.00	0.14	27.94
8/28/2008	96.3	6.41	0.74	0.54	0.38	0.00	0.01	0.06	112.03
9/27/2008	0.4	6.58	0.48	0.55	0.39	0.00	---	0.13	32.69
12/12/2008	196.4	6.51	0.75	0.25	0.17	0.00	0.00	0.05	36.29
1/7/2009	123.1	6.38	0.98	0.32	0.22	0.00	0.00	0.04	39.46
--- = No Data <DL = Below Detectable Levels									

Table 9: Right Well Reservoir Water Quality Results for Wilmore Walk in Charlotte, NC from December 31, 2007 to May 7, 2009.

Date	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)	Volume (m^3)
4/16/07	169.0	6.69	0.98	0.98	0.49	<DL	<DL	0.33	2.02
9/15/07	155.7	6.21	1.80	1.42	0.75	0.20	0.04	0.51	29.38
10/26/07	131.1	6.25	1.87	1.95	1.11	0.06	0.16	1.05	22.18
12/16/07	119.3	6.14	3.16	1.52	0.40	0.20	0.16	0.82	20.48
12/31/07	78.3	6.92	0.98		0.18	0.00	0.20	1.02	29.09
1/20/08	51.7	6.33	---	---	---	---	---	---	21.74
2/1/08	69.8	6.22	6.66	1.37	0.36	0.03	0.40	2.07	23.47
3/5/08	83.4	6.43	0.56	2.07	0.23	0.58	0.10	0.63	24.91
3/16/08	98.7	6.76	0.54	1.40	0.81	<DL	0.09	0.55	22.61
3/20/08	6.75	134.50	1.07	1.81	1.13	<DL	0.07	0.58	12.10
6/23/08	122	7.03	2.82	1.69	1.44	0.00	0.14	0.49	35.28
7/9/08	97	6.98	1.44	1.22	0.86	0.00	0.16	0.72	27.94
8/28/08	52.1	7.21	0.71	0.49	0.29	0.00	0.11	0.45	112.03
9/27/08	84.4	6.72	1.62	0.69	0.22	0.00	0.16	0.72	32.69
12/12/08	83.4	6.57	2.49	0.48	0.15	0.00	0.19	0.43	36.29
1/7/09	12.3	6.10	3.71	1.17	0.10	0.00	0.23	0.91	39.46
3/2/09	34.8	6.26	0.08	0.25	0.00	0.00	0.01	0.36	51.26
5/7/09	59.5	5.72	0.06	0.15	6.40	1.04	2.12	0.23	65.81
--- = No Data <DL = Below Detectable Levels									

Table 10: Bulk Precipitation Load Summary for samples collected at Wilmore Walk in Charlotte, NC from April 16, 2007 to May 7, 2009.

Date	Conductivity (µs/cm)	pH	Cl^- (kg/m3)	TDN	NO_3-N (kg/m3)	NH_4^+-N (kg/m3)	PO_4-P (kg/m3)	TP (PO_4-3) (kg/m3)
4/16/2007	17.0	5.11	0.00	0.00	0.00	0.00	0.00	0.00
9/15/2007	28.3	4.68	0.05	0.12	0.01	0.09	0.00	0.09
10/26/2007	11.7	5.37	0.21	0.03	0.02	0.01	0.00	0.02
12/16/2007	21.0	5.13	0.02	0.03	0.01	0.01	0.00	0.01
12/31/2007	6.2	4.87	0.01	0.01	0.00	0.01	0.00	0.01
1/20/2008	14.6	6.12	0.00	0.00	0.00	0.00	0.00	0.00
2/1/2008	23.1	5.33	0.02	0.02	0.00	0.01	0.00	0.00
3/4/2008	28.2	5.68	0.03	0.07	0.01	0.02	0.01	0.04
3/15/2008	16.7	6.26	0.00	0.02	0.01	0.02	0.00	0.01
3/19/2008	27.5	7.09	0.01	0.01	0.00	0.00	0.00	0.00
4/6/2008	19.9	6.24	0.01	0.03	0.01	0.01	0.00	0.01
4/29/2008	200.0	6.48	0.03	0.04	0.01	0.02	0.00	0.03
7/9/2008	19.3	5.93	0.00	0.05	0.01	0.03	0.00	0.02
8/27/2008	28.7	5.00	0.06	0.25	0.04	0.06	0.02	0.05
9/27/2008	16.9	5.26	0.01	0.05	0.02	0.03	0.00	0.02
12/12/2008	13.1	4.62	0.04	0.04	0.02	0.02	0.00	0.00
1/7/2009	18.5	5.32	0.02	0.02	0.01	0.02	0.00	0.00
3/2/2009	30.1	5.83	0.13	0.05	0.02	0.04	0.00	0.01
5/7/2009	21.4	4.90	0.08	0.17	0.09	0.09	0.01	0.10

Table 11: Reservoir Load Summary for samples collected at Wilmore Walk in Charlotte, NC from April 16, 2007 to May 7, 2009.

Date	Conductivity (µs/cm)	pH	Cl^- (kg/m3)	TDN	NO_3-N (kg/m3)	NH_4^+-N (kg/m3)	PO_4-P (kg/m3)	TP (PO_4-3) (kg/m3)
4/16/2007	164.1	6.76	0.00	0.00	0.00	0.00	0.00	0.00
9/15/2007	78.1	6.24	0.04	0.04	0.02	0.01	0.00	0.01
10/26/2007	174.6	6.45	0.03	0.03	0.02	0.00	0.00	0.01
12/16/2007	119.3	6.14	0.06	0.03	0.01	0.00	0.00	0.02
12/31/2007	109.4	6.72	0.02	0.01	0.01	0.00	0.00	0.02
1/20/2008	90.0	6.41	0.01	0.00	0.00	0.00	0.00	0.00
2/1/2008	137.2	6.29	0.21	0.03	0.02	0.00	0.00	0.02
3/4/2008	125.0	6.63	0.02	0.04	0.01	0.00	0.00	0.01
3/15/2008	135.7	6.84	0.01	0.02	0.01	0.00	0.00	0.01
3/19/2008	153.3	6.89	0.01	0.01	0.01	0.00	0.00	0.00
4/6/2008	152.2	6.76	0.02	0.02	0.01	0.00	0.00	0.00
4/29/2008	92.9	6.15	0.03	0.02	0.01	0.00	0.00	0.01
7/9/2008	137.1	6.73	0.03	0.03	0.02	0.00	0.00	0.01
8/27/2008	80.7	6.55	0.08	0.06	0.04	0.00	0.01	0.03
9/27/2008	28.7	6.54	0.03	0.03	0.02	0.00	0.00	0.01
12/12/2008	131.8	6.43	0.05	0.02	0.01	0.00	0.00	0.01
1/7/2009	80.3	6.19	0.10	0.04	0.02	0.00	0.01	0.02
3/2/2009	62.5	6.28	0.01	0.01	0.00	0.00	0.00	0.01
5/7/2009	68.9	5.80	0.00	0.01	0.82	0.09	0.27	0.01

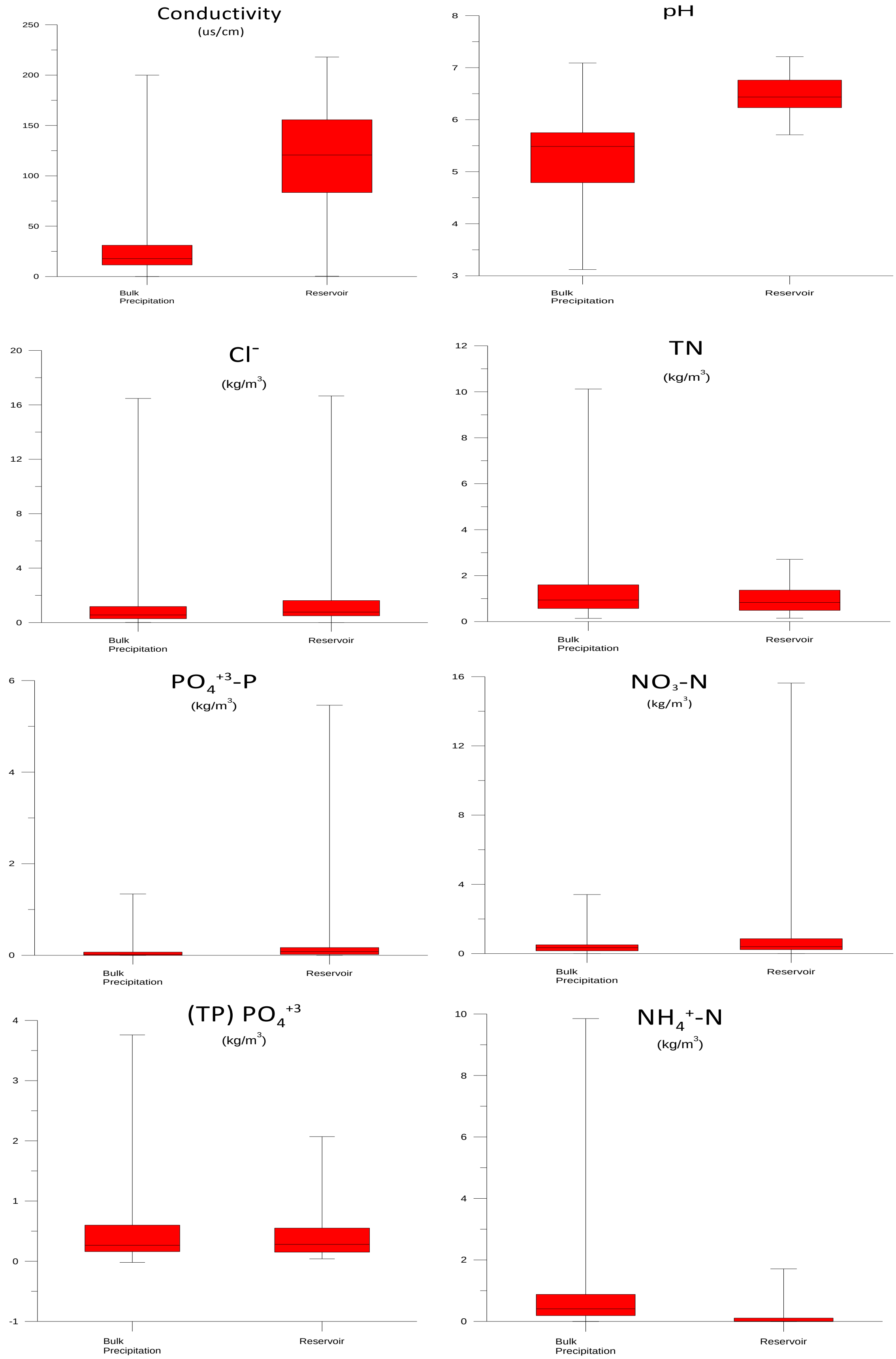
Table 12: Percent Change in Concentration from Bulk Precipitation to Reservoir for water samples taken from Wilmore Walk in Charlotte, NC from April 16, 2007 to May 7, 2009.

Date	Conductivity (µs/cm) % Change	pH	Cl^- (kg/m3) % Change	TDN % Change	NO_3-N (kg/m3) % Change	NH_4^+-N (kg/m3) % Change	PO4-P (kg/m3) % Change	TP (PO_4^{-3}) (kg/m3) % Change
4/16/2007	*-865.3	**-1.65	-44.9	-45.8	-170.8	89.2	100.0	63.2
9/15/2007	-175.5	-1.56	11.9	69.1	-109.8	94.1	62.4	88.4
10/26/2007	-1387.6	-1.07	86.2	-30.4	3.6	90.5	29.3	50.0
12/16/2007	-468.1	-1.01	-247.5	-24.2	-52.4	41.2	-134.9	-103.7
12/31/2007	-1678.3	-1.85	-38.3	34.4	-106.1	100.0	0.0	-217.1
1/20/2008	-516.1	-0.29	-131.3	-3.8	-103.6	100.0	100.0	100.0
2/1/2008	-494.1	-0.97	-933.4	-71.8	-1068.5	87.6	-5423.9	-521.4
3/4/2008	-343.1	-0.94	48.2	45.5	23.2	76.8	81.3	72.8
3/15/2008	-715.0	-0.58	-198.6	6.5	-104.2	100.0	-83.3	-22.8
3/19/2008	-457.3	0.21	21.5	-99.2	-435.7	100.0	0.0	-6.1
4/6/2008	-664.8	-0.52	-139.2	42.3	-74.4	100.0	0.0	71.5
4/29/2008	53.6	0.32	2.0	43.2	-82.9	100.0	77.2	73.1
7/9/2008	-610.4	-0.80	-514.6	40.3	-259.7	97.5	47.6	37.0
8/27/2008	-181.7	-1.56	-25.8	76.5	0.4	98.8	67.5	48.7
9/27/2008	-69.6	-1.28	-145.6	45.9	-6.3	100.0	-72.7	20.6
12/12/2008	-903.9	-1.81	-9.6	65.5	49.4	100.0	-471.6	-86.3
1/7/2009	-333.8	-0.87	-315.1	-60.1	-97.4	100.0	-2227.0	-638.6
3/2/2009	-107.3	-0.45	94.6	77.2	86.4	100.0	48.0	-13.1
5/7/2009	-222.6	-0.90	97.5	91.3	-764.5	-8.9	-2431.4	89.3

* A positive % change means the Reservoir sample shows a decrease in concentration in relation to bulk precipitation values

** A negative % change means the Reservoir sample shows an increase beyond bulk precipitation input

Table 13: Box-whisker plot comparisons of bulk precipitation and reservoir water quality samples from Wilmore Walk in Charlotte, NC. TN = Total Dissolve Nitrogen (TDN)



Green Ampt Model

A summary of the application of the Green Ampt (GA) model for ten individual rain events, and the resulting water level responses and the Root Mean Square Deviation (RMSD) that occurred at the study site, are shown in Table 14. The ten rain events were split into five "dry" antecedent events where it rained 0.24" or less within 10 days prior to event, and five wet antecedent events where it rained ≥0.25" within the previous 10 days. All 10 storm events that were examined indicated that utilizing a sand texture produced the best fit between model results and observed data for this site. This is likely due to the saprolite subsoils beneath the structure, which is chemically weathered bedrock that is crushed into various sized particles of sand, silt, and clay. It has been reported that water moves through saprolite in an anisotropic way through natural joints, foliations, and tubular pores. These joints, foliations, and pores can allow water to pass more quickly through the subsoil and will affect the porosity of the soils and may have similar porosity values to sand (Amoozegar et al, 1991).

The RMSD values in Table 14 for all 10 storms range from 0.086 to 0.21 with an average of 0.16 and a standard deviation of 0.04. The lowest RMSD value (0.086) was of the 7/8/2008 rain event using the sand texture parameters of porosity (η) at 0.34, and wetting front tension (S) set at 3.75. The highest RMSD value calculated was 0.21 for 12/15/2007 rain event using the Sand texture parameters of porosity (η) at 0.34, and wetting front tension (ψ_f/S) at 3.75. The low RMSD for 7/8/2008 is associated with a short duration storm (2.5 hours) and a 5 minute peak rainfall rate of 0.34 inches. The high RMSD for 12/15/2007 event can be attributed to the GA model predicting a lower rate of cumulative infiltration between 3,000 and 5,000 minutes than what was actually recorded (Figure A.2-3).

For storm events on 04/14/2007, 07/27/2007, 03/01/2009 the wetting front tension (ψ_f) was adjusted to the highest value recommended (8.62) (Dingman 2002) in order to achieve the best fit of the model. The utilization of a higher ψ_f (within 1 standard deviation) may be necessary to apply this form of the GA model for larger rain events or for soils that are already wet. The wetting front tension is based on air entry tension and pore distribution size of the soil, and according to Dingman (2002) the air entry tension at specific water moisture content is dependent upon the recent history of the soil's changing moisture levels. Relating a range of ψ_f values to antecedent moisture conditions may be viable approach to model different types of precipitation events more effectively.

In Figure A.2-1 through A.2-10, most of the 10 events show the GA model simulates a faster infiltration rate than the actual data within the first 500 - 1,000 minutes. Then the infiltration rate for the model and actual data tends to converge after the 1,000 minute mark. This suggests that while the GA model can give a close representation of the infiltration rate into the subsoil, the "best fit" soil parameters do not represent the soil type that is currently present. We know that the subsoil is composed largely of red and yellow saprolite subsoils that have been compacted by heavy construction equipment, which should have a slower the rate of infiltration than sand, but the coarser sand texture values fit the observed data results best. This could be an indicator that the construction pre-treatment of scribing the surface of the subsoil with a backhoe effectively increased the infiltration capacity of the substrate beyond that predicted by the soil texture alone. In almost all events shown in Figure A.2-1 through A.2-10, the GA infiltration rates level off and track the measured data in the amount of rain water infiltrated and the total amount of time required to infiltrate the ponded water.

Green Ampt Model Results to 10 Well Responses within the Permeable Pavement Surface

Event Details					**Green Ampt - Best Fit**			
Storm Event Date	**Present Soil Conditions** (Wet if 0.25"+ occurs within 10 days of current event)	**Duration** (Hours)	**Precipitation** (Inches)	**Well Response** (Inches)	**K_h^*** (Sand)	**ϕ**	**ψ_f (S)**	**RMSE**
07/27/2007	Dry (No rain previous 9 days)	2.20	1.98	6.03	0.0069	0.34	8.62	0.16
09/14/2007	Dry (No rain previous 3 days)	18.97	1.60	3.09	0.0069	0.34	3.75	0.10
12/15/2007	Dry (No rain previous 10 days)	UNK	1.12*	3.49	0.0069	0.34	3.75	0.21
09/26/2008	Dry (No rain previous 9 days)	22.08	1.54	3.34	0.0069	0.34	3.75	0.18
01/09/2009	Dry (No rain previous 7 days)	2.37	1.33	3.71	0.0069	0.34	3.75	0.16
04/14/2007	Wet (0.91" w/in 3 days)	UNK	1.29*	3.30	0.0069	0.34	8.62	0.17
12/30/2007	Wet (0.58" w/in 10days)	13.18	0.93	2.08	0.0069	0.34	3.75	0.20
07/08/2008	Wet (0.51" w/in 5 days)	2.32	1.53	3.48	0.0069	0.34	3.75	0.086
03/01/2009	Wet (0.60" w/in 7 days)	14.03	1.39	6.23	0.0069	0.34	8.62	0.21
03/28/2009	Wet (1.01" w/in 3 days)	8.03	0.94	2.75	0.0069	0.34	3.75	0.17
	UNK = No Data	**Precipitation*** = Retrieved data from Charlotte Douglas Airport Rain Gauge						

Table 14: Application of the Green Ampt Model to 10 Well Responses within the Permeable Pavement Surface at Wilmore Walk Watershed in Charlotte, NC for 5 Dry/Semi-Dry Precipitation Events and 5 Wet Events (2007-2009). "UNK" = No Data, Precipitation* = Alternate data collected from Charlotte Douglas Airport Rain Gauge Records.

Stormwater Modeling: SCS Runoff Curve Number Method with ArcGIS

The Wilmore Walk Sub-basin (WWS) National Elevation Dataset (NED) is presented in Figure A.3-1. The WWS NED was applied to a raster calculator to create a precipitation map for the seven storm scenarios used in this study. An example of one such Precipitation map is shown in Figure A.3-2, and the rainfall amounts applied to each Precipitation map are shown in Table 15.

Table 15: Storm Interval 24 Hour Period	Rainfall (Inches)
1.25yr Storm	2.93
2yr Storm	3.36
5yr Storm	4.22
10yr Storm	4.89
25yr Storm	5.81
50yr Storm	6.54
100yr Storm	7.28

The SSURGO Soil Hydrogroup Map variable, in Figure A.3-3, was combined with the Land-Use Map (Figure A.3-4), to create a 'combined' map that is re-classified four times to represent the four scenarios of this study (present conditions, etc.). The values of the combined soils and landuse map, and the Curve Number classifications are shown in Table 16. The summary of pervious vs. impervious surfaces for each scenario is shown in

Table 17, and any CN value less than 98 was considered somewhat pervious. The visual results of each CN map, using ArcGIS, are shown below in Figure 18, and Figure A.3-5 through A.3-7.

The four CN maps were applied to the Equation 11 and the resulting four S maps are shown in Figure 19, and Figure A.3-8 through A.3-10. Each precipitation map or "P" variable (7 maps) and each of the four S maps were applied to the SCS Runoff CN equation 10 to generate separate Q (Runoff) map for each landcover/precipitation scenario. Examples of a runoff map for each scenario related to a 100yr storm event are shown below in Figure 20, and Figure A.3-11 through A.3-13. An example of an Accumulated Runoff (AQ) map for a 100yr storm event with present conditions is shown in Figure A.3-14. The AQ maps do not show noticeable visual differences between each scenario and the total runoff values from each map are summarized in Table 19.

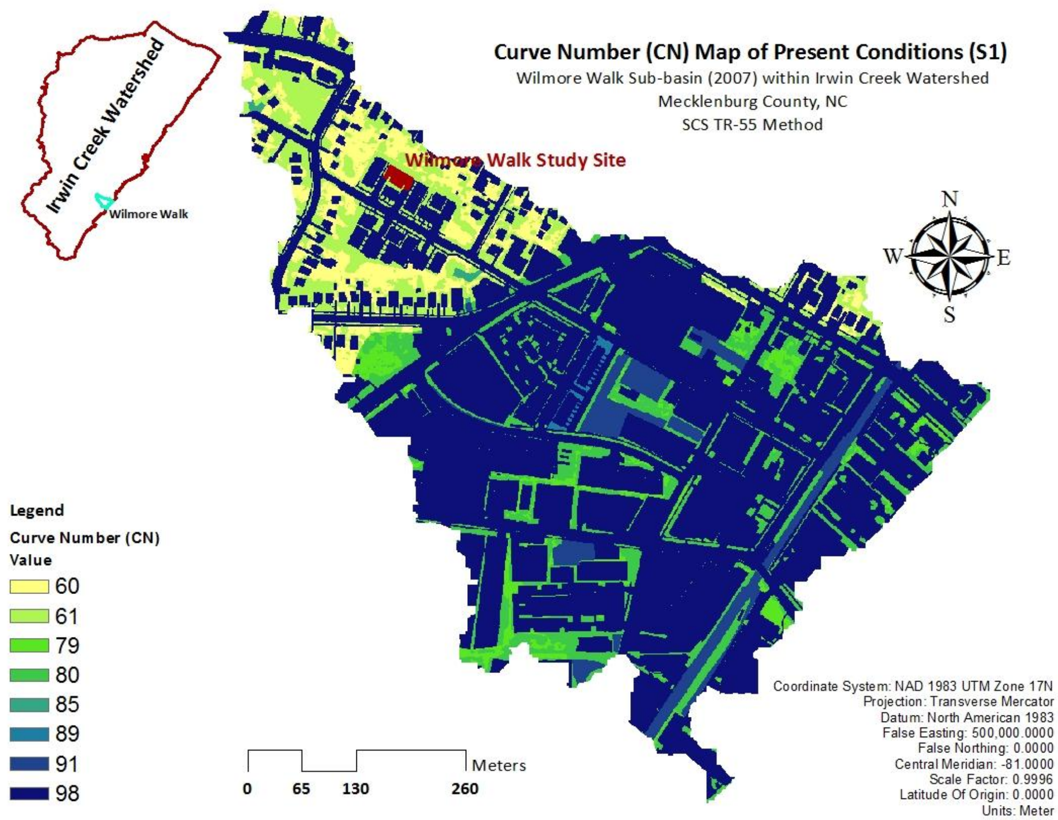


Figure 18: Curve Number Map of Present Conditions (S1) for Wilmore Walk Sub-basin.

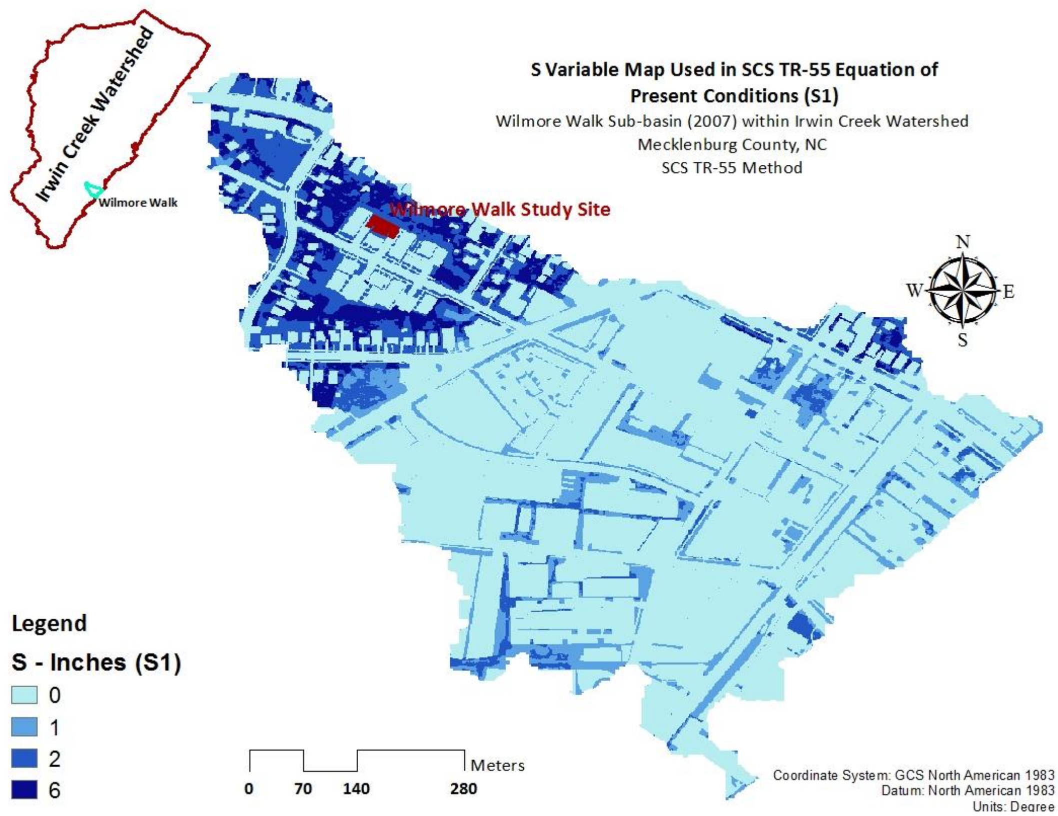


Figure 19: S Variable Map applied to SCS TR-55 Equation for Present Conditions (S1) of Wilmore Walk Sub-basin.

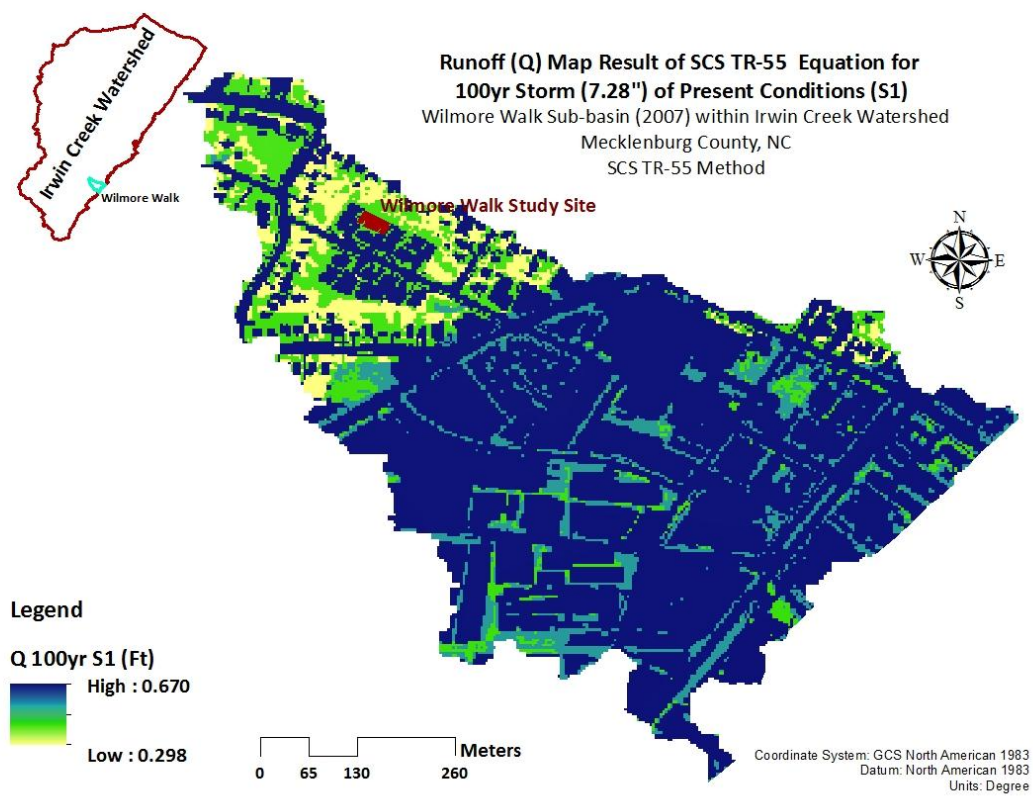


Figure 20: Runoff (Q) result of SCS TR-55 Equation application for 100yr Storm (7.28") in Present Conditions within Wilmore Walk Sub-basin

Table 16: Curve Number (CN) Data Results from Wilmore Walk GIS Study (Mecklenburg County, NC).

Land	Soil	Count	Acres	Present Conditions (CN1)	Parking Lots, etc. as a pervious surface (CN2)	Secondary roads as a pervious surface (CN3)	Parking lots, etc., & secondary roads as a pervious surface (CN4)
Gravel	B	519	0.13	85	85	85	85
	U	15423	3.81	91	91	91	91
Barren	U	805	0.20	89	89	89	89
Trees	B	21216	5.24	60	60	60	60
	U	10505	2.60	79	79	79	79
Grass	B	30450	7.52	61	61	61	61
	U	36439	9.00	80	80	80	80
Parking Lots	B	6092	1.51	98	61	98	61
	U	63732	15.75	98	61	98	61
Driveways	B	9075	2.24	98	61	98	61
	U	16112	3.98	98	61	98	61
Secondary Roads	B	8546	2.11	98	98	61	61
	U	22961	5.67	98	98	61	61
Primary Roads	B	4104	1.01	98	98	98	98
	U	9468	2.34	98	98	98	98
Building	B	15370	3.80	98	98	98	98
	U	85353	21.09	98	98	98	98
		Total Acres:	**88.01**	**89.93**	**79.96**	**86.56**	**76.69**
				Total - Weighted CN Values for each Scenario			

Table 17: Percentage of Pervious Surfaces for each of the 4 Scenarios used in ArcGIS Model for Wilmore Walk Watershed (Charlotte NC, 2007)

	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	Present Conditions - 2007			Pervious Driveways, Sidewalks, & Parking Lots			Pervious Secondary Roads Only			Scenarios 2 & 3 Combined (Pervious Driveways, Sidewalks, Parking Lots, & Secondary Roads)		
	%	**Acres**	**Avg CN**	**%**	**Acres**	**Avg CN**	**%**	**Acres**	**Avg CN**	**%**	**Acres**	**Avg CN**
Pervious	32.39	28.51	89.93	59.06	51.98	79.96	41.23	36.29	86.56	67.91	59.77	76.69
Impervious	67.61	59.51		40.94	36.03		58.77	51.72		32.09	28.24	
Difference	0	0	0	26.67	23.47	-9.97	8.84	7.78	-3.37	35.52	31.26	-13.24

Stormwater Modeling: SCS Runoff Curve Number Method with HydroCAD®

The same precipitation and CN data used in the ArcGIS model runs were also applied in the HydroCAD® stormwater modeling software. The main difference in this approach is the use of Time of Concentration (T_c) data, shown in Table 18. The T_c data varied with each model scenario – i.e. in

Scenario 2, the T_c data for a parking lot would then be replaced with the T_c values for grass. The T_c data requires an average slope for each flow segment, which is the only slope or elevation data used in this method.

The final runoff results from the HydroCAD® Models for each scenario are shown in Table 19. When comparing the ArcGIS and HydroCAD® results, the smaller storm results show a significant difference in runoff totals, with differences between the two methods decreasing with increasing event size (Table 19). When comparing scenarios 1-4 for each storm interval, the expected reductions in runoff levels for with increasing imperviousness are evident (Table 19, Figures 19 and 20).

Figure 22 and Figure 23 display the predicted runoff results for all four CN scenarios as modeled with the HydroCAD® approach for a 1.25 year and a 100 year, 24-hr event. All four scenarios show the expected general outflow responses for both rain events. Beyond peak flow reductions model scenarios 2 and 4 also show that the peak flows for both storm events are delayed by ≈30 minutes when compared to scenarios 1 and 3. The runoff data for scenario 1 indicates that the peak flow of the 1.25-year, 24-hour storm (Figure 22), is reduced by 55% in scenario 2, a 13% reduction in scenario 3, and by 62% in scenario 4. The runoff data for scenario 1 indicates that the peak flow for the 100-year, 24-hour storm (Figure 23), is reduced by 37%, 8.5% scenario 3, and by 42% in scenario 4.

As could be expected the simulations suggest that scenario 4 (pervious parking lots, driveways, sidewalks, and secondary roads) will have the most impact at the watershed scale in reducing stormwater runoff. A comparison with scenario 2 indicates that parking lots, driveways, and sidewalks account for the majority of the reduction in runoff. It must be recognized that aspects of scenario 2 however may prove difficult to convert to pervious pavement since the majority of this type of landuse is privately owned. It would require the support of local and state governments via tax credits and incentives and likely redevelopment ordinances, in order for these surfaces to eventually be converted to PP. If the majority of the currently paved surfaces were converted to PP, the application of PP has the potential to have a significant impact on reducing and delaying stormwater runoff within a highly urbanized watershed.

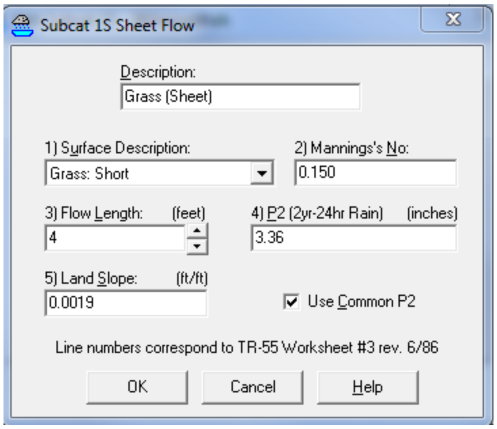


Figure 21: A screenshot of "Sheet Flow" settings within HydroCAD Modeling Software.

A comparison of the ArcGIS and HydroCAD® results for each PP application scenario under each rain event return interval is presented Figure 24 and Figure 25. The ArcGIS runoff results indicate an even and steady decline in the difference in runoff ratios with increasing storm size, whereas the HydroCAD® results display a much greater reduction in runoff under the Scenario 2 PP application as compared to the ArcGIS methodology. This is likely attributed to the HydroCAD® software utilizing additional site specific variables in addition to CN data, in order to determine the runoff hydrograph for each scenario (Figure 21). HydroCAD® utilizes Time of Concentration data, manning's equation values (represents surface roughness), and site specific flow path values which are not included in the ArcGIS method.

Table 18: Time of Concentration Data Applied to Wilmore Walk Study of Present Conditions in HydroCAD® Model

#	Land-use	Distance (m)	Average Slope
1	Grass (Sheet Flow)	1.22	0.00190
2	Parking Lots (Sheet Flow)	8.53	0.00100
3	Building (Sheet Flow)	20.73	0.00980
4	Grass	3.83	0.00187
5	Parking Lots	28.31	0.00100
6	Building	6.49	0.00057
7	Building	61.37	0.00983
8	Building	15.65	0.00511
9	Grass	3.72	0.00088
10	Gravel	16.65	0.00137
11	Parking Lots	12.85	0.00306
12	Building	17.12	0.00322
13	Grass	6.04	0.00167
14	Parking Lots	23.84	0.00062
15	Grass	2.1	0.00009
16	Sidewalk	9.54	0.00040
17	Building	14.33	0.00018
18	Grass	3.18	0.00009
19	Parking Lots	28.61	0.00384
20	Secondary Road	32.8	0.00270
21	Grass	38.04	0.00280
22	Parking Lots	1.68	0.00080
23	Grass	1.77	0.00000
24	Secondary Road	13.01	0.00272
25	Sidewalk	5.35	0.00071
26	Building	3.93	0.00045
27	Grass	1.52	0.00000
28	Parking Lots	38.2	0.00215
29	Trees	3.11	0.00179
30	Building	29.53	0.01213
31	Parking Lots	21.28	0.00323
32	Grass	13.9	0.00082
33	Secondary Road	12.36	0.00046
34	Grass	3.89	0.00000
35	Sidewalk	3.433	0.00036
36	Building	11.77	0.00590
37	Grass	3.43	0.00023
38	Parking Lots	11.31	0.00115
39	Barren	5.37	0.00069
40	Building	16.3	0.00475
41	Barren	0.74	0.00000

Table 18 Cont.: Time of Concentration Data Applied to Wilmore Walk Study of Present Conditions in HydroCAD® Model

#	Land-use	Distance (m)	Average Slope
42	Sidewalk	1.88	0.00037
43	Secondary Road	11.86	0.00106
44	Parking Lots	14.55	0.00005
45	Grass	0.68	0.00013
46	Building	5.74	0.00000
47	Grass	6.10	0.00019
48	Sidewalk	2.89	0.00046
49	Grass	2.50	0.00056
50	Parking Lots	62.04	0.00153
51	Sidewalk	7.94	0.00028
52	Grass	1.67	0.00009
53	Building	14.02	0.00074
54	Sidewalk	2.16	0.00074
55	Grass	5.20	0.00227
56	Primary Road	12.78	0.00135
57	Secondary Road	4.66	0.00060
58	Parking Lots	9.67	0.00028
59	Grass	11.21	0.00023
60	Grass	15.13	0.00107
61	Trees	27.79	0.00158
62	Shallow Channel	84.61	0.00089
63	Shallow Channel	104.35	0.00168
	Total:	**966.27**	

Table 19: Accumulated Runoff (AQ) and peak flow results for ArcGIS and HydroCAD® applications of the SCS TR-55 Method for 1.25, 2, 5, 10, 25, 50, and 100 Year Storm Events for Wilmore Walk Sub-basin in Charlotte, NC (2007).

1.25 Year Storm Event (2.93")						
Scenario	ArcGIS			HydroCAD		
	(cfs)	(af)	%	(cfs)	(af)	%
1	11.25	22.31	0.00	76.18	14.08	0.00
2	10.54	20.91	-6.28	34.30	8.79	-37.61
3	10.72	21.26	-4.71	66.39	12.88	-8.53
4	9.17	18.19	-18.47	29.23	7.92	-43.78

2 Year Storm Event (3.36")						
Scenario	ArcGIS			HydroCAD		
	(cfs)	(af)	%	(cfs)	(af)	%
1	12.69	25.17	0.00	91.78	17.00	0.00
2	11.09	22.00	-12.59	44.41	11.19	-34.15
3	12.14	24.08	-4.33	81.05	15.71	-7.58
4	10.54	20.90	-16.96	38.51	10.21	-39.94

5 Year Storm Event (4.22")						
Scenario	ArcGIS			HydroCAD		
	(cfs)	(af)	%	(cfs)	(af)	%
1	15.59	30.93	0.00	123.03	22.94	0.00
2	13.91	27.58	-10.83	65.87	16.32	-28.88
3	15.01	29.78	-3.72	110.81	21.52	-6.22
4	13.32	26.43	-14.55	58.38	15.14	-34.03

10 Year Storm Event (4.89")						
Scenario	ArcGIS			HydroCAD		
	(cfs)	(af)	%	(cfs)	(af)	%
1	17.87	35.45	0.00	147.5	27.65	0.00
2	16.13	32.00	-9.73	83.32	20.52	-25.80
3	17.27	34.26	-3.36	134.19	26.14	-5.45
4	15.53	30.80	-13.12	74.7	19.21	-30.54

25 Year Storm Event (5.81")						
Scenario	ArcGIS			HydroCAD		
	(cfs)	(af)	%	(cfs)	(af)	%
1	21.02	41.69	0.00	181.02	34.16	0.00
2	19.22	38.12	-8.56	107.91	26.48	-22.49
3	20.40	40.46	-2.95	166.37	32.59	-4.62
4	18.59	36.88	-11.54	97.93	25.02	-26.76

50 Year Storm Event (6.54")						
Scenario	ArcGIS			HydroCAD		
	(cfs)	(af)	%	(cfs)	(af)	%
1	23.52	46.66	0.00	207.53	39.36	0.00
2	21.69	43.02	-7.80	127.74	31.33	-20.39
3	22.89	45.41	-2.68	191.88	37.74	-4.11
4	21.05	41.75	-10.52	116.78	29.78	-24.35

100 Year Storm Event (7.28")						
Scenario	ArcGIS			HydroCAD		
	(cfs)	(af)	%	(cfs)	(af)	%
1	26.07	51.72	0.00	234.33	44.64	0.00
2	24.20	48.01	-7.17	148.02	36.33	-18.61
3	25.43	50.44	-2.47	217.7	43.00	-3.68
4	23.55	46.72	-9.67	136.12	34.69	-22.29

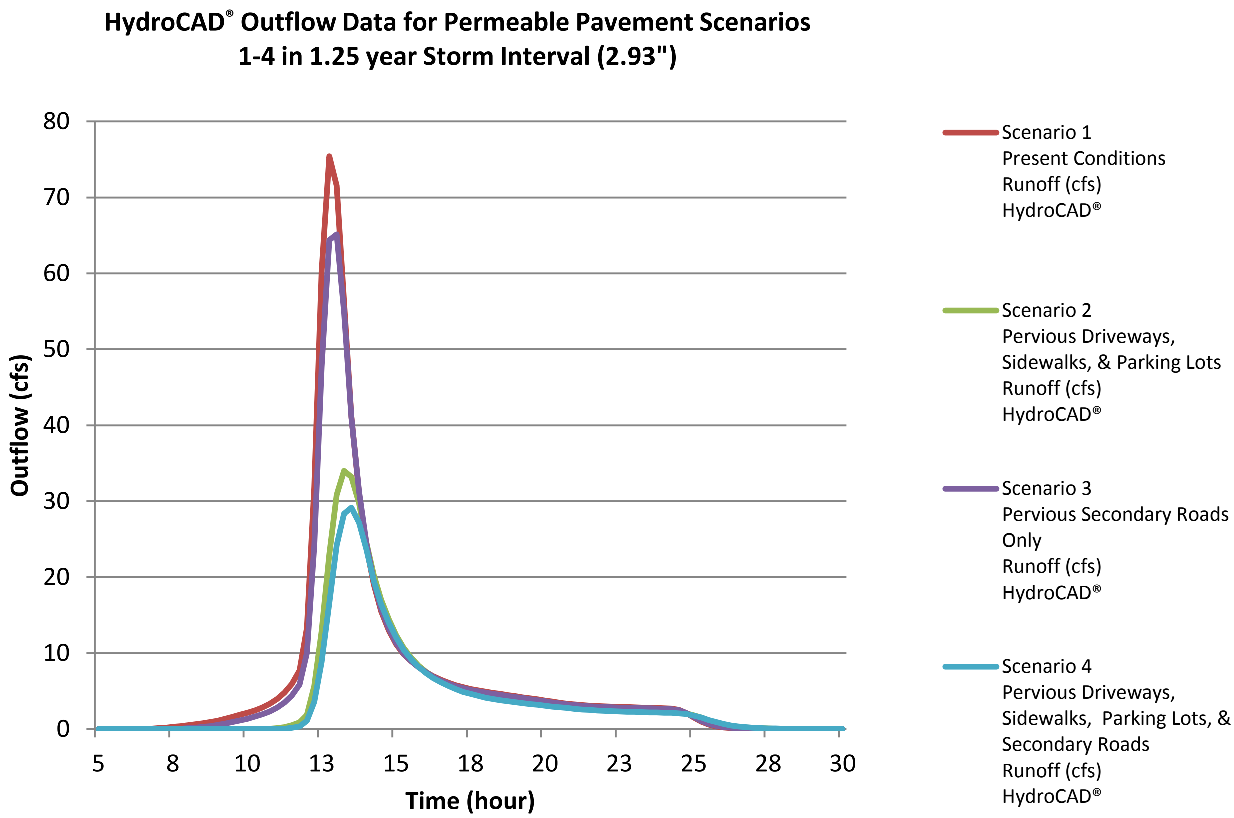


Figure 22: HydroCAD® Outlfow Data for Permeable Pavement Scenarios 1-4 in 1.25 year Storm Interval (2.93") for Wilmore Walk Sub-basin in Charlotte, NC.

Peak Flow details for 1.25 Year Shown in Figure 22

	Peak Flow (cfs)	**Timing of Peak Flow** (hours)	**Total Runoff Volume** (af)
Scenario 1 Present Conditions 2007	76.18	12.75	14.08
Scenario 2 Pervious Driveways, Sidewalks, & Parking Lots	34.3	13.25	8.79
Scenario 3 Pervious Secondary Roads Only	66.39	12.75	12.88
Scenario 4 Pervious Driveways, Sidewalks, Parking Lots, & Secondary Roads	29.23	13.25	7.92

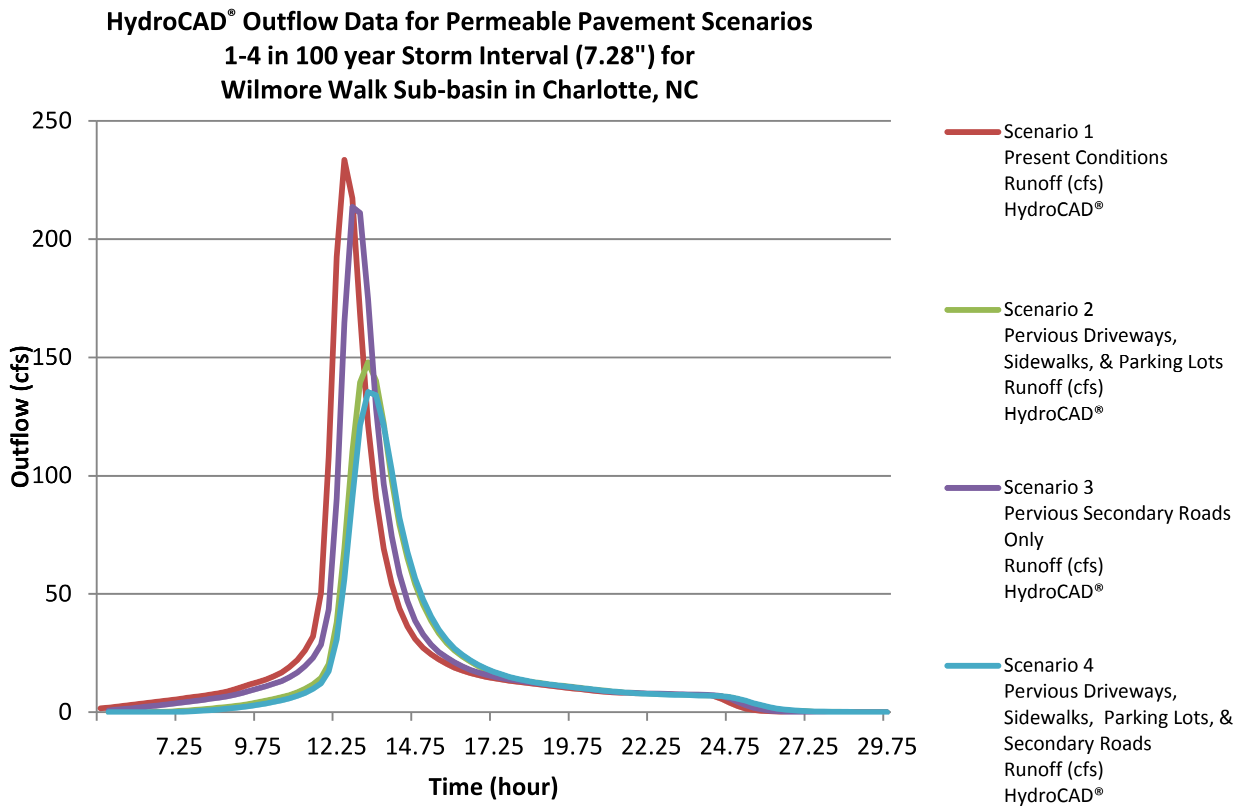


Figure 23: HydroCAD® Outflow Data for Permeable Pavement Scenarios 1-4 in 100 year Storm Interval (7.28") for Wilmore Walk Sub-basin in Charlotte, NC

Peak Flow for 100 Year Storm Interval Shown in Figure 23

	Peak Flow (cfs)	**Timing of Peak Flow** (hours)	**Total Runoff Volume** (af)
Scenario 1 Present Conditions 2007	233.56	12.75	44.64
Scenario 2 Pervious Driveways, Sidewalks, & Parking Lots	147.93	13.25	36.33
Scenario 3 Pervious Secondary Roads Only	213.74	12.75	43.00
Scenario 4 Pervious Driveways, Sidewalks, Parking Lots, & Secondary Roads	135.42	13.25	34.69

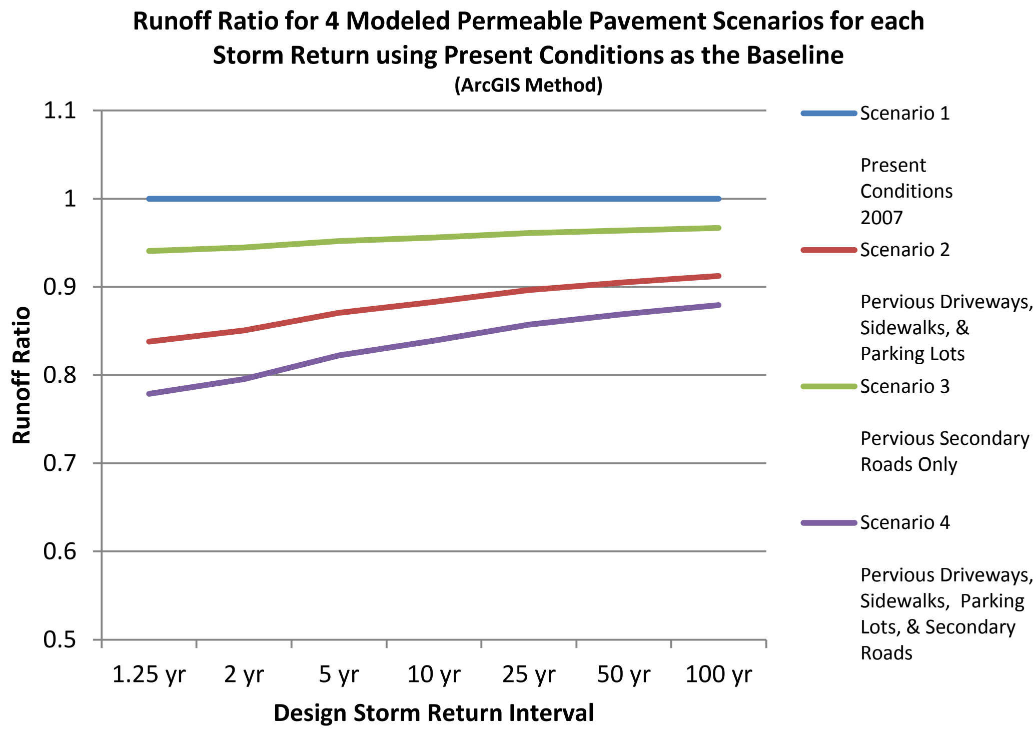


Figure 24: Comparison of Runoff Ratio for 4 Modeled Permeable Pavement Scenarios for 7 Design Storm Return Intervals, using Present Conditions as the Baseline (ArcGIS Method).

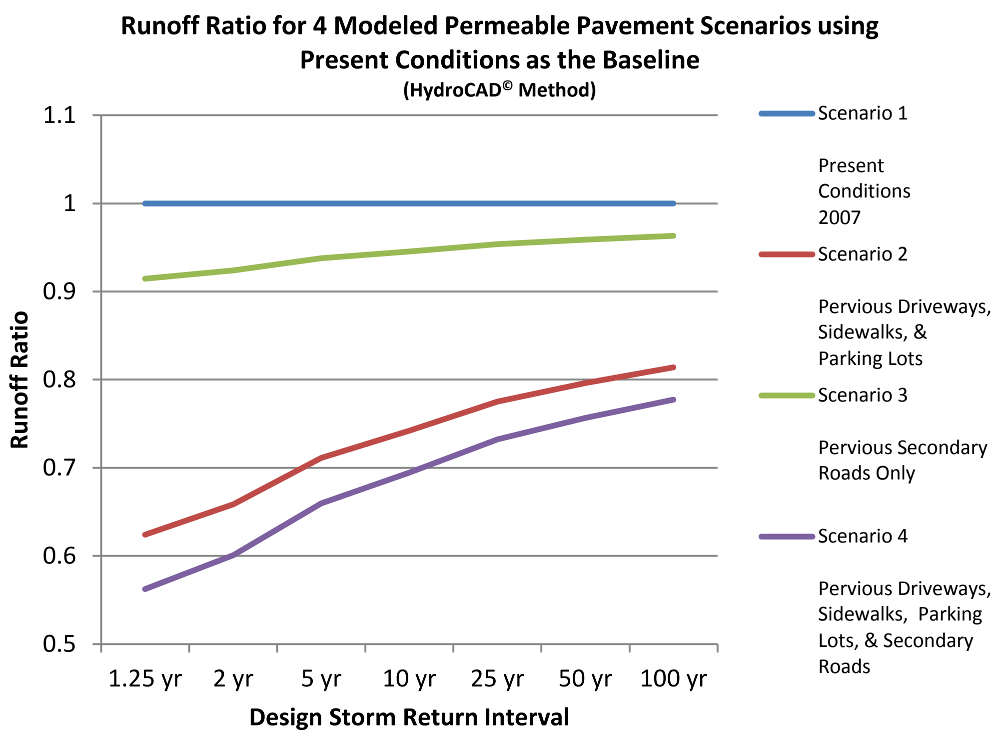


Figure 25: Comparison of Runoff Ratio for 4 Modeled Permeable Pavement Scenarios for 7 Design Storm Return Intervals, using Present Conditions as the Baseline (HydroCAD® Method).

Cost Benefit Analysis

The estimated range of cost per square foot, advantages and disadvantages, and estimated lifespan for each BMP examined, is summarized in

Table 20. The overall cost per square foot of land within Wilmore Sub-basin is presented in Table 21. The retrieved tax values of parcels that were used to determine the cost of land, is summarized in Appendix 3. The estimated construction and maintenance cost results for porous asphalt (PA), permeable concrete (PC), and permeable interlocking concrete pavers (PICP) are depicted in Table 22. The wet and dry pond, bioretention area, and infiltration basin sizing calculations, estimated total construction costs, land costs, and operating and maintenance costs results are presented in

Table **23** and Table 24.

The annual maintenance costs (AMC) were determined according to the reported percentage of construction costs or costs/acre from the U.S. EPA fact sheets for each BMP (US EPA, 1999); (US EPA, 2005). Wet and dry ponds were reported to have an annual maintenance cost of 3-5% of total construction costs. Bioretention areas have an assumed annual maintenance cost of 5-7% according to the U.S. EPA's 1999 preliminary study on "Cost and Benefits of Storm Water BMPs." Infiltration trenches have a reported maintenance cost of 5-20% of total construction costs (US EPA, 2005). For the purposes of this study, the highest reported percentage was used to calculate the AMC values for wet and dry ponds, bioretention area, and infiltration basin. This is to simplify the reporting of AMC and overall costs to make it clear what the highest expected costs might be for each BMP type. Each pervious pavement's AMC values were calculated using the reported maintenance values within the 1999 EPA fact sheet on Porous Pavements, ≈ $200/acre. The $200/acre was adjusted for inflation from 1999 to 2013 to a value of $278.71/acre. The total maintenance costs (MC_{20YR}) for all BMPs were calculated by multiplying AMC results times 20 years, the general lifespan of a stormwater BMP.

The average construction and maintenance costs for PA, PC, and PICP, shown in Table 22, are similar, and range from $6.42/Ft^2$ to $8.44/Ft^2$. The median cost values for PA and PC are those referenced by Montalto, et al, 2007. Unit area costs for PICP were derived from a 2009 report titled "Doing is Believing: PICP at Ft. Stewart, Georgia" within the Interlocking Pavement Concrete Pavement

Magazine. The referenced values for PA, PC, and PICP were adjusted for inflation for the year 2013 to ensure consistency. The estimated cost of the application of PC for Scenario 4, where driveways, sidewalks, parking lots, and secondary roads are considered pervious for Wilmore Walk Sub-basin is $2.75 million less than PA for the same scenario (Table 22). While PA, PC, and PICP are similar in costs, it is important to note that when installed over a large area of 10 acres or more, the difference of two dollars per square foot can have a large impact on the overall cost

The overall cost for wet retention and dry detention ponds are determined by adding the following items together; land costs ($LC_{overall}$) + total construction costs (TC_X) + maintenance costs for 20 years (MC_{20yr}). The calculated construction costs for both ponds are similar due to the same calculations being used to size the BMPs for the designated design storms.

Table 23 however shows that *overall* costs for a detention pond for a 25 Year, 6 Hour design storm is approximately $100,000 more than a retention pond of the same size. This is in part attributed to a higher calculated O and M budget for detention ponds compared to retention ponds. Meanwhile, in a side by side comparison for a 4.80 acre area, retention and detention ponds total construction costs (TC) are approximately $580,000 compared to $1,340,000 for PC ($6.42/Ft^2 x 4.80acres x $43,560Ft^2), which means that both pond types construction costs are approximately one half of PC's constructions costs. The land costs (LC) however for both pond types designed to handle a 25 Year, 6 Hour design storm (4.80 acre surface area with 5' depth), account for 89% of the total overall costs. Table 21 shows that the overall estimated cost per acre in the Wilmore Sub-basin is $2,151,225. The overall costs for a 4.80 acre site for the retention/detention ponds equals approximately $11.5 million, whereas the overall costs of an equivalent PC area would equal approximately $1,370,000 (TC = $1,340,000 for 4.80 acres, MC_{20YR} = $26,756). Retention/detention ponds in this scenario cost approximately 89% more than the equivalent area dedicated to PC. Thus the most cost effective BMP to meet the water volume requirements required in the Charlotte-Mecklenburg Stormwater BMP Design Manual according to the findings of this study is permeable concrete.

The bioretention area and infiltration basin data shown in Table 24 was calculated to determine the cost of each BMP on a comparable scale to a small pervious pavement structure for a drainage area of 5 acres or less. According to the design standards summarized in Table 25 referenced from the Charlotte-Mecklenburg Stormwater BMP Design Manual, an infiltration basin or bioretention area have medium to high suitability for small rain events that meet the WQ_V requirements for a 1 inch, 6 hour storm or the Channel Protection Volume (CP_v) of a 1 year, 24 hour storm. For larger events, the infiltration basin or bioretention area will reach its design capacity quickly, and stormwater design measures must be taken to re-route stormwater to conventional storm drain systems. The calculated surface area, summarized in Table 24, for the infiltration basin at 2,741 ft^2 is nearly one third the size of the calculated bioretention area of 9,894 ft^2 for the same design storm (1 inch). The overall cost however is higher for the infiltration basin at \$106.98/ft^2, compared to \$63.56/ft^2 for the bioretention area. When compared to infiltration basins or bioretention areas, a PC structure of comparable sizes to each BMP would cost approximately \$17,600 and \$63,600, respectively. Overall PC costs for comparable structures to an infiltration trench and bioretention area would be 6% at of the overall costs of the infiltration trench (\$293,000), and 10% of the overall costs of bioretention areas. This significant difference in cost percentages between PC and bioretention areas/infiltration trenches, are due in large part to a higher maintenance cost as well as the additional costs to purchase the land necessary to accommodate bioretention areas and infiltration trenches.

The suitability and pollutant removal capabilities for each of the four BMPs compared in this study are summarized in Table 25 and Table 26 (Charlotte-Mecklenburg BMP Manual, 2010). According to details listed in Table 23 for retention ponds, they indicate a “High” suitability to handle each of the four design storms (1-in, 6-hr, 1-yr, 24-hr, 10-yr, 6-hr, 24-yr, 6-hr). Detention ponds on the other hand are applicable to most storms for water quantity purposes however, they are not the best choice for water quality scenarios as they only remove 30% TSS and 30% TP from storm water compared to all three of the other BMPs which list 85% TSS, 70% TP removal (as shown in Table 26). Bioretention areas and infiltration basin/trenches have a “Medium-High” capability to handle 1 inch and 1 year storm events, and are not intended for larger events such as the 10 and 25 year events. According to the U.S. EPA fact sheets on PA, PC, and PICP (2012), the structure must be able to reduce total suspended solids (TSS) by 80% for it to receive recognition and tax credits. The U.S. EPA fact sheet however did not state that pervious pavements are required to be designed to reduce TP levels as all other BMPs listed in Table 26 are.

The most effective BMPs for pollutant removal within this analysis are retention ponds and bioretention areas. According to the calculated cost values for the WQ_v of a 1” storm displayed in Table 23 and Table 24, bioretention areas cost \$14,271/acre whereas retention ponds cost approximately \$886/acre (with respect to watershed basin surface area). If the size of the watershed permits (at least 10 acres), the most cost effective BMP to meet typical water quality requirements required by Charlotte-Mecklenburg for both TSS and TP levels are retention ponds. However, if the watershed is limited to 5 acres or less, then bioretention areas are the most cost-effective option for water quality control.

Table 20: Summary and cost benefit analysis of various studies' results on performance of best management practices; porous asphalt, permeable concrete, permeable interlocking concrete pavement (PICP), retention pond, detention pond, bioretention, swale, and infiltration trench.

Best Management Practice	Cost per ft^2	Pros	Cons	Lifespan
Porous Asphalt (Ferguson, 2005; Grey, et al. 2013; U.S. EPA, 1999; U.S. EPA, 2012)	\$2.50-\$20	- On site treatment of stormwater runoff & retention - Uses less land & resources as conventional asphalt (CA) or other BMPs - Better surface traction for vehicles than CA 'Does not need specialized equipment for install - Nearly double the lifespan than CA - Fewer cracks and potholes than CA - Needs far less de-icing material than CA	- Can melt in high temperatures and lose its porosity - Recommended for low volume and low speed areas - Must be maintained regularly to retain surface porosity - Less strength than CA - Cannot drive on surface within 24 to 48 hours after install - Cannot use sand for snow/ice conditions - Not appropriate for stormwater hotspots (hazardous waste)	Up to 30 years for a parking lot
Porous Concrete (Green Streets & Green Alleys , 2009; Ferguson, 2005; Grey, et al. 2013; U.S. EPA, 1999; U.S. EPA, 2012)	\$2 - \$20	- On site treatment of stormwater runoff & retention - Uses less land & resources as CA or other BMPs - Better surface traction for vehicles than CA - Needs far less de-icing material than CA - Reduces Heat Island Effect due to lighter colors - Provides ground water recharge	- Must be maintained regularly to retain surface porosity - Cannot use sand for snow/ice conditions - Not appropriate for stormwater hotspots (hazardous waste) - Needs to cure for at least 7 days after installation	20-40 Years
Permeable Interlocking Concrete Pavement (Green Streets & Green Alleys , 2009; Ferguson, 2005; Grey, et al. 2013; U.S. EPA, 1999; U.S. EPA, 2012)	\$4 - \$20	- On site treatment of stormwater runoff & retention - Uses less land & resources as CA or other BMPs - Better surface traction for vehicles than CA - Needs far less de-icing material than CA - Reduces Heat Island Effect due to lighter colors - Provides ground water recharge	- Must be maintained regularly to retain surface porosity - Cannot use sand for snow/ice conditions - Not appropriate for stormwater hotspots (hazardous waste) - Some PICP not applicable to walkways due to gaps	45 Years (ICPM, 2009)

Wet Retention Pond (Brown & Schueler, 1997; U.S. EPA, 2012)	$2.77-$3.42 (Estimated for 2013 using calculations from Brown & Schueler, 1997)	- Pollutant removal done by allowing settling and biological uptake of nutrients - Can be used to take runoff from stormwater hotspots if enough separation from water table - Perceived value of homes increase 15 - 25%	- Limited ability to be used in urban settings - Known to increase temperatures of stormwater - Must receive a large area in order to maintain pond - Needs to treated and maintained to ensure integrity	20+ Years
Dry Detention Pond (Brown & Schueler, 1997; U.S. EPA, 2012)	$3.01-$3.58 (Estimated for 2013 using calculations from Brown & Schueler, 1997)	- Is designed for flood control by reducing peak flow - Can be applied in all regions of the US - Can be used to store and treat spring snowmelt - Helps reduce peak flows during storm events	- Can detract perceived home values between 3 - 10% - Requires a large area to build to treat runoff volume in addition to main site - Improper maintenance of stagnant water can cause excessive populations of mosquitos	20+ Years
Bioretention (Brown & Schueler, 1997); Grey, et al., 2013); Perot, et al., 2005; U.S. EPA, 2012)	$1-$28	- On site treatment - Applicable in nearly any urban area - Can be used for post construction retrofit - Reduces stormwater runoff temperatures for sensitive streams - Can be used for any soil type - Aids in maintaining pre-development conditions	- Can only apply to drainage areas with 5 acres or less - Must have shallow slopes to allow water to drain - Requires landscape maintenance - Is not used for controlling runoff	25 Years (Perot, et al., 2005)
Infiltration Trench/Basin (Brown & Schueler, August 1997; Grey, et al. 2013; U.S. EPA, 2012)	$2.80-$63	- Can be applied to Ultra-Urban areas - Provides ground water recharge - Removes pollutants	- Must be placed on a relatively flat slope - Must be at least 2 to 5 feet above groundwater - Underlying subsoil must be permeable (with infiltration rate between 0.5 and 3 inches/hr) - Cannot be used everywhere (e.g. areas with limestone) - Maintenance is required	2 Years **More if properly maintained (Idaho Department of Environmental Equality, 2005)

Table 21: Summary of cost per acre and per square foot for Wilmore Sub-basin in Charlotte, NC using 2011 Tax Values.

Cost per acre for Wilmore Sub-basin per 2011 Tax Values

	Southend	**Wilmore**	**Total Cost per/Acre**
Commercial	$ 1,790,720	$ 544,243	$ 1,758,726
Residential	$ 13,164,747	$ 980,994	$ 3,664,769
Other	$ 3,783,327	$ 1,077,623	$ 1,502,149
Vacant	$ 1,329,287	$ 316,751	$ 891,098

Cost/acre for ***vacant lot***	**$ 891,098**
Cost/acre for ***total watershed***	**$ 2,151,225**

Cost per ft^2 for Wilmore Sub-basin per 2011 Tax Values

	Southend	Wilmore	Total Cost per/Acre
Commercial	$ 67	$ 12	$ 65
Residential	$ 302	$ 23	$ 84
Other	$ 87	$ 25	$ 34
Vacant	$ 31	$ 8	$ 21
		Cost/ ft^2 for ***vacant lot***	**$ 21**
		Cost/ft^2 for ***total watershed***	**$ 49**

Table 22: Calculated and applied values for Wilmore Sub-basin (88.01 Acres) to determine an estimated cost for Porous Asphalt, Permeable Concrete, and PICP depending on the three interchangeable scenarios mentioned in the SCS TR-55 Runoff Section of this paper (Scenario 2 (Driveways, sidewalks, and parking lots are pervious), Scenario 3 (Secondary Roads are pervious), and Scenario 4 (Driveways, sidewalks, parking lots and secondary roads are pervious) using compiled CN data from

Table **17** and cost data from Table 21.

Calculated values for Wilmore Sub-basin (88.01 Acres) to determine an estimated cost for Porous Asphalt, Permeable Concrete, and PICP if application was applied to watershed.					
		Scenario 2 Pervious Driveways, Sidewalks, & Parking Lots	**Scenario 3** Pervious Secondary Roads Only	**Scenario 4** Pervious Driveways, Sidewalks, Parking Lots, & Secondary Roads	**Dimensions**
	Area =	23.48	7.79	31.26	**Acres**
		Porous Asphalt			
(Cost with inflation rate = 2013)	**C_{PA} =**	8.44	8.44	8.44	**Cost/Ft^2**
	TC_{PA} =	8,632,337.47	2,863,965.46	11,492,626.46	**$**
($278.71 per acre/yr)	**AMC_{PA} =**	6,544.11	2,171.15	8,712.47	**$ (2013)**
	MC_{20YR} =	130,882.22	43,423.02	174,249.49	**$**
	Overall Cost =	8,763,219.69	2,907,388.47	11,666,875.96	**$**
		Permeable Concrete			
(Cost with inflation rate = 2013)	**C_{PC} =**	6.42	6.42	6.42	**Cost/Ft^2**
	TC_{PC} =	6,566,304.10	2,178,514.01	8,742,021.55	**$**
($278.71 per acre/yr)	**AMC_{PC} =**	6,544.11	2,171.15	8,712.47	**$ (2013)**
	MC_{20YR} =	130,882.22	43,423.02	174,249.49	**$**
	Overall Cost =	6,697,186.31	2,221,937.03	8,916,271.04	**$**
		PICP			
(Cost with inflation rate = 2013)	**C_{PICP} =**	8.33	8.33	8.33	**Cost/Ft^2**
	TC_{PICP} =	8,519,830.70	2,826,638.89	11,342,841.05	**$**
($278.71 per acre/yr)	**AMC_{PICP} =**	6,544.11	2,171.15	8,712.47	**$ (2013)**
	MC_{20YR} =	130,882.22	43,423.02	174,249.49	**$**
	Overall Cost =	8,650,712.92	2,870,061.91	11,517,090.54	**$**
C = Cost/Ft2 (2013 rate), TC = Total Construction Costs (TC 2013 = C x Area x 43,560ft), AMC = Annual Maintenance Costs. (Montalto, et al., 2007); (US EPA, 1999)					

Table 23: Calculated Values and predicted costs for Wet & Dry Pond Calculations for Wilmore Sub-basin in Charlotte, NC according to the design standards in the Charlotte-Mecklenburg BMP Design Manual for 1 inch storm, 1 year-24 hour storm, 10 year-6 hour storm, and 25 year-6 hour storm.

Calculated and Applied Watershed Values for Wilmore Sub-basin (88.01 Acres) to determine an estimated cost for Wet and Dry Ponds depending on the required design storms.						
		1 inch storm (1 in)	**1 Year, 24 Hour** (2.58 in)	**10 Year, 6 Hour** (3.72 in)	**25 Year, 6 Hour** (4.38 in)	**Dimensions**
	WQ_v =	3.86	3.86	3.86	3.86	**Acre-Ft**
	WQ_v =	101,494.80	168,297.56	168,297.56	168,297.56	**Ft^3**
	Q =	0.32	1.60	2.65	3.27	**Inches**
	CP_v =	2.33	11.71	19.42	24.01	**Acre-Ft**
	CP_v =	101,494.80	510,087.60	845,935.20	1,045,875.60	**Ft^3**
(with avg depth 5')	**Surface Area**	0.77	2.34	3.88	4.80	**Acres**
($49/ft2 = Wilmore area lot)	**$LC_{overall}$ =**	1,647,787.68	5,000,083.35	8,290,329.33	10,250,306.92	**$**
Wet Retention Ponds						
		1 inch storm	**1 Year, 24 Hour**	**10 Year, 6 Hour**	**25 Year, 6 Hour**	**Dimensions**
	TC_{wet} =	78,089.11	243,745.81	348,193.17	404,371.94	**$ (1997)**
(With Inflation)	**TC_{wet} =**	111,715.46	348,706.45	498,130.43	578,500.64	**$ (2013)**
(Cost With Inflation)	**C_{wet} =**	3.32	3.42	2.94	2.77	**$Cost/Ft^2$**
(w/inflation at 5% of TC per year)	**AMC_{wet} =**	5,585.77	17,435.32	24,906.52	28,925.03	**$ (2013)**
	MC_{20YR} =	111,715.46	348,706.45	498,130.43	578,500.64	**$**
	Overall Cost =	1,871,218.61	5,697,496.25	9,286,590.19	11,407,308.19	**$**
Dry Detention Ponds						
		1 inch storm	**1 Year, 24 Hour**	**10 Year, 6 Hour**	**25 Year, 6 Hour**	**Dimensions**
	TC_{dry} =	74,786.79	255,115.96	374,717.35	440,283.53	**$ (1997)**
(With Inflation)	**TC_{dry} =**	106,991.12	364,972.77	536,076.33	629,876.29	**$ (2013)**
(Cost With Inflation)	**C_{dry} =**	3.18	3.58	3.17	3.01	**$Cost/Ft^2$**

(w/inflation at 5% of TC per year)	AMC_{dry} =	5,349.56	18,248.64	26,803.82	31,493.81	$ (2013)
	MC_{20YR} =	106,991.12	364,972.77	536,076.33	629,876.29	$
	Overall Cost =	1,861,769.91	5,730,028.88	9,362,481.98	11,510,059.49	$
WQ_v = Water Quality Volume, Q = Storm Runoff, CP_v = Channel Protection Volume, TC = Total Construction Costs (TC 2013 = TC 1997/0.699 inflation b/w 1997 & 2013), C = TC/Ft^3, AMC = Annual Maintenance Costs, MC_{20YR} = 2O year maintenance costs, LC = Land Cost. (Brown & Schueler, August 1997);(US EPA, 2005)						

Table 24: Calculated Values and predicted costs for Bioretention and Infiltration Basin calculations for Wilmore Sub-basin in Charlotte, NC according to the design standards in the Charlotte-Mecklenburg BMP Design Manual for 1 inch storm, 1 year-24 hour storm, 10 year-6 hour storm, and 25 year-6 hour storm.

Calculated and Applied Watershed Values for Wilmore Walk Subdivision (3.53 Acres) to determine an estimated cost for a bioretention area or infiltration trench depending on the required design storms.						
		1 inch storm (1 in)	**1 Year, 24 Hour (2.58 in)**	**10 Year, 6 Hour (3.72 in)**	**25 Year, 6 Hour (4.38 in)**	**Dimensions**
	WQ_v =	0.18	0.18	---	---	**Acre-Ft**
	WQ_v =	7,932.28	7,932.28	---	---	**Ft^3**
	Q =	0.16	1.20	---	---	**Inches**
	CP_v =	0.05	0.35	---	---	**Acre-Ft**
	CP_v =	2,037.49	15,375.47	---	---	**Ft^3**
		Bioretention Areas				
		1 inch storm	**1 Year, 24 Hour**	**10 Year, 6 Hour**	**25 Year, 6 Hour**	**Dimensions**
(**Equation 15**)	TC_{bio} =	50,337.50	96,991.91	---	---	**$ (1997)**
(With Inflation)	TC_{bio} =	72,013.60	138,758.10	---	---	**$ (2013)**
(Cost With Inflation)	C_{bio} =	7.28	7.30	---	---	**Cost/Ft^3**
(w/inflation at 7% of TC per year)	AMC_{bio} =	3,600.68	6,937.90	---	---	**$ (2013)**
	MC_{20YR} =	72,013.60	138,758.10	---	---	**$**
	Area =	**9,893.67**	19,020.35	---	---	**Ft^2**
($49/ft2 = Wilmore area lot)	$LC_{overall}$ =	484,789.81	931,997.15	---	---	**$**
	Overall Cost =	628,817.00	1,209,513.34	---	---	**$**
		Infiltration Trench/Basin				
		1 inch storm	**1 Year, 24 Hour**	**10 Year, 6 Hour**	**25 Year, 6 Hour**	**Dimensions**
(**Equation 16**)	TC_{basin} =	22,210.37	43,051.33	---	---	**$ (1997)**
(With Inflation)	TC_{basin} =	31,774.50	61,589.88	---	---	**$ (2013)**

(Cost With Inflation)	**C_{basin} =**	2.80	2.80	---	---	**Cost/Ft^3**
(w/inflation at 20% of TC per year)	**AMC_{basin} =**	6,354.90	12,317.98	---	---	**$ (2013)**
	MC_{20YR} =	127,097.98	246,359.54	---	---	**$**
	Area =	**2,740.92**	5,269.35	---	---	**Ft^2**
($49/ft2 = Wilmore area lot)	**$LC_{overall}$ =**	134,305.07	258,198.15	---	---	**$**
	Overall Cost =	293,177.55	566,147.57	---	---	**$**

WQ_v = Water Quality Volume, Q = Storm Runoff, CP_v = Channel Protection Volume, TC = Total Construction Costs (TC 2013 = TC 1997/0.699 inflation b/w 1997 & 2013), C = TC/Ft^3, AMC = Annual Maintenance Costs, LC = Land Cost.
[--- = BMP not most appropriate use for particular design storm] (Brown & Schueler, 1997; U.S. EPA, 1999; US EPA, 2012)

Table 25: Summary of Stormwater Management BMP Suitability Guidelines from the Charlotte-Mecklenburg Stormwater BMP Design Manuals for Retention and Detention ponds, Bioretention areas, and Infiltration Trench.

Suitability Guidelines from Charlotte-Mecklenburg BMP Design Manual

	Storm Return Intervals			
BMP	1 inch, 6-hr	1-yr, 24-hr	10-yr, 6-hr	25-yr, 6-hr
Retention Pond	H	H	H	H
Detention Pond	M	H	H	H
Bioretention area	H	M	L	L
Infiltration Basin	M	M	L	L

(L = Low Suitability, M = Moderate, H = High)

Table 26: Summary of Pollutant Removal Guidelines and Primary Pollutant Removal direct from Charlotte-Mecklenburg BMP Design Manuals for Retention and Detention ponds, Bioretention areas, and Infiltration Trench using Optimal Efficiency Design Standards for each BMP.

Summary of Pollutant Removal Guidelines and Primary Pollutant from Charlotte-Mecklenburg BMP Design Manual

BMP	**Pollutant Removal Rates** (using Optimal efficiency guidelines)	**Primary Pollutant Removal Process**
Retention Pond	85% TSS, 70% TP	Settling
Detention Pond	30% TSS, 30% TP	Settling
Bioretention area	85% TSS, 70% TP	Filtration, Biological
Infiltration Basin	85% TSS, 70% TP	Filtration

Conclusions

Hydrology

The study of the permeable concrete structure at Wilmore Walk has indicated no significant change in the infiltration capacity of the structure itself; however there may be a slight decline in the infiltration performance of the subsoil below the structure. More research would be needed to determine if the infiltration capacity of the soil will decline further over the long term or if it has leveled off.

The estimated porosity (η) of the crushed rock reservoir is 38.5% ± 10.5%. The average measured corrected infiltration rate IR_c at 0.041 inches/hour ± 0.032 inches/hour would take approximately 61 hours to infiltrate a 1" rain event. A crushed rock reservoir averaging 8" thick would accommodate a rainfall event of approximately 3.10" before significant storm drainage overflow would occur.

Water Quality

The treatment of water quality is minimal at this site because it is treating only the precipitation that hits the pavement surface. Further studies could be conducted to study a wider range of compounds including oil and grease, trace metals and bacterial contamination to measure chemical inputs from parked automobiles and other human or animal activities on the pavement surface. In addition there does not appear to be an accumulation of infiltrated nutrients (N or P) within the structure itself.

Green Ampt Model

The application of the Green Ampt model to the Wilmore Walk precipitation and well response data shows that the predicted well responses did emulate actual infiltration data for 7 of 10 events when applying the Sand texture parameters of porosity (ϕ) at 0.34, and wetting front tension (ψ_f) at 3.75. The GA model for most of the events had a faster initial infiltration rate, but leveled off to where it emulated the actual data in time and amount of infiltration. Three of the ten events modeled were found to have the best fit when extending the ψ_f to 8.62, and this is likely attributed to the soil's antecedent moisture levels or of the magnitude of the rain event itself. There is also the possibility that some lateral leakage from the structure might occur under high water level conditions.

The GA model does appear to be useful in predicting the infiltration response to rain events within the PC structure but more research is required to relate ψ_f to antecedent moisture conditions.

Stormwater Modeling: SCS Runoff Curve Number Method with ArcGIS and HydroCAD©

In applying the SCS Runoff Curve Number model application to the Wilmore Walk sub-watershed it was found that the peak flow of a 1.25-year, 24-hour storm is reduced by 55% in Scenario 2, 13% in Scenario 3, and 62% in Scenario 4. The peak flow for a 100-year, 24-hour storm, is reduced by 37%, 8.5% in Scenario 3, and 42% in Scenario 4.In addition to peak flow reductions, under scenarios 2 and 4 the time of the peak flow occurrence for all storm return intervals were delayed by approximately 30 minutes when compared to Scenarios 1 & 3.

As could be expected, Scenario 4 (PC parking lots, driveways, sidewalks, and secondary roads) will have the most impact on the watershed in reducing runoff if all of the surfaces were converted to pervious pavement. In reality however, Scenario 2 (parking lots, driveways, and sidewalks) accounts 75% of the potential surfaces where PC might be installed and are typically privately owned. In order to make PP a viable and cost effective option, tax credits and incentives to private landowners and developers from local and state governments will need to be provided in order to convert currently impervious surfaces to PP. If these surfaces were converted successfully over time, it has the potential to significantly reduce and delay stormwater runoff within the urban watershed. However, it must be realized that neither the ArcGIS and HydroCAD® methods include the existing stormwater infrastructure (i.e. storm drains) and the actual magnitude of the runoff peak flow reduction and the timing of the peak flow from these two simulations would likely differ if it was included. To incorporate stormwater infrastructure, a model such as the USEPA Storm Water Management Model (SWIMM) would need to be applied, but this is beyond the scope of this study.

Cost Benefit Analysis

The most cost effective BMP to meet the water volume requirements required in the Charlotte-Mecklenburg Stormwater BMP Design Manual according to the findings of this study is PC. For a 4.80 acre area, the land costs (LC) for retention/detention ponds for a 25 Year, 6 Hour design storm (5" depth), account for 89% of the total overall costs, which equal ≈$10,250,000. The overall cost of an equivalent area of PC to the retention/detention pond area equals approximately $1,370,000. Permeable Concrete is the most cost effective scenario in this situation due to the total costs and its duality as a BMP and pavement surface, when compared to other BMPs that require significant amounts of dedicated land for their installation.

The most effective BMP for pollutant removal are retention ponds and bioretention areas (Charlotte Stormwater Services, 2008). The calculated cost values of a bioretention area designed to handle the Water Quality Volume (WQ_v) of a 1", 6 hour storm (displayed in

Table **23** and Table 24) is approximately $14,271/acre whereas retention ponds cost approximately $886/acre (with respect to watershed basin surface area). If the size of the watershed permits (at least 10 acres), the most cost effective BMP to meet typical water quality improvements (removal of 85% TSS, and 70% TP) required by Charlotte-Mecklenburg for both TSS and TP levels are retention ponds. However, if the watershed is limited to 5 acres or less, then bioretention areas are the most cost-effective option for water quality control.

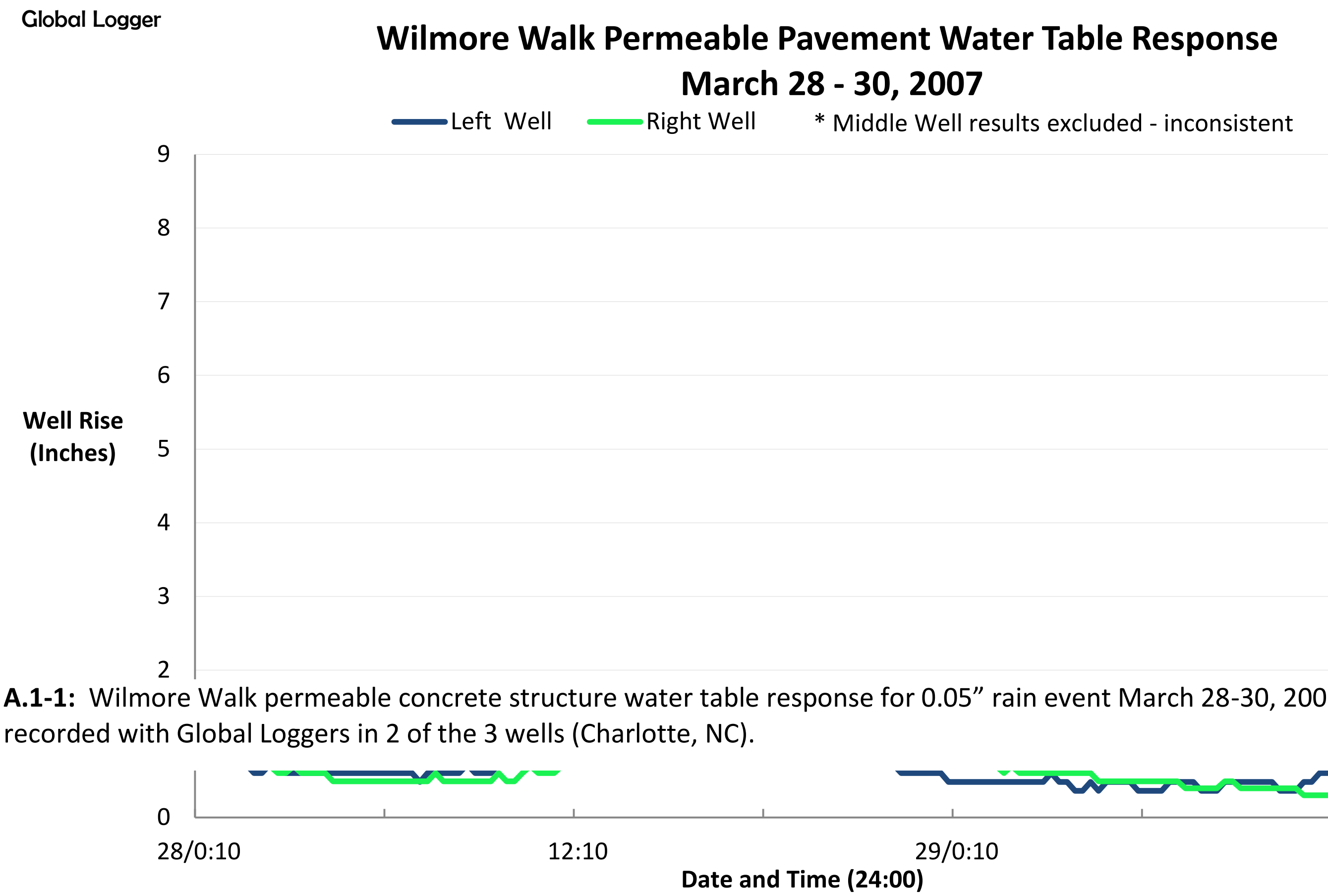
Infiltration Rate of Wilmore Walk in Comparison to Other Studies

Wilmore Walk Permeable Concrete study found the average corrected infiltration rate to be 0.041 inches/hr. According to Table 27 below, the infiltration rates of other studies vary from 0.013 to 0.70 inches/hr for various permeable pavement types over several general soil types. The majority of the studies listed here do not indicate whether or not porosity was accounted for within the reservoir and the infiltration rates listed may not be corrected. Wilmore Walk's infiltration rate results do indicate that it is on the lower end of the infiltration rate spectrum when compared to other studies, but it does indicate a reasonable rate over clay type soils.

Table 27: Infiltration Rate comparisons of Wilmore Walk permeable concrete results compared to multiple other studies.

Study	Year	Location	Pavement Type	Soil Type	Treatment	Porosity	Average IR (in/hr)	St. Dev (in/hr)
Allan & Gray (Wilmore Walk)	2009	Charlotte, NC	Permeable Concrete	Clay	Raked	0.385	0.041	0.32
Tyner, Wright, and Dobbs	2009	Eastern TN	Permeable Concrete	Clay	Control	N/A	0.013	0.012
Tyner, Wright, and Dobbs	2009	Eastern TN	Permeable Concrete	Clay	Borehole	N/A	0.075	N/A
Tyner, Wright, and Dobbs	2009	Eastern TN	Permeable Concrete	Clay	Ripped	N/A	0.16	N/A
Tyner, Wright, and Dobbs	2009	Eastern TN	Permeable Concrete	Clay	Trench	N/A	0.43	N/A
Braga, Andrea M.	2005	Radnor, PA	Multiple Permeable Pavements	Silty Sand	N/A	N/A	0.35	N/A
Ladd, Tyler C.	2004	Radnor, PA	Permeable Concrete	Silty Sand	N/A	N/A	0.10 - 0.30	N/A
Brattebo and Booth	2003	Seattle, WA	Grassy Pavers™	N/A	N/A	N/A	0.70	N/A
Brattebo and Booth	2003	Seattle, WA	Turfstone®	N/A	N/A	N/A	0.05-0.16	N/A

Appendix 1: Individual Storm Event Hydrological and Water Quality Results



A.1-1: Wilmore Walk permeable concrete structure water table response for 0.05" rain event March 28-30, 2007 recorded with Global Loggers in 2 of the 3 wells (Charlotte, NC).

<u>**Rain Event Details for 3/28-30/07**</u>		<u>Global Logger</u>	<u>**Left Well**</u>	<u>**Middle Well**</u>	<u>**Right Well**</u>	<u>**Average**</u>
Precipitation Total (Inches)	0.05	**Total Rise (Inches)**	0.72	---	0.70	0.71
Duration (Hours)	---	**Porosity**	NC	---	NC	NC

(Table heading: <u>**Wilmore Walk Well Rise Results**</u>)

Peak 5 min Intensity (Inches/Hour)	---	**Infiltration Uncorrected (Inches/Hour)**	0.15	---	0.31	0.23
Average Intensity (Inches/Hour)	---	**Infiltration Corrected (Inches/Hour)**	0.02	---	0.03	0.03

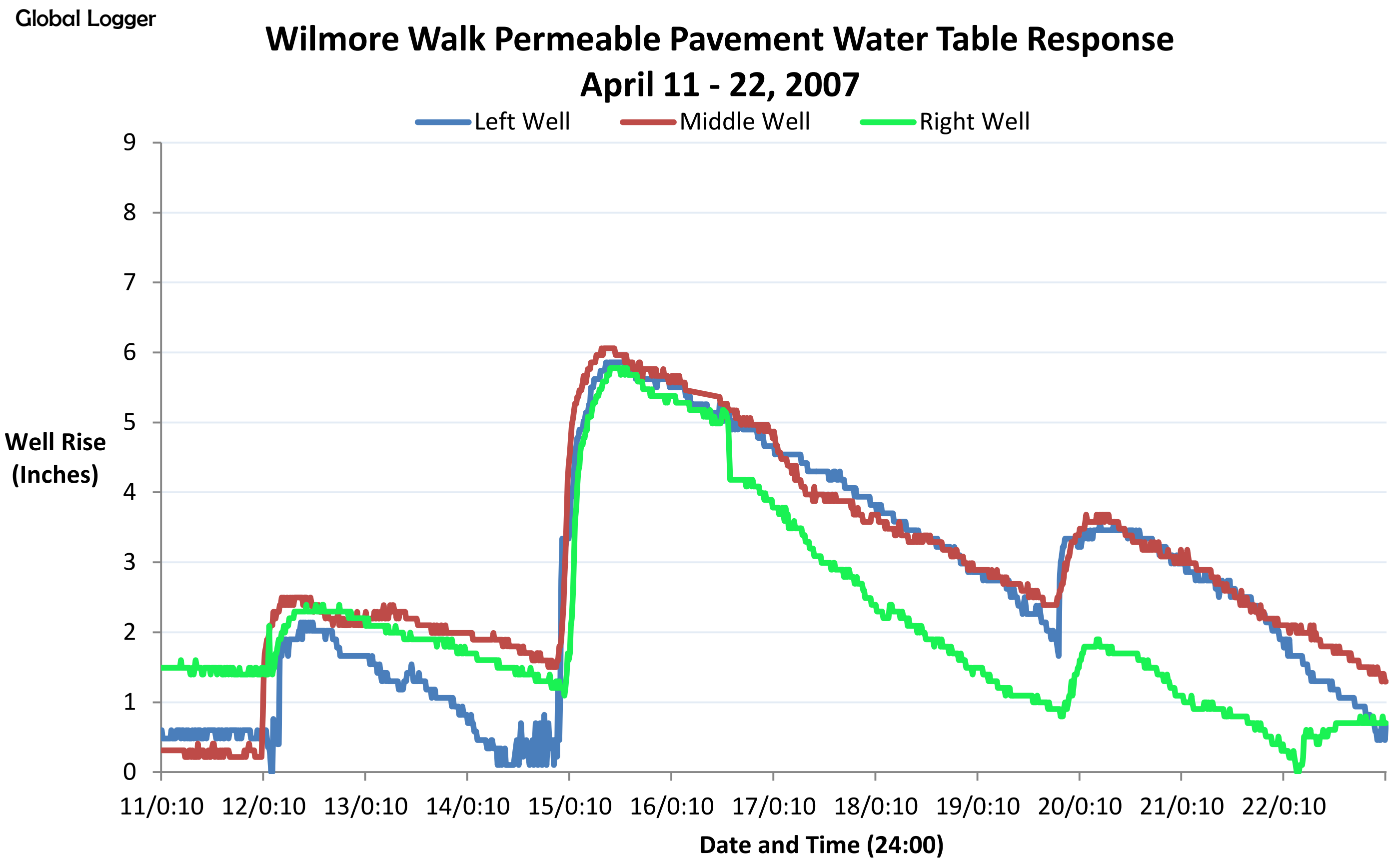
--- = No Data --- = No Data NC = Not Calculated

Wilmore Walk March 28, 2007 Water Quality Results

Sample	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	---	---	---	---	---	---	---	---
Reservoir (Wells)	---	---	---	---	---	---	---	---

--- = No Data

A.1-2: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger), rain event details (Charlotte Douglas Airport), and water quality results for March 28-30, 2007 (Charlotte, NC).



A.1-3: Wilmore Walk permeable concrete structure water table response for 0.91" rain event April 11-22, 2007 recorded with Global Loggers in each of the 3 wells (Charlotte, NC).

Rain Event Details for 4/11/07		Wilmore Walk Well Rise Results				
		Global Logger	Left Well	Middle Well	Right Well	Average
Precipitation Total (Inches)	0.91	Total Rise (Inches)	1.62	2.18	1.19	1.66
Duration (Hours)	---	Porosity	0.56	0.42	0.77	0.58
Peak 5 min Intensity (Inches/Hour)	---	Infiltration Uncorrected (Inches/Hour)	0.12	0.12	0.07	0.10
Average Intensity (Inches/Hour)	---	Infiltration Corrected (Inches/Hour)	0.07	0.05	0.05	0.06

Rain Event Details for 4/14/07		Global Logger	Left Well	Middle Well	Right Well	Average
Precipitation Total (Inches)	1.29	Total Rise (Inches)	3.36	2.96	3.57	3.30
Duration (Hours)	---	Porosity	0.38	0.44	0.36	0.39
Peak 5 min Intensity (Inches/Hour)	---	Infiltration Uncorrected (Inches/Hour)	0.10	0.10	0.11	0.10
Average Intensity (Inches/Hour)	---	Infiltration Corrected (Inches/Hour)	0.04	0.04	0.04	0.04

Rain Event Details for 4/19/07		Global Logger	Left Well	Middle Well	Right Well	Average
Precipitation Total (Inches)	1.29	Total Rise (Inches)	1.70	1.30	1.00	1.33
Duration (Hours)	---	Porosity (Inches/Hour)	0.31	0.41	0.53	0.42
Peak 5 min Intensity (Inches/Hour)	---	Infiltration Uncorrected (Inches/Hour)	0.13	0.12	0.11	0.12
Average Intensity (Inches/Hour)	---	Infiltration Corrected (Inches/Hour)	0.04	0.05	0.06	0.05

--- = No Data

Wilmore Walk April 11, 2007 Water Quality Results

Sample	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	17.0	5.11	0.49	0.48	0.12	1.44	0.03	0.68
Left Well	---	---	---	---	---	---	---	---
Middle Well	159.2	6.83	0.44	0.42	0.16	0.31	<DL	0.17
Right Well	169.0	6.69	0.98	0.98	0.49	<DL	<DL	0.33

--- = No Data

A.1-4: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger), rain event details (Charlotte Douglas Airport), and water quality results for April 11, 14, & 19, 2007.

Rain Event Details for 6/12/07

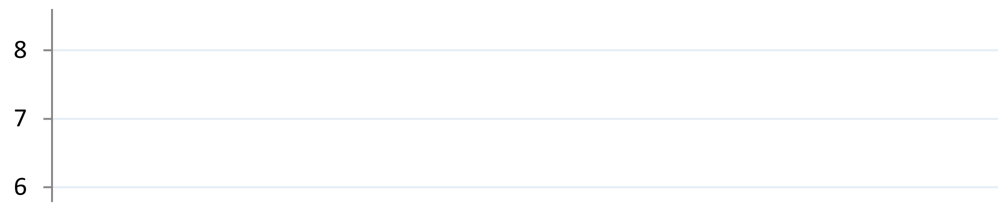
Precipitation Total (Inches)	0.69
Duration (Hours)	---
Peak 5 min Intensity (Inches/Hour)	---
Average Intensity (Inches/Hour)	---

Wilmore Walk Well Rise Results

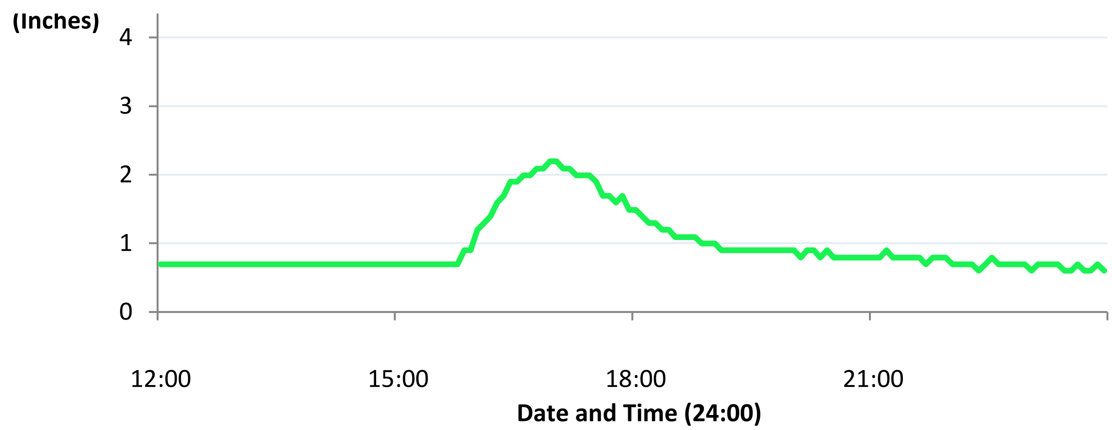
Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	---	---	1.50	1.50
Porosity	---	---	0.46	0.46
Infiltration Uncorrected (Inches/Hour)	---	---	0.32	0.32
Infiltration Corrected (Inches/Hour)	---	---	0.15	0.15

*Left and Middle Well results excluded - inconsistent

--- = No Data



A.1-5: Wilmore Walk permeable concrete structure water table response for 0.69" rain event June 12, 2007 recorded with Global Logger in 1 of 3 wells (Charlotte, NC).



Wilmore Walk June 12, 2007 Water Quality Results

Sample	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	23.8	3.12	0.33	1.58	0.26	0.87	0.05	0.36
Reservoir (Wells)	---	---	---	---	---	---	---	---

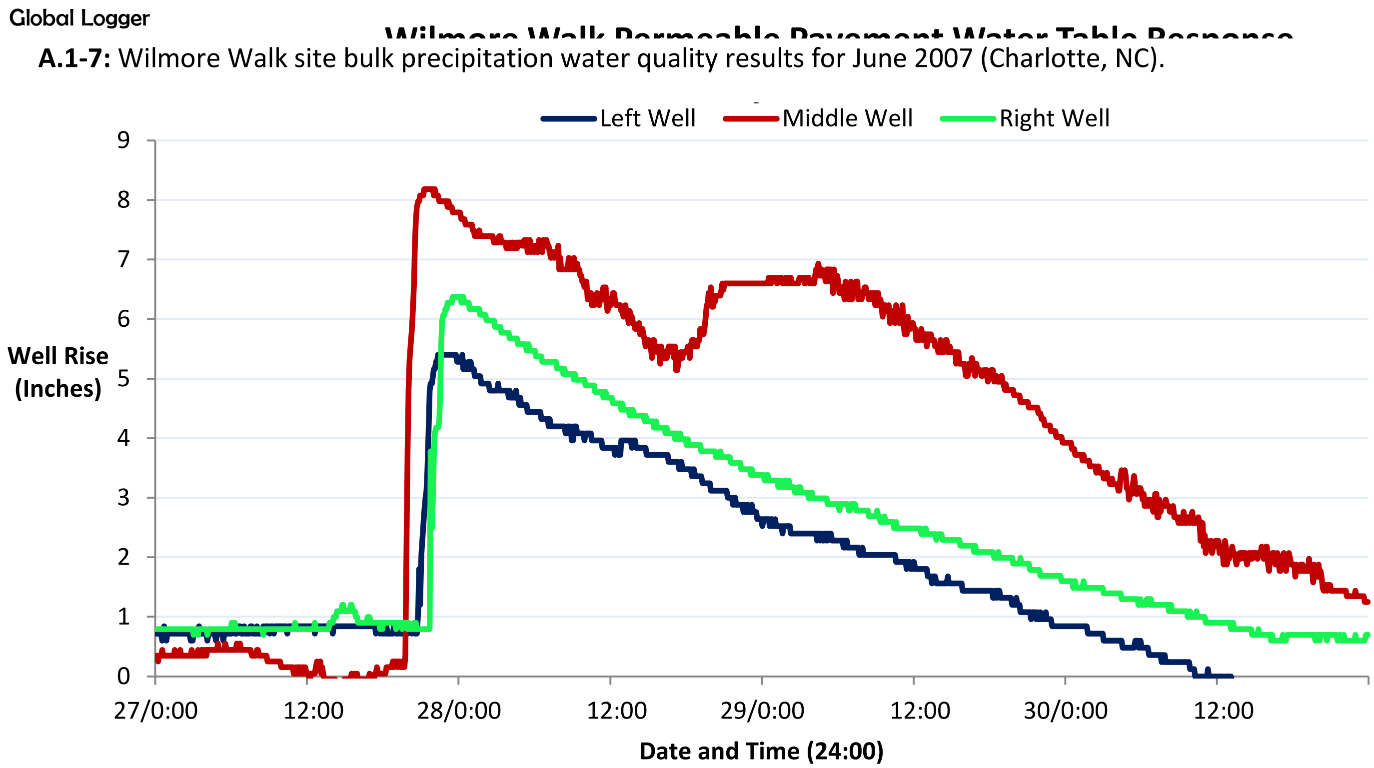
--- = No Data

A.1-6: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger), rain event details (Charlotte Douglas Airport), and water quality results for June 12, 2007.

Wilmore Walk June 2007 Water Quality Results

Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
6/4	Bulk Precipitation	15.7	4.91	---	0.28	---	0.17	---	0.29

A.1-7: Wilmore Walk site bulk precipitation water quality results for June 2007 (Charlotte, NC).



Rain Event Details for 7/27/07		Wilmore Walk Well Rise Results Global Logger	Left Well	Middle Well	Right Well	Average
Precipitation Total (Inches)	1.98	Total Rise (Inches)	4.68	7.84	5.58	6.03
Duration (Hours)	2.20	Porosity	0.42	0.25	0.36	0.34
Peak 5 min Intensity (Inches/Hour)	0.90	Infiltration Uncorrected (Inches/Hour)	0.09	0.19	0.09	0.12
Average Intensity (Inches/Hour)	0.11	Infiltration Corrected (Inches/Hour)	0.04	0.05	0.03	0.04

A.1-8: Wilmore Walk permeable concrete structure water table response for 1.98" rain event July 27, 2007 recorded with Global Loggers in each of the 3 wells (Charlotte, NC).

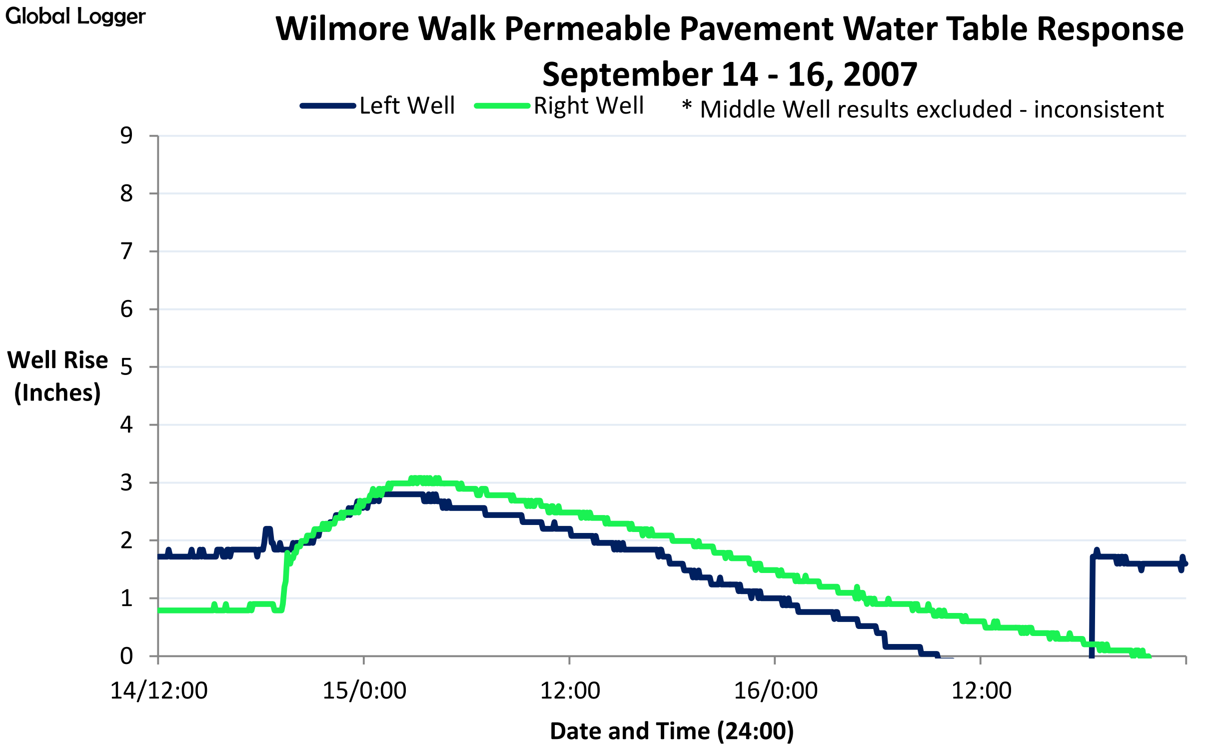
Wilmore Walk July 27, 2007 Water Quality Results

Sample	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	---	---	---	---	---	---	---	---
Reservoir (Wells)	---	---	---	---	---	---	---	---

--- = No Data

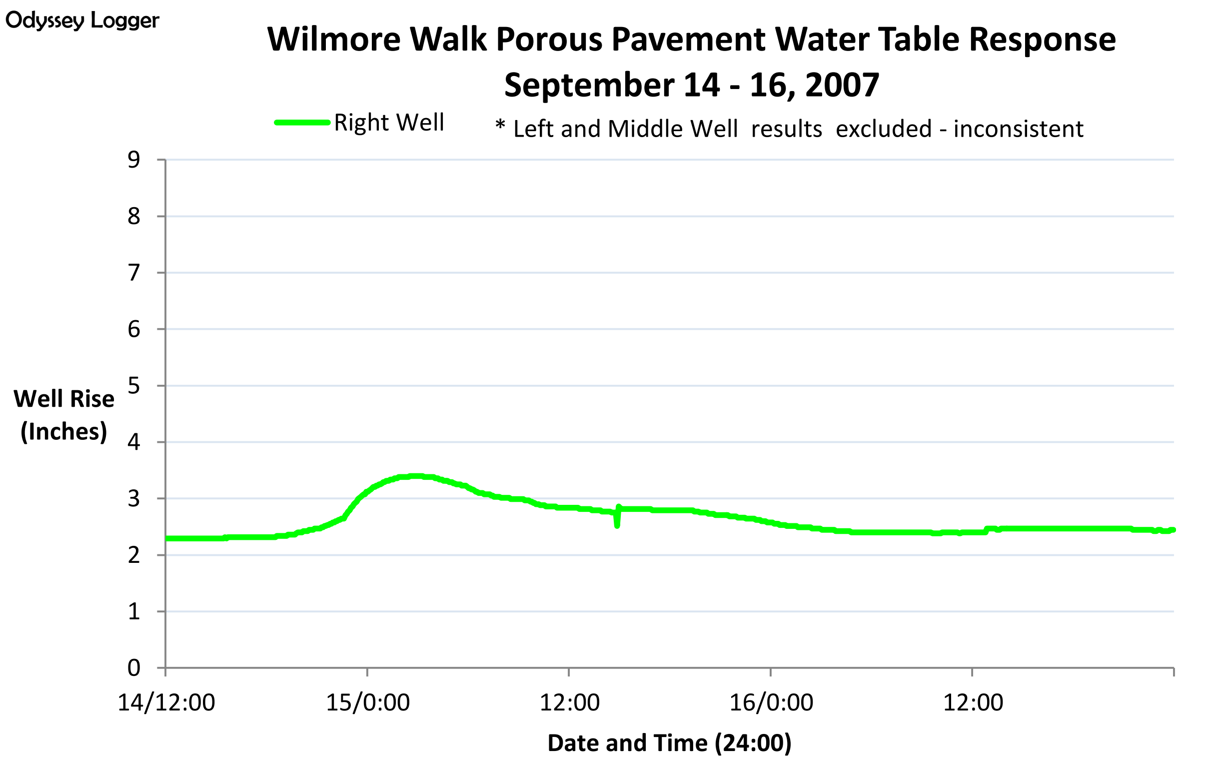
A.1-9: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger), rain event details (Hobo Logger), and water quality results for July 27, 2007.

Global Logger



A.1-10: Wilmore Walk permeable concrete structure water table response for 1.61” rain event Sept. 14-16, 2007 recorded with Global Loggers in 2 of 3 wells (Charlotte, NC).

Odyssey Logger



A.1-11: Wilmore Walk permeable concrete structure water table response for 1.61” rain event Sept. 14-16, 2007 recorded with Odyssey Capacitance Logger in 1 of 3 wells (Charlotte, NC).

Rain Event Details for 9/14/07

Precipitation Total (Inches)	1.61
Duration (Hours)	18.95
Peak 5 min Intensity (Inches/Hour)	0.08
Average Intensity (Inches/Hour)	0.04

Wilmore Walk Well Rise Results

Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	2.80	---	3.08	2.94
Porosity	0.57	---	0.52	0.55
Infiltration Uncorrected (Inches/Hour)	0.07	---	0.08	0.08
Infiltration Corrected (Inches/Hour)	0.04	---	0.04	0.04

Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	---	---	3.40	3.09
Porosity	---	---	0.47	0.52
Infiltration Uncorrected (Inches/Hour)	---	---	0.13	0.09
Infiltration Corrected (Inches/Hour)	---	---	0.06	0.05

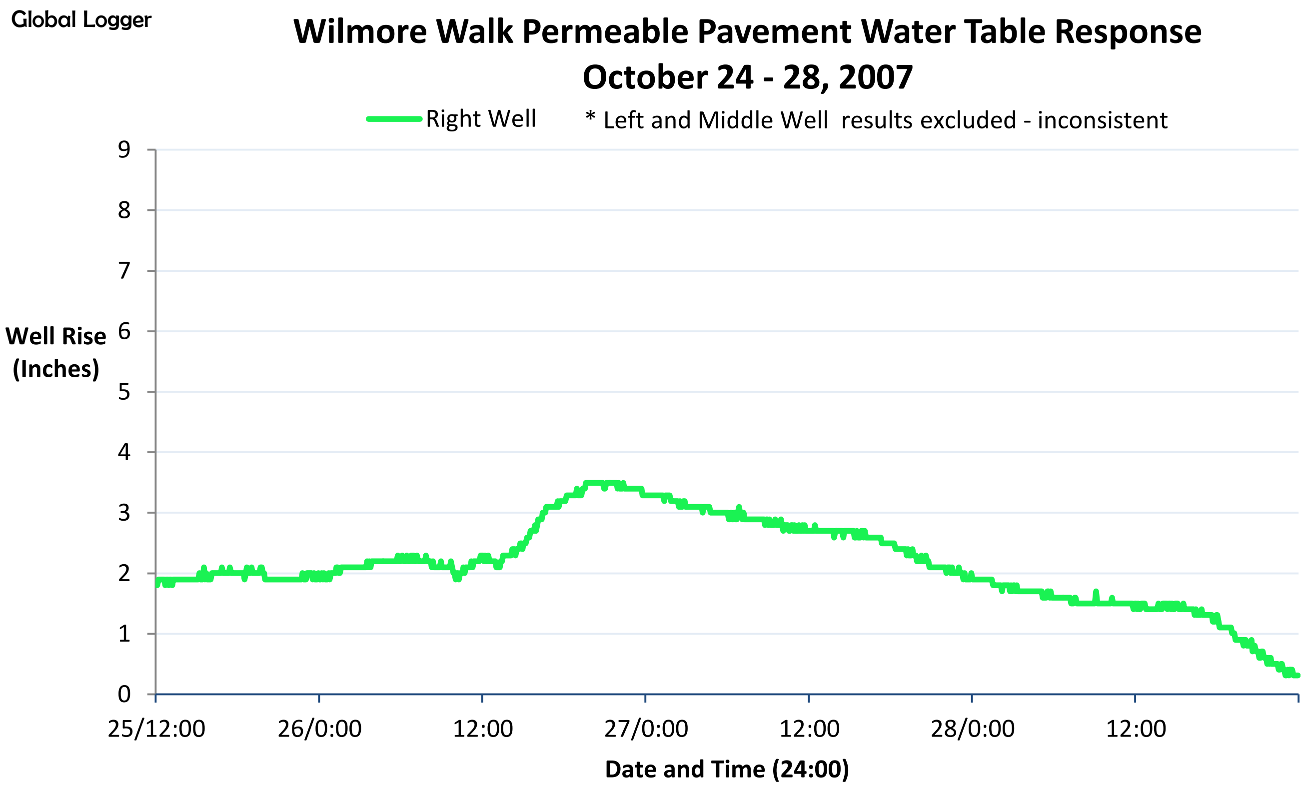
--- = No Data

Wilmore Walk September 14, 2007 Water Quality Results

Sample	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	0.0	5.23	1.14	0.66	0.16	0.23	0.01	0.25
Left Well	---	---	---	---	---	---	---	---
Middle Well	0.4	6.27	1.07	1.15	0.58	0.15	<DL	0.18
Right Well	155.7	6.21	1.80	1.42	0.75	0.20	0.04	0.51

--- = No Data

A.1-12: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger), rain event details (Hobo Logger), and water quality results for September 14, 2007.



A.1-13: Wilmore Walk permeable concrete structure water table response for 1.83" rain event occurring October 24-28, 2007, recorded with a Global Logger in 1 of 3 wells (Charlotte, NC).

Rain Event Details for 10/24-26/07		**Wilmore Walk Well Rise Results**				
		Global Logger	**Left Well**	**Middle Well**	**Right Well**	**Average**
Precipitation Total (Inches)	1.83	**Total Rise** (Inches)	---	---	3.18	3.18
Duration (Hours)	29.97	**Porosity**	---	---	0.58	0.58
Peak 5 min Intensity (Inches/Hour)	0.11	**Infiltration Uncorrected** (Inches/Hour)	---	---	0.06	0.06
Average Intensity (Inches/Hour)	0.02	**Infiltration Corrected** (Inches/Hour)	---	---	0.04	0.04

--- = No Data

Wilmore Walk October 26, 2007 Water Quality Results

Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	8.3	5.52	0.21	0.41	0.13	0.21	0.00	0.15
Left Well	---	---	---	---	---	---	---	---
Middle Well	218	6.64	0.77	1.05	0.64	0.00	<DL	
Right Well	131.1	6.25	1.87	1.95	1.11	0.06	0.16	

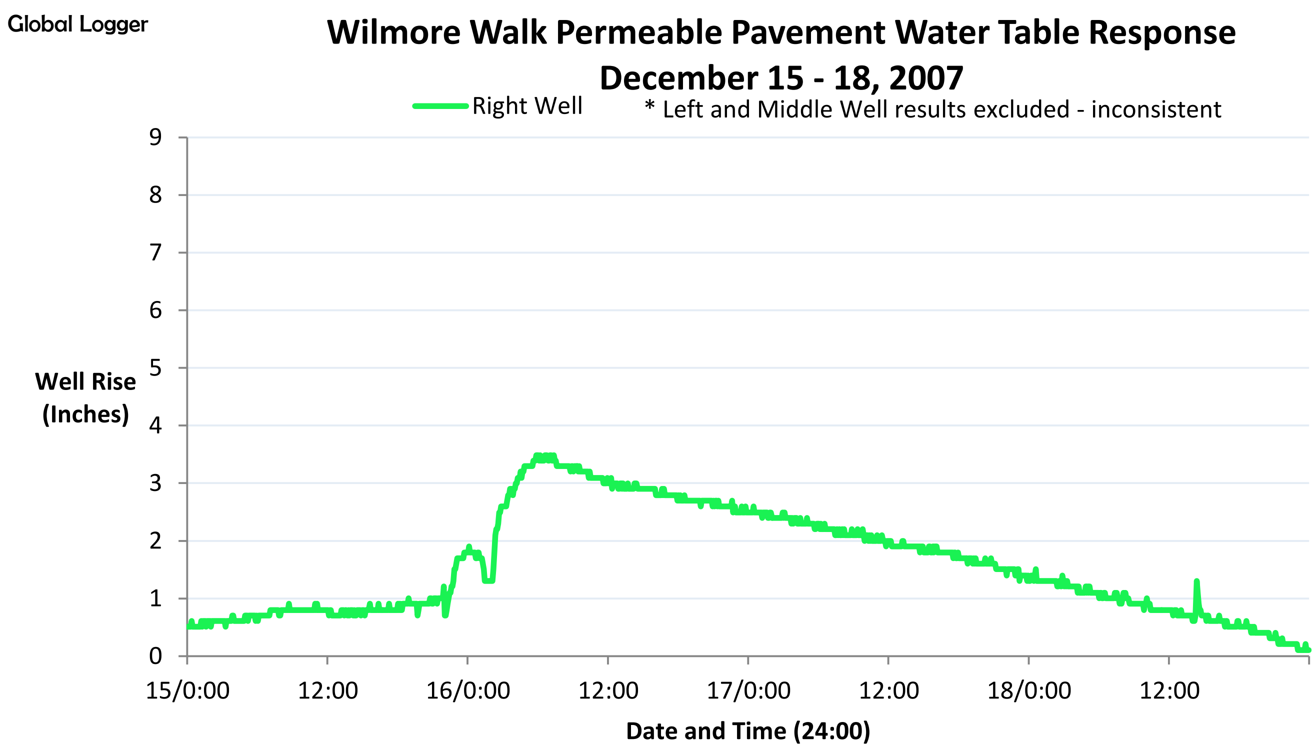
--- = No Data

A.1-14: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger), rain event details (Hobo Logger), and water quality results for October 26, 2007.

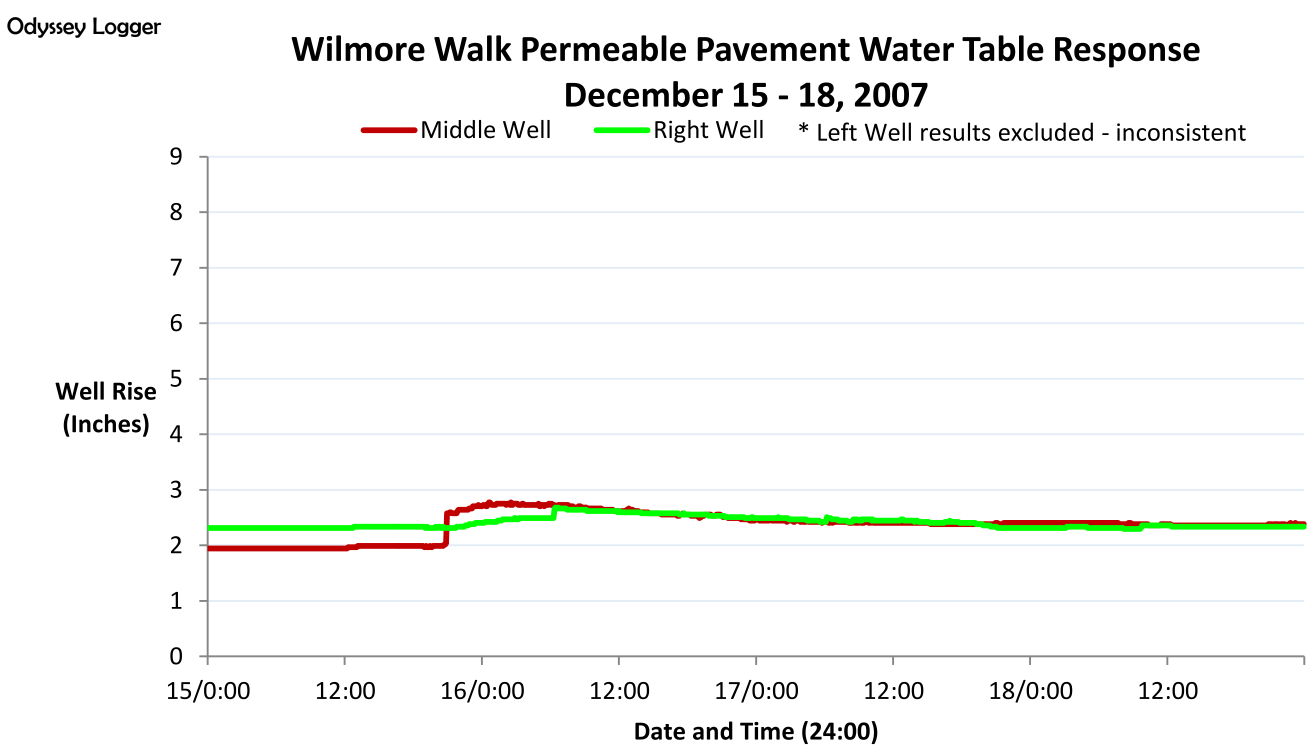
Wilmore Walk October 2007 Water Quality Results

Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
10/21	Bulk Precipitation	15.6	5.62	1.55	0.53	0.15	0.08	0.00	1.62
10/24	Bulk Precipitation	11.3	4.98	16.47	1.08	1.36	0.15	0.21	

A.1-15: Wilmore Walk site bulk precipitation water quality results for October 2007 (Charlotte, NC).



A.1-16: Wilmore Walk permeable concrete structure water table response for 1.12” rain event occurring December 15-18, 2007, recorded with a Global Logger in 1 of 3 wells (Charlotte, NC).



A.1-17: Wilmore Walk permeable concrete structure water table response for 1.12” rain event occurring December 15-18, 2007, recorded with a Odyssey Capacitance Logger in 2 of 3 wells (Charlotte, NC).

Rain Event Details for 12/16/07	
Precipitation Total (Inches)	1.12
Duration (Hours)	---
Peak 5 min Intensity (Inches/Hour)	---
Average Intensity (Inches/Hour)	---

Wilmore Walk Well Rise Results

Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	---	---	3.58	3.58
Porosity	---	---	0.31	0.31
Infiltration Uncorrected (Inches/Hour)	---	---	0.06	0.06
Infiltration Corrected (Inches/Hour)	---	---	0.02	0.02

Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	---	2.75	2.68	3.00
Porosity	---	0.41	0.42	0.38
Infiltration Uncorrected (Inches/Hour)	---	0.08	0.07	0.07
Infiltration Corrected (Inches/Hour)	---	0.03	0.03	0.03

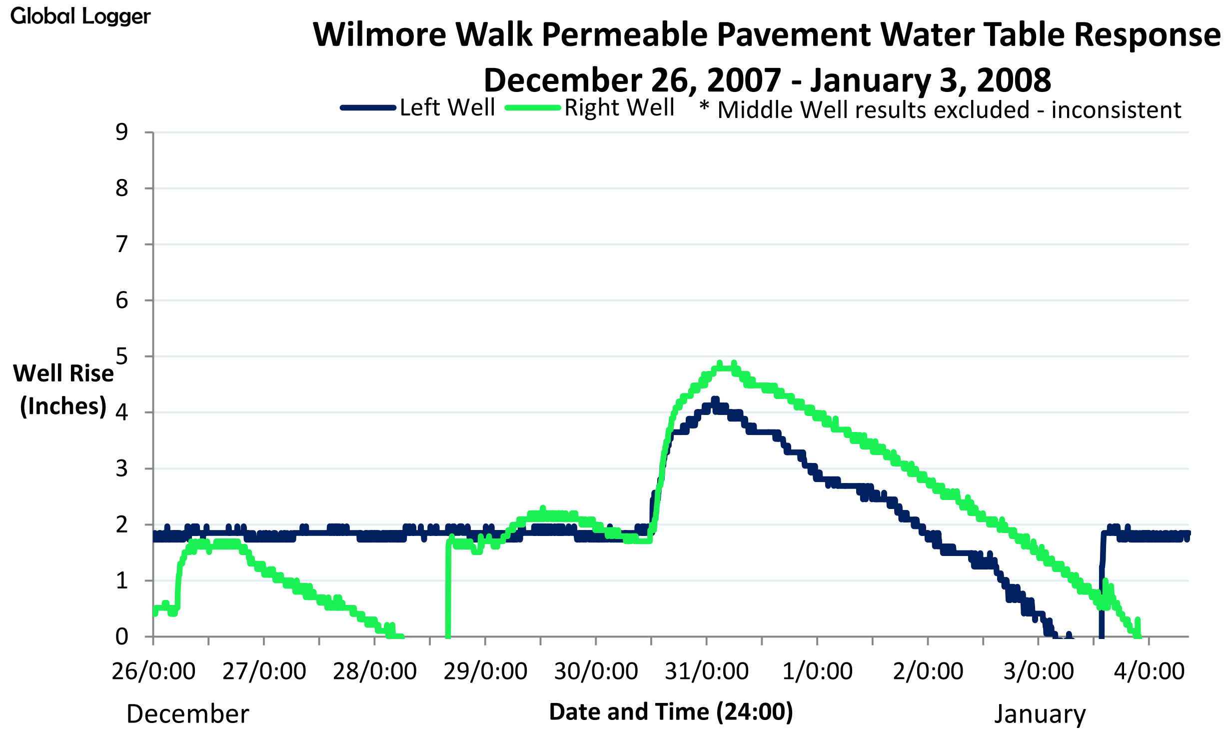
--- = No Data

Wilmore Walk December 16, 2007 Water Quality Results

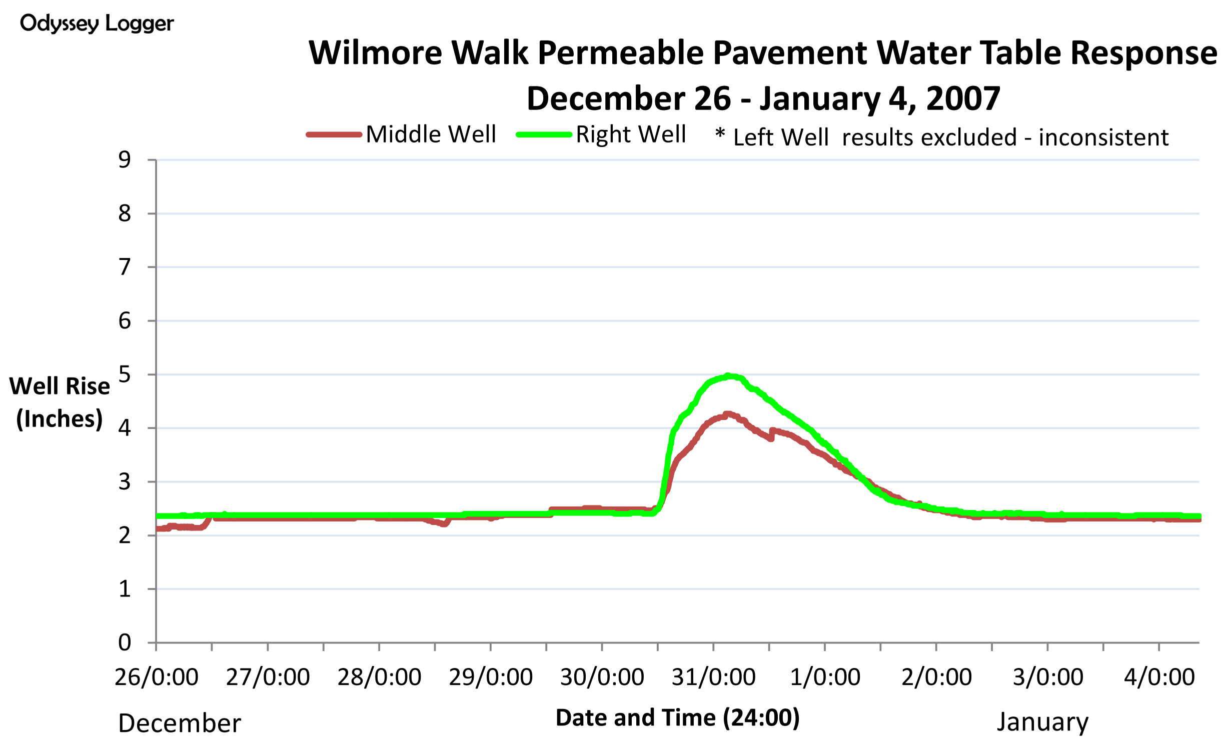
	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	6.3	5.03	0.3	0.47	0.15	0.19	0.01	0.14
Left Well	---	---	---	---	---	---	---	---
Middle Well	---	---	---	---	---	---	---	---
Right Well	119.3	6.14	3.16	1.52	0.4	0.2	0.16	

--- = No Data

A.1-18: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger), rain event details (Charlotte Douglas Airport), and water quality results for December 16, 2007.



A.1-19: Wilmore Walk permeable concrete structure water table response for 0.48" rain event occurring December 26, 2007, recorded with Global Logger in 2 of 3 wells (Charlotte, NC).



A.1-20: Wilmore Walk permeable concrete structure water table response for 0.48" rain event occurring December 26, 2007, recorded with Odyssey Capacitance Logger in 2 of 3 wells (Charlotte, NC).

Rain Event Details for 12/26-30/07 — **Wilmore Walk Well Rise Results**

12/26/07		Global Logger	Left Well	Middle Well	Right Well	Average
Precipitation Total (Inches)	0.48	**Total Rise** (Inches)	---	---	1.19	1.19
Duration (Hours)	9.00	**Porosity**	---	---	0.40	0.40
Peak 5 min Intensity (Inches/Hour)	0.28	**Infiltration Uncorrected** (Inches/Hour)	---	---	0.06	0.06
Average Intensity (Inches/Hour)	0.05	**Infiltration Corrected** (Inches/Hour)	---	---	0.02	0.02

12/28/07		Global Logger	Left Well	Middle Well	Right Well	Average
Precipitation Total (Inches)	0.60	**Total Rise** (Inches)	2.52	---	3.58	3.19
Duration (Hours)	10.38	**Porosity**	0.37	---	0.31	0.29
Peak 5 min Intensity (Inches/Hour)	0.94	**Infiltration Uncorrected** (Inches/Hour)	0.05	---	0.06	0.05
Average Intensity (Inches/Hour)	0.06	**Infiltration Corrected** (Inches/Hour)	0.02	---	0.02	0.01

12/30/07		Global Logger	Left Well	Middle Well	Right Well	Average
Precipitation Total (Inches)	0.93	**Total Rise** (Inches)	2.52	---	3.19	2.86
Duration (Hours)	13.18	**Porosity**	0.37	---	0.29	0.33
Peak 5 min Intensity (Inches/Hour)	0.57	**Infiltration Uncorrected** (Inches/Hour)	0.05	---	0.05	0.05
Average Intensity (Inches/Hour)	0.07	**Infiltration Corrected** (Inches/Hour)	0.02	---	0.01	0.02

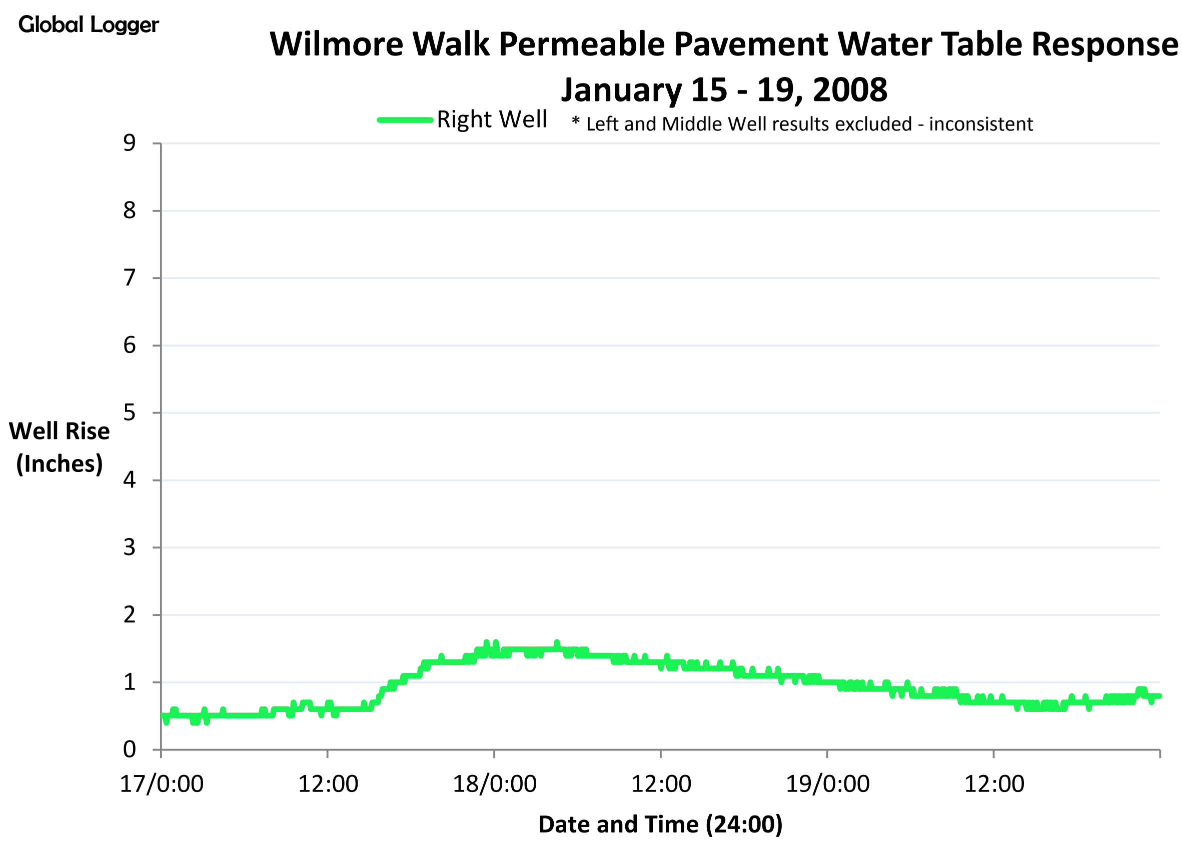
Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	---	2.75	2.68	2.63
Porosity	---	0.41	0.42	0.37
Infiltration Uncorrected (Inches/Hour)	---	0.08	0.07	0.06
Infiltration Corrected (Inches/Hour)	---	0.03	0.03	0.02

--- = No Data

Wilmore Walk December 31, 2007 Water Quality Results

Sample	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	7.4	5.18	0.47	0.32	0.11	0.15	<DL	0.12
Left Well	141.0	6.81	0.53	0.57	0.33	0.00	0.03	0.45
Middle Well	108.8	6.44	0.44	0.27	0.17	0.00	0.01	0.18
Right Well	78.3	6.92	0.98		0.18	0.00	0.20	1.02

A.1-21: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for December 26, 28, and 30, 2007.



A.1-22: Wilmore Walk permeable concrete structure water table response for 0.90" rain event occurring January 15, 2007, recorded with a Global Logger in 1 of 3 wells (Charlotte, NC).

Rain Event Details for 1/17/08		Wilmore Walk Well Rise Results				
		Global Logger	Left Well	Middle Well	Right Well	Average
Precipitation Total (Inches)	0.90	**Total Rise** (Inches)	---	---	0.89	0.89
Duration (Hours)	13.72	**Porosity**	---	---	NC	NC
Peak 5 min Intensity (Inches/Hour)	0.01	**Infiltration Uncorrected** (Inches/Hour)	---	---	0.03	0.03
Average Intensity (Inches/Hour)	0.07	**Infiltration Corrected** (Inches/Hour)	---	---	0.03	0.03

--- = No Data NC = Not Calculated

Wilmore Walk January 17, 2008 Water Quality Results

Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	32.1	4.62	8.76	0.97	0.38	0.50	0.04	0.19
Middle Well	128.2	6.48	0.50	0.43	0.22	---	<DL	---
Right Well	51.7	6.33	---	---	---	---	---	---

--- = No Data

A.1-23: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger), rain event details (Hobo Logger), and water quality results for January 17, 2008.

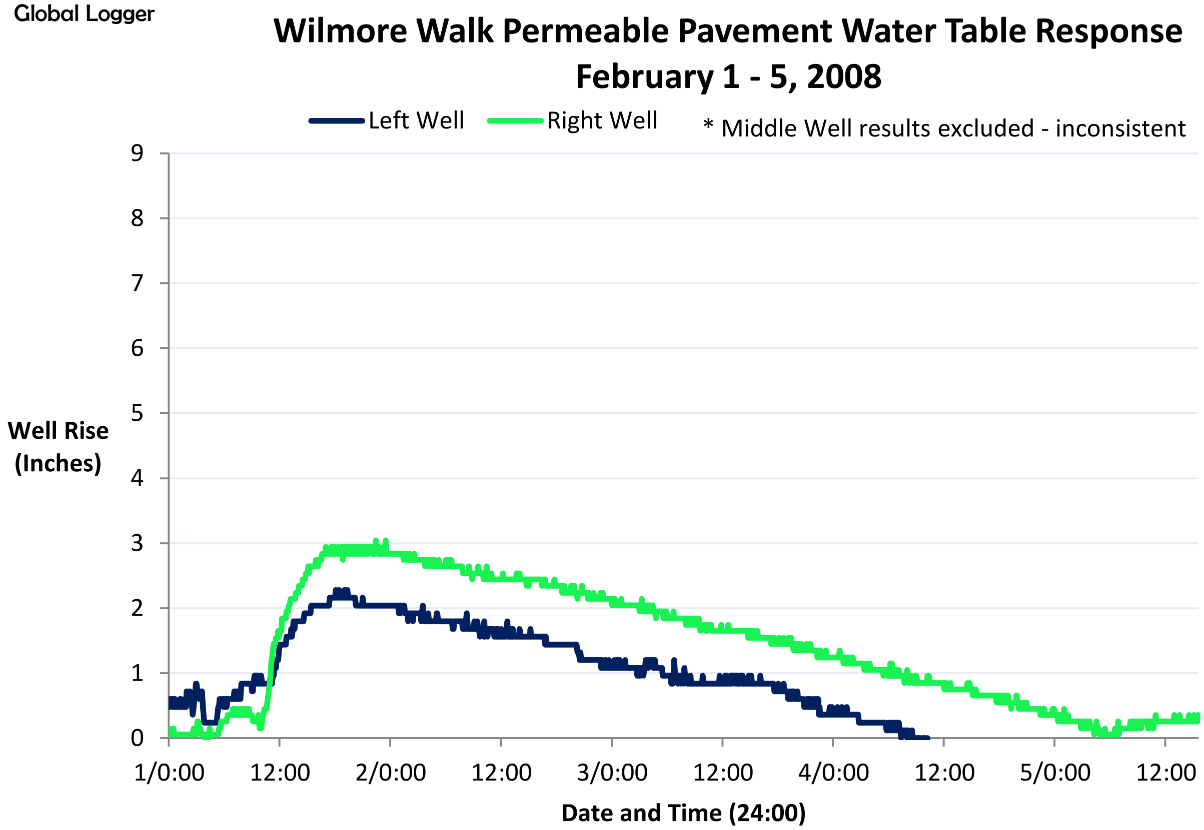
Wilmore Walk January 2008 Water Quality Results

Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
1/12	Bulk Precipitation			0.48	0.92	0.24	0.48	0.01	0.17
1/30	Bulk Precipitation	24.3	5.73	0.77	0.82	0.3	0.4	0	0.19

--- = No Data

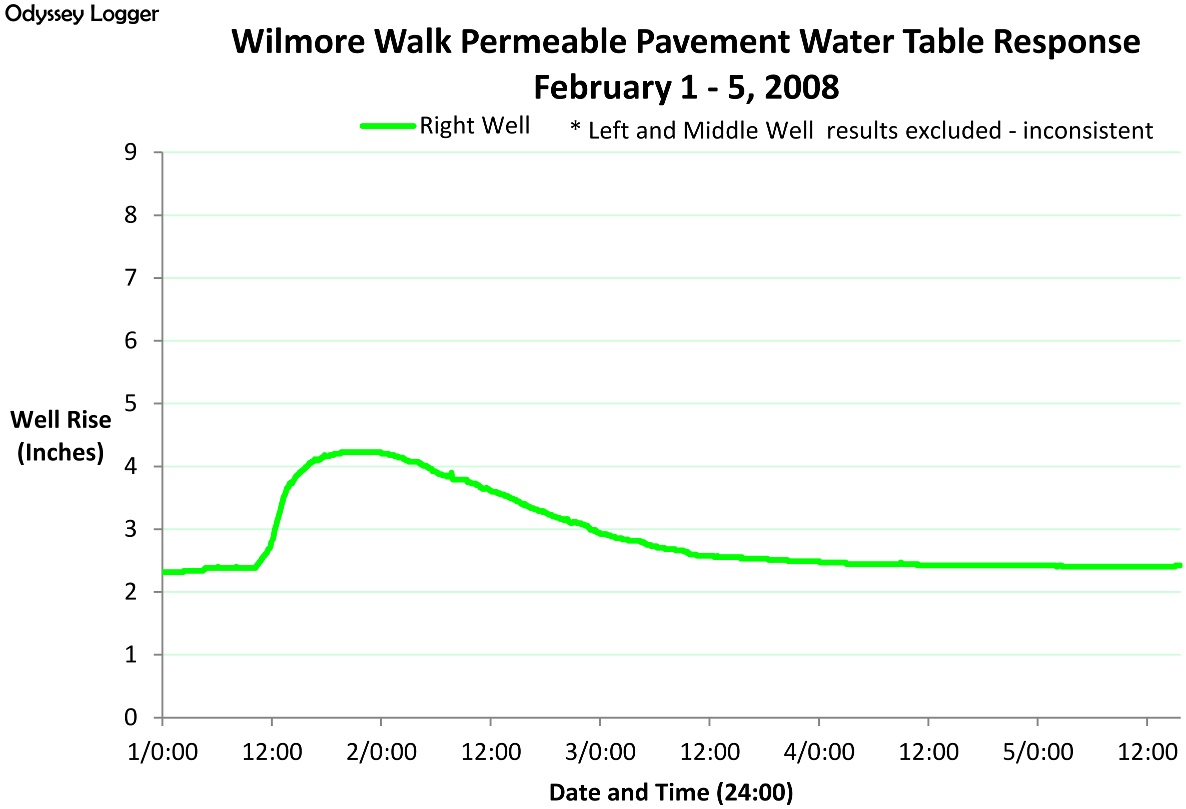
A.1-24: Wilmore Walk site bulk precipitation water quality results for January 2008 (Charlotte, NC).

Global Logger



A.1-25: Wilmore Walk permeable concrete structure water table response for 1.15” rain event occurring February 1, 2008, recorded with Global Logger in 2 of 3 wells (Charlotte, NC).

Odyssey Logger



A.1-26: Wilmore Walk permeable concrete structure water table response for 1.15” rain event occurring February 1, 2008, recorded with a Odyssey Capacitance Logger in 1 of 3 wells (Charlotte, NC).

Rain Event Details for 2/1/08		Wilmore Walk Well Rise Results				
		Global Logger	**Left Well**	**Middle Well**	**Right Well**	**Average**
Precipitation Total (Inches)	1.15	**Total Rise** (Inches)	2.04	---	2.99	2.52
Duration (Hours)	12.07	**Porosity**	0.56	---	0.38	0.47
Peak 5 min Intensity (Inches/Hour)	0.10	**Infiltration Uncorrected** (Inches/Hour)	0.04	---	0.04	0.04
Average Intensity (Inches/Hour)	0.02	**Infiltration Corrected** (Inches/Hour)	0.02	---	0.01	0.02
		Odyssey Logger	**Left Well**	**Middle Well**	**Right Well**	**Total Average**
		Total Rise (Inches)	---	---	2.85	2.63
		Porosity	---	---	0.40	0.45
		Infiltration Uncorrected (Inches/Hour)	---	---	0.03	0.04
		Infiltration Corrected (Inches/Hour)	---	---	0.03	0.02

--- = No Data NC = Not Calculated

Wilmore Walk February 1, 2008 Water Quality Results

Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	12.9	5.63	---	0.51	---	0.30	---	0.13
Left Well	194.5	6.43	16.66	1.51	1.31	0.11	0.21	0.80
Middle Well	147.4	6.23	3.43	0.52	0.33	<DL	<DL	0.14
Right Well	69.8	6.22	6.66	1.37	0.36	0.03	0.40	2.07

--- = No Data

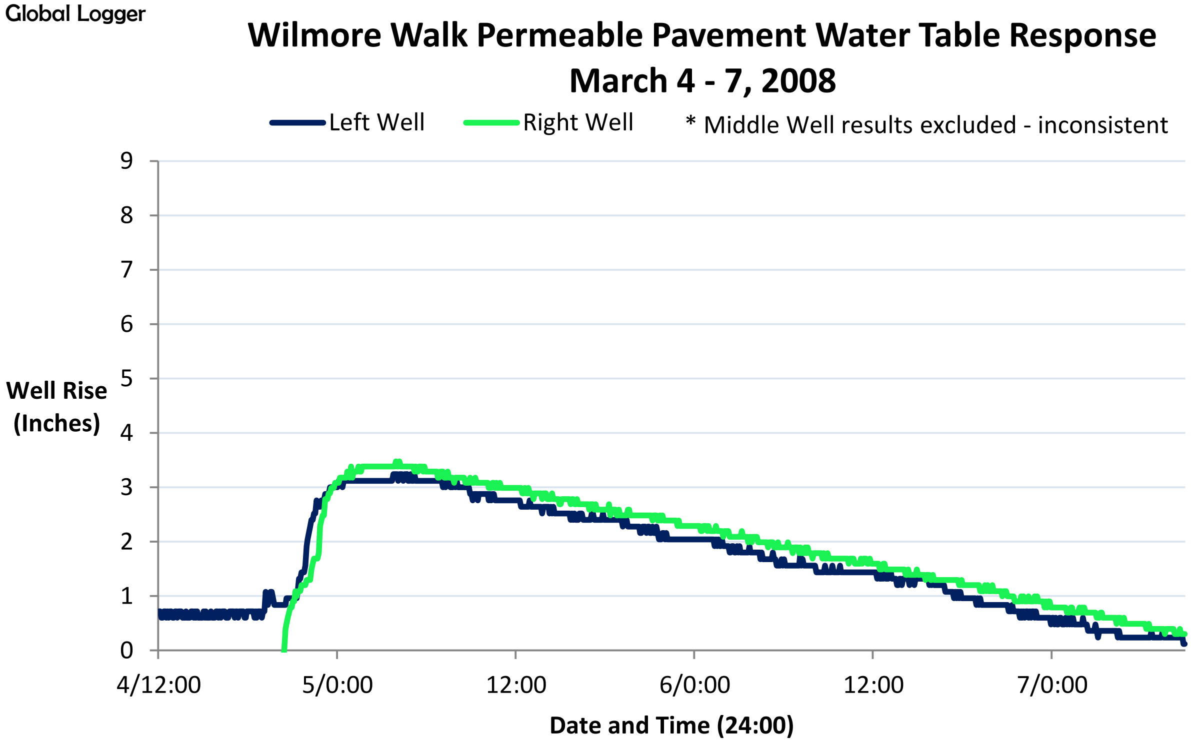
A.1-27: **Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for February 1, 2008.**

Wilmore Walk February 2008 Water Quality Results

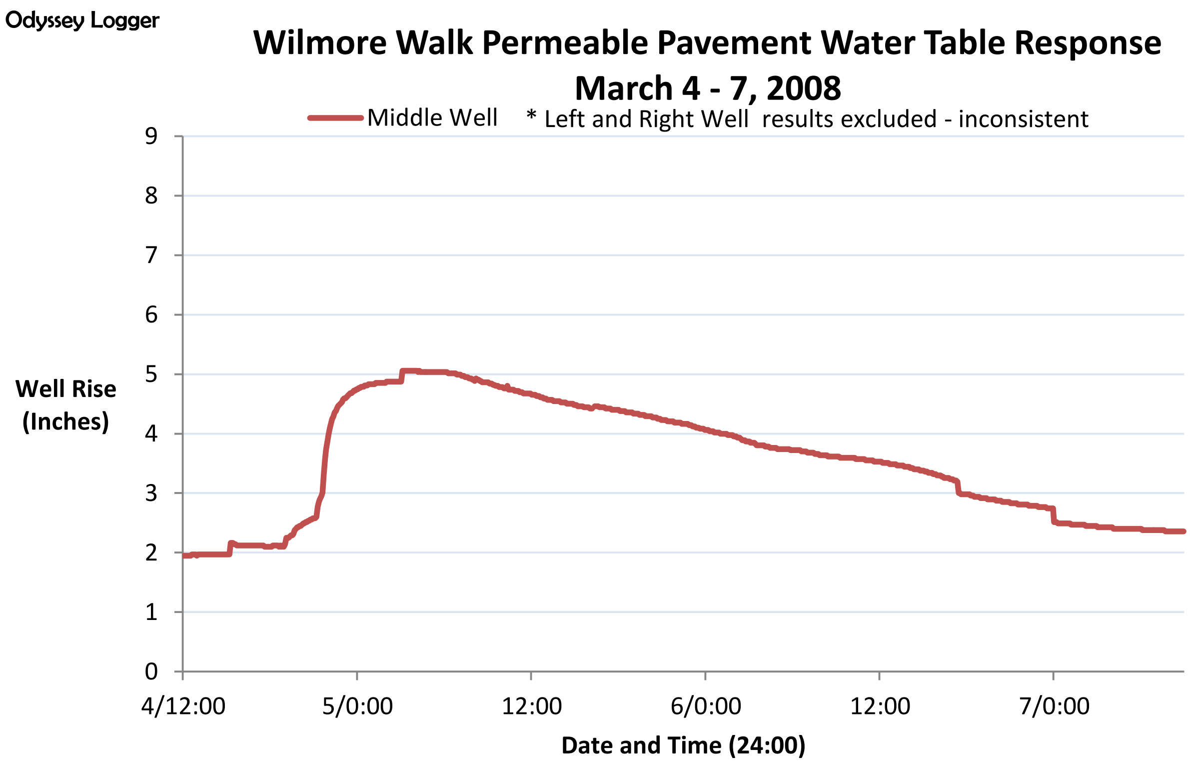
Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
2/7	Bulk Precipitation	31.9	5.40	---	0.94	---	0.37	---	0.25
2/14	Bulk Precipitation	12.8	6.25	0.39	0.59	0.24	0.31	<DL	0.16
2/19	Bulk Precipitation	56.5	5.75	1.74	4.74	0.54	2.19	0.87	3.64
2/24	Bulk Precipitation	40.3	5.62	0.94	1.30	0.27	0.15	0.01	0.34
2/27	Bulk Precipitation	16.0	5.46	0.29	0.75	0.30	0.38	<DL	0.21

--- = No Data

A.1-28: Wilmore Walk site bulk precipitation water quality results for June 2007 (Charlotte, NC).



A.1-29: Wilmore Walk permeable concrete structure water table response for 1.36” rain event occurring March 4, 2008, recorded with Global Logger in 2 of 3 wells (Charlotte, NC).



A.1-30: Wilmore Walk permeable concrete structure water table response for 1.36” rain event occurring March 4, 2008, recorded with a Odyssey Capacitance Logger in 1 of 3 wells (Charlotte, NC).

Rain Event Details for 3/4/08

Precipitation Total (Inches)	1.36
Duration (Hours)	7.45
Peak 5 min Intensity (Inches/Hour)	0.18
Average Intensity (Inches/Hour)	0.02

Wilmore Walk Well Rise Results

Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	2.52	---	3.38	2.95
Porosity	0.54	---	0.40	0.47
Infiltration Uncorrected (Inches/Hour)	0.05	---	0.07	0.06
Infiltration Corrected (Inches/Hour)	0.03	---	0.03	0.03

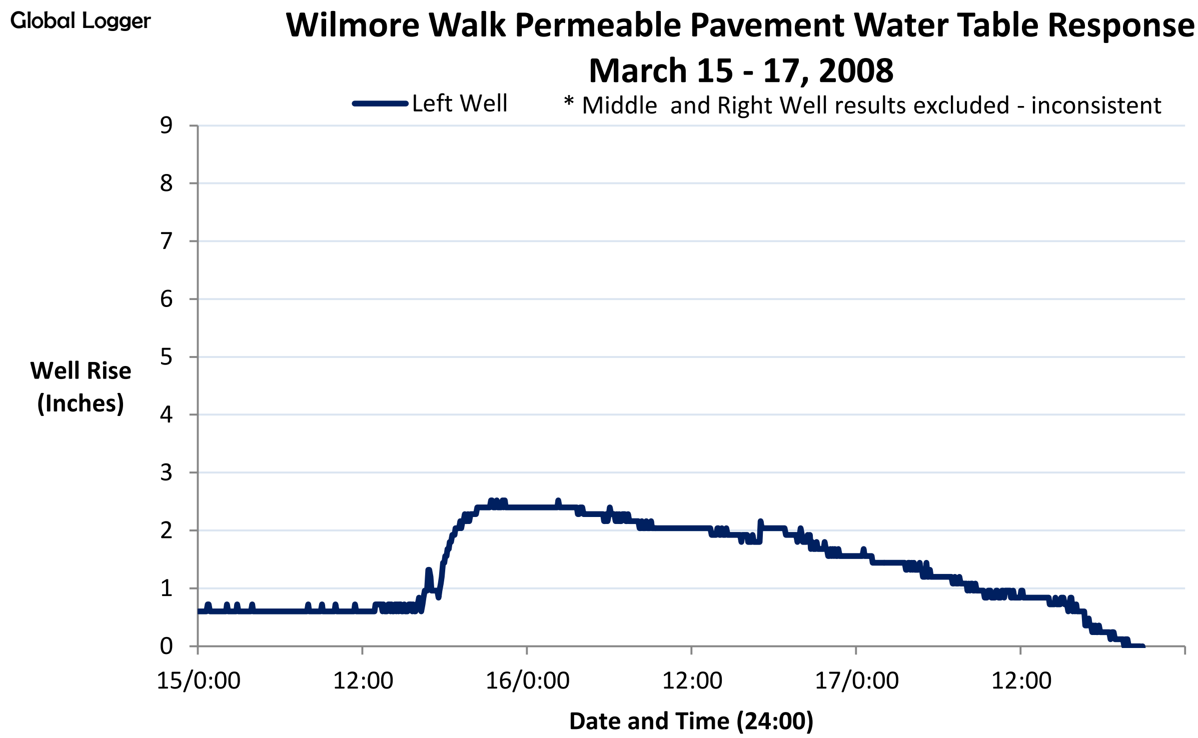
Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	---	3.68	---	3.19
Porosity	---	0.44	---	0.46
Infiltration Uncorrected (Inches/Hour)	---	0.08	---	0.07
Infiltration Corrected (Inches/Hour)	---	0.04	---	0.03

--- = No Data

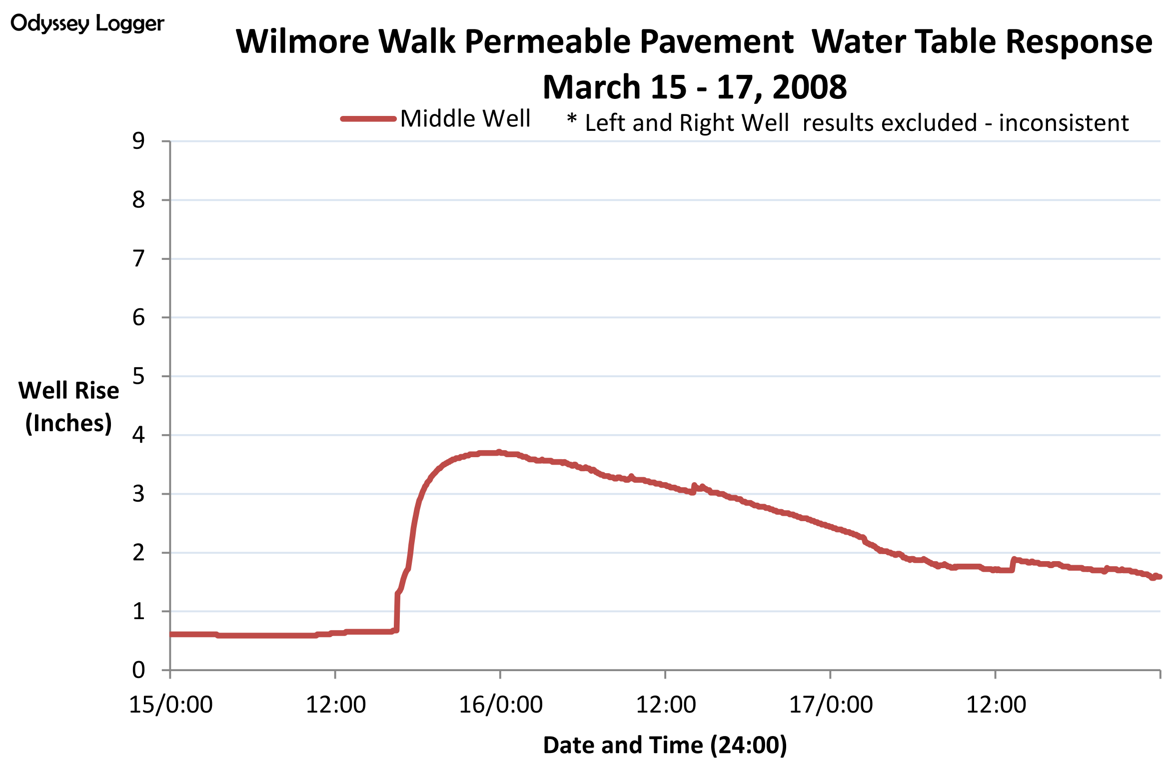
Wilmore Walk March 4, 2008 Water Quality Results

Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	11.7	5.62	0.63	1.42	0.08	0.34	0.23	1.14
Left Well	129.0	6.69	0.84	1.23	0.42	<DL	0.07	0.56
Middle Well	162.5	6.76	0.61	1.15	0.25	<DL	<DL	0.18
Right Well	83.4	6.43	0.56	2.07	0.23	0.58	0.10	0.63

A.1-31: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for March 4, 2008.



A.1-32: Wilmore Walk permeable concrete structure water table response for 1.24” rain event occurring March 15, 2008, recorded with a Global Logger in 1 of 3 wells (Charlotte, NC).



A.1-33: Wilmore Walk permeable concrete structure water table response for 1.24” rain event occurring March 15, 2008, recorded with a Odyssey Capacitance Logger in 1 of 3 wells (Charlotte, NC).

Rain Event Details for 3/16/08	
Precipitation Total (Inches)	1.24
Duration (Hours)	13.67
Peak 5 min Intensity (Inches/Hour)	0.03
Average Intensity (Inches/Hour)	0.09

Wilmore Walk Well Rise Results

Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	2.40	---	---	2.40
Porosity	0.52	---	---	0.52
Infiltration Uncorrected (Inches/Hour)	0.06	---	---	0.06
Infiltration Corrected (Inches/Hour)	0.03	---	---	0.03

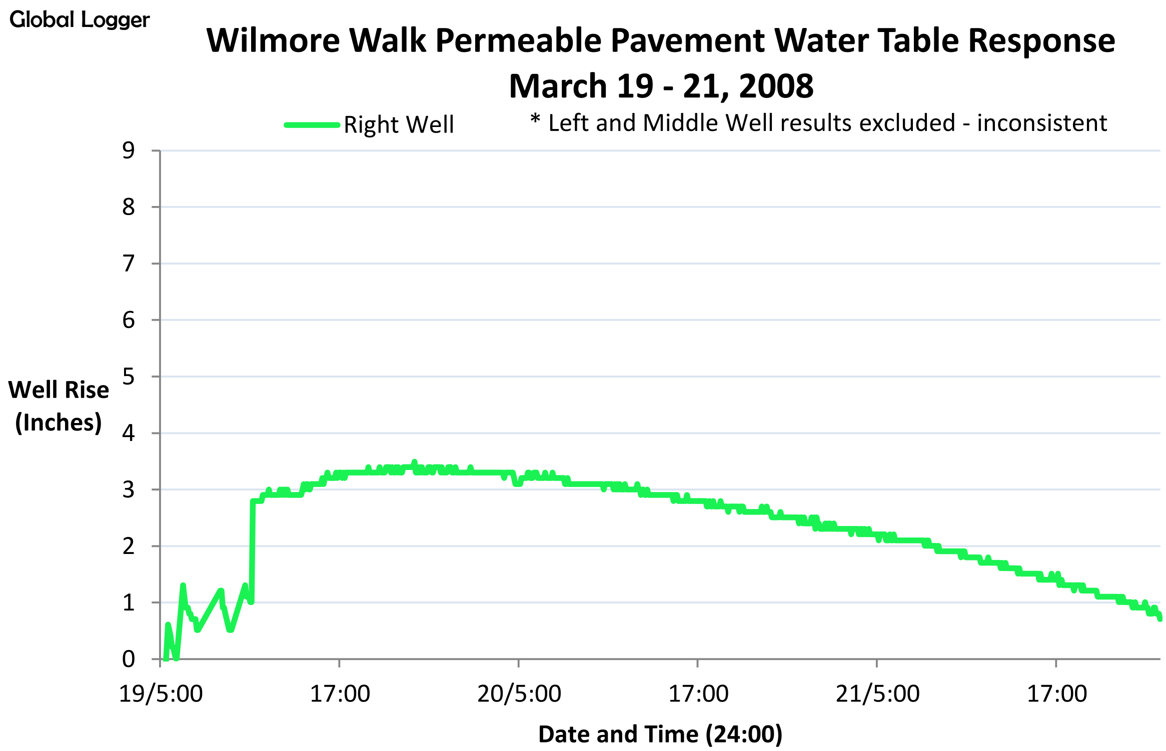
Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	---	3.09	---	2.75
Porosity	---	0.40	---	0.46
Infiltration Uncorrected (Inches/Hour)	---	0.06	---	0.06
Infiltration Corrected (Inches/Hour)	---	0.02	---	0.03

--- = No Data

Wilmore Walk March 16, 2008 Water Quality Results

Sample	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	19.5	6.85	0.11	0.72	0.17	0.53	0.02	0.21
Left Well	185.7	6.94	0.96	1.04	0.63	<DL	0.02	0.35
Middle Well	122.7	6.81	0.42	0.49	0.29	<DL	<DL	0.14
Right Well	98.7	6.76	0.54	1.40	0.81	<DL	0.09	0.55

A.1-34: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for March 16, 2008.



A.1-35: Wilmore Walk permeable concrete structure water table response for 0.66” rain event occurring March 19, 2008, recorded with a Global Logger in 1 of 3 wells (Charlotte, NC).

Rain Event Details for 3/19/08		Wilmore Walk Well Rise Results				
		Global Logger	Left Well	Middle Well	Right Well	Average
Precipitation Total (Inches)	0.66	**Total Rise** (Inches)	---	---	2.39	2.39
Duration (Hours)	2.18	**Porosity**	---	---	0.28	0.28
Peak 5 min Intensity (Inches/Hour)	0.03	**Infiltration Uncorrected** (Inches/Hour)	---	---	0.05	0.05
Average Intensity (Inches/Hour)	0.30	**Infiltration Corrected** (Inches/Hour)	---	---	0.01	0.01

--- = No Data

A.1-36: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger), rain event details (Hobo Logger), and water quality results for March 19, 2008.

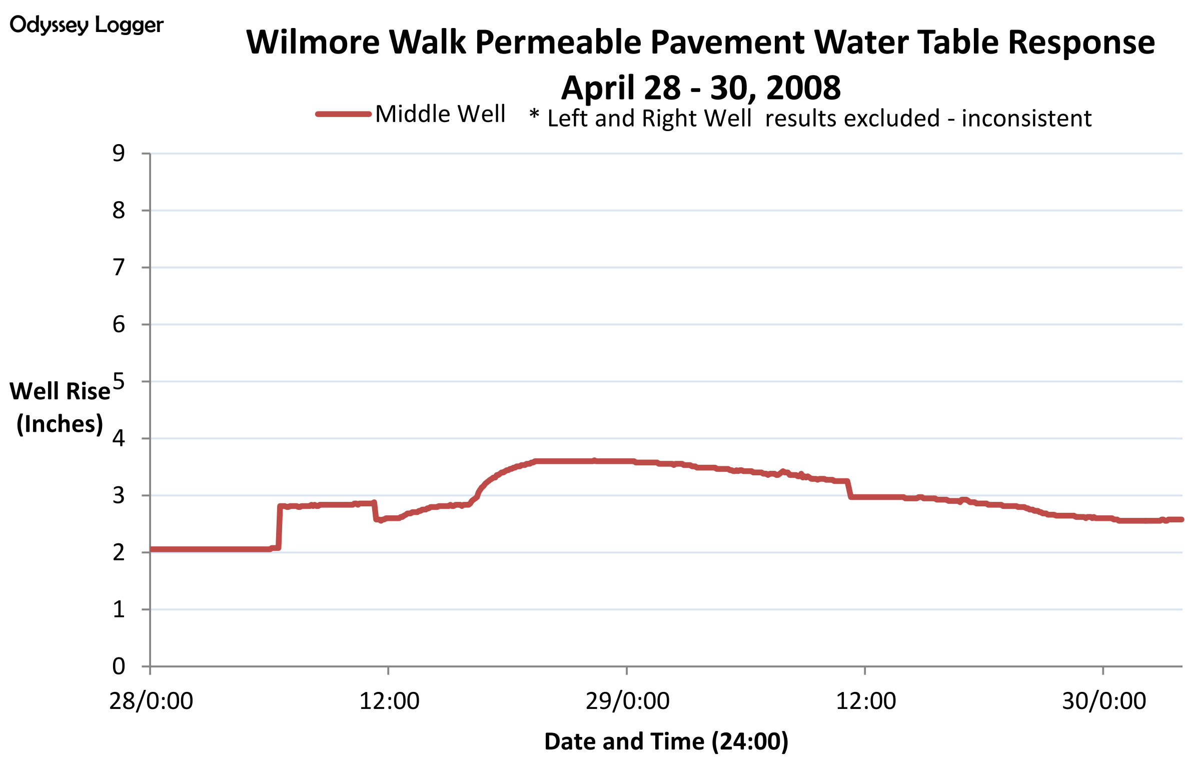
Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	27.5	7.09	1.00	0.62	0.14	0.32	<DL	0.33
Left Well	---	---	---	---	---	---	---	---
Middle Well	172.0	7.02	0.50	0.66	0.37	<DL	<DL	0.12
Right Well	134.50	6.8	1.07	1.81	1.13	<DL	0.07	0.58

--- = No Data

Wilmore Walk March 2008 Water Quality Results Summary

Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
3/9	Bulk Precipitation	13.8	5.66	0.26	0.81	0.28	0.43	<DL	0.18

A.1-37: Wilmore Walk site bulk precipitation water quality results for June 2007 (Charlotte, NC).



A.1-38: Wilmore Walk permeable concrete structure water table response for 0.85” rain event occurring April 28, 2008, recorded with a Odyssey Capacitance Logger in 1 of 3 wells (Charlotte, NC).

Rain Event Details for 4/28/08

Precipitation Total (Inches)	0.85
Duration (Hours)	13.58
Peak 5 min Intensity (Inches/Hour)	0.03
Average Intensity (Inches/Hour)	0.06

Wilmore Walk Well Rise Results

Odyssey Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	---	2.24	---	2.24
Porosity	---	0.38	---	0.38
Infiltration Uncorrected (Inches/Hour)	---	0.08	---	0.08
Infiltration Corrected (Inches/Hour)	---	0.03	---	0.03

--- = No Data

Wilmore Walk April 28, 2008 Water Quality Results

Sample	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	0.9	6.26	0.30	0.35	0.14	<DL	0.06	0.20
Left Well	---	---	---	---	---	---	---	---
Middle Well	200	6.69	1.18	0.67	0.28	<DL	0.05	0.45
Right Well	92.9	6.15	0.96	0.82	0.49	<DL	0.03	0.18

--- = No Data

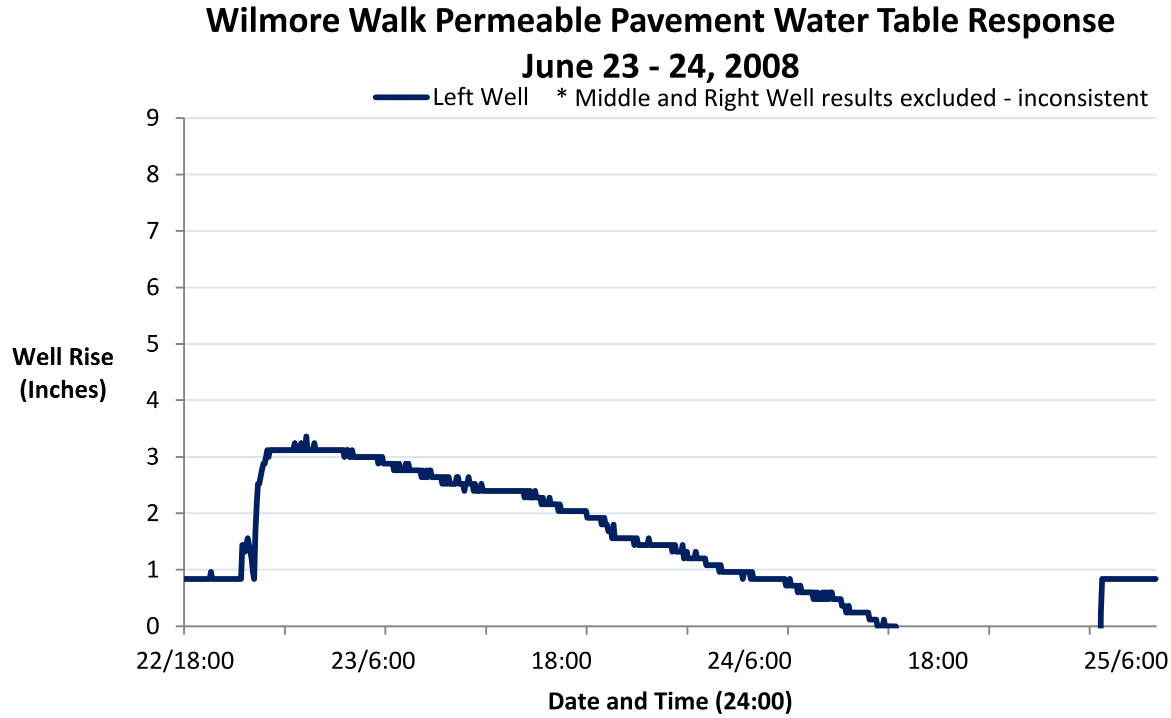
A.1-39: Wilmore Walk permeable concrete structure well rise details (Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for April 28, 2008.

Wilmore Walk April 2008 Water Quality Summary

Date	Sample	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
4/2	Bulk Precipitation	25.3	6.26	0.99	1.46	0.36	0.68	<DL	0.23
4/4	Bulk Precipitation	19.8	6.15	0.27	1.75	0.37	0.61	<DL	0.78
4/6	Bulk Precipitation	ND	ND	0.39	0.57	0.16	0.22	<DL	0.16
4/14	Bulk Precipitation	ND	ND	1.36	5.78	0.34	3.19	0.48	3.55

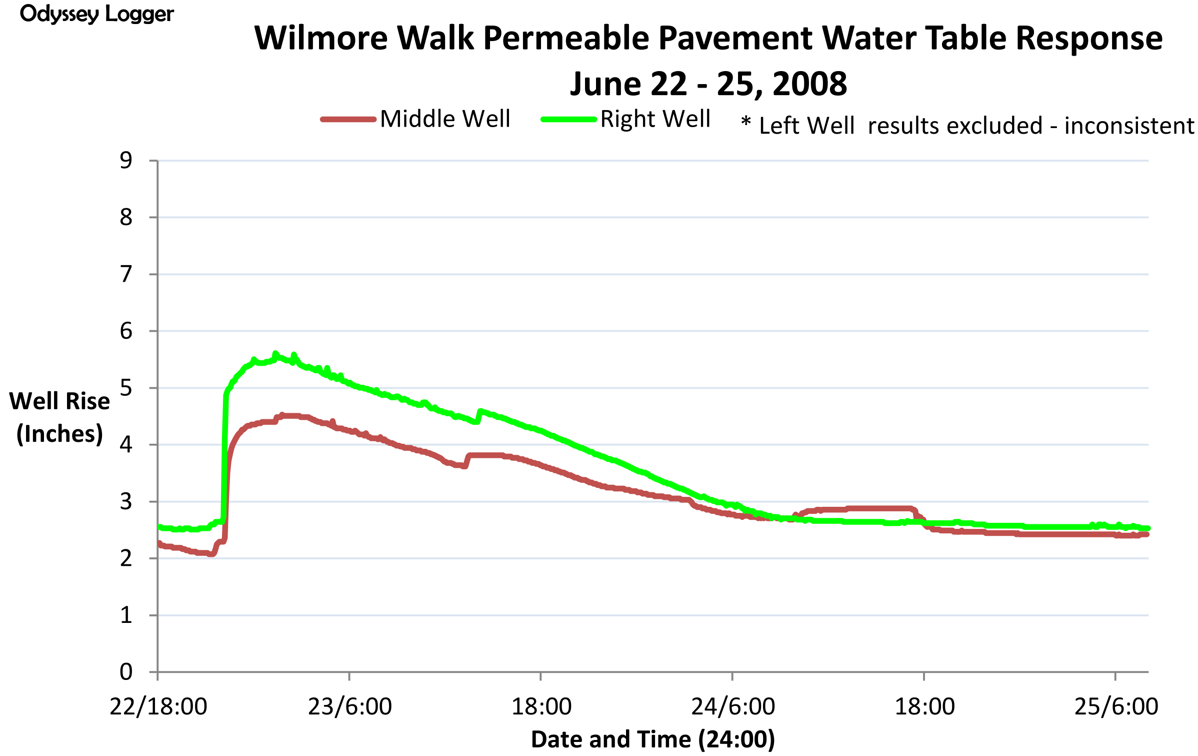
A.1-40: Wilmore Walk site bulk precipitation water quality results for April 2008 (Charlotte, NC).

Global Logger



A.1-41: Wilmore Walk permeable concrete structure water table response for 1.19" rain event occurring June 23, 2008, recorded with a Global Logger in 1 of 3 wells (Charlotte, NC).

Odyssey Logger



A.1-42: Wilmore Walk permeable concrete structure water table response for 1.194" rain event occurring June 23, 2008, recorded with Odyssey Capacitance Loggers in 2 of 3 wells (Charlotte, NC).

Rain Event Details for 6/22/08		Wilmore Walk Well Rise Results				
		Global Logger	**Left Well**	**Middle Well**	**Right Well**	**Average**
Precipitation Total (Inches)	1.19	**Total Rise** (Inches)	2.52	---	---	2.52
Duration (Hours)	3.90	**Porosity**	0.47	---	---	0.47
Peak 5 min Intensity (Inches/Hour)	0.05	**Infiltration Uncorrected** (Inches/Hour)	0.09	---	---	0.09
Average Intensity (Inches/Hour)	0.30	**Infiltration Corrected** (Inches/Hour)	0.04	---	---	0.04
		Odyssey Logger	**Left Well**	**Middle Well**	**Right Well**	**Total Average**
		Total Rise (Inches)	---	2.38	3.06	2.65
		Porosity	---	0.50	0.39	0.45
		Infiltration Uncorrected (Inches/Hour)	---	0.07	0.09	0.08
		Infiltration Corrected (Inches/Hour)	---	0.04	0.04	0.04

--- = No Data

Wilmore Walk June 22, 2008 Water Quality Results

Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	17.4	4.1	0.20	0.93	0.38	0.56	0.01	0.10
Left Well	191	6.25	2.03	2.71	2.46	0.00	0.09	0.28
Middle Well	206	6.5	0.53	0.85	0.68	0.00	0.00	0.06
Right Well	122	7.03	2.82	1.69	1.44	0.00	0.14	0.49

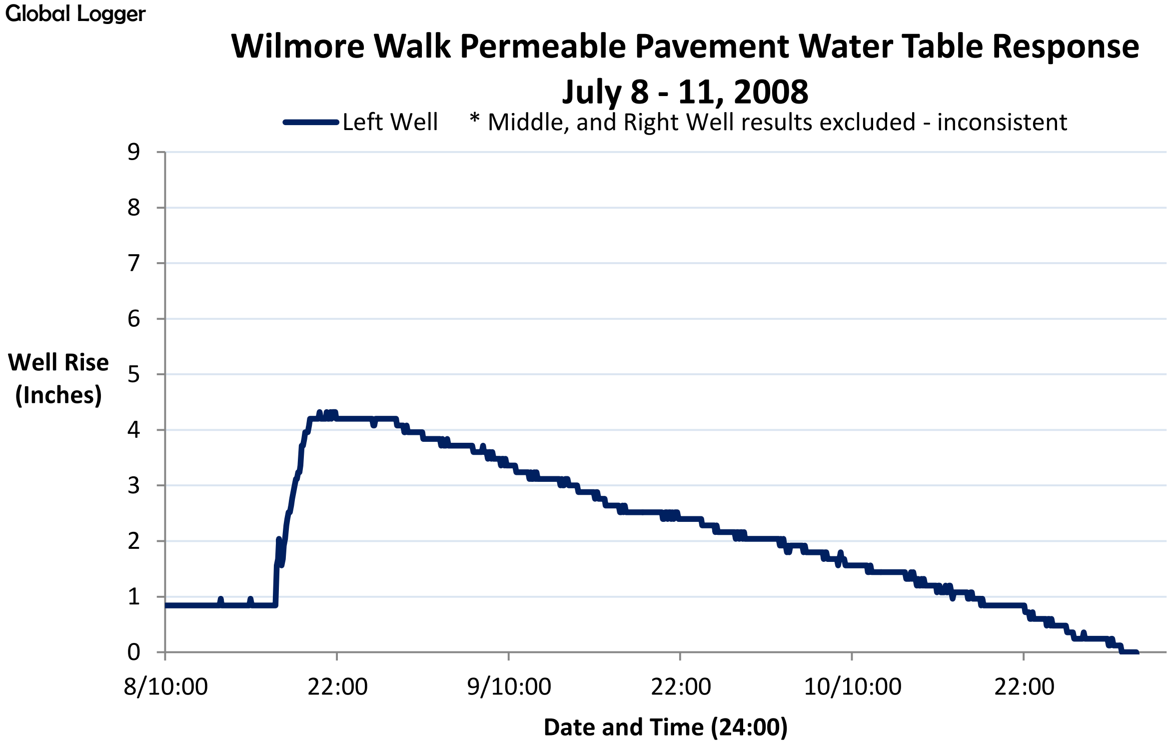
A.1-43: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for June 22, 2008.

Wilmore Walk June 2008 Water Quality Summary

Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
6/12	Bulk Precipitation	43.4	6.4	0.56	3.00	1.21	1.26	0.12	1.25

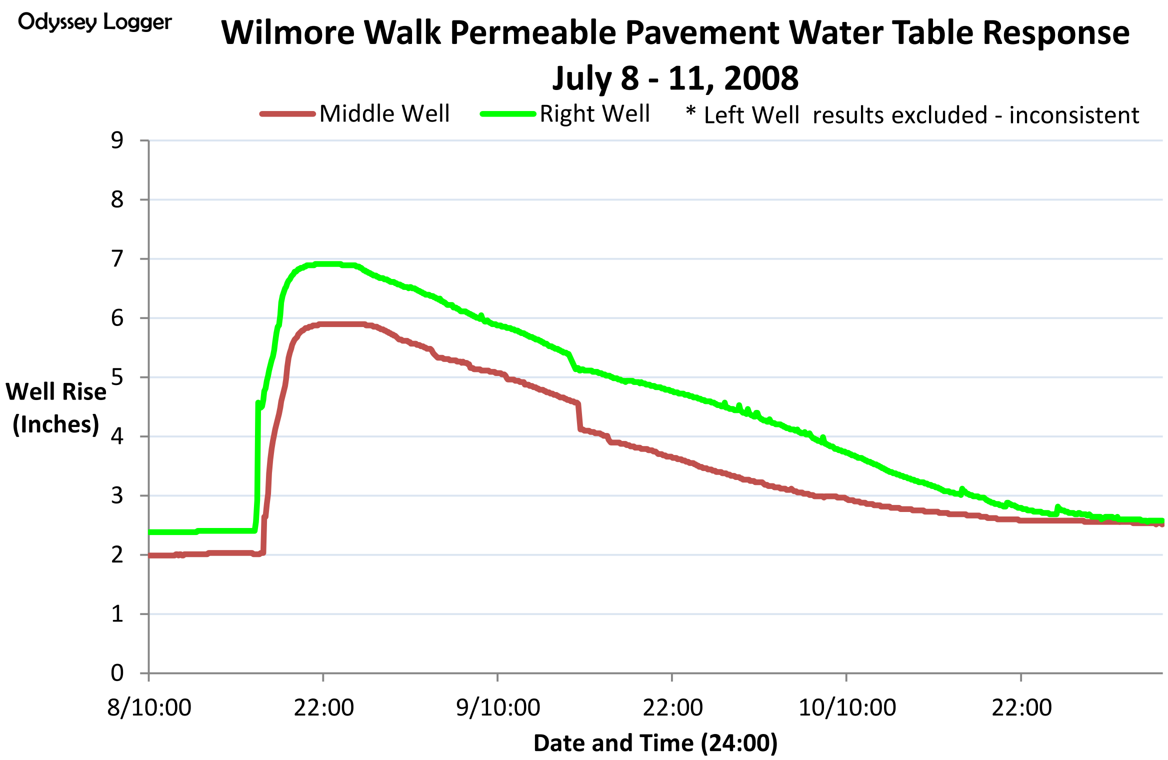
A.1-44: Wilmore Walk site bulk precipitation water quality results for June 2008 (Charlotte, NC).

Global Logger



A.1-45: Wilmore Walk permeable concrete structure water table response for 1.53" rain event occurring July 8, 2008, recorded with a Global Transducer Logger in 1 of 3 wells (Charlotte, NC).

Odyssey Logger



A.1-46: Wilmore Walk permeable concrete structure water table response for 1.53" rain event occurring July 8, 2008, recorded with Odyssey Capacitance Loggers in 2 of 3 wells (Charlotte, NC).

Rain Event Details for 7/8/08

Precipitation Total (Inches)	1.53
Duration (Hours)	2.32
Peak 5 min Intensity (Inches/Hour)	0.07
Average Intensity (Inches/Hour)	0.66

Wilmore Walk Well Rise Results

Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	3.48	---	---	3.48
Porosity	0.44	---	---	0.44
Infiltration Uncorrected (Inches/Hour)	0.08	---	---	0.08
Infiltration Corrected (Inches/Hour)	0.03	---	---	0.03

Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	---	3.91	4.54	3.98
Porosity	---	0.39	0.35	0.39
Infiltration Uncorrected (Inches/Hour)	---	0.07	0.08	0.08
Infiltration Corrected (Inches/Hour)	---	0.03	0.03	0.03

--- = No Data

Wilmore Walk July 8, 2008 Water Quality Results

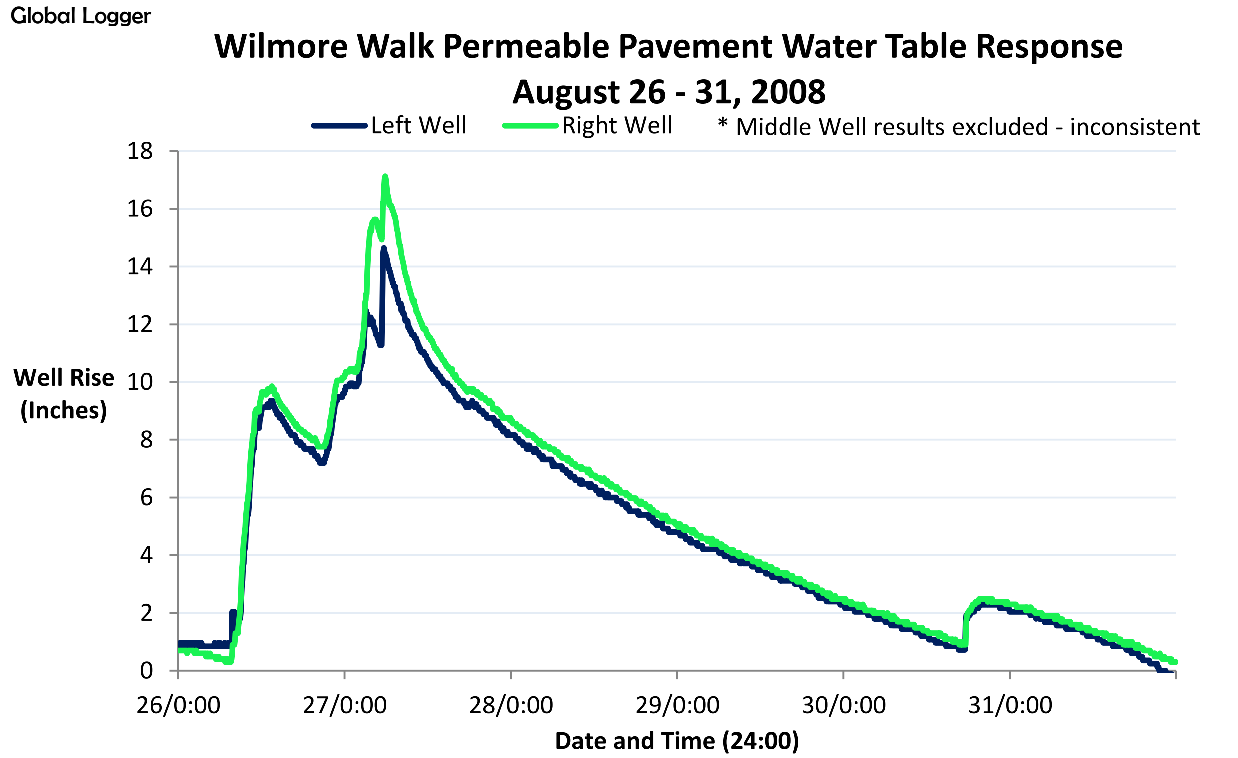
Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	19.3	5.93	0.16	1.87	0.24	1.06	0.14	0.63
Left Well	139.1	6.32	1.08	1.50	1.26	0.08	0.06	0.33
Middle Well	175.2	6.90	0.43	0.63	0.47	0.00	0.00	0.14
Right Well	97.0	6.98	1.44	1.22	0.86	0.00	0.16	0.72

A.1-48: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for July 8, 2008.

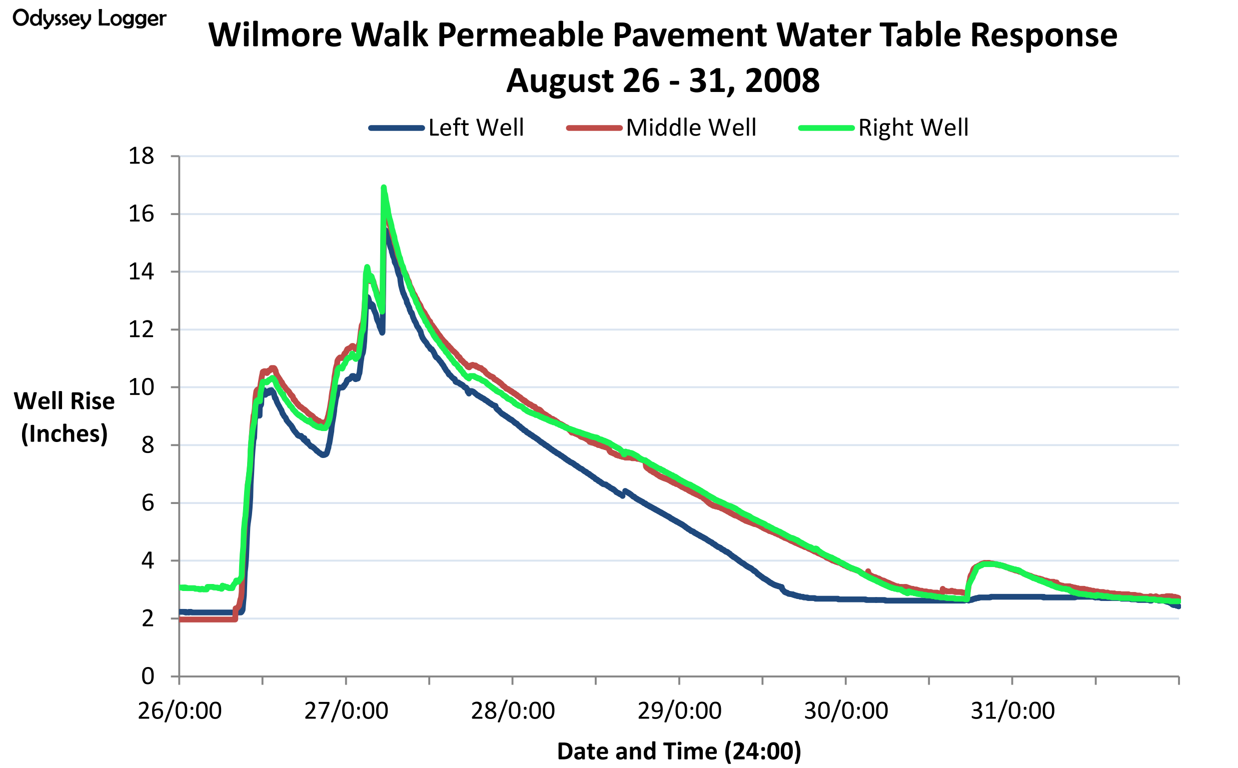
Wilmore Walk July 2008 Water Quality Summary

Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
7/11	Bulk Precipitation	32.5	5.63	1.46	1.72	0.66	0.00	0.04	0.27
7/14	Bulk Precipitation	13.7	3.97	0.11	0.67	0.19	0.53	0.00	0.16
7/23	Bulk Precipitation	17.4	4.60	0.19	1.23	0.43	0.36	0.03	0.38
7/30	Bulk Precipitation	19.3	5.74	0.32	1.02	0.38	0.10	0.00	0.18

A.1-47: Wilmore Walk site bulk precipitation water quality results for July 2008 (Charlotte, NC).



A.1-49: Wilmore Walk permeable concrete structure water table response for 5.69" rain event starting August 26, 2008, recorded with Global Transducer Loggers in 2 of 3 wells (Charlotte, NC).



A.1-50: Wilmore Walk permeable concrete structure water table response for 5.69" rain event starting August 26, 2008, recorded with Odyssey Capacitance Loggers in all 3 wells (Charlotte, NC).

Wilmore Walk Well Rise Results

Rain Event Details for 8/26/08

Precipitation Total (Inches)	5.69
Duration (Hours)	22.60
Peak 5 min Intensity (Inches/Hour)	0.03
Average Intensity (Inches/Hour)	0.16

Global Logger	**Left Well**	**Middle Well**	**Right Well**	**Average**
Total Rise (Inches)	13.80	---	16.43	15.12
Porosity	0.41	---	0.35	0.38
Infiltration Uncorrected (Inches/Hour)	0.17	---	0.20	0.19
Infiltration Corrected (Inches/Hour)	0.07	---	0.17	0.12

Odyssey Logger	**Left Well**	**Middle Well**	**Right Well**	**Total Average**
Total Rise (Inches)	13.21	14.34	13.84	14.32
Porosity	0.43	0.40	0.41	0.40
Infiltration Uncorrected (Inches/Hour)	0.18	0.19	0.18	0.18
Infiltration Corrected (Inches/Hour)	0.08	0.08	0.08	0.10

Rain Event Details for 8/31/08

Precipitation Total (Inches)	0.57
Duration (Hours)	6.72
Peak 5 min Intensity (Inches/Hour)	0.06
Average Intensity (Inches/Hour)	0.08

Global Logger	**Left Well**	**Middle Well**	**Right Well**	**Average**
Total Rise (Inches)	0.96	---	1.09	1.03
Porosity (Inches/Hour)	0.43	---	0.41	0.42
Infiltration Uncorrected (Inches/Hour)	0.09	---	0.08	0.09
Infiltration Corrected (Inches/Hour)	0.04	---	0.03	0.04

Odyssey Logger	**Left Well**	**Middle Well**	**Right Well**	**Total Average**
Total Rise (Inches)	0.39	2.96	3.57	1.79
Porosity	0.38	0.44	0.36	0.40
Infiltration Uncorrected (Inches/Hour)	0.10	0.10	0.11	0.10
Infiltration Corrected (Inches/Hour)	0.04	0.04	0.04	0.04

--- = No Data

A.1-51: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger) for August 26, and 31, 2008.

Wilmore Walk August 28, 2008 Water Quality Results

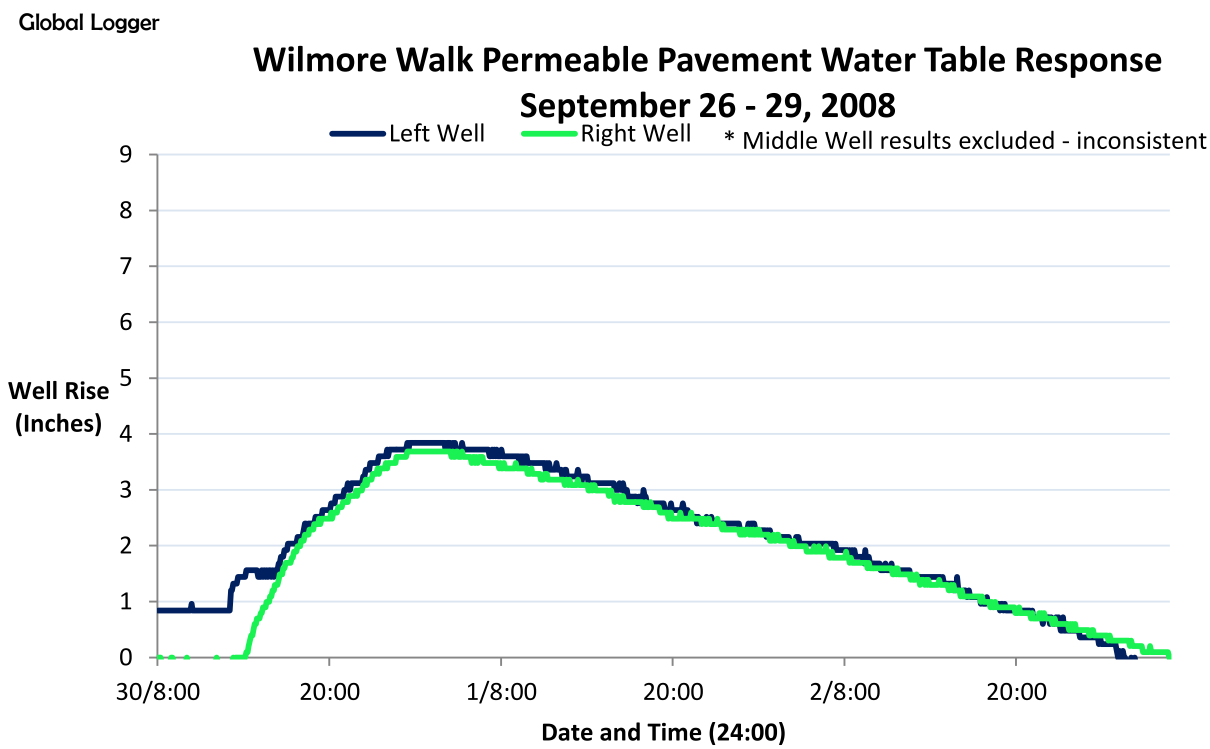
Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	66.5	4.79	0.13	0.43	0.08	0.04	0.01	0.12
Left Well	93.8	6.03	0.56	0.52	0.29	0.02	0.04	0.2
Middle Well	96.3	6.41	0.74	0.54	0.38	<DL	0.01	0.06
Right Well	52.1	7.21	0.71	0.49	0.29	<DL	0.11	0.45

A.1-52: Wilmore Walk permeable concrete structure water quality results for August 26, and 30, 2008.

Wilmore Walk August 2008 Water Quality Summary

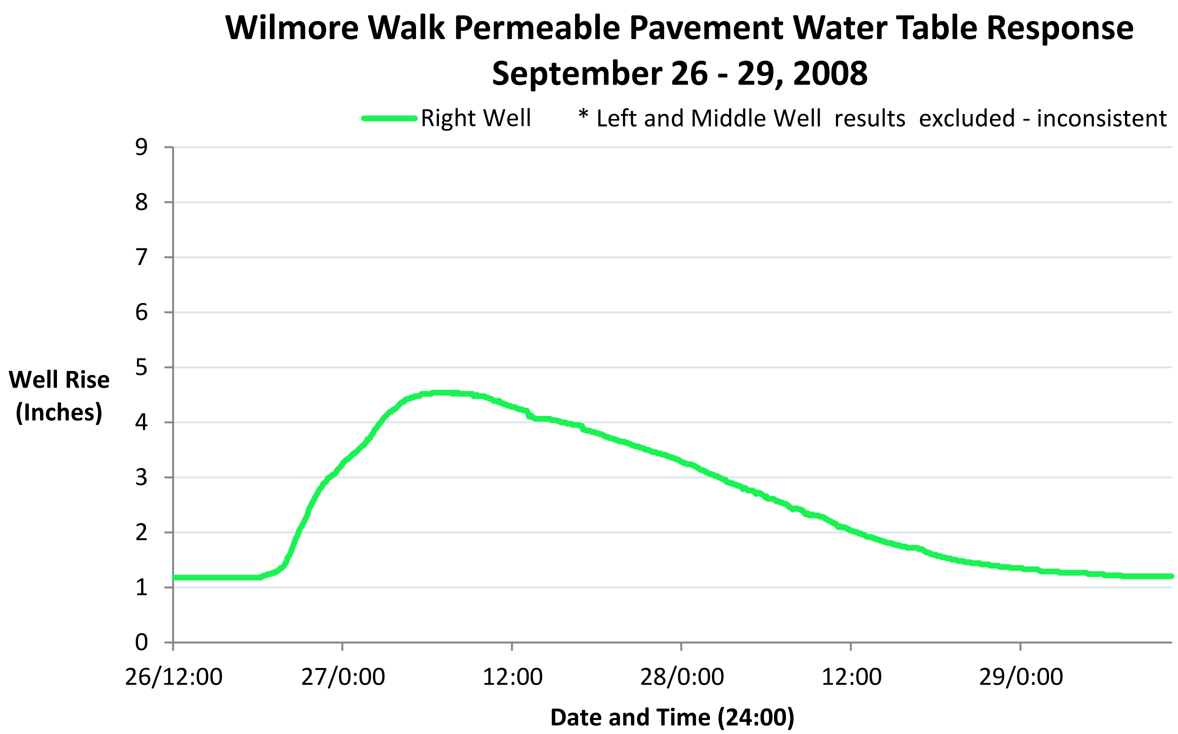
Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
8/1	Bulk Precipitation	27.7	6.00	0.42	1.20	0.52	0.19	<DL	0.27
8/13	Bulk Precipitation	83.1	5.73	2.27	10.12	0.51	4.32	1.34	ND
8/16	Bulk Precipitation	1.5	4.59	1.15	3.13	0.68	0.88	0.11	0.74
8/17	Bulk Precipitation	13.6	4.11	0.09	0.85	0.35	0.33	<DL	0.02
8/26	Bulk Precipitation	11.3	4.79	0.20	1.00	0.09	<DL	0.07	0.44

A.1-53: Wilmore Walk site bulk precipitation water quality results for August 2008 (Charlotte, NC).



A.1-54: Wilmore Walk permeable concrete structure water table response for 1.54” rain event occurring September 26, 2008, recorded with Global Transducer Loggers in 2 of 3 wells (Charlotte, NC).

Odyssey Logger



A.1-55: Wilmore Walk permeable concrete structure water table response for 1.54” rain event occurring September 26, 2008, recorded with a Odyssey Capacitance Logger in 1 of 3 wells (Charlotte, NC).

Rain Event Details for 9/27/08

Precipitation Total (Inches)	1.54
Duration (Hours)	4.67
Peak 5 min Intensity (Inches/Hour)	0.01
Average Intensity (Inches/Hour)	0.07

Wilmore Walk Well Rise Results

Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	3.00	---	3.68	3.34
Porosity	0.51	---	0.42	0.47
Infiltration Uncorrected (Inches/Hour)	0.09	---	0.08	0.09
Infiltration Corrected (Inches/Hour)	0.05	---	0.03	0.04

Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	---	---	3.34	3.34
Porosity	---	---	0.46	0.46
Infiltration Uncorrected (Inches/Hour)	---	---	0.07	0.08
Infiltration Corrected (Inches/Hour)	---	---	0.03	0.04

--- = No Data

Wilmore Walk September 27, 2008 Water Quality Results

Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	4.60	4.80	0.10	0.26	0.12	0.05	0.00	0.10
Left Well	1.20	6.32	0.64	1.16	0.98	0.00	0.06	0.33
Middle Well	0.40	6.58	0.48	0.55	0.39	0.00	<DL	0.13
Right Well	84.40	6.72	1.62	0.69	0.22	0.00	0.16	0.72

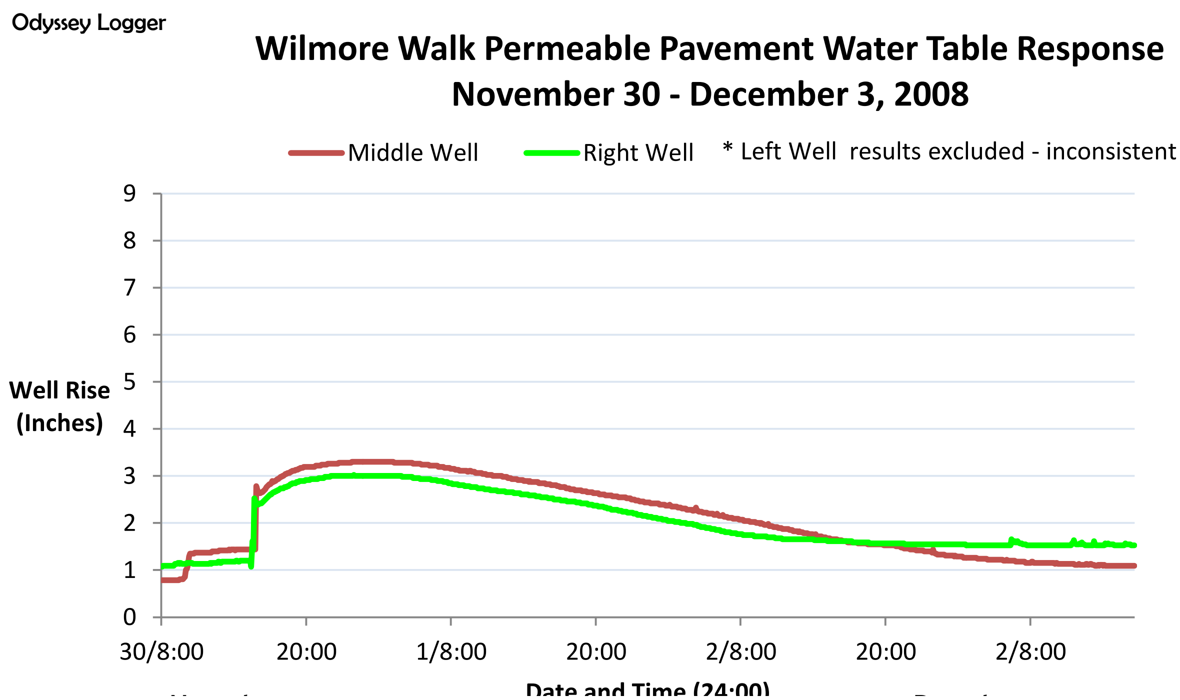
A.1-57: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for September

Wilmore Walk September 2008 Water Quality Results

Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
9/2	Bulk Precipitation	18.50	5.49	0.15	1.86	0.41	1.50	0.08	0.44
9/11	Bulk Precipitation	9.10	5.68	0.22	0.52	0.19	0.27	0.04	0.21
9/14	Bulk Precipitation	38.80	5.71	---	---	---	---	---	1.25
9/19	Bulk Precipitation	13.50	4.61	0.29	0.94	0.38	0.67	0.00	0.29

--- = No Data

A.1-56: Wilmore Walk site bulk precipitation water quality results for September 2008 (Charlotte, NC).



A.1-58: Wilmore Walk permeable concrete structure water table response for 0.98" rain event occurring November 30, 2008, recorded with Odyssey Capacitance Loggers in 2 of 3 wells (Charlotte, NC).

Rain Event Details for 11/30/08	
Precipitation Total (Inches)	0.98
Duration (Hours)	17.08
Peak 5 min Intensity (Inches/Hour)	0.01
Average Intensity (Inches/Hour)	0.06

Wilmore Walk Well Rise Results

Odyssey Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	---	2.52	3.02	2.77
Porosity	---	0.39	0.32	0.36
Infiltration Uncorrected (Inches/Hour)	---	0.05	0.06	0.06
Infiltration Corrected (Inches/Hour)	---	0.02	0.02	0.02

--- = No Data

Wilmore Walk November 30, 2008 Water Quality Results

Sample	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	6.20	4.25	0.11	0.33	0.12	0.12	0.00	-0.02
Reservoir (Wells)	---	---	---	---	---	---	---	---

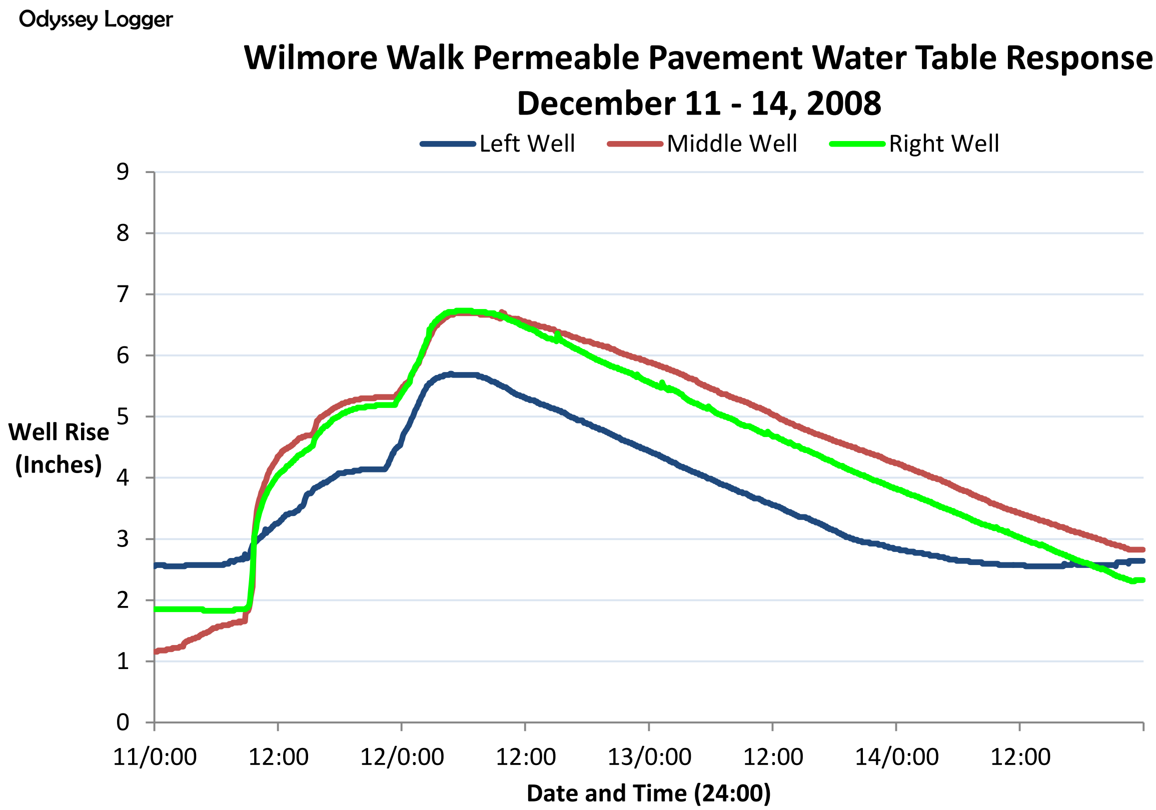
--- = No Data

A.1-59: Wilmore Walk permeable concrete structure well rise details (Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for November 30, 2008.

Wilmore Walk November 2008 Water Quality Results

Date	Sample	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
11/15	Bulk Precipitation	8.40	4.46	0.53	0.41	0.15	0.20	0.00	0.11
11/25	Bulk Precipitation	26.70	4.52	0.60	0.94	0.42	0.49	0.00	0.19

A.1-60: Wilmore Walk site bulk precipitation water quality results for November 2008 (Charlotte, NC).



A.1-61: Wilmore Walk permeable concrete structure water table response for 1.37” rain event occurring December 11, 2008, recorded with Odyssey Capacitance Loggers in all 3 wells (Charlotte, NC).

Rain Event Details for 12/11-12/08		Wilmore Walk Well Rise Results: Odyssey Logger	Left Well	Middle Well	Right Well	Average
Precipitation Total (Inches)	1.37	Total Rise (Inches)	3.15	5.53	4.48	4.39
Duration (Hours)	5.67	Porosity	0.43	0.25	0.28	0.32
Peak 5 min Intensity (Inches/Hour)	0.01	Infiltration Uncorrected (Inches/Hour)	0.06	0.09	0.08	0.08
Average Intensity (Inches/Hour)	0.04	Infiltration Corrected (Inches/Hour)	0.02	0.02	0.02	0.02

Wilmore Walk December 12, 2008 Water Quality Results

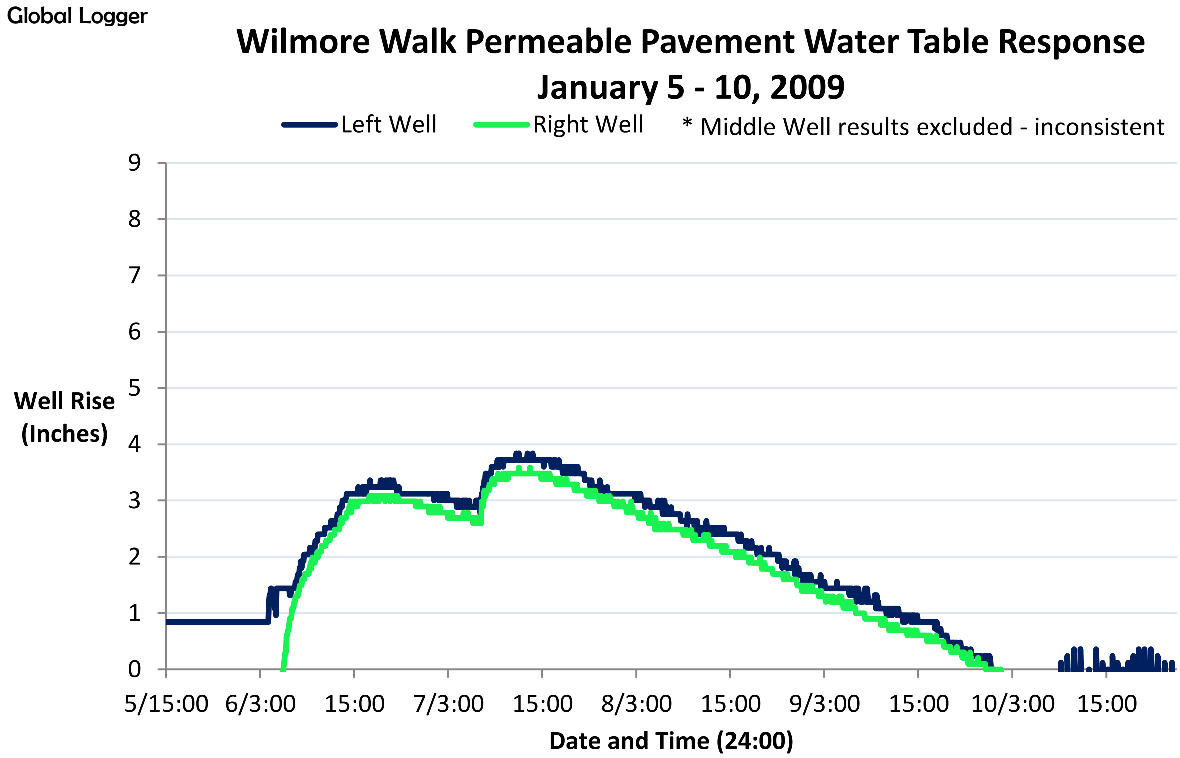
Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	6.5	4.38	0.52	0.25	0.09	0.08	0.00	0.00
Left Well	115.6	6.20	0.76	0.54	0.40	0.00	0.04	0.22
Middle Well	196.4	6.51	0.75	0.25	0.17	0.00	0.00	0.05
Right Well	83.4	6.57	2.49	0.48	0.15	0.00	0.19	0.43

A.1-63: Wilmore Walk permeable concrete structure well rise details (Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for December 12, 2008.

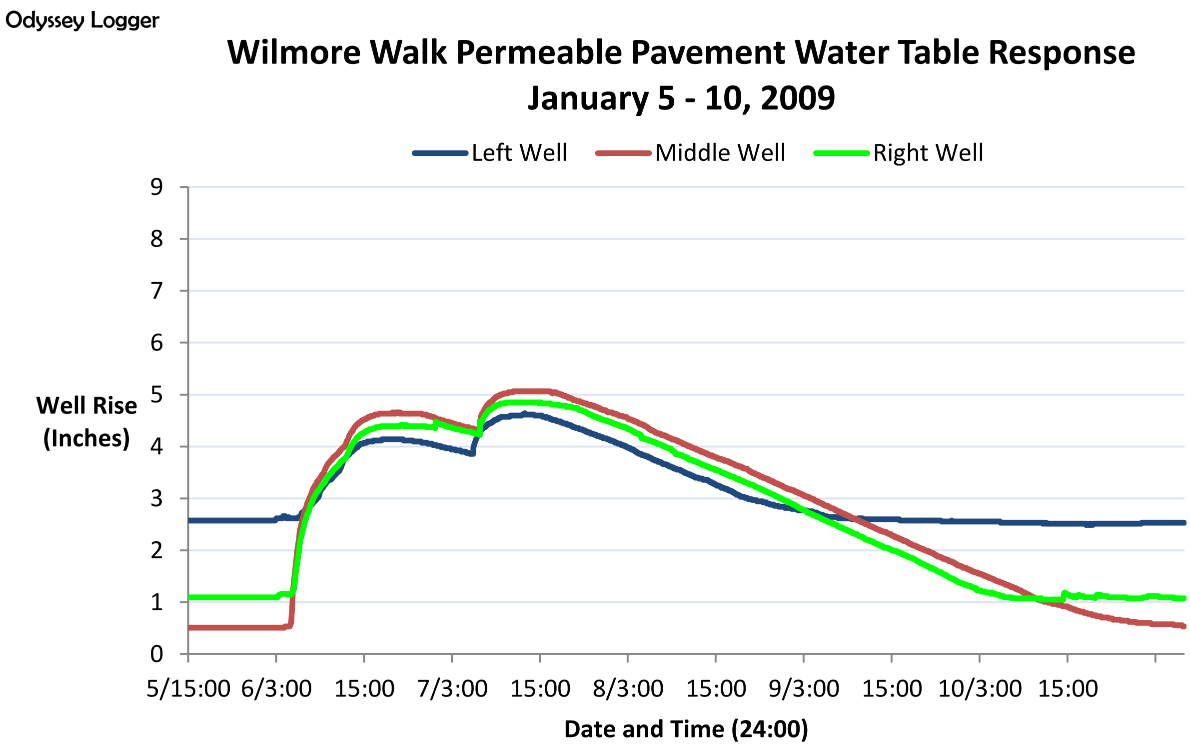
Wilmore Walk December 2008 Water Quality Results

Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
12/19	Bulk Precipitation	62.0	3.94	0.85	1.87	0.93	0.97	0.05	0.35
12/25	Bulk Precipitation	14.7	4.95	1.33	0.81	0.34	0.50	0.00	0.04
12/27	Bulk Precipitation	1.5	5.48	0.99	1.42	0.43	1.34	0.00	0.09
12/30	Bulk Precipitation	2.5	5.96	3.34	1.55	0.47	1.63	0.02	0.26

A.1-62: Wilmore Walk site bulk precipitation water quality results for December 2008 (Charlotte, NC).



A.1-64: Wilmore Walk permeable concrete structure water table response for 1.33” rain event occurring January 5, 2009, recorded with Global Transducer Loggers in 2 of 3 wells (Charlotte, NC).



A.1-65: Wilmore Walk permeable concrete structure water table response for 1.33” rain event occurring January 5, 2009, recorded with Odyssey Capacitance Loggers in all 3 wells (Charlotte, NC).

Rain Event Details for 1/6/09	
Precipitation Total (Inches)	1.33
Duration (Hours)	2.37
Peak 5 min Intensity (Inches/Hour)	0.03
Average Intensity (Inches/Hour)	0.12

Wilmore Walk Well Rise Results

Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	2.52	---	3.08	2.80
Porosity	0.53	---	0.42	0.48
Infiltration Uncorrected (Inches/Hour)	0.31	---	0.30	0.31
Infiltration Corrected (Inches/Hour)	0.16	---	0.13	0.15

Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	4.14	4.12	3.32	3.44
Porosity	0.32	0.32	0.40	0.40
Infiltration Uncorrected (Inches/Hour)	0.43	0.38	0.33	0.35
Infiltration Corrected (Inches/Hour)	0.14	0.12	0.13	0.14

Rain Event Details for 1/7/09	
Precipitation Total (Inches)	0.29
Duration (Hours)	5.78
Peak 5 min Intensity (Inches/Hour)	0.01
Average Intensity (Inches/Hour)	0.01

Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	2.52	---	3.68	3.10
Porosity	0.53	---	0.42	0.48
Infiltration Uncorrected (Inches/Hour)	0.07	---	0.07	0.07
Infiltration Corrected (Inches/Hour)	0.02	---	0.02	0.02

Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	0.78	0.76	0.56	1.66
Porosity	0.37	0.38	0.52	0.44
Infiltration Uncorrected (Inches/Hour)	0.05	0.05	0.04	0.06
Infiltration Corrected (Inches/Hour)	0.02	0.02	0.02	0.02

--- = No Data

A.1-66: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger) for January 6 and 7, 2007.

Overall Storm Event Results for January 6 and 7, 2009

Rain Event Details for 1/6-7/09	
Precipitation Total (Inches)	1.62
Duration (Hours)	8.15
Peak 5 min Intensity (Inches/Hour)	0.03
Average Intensity (Inches/Hour)	0.12

Wilmore Walk Well Rise Results

Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	3.84	---	3.59	3.72
Porosity	0.42	---	0.45	0.44
Infiltration Uncorrected (Inches/Hour)	0.07	---	0.06	0.07
Infiltration Corrected (Inches/Hour)	0.03	---	0.03	0.03

Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	4.64	4.56	3.75	4.08
Porosity	0.35	0.36	0.43	0.40
Infiltration Uncorrected (Inches/Hour)	0.08	0.06	0.05	0.06
Infiltration Corrected (Inches/Hour)	0.03	0.02	0.02	0.03

--- = No Data

Wilmore Walk January 7, 2009 Water Quality Results

Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	11.9	6.29	0.29	0.31	0.09	0.27	0.00	0.02
Left Well	105.6	6.10	3.13	1.53	1.00	0.00	0.17	0.61
Middle Well	123.1	6.38	0.98	0.32	0.22	0.00	0.00	0.04
Right Well	12.3	6.10	3.71	1.17	0.10	0.00	0.23	0.91

A.1-67: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for January

Wilmore Walk January 2009 Water Quality Results

Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
1/11	Bulk Precipitation	27.3	6.15	0.75	1.05	0.37	0.86	0.00	0.12
1/30	Bulk Precipitation	34.2	5.46	3.32	2.54	1.02	2.48	0.01	0.24

--- = No Data

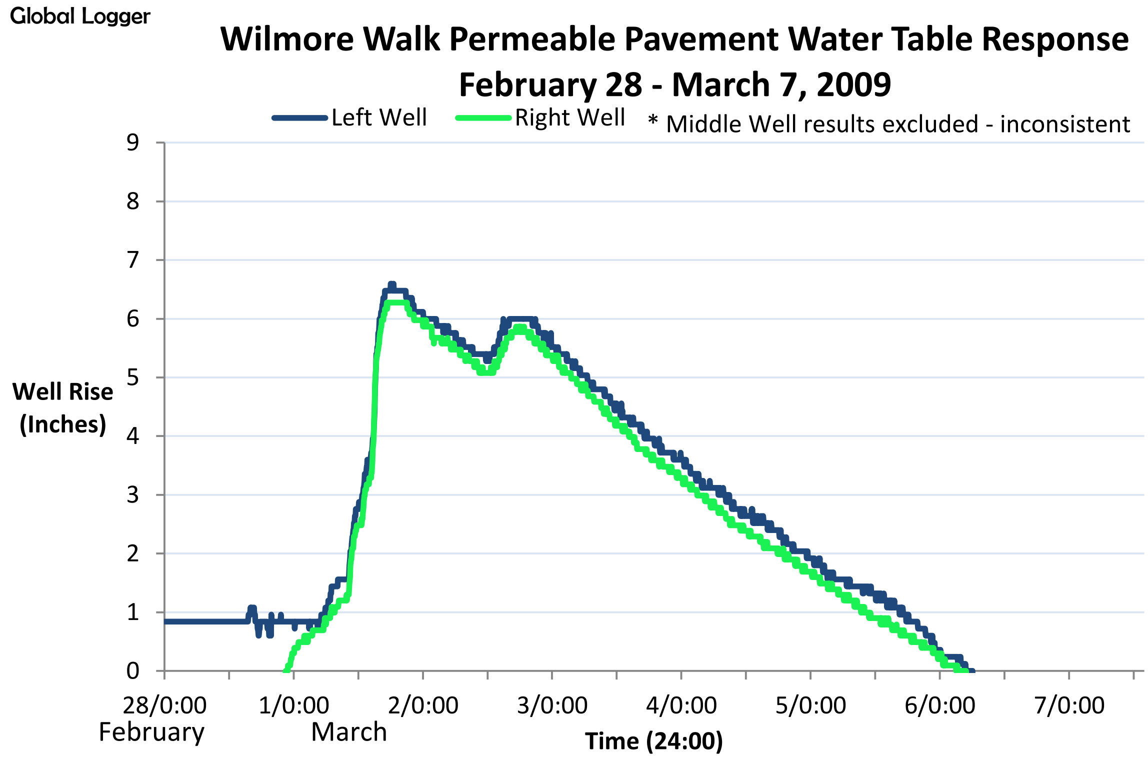
A.1-68: Wilmore Walk site bulk precipitation water quality results for January 2009 (Charlotte, NC).

February had no significant Well Response Results

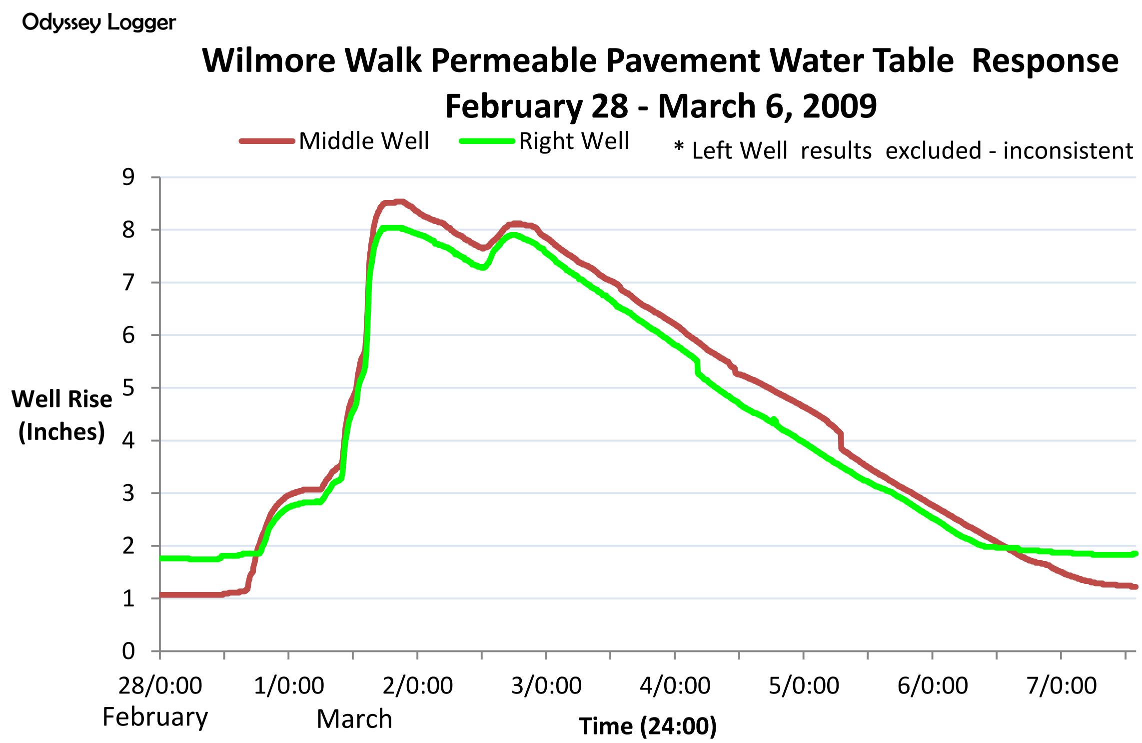
Wilmore Walk February 2009 Water Quality Results

Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
2/4	Bulk Precipitation	87.2	5.83	2.14	1.20	0.00	0.17	0.00	1.14
2/13	Bulk Precipitation	18.1	5.74	1.62	0.99	0.34	0.77	0.00	0.27
2/17	Bulk Precipitation	27.5	5.73	0.29	1.44	0.54	1.08	0.01	0.19

A.1-69: Wilmore Walk site bulk precipitation water quality results for February 2009 (Charlotte, NC).



A.1-70: Wilmore Walk permeable concrete structure water table response for 1.39” rain event occurring March 1, 2009, recorded with Global Transducer Loggers in 2 of 3 wells (Charlotte, NC).



A.1-71: Wilmore Walk permeable concrete structure water table response for 1.39” rain event occurring March 1, 2009, recorded with Odyssey Capacitance Loggers in 2 of 3 wells (Charlotte, NC).

Rain Event Details for 3/1/09

Precipitation Total (Inches)	1.39
Duration (Hours)	2.50
Peak 5 min Intensity (Inches/Hour)	0.01
Average Intensity (Inches/Hour)	0.09

Wilmore Walk Well Rise Results

Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	5.76	---	6.28	6.02
Porosity	0.24	---	0.22	0.23
Infiltration Uncorrected (Inches/Hour)	NC	---	NC	NC
Infiltration Corrected (Inches/Hour)	0.07	---	0.10	0.09

Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	---	7.47	6.28	6.45
Porosity	---	0.19	0.22	0.22
Infiltration Uncorrected (Inches/Hour)	---	NC	NC	NC
Infiltration Corrected (Inches/Hour)	---	0.09	0.09	0.09

Rain Event Details for 3/2/09

Precipitation Total (Inches)	0.56
Duration (Hours)	6.50
Peak 5 min Intensity (Inches/Hour)	0.01
Average Intensity (Inches/Hour)	0.22

Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	0.60	---	0.79	0.70
Porosity	NC	---	NC	NC
Infiltration Uncorrected (Inches/Hour)	0.01	---	0.01	0.01
Infiltration Corrected (Inches/Hour)	0.01	---	0.01	0.01

Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	---	1.85	0.62	0.97
Porosity	---	0.30	NC	0.30
Infiltration Uncorrected (Inches/Hour)	---	0.25	0.07	0.09
Infiltration Corrected (Inches/Hour)	---	0.08	0.06	0.04

--- = No Data

A.1-72: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for March 1 and 2, 2009.

Overall Storm Event Results for February 28 - March 2, 2009

Rain Event Details for 2/28-3/2/09	
Precipitation Total (Inches)	2.81
Duration (Hours)	48.90
Peak 5 min Intensity (Inches/Hour)	0.01
Average Intensity (Inches/Hour)	0.06

Wilmore Walk Well Rise Results

Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	6.00	---	5.87	5.94
Porosity	0.33	---	0.33	0.33
Infiltration Uncorrected (Inches/Hour)	0.08	---	0.08	0.08
Infiltration Corrected (Inches/Hour)	0.03	---	0.03	0.03

Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	---	6.84	6.05	6.19
Porosity	---	0.29	0.32	0.32
Infiltration Uncorrected (Inches/Hour)	---	0.06	0.06	0.07
Infiltration Corrected (Inches/Hour)	---	0.02	0.02	0.03

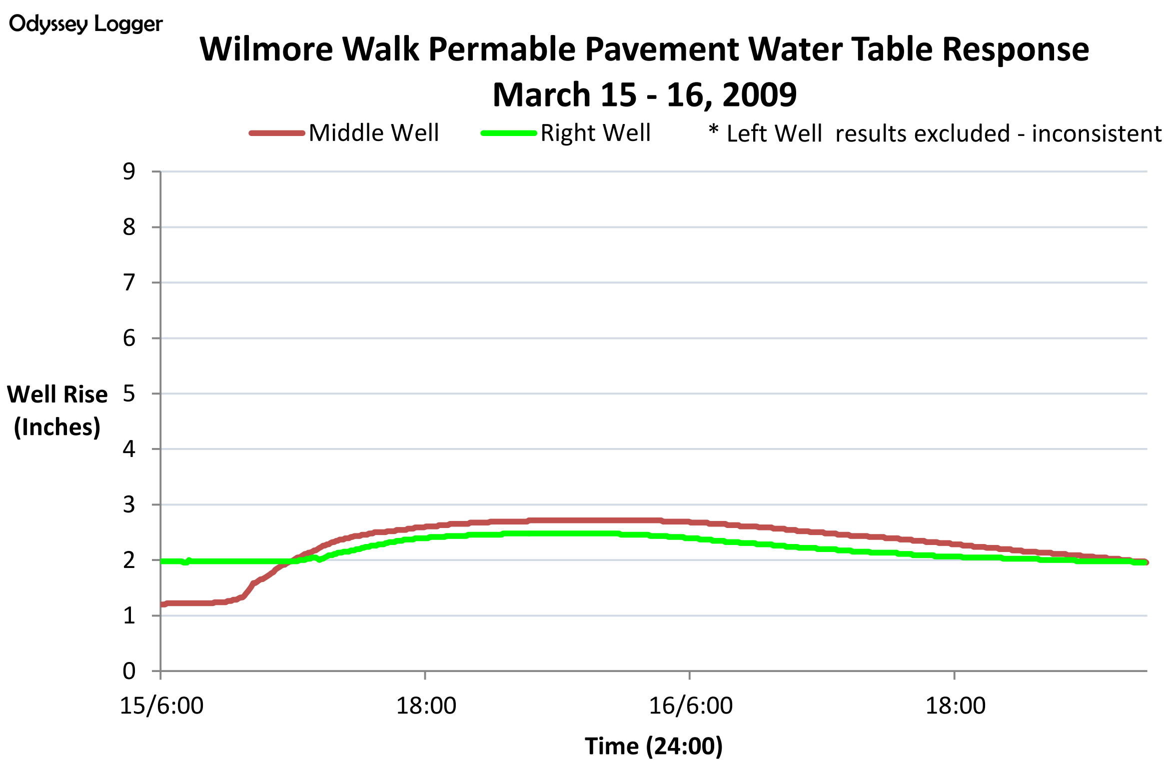
--- = No Data

Wilmore Walk March 2, 2009 Water Quality Results

Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	5.5	6.13	0.45	0.29	0.23	0.23	0.01	0.04
Left Well	90.2	6.30	0.20	0.20	0.13	0.00	0.01	0.19
Middle Well	---	---	---	---	---	---	---	---
Right Well	34.8	6.26	0.08	0.25	0.00	0.00	0.01	0.36

--- = No Data

A.1-73: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for February 28-March 2, 2009.



A.1-74: Wilmore Walk permeable concrete structure water table response for 0.53" rain event occurring March 15, 2009, recorded with Odyssey Capacitance Loggers in 2 of 3 wells (Charlotte, NC).

Rain Event Details for 3/15/09		Odyssey Logger	Left Well	Middle Well	Right Well	Average
Precipitation Total (Inches)	0.53	**Total Rise** (Inches)	---	1.52	2.46	1.99
Duration (Hours)	17.38	**Porosity**	---	0.35	0.22	0.29
Peak 5 min Intensity (Inches/Hour)	0.00	**Infiltration Uncorrected** (Inches/Hour)	---	0.07	0.10	0.09
Average Intensity (Inches/Hour)	0.03	**Infiltration Corrected** (Inches/Hour)	---	0.02	0.02	0.02

Wilmore Walk Well Rise Results

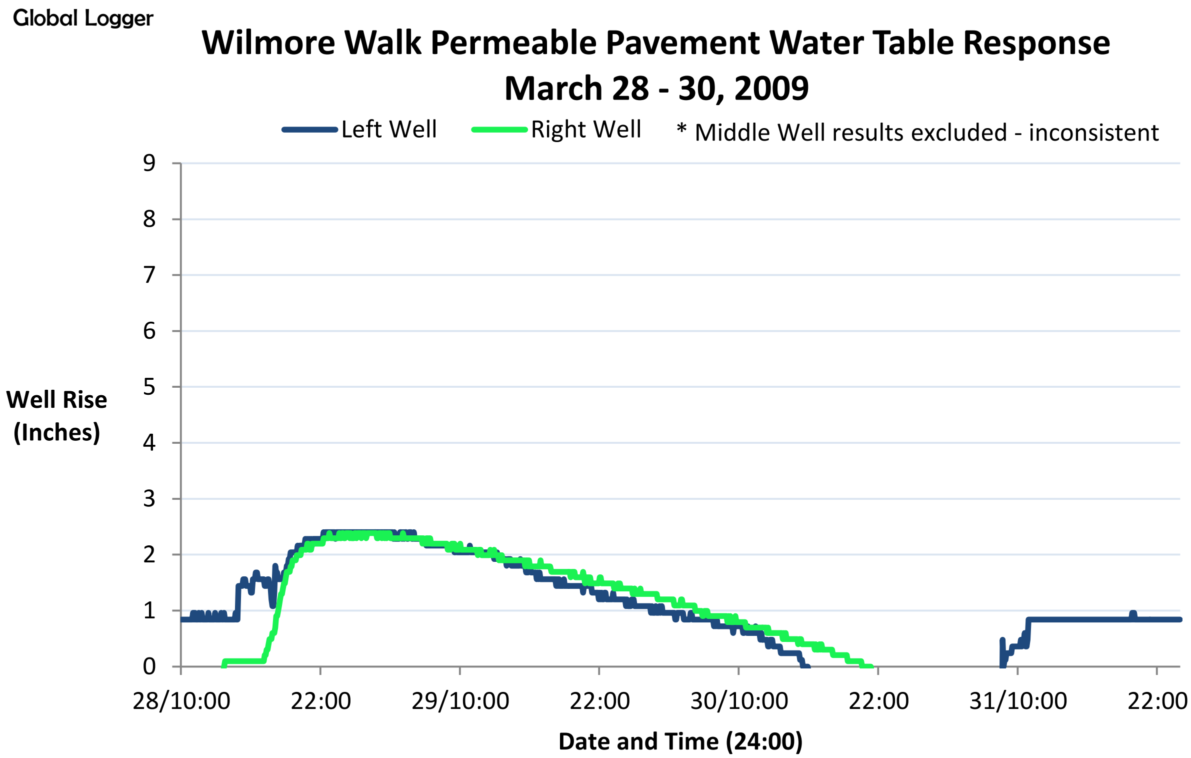
--- = No Data

Wilmore Walk March 15, 2009 Water Quality Results

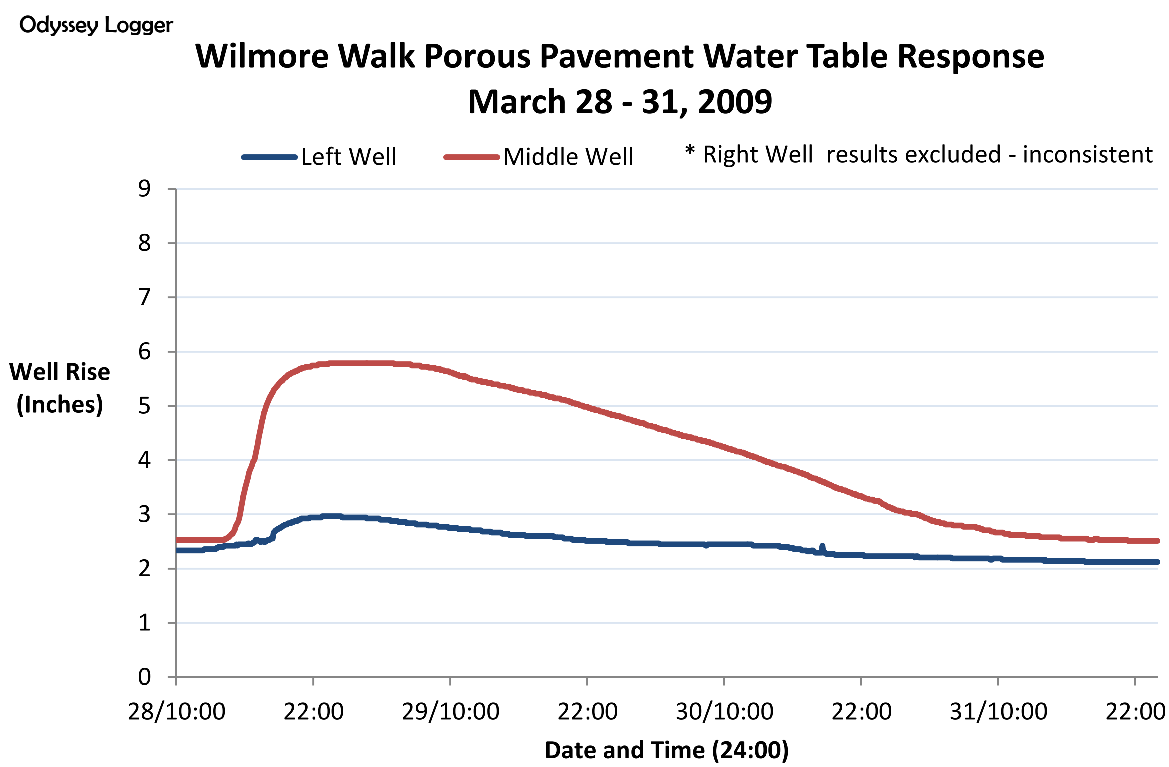
Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	22.2	5.13	2.14	0.85	0.44	0.2	1.43	1.1
Reservoir (Wells)	---	---	---	---	---	---	---	---

--- = No Data

A.1-75: Wilmore Walk permeable concrete structure well rise details (Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for March 15, 2009.



A.1-76: Wilmore Walk permeable concrete structure water table response for 0.94” rain event occurring March 28, 2009, recorded with Global Transducer Loggers in 2 of 3 wells (Charlotte, NC).



A.1-77: Wilmore Walk permeable concrete structure water table response for 0.94” rain event occurring March 28, 2009, recorded with Odyssey Capacitance Loggers in 2 of 3 wells (Charlotte, NC).

Rain Event Details for 3/27/09

Precipitation Total (Inches)	0.94
Duration (Hours)	8.04
Peak 5 min Intensity (Inches/Hour)	0.01
Average Intensity (Inches/Hour)	0.12

Wilmore Walk Well Rise Results

Global Logger	Left Well	Middle Well	Right Well	Average
Total Rise (Inches)	2.40	---	2.38	2.39
Porosity	0.39	---	0.39	0.39
Infiltration Uncorrected (Inches/Hour)	0.07	---	0.06	0.07
Infiltration Corrected (Inches/Hour)	0.03	---	0.02	0.03

Odyssey Logger	Left Well	Middle Well	Right Well	Total Average
Total Rise (Inches)	2.97	3.25	---	2.75
Porosity	0.32	0.29	---	0.35
Infiltration Uncorrected (Inches/Hour)	0.06	0.06	---	0.06
Infiltration Corrected (Inches/Hour)	0.02	0.02	---	0.02

--- = No Data

Wilmore Walk March 28, 2009 Water Quality Results

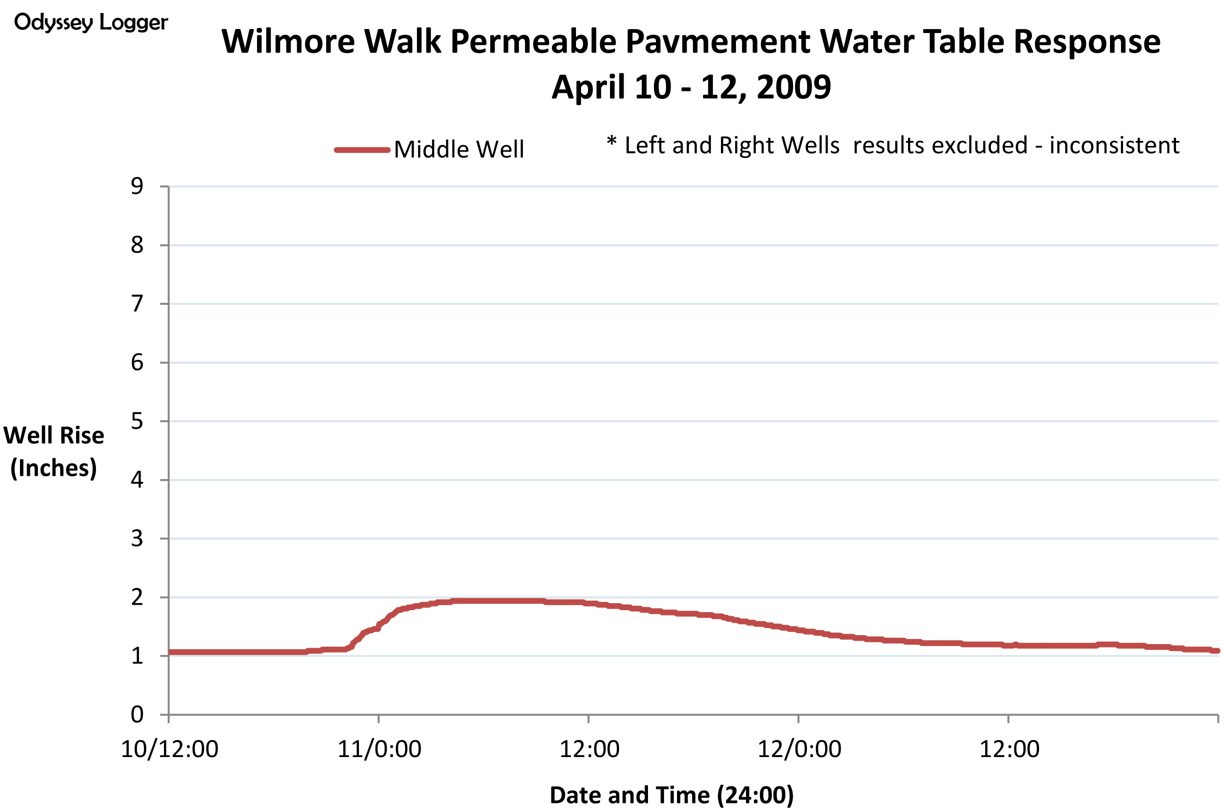
Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	22.2	5.13	2.14	0.85	0.44	0.20	1.43	1.10
Reservoir (Wells)	---	---	---	---	---	---	---	---

--- = No Data

A.1-79: Wilmore Walk permeable concrete structure well rise details (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for March 28, 2009.

Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
3/26	Bulk Precipitation	21.80	4.74	0.31	1.93	0.89	1.26	0.03	0.24
3/30	Bulk Precipitation	13.50	5.41	0.90	0.91	0.31	0.58	0.07	0.37

A.1-78: Wilmore Walk site bulk precipitation water quality results for March 2009 (Charlotte, NC).



A.1-80: Wilmore Walk permeable concrete structure water table response for 0.80" rain event occurring April 11, 2009, recorded with a Odyssey Capacitance Logger in 1 of 3 wells (Charlotte, NC).

Rain Event Details for 4/11/09		Wilmore Walk Well Rise Results: Odyssey Logger	Left Well	Middle Well	Right Well	Average
Precipitation Total (Inches)	0.80	Total Rise (Inches)	---	1.84	---	1.84
Duration (Hours)	19.22	Porosity	---	0.41	---	0.41
Peak 5 min Intensity (Inches/Hour)	0.03	Infiltration Uncorrected (Inches/Hour)	---	0.05	---	0.05
Average Intensity (Inches/Hour)	0.04	Infiltration Corrected (Inches/Hour)	---	0.02	---	0.02

--- = No Data

Wilmore Walk April 11, 2009 Water Quality Results

Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	26.7	4.88	0.68	1.88	0.3	1.71	0.15	0.71
Reservoir (Wells)	---	---	---	---	---	---	---	---

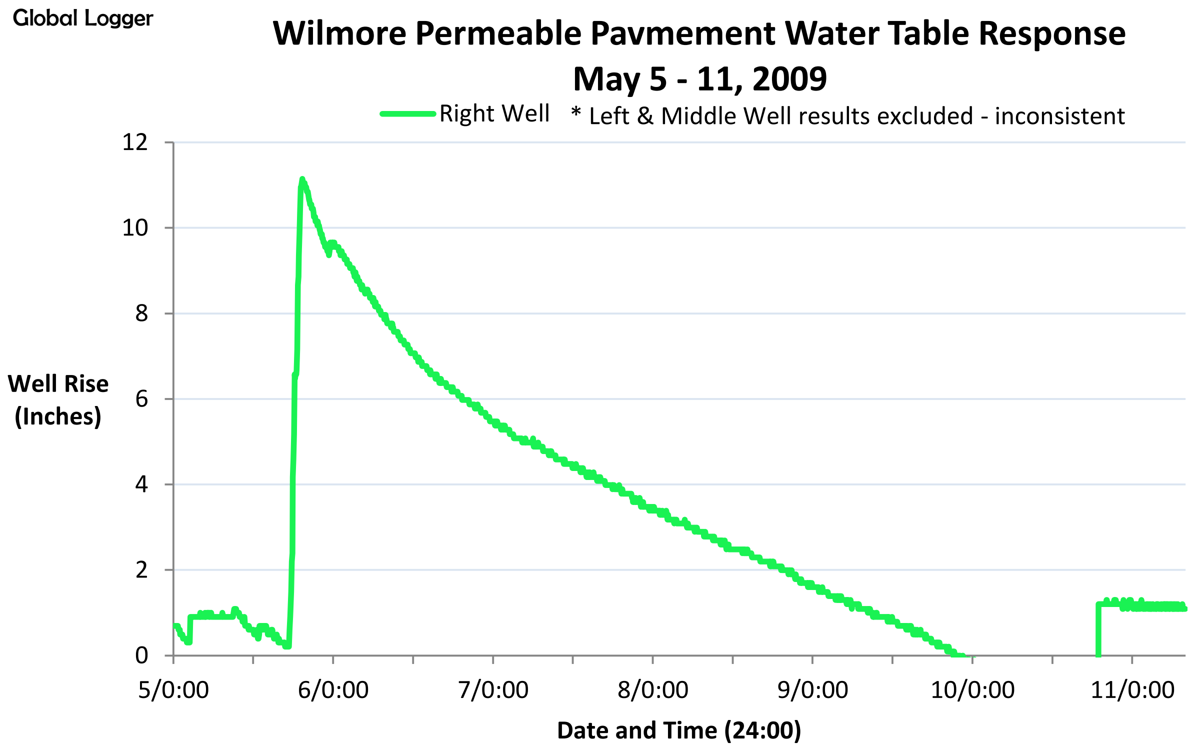
--- = No Data

A.1-81: Wilmore Walk permeable concrete structure well rise details (Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for April 11, 2009.

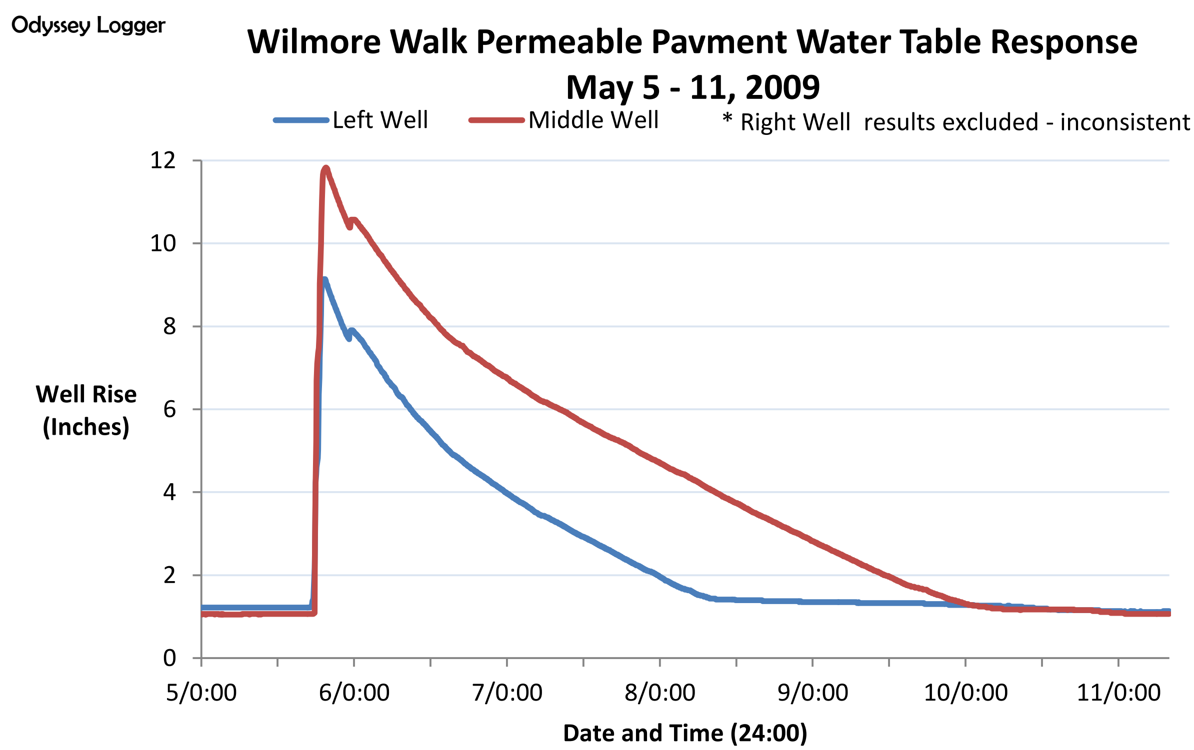
Wilmore Walk April 2009 Water Quality Results

Date	Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
4/5	Bulk Precipitation	1.1	4.78	0.64	3.95	0.37	4.15	0.41	3.04
4/23	Bulk Precipitation	56.9	4.93	3.16	6.39	0.60	0.14	0.31	3.76

A.1-82: Wilmore Walk site bulk precipitation water quality results for April 2009 (Charlotte, NC).



A.1-83: Wilmore Walk permeable concrete structure water table response for 2.61” rain event occurring May 5, 2009, recorded with a Global Transducer Logger in 1 of 3 wells (Charlotte, NC).



A.1-84: Wilmore Walk permeable concrete structure water table response for 2.61” rain event occurring May 5, 2009, recorded with Odyssey Capacitance Loggers in 2 of 3 wells (Charlotte, NC).

Rain Event Details for 5/5/09

Precipitation Total (Inches)	2.61
Duration (Hours)	18.67
Peak 5 min Intensity (Inches/Hour)	0.06
Average Intensity (Inches/Hour)	0.14

Wilmore Walk Well Rise Results

Global Logger	**Left Well**	**Middle Well**	**Right Well**	**Average**
Total Rise (Inches)	---	---	10.05	10.05
Porosity	---	---	0.26	0.26
Infiltration Uncorrected (Inches/Hour)	---	---	0.10	0.10
Infiltration Corrected (Inches/Hour)	---	---	0.03	0.03

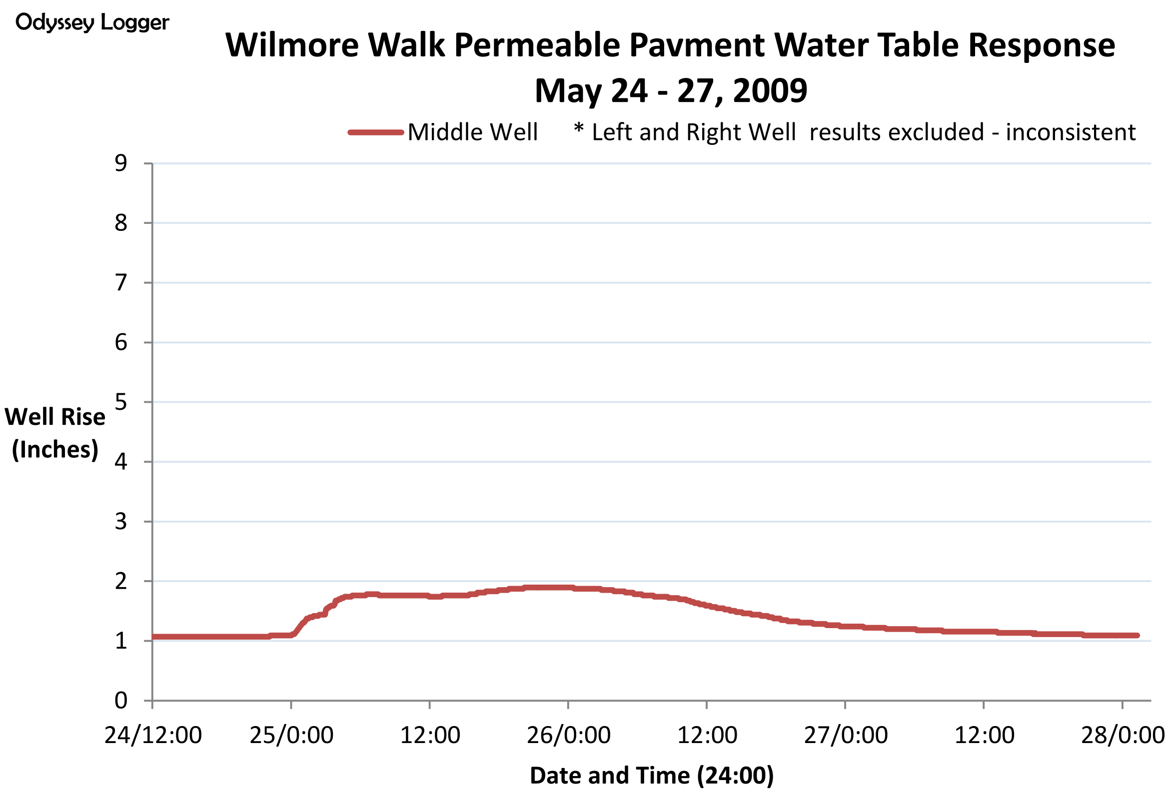
Odyssey Logger	**Left Well**	**Middle Well**	**Right Well**	**Total Average**
Total Rise (Inches)	7.92	10.76	---	9.58
Porosity	0.33	0.24	---	0.28
Infiltration Uncorrected (Inches/Hour)	0.14	0.11	---	0.12
Infiltration Corrected (Inches/Hour)	0.05	0.03	---	0.04

--- = No Data

Wilmore Walk May 5, 2009 Water Quality Results

Sample	Conductivity (µs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	7.3	4.44	0.01	0.14	1.02	0.19	0.00	0.23
Left Well	3.2	5.71	0.03	0.24	15.63	1.58	4.87	0.09
Middle Well	144	5.98	0.00	0.28	15.34	1.71	5.46	0.15
Right Well	59.5	5.72	0.06	0.15	6.40	1.04	2.12	0.23

A.1-85: Wilmore Walk permeable concrete structure well rise results (Global Transducer Logger & Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for May 5, 2009.



A.1-86: Wilmore Walk permeable concrete structure water table response for 0.70” rain event occurring May 25, 2008, recorded with a Odyssey Capacitance Logger in 1 of 3 wells (Charlotte, NC).

Rain Event Details for 5/24/09		**Wilmore Walk Well Rise Results**				
		Odyssey Logger	**Left Well**	**Middle Well**	**Right Well**	**Average**
Precipitation Total (Inches)	0.70	**Total Rise** (Inches)	---	0.82	---	0.82
Duration (Hours)	12.43	**Porosity**	---	0.29	---	0.29
Peak 5 min Intensity (Inches/Hour)	0.02	**Infiltration Uncorrected** (Inches/Hour)	---	0.02	---	0.02
Average Intensity (Inches/Hour)	0.06	**Infiltration Corrected** (Inches/Hour)	---	0.01	---	0.01

--- = No Data

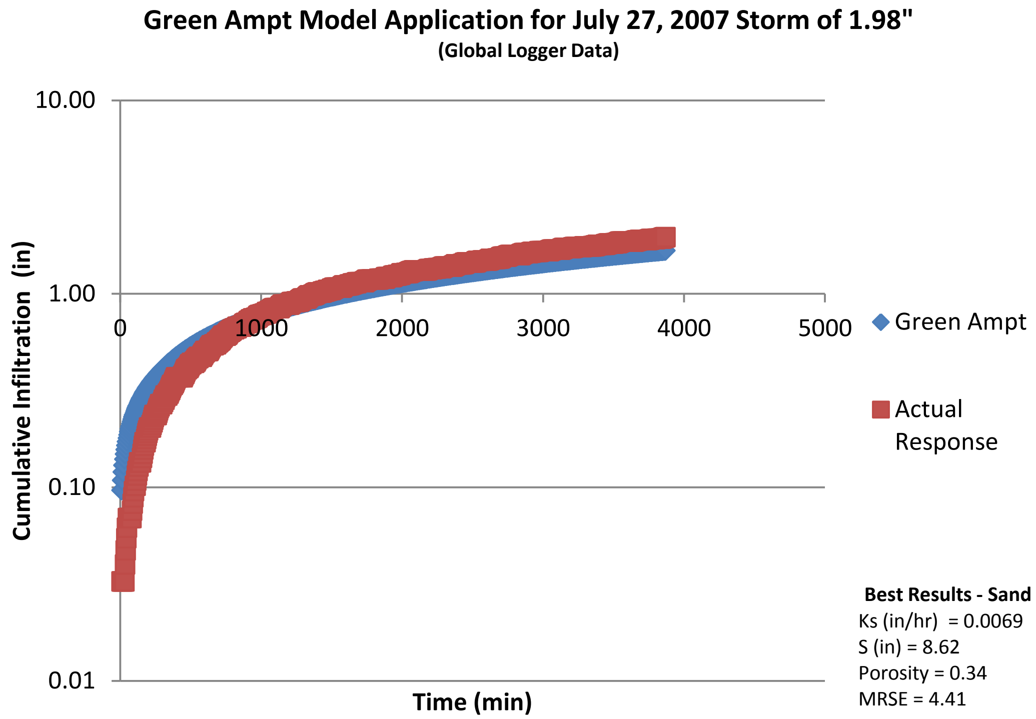
Wilmore Walk May 24, 2009 Water Quality Results

Sample	Conductivity (μs/cm)	pH	Cl^- (mg/L)	TDN	NO_3-N (mg/L)	NH_4^+-N (mg/L)	PO_4-P (mg/L)	TP (PO_4^{-3}) (mg/L)
Bulk Precipitation	---	---	---	---	---	---	---	---
Reservoir (Wells)	---	---	---	---	---	---	---	---

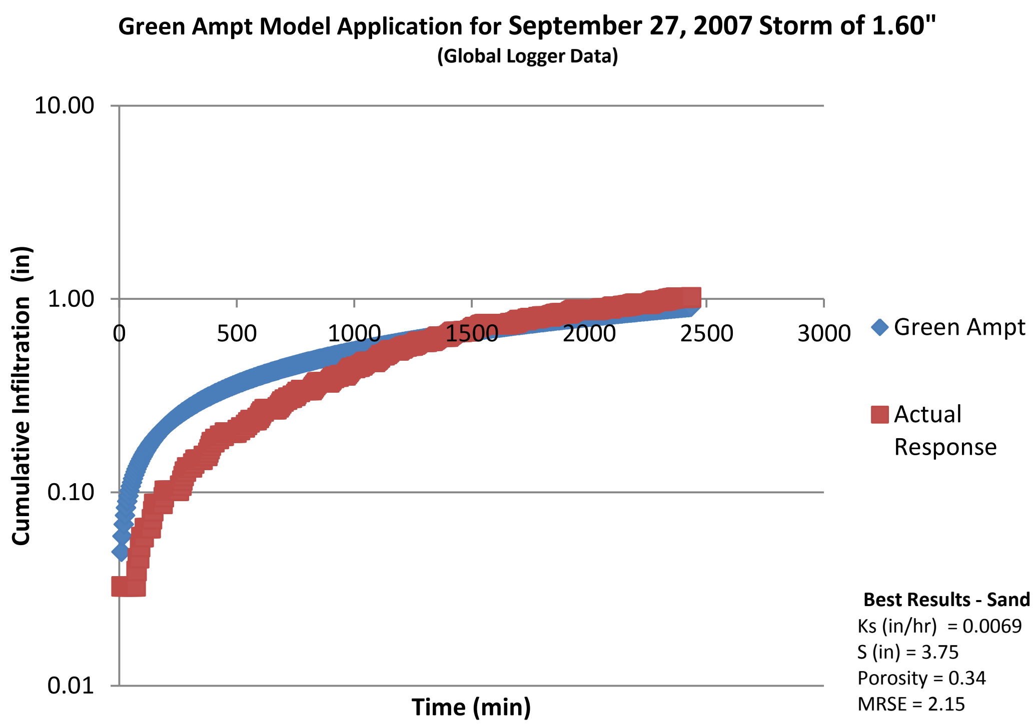
--- = No Data

A.1-87: Wilmore Walk permeable concrete structure well rise details (Odyssey Capacitance Logger), rain event details (Hobo Logger), and water quality results for May 24, 2009.

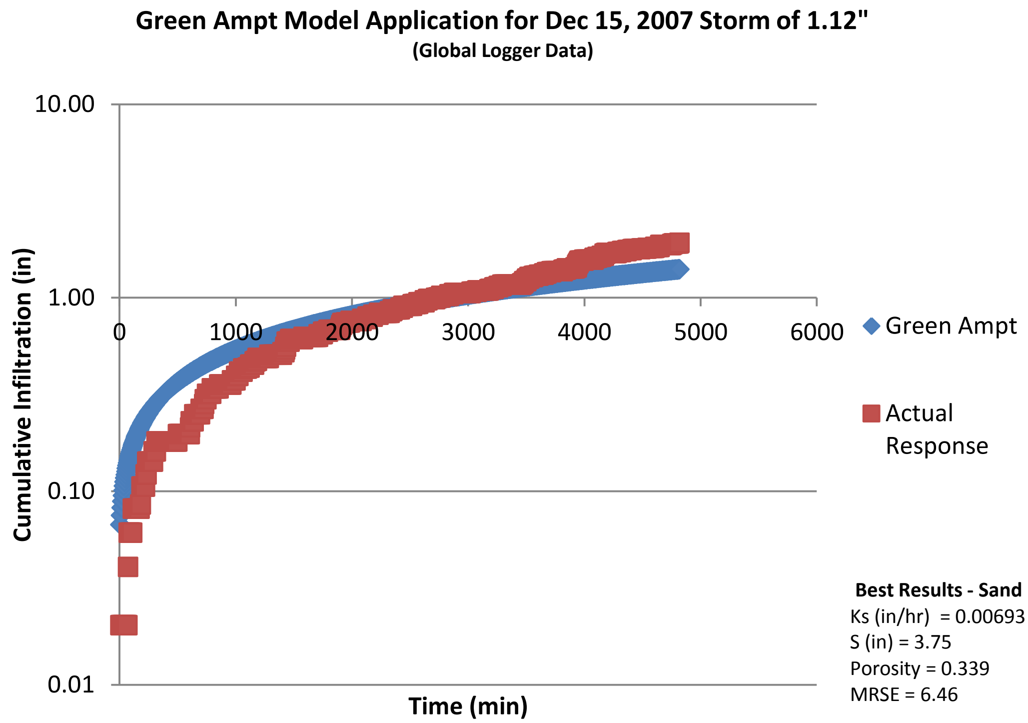
Appendix 2: Green Ampt Results for Wilmore Walk Sub-basin



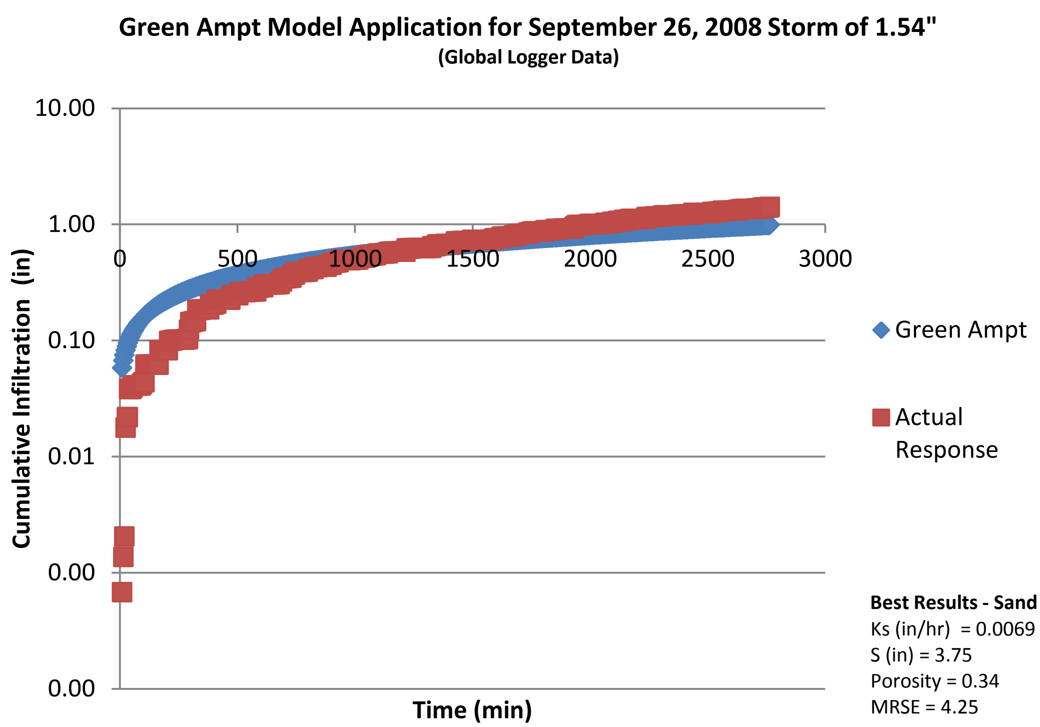
A.2-1: Green Ampt Model Application for July 27, 2007 Storm of 1.98" Precipitation with Prior Dry Conditions at Wilmore Walk Watershed in Charlotte, NC (Global Logger Data).



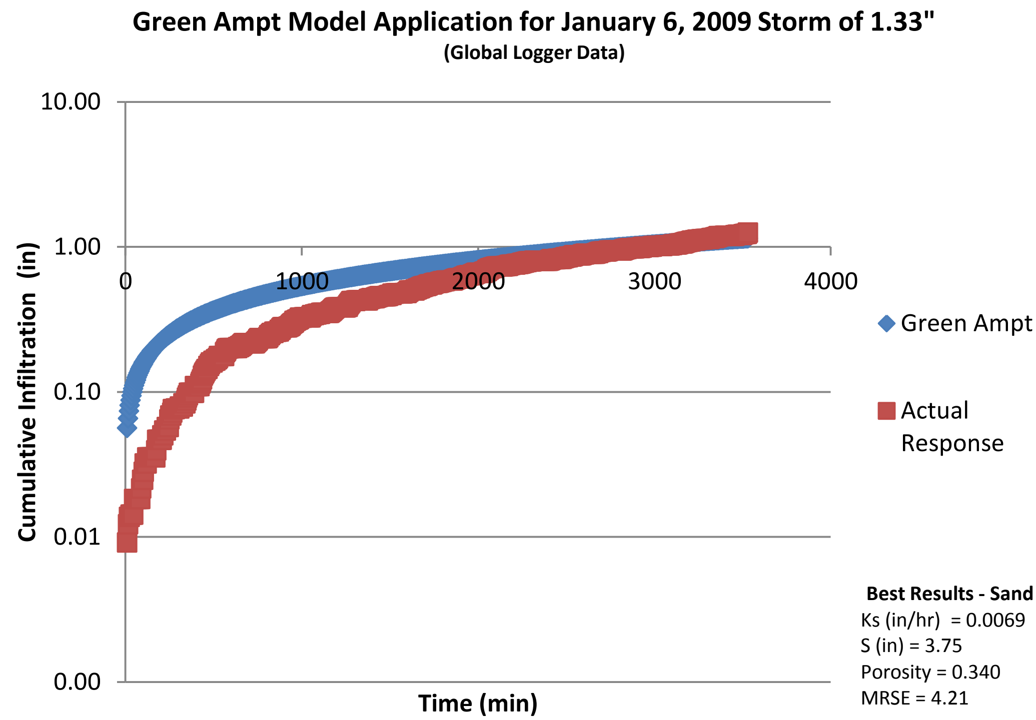
A.2-2: Green Ampt Model Application for September 27, 2007 Storm of 1.60" Precipitation with Prior Dry Conditions at Wilmore Walk Watershed in Charlotte, NC (Global Logger Data).



A.2-3: Green Ampt Model Application for December 15, 2007 Storm of 1.12" Precipitation with Prior Dry Conditions at Wilmore Walk Watershed in Charlotte, NC (Global Logger Data).



A.2-4: Green Ampt Model Application for September 26, 2008 Storm of 1.54" Precipitation with Prior Dry Conditions at Wilmore Walk Watershed in Charlotte, NC (Global Logger Data).



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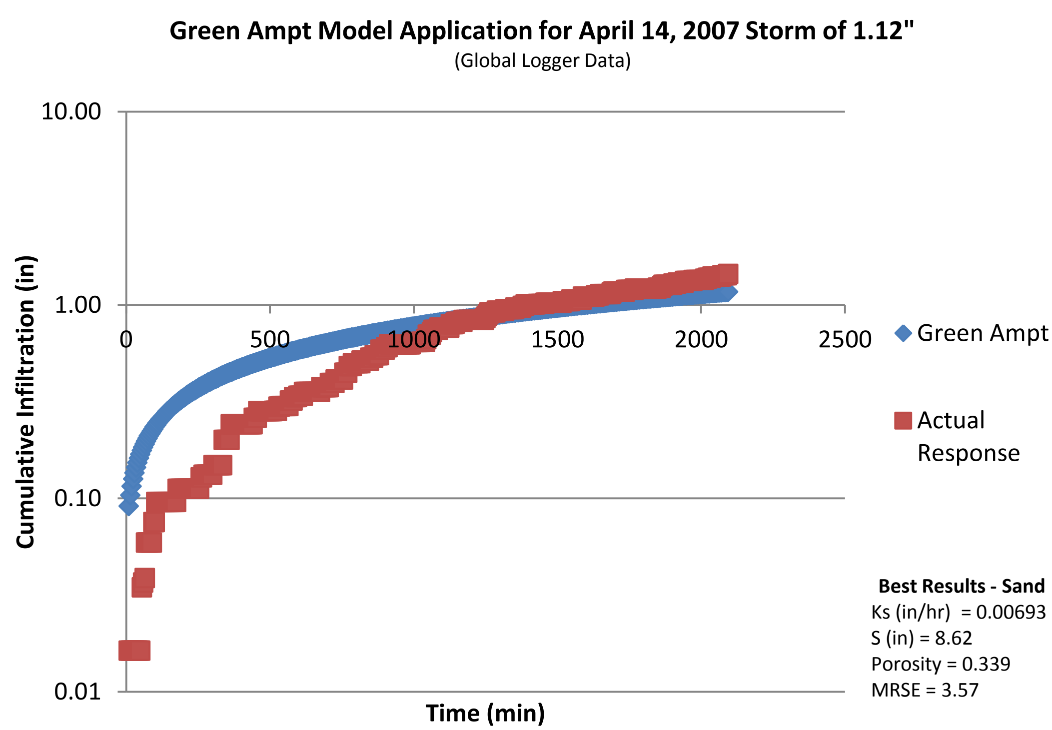
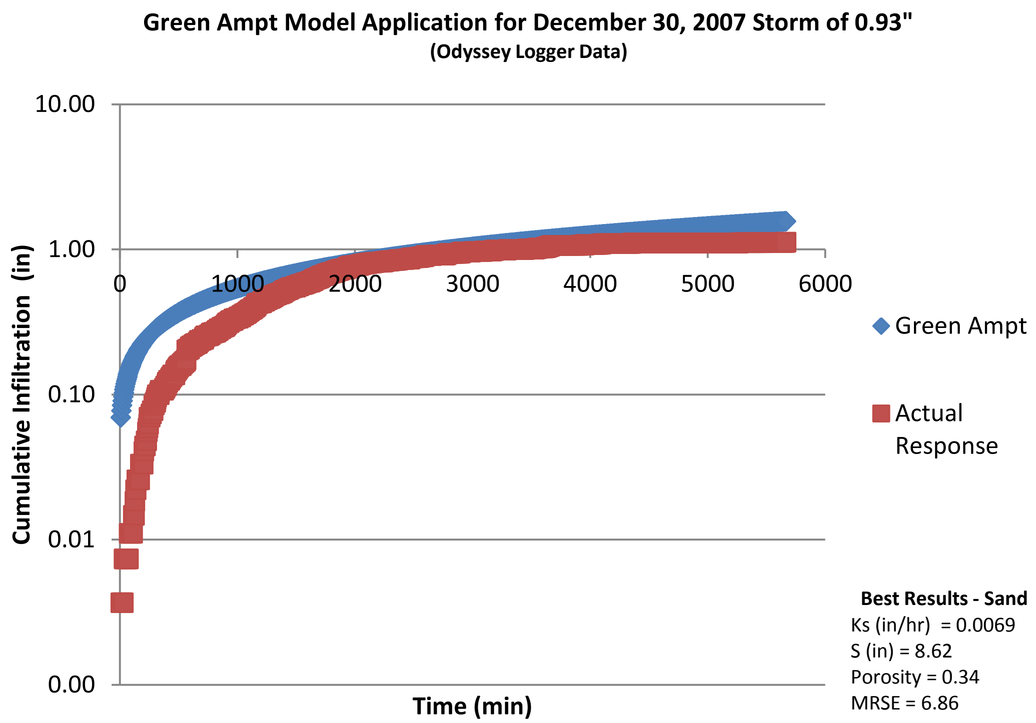
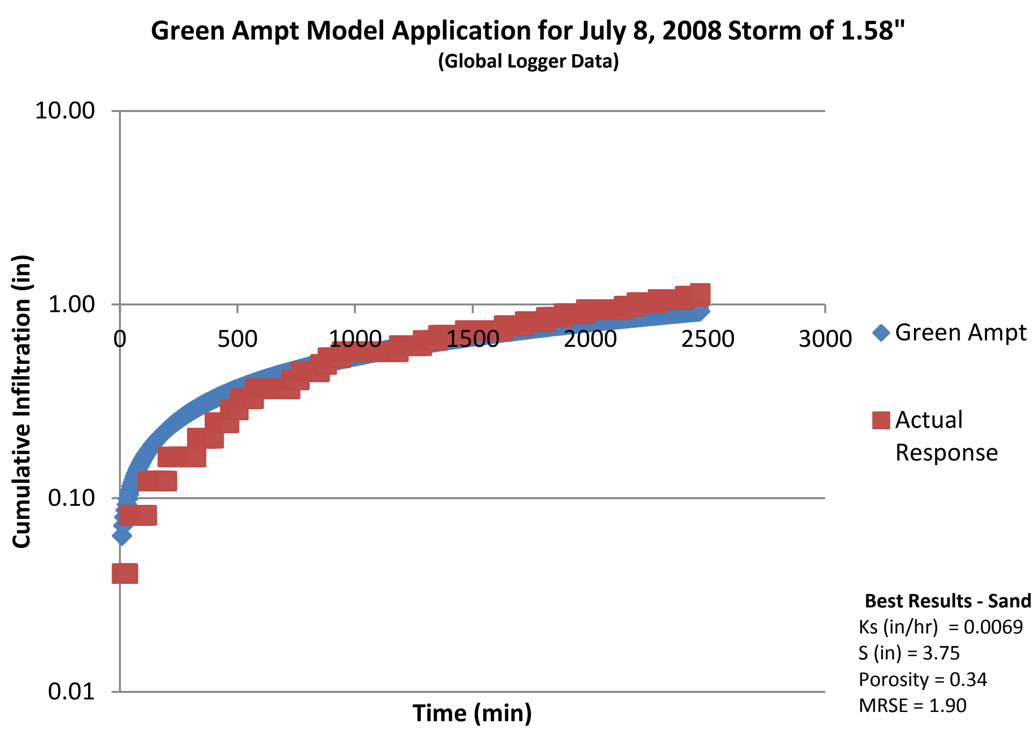
A.2-5: Green Ampt Model Application for January 6, 2009 Storm of 1.33" Precipitation with Prior Dry Conditions at Wilmore Walk Watershed in Charlotte, NC (Global Logger Data).



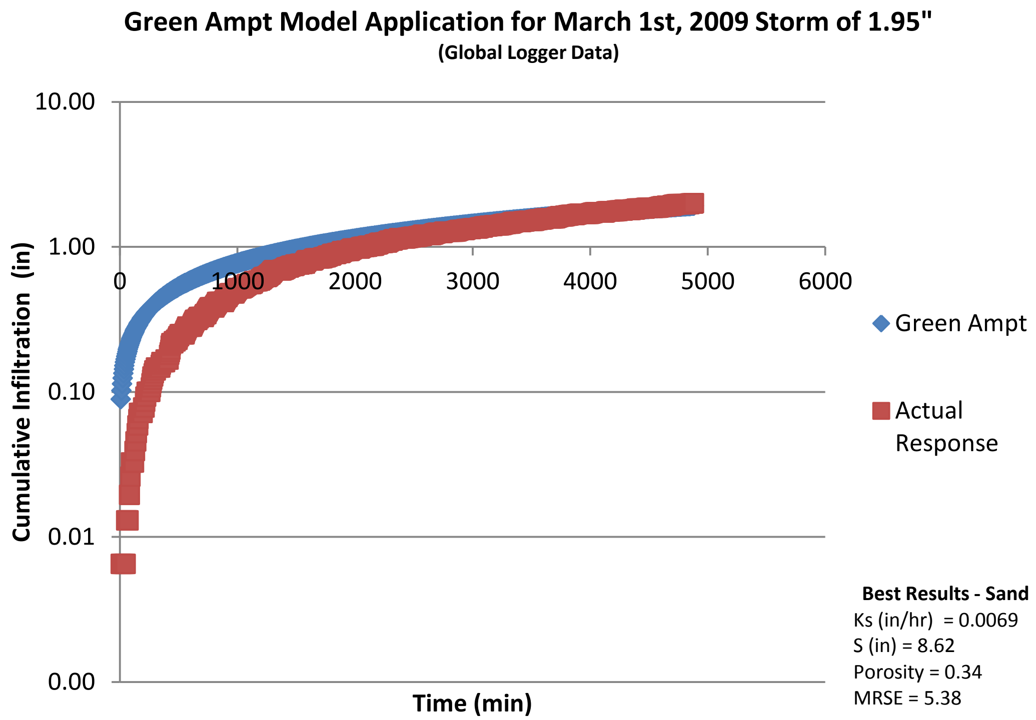
A.2-6: Green Ampt Model Application for April 14, 2007 Storm of 1.12" Precipitation with Prior Wet Conditions at Wilmore Walk Watershed in Charlotte, NC (Global Logger Data).



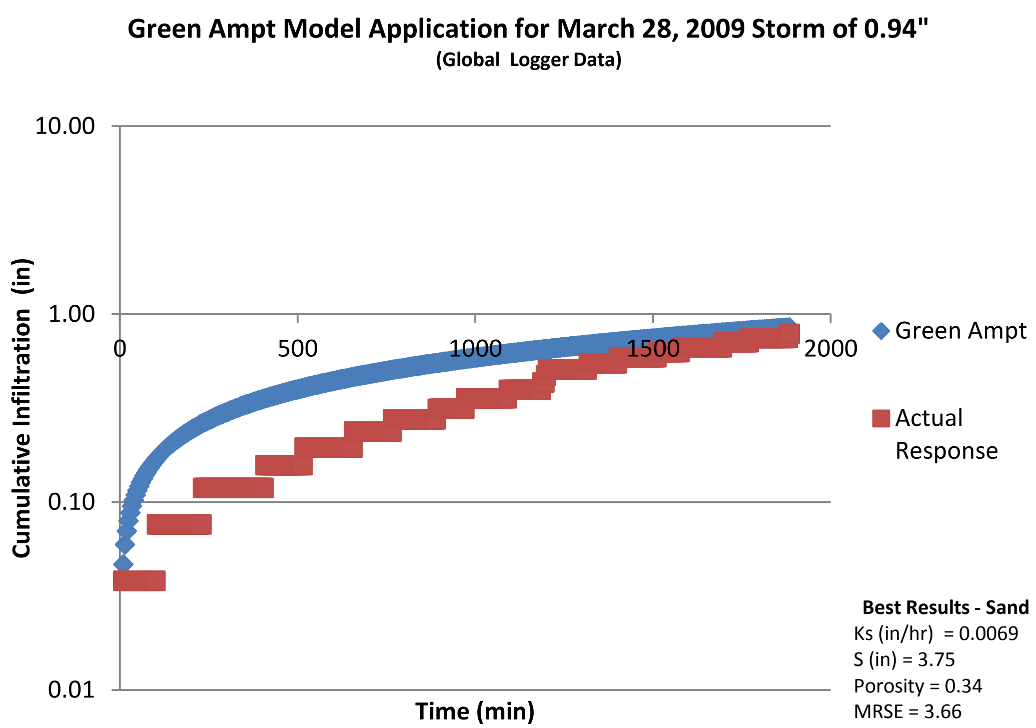
A.2-7: Green Ampt Model Application for December 30, 2007 Storm of 0.93" Precipitation with Prior Wet Conditions at Wilmore Walk Watershed in Charlotte, NC (Odyssey Logger Data).



A.2-8: Green Ampt Model Application for July 8, 2008 Storm of 1.58" Precipitation with Prior Wet Conditions at Wilmore Walk Watershed in Charlotte, NC (Global Logger Data).

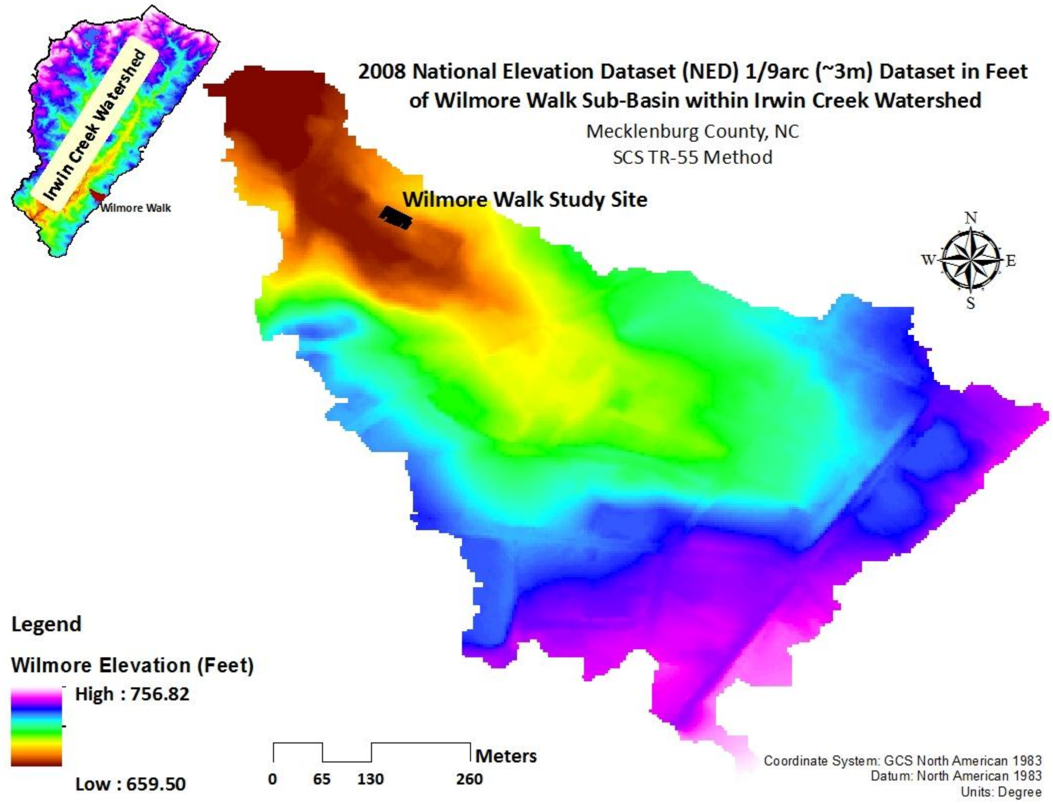


A.2-9: Green Ampt Model Application for March 1st, 2009 Storm of 1.95" Precipitation with Prior Wet Conditions at Wilmore Walk Watershed in Charlotte, NC (Global Logger Data).

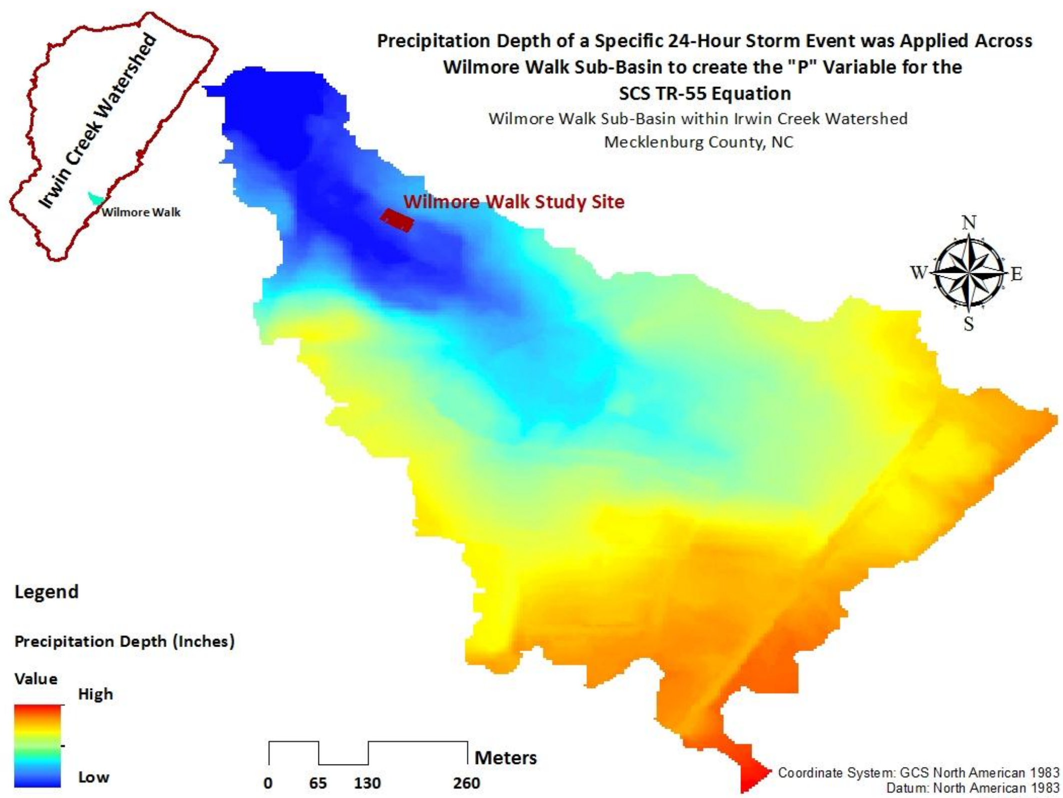


A.2-10: Green Ampt Model Application for March 28, 2009 Storm of 0.94" Precipitation with Prior Wet Conditions at Wilmore Walk Watershed in Charlotte, NC (Global Logger Data).

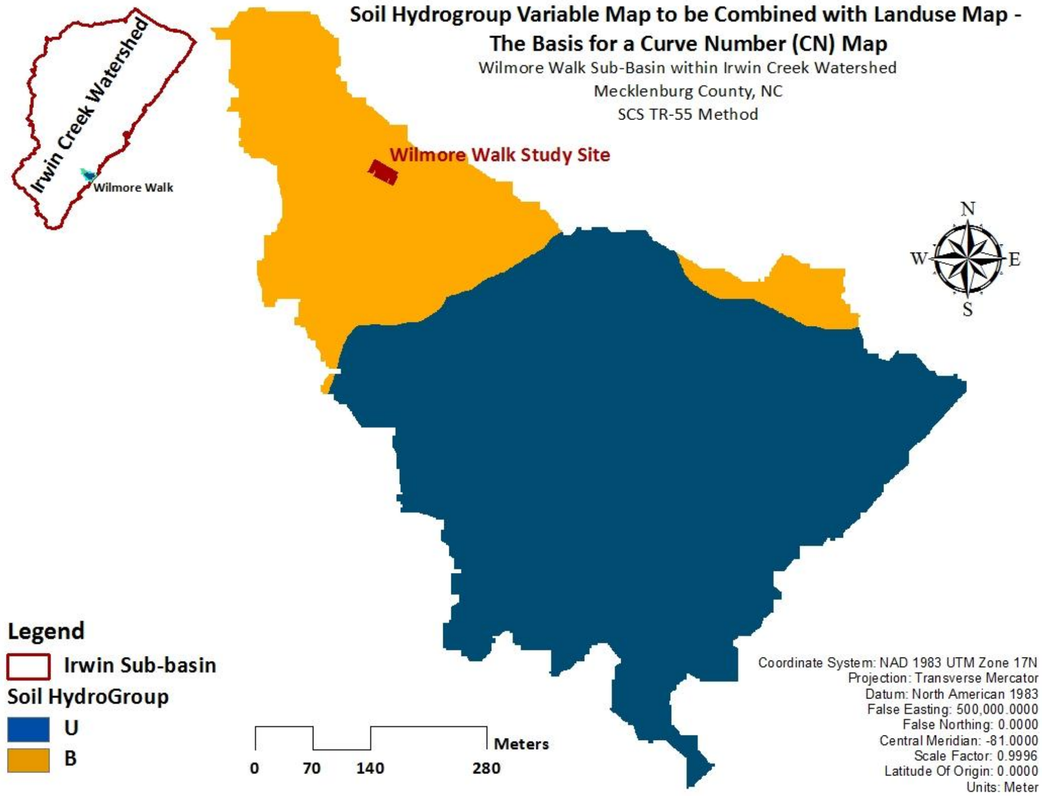
Appendix 3: ArcGIS© Map Results of SCS TR-55 Application for Wilmore Walk Sub-basin



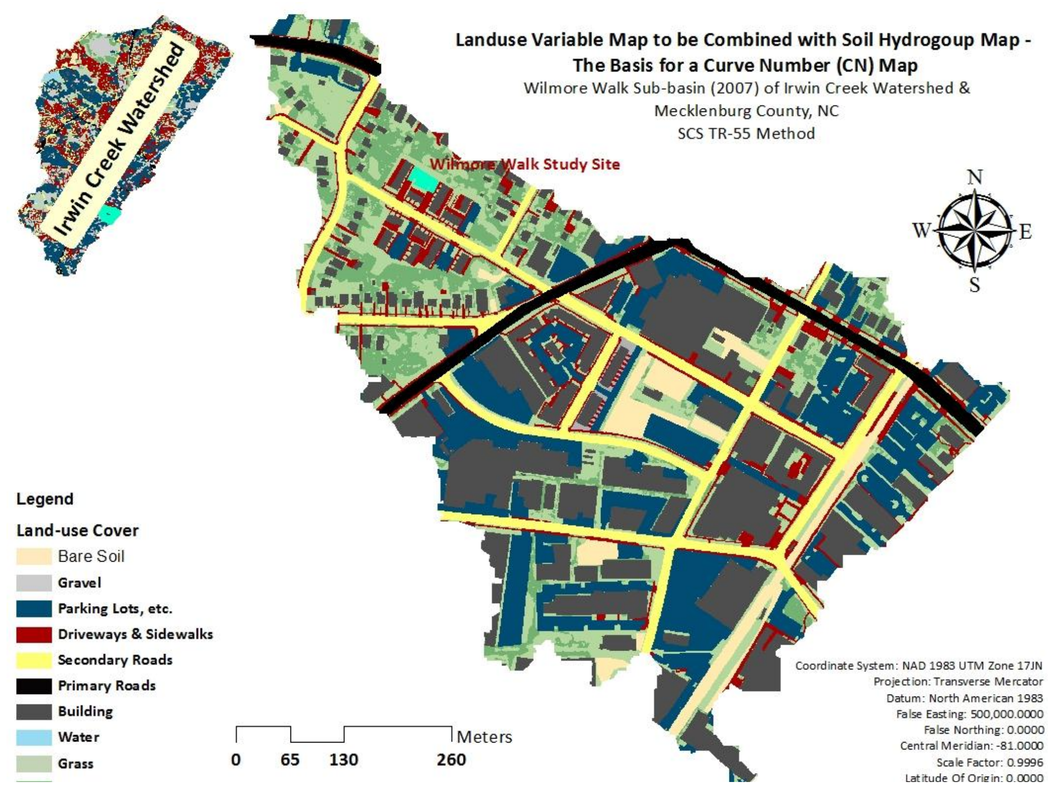
A.3-1: 2008 National Elevation Dataset (NED) 1/9arc (Approximately 3m resolution) with elevation shown in feet of Wilmore Walk Sub-basin with Irwin Creek Watershed in Charlotte, NC.



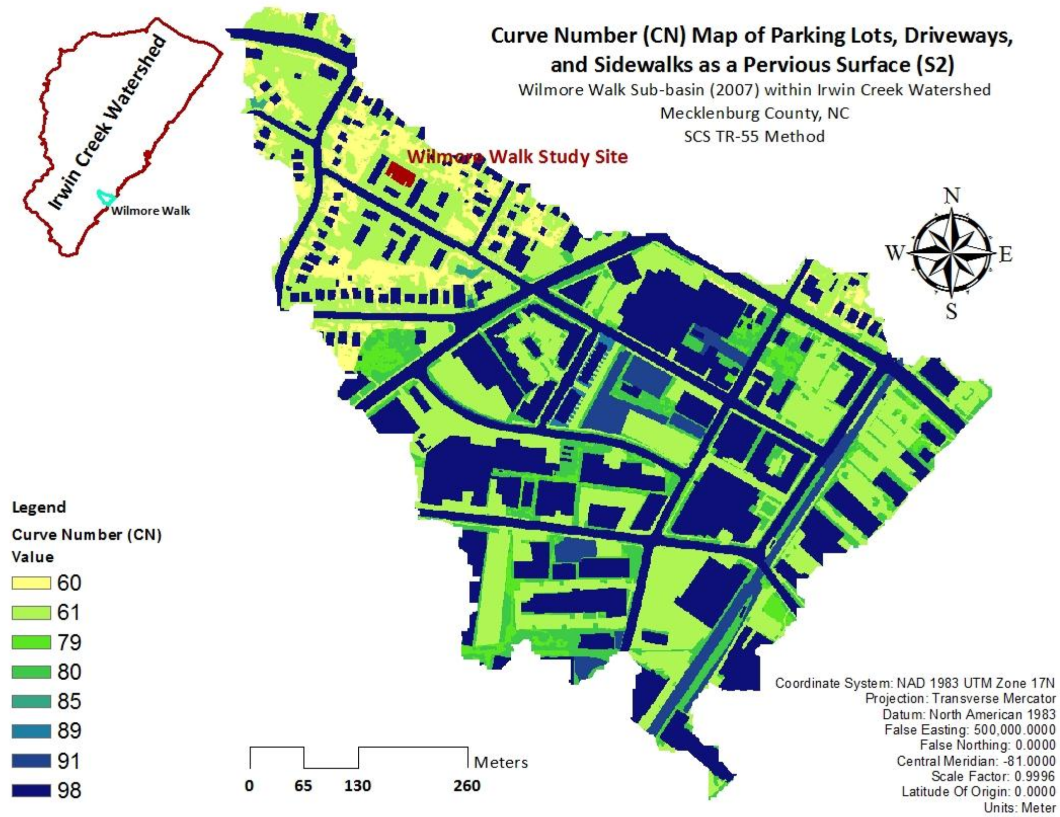
A.3-2: General Display of Precipitation Depth of a 24 Hour Storm Event Applied to Wilmore Walk Sub-Basin to create the "P" variable that is applied to the SCS TR-55 Equation.



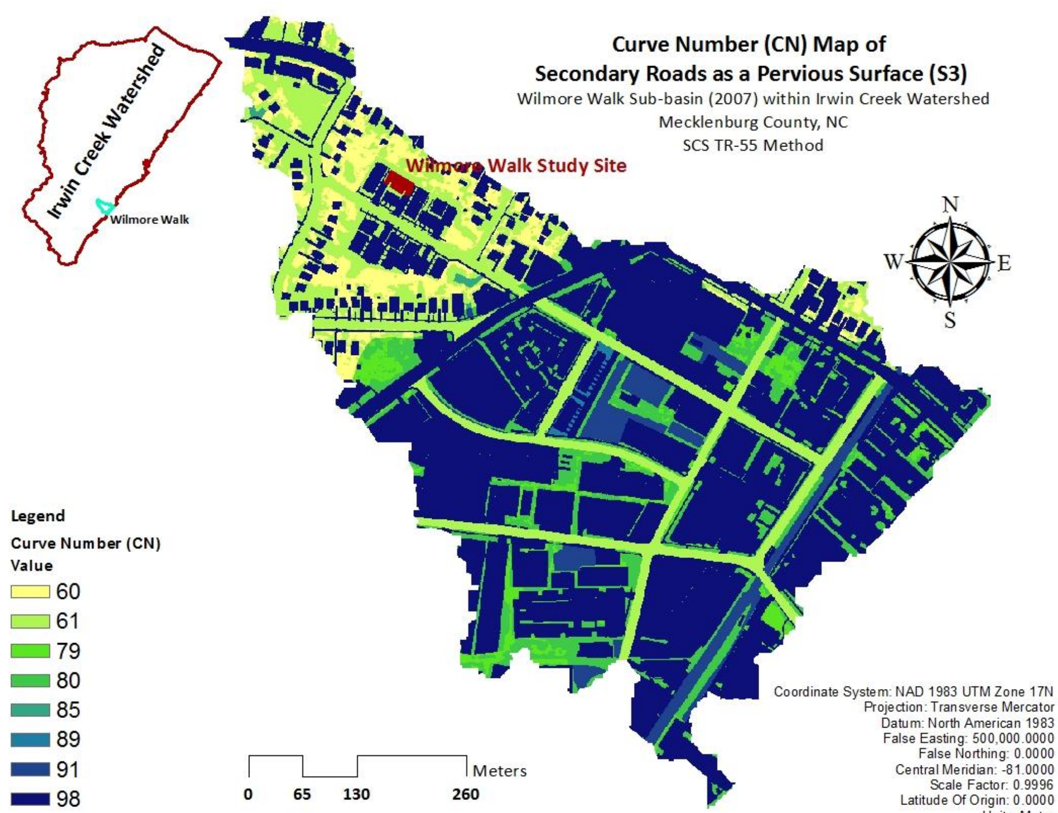
A.3-3: Soil Hydrogroup Variable Map to be combined with the Wilmore Walk Sub-basin Landuse Map, which is the basis for the Curve Number (CN) Map for the watershed.



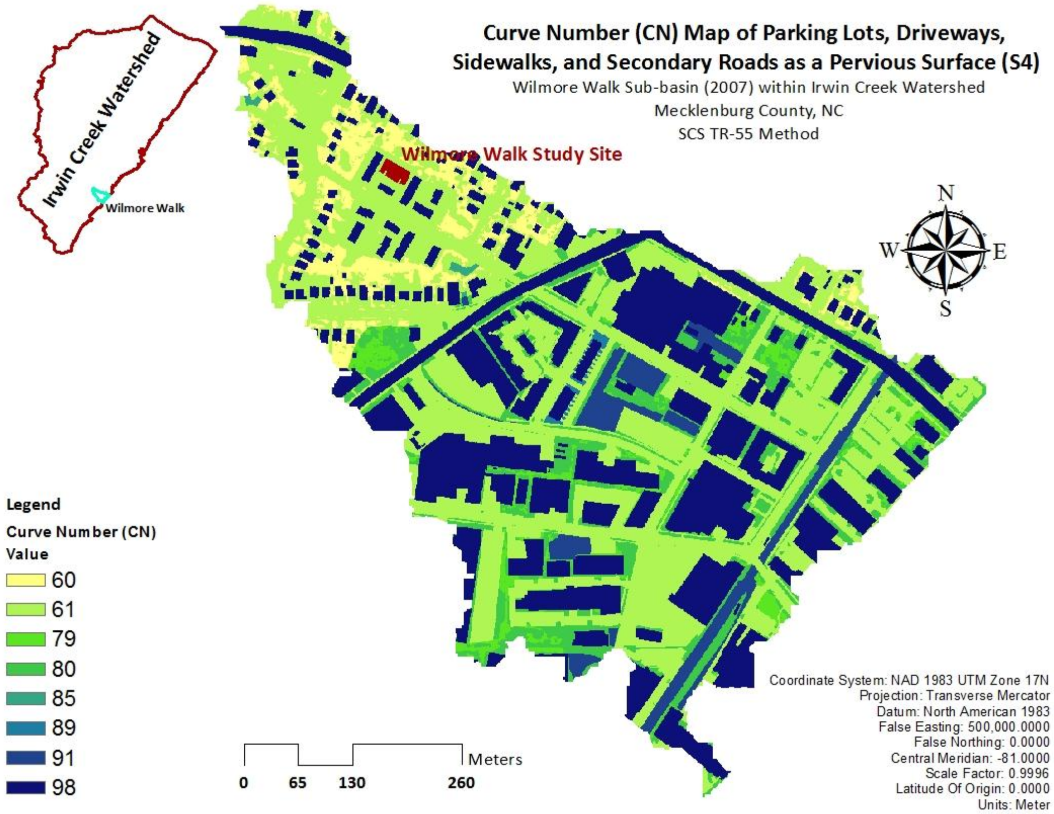
A.3-4: Wilmore Walk Sub-basin Landuse Variable Map to be combined with Soil Hydrogroup Map to create Curve Number (CN) Map for the SCS TR-55 Equation.



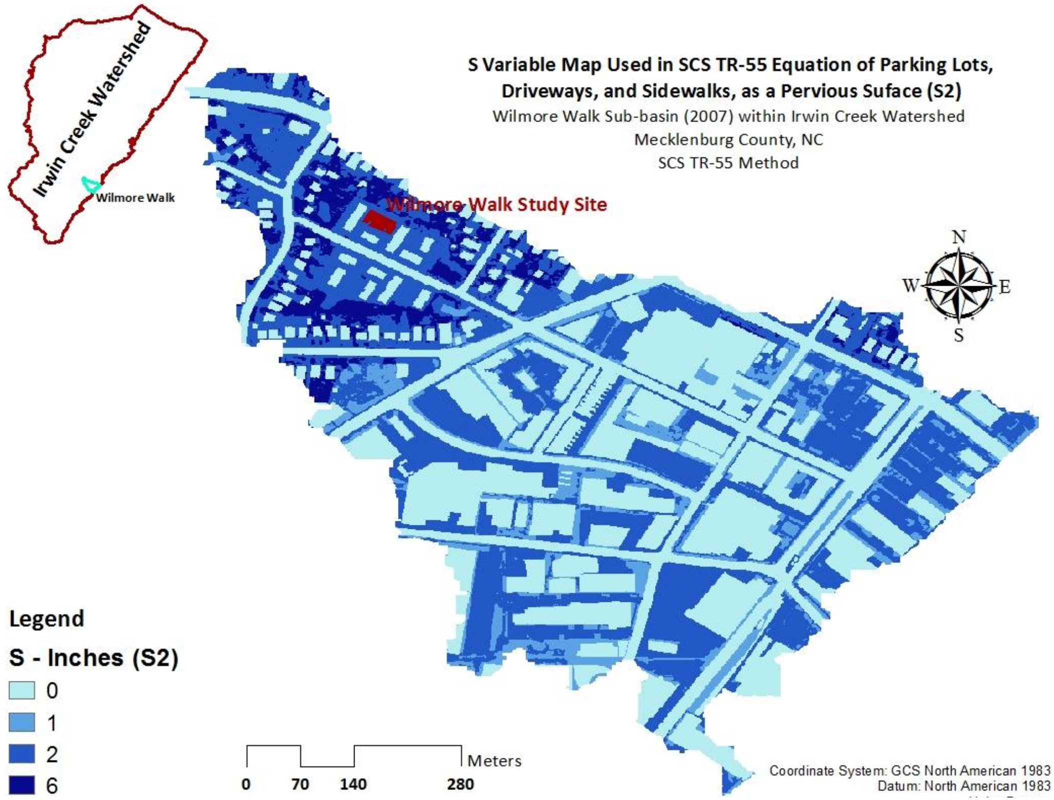
A.3-5: Curve Number map of Parking lots, driveways, and sidewalks as a pervious surface (S2) for Wilmore Walk Sub-basin.



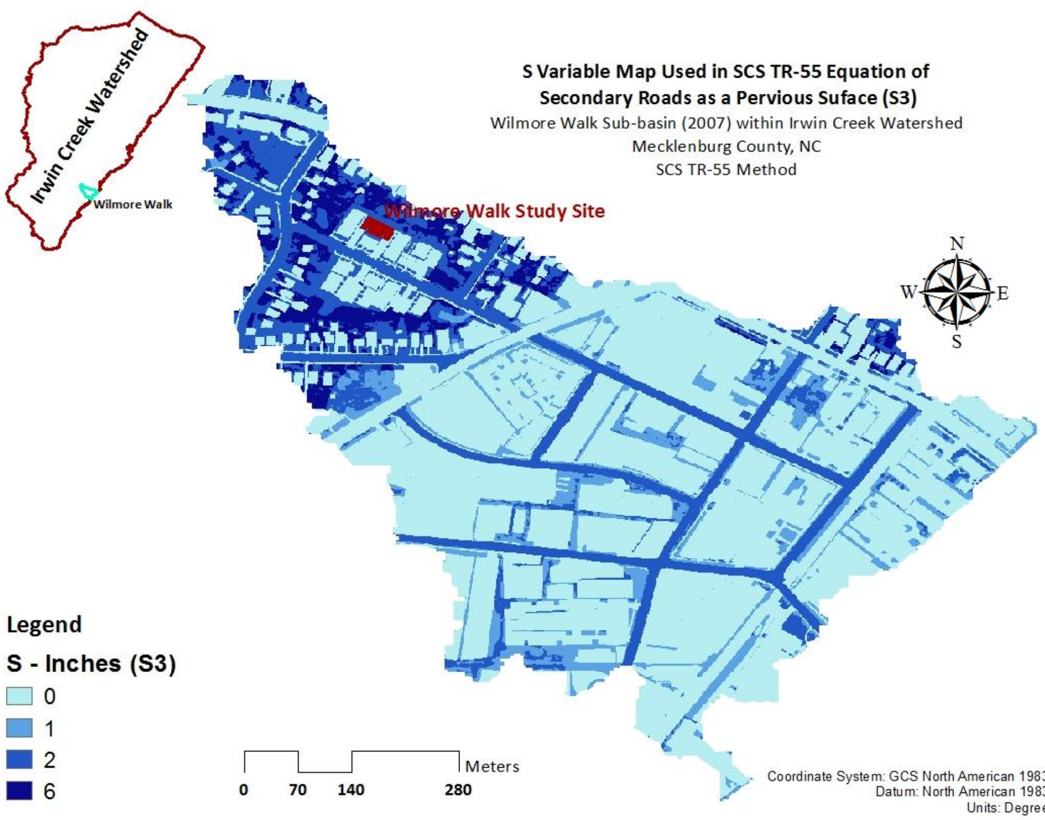
A.3-6: Curve Number map of Secondary roads as a pervious surface as a pervious surface (S3) for Wilmore Walk Sub-basin.



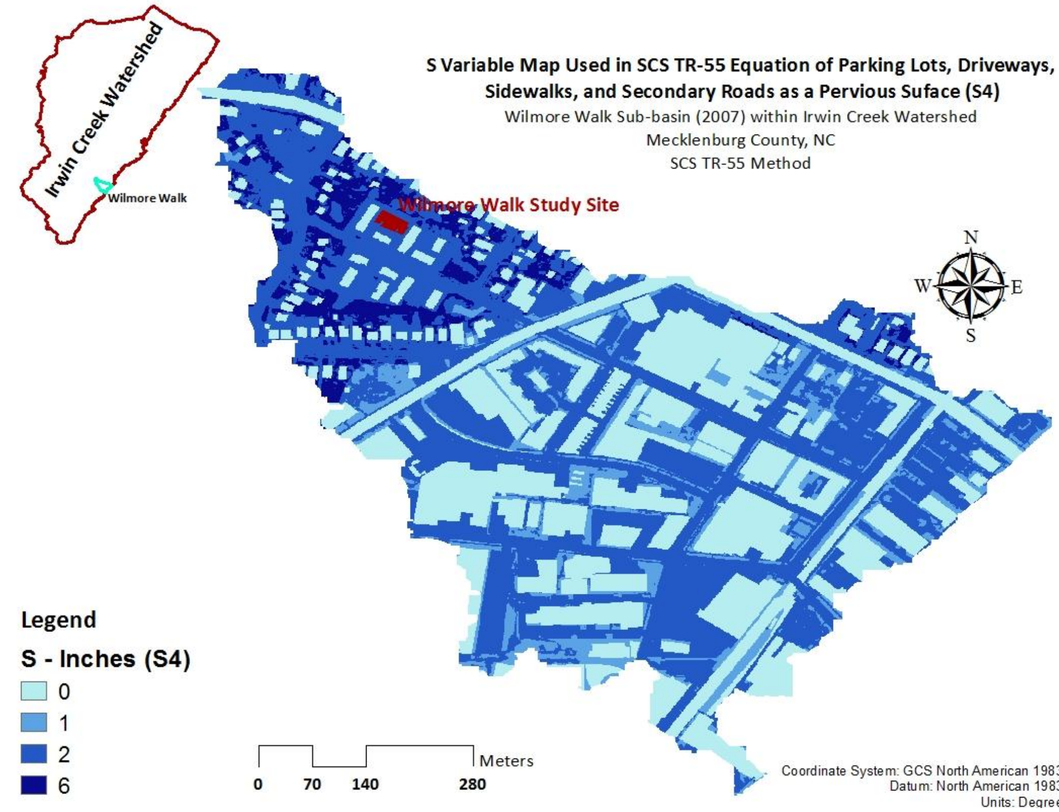
A.3-7: Curve Number map of Parking lots, driveways, sidewalks, and secondary roads as a pervious surface (S4) for Wilmore Walk Sub-basin.



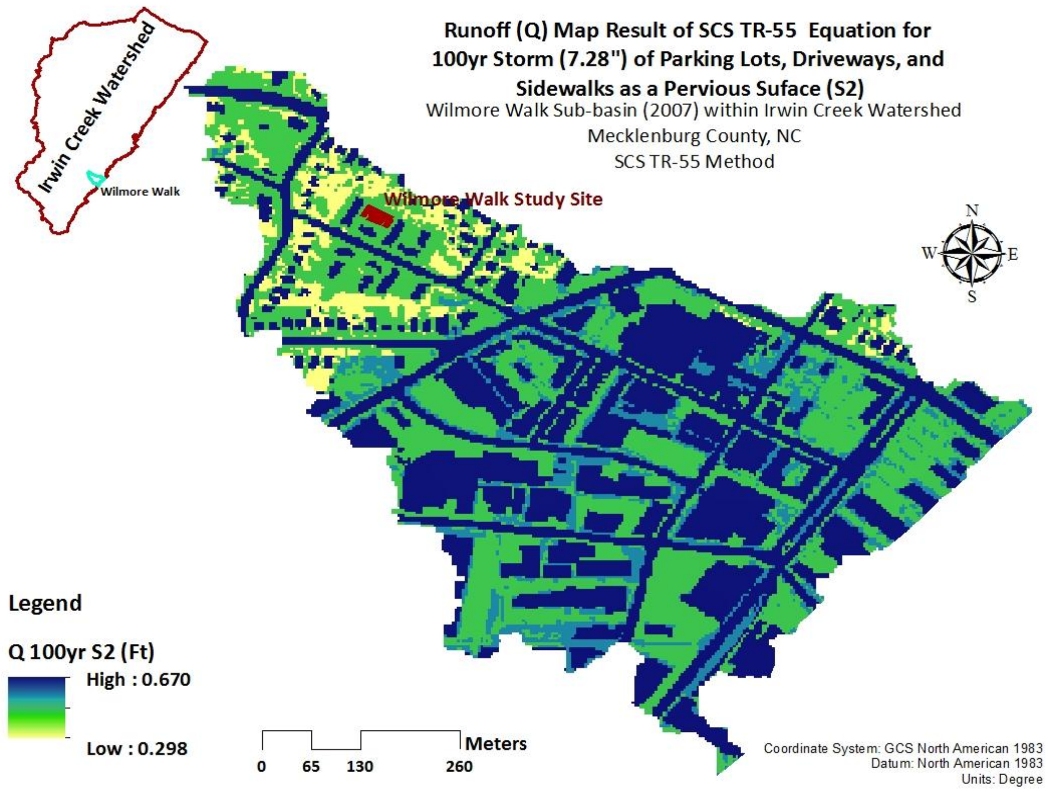
A.3-8: S Variable Map applied to SCS TR-55 Equation for Parking Lots, driveways, and sidewalks as a pervious surface (S2) of Wilmore Walk Sub-basin.



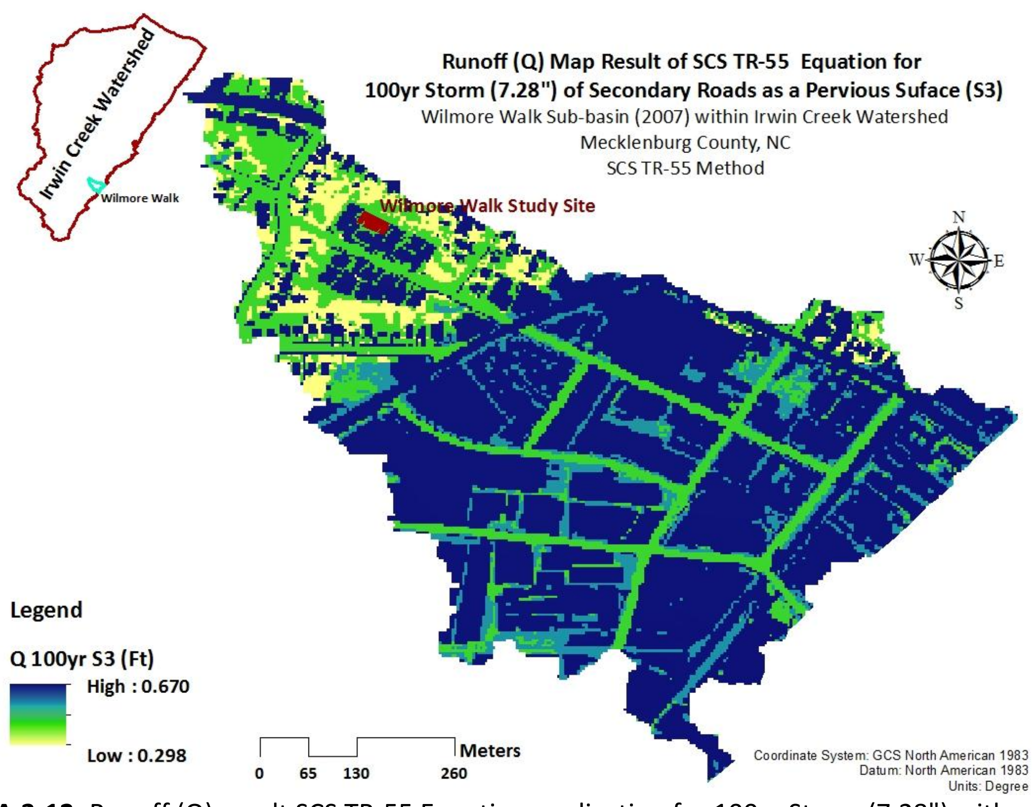
A.3-9: S Variable Map applied to SCS TR-55 Equation for Secondary conditions (S3) of Wilmore Walk Sub-basin.



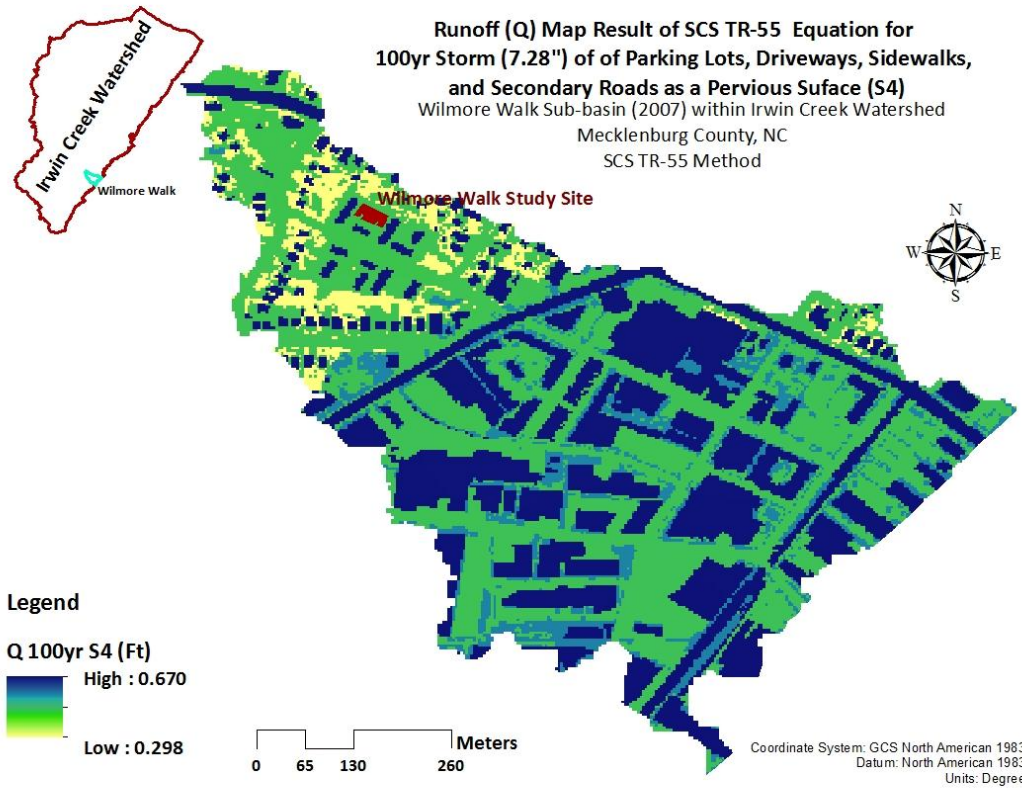
A.3-10: S Variable Map applied to SCS TR-55 Equation for Parking lots, driveways, sidewalks, and secondary roads (S4) of Wilmore Walk Sub-basin.



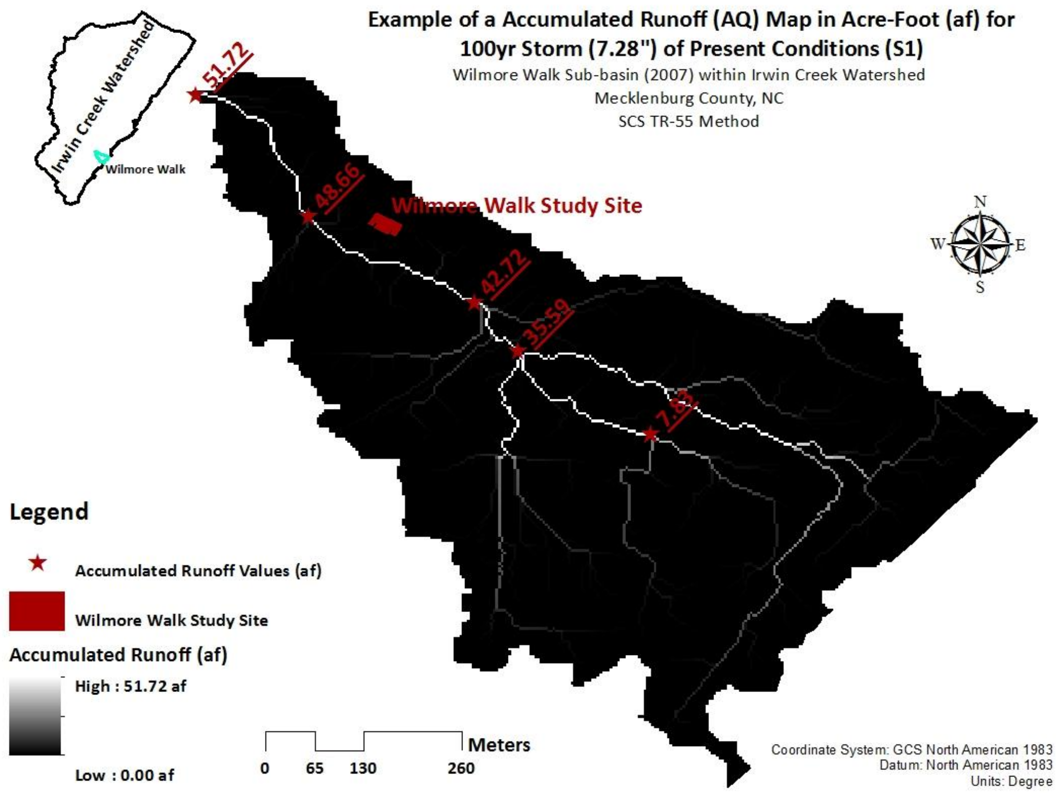
A.3-11: Runoff (Q) result SCS TR-55 Equation application for 100yr Storm (7.28") with the scenario of Parking lots, driveways, and sidewalks (S2) as pervious surfaces of Wilmore Walk Sub-basin.



A.3-12: Runoff (Q) result SCS TR-55 Equation application for 100yr Storm (7.28") with the scenario of Secondary roads (S3) as pervious surfaces of Wilmore Walk Sub-basin.



A.3-13: Runoff (Q) result SCS TR-55 Equation application for 100yr Storm (7.28") with the scenario of Parking lots, driveways, sidewalks, and secondary roads (S4) as pervious surfaces of Wilmore Walk Sub-basin.



A.3-14: Accumulated Runoff (AQ) result example of SCS TR-55 Equation application for 100yr Storm (7.28") with the scenario of Present conditions (S1) as pervious surfaces of Wilmore Walk Sub-basin.

Appendix 4: Cost Benefit Analysis for Wilmore Walk Sub-basin

A.4-1: Compiled 2011 tax values of commercial and residential parcels that fall within the Wilmore Sub-basin in Charlotte, NC, and was used to calculate cost per acre or square foot for each Land Type (Residential, Commercial, Vacant, Other).

Address	Property Value		Sq Ft	Neighborhood	Type	Acres	Land Type
Hawkins St, 2151	$	2,499,800	25140	Southend	Office	2.21	Commercial
Tremont Ave, 306 W	$	577,100	11164	Southend	Office	0.34	Commercial
Tryon St, 1815 S - Ste D	$	1,454,300	11566	Southend	Office	0.57	Commercial
Tryon St, 2001 S	$	674,100	3696	Southend	Office	0.30	Commercial
Worthington Ave, 118 W	$	614,000	3366	Southend	Office	0.28	Commercial
Abbott Street, 1900 - #100	$	329,600	1895	Southend	Office Condo	2.69	Commercial
Abbott Street, 1900 - #100	$	329,600	1895	Southend	Office Condo	0.09	Commercial
Abbott Street, 1900 - #101	$	326,600	1838	Southend	Office Condo	0.09	Commercial
Abbott Street, 1900 - #102	$	326,600	1838	Southend	Office Condo	0.09	Commercial
Abbott Street, 1900 - #103	$	326,600	1838	Southend	Office Condo	0.09	Commercial
Abbott Street, 1900 - #104	$	326,600	1838	Southend	Office Condo	0.09	Commercial
Abbott Street, 1900 - #105	$	326,600	1838	Southend	Office Condo	0.09	Commercial
Abbott Street, 1910 - #200	$	339,300	1934	Southend	Office Condo	0.09	Commercial
Abbott Street, 1910 - #201	$	339,300	1934	Southend	Office Condo	0.09	Commercial
Abbott Street, 1910 - #202	$	339,300	1934	Southend	Office Condo	0.09	Commercial
Abbott Street, 1910 - #203	$	339,300	1934	Southend	Office Condo	0.09	Commercial
Abbott Street, 1910 - #204	$	286,700	1560	Southend	Office Condo	0.09	Commercial
Abbott Street, 1920 - #300	$	315,700	1666	Southend	Office Condo	0.09	Commercial
Abbott Street, 1920 - #301	$	315,700	1666	Southend	Office Condo	0.09	Commercial
Abbott Street, 1920 - #302	$	315,700	1666	Southend	Office Condo	0.09	Commercial
Abbott Street, 1920 - #303	$	315,700	1666	Southend	Office Condo	0.09	Commercial
Abbott Street, 1920 - #304	$	336,300	1864	Southend	Office Condo	0.09	Commercial
Abbott Street, 1920 - #305	$	349,400	1864	Southend	Office Condo	0.09	Commercial
Abbott Street, 1930 - #400	$	353,200	1922	Southend	Office Condo	0.09	Commercial
Abbott Street, 1930 - #401	$	353,200	1922	Southend	Office Condo	0.09	Commercial
Abbott Street, 1930 - #402	$	353,200	1922	Southend	Office Condo	0.09	Commercial
Abbott Street, 1930 - #403	$	287,900	1922	Southend	Office Condo	0.09	Commercial
Abbott Street, 1930 - #404	$	353,200	1922	Southend	Office Condo	0.09	Commercial
Abbott Street, 1940 - #500	$	317,500	1663	Southend	Office Condo	0.09	Commercial
Abbott Street, 1940 - #501	$	371,600	2090	Southend	Office Condo	0.09	Commercial
Abbott Street, 1950 - #600	$	489,900	2856	Southend	Office Condo	0.09	Commercial
Abbott Street, 1950 - #601	$	489,900	2856	Southend	Office Condo	0.09	Commercial
Abbott Street, 1950 - #602	$	338,900	1948	Southend	Office Condo	0.09	Commercial
Abbott Street, 1950 - #603	$	338,900	1948	Southend	Office Condo	0.09	Commercial
Abbott Street, 1950 - #604	$	326,600	1838	Southend	Office Condo	0.09	Commercial
Abbott Street, 1950 - #605	$	329,200	1895	Southend	Office Condo	0.09	Commercial
Camden Rd, 1800 - #100	$	293,800	2014	Southend	Office Condo	0.07	Commercial
Camden Rd, 1800 - #101	$	293,800	2014	Southend	Office Condo	0.07	Commercial
Camden Rd, 1800 - #102	$	284,700	1923	Southend	Office Condo	0.07	Commercial
Camden Rd, 1800 - #103	$	284,700	1923	Southend	Office Condo	0.07	Commercial
Camden Rd, 1800 - #104	$	311,600	2014	Southend	Office Condo	0.07	Commercial
Camden Rd, 1800 - #105	$	311,600	2014	Southend	Office Condo	0.07	Commercial

Camden Rd, 1800 - #106	$	576,500	4032	Southend	Office Condo	0.07	Commercial
Camden Rd, 1800 - #107	$	284,700	1923	Southend	Office Condo	0.07	Commercial
Camden Rd, 1800 - #108	$	284,700	1923	Southend	Office Condo	0.07	Commercial
Camden Rd, 1800 - #109	$	577,600	4026	Southend	Office Condo	0.07	Commercial
Tremont Ave, 214 W	$	345,100	1764	Southend	Office Condo	0.84	Commercial
Tryon St, 1927 S	$	1,175,200	4854	Southend	Office Condo	1.38	Commercial
Tryon St, 1927 S - #100	$	841,400	4854	Southend	Office Condo	0.15	Commercial
Tryon St, 1927 S - #103	$	788,100	4329	Southend	Office Condo	0.15	Commercial
Tryon St, 1927 S - #105	$	991,900	5845	Southend	Office Condo	0.15	Commercial
Tryon St, 1927 S - #107	$	944,200	5375	Southend	Office Condo	0.15	Commercial
Tryon St, 1927 S - #109	$	515,800	2893	Southend	Office Condo	0.15	Commercial
Tryon St, 1927 S - #200	$	1,918,000	9147	Southend	Office Condo	0.15	Commercial
Tryon St, 1927 S - #203	$	784,500	4800	Southend	Office Condo	0.15	Commercial
Tryon St, 1927 S - #205	$	395,900	1966	Southend	Office Condo	0.15	Commercial
Tryon St, 1927 S - #207	$	1,340,300	5579	Southend	Office Condo	0.15	Commercial
Doggett St, 1916	$	1,885,400		Southend	Parking Lot	1.42	Commercial
East Blvd, 101	$	791,200		Southend	Parking Lot	0.54	Commercial
South Blvd, 1720	$	562,800		Southend	Parking Lot	0.32	Commercial
South Blvd, 1816	$	799,100		Southend	Parking Lot	1.26	Commercial
West Blvd, 113	$	608,100		Southend	Parking Lot	0.46	Commercial
Worthington Ave, 100 W	$	326,900		Southend	Parking Lot	0.23	Commercial
Worthington Ave, E	$	797,100		Southend	Parking Lot	0.48	Commercial
Camden Road, 1930	$	11,592,400	139572	Southend	Retail	2.82	Commercial
East Blvd, 115	$	2,253,900	12067	Southend	Retail	0.35	Commercial
Hawkins St, 2127	$	372,500	3790	Southend	Retail	0.52	Commercial
Hawkins St, 2161	$	1,090,900	8470	Southend	Retail	1.62	Commercial
Hawkins Street, 2116	$	5,328,000	32055	Southend	Retail	2.13	Commercial
South Blvd, 1812	$	935,700	7828	Southend	Retail	0.20	Commercial
South Blvd, 1820	$	1,202,900	15858	Southend	Retail	0.29	Commercial
South Blvd, 1900	$	3,742,000	41366	Southend	Retail	1.22	Commercial
South Blvd, 1910	$	5,328,300	71444	Southend	Retail	1.56	Commercial
South Blvd, 2000	$	21,210,300	118802	Southend	Retail	9.78	Commercial
Tryon St, 1807 S	$	6,468,000	104000	Southend	Retail	3.62	Commercial
West Blvd, 121	$	380,800	1472	Southend	Retail	0.23	Commercial
West Blvd, 126	$	384,800	1588	Southend	Retail	0.23	Commercial
West Blvd, 129	$	453,200	2688	Southend	Retail	0.23	Commercial
West Blvd, 130	$	525,400	3588	Southend	Retail	0.23	Commercial
Worthington Ave, 101 W	$	7,942,600	54476	Southend	Retail	1.03	Commercial
Worthington Ave, 126 W	$	505,000	7600	Southend	Retail	0.29	Commercial
West Blvd, 125	$	300,000		Southend	Vacant	0.23	Commercial
Worthington Ave, 213 W	$	222,200		Southend	Vacant	0.17	Commercial
Worthington Ave, 217 W	$	235,200		Southend	Vacant	0.18	Commercial
Worthington Ave, 221 W	$	235,200		Southend	Vacant	0.18	Commercial
Worthington Ave, 307 W	$	254,400		Southend	Vacant	0.18	Commercial

Doggett St, 305	$	1,177,400	36484	Southend	Warehouse	1.72	Commercial
Hawkins St, 2000	$	1,204,300	29150	Southend	Warehouse	1.03	Commercial
Hawkins Street, 2132	$	449,700	7620	Southend	Warehouse	0.85	Commercial
Hawkins Street, 2150	$	810,600	17020	Southend	Warehouse	1.02	Commercial
Rampart St, 210	$	856,500	19170	Southend	Warehouse	1.20	Commercial
Rampart St, 2139	$	299,800	7056	Southend	Warehouse	0.39	Commercial
Rampart St, 222	$	1,262,400	24582	Southend	Warehouse	1.00	Commercial
Rampart St, 300	$	1,767,300	65051	Southend	Warehouse	2.11	Commercial
Tremont Ave, 200 W	$	1,102,300	17280	Southend	Warehouse	0.29	Commercial
Tremont Ave, 201 W	$	712,400	13800	Southend	Warehouse	0.77	Commercial
Tremont Ave, 224 W	$	252,000	6125	Southend	Warehouse	0.17	Commercial
Tremont Ave, 225 W	$	270,600	5525	Southend	Warehouse	0.43	Commercial
Tremont Ave, 228 W	$	316,500	13562	Southend	Warehouse	0.34	Commercial
Tremont Ave, 232 W	$	180,000	4000	Southend	Warehouse	0.22	Commercial
Tremont Ave, 235 W	$	567,100	14165	Southend	Warehouse	0.66	Commercial
Tremont Ave, 242 W	$	383,500	9605	Southend	Warehouse	0.43	Commercial
Tremont Ave, 307 W	$	3,365,500	64430	Southend	Warehouse	3.89	Commercial
Tremont Ave, 312 W	$	1,308,100	47541	Southend	Warehouse	2.18	Commercial
Tremont Ave, 327 W	$	3,046,400	85394	Southend	Warehouse	3.93	Commercial
Tryon St, 2027 S	$	1,441,300	27495	Southend	Warehouse	2.10	Commercial
Tryon St, 2101 S	$	396,500	10270	Southend	Warehouse	0.53	Commercial
Tryon St, 2111 S	$	201,600	5056	Southend	Warehouse	0.29	Commercial
Tryon St, 2119 S	$	192,400	5126	Southend	Warehouse	0.27	Commercial
Tryon St, 2123 S	$	263,400	5056	Southend	Warehouse	0.27	Commercial
Tryon St, 2127 S	$	192,300	5056	Southend	Warehouse	0.27	Commercial
Tryon St, 2131 S	$	192,400	5056	Southend	Warehouse	0.27	Commercial
Tryon St, 2135 S	$	163,700	3630	Southend	Warehouse	0.30	Commercial
Worthington Ave, 201 W	$	943,700	12900	Southend	Warehouse	0.59	Commercial
Worthington Ave, 221 W	$	551,800	2000	Southend	Warehouse	0.40	Commercial
Abbott Street, 1905	$	282,400	2083	Southend	Condo	0.06	Residential
Abbott Street, 1909	$	277,900	1992	Southend	Condo	0.06	Residential
Abbott Street, 1913	$	276,500	1972	Southend	Condo	0.06	Residential
Abbott Street, 1917	$	277,900	1992	Southend	Condo	0.06	Residential
Abbott Street, 1921	$	276,500	1972	Southend	Condo	0.06	Residential
Abbott Street, 1925	$	277,900	1992	Southend	Condo	0.06	Residential
Abbott Street, 1929	$	276,500	1972	Southend	Condo	0.06	Residential
Abbott Street, 1933	$	277,900	1992	Southend	Condo	0.06	Residential
Abbott Street, 1937	$	282,400	2083	Southend	Condo	0.06	Residential
Abbott Street, 1943	$	281,600	2021	Southend	Condo	0.06	Residential
Abbott Street, 1947	$	280,000	1951	Southend	Condo	0.06	Residential
Abbott Street, 1951	$	279,100	1935	Southend	Condo	0.06	Residential
Abbott Street, 1955	$	280,000	1951	Southend	Condo	0.06	Residential
Abbott Street, 1959	$	279,100	1935	Southend	Condo	0.06	Residential
Abbott Street, 1963	$	280,000	1951	Southend	Condo	0.06	Residential
Abbott Street, 1967	$	279,100	1935	Southend	Condo	0.06	Residential

Tremont Blvd, 125 W	$	57,994,900	376000	Southend	Condo	2.62	Residential
West Blvd, 112 (etc.)	$	1,949,300	15816	Southend	House	0.98	Residential
West Blvd, 118	$	342,600	1980	Southend	House	0.23	Residential
West Blvd, 205	$	339,500	1410	Southend	Residential	0.23	Residential
West Blvd, 120	$	300,000		Southend	Vacant	0.23	Residential
South Blvd, 1800	$	2,281,200	13805	Southend	Church	0.60	
Doggett St, 1916	$	1,885,400		Southend	Vacant	1.42	
Mint St, 1824 S	$	60,200	2552	Wilmore Walk	Retail	0.07	Commercial
Tryon St, 1800 S	$	174,500	1323	Wilmore Walk	Retail	0.24	Commercial
Tryon St, 1814 S	$	353,100	6625	Wilmore Walk	Retail	0.33	Commercial
Tryon St, 1830 S	$	133,000	1960	Wilmore Walk	Retail	0.48	Commercial
Tryon St, 1926 S	$	72,200	1744	Wilmore Walk	Retail	0.29	Commercial
Worthington Ave, 510 W	$	5,300		Wilmore Walk	Vacant	0.06	Commercial
Tryon St, 1900 S	$	127,500	3118	Wilmore Walk	Warehouse	0.32	Commercial
Worthington Ave, 308 W	$	114,800	6350	Wilmore Walk	Warehouse	0.17	Commercial
Vision Dr, 2103	$	152,500	1064	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2104	$	152,500	1064	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2107	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2108	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2111	$	155,200	1121	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2112	$	155,200	1121	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2115	$	154,600	1100	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2116	$	154,600	1100	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2204	$	152,500	1064	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2208	$	155,200	1121	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2212	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2216	$	152,500	1064	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2220	$	155,200	1121	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2224	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2236	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2240	$	155,200	1121	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2244	$	152,500	1064	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2248	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2252	$	155,200	1121	Wilmore Walk	Condo	0.06	Residential
Vision Dr, 2256	$	152,000	1064	Wilmore Walk	Condo	1.19	Residential
Wilmore Walk Dr, 1802	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Wilmore Walk Dr, 1806	$	155,200	1121	Wilmore Walk	Condo	0.06	Residential
Wilmore Walk Dr, 1810	$	154,600	1100	Wilmore Walk	Condo	0.06	Residential
Wilmore Walk Dr, 1905	$	152,500	1064	Wilmore Walk	Condo	0.06	Residential
Wilmore Walk Dr, 1906	$	152,500	1064	Wilmore Walk	Condo	0.06	Residential
Wilmore Walk Dr, 1909	$	155,200	1121	Wilmore Walk	Condo	0.06	Residential
Wilmore Walk Dr, 1910	$	155,200	1121	Wilmore Walk	Condo	0.06	Residential
Wilmore Walk Dr, 1913	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Wilmore Walk Dr, 1914	$	135,200	926	Wilmore Walk	Condo	0.06	Residential

Wilmore Walk Dr, 1917	$	152,500	1064	Wilmore Walk	Condo	0.06	Residential
Wilmore Walk Dr, 1918	$	152,500	1064	Wilmore Walk	Condo	0.06	Residential
Wilmore Walk Dr, 1922	$	155,200	1121	Wilmore Walk	Condo	0.06	Residential
Wilmore Walk Dr, 1926	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Worthington Ave, 420 W	$	154,600	1100	Wilmore Walk	Condo	0.06	Residential
Worthington Ave, 424 W	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Worthington Ave, 428 W	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Worthington Ave, 432 W	$	152,500	1064	Wilmore Walk	Condo	0.06	Residential
Worthington Ave, 435 W	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Worthington Ave, 439 W	$	155,200	1121	Wilmore Walk	Condo	0.06	Residential
Worthington Ave, 443 W	$	154,600	1100	Wilmore Walk	Condo	0.06	Residential
Worthington Ave, 446 W	$	154,600	1100	Wilmore Walk	Condo	0.06	Residential
Worthington Ave, 450 W	$	155,200	1121	Wilmore Walk	Condo	0.06	Residential
Worthington Ave, 451 W	$	154,600	1100	Wilmore Walk	Condo	0.06	Residential
Worthington Ave, 454 W	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Worthington Ave, 455 W	$	155,200	1121	Wilmore Walk	Condo	0.06	Residential
Worthington Ave, 459 W	$	135,200	926	Wilmore Walk	Condo	0.06	Residential
Mint St, 1726 S	$	150,000	1989	Wilmore Walk	House	0.18	Residential
Mint St, 1813 S	$	118,800	868	Wilmore Walk	House	0.17	Residential
Mint St, 1821 S	$	116,900	868	Wilmore Walk	House	0.17	Residential
Mint St, 1829 S	$	109,700	830	Wilmore Walk	House	0.26	Residential
Mint St, 1900 S	$	328,900	3072	Wilmore Walk	House	0.20	Residential
Mint St, 1901 S	$	125,100	1045	Wilmore Walk	House	0.17	Residential
Mint St, 1904 S	$	142,800	1748	Wilmore Walk	House	0.12	Residential
Mint St, 1907 S	$	126,900	1024	Wilmore Walk	House	0.15	Residential
Mint St, 1908 S	$	126,100	966	Wilmore Walk	House	0.14	Residential
Mint St, 1911 S	$	134,100	1326	Wilmore Walk	House	0.14	Residential
Mint St, 1915 S	$	129,000	1068	Wilmore Walk	House	0.14	Residential
Mint St, 1919 S	$	165,800	2044	Wilmore Walk	House	0.18	Residential
Mint St, 1923 S	$	157,900	1790	Wilmore Walk	House	0.16	Residential
Mint St, 1927 S	$	132,300	1232	Wilmore Walk	House	0.13	Residential
Mint St, 1931 S	$	124,700	1105	Wilmore Walk	House	0.10	Residential
West Blvd, 313	$	323,600	4100	Wilmore Walk	House	0.12	Residential
West Blvd, 317	$	83,100	2940	Wilmore Walk	House	0.10	Residential
West Blvd, 321	$	181,900	3314	Wilmore Walk	House	0.23	Residential
West Blvd, 325	$	173,700	1680	Wilmore Walk	House	0.23	Residential
West Blvd, 329	$	157,100	1843	Wilmore Walk	House	0.23	Residential
West Blvd, 333	$	249,600	1980	Wilmore Walk	House	0.17	Residential
West Blvd, 337	$	135,600	1550	Wilmore Walk	House	0.17	Residential
West Blvd, 401	$	267,400	1887	Wilmore Walk	House	0.17	Residential
West Blvd, 405	$	301,600	3494	Wilmore Walk	House	0.17	Residential
West Blvd, 409	$	170,000	1777	Wilmore Walk	House	0.23	Residential
West Blvd, 415	$	169,800	2025	Wilmore Walk	House	0.23	Residential
West Blvd, 417	$	127,000	1369	Wilmore Walk	House	0.23	Residential
West Blvd, 421	$	163,800	1956	Wilmore Walk	House	0.23	Residential

West Blvd, 425	$	189,700	1444	Wilmore Walk	House	0.23	Residential
West Blvd, 429	$	140,200	1702	Wilmore Walk	House	0.23	Residential
West Blvd, 439	$	138,800	2359	Wilmore Walk	House	0.23	Residential
West Blvd, 441	$	143,900	1516	Wilmore Walk	House	0.23	Residential
West Blvd, 445	$	153,200	2180	Wilmore Walk	House	0.17	Residential
West Blvd, 449	$	137,200	1457	Wilmore Walk	House	0.17	Residential
West Blvd, 453	$	156,400	2225	Wilmore Walk	House	0.17	Residential
Wickford Pl, 1812	$	273,500	2494	Wilmore Walk	House	0.12	Residential
Wickford Pl, 1815	$	114,100	780	Wilmore Walk	House	0.11	Residential
Wickford Pl, 1816	$	128,800	1215	Wilmore Walk	House	0.35	Residential
Wickford Pl, 1819	$	134,600	1281	Wilmore Walk	House	0.17	Residential
Wickford Pl, 1825	$	126,300	1843	Wilmore Walk	House	0.17	Residential
Wood Dale Tr, 1901	$	139,800	1626	Wilmore Walk	House	0.19	Residential
Wood Dale Tr, 1905	$	139,700	1428	Wilmore Walk	House	0.20	Residential
Woodcrest Ave, 1904	$	168,600	1542	Wilmore Walk	House	0.12	Residential
Woodcrest Ave, 1908	$	140,800	1600	Wilmore Walk	House	0.15	Residential
Woodcrest Ave, 1914	$	145,200	1881	Wilmore Walk	House	0.17	Residential
Woodcrest Ave, 1918	$	151,700	2178	Wilmore Walk	House	0.17	Residential
Woodcrest Ave, 1920	$	157,400	2212	Wilmore Walk	House	0.19	Residential
Woodcrest Ave, 1926	$	133,900	1372	Wilmore Walk	House	0.20	Residential
Woodcrest Ave, 1930	$	146,500	1732	Wilmore Walk	House	0.20	Residential
Woodcrest Ave, 1933	$	140,700	1490	Wilmore Walk	House	0.18	Residential
Woodcrest Ave, 1934	$	209,600	2333	Wilmore Walk	House	0.22	Residential
Woodcrest Ave, 1936	$	133,200	1260	Wilmore Walk	House	0.21	Residential
Woodcrest Ave, 1937	$	175,100	1626	Wilmore Walk	House	0.18	Residential
Woodcrest Ave, 1940	$	152,900	1527	Wilmore Walk	House	0.18	Residential
Woodcrest Ave, 1941	$	152,200	1893	Wilmore Walk	House	0.18	Residential
Woodcrest Ave, 1944	$	131,700	1312	Wilmore Walk	House	0.13	Residential
Woodcrest Ave, 1950	$	114,500	897	Wilmore Walk	House	0.09	Residential
Woodcrest Ave, 1954	$	150,500	2584	Wilmore Walk	House	0.12	Residential
Worthington Ave, 516 W	$	87,100	864	Wilmore Walk	House	0.09	Residential
Worthington Ave, 518 W	$	87,100	864	Wilmore Walk	House	0.09	Residential
Worthington Ave, 520 W	$	95,700	1344	Wilmore Walk	House	0.09	Residential
Worthington Ave, 522 W	$	95,700	1344	Wilmore Walk	House	0.09	Residential
West Blvd, 531	$	245,400	4848	Wilmore Walk	Municipal	1.01	Residential
Mint St, 1808 S	$	75,000		Wilmore Walk	Vacant	0.33	Residential
Mint St, 1817 S	$	75,000		Wilmore Walk	Vacant	0.23	Residential
Mint St, 1818 S	$	75,000		Wilmore Walk	Vacant	0.18	Residential
West Blvd, 433	$	75,000		Wilmore Walk	Vacant	0.23	Residential
Woodcrest Ave, 1917	$	75,000		Wilmore Walk	Vacant	0.18	Residential
Woodcrest Ave, 1923	$	75,000		Wilmore Walk	Vacant	0.18	Residential
Woodcrest Ave, 1929	$	150,000		Wilmore Walk	Vacant	0.36	Residential
Worthington Ave, 401 W	$	18,700		Wilmore Walk	Vacant	0.22	Residential
Tryon St, 1916 S	$	246,900	4256	Wilmore Walk	Church	0.22	Other

West Blvd, 512	$	2,783,500	19580	Wilmore Walk	Church	2.40	Other
West Blvd, 501	$	461,100	5403	Wilmore Walk	Municipal	0.62	Other

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