# Laboratory and Field Studies of Soil Characteristics of Proposed Stormwater Bioinfiltration Sites

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## ABSTRACT

Small scale, rapid, tests are needed to quickly inventory soil conditions in areas undergoing planning following natural disasters, or to meet short schedules associated with accelerated construction goals. Field-scale and laboratory studies of local soils in the Tuscaloosa, AL, were conducted to provide insight into the existing soil characteristics at proposed stormwater bioinfiltration sites in areas devastated by severe tornados that will be undergoing reconstruction. Disturbed urban soils have dramatically reduced infiltration rates, usually associated with compaction of the surface soils. Local measurements of the actual infiltration rates can be a very useful tool in identifying problem areas and the need for more careful construction methods. Having accurate infiltration rates are also needed for proper design of stormwater bioinfiltration controls.

## KEYWORDS

Stormwater, bioinfiltration, infiltration rates, compaction.

## INTRODUCTION

There are increasing interests in the use of infiltration practices for managing stormwater runoff, as these systems promote groundwater recharge, reduce runoff peak flow rates and volumes, and can reduce pollutant discharges to surface water bodies. Infiltration practices recharge stormwater directly to groundwater, they can potentially contaminate groundwater supplies with dissolved pollutants contained in stormwater runoff or mobilized from subsurface contamination. Infiltration practices are not appropriate in areas that contribute high concentrations of sediment, hydrocarbons, or other floatables without adequate pretreatment (Connecticut 2004).

Infiltration practices are becoming more common in many residential and other urban areas to compensate for the decreased natural infiltration areas associated with land development, but must consider local soil degradation conditions to be most effective (Pitt et al., 2002 and 2008).

Infiltration facilities, which historically have included percolation ponds, dry wells, infiltration galleries, and swales, are designed to capture and retain runoff and allow it to infiltrate rather than to discharge directly to surface water (Massman, 2003). Properly designed and constructed infiltration facilities can be one of the most effective flow control (and water quality treatment) stormwater control practices, and should be encouraged where conditions are appropriate (Ecology, 2005). However the performance of stormwater infiltration systems can be affected by factors such as texture, structure and degree of compaction of the media during their construction.

Infiltration facilities have the greatest runoff reduction capabilities of any stormwater control practices and are suitable for use in residential and other urban areas where measured soil permeability rates exceed locally determined critical values (such as 0.5 in/ hr as specified by VA DCR, 2010). However, the design of these facilities is particularly challenging because of the large uncertainties associated with predictions of both short-term and long-term infiltration rates (Massman, 2003). Infiltration rates cannot be estimated solely on the basis of soil types (grain size texture) or saturated hydraulic conductivity, but other site-specific characteristics need to be considered to accurately design infiltration facilities (Massman, 2003). Small-scale infiltrometers measure short-term infiltration rates which apply only to the initiation of the infiltration process (Philips, 2011). Factors such as infiltrate quality, frequency of infiltration system maintenance and site variability will affect long-term (design) infiltration rates.

Understanding the physical and hydrologic properties of different bioretention media mixtures as well as their response to compaction may increase the functional predictability of bioretention systems and thus improve their design (Pitt et al., 2002 and 2008; Thompson et al., 2008). Premature clogging by silt is usually responsible for early failures of infiltration devices, although compaction (during either construction or use) is also a recognized problem (Pitt et al., 2002 and 2008). Pitt et al., (1999b) found substantial reductions in infiltration rates due to soil compaction, especially for clayey soils.

Compaction was seen to have about the same effect as moisture saturation for clayey soils, with saturated and compacted clayey soils having very little effective infiltration rates (Pitt et al., 2008). Sandy soils can still provide substantial infiltration capacities, even when greatly compacted, in contrast to soils containing large amounts of clays that are very susceptible to compaction’s detrimental effects. In a similar study, Gregory et al. (2006) examined the effects of compaction on infiltration rates at urban construction sites in north-central Florida. Infiltration was measured in noncompacted and compacted soils from three land types (natural forest, planted forest, and pasture sites). Although infiltration rates varied widely across the three land types, construction activity reduced infiltration rates by 70 to 99 percent at all sites.

Soil amendments (such as organic composts) improve soil infiltration rates and water holding characteristics and add protection to groundwater resources, especially from heavy metal contamination in urban areas (Pitt et al., 1999a and 1999b). Groundwater contamination problems were noted more often in commercial and industrial areas that incorporated subsurface infiltration and less often in residential areas where infiltration occurred through surface soil (Pitt et al., 1999a and Clark et al., 2006). However, pretreatment of stormwater runoff before infiltration can reduce groundwater contamination of many pollutants and also prolong the life of the infiltration device.

## FIELD SURFACE AND SUBSURFACE INFILTRATION TESTS

Four surface double-ring infiltration tests (comprised of three separate setups each) and three large borehole infiltration measurements were conducted in the field to determine the surface infiltration characteristics and the subsurface infiltration characteristics (located at the depths at the bottom of proposed bioinfiltration devices). In addition, controlled laboratory column tests were also conducted on surface and subsurface soil samples under the three different compaction conditions(hand compaction, standard proctor compaction, and severe modified proctor compaction) to see if depth of the test (and response to compaction) affected the infiltration results. The proposed bioinfiltration sites are located in areas which were severely affected by the April 27, 2011 tornado that devastated the city of Tuscaloosa, AL, and are undergoing reconstruction (Figure 1).

**Figure 1. View of the Tornado Hit Area Near the Proposed Stormwater Bioinfiltration Site.**

## SURFACE INFILTRATION TEST

Turf-Tec infiltrometers (Turf Tec 1989) were used to measure the surface infiltration rates at 4 test locations where reconstruction with stormwater infiltration controls is planned. These small devices have an inner ring about 64 mm (2.5 in.) in diameter and an outer ring about 114 mm (4.5 in.) in diameter. The infiltrometers were gently driven into the surface of the soil until the "saturn" ring was against the soil surface (Figure 2). Relatively flat areas were selected in the test sites to install the Turf-Tec infiltrometers and small obstacles such as stones and twigs were removed. Three infiltrometers were inserted within about a meter from each other to measure the variability of the infiltration rates of the soil media in close proximity. After the soil was inspected and sealed around each ring to make sure that it was even and smooth, clean water was poured into the inner ring and allowed to overflow and fill up the outer ring (Figure 2).

The rate of decline in the water level was measured by starting the timer immediately when the pointer reached the beginning of the depth scale. Additional water was added to both rings when the level in the inner ring dropped a measurable amount. The change in water level and elapsed time were recorded since the beginning of the first measurement. The measurements were taken every five minutes at the beginning of the test and less frequently as the test progressed until the rate of infiltration was considered constant. The tests were conducted for a period of one to two hours, until the infiltration rate become constant. The infiltration rate was calculated from the rate of fall of the water level in the inner ring.

**Figure 2. Double Ring Installation at Test Site 1.**

**Figure 3. Double Ring Infiltration Measurement Installations at Test Site 3.**

## BOREHOLE INFILTRATION TEST

The borehole tests required drilling a hole and placing a Sonotube cardboard concrete form into the hole to protect the hole sides. A 2 to 3 ft diameter auger was used to create holes about 3 to 4 ft deep (depending on subsoil conditions) (Figure 4). An approximate 5 ft length of sonotube was inserted in the boreholes to maintain structural integrity and had a several inch layer of coarse gravel placed on the bottom to protect the native soil (Figure 5). The borehole tests required boring a hole and placing a Sonotube cardboard form into the hole to protect the hole sides. The bare soil at the bottom of the tube was roughened to break up any smeared soil and back-filled with a few inches of coarse gravel to prevent the native soil erosion during water filling. The tubes were filled with water from adjacent fire hydrants and the water elevation drop was monitored using a recording depth gage (a simple pressure transducer with a data logger).

**Figure 4. View of Borehole Drilling at Test Site 3.**

**Figure 5. Borehole Installation at Test Site 3.**

The borehole test sites were all located adjacent to fire hydrants (for water supply for the large borehole tests) and are located in the City's right-of way next to roads. During the tests, these boreholes were filled with water from the fire hydrants and the water elevations were manually measured with time until the infiltration rates reached an approximate steady rate.

## LABORATORY COLUMN TESTS

Controlled laboratory column tests were also conducted on surface and subsurface soil samples under the three different compaction levels (hand compaction, standard proctor compaction, and severe modified proctor compaction) to see if depth of the test (and response to compaction) affected the infiltration results. Both standard and modified proctor compactions follow ASTM standard (D 1140-54). The standard proctor compaction hammer is 24.4 kN and has a drop height of 300 mm (12 in.). The modified proctor hammer is 44.5 kN and has a drop height of 460 mm (18 in.). For the standard proctor setup, the hammer is dropped on the test soil 25 times on each of three soil layers, while for the modified proctor test, the heavier hammer was also dropped 25 times, but on each of five soil layers. The modified proctor test therefore results in much more compacted soil, and usually reflects the most compacted soil observed in the field. The hand compaction is done by gently hand pressing the media material to place it into the test pipe with as little compaction as possible, with no voids or channels. The hand compacted soil specimens therefore have the least amount of compaction.

A 4 inch (100 mm) diameter PVC pipe (Charlotte Pipe TrueFit 4 in. x 10 ft. PVC Schedule 40 Foam-Core Pipe) purchased from a local building supply store in Tuscaloosa, AL was used to construct the columns for these tests. A total of nine columns, each 3ft (0.9 m) long, were constructed as shown in Figure 6. The bottom of the columns had a fiberglass window screen secured to contain the media and were placed in funnels. The columns were filled with about 2 inch of cleaned pea gravel purchased from a local supplier. To separate the gravel layer from the soil layer, a permeable fiberglass screen was placed over the gravel layer and then filled with the soil media imported from the test sites. The media layer was about 1.5 ft thick.

The infiltration through the soil media was measured in each column using municipal tap water. The surface ponding depths in the columns ranged from 11 to 14 inches (28 to 36 cm), corresponding to the approximate maximum ponding depth at the Shelby Park biofilter. The freeboard depth above the media to the top of the columns was about 2 to 3 inches (50 to 75 mm). Infiltration rates in the media mixtures were determined by measuring the rates with time until apparent steady state rates were observed.

**Figure 6. Laboratory Column Setup.**

Soil samples extracted from the surface of the proposed bioinfiltration sites were also delivered to Auburn University's Soil Testing Laboratory, where soil texture (% sand, % silt, and % clay), organic matter, and general nutrients were also analyzed. Summary of the soil texture report is shown in Table 1.

Table 1. Summary of the soil texture report from the test sites.

| Sample | Percent (%) | | | | $H_2O$ availability |
|---|---|---|---|---|---|
| Test site | Sand | Silt | Clay | Textural Class | $cm^3/cm^3$ |
| 1 | 42.5 | 30 | 27.5 | Clay Loam | 0.12 |
| 2 | 50 | 30 | 20 | Loam | 0.12 |
| 3 | 58.75 | 17.5 | 23.75 | Sandy Clay Loam | 0.10 |
| 4 | 70 | 10 | 20 | Sandy Clay Loam | 0.09 |

## FIELD SURFACE AND SUBSURFACE INFILTRATION TEST RESULTS

The average initial infiltration rate for the surface double-ring infiltration tests was about 11 in/hr (280 mm/hr) and ranged from 2 to 17 in/hr (50 to 430 mm/hr). The final infiltration rates had an average value of about 4.5 in/hr (115mm/hr) and ranged from 2 to 8 in/hr (50 to 200 mm/hr). The variations of the observed surface infiltration rates among the test sites were relatively large, but all indicated large infiltration potentials. The average initial infiltration rate for the subsurface infiltration tests was about 188 in/hr (478 cm/hr) and ranged from 130 to 240 in/hr (330 to 610 cm/hr). The final rates had an average value of about 8 in/hr (200 mm/hr) and ranged from 7 to

10 in/hr (180 to 250 mm/hr). The variations of the observed surface and subsurface infiltration rates along these test sites were also relatively large and showed larger infiltration potential.

The initial rates from the subsurface tests were very large and are not indicative of actual rates that would be available during actual storm conditions. However, the long-term final rates measured at both the surface and subsurface locations (generally in the 2 to 8 inch/hour range) both indicated very good infiltration potentials. Obviously, care will need to be taken to prevent any compaction at the infiltration sites during construction. It is important that stormwater practice designers determine the subsoil characteristics before designing stormwater treatment facilities.

## LABORATORY COLUMN INFILTRATION TEST RESULTS

During the laboratory compaction/infiltration tests, the average initial rates through the surface soil for the three levels of compaction were 34, 4.2, and 1.5 in/hr (860, 105, and 40 mm/hr) using the hand compaction (little compaction), standard proctor compaction (typical compaction during construction activities) and modified proctor compaction methods (the most severe compaction level). The final infiltration rates through the surface soil for the three levels of compaction were 15.6, 0.8, and 0.3 in/hr (395, 20, and 8 mm/hr) respectively, at approximate 13 in (330 mm) of head.

During the laboratory compaction/infiltration tests, the average initial rates through the subsurface soil for the three levels of compaction were 15, 2.5, and 0.45 in/hr (380, 65, 12 mm/hr) using the hand compaction (little compaction), standard proctor compaction (typical compaction during construction activities) and modified proctor compaction methods (the most severe compaction level). The final infiltration rates through the subsurface soil for the three levels of compaction were 4, 0.75, and 0.1 in/hr (100, 20, 2.5 mm/hr) respectively, at approximates 13 in (330 mm) of head.

The saturated infiltration rate measured with the double-ring infiltrometer is similar to the saturated infiltration rate value through the surface soil for standard proctor compaction method.

## SUMMARY AND CONCLUSIONS

Small-scale infiltrometers work well if surface characteristics are of the greatest interest (such as infiltration thru surface landscaped soils, as in turf areas, grass swales or in grass filters). Larger, conventional double-ring infiltrometers are not very practical in urban areas due to the excessive force needed to seat the units in most urban soils (usually requiring jacking from a heavy duty truck) and the length of time and large quantities of water needed for the tests. In addition, they also only measure surface soil conditions. Large-scale (deep) infiltration tests would be appropriate when subsurface conditions are of importance (as in bioinfiltration systems and deep rain gardens).

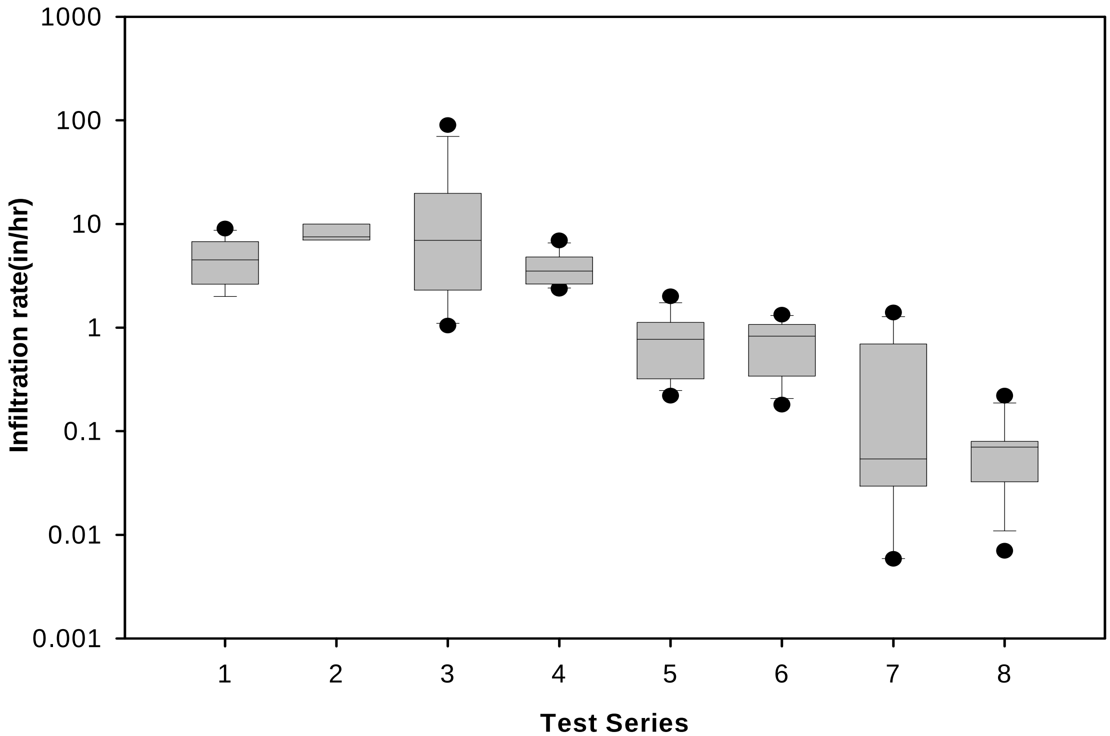


**Figure 4. Box and Whisker Plots Comparing Saturated Soil Infiltration Rates (in/hr).**

Test series descriptions (12 replicates in each test series except for the borehole tests which only included 3 observations):

1) Tur-Tec small double ring infiltrometer
2) Pilot-scale borehole infiltration tests
3) Surface soil composite sample with hand compaction
4) Subsurface soil composite sample with hand compaction
5) Surface soil composite sample with standard proctor compaction
6) Subsurface soil composite sample with standard proctor compaction
7) Surface soil composite sample with modified proctor compaction
8) Subsurface soil composite sample with modified proctor compaction

The borehole and Sonotube test used above is relatively easy and fast to conduct, if a large borehole drill rig is available along with large volumes of water (such as from a close-by fire hydrant). For infiltration facilities already in place, simple stage recording devices (small pressure transducers with data loggers) are very useful for monitoring during actual rain conditions. In many cases, disturbed urban soils have dramatically reduced infiltration rates, usually associated with compaction of the surface soils. Local measurements of the actual infiltration rates, as described above, can be a very useful tool in identifying problem areas and the need for more careful construction methods. Having accurate infiltration rates are also needed for proper design of stormwater bioinfiltration controls.

## REFERENCES


Clark, S.E; Baker, K.H; Mikula, J.B; Burkhardt, C.S; Lalor, M.M (2006) *Infiltration vs. surface water discharge: Guidance for stormwater managers*; Water Environment Research Foundation. Project No. 03-SW-4. 220 pages.

Connecticut Stormwater Quality Manual. 2004; The Connecticut Department of Environmental Protection. Volume 1.

Ecology (2005) *Stormwater Management Manual for Western Washington*; Olympia, WA. Washington State Department of Ecology Water Quality Program. Publication Numbers 05-10-029 through 05-10-033. http://www.ecy.wa.gov/pubs/0510029.pdf

Gregory, J. H; Dukes, M. D; Jones, P. H, and Miller, G. L (2006) *Effect of urban soil compaction on infiltration rate*; J. Soil Water Conserv., 61(3), 117-123.

Massman, J.W (2003) *Implementation of infiltration ponds research*. Final Research Report, Research Project Agreement No. Y8265; Washington State Department of Transportation. http://www.wsdot.wa.gov/research/reports/fullreports/578.1.pdf

Philips, C.E. and Kitch, W.A. (2011) *A Review of Methods for Characterization of Site Infiltration with Design Recommendations*; Proceedings: 43rd Symposium on Engineering Geology and Geotechnical Engineering, University of Las Vegas, NV, March 23-25

Pitt, R.; S. Clark, and R. Field (1999a) *Groundwater Contamination Potential from Stormwater Infiltration Practices*; Urban Water, 1(3), 217-236.

Pitt, R.; J. Lantrip; R. Harrison; C. Henry, and D. Hue (1999b) *Infiltration through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity*; EPA 600-R-00-016. U.S. Environmental Protection Agency. National Risk Management Research Laboratory. Office of Research and Development. Cincinnati, OH: 231 pp.

Pitt, R; Chen, S.-E; Clark, S.E (2002) *Compacted Urban Soils Effects on Infiltration and Bioretention Stormwater Control Designs*; Proc., 9th Int. Conf. on Urban Drainage (9ICUD). Portland, Oregon.

Pitt, R; Chen, S-E; Clark, S; Swenson, J., and Ong, C.K (2008) *Compaction's Impacts on Urban Storm-Water Infiltration;* J. Irrig. and Drain. Engrg., 134(5), 652-658.

Thompson, A.M; A.C. Paul, and N.J. Balster (2008); *Physical and Hydraulic Properties of Engineered Soil Media for Bioretention Basins*; Transactions of the American Society of Agricultural Engineers, 51(2), 499-514.

Turf Tec International (1989) *Turf Tec instructions*; Oakland Park, Fla.

Virginia Department of Conservation and Recreation (VA DCR) (2010). *Stormwater Design Specification No. 8*; Infiltration Practices Version 1.7. http://www.cwp.org/cbstp/Resources/d2s4a-dcr-bmp-infiltration.pdf