Enhanced Infiltration of Stormwater on Development Sites in North Carolina Piedmont

By Barrett L. Kays, Ph.D.[1]

Traditionally stormwater treatment was approached with “end of the pipe” solutions. Sustainable site restoration allows for more creative solutions such as infiltration systems. Engineers, architects, and landscape architects are increasingly using infiltration for stormwater runoff control. Infiltration is a natural sustainable process that works well on healthy undisturbed soils. However, infiltration can be problematic when, because of compaction, most of the natural soil pore network system is damaged or destroyed. So, how can soil scientists best evaluate and design for effective infiltration on sites having disturbed soils?

It is always important to protect as much as possible of the natural soils on the site. However, to use infiltration in areas of the site that have been altered during grading, we need to restore the damaged soils to achieve long-term sustainability of the site.

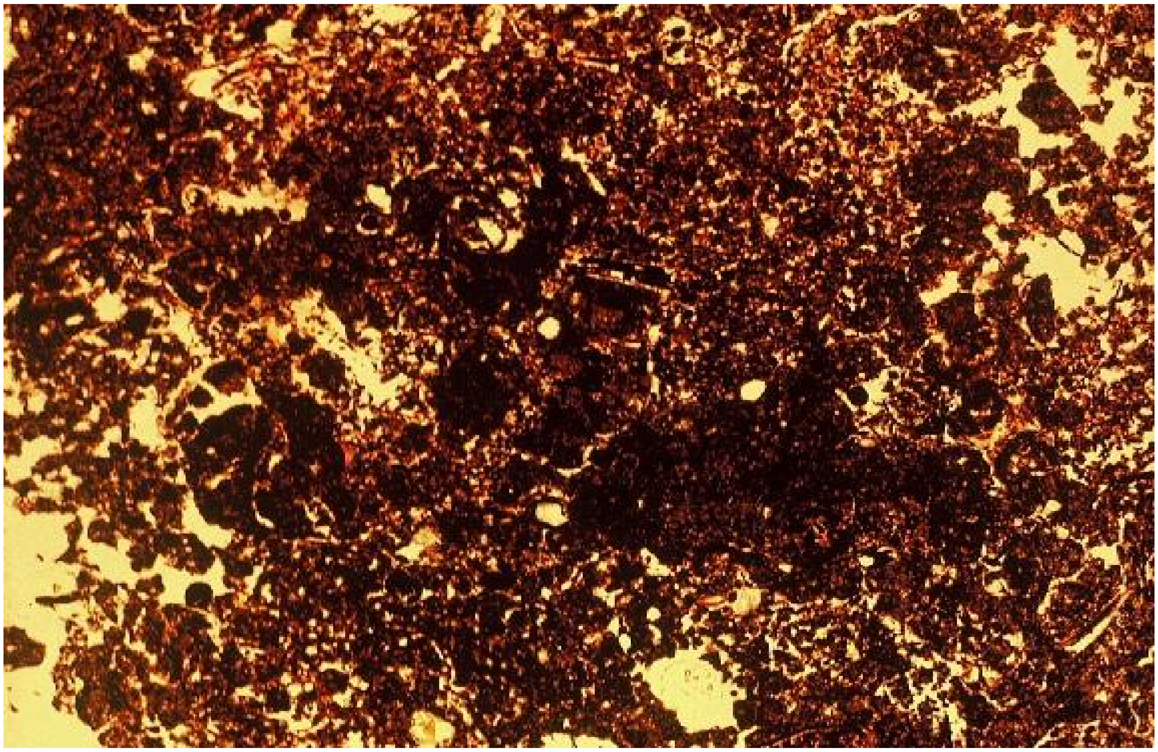
Infiltration Processes

First, let’s examine how infiltration works on a natural soil profile formed under mature forest conditions. The natural soil profile has an extremely porous humus layer and a small sample of the A-horizon contains thousands of macro pores (these are pores that have diameter about the size of sand grains or larger, and can be seen by eye or with use of a hand magnification lens). You can see that the A-horizon is in good condition, because it contains a great abundance of roots and the soil is very loose and friable. If the landscape has had a stable forest cover without erosion for hundreds of years, then we expect that the A-horizon will be 6 to 12+ inches in thickness.

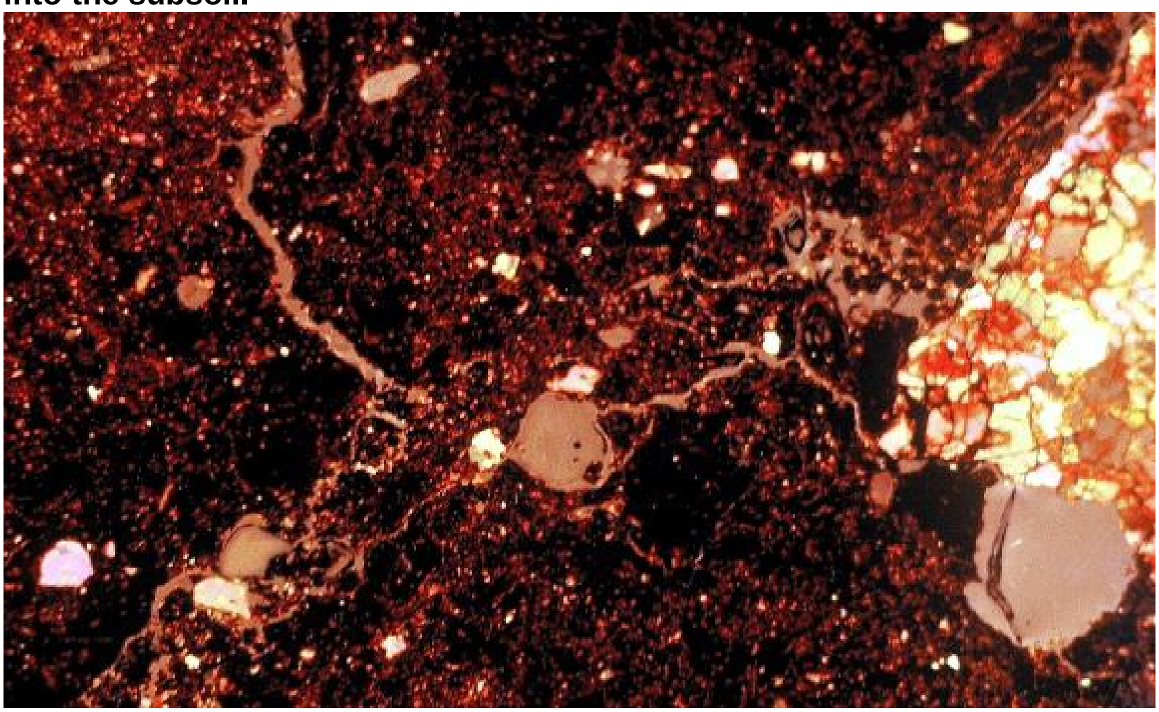
The A-horizon serves as the soil’s reservoir for detention storage during a rainfall event. A healthy thick A-horizon might store two to four inches of rainfall or more, although less on hill slopes. For continued infiltration of larger rainfall events, the macro pores in the A-horizon must be well connected to tubular macro pores in the subsoil. Therefore, water in the surface reservoir flows into the macro pores in the subsoil. The macro pores transmit the water deep into the subsoil and then into millions of micro pores.

Macro pores are fragile and can be easily disturbed or destroyed by grading and compaction. Think of the macro and micro pores as a complex network of pores, somewhat like the network of veins in the heart. Blockage and disruption of your heart’s veins can paralyze the hearts ability to pump blood. In a similar fashion, blockage and

[1] Barrett L. Kays, Ph.D., NC Licensed Soil Scientist, Landis, Inc., Raleigh, NC



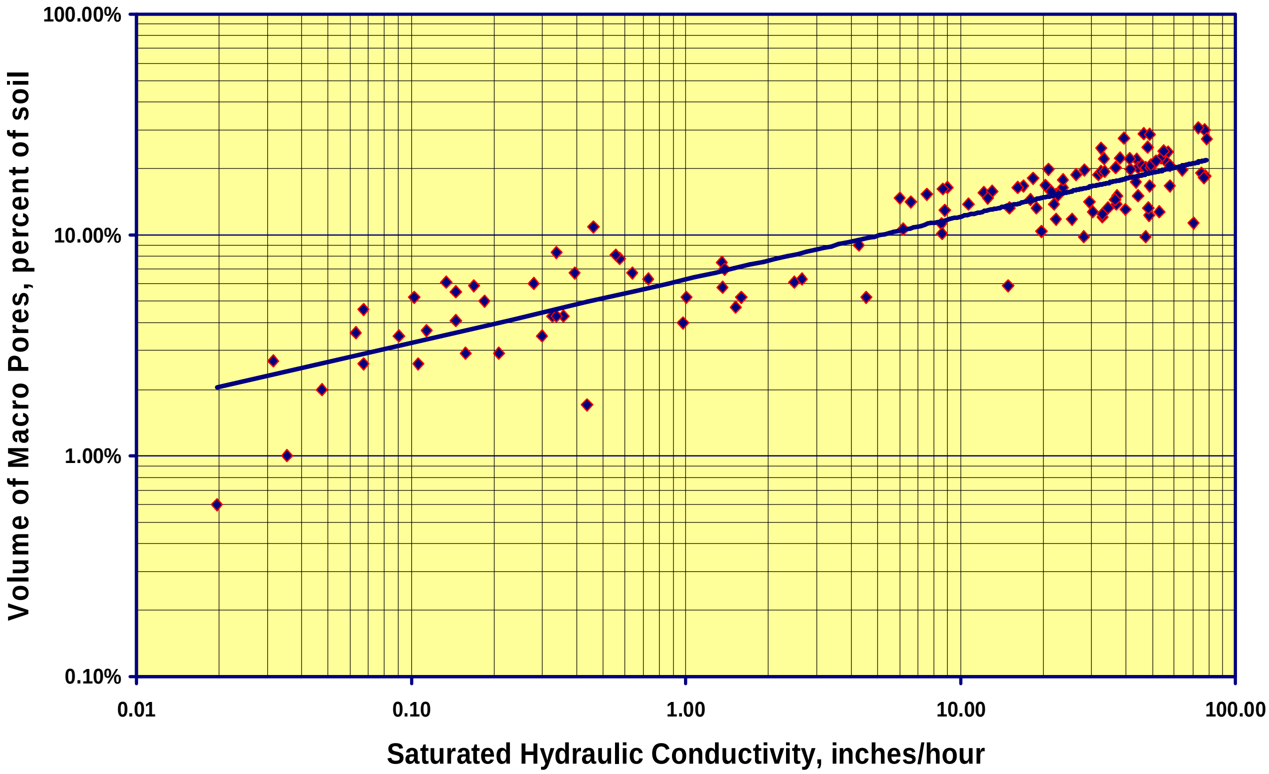
Cecil sandy loam topsoil at forested site is very loose and porous (light areas are pores). Rainfall ponds in the topsoil reservoir prior to flowing into the subsoil.



Enlarged microscopic view of Cecil clay subsoil at forested site shows cross section of two tubular macro pores which receive water from topsoil reservoir (light gray areas are pores; the photograph also shows a large multi-colored sand grain).

disruption of the soil pore network will cripple the infiltration process. Compaction significantly reduces the capacity in the A-horizon and it can block and tear the pathways into the subsoil, as well as compact the subsoil. The macro pore network is the first casualty caused by introduction of motorized equipment in the forest, as the first trees are cut.

Relationship Between Macro Pores and Saturated Hydraulic Conductivity for Cecil Soils, Charlotte, NC



Water flows faster through a soil which has a greater volume of macro pores. Conversely, as the volume of macro pores is reduced the saturated hydraulic conductivity is severely restricted.

Impacts of Urbanization

A study of infiltration rates in Cecil Series soils in Charlotte, NC shows that the infiltration rate was drastically impaired by agriculture and urban development (Table 1). The soils and their infiltration were studied across the Sudbury one square mile portion of Sugar Creek watershed. Sugar Creek has experienced significant flooding. Urbanization in the 1960's left the watershed with an average topsoil depth of about one inch in thickness. Agricultural mold board plowing into the clayey subsoil prior to the 1960's compacted the upper portion of the subsoils, restricted the flow of water into the subsoils, reduced infiltration rates, and caused runoff in smaller storm events.

During the 1960's, urbanization further reduced the infiltration capacity of the soils by grading and compaction. The table shows that the largest reductions in infiltration rates were caused by construction grading and compaction. Grading and heavy compaction of the soil produced the worst results. Cutting into the subsoil, filling with clayey subsoils, or compaction all had significant reductions in infiltration capacity. After construction and revegetation, the depth of vigorous rooting of grasses, trees and shrubs was the best indicator of improved soil conditions and better infiltration rates.

Table 1 - Impacts of Urbanization on Infiltration Rate of Cecil Soils Sugar Creek Watershed, Charlotte, NC

#	Pre-1960's Land Use	Pre-1960's Alteration	Post-1960's Alteration	Average Infiltration Rate & Percent Reduction	
				Inches/Hour	% Reduction
1	Mature Forest	No alteration	No alteration	**12.43**	**0.0**
2	Cultivated field	Cultivation	No alteration	**4.41**	**64.5**
3	Cultivated field	Plow pan	No alteration	**1.89**	**84.8**
4	Cultivated field	Plow pan	Compaction	**0.29**	**97.7**
5	Mature Forest	No alteration	Cuts into subsoil	**0.67**	**94.6**
6	Mature Forest	No alteration	Fills with subsoil	**0.49**	**96.1**
7	Cultivated field	Cultivation	Heavy compaction	**0.17**	**98.6**

Infiltration rate measured after 1 hour with saturation of soil profile to surface and proceeded by wet one-day antecedent conditions.

The change in infiltration rates is related to the changes in percent of macro pores and micro pores in the soils across the watershed (Table 2). The reduction in the percent of macro pores is closely related to the reduction in infiltration rates caused by grading and compaction.

The Natural Resource Conservation Service (NRCS) provides Hydrologic Groups for soil series. The hydrologic groups are rated as: Group A – 0.30 to 0.45 inches/hour, Group B – 0.15 to 0.30 inches/hour, Group C – 0.05 to 0.15 inches/hour, and Group D – 0 to 0.05 inches/hour. These values are frequently used in conjunction with TR-55 (NRCS runoff computation program). The Charlotte and other studies have shown that infiltration rates vary greatly within a single soil series. Actual infiltration rates are dependent upon the historical condition of the soils. The NRCS hydrologic groups are based upon soil studies over 75 years ago on agricultural soil erosion sites that were excessively damaged, and as such the values do not represent the full range of values that actually occurs across our landscapes.

Although the Cecil Series soils are rated as Hydrologic Group B, most of the Cecil soils in Charlotte exceeded 0.15 to 0.30 inches/hour. Most importantly, the hydrologic groups underestimate the infiltration capacity of undisturbed soils and thus does not allow for properly valuing the benefits of protecting undisturbed sites. They also underestimate the infiltration capacity of soils that have been restored.

Table 2 - Soil Porosity vs. Infiltration of Cecil Soils
Sugar Creek Watershed, Charlotte, NC

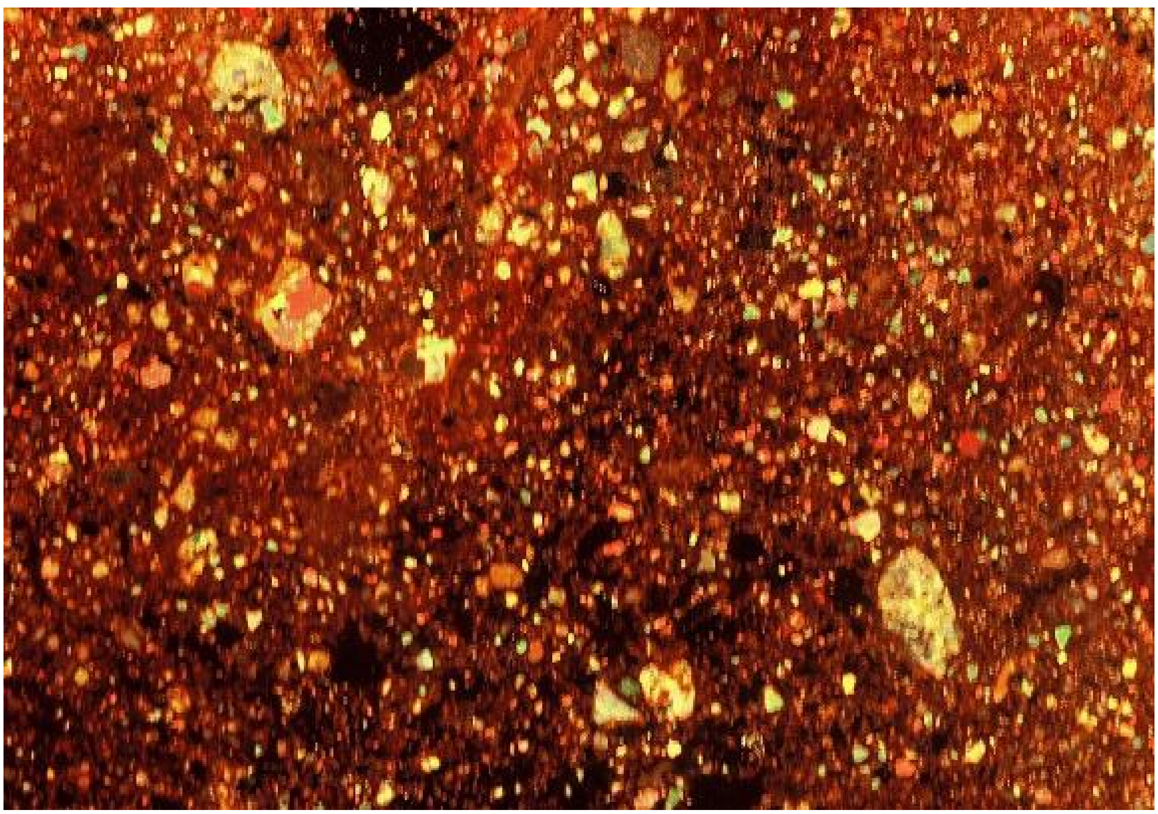
#	Topsoil		Subsoil		Average
	Percent Macro Pores	**Percent Micro Pores**	**Percent Macro Pores**	**Percent Micro Pores**	**Infiltration Rate** Inches/Hour
1	35	15	15	35	12.43
2	20	20	30	20	4.41
3	15	15	30	30	1.89
4	55	8	36	30	0.29
5	55	8	36	30	0.67
6	55	8	36	30	0.49
7	58	4	38	30	0.17

It is best to measure existing infiltration rates on project sites that will depend upon infiltration for the control of stormwater runoff. Measuring infiltration rates allows you to accurately design and size bioretention systems.

However, should you not obtain on-site measurements; you can estimate or arrive at a conservative value of infiltration for the design storm.   Identify the hydrologic group for the soil series shown on the county soil survey. The county soil survey or the TR-55 program will provide the hydrologic group for each soil series. Assume that the final constant infiltration rate equals the mid-range of the hydrologic group. Then determine the depth of soil that is going to be physically amended. Assume an effective porosity of 15 to 35% of volume of the amended soil. Therefore, a one acre area amended to a twelve inch depth would store approximately 1.8 to 4.2 acre-inches, which will slowly drain into the unamended subsoil at the rate of 0.225 inches/hour (assuming group B) and the excess water in the A-horizon will drain into the subsoil in 8 to 19 hours.

Soil Restoration

Restoration of damaged soils requires the use of physical, chemical, and biological amendments. Typically, all three types of amendments are required to recover or restore the infiltration capacity of the soils. Physical amendments include deep ripping, chisel plowing, tillage, or some combination of these methods. Physical amendments may also include addition of light weight aggregate or coarse sand, although it may not be cost effective due the high amounts needed for clayey soils.



Cecil clay subsoil compacted by grading activities is dense and has few macro pores. Water ponds over the compacted clay horizon, quickly backs up to the surface, and produces more surface runoff and more frequently.

Chemical and biological amendments are important especially in reducing the acidity of low pH subsoils. Organic amendments are valuable in most soils, but are not recommended for low pH soils since the amendments will tend to lower the pH in acid soil. All amendments need to be thoroughly incorporated into the soil by mixing, tillage, or other effective method.

Why is it important to restore all of the graded areas on the site? What is an appropriate depth to amend the soils? To achieve sustainability, we need to restore deep rooting across the site and this requires amending all damaged areas. We need to achieve vigorous rooting to a depth of at least nine to twelve inches; this depth can be achieved with a combination of tillage equipment (Table 3). Heavy duty chisel plows, subsoilers, or rippers will be needed to physically amend to depths of twelve to twenty-four inches.

Table 3 – Types of Tillage Equipment***

Types	Blade Diameter Inches	Shank Height Inches	Effective Tillage Depth[a] Inches
Disks	**16 – 24**[b]		**4 – 6**
Rotary Tillers	**12 – 18**[c]		**6 – 10**
Chisel Plows		**20 – 30**	**8 – 18**
Subsoilers		**20 – 30**	**12 – 18**
V-Rippers		**20 – 30**	**16 – 20**

a Effective tillage depth depends upon equipment model, horse power, soil texture, soil moisture, and number of tillage passes. Chisel plows typically have an effective depth of 8 to 12 inches, some can achieve 18 inches. Chisel plows, subsoilers, and rippers all require about 30 Hp per shank to achieve deep effective tillage.
b Agricultural disks are commonly 16 to 20 inch diameter.
c Large rotary tillers are typical have 12 to 16 inch tines.
*****Based upon experience and recommendations of Dr. George Naderman, NCSU.

Thomas O. Perry, renowned forester, proposed that trees need eighteen inches of rooting depth and that entire soil surfaces on urban sites should be amended to that depth. Perry based his reasoning on the rooting volume, soil moisture volume, and water needed to achieve mature trees. Perry's rooting depth goal of eighteen inches seems to be the gold standard in achieving true soil sustainability.

The effective depth of the soil amendments will control the depth of rooting in the early years after amendments. Success can be observed by checking the rooting depth in the amended soil. Normally we like to dig cores in lawn areas to check the depth of rooting, rather than damaging the roots of shrubs and trees.

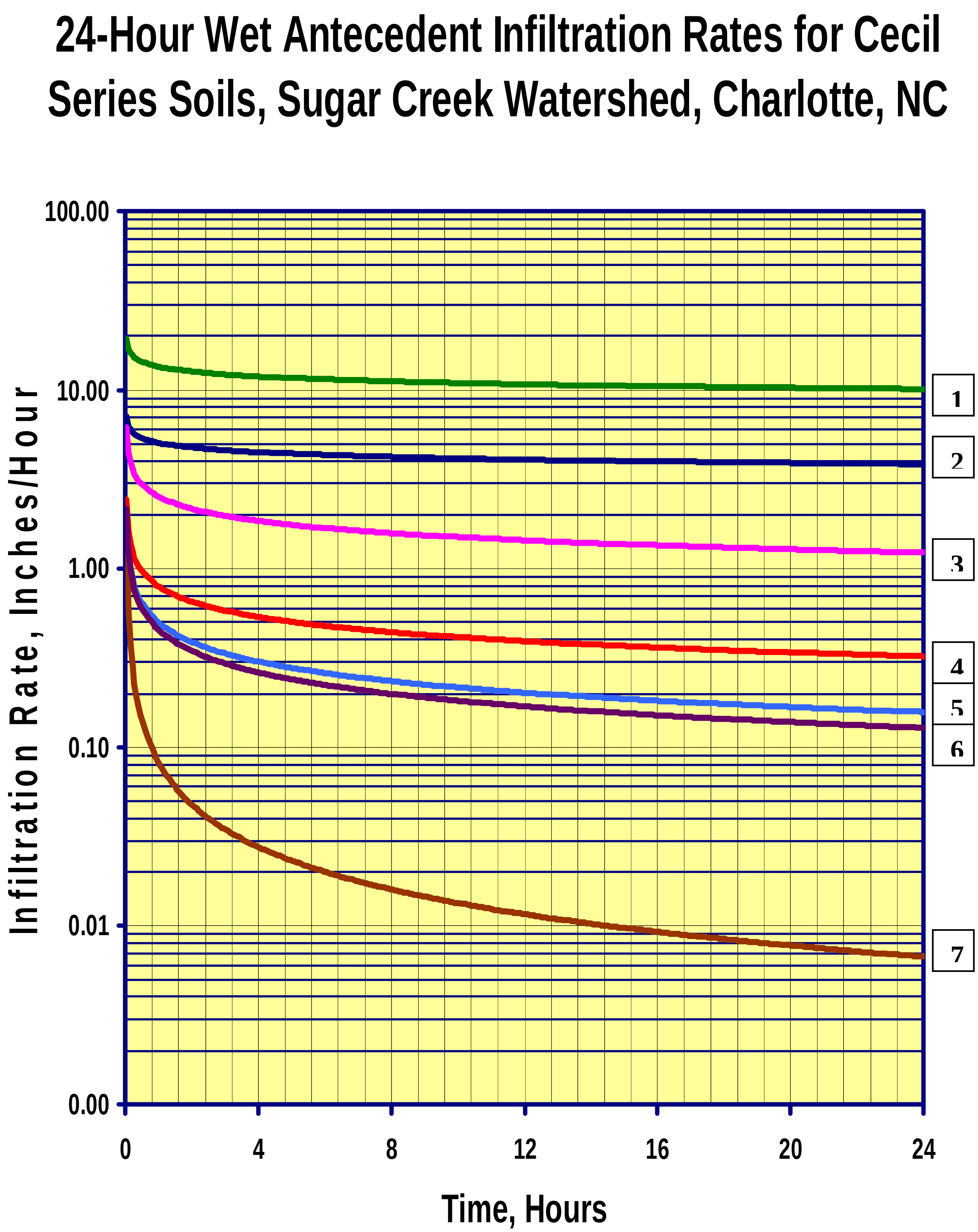
We like to obtain vigorous rooting throughout the amended soil in the first year; this helps to protect and maintain the porosity in the amended soil.

At a recent project, our budget allowed us to achieve an initial rooting depth of nine inches. I checked the depth of physical and chemical amendments installed by the contractor. And two months after landscaping, I dug cores to check the actual rooting depth. The results showed that we achieved vigorous average rooting to a depth of nine or more inches.

Agricultural chisel plow used for ripping subsoil to depths from 8 to 12 inches.

24-inch diameter agricultural disk is used to break up compacted soils at the surface.

Warrior 1400 power screener and loader is used for custom processing and blending of on-site soil materials, thus reducing or eliminating the need for importing topsoil.



Infiltration rates for Charlotte, NC study for longer storm events. Infiltration rates are shown for storm durations extending out to 24 hours. Curve numbers correspond to numbers and descriptions in Table 2.

Within two months after sodding, 'Celebration' Bermuda grass roots extended over nine inches into amended clayey soil at Reedy Fork Elementary School in Greensboro, NC.

Deep rooting allowed for good infiltration for at least a nine inch depth. This will generally allow for infiltration of about 0.75 inches/hour which equates to 18 inches for a 24 hour storm event. Below the amended layer the water movement will be restricted until roots find deeper crevices. After years of root growth some properly amended sites of Cecil soil have achieved rooting to twenty-four to thirty inches and infiltration rates ranging from 1.56 to 6.58 inches/hour and averaging 3.65 inches/hour. Thus, long term recovery can be achieved, but first proper amendments need to achieve initial rooting depth of nine to twelve inches, or twelve to eighteen inches with use of deep tined chisel plows.

Runoff rates are normally computed using a NRCS TR-55 Type II Rainstorm Event. Applying the Type II Rainstorm with an infiltration rate of 0.75 inches yields the following percent runoff:

Table 4 - Runoff from Amended Cecil Subsoils, Greensboro, NC
Infiltration Rate 0.75 inches/hour

Rainstorm Frequency	Rainstorm Amount inches	Runoff Amount inches	Runoff Percent
2 Year	3.75	0.00	0.00
5 Year	4.75	0.08	1.67
10 Year	5.70	0.56	10.47
25 Year	6.40	0.92	15.51
50 Year	7.20	1.28	21.61
100 Year	8.50	1.94	25.46

If an initial rooting depth of nine to twelve inches is not achieved in the first year, you need to consult further with soil scientists, agricultural extension agents, or agricultural soil testing specialists in your local area. It will be necessary to change your practices, change contractors, and or use performance based payments, until you consistently are achieving deep rooting into disturbed soils. Deep rooting and increased infiltration can be achieved on disturbed soil, and it is essential to creating sustainable sites.

References

Craul, Phillip J. 2006. Soil Design Protocols for Landscape Architects and Contractors. John Wiley & Sons, Inc.

Craul, Phillip J. 1999. Urban Soils Applications and Practices. John Wiley & Sons, Inc.

Craul, Phillip J. 1992. Urban Soil in Landscape Design. John Wiley & Sons, Inc.

Ferguson, Bruce K. 1994. Stormwater Infiltration. CRC Press, LLC.

Kays, Barrett L. 2008. Strategies for Clay Soils, Landscape Architecture Magazine, 2008(5) 66 -74.

Kays, Barrett L. 2006. Problem Solving in Stormwater Bioretention Systems: Pitfalls in Bioretention Systems and How to Avoid Them, Landscape Architecture Magazine, 2006(6) 94-105.

Kays, Barrett L. 1982. Methodology for On-Site Analysis, Chapter 7, in Urban Forest Soils Notebook, Soils Training Workshop for Landscape Architects, Phillip J. Craul (Ed.), U.S. Forest Service. http://www.barrettkays.com/press-downloads.html

Kays, Barrett L. and James C. Patterson. 1982. Soil Drainage and Infiltration, Chapter 5, in Urban Forest Soils Notebook, Soils Training Workshop for Landscape Architects, Phillip J. Craul (Ed.), U.S. Forest Service. http://www.barrettkays.com/press-downloads.html

Kays, Barrett L. 1980. Relationship of Forest Destruction and Soil Disturbance to Increased Flooding in Suburban North Carolina Piedmont, Proceeding of Metropolitan Tree Improvement Alliance, New Brunswick, NJ. http://www.barrettkays.com/press-downloads.html

Perry, Thomas O. 1994. Size, Design, and Management of Tree Planting Sites, in The Landscape Below Ground, Proceeding of an International Workshop on Tree Root Development in Urban Soils, Gary W. Watson & Dan Neely (Ed.), International Society of Arboriculture.