Impact of Soil Disturbance During Construction on Bulk Density and Infiltration in Ocean County, New Jersey

By

Ocean County Soil Conservation District
Schnabel Engineering Associates, Inc.
USDA Natural Resources Conservation Service

March 2001 (Rev. 06/01/01)*

Abstract

A study was conducted of undisturbed and disturbed urban soils in Ocean County, New Jersey to investigate the impact on soil infiltration rates due to modification and compaction during construction operations, to examine if the effects are significant enough to alter the Hydrologic Soil Group (HSG) classification or Runoff Curve Number, and to provide additional guidance in the use of TR-55 for the design of structural stormwater management practices.

In soils highly disturbed by heavy equipment and in pasture in good hydrologic condition, measurements of bulk density and infiltration rates were conducted both *in situ* and on reconstituted samples prepared by the USDA, NRCS National Soil Mechanics Center. The results show that as soil bulk density increases to 1.65 g/cm^3, infiltration rates of the soil decrease rapidly. When the bulk density increases above 1.65 g/cm^3, infiltration rates decline slowly, approaching zero. The measured infiltration rates for disturbed soils with high bulk densities were significantly lower than expected. NRCS Technical Release 55 (TR-55) provides guidance for estimating the runoff for undisturbed and uncompacted disturbed conditions, but not for the compacted condition. Recommendations have been made for further research to allow the development of additional guidance for estimating Runoff Curve Numbers from vegetated disturbed soils in Ocean County.

The measured infiltration rates of undisturbed wooded and pastured soil were higher than expected. It is recommended that additional data be obtained and analyzed to determine if the USDA NRCS Runoff Curve Numbers accurately reflect the runoff from undisturbed soils in Ocean County.

* A typographical error between Table 2 and the data in the Appendix and other tables and graphs was corrected.

An Investigation of the Effects of Soil Disturbance on Bulk Density and Infiltration in Ocean County, New Jersey
March 2001

Introduction
Ocean County Soil Conservation District (OCSCD) personnel have observed that runoff from many recently constructed housing developments exceeds estimates made using the procedures contained in NRCS Technical Release 55, (TR-55), Urban Hydrology for Small Watersheds. In addition, OCSCD personnel have observed lawn areas that remain saturated for extended periods of time even though the underlying soils are sandy in texture. This led to an investigation by OCSCD to determine whether these observations have any basis in fact. OCSCD received the assistance of the USDA Natural Resources Conservation Service (NRCS) and obtained the services of Schnabel Engineering Associates in conducting this study.

Objective
The objectives of the study are to investigate the impacts on soil infiltration rates due to modification and compaction during construction operations, to examine if the effects are significant enough to alter the Hydrologic Soil Group (HSG) classification or Runoff Curve Number, and to provide additional guidance in the use of TR-55 for the design of structural stormwater management practices.

Background
Saturated yards, pools of standing water in crawl spaces, and the premature death of landscape plants are common in some recently constructed large housing developments. Lawns will not grow without placement of sod and installation of irrigation systems. Even brief irrigation causes runoff into the street and/or ponding. However, if the lawns are not watered at least every second day during hot weather, they suffer from drought. Iron stains on the sidewalks indicate the formation of ferrous iron oxide in the lawn areas and its subsequent precipitation as ferric iron oxide as the seepage water flows over the concrete and is exposed to air. While front yards usually have positive drainage to the street, many less sloping backyards have surface inlets connected to shallow perforated drains running out to the curb to remove excess water. These curb drains may seep for a week or more after a rain, even when irrigation systems are turned off. On compacted soils, these indicators of surface and lateral subsurface flow occur regularly on soils considered to be porous, well drained to excessively drained, with a water table deep below the surface.

The primary method of site preparation on most recent housing developments involves extensive clearing and grading with significant cuts and fills. High soil density is desired to eliminate settlement cracking of foundations.

A less prevalent method of construction, although more common in the 1950 s, is to build an individual house on a separate lot where the limit of disturbance is confined to that footprint alone. When construction is confined to areas selectively cleared and to limited grading, the size of the equipment is usually reduced and there is less soil disturbance.

Typically most stormwater management designs rely solely on structural practices to reduce adverse impacts of urban development. These practices are dependent on accurate design data, particularly the land use/soil information for both pre- and post-development conditions. Infiltration practices that mimic natural pre-development hydrology are seldom used. Presently, there are few incentives to leave areas undisturbed to establish a rain garden or to utilize such areas for infiltration to reduce the total volume of runoff and provide water quality benefits. The ability of healthy soils to accept rainfall at the point of impact is an essential component of any stormwater management design, and the condition of the soil following land disturbance has a profound impact on the runoff, infiltration, and groundwater recharge. Soil management can provide greater opportunities to enhance the overall stormwater management design by incorporating infiltration into the design to mimic natural hydrologic conditions.

Methodology

Both bulk density and infiltration tests were conducted at eight locations in Ocean County. At each site a soil pit was dug to provide a soil description and to collect bulk density data from all layers within 20 inches of the ground surface. After evaluation of the bulk density results, infiltration measurements were conducted in the densest layer. Three replications of all bulk density and infiltration measurements provide the basis for the mean values presented herein.

The bulk density data were collected using the Core Method for Determining Bulk Density 30-2, Method of Soil Analysis, Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling, Agronomy No. 9 Part 1, American Society of Agronomy. The procedure is briefly described as follows:

With this method, a cylindrical metal sampler is pressed or driven into the soil to the desired depth and carefully removed to preserve a known volume of sample as it existed *in situ.* The sample is dried at 105° C and weighed. Bulk density is the oven-dried mass divided by the field volume of the sample. The calculation of bulk density is on a whole soil basis.

Samples were taken using a 3 X 3 Uhland sampler and heated in a laboratory oven until a constant weight was obtained. After the surface was sampled, successive layers were removed so sampling could take place on a level surface. To gain access to the lower depths, a pit about 30 inches square was dug by carefully removing the soil in level layers so that three samples could be accurately obtained from each depth. The sampler had over-cuts of about one inch below and _ above, which were trimmed off after the sample was removed from the sampling tool.

The measurement of infiltration was conducted in conformance with the procedure outlined in ATSM D-3385 - 75 Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer with a single exception. The method calls for an outer ring of 24 in diameter and an inner ring of 12 inches. The soils were so dense that it was not possible to hammer the larger ring to the required depth. Therefore, the 12 diameter ring was used as the outside ring and the 3 diameter bulk density sampler was substituted as the inside ring. The difference in diameter of the outer ring was considered to have adequately restricted the lateral flow away from the inner ring. By digging down to the dense layer, not only was the infiltration of that layer determined, but also its saturated permeability. The length of time to obtain a constant rate varied but all had nearly leveled within a few hours.

The sites selected for testing represent a range of soil conditions, from undisturbed woods, pasture in good condition, to highly disturbed or modified. The sites identified as Subdivision Lawn 1 , Garage Lawn , Subdivision Lawn 2 and Athletic Field are representative of highly disturbed sites where significant grading of the original topography by heavy construction equipment has taken place. The Cleared Woods site has been cleared and the duff layer removed by heavy equipment but has not undergone any significant grading. In order to compare the typical large tract construction to a less intensive type, the single house site was selected. This location is representative of the lot-by-lot construction where overall topography changes are minimal and light construction equipment is used. Pasture was particularly included since the runoff attributes of this land use are assumed in TR-55 as characteristic of the pervious lawn areas used in determining CN s for residential areas.

Data and Results

The results of the testing conducted at each location are summarized in Tables 1 and 2. The bulk density and permeability data presented in Table 1 are the mean of the three replications in a layer within 20 inches of the soil surface at each of the seven locations. Table 2 indicates the original soil series and the HSG, as identified in the soil survey and listed in TR-55. The assigned HSG for the Athletic Field was based on the soil texture in conformance with Appendix A of TR-55. This location was mapped as a sand pit in the Ocean County Soil Survey and, therefore, did not have a HSG designation. The *minimum* infiltration rates for row crops corresponding to each HSG are referenced in Appendix A of TR-55. Group A has a rate greater the 0.3 in/hr, Group B has a rate between 0.15 and 0.3 in/hr, Group C has a rate between 0.05 and 0.15 in/hr, and Group D has a rate less than 0.05 in/hr.

Appendix A of this report contains the detailed logs of the soil profiles recorded at each site, a description of the site condition and a complete listing of the bulk density and infiltration test results. Appendix B contains the results of tests conducted at the NRCS National Soil Mechanics Center located in Lincoln, Nebraska. Samples from each of the test sites were sent to the lab for index and permeability tests. The index test includes gradation analysis and determination of the liquid and plastic limits for classification of the sample in conformance with the Unified Soil Classification System. Maximum dry densities and optimum moisture contents were determined using the Standard Proctor Method. At optimum moisture, cores were packed to the approximate density of the field condition. Without drying the cores, measurements of hydraulic conductivity were conducted.

Table 1.

Permeability Measurements of Sampled Layers within 20 of Soil Surface		
Site	Bulk Density (g/cm^3)	Permeability (in/hr)
Woods	1.42	15
Pasture	1.47	9.9
Single House	1.67	7.1
Subdivision Lawn 1	1.79	0.14
Garage Lawn	1.82	0.04
Cleared Woods	1.83	0.13
Subdivision Lawn 2	2.03	0.03
Athletic Field	1.95	0.01

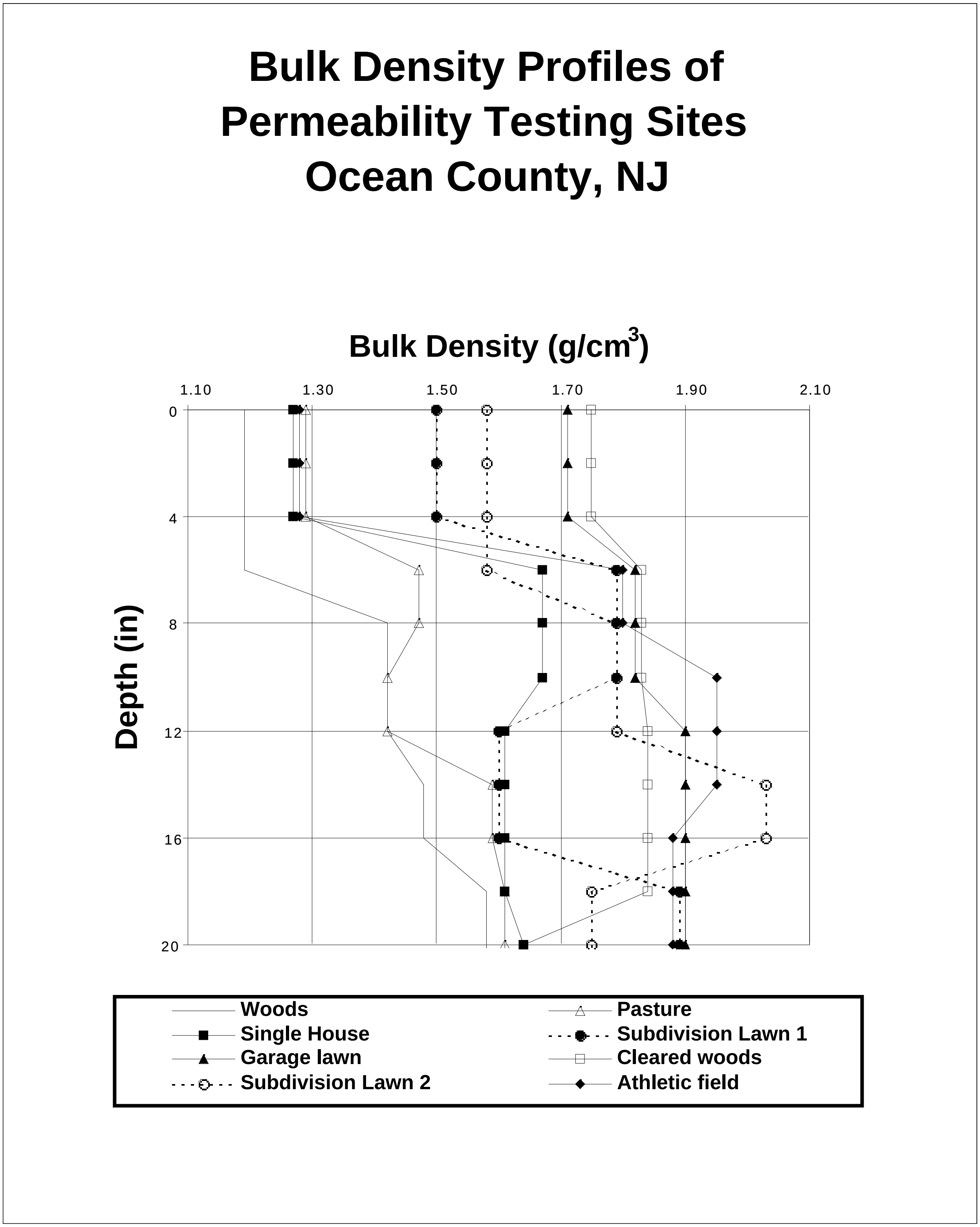
Table 2.

Site	Level of Disturbance	Soil Series as shown in the soil survey	HSG in TR-55 as assigned by soil survey	Field Measured Permeability (in/hr)	Field Estimated HSG[2]
Woods	Undisturbed	Downer	B	15	A
Pasture	Somewhat Disturbed	Downer	B	9.9	A
Single House	Somewhat Disturbed	Downer	B	7.1	A
Subdivision Lawn 1	Disturbed	Lakewood	A	0.14	C
Garage Lawn	Disturbed	Urban land	A[1]	0.04	D
Cleared Woods	Disturbed	Downer	B	0.13	C
Subdivision Lawn 2	Disturbed	Downer	B	0.03	D
Athletic Field	Disturbed	Sand Pit	A[1]	0.01	D

[1] HSG assigned based on soil texture in conformance with Appendix A of TR-55.
[2] Based on water transmission rates for row crops in TR-55, Appendix A.

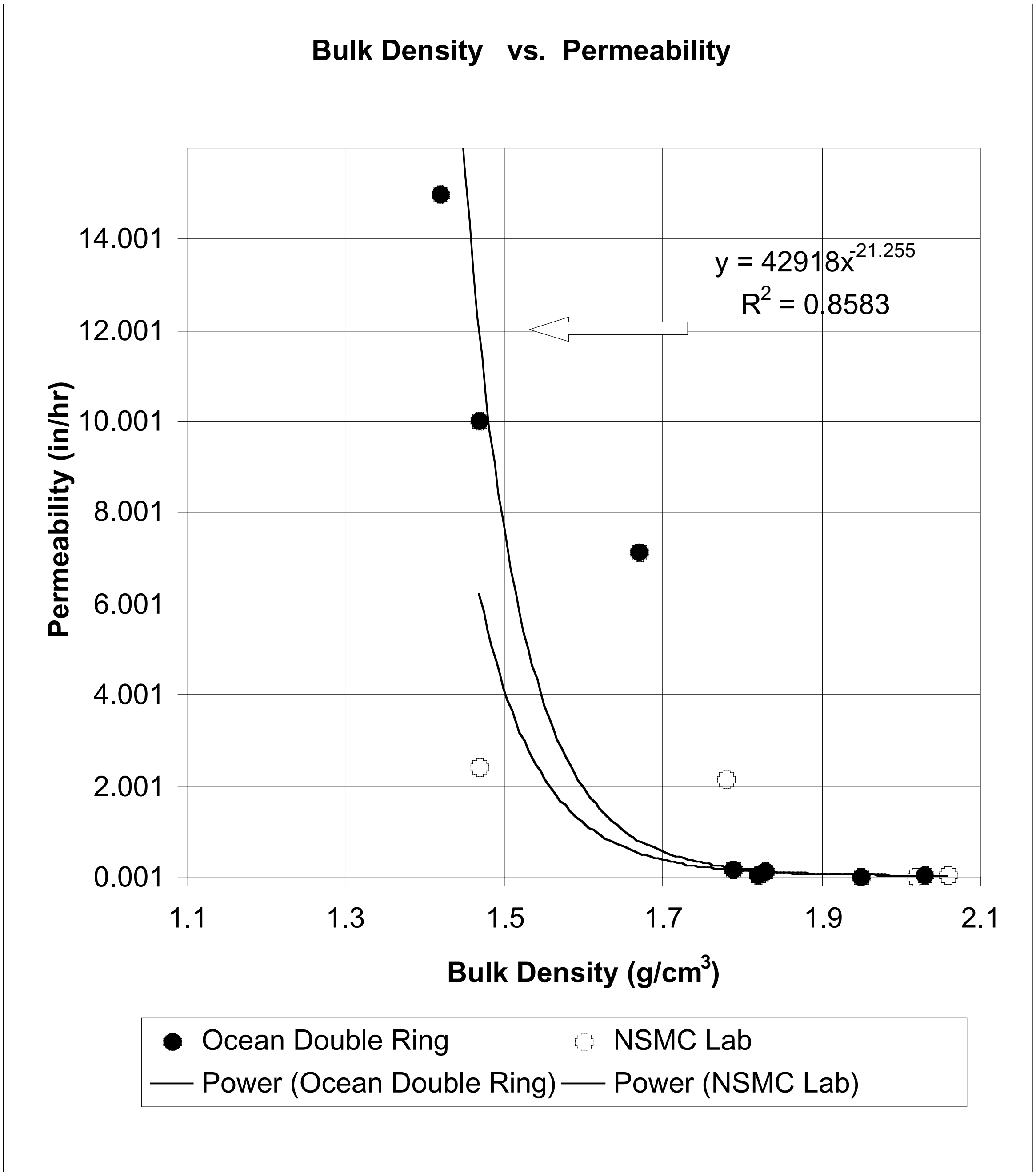
The following graphs summarize the sites sampled in Ocean County. Graph 1 shows the distribution of bulk density with depth in the sites sampled. In the graded condition, the soil is more dense in all layers, especially just below the topsoil that was applied after most grading activities and loosened during seedbed preparation. Graph 2 relates permeability rate to bulk density for the specific layers sampled in Table 1.

Graph 1.



Bulk Density Profiles of
Permeability Testing Sites
Ocean County, NJ
Bulk Density (g/cm3)
1.10
1.30
1.50
1.70
1.90
2.10
0
4
8
12
16
20
Depth (in)
Woods
Pasture
Single House
Subdivision Lawn 1
Garage lawn
Cleared woods
Subdivision Lawn 2
Athletic field

Graph 2.



There is general agreement in the shape and relative trends of the data from both the lab and *in-situ* tests. As soil bulk density increases to 1.65 g/cm^3, the infiltration rate decreases rapidly. When the bulk density increases above 1.65 g/cm^3, infiltration rate declines slowly, approaching zero. Unless the soil surface becomes crusted or covered with an impermeable surface such as concrete, this permeability becomes the limiting factor for infiltration into the soil profile. Thus the permeability measurements were used to develop the following technique to estimate infiltration rates of densities not specifically measured. For example, using the formula from the *in-situ* data above [Permeability = (42198)(Bulk Density)$^{-21.255}$] it can be estimated that soil with a bulk density of less than 1.75 g/cm^3 would be expected to have an infiltration rate of greater than 0.3 in/hr.

Discussion

The amount of surface runoff is dependent on a complex interrelationship between the soil surface, the soil profile, and the land cover. The soil surface can be the limiting factor for infiltration if a crust on the surface restricts movement of water into the soil profile. The soil profile can be the limiting factor for infiltration if its rate of permeability is less than the rate at which the water can enter the soil. For example, a soil that has a restrictive layer within 20 inches is considered shallow, with a limited pore space volume in which to store water. The land cover can influence either factor. For example, an impervious surface such as concrete will prevent any water from entering the soil profile. Over the long term, vegetation will increase the permeability of the soil profile by providing preferential flow paths in decomposed root channels.

The NRCS Runoff Curve Number procedure accounts for this interrelationship by assigning Runoff Curve Numbers (CN s) to unique combinations of Hydrologic Soil Groups (HSG s), land cover, land treatment, and hydrologic condition. The soil characteristics have a major impact on the infiltration, permeability, and moisture holding capacity of the soil. To partially account for this, a soil series is assigned to a HSG by soil scientists and published in TR-55. It is based upon an evaluation of infiltration, structure, permeability, and especially texture.

In naturally developed soils, when a layer has a high bulk density, such as a dense pan or bedrock, it is usually restrictive to roots and water. Such soils commonly have a perched zone of saturation above the dense layer. When the dense layer or bedrock perches water within 20 inches of the surface, it is similar to any soil that has an apparent water table within 20 inches of the surface. A soil that has an unrestricted thickness of less than 20 inches is considered shallow with a limited pore space volume in which to store water. Therefore, it is assigned the highest runoff classification, HSG D. When these restrictive features occur below the 20-inch depth, they are not considered to contribute to additional runoff because the soil does not become filled with water over the impervious or saturated layer during most storms. In many disturbed soils, the dense layer is immediately below the surface layer that was loosened during seedbed preparation. So little water is stored in the profile that, although it can be depleted by plant consumption during the interval between rains, the soil profile fills up very quickly during a storm and increased runoff occurs.

The CN procedure recognizes that land cover, land treatment, and hydrologic condition also have an impact on the infiltration, permeability, and moisture holding capacity of the soil, resulting in a set of overlapping CN s with respect to HSG s. Thus sand (HSG A) that is bare could produce more runoff than sandy clay loam (HSG C) that is pastured.

The original work that was used for defining the HSG s, as shown in Appendix A of TR-55, was by Musgrave, as reported in 1955. Appendix E of TR-55 cites the reference. Musgrave described these HSG s in terms of minimum infiltration rates with row crops on wet soils . These ranges provide a full continuum and do not overlap. It should be noted that these rates are specific to a unique land cover. Thus, for other land covers, different infiltration rates would be expected for defining the HSG classification. For a vegetated condition, the infiltration rates for defining A, B, C, and D classifications would be higher than for row crops. Likewise, for a bare soil condition, the rates would be lower. The results of this study show that the field measured permeability rate for each disturbed and now vegetated site is lower that the infiltration rate determined by Musgrave for row crops. This is opposite of what would be expected at vegetated sites without soil disturbance. While based on row crop infiltration rates Subdivision Lawn 1 and Subdivision Lawn 2 appear to be in the C HSG, actually they may be in the D group. The field measured permeability rate for the Cleared Woods site with a bare soil cover also indicates a C HSG based on the row crop infiltration values. Since it is at the low end of the range, this may in fact be a proper classification even though it is in a bare condition. The undisturbed and somewhat disturbed sites including Woods , Pasture , and Single House had field measured permeability rates in the range of 7.1 to 15 inches per hour. Even considering that the rates should be higher than for the row crop condition, the measured rates are still significantly higher than expected.

Applying the textural-based HSG classification guidance from Appendix A of TR-55 to the disturbed sites tested in Ocean County would indicate that all of the soils still could be classified as A or B. The results show that the level of disturbance at these sites has produced significant compaction and has altered the HSG classification, likely to a D condition. Therefore, it is clear that the classification of a disturbed and compacted soil based on texture alone is not adequate and additional guidance is needed for planners and designers to properly model hydrologic changes due to land use conversion.

The first edition of TR-55, issued in 1975, briefly discussed the impacts of soil compaction by heavy equipment, bare ground with little established sod, and the mixing of surface and subsurface soils. It indicated that any one of these conditions could cause a soil normally in HSG A or B to be classified in group B or C, respectively. It is understood that this guidance was removed from the current edition of TR-55 due to lack of supporting data; however, the results of our study suggest that the impact of soil disturbance in urban areas may be greater than described by this earlier guidance.

The USDA NRCS Soil Quality Institute has developed the following table that shows a relationship between soil bulk density and root growth and has included it in Soil Quality — Urban Technical Note 2. This relationship is very similar to the relationship that we have observed between bulk density and infiltration. The values of soil bulk density that severely restrict root growth correspond very closely to those measured values that severely impede infiltration.

Table 3.

General relationship of soil bulk density to root growth based on soil texture (Adapted from NRCS Soil Quality Institute, 2000)			
Soil Texture	Ideal bulk density (g/cm^3)	Bulk densities that may affect root growth (g/cm^3)	Bulk densities that restrict root growth (g/cm^3)
Sands, loamy sands	< 1.60	1.69	>1.80
Sandy loams, loams	< 1.40	1.63	>1.80
Sandy clay loams	< 1.40	1.60	>1.75
Loams, clay loams	< 1.40	1.60	>1.75
Silts, silt loams	< 1.30	1.60	>1.75
Silt loams, silty clay loams	< 1.10	1.55	>1.65
Sandy clays, silty clays, clay loams (35-45% clay)	< 1.10	1.49	>1.58
Clays (>45% clay)	< 1.10	1.39	>1.47

Further examination of this relationship and the data from this study reveals that both the bulk densities that restrict root growth for sandy soils and those observed at sandy sites with very low permeability rates are greater than 1.8 g/cm^3.

The amount of vegetative cover is the determining factor for the hydrologic conditions of open space in urban areas as defined in Table 2-2a of TR-55. The applicable portion of this table follows.

Table 4.

Hydrologic Condition of Open Space	Runoff Curve Numbers for Hydrologic Soil Group			
	A	B	C	D
Poor	68	79	86	89
Fair	49	69	79	84
Good	39	61	74	80

It is recognized that a good root system is required to sustain good vegetative cover. Even when the soil has been converted to a lawn the soil remains compacted, reducing pore space. These post-developed lawns generate significantly more runoff than estimated using TR-55. TR-55 assumes that the lawns for urban and residential districts in Table 2-2a are in good hydrologic condition. Good condition implies average to better than average ground cover conditions. The findings of this study indicate that the compacted soil conditions of the lawns and athletic fields are not in good hydrologic condition. The measured values of soil bulk density that severely impede infiltration correspond very closely to those that severely restrict root growth. Thus the relationship between soil bulk density and root growth, shown in Table 3 and the results of this study can be combined into Table 5. By assuming that both the hydrologic conditions in TR-55 and the bulk densities shown in Soil Quality — Urban Technical Note 2 envelop the typical conditions, it is possible that the results of the two studies can be used to determine the hydrologic condition of open space in urban areas from bulk density (Table 5). Additional study is needed to confirm this relationship because hydrologic condition refers to the ground cover of the vegetation and not the infiltration rate.

Table 5.

General relationship of maximum soil bulk density within 20 of the surface to hydrologic condition of open space in urban areas based on soil texture			
Soil Texture	Bulk Densities for Hydrologic Condition of Open Space in Urban Areas (g/cm^3)		
	Good	Fair	Poor
Sands, loamy sands	< 1.60	1.60 - 1.80	> 1.80
Sandy loams, loams	< 1.40	1.40 - 1.80	> 1.80
Sandy clay loams	< 1.40	1.40 - 1.75	> 1.75
Loams, clay loams	< 1.40	1.40 - 1.75	> 1.75
Silts, silt loams	< 1.30	1.30 - 1.75	> 1.75
Silt loams, silty clay loams	< 1.10	1.10 - 1.65	> 1.65
Sandy clays, silty clays, clay loams (35-45% clay)	< 1.10	1.10 - 1.58	> 1.58
Clays (>45% clay)	< 1.10	1.10 - 1.47	> 1.47

Recommendations

Recommendation 1: Perform additional study of rainfall and runoff data from undisturbed watersheds in the coastal plain of New Jersey.

Discussion: The relatively high measured permeability rates at the undisturbed and somewhat disturbed sites raise the question of whether the CN s in TR-55 accurately reflect the runoff from undisturbed woods and pasture in the coastal plain of New Jersey. Although a study conducted in 1981 indicated that the CN s for woods in the Pinelands are adequate, the data collected as part of this study indicate that more study is needed.

Recommendation 2: Conduct further research to allow the development of additional guidance for the determination of the HSG and hydrologic condition for compacted urban sites based on the expected method of construction and degree of site modification.

Discussion: Currently there is limited guidance available for the determination of the HSG, and hence the CN, for disturbed soils where significant compaction has occurred. Appendix A of TR-55 provides a texture-based means for classification that applies to disturbed but not compacted soils. This study indicates that construction techniques that significantly alter the site topography with heavy equipment do result in significant compaction, thus reducing the permeability rate of the soil. While an after the fact procedure may be developed based on site-measured bulk densities and/or permeability rates, what would be most useful to planners and designers would be a qualitative procedure based on the expected method of construction and degree of site modification. The effects of significant compaction likely can be reflected by a shift to the HSG D condition. Also, there may be an opportunity to use the soil bulk density to reflect the hydrologic condition of open space in urban areas. At this time, the determination of how to account for an expected increase in runoff due to compaction should be made on a site-by-site basis considering the extent of disturbance, degree of topographic alteration, and expected method of construction.

Recommendation 3: Continue OCSCD s storm water management basin monitoring that has been initiated and expand it to include basins in highly disturbed sites.

Discussion: The results of this study will provide valuable total site runoff data from a variety of developed urban sites. These site-scale data are needed to verify that small plot data are properly interpreted and used to develop procedures and criteria.

Recommendation 4: Evaluate other aspects of the NRCS procedures for estimating peak discharge before permanent changes are made to procedures and criteria.

Discussion: The results of this study indicate that soil modification and compaction associated with current construction techniques do alter a soil s pre-developed HSG classification. Implementation of a change in HSG for the developed condition will impact both the predicted volume and the rate of runoff. While this study focused on the impacts on runoff volume, it is important to recognize that the NRCS procedures for estimating peak discharges include other aspects that need to be evaluated including the dimensionless unit hydrograph and the ability of undisturbed areas to serve as infiltration buffers.

Recommendation 5: Conduct additional analysis to develop construction guidelines and specifications that would minimize and remediate the impact of urbanization on runoff.

Discussion: This study indicates the effects of urbanization on runoff. However, little information exists as to specific soil remediation techniques and what level of soil restoration will likely result. Developers, planners and units of government need to know the effectiveness of restoration techniques so that informed land-use planning choices can be evaluated.

Appendix A Infiltration Sampled Sites

Woods

Described and Bulk Density samples taken 10/10/97
Infiltration measured using single rainfall simulator ring as inner ring on 9/27/99
Woods neither grazed nor harvested by heavy equipment.

Oi 2-1 inches; hemic organic soil materials.
Oa 1-0 inches; sapric organic soil materials; many fine roots forming a roots mat, a grub was present
A 0-1 inches; dark gray (10YR 4/1) loamy sand; common medium roots.
A/B 1-7 inches; yellowish brown light (10YR 5/8) light sandy loam: 12-14% clay: friable: common medium roots.
Bt1 7-15 inches; yellowish brown(10YR5/8) sandy loam: friable: few medium roots.
Bt2 15-22 inches; yellowish brown(10YR5/8) gravelly sandy loam: friable.
C 22-48 inches; dark yellowish brown (10YR4/6) gravelly coarse sand: single grain: loose

Sampled Depth (in)	Sample 1	Sample 2	Sample 3	Average
Bulk Density (g/cm^3)				
0 — 3	1.17	1.14	1.25	1.19
5 — 8	1.44	1.38	1.43	1.42
9 — 12	1.44	1.40	1.58	1.48
14 — 17	1.55	1.66	1.53	1.58
Infiltration Rate (in/hr)				
4 — 7	15			15

Pastures

Described and sampled for Bulk Density 10/10/99.
Infiltration Sampled 10/14/99
Ap1 0-6 inches;very dark grayish brown (10YR 3/2) loamy sand: weak fine granular structure: friable: many fine roots: common earthworms.
Ap2 6-12 inches; very dark grayish brown (10YR 3/2) loamy sand: weak fine granular structure: friable: few fine roots: common earthworms.
Bt 12-24 inches; yellowish brown (10YR 5/8) sandy loam with 5% rounded quartoze gravel: weak medium subangular structure: friable.
C 24-36 inches; yellowish brown (10YR 5/8) loamy sand: single grain: friable.

Sampled Depth (in)	Sample 1	Sample 2	Sample 3	Average
Bulk Density (g/cm^3)				
0 - 3	1.29	1.34	1.24	1.29
6 —9	1.50	1.38	1.52	1.47
9 — 12	1.39	1.50	1.37	1.42
13 — 16	1.55	1.59	1.63	1.59
16 — 19	1.61	1.63	1.60	1.61
Infiltration Rate (in/hr)				
8-13	8.0	15.6	6.1	9.9

Single House
Described and sampled for Bulk Density 9/1/99
Infiltration measured 9/27/99

0-6 inches; dark brown (10YR 3/3) loamy fine sand: weak medium granular structure: friable: many fine and medium roots.

6-13 inches; yellowish brown (10YR 5/6) loamy coarse sand: massive parting to single grain or just single grain: loose: few roots.

13-19 inches; Ab very dark grayish brown (10YR 3/2): loamy fine sand: massive parting to single grain: friable: many fine and medium roots: many ant eggs and ant nests.

19-24 inches; Btb yellowish brown (10YR 5/8): light sandy loam: weak medium subangular structure: friable: few medium roots.

Sampled Depth (in)	Sample 1	Sample 2	Sample 3	Average
Bulk Density (g/cm^3)				
0 - 3	1.26	1.24	1.25	1.25
6 - 9	1.63	1.70	1.68	1.67
12 - 15	1.52	1.62	1.68	1.61
16 - 19	1.62	1.57	1.64	1.61
20 - 23	1.57	1.69	1.68	1.64
Infiltration Rate (in/hr)				
3 - 7	8.6	6.6	6.3	7.1

Subdivision Lawn 1
Infiltration measured 9/22/99
Water ponded within the soil to the surface.

0-6 inches; very dark gray (10YR3/1) loamy coarse sand: loose non-sticky non-plastic; many fine roots

6 —11 inches; yellowish brown (10YR 5/6) loamy coarse sand; massive: non-sticky: non-plastic

11 —17 inches; very dark grayish brown (10YR 3/2) loamy coarse sand; massive parting to single grain: single layer of 2-3 trap rock at the bottom of layer as if old construction entrance. Pieces of old sod.

17-36 inches; light olive brown (2.5Y 5/4) loamy sand: massive and brittle parting first to coarse platy and then to single grain

36-39 inches;very dark grayish brown (10YR3/2) loamy sand: non-sticky: non-plastic: remnants of old sod.

39-57 inches; yellowish brown (10YR 5/4) loamy sand: non-sticky: non-plastic.

57-60 inches; Ab black (10YR 2/1) sand: massive structure parting to single grain: original surface with old tree roots.

60-85 inches; Eb light brownish gray (10YR 6/2) sand: single grain

85-93 inches; Bwb brown (10YR 4/3) loamy sand: single grain

93-110 inches; Cb yellowish brown (10YR 5/6) sand: single grain

The original soil before any fill was the Lakewood series, HSG A. The surface is continuously saturated. The sidewalk in the site is on the upper 1/3 of the slope 20-40 from the top of slope. The concrete is darkly stained, even in the nose slope position with precipitation of iron oxides as water flows across the top of the sidewalk.

Sampled Depth (in)	Sample 1	Sample 2	Sample 3	Average
Bulk Density (g/cm^3)				
0 - 6	1.54	1.46	1.50	1.50
6 - 11	1.77	1.77	1.81	1.79
11 - 17	1.65	1.51	1.65	1.60
17 - 20	1.85	1.91	1.90	1.89
Infiltration Rate (in/hr)				
5 - 9	0.17	0.20	0.06	0.14

Garage Lawn
Described and Bulk Density samples taken 5/21/98
Infiltration measured 9/27/99
Site is vegetated with sod and irrigated. The area around the county parking garage is fill varying in thickness from less than 12 to about 48 . An old house was on the site and had to be torn down before the garage could be built. Hammonton-like fill materials bury an Atsion soil in place. The upper 6 of soil was saturated.
0-3 inches; sod layer not sampled
3-6 inches; very dark grayish brown (10YR 3/2) sandy loam: wet: many fine roots to depth of 6 .
6-31 inches; brown (10YR 4/3) sandy loam: gravelly sandy loam: loamy sand and gravelly loamy sand with pieces of china, wood, rags, blacktop and rocks and brick.
31 inches; surface of original Atsion soil,

Sampled Depth (in)	Sample 1	Sample 2	Sample 3	Average
Bulk Density (g/cm^3)				
3 — 6	1.59	1.77	1.77	1.71
5 — 8	1.84	1.82	1.79	1.82
9 — 12	1.88	1.90	1.91	1.90
14 — 17	1.90	1.89	1.91	1.90
Infiltration Rate (in/hr)				
5 — 9	0.01	0.04	0.07	0.04

Cleared Woods
Bulk Density samples taken 7/6/99and profile described 2/12/01.
Infiltration measured 9/27/99
This site was cleared of trees and stumps and the duff layer was removed. No site grading was performed. The site commonly has standing pools of water in shallow depressions for extended periods
E 0-2 inches; grayish brown (10YR 5/2) loamy sand, no roots; frozen.
B/E 2-9 inches; yellowish brown (10YR 5/4) loamy sand; massive parting to single grain; no roots.
Bt 9-16 inches; dark yellowish brown(10YR 4/4) gravelly sandy loam: massive parting to single grain; friable: few medium and coarse tree roots.
B/C 16-24 inches; yellowish brown (10YR 5/6) gravelly loamy sand: friable; no roots.
C1 24-36 inches; yellowish brown (10YR 5/4) loamy sand: single grain: loose
C2 36-48 inches; light yellowish brown (10YR 6/4) sand: single grain: loose
C3 48-60 inches; pale brown (10YR 6/3) very gravelly sand: single grain: loose; moist
C4 60-96 inches; pale brown (10YR 6/3) loamy sand; single grain; loose; moist.
C5 96-100 inches; light gray (10YR 7/2) medium sand; with coarse common distinct yellowish brown (10YR 5/4) and few medium distinct yellowish brown (10YR 5/8) iron accumulations; single grain: loose; abrupt boundary; moist.
C6 100-108 inches; pale brown (10YR 6/3) very gravelly sand: single grain: loose
C7 108-120 inches; yellow (10YR 7/3) sandy loam: massive parting to moderate medium subangular blocky structure; dry.
Estimated seasonal high water table > 10 feet.

Sampled Depth (in)	Sample 1	Sample 2	Sample 3	Average
Bulk Density (g/cm^3)				
0 - 3	1.80	1.69	1.75	1.75
6 - 9	1.81	1.82	1.85	1.83
12 - 15	1.82	1.80	1.90	1.84
18 - 21	1.53	1.65	1.72	1.64
Infiltration Rate (in/hr)				
5 — 9	0.09	0.16	1.51 *	0.13

* Outlier not used in average.

Subdivision Lawn 2
Infiltration measured 9/27/99

0 - 6 inches; dark gray (10YR3/2) loamy sand: thin sod on top of this layer with many fine roots from the sod extending into this layer.
6 - 8 inches; dark gray (10YR 3/2) loamy sand with stratified layers of yellowish brown10YR 5/6) sand with few large root fragments 1-11/2 dia. The bottom of this layer ranges to 12 .
8 - 12 inches; dark grayish brown (10YR4/2) sandy loam: massive: dense: hard, few medium roots. Few strong brown (7.5YR 5/8) iron accumulations as soft masses along root channels and macropores where water is probably moving as unsaturated flow.
12 - 12 inches; (1mm thick) strong brown (7.5YR 5/8) loamy sand with iron accumulations as soft masses as a thin ribbon just below the compacted zone: loose.
12 - 24 inches; yellowish brown (10YR 5/6) loamy sand: loose no roots.

Sampled Depth (in)	Sample 1	Sample 2	Sample 3	Average
Bulk Density (g/cm^3)				
0 — 3	1.60	1.53	1.62	1.58
7 — 10	1.95	1.67	1.77	1.79
13 — 16	2.07	1.96	2.07	2.03
18 — 21	1.85	1.73	1.67	1.75
Infiltration Rate (in/hr)				
9 — 13	0.03	0.03	0.74 *	0.03

* Outlier not used in average.

Athletic Field
Described and Bulk Density samples taken 11/26/97
Infiltration Measured 9/29/1999
Site is vegetated with sod and irrigated.
0 - 5 inches; very dark gray (10YR 3/1) loamy sand: single grain: friable: many fine roots
5 - 18 inches; yellowish brown (10YR 5/6) light sandy loam: massive: dense: hard: no roots.
18 — 36 inches;yellowish brown (10YR 5/6) loamy sand: friable.

Sampled Depth (in)	Sample 1	Sample 2	Sample 3	Average
Bulk Density (g/cm^3)				
0 — 3	1.28			1.28
5 — 8	1.83	1.80	1.76	1.80
9 — 12	1.96	1.97	1.91	1.95
14 — 17	1.87	1.90	1.86	1.88
Infiltration Rate (in/hr)				
6 — 10	0.01	0.01	0.01	0.01

Appendix B.

New Jersey Permeability Test Sites

Summary of Index and Permeability Tests

Sample	Site	Percent Passing										USCS	LL	PI	BD Field	Max DD	Water opt	Gs	D @ test	Wc @ test	Comp Perm
No.	Name	0.002	0.005	0.02	0.05	#200	#140	#40	#10	#4	3/4"	Class			g/cm^3	g/cm^3	%	g/cm^3	g/cm^3	%	cm/sec
00-203	Woods	5	6	13	16	16	17	64	93	96	100	SM	NP	NP	1.58	1.83	11.5	2.64			
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°		°		°	°
00-204	Subdivision Lawn 2	8	9	17	22	23	23	61	90	94	100	SM	NP	NP	1.80	2.00	9.0	2.66			
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°		°		°	°
00-205	Pasture	6	6	15	18	18	19	59	93	97	100	SM	NP	NP	1.47	2.00	8.5	2.68	1.47	9.5	1.7E-03
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
00-206	Single House					7	8	39	75	84	100	SW-SM	NP	NP	1.67	1.92	8.5	2.65			
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
00-207	Subdivision Lawn 1	°	°	°	°	7	7	54	95	99	99	SP-SM	NP	NP	1.78	1.78	10.5	2.66	1.78	10.5	1.5E-03
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
00-208	Garage Lawn					7	8	32	64	76	97	SP-SM	NP	NP	1.82	2.06	8.1	2.64	2.06	8.1	4.1E-05
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	7.1E-05
00-209	Cleared Woods	9	10	16	22	24	27	60	81	86	99	SM	14	2	1.83	2.04	9.0	2.68			
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
00-210	Athletic Field	9	13	16	20	20	21	73	91	94	100	SM	16	3	1.95	1.92	11.0	2.66	2.02	10	2.2E-07

BD Field: Bulk Density, Field Test
Max DD: Maximum Dry Density using Standard Proctor Test
Water opt: Water Content at which Maximum Dry Density was obtained
Gs: Particle Density
D @ test: Density of repacked sample when tested
Wc @ test: Water Content of tested repacked sample
Comp Perm: Computed Permeability

This study was conducted by:

David Friedman, District Manager
Ocean County Soil Conservation District

Carl Montana, P.E., Principal
Schnabel Engineering Associates, Inc.

Paul Welle, P.E., Senior Associate
Schnabel Engineering Associates, Inc.

Chris Smith, Soil Scientist
USDA Natural Resources Conservation Service

David Lamm, P.E., State Conservation Engineer (3)
USDA Natural Resources Conservation Service

Additional contributions by the following were most appreciated:

Alan Perry, Bill Slack, Alfred Galvan, Chuck Collins, Mike Marcella, and Kerry Jennings, Ocean County Soil Conservation District

Ed Jakubowski, Senior Staff Scientist, Schnabel Engineering Associates, Inc.

March 2001