United States
Environmental Protection
Agency

Office of Research and
Development
Washington, DC 20460

EPA#/000/x/000/000
December 1999

Infiltration through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity

Project Summary

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This project examined a common, but poorly understood, problem associated with land development and the modifications made to soil structure. Development tends to reduce rainfall infiltration and increase runoff. The project was divided into two tasks:

1) testing infiltration rates of impacted soils, and

2) enhancing soils by amending with compost to increase infiltration and prevent runoff .

The first task examined more than 150 infiltration tests in disturbed, urban soils and compared these data with site conditions. A complete factorial experiment fully examined the effects, and interactions, of soil texture, soil moisture, and compaction. In addition, age since development was briefly examined. Compaction

had dramatic effects on infiltration rates through sandy soils and was generally just as important as soil moisture at sites with predominately clayey soils. Moisture levels had little effect on infiltration rates at sandy sites. Because of the large amounts of variability in the infiltration rates found, it is important that engineers obtain local data to estimate the infiltration rates associated with local development practices.

The second task examined the benefits of adding a large amount of compost to a glacial till soil at the time of development. The compost-amended soils significantly increased infiltration rates, but also increased concentrations of nutrients in the surface runoff. The overall mass of nutrient discharges will more than likely decrease when using compost, although the collected data did not always support this hypothesis. The sorption and ion-exchange properties of the compost reduced the concentration of many cations and toxicants in the infiltrating water, but nutrient concentrations significantly increased. In addition, the compost-amended test plots produced superior turf, with little or no need for establishment or maintenance fertilization.

This Project Summary was developed by EPA's National Risk Management Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Field Studies on Infiltration Capabilities of Disturbed Urban Soils

Prior research (Pitt 1987) examined runoff losses from paved and roofed surfaces in urban areas and showed significant losses at these surfaces during the small and moderate sized events of most interest for water quality evaluations. Earlier research also found that disturbed urban soils did not behave as predicted by stormwater models.

Early unpublished double-ring infiltration tests conducted by the Wisconsin Department of Natural Resources (DNR) in Oconomowoc, Wisconsin, indicated highly variable infiltration rates for soils that were generally sandy (Natural Resources Conservation Service (NRCS) A/B hydrologic group soils) and dry. The median initial rate was about 75 mm/hr (3 in/hr), but ranged from 0 to 600 mm/hr (0 to 25 in/hr). The median final rate also had a value of about 75 mm/hr (3 in/hr) after at least two hours of testing, but ranged from 0 to 400 mm/hr (0 to 15 in/hr). Many infiltration rates actually increased with time during these tests. In about 1/3 of the cases, the observed infiltration rates remained very close to zero, even for these sandy soils. Areas that experienced substantial disturbances or traffic (such as school playing fields), and siltation (as in some grass swales) had the lowest infiltration rates. It was hoped that more detailed testing could explain some of the large variations observed.

The first major task of this project was to attempt to explain much of the variation observed in previous infiltration tests of disturbed urban soils. About 150 individual double-ring infiltration tests were conducted for this study in the Birmingham, Alabama area. These tests were separated into eight categories of soil conditions (comprising a full factorial experiment). Factors typically considered to cause infiltration rate variations are texture and moisture. These tests examined texture and moisture, plus soil compaction (as measured by a cone penetrometer and by site history). It was also hoped that age since disturbance and cover conditions could also be incorporated to help explain some of the infiltration variations, but these conditions were unevenly represented at the test sites and did not allow for a complete statistical examination.

Infiltration Mechanisms

Infiltration rainfall losses on pervious surfaces are controlled by three mechanisms, the initial entry of the water through the soil/plant surface (percolation), followed by movement of the water through the vadose (unsaturated) zone, and finally, depletion of the soil-water storage capacity. Overall infiltration is the least of these three rates, and the surface runoff rate is assumed to be the excess of the rainfall intensity greater than the infiltration rate. The infiltration rate typically decreases during the rain. Storage capacity is recovered when the movement of the water through the soil is faster than the percolation rate, which usually takes place after the rainfall has ended.

The surface entry rate of water may be affected by the presence of a thin layer of silts and clay particles at the surface of the soil and vegetation. These particles may cause a surface seal that would decrease a normally high infiltration rate. The movement of water through the soil depends on the characteristics of the underlying soil. Water cannot enter soil faster than it is being transmitted away, so this movement rate affects the overall infiltration rate. The depletion of available storage capacity in the soil also affects the overall infiltration rate. This storage capacity depends on the thickness, moisture content, and porosity of the soil. Many factors, i.e., texture, root development, structure, and presence of organic matter, affect the porosity of soil.

The infiltration of water into the surface soil is responsible for the largest abstraction (loss) of rainwater in natural areas. Once the infiltration capacity of the soil has been reached, most of the rain will become surface runoff. The infiltration capacity of most soils allows low intensity rainfall to totally infiltrate, unless the soil voids become saturated or the underlying soil is much more compact than the top layer. Intense rainfalls generate substantial runoff because the infiltration capacity of the upper soil layer is surpassed, even though the underlying soil might be very dry.

The classical assumption is that the infiltration capacity of a soil is highest at the very beginning of a storm and decreases with time. The moisture content of the soil, whether it is initially dry or still wet from a recent storm, will have a great affect on the infiltration capacity of certain soils. One of the oldest and most widely used infiltration equations was developed by Horton (1939). This equation was used in this study to compare the measured equation parameters with published literature values. The equation is as follows:

$$f = f_c + (f_o - f_c)e^{-kt}$$

where:
f= infiltration capacity (in/hr),
f_o = initial infiltration capacity (in/hr),
f_c = final capacity (in/hr),
k = empirical constant (hr^{-1})

The Horton equation assumes that the rainfall intensity is greater than the infiltration capacity at all times and that the infiltration rate decreases with time. The capacity of the soil decreases as the time of the storm increases because the pores in the soil become saturated with water and do not allow water to continuously infiltrate through the surface. The Horton equation's major drawback is that it does not consider storage availability in the soil after varying amounts of infiltration have occurred, but only considers infiltration as a function of time.

It is recommended that fc, fo, and k be obtained through field data, but these parameters are rarely measured locally. More commonly, they are determined through calibration of relatively complex stormwater drainage models, or by using published values. The use of published values in place of reliable field data is a cause of much concern.

Field Studies on Compost-Amended Soils

This second project task examined the benefits of using compost as a soil amendment to improve the infiltration capacity and pollutant retention capacity of disturbed urban soils. Currently, due to their wide distribution and inherent stability, most residential housing developments in the Seattle, Washington area are sited on the Alderwood soil series, which is characterized by a compacted subsurface layer that restricts vertical water flow. When disturbed and particularly when disturbed with cut and fill techniques as with residential or commercial development, uneven water flow patterns develop due to restricted permeability. This contributes to excessive overland flow, especially during storm events, and transport of dissolved and suspended particulate to receiving waters.

Research has demonstrated compost's effectiveness in improving the soil physical properties of porosity and continuity of macropores which influence soil-water relationships. Compost's chemical properties can also be valuable in some cases, such as in complexing potentially harmful trace metals including copper, lead, and zinc.

The University of Washington's (UW) College of Forest Resources (CFR) examined the effectiveness of using compost as a soil amendment to increase surface water infiltration and to reduce the quantity and/or intensity of surface runoff and subsurface flow from land development projects. In addition, runoff and subsurface flow was evaluated for dissolved nutrients and other constituents.

The CFR utilized the existing Urban Water Resource Center (UWRC) project site at the UW's Center for Urban Horticulture (CUH) for conducting the study. The CFR also used the UWRC design of large plywood beds for containing soil and soil-compost mixes. Additional sites of a similar design were constructed at public schools.

These test plots at the CUH were developed and tested previously during a study conducted for the city of Redmond, Washington. The following paragraphs summarize some of the findings and conclusions from that earlier study, conducted when the test plots were newly constructed:

The earlier project specifically examined the use of compost as an amendment to Alderwood series soil to increase water-holding capacity, reduce peak flow runoff, and decrease phosphorus in both surface runoff and subsurface flows. Seven 2.4 x 9.8 m (8 x 32 ft) beds were constructed out of plywood lined with plastic and filled with

Alderwood subsoil or mixtures of soil and compost. Surface and subsurface flow samples were obtained over the period from March 7 to June 9, 1995, during a series of seven simulated rainfall events. To create different antecedent soil moisture conditions, some storm events were quickly followed by another event. Simulated rainfall was applied at total amounts ranging from 19 to 62.4 mm (0.76 to 2.46 in.) per storm, with rainfall intensities ranging from 7.4 to 16 mm (0.29 to 0.63 in/hr). Compost amendments had the following effects on physical water properties:

Water-holding capacity of the soil was nearly doubled with a 2:1 compost:soil amendment.

Water runoff rates were moderated with the compost amendment, with the compost-amended soil showing greater lag time to peak flow at the initiation of a rainfall event and greater base flow in the interval following a rainfall event.

Runoff from the compost-amended soil had 24% lower average total P concentration (2.05 vs 2.54 mg/L) compared to the Alderwood soil that did not receive compost.

Soluble-reactive P was 9% lower in the compost-amended soil (1.09 vs 1.19 mg/L) compared to the Alderwood soil that did not receive compost amendment.

Nitrate-nitrogen was 17% higher in the compost-amended soil (1.68 vs 1.39 mg/L) compared to the Alderwood soil that did not receive compost amendment.

This earlier study highlighted the promise of organic amendments to improve water-holding capacity and runoff quality of Alderwood soils converted to turfgrass during urban development and was the basis for this current study. This study examined some of these same test plots at the CUH several years after their initial establishment, and during natural rains, to see if their behavior is substantially different with age. In addition, new test sites were established at two school locations for comparison.

Methodology and Test Site Descriptions

Sampling and Test Site Descriptions

Infiltration Tests in Disturbed Urban Soils

Birmingham, Alabama, the location of many of the test sites for disturbed urban soils, receives about 1400 mm (54 in.) of rain and about 110 separate rain events per year. Typical antecedent, dry periods range from about 2 to 5 days and it is unusual to go more than 10 days without recorded rainfall. The driest months are October and November, averaging 66 and 91 mm (2.6 and 3.6 in.), respectively, while March is the wettest month averaging 160 mm (6.3 in.) of rainfall. Snow is rare, with snowfalls of 130 mm (5 in.) or more occurring about once every 10 years. The growing season (temperature > 28° F) is at least 243 days per year in 5 out of 10 years. Average daily maximum temperatures are about 90° F in the summer months (June through August) and about 55° F in the winter months (December through February). Average daily minimum temperatures are about 65 to 70° F in the summer and about 34° F in the winter. The extreme recorded temperatures in Birmingham have ranged from about 0 to 110° F. Many of the sandy soil tests were located near Mobile, Alabama, where the rainfall averages about 250 mm (10 in.) more than in Birmingham.

Compost-Amended Soil and Soil Only Test Sites

The field study sites for testing the benefits of compost-amended soils were all located in the Seattle, Washington area. Seattle is relatively wet, receiving about 890 mm (35 in.) of rain a year; however, the typical rain intensity is quite low. Many of the tests were conducted at the existing test beds located at the UW's CUH demonstration site. Additional tests were conducted at newly established test sites at the Timbercrest High School and at the Woodmoor High School in Northern King County, Washington. The high school sites were characterized as having poorly-sorted and compacted glacial till soils of the Alderwood soil series. The three sites typified the problem areas for urban runoff in the region and represented development on glacial till soils in watersheds with water bodies of high quality. The three sites represent three replications of control and compost-amended soils for this study.

The CFR utilized the existing CUH site and associated UW facilities. The system included two different Alderwood glacial till soils that were transported to the site, and several mixtures of the glacial till soils and compost mixtures readily available in the Seattle area. Two plots each of glacial till-only soil and 2:1 mixtures of soil:compost were studied. The soil-compost mixture rates were also the same for the Timbercrest and Woodmoor sites, using Cedar Grove compost. The two composts used at the CUH sites were Cedar Grove and GroCo. The GroCo compost-amended soil at the CUH test site is a sawdust/municipal waste mixture (3:1 ratio, by volume) that is composted in large windrows for at least 1 year. The Cedar Grove compost is a yard waste compost that is also composted in large windrows.

Measurement of Infiltration Rates in Disturbed Urban Soils (Task1)

Experimental Design

A series of 153 double ring infiltrometer tests were conducted in disturbed urban soils in the Birmingham, and Mobile, Alabama, areas. The tests were organized in a complete 23 factorial design to examine the effects of soil moisture, soil texture, and soil compactness on water infiltration through historically disturbed urban soils. Turf age was also examined, but insufficient sites were found to thoroughly examine the effects of age on infiltration rates. Ten sites were selected representing a variety of desired conditions (compaction and texture) and numerous tests were conducted at each test site area. Moisture and soil texture conditions were determined by standard laboratory soil analyses. Compaction was measured in the field using a cone penetrometer and confirmed by the site history. Moisture levels were increased using long-duration surface irrigation before most of the saturated soil tests. From 12 to 27 replicate tests were conducted in each of the eight experimental categories in order to measure the variations within each category for comparison to the variation between the categories.

The expectation was that soil infiltration was related to the time since the soil was disturbed by construction or grading operations (turf age). In most new developments, compact soils are expected to be dominant, with reduced infiltration compared to pre-construction conditions. In older areas, the soil may have recovered some of its infiltration capacity due to root structure development and soil insects or other digging animals. Soils with a variety of times since development, ranging from current developments to those about 50 years old, were included in the sampling program. However, because these sites were poorly distributed in representation to the other primary test conditions, these effects were not directly determined. The Wisconsin DNR and the University of Wisconsin have conducted some soil infiltration tests on loamy soils to examine the effects of age of urbanization on soil infiltration rates. Their preliminary tests have indicated that several decades may be necessary before compacted loam soils recover to conditions similar to pre-development conditions.

Infiltration Rate Measurements

The infiltration test procedure included several measurements. Before a test was performed, the compaction of the soil was measured with the DICKEY-john Soil Compaction Tester Penetrometer and a sample was obtained to analyze moisture content. TURF-TEC Infiltrometers were used to measure the soil infiltration rates. These small devices have an inner ring about 64 mm (2.5 in.) in diameter and an outer ring about 110 mm (4.25 in.) in diameter.

The water depth in the inner compartment starts at 125 mm (5 in.) at the beginning of the test, and the device is pushed into the ground 50 mm (2 in.). The rings are secured in a frame with a float in the inner chamber and a pointer next to a stop watch. These units are smaller than standard double-ring infiltrometers, but their ease of use allowed many tests under a wide variety of conditions to be conducted. The use of three infiltrometers placed within a meter from each other also enabled better infiltration-rate site variability to be determined than if one larger unit was used.

Both the inner and outer compartments were filled with clean water by first filling the inner compartment and allowing it to overflow into the outer compartment. As soon as the measuring pointer reached the beginning of the scale, the timer was started. Readings were taken every five minutes for a duration of two hours. The two hour test duration was chosen to replicate the typical two hour rain durations and the expected time needed to reach saturation conditions. The instantaneous infiltration rates were calculated by noting the drop of water level in the inner compartment over the 5 min time period.

Tests were recorded on a field observation sheets and contained information such as: relative site information, testing date and time, compaction data, moisture data, and water level drops over time, with the corresponding calculated infiltration rate for the 5-minute intervals. All measurements are taken in natural soils in the field (leaving the surface sod in place), with no manipulation besides possibly increasing the moisture content before “wet” soil tests are conducted (if needed). At each site location, a field sample was obtained for a soil classification. The compaction of the test areas was obtained by pushing a DICKEYjohn Soil Compaction Tester Pentrometer into the ground and recording the readings from the gauge. For these tests, compact soils are defined as a reading of greater than 300 psi at a depth of three in., while uncompacted soils have readings of less than 300 psi. Compaction was confirmed based on historical use of the test site location.

Moisture values relating to dry or wet conditions are highly dependent on soil texture and are mostly determined by the length of antecedent dry period before the test. Soil moisture is determined in the laboratory using the ASTM D 2974-87 method. For typical sandy and clayey soil conditions at the candidate test areas, the dry soils have moisture contents ranging from 5 to 20% (averaging 13%) water, while wet soils have moisture contents ranging from 20 to 40% (averaging 27%) water.

The actual infiltration test procedure follows several basic steps. Whenever a test was performed, the compaction of the area was measured with the DICKEYjohn Soil Compaction Tester Penetrometer and a sample was obtained to analyze the moisture content. Then, three TURF-TEC Infiltrometers were pushed into the turf. This was accomplished by pushing down on the handles and twisting slightly until the saturn ring is level with the surrounding turf.

Soil Moisture Measurements

The moisture condition at each test site was an important test factor. The weather occurring during the testing enabled most site locations to produce a paired set of dry and wet tests. The dry tests were taken during periods of little rain, which typically extended for as long as two weeks with no rain and with sunny, hot days. The saturated tests were conducted through artificial soaking of the ground, or after prolonged rain. The soil moisture was measured in the field using a portable moisture meter (for some tests) and in the laboratory using standard soil moisture methods (for all tests). The moisture content was defined as the ratio of the weight of water to the weight of solids in a given volume of soil. This was obtained using ASTM method D 2974-87, by weighing the soil sample with its natural moisture content and recording the mass. The sample was then oven dried and its dry weight recorded. Saturated conditions occurred for most soils with soil moisture contents greater than about 20%.

Soil Texture Measurements

The texture of the samples were determined by ASTM standard sieve analyses to verify the soil conditions estimated in the field and for comparison to the NRCS soil maps. The sieve analysis used was the ASTM D 422-63 Standard Test Method For Particle Size Analysis of Soils for the particles larger than the No. 200 sieve, along with ASTM D 2488-93 Standard Practice for Description and Identification of Soils (Visual - Manual Procedure). The sample was prepared based on ASTM 421 Practice for Dry Preparation of Soil Samples for Particle Size Analysis and Determination of Soil Constants. The procedure requires a representative dry sample of the soil to be tested. After the material was dried and weighed, it was then crushed to allow a precise sieve analysis. The sample was then treated with a dispersing agent (sodium hexametaphosphate) and water at the specified quantities. The mixture was then washed over a No. 200 sieve to remove all soil particles smaller than the 0.075 mm openings. The sample was then dried again and a dry weight obtained. At that point, the remaining sample was placed in a sieve stack containing No. 4, No. 8, No. 16, No. 30, No. 50, No. 100, No. 200 sieves, and the pan. The sieves were then placed in a mechanical shaker and allowed to separate onto their respective sieve sizes. The cumulative weight retained on each sieve was then recorded.

The designation for the sand or clay categories follows the Unified Soil Classification System, ASTM D 2487. Sandy soils required that more than half of the material be larger than the No. 200 sieve, and more than half of that fraction be smaller than the No. 4 sieve. Similarly, for clayey soils, more than half of the material is required to be smaller than the No. 200 sieve.

Soil Compaction Measurements

The extent of compaction at each site was measured using a cone penetrometer before infiltration testing. Soils, especially clayey soils, are obviously more spongy and soft when wet as compared to extremely dry, hard conditions. Because the cone penetrometer measurements are sensitive to moisture, measurements were not made for saturated conditions and the degree of soil compaction was also determined based on the history of the specific site (especially the presence of parked vehicles, unpaved lanes, well-used walkways, etc.). Compact soils were defined as having a reading of greater than 300 psi at a depth of three in. Other factors that were beyond the control of the experiments, but also affect infiltration rates, include bioturbation by ants, gophers and other small burrowing animals, worms, and plant roots.

Soil/Compost Test Site Characterization (Task 2)

Plot Establishment

Plots were planted using a commercial turfgrass mixture during the Spring, 1994, season for the CUH sites and in the fall of 1997 for the Timbercrest and Woodmoor sites. The soil and compost for this study was mixed on an asphalt surface with a bucket loader and hauled and dumped into the plot bays. A system of collection buckets to allow sampling of both surface runoff and subsurface flows at intervals ranging from 15 minutes to longer was located at the CUH site, along with a tipping bucket rain gage. Similar setups were also installed at the two high school locations for these experiments.

Fertilizer was added to all plots during plot establishment (16-4-8 N-P_2O_5-K_2O) broadcast spread over the study bays at the rate of 0.024 kg fertilizer/m^2 (0.005 lb fertilizer/ft^2) as recommended on the product's label. The initial application resulted in an application of 0.010 kg (0.023 lb) of elemental phosphorus (P) as orthophosphate (PO_4^-) per plot, or 0.00043 kg P/m^2 (0.000087 lb P/ft^2). This resulted in an application of 0.091 kg (0.20 lb) of elemental nitrogen (N) as ammonium (NH_4^+) and nitrate (NO_3^-) (undetermined distribution) per plot, or 0.0039 kg N/m^2 (0.00080 lb N/ft^2). Due to the poor growth of turf on the control plots, and in order to simulate what would have likely been done anyway on a typical residential lawn, an additional application of 0.024 kg/m^2 (0.005 lb/ft^2) was made to the CUH control plots on May 25, 1995.

Characterization of Compost-Amended Soils

The study design for this phase of the research was a randomized complete block design, with four blocks of two treatments. Treatments included the following:

(1) control turf plots with Alderwood soil-only, and
(2) compost-amended turf plots with a 2:1 soil:compost mixture.

The four blocks were tested at the three locations, with one block each at Timbercrest and Woodmoor High School, and two blocks at the CUH facility. The blocks are differentiated by differences in the native soil characteristics. Differences in the physical and chemical parameters of the infiltrating water during this study were examined using nonparametric comparison tests, augmented with exploratory data analyses procedures.

Soil and soil/compost mixture samples were taken 1 month after the initiation of the study and analyzed by the CFR analytical labs for the following parameters:

1) total carbon (C),
2) total N,
3) gravimetric water holding capacity (field capacity) moisture,
4) volumetric water holding capacity (field capacity) moisture,
5) total porosity,
6) bulk density,
7) particle density,
8) particle size analysis, and
9) soil structure.

Total C and N, which are considered to be the primary measures of soil productivity in these soils, were determined using an automated CHN analyzer. Bulk density was estimated using a coring device of known volume (bulk density soil sampler). The core was removed, oven dried, and weighed. Bulk density was calculated as the oven dry weight divided by the core volume. Particle density was determined by using a gravimetric displacement. A known weight of soil or soil/compost mixture was placed in a volumetric flask containing water. The volume of displacement was measured and particle density was calculated by dividing the oven dry weight by displaced volume.

Gravimetric water holding capacity was determined using a soil column extraction method that approximates field capacity by drawing air downward through a soil column. Soil or soil/compost mixture was placed into 50 ml syringe tubes and tapped down (not compressed directly) to achieve the same bulk density as the field bulk density measured with coring devices. The column was saturated by drawing 50 ml of water through the soil column, then brought to approximate field capacity by drawing 50 ml of air through the soil or soil/compost column.

Volumetric water holding capacity was calculated by multiplying gravimetric field capacity by the bulk density.

Particle size distribution was determined both by sieve analysis and sedimentation analysis for particles less than 0.5 mm in size. Due to the light nature of the organic matter amendment, particle size analysis was sometimes difficult, and possibly slightly inaccurate. Soil structure was determined using the feel method and comparing soil and soil/compost mixture samples to known structures.

Before any runoff tests were conducted, background soil samples were analyzed. The relative concentrations and mass of nutrients and metal species in the soil and compost is of interest, as is the mass movement into and out of the soil. Additionally, because some nutrients interact strongly with several soil metals, determining these elements and relative amounts is useful in making inferences about nutrient and metal retention or loss in runoff. Another important aspect is the possibility of establishing a concentration gradient in the soil profile.

Flow Measurements at Field Test Sites

The design for the test bay system developed by the UWRC (Harrison, et al. 1997) was used to enclose soil-compost mixes and collect surface and subsurface runoff. These systems consist of enclosed bays with tipping buckets attached to data recorders. Similar systems were constructed and used at Timbercrest and Woodmoor high schools.

Glacial till soil was added to the bays and compacted before adding compost. Cedar Grove compost was added at a 2:1 soil:compost rate and rototilled into the soil surface. Particular attention was placed on simulating a compacted glacial till layer to represent natural field conditions. Once installed, all bays were cropped with perennial ryegrass. Separate surface runoff and subsurface flow collectors were installed within each bay. Collection basins were equipped with tipping buckets to record flow over time, every 15 min. Each tip of the bucket was calibrated for each site and checked on a regular basis to give rates of surface and subsurface runoff from all plots.

Double-ring infiltration tests, based on ASTM method D 3385, were performed. However, due to the small size of the plots and the potential for destruction of the plots by installation of large rings, the small ring was 7.5 cm in diameter and the large ring was 14 cm in diameter. The rings were driven into the soil to a maximum depth of 7.5 cm. Measurements were taken on surface infiltration only.

The Timbercrest High School and WoodMoor High School field sites in Northern King County, Washington were located on poorly-sorted, compacted Glacial Till soils of the Alderwood soil series. Sampling installations included in-situ installations. Surface runoff and subsurface flows were collected from bucket tips during 7 separate intervals.

There were several problems with flow monitoring and water sampling at the sites, especially at the new test sites. At Timbercrest, the very high water table and the pressure on the sealed container that was supposed to exclude surface water from entering the collector box, caused the tipping buckets to function improperly. Thus, they were removed and collection bottles were substituted that did not record flow versus time. Problems were not as severe at the Woodmoor site, and samples were collected versus time for the duration of the study. At the CUH site, tipping buckets did not record during the last two time periods. However, during each of the 5 to 6 fully monitored time periods at each site, many individual rains were included in the data.

Both surface runoff and subsurface flow were separately collected following the seven rainfall periods during the months of December 1997 through June 1998. Surface runoff and subsurface flows were collected monthly from the surface and subsurface collection basins. At the beginning of the project, to help establish the new turf, a typical lawn herbicide/fertilizer combination was broadcast spread over the study bays at the rate recommended on the product label.

Samples were collected in polypropylene bottles and immediately placed in cold storage on-site. Subsurface flow samples were collected in a similar manner. Sample times varied depending on antecedent moisture conditions and amount of flow generated by simulated rainfall. All water samples were immediately taken to the analytical lab and stored at 4°C until analysis.

Analytical Measurements and Procedures

Selected laboratory noncritical measurement were made to supplement the above critical physical measurements. These included periodic particle size analyses and toxicity screening analyses, plus nutrient and heavy metal analyses at the compost-amended test sites. The following list shows these measurements that were also conducted on the samples collected from the Seattle area tests:
Acid hydrolyzable P, Chlorine (Cl), nitrite (NO2), NO3, PO4- – P, sulfate (SO4), Total arsenic (As), boron (B), barium (Ba), calcium (Ca), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), magnesium (Mg), potassium (K), manganese (Mn), N, sodium (Na), nickel (Ni), P, lead (Pb), sulfer (S), selenium (Se), and zinc (Zn)

All work was done in accordance with UW analytical laboratory QA/QC procedures. In addition, most of the surface runoff and subsurface flow samples were also screened for toxicity (using the Azur Microtox procedure) and analyzed for particle sizes (using a Coulter counter) at UAB's Department of Civil and Environmental Engineering laboratory.

Conclusions

This project evaluated a widespread problem, decreased infiltration due to disturbed soils, and a potential solution, soil amendment with compost. The elements associated with the problem of disturbing natural soils during land development were examined over a wide variety of site conditions (soil texture, age, moisture, and compaction) and at several locations. A large number of infiltration tests were conducted to identify the factors significantly affecting infiltration parameters. In addition, the project also examined a potential solution, amending soils with large amounts of compost, to reduce the problems associated with altering the surface and subsurface hydrology during development. The benefits of compost amendment were measured at special test plots exposed to typical developmental construction practices.

Infiltration Rates in Disturbed Urban Soils (Task 1)

The initial exploratory analyses of the data showed that sandy soils were mostly affected by compaction, with little change due to moisture levels. However, the clayey soils were affected by a strong interaction of compaction and moisture. The variations of the observed infiltration rates in each category were relatively large, but four soil conditions were found to be distinct, as shown in Table 1. The data from each individual test were fitted to the Horton equation, but the resulting equation coefficients were relatively imprecise (Table 2) and it may not matter which infiltration model is used, as long as the uncertainty is considered in the evaluation. Therefore, when modeling runoff from urban soils, it may be best to assume relatively constant infiltration rates throughout an event, and to utilize Monte Carlo procedures to describe the observed random variations about the predicted mean value, possibly using the time-averaged infiltration rates and coefficient of variation (COV) values shown in Table 3.

Very large errors in soil infiltration rates can easily be made if published soil maps and most available models are used for disturbed urban soils, as these tools ignore compaction. Knowledge of compaction (which can be mapped using a cone penetrometer, or estimated based on expected activity on grassed areas) can be used to much more accurately predict stormwater runoff quantity.

In most cases, the mapped soil textures were similar to what was actually measured in the field. However, important differences were found during many of the 153 tests. Table 1 showed the 2-hr averaged infiltration rates and their COV in each of the four major groupings. Although these COV values can be generally high (up to 1.5), they are much less than if compaction was ignored. The results of the factorial analysis indicated that the best models were separated by the soil texture. For more accurate modeling, it is recommended that site specific data be obtained. Once the texture, moisture and compaction of the soil are known, a model can be developed. The high variations within each of these categories makes it difficult to identify legitimate patterns, implying that average infiltration rates within each event may be most suitable for predictive purposes. The remaining uncertainty can probably best be described using Monte Carlo components in runoff models.

The measured infiltration rates during these tests were all substantially larger than expected, but comparable to previous standard double-ring infiltrometer tests in urban soils. Other researchers have noted the general over-predictions of ponding by infiltrometers compared to actual observations during natural rains. In all cases, these measurements are suitable to indicate the relative effects of soil texture, compaction, and moisture of infiltration rates, plus the measured values can be directly used to predict the infiltration rates that may be expected from stormwater infiltration controls that utilize ponding. Additional research is needed in other urban areas to measure site specific effects of these soil conditions on infiltration rates.

Water Quality and Quantity Effects of Amending Soils with Compost (Task 2)

There was a substantial difference in appearance of amended and unamended plots. There was insufficient grass growth in the unamended plots, even following initial establishment fertilization. The compost-amended plots were very attractive and needed no fertilization. In fact, the initial establishment fertilization may not have been necessary based on studies at the University of Washington of growing turfgrass in similar compost-amended soils without inorganic fertilization. Besides fertilizer applications, other external sources of nutrients to the test plots included wildlife (especially geese that were noted to selectively graze the compost-amended plots).

Application of compost material similar to that used during these studies would be possible by applying 4 in. of compost onto the surface of an soil and tilling to a total depth of 30 cm (12 in.), including the compost amendment 20 cm (8 in.) into the soil). This mixing would probably need to be thorough and deep to achieve the conditions of this study. However,

Table 1. Infiltration Rates for Significant Groupings of Soil Texture, Moisture, and Compaction Conditions

Group	Number of tests	Average infiltration rate, mm/hr (in/hr)	COV
noncompacted sandy soils	36	414 (16.3)	0.4
compact sandy soils	39	64 (2.5)	0.2
noncompacted and dry clayey soils	18	220 (8.8)	1.0
all other clayey soils (compacted and dry, plus all saturated conditions)	60	20 (0.7)	1.5

Table 2. Observed Horton Equation Parameter Values for Sandy and Clayey Soils

	f_o mm/hr (in/hr)		f_c mm/hr (in/hr)		k (1/min)	
	mean	range	Mean	range	mean	range
Observed noncompacted sandy soils	990 (39)	110–3700 (4.2–146)	381 (15)	10–635 (0.4–25)	9.6	1.0–33
Observed compact sandy soils	381 (15)	3–2200 (0.1–86)	46 (1.8)	3–240 (0.1–9.5)	11	1.8–37
Observed dry noncompacted clayey soils	460 (18)	64–1500 (2.5–58)	170 (6.6)	3–610 (0.1–24)	8.8	-6.2–19
Observed for all other clayey soils (compacted and dry, plus all saturated conditions)	86 (3.4)	0–1200 (0–48)	10 (0.4)	-15–170 (-0.6–6.7)	5.6	0–46

Table 3. Soil Infiltration Rates for Different Categories and Storm Durations - mean [COV]

	15 minutes mm/hr (in/hr)	30 minutes mm/hr (in/hr)	60minutes mm/hr (in/hr)	120 minutes mm/hr (in/hr)
Sand, Non-compacted	582 (22.9) [0.4]	495 (19.5) [0.4]	429 (16.9) [0.4]	414 (16.3) [0.4]
Sand, Compacted	170 (6.7) [0.2]	120 (4.9) [0.2]	97 (3.8) [0.2]	64 (2.5) [0.2]
Clay, Dry Non-compacted	323 (12.7) [1.0]	244 (10.8) [1.0]	240 (9.6) [1.0]	220 (8.8) [1.0]
All other clayey soils (compacted and dry, plus all saturated conditions)	46 (1.8) [1.5]	25 (1.3) [1.5]	25 (1.0) [1.5]	20 (0.7) [1.5]

this may not be possible with most existing equipment.

The results of this study clearly show that amending soil with compost alters soil properties known to affect water relations of soils, i.e., the water holding capacity, porosity, bulk density, and structure, as well as increasing soil C and N, and probably other nutrients as well. The mobilization of these constituents probably led to observed increases in P and N compounds in surface runoff compared to unamended soil plots.

Results of the earlier tests (Harrison, et al. 1997) were somewhat different than obtained from the current tests. Some of these differences were likely associated with the age of the test plots, plus different rainfall conditions, and other site characteristics. The results of the earlier study clearly showed that compost amendment is likely an effective means of decreasing peak flows from all but the most severe storm events, even following very wet, antecedent conditions. The increases in water holding capacity with compost amendment showed that storms up to 20 mm (0.8 in.) total rainfall would be well buffered in amended soils and not result in significant peak flows, whereas without the amendment, only a 10 mm (0.4 in.) rainfall storm would be similarly buffered.

This study found that the infiltration rate increased by 1.5 to 10.5 times after amending the soil with compost, compared to unamended sites. There were mixed results with surface runoff results. Two of the older CUH test plots appeared to have no effect, the Woodmoor site had a ratio of 5.6 reduced runoff and the Timbercrest site had no reported runoff. Because the older CUH sites did not show any runoff improvements in these test while the new Timbercrest and Woodmoore sites did, further study should determine, if possible, the limits of effectiveness of compost amendment, i.e. age or decay rate, and a maintenance/reapplication schedule.

If a significant percentage of disturbed glacial till soils were amended with compost as described in this report, it would have a significant beneficial effect on watershed hydrology. The absolute amount depends on many factors, but it is clear that compost amendment is an excellent means of retaining runoff on-site and reducing the rate of runoff from all but the most intense storm events, especially during the early critical years following development.

One drawback is that the concentrations of many pollutants increased in the surface runoff, especially associated with leaching of nutrients from the compost. The surface runoff from the compost-amended soils had greater concentrations of almost all constituents, compared to the surface runoff from the soil-only test sites. The only exceptions were some cations (Al, Fe, Mn, Zn, Si), and toxicity, which were all lower in the surface runoff from the compost-amended soil test sites. The concentration increases in the surface runoff and subsurface flows from the compost-amended soil test site were quite large, typically in the range of 5 to 10 times greater. Subsurface flow concentration increases for the compost-amended soil test sites were also common and about as large. The only exceptions being for Fe, Zn, and toxicity. Toxicity tests indicated reduced toxicity with filtration at both the soil-only and at the compost-amended test sites, likely due to the sorption or ion exchange properties.

When the decreased surface flow quantities were considered in conjunction with the increased surface runoff concentrations, it was found that all of the surface runoff mass discharges were reduced by large amounts (to 2 to 50 percent of the unamended discharges). However, many of the subsurface flow mass discharges are expected to increase, especially for ammonia, phosphate, total phosphorus, nitrates, and total nitrogen. The large phosphorus and nitrogen compound concentrations found in surface runoff and subsurface flows at the compost-amended soil sites decreased significantly during the time of the tests (about 6 months). The older CUH test sites also had lower nutrient concentrations than the new sites, but still had elevated concentrations when compared to the soil-only test plots.

In conclusion, adding large amounts of compost to marginal soils enhanced many desirable soil properties, including improved water infiltration (and attendant reduced surface runoff), increased fertility, and significantly enhanced aesthetics of the turf. The need for continuous fertilization to establish and maintain the turf is reduced, if not eliminated, at compost-amended sites. Unfortunately, the compost also increased the concentrations of many nutrients in the runoff, especially when the site was newly developed but with increased infiltration of the soil, the nutrient mass runoff would be significantly decreased. Further research is needed to determine the optimum amount of compost amendment to benefit urban soils without the associated problems of leaching nutrients.

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The full report was submitted in partial fulfillment of Contract No. 7C-R369-NTSX by Robert Pitt under the sponsorship of the U.S. Environmental Protection Agency. The mention of trade names or commercial products does not imply endorsement by the United States government. Thomas P. O'Connor is the EPA Project Officer (see below).

The complete report, entitled "Infiltration through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity", EPA#/000/x/000/000 will be posted on U.S. Environmental Protection Agency, Office of Research and Development Web-site at: http://www.epa.gov and available from the National Technical Information Service (Order No. PB00-XXX XXX/AS; Cost:$XX.00, subject to change):

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