United States
Environmental Protection
Agency

EPA Publication No. 905R1103

Evaluation of Urban Soils:
Suitability for Green Infrastructure or Urban Agriculture

December 2011

Acknowledgments

This report was prepared for the United States Environmental Protection Agency, Region 5 by Tetra Tech, Inc. Significant contributions were made to this report by Richard S. Poruban under subcontract to Tetra Tech, Inc. U.S. EPA also wishes to acknowledge and extend appreciation to the Bellaire-Puritas Development Corporation, Park Works, Inc., and Neighborhood Progress, Inc., in Cleveland, Ohio, the organizations that planned and managed the green infrastructure retrofit project described as a case study in this report.

EPA Publication No. 905R11003

Contents

Figures

Tables

Acronyms and Units of Measure

ASTM	American Society for Testing and Materials
CEC	cation exchange capacity
EPA	Environmental Protection Agency
NCSS	National Cooperative Soil Survey
NRCS	Natural Resources Conservation Service (U.S. Department of Agriculture)
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
ppm	parts per million
SVOC	semi-volatile organic compound
SWCS	Soil and Water Conservation Society
USDA	U.S. Department of Agriculture
VOC	volatile organic compound

Executive Summary

Many urban areas are experiencing a significant increase in the number of vacant properties and a corresponding underutilization of substantial tracts of land. As part of efforts to revitalize these areas, communities are looking at *green* reuses of vacant properties, including parks, green infrastructure, and urban agriculture. The poor condition of the soils on these properties, however, can often be a significant impediment to green infrastructure and urban agriculture uses. The soils are often severely compacted, lack sufficient organic matter, and can contain large amounts of construction debris, making them unsuitable as a growing medium.

This report provides a concise, practical, and scientifically-based overview of the typical conditions of urban soils, and offers recommendations for how such soils can be rehabilitated or reconditioned to support green infrastructure or urban agriculture. Reconditioning methods for improving poor quality soils will vary depending on soil conditions and the intended use of the site. In general, the objective is to restore disturbed urban soils to a condition more consistent with the functions and services of native soils. Sites intended for urban agriculture might need considerable reconditioning to achieve the characteristics needed to grow certain crops, whereas areas intended for recreation (e.g., parks, playgrounds, hiking trails) might need only moderate improvement to allow for vegetation.

Reconditioning of urban soils is intended to adjust drainage characteristics, improve soil structure, add organic matter, and mitigate compaction. Examples of soil reconditioning techniques include:

- Raking out construction debris and using a subsoiler to break up compacted soils
- Adding compost and tilling
- Altering the soil chemistry to achieve desired parameters (e.g., pH)
- Manipulating organism populations to achieve a desired change in soil characteristics (e.g., using earthworms to promote easier air, water, and nutrient penetration into the soil profile).

In many cases, reconditioning of soils on vacant parcels involves raking out rubble and debris and tilling in compost or topsoil. In procuring compost or topsoil, care should be taken to bring in materials from sources where the origin of the compost or soil is known and the quality of the materials is certified or otherwise ensured. This is important to make certain there are not undesirable characteristics in the soil or compost being brought to the site, such as contaminants or seeds from invasive plant species.

In some cases urban soils may have concentrations of contaminants from past land uses or air deposition. Possible soil contamination issues should be considered when planning reuses of urban parcels. This report does not specifically address assessment or remediation of contaminated soils. The U.S. EPA Brownfields Program and/or State Brownfield or Voluntary Clean-up Programs should be consulted for technical information on assessing sites and addressing soil contamination, if identified. This report focuses on assessing and reconditioning soils to provide good drainage and support plant growth.

Soil quality and characteristics should be assessed during the project planning phase, and initial reconditioning should be done before vegetation is established. Project planners need to understand that long-term management of the soils is needed to ensure success. Soil management is a dynamic process that usually requires a large initial effort followed by smaller sustained efforts to achieve a lasting beneficial result.

(This page intentionally left blank.)

1.0 Introduction

Many urban areas, especially within the industrial Midwest, are experiencing a significant increase in the number of vacant properties and underutilization of substantial tracts of land. In an effort to revitalize these areas, communities are looking at using vacant properties as locations for green infrastructure and urban agriculture. The poor conditions of soils on these properties, however, can often be a significant impediment to successfully implementing green infrastructure or urban agriculture projects. Soils are often lacking organic matter and/or are severely compacted, and may contain large amounts of construction debris, making them unsuitable as a growing medium.

This report provides a concise, practical, and scientifically-based overview of the typical conditions of urban soils, and offers recommendations for how such soils can be rehabilitated or reconditioned to support green infrastructure or urban agriculture. The focus of the document is on conditions within the Great Lakes Basin, although many of the principles apply to urban environments throughout the U.S.

U.S. EPA defines *green infrastructure* as “an adaptable term used to describe an array of products, technologies, and practices that use natural systems—or engineered systems that mimic natural processes––to enhance overall environmental quality and provide utility services. Green infrastructure can be used as a component of a stormwater management system when soils and vegetation are used to infiltrate, evapotranspire, or recycle stormwater runoff.” Rain gardens, permeable pavement, trees and urban forestry, downspout disconnection from storm sewers, vegetated swales, green parking and green streets, and riparian buffers are examples of green infrastructure. Many communities and neighborhood groups are working to implement green infrastructure on vacant properties.

Figure 1. Community garden in Detroit

Green infrastructure has the potential to provide the following benefits:

- Reduced and delayed stormwater runoff volumes;
- Enhanced groundwater recharge;
- Stormwater pollutant reduction;
- Reduced sewer overflow events;
- Increased carbon sequestration;
- Urban heat island mitigation;
- Reduced energy demand;
- Improved air quality;
- Additional wildlife habitat and recreational space;
- Improved human health; and
- Increased land values.

Urban agriculture is the cultivation of crops in urban or suburban areas for local consumption or sale. While individuals may develop backyard gardens or begin a for-profit venture, the focus of this report is on community gardens that can be established on a vacant parcel or at a school or another communal location in a neighborhood. Urban agriculture can provide many benefits, including:

- Improving the quality of life for people living near the garden;
- Providing a catalyst for neighborhood and community development and neighborhood stabilization;
- Stimulating social interaction;
- Beautifying neighborhoods;
- Producing nutritious food;
- Reducing family food budgets;
- Conserving resources, including those which would otherwise be needed to transport food from remote areas to urban dwellers;
- Creating an opportunity for recreation, exercise, therapy, and education;
- Preserving green space;
- Creating income opportunities and economic development;
- Reducing city heat from streets and parking lots;
- Reducing impervious urban land area; and
- Providing opportunities for intergenerational and cross-cultural connections.

The use of certain green infrastructure practices and the development of urban agriculture can be challenging in an urban environment due to a number of factors, including the poor condition of the soils.

This report provides information on the characteristics of urban soils (Section 2), summarizes how urban soils should be assessed before initiating a project (Section 3), and provides recommendations for reconditioning urban soils (Section 4). The report concludes with a description of a case study (Section 6)

2.0 Characteristics of Urban Soils

Soil is the unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of plants. Soil characteristics reflect the effects of climate (including water and temperature effects) and macro- and microorganisms acting on parent material over time. An *urban soil* on a parcel in a metropolitan area has typically been moved, graded, and/or or compacted over time, often as a result of construction and demolition activity at the site. Movement of soil and addition of non-native soils is relatively common in developed areas. As low areas are filled and hills are graded, soils are shifted and relocated, resulting in mixing of the soil profile or placement in a different order. Fill is often brought on-site from nearby areas and frequently has characteristics different from the native soils on site. Because of the ways soils have been altered, there can be great variation in the characteristics of soils within an urban land parcel.

Soil studies in urban areas have found that soil compaction, low organic matter content, and low levels of contamination, usually from air deposition or from historical uses on site, are common attributes of urban soils. The issue of assessing soil quality becomes two-fold: the health of the soil as a growing medium needs to be addressed as well as the possible contamination that may be present.

The history of a vacant parcel can provide valuable information to help identify possible soil contamination. In industrial areas, historical contaminates might include heavy metals, hydrocarbons, or chemicals used during the manufacturing process. In residential areas built before the early 1980s, contaminants generally include lead paint residues, and may have asbestos, coal and wood ash deposits, fuel oil, used motor oil residues, or pesticides. Remnants of abandoned septic systems, cisterns, and wells are also often uncovered during redevelopment of residential sites. Residential areas tend to have relatively less compaction and better-quality soils than more heavily urbanized areas. Knowing the development history of a parcel is key to determining what type of soil testing should be done, if any, prior to redevelopment or reuse.

Figure 2. Vacant residential lot, Cleveland, Ohio

Photo: William Shuster (U.S. EPA)

Some vacant parcels in an urban environment are referred to as Brownfields. Brownfield sites are properties that are available for redevelopment, but site redevelopment is complicated by the presence or potential presence of contaminants in the soil and/or the groundwater. U.S. EPA's Brownfield Program and many States provide funding for the assessment and clean-up of Brownfields through grants and loans. In many cities Brownfields and other vacant properties have been successfully remediated and are being reused as community gardens and stormwater parks (U.S. EPA, 2009).

This report does not specifically address how to assess or remediate contaminated soils. U.S. EPA Brownfields Program and/or State Brownfield, Voluntary Clean-up Programs, or health agencies should be consulted for technical information on assessing sites and addressing soil contamination. The focus in this report is on improving urban soils so that they provide an adequate growing medium for urban agriculture or native plants, and/or so the soils are suitable to support green infrastructure strategies for managing stormwater.

3.0 Site Suitability Evaluation

Before urban agriculture or green infrastructure is implemented at a site, the suitability of the site for these practices must be evaluated. This section of the report provides general guidance for assessing soil quality at an urban site.

The suitability of a site is dependent on redevelopment goals and must take into account possible human health concerns. Sites where the planned end use is a green space or a stormwater park may have different site preparation and soil reconditioning needs as compared to a parcel where food products will be grown. For example, if a site is to become a swale for stormwater runoff, the risk to human health from low-level historical contamination is relatively small (note risks to workers coming in contact with soil should always be considered. Risks to human health must be more explicitly evaluated for urban agriculture because the food products grown will be eaten, and adults and children will come into direct contact with the soil as agricultural activities are carried out.

Suitability assessments also vary depending on what type of vegetation the soil will need to support. The types of testing used to determine soil quality for urban agriculture focuses on whether the desired crops can be grown, and whether there may be uptake of contaminants into plants grown for consumption. Testing to determine if the soil is suitable for infiltration or green infrastructure focuses on the soil as a growing medium for plans, the capacity of soil to store water and infiltrate water, and the possibility of mobilization or migration of contaminants.

3.1 Characterization of the Site and Soils

After determining the goals for the site, site characterization is an important next step in the process. Site characterization includes assessing the site's historical, physical, chemical, and biological characteristics by reviewing available records and visiting the site.

3.1.1 Historical Uses

After the objectives of the site are decided upon, an assessment of the historical usage of the site is valuable to determine the potential for contamination. If the site has been used for residential housing for the entire time period since the neighborhood was developed, it is less likely that there will be significant soil contamination as compared to a site in an industrial area. The full process for determining the characteristics of historical use and potential environmental concerns is called a Phase I Environmental Site Assessment (ASTM E1527-05). This includes interviewing neighbors, local city officials, or former property owners and trying to acquire old aerial photographs or maps. Useful information is available from many sources, including local conservation district offices (e.g., soil surveys), city halls (e.g., permits), county offices (e.g., tax records), libraries, and historical societies and preservation offices (e.g., photos, hand-drawn site maps, paintings). Doing a Phase I Environmental Site Assessment will typically include evaluations of public land ownership records and environmental databases. Phase I assessments which identify potential environmental concerns are followed by field data collection, known as Phase II Environmental Site Assessments (ASTM E1903).

3.1.2 Field Assessment

A site visit and field assessment is critical to helping guide future activities. Notes should be recorded and photographs should be taken for future analyses. Example field sheets are available from the *Urban Watershed Forestry Manual,* Part 3: *Urban Tree Planting Guide* (USDA, 2006).

The site history is used to guide the field visit. For example, if records show a former structure, site visitors can use local landmarks to try to locate the former location of the structure. Also, if remediation occurred at the surface, it might be observable. Field visitors can use current and historical aerial imagery in an effort to ground-truth the imagery and to help focus the on-the-ground analysis.

Existing utilities should be documented during the field assessment. Underground and aboveground utilities can pose hazards and might limit the site's restoration or re-use potential. Public utilities are typically identified through a statewide utility locator company, such as Miss Digg in Michigan, Gopher State One in Minnesota, and the Ohio Utilities Protection Service in Ohio. Private utilities need to be identified by a property owner or by using plans and maps.

Site topographic, hydrologic, and biological conditions should also be thoroughly assessed. Both urban agriculture and stormwater management practices require an accurate understanding of the hydrologic condition of the urban site. Existing drainage patterns should be identified, as well as the general slope of the site and locations of concentrated flow or erosion. The contributing drainage area to the site, or watershed, should be evaluated for land use. Land uses that are higher in paved areas or are impervious generate larger volumes of runoff and peak flows that could impact the site. Areas of depressional storage and the presence of wetlands should be identified. Soil type should also be evaluated to determine infiltration potential.

Many methods are available to determine the degree of soil compaction on a site. These methods range from visual observations to field measurements to laboratory analyses. Typically, visual observations provide enough information to determine reconditioning needs. Compaction can be identified by observing a lack of or poor plant growth at the surface or a lack of roots or biological activity within the soil profile. A professional can perform laboratory and field tests when needed. Also, soil particle size can be evaluated in the field to determine the relative proportions of various particle sizes, or can be analyzed in a laboratory through grain size and hydrometer analysis.

Vacant properties that have had recent demolition occur are likely to include a significant amount of construction debris and fill. In addition, basement foundations might still be present several feet below the ground surface, possibly with fill material placed into what was once the basement. It is important to note the presence of any remnant structures or evidence of structures in order to anticipate possible construction costs and expected performance of a green infrastructure practice. The site might also have been further compacted as a result of the demolition work.

Finally, soil sampling for suitability as a growing medium is strongly recommended for urban agriculture and green infrastructure sites. At a minimum, the soil test should include pH, percent organic matter, nutrients, micronutrients, and metals, including lead. Local soil testing information can be obtained from or performed by USDA Cooperative Extension System offices and from many land grant universities and private local laboratories. Information on interpretation of soil test results is presented in this fact sheet: **http://www.soiltest.uconn.edu/factsheets/InterpretationResults_new.pdf**

Further information on Evaluating Soil Suitability is presented in Appendix A.

Figure 3. Example of raised planting beds being used to support urban agriculture in Cleveland, Ohio

Photo: Jennifer Olson (Tetra Tech)

3.2 Strategies to Address Unsuitable Soils

If the preliminary evaluations determine that soils are unsuitable for the site's intended purpose, efforts can often be made to enhance the condition of the soils. Where soil reconditioning is feasible, it is likely that multiple strategies will be needed, with a relatively large effort at the beginning and smaller sustained efforts over time. In cases where it is not feasible to recondition soil, or there are contamination issues that preclude use of site soils, altering the plans for site use may be an option.

In some cases, raised planting beds, vertical gardening, and container gardening can be used in lieu of using existing site soils for urban agriculture. These garden alternatives can be used if the existing soils are unsuitable for the intended crops for urban agriculture, or if the existing soil is contaminated at the surface or in the root zone. Procedures to prevent contamination during the installation of raised beds or containers can be used to minimize or eliminate plant and human contact. In Connecticut, Stilwell et al. (2008) found that using raised planting beds with imported clean soils for planting above areas contaminated with high existing levels of lead or other heavy metals was a cost-effective method for community gardening on a site with unsuitable soils. The authors also recommend using physical barriers such as mulch around the planting beds and a porous barrier between the planting bed media and the site soils.

If a site has soils that cannot support the intended use, it might be possible to use the parcel for another use. For example, a site that turns out to be not well-suited for stormwater runoff control might still be suitable for urban agriculture. Another example: if soils are of relatively poor quality and cannot support urban agriculture, they might still be satisfactory for hearty native plants. In many cases, native landscaping can be aesthetically pleasing, and seeds can be collected for sale or use at another site.

4.0 Reconditioning Urban Soils

Soil reconditioning goals are dependent on the intended use of the site. In general, the objective is to increase the soils' ability to support different types of plants and their ability to infiltrate stormwater. Sites intended for urban agriculture might need relatively more work to achieve the specific characteristics needed to grow certain crops, whereas areas intended for recreation (e.g., parks, playgrounds, hiking trails) might need only moderate work to allow for urban grasses, certain manicured plants, or native vegetation. Soils on green infrastructure sites that will be used for stormwater management might need to be modified to promote increased infiltration and to support the desired plant types. Longer term methods for reconditioning soils include amending existing soils with mulch and compost, and/or planting cover crops to provide additional nutrients and erosion control over the winter months.

4.1 Types of Reconditioning

Physical reconditioning of urban soils is intended to adjust drainage characteristics, improve soil structure, and mitigate compaction. The mitigation of compaction is important for both urban agriculture (e.g., for root penetration) and stormwater management (e.g., for infiltration capacity). After physical reconditioning is performed, chemical and biological reconditioning techniques can be used to improve soil productivity. *Chemical reconditioning* involves altering the soil chemistry to achieve desired parameters (e.g., altering soil pH). Chemical reconditioning should be performed only after evaluating soil chemistry through the laboratory analysis of field-collected samples. Testing should also occur after chemical reconditioning and into the future to determine whether the reconditioning was successful and whether supplemental reconditioning is necessary.

Biological reconditioning practices involve manipulating organism populations to achieve a desired change in soil characteristics. Biological conditioning should be performed after physical and chemical reconditioning because the latter two prepare the soil ecosystem for biological production.

In general, physical techniques should be performed first, followed by chemical and then finally biological techniques.

The most common types of physical, chemical, and biological reconditioning that are used with urban soils are presented in Table 1 and discussed throughout the remainder of this section.

Table 1. Reconditioning Methods

Method	Physical	Chemical	Biological
Soil Removal	X		
Raking	X		
Tillage and subsoiling	X		
Drainage	X		
Soil amendments and additives	X	X	X
Recyclers			X
Cover crops			X
Mulch	X	X	X

4.1.1 Soil Removal

Excavation typically involves removing contaminated soils or structures. Depending on the level of existing contamination, soils can be managed or capped on site or hauled off-site for disposal. Excavation is typically the most expensive reconditioning or remediation technique and is often very costly for privately funded residents or community groups. Local municipalities might already own the necessary equipment which lowers costs and may make excavation a viable alternative for city-owned properties.

4.1.2 Raking

Some urban soils, especially those on vacant parcels that have recently had structures removed, might have extensive rocks, rubble, and debris resulting from the demolition activity and the placement of fill material (see Case Study in Section 6 as an example). In these situations, it is advisable to rake and remove the debris. Small areas can be raked by hand, or for larger areas, landscape rakes can be rented and used with a compact tractor. Raking can efficiently collect small rocks (as small as ¾ inch) while at the same time leveling the soil.

4.1.3 Tillage and Subsoiling

In most situations, compaction problems are in the top 12 to 24 inches of site soils, the root zone of most plants. Compaction is typically the result of construction on the site, historical use of the site (e.g., driving on the driveway, parking a vehicle in a garage), and use of heavy equipment during demolition. Often deeper soil layers are relatively less compacted.

Tillage is the process of turning over or mixing the soil for the purpose of loosening and aerating in preparation for seeding or plantings. Deep tillage or subsoiling techniques such as ripping or scarification of the soils can be used to recreate soil structure and break up compacted soils. These techniques typically involve tilling to depths from three to eight feet, where soil is typically ripped in a gridded pattern using metal shanks to create pore spaces and flow paths for water and air in the soil. Subsoiling can be used in combination with other tilling techniques to mitigate the effect of compaction, and is commonly used for agricultural purposes. Tilling or subsoiling for compaction mitigation will likely only be required once. Care should be taken to ensure newly-exposed soils are properly stabilized to prevent erosion.

In the Great Lakes region, soil freezing and thawing is a key factor affecting soil conditions, and it can be a beneficial tool for soil manipulation in urban areas. Fall plowing can be used to expose soils to freezing and thawing. As soil water freezes, it expands and acts as a wedge to break compacted soil clods. As thawing occurs, pore spaces remain, allowing air and soil microorganisms to thrive. These processes can improve soil structure, allow better water infiltration, and kill weed seeds, insects, and pathogens. Combined with other soil manipulation techniques, tillage and freezing can be an effective and inexpensive soil-conditioning tool.

4.1.4 Drainage

Ensuring appropriate drainage of a project site is a necessary component of a successful green infrastructure or urban agriculture project. The object of drainage in a horticultural context is to promote a healthy root environment; therefore the root zone is the target area for moisture control. Every plant has a soil moisture range in which it thrives. Surface drainage can be modified with grading, excavating, and restricting drainage outlets. Soil amendments can also modify surface drainage patterns by increasing infiltration capacity and the moisture conditions of the soils. Care should be taken to modify soils to the appropriate root zone depth for desired plant materials. If drainage modification is difficult, plants should be selected accordingly (e.g., native wetland vegetation).

4.1.5 Soil Amendments and Additives

Soil amendments and additives introduced into soils to modify specific physical soil characteristics. Any materials brought in to improve a soil's condition should be of known origin and quality to ensure that diseases, unwanted chemicals or seeds, and allergens are not introduced. Urban (2008, p. 176) categorizes soil amendments into five types:

Organic: Composted plant residues that increase the organic matter content of the soil.

Mineral: Natural or processed mineral products that change the texture of the soil.

Physical: Manufactured additives designed to amend or replace natural soil structure and improve the soils' resistance to compaction or erosion.

Biological: Condensed organic compounds and biological inoculants used in small amounts to alter soil biology or soil chemistry.

Chemical: Compounds used in small amounts to add nutrients, change pH, or stimulate biological activity.

These five types of soil amendments are discussed in the remainder of this subsection.

4.1.5.1 *Organic Amendments*

Organic soil amendments and additives are organic materials added to improve the soil food web, both by introducing organisms and providing the carbon source to support those organisms (Urban 2008, p. 176). Organic amendments can also improve the CEC, chemical buffering, and initial aeration of the soils.

One of the most common organic amendments is compost. Research conducted by Pitt et al. (1999) determined that compost added to an urban soil improved the physical properties and the nutrient content of the soil. Compost also provides plant-protection benefits and stimulates biological activity. The quality of compost can vary significantly and should be taken into account when selecting a supplier. The U.S Composting Council sets standards for compost and provides specifications that can be used to ensure high-quality compost.

Food scrap items such as vegetable and fruit waste, meal leftovers, coffee grounds, tea bags, stale bread, grains, and general refrigerator spoilage can be effectively composted to be used as organic amendments. Food scraps should be adequately secured in a bin while they degrade to avoid attracting rodents and other scavengers, and should not be directly tilled or applied into the soil. It is important that organic materials be composted properly to avoid introducing noxious weed seeds, insect eggs, and other undesirable organisms to any site. Composting does not eliminate all pesticide residues or chemicals. Other organic amendments and additives include peat moss, sludge, and manure.

Organic materials hold abundant moisture and require proper aeration. Organic amendments are therefore typically not effective for improving drainage in compacted or abused soils where excess water cannot move from the root zone. To be effective, organic materials generally must be periodically replenished to maintain benefits.

4.1.5.2 *Mineral Amendments*

Mineral amendments are inorganic and “are generally permanent and dimensionally stable in the soil, and may increase drainage if used in sufficient quantity” (Urban 2008, p. 179). Perlite, hadite, and pumice are three mineral amendments excellent for soil mixing because they have large internal pore spaces and hold air and water in suitable proportions for plant growth. Perlite is an inert volcanic rock structurally expanded with steam. It comes in different grades and is used for a wide array of applications. Hadite is a clay product baked at high temperatures to form a porous, inert additive. Pumice is a light, foamy volcanic rock. They are all chemically stable and sterile, and they make excellent soil additives. Powdered charcoal can be beneficial for soils because it is chemically stable, has high CEC, can absorb a wide array of chemicals, stabilizes pH, and stimulates secondary biological activity.

Gravel and sand are commonly recommended to improve drainage and are typically used in drainage structures and green infrastructure practices. Sand mixed with compost and topsoil is typically used as a soil amendment beneath rain gardens and bioretention facilities. Sand and gravel can also be used in other filtering practices such as a rain garden with an underdrain (biofiltration). However, infiltration capacity typically does not improve in clayey soils with just the addition of sand and gravel.

Figure 4. Example of compost amendment used for green infrastructure projects

Photo: Jennifer Olson (Tetra Tech)

Additional mineral amendments include:
- Calcine clay – increases moisture retention;
- Expanded shale, clay, and slate (ESCS) – increases porosity;
- Diatomaceous earth – increases moisture retention; and
- Vermiculite – increases moisture retention (not recommended for agricultural uses).

4.1.5.3 *Physical Amendments*

Physical amendments are structures that stabilize loosely compacted soil within the root zone. Physical amendments include soil stabilizer grids, geowebs, and turf cells. This type of physical control commonly has the ability to support loads or control erosion and is recommended for certain types of green infrastructure such as permeable parking areas. These amendments are not appropriate for urban agriculture and are generally used to stabilize soils for grasses and small plants.

4.1.5.4 *Biological Amendments*

Biological amendments are used to improve the soil ecosystem by improving the soil food web. Types of biological amendments include:

- Mycorrhizae, a symbiotic fungus that colonizes plant roots and increases water and nutrient absorption;
- Kelp extracts, which contain trace minerals and nutrients;
- Humic acid, which stimulates microbial activity and increases nutrient uptake;
- Compost tea, which inoculates microbial life into the soil and adds soluble nutrients; and
- The addition of macrofauna or microfauna to break down organic material.

In terms of their abundance and their soil forming roles, earthworms, termites and ants are the most important macrofauna components of soils. Many of these animals burrow in the soil, aiding soil drainage and aeration; in addition, some organic material passes into the soil through the burrows. Most macrofauna consume decaying plant material and organic debris. They bury seeds, provide readily available nutrition and air to the root zone by burrowing and excreting, and cull weak plants to allow stronger ones to grow.

The most effective and readily manipulated soil macrofauna are earthworms. Many earthworm species burrow several feet deep, and all ingest soil. Earthworms leave castings that aggregate soil particles and resist degradation and promote easier air, water, and nutrient penetration into the soil profile. Earthworms alter soil in a variety of ways, including:

- Altering soil chemistry, including pH, CEC, and other major soil parameters
- Efficiently burying seeds and other organic debris
- Detoxifying a wide array of contaminants, including petrochemicals
- Altering heavy metal bioavailability
- Promoting microorganism growth and dissemination
- Providing ideal macropore space for microfauna and root penetration.

Compacted, rocky, biologically barren, and extremely wet or dry soils require modification before earthworms will thrive. Reconditioning using earthworms is a relatively new, but maturing and viable, technology for improving soils in urban areas, provided species are properly selected and sites are made suitable. For example, “red worms” are extensively used for composting but are not as well suited to survive in soil, and common bait worms and night crawlers thrive in soil but are not really efficient composters.

4.1.5.5 *Chemical Amendments*

Chemical amendments are added to affect soil chemistry (usually to alter nutrient levels or soil pH), but changing the chemical composition of a soil is difficult. Chemical amendments should be applied only after the soil has been physically reconditioned using the techniques described previously. Chemical amendments should also be applied only after the chemistry of the urban site has been analyzed and after proper chemicals have been selected. The application of a chemical amendment, often a fertilizer, is intended to rectify a chemical imbalance in the soil. Chemical amendments can have unintended side-effects (e.g., soil salinization[1]) that can be avoided or limited through review of the amendments and existing soils conditions. It should also be noted that over-application of fertilizers is common; every effort should be made to apply the least amount of fertilizer that is necessary to achieve the intended results. This is especially true because phosphorus, included in many fertilizers, is often a limiting nutrient in waterways and over-fertilization can lead to excessive algae growth in lakes, streams, and ponds.

[1] The accumulation of salts in the soil, which affects the fertility of the soil. Salinization is commonly a problem for irrigated areas.

Table 2. Recommended reconditioning measures (after USDA 2006).

Soil Characteristic	Moderately Impacted Threshold	Severely Impacted Threshold	Reconditioning Measure
Infiltration, percolation, and permeability rates (in/hr)	<0.25	<0.20	Adjust drainage depending on type of vegetation; refer to Table **3**
Percent sand	>75	>90	Add compost or peat
Percent clay	>50	>65	Add compost or peat
Bulk density of clay (mg/m^3)	>1.4	>1.5	Add compost or peat
Bulk density of loam (mg/m^3)	>1.5	>1.7	Add compost or peat
Depth to bedrock (ft)	<4	<2	Add new soil
Acidic soils (pH)	<6	<4	Add lime
Alkaline soils (pH)	>7.5	>8.5	Add compost or peat, add iron sulfate/iron oxide
Cation exchange capacity (meg/100g)	<5	<3	Add compost and/or peat
Potassium (lbs/acre)	<124		Add compost
Phosphorus (lbs/acre)	<44		Add compost
Percent organic matter	<1		Add compost or peat
Soluble salt (ppm)	600	1,000	Add gypsum, add compost or peat

4.1.5.2 Cover Crops

Cover crops can be used to create organic matter; stimulate biological activity; inhibit weed species; buffer moisture, temperature, and pH; and in some instances, fertilize and improve infiltration with root systems. Cover crops double as secondary biological indicators to show troublesome areas not observed by spot tests. Cover crops can be planted in the late fall or winter to provide soil cover. Common winter cover crops include clover, oats, and rye. Summer cover crops, sometimes referred to as green manure, are often used to provide improved conditions of poor soils or prepare land for a perennial crop. Legumes, such as soybeans, can be used as summer cover crops to add nitrogen and organic matter to the soil. Non-legumes such as millet, forage sorghum, annual rye, clover, oats, or alfalfa can be used to provide biomass, control weeds, and improve soil conditions.

A living mulch is a cover crop that is planted along with an annual or perennial cash crop. Living mulches suppress weeds, reduce soil erosion, enhance soil fertility, and improve water infiltration. Examples of living mulches in annual cropping systems include overseeding hairy vetch into corn at the last cultivation, no-till planting of vegetables into subclover, sweetclover drilled into small grains, and annual ryegrass broadcast into vegetables. Living mulches in perennial cropping systems are simply the grasses or legumes planted in the alleyways between rows in orchards, vineyards, berry farms, windbreaks, and field nursery trees to control erosion and provide traction.

Cover crop seed is relatively inexpensive and easy to plant. Since even common pre-grown conservation plant species are relatively more expensive and labor-intensive to install than cover crops, it makes proper fiscal sense to use cover crops to ensure soil characteristics are satisfactory before incurring the expense, and doing so allows more time to properly plan the site. *Managing Cover Crops Profitably* (SAN 2007) has a great deal of detailed information on cover crops; this publication is available online:
http://www.sare.org/publications/covercrops/covercrops.pdf.

4.1.6 Mulch

Mulch is “material placed on the soil surface primarily for the purpose of reducing evaporation or controlling weeds” (Brady and Weil 1999, p. 231). Mulch can also help reduce compaction by retaining soil moisture (compaction naturally decreases because of the freeze-thaw cycle) and promoting biological activity (Urban 2008). Mulch can include granulated or pulverized soil; organics, including peat moss, leaves, wood chips, bark, compost, rice hulls, and straw; synthetic materials, including shredded tires, sheet plastic, shredded paper, crushed glass and cans; and geotextiles. Mulches can serve as walking paths through green infrastructure parks or in urban agriculture areas.

Each type of mulch has benefits and disadvantages, but all modify soil surface temperatures, soil air and moisture relations, compaction potential, and biological activity. Mulches are usually intended to keep root systems cool, moist, uncompacted, biologically active, and protected from freezing. Mulch can help soil recover from light compaction and shallow surficial compaction, but it is decreasingly effective in warmer and drier climates and as biological activity decreases and root penetration diminishes (Urban 2008).

Properly executed mulching can be beneficial, but overuse or misuse can harm the soil and can even kill long-established shrubs and trees. Unless used as a growth medium, more than two inches of any non-living mulch application can result in biological degradation through soil anoxia and by providing a home for detrimental animals.

Organic non-living mulches are the most common mulches used in landscaping and perennial crop production. They have distinct advantages over other mulch forms because with few exceptions, they decompose readily and are easily obtainable in bulk quantities. Decomposition allows mulch matter to be incorporated into soil, benefitting many levels of soil organisms and releasing nutrients slowly to roots. Organic mulches of proper thickness are highly insulating and are the best choice to keep underlying soil cool and moist in summer and above freezing in winter. Organic materials can be used to introduce beneficial microorganisms and fungi to gardens.

However, slowly decomposing mulches such as cypress mulch, while requiring fewer applications, can form a water and air impermeable barrier because their fine structure can act like a thatched roof, repelling water and preventing necessary air movement. Plants tolerate such mulches poorly over time if the mulches are not mechanically disturbed. Poor mulching practices can also introduce diseases, chemicals, unwanted seeds, and allergens. It is important to research the intended plants and mulches carefully, and to match the mulch with the desired crop and function. Over time decomposition of mulches will allow “thatched” or compacted mulches to develop a porous structure and be more water absorbent.

Table 3. Reconditioning considerations for compacted urban soils with low organic matter

Type of Vegetation	Goals	Reconditioning Considerations
Native plants	The purpose is to cover the ground with native species that survive and outcompete nonnative species under less-than-ideal conditions with little or no maintenance. Common impediments include low nutrition, slow drainage, and no or very little supplemental water (Survival)	Compost should be incorporated into existing soil to a depth of 4 to 8 inches until soil works easily with tools. (Deeper depths will be needed if planting trees.) Generally no supplemental drainage is required or needed other than subsoil plowing.
Ornamental plants	The purpose is to cover the ground with vegetation that looks good under moderately maintained conditions, including low to moderate nutrition levels and only occasional supplemental water. (Survival and aesthetics)	Adequate drainage and a deep root zone are critical to long-term survival because most ornamentals do not tolerate more than occasional saturation in root systems. Root zone incorporation of compost and perlite should be 12 to 18 inches deep until soil is uniform and has no aggregates larger than marbles. Supplemental drainage beyond subsoil plowing might be necessary, depending on plant selection, because excess water in the root zone should be gone within 30 minutes to 8 hours. Supplemental drainage is passive and only allows water to leave without actively drawing moisture out of the soil.

Food plants	The purpose is to produce vigorous growth and large, edible parts under high-maintenance conditions. No growth impediments and luxury consumption of nutrients, rapid drainage, deep root zones, and all needed supplemental water and nutrition. (Survival, aesthetics, vigorous growth, and safe to eat)	Compost should be incorporated into the root zone (12 inches deep for root crops; 6 to 8 inches for other crops). Contamination control is critical for safety. Excess water should be out of the root zone in 15 to 20 minutes. Soil should be worked easily with hands, and aggregates should be marble-sized or smaller. More frequent and larger quantities of compost are needed with frequent tillage. Organic additions will decompose quickly due to frequent aerating activities. Perlite or other porous additive is not generally necessary because of the frequent tillage (at least once in the growing season). Supplemental drainage may be necessary. Supplemental watering and nutrition are typical. Use cover crops to store nutrients and improve soil structure.

5.0 Bioremediation

Project managers who wish to implement site/ soil remediation before implementing green infrastructure or urban agriculture are encouraged to engage State Brownfield, Voluntary Clean-up Programs, or health agencies for technical information on addressing soil contamination. In some cases, bioremediation and phytoremediation are long- term strategies for remediation that may be integrated into a green infrastructure management plan.

Bioremediation involves the use of "enhanced plant and/or microbial action to degrade organic contaminants into harmless metabolic products" (Brady and Weil 1999, p. 737). The concept of bioremediation is based on the use of organisms' natural abilities to repair the urban soil ecosystem. Bioremediation typically involves plants, microorganisms and application of compost or soil amendments to digest harmful chemicals such as gasoline or oil, resulting in harmless byproducts (U.S. EPA 2001a). All of these must work in concert to achieve maximum benefit.

Phytoremediation is a type of bioremediation that uses plants to take up harmful chemicals from the soil and groundwater and then store the chemicals in their roots, stems, or leaves, changing the chemicals into less-harmful substances, or releasing them into the atmosphere. For example, prairie grass can stimulate the breakdown of petroleum products (NRCS 2000b). While some plants can absorb and metabolize specific organic constituents and others help degrade pollutants at the root level, the primary agents of phytoremediation are the microorganisms associated with the rhizosphere of the plants (Brady and Weil 1999, p. 738). Phytoremediation is typically used on sites that are not severely contaminated. This practice often includes harvesting of the plant material to remove contaminants from a site.

6.0 Case Study

ReImagining A More Sustainable Cleveland was adopted by the Cleveland City Planning Commission in December 2008. "ReImagining Cleveland" is a collaborative grant and technical assistance program of the Cleveland Community Development Department and partnering nonprofit organizations aimed at creating sustainable land reuses on vacant land parcels in Cleveland. The Bellaire-Puritas Development Corporation (BPDC) in Cleveland is working in partnership with community members, Neighborhood Progress, Inc., Park Works, Inc., Cuyahoga County Soil and Water Conservation District (SWCD), Ohio State University, the Northeast Ohio Regional Sewer District, and other partners to enhance vacant parcels with community gardens and green infrastructure.

An objective of the BPCD projects is to demonstrate many of the types of sustainable land reuse projects suggested in the report and in the companion *ReImagining Cleveland Pattern Book.* The goals for implementing green infrastructure included:

- **Improving stormwater management:**
  - reducing delivery of pollutants to local waterways;
  - reducing erosion in stream channels due to stormwater; and
  - reducing localized flooding.

- **Providing amenities for the neighborhood:**
  - green open space;
  - aesthetically pleasing landscaping (using native plants to the extent practicable);
  - educational signage;
  - source of neighborhood pride; and
  - reduction in supply of vacant properties.

6.1 Project Overview

In 2010 the BPDC undertook a project to implement green infrastructure at a vacant parcel located on West 131st Street in Cleveland (Figure 5). Green infrastructure was seen as a beneficial site reuse at this location because the parcel is adjacent to a perennial stream, the Chevy Branch of Big Creek, which is greatly affected by wet weather flows. The amount of water in the Chevy Branch increases dramatically during and after rain events due to the runoff from impervious surfaces in the area. Green infrastructure practices will retain and infiltrate stormwater, which helps to reduce the volumes of water in the stream and the associated adverse water quality impacts.

Prior to site work, a residential home was demolished at the site. Based on visual observations and field work done by a U.S. EPA National Risk Management Research Laboratory (NRMRL) team, it was found that much of the demolition debris (rubble-type material, rocks, and debris) had been left at the site, much collected into the basement of the former structure (Figure 5). The home and driveway had been leveled and compacted, leaving the area poorly suited for infiltration or the establishment of vegetation. The NRMRL team observed that there had been an unsuccessful attempt to establish turf grass at the site after demolition. The compaction and amount of construction debris mixed into the top 1.5 feet of fill limited the stormwater management opportunities at the site if soil restoration work was not undertaken. Soil tests, conducted May 17, 2010, indicated low levels of organic matter, low levels of nitrogen and phosphorus, and a slightly higher than normal pH. Low levels of lead were detected in the soils. Other parameters were normal.

The restoration work was completed in November 2010. The goal for the site was to provide a natural area in the neighborhood that would serve as an amenity and learning center and provide stormwater treatment. Restoration activities included:

1. Chisel tilling and debris/rock removal in the upper one foot of soil on the site
2. Amendment of the topsoil with compost
3. Grading and excavation of a rain garden and swale, which will retain runoff from the contributing drainage area and overflow to the Chevy Branch of Big Creek
4. Soil amendment in the rain garden and swale, consisting of a mix of compost, sand, and topsoil
5. Planting of the rain garden and swale with native plant plugs and broadcast seeding of the remaining portions of the site using a native grass and forb mix (Figure 6)
6. Installation of a permeable paver path on the site
7. Installation of signage with information on the Chevy Branch, native plants, and green infrastructure.

Figure 5. The case study location. Left photo shows the site post-demolition. Photo on the right shows an example of construction debris left after demolition.

Photos: William Shuster, EPA and Jennifer Olson, Tetra Tech

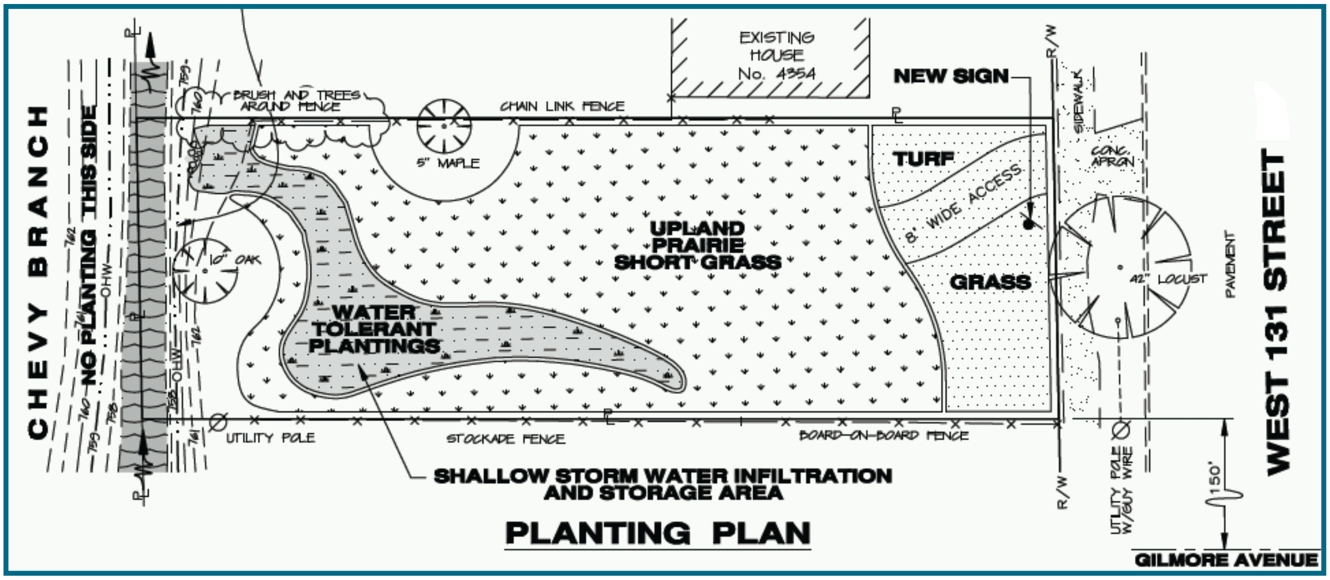

Figure 6. Planting plan for the case study site. Plan developed by Zwick Assoc., Inc., 2010.

The soil restoration and the establishment of vegetation improved infiltration in the areas of the site where demolition debris had been present and made the site more aesthetically pleasing for residents in the neighborhood. The infiltration area now stores and infiltrates stormwater runoff that does not soak into the ground on the upland areas of the site in larger storms; under certain circumstances, the green infrastructure can accept some high-water flows from the Chevy Branch. The vegetation and enhanced infiltration reduce stormwater discharges to the Chevy Branch during and after rain events and thus help to reduce localized flooding in the area.

6.2 Challenges and Lessons Learned

Restoration of vacant properties can pose many challenges. The West 131st Street site is an example of a vacant residential property where a structure (and related features such as a driveway) was demolished. Restoration of the site (following a period of project planning) was completed in less than a month. The BPDC, along with many local nonprofits, agencies, and organizations, as well as community members, provided input and support of the project.

Key challenges were created in large part due to the demolition practices implemented at the site. Stormwater infiltration is reduced due to the presence of the remaining structure of the basement. The incorporation of rubble and debris into the basement and within fill material reduced the infiltration capacity and ability of the existing soils to sustain plant life, and was the most expensive task to remediate during construction. Increased soil compaction was created while removing aboveground structures, which resulted in poor performing soils that could not establish vegetation prior to restoration.

The development and use of contract/bid specifications for demolition work that would take into account *green* reuses of the site could be an important step to facilitate green infrastructure and urban agriculture on vacant urban parcels. Such contract/bid specifications could potentially address:

- Deconstruction for reuse of materials;
- Consideration of air quality and dust issues during demolition;
- Proper removal and disposal of debris;
- Creating an infiltration pathway through any basement or foundation remaining onsite;
- Establishing vegetative cover to reduce erosion; and
- Minimizing compaction during demolition activities.

Demolition procedures that minimize compaction and minimize the amount of debris and rubble left on the site would have lessened the amount of work that need to be done at the case study site to make it ready for green infrastructure.

References and Resources

Brady, N. and R. Weil. 1999. *The Nature and Property of Soils*, 12th ed. Prentice-Hall Inc., Upper Saddle River, New Jersey.

Cleveland Botanical Garden. 2011. *Vacant Lot Stabilization: Cleveland Best Practices*. Final Report for the Lake Erie Protection Fund, SG 394-10. Geri Unger, Project Manager; Sandra Albro, Research Technician. November 2011.

Craul, P. 1994. Urban Soils: An Overview and Their Future. In *The Landscape Below Ground: Proceedings of an International Workshop on Tree Root Development in Urban Soils*, Morton Arboretum, Sept. 30–Oct. 1, 1993, pp. 115–125. Ed. G.W. Watson and D. Neely. International Society of Arboriculture.

Easterbrook, D. 1999. *Surface Processes and Landforms*, 2nd ed. Prentice-Hall Inc. Upper Saddle River, New Jersey. 546 pp.

Finster, M., K. Gray, and H. Binns, 2004. Lead Levels of Edibles Grown in Contaminated Residential Soils: A Field Survey. *Science of the Total Environment* 230: 245–257.

Foth, H. 1984. *Fundamentals of Soil Science*, 7th ed. John Wiley and Sons, New York.

Harris, R., D. Karlen, and D. Mulla. 1996. A Conceptual Framework for Assessment and Management of Soil Quality and Health. In *Methods for Assessing Soil Quality*, ed. J.W. Doran and A.J. Jones, pp. 61-82. Soil Science Society of America Special Publication 49. Soil Science Society of America, Madison, Wisconsin.

Holmgren, G., M. Meyer, R. Chaney, and R. Daniels. 1993. Cadmium, Lead, Copper, and Nickel in Agricultural Soils of the United States of America. *Journal of Environmental Quality* 22: 335–348.

ITRC (Interstate Technology and Regulatory Council). 2003. *Vapor Intrusion Issues at Brownfield Sites*. The Interstate Technology and Regulatory Council. December.

King County Department of Natural Resources. 1999. *The Relationship between Soil and Water How Soil Amendments and Compost Can Aid in Salmon Recovery*.

Koenig, R., and V. Isaman. 1997. *Topsoil Quality Guidelines for Landscaping*. AG/SO-02. Utah State University Cooperative Extension.

Murray, K., D. Rogers, and M. Kaufman. 2004. Heavy Metals in an Urban Watershed in Southeastern Michigan. *Journal of Environmental Quality* 33: 163–172.

NRCS (Natural Resources Conservation Service). 2000a. *Urban Soil Compaction*. Urban Technical Note No. 2. U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Quality Institute, Auburn, Alabama.

NRCS. 2000b. *Heavy Metal Soil Contamination*. Urban Technical Note No. 3. U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Quality Institute, Auburn, Alabama. September.

NRCS. 2010. *Glossary of Soil Science Terms*. Natural Resources Conservation Service.
https://www.soils.org/publications/soils-glossary

NRCS. 2011. Soil Quality – Improving How Your Soil Works. **http://soils.usda.gov/sqi/index.html**

Olson, Nicholas, John S. Gulliver (Department of Civil Engineering, University of Minnesota) and John L. Nieber (Department of Biosystems and Bioproducts Engineering, University of Minnesota), 2011. *Soil Remediation with Compost*. **http://stormwater.safl.umn.edu/content/updates-april-2011**

Pitt, R., J. Lantrip, R. Harrison, C. Henry, and D. Xue. 1999. *Infiltration through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity*. EPA/600/R-00/016. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Pouyat, R., I. Yesilonis,J. Russell-Anelli, and N. Neerchal. 2007. Soil Chemical and Physical Properties that Differentiate Urban Land-Use and Cover Types. *Journal of the Soil Science Society of America* 71: 1010–1019.

Rosen, C. 2002. *Lead in the Home Garden and Urban Soil Environment*. F-02543. University of Minnesota Extension.

Rossiter, D. 2007. Classification of Urban and Industrial Soils in the World Reference Base for Soil Resources. *Journal of Soils and Sediments* 7: 96-100.

SAN (Sustainable Agriculture Network). 2007. *Managing Cover Crops Profitably,* 3rd ed. Published by the Sustainable Agriculture Network with funding from the Sustainable Agriculture Research and Education Program. Beltsville, Maryland.

Scheyer, J., and K. Hipple. 2005. *Urban Soil Primer*. U.S. Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, Nebraska. **http://soils.usda.gov/use/urban/primer.html**.

Shuster W.D. et al. 2011. *Moving Beyond the Udorthent - A Proposed Protocol for Assessing Urban Soils to Service Data Needs for Contemporary Urban Ecosystem Management.* Soil Survey Horizons, Spring 2011, Volume 52 Number 1.

Stilwell, D., T. Rathier, C. Musante, and J. Ranciato, 2008. *Lead and Other Heavy Metals in Community Garden Soils in Connecticut.* Bulletin 1019. The Connecticut Agricultural Experiment Station, New Haven, Connecticut.

SWCS (Soil and Water Conservation Society). 2007. *Framework for Sustainable Soil Management*. Special Publication 2007-001. Prepared by John S. Kruse. Soil and Water Conservation Society. Ankeny, Iowa.

Urban, J. 2008. *Up by Roots: Healthy Soils and Trees in the Built Environment*. International Society of Arboriculture.

USDA (U.S. Department of Agriculture). 2006. *Urban Watershed Forestry Manual*. Part 3. *Urban Tree Planting Guide*. Prepared by the Center for Watershed Protection.

U.S. EPA (U.S. Environmental Protection Agency). 1997. *Innovative Uses of Compost: Bioremediation and Pollution Prevention*. EPA 530-F-97-042. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. EPA. 1998. *Sources of Lead in Soils: A Literature Review*. EPA747-R98-001a. U.S. Environmental Protection Agency, Washington, D.C.

U.S. EPA. 2001a. *A Citizen's Guide to Bioremediation*. EPA 542-F-01-001. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. EPA. 2001b. *A Citizen's Guide to Phytoremediation*. EPA 542-F-01-002. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. EPA. 2005. *Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup*, 4th ed. EPA-542-B-05-001. U.S. Environmental Protection Agency, Washington, D.C. September.

U.S. EPA. 2008a. *Design Principles for Stormwater Management on Compacted Contaminated Soils in Dense Urban Areas.* EPA-560-F-07-231. U.S. Environmental Protection Agency, Washington, D.C.

U.S. EPA. 2008b. *The Great Lakes Atlas*. U.S. Environmental Protection Agency, Washington, D.C. July 2008. **http://epa.gov/greatlakes/atlas/index.html**.

U.S. EPA. 2009. *How Does Your Garden Grow? Brownfields Redevelopment and Local Agriculture*. EPA-560-F-09-024. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response (5105T), Washington, D.C.

APPENDIX A
Evaluating Soil Suitability

Soil suitability evaluations vary depending on the end use of the site. For green infrastructure, testing should focus on the capacity of the soil to retain and infiltrate stormwater runoff and to support naturalized or ornamental vegetation. For urban agriculture, soil nutrient levels and the capacity of the soils to sustain certain crops are of greatest interest. Particle size distribution, infiltration capacity, nutrient content and soil chemistry are all factors that determine soil health and its ability to support plant life. Each of these are components of a sampling strategy to evaluate the existing conditions of the soil and what improvements may be necessary in order to implement the planned reuse of the site.

Soils Background

In assessing soils it is important to consider the physical, chemical, and biological conditions and characteristics of the soil.

Physical characteristics of urban soils that are relevant to *green* reuses of a site include soil texture, structure, permeability and porosity, and organic matter content. Physical characteristics can be observed and assess to help determine soil rehabilitation or reconditioning needs.

Soil Texture

Soil infiltration rate, which is heavily dependent upon the soil texture, is a critical factor when designing and constructing many stormwater practices. The USDA's Soil Texture Triangle (Figure A-1) illustrates soil textures and provides the relative sand, silt, and clay content for each soil class. Soils with extensive clay content slow the infiltration process, and facilities to be constructed on such soils must be appropriately evaluated and designed. When amending soil for a green infrastructure practice it is common to use a mix of topsoil, sand, and compost to have a soil condition conducive to plant growth and infiltration.

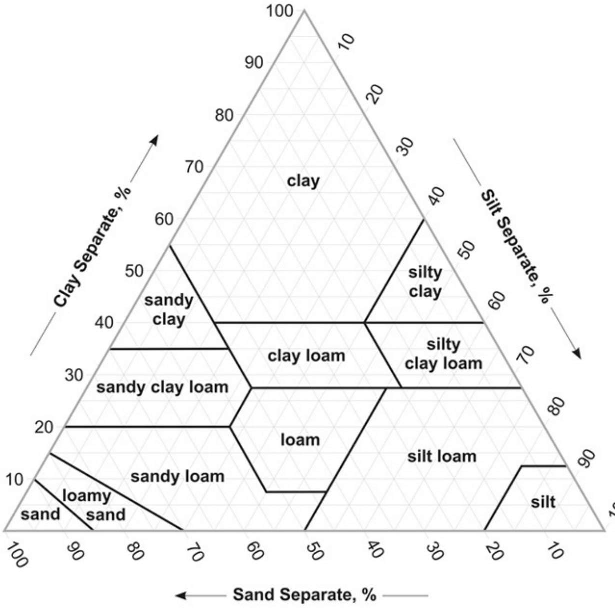

Figure A-1. USDA Soil Texture Triangle

Sandy Soil

Sandy soils can typically retain their structure and are less likely to have severe compaction and drainage-related problems. However, they typically have the lowest nutrient levels, and may need amendments to support dense vegetation. Sandy soils are not likely to retain high soluble contaminant concentrations, and they typically respond well to organic additions. Green infrastructure practices planned to infiltrate stormwater work particularly well on sandy soils, although pretreatment practices should be included to ensure the stormwater is free of trash and high sediment loads prior to infiltrating.

Loamy Soil

Loamy soils can be described as a mixture of sand, silt, and clay that exhibits properties of each in equal proportion. Loamy soils have historically been the most productive soil type for food crops. These soils are typically friable,[2] soft, and rich in organic material. The same features that make this soil so conducive to plant growth make it prone to compaction, and wind and water erosion. Drainage and infiltration rates in loamy soils vary based on silt and clay content. In uncompacted loamy soils, drainage is typically sufficient to ensure soil moisture conditions that are ideal for plant growth.

Clayey Soil

Clay is the smallest soil particle size, and because clay particles are flat, clay has "tremendous capacity to absorb water and other substances" (Brady and Weil 1999). Certain clays have the propensity to shrink when

---

[2] A friable substance can be easily crumbled or broken into smaller pieces.

dry and swell when wet. The small particles give clay cohesiveness and a unique ability to resist wind erosion; however, water erosion can be severe. Clayey soil is typically poorly drained, and is the easiest to compact by both human activity and natural phenomena. Establishing vegetation in clayey soils can often require aeration or soil amendments.

In the field, clay can easily be pressed into a ribbon between the fingers, and the length of ribbon created before it breaks can be used as a field assessment tool for determining clay content. If you create a small ball of moist soil in the palm of your hand and the soil does not retain the ball shape, the soil is silty, not clayey.

Soil Structure

Soil is made up of distinct horizontal layers; these layers are called horizons. Soil horizons in natural conditions include from rich, organic upper layers (humus and topsoil) to underlying rocky layers (subsoil, regolith and bedrock). Different soil horizons are important for various soil functions and processes.

Natural soils have a variety of structures depending on parent material, weathering, and biological factors. Soil particles arrange in aggregates with pore spaces between them that allow air and water to penetrate. In compacted soils, these areas (identified as “Soil Air” and “Soil Water” in Figure A-2) are reduced. Soil structure provides physical resiliency, as well as allowing moisture buffering and temperature insulation because of the air spaces in the soil matrix. Soil structure is preserved when protected from erosion, compaction, and other disturbing activities.

Soil structure tends to deteriorate during and after site development, a result of grading, filling, construction and demolition activities, and the absence of deep-rooted vegetation. Degraded soil structure results in compaction, decreased aeration, decreased drainage, decreased water-holding capacity, and decreased root penetration (Craul 1994), as well as reduced soil biological activity and reduced plant uptake of water and nutrients.

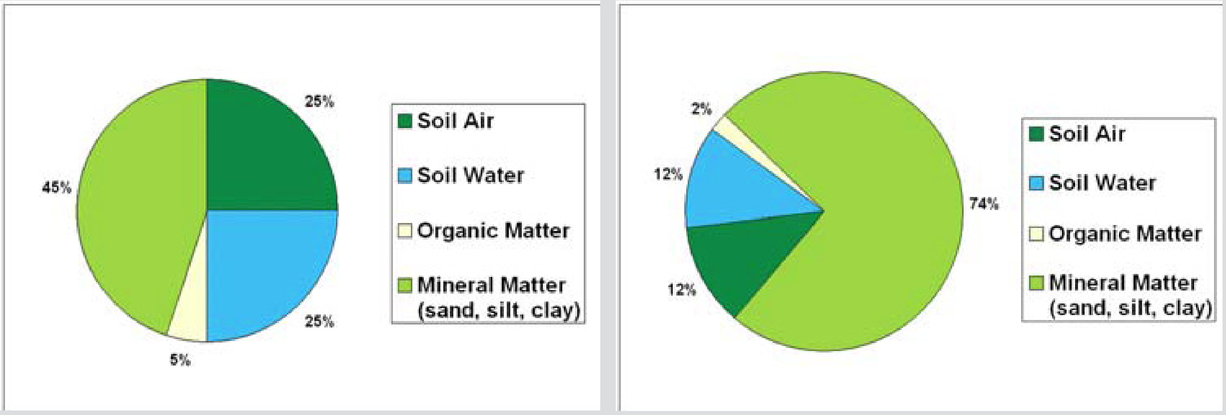

Figure A-2. Comparison of a natural soil (left) to a compacted urban soil (right) by weight (adapted from Scheyer et al. 2005).

Compaction occurs when heavy weight on a soil surface collapses the pore space between soil particles. It can be caused by pressure exerted by heavy equipment and vehicle traffic, tillage practices, water, or construction activities. Compacted soil becomes more dense, increasing heat transfer and resulting in soil temperature extremes. Temperature extremes result in unnaturally dry or oversaturated areas, and the ability of the soil to support plant life is diminished. Heavy compaction produced by construction, grading, and heavy or repetitive traffic, causes impervious layers that prevent water and air movement and results in root mortality. Heavily compacted soils can exhibit stormwater runoff characteristics that are comparable to those of impervious surfaces such as streets and parking lots.

Soil Moisture/Infiltration

Permeability is “the ease with which water passes through the soil,” and it “depends on the amount, size, and distribution of pore spaces in the soil” (Easterbrook 1999, p. 101). A sandy soil that is composed of rounded particles has a high permeability, whereas a clayey soil that is composed of flat particles has a low permeability, because water and air cannot move through clay easily. Porosity is the ratio of the volume of pore space to the total volume, (Easterbrook 1999, p. 531) or, a measure of the amount of pore space between particles. Fine-grained, uniform materials like clay tend to have higher porosities, while soils comprised of varying grain sizes have low porosity. Soil porosity tends to decrease with increasing depth due to compaction from the weight of overlying soils.

A soil with high porosity does not necessarily have high permeability. Permeability is dependent on the interconnectedness of pore spaces (Easterbrook 1999). Thus, a soil like clay, with a large volume of pore spaces that are not interconnected, has high porosity but low permeability, and water and air have limited opportunity for movement within the clay. A sandy soil can have a high permeability but less porosity, allowing for drainage, but limiting the moisture retained in the soil profile. Soil remediation efforts and plant selection should take into account the porosity and permeability of existing soils.

Soil moisture content is an important factor when considering green infrastructure or urban agriculture. The best time to observe soil water movement over the entire project site is immediately after a soaking thunderstorm or during snowmelt when the ground is thawed. Results should be recorded over several hours and days and should include the time when the soil surface starts to dry and whether standing water is still in the root zone (depth of 12 to 18 inches). Long dry periods later in the spring and summer are perfect for observing soil water retention and unusual saturation areas such as those caused by clogged drainage systems, leaking subterranean pipes, springs, and other unusual soil features.

Once general soil characteristics have been determined, simple tests can be performed to further test the soil for supporting vegetation. As a simple screening-level assessment, one can dig into the soil about six inches, grab a handful of soil, and squeeze. If the soil remains in a "ball" and a wet outline of water appears, it is considered very moist. If the "ball" breaks apart but remains in large clumps, the soil is moist. (Note that this assessment does not work for very sandy soils.) Because the root zone soil will most likely be amended or manipulated, it is useful to see if water can leave the root zone within a suitable time. To evaluate this, one can dig a 12- to 18-inch-deep hole and fill it with three inches of water. If the water drains within 15 to 20 minutes, the soil is suitable for most plants and root crops; if it takes between one-half and eight hours to drain, the soil is suitable for most general woody and grass species; if water is still present after eight hours, drainage modification is probably necessary for all but wetland vegetation.

Soil Chemistry

Soil chemistry is an important factor regardless of the intended use of a site. Soil chemistry is particularly important for the growth of food products. Soil should be tested at sites that will be used for urban agriculture.

Soil chemical characteristics are a function of soil reactions with nutrients, contaminants, air, and water, and they are greatly dependent on temperature and biological activity. Interactions are complex, but for green infrastructure purposes, knowledge of the presence and quantities of nutrients and contaminants, and the soil pH will allow you to gauge the soil's ability to serve as a growing medium. All chemical soil chemical reactions require water, and many are influenced by oxygen and other air components.

Standard test parameters usually include soil pH, potassium, phosphorus, and lime index (calcium and magnesium), and cation exchange capacity (CEC), which is a gauge of soil's potential nutrient holding capacity. Widely offered tests also include nitrogen (total nitrogen, nitrate, and ammonium), heavy metals (aluminum, arsenic, cadmium, lead, and mercury), salinity, and micronutrient tests that vary by locale.

Because plants take up only nutrients that are dissolved in the soil solution and are in contact with the root surface, plant nutrient availability is largely controlled by pH. pH is a measure of the acidity or alkalinity of a substance (see Figure A-3). In soils, a high pH can prevent chemicals from entering a plant, and low pH (a more acidic soil) can result in certain elements concentrating in the soil (Urban 2008, p. 64). The optimal soil pH range is between 6.0 and 7.5 standard units. Most native soils around the Great Lakes have

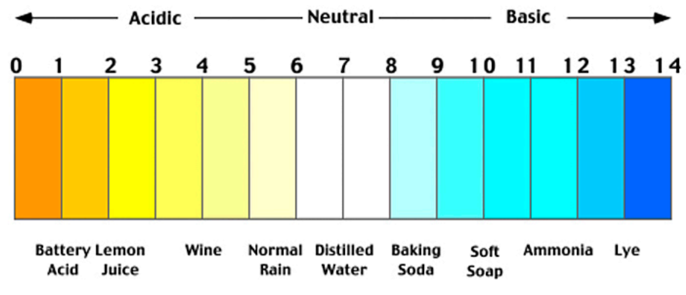

Figure A-3. pH scale.

a pH in the range of 6.0 to 8.0 standard units. This pH range is where most plants and soil microorganisms thrive. Great Lakes soils also have a large buffering capacity, or ability to withstand a rapid change in pH, due to generally high natural amounts of silt, clay, or organic matter in the soils. In urban areas, concrete and masonry construction may have leached lime into the soil, increasing the soil pH (Urban 2008, p. 63).

Local soil testing lab information can be obtained from State Cooperative Extension Service offices and from many land grant universities. The University of Massachusetts at Amherst[2] also performs a series of soil tests to help determine the suitability of site soils for green infrastructure or urban agriculture. For green infrastructure, such tests might include the University's *Soil Texture* test, which provides the USDA Textural Classification. Various soil tests that provide pH, nutrients, or metals data can be used to determine the suitability of urban agriculture. Soil tests that cover standard test parameters typically cost $25 to $30.

Note again the while focus of this report is on assessing and reconditioning soils so they can effectively support plant growth, assessing soils for possible contamination issues is also very important. There can be health risks associated with touching and tilling contaminated soil, and for urban agriculture sites, there can be risks from eating food products grown in contaminated soils. Root vegetables may require more attention and concern than aboveground, fruiting plants or woody perennial crops because of the potential for uptake and increased soil interaction by gardeners. Check the site history and where appropriate seek assistance from State or local Brownfield authorities as you evaluate a site for green infrastructure or urban agriculture uses.

Biological Characteristics

The biological characteristics of urban soils vary based on factors such as drainage, land use, and contamination. During a site visit, the growing condition of the soil can be determined based on the status and species of the plants growing on it; plants should be observed and their condition recorded. Existing large trees "are often the best long-term indicators of soil condition" (Urban 2008). Various plant species can also indicate soil conditions. Plant species vary regionally, and local professionals should be contacted to determine what various species might indicate about the soils.

Soil organic matter is derived from decomposed plant leaves and other carbonaceous materials on the ground surface. The amount of organic matter that accumulates is influenced by temperature and moisture (Urban 2008). Organic matter levels generally vary by soil type: forest soils typically contain 4 to 5 percent organic matter; agricultural soils can contain up to 15 percent organic matter (Craul 1994); and horticulturally productive soils can contain around 3 to 4 percent organic matter (Urban 2008). Soils that are well watered and have high plant productivity generate higher levels of soil organic matter (Brady and Weil 1999). Colder climates also inhibit rapid decomposition and allow organic matter to accumulate faster.

The natural processes that generate soil organic matter are often interrupted in an urban environment (Craul 1994). Various aspects of the urban environment (e.g., pavement, bagging leaves/grass clippings, removal of tree branches) prevent the cycling of organic matter and nutrients back into the soil. Without decay of plant materials, microorganisms in the soil cannot persist. Therefore, the restoration of urban soils (to make them more suitable for green infrastructure and urban agriculture) often involves increasing the amount of soil organic matter.

On sites with no or little vegetation, soil odors can also indicate biological activity. If soil has little or no odor, microbial activity is poor or absent, and the amount of organic matter is often low. If soil has an "earthy" odor, microbial activity is good and aerated organic matter is present in the soil. Soil with a putrid or sour odor either has been wet for a long time or has had improperly processed compost applied.

The presence of earthworms in a soil is a sign of good soil conditions, but if the earthworms are skinny or anemic-looking, the soil might lack good nutrition and be low in organic matter. Lack of earthworms is a fair indicator of compaction; in the case of friable soils, this condition can indicate heavy metal or chemical contamination or extremely low organic matter content.

---

[2] Refer to the University of Massachusetts at Amherst website: **http://www.umass.edu/soiltest/index.htm**.