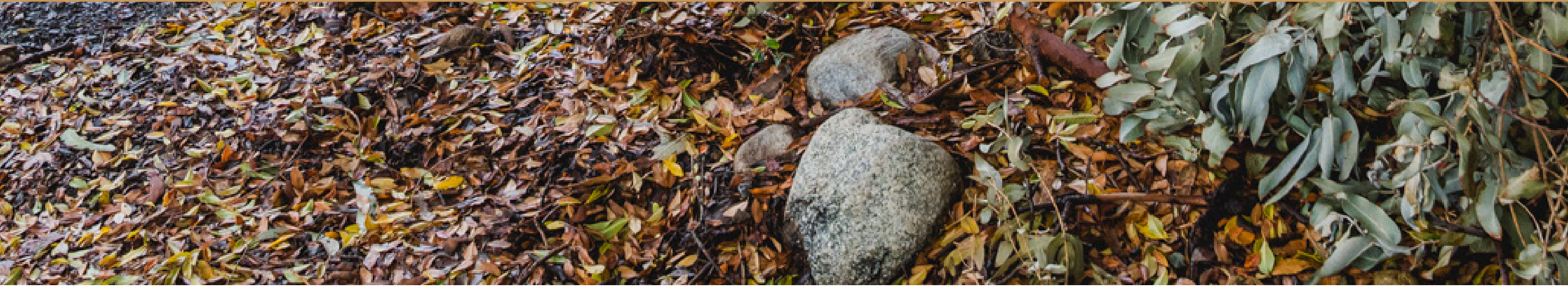
Urban Soil Management for Climate Resilience

A Guide for Adopting Best Practices from TreePeople and ARLA

March 2023



TreePeople ARLA

Authors

Dustin L. Herrmann, Ph.D., TreePeople
Mary Hillemeier, MPH, MSW, TreePeople
Richard V. Pouyat, Ph.D., Chesapeake Bay Consulting and Emeritus, US Forest Service
Susan D. Day, Ph.D., University of British Columbia
Yujuan Chen, Ph.D., Tennessee State University
Lia Soorenian, MS, TreePeople

Graphic Design

Bliss Parsons, MFA, TreePeople
Cez Cruz, TreePeople

Photography

Adam Corey Thomas, TreePeople

Recommended Citation

Herrmann, Dustin et al. *Urban Soil Management for Climate Resilience: A Guide for Adopting Best Practices from TreePeople and ARLA.* TreePeople. 2023.

Funding Agency

Accelerate Resilience L.A. (ARLA),
a sponsored project of Rockefeller Philanthropy Advisors

ARLA

TreePeople
12601 Mulholland Drive | Los Angeles, CA 90210
treepeople.org

Table of Contents

Ode to Dirt

Dear dirt, I am sorry I slighted you,
I thought that you were only the background
for the leading characters—the plants
and animals and human animals.
It's as if I had loved only the stars
and not the sky which gave them space
in which to shine. Subtle, various,
sensitive, you are the skin of our terrain,
you're our democracy. When I understood
I had never honored you as a living
equal, I was ashamed of myself,
as if I had not recognized
a character who looked so different from me,
but now I can see us all, made of the
same basic materials—
cousins of that first exploding from nothing—
in our intricate equation together. O dirt,
help us find ways to serve your life,
you who have brought us forth, and fed us,
and who at the end will take us in
and rotate with us, and wobble, and orbit.

—Sharon Olds

Prologue

Our health and well-being in urban southern California are beset by an array of environmental threats and challenges being amplified by the unfolding climate crisis. We must increasingly turn to nature-based solutions to address these threats and challenges while creating healthy and resilient communities for all. The soil beneath our feet is perhaps the essential resource in realizing the potential of nature-based solutions for our neighborhoods, our region, and the planet.

Importantly, individuals and communities in Los Angeles and elsewhere have identified soil as a resource they want to better use towards improving their well-being. To realize its full potential, urban soils require management to both redress the legacies of urban development that impair soil health and function and to steward soils to achieve the ambitious goals we have for our urban ecosystems. Building climate resilience on a foundation of healthy soils requires implementing ensembles of urban soil best management practices that will help generate healthy, just, and climate resilient communities.

This document is intended for individuals, communities, and municipalities to be a resource for understanding and communicating the potential of urban soils to build climate resilience and a toolkit for identifying and implementing best management practices for realizing that potential. The capacity of our manifold urban systems–water, waste, energy, forests, among others–are all greater and their sustainability and resilience bolstered through the implementation of best management practices for soils in urban landscapes.

1. Securing abundance through climate resilience

The Earth has ample water and land, with a climate perfect for the two to work together to create an abundance of life. Humans have built flourishing societies with this abundance as it is the basis of our health and well-being. While the Earth's abundance is not fragile, it can be compromised and greatly diminished. Therefore, it is our responsibility to steward and share Earth's abundance with human and non-human life and with current and future generations.

Unsustainable modes of urbanization and economic enterprise have degraded Earth's abundance. Notable and substantive consequences of our poor stewardship are climate change and biodiversity loss. Climate change and the diminished capacity of Earth's ecological systems are now themselves threats to the resilience of Earth's abundance and flourishing societies.

Climate change is a slow-moving phenomenon, but it is picking up speed. Rising levels of atmospheric greenhouse gases are direct mechanisms of climate change, trapping more of the sun's energy in the Earth's atmosphere causing shifts in climate patterns. Globally, consequences of climate change are realized as mean temperatures increasing, sea levels rising, and terrestrial systems becoming more arid. In southern California, average temperatures have risen 3 degrees Fahrenheit (F) in the last century and another 6 degrees F rise is projected for the 21st century (California's Fourth Climate Change Assessment). Sea level rise is also accelerating on the U.S. West Coast shifting from about an inch of rise every decade in the 20th century to about an inch of rise every three years expected over the next few decades (Sweet et al. 2022). Drought conditions have persisted over much of the 21st century in California and are likely to continue (MacDonald et al. 2016). Even if 20th century levels of rain and snow return, warmer temperatures mean more arid conditions are locked in (Cook et al. 2004).

The consequences of climate change are two-fold. Climate change strains the natural resource systems that support us and generates more extreme weather events. In California, enduring drought conditions and increased aridity have reduced our water resources and degraded ecosystems through hotter, drier environmental conditions. The rise in average temperatures will be increasingly experienced as more frequent extreme heat events of greater duration and intensity (Argüeso et al. 2016). Perhaps surprising to many familiar with the mild climate coasts and hot, dry inlands of California, it is the temperature buffering effects near the coast that are most threatened. Coastal southern California specifically is anticipated to experience the most substantial warming across all of California with greater humidity and higher nighttime temperatures coupled with more extreme heat events (Gershunov and Guirguis 2012). Warmer temperatures can affect already strained water resources. Continued human demand for water resources exacerbates persistent drought conditions (Wada et al. 2013) by driving greater consumption (Rasifaghihi, Li, and Haghighat 2020) and greater evaporative losses of surface and soil water (Pan et al. 2015).

The same unsustainable modes of urbanization and economic enterprise that drive climate change have also created social injustices. Neighborhoods with white or wealthy-skewed demographics, for instance, have greater tree canopy than neighborhoods with greater populations of people of color or lower income households (Schwarz et al. 2015). The case is extreme in Los Angeles. Five neighborhoods (i.e., Census block groups) in the Pacific Palisades, Los Feliz, Brentwood, and Shadow Hills contain 18% of the total urban tree canopy in the City of Los Angeles despite only being home to 1% of the city's population (Galvin et al. 2019). At the other extreme, some neighborhoods in Los Angeles have as little as 1% tree canopy coverage compared to the citywide total of 25% (Galvin et al. 2019). Communities of color and low-income communities also have more proximity and exposure to environmental hazards (Bullard 2018). In Los Angeles, the dramatic case of Exide, a lead-battery recycling company with operations next to predominantly Latino neighborhoods, was permitted to pollute heavy metal emissions leaving a legacy of air and soil pollution (Johnston and Hricko 2017). Collectively, environmental benefits and hazards are unequally distributed in the urban landscape. In Los Angeles, neighborhoods with a paucity of tree canopy and soils that are a public health hazard combine with the broader issues of racism and poverty challenges to make the threats and challenges of climate change much greater to these communities. Building climate resilience, therefore, requires addressing social injustice.

The threats and challenges created by climate change bring insecurity to our realizing Earth's abundance sustainably and justly. Climate change is a wicked problem for society in that it is a complex issue with no easy or straightforward solutions (Rittel and Webber 1973). The wicked problem of climate change, broadly framed, is:

> ***We must ensure human health and well-being through extreme weather events while improving our natural resources to continually provide critical ecosystem functioning in the face of on-going and accelerating climate-related stressors.***

However, rather than problematizing the situation, building climate resilience to secure our abundance can be framed as a wicked opportunity. Climate change is a wicked opportunity to spur innovation and bring about major shifts in how we manage our ecosystems and natural resources. It is an opportunity to pursue nature-based solutions that redress injustices in our urban landscapes and create desirable futures of abundance.

2. Building climate resilience through nature-based solutions

As climate changes, society must adapt in response and in anticipation of future change. Water resources are perhaps the biggest challenge related to climate change and resilience in California. Drought has loomed large in recent California history as a mix of water use consumption pressures–economic, environmental, and basic human needs in nature–have leveraged water supplies beyond supply capacity in increasingly common dry years. Importantly, constraints in water supplies have led to system changes in California (Lund et al. 2018). For example, urban water use in California has declined since the 1990s even as the human population has increased by one-third (Mount and Hanak 2019). Similarly, agricultural water users have increased economic output over the same period while cutting water consumption (Mount and Hanak 2019).

While efficiency in resource use can reduce the strain on systems, it is not sufficient for building climate resilience. Droughts in the last decade in California, unlike those in the 20th Century, revealed cities and nature are at the edge of their capacity for resilience. Forest ecosystems are vulnerable to drier, hotter conditions. Millions of forest trees in the Central and Southern Sierra Nevada died from the near persistent drought conditions of the 2010s as soil moisture was depleted deep into the soil and unable to buffer against heat stress (Daley 2019; Goulden and Bales 2019). Tree mortality from climate change stress is also found in the urban forest. A major drought in east Texas, where dry conditions are not as common historically as in California, increased annual tree mortality ten-fold (National Integrated Drought Information System 2019). In Los Angeles, total tree canopy cover has remained largely the same through recent droughts (Locke et al. 2017) despite major efforts by tree planting organizations and at all levels of government to increase tree canopy (e.g., Million Trees LA, McPherson 2014). Drought stress, land use requirements stipulating less green space for redeveloped private parcels, and pest infestations have offset the gains tree planting campaigns have realized ("LA Is Losing Its Trees" 2019; Lee et al. 2017). Perhaps understandably, after decades of reducing and restricting water use and witnessing drought-stressed urban vegetation in their neighborhoods, residents of California have diminished capacity to further cut water use in the present drought, with many urban water users in practice having an appetite for more water (Becker 2022).

Instead of focusing on ever greater efficiency from existing systems, building climate resilience requires investing in nature-based infrastructure for solutions to the challenges of climate change and inequality.

> ***Nature-based solutions integrate natural processes into cities that have the capacity to both protect people and the urban environment from the impacts of climate change and facilitate adaptation to changes.***

They can be integrated into urban landscapes in numerous ways, such as trees and forests, grass- and shrublands, wetlands, agriculture (especially as community gardens with agroecology operations), and green rooftops, among others. Importantly, nature-based solutions, more so than traditionally engineered infrastructure strategies for building climate resilience, create more inviting urban landscapes and provide many more community benefits. The benefits of nature-based solutions, some of which unfold in the short term and others gradually over time, include enhancing or improving water quality, water conservation, flood protection, increasing water supplies, carbon sequestration, greenhouse gas (GHG) emissions reduction, increased biodiversity, and enhanced community health and well-being. Importantly, they are intended to adapt and change over time, increasing in their contributions to our abundance rather than declining in performance over time like most traditional engineered infrastructure. In this way, nature-based solutions provide pathways to resilience and mechanisms for creating abundance within urban ecosystems.

3. Soil health as the linchpin of nature-based solutions

As the foundation of ecosystem functioning, healthy urban soils are critical to climate resilience as the linchpin of nature-based solutions. An urban soil can be considered healthy if it supports or provides desired goals through its contributions to ecosystem structure and function. These goals might include supporting plant communities, regulating the water cycle, filtering and buffering potential pollutants, cycling nutrients, physically supporting infrastructure, and promoting biodiversity. We cannot always directly assess whether our actual goals are being realized. Instead, we can evaluate readily measured proxies that can indicate how soils are doing. Indicators of urban soil health include presence of vegetation representative of native plant communities; suitable physical, chemical, and biological characteristics; ability to support a biologically complex group of plants with minimal intervention; land-use history indicating minimal disturbance from scraping, construction, dumping/contamination or industry; or a history of sustainable soil management/restoration after a disturbance. Thoughtfully selected soil management practices relevant to a given context are key to maintaining and restoring soil health in the urban environment.

Historically, cities have failed to sustainably manage the health of their soil, resulting in vast untapped potential of soils for provisioning an array of ecosystem services for communities. Los Angeles is no exception. Forty-four percent of the land in Los Angeles County is bare soil, and thus a prime candidate for best management practices and restoration efforts (Chen et al., 2021). Additionally, Los Angeles residents are thinking about soil health and looking for strategies to leverage soils for their nature-based solutions needs. A needs assessment conducted in 2021 found that Los Angeles residents care deeply about the health of their soil, and pollutants and soil contamination are a key concern (Chen et al., 2021). Residents, educators, policymakers, and soil-related professionals all expressed a desire to learn about urban soils and take action to improve soil health (Chen et al., 2021).

> ***An important next step in leveraging soils as a key nature-based solution is sharing information about how to adopt Best Management Practices (or BMPs) for enhancing and restoring soil functions in urban landscapes.***

This report functions as a toolkit to support individuals, communities, and municipalities in facilitating understanding, communication, and action about healthy urban soils by identifying BMPs for addressing soil issues relevant to urban landscapes. In the face of on-going threats, limits, and challenges to harnessing the potential of urban soil systems, the knowledge and guidance to drive urban soil development and sustainable ecosystem functioning are critical. The resources herein provide readers with foundational knowledge about urban soil health, best management practices for urban soils, and frameworks for the selection and management of those practices in service of generating healthy urban soils for generating climate resilience through nature-based solutions.

4. Five ways urban soils build climate resilience for cities

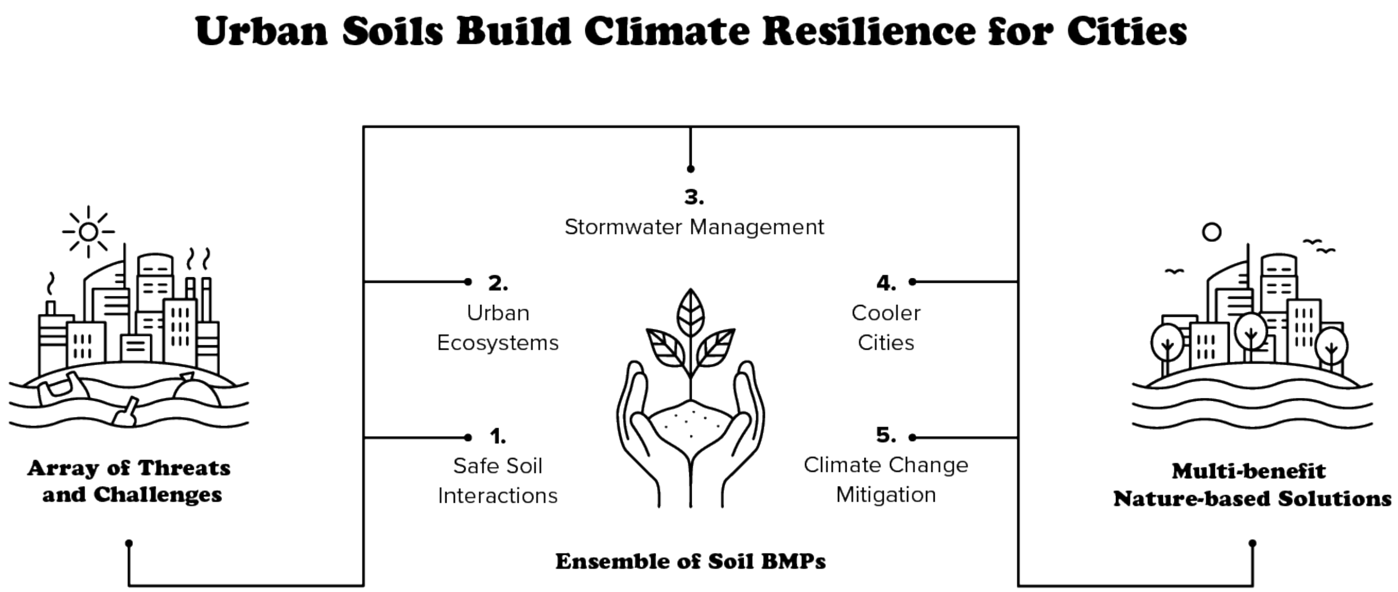


Figure 1. *Ensembles of soil BMPs can address an array of threats and challenges to support multi-benefit nature-based solutions and build climate resilience.*

When best management practices are implemented, urban soils help us create climate resilient cities. There are five critical areas where soil BMPs can contribute to climate resilience.

1. Resilience through safe interactions with soil

Enabling safe community interactions with soil is a critical foundation for public health and well-being. The complex causes of urban soil contamination include legacy pollution, land use, land management, and climate change impacts. Contaminated soils contain substances that endanger human and environmental health including lead, pesticide residues, petroleum products, and asbestos. Managing urban soils for resilience in the face of these challenges requires addressing soil contamination to safeguard public health in the short term and managing and conserving soil health in the long term. Soil best management practices represent a long-term investment in nature-based solutions with the power to transform urban soils from a vulnerability to a source of Earth's abundance. Healthy urban soils support thriving green spaces where residents can exercise, play, garden, stay cool, conserve natural resources, recycle organic waste, and use water resources sustainably and effectively.

2. Resilience through robust and adaptive urban ecosystems in which trees and nature thrive

Urban ecosystems contain soils, waterways, airways, human, animal, and plant life that are interdependent; the health of one element impacts the whole. Just as history has shown that the waste and degradation of natural resources leads to scarcity and vulnerability, nature-based solutions in urban ecosystems demonstrate that conservation and regeneration are pathways to abundance. When supported by clean air and water, biodiversity, and residents utilizing best management practices, urban landscapes can thrive and deliver long-term climate and public health benefits. Healthy urban forests and green spaces provide shade and cool our cities through evapotranspiration, reducing energy demand. Healthy soils and greenspaces enhance carbon sequestration, improve air and water quality, and protect water supplies through stormwater runoff management. In addition, benefits such as improved wildlife habitat, enhanced community cohesion, and improved human health and well-being are critical benefits of these nature-based solutions (de Guzman et al., 2020).

3. Resilience through management of stormwater for cleaner, more abundant water resources and reduced risk

During extreme weather events, exemplified in the recurring cycles of drought and floods experienced in Los Angeles, urban soil infrastructure plays a key role in regenerative stormwater management. Healthy urban soils hold the potential to capture, store, and filter stormwater, water-efficient characteristics that can replenish green spaces and buffer adverse climate impacts. Soils can also filter contaminants that could otherwise harm the health of beaches, oceans, marine life and humans. When urban soils are managed for optimal health and function, they represent an integrated stormwater management system that both builds resilience to climate-related challenges and reduces risk from adverse impacts on public and environmental health.

4. Resilience through cooler cities

Healthy urban soils lay the foundation for thriving trees and the cooling shade they provide, making cities safer and more resilient for all residents in the years to come. Urban infrastructure like buildings and roads absorb and re-emit heat, causing the "urban heat island effect" and making city residents more vulnerable to climate change. Extreme heat events are slated to occur more frequently on our current trajectory, with some Los Angeles cities projected to experience 5 or 6 times the number of extreme heat days compared to the present by midcentury (Hall, 2013). In a changing climate, public health hinges on effective urban cooling strategies, especially in the case of vulnerable communities that are disproportionately impacted by extreme heat such as low-income populations and communities of color (Jesdale et. al, 2013). Expanding tree cover is a proven cooling strategy that can make our cities more equitable and resilient in a changing climate. Tree cover provides shading and evapotranspiration, reduced energy demand, and carbon sequestration (de Guzman et al., 2020).

5. Resilience through global climate change mitigation

Cities are hubs of human activity that through their use of fossil fuels for transportation, heating, cooling, and embodied in production of its resources are also sources of the greenhouse gases that drive climate change. Healthy soils, by supporting the establishment and performance of nature-based solutions, can support urban design that prioritizes the safety, comfort, and dignity of mobility without using personal cars. Further, by cooling the city, we can reduce energy demand for air conditioning. By reducing these heavy demands on our energy portfolio, Los Angeles can meet its energy needs without greenhouse gas emissions. Further, healthy urban soils and urban forests can lead to substantive sequestration of atmospheric carbon dioxide, drawing down this greenhouse gas as we eliminate carbon emissions that are driving its buildup. By being a part of global strategy, urban soils can contribute to mitigating the worst scenarios of climate change which makes local climate adaptation a less steep hill to climb.

5. Fundamentals of urban soils

Before discussing the use of urban soil BMPs and their implementation, we provide a brief primer on urban soils in our urban ecosystems.

What is urban soil?

Urban soils are those found within cities or towns, thus largely associated with built environments and in areas with high human population density. Often, soils in urbanized landscapes have been significantly altered by urbanization (development and redevelopment processes) and on-going human activities (Herrmann et al. 2017, 2018, & 2020). As such, they often contain human-transported or human-altered materials and tend to display a wide variety of properties and conditions (Craul, 1992; Pouyat et al. 2020; Zemlyanitskiy, 1963). Urban soils can also be relatively undisturbed by heavy equipment yet altered by urban environmental changes, such as the urban heat island effect or inputs of pollutants (Pouyat et al. 2010). Even with these alterations, urban soils have the potential to support important ecosystem functions, including climate regulation, stormwater management, and biodiversity support, among others. As such, understanding and caring for the health of urban soils and implementing specific management practices that enhance this functioning is paramount in the development of resilient and sustainable cities under a changing climate (Chen et al., 2021; LA Sanitation & Environment, 2021).

Urban landscapes contain a range of soil conditions

Soil conditions in urban areas generally correspond to anthropogenic impacts. Urbanization can impact soils directly through disturbance (e.g., trampling) and management (e.g., irrigation) and indirectly via changes in the environment (e.g., increased pollution or the urban heat island effect) (Pouyat et al., 2010). Soils may be scraped and compacted during land development or contaminated from industrial activity. Historic organic inputs from vegetation that help soils stay healthy may be disrupted, while new organic materials (composts and other "waste" products) may be generated and distributed. Highly impacted urban soils can be disturbed, contain human-transported materials, and sealed by impervious surfaces like asphalt or concrete (Scalenghe and Marsan 2009). Whereas relatively undisturbed soils that are impacted by environmental changes also may occur in urban landscapes, such as remnant forests or grasslands (Pouyat et al. 2010). Herein we are focused on those soils disturbed by urbanization such that they are not able to provide desired support for the social-ecological system.

Urban soil as a habitat for organisms

Recognizing that the biological functions of soil cannot be separated from other soil properties is key to harnessing the potential of soil in the urban context. Soil is a living system, and organic matter is the fundamental food for soil life. The community of organisms living in urban soil are a unique combination of native species surviving or thriving in the urban landscape and species introduced from other regions, or even continents. Urban centers are typically hubs for receiving horticultural products, food, and wood packaging material from other regions of the globe, and thus are entry points for many non-native species, including those living in soil. Management practices also contribute to the uniqueness of urban soil communities. For instance, yard maintenance, such as irrigation practices, can help soil organisms overcome water limitations, while pesticides can eliminate non-target species (Szlavecz et al., 2018). The sealing (i.e., the use of impervious surface materials) of urban soil by asphalt or concrete can limit many soil organisms, although some organisms, such as earthworms and ants, can survive under impervious surfaces (Youngsteadt and others 2015). Yard maintenance, such as removal of leaf litter, deprives many soil organisms of shelter and food resources, while composting and mulching create new ones.

The role of urban soils in urban ecosystems

Despite the high levels of disturbance typically experienced by urban soils, they, like their rural counterparts, have the potential to support plant, animal, and microbial organisms and mediate hydrological (water) and biogeochemical (nutrient and carbon) cycles (Pouyat and others 2010). Additionally, soils play other critical functions that are unique to urban landscapes. For example, they provide a stable base for built structures such as buildings and roads, as well as providing physical support for underground utilities. Furthermore, urban soils may serve roles in processing waste, whether from septic systems or food and yard waste recycling programs.
Urban soils can be thought of as infrastructure supporting our urban ecological systems, i.e., our urban greenspaces (Pouyat et al. (2010). The ability of greenspace in cities to provide critical ecosystem services, such as water infiltration and storage, carbon storage, and recreation, is dependent on the underlying soil condition and its health. Similarly, as mentioned above, soils are vital as the foundation for traditional engineered infrastructure within cities, i.e., roads and buildings. Therefore, soils deserve recognition and support for the essential ecosystem services they provide within developed landscapes.

Mitigating climate change impacts

Global environmental change factors such as increased temperatures, altered precipitation patterns, and invasive species spread are currently affecting terrestrial ecosystems worldwide. Soils, including in urban contexts, have the potential to buffer the consequences of global change by maintaining biogeochemical cycles that provide water and nutrients for plant health and growth.

Forests and native grasslands are essential for global and regional water cycles due to their high capacity to store and redistribute water. Evapotranspiration by forest trees is an important cooling mechanism that can alleviate warming temperatures from urbanization and global climate change (e.g., Bowler et al. 2010). In urban forests, this essential ecosystem service is, however, dependent on tree condition and soil moisture status. Soil moisture status, in turn, is based on the condition of the soil, which in urban areas is often poor due to compaction and the lack of organic matter and soil organism activity, meaning it is unable to infiltrate and store rainwater. Under such conditions, management interventions are necessary to restore water infiltration and the water holding capacity of the soil.

The importance of soils in mitigating climate change via carbon storage and sequestration has received a great deal of attention, and awareness of the potential of urban soil to mitigate global change via carbon storage is gaining ground (e.g., Pouyat et al. 2006, Ziter and Turner 2018). The carbon storage and sequestration potential of urban soils varies across urban landscapes as various urban related impacts can increase or decrease urban soil carbon (Pouyat et al. 2006; Trammell et al. 2018). For example, the urban heat island effect can potentially enhance plant productivity (e.g., Neil and Wu 2006, Ziska et al. 2004), increasing organic matter in the soil. However, the heat island effect can also enhance decomposition rates, thus trace gas emissions, offsetting the effect of greater plant productivity on soil carbon storage (Pouyat and Trammell, 2019). Biotic factors, such as invasive plants, can also affect the rates of organic matter inputs to soil and soil microbial activity. For example, non-native invasive plants dampen soil carbon storage in forests adjacent to urban interstates (Trammell and Carreiro 2012). Whether urban soils store and sequester significant amounts of carbon will depend on many factors that impact plant productivity relative to soil microbial activity in urban forests (Trammell et al. 2018). Soil management strategies need to take these factors into consideration under urban conditions.

6. Implementing urban soil best management practices

Given the array of threats and challenges our urban soils and ecosystems face, practitioners need ensembles of best management practices in their toolkit. To specify, an urban soil best management practice (BMP) is a practice that is determined to be an effective and practical means of promoting urban soil health. BMPs can be either short or long-term in realizing their impact, and they are designed to be cost efficient and as simple as possible while being effective and environmentally sound. As noted above, soil is part of a living system that requires actions and time to realize intended outcomes. Practitioners should approach urban soil management as guiding a living process intended to influence naturally occurring soil building processes that over time will yield more healthy soils that have greater resilience to climate change and urban impacts.

Indeed, urban soils can significantly improve and provide valuable climate resilience benefits when BMPs are selected, applied, and managed through a holistic, iterative process. Here, we present a set of resources or tools for soil practitioners, communities, and municipalities to utilize BMPs in service of optimizing urban soil health. These include 1) an adaptive loop for situating urban soil BMP use iteratively into governance systems, 2) a decision matrix to guide users to categories of BMPs based on their goals, and 3) an orientation with the categories of urban soil BMPs such that practitioners can confidently seek out specific BMP protocols. Links to additional resources, including more extensive soil BMP inventories, can be found in the reference section.

Adaptive Loop for Building Resilience through Urban Soils

How can we transform the way we approach urban soils and use the opportunity soils present to build resilience in our cities? Implementation of BMPs is essential, but the process of integrating these into our governance systems requires a systematic approach. The Adaptive Loop offers a strategy for transforming urban soil management in an iterative, constructive approach (Fig. 2). The Adaptive Loop instigates a process that adapts to the current situation with each iteration and offers multiple touchpoints with governance and policy. First, we use our community needs assessment and understanding of societal needs, especially those tied to climate change, to develop objectives **(Set Goals)**. Then, at the community level, existing site and soil conditions are assessed to understand gaps where soil health is impeding our ability to meet these objectives and where there are opportunities (bare soil, for example) to use BMPs **(Learn)**. Then, using the Ensemble of BMPs and the decision matrix (see below, Fig. 3), we can decide what BMPs will best meet community needs **(Decide)**. This is a key touchpoint with policy. Soil BMPs address multiple objectives and community needs to build climate change resilience (for example, mitigate stormwater and support better root systems that can withstand drought). Existing guidelines and policies may benefit from BMP inclusion. When BMPs are implemented in initial stages, demonstration projects and other high visibility learning spaces can be emphasized **(Implement)**. Subsequent iterations may see BMPs implemented more broadly as the path forward and successes become more clearly identified. And finally, BMPs are monitored to ascertain how they are meeting objectives as well as working through any barriers and celebrating successes **(Monitor)**. Then the loop begins again by reassessing objectives and possibilities. In this fashion, BMPs become a part of the urban fabric and the accepted way of "doing business," leading to more climate resilience through healthy soils. This Adaptive Loop works equally well at site and city-wide scales.

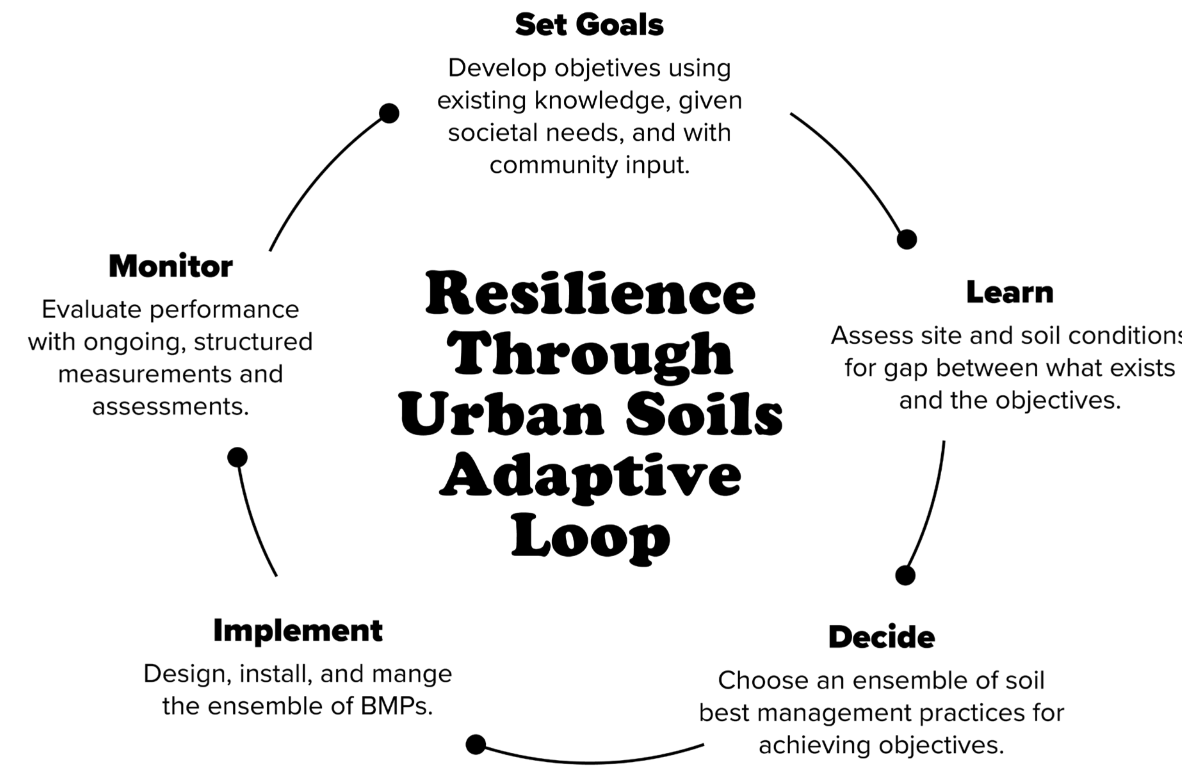


Figure 2. *Resilience Through Urban Soils Adaptive Loop.*

Goal-based Urban Soil BMP Guidance Matrix

Maximizing the potential for climate resilience in soils, and by extension nature-based solutions, depends on selecting, applying and managing BMPs appropriately for a given social and ecological context. How we guide our supporting soil systems will depend on our goals and objectives. As illustrated in the Adaptive Loop (Fig. 2), after setting goals and assessing the current site and conditions, it is time to select the appropriate ensemble of BMPs to bridge the gap.

The urban soil BMP guidance matrix (Fig. 3) directs users in selecting the categories of soil management concern that correspond with their goals. The goals highlighted in the matrix represent activities or objectives of individual and societal interest influenced by soil management. The goals are listed vertically queued beneath the leader "Our Goals…" and include tree health, agriculture & horticulture, cooling, carbon, water quality/availability, recreation, biodiversity, and soil contamination. This is not an exhaustive list, but most endeavors for which soil is relevant can be fit into one of these broad interest categories.

Once the urban soil goal is identified, the matrix guides users to the categories of Best Management Practices (BMPs) that are either often, sometimes, or rarely going to be of importance. The component categories are organic matter, compaction, protection, quantity, geodiversity, contamination, and engineering. Often (filled circles) indicates that in most cases this component of the soil and its management will need to be considered. Sometimes (half-filled circles) indicates that it can be case dependent. Rarely (empty circles) indicates that this component is not typically of strong relevance to the goal.

The usefulness of the matrix format is that users can quickly identify what they need to consider about soils. The matrix also allows users to see how multiple interests are affected by the same soil concern. Further, the matrix is organized such that the aspects of soil and its management are organized from most to least universal to a broad range of interests from left to right. Finally, the matrix begins the organization of BMPs into an ensemble of BMPs as it shows the multiple categories of soil and its management that are relevant to what we are interested in managing for.

Deciding on specific BMPs is next. Best management practices and their packaging into ensembles is a large field of knowledge and information that has been developed over millennia and is hosted on websites, written in books, and held in people minds that has been earned through experience or verbally shared. We cannot recreate here all the necessary protocols for BMPs for what will be needed to effectively manage urban soils. Instead, we provide brief orientations to practices for each category of soil and its management identified in the guidance matrix. In this manner, what is provided here is a stepping off point for developing an ensembles of urban soil BMPs for real world applications nested within adaptive loop processes described above.

● Often ◐ Sometimes ○ Rarely

Best Management Practices Categories

Our Goals...

	Organic Matter	Compaction	Protection	Quantity	Geodiversity	Contamination	Engineering
Tree Health	●	●	◐	●	◐	○	◐
Agriculture & Horticulture	●	●	◐	◐	●	◐	○
Cooling	●	●	◐	●	○	○	◐
Carbon	●	●	◐	●	◐	○	○
Water Quality/Availability	◐	●	●	◐	◐	◐	◐
Recreation	●	●	◐	○	◐	◐	◐
Biodiversity	◐	◐	●	◐	●	○	○
Soil Contamination	◐	○	○	○	○	●	○

Figure 3. *Urban Soil Best Management Practices (BMP) Decision Matrix. A guide for aligning soil management goals with BMP selection.*

Urban Soil Management Diagram

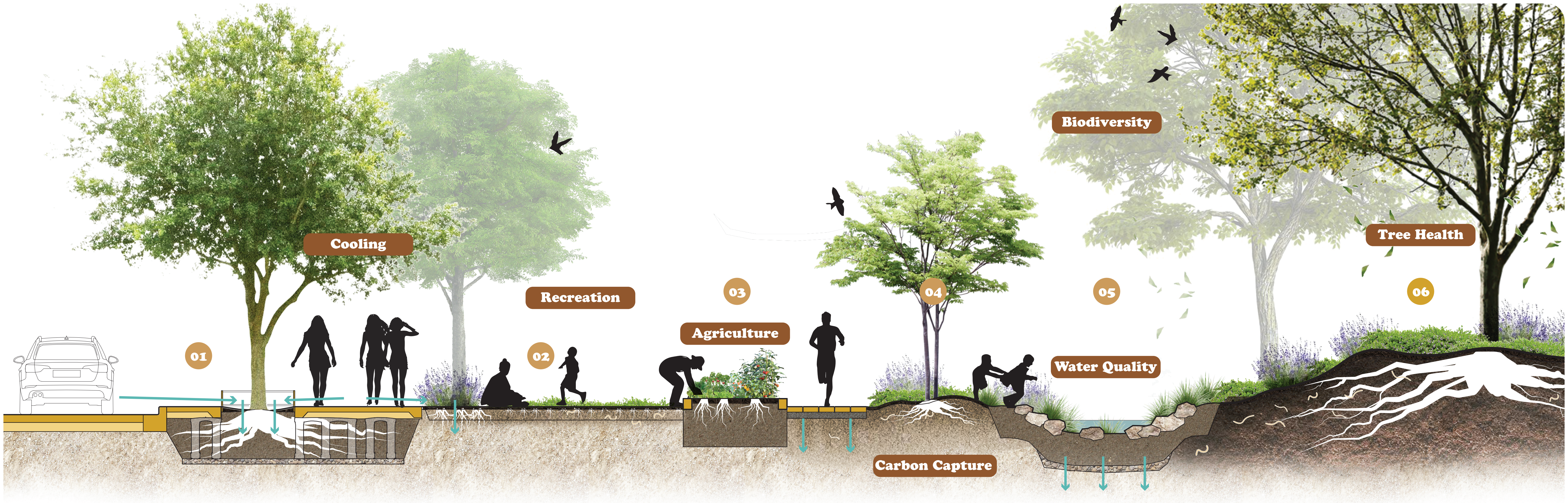


Image credit: Emily Tyrer

01

A limiting factor for tree growth in urban environments is the quantity of soil available for root growth and the compaction of that soil. Adequate soil volume can be achieved by using engineered soils such as structural soils or constructing vaulted sidewalks or soil vault systems that create corridors for root expansion and prevent compaction from urban traffic.

02

Overly compacted soils do not support recreation as it prevents plant growth and water infiltration. Protecting soils from compaction in the first place is the best solution, and can be achieved through protection, or preventing access when soils are most susceptible such as after rain events. Decompaction methods include the Soil Profile Rebuilding technique, subsoiling, tillage, and the use of deep rooted plants combined with organic amendments. Soils should be decontaminated if intended for recreation.

03

While restoring existing soils is recommended and generally more sustainable, there are some instances where soil replacement is required. In this community garden, new soil is imported to better support plant growth and to ensure soils are safe and decontaminated. Organic matter such as mulch and compost should be added to improve soil aeration, water infiltration, and water and nutrient holding capacity.

04

Specially designed, engineered soils are employed to achieve specific goals. For example, engineered soils are often used in rain gardens or beneath permeable pavers to intercept water readily, store water temporarily and support plant growth in gardens where applicable.

05 06

Where possible, healthy native soils should be left undisturbed and geodiversity should be protected. Soils have taxonomic diversity analogous to plants and animals where unique soils are formed based on differences in space and time of soil forming factors. Soil geodiversity creates the diverse stage for biological communiies to form.

7. Orientations to urban soil best management practices

Organic matter

Organic matter is relevant to many goals and can be managed using soil amendments. There are many different types of amendments to use depending on specific objectives and pre-existing soil conditions. Overall, organic amendments increase soil organic matter content and offer many chemical and physical benefits to soils that have been disturbed or overused. Over time, organic matter amendments can improve soil aeration, water infiltration, and both water- and nutrient-holding capacity. Many organic amendments contain plant nutrients and act as slow-release organic fertilizers. Additionally, organic matter drives nutrient cycling and soil development by being an energy source for bacteria, fungi, earthworms, and other soil organisms. Organic matter amendments can be directly added in various ways and with an array of organic materials that include sphagnum peat, wood chips, grass clippings, straw, compost, manure, biosolids, sawdust, wood ash, and biochar. Organic matter can be indirectly added to soil by supporting natural soil building processes using cover crops and perennial plants or via inoculation with soil fungi and bacteria.

How amendments are added depends on the current state of the soil and its projected functions and use. For example, if trees are to be established on a site with fill soil to depths of greater than 10 cm, organic matter amendments should be made to a depth of at least 30 cm and greater with maintenance occurring using soil injection. In contrast, supporting herbaceous plant species may require additions of organic materials as only a top dressing to not destroy their fine roots.

Prior to amending soils with organic matter, there are specific considerations that can be generalized by placement and organic matter type:

Placement. Organic materials can be placed as a top dressing (typically referred to as mulch) or incorporated into lower layers of the soil stratum. Top dressings are typically used to prevent weed establishment and growth, add organic matter to the soil, and to prevent evaporative loss of water through the surface of the soil. Organic materials that are incorporated into lower strata in a soil are done via vertical mulching, tilling, subsoiling, or by injections, each with its advantages and disadvantages depending on the current soil conditions and purpose for introducing the organic matter (e.g., stimulating deeper root growth, encouraging water infiltration, etc.). Although not an amendment per se, roots produce exudates and fine roots turnover (grow and die) relatively quickly, introducing organic matter deep in the soil profile. Thus, practices that encourage deep rooting can also increase soil organic matter.

Organic Matter Type. The quality of the mulch material, or how recalcitrant it is to decomposition, can vary considerably across mulch types. In general, mulches with high C:N ratios take much longer to decompose and therefore provide adequate "cover" to prevent evaporation from soil surfaces or to prevent light from reaching germinating seeds. However, high C:N ratio mulches over time can reduce the amount of available N to plant roots. Types of organic matter that can be used as mulch include sphagnum peat, wood chips, grass clippings, straw, compost, manure, biosolids, sawdust, wood ash, biochar.

Figure 4. *Wood chip mulch applied as a top dressing on the Urban Carbon Farm managed by LA Compost in Griffith Park, Los Angeles.*

Soil compaction

Urban soil is commonly disturbed through cut and fill operations and repetitive use by people, vehicles, and other activities. This repeated trafficking and disruption compresses the soil, destroying the soil structure that would normally allow air and water to move freely in the soil. Furthermore, compacted soils restrict plant roots from penetrating and other living organisms from movement, thus making recovery of healthy soils through natural processes unlikely without intervention. As a result, compacted soil leads to stormwater runoff, erosion, and poor plant health.

Compaction of urban soil can best be addressed by techniques that address the root causes. Protecting soils from compaction in the first place is the best solution. Once compacted, soil best management practices create conditions that support soil recovery and the formation of aggregates, soil particles that are bound more closely to each other than to surrounding particles, a principal feature of soil structure.

Examples of decompaction methods include deconsolidation techniques, such as subsoiling (deep tillage, typically more than 14 inches deep) and the use of deep-rooted plants combined with organic amendments that allow soils to rebuild structure over time. See the case study in this report highlighting the use of Soil Profile Rebuilding, a BMP for rehabilitating compacted urban soils.

Protection

All soil types under specific conditions are more susceptible to the impacts of disturbance. These conditions may be due to moisture content, lack of plant or litter cover, and being positioned on a steep and long slope. For example, a loamy soil that is at or near its "field capacity" of water content is highly vulnerable to surface compaction from trampling, thus preventing site use after a major rainfall event would prevent significant surface compaction.

Controlling the type and timing of uses under highly vulnerable site conditions is an important category of

BMPs. For example, physical barriers or raised paths are effective ways to prevent healthy or developing soils from being negatively impacted. Where direct use is necessary, soil can be engineered to resist the negative impacts of disturbance or protected from surface disturbance with the use of protective coverings, such as organic (wood chips) and inorganic mulches (gravel).

Importantly, it is critical to first consider protection in the case of remnant soils in good condition rather than apply BMPs that disturb these soils. Remnant soils are those that have not been previously disturbed by urbanization activities. In these soils, major soil disturbance can do more harm than good. “Remnant” might also be applied to more recently developed soils. Soils which have not been disturbed for several decades may have recovered significant beneficial soil development; physical disruption to these soil profiles may also lead to declines in performance rather than intended positive effects of a BMP (other than protection or surface management BMPs).

Quantity

Soil area and soil volume

An important limiting factor for tree growth in urban environments is the amount, or volume, of soil available for root growth. The lack of soil volume for root growth is particularly acute along roadways, parking lots, and other locations with high amounts of impervious surfaces, solid surfaces that don’t allow water infiltration into the substrate beneath. Besides expanding the size of tree pits there are other methods to essentially increase the volume of soil that tree roots can exploit even in sites with a high proportion of impervious surfaces. These would include using structural soils, vaulted sidewalks or soil vault systems, and designing underground corridors for root expansion. See ‘Engineering soils’ section below for more details on these strategies.

Design interventions

Below-ground design can increase soil volume in dense urban areas (e.g. vaulted sidewalks, structural soils, soils cells, etc.). However, streetscape design and other urban design interventions can help cluster planting areas to increase volume and protect soils from vehicular or pedestrian traffic, thus reducing compaction and increasing the volume of healthy soils. There is great potential in creating shared rooting spaces through thoughtful design.

Replacement soils

While soil restoration is generally a more sustainable practice than soil removal and replacement, there are some instances where soil replacement is required. Selecting the material used for soil replacement carefully is key to maintaining healthy soils. Clean soil banks are one strategy for ensuring replacement soils do not simply move contaminants around. In addition, soil texture, structure, and organic matter content are key components that influence soil health and resilience over time.

Geodiversity

Biodiversity is a well-known concept. It is the variety of living organisms, often characterized as the number and abundances of different species of plants and animals in an ecosystem. We value biodiversity because we want to support the conservation of the diversity of life, it can make ecosystems more desirable to us generally through our experiences with them, and it is a key factor in ecological resilience.

Geodiversity is less known, but is also fundamentally important to ecosystems, our experiences with them, and their resilience. Geodiversity is the physical diversity of a landscape. Physical components of landscapes include soils and their layers, the terrain and its many forms from the tiny like an ant mound to the massive like a mountain range, and processes like water movement. Without geodiversity, we cannot have biodiversity.

Considering the physical diversity of a city or site can include the diversity in soils, landscape forms, and processes. Soils have taxonomic diversity analogous to plants and animals where unique soils are formed based on differences in space and time of soil forming factors. Soil diversity itself is of conservation interest to many, but it is also of interest because it creates the diverse stage for biological species communities to form. Landscape forms and physical processes, like soil diversity as well as a creator of soil diversity, must be considered in shaping soil through BMPs in order to manage for the range in performance and ecosystem representation we desire within and across managed sites in the urban landscape.

Contamination

Soil can be contaminated by a variety of human activities. Instances of soil contamination are highest in urban areas and former industrial sites, where manufacturing, industrial dumping, old housing developments, and waste disposal could potentially occur. Some contaminants, such as horticultural chemicals used as pesticides, are applied to the soil surface. Others are released below the surface, due to leaks from buried tanks, sewage pipes, or landfills. Atmospheric contaminants resulting from vehicle use, use in building materials and paint, and from cleaning products are also a significant source. Furthermore, contamination is not always limited to a specific site and can seep through the soil into groundwater or be carried to nearby land and waterways in rainwater, or as dust.

People and animals living in urban areas can be exposed to soil contaminants in several ways: by ingesting soil; by breathing violates and dust; by absorbing contaminants through the skin; or by eating food grown in contaminated soil. Depending on the type of contaminant and the level of exposure, soil contamination can have serious health implications. For example, blood lead (Pb) levels in children have been shown to be elevated in urban areas, particularly lower income communities. These elevated levels have been associated with the use of lead-based paint and the use of leaded gasoline. Dust carried in from contaminated soil has been shown to be a key contributor to high blood lead levels.

Options for treating contaminated soil include 1) bioremediation, which uses microorganisms, plants, or earthworms to break down or take up substances in the soil, 2) chemical oxidation or the addition of iron and manganese oxides, which uses “oxidants” to help change harmful contaminants into less toxic ones, 3) soil stabilization, which involves the addition of immobilizing agents to reduce a contaminants’ leachability, and 4) physical methods, such as soil washing, which uses water or chelating agent to separate or remove contaminants from soil particles or aggregates. Other strategies include reducing air and water erosion of contaminated soils, removal of the contaminated soil from the site, and covering or isolating contaminated soils.

Engineering soils

Soils can be created with manufactured or natural materials that are blended to replace the natural soils that are not always available in cities, or to achieve specific goals that may not be provided by natural soils. In many urban environments, natural soils are completely removed or buried by development over time, contaminated to the degree that they must be sealed or removed for safety, or never present in the first place. Engineering soils can sometimes be used as part of best management practices—although, if it’s an option, rehabilitating or modifying natural soils is generally preferable as it is harder to recreate soils as living components through engineering. Engineered soils can be subdivided into the categories of manufactured, blended, and specialized engineered soils.

Manufactured soils: These soils have components that are manufactured or use byproducts from other human activities. Examples include green roof media that use expanded shale products to achieve light weight (e.g., Permatill) or use recycled roofing tiles to achieve optimum drainage characteristics and relatively light weight.

Blended soils: These soils are made from natural constituents blended to resemble natural soils and installed in planting areas in new development or construction. These are often mixes with high proportions of sand and compost. The high sand content in many of these soils may reduce water holding capacity and nutrient cycling.

Figure 5. *Mixing an engineered structural soil on site. The structural soil pictured here is composed of angular crushed stone that can support pavement and loose soil that can support root growth. (Photo: Susan Day)*

Specialized engineered soil: These soils are “engineered” or designed to perform a specific function that natural soils cannot perform. For example, structural soils are engineered to both support pavement and allow tree root growth—two functions that would be normally incompatible with each other in most natural soils (Fig. 5).

Engineering soils further requires specific catering to the system that is being designed. Three examples are provided below.

Expanding rooting volume beneath pavement with structural soils. This is a classic opportunity for using “structural soils”, a type of engineered soil. These are created by mixing large-diameter gravel with soil. The mix is held together until installation using a hydrogel tackifier and, when compacted, can support heavy loads such as sidewalks or roads. The matrix created by the gravel bears the load, allowing the soil in the mix to remain uncompacted and air and water to move freely. This engineered system allows tree roots to grow while simultaneously storing stormwater in areas with limited green space (city centers, for example).

Bioretention systems. These best management practices include using soils as a primary means of intercepting and storing rainwater before it becomes urban runoff that can impair water quality or contribute to downstream flooding. While plants are an important component of rain gardens, bioswales, and other bioretention systems, they all rely primarily on specially designed soils. These soils are engineered to intercept water readily, store water temporarily, and support plant growth.

Modular rooting spaces. While not a soil, these are engineered systems that expand space for soil beneath pavement. Popular types are SilvaCells and StrataCell, both of which use plastic structures to support pavement while creating a box beneath pavement to hold high quality soil. However, these spaces can also be constructed with more traditional vaulted sidewalk construction (concrete and rebar). These can greatly increase the likelihood of growing significant trees in highly paved areas, especially where natural soils are high in clay and susceptible to compaction.

8. Best management practices case study: Soil Profile Rebuilding

Urban development often results in stripped and compacted soils that provide limited support for tree growth and result in landscapes with reduced environmental benefits such as water infiltration. Soil Profile Rebuilding (SPR) is a best management practice that is a cost-effective technique to rehabilitate these soils so they can once again provide a foundation for urban trees and landscapes that enhances resilience to drought and other climate stressors. SPR provides documented increases in tree growth and ecosystem services such as carbon sequestration and stormwater management.

Soil Profile Rebuilding incorporates applying compost, subsoiling, and tree planting. The procedure includes five steps (Fig. 6) that are provided in a new illustrative graphic here and as open-access specifications (brief specification; full specification) that can be used to guide implementation.

Quick Facts about the BMP– Soil Profile Rebuilding

PROBLEM: Compacted soils are very common in cities. These soils prevent the establishment and growth of healthy trees and other vegetation and increase stormwater runoff.

THE BMP: Soil Profile Rebuilding reduces soil compaction before planting and sets soil up to develop a healthy profile over time.

BENEFITS:

- ✓ Decreased soil compaction and deeper root systems
- ✓ Increased tree canopy and resilience to climate change stress
- ✓ Greater soil permeability to mitigate stormwater
- ✓ More carbon sequestered in the soil
- ✓ Cost-effective and easily integrated into policy

WHERE TO USE: After land development or around new construction; to reclaim previously damaged or paved-over soils; in tight spaces, such as medians; trampled soils; or anywhere soil compaction limits plant growth. Not for use around existing large trees.

Soil Profile Rebuilding

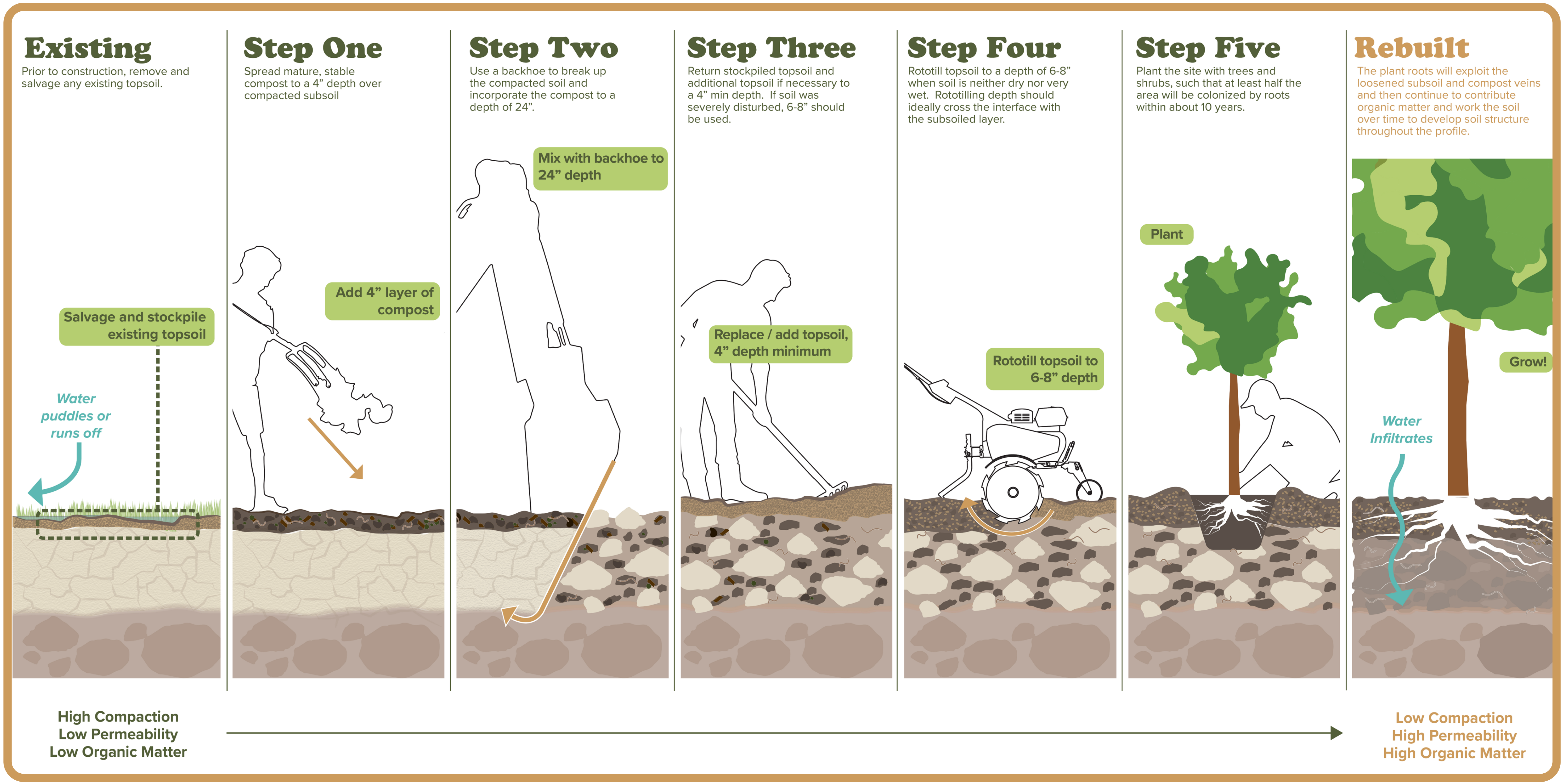


Figure 6. *The five steps of Soil Profile Rebuilding. The interaction of plant roots and treated soil sets the stage for healthy soil development.*
Image credit: Emily Tyrer.

The Science Behind Soil Profile Rebuilding

This technique has been rigorously evaluated and has been demonstrated to improve tree establishment and growth, increase carbon sequestration, and mitigate stormwater runoff. Researchers from Virginia Tech found:

- Reductions in soil compaction from SPR persisted after five years.
- In only six years, trees in SPR-rehabilitated soils had almost twice the canopy of trees in unrehabilitated soil.
- SPR treated soil had equivalent or greater permeability relative to unimpacted reference soil.
- SPR treated soil had greater organic carbon levels in subsurface soils relative to unimpacted reference soil.
- Trees in SPR-treated soils developed deeper root systems, a key factor in climate resilience.

How can communities use Soil Profile Building? The Case of Arlington County, Virginia

Arlington County, Virginia is located within the Washington D.C. metropolitan area and is part of the Chesapeake Bay watershed–a critically important and sensitive estuary. Urbanization pressures are extensive and water quality protection is paramount. Protecting water quality within this urbanized landscape is regulated by a matrix of federal, regional, and local policies and agreements. Adopting best management practices is necessary to achieve regulatory goals.

After a partnership with researchers at Virginia Tech demonstrated the effectiveness of SPR for dramatically improving tree growth in Arlington County, SPR was incorporated into land development policy. It is now the standard practice requirement following construction activities for single-family home development in Arlington County and a key tool for stormwater mitigation since its inclusion in Arlington County's Stormwater Manual effective September 13, 2021 (see section 2.9.1.1 here).

While Arlington policies are primarily motivated by requirements to reduce pollution from urban runoff, SPR and other strategies for linking soil best management practices to policy are relevant to supporting multifunctional objectives including climate resilience. Furthermore, and as illustrated below in Arlington County's experiences with SPR, this case demonstrates the challenges and rewards that result from integrating soil BMPs into policy.

> ***"Soil compaction significantly reduces the ability of plant roots to access water and nutrients and is one of the biggest obstacles to growing healthy trees. Incorporating Soil Profile Rebuilding into our stormwater guidelines made it possible to really deal with this challenge head on and consistently across the county. This practice will help us maintain our community's tree canopy goals and grow trees for the future."***

—Vincent Verweij, Urban Forest Manager, Arlington County, Virginia

Problem-solving for a new street median

Arlington County's interest in SPR began when it was installing planted street medians as part of a traffic-calming effort. Project managers were looking for a cost-effective way to restore soil that has been under pavement for 30 years so it could support new tree plantings. Vincent Verweij, Urban Forester for the County, partnered with researchers at Virginia Tech who had developed SPR to conduct experiments as part of this street median project to evaluate the effectiveness of SPR in local landscape conditions. Vincent was impressed by the potential of SPR for both growing trees and mitigating stormwater and he wanted to share it with his colleagues and the communities that he serves. Arlington County had recently experienced major flooding and was looking for nature-based solutions for stormwater management. Vincent saw the potential of SPR to provide an alternative for developers for meeting stormwater mitigation requirements that focused holistically on a healthy landscape rather than relying on engineered systems (e.g., dry wells or rain gardens). The timing was perfect for integrating a technique like SPR as a requirement for new land development into the County's stormwater manual. But introducing new approaches into policy is challenging and requires significant outreach.

Demonstration projects serve as a testbed and a showcase

Adopting a new BMP requires buy-in from the many individuals and groups involved. In this instance, county engineers and stormwater managers needed to be convinced that the SPR technique was effective; contractors needed to be supported and trained on how to implement it; staff responsible for monitoring compliance needed to know what to look for and be confident enforcement was worthwhile. Of special note, while the actors involved in Arlington County are common to many localities, the mix of relevant participants depends on local governance structures and social dynamics.

To convince these key actors, there was the need for direct experience of how SPR affected stormwater, erosion, settling, and plant growth in a local setting and to work through other concerns people had. An opportunity arose when a small county park building was irreparably damaged during a flood. The building and surrounding paved areas were removed and the site was revegetated. However, the site's compacted soil led to water regularly ponding and plants struggled to establish and survive (Fig. 8).

Figure 7. *Trees planted as part of the research partnership between Arlington County and Virginia Tech. Left: Scarlet oak tree planted in untreated roadside planting showing reduced growth and poor structure resulting from transplant stress. Right: Scarlet oak planted in soil rehabilitated by SPR showing faster growth and improved structure. (photos: Susan Day)*

Figure 8. *The demonstration site before (left) and after (right) SPR application and planting in Arlington County. A small county building had been removed, leaving the soil compacted, prone to flooding, and unsuitable for vegetation. (photos: Vincent Verweij)*

Turning "lemons into lemonade", this site became the location of an Arlington County demonstration project for SPR (Fig. 8). Soil profile rebuilding including revegetation was carried out in line with SPR specifications. The goal was to demonstrate SPR's effectiveness and its straightforward construction and management to support further policy development and drive adoption into practice. Vincent and his team engaged developers, contractors, and community members through site tours, creating demonstration videos (*see here for the outreach video*) and offering hands-on experience in SPR implementation and monitoring (Fig. 9). Additionally, they worked with volunteers to maintain the demonstration site, involving the community. Collectively, they raised awareness, trained practitioners, and built capacity for implementation. It is a great model about how to move urban soil BMPs from the drawing board to standard, accepted practice.

Figure 9. *Monitoring changes in soil compaction at the demonstration project was key to communicating BMP effectiveness. Here a soil penetrometer is used to measure compaction: unrehabilitated site (left) vs rehabilitated site (right). (photos: Vincent Verweij)*

Key factors driving SPR adoption:	Tips for SPR implementation:
• Need for stormwater mitigation (major floods, overland flow issues) • Continued concerns about tree health and survival • Urban trees experiencing climate impacts • Desire for better tree establishment and reduced maintenance requirements • Better understanding of the role of soils in stormwater	• Educate site crews to avoid re-compaction of soil • Not all types of organic material are appropriate (e.g., avoid biosolids and wood chips) • Terracing is effective on sloped sites • Grading should account for minor settling of rehabilitated soils • Get a list of compost sources for contractors

Source: Vincent Verweij

What's Next?

Los Angeles County, CA is an ideal opportunity to explore the potential of SPR to support climate resilience. The Healthy Soils for Healthy Communities needs assessment indicates that 44% of Los Angeles is bare soil, meaning there are extensive opportunities for action (Chen et al., 2021).

For more information about SPR, including links to published research studies, please visit: www.urbanforestry.frec.vt.edu/SRES/.

References

Argüeso, D., Di Luca, A., Perkins-Kirkpatrick, S. E., & Evans, J.P. (2016). Seasonal mean temperature changes control future heat waves. *Geophysical Research Letters* 43(14), 7653–60. https://doi.org/10.1002/2016GL069408

Becker, R. (2022, March 15). Californians used more water as state braces for another dry year. *CalMatters*. https://calmatters.org/environment/2022/03/california-water-use-up/

Bedsworth, L., Cayan, D., Franco, G., Fisher, L., & Ziaja, S. *California's fourth climate change assessment*. California Governor's Office of Planning and Research, California Energy Commission, California Natural Resources Agency. https://www.energy.ca.gov/sites/default/files/2019-11/Statewide_Reports-SUM-CCCA4-2018-013_Statewide_Summary_Report_ADA.pdf

Bowler D. E., Buyung-Ali L., Knight T. M., & Pullin A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning* 97(3), 147–155. https://doi.org/10.1016/j.landurbplan.2010.05.006

Bullard, R. D. (2018). *Dumping in dixie: Race, class, and environmental quality* (3rd Ed.). Taylor & Francis.

Chen, Y., Day, S. D., Shrestha, R. K., Strahm, B. D., & Wiseman, P.E. (2014). Influence of urban land development and soil rehabilitation on soil-atmosphere greenhouse gas fluxes. *Geoderma* 226-227 (1), 348-353. https://doi.org/10.1016/j.geoderma.2014.03.017

Chen, Y., Day, S. D., Wick, A. F. & McGuire, K. J. (2014). Influence of urban land development and subsequent soil rehabilitation on soil aggregates, carbon, and hydraulic conductivity. *Science of The Total Environment* 494-495, 329–336. https://doi.org/10.1016/j.scitotenv.2014.06.099

Chen, Y., Day, S. D., Wick, A. F., Strahm, B. D., Wiseman, P. E. & Daniels, W. L. (2013). Changes in soil carbon pools and microbial biomass from urban land development and subsequent post-development soil rehabilitation. *Soil Biology and Biochemistry 66*, 38–44. https://doi.org/10.1016/j.soilbio.2013.06.022

Chen, Y., Pouyat, R.V., Day, S.D., Wohldmann, E.L., Schwarz, K., Rees, G.L., Gonez, M., de Guzman, E. B. & Mao, S. (2021). *Healthy soils for healthy communities, Phase 1: Needs assessment.* TreePeople. https://www.treepeople.org/wp-content/uploads/2021/03/Healthy-Soils-for-Healthy-Communities-Phase-1-Needs-Assessment-Report.pdf

Cook, E. R., Woodhouse, C. A., Eakin, C. M., Meko, D. M., & Stahle, D.W. (2004). Long-Term aridity changes in the western United States. *Science 306*(5698), 1015–18. https://doi.org/10.1126/science.1102586

Craul, P. J. (1992). *Urban soil in landscape design*. Wiley.

Daley, J. (2019, July 10). California's Drought Killed Almost 150 Million Trees. *Smithsonian Magazine*. https://www.smithsonianmag.com/smart-news/why-californias-drought-killed-almost-150-million-trees-180972591/

Day, S.D. (2016, Sept/Oct). Soil Profile Rebuilding: An Alternative to Soil Replacement. *City Trees*. http://read.dmtmag.com/i/723399-september-october-2016/29

Day, S. D., & Dickinson, S., B. Eds. (2008). Managing stormwater for urban sustainability using trees and structural soils. Virginia Polytechnic Institute and State University. https://www.urbanforestry.frec.vt.edu/stormwater/Resources/TreesAndStructuralSoilsManual.pdf

De Guzman, E., Kalstein, L. S., Sailor, D., Eisenman, D., Sheridan, S., Kirner, K., Maas, R., Shickman, K., Fink, D., Parfrey, J., & Chen, Y. (2020). *RX for hot cities: Climate resilience through urban greening and cooling in Los Angeles*. TreePeople. https://www.treepeople.org/wp-content/uploads/2020/09/RX-for-hot-cities-report.pdf

Galvin, M., O'Neil-Dunne, J., Locke, D., & Romolini, M. (2019). Los Angeles County Tree Canopy Assessment. *Center for Urban Resilience Reports 5*. https://digitalcommons.lmu.edu/cures_reports/5

Gershunov, A., & Guirguis, K. (2012). California heat waves in the present and future. *Geophysical Research Letters 39*(18). https://doi.org/10.1029/2012gl052979

Goulden, M. L., & Bales, R. C. (2019). California forest die-off linked to multi-year deep soil drying in 2012–2015 drought. *Nature Geoscience 12* (8): 632–37. https://doi.org/10.1038/s41561-019-0388-5

Hall, A. (2013, December 1). Climate change in the Los Angeles region: Temperature results. http://research.atmos.ucla.edu/csrl//docs/Hall-LA_temp_study_fact_sheet-Dec2013.pdf

Herrmann, D. L., Schifman, L. A., & Shuster, W. D. (2020). Urbanization drives convergence in soil profile texture and carbon content. *Environmental Research Letters 15*(11), 114001. https://doi.org/10.1088/1748-9326-abbb00

Herrmann, D. L., Shuster, W. D., & Garmestani, A. S. (2017). Vacant urban lot soils and their potential to support ecosystem services. *Plant Soil 413*, 45-57. https://doi.org/10.1007/s11104-016-2874-5

Herrmann, D. L., Schifman, L. A., & Shuster, W. D. (2018). Widespread loss of intermediate soil horizons in urban landscapes. *PNAS 115*(26), 6751-6755. https://doi.org/10.1073/pnas.180030511

Jesdale, B.M., Morello-Frosch, R. & Cushing, L. (2013). The racial/ethnic distribution of heat risk-related land cover in relation to residential segregation. *Environmental Health Perspectives, 121*(7), 811-817. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3701995/

Johnston, J. E., & Hricko, A. (2017). Industrial lead poisoning in Los Angeles: Anatomy of a public health failure. *Environmental Justice 10* (5), 162–67. https://doi.org/10.1089/env.2017.0019

LA Sanitation & Environment. (2021). *Healthy soils strategy for the city of Los Angeles*. https://www.lacitysan.org/cs/groups/public/documents/document/y250/mdy3/~edisp/cnt067543.pdf

United Neighborhoods for Los Angeles. (2019, September 1). *LA is losing its trees*. UN4LA. https://www.un4la.com/blog/la-is-losing-its-trees

Layman, R.L., Day, S.D., Mitchell, D.K., Chen, Y., Harris, J.R. & Daniels, W.L. (2016). Below ground matters: Urban soil rehabilitation increases tree canopy and speeds establishment. *Urban Forestry & Urban Greening 16*: 25-35. https://doi.org/10.1016/j.ufug.2016.01.004

Lee, S. J., Longcore, T., Rich, C., & Wilson., J.P. (2017). Increased Home Size and Hardscape Decreases Urban Forest Cover in Los Angeles County's Single-Family Residential Neighborhoods. *Urban Forestry & Urban Greening 24* (May): 222–35. https://doi.org/10.1016/j.ufug.2017.03.004

Locke, D. H., Romolini, M., Galvin, M., Jarlath, P. M. O'Neil-Dunne, and Eric G. Strauss. (2017). Tree canopy change in coastal Los Angeles, 2009 - 2014. *Cities and the Environment 10*(2), Article 3. https://digitalcommons.lmu.edu/cate/vol10/iss2/3

Lund, J., Medellin-Azuara, J., Durand, J., & Stone, K. (2018.) Lessons from California's 2012–2016 drought. *Journal of Water Resources Planning and Management 144*(10): 04018067. https://doi.org/10.1061/%28ASCE%29WR.1943-5452.0000984

MacDonald, G. M., Moser, K. A., Bloom, A. M., Potito, A. P., Porinchu, D. F., Holmquist, J. R., Hughes, J. & Kremenetski, K.V. (2016). Prolonged California aridity linked to climate warming and Pacific sea surface temperature. *Scientific Reports 6*, 33325. https://doi.org/10.1038/srep33325

McPherson, E. G. (2014). Monitoring million trees LA: Tree performance during the early years and future benefits. *Arboriculture & Urban Forestry 40* (5). https://doi.org/10.48044/jauf.2014.027

Morel, J., Chenu, C., & Lorenz, K. (2015). Ecosystem services provided by soils of urban, industrial, traffic, mining, and military areas (SUITMAs). *Journal of Soils and Sediments 15*, 1659-1666. https://doi.org/10.1007/s11368-014-0926-0

Mount, J., & Hanak, E. (2019). *Water Use in California*. Public Policy Institute of California. https://www.ppic.org/wp-content/uploads/jtf-water-use.pdf.

National Integrated Drought Information System. (2019). *NASA DEVELOP Analyzes drought impacts on urban tree recovery in Texas*. Drought.gov. https://www.drought.gov/news/nasa-develop-analyzes-drought-impacts-urban-tree-recovery-texas#:~:text=Measuring%20Tree%20Mortality%20Related%20to%20Drought%20Based%20on,killed-%20an%20estimated%205.6%20million%20urban%20shade%20trees

Neil, K., & Wu, J. (2006). Effects of urbanization on plant flowering phenology: A review. *Urban Ecosystems 9*, 243–257. https://doi.org/10.1007/s11252-006-9354-2

Pouyat, R. V., Page-Dumroese, D. S., Patel-Weynand, T., & Geiser, L. H. (2020). Forest and rangeland soils of the United States under changing conditions: A comprehensive science synthesis (1st ed.). Springer international publishing. https://doi.org/10.1007/978-3-030-45216-2.

Pan, S., Tian, H., Dangal, S. R. S., Yang, Q., Yang, J., Lu, C., Tao, B., Ren, W., & Ouyang Z. (2015). Responses of global terrestrial evapotranspiration to climate change and increasing atmospheric CO 2 in the 21st Century. *Earth's Future 3* (1): 15–35. https://doi.org/10.1002/2014EF000263

Pouyat, R. V., Szlavecz, K., Yesilonis, I. D., Groffman, P. M., & Schwarz, K. (2010). Chemical, physical, and biological characteristics of urban soils. In: Aitkenhead-Peterson, J., & Volder, A. (Eds.), *Urban ecosystem ecology* (pp. 119-152) American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. https://www.nrs.fs.usda.gov/pubs/jrnl/2010/nrs_2010_pouyat_001.pdf

Pouyat, R. V., & Trammell, T. L. E. (2019). Climate change and urban forest soils. (2019). *Developments in Soil Science 36*(189-211). https://doi.org/10.1016/B978-0-444-63998-1.00010-0

Pouyat, R. V., Yesilonis, I. D., & Nowak, D. J. (2006). Carbon storage by urban soils in the United States. *Journal of Environmental Quality 35*(4), 1566–1575. https://doi.org/10.2134/jeq2005.0215

Rasifaghihi, N., Li, S. S. & Haghighat, F. (2020). Forecast of Urban Water Consumption under the Impact of Climate Change. *Sustainable Cities and Society 52* (January), 101848. https://doi.org/10.1016/j.scs.2019.101848

Rittel, H.W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences 4*(2): 155–69. https://doi.org/10.1007/BF01405730

Scalenghe, R., & Marsan, F. A. (2009). The anthropogenic sealing of soils in urban areas. *Landscape and Urban Planning, 90*(1-2), 1-10. https://doi.org/10.1016/j.landurbplan.2008.10.011

Schwarz, K., Fragkias, M., Boone, C. G., Zhou, W., McHale, M., Grove, J.M., O'Neil-Dunne, J., Mcfadden, J. P., Buckley, G. L., Childers, D., Ogden, L., Pinceti, S., Pataki, S., Whitmer, A., & Cadenasso, M.L. (2015). Trees Grow on Money: Urban Tree Canopy Cover and Environmental Justice. *PloS One 10* (4), e0122051. https://doi.org/10.1371/journal.pone.0122051

Soil Survey Staff. (1999). Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys (2nd ed.). U.S. Department of Agriculture Natural Resources Conservation Service. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051232.pdf

Sweet, W.V., Hamlington, B.D., Kopp, R.E., Weaver, C.P., Barnard, P.L., Bekaert, D., Brooks, W., Craghan, M., Dusek, G., Frederikse, T., Garner, G., Genz, A. S., Krasting, J.P., Larour, E., Marcy, D., Marra, J. J.. Obeysekera, J., Osler, M. Pendleton, M., Roman, D., Schmied, L., Veatch, W., White, K. D., & Zuzak, C. (2022) Global and regional sea level rise scenarios for the United States: Updated mean projections and extreme water level probabilities along U.S. coastlines. National Oceanic and Atmospheric Administration, National Ocean Service. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf

Szlavecz, K., Vilisics, F., Tóth, Z., & Hornung, E. (2018). Terrestrial isopods in urban environments: An overview. *Zookeys 801*, 97-126. https://doi.org/10.3897/zookeys.801.29580

Trammell, T.L.E., & Carreiro, M.M. (2012). Legacy effects of highway construction disturbance and vegetation management on carbon dynamics in forested urban verges. In Lal, R., & Augustin, B. (Eds.), *Carbon Sequestration in Urban Ecosystems* (pp. 331-352). Springer. https://doi.org/10.1007/978-94-007-2366-5_17

Trammell, T. L. E., Day, S., Pouyat, R. V., & Rosier, B., Scharenbroch, B., & Yesilonis, I. (2017). Drivers of urban soil carbon dynamics. In Lal, R., & Stewart, B.A. (Eds.), *Urban Soils* (pp. 93-120). Taylor & Francis Group. https://doi.org/10.1201/9781315154251

United States Department of Agriculture, Natural Resources Conservation Service. (2010). From the surface down: An introduction to soil surveys for agronomic use (2nd ed.). https://www.nrcs.usda.gov/sites/default/files/2022-11/from-the-surface-down.pdf

Wada, Y., van Beek, L. P. H., Wanders, N., & Bierkens, M. F. P. (2013). Human water consumption intensifies hydrological drought worldwide. *Environmental Research Letters 8*(3), 034036. https://doi.org/10.1088/1748-9326/8/3/034036

Youngsteadt, E., Henderson, R.C., Savage, A. M., Ernst, A.F., Dunn, R.R., & Frank, S.D. (2014). Habitat and species identify, not diversity, predict the extent of refuse consumption by urban arthropods. *Global Change Biology 21*, 1103-1115. https://doi.org/10.1111/gcb.12791

Zemlyanitskiy, L. T. (1963). Characteristics of the soils in the cities. *Soviet Soil Science 5*, 468–475.

Ziter, C. & Turner, M.G. (2018). Current and historical land use influence soil-based ecosystem services in an urban landscape. *Ecological Applications 28*(3), 643-654. https://doi.org/10.1002/eap.1689

Ziska, L.H., Morris, F.C., & Goins, W. (2004). Quantitative and qualitative evaluation of selected wheat varieties released since 1903 to increasing atmospheric carbon dioxide: can yield sensitivity to carbon dioxide be a factor in wheat performance? *Global Change Biology 10*(10), 1810-1819. https://doi.org/10.1111/j.1365-2486.2004.00840.x

TreePeople

12601 Mulholland Drive | Los Angeles, CA 90210
www.treepeople.org