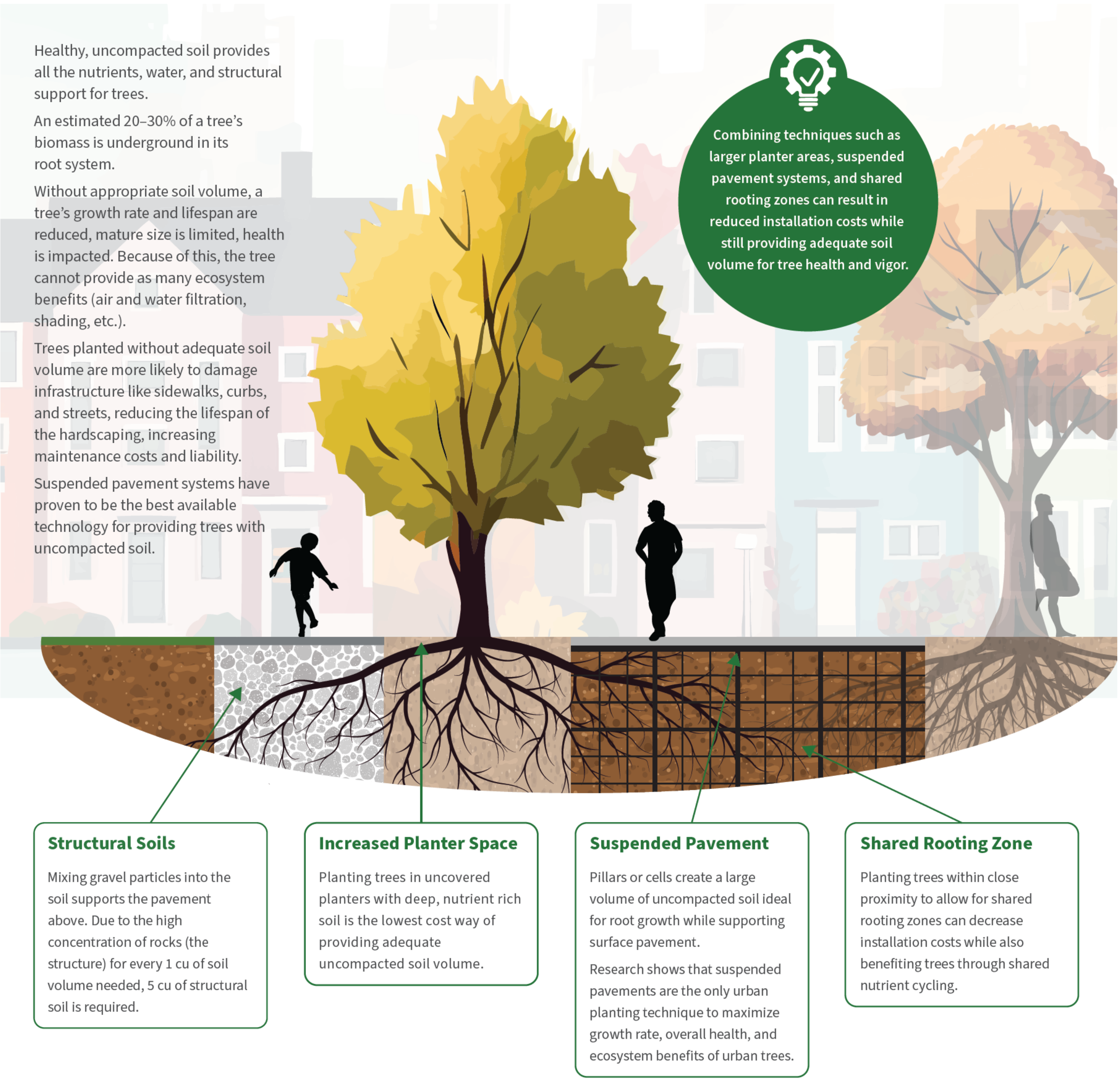
Technical Report:

Tree Planting Methods in Urbanized Environments



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Introduction

The City of Missoula contracted with Davey Resource Group, Inc. to explore several alternative tree planting methods designed to prevent soil compaction and improve the health and longevity of its urban trees. The synthesis of scientific literature and case studies contained in this document and the accompanying *Tree Planting Methods Pamphlet* serve as tools for the community to better understand and implement various methods of tree planting to better sustain individual trees and progress toward meeting the carbon capture, walkability, and shade goals the City has identified in policy documents.

The most successful and feasible urban tree planting methods identified in the literature review were suspended pavements, structural soils, and uncovered tree planting pits. These are described in detail in the results section of the report. Additional systems were explored and are briefly outlined. Each of the methods require proper implementation and adequate soil volume to maximize their effectiveness and allow the tree to achieve its full potential. By supporting tree growth and longevity, these methods will enhance the many benefits trees provide for the community.

Background

Benefits of Trees in the Urban Environment

Trees in urban environments are able to offer a wide range of ecosystem services that directly mitigate the challenges posed by the pollutants and atmospheric carbon generated by increasing population, density, and development (Roy 2012). As Missoula has already described in many guiding City plans and policies, such as the Our Missoula 2045 Land Use Plan , trees are able to produce oxygen, filter harmful pollutants from the air, and provide shade. In turn, trees beautify outdoor spaces, encourage increased usage of bike trails and bus stops, reduce the energy costs of cooling buildings, capture stormwater runoff / reduce the risk of flooding, provide habitat for wildlife, and even contribute to less tangible metrics such as improved mental health, increased spending in commercial areas, and higher property values.

The diameter, height, and canopy spread of trees, and thereby the benefits that they are able to provide, progressively increase with their age and size, until they eventually reach a state of maturity and begin to decline; however, many trees in cities are never able to grow to their full potential due to the restrictive environments in which they are planted (MacDonough 2011). By prioritizing higher up-front investment to ensure that trees are planted in locations and conditions that will promote their vitality and longevity and minimize impacts to infrastructure, cities can maximize the benefits that they are able to receive and increase their return on investment in the long run.

Challenges Faced by Trees in the Urban Environment

Planting and maintaining urban trees must follow industry best management practices to avoid negative consequences. For example, improperly planted trees often conflict with infrastructure and utilities like sidewalks, underground pipes, and overhead powerlines (Watson et al 2014). Oftentimes, trees are planted too close to other features, which can be detrimental, resulting in the loss of the tree as well as costly damage to the infrastructure. Cities must be strategic and intentional when deciding where, and how, to plant urban trees in order to maximize the value of their investment.

Trees in an urban environment face many unique challenges that are not found in forests and natural areas. Smiley et al (2006) identified “a lack of usable soil for root growth” as the most limiting growth factor of urban trees. A lack of usable soil typically results from (1) inadequate soil volume, where the planting space is too small and/or shallow for the roots to reach their full size, and/or (2) compacted soils, where compressive forces of pavement and other heavy loads leads to a lack of soil function (e.g., a loss of soil porosity and permeability) due to the compressive forces of pavement and other heavy loads above it, even when there is adequate space available (Solloway et al 2013). In addition to soil volume and degree of compaction, the quality of soils varies as well, and soils with low organic matter and microbial activity can result in tree stress. In such cases, the lack of usable soil by volume and/or quality directly contributes to the slowed growth, compromised health and eventual failure of the tree, thereby leading to the loss of benefits the tree was providing and the need for replacement planting.

Support for this Project

In order to better promote its mission of preserving and increasing its urban forest resource and all of the benefits that it provides, and to ensure that the City's standard operating procedures are aligned with the most up-to-date industry knowledge and trends, the City of Missoula has chosen to explore best management practices for urban tree planting to prevent soil compaction and improve the health and longevity of its urban trees.

The need for a review of best management practices for planting trees is supported by the City's newly adopted Our Missoula 2045 Land Use Plan:

- Implementation Action #56 is to "Develop standards for tree planting requirements and design standards to optimize tree health in urban areas."
- Policy Objective #5 of the "Environmental Quality and Climate Resilience" theme includes protecting and strengthening the urban forest.

Additionally, a primary focus of the City's Urban Forest Master Management Plan is establishing a "well-developed planting plan" that prioritizes trees while reducing tree and infrastructure conflicts. Goals and Objectives that are directly supported by tree planting include: 1.1, 1.2, 1.3, 1.4, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 6.1, 7.1, 7.2, 7.3, 8.3, 9.4, 11.1, 11.2, 11.3, 11.5, 11.6, 12.1, 12.2, 12.3, 12.4, 14.3.

Adoption of the soil volumes and planting methods recommended in this report will also increase the benefits that Missoula receives from its urban forest resource. In a projection of total annual benefits of trees planted in two soil volume scenarios – the current standards required by the 2018 Missoula Parks & Recreation Design Manual, and the increased soil volumes recommended in this report, for each class of tree (I-III) – trees planted in increased soil volumes could provide 145-1167% more benefits to the City when mature. In this analysis, six sample species were selected based on their prevalence in Missoula's current tree population (UFMMP 2015), their average value per tree in the state of Montana (Montana DNRC 2017), their likelihood of success in the proposed alternative planting methods (Bartens et al 2009), and their presence on Missoula's approved street tree planting list. Size (diameter) and condition ratings were assigned for each species and scenario, with the trees planted in increased soil volumes reaching a larger size and better overall condition. The resulting annual benefits were estimated using iTree *Eco*, a peer-reviewed software developed by the USDA Forest Service and industry partners.

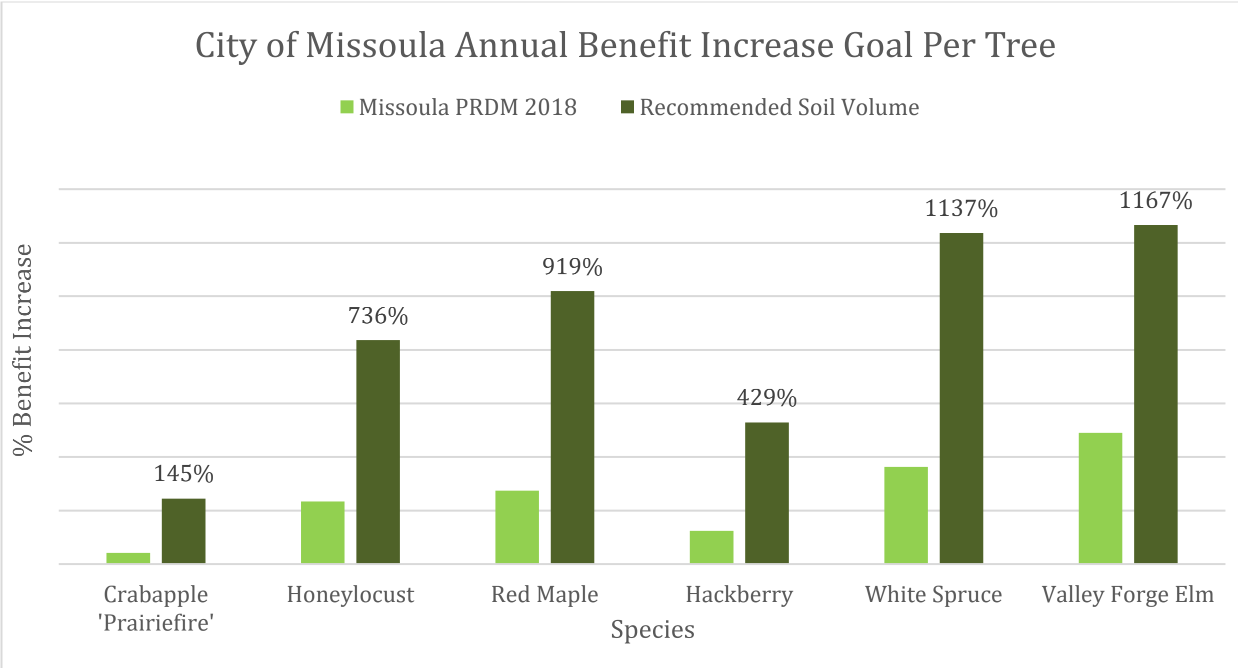


Figure 1: Potential annual tree benefit increases for six sample species in Missoula based on the projected size and condition of the trees at maturity if planted in recommended soil volumes based on industry best practices (iTree Eco).

Methods

Background & Literature Review

The City of Missoula is focused on protecting and promoting its urban tree canopy, as reflected in code, plans, and technical specifications. In order to ensure alignment with the City's existing goals and policies, and to identify opportunities for potential revisions, DRG conducted a thorough review of City background documents and scientific literature.

City Background Documents: The full list of City documents reviewed is included in the Appendix of this report. Potential revisions to these documents that incorporate the recommended planting methods were provided to the City as a separate document.

Scientific Literature: References are included throughout the document to support a review of methods for planting trees in an urban environment and evaluate their suitability for use in Missoula. Studies assessed trees planted in increased volumes of soil, as well as trees planted in suspended pavement systems, structural soils, and uncovered tree pits, among other methods. Studies that evaluated tree performance compared to conventional planting methods in terms of both the tree's own growth and health and other environmental benefits such as stormwater control were prioritized.

Example Cities

Based on the literature review, a table was created to document examples of cities currently implementing one or more of the recommended urban tree planting methods (See Table 4). The purpose of this step was to determine how widespread the current adoption of the planting methods is, evaluate their success over time, identify potential limitations or challenges experienced by other communities, and provide examples of how other cities are incorporating these new planting methods into their city codes and policies. Ultimately, the City of Missoula could model its own potential revisions to guiding documents after example communities that have successfully implemented one or more of the methods. The full list of cities identified is included in the Appendix.

Soil Volume and Feasibility Calculations

Soil volumes were compiled from the literature review and example cities' tree planting ordinances into one recommended value or range of values, for each planting method, for each of Missoula's three size classes of trees. After the most suitable tree planting methods had been identified and the site-specific requirements for successful implementation were understood, the City contacted suppliers and calculated a rough order of magnitude cost estimates for the recommended volumes of soil needed to plant each size class of tree in suspended pavements and structural soils. The up-front costs, expected lifespan, and projected environmental benefits of trees planted using each tree planting method can be compared to aid decision making.

Findings

Summary

Three primary methods for planting trees in urban areas were identified in the research: suspended pavements, structural soils, and expanded tree planting pits. In all cases, providing the tree with an adequate volume of quality, uncompacted soil is the primary objective to growing healthy mature trees. Though the industry has not defined a standard for soil volume, the widely accepted requirements are between 1 to 3 cubic feet per square foot of mature tree canopy (Solloway et al 2013). Davey Resource Group recommends 2 cubic feet per square foot of tree canopy (See Recommendations section of this report).

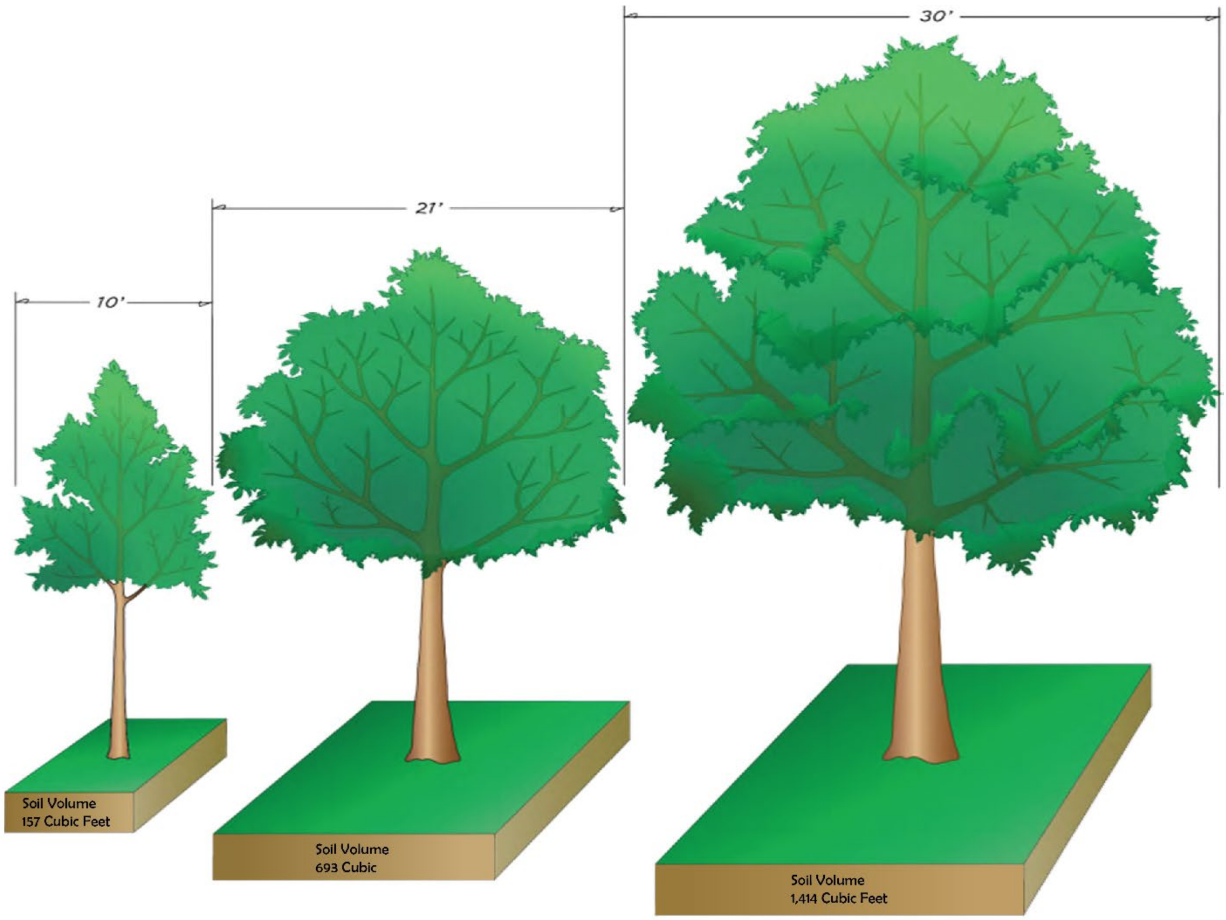


Figure 2: Uncompacted soil volume needs based on tree size (adapted from Solloway et al 2013 to reflect 2 cubic feet per square foot of tree canopy).

Of the methods identified, the most straightforward and successful at achieving this objective was expanded planting pits or simply providing an increased volume of soil and leaving a larger surface area unpaved. However, this planting method also requires the most uncovered soil surface area, which is not always available for trees in urban areas. When providing adequate soil volume is competing with urban infrastructure such as roads, sidewalks and bike lanes for limited right-of-way space, the two most frequently utilized methods are suspended pavements and structural soils. In both systems, a mechanism is used to redistribute the weight of the load-bearing pavement above the tree planting pit to a base level below it, keeping the soil in between the two layers uncompacted and available for the tree's root system to grow and filter water and nutrients. Although both methods have been successfully implemented by many communities, suspended pavements (which utilize cells or pillars to transfer the weight) have been proven more effective than structural soils (which involve mixing small pieces of gravel into the soil to support the weight of the pavement above) for promoting the health and growth of the tree.

Additionally, a variety of other techniques can be used in conjunction with suspended pavements, structural soils, or expanded tree planting pits to promote additional benefits, protect the tree, or preserve the surrounding infrastructure. Some of these include permeable pavements, root barriers, air gaps, flexible sidewalks, and stormwater trenches or tree pits.

Suspended Pavements

Description

Suspended pavement systems, also referred to as structural cells, are designed to keep the soil underneath an area of pavement non-compacted so that tree roots have adequate conditions to grow and filter water and nutrients. This is accomplished by placing individual columns, pillars, or cells throughout the load-bearing area (Solloway et al 2013), which, in turn, allow the weight of the infrastructure, vehicles, or other load bearing objects to be transferred from the upper pavement to a lower sub-base while keeping the soil in between the two layers uncompacted.

> ***By transmitting surface loads to a compacted subbase, suspended pavement systems create a matrix of uncompacted soil that promotes tree health through increased root access to oxygen, water, and nutrients.***
> ***- Tirkpak 2019***

Common brand names of ready-made structural cell systems include Silva Cells® (produced by Deeproot) and Stratavault™ (produced by Citygreen), but a suspended pavement system can be achieved through a variety of construction methods.

Figure 3: Suspended pavements utilize a network of pillars or cells to transfer weight from the load-bearing pavement above the tree's root system to a sub-base below it, keeping the soil in between uncompacted and available for the tree's use.

Benefits

Urban (2017) identified suspended pavements as the most effective method for promoting tree growth. Additional literature supports this finding. Trees planted in suspended pavements have been shown to live up to twice as long as urban trees planted in compacted soils: for example, the average lifespan of an urban tree has been estimated at 13 years, but 98% of two groups of trees planted in suspended pavement systems in Charlotte, NC and Bethesda, MD in 1986 were still thriving 25 years later in 2011 (MacDonagh 2011). Additionally, a study projected that the same tree's life expectancy in Minneapolis, MN would be increased from 13 to 50 years if planted in suspended pavement as opposed to compacted soil (MacDonagh 2011).

A 2006 study by Smiley et al compared five different treatments for trees surrounded by pavement and found that the suspended pavement over uncompacted soil treatment outperformed the other treatments in most categories at 14 months. The trees planted in suspended pavement had greater trunk diameter growth, twig growth, and chlorophyll rating than trees planted in other treatments, including a gravel-soil mixture. Smiley et al summarized that "suspended pavement over noncompacted soil provided the greatest amount of tree growth and health and should be considered when designing urban planting sites for trees." In another study, trees planted in suspended pavements grew to a greater height on average than trees in any other method, including structural soils, and in some cases grew even faster than trees planted without any paving at all (Urban 2017).

Suspended pavement systems offer the opportunity to install the greatest amount of soil in the smallest space. For projects with the goal of providing sufficient quantities of unscreened soil to support large, mature trees they may be the only option.
- Urban 2017

Suspended pavements also contribute to substantially greater tree stability compared to trees planted in compacted soils, and slightly greater tree stability than those planted in structural soils (Bartens 2010), as the roots are able to extend deeper and wider into the uncompacted soil and form a larger, sturdier base to support the tree. This same effect contributes to a reduction in root heaving of pavement such as sidewalks, which in turn extends the lifespan of the surrounding infrastructure.

In addition to their benefits to trees, suspended pavements have significant benefits to stormwater management and can be constructed around underground water drainage systems to prevent flooding or ponding that suffocates trees (Soloway et al 2013). In other words, when soil is uncompacted, it has an increased water-holding capacity, so more water is able to infiltrate deeper into the ground instead of accumulating at the surface. Suspended pavements can also be used in combination with other proposed planting methods to further increase stormwater benefits. For example, a suspended pavement system could be constructed topped with a permeable pavement (discussed in the supplementary methods section) and/or filled with structural soil to allow for even greater amounts of surface water infiltration and more rapid rates of drainage into the stormwater system.

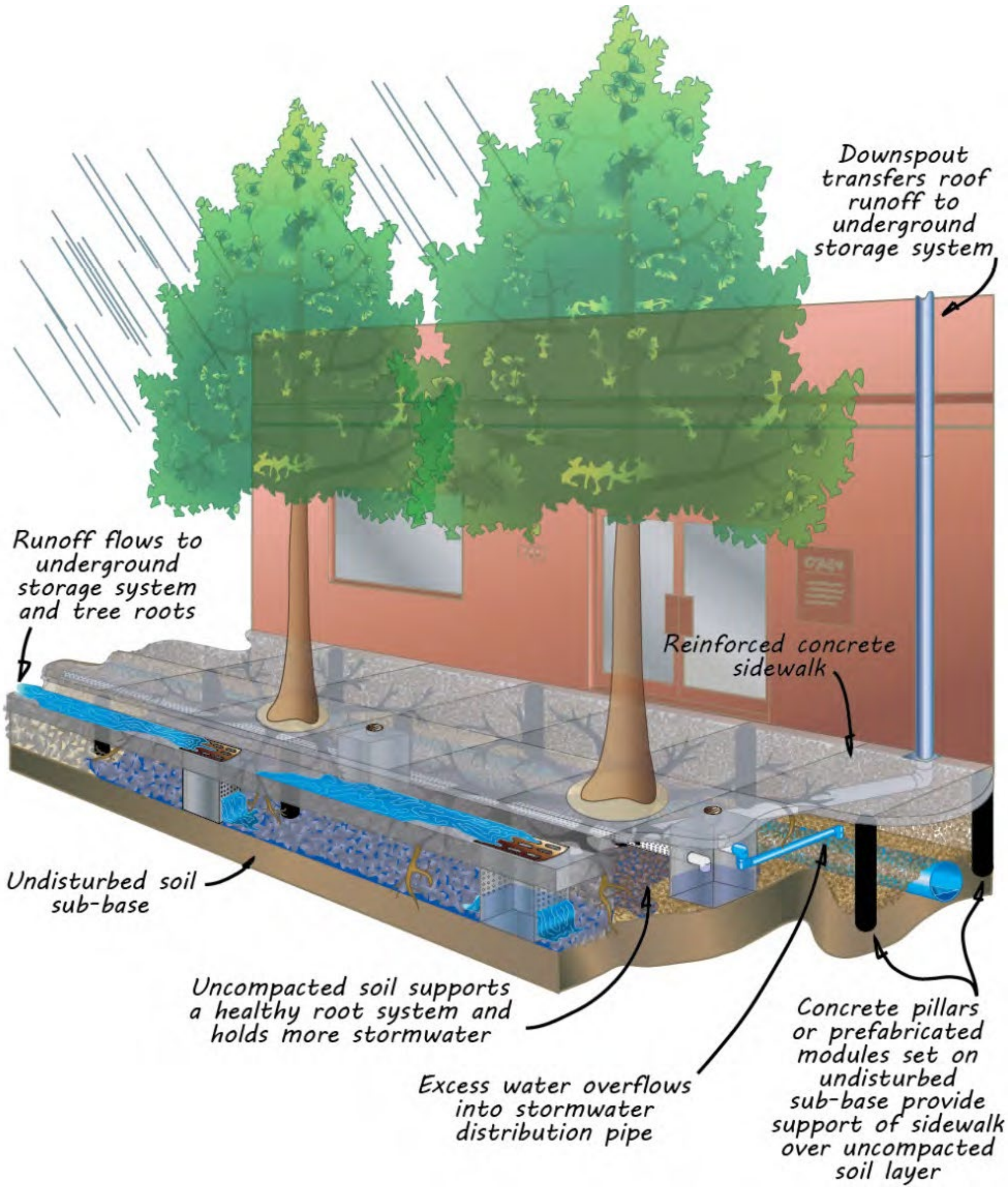


Figure 4: Suspended pavements are frequently implemented in places where trees are serving as a tool for stormwater capture and filtration, contributing to significant reductions in runoff, improvements to water quality, and dollars saved (Solloway et al 2013).

Limitations

The primary drawback of implementing a suspended pavement system compared to conventional tree planting is the increased cost. However, when compared to structural soils, suspended pavements were found to be easier to assemble (Smiley 2006).

Feasibility

The primary benefit of suspended pavements compared to other methods for preventing soil compaction, such as structural soils (discussed below), is that any type of existing or imported planting medium can be used within the cells. This is important because access to high-quality soil is beneficial for most species of trees.

The size and construction of the pillars or cells can vary widely, and the specifications needed will depend on the resulting load the pavement is intended to bear (pedestrian traffic, motor vehicles, utilities, buildings, etc.). Implementing a suspended pavement system in Missoula currently costs around $20 per cubic foot of soil (estimate provided by Missoula Parks and Recreation). Although up-front costs of installation are higher than traditional tree plantings, tree survival and longevity is substantially improved. In addition, the long-term impacts of providing adequate soil volume for trees results in reduced damage to surrounding infrastructure. See Table 1 for more context on price based on the size of the installation for a single tree in Missoula.

Table 1: Current cost estimates to implement suspended pavements in Missoula

Tree Class	Planter Volume, cubic feet ($20/cu ft)	Planter Volume, cubic yards ($540/cu yd)	Total Cost/Tree ($)
Class I (Small, <30’)	500	18.5	$10,000
Class II (Medium, 30-60’)	1,000	37.1	$20,000
Class III (Large, >60’)	1,500	55.6	$30,000

Current Usage

Suspended pavements have been implemented in many places with primary goals around stormwater management. Trees planted in suspended pavements will have dramatically increased benefits to stormwater compared to trees planted in compacted soil. Urban (2013) highlights the value of this relationship between trees and stormwater when considering adding the requirement of suspended pavements or other alternative planting methods to the city code and said "Making the tree a part of the storm water management system was a critical alliance to gaining acceptance of the new standards."

Importantly, in the arid west, this method has also been implemented based on goals to increase tree growth rates and improve long-term success from providing uncompacted soil that can hold moisture (e.g., Boise, ID).Other cities that have successfully implemented suspended pavements include Minneapolis, MN; Charlotte, NC; and Knoxville, TN. Additionally, Emeryville, CA, offers a 50% reimbursement to residents who plant trees in suspended pavements, and several cities in Ontario and British Columbia, Canada, require their use in city guiding documents. The oldest known trees planted in suspended pavement were planted in a plaza in Boston, MA in 1968, making them 57 years old. These trees were deemed healthy at 45 years of age (Urban 2017).

Figure 5: Boston, MA plaza trees planted in suspended pavement installed in 1968 (Deeproot).

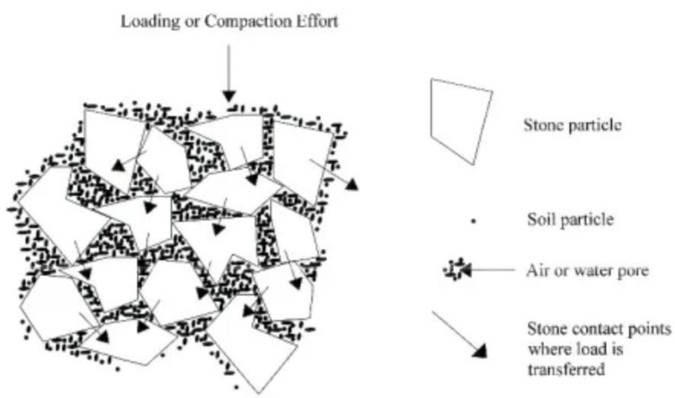
Potential Usage in Missoula

Suspended pavements are suitable for all of Missoula's classes of trees, but they would be especially beneficial to larger trees with greater soil volume requirements (Class II-III on Missoula's Approved Street Tree List). This planting method is a good option for trees located anywhere that uncompacted soil is limited and space is not available for expanding tree planters: traffic medians, along sidewalks and near sidewalk cafes, parking lots, urban plazas, etc. Suspended pavements can be installed during both new and retrofit construction and can be used in combination with structural soils and permeable pavements. Installation costs will vary based on site characteristics.

Structural Soils

Description

Structural soils combine rigid, crushed stone with uncompacted, nutrient-rich soil into a highly-porous aggregate mixture. This method is meant to remedy the issue of soil compaction and in turn allow for better root growth and overall tree health within highly urbanized and/or unusually-shaped growing spaces. Although Cornell University was the first to patent and popularize the concept with CU-Structural Soil®, there are now a variety of options that achieve the same result by adding gravel particles to soil to promote its porosity while maintaining a load-bearing capacity.



CU-Soil conceptual diagram

Figure 6: Structural soil is created by aggregating angular pieces of crushed stone into soil, so that the gravel can support the load of the pavement above while the soil remains uncompacted and available for trees. Image: Cornell University (Denig et al 2015).

In terms of its physical composition, structural soils typically consist of “70% to 80% angular gravel and 20% to 30% clay loam soil and a small amount of hydrogel (~3%) to prevent separation during mixing,” as well as “20% to 25% void space which supports root growth and accommodates stormwater runoff” (Solloway et al 2013). Throughout this report, a simplified ratio of 80% gravel and 20% soil was used for soil volume calculations involving structural soils.

"The stone components [...] come together during compaction, forming a strong, load-bearing, compacted stone base suitable for paving over, while the large voids between the stones provide room for an uncompacted clay loam soil and allow for root growth and aeration of the root zone.
- Denig et al 2015

Figure 7: Structural soils allow trees to survive in paved urban areas by mixing load-bearing stone particles into the soil at a ratio of approximately 80% stone to 20% soil.

Benefits

The primary benefit of structural soil is that it can provide an adequate environment to support trees while still preserving the load-bearing capacity of the surrounding area for paving and development. Minimal upkeep is needed once the soil is installed, and it can benefit the surrounding infrastructure as well. One of the earliest and most prevalent proponents of this method, CU-Structural Soil, cited case studies dating back to 1994 that did not show soil migration, evidence of frost heaving, or increased sidewalk heaving (Denig et al 2015). Trees planted in structural soil have been shown to have greater stability in the long run compared to trees planted in compacted soils, such as Missoula's traditional tree wells, due to their enhanced ability to spread out their root system (Bartens et al 2010). However, not all species benefit to the same degree. In the Bartens et al study, *Prunus* (cherry) species experienced significantly greater root volume and stability in structural soils compared to compacted soil, while *Ulmus* (elm) species had very slight differences.

Additionally, structural soils offer major benefits for stormwater management. In fact, trees planted in structural soils are often proposed as a tool for urban stormwater management as opposed to a tool to promote the growth/health of the urban trees themselves (Solloway et al 2013). This is because the porosity of the structural soils causes them to drain more quickly than traditional compacted soils, allowing more water to infiltrate into the system at a faster rate.

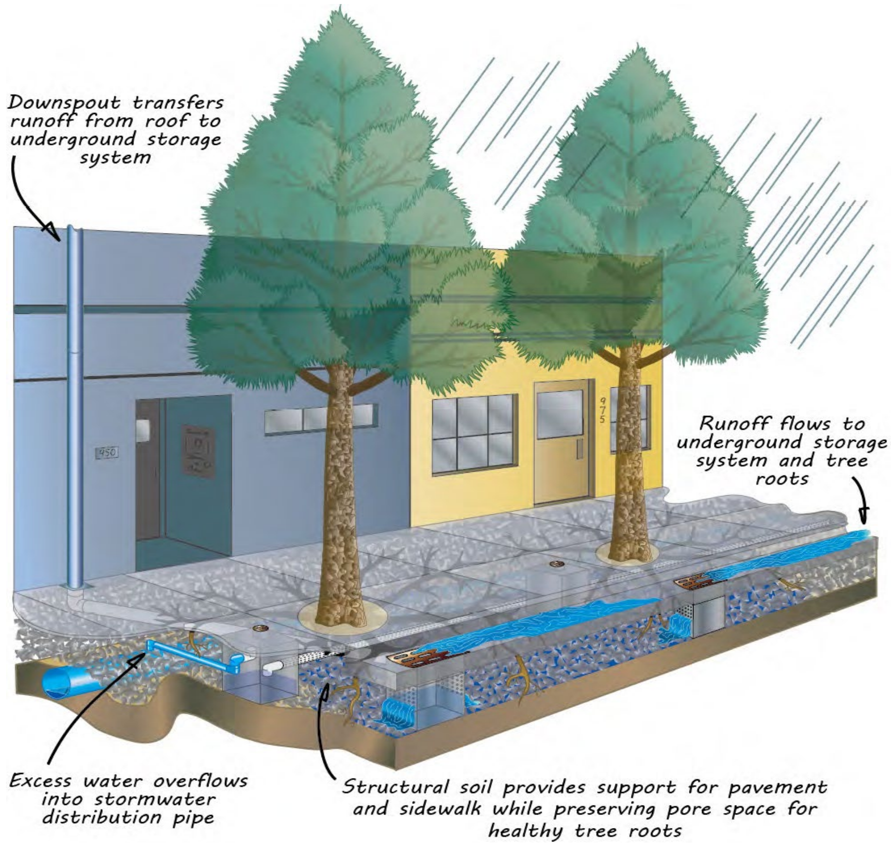


Figure 8: Structural soils are commonly implemented where trees are planted as a tool for stormwater management due to their increased porosity and decreased water-holding capacity, which allows water to quickly infiltrate the system (Solloway et al 2013).

Limitations

Although structural soils provide a solution for supporting load-bearing pavement, they have not been shown to increase the growth and health of the trees as much as suspended pavements or increased soil volumes. Buhler & Kristofferson (2011) compared four tree planting methods over a 15-year time period and found nearly identical growth rates for trees planted in conventional planting methods (i.e. compacted soil such as Missoula’s traditional tree wells), structural soil, and a sand-soil mix. Other studies have confirmed that trees planted in structural soils did not grow as much during the same time period as trees planted in suspended pavements (Smiley 2006).

Due to the abundance of rock components, structural soils have less water-holding capacity than conventional soils and might thereby require more irrigation and fertilization (Denig et al 2015). The higher rock content also means that a greater volume of structural soil is needed to achieve the desired amount of soil that is able to hold moisture and nutrients. Since 80% of the structural soil mixture is load-bearing rock particles and only 20% is actual soil, the Minnesota Stormwater Manual recommends that if using structural soils, the total soil volumes should be multiplied by 5 to obtain equivalent volume of usable soil for the tree (State of Minnesota 2019).

The increased infiltration rates of runoff through structural soils compared with traditional soils can also affect tree performance (size, rooting depth, & transpiration rates); therefore, not all species of trees are well suited for structural soil plantings, and it is recommended to use drought-tolerant species to ensure that adequate root distribution is possible given the increased drainage rates and decreased water-holding capacity (Bartens et al 2009).

Anecdotal evidence from prominent researchers in this field suggests that structural soils may have a shortened useful life compared to other types of soil if the same total volume of planting material is used. Urban, who has published numerous scientific papers, web blogs, and a book on this subject, reflected in a 2017 conference paper that "[my] personal observations of numerous gravel based structural soil installations in the US indicate that trees generally grow well at first (5 years), and then slow or decline as they reach the limits of the soil in the stone" (again, likely the result of the limited amount of soil compared to rock in structural soils).

Feasibility

Denig et al (2015) recommend that the same minimum volume should be applied to structural soils, like any other soil type (approximately 2 cubic feet per every square foot of the tree's projected mature crown spread), but if possible, higher volumes are preferable due to its decreased water-holding capacity (Denig et al, 2015). The Minnesota Stormwater Manual offers a different view, and states that 5x the amount of structural soil is required to give the tree the same usable soil volume.

Although there are no minimum length/width requirements for the soil installation, it is recommended to be used throughout "entire pavement areas," not just the tree pit itself (Denig et al 2015). This makes structural soils more feasible as part of larger-scale construction projects.

Structural soils can be used with both newly-planted and existing trees during retrofitting construction, as demonstrated in a case study in Ithaca, NY (Denig et al, 2015). In addition, they can be used in combination with the other methods discussed (e.g. structural soil underneath a permeable and/or suspended pavement) to further enhance tree benefits. Structural soils can also support other types of vegetation besides trees, and would have minimal impacts on the aesthetics of a place since they can be installed underneath any kind of pavement.

Although Cornell University was the first to patent and popularize this concept, there are now a variety of options for achieving this general result of adding stone to soil to promote its porosity while maintaining a load-bearing capacity (other examples include Carolina Stalite Company's porous expanded slate rock assessed in Smiley et al 2006, or mixtures of sand-structural soil assessed in Buhler & Kristofferson 2011). The process will require either amending or replacing the existing soil within a given area (including testing, mixing, transport, etc.). Cities may have a variety of options for purchasing pre-mixed structural soils from landscaping companies or potentially creating it themselves based on available guidelines. The Urban Tree Foundation offers options for creating soil mixes to achieve 3 levels of compaction based on what is deemed acceptable by the city (Gilman 2014). In the 2006 study by Smiley et al, mixing the soil/gravel mixture made it the most time-consuming of all 5 methods assessed, but this challenge could be remedied if a pre-mixed soil mixture was purchased rather than created onsite.

Currently, there is not a local supplier of the pre-manufactured structural soil near Missoula. Though there are local sources to obtain the raw materials (crushed stone, clay loam soil, and hydrogel). Based on recent project cost data, the City of Missoula Parks and Recreation staff estimated costs, including sourcing material, hauling, mixing and delivery to be around $150-$200 per cubic yard (Table 2).

Table 2: Current cost estimates to implement structural soils in Missoula

Tree Class	Planter Volume, cubic feet ($3.70-4.44/cu ft)	Planter Volume, cubic yards ($100-120/cu yd)	Total Cost/Tree ($)
Class I (Small, <30’)	2,500 (500*5)	92	$13,800-$18,400
Class II (Medium, 30-60’)	5,000 (1,000*5)	185	$27,750-$37,000
Class III (Large, >60’)	7,500 (1,500*5)	277	$41,000-$55,400

***Structural soils are composed of approximately 20% soil (usually clay loam) and 80% load-bearing gravel particles. In other words, the amount of structural soil used will represent 20% actual soil volume. When using a traditional 20-80 structural soil mix, it is recommended that five times the soil volume is used (State of Minnesota 2019).**

Current Usage

Structural soils are most frequently utilized in climatic regions with high rates of precipitation as a tool for stormwater management. Six communities, primarily in the eastern United States were documented using structural soils. Cities such as Brooklyn and Ithaca, NY; Olympia, WA; Birmingham, AL; and Blacksburg, VA, are currently using structural soils to plant trees.

Potential Usage in Missoula

This planting method is suitable for all classes of trees, but due to its decreased water-holding capacity, structural soils will require an increased level of caution with species selection or additional irrigation may be required. Bartens et al (2009) documented tree species that are tolerant of drought and flooding to be most conducive with the method; in Missoula's climatic conditions, red maple (*Acer rubrum*), hackberry (*Celtis occidentalis*), and American elm (*Ulmus americana*) are among these appropriate species.

Since structural soils can be used to fill planting spaces of any size or shape, as long as an adequate volume of soil can be provided, they are a good option for places where minimal changes in aesthetics are possible, such as historic areas or commercial areas with strict design requirements. Furthermore, because they offer significant benefits to stormwater due to their increased drainage rates, structural soils are suitable for use with trees planted specifically in a stormwater mitigation facility or in places where stormwater is currently creating a major problem for a City.

Uncovered Tree Planting Pits

Description

Uncovered tree planting pits are large, unpaved planting areas with large amounts of uncompacted soil. "Super planting pits" involve deep soil loosening (~4ft depth) and provides at least 525 cubic feet of soil, compared to a conventional tree pit which involves more limited soil loosening (~2ft) and provides around 68 cubic feet of soil (Buhler et al 2007).

Figure 9: Uncovered planting pits are implemented in areas with adequate space to increase tree performance and decrease damage to neighboring infrastructure.

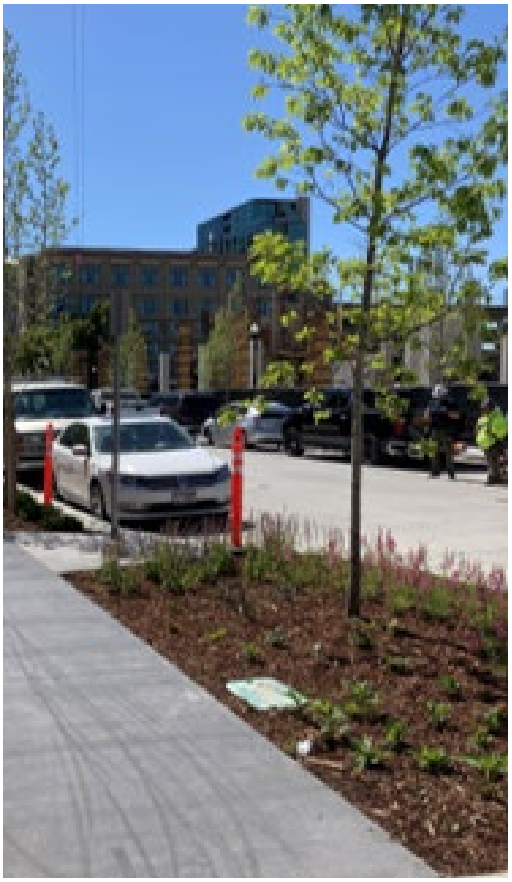


Figure 10: Example of a large, uncovered tree pit (Boise, ID).

Benefits

Uncovered planting pits require minimal structural interventions when compared to suspended pavements and structural soils (Urban and Simon 2013). Research has shown a positive relationship between the size of the planter space opening and tree size measured by diameter breast height and canopy area (Grabowsky and Gilman 2004). In addition, Buhler et al (2007) documented trees in "super planting pits" exhibiting increased tree growth rates and vitality when compared to trees in conventional planting pits with less soil volume.

Limitations

Uncovered planting pits require adequate above-ground space and must be located in areas with limited risk of compaction to the unsealed surface.

Feasibility

Uncovered planting pits do not require the installation of structural components and can be used with native soil. Therefore, they may be the least cost-intensive option but may not be feasible in densely developed areas with high amounts of impervious surfaces.

Current Usage

In addition to the literature, cities, both nationally and internationally, such as Bellevue, WA; Columbus, OH; Prince William County, VA; Kitchener, ON, CA; and Toronto, ON, CA, currently require uncovered tree planting pits with increased minimum soil requirements in their tree ordinances.

Potential Usage in Missoula

This planting method can be used for all classes of trees but may be better suited for less densely developed areas of the community and in new development where a greater right-of-way width is available. Several of Missoula's existing planters could be considered "super planting pits" (e.g., 3rd and Higgins). In addition, several projects in the Mullan- Sxʷtpqyen area currently in the design phase use this method with dimensions that meet Missoula's current soil volume standard for class 2 trees (8' wide by 15' long by 5' deep). Moving forward, expanding the amount of uncovered surface area of planting pits should be considered in new construction.

Supplemental Technologies

Permeable Pavements

Permeable pavements include pavers that exhibit interconnected pores that allow water and air to permeate through them, thereby promoting tree health (Morgenroth and Visser 2011). When used to supplement the other planting methods discussed, sites with permeable pavements captured the highest volume of surface runoff compared to the other methods alone (Solloway et al 2013). They were not selected as a primary method because they require application over a compacted sub-base or structural system. Permeable pavement systems require more ongoing maintenance than other planting methods and are typically not compatible with deicer or sand (Solloway et al 2013).

Root Barriers

Root barriers seek to lessen damage to other nearby infrastructure by installing a physical barrier on one or more sides of the tree's root system to prevent the roots from growing in that direction. Root barriers can significantly increase the lifespan of adjacent infrastructure by reducing the risk of nearby tree roots heaving sidewalks and curbs.

Air Gaps (aka "burrito wraps)

This method provides free–draining aggregate (granular material – 1 ½" to 3" washed rock) under sidewalks as an air gap and to ensure drainage and deflect roots thereby reducing infrastructure conflicts (Gilman 2006).

Roof Drains and Stormwater Inlets

Roof drains are designed specifically to divert rooftop runoff into planting areas (Solloway et al. 2013). Drainage and overflow factors should be considered during design. Stormwater inlets collect stormwater runoff as it enters the inlet. Large debris is filtered out before the runoff proceeds through the stormwater system to downstream uses. Stormwater inlets are effective in areas with significant amounts of impervious surfaces (EPA, 2021).

Figure 11: Example of a typical New York City planter with stormwater inlets (Deeproot).

Recommendations

Soil Volumes

When determining the use of any of the tree planting methods, the main concern is having an adequate volume of soil available for the tree. Increasing the planter soil volume can alleviate the challenges urban trees face by helping to reduce conflicts with other city infrastructure that is close in proximity. It also promotes higher rates of stormwater capture, nutrient cycling, tree stability, survivability, and growth. This aligns with the City's goal to grow large, healthy shade trees while minimizing conflicts with other infrastructure.

> ***"For satisfactory, long-term landscape performance, adequate soil volume must be provided."***
> ***- City of Missoula Parks & Recreation Design Manual***

Soil volumes are required in standards to ensure that trees are provided appropriate growing conditions (Urban and Simon 2013). In a summary of soil volume requirements for communities across the United States and Canada, the ranges of minimum soil volume required by municipal codes fell between 1 and 3 cubic feet of soil per square foot of tree canopy at maturity. The municipal requirements that aligned with industry best practices and can be visualized in Figure 12 (Solloway et al 2013). As tree DBH / canopy size increases, the amount of soil volume needed to adequately support the tree also increases. Likewise, studies have shown that as trees' available soil volume is increased, greater DBH and canopy sizes are possible (Solloway et al 2013).

"Assuming 2 cubic feet of soil per square foot of canopy, 1,500 cubic feet of soil would be able to support a 31 foot wide tree."
- Solloway et al 2013

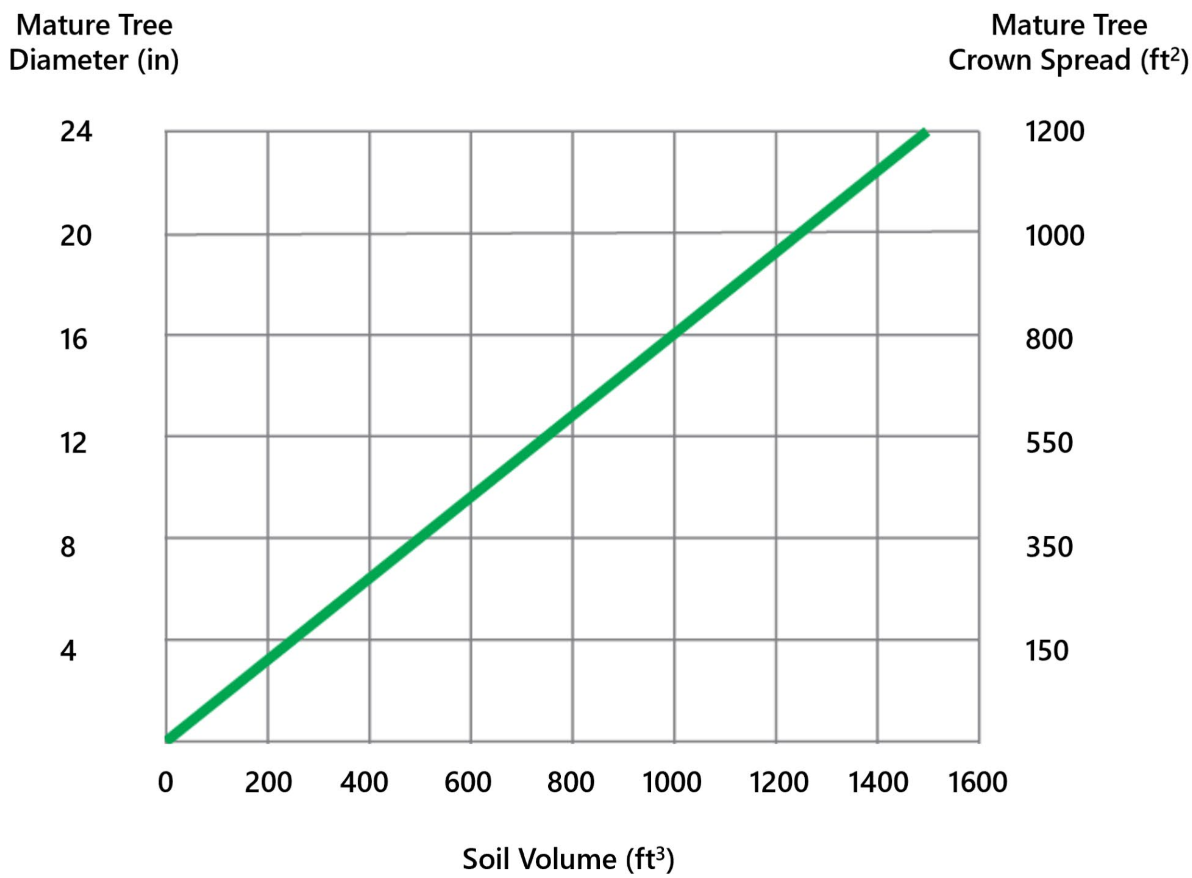


Figure 12: Soil volume requirements (adapted from James Urban (1992), Bassuk and Lindsey (1991), Solloway et al (2013), and others to determine a relationship between soil volume requirements and mature tree size).

Soil volume is calculated by determining the space available to fill with soil. Therefore, it does not include the components providing structure (for example, the gravel in structural soils). Missoula's current minimum soil volumes for trees are based on the class of the tree species and are specified in the current Missoula Parks & Recreation Design Manual (PRDM). The PRDM standards define soil volume and planter size required for all new street trees. Based on the literature review, Davey Tree Group recommends that the City of Missoula increase minimum soil volume requirements to meet national best practices and promote individual tree health (Table 3).

Table 3: Tree Planting Method and Recommended Soil Volume

	Design Specification (cubic ft, cubic yards)		Planter Volume (cubic ft)		
Tree Class Type (Average Height at Maturity)	Missoula PRDM (2018)	Industry Best Practice / Recommended Soil Volume	Suspended Pavement (Soil)	Structural Soil* (Soil/Gravel Mix)	Uncovered Planting Pits (Soil)
Class I (Small >30’)	150, 5.5	500, 18.5	500	2,500	500
Class II (Medium 30-60’)	600, 22.2	1,000, 37.0	1,000	5,000	1,000
Class III (Large >60’)	950, 35.1	1,500, 55.6	1,500	7,500	1,500

***Structural soils are composed of approximately 20% soil (usually clay loam) and 80% load-bearing gravel particles. In other words, the amount of structural soil used will represent 20% actual soil volume. When using a traditional 20-80 structural soil mix, it is recommended that five times the soil volume is used (State of Minnesota 2019).**

Currently, the general consensus amongst example communities and scientific literature is that an acceptable minimum landscape planter depth is 2-3 feet, though even greater success was achieved with 3-4 feet (Buhler et al 2007).

Conclusion

This literature review determined that suspended pavements, structural soils, and uncovered tree planting pits can be implemented based on the specific site requirements to achieve city goals to promote mature, healthy trees. These different approaches have unique benefits and limitations and will be suitable for application based on the unique site conditions and soil quality. Overall, suspended pavements were the most successful method where space limited the use of uncovered, large tree planting pits. Although the alternative tree planting methods have a greater initial cost (suspended pavements or structural soils) or require more unpaved surface area (uncovered tree planting pits) than conventional methods, the benefits received as a result will be greater in total value, realized more immediately, and experienced for a longer period of time.

Proposed revisions to the Parks & Recreation Design Manual, Municipal Code Title 12, and other City documents that reflect recommendations based on the findings in this report are included in a separate document.

Appendix

Missoula Background Documents Reviewed

- Parks & Recreation Design Manual (MPRDM, 2018)
- Missoula Municipal Code (MMC), Title 12: Streets, Sidewalks, and Public Spaces – Chapter 12.32, Comprehensive Tree and Shrub Planting, Pruning and Maintenance Regulations; and Chapter 12.48, Boulevards
    - MMC Ordinance 3043 (1997)
    - MMC Tree Planting Technical Appendix (1997)
- Missoula City Public Works Standards & Specifications Manual (MCPWSS, 2024): Appendix-2-A--Standard Modifications to Montana Public Works Standards and Specs
- Street Tree Planting List (2014; revised 2024)
- Tree Planting Standards
- Urban Forest Master Management Plan (UFMMP, 2015)
    - UFMMP Appendix (2015)
- Missoula City Strategic Plan (FY 2025-2026)
- 2035 Missoula Growth Policy (2015)
- Park Asset Management Plan (2014)
- Turf Management Plan (2014)
- FMRP Master Plan (2012)
- Active Transportation Plan (2011)
- Conservation Lands Management Plan (2010)
- Complete Streets Resolution (2009)
- Missoula Urban Area Open Space Plan (2006)
- Master Park Plan (2004)
- Traffic Circle Plant List

Example Cities

Table 4: Example City and New Soil Method Referenced

City	Planting Method(s) Implemented	Description
Annapolis, MD	Suspended Pavement with Permeable Pavement	Case study, cited by Urban 2007
Bellevue, WA	Increased Soil Volume, Shared Soil Volume	Required by city, cited as example in Minnesota Stormwater Manual, Environmental Best Management Practices & Design Standards 2020
Bethesda, MD	Suspended Pavement	Case study, cited by MacDonough 2011
Birmingham, AL	Structural Soil	Case study, cited by Denig et al 2015
Blacksburg, VA	Structural Soils (specifically in a stormwater facility)	Case study, cited by Bartens et al 2009
Boise, ID	Suspended Pavement	Required by city in Downtown Boise Streetscape Standards & Specifications Manual 2016
Boulder, CO	Permeable Pavement	Required by city in City of Boulder Design and Construction Standards, 2000
Brooklyn, NY	Structural Soil	Case study, cited in Denig et al 2015
Charlotte, NC	Suspended Pavement	Case study, cited by Solloway et al 2013, MacDonagh 2011, and Smiley 2006
Chattanooga, TN	Permeable Pavement	Case study, cited by Solloway et al 2013
Christchurch, NZ	Permeable Pavement	Case study, cited by Morgenroth & Visser 2011
Columbus, OH	Increased Soil Volume, Shared Soil Volume	Required by city in Downtown Streetscape Standards, 2015
Copenhagen, Den.	Structural Soil and Uncovered (“Super”) Planting Pits	Case study, cited by Buhler et al 2007

Emeryville, CA	Suspended Pavement (50 percent credit offered for planting areas under adjacent paving using 100% planting soil with Silva Cell or similar products)	Required by city, cited as example in Minnesota Stormwater Manual
Ithaca, NY (4 studies)	Structural Soil with Permeable Pavement	Case study, cited by Solloway et al 2013 and Denig et al 2015
Kitchener, ON, CA	Increased Soil Volume, Shared Soil Volume, Suspended Pavement (required in tree planting guidelines)	Required by city, cited as example in Minnesota Stormwater Manual
Knoxville, TN	Suspended Pavement	Case study, cited by Tirpak 2019
Langley, BC	Suspended Pavement (required in tree planting guidelines)	Required by city, cited as example in Minnesota Stormwater Manual
Minneapolis, MN	Suspended Pavement	Case study, cited by Solloway et al 2013 and MacDonagh 2011
Olympia, WA	Structural Soil	Case study, cited by Solloway et al 2013
Prince William County, VA	Increased Soil Volume	Required by city in Design Construction Manual Section 800, 2018
Toronto, ON, CA	Increased Soil Volume, Shared Soil Volume	Required by city in Toronto Green Standard V3, 2019
Toronto, ON, Can.	Suspended Pavement	Case study, cited by MacDonough 2011
Winnipeg, MB, CA	Increased Soil Volume, Shared Soil Volume	Required by city in Tree Planting Standards, Details and Specifications - Downtown Area and Regional Streets, 2022

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