Reducing Tree Root and Sidewalk Conflicts: Analysis and Strategies for the City of Palo Alto

Submitted to: City of Palo Alto

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CANOPY
20 YEARS

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1.0 Abstract

The conflicts between tree roots and sidewalks in Palo Alto are widespread, resulting in recurring expenses for repair, injurious practices to offending trees, and premature tree removals. Alternative solutions exist, but are not always utilized. This report presents potential solutions and management recommendations to reduce conflicts between tree roots and sidewalks. Evaluations of tree-based, infrastructure-based, and rootzone-based solutions are provided with cost comparisons and approximate expected useful life. Decision trees are recommended to enhance operations procedures in project planning and implementation. And finally, the solutions are grouped into Strategy Packages in order to inform decision-making at the early stages of Capital Improvement Plans (CIP), Development Review, and the Sidewalk Repair Program.

This document is intended primarily for internal use by the City of Palo Alto staff - Public Works, Planning and Community Environment, Utilities, Transportation, Parks and Recreation, and Development Services offices. The Urban Forestry and Engineering divisions within Public Works may use this as a resource for management and planning the Sidewalk Repair Program, CIPs, and other activities requiring street tree and sidewalk maintenance.

2.0 Introduction

The urban environment is a web of natural and built features interacting daily. The sun beats down on sidewalks, streets, and parking lots. Rain races off asphalt and saturated lawns into the gutters. Buildings bake in the summer and freeze in the winter. Cars zip around spewing fumes and exhaust. These are the daily workings of life in a city, and are all interrupted by an important piece of infrastructure - trees.

Trees are combatants of the urban heat island effect, providing necessary shade to streetscapes. Trees are interceptors of rainwater, providing stormwater retention for overloaded drainage systems. Trees are absorbers of air and water pollutants, improving health and wellness in neighborhoods. Trees are beautiful green canopies housing wildlife and improving the character of communities. Trees are an integral piece of green infrastructure surrounded by grey, and their benefits have grabbed the attention of leaders who are working to make them a priority in cities around the world.

The City of Palo Alto Urban Forest Master Plan Survey responses spurred the need for this study. When Palo Alto residents were asked what they do not like about the private and public trees around them, 51% responded “damage caused by tree roots” - the highest percentage out of all the options provided. Many Palo Alto city staff and residents are open to utilizing innovative solutions that will improve sidewalk conditions while simultaneously supporting long-term health and growth of trees.

The i-Tree streets analysis revealed that Palo Alto’s Benefit-Investment Ratio (BIR), which compares the cost of tree planting and maintenance to the annual benefits it provides, is 3.22:1. This high BIR means that for every $1 that the City spends on street trees, the City reaps $3.22 in benefits (Davey Resource Group, 2010). “Unlike traditional infrastructure, such as pipelines, buildings and roadways, urban forests appreciate in value over time, meaning a low-cost solution now in the form of urban forest investments becomes a long-term benefit” (American Forests, 2014). This is significant, because with every tree prematurely removed the City is losing benefits before return on investment can be fully achieved.

However, the services of trees do not outweigh the services of other city frameworks, because they enhance the quality of life for people by working together. In 2011 Palo Alto’s City Council adopted recommendations to reach a Pavement Condition Index (PCI) of 85 citywide as soon as possible. The Public Works Engineering group is aiming for a PCI of 60 or above for every street, and in order to achieve this goal they need to incorporate creative solutions that reduce conflicts between trees and infrastructure. In addition, the Americans with Disabilities Act (ADA) and the US Access Board Public Right-of-Way Accessibility Guidelines (PROWAG) provide guidelines and regulations that ensure sidewalks in the public right-of-way and public

spaces are accessible, continuous, unobstructed for people. These activities are of high priority for city staff and residents.

Palo Alto has over 29,000 street trees providing annual benefits of over $6.6 million ($103.73 per capita), and the Public Works Department's (PWD) Urban Forestry group is responsible for maintaining the trees in the public right-of-way. The annual investment required to care for these resources is around $2.1 million, but the community receives a net benefit of over $4.5 million in ecosystem services (Davey Resource Group, 2011).

The Public Works department also estimates that Palo Alto has over 250 miles of sidewalk, with the city's Sidewalk Repair Program costs exceeding $26 million over the last 29 years. The new sidewalk repair and replacement budget for fiscal year 2017 alone is $1.5 million. Requirements for ADA and PROWAG compliance mandate the PWD to uphold regulations for sidewalks in the public right-of-way, and to maintain these sidewalks per the Palo Alto Municipal Code.

This report offers potential solutions and management recommendations to reduce conflicts between tree roots and sidewalks. Many of these strategies and tools are being employed by other cities throughout the US, and each is provided with brief descriptions, cost comparisons, and the expected useful life. We also clarify processes and procedures currently used in Palo Alto, and offer sample decision trees and strategy packages.

3.0 Key Findings

At the beginning of this analysis, a conference call was held with City of Palo Alto staff and other urban forestry and arboriculture professionals from cities in California. To jump-start the exploration of potential solutions, the group members took turns listing familiar strategies, including alternative sidewalk base materials, alternative surface materials, and the importance of providing proper rootable soil and space for trees. Some strategies were specifically named, while others were deemed possible but needing more research.

Interviews were also conducted one on one in order to further understand Palo Alto's past and present processes and experiences with sidewalk and tree root management. Staff and Managers for the Public Works Department explained some of the relevant city processes and requirements for sidewalk maintenance and tree protection described below.

Literature review included influential publications and management documents from other cities. The Seattle Department of Transportation (SDOT) completed their Trees and Sidewalks Operations Plan in 2015, which presents the extremely relevant and up to date Solutions Toolkit referenced throughout this report. Reducing Infrastructure Damage By Tree Roots: A Compendium of Strategies by Larry Costello and Kristin Jones also elucidates many potential solutions and provides samples of standard drawings used in various cities. These, among some

other articles, provided the basis for the strategies listed and should be used for more information on specific solutions.

3.1 City of Palo Alto Public Works Sidewalk Repair Program

The City of Palo Alto Public Works Sidewalk Repair Program budget for Fiscal Year (FY) 2017 (July 1, 2016 - June 30, 2017) is up to $1.5 million per year with more emphasis on creating handicap ramps and addressing the backlog in sidewalk repair and replacement work. CIP for curb and gutter repair and replace is separate from the sidewalk repair, with a budget of $25,000 per year. Interestingly, it has generally been cheaper to do “piece by piece” sidewalk repair and replacement than doing a large area all at once.

In 1986 Palo Alto created a management plan that divided the city into 23 districts where all of the sidewalks were to be assessed and repaired over a period of 30 years. A Request for Proposal (RFP) for FY2017 will propose to contract out the sidewalk work and no longer work “District by District,” but likely work by highest priority across the city. A consultant will be selected to help review the previous management plan and recommend how the city should proceed into the future.

Jim Amores, City of Palo Alto Engineer, has overseen the Sidewalk Repair Program for the last 30 years, and had valuable insight and observations about the program. He has witnessed that the most common result of sidewalk and tree root conflicts included lifting at the expansion joints (concrete poured in lengths of 60 feet) and deep joints (located every 20 feet) in the sidewalk.

For the last few years, the process has simply been for the contractor to call Bill Croft (Urban Forestry Arborist) to inspect if the sidewalk repair/replacement requires special care while working around a tree. This case by case predominantly reactionary inspection process usually requires staff to visit sites multiple times per day on average. Instances of special care typically include determining whether to prune roots 4 inches or larger, increasing the sidewalk radius around the trunk (reducing the sidewalk width), or routing the entire new sidewalk section to be farther from the tree trunk (moving part of the sidewalk onto the adjacent property). Bill will also perform a pull test to determine if too many roots have been cut, and if so, will schedule tree removal and replacement by his crew.

Probably the most common “tree-centric” remedial method for sidewalk work is to saw the sidewalk to curve away from the trunk, which reduces the sidewalk width and increases the area in the planter. City staff and contracting companies doing the work have a Specifications (Spec) Book on site. The Spec Book specifies that PW Urban Forestry (Bill Croft) should be called prior to cutting any roots 4” or larger.

How does Engineering determine the fix needed (i.e. repair or replace the sidewalk)? Jim walks the sidewalk and spray paints areas that need repair, replace, or remove and no replace. If the sidewalk is raised by ¾ inch or more it is considered a tripping hazard and needs replacement. If the sidewalk is raised by ¼ inch to ¾ inch it is technically not a tripping hazard, and therefore must at minimum be ground down or beveled with asphalt. ADA requires that the minimum allowable sidewalk width is 4 feet, which limits available solutions in the field.

Oscar Godinez is the Manager of Maintenance Operations for the PWD Operations Storm Drainage, and he evaluates citizen complaints and performs "hot-spot" sidewalk grinding and other work that is outside of Jim's district. While many of his activities remain the most viable option for quick sidewalk repairs and short-term remedial treatment, they also present opportunities to communicate more with the public and install some alternative sidewalk materials.

3.2 Tree-based, Infrastructure-based, and Rootzone-based Solutions

Over time, most cities have come to incorporate trees in parks, along streets, and in subdivisions and commercial districts. And as city planning and maintenance practices evolve, urban tree experts have formed strategies to grow large-canopy trees that reap the maximum environmental benefits despite increasingly constrained environments.

Trees cause less damage when they are provided rootable space, quality soil conditions, and are situated far from hardscape. Conflicts between tree roots and sidewalks appear to be more related to growing conditions, tree age, and amount of rooting volume than to species (Randrup et al, 2003); therefore, most of the solutions listed address these problems. It has also been observed that sidewalk damage can occur without tree roots present, and roots can actually seek out these cracked areas after they are formed to take advantage of the air spaces (Syndor et al, 2000). Providing rootable soil under sidewalks can help roots to grow deeper, while alternative surface materials may reduce or prolong chance of pavement cracking.

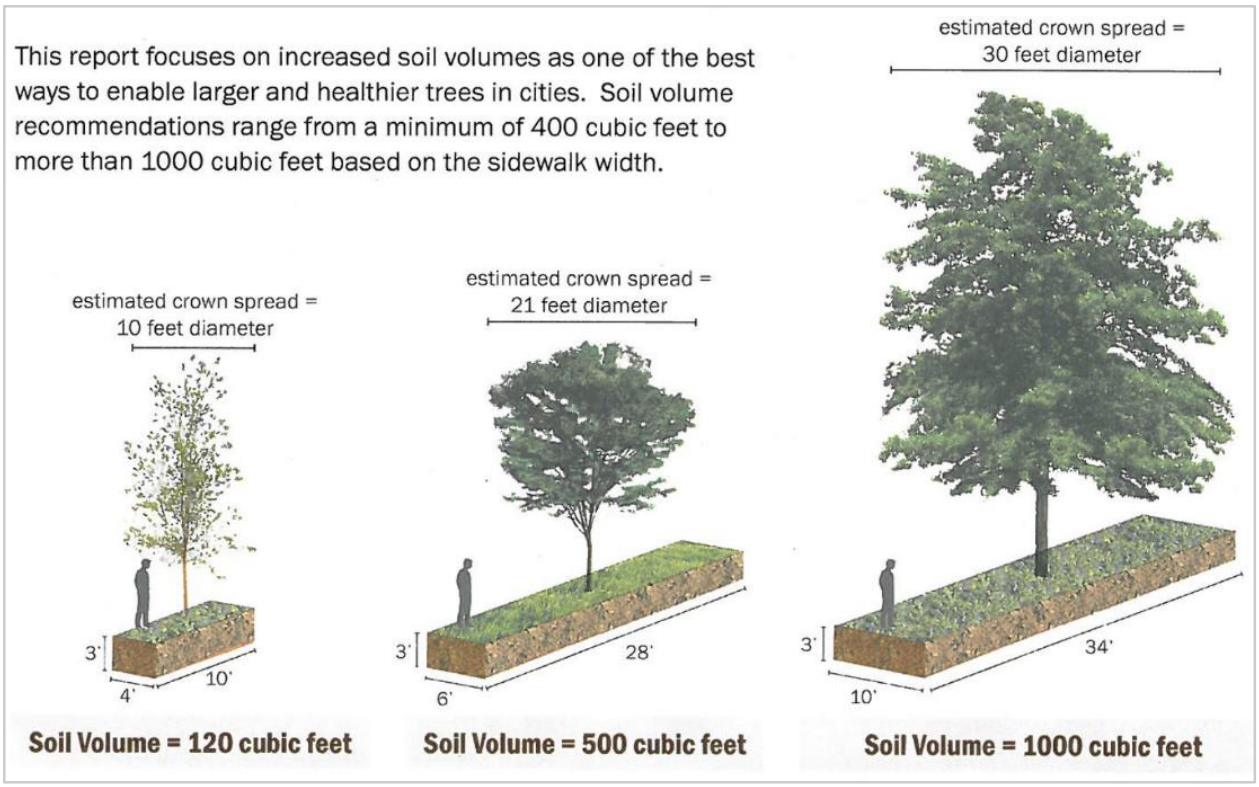


Figure 1. Recommended Tree Soil Volumes (Casey Trees).

The Seattle Department of Transportation (SDOT) completed a Trees and Sidewalks Operations Plan in February of 2015. The plan was developed through a process of thorough research, community outreach, and inter-departmental collaboration, producing a Solutions Toolkit found on pages 31-69 of the plan. The toolkit provides the necessary information about almost all of the recommended materials and strategies in this report. Find the full Solutions Toolkit at http://www.seattle.gov/transportation/treesandsidewalks_comp.htm or the pdf file directly at http://www.seattle.gov/transportation/docs/TreeSidewalksOperationsPlan_final215.pdf.

SOLUTIONS TOOLKIT

The purpose of this toolkit is to identify solutions that may be employed to plant and retain healthy trees and provide accessible, walkable surfaces. This toolkit was created as part of the SDOT Trees and Sidewalks Operations Plan for use by SDOT Urban Forestry and Street Maintenance. However, this toolkit may also be used as a resource for other Seattle departments and private developers or property owners seeking guidance on installation and maintenance of trees and sidewalks adjacent to their property.

This toolkit includes both tree-based and infrastructure-based techniques and materials to guide design, construction, and maintenance activities related to trees and sidewalks. The toolbox is organized into the following four categories and identifies each as:

P **proactive** (at new installations and major reconstruction)

R **responsive** (as part of maintenance)

MATERIAL **Paving and Other Surface Materials**
These materials can be used to create a walkable surface or to delineate space for people and/or the tree.

DESIGN **Infrastructure-Based Design Solutions**
These design considerations can be employed to support a tree and/or sidewalk.

ROOT **Rootzone-Based Materials**
These tools can support tree health and guide tree growth below the ground.

TREE **Tree-Based Solutions**
These solutions are focused on tree selection and tree maintenance.

For most projects, multiple solutions will be required to resolve existing conflicts between trees and sidewalks. Each solution includes the following information as applicable:

- Description of the solution
- Application for the solution
- When the solution should be applied and when it should not be applied
- Cost
- Expected useful life
- If the solution is currently in the standard plans, specifications, or ROWIM.

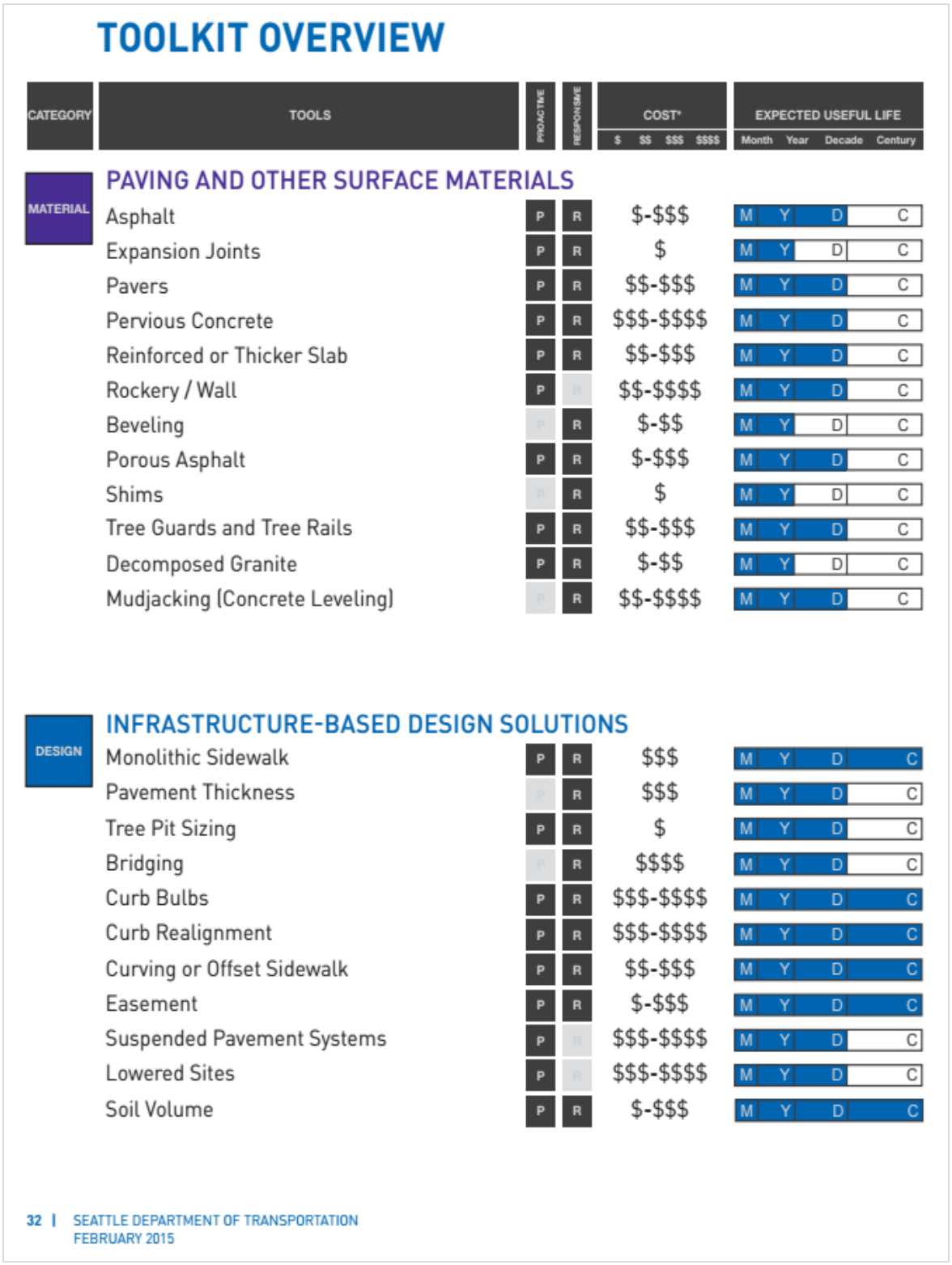
Many of these solutions are currently used by SDOT but have been updated in the toolbox with information collected during the best practices research. However, some of solutions are not currently part of SDOT's ROWIM or Seattle's Standard Plans and Specifications and will require further review and approval, potentially on a project-by-project basis. The use of some non-standard solutions may require the following actions by SDOT:

- engineering review;
- asset ownership agreements;
- maintenance regimens; and/or
- standardization.

There is a note on the left side of each tool summary page that indicates whether or not there is a City of Seattle standard or guidance for that tool.

The following pages contain a table of contents for the solutions toolkit.

Figure 2. Solutions Toolkit overview in the SDOT Trees and Sidewalks Operations Plan.



TOOLKIT OVERVIEW

CATEGORY	TOOLS	PROACTIVE	RESPONSIVE	COST* $ $$ $$$ $$$$	EXPECTED USEFUL LIFE Month Year Decade Century
MATERIAL	**PAVING AND OTHER SURFACE MATERIALS**				
	Asphalt	P	R	$-$$$	M Y D C
	Expansion Joints	P	R	$	M Y D C
	Pavers	P	R	$$-$$$	M Y D C
	Pervious Concrete	P	R	$$$-$$$$	M Y D C
	Reinforced or Thicker Slab	P	R	$$-$$$	M Y D C
	Rockery / Wall	P		$$-$$$$	M Y D C
	Beveling		R	$-$$	M Y D C
	Porous Asphalt	P	R	$-$$$	M Y D C
	Shims		R	$	M Y D C
	Tree Guards and Tree Rails	P	R	$$-$$$	M Y D C
	Decomposed Granite	P	R	$-$$	M Y D C
	Mudjacking (Concrete Leveling)		R	$$-$$$$	M Y D C
DESIGN	**INFRASTRUCTURE-BASED DESIGN SOLUTIONS**				
	Monolithic Sidewalk	P	R	$$$	M Y D C
	Pavement Thickness		R	$$$	M Y D C
	Tree Pit Sizing	P	R	$	M Y D C
	Bridging		R	$$$$	M Y D C
	Curb Bulbs	P	R	$$$-$$$$	M Y D C
	Curb Realignment	P	R	$$$-$$$$	M Y D C
	Curving or Offset Sidewalk	P	R	$$-$$$	M Y D C
	Easement	P	R	$-$$$	M Y D C
	Suspended Pavement Systems	P		$$$-$$$$	M Y D C
	Lowered Sites	P		$$$-$$$$	M Y D C
	Soil Volume	P	R	$-$$$	M Y D C

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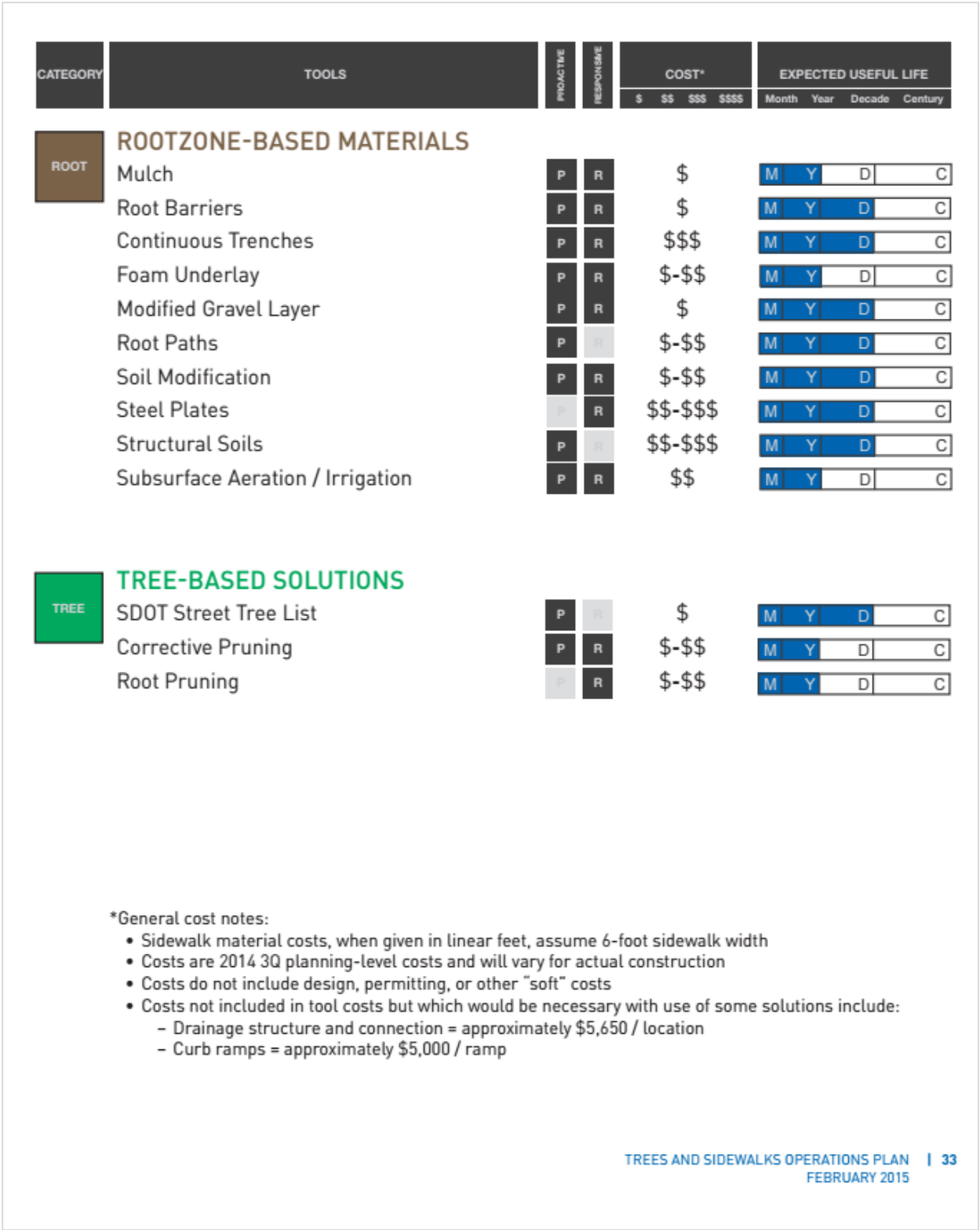
Figure 3. Solutions Toolkit overview in the SDOT Trees and Sidewalks Operations Plan (continued).



CATEGORY	TOOLS	PROACTIVE	RESPONSIVE	COST* $ $$ $$$ $$$$	EXPECTED USEFUL LIFE Month Year Decade Century
ROOT	**ROOTZONE-BASED MATERIALS**				
	Mulch	P	R	$	M Y D C
	Root Barriers	P	R	$	M Y D C
	Continuous Trenches	P	R	$$$	M Y D C
	Foam Underlay	P	R	$-$$	M Y D C
	Modified Gravel Layer	P	R	$	M Y D C
	Root Paths	P		$-$$	M Y D C
	Soil Modification	P	R	$-$$	M Y D C
	Steel Plates		R	$$-$$$	M Y D C
	Structural Soils	P		$$-$$$	M Y D C
	Subsurface Aeration / Irrigation	P	R	$$	M Y D C
TREE	**TREE-BASED SOLUTIONS**				
	SDOT Street Tree List	P		$	M Y D C
	Corrective Pruning	P	R	$-$$	M Y D C
	Root Pruning		R	$-$$	M Y D C

*General cost notes:

- Sidewalk material costs, when given in linear feet, assume 6-foot sidewalk width
- Costs are 2014 3Q planning-level costs and will vary for actual construction
- Costs do not include design, permitting, or other "soft" costs
- Costs not included in tool costs but which would be necessary with use of some solutions include:
  - Drainage structure and connection = approximately $5,650 / location
  - Curb ramps = approximately $5,000 / ramp

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Figure 4. Solutions Toolkit overview in the SDOT Trees and Sidewalks Operations Plan (continued).

Today more than ever before, there are publications and websites providing potential ways to reduce conflicts between tree roots and infrastructure. Below is the list of tools/strategies with brief descriptions, cost estimates (feasibility), and useful life expectancy (longevity) from the SDOT Solutions Toolkit. Each one can be classified as a preventative strategy (prevents damage), remedial strategy (corrects damage or avoids further damage), or both. Both types should be incorporated into management plans for a multidimensional approach to management of sidewalks and the urban forest.

Many of the tools in the toolkit are still being developed and researched, and some are just starting to be employed in Palo Alto. Alternative surface materials are also scarcely used in Palo Alto, which forces staff to rely on consumer experiences from other cities with different environmental influences. Therefore, many of these alternatives in the toolkit need to be carefully considered before selection on a case by case basis, at least in the first few trials. Below are the most feasible, promising, and cost-effective tools.

3.2.1 Tree-based solutions

Tree-based solutions, such as species selection and root pruning, focus on action to the tree to reduce potential for conflicts between trees and infrastructure.

1. **Species selection**

Species selection is a critical step in determining an appropriate tree for a site with minimal future sidewalk conflicts. Selecting trees that are most appropriate for a site should consider constraints such as overhead wires, underground utilities, planter width, required clearances, and sometimes adjacent property owner preference.

Tree species selection should also account for trunk-flare and root buttress characteristics. Trunk Diameter at Ground Level (DGL) varies by species, so if the tree trunk has a high DGL and/or trunk diameter ratio (TDR) it should only be planted in larger planter strips (greater than 3’ wide and in landscaped areas only). Reference pages 9-13 of Reducing Infrastructure Damage By Tree Roots: A compendium of Strategies for the DGL Test Survey based on reports from cities in the San Francisco Bay area.

Of the 230 distinct tree species in the right-of-way in Palo Alto, southern magnolia (*Magnolia grandiflora*) and sweetgum (*Liquidambar styraciflua*) alone make up 23% of the population. These species pose a significant challenge because they tend to litter the sidewalk with large debris and surface roots are aggressive and crack and uplift sidewalks. City staff may see these trees as a nuisance because they have caused recurring issues needing repair, but they also present an opportunity to test remedial methods. Additionally, their premature removal may

present opportunities to replant with more suitable species and adjacent infrastructure that prevents future negative impacts.

Figure 5. Camphor (Cinnamomum camphora) (left) and cork oak (Quercus suber) (right) have expanded and outgrown their narrow and small planting areas in downtown areas. Remedial treatments (sidewalk width reduction and removal) have been employed so far (Palo Alto).

2. Root pruning

Root pruning is a common occurrence when tree roots are uplifting or cracking a part of the sidewalk that is slated for replacement or repair. Knowledge and understanding of the proper pruning tools, distance from trunk, timing, frequency, age and condition, trees/conditions to avoid, and species selection to avoid root pruning are critical to effective decision-making. City arborists inspecting root pruning activities determine the threshold for root pruning, which is a challenging task requiring careful consideration of important variables.

Root pruning may also be used to prevent future damage, but should not be used if the arborist determines that it would significantly impact health or structural integrity of the tree. These

decisions can be difficult to discern, therefore additional staff training and/or field protocols may add another layer of assurance that best practices are being applied.

Figure 6. City of Palo Alto uses their air spade to employ minimal impacts during tree root excavation prior to determining allowable root pruning.

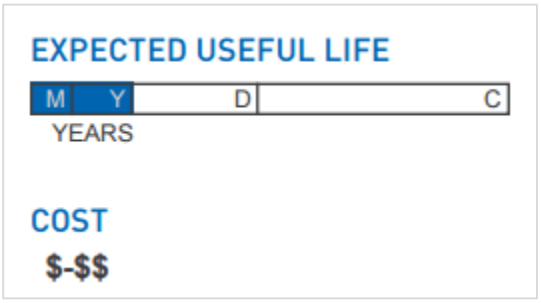

Figure 7. SDOT estimate of expected useful life (number of years the solution will be effective) and cost of root pruning.

3.2.2 Infrastructure-based solutions

Infrastructure-based solutions focus on wise design and materials to reduce conflicts. Two main strategies include designing planting spaces that are large enough to reduce the proximity of trees and infrastructure, and using materials that increase the tolerance of concrete cracking/lifting or replacing concrete with alternative materials.

<u>Design modifications to tree space</u>

1. **Increasing planting space**
    a. Tree pit sizing should allow adequate room for trunk and root growth for the species of tree being planted. Enlarging tree pits where a tree has outgrown the area by removing and not replacing hardscape is a viable strategy that Palo Alto currently uses in some areas.

Figure 8. Example of Sidewalk Repair Program marking cracked/lifted concrete adjacent to a street tree to be removed and not replaced in order to increase the planter length (Palo Alto).

Figure 9. Example where street trees share a continuous planter strip, and landscape trees are set back with a large landscape area for root growth (Palo Alto).

2. **Curving sidewalks**
    a. Curving sidewalks can be used to meander around planting areas to give trees more space to grow. They are best used around high-value trees and where there are numerous planting areas, so it should not be used where space is limited in the right-of-way.
    b. Increasing the radius of the sidewalk around an existing tree is a common practice in Palo Alto. This practice benefits the tree to an extent, but may have to be revisited for future root pruning if the tree/roots continue to grow. Fortunately, if the tree has to be removed, the replacement will automatically have a larger planting space for trunk growth.

Figure 10. Example of contact stress response with growth over the sidewalk (left) and an example of a different tree with an increased curve radius (right) to accommodate future trunk growth to hopefully reduce likelihood of future contact (Palo Alto).

Figure 11. City curved the sidewalk around the mature oak's trunk to provide extra space (Palo Alto).

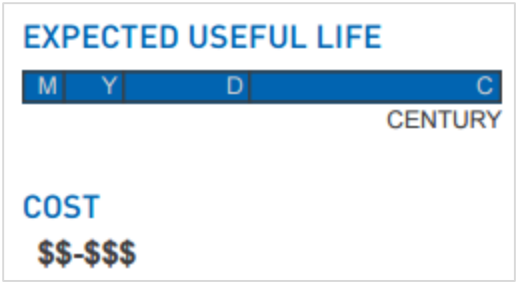

Figure 12. SDOT estimate of expected useful life and cost of curving sidewalks.

3. **Pop-outs/bulb-outs**
    a. Radial extensions of a sidewalk at an intersection shorten the crossing distance for pedestrians and thereby make walking safer. They can also serve as stormwater treatment and tree growing areas. Using pop-outs/bulb-outs in these public improvements provide a larger rootable area while benefitting public safety, water management, and improving the aesthetic quality of streetscapes.

Figure 13. Example of Bioretention planter bulb-outs in Southgate neighborhood (Palo Alto) that could potentially incorporate trees in the future.

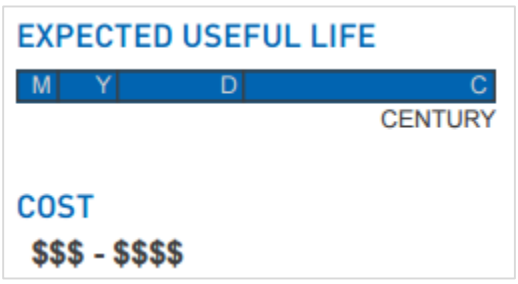

Figure 14. SDOT estimate of expected useful life and cost of bulb-outs.

4. **Monolithic sidewalks**
    a. Monolithic sidewalks are a continuous installation; therefore, there is more weight to resist the uplift of tree roots. It is a more long-term solution, but should not be used near trees with future vigorous root growth. Numerous neighborhoods (especially in south Palo Alto) have monolithic sidewalks, which enables new trees to use soil into larger yards and landscaped areas. However, trees planted behind monolithic sidewalks are less likely to touch canopies across the street, which is a marked difference from many neighborhoods with planter strips.

5. **Tree islands**
    a. Tree islands group tree plantings into landscaped areas or in larger parking lot islands in order to facilitate tree growth in shared soil spaces. This design has the potential to grow larger trees for shading by grouping trees in a way that mimics a natural forest with shared soil for roots to grow (eg. Large trees seen in some medians along El Camino Real in Palo Alto). However, in some situations this design may compromise some above-ground space that would otherwise be used for parking and buildings and may not be aesthetically desirable for all architects.

6. **Easement (to increase right-of-way space)**
    a. Easements may allow construction of a sidewalk on private property in order to provide more space to existing or new street trees. This strategy can provide more space for the tree, but requires coordination between the City and the property owner. Palo Alto currently does not have a standardized easement acquisition policy.

7. **Suspended Pavement Systems (AKA Soil Cells)**
    a. Suspended pavement systems may be used in new tree plantings where there is not adequate soil volume for root growth. They provide structural support for placement and rootable soil for trees underneath the hardscape. Soil cell products can be more expensive than many of the other solutions listed, so they should be considered more often for CIPs and development projects where there is adequate funding and constrained sites that preclude open planting areas.
    b. The use of suspended pavement systems and structural soil are relatively familiar for use on commercial properties, but these alternative base materials are not always cost effective enough for use in public projects. For information about soil cell use in Palo Alto, reference the Mitchell Park Library and Community Center parking lot plan.

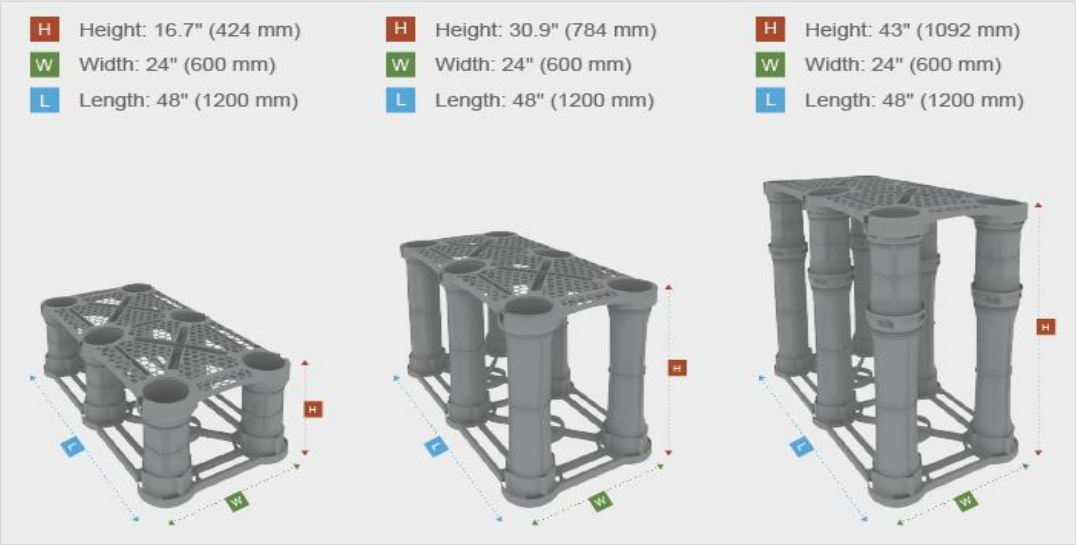

Figure 15. Deeproot Silva Cells

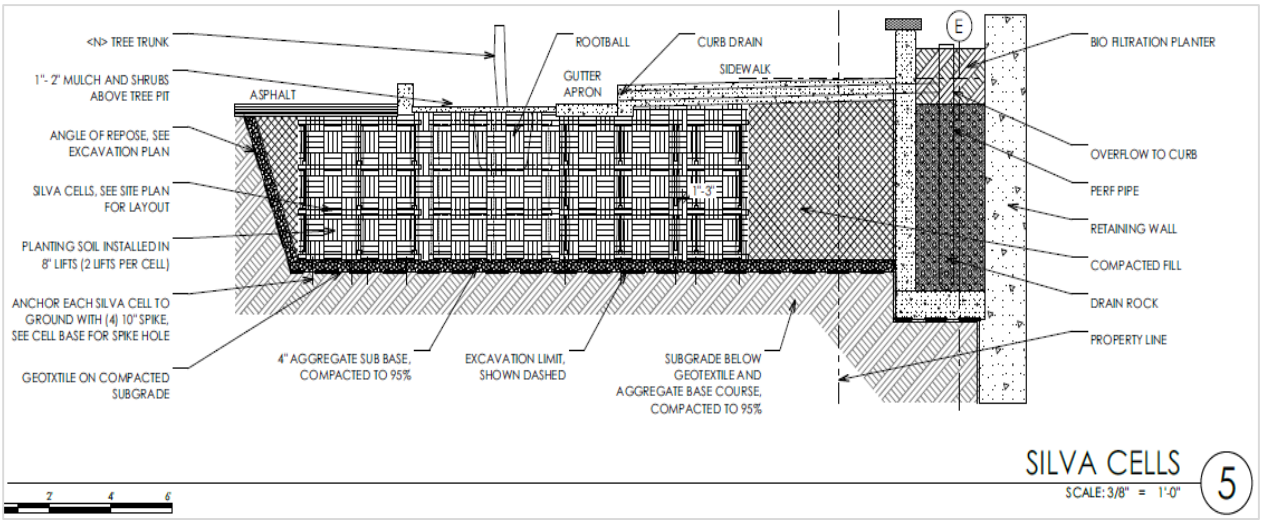

Figure 16. Cross-sectional view of Silva Cells under hardscape around new street trees during new commercial development project (2555 Park Blvd, Palo Alto).

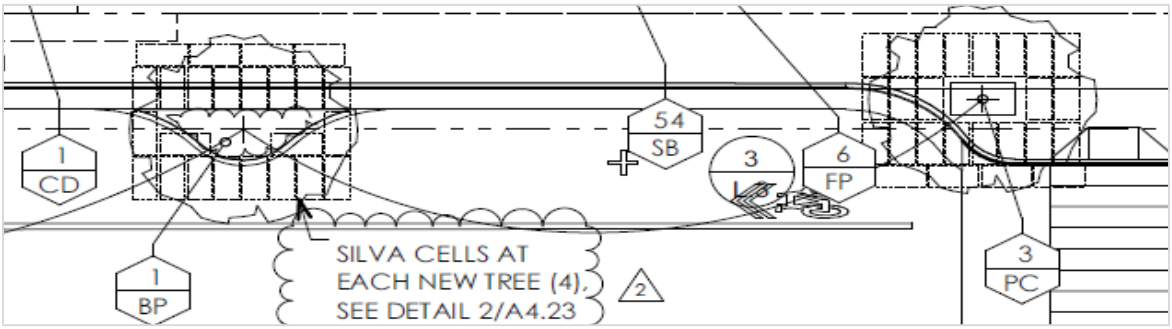

Figure 17. Overhead view of Silva Cell installation in public right-of-way under new trees to be planted in curb bulb-outs for new commercial development project (2555 Park Blvd, Palo Alto).

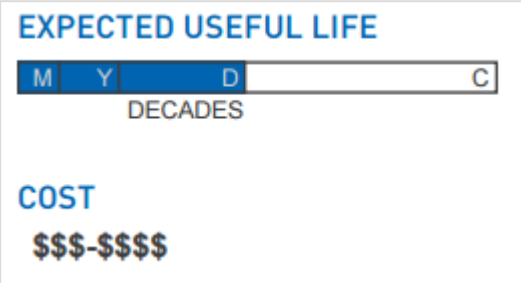

Figure 18. SDOT estimate of expected useful life and cost of suspended pavement systems.

8. **Bridging and Ramping**
    a. Bridging and ramping provide a grade separation between the sidewalk and root zone of a tree. Numerous techniques exist, including pier and beam bridges, cantilevered sections, and boardwalks. They are best used to preserve high-value trees while meeting ADA requirements. Bridging does have height and slope requirements (e.g. if drop to adjacent grade is greater than 18 inches then the bridge requires a handrail), and should be non-slip texture. Unfortunately, it can be expensive and there were no well-known specifications or details to build bridges over tree roots found during research for this report.

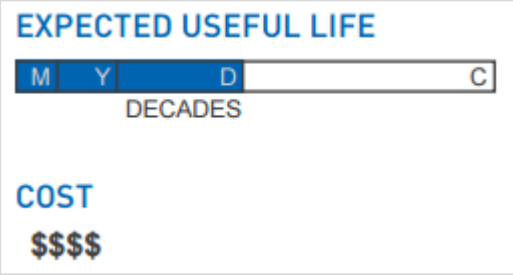

Figure 19. SDOT estimate of expected useful life and cost of bridging.

9. **Lowered sites**
    a. Lowered sites provide spatial separation between the finished grade of the planting pit and the surrounding sidewalk. Tree grates are often installed in conjunction with lowered sites to provide walkable surface. These are viable options for areas with high pedestrian volumes with little available planting space, such as the downtown areas of Palo Alto.

<u>Material modifications – paving and other surface materials</u>

10. **Expansion joints**
    a. Expansion joints may be strategically located near trees to reduce potential of differential lifting of slabs. Employ if roots can be pruned adjacent to the new slab, or if there is ample root growing area (eg. wide planter strip or tree is adjacent to a monolithic sidewalk). Should not be used adjacent to trees with vigorous root growth and if the goal is a long-term solution.

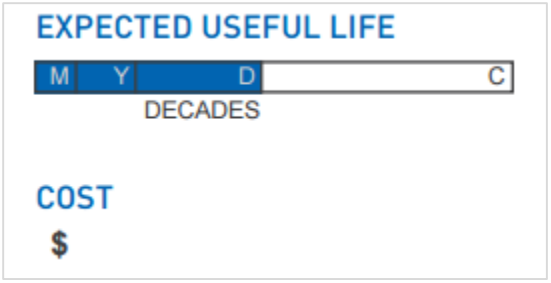

Figure 20. SDOT estimate of expected useful life and cost of strategically locating expansion joints.

11. Thicker slabs

a. A reinforced or thicker sidewalk can be used to help resist the uplift of tree roots. Reinforcing with steel rebar or wire mesh, or thickening to six to eight inches thick, may be used adjacent to trees with minimal future root growth and/or adequate soil volume. However, reinforced pavement may not be allowed in areas where future utility installation is required or the tree root growth is vigorous.

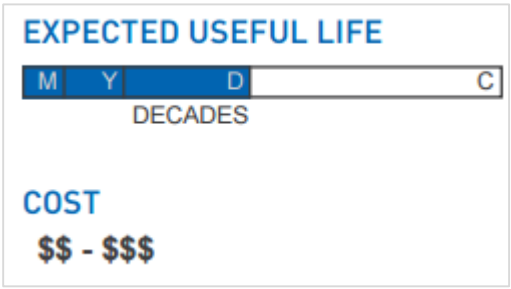

Figure 21. SDOT estimate of expected useful life and cost of installing a thicker concrete slab.

12. Grinding (beveling)

a. Grinding/beveling is a viable short-term solution with sidewalks lifted less than one inch. If the lifted portion of the sidewalk can't be replaced or removed at that time, beveling is often a cost-effective alternative widely used in Palo Alto.

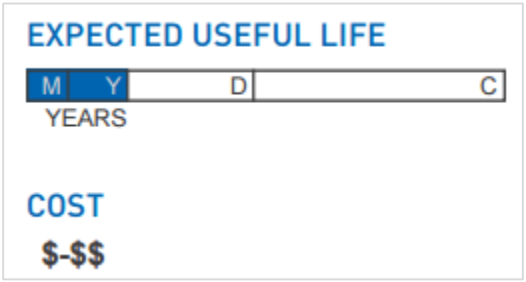

Figure 22. SDOT estimate of expected useful life and cost of beveling.

13. Decomposed granite

a. Decomposed granite (and in some cases mulch) may be used for paths/walkway surfaces in some residential areas and on top of soil in planting pits. Requires some maintenance and may be used in areas of low pedestrian traffic where there is another ADA-compliant route available nearby. Cost is relatively low, and may be used in areas such as Barron Park neighborhood, and in landscaped areas/parks.

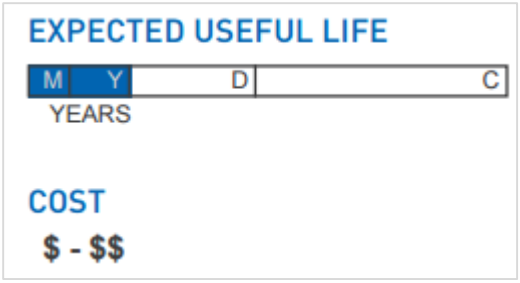

Figure 23. SDOT estimate of expected useful life and cost of decomposed granite.

14. Asphalt shim (wedge)

a. Asphalt shims (or wedges) are used for temporary or interim measures to treat cracked or lifted sidewalks. This spot treatment may be used when grinding will not make the sidewalk a safe height, or if removal/replacement are not available options at the requested time.

Figure 24. Example of asphalt shim used next to street tree (Palo Alto).

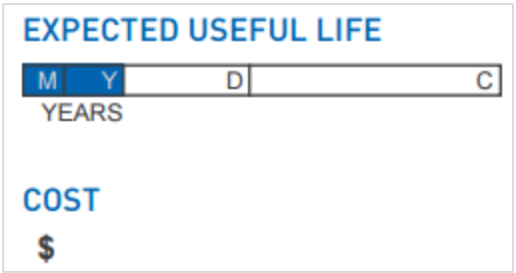

Figure 25. SDOT estimate of expected useful life and cost of asphalt shims.

15. Porous asphalt

a. Porous asphalt allows water to pass through the pavement. It is best used if installed along long corridors where concrete sidewalks cannot be constructed and water infiltration is desired. It should not be used for short segments or if short-term solutions are desired adjacent to existing trees.

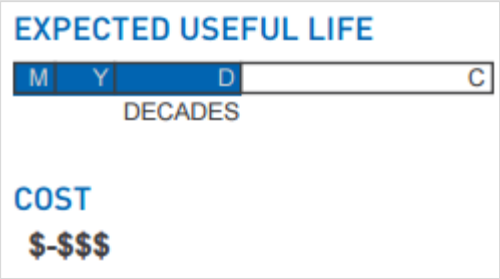

Figure 26. SDOT estimate of expected useful life and cost of porous asphalt.

16. Pervious concrete

a. Pervious concrete allows air and water to pass through to the soil and bedding layers below, so it is meant to deter shallow root growth that could uplift regular concrete. More likely to be used in parking lot areas rather than public sidewalks adjacent to street trees because it is difficult to repair/replace (poured in place). See Mitchell Park Library parking lot for example adjacent to landscaping/stormwater treatment areas.

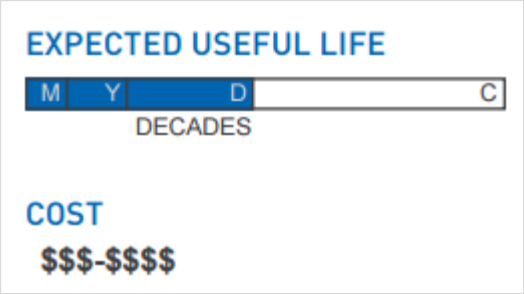

Figure 27. SDOT estimate of expected useful life and cost of pervious concrete.

17. Pavers

a. Pavers come in many materials, colors, and shapes in order to meet different objectives and site requirements. Rubber sidewalk pavers provide a more flexible surface than concrete, which in many cases are modular and may be applied adjacent to trees and pulled up for periodic root pruning and laid back down. Non-rubber pervious pavers and permeable pavers are often used when stormwater infiltration is needed, and can be used to cover large or small areas. Maintenance needs and durability varies by product, but overall pavers should be avoided when the sidewalk is curved or there are many utility structures that the pavers have to be cut around.

Figure 28. Site preparation prior to rubber sidewalks (Terrecon, Inc) installation adjacent to existing trees for a new walking path (University Circle, Palo Alto 2016).

Figure 29. Close-up view of rubber sidewalk installation (University Circle, Palo Alto 2016).

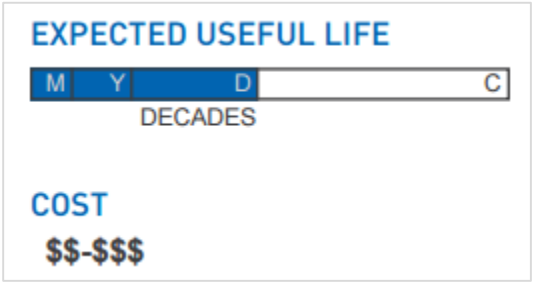

Figure 30. SDOT estimate of expected useful life and cost of pavers.

18. Terrewalks®

a. Terrewalks® are modular sidewalks that can be installed as a permanent or temporary alternative sidewalk surface material. They allow water infiltration and are made to match typical sidewalk aesthetics. The modular style may enable future maintenance by simply lifting the pieces, and can be reused at different sites if employed as temporary sidewalk in areas where needed.
b. These are a financial investment, so City staff should perform cost-benefit analysis to determine if these are worthwhile compared to other strategies.
c. Additional information can be found on the Terrecon website.

Figure 31. Photo of Terrewalks® installation in Galveston, Texas.

3.2.3 Rootzone-based solutions

Rootzone-based solutions focus on directing (guiding) roots away from infrastructure or creating conditions that encourage greater root distribution.

1. Root barriers

a. Root barriers are physical barriers (commonly plastic sheeting or interlocking panels) installed from surface level to a depth of 12 to 24 inches or more. They are intended to deter root growth near the surface, and are fairly inexpensive. They should not be installed adjacent to planting areas where the roots are meant to grow (eg. adjacent to root channels, suspended pavement systems, or large open planting areas). Typical placement is vertical.
b. Barrier types include deflectors, inhibitors, and traps.
c. Barrier configuration can be linear or circular. Linear is preferred in most cases.

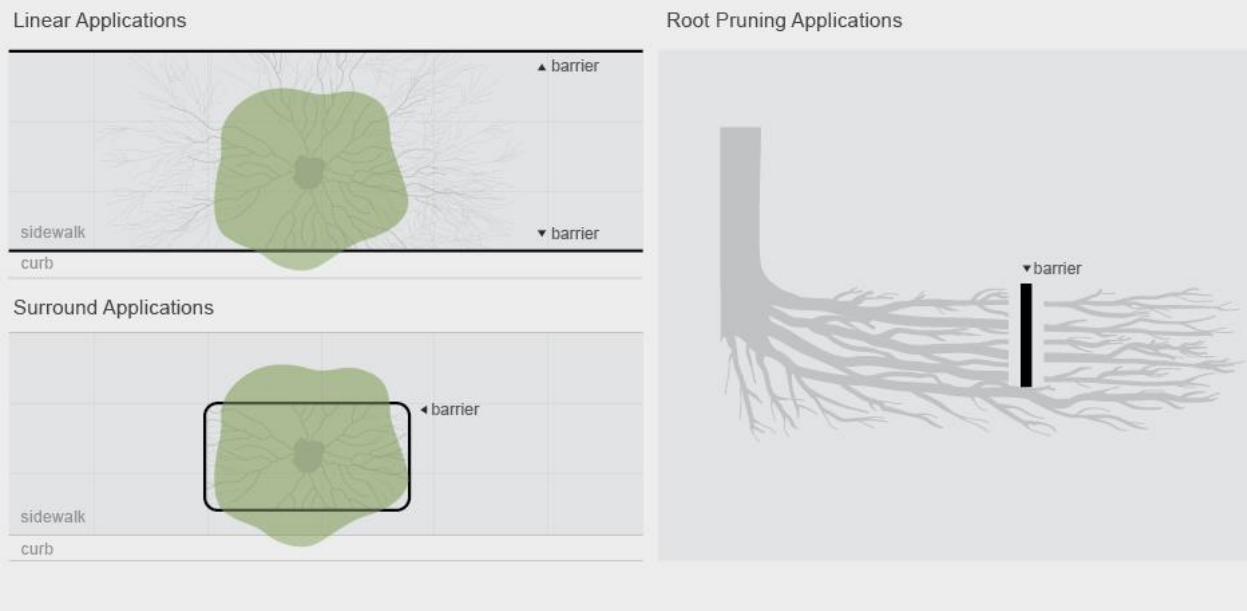

Figure 32. Deeproot linear and surround (circular) root barriers.

Figure 33. Deeproot linear root barriers of various depths.

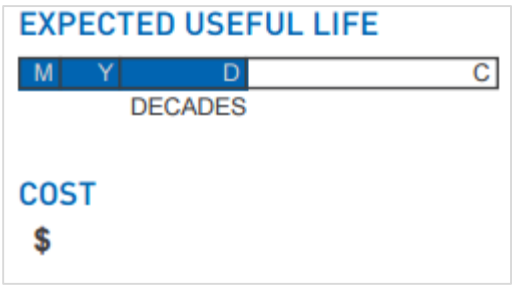

Figure 34. SDOT estimate of expected useful life and cost of root barriers.

2. **Root paths**
    a. Root paths are narrow trenches, roughly 4 inches wide and 12 inches deep, installed in compacted subgrade before the gravel base for pavement is added. Root paths may be installed for new plantings, in areas where tree roots should be guided around utilities in constrained sites, and as a measure to improve site conditions for mature high-value trees.

Figure 35. Root path installation radiating out into parking lot to improve the root zone of a high-value tree (Palo Alto).

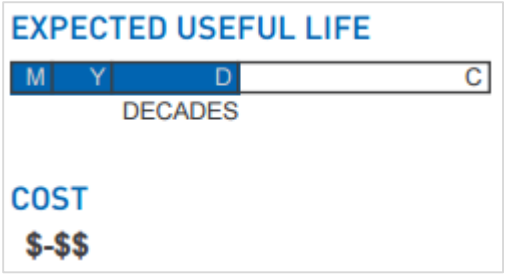

Figure 36. SDOT estimate of expected useful life and cost of root paths.

3. **Structural Soils (as a continuous trench)**
    a. Structural soils are specially designed to provide nutrients, space, and porosity to accommodate root growth while enabling compaction to support pavement without settling. It may be placed to adequate depths to enable root growth downward and into the soil (usually between 24 inches and 36 inches deep).
    b. Engineered Soil Mix (ESM) (Palo Alto's structural soil) is being required as a root channel sidewalk base under public sidewalks at many sites in Palo Alto when new street trees are to be planted as part of development projects. Specifications are already being drafted by city staff, and this also provides an opportunity to modify City policy to require this at more sites.
    c. Cost comparison:
        i. ESM: about $34/cubic foot in 2015 for mix and delivery
        ii. Regular soil: $29/cubic foot in 2015 for mix and delivery

Figure 37. Engineered Soil Mix in trench during installation (left) and equipment used to compact the ESM for engineering standards (right).

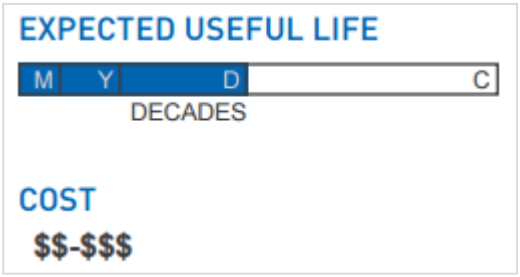

Figure 38. SDOT estimate of expected useful life and cost of structural soils.

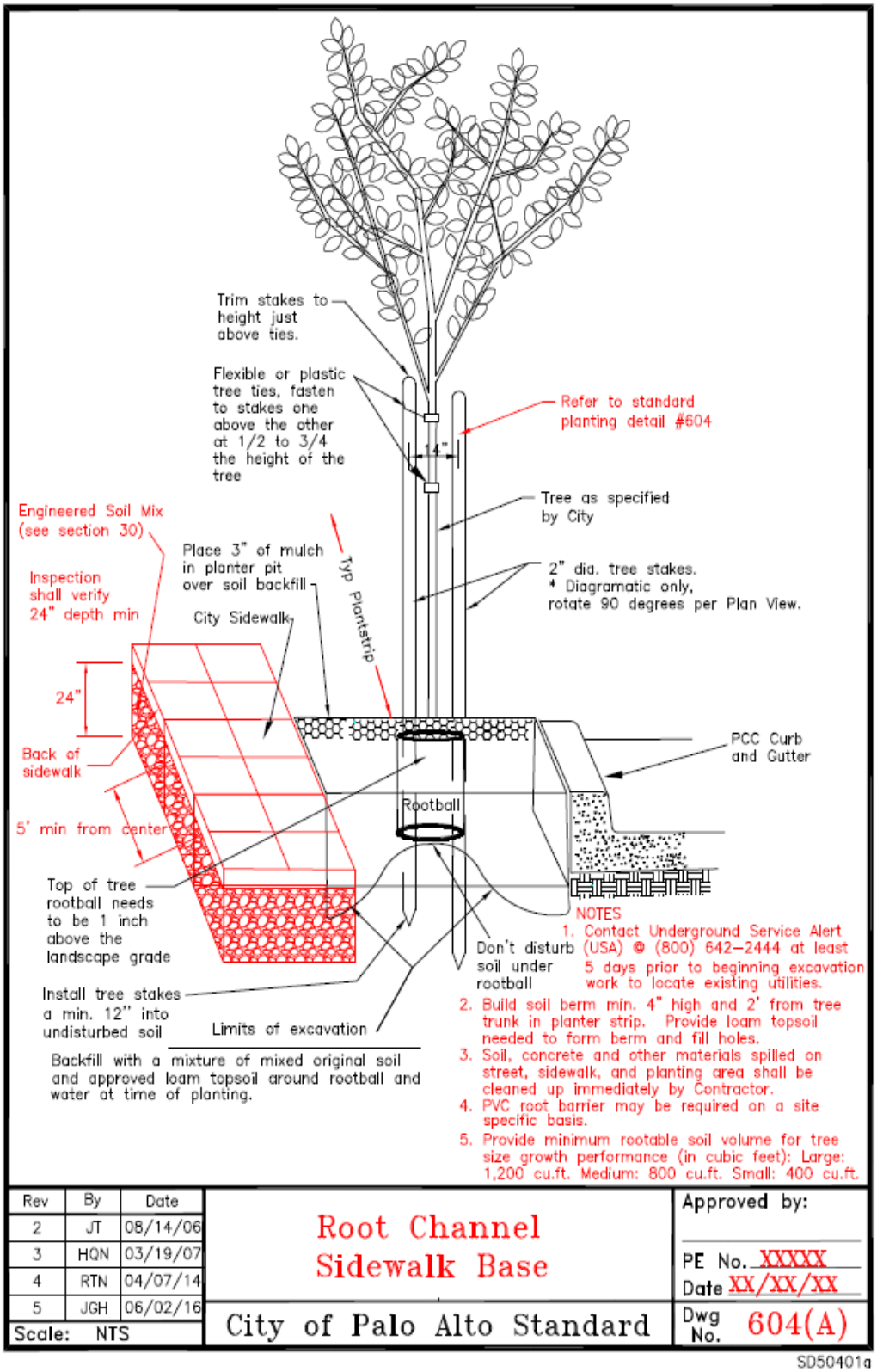

Figure 39. Draft of a new City of Palo Alto standard detail of a root channel sidewalk base.

4.0 Recommendations

Sustainability and development trends are influencing management strategies across Palo Alto, thereby necessitating an upgrade of the toolbox for City staff. The daily processes for decision-making were reviewed and may be improved through recorded and easily accessible decision trees. With each course of action to be taken, best management practices should be employed by involved city staff and contractors. Lastly, we recommend strategy packages to be used for consideration at the early planning stages of Capital Improvement Projects, Development Review, and the Sidewalk Repair Program.

4.1 City Processes, Planning, and Prioritization

City departments should consider tree health and maintenance one of the top priorities during any work on sidewalks and other surrounding infrastructure. Taking time to evaluate actions that preserve existing trees when encountered and incorporate trees in the early planning stages of projects pays significant dividends over time.

Prioritizing trees can be challenging on constrained sites and streets, but there are opportunities throughout Palo Alto to incorporate innovative strategies and new materials. The Green Infrastructure Permit Plan is calling for solutions that will accomplish goals for managing stormwater and trees. Exploring use of pervious pavers strategically rather than in random small sites opens options throughout parking lots or piloting use on larger street and sidewalk sections. Public Works can coordinate activities with Parks and Recreation for maintenance on medians, and work with project managers for landscaping on other public property.

Figure 40. San Pablo Avenue in Cerrito, CA with surplus of pavement and no trees (top) and the new trees and biotreatment installed in 2011 (bottom).

Communication between Urban Forestry and Transportation may be enhanced by sending an arborist representative to the Project Kickoff Meetings that happen for all new transportation CIPs. And there is an open invitation to join the monthly "Coordination Meeting" between Public Works, Utilities, and Transportation, in which projects are discussed between departments so everyone knows the upcoming work and avoids issues.

CIPs are currently being evaluated by City staff to determine where there is green infrastructure potential. Trees have greater potential for long-term growth when they are prioritized at the early planning stages of a project. Implementing "complete streets" principles is not a thing of the future, because today smart street design is in the news daily, with trees as an integral piece of the streetscape.

In addition, many cities including Palo Alto are considering the effects of climate change when selecting species for new plantings, with emphasis on native and drought-tolerant species throughout California. When reviewing “thirsty” trees that make up a significant percentage of the street tree population in Palo Alto, staff should include long-term feasibility when determining appropriate removal and replacement.

Figure 41. Palo Alto street (downtown) where complete street principles were incorporated to provide a new safe bike lane, planter strip with trees, and stormwater management through cuts in the concrete.

The Urban Forestry group should use GIS and TreeKeeper to track uses of alternative solutions and recommend sites for future use of the toolkit. Creating forced dropdowns in TreeKeeper for work history can be a part of the decision process to clearly track all approved activities around trees such as root pruning, curved sidewalks, adjacent pavement removal, etc. In addition, sites with potential use of new sidewalk material or shape may be listed and uploaded to GIS for other departments to see when planning work in the right-of-way.

Another key component to effectively integrating trees into other city plans and priorities is to include stakeholders. These processes should be transparent and up-to-date for the public. The city website should be updated to notify people of the public projects and tree removals and include opportunities to give their input through open response portals. In addition, by posting links to the toolkit and best management practices online, people can be knowledgeable about opportunities and be more informed throughout the public outreach process.

4.2 Decision Trees and Best Management Practices

Decision trees and Best Management Practices that are easily accessible enable City staff, contractors, and the public to better understand and interpret procedures used to determine tree and sidewalk solutions.

4.2.1 Decision Trees

There is currently a very general procedure that the Public Works Department uses for the Sidewalk Repair Program, which may be improved by recording the steps and evaluations made during site assessments. CIPs will also benefit from more detailed guidelines for choosing solutions that reduce conflicts between trees and sidewalks at the early stages of project planning and design.

In order to clarify the typical processes and make them more transparent and consistent for staff and the public, the following diagrams may be used to highlight key decision points. See below for a summary diagram and the Appendices (7.1) for more detailed decision trees. The decision trees are intended to work for projects on many scales, including spot treatments, corridor projects, and more. Program managers should use this process to plan for the necessary time and resources that are needed to promote tree canopy growth and accessible sidewalks.

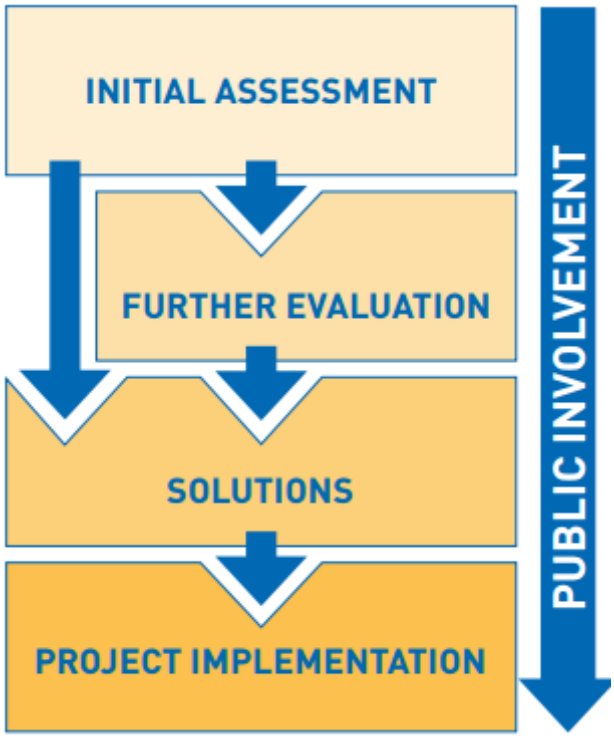

Figure 42. SDOT Trees and Sidewalks Operations Plan Decision Process flowchart.

Initial Assessment requires the Program Manager to collect tree information no later than the 30% design or equivalent level. Tree preservation potential, tree mitigation exploration, and public safety risk should be key components of this analysis. See section 7.1 for the sample Initial Assessment Form used in Seattle.

Initial Tree Decision requires that an engineer and arborist/landscape architect be together at the site (ie. project location) to facilitate coordination and sharing information between experts in the field. They must review the information collected and identify an action to move forward. Actions include removing the tree and replacing the sidewalk, keeping the tree and maintaining the sidewalk, or evaluate further. If the tree is unhealthy or hazardous, it should be replaced in accordance with the Tree Technical Manual Canopy Replacement Standard (Section 3.20) or minimum 1:1 replacement ratio. Planting should be in the same location, on the same street, or as close as geographically feasible. If the tree is to be kept and sidewalk maintained, staff should identify the targeted sidewalk maintenance cycle, estimate cost to achieve lifecycle for repair, and any tree maintenance needed. The third option, evaluation of the tree and/or sidewalk further, may be necessary if initial assessments are limited by time or necessary information. Identifying areas for future actions enables program managers to properly plan the schedule and budget to assess alternative approaches (ie. alternative sidewalk materials, adjustments to the tree pit, etc) at problem locations.

TABLE 3-1

Tree Canopy - Replacement Standard

COLUMN 1	COLUMN 2	COLUMN 3
Canopy of the Removed Tree (Avg. dist. across the canopy*)	Replacement Trees	Alternative Tree
4'-9'	Two 24" Box Size (minimum)	One 36" Box Size
10'-27'	Three 24" Box Size	Two 36" Box Size
28'-40'	Four 24" Box Size	Two 48" Box Size
40'-56'	Six 24" Box Size	Two 48" Box & Two 36" Box Size
56'-60'	Two 24" Box & Two 36" Box + Two 48" Box Size	**
60'+	**	**

*Add half of the difference between the two to the narrowest measurement for the average canopy.
** Replace the tree with a combination of both Tree Canopy and Tree Value Standards.

Note: Basis of this table is determined by the growth of one 24" box size tree, growing at a rate equivalent to 9 feet of canopy over the course of ten years.

Figure 43. Tree Canopy Replacement Standard from the City of Palo Alto Tree Technical Manual.

Further Evaluation should be conducted by a team of professionals with expertise relevant to the project details. In addition to the technical information, the group should evaluate level of impact, risks, cost/benefit, anticipated maintenance, public/environmental benefit, community values, policy guidance, neighborhood context, and historic districts. Palo Alto should incorporate these criteria and refine them to ensure that best practices are being followed.

Solutions may then be identified for potential use after assessment and evaluation. If a tree is to be removed, replacement with appropriate placement, soil/water requirements, and species are key considerations. Using the Toolkit, alternative sidewalk solutions may be used in conjunction with tree retention and/or replacement, and should provide overall improvement to site conditions for the future.

Project Implementation requires City Municipal Code and ADA compliance, as well as public involvement. Public involvement is a key component which is an inherent part of public improvements with trees and sidewalks. Opportunities for involvement should arise at the initial tree/sidewalk assessment stage, following the initial assessment, and following selection of solutions. Public outreach can begin with postings on trees and mailers, and extend through the project with public forums and design charettes depending on the scope of the project.

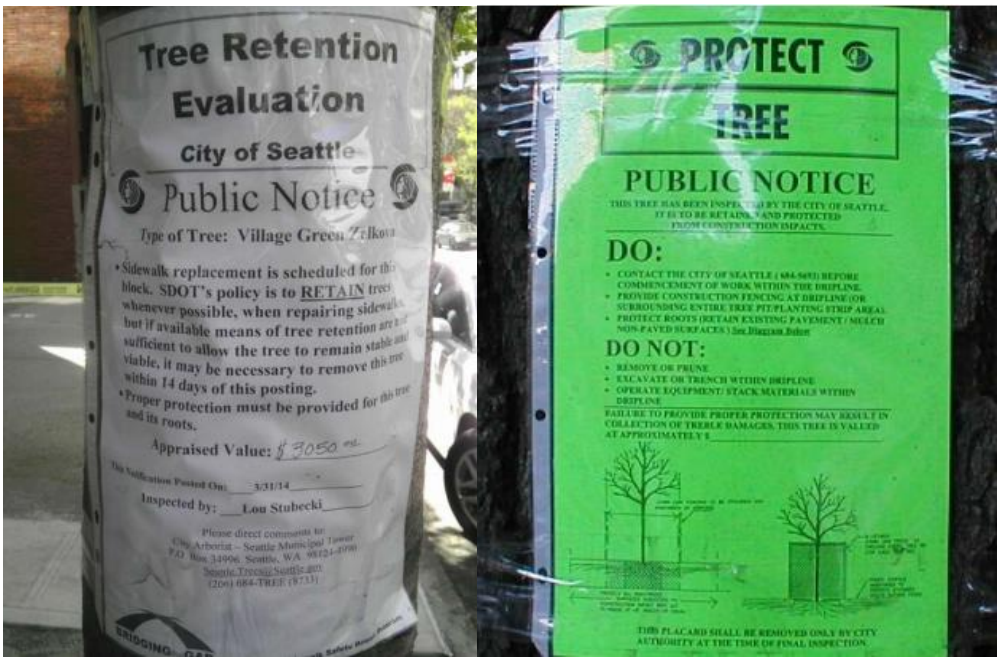

Figure 44. SDOT posting notices on trees to communicate plans for tree removal/retention during assessments.

Maintenance of new and repaired sidewalks and trees should be tracked and documented for the benefit of City staff, contractors, and the public. This tracking will provide information about durability of materials and life cycle of repair methods, which over time enhances the accuracy of solution recommendations for a particular site.

4.2.2 Best Management Practices (BMPs)

Being knowledgeable of and equipped to employ the most up to date Best Management Practices (BMPs) is critical to the success of any coordinated efforts to reduce tree root and sidewalk conflicts. Appendix B (pages 1-5) of the SDOT Trees & Sidewalks Operations Plan provides a technical research compilation for BMPs used across the U.S. The City of Palo Alto Tree Technical Manual also provides guidelines for root pruning, utility work, and other work around regulated trees.

Certified Arborists Larry Costello and Gary Watson are currently working to write the new Root Management BMPs, which are expected to be made available to the public through the International Society of Arboriculture (ISA) in August of 2016. This update will likely provide the most recent and proven practices and procedures used in the field today.

4.3 Strategy Packages

In a very recent article, James Urban states, "When designing the tree opening, ask yourself what would be the minimum size of the *paving* instead of the minimum size of the *tree opening*" (Urban, 2016). This tree-centric vision for properties has been employed on many commercial and public properties throughout Palo Alto, but needs to be promoted for all lands and prioritized among city staff as a guiding principle when reviewing projects of all kinds. With this mindset, trees are more likely to get the space they need and other sustainable green components are more readily applied.

Many of Palo Alto's sidewalks and trees are managed in a site-by-site manner. This approach has been successful in some ways, but more efficiency and effectiveness can be achieved with Strategy Packages made available to staff and the public for review. The following packages are grouped into the categories: 1) Capital Improvement Plans, 2) Development Review, and 3) Sidewalk Repair Program. Each of these plans/programs differ in budget constraints, longevity, and city staff involvement, therefore they can be separated and provided general guidelines for using the tree-based, infrastructure-based, and rootzone-based solutions.

4.3.1 Capital Improvement Plans (CIP)

SDOT conducted three case studies to test their process for evaluating streets in different parts of the city. With a City Arborist and City Engineer present (at least), the team would determine the course of action to be 1) keep the tree and repair the sidewalk, 2) remove the tree and repair the sidewalk, or 3) evaluate further. The plan includes a map of the street (to scale), photos of each tree/sidewalk site, and a key with descriptions of the treatments and associated costs. There are a variety of treatments considered at the evaluation and planning stage, providing a multi-faceted approach to tree and sidewalk management. Treatments include identification of areas for soil replacement at the tree, sidewalk removal in the planter strip, driveway removal, curb bulb and ramp upgrades/opportunities, easement negotiations with adjoining property owner, new tree, shim/beveling, curb realignment opportunity, and trees to be replaced in the future. Additional information about the case studies can be found on pages 71-73 of the Operations Plan, and directly at http://www.seattle.gov/transportation/docs/TreeSidewalksAppendices_final215.pdf.

Pilot packages for the city staff to use for early considerations during projects could be used to compare costs after getting resident's feedback/preferences at design charrettes and community meetings. For example, people decide they want a narrower planter, so trees will be smaller and require and ESM root channel. Another scenario: if people want a large planter they may not need to incorporate ESM root corridor.

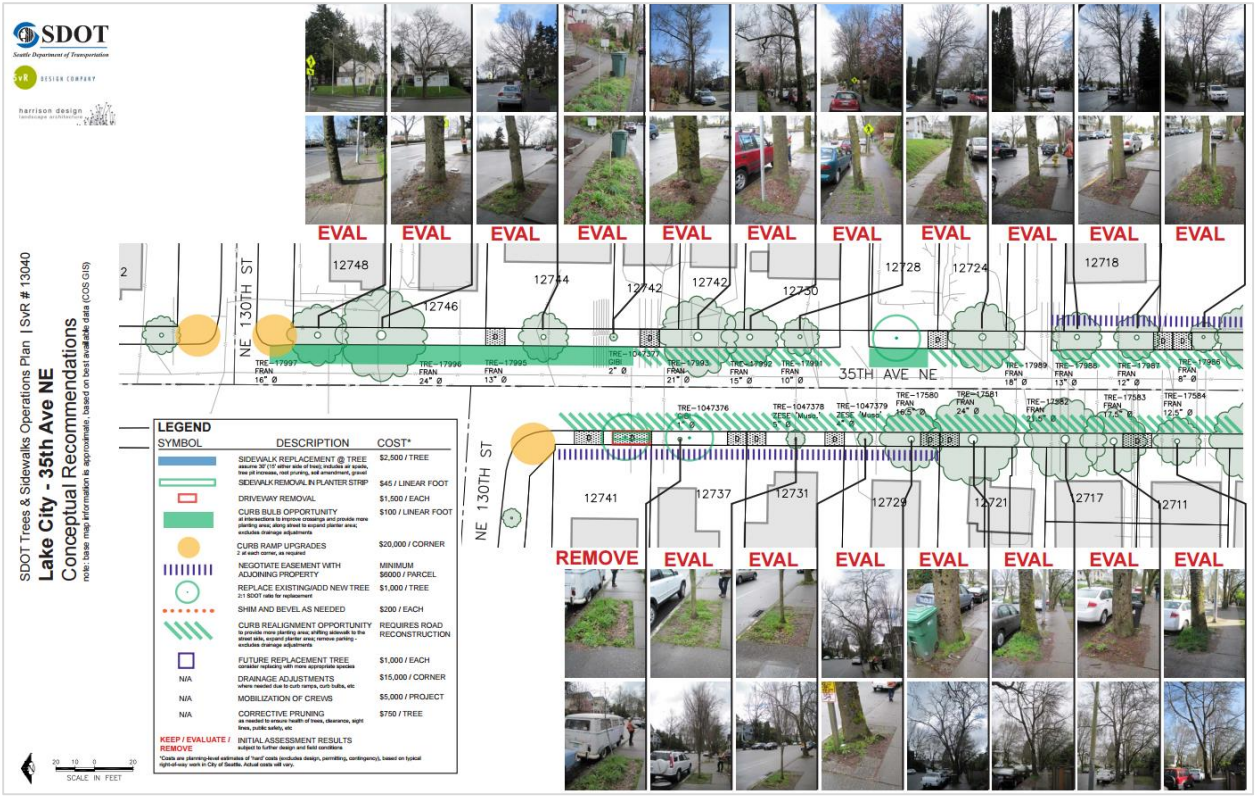

Figure 45. SDOT's case studies included concept plans with detailed assessments and recommendations.

Figure 46. Potential uses for rubber sidewalks include replacing concrete around significant landscape trees, such as this valley oak (Quercus lobata) at the Palo Alto History Museum.

4.3.2 Development Review

City staff reviews development projects throughout Palo Alto to ensure code compliance and enhance customer service. Redevelopment of residential and commercial properties is occurring rapidly, and City Council has recommended expansion of alternatives to tree removal during development and expansion of tree protection in municipal codes, policies, and procedures. With these goals in mind, the Development Services, Planning and Community Environment, and Public Works Departments play a critical role in code enforcement and development review that prioritized trees.

The following strategy packages are intended for use by city staff, applicants, and the public. If made available on the City website, during early planning review, and during building permit plan check, all involved parties can have access to a variety of solutions that provide for trees and hardscape. Providing these packages to applicants will enhance transparency and provide consistent expectations from the City at early stages of project planning and budgeting. Many of the strategies are currently being employed throughout properties in Palo Alto, but are not formally written into policy or made widely available.

The two packages provided may be used generally for a) Commercial and b) Residential development review. A snapshot is provided below, and the appendices provide some standard details/specifications. Parameters are listed for each type of property, requiring provisions for trees including minimum rootable soil and best solutions for a given site design. These parameters allow flexibility during the review process, because the applicant can choose from a variety of site designs, materials, and tree species that satisfy their preferences, while meeting the minimum requirements for tree growth.

a) Commercial Development Review
    - All commercial zoned properties, including multi-use and Stanford land
    - Planning process for Entitlement: Architectural Review Board (ARB), Minor ARB, Development Review Committee (DRC)
b) Residential Development Review
    - New 2-story R-1 and R-2 zoned properties, and Multi-family residential zoned properties
    - Planning process for Entitlement: Architectural Review Board (ARB), Minor ARB, Individual Review (IR)

Parameter 1	Commercial Development Review Strategies	Residential Development Review Strategies
Provide adequate soil volume per tree: Small tree (400-600 cubic feet), medium tree (600-800 cubic feet), large tree (800-1200 cubic feet)	-Incorporate open landscaped area where trees share soil in enlarged planters and parking lot islands. -Install alternative sidewalk/hardscape base material (eg. structural soils and soil cells) adjacent to new street/landscaping trees where open planters are not desired*	-Structural soil rooting corridor under sidewalk adjacent to new street trees. -Biaxial geogrid underlayment for new driveways within the dripline of street trees and protected trees.
Parameter 2	**Commercial Development Review Strategies**	**Residential Development Review Strategies**
Species selection compatible with site: buttress, rooting characteristics, and size/shape considered	-Choose from Preferred and Restricted Species List to match the right tree to the right place. -Redevelopment should prioritize larger trees and tree planters when designing new landscaped areas next to hardscape. -Minimize utilities conflicts.	-Choose from Preferred and Restricted Species List to match the right tree to the right place. Often there are more design restrictions, so for existing trees modify the sidewalk width and/or material, and for new trees modify the sidewalk base and choose a species with buttress and size that matches the planter size.
Parameter 3	**Commercial Development Review Strategies**	**Residential Development Review Strategies**
Regulated trees to be protected: protected trees, street trees, and designated landscape trees	-Comply with Tree Technical Manual and project arborist tree protection measures -Biaxial geogrid underlayment for new driveways and other hardscape within the dripline of street trees and protected trees.	-Comply with Tree Technical Manual and project arborist tree protection measures -Biaxial geogrid underlayment for new driveways and other hardscape within the dripline of street trees and protected trees.

Parameter 4	Commercial Development Review Strategies	Residential Development Review Strategies
Parking lot trees: reach sufficient size for 50% shading ordinance through adequate rootable soil area and site design	-Create tree islands for shared rooting space and stratification of tree sizes, and prioritize larger planters where possible. -Finger-shaped parking lot tree islands receive structural soil or soil cells at 24-48-inch depth underneath the two adjacent parking spaces. -Parking lot tree planters surrounded by pavement and/or on top of parking structures should receive adequate rooting soil (soil cells preferably). -Integrate green infrastructure (pervious/permeable pavers, concrete, or asphalt)	-Parking lot tree planters surrounded by pavement, and/or on top of parking structures, should receive adequate rooting soil (soil cells preferably). -Integrate green infrastructure (pervious/permeable pavers, concrete, or asphalt)
Parameter 5	**Commercial Development Review Strategies**	**Residential Development Review Strategies**
Approved landscape that is acceptable to other departments: screening trees/shrubs, water efficient landscape, contributes to on-site stormwater treatment, compatible with utilities, ADA compliant, etc.	-Incorporate appropriate trees and tree space in the early stages of project development and review. Trees should be prioritized and rooting needs respected during ARB and DRC review.	-Incorporate appropriate new trees and tree protection in the early stages of project development and review (ie. driveway and utility placement routed around regulated trees). Trees should be prioritized and rooting needs respected during ARB and IR.

(*)-If the street trees share an open planter strip, deduct soil additions under the hardscape from the final soil goal.
-In areas with more hardscape (ie. downtown and commercial/industrial) alternative base materials will be more widespread. New large/prominent landscape trees/street trees with roots almost completely covered with hardscape should be supplied standard planting soil available in soil cells, rather than structural soils.

Table 1. Some potential opportunities to meet parameters for development review.

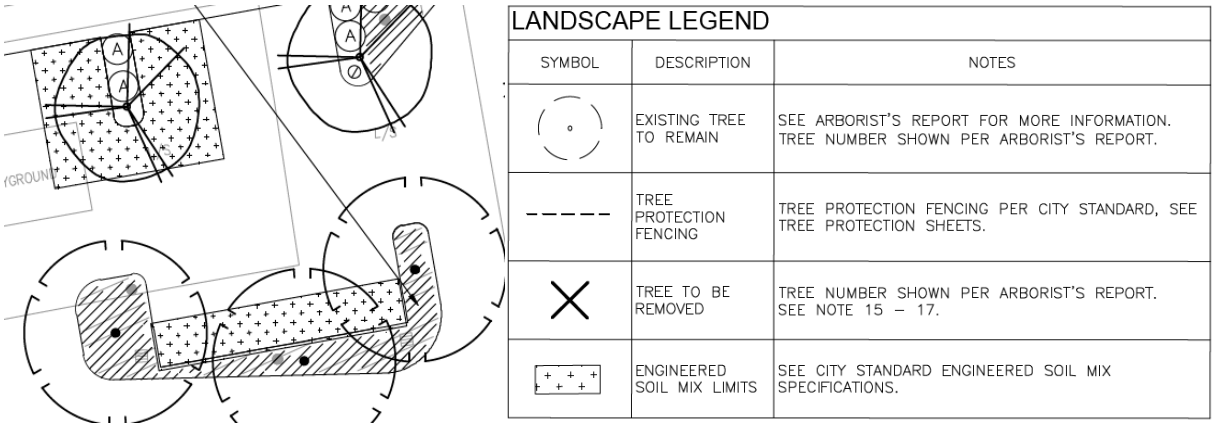

Figure 47. Architectural drawing of ESM under parking spaces adjacent to tree planters.

Thresholds for changing tree requirements need to be determined for advanced levels of development. Greater project valuation, size of the property, scope of work, and zoning are some ways to set up thresholds that trigger higher standards for tree protection and landscaping. Other reviewing departments currently have policies in place in which a higher sustainable building practice is triggered once a project's scope of work exceeds a predetermined amount. The Urban Forestry staff should work with the Planning and Community Environment Department to assess the varying requirements for different types of projects. Whether it be that a certain percent of project budget be solely devoted to tree protection and planting, or require more trees be planted then removed, staff should discuss innovative potential policies.

4.3.3 Sidewalk Repair Program

The Sidewalk Repair Program has a fairly simple, predominantly reactionary and unsustainable process for involving City arborists in work where tree roots are encountered. However, the process may be improved with regular use of an assessment checklist to review trees and sidewalk repair areas systematically and with a predictable, easily replicated, and transparent evaluation process. The City of Palo Alto should use the SDOT or similar assessment forms to craft a checklist for Palo Alto to be used in hard copy form or in TreeKeeper dropdown lists during site evaluation.

Cost evaluation is another important component to determine which solutions are employed. The Bicycle Pedestrian (Transportation) budget is not very limited (high funding for infrastructure), therefore it is a potential source of funding for implementing new strategies. Funding can also come from grants, but sometimes grant writing is more trouble than it is worth because of the time and contract staffing required. Ultimately, the PWD should budget appropriately for use of some more innovative solutions, for the benefit of long-term tree health and the opportunity to test new strategies that may benefit the City long-term.

Public Works Engineering could initiate a pilot program to test different materials in a receptive area of the city. For example, in a neighborhood where PW is planning to remove the sidewalk, plan an interactive section where you install different types of sidewalk surface materials and encourage viewer feedback to the City website. Another opportunity might be incorporating new alternative sidewalk surface materials in a recommended package to homeowners via door hangers or mailers when their street is being assessed for new solutions during the next sidewalk management plan.

Alternative surface materials such as Terrawalks® may serve as temporary sidewalks in high traffic areas or where there will be more than a couple days between sidewalk removal and replacement. The material could be installed on a temporary basis until the work is complete, then picked up and stored for the next use on another site. If they are well received by the public, and are more cost-effective than alternatives, they may be installed for long-term use rather than just temporary projects.

5.0 Conclusion

Many US cities, including Palo Alto, are striving to reach goals for accessibility, health, environment, equity, efficiency, sustainability, and more. The strategies presented explore ways to enhance neighborhood streets throughout residential, downtown, and even commercial districts. In order to facilitate coexistence between substantial trees and hardscape, repair procedures must be crafted site by site. Utilizing viable Strategy Packages with remedial and preventative tools, City staff can have access to sophisticated solutions beyond the short list of options they have long had to reuse.

5.1 Action Items

The process of developing recommendations for this report led to identification of some items that the City of Palo Alto staff may consider for future action:

- Update the Preferred and Restricted Species List or similar (ie. Canopy Tree Library), to provide additional information on soil volume, rooting and trunk characteristics, and minimum allowable tree pit size.
- Integrate tree assessment with other city programs such as asphalt paving, Capital Improvement Plans, and other right-of-way permits.
- Update standard plans and specifications to align with the tree and sidewalk best management practices associated with tree pit size, soils, and accessibility requirements.
- Develop forms/online checklists for tree and sidewalk evaluations to track activities for staff and public review as needed.
- Staff adoption of the decision trees and future consideration of strategy packages for a variety of different projects now and in the future.

6.0 References

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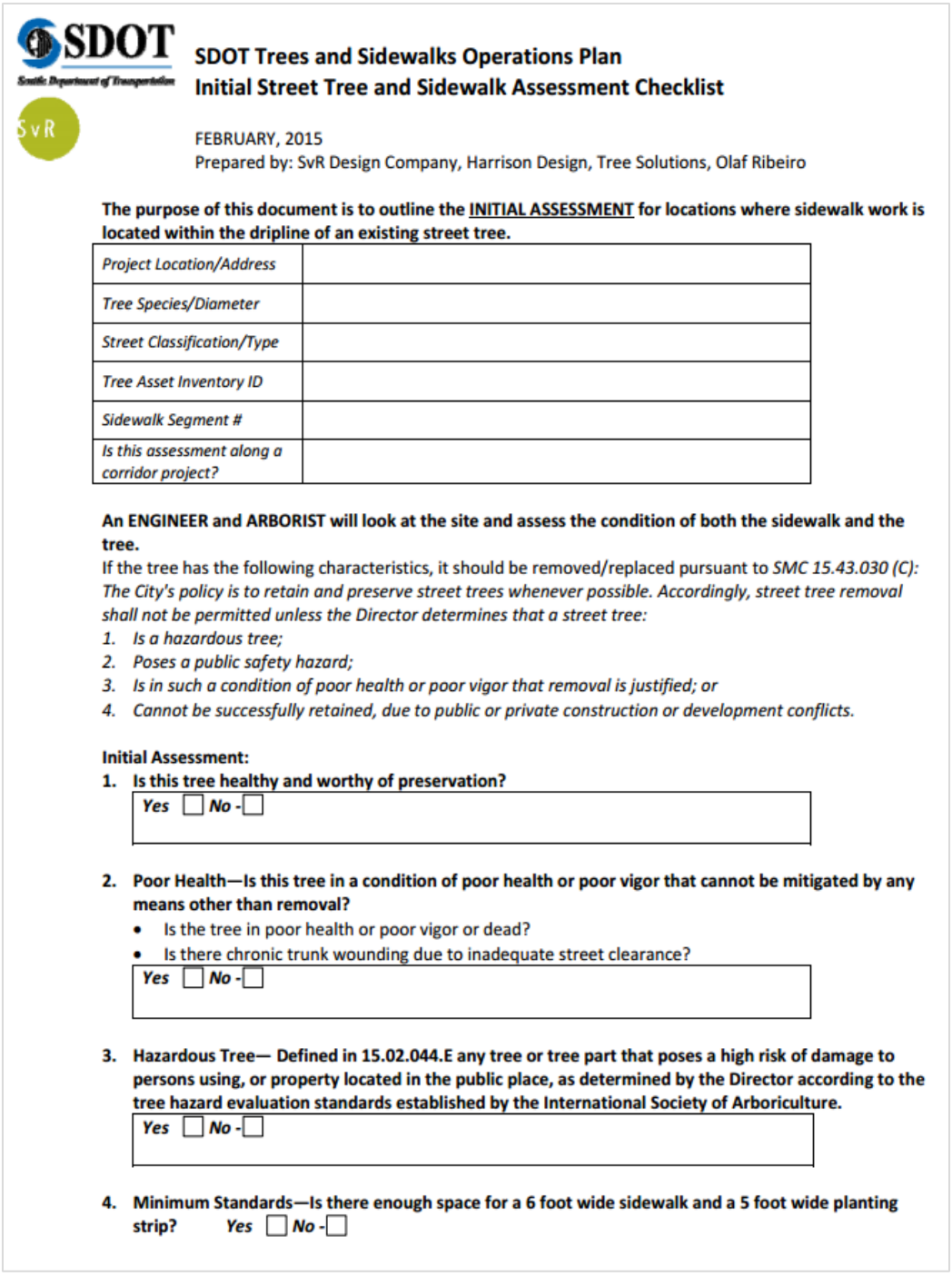
7.0 Appendices

7.1 Decision Trees and Sample Assessment Forms



SDOT Trees and Sidewalks Operations Plan
Initial Street Tree and Sidewalk Assessment Checklist

FEBRUARY, 2015
Prepared by: SvR Design Company, Harrison Design, Tree Solutions, Olaf Ribeiro

The purpose of this document is to outline the INITIAL ASSESSMENT for locations where sidewalk work is located within the dripline of an existing street tree.

Project Location/Address	
Tree Species/Diameter	
Street Classification/Type	
Tree Asset Inventory ID	
Sidewalk Segment #	
Is this assessment along a corridor project?	

An ENGINEER and ARBORIST will look at the site and assess the condition of both the sidewalk and the tree.
If the tree has the following characteristics, it should be removed/replaced pursuant to *SMC 15.43.030 (C): The City's policy is to retain and preserve street trees whenever possible. Accordingly, street tree removal shall not be permitted unless the Director determines that a street tree:*

1. *Is a hazardous tree;*
2. *Poses a public safety hazard;*
3. *Is in such a condition of poor health or poor vigor that removal is justified; or*
4. *Cannot be successfully retained, due to public or private construction or development conflicts.*

Initial Assessment:

1. **Is this tree healthy and worthy of preservation?**
   Yes ☐ ***No -*** ☐

2. **Poor Health—Is this tree in a condition of poor health or poor vigor that cannot be mitigated by any means other than removal?**
   - Is the tree in poor health or poor vigor or dead?
   - Is there chronic trunk wounding due to inadequate street clearance?

   Yes ☐ ***No -*** ☐

3. **Hazardous Tree— Defined in 15.02.044.E any tree or tree part that poses a high risk of damage to persons using, or property located in the public place, as determined by the Director according to the tree hazard evaluation standards established by the International Society of Arboriculture.**
   Yes ☐ ***No -*** ☐

4. **Minimum Standards—Is there enough space for a 6 foot wide sidewalk and a 5 foot wide planting strip?** ***Yes*** ☐ ***No -*** ☐

Figure 48. Initial Street Tree and Sidewalk Assessment Checklist used by SDOT staff during sidewalk and street tree review (page 1).

SDOT
Seattle Department of Transportation

SvR

SDOT Trees and Sidewalks Operations Plan
Initial Street Tree and Sidewalk Assessment
Page 2 of 2

5. **Public Safety Hazard—Does the tree present a public safety hazard that cannot be mitigated by any means other than removal?**
   - Does the tree location obstruct the visibility for pedestrians, cyclists, and/or cars at an intersection?
   - Is the tree impacting a curb ramp such that it no longer meets City of Seattle ADA requirements?
   - Is the tree potentially impacting private property?

Yes ☐ ***No*** - ☐
Use this space to draw a sketch of the location. Identify existing clearances from nearby infrastructure.

Recommendation for this tree:

☐ ***–Remove Tree / Replace Sidewalk***
A tree is identified to be removed if it is not healthy or if it is hazardous as identified in the Street Tree Ordinance.

☐ ***–Keep Tree and Maintain Sidewalk***
A tree will be kept and the sidewalk will be maintained if a sidewalk of standard width and a tree pit of standard width (at a minimum) can be installed or retained around a healthy tree.

☐ ***–Evaluate Sidewalk and/or Tree Further***
SDOT views trees and sidewalks as important public infrastructure assets. SDOT intends to keep healthy trees and have accessible sidewalks. If standard widths cannot be met then SDOT will take the time and resources to evaluate if alternative approaches (such as sidewalk width reduction, alternative sidewalk materials, adjustments to the tree pit and/or tree root pruning) can be used to retain a tree and provide an accessible sidewalk at problem locations.

NEXT STEPS

If Tree is REMOVED –Replace the removed tree with the minimum 2:1 replacement ratio. Identify if the replacement trees can be located in the same location or on the same street as the removed tree. If not, replacements should be planted as close to the removal as geographically feasible. Identify the estimated cost to remove the tree(s), repair the sidewalk, and plant replacement trees.

If Tree is KEPT –Estimate the cost of the sidewalk repair that would achieve the desired lifecycle for the repair. Estimate sidewalk and tree maintenance needs/costs and any maintenance to the tree that is being retained (e.g., root pruning, branch pruning, soil amendments).

If EVALUATE Further – Use Tree and Sidewalk Evaluation Form (IN DEVELOPMENT) and/or the tree risk assessment should follow ISA TRAQ guidelines:
http://www.isa-arbor.com/education/onlineresources/basictreeriskassessmentform.aspx

Arborist	**Engineer**
Title	**Title**
Date	**Date**

Figure 49. Initial Street Tree and Sidewalk Assessment Checklist used by SDOT staff during sidewalk and street tree review (page 2).

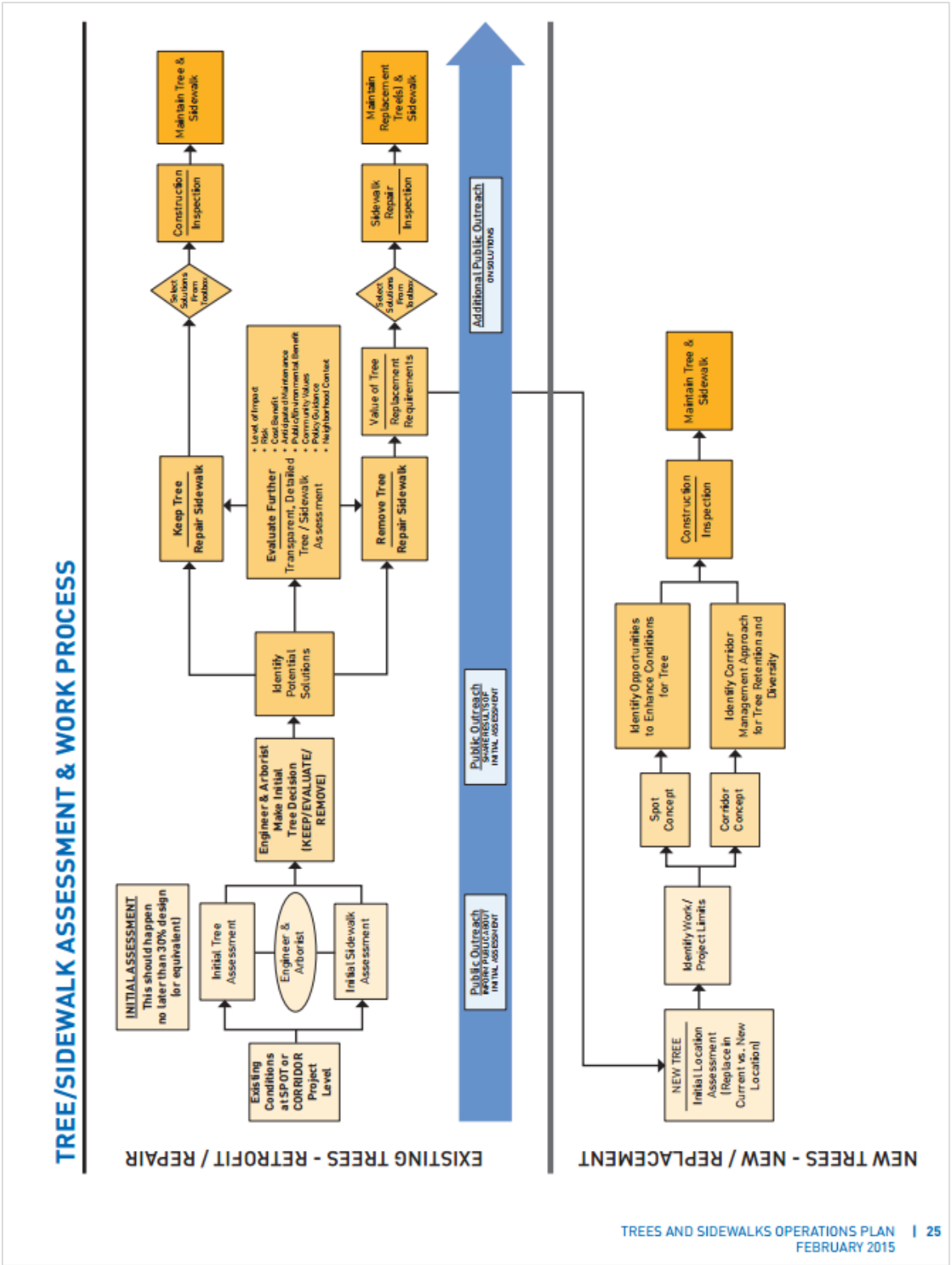


Figure 50. SDOT Tree/Sidewalk Assessment and Work Process (expanded).

7.2 Standard Details and Specifications

Many other standard drawings and specifications used by the City of Palo Alto Public Works Departments can be found at
http://www.cityofpaloalto.org/news/displaynews.asp?NewsID=1834&TargetID=145

Specific vendors/manufacturers also provide this information and sometimes Autocad drawings for their specific product.

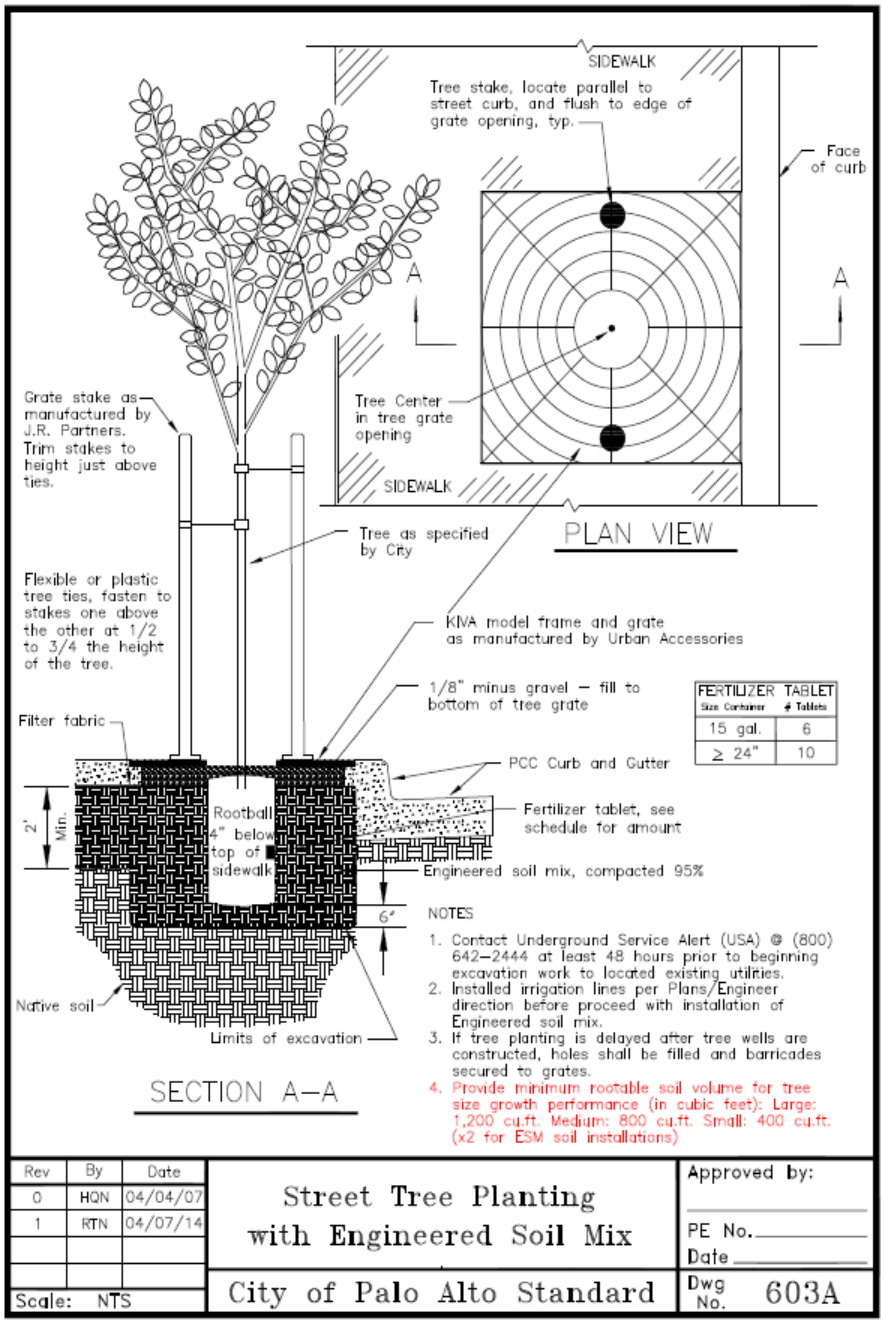


Figure 51. City of Palo Alto tree planting with Engineered Soil Mix standard drawing.

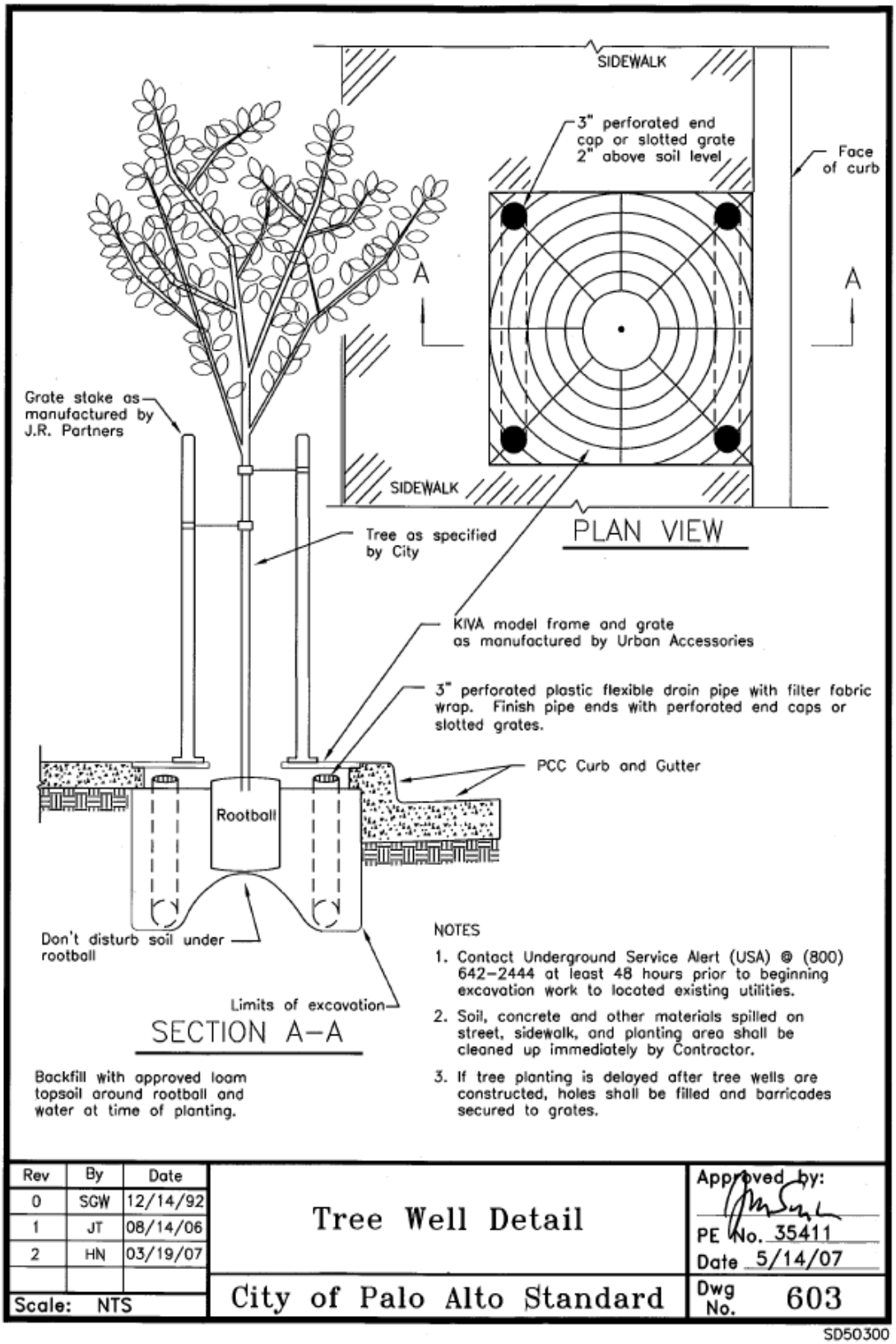


Figure 52. City of Palo Alto street tree well standard drawing.

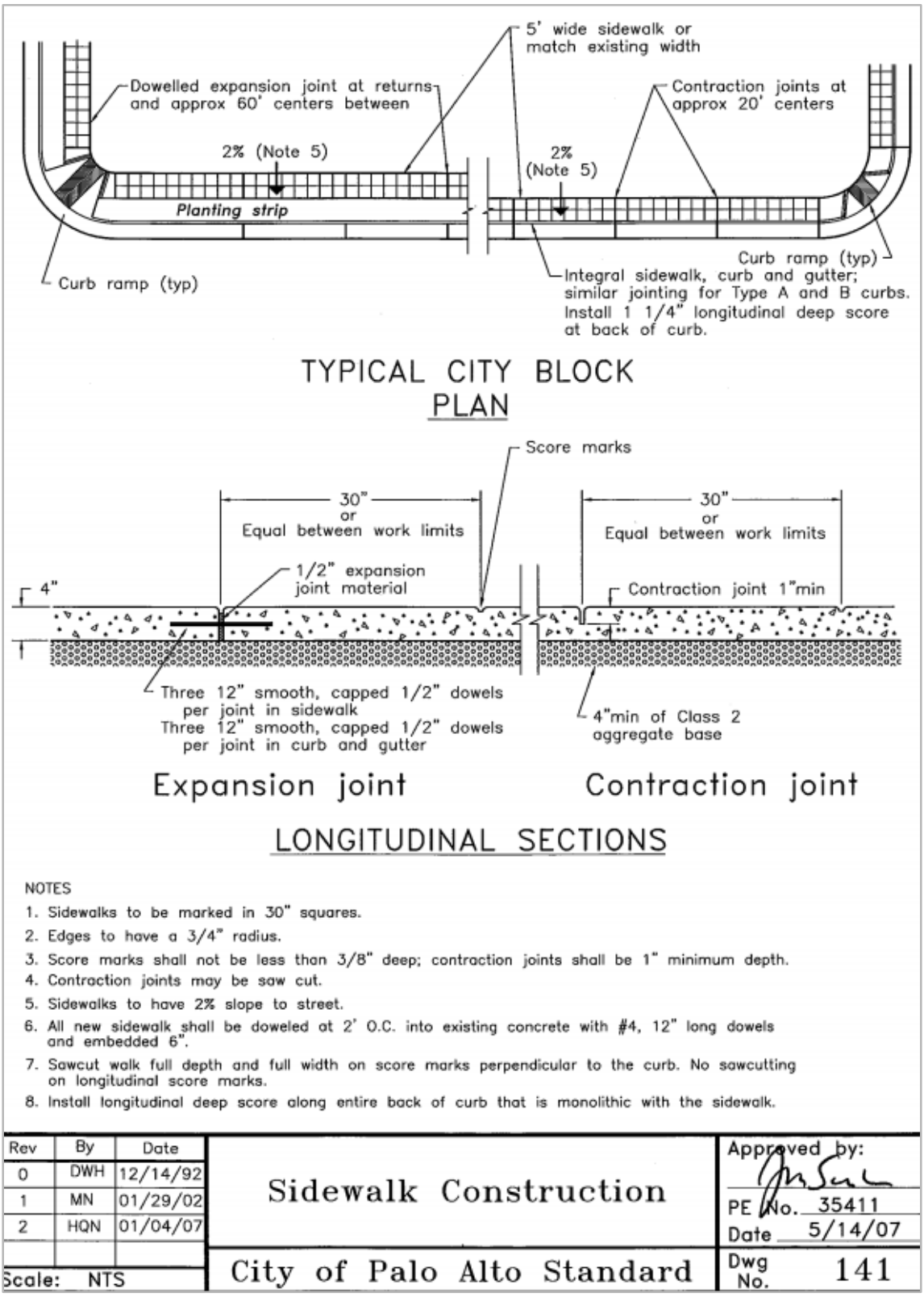
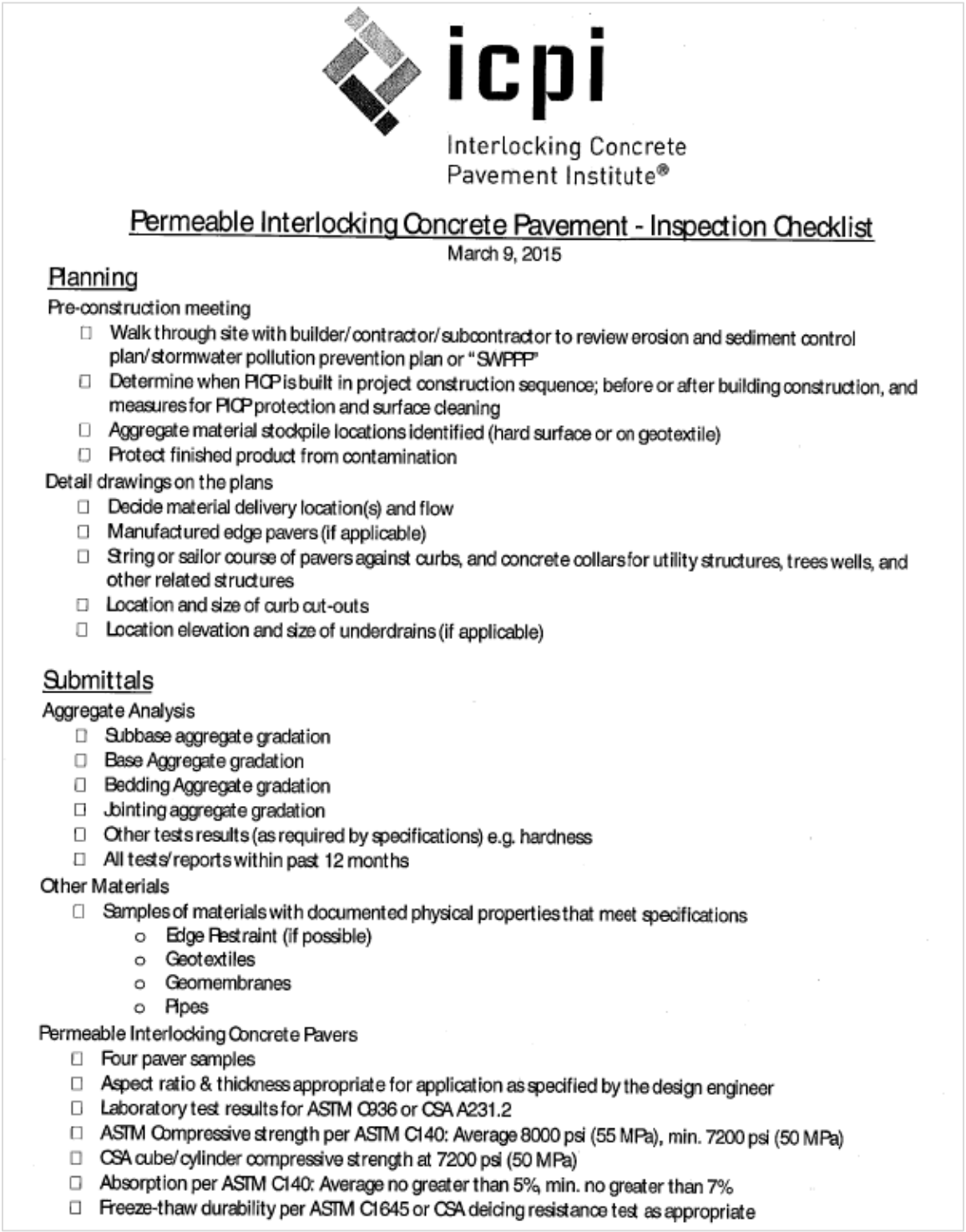


Figure 53. City of Palo Alto Standard Drawing for sidewalk construction.



icpi
Interlocking Concrete Pavement Institute®

Permeable Interlocking Concrete Pavement - Inspection Checklist

March 9, 2015

Planning

Pre-construction meeting

- ☐ Walk through site with builder/contractor/subcontractor to review erosion and sediment control plan/stormwater pollution prevention plan or "SWPPP"
- ☐ Determine when PICP is built in project construction sequence; before or after building construction, and measures for PICP protection and surface cleaning
- ☐ Aggregate material stockpile locations identified (hard surface or on geotextile)
- ☐ Protect finished product from contamination

Detail drawings on the plans

- ☐ Decide material delivery location(s) and flow
- ☐ Manufactured edge pavers (if applicable)
- ☐ String or sailor course of pavers against curbs, and concrete collars for utility structures, trees wells, and other related structures
- ☐ Location and size of curb cut-outs
- ☐ Location elevation and size of underdrains (if applicable)

Submittals

Aggregate Analysis

- ☐ Subbase aggregate gradation
- ☐ Base Aggregate gradation
- ☐ Bedding Aggregate gradation
- ☐ Jointing aggregate gradation
- ☐ Other tests results (as required by specifications) e.g. hardness
- ☐ All tests/reports within past 12 months

Other Materials

- ☐ Samples of materials with documented physical properties that meet specifications
  - o Edge Restraint (if possible)
  - o Geotextiles
  - o Geomembranes
  - o Pipes

Permeable Interlocking Concrete Pavers

- ☐ Four paver samples
- ☐ Aspect ratio & thickness appropriate for application as specified by the design engineer
- ☐ Laboratory test results for ASTM C936 or CSA A231.2
- ☐ ASTM Compressive strength per ASTM C140: Average 8000 psi (55 MPa), min. 7200 psi (50 MPa)
- ☐ CSA cube/cylinder compressive strength at 7200 psi (50 MPa)
- ☐ Absorption per ASTM C140: Average no greater than 5%, min. no greater than 7%
- ☐ Freeze-thaw durability per ASTM C1645 or CSA deicing resistance test as appropriate

Figure 54. Permeable Interlocking Concrete Pavement Inspection Checklist.

- ☐ ASTM optional abrasion durability per ASTM C418
- ☐ Manufacturer'☐pro☐uct (cut) ☐☐eet☐for ☐pecifie☐paver(☐)
- ☐ Material Safety Sheet

Installer/ Sub-contractor Documents

- ☐ Installer job references: minimum two references of jobs of similar size and complexity
- ☐ Current ICPI Certified Installer - PICP Specialist (full designation or at least Record of Completion): at least one person on-site with certificate (typically job foreman or crew leader)
- ☐ State/provincial, local licenses
- ☐ Contract specific insurances (liability, workers compensation, etc.), performance bonds

On Site Preparation

Mock-up

- ☐ Location, size, completion date
- ☐ Surcharge (settlement after plate compaction)
- ☐ Shows color range
- ☐ Joint widths per ☐pec☐☐manufacturer'☐literature
- ☐ Paver pattern(s) and direction per drawings

Storage

- ☐ Paver bundles with steel/plastic bands or plastic wrap
- ☐ Each paver cube labeled and numbered
- ☐ Paver cubes stacked up 2 high maximum on level ground
- ☐ Pavers should be kept off any unpaved ground surface by pallets, plywood, etc.
- ☐ Stockpile aggregate on hard surfaces or geotextile to prevent contamination from site soils and sediment

Sediment management

- ☐ Access routes for delivery and construction vehicles identified
- ☐ Vehicle tire/track washing station (if specified in Erosion & Sediment plan/SWPPP) location/ maintenance

Sediment management post-excavation

- ☐ Excavation hole as sediment trap: cleaned to final subgrade elevation immediately before subbase stone placement and runoff sources with sediment diverted away from the PICP,

or

- ☐ All runoff diverted away from excavated area
- ☐ Temporary soil stockpiles should be protected from run-on, run-off from adjacent areas and from erosion by wind
- ☐ Ensure linear sediment barriers (if used) are properly installed, free of accumulated litter, and built up sediment less than 1/3 the height of the barrier
- ☐ No runoff enters PICP until soils stabilized in area draining to PICP

Verify Site Conditions

Foundation Walls

- ☐ PICP should be installed no closer than 10 ft (3 m) from foundation walls with no waterproofing or consideration for subsurface drainage

Proximity to Water Supply

- ☐ PICP should be installed no closer than 100 ft (30 m) from municipal water supply wells or open water

Soil Subgrade

- ☐ Rocks & roots removed, voids refilled with aggregate & compacted
- ☐ No groundwater seepage or standing water
- ☐ If no compacted subgrade, confirm no compaction from construction equipment, scarify if needed
- ☐ Soil compacted as specified – verify soil density & infiltration (saturated hydraulic conductivity)

Figure 55. Permeable Interlocking Concrete Pavement Inspection Checklist (continued).

Verify Materials Delivered to the Ste

Pavers

- ☐ Source on tags matches specification
- ☐ Dimensions match specification
- ☐ Colors match samples submitted and mock up
- ☐ Delivery amounts and dates recorded

Aggregates

- ☐ Sieve analysis from quarry and general appearance of subbase, base, bedding, and jointing aggregates conforms to specifications

Additional Materials

- ☐ Edge restraints matches specification
- ☐ Geotextile matches specification
- ☐ Geomembrane matches specification

Excavate and Construct Subbase & Base

Weather conditions

- ☐ No work in heavy rain or snow – bedding is not saturated
- ☐ No aggregates and pavers placed on frozen base or subgrade
- ☐ No frozen aggregates

Excavation

- ☐ Utilities located and marked by local service
- ☐ Excavated area marked with paint and/or stakes
- ☐ Excavation size and location conforms to plan
- ☐ Soil compaction as specified – verify soil subgrade infiltration (hydraulic conductivity) with testing

Geotextile (if specified)

- ☐ Placement and down slope overlap (min. 1 ft or 0.3 m) conform to specifications and drawings
- ☐ Sides of excavation covered with geotextile prior to placing aggregate base/subbase
- ☐ No tears or holes
- ☐ No wrinkles, pulled taught and staked

Geomembranes (if specified)

- ☐ Placement
- ☐ Field welding, seams, and seals at pipe penetrations done per specifications
- ☐ Top and bottom protected with non-woven geotextile (typ. 10 oz/sy)

Drain pipes, observations wells and cleanouts

- ☐ Size, perforations, locations, slope, and outfalls meet specifications and drawings
- ☐ Verify elevation of overflow pipes

Subbase, base and bedding aggregates

- ☐ Spread (not dumped) with a front-end loader to avoid aggregate segregation
- ☐ Storage on hard surface or geotextile to keep sediment-free
- ☐ Thickness, placement, compaction and surface tolerances meet specifications and drawings
- ☐ Subbase and base compaction equipment meets specifications
- ☐ Subbase and base stiffness testing for consistency
- ☐ Bedding layer screeding: not compacted using various installation methods (manual & powered)

Edge restraints

- ☐ Elevation, placement meet specifications and drawings

Figure 56. Permeable Interlocking Concrete Pavement Inspection Checklist (continued).

Install Permeable Interlocking Concrete Pavement

Paver installation

- ☐ Elevations, slope, laying pattern, joint widths, and placement/compaction meet drawings and specifications
- ☐ No cut paver subject to tire traffic is less than 1/3 of a whole paver
- ☐ Six passes: min. 5,000 lbf (22 kN) plate compactor (or 2 passes w/ min. 10,000 lbf (44 kN) plate compactor)
- ☐ All pavers within 2 m or 6 ft of the laying face fully compacted at the completion of each day
- ☐ Surface tolerance of compacted pavers deviate no more than ±10 mm (3/8 in.) under a 3 m (10 ft) long straightedge

Jointing Aggregate

- ☐ Remove any aggregate from the pavement surface before compacting pavers and vibrating jointing aggregate
- ☐ Broken and chipped pavers marked, removed and replaced after initial compaction
- ☐ Alternate sweeping and vibrating sand into joints with minimum of 6 passes of plate compactor
- ☐ No compaction within 6 ft (2 m) of an unrestrained edge of pavers
- ☐ All pavers compacted within 6 ft (2 m) of the laying face at the end of each day

Quality Control

- ☐ Surface elevation of pavers 1/8 to 3/8 in. (3 to 10 mm) above edge restraints, drainage inlets, concrete collars, or channels (for non-ADA accessible paths of travel); to ¼ in. or 6 mm (for ADA accessible paths of travel)
- ☐ Surface elevations conform to drawings
- ☐ Pavers 1/8 to ¼ in. (3 to 6 mm) above curbs, inlets, concrete collars and channels
- ☐ Lippage: no greater than 1/8 in. (3 mm) difference in height between adjacent pavers
- ☐ Bond (joint lines) lines: ±1/2 in. (15 mm) over 50 ft. (15 m) string line
- ☐ Check filling of joints with sand with putty knife: max 1/4 in. (6 mm) below chamfer edge at completion. Fill and re-compact if necessary

Finished Project

Final inspection

- ☐ Surface swept clean
- ☐ Elevations and slope(s) conform to drawings
- ☐ Transitions to impervious paved areas separated with edge restraints
- ☐ Stabilization of soil in area draining into permeable pavement (min. 20 ft or 6 m wide vegetative strips recommended)
- ☐ Drainage swales or storm sewer inlets for emergency overflow. If storm sewer inlets are used, confirm overflow drainage to them
- ☐ Runoff from non-vegetated soil diverted from PICP surface
- ☐ Test surface for infiltration rate per specifications using ASTM C1781; minimum 100 in./hr (254 cm/hr) recommended

Maintenance Pavers

- ☐ Delivery location, date and time
- ☐ Verify amount delivered

Protection

- ☐ General contractor to protect paver area after paver installation subcontractor completes work and leaves site

Figure 57. Permeable Interlocking Concrete Pavement Inspection Checklist (continued).

7.3 Material and Vendor Resources

Manufacturers, vendors, installation, and financial costs for some of the recommended solutions. This is not an all-inclusive list, but an overview of some of the most prominent and local options for Palo Alto.

Each supplier provides ample information on their website. Phone numbers and email addresses for sales, services, and technical assistance are available. Other resources include listing of products and services, research findings, case studies, FAQs, specifications, standard drawings.

1. Local nurseries for tree purchasing
    a. Nurseries:
        i. Valley Crest (925)862-2485
        ii. Boething (650)851-4770
        iii. Menlo Growers (408)683-4862
        iv. Belmont Nursery (559)255-6860
        v. Village Nursery (916)364-2945
        vi. Mid Valley Trees (559)734-4641
        vii. Western Tree (408)842-4892
        viii. Calaveras Nursery (209)772-1823
        ix. Bonfante Nursery (408)840-7143
    b. Tree installation should be completed by qualified City of Palo Alto staff (Urban Forestry group) or ISA Certified Arborists/teams overseen by a Certified Arborist.
    c. Cost varies by size and species. Larger trees cost more than smaller trees, and species availability may affect price (ie. trees in high demand but with limited supply may be more expensive than trees that are widely available at most nurseries).
2. Root Pruning
    a. Root pruning activities should only be performed by a Certified Arborist.
    b. Expected cost should cover personnel time, and the City already owns most of the necessary equipment (hand saws, root shaving device, pneumatic or hydro device to remove soil and expose roots without digging).
3. Structural Soils - TMT Enterprises, Inc - www.tmtenterprises.net/products.php
4. Suspended pavement systems (ie. soil cells)
    a. Deeproot - www.deeproot.com
        i. Silva Cell
        ii. Silva Cell 2
    b. Citygreen – www.citygreen.com
        i. Strata Cell
        ii. Stratavault
    c. Greenblue – www.greenblue.com

i. StrataVault
ii. GrassRings
iii. RootCell
iv. StrataCell

5. Pervious pavers, permeable pavers and pervious concrete

Company Name	Vendor Information
Bay Area Pervious Concrete 408-650-273-6073 (ph) www.bayareaperviousconcrete.com questions@bayareaperviousconcrete.com	Sonja O'Claire 650-273-6073 (ph) sonja@bayareaperviousconcrete.com
Pacific Interlock Pavingstone 831-637-9163 (ph) 831-637-0756 (fax) www.pacinterlock.com jphath@gmail.com	Paul Hathaway 831-578-4978 (ph) jphath@gmail.com Tim Donovan
Calstone 408-598-0518 (ph) http://calstone.com/	Mike Marhenke 408-598-0518 (ph) mikemarhenke@calstone.com

6. Recycled rubber sidewalk
    a. Terrecon Inc – www.terrecon.com
        i. Rubbersidewalks™
        ii. Verlayo®
7. Terrewalks®
    a. Terrecon Inc – www.terrecon.com
8. Biaxial geogrid underlayment – various suppliers
    a. Example pricing: 13.12' x 246' Tensar type (143 pounds): $548.49 +tax
9. Root barriers – various suppliers