# Green Stormwater Infrastructure Handbook

## *Guidance for Implementing Green Stormwater Infrastructure in Public Streetscapes, Parking Lots and Parks*

Santa Clara Valley
*Urban Runoff*
Pollution Prevention Program

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**Campbell • Cupertino • Los Altos • Los Altos Hills • Los Gatos • Milpitas • Monte Sereno • Mountain View • Palo Alto**
**San Jose • Santa Clara • Saratoga • Sunnyvale • Santa Clara County • Santa Clara Valley Water District**

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Guidance for Integrating Green Stormwater Infrastructure in Public Streetscapes, Parking Lots and Parks

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Prepared for the
Santa Clara Valley Urban Runoff
Pollution Prevention Program
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# CREDITS

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- Sustainable Green Streets and Parking Lots Design Guidebook (San Mateo Countywide Water Pollution Prevention Program), 2009
- Green Streets Design Manual and Appendices (City of Philadelphia Water Department), 2011
- Urban Street Design Guide (National Association of City Transportation Officials), 2013
- Greening DC Streets – A Guide to Green Infrastructure in the District of Columbia, 2014
- Green Stormwater Infrastructure Design Specifications (City of Philadelphia Water Department), 2014
- Stormwater Management Guidelines City Heights Urban Greening Plan (City of San Diego), 2014
- Washington DC DOT Green Infrastructure Standards (2014)
- Sustainable Streets Plan and Design Guidelines (City of San Mateo), 2015
- Separated Bicycle Lane Planning and Design Guide (Massachusetts Department of Transportation), 2015
- Green Streets Design Criteria (County of San Diego), 2016
- Stormwater Management Requirements and Design Guidelines (San Francisco Public Utilities Commission), 2016, including Appendix B Green Stormwater Infrastructure Typical Details and Specifications
- Green Infrastructure Design Details (City of New York City) 2016
- Stormwater Management Manual (City of Portland), 2016
- Bioretention Engineering Standards: Details and Technical Specifications (Central Coast Low Impact Development Initiative), 2017
- Urban Street Stormwater Guide (National Association of City Transportation Officials), 2017
- Silva Cell Fact Sheet (DeepRoot Green Infrastructure, LLC), 2017

Cover page images (clockwise from top left) – Hacienda Avenue in Campbell, Martha Gardens Green Alleys in San Jose, Rosita Park Neighborhood Stormwater Curb Extension in Los Altos, and Southgate Neighborhood in Palo Alto. Green Streets-Blue Bay Logo courtesy of the City of San Jose.

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# Glossary of Terms

See the C.3 Stormwater Handbook for a comprehensive glossary of Low Impact Development control measure definitions.

| | |
|---|---|
| Bay-Friendly Landscaping | A holistic system of sustainable landscaping practices for landscape design, construction and maintenance developed for the San Francisco Bay Area region and managed by the non-profit organization, ReScape California, at www.rescapeca.org |
| Bicycle Boulevard | A street with low motorized vehicle volumes and speeds that has been designed to prioritize bicycle travel through enhanced signage and traffic calming measures. |
| Bioinfiltration | A Low Impact Development (LID) or Green Stormwater Infrastructure (GSI) measure designed to detain stormwater runoff, filter stormwater runoff through biotreatment soil media and plant roots, and infiltrate stormwater runoff to underlying soils as allowed by site conditions. |
| Bioretention | A type of LID or GSI measure designed to retain stormwater runoff, filter stormwater runoff through biotreatment soil media and plant roots, and either infiltrate stormwater runoff to underlying soils, as allowed by site conditions, or release treated stormwater runoff to the storm drain system, or both. The difference between a bioinfiltration area and a bioretention area is that the bioinfiltration area is never lined with an impermeable layer; whereas, a bioretention area may be lined or unlined. |
| Biotreatment | A type of LID or GSI measure designed to detain stormwater runoff, filter stormwater runoff through biotreatment soil media and plant roots, and release the treated stormwater runoff to the storm drain system. Biotreatment systems must be designed to have a surface area no smaller than what is required to accommodate a 5 inches/hour stormwater runoff surface loading rate and must use biotreatment soil as specified in the C.3 Handbook Appendix C. |
| Biotreatment Soil Media (BSM) | An engineered media for treating stormwater runoff that meets the requirements in Provision C.3 of the MRP, the specification developed by BASMAA and approved by the Water Board in 2016, and consists of specific types and amounts of sand and compost as described in Appendix C of the SCVURPPP C.3 Handbook. |
| Building Interface Zone | The area of the sidewalk between the building frontage and the edge of the pedestrian zone. Also known as the Frontage Zone. |
| C.3.d Amount of Runoff | The water quality design flow or design volume of runoff, as determined by the methodologies described in Provision C.3.d of the MRP, required to be treated for compliance with Provision C.3. |

| | |
|---|---|
| Class I Bikeway | A non-vehicular, off-street facility that can be for bicycles only or designed as a multi-use path for bicycles, pedestrians and other forms of non-vehicular transportation. Also known as a bicycle path or trail. |
| Class II Bikeway | A striped travel lane for one-way bicycle travel on a street or highway. Also known as a bicycle lane. |
| Class III Bikeway | A roadway designed for shared use with bicycles and motor vehicles typically on low-volume roadways, designated by signage. Also known as a bicycle route. |
| Class IV Bikeway | A bicycle facility separated from vehicle traffic by curbs, parked vehicles or other physical barriers such as railings, walls, planters or landscaped areas. Also known as a Cycletrack, or a Separated or Protected Bikeway. |
| Collector Street | A street that connects a neighborhood, a Local Street, or an area of homogenous land use, to a Minor Arterial or Principal Arterial roadway. |
| Cycletrack | A bicycle facility separated from vehicle traffic by curbs, parked vehicles or other physical barriers such as railings, walls, planters or landscaped areas. Also known as a Class 4 Bikeway or a Separated or Protected Bikeway. |
| Flexible Zone | The area of the street adjacent to the curb that can be designed as street parking, a bike lane, a road shoulder, transit stop, street tree planting area or other alternate use. |
| Frontage Zone | The area of the sidewalk between the property line and the edge of the pedestrian zone. Also known as Building Interface Zone. |
| Furniture Zone | The area of the sidewalk where furnishings or infrastructure such as seating, fire hydrants, signs, street lights, refuse bins and transit shelters may be placed. Also used for street tree planting and known as Parkway Zone. |
| Green Infrastructure (GI) / Green Stormwater Infrastructure (GSI) | Stormwater and rainwater infrastructure that uses vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a city or county, GSI refers to the patchwork of natural and landscaped areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood, street, or site, GSI refers to stormwater management systems that mimic nature by soaking up, storing, and/or improving the quality of water. |
| Green Stormwater Infrastructure Measure (GSI Measure) | An engineered stormwater control measure that manages stormwater through biotreatment, infiltration, evapotranspiration and/or harvest and use. It is differentiated from a LID treatment measure due to its location in the public right-of-way, special design considerations because of its location, and alternative sizing methodology allowed. In this GSI Handbook, there are seven |

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|---|---|
| | categories of GSI Measures: Stormwater Planter, Stormwater Curb Extension, Stormwater Tree Well Filter, Pervious Pavement, Infiltration Trench, Dry Well, and Subsurface Infiltration System. |
| Green Street | A public or private roadway in which GSI Measures or other stormwater control measures are installed. |
| Infiltration Device | Infiltration facilities that are designed to infiltrate stormwater runoff directly into the subsurface and, as designed, bypass the natural groundwater protection afforded by surface soil. These devices include dry wells, deep infiltration wells, infiltration trenches, and subsurface infiltration systems. |
| Infiltration Facility | A general term that refers to infiltration devices and measures. |
| Infiltration Measure | Infiltration facilities that allow stormwater runoff to percolate through and be filtered by surface soils prior to infiltrating into subsurface soils. Examples include bioinfiltration and bioretention facilities, infiltration basins, and self-treating and self-retaining areas. |
| Infiltration Trench | Long narrow trench filled with stone aggregate, designed to store and infiltrate stormwater through the bottom and sides into the subsurface soil. |
| Local Street | A street that is designed to provide access from the immediately adjacent land use area or neighborhood to a Collector Street. |
| Low Impact Development (LID) | A land planning and engineering design approach with a goal of reducing stormwater runoff and mimicking a site's predevelopment hydrology by minimizing disturbed areas and impervious cover and infiltrating, storing, detaining, evapotranspiring, and/or biotreating stormwater runoff close to its source, or onsite. |
| Minor Arterial | A street that acts as a distributor in urban areas, connects Local Streets and Collector Streets to Principal Arterials and provides service for moderate length trips. |
| Parkway Zone | The area of the sidewalk where furnishings or infrastructure such as seating, fire hydrants, signs, street lights, refuse bins and transit shelters may be placed. Also used for street tree planting and known as Furniture Zone. |
| Pedestrian Zone | The area of the sidewalk accommodating pedestrian travel which is free of obstacles. Also known as Walking Zone. |
| Pervious Pavement | A LID or GSI Measure consisting of a pavement system that is designed to store and infiltrate stormwater. There are several kinds of Pervious Pavement described in Chapter 2 of this GSI Handbook including: Grid Paving, Permeable Pavers, Permeable Interlocking Concrete Pavers, Pervious Concrete, Porous Asphalt and Porous Rubber. |

| | |
|---|---|
| Principal Arterial | A street that carries the highest traffic volumes in urban areas. It carries most of the trips to and from major urban areas and most of the traffic through urban centers. |
| Rootable Soil Volume | The volume of soil that is compacted less than 85% allowing for tree roots to grow through the soil. Typically used to measure the amount of soil available to tree roots. It may be located under adjacent pavement areas using suspended pavement systems. |
| Step-out Zone | The area of the sidewalk or roadway adjacent to an on-street parking area that provides space for door swings and for passengers entering and exiting vehicles or mounting bicycles. |
| Stormwater Curb Extension | A GSI Measure consisting of a bioinfiltration or bioretention area typically at an intersection or mid-block and within the flexible zone of a street. Stormwater curb extensions may help achieve complete streets goals of improving pedestrian access and safety. |
| Stormwater Planter | A GSI Measure consisting of a bioinfiltration or bioretention area that manages stormwater runoff from roadways, sidewalks or other impervious surfaces, located in the public right-of-way (e.g., Parkway Zone, Flexible Zone, medians, traffic circles, or the empty space adjacent to parking stalls in streets). |
| Stormwater Tree Well Filter | A GSI Measure consisting primarily of a tree in a bioinfiltration or bioretention area that manages stormwater runoff from roadways, sidewalks or other impervious surfaces, located in the public right-of-way (e.g., Parkway Zone, Flexible Zone, medians, traffic circles, or the empty space adjacent to parking stalls in streets). Can be combined with Suspended Pavement Systems and adjacent landscaped areas to maximize Rootable Soil Volume and access for tree roots to non-BSM soils. |
| Stormwater Tree Trench | A series of hydraulically connected Stormwater Tree Well Filters. |
| Structural Soil | An engineered media consisting primarily of crushed angular granite rock or sand combined with soil and sometimes a hydrogel that adheres the rock and soil together during transportation and installation. Structural Soil can be used to increase the Rootable Soil Volume of a tree planting area. The Cornell Mix is an example of a proprietary Structural Soil. |
| Subsurface Infiltration System | A GSI Measure consisting of underground vaults or pipes, also known as infiltration galleries, that store and infiltrate stormwater or rainwater, while preserving the land surface above for parking lots, parks, or playing fields. Another type of subsurface infiltration system is an exfiltration trench, which consists of perforated pipe laid in a bed of gravel. It is similar to an infiltration trench with the exception that it can be placed below paved surfaces, such as parking lots and streets. |

| | |
|---|---|
| Suspended Pavement System | An underground system, such as Structural Soil or structural modules that provide rootable soil volume for tree root growth under pavement areas adjacent to the tree planting area. The system provides structural support for the pavement material and can be designed for underground bioretention or bioinfiltration. Silva Cells are an example of a proprietary modular suspended pavement system. |
| Total Maximum Daily Load (TMDL) | The amounts of pollutants of concern such as PCBs and Mercury that can be discharged to the San Francisco Bay or other impacted waterbodies as defined in the MRP. |

# Acronyms

The following acronyms may be found in this document:

| | |
|---|---|
| ADA | Americans with Disabilities Act |
| AASHTO | American Association of State Highway Transportation Officials |
| BASMAA | Bay Area Stormwater Management Agencies Association |
| BSM | Biotreatment Soil Media |
| CAMUTCD | California Supplement to the Manual on Uniform Traffic Control Devices |
| CIP | Capital Improvement Project or Program |
| CCR | California Code of Regulations |
| DDOT | District Department of Transportation (Washington D.C.) |
| EPA | Environmental Protection Agency |
| FDR | Full Depth Reclamation |
| FHWA | Federal Highway Administration |
| GI | Green Infrastructure |
| GSI | Green Stormwater Infrastructure |
| HDM | Highway Design Manual |
| HM | Hydromodification Management |
| IPM | Integrated Pest Management |
| LID | Low Impact Development |
| LOS | Level of Service |
| MassDOT | Massachusetts Department of Transportation |
| MAP | Mean Annual Precipitation |
| MRP | Bay Area Municipal Regional Stormwater Permit |
| MS4 | Municipal Separate Stormwater System |
| MOU | Memorandum of Understanding |
| MUTCD | Manual on Uniform Traffic Control Devices |
| NACTO | National Association of City Transportation Officials |
| NPDES | National Pollutant Discharge Elimination System |
| NRPA | National Recreation and Park Association |
| PCBs | Polychlorinated biphenyls |
| PG&E | Pacific Gas and Electric Company |
| PICP | Permeable Interlocking Concrete Pavement |
| POC | Pollutants of Concern |
| PP | Permeable Pavers |
| PWD | City of Philadelphia Water Department |

| | |
|---|---|
| RAA | Reasonable Assurance Analysis |
| RWQCB | San Francisco Bay Regional Water Quality Control Board (“Water Board”) |
| SCVWD | Santa Clara Valley Water District |
| SCVURPPP | Santa Clara Valley Urban Runoff Pollution Prevention Program |
| SFEI | San Francisco Estuary Institute |
| SFPUC | San Francisco Public Utilities Commission |
| SMCWPPP | San Mateo Countywide Water Pollution Prevention Program |
| SWRCB | California State Water Resources Control Board |
| TMDL | Total Maximum Daily Load |
| TNC | Transportation Network Company |
| VMT | Vehicle Miles Traveled |
| VPD | Vehicles per Day |
| WUCOLS | Water Use Classification of Landscape Species |

# CHAPTER 1

# Introduction

*This Chapter describes the purpose of this Handbook and provides an overview of its contents.*

The Green Stormwater Infrastructure (GSI) Handbook was written to assist municipal staff, designers, engineers and developers with implementation of the municipalities' Green Infrastructure (GI) Plans[1] to meet the requirements of the San Francisco Bay Region Municipal Regional Stormwater National Pollutant Discharge Elimination System (NPDES) Permit (MRP)[2]. This is a companion document to the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) Guidance for Implementing Stormwater Requirements for New Development and Redevelopment Projects (C.3 Stormwater Handbook)[3]. The complete GSI Handbook includes two Parts:

- Part 1 - General Guidelines, which provides an overview of streetscape and project designs that integrate stormwater capture and treatment measures into the range of functions associated with projects in public rights-of-way and on other public properties
- Part 2 - Details and Specifications, which includes typical details and design specifications and guidance.

The focus of this Handbook is to provide guidance to municipal staff on how to incorporate GSI into non-regulated public street, parking lot and park retrofit projects. Regulated projects, as defined in the C.3 Stormwater Handbook, are new development and redevelopment projects, both private and public, that meet the thresholds in MRP Provision C.3.b and must implement site design measures, source control measures, stormwater treatment measures and hydromodification management measures, if applicable. The GSI Handbook focuses on non-regulated projects but uses similar stormwater control measure concepts as those described in the C.3 Stormwater Handbook. Unlike the C.3 Stormwater Handbook, this GSI Handbook addresses the additional considerations that must be included in the non-regulated transportation-related public projects and that add to the projects' overall environmental, safety and accessibility benefits.
The reader should be familiar with the concepts of Low Impact Development (LID), stormwater treatment measures, and sizing methodology from the C.3 Stormwater Handbook when using this GSI Handbook.

*The GSI Handbook is designed to assist municipal staff in planning and designing stormwater controls for non-regulated projects in public roadways, parking lots, and parks.*

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[1] The term "green stormwater infrastructure" or "GSI" was chosen for this Handbook because it more specifically distinguishes this type of green infrastructure from other green building and roadway sustainability concepts related to energy, materials, lighting, etc., and it is more widely used by other agencies across the U.S. The MRP uses the term "green infrastructure" or "GI". For the purposes of this Handbook, the two terms are equivalent and interchangeable, but GSI is preferred.

[2] CA RWQCB, 2015

[3] SCVURPPP, 2016. Online at https://scvurppp.org/2016/06/20/c-3-stormwater-handbook-june-2016/

## 1.1 Green Stormwater Infrastructure

Green Stormwater Infrastructure (GSI) is infrastructure that uses vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a town, city or county, GSI refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or project site, GSI refers to stormwater management systems that mimic nature by soaking up and storing water.

Examples of GSI measures include resilient, sustainable systems that slow, filter, harvest, infiltrate and/or evapotranspirate runoff such as landscape-based stormwater biotreatment using soil and plants ranging in size from grasses to trees, pervious pavement systems (e.g., interlocking concrete pavers, porous asphalt, and pervious concrete), rainwater harvesting systems (e.g., cisterns and rain barrels), and other methods to capture and treat stormwater. These practices are also known as Low Impact Development (LID) site design and treatment measures and are explained in detail in the C.3 Stormwater Handbook.

Roadways with GSI are often called “Green Streets” or “Sustainable Streets” projects. Another term related to street design is “Complete Streets” which comes from the transportation field. The goal of the Complete Streets approach is to design streets that safely accommodate all users including pedestrians, bicyclists, and transit users. The integration of the goals of both Complete Streets and Green Streets recognizes that environmentally and holistically designed streets achieve many benefits: increased multi-modal travel and safety; clean water and air; climate change resilience and mitigation; placemaking and community cohesion; habitat and energy savings; flood reduction; and neighborhood beautification. Institutionalizing the integration of GSI into Complete Streets, such as integration of GSI with safety, accessibility and infrastructure for pedestrian and bicycle features, is one of the goals of this Handbook.

## 1.2 Regulatory Context

The MRP (Provision C.3.j.i.(2))[4] requires Permittees to develop and implement long-term Green Infrastructure (GI) Plans for the inclusion of LID measures[5] in storm drain infrastructure on public and private lands, including streets, roads, storm drains, parking lots, building roofs, and other elements. Other sections of the MRP include requirements for municipalities to prevent pollutants of concern to water quality, including polychlorinated biphenyls (PCBs), mercury, trash and pesticides, from entering storm drain systems and creeks. LID measures that transform storm drain infrastructure from “gray” to “green” can help remove these pollutants from stormwater runoff.

A key part of the GSI requirements in the MRP is the inclusion of both private and public property locations for GSI systems. This has been done in order to plan, analyze, implement and credit GSI systems for pollutant load reductions on a watershed scale, as well as recognize all GSI accomplishments within a municipality. The focus of the GSI Plan and this Handbook is the integration of GSI systems into <u>public projects,</u> such as public parks, parking lots and rights-of-way. The GSI Plan is not intended to impose retrofit requirements on private property, outside the standard development application review process for projects already regulated by the MRP, but may provide incentives or opportunities for private property owners to add or contribute towards GSI elements if desired.

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[4] CA RWQCB, 2015

[5] This Handbook refers to LID measures retrofit into public parcels and rights-of-way as GSI measures.

This Handbook was developed to specifically address the following MRP Provisions C.3.j.i.(2)(e) and (f) in Part 1 and Part 2, respectively.

> *C.3.j.i Green Infrastructure Program Plan Development*
>
> *Each Permittee shall:…*
>
> *(2) Prepare a Green Infrastructure Plan, subject to Executive Officer approval, that contains the following elements:…*
>
> *(e) General guidelines for overall streetscape and project design and construction so that projects have a unified, complete design that implements the range of functions associated with the projects. For example, for streets, these functions include, but are not limited to, street use for stormwater management, including treatment, safe pedestrian travel, use as public space, for bicycle, transit, vehicle movement, and as locations for urban forestry. The guidelines should call for the Permittee to coordinate, for example, street improvement projects so that related improvements are constructed simultaneously to minimize conflicts that may impact green infrastructure.*
>
> *(f) Standard specifications and, as appropriate, typical design details and related information necessary for the Permittee to incorporate green infrastructure into projects in its jurisdiction. The specifications shall be sufficient to address the different street and project types within a Permittee's jurisdiction, as defined by land use and transportation characteristics.*

## 1.3 Design Approach

This Handbook provides guidance for common GSI measures that can readily be incorporated into the design of parking lots, parks, streets and other public rights-of-way. The Handbook is intended to help identify GSI opportunities, provide guidance on how to address common design approaches and site constraints, and provide design tools that can be customized to assist agencies in implementing GSI effectively within their existing design standards and policies.

Effective GSI solutions can be designed to be sustainable, attractive, and cost effective. Using the information in this Handbook will guide users on GSI implementation; however, agencies may want to consider customized designs and options on a case-by-case basis.

GSI technologies and design standards may be added or enhanced in the future as innovative projects are implemented. Updates to the GSI Handbook will include additional guidance, details, and standards and will be provided to all SCVURPPP municipal agencies.

As stated previously, the focus of this Handbook is to provide guidance on how to incorporate GSI measures into non-regulated, public projects. The LID site design approach for new development and redevelopment projects is described in the C.3 Stormwater Handbook[6]. Table 1-1 presents a comparison

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[6] SCVURPPP, 2016

of the difference in design approach for GSI retrofit versus parcel-based new and redevelopment (C.3 regulated) projects.

*Table 1-1. Comparison of Design Approach to Parcel-based New Development and Redevelopment Projects versus Design Approach to GSI Retrofit Projects in the Public Right-of-Way.*

| LID Site Design for New Development and Redevelopment Projects (C.3 Stormwater Handbook) | Design Approach for GSI Retrofit Projects in the Public Right-of-Way and on Public Properties (GSI Handbook) |
|---|---|
| • Conserve and protect natural areas<br>• Cluster buildings<br>• Minimize disturbance to natural drainages | • Work within confines of existing site<br>• Combine with other street or parking lot improvements<br>• Integrate with a site redesign for another purpose |
| • Strategically locate treatment areas | • Look for opportunities for locating treatment areas in existing features |
| • Minimize impervious area | • Convert impervious area to pervious area/ vegetation |
| • Use impervious area efficiently | • Convert inefficient use (e.g., leftover or excess pavement) to more efficient use<br>• Integrate landscaping into existing impervious areas, such as parking areas |
| • Design landscaping as a self-retaining area for runoff from new impervious area | • Redirect existing impervious area to existing landscaping<br>• Convert existing landscaping into a stormwater treatment area (e.g. bioretention area or stormwater planter) |

Designers of GSI measures will encounter a number of challenges regarding siting, sizing, integration, and maintenance. This Handbook provides guidance on ways to address these challenges. Table 1-2 presents examples of specific challenges when siting GSI measures in the public right-of-way and references to sections within the Handbook in which the challenges and solutions are covered.

*Table 1-2. Overview of Challenges and Solutions for Siting GSI measures in the Public Right-of-Way.*

| GSI Measure Siting Challenge | Example Solutions | Reference |
|---|---|---|
| • Competition for space with various modes of travel, roadway structures, utilities, public safety, trees and other landscaping | • Use multi-modal analysis to look for under-utilized roadway space.<br>• Integrate multi-disciplinary designs to stack benefits and eco-system services. | Chapter 2 and Sections 3.2-3.4 |
| • Low permeability of native soils limits size and type of GSI measures | • Install underdrains where feasible.<br>• Create additional underground storage or expand GSI measure footprint to facilitate infiltration.<br>• Extend gravel columns down to soil horizon with greater permeability. | Section 2.2 |
| • Storm drain system proximity and elevation of components for connecting overflows and underdrains | • Utilize permeable soils or infiltration systems where feasible.<br>• Modify design to minimize GSI measure depth. | Sections 2.2 and 3.5 |
| • Ability to direct runoff to location where space is available for GSI measures | • Pervious pavement, suspended pavement systems, and conveyances can provide flexibility. | Sections 2.2, 2.3 and 3.1 to 3.4 |
| • Existing underground and above ground utilities limit GSI placement | • Coordinate with utility owners on relocation or protection in place. | Section 3.5 |
| • High on-street vehicle and/or bicycle parking demand | • Consider GSI measures that do not remove parking spaces such as pervious pavement and suspended pavement systems.<br>• Provide new off-street parking where feasible.<br>• Locate GSI measures in red curb (no parking) areas. | Sections 2.2, 2.3 and 3.2 to 3.4 |
| • Lack of irrigation system or excessive distance to tie into existing irrigation system | • Select native and climate appropriate vegetation that only needs irrigation for a short establishment period with truck watering. | Section 3.6 |
| • High maintenance costs, location risk and/or inability to use automated maintenance systems | • Select low maintenance plants.<br>• Design GSI measures to maximize use of street sweepers, vactor trucks or other methods that collect debris, and sediment at a lower cost than manual methods.<br>• Locate GSI measures in locations that are lower risk for maintenance such as in the parkway zone instead of in roadway medians. | Sections 2.2, 3.6, and 3.7 |
| • Insufficient soil volumes for street trees and/or protection of roots | • Develop and specify minimum soil volumes for trees and utilize suspended pavement systems where feasible. | Section 3.6 |

## 1.4 Using This Handbook

Part 1 of this Handbook is intended to guide the user through the planning and preliminary design process for GSI projects. Remaining chapters provide the following information:

- Chapter 2 identifies the public areas and street types available for GSI retrofits; provides descriptions of GSI measures, key limitations, sizing strategies and technical design considerations; and provides guidance on identifying potential GSI sites.
- Chapter 3 presents more detailed information on the integration of GSI measures into public parcels and the public right-of-way, multi-modal design issues, as well as information on key street retrofit, urban forestry and other landscaping elements.
- Chapter 4 discusses the sizing methodology for GSI measures for non-regulated projects, including the standard “C.3.d” approach and the alternative sizing approach when there are constraints within the public right-of-way.
- Chapter 5 discusses post-construction maintenance guidance for GSI measures.
- Chapter 6 provides examples of GSI applications.

Part 2 of the Handbook contains a compilation of typical details and design specifications and guidance that can serve as a reference when updating public works standards and developing site-specific plans for GSI measures.

## 1.5 Relationship with Other Plans

This Handbook was written to assist SCVURPPP municipal agencies with the implementation of their GSI Plans. The design of GSI within a municipality must be consistent with local policies, procedures and/or design standards. Municipal staff should be aware of other governing documents that may take precedence over, or complement, the guidance in this Handbook, such as Climate Action Plans, Bicycle and Pedestrian Master Plans, Complete Streets Policies, Transportation Plans, Storm Drain Master Plans, Urban Forestry Plans, Parks and Open Space Plans, and certain public works details and standards.

# CHAPTER 2

# Integration of Green Stormwater Infrastructure with Public Streets, Parking Lots, Parks and Other Public Outdoor Areas

*This chapter describes the identification and prioritization of potential GSI sites and applications.*

Siting GSI measures in public projects is generally more challenging than siting LID measures in parcel-based development projects because GSI measures are typically retrofit into public spaces and must fit into areas with numerous functions and constraints. Therefore, there are special design considerations that need to be taken into account when designing stormwater treatment measures in public areas, particularly for projects in the public right-of-way. Section 2.1 of this chapter describes the classification of public streets, to orient the reader to common terminology that will be used throughout the Handbook. The GSI measures recommended for public streets and other areas, and specific design considerations associated with each of the measures, are provided in Section 2.2. Section 2.3 contains guidance on identifying opportunities for GSI in public areas, and for evaluating public parking lots, parks, plazas, streets, and other public rights-of-way for potential GSI retrofits.

## 2.1 Classification of Public Streets

Public streets serve many purposes and include a variety of elements. These elements include vehicle travel lanes, bikeways, pedestrian accommodations, plazas, bus stops, and on-street parking areas. Streets and plazas are also used for events or other uses such as fairs, festivals, food trucks, flea markets and concerts. In addition, streets often act as the principal drainage systems of many jurisdictions.

Roadway projects have a significant impact on the built and natural environment. Incorporating GSI measures into roadway design provides an opportunity to reduce localized flooding, increase safety for all modes of transportation, and enhance ecological habitat, as well as improve water quality. As the knowledge and experience with Complete Street design has evolved over the last 15 years, practitioners in leading jurisdictions across the U.S. are beginning to add GSI to their list of basic assumptions. Combining GSI measures with other street enhancement projects also provides an opportunity to use a variety of funding sources, including transportation-oriented grants.

In addition to public streets, other types of public areas include parking lots, parks, public plazas, and parklets. When discussing the siting and design of GSI in parking lots, parks, public plazas, and parklets, the terminology and design considerations are similar to the parcel-based redevelopment guidance found in the C.3 Stormwater Handbook. However, discussing the siting of GSI in public streets introduces new terminology that will be used throughout the Handbook. The areas within a streetscape, the types of roadways, and types of bikeways are defined below to orient the reader.

## 2.1.1 Street Cross Section

The public right-of-way is the publicly owned or dedicated and accessible area along a street, which generally consists of the street itself, sidewalks, planter strips or parkways, and various other streetscape elements. Design standards require identifying subsections within these areas.
Figure 2-1 provides an illustration of these subsections as described below. GSI measures can be retrofitted into any of the subsections. For more ideas on what GSI measures can be used where, refer to the "potential location" discussion for each GSI measure in Section 2.2 and the Stormwater Matrix from San Diego's City Heights Urban Greening Plan[7] in Section 3-3, Figure 3-19.

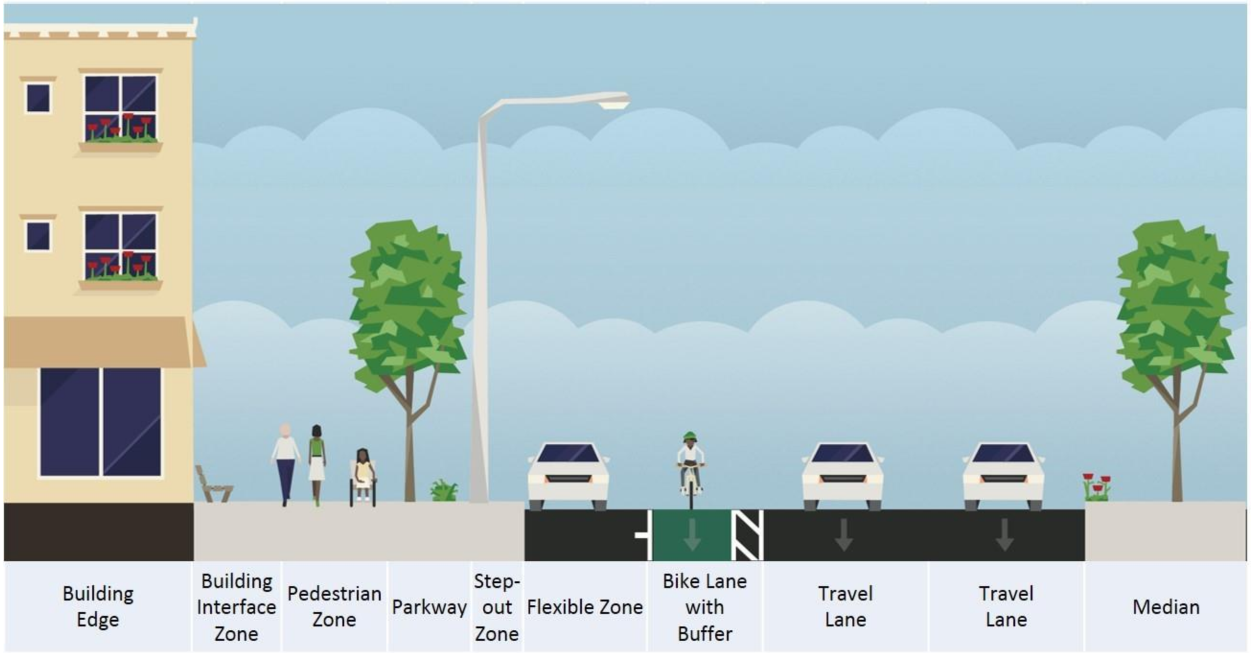

*Figure 2-1. Street and sidewalk cross section, conceptual example (courtesy of Streetmix.net)*

### *Sidewalk Subsections*

The sidewalk in Figure 2-1 is shown divided into four regions:

1. The building interface zone (or frontage zone)
2. The pedestrian zone (or walking zone)
3. The parkway (or furniture zone)
4. The step-out zone

The building interface zone is the area between the building edge and the pedestrian zone. In a commercial area, typical design practice is to allow space for opening doors, outdoor restaurant seating, merchant displays, landscaping, and signage. In a residential area, there may be a smaller standard allowance for fences or other features that demarcate the transition from public to private space.

The pedestrian zone is the area accommodating pedestrian travel and is free of obstacles. There may be different pedestrian travel widths for commercial and residential areas. This width of the pedestrian

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[7] City of San Diego, 2014

zone should be four feet at a minimum (or three feet at specific locations if there are existing obstacles or right-of way restrictions) to comply with ADA (Americans with Disabilities Act) guidelines[8] for a pedestrian access route. Individual agency guidelines or plans may recommend or require larger sidewalk widths in commercial areas than they do in residential areas. For example along El Camino Real in Palo Alto, an 8-foot wide clear sidewalk is required.

The parkway is where landscaping, street trees and other public infrastructure is placed, such as benches, fire hydrants, signs, street lights, trash/recycling bins and transit shelters. It frequently contains underground utilities and irrigation systems.

The step-out zone is an area between a landscaped area and the street (or between the parkway and the flexible zones shown in Figure 2-1). It provides a space for people getting in and out of cars and other vehicles or dismounting from bicycles to avoid having to step into a landscaped area or stormwater planter, especially when the planter has a vertical side or steep drop off from the street grade which could cause a tripping hazard. See Figure 2-2 below for an example of a step-out zone.

*Figure 2-2. Street with step-out zone and on-street parking in Campbell (Credit: EOA)*

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[8] 2013 CA Access compliance advisory reference manual: CA building code CCR Title 24 11B-403.5.1 Exception 3: The clear width for sidewalks and walks shall be 48 inches (1219 mm) minimum. When, because of right-of-way restrictions, natural barriers or other existing conditions, the enforcing agency determines that compliance with the 48-inch (1219 mm) clear sidewalk width would create an unreasonable hardship, the clear width may be reduced to 36 inches (914 mm)" https://www.documents.dgs.ca.gov/dsa/pubs/2013cbc_advisory_manual.pdf

## Street Subsections

The travel lanes in the roadway are the areas designed to accommodate vehicular and cycling travel. Travel lane widths may vary by jurisdiction or street classification; fire, garbage, or delivery truck widths; or natural or human-made restrictions on street width.

The area between the travel lanes and the sidewalk is referred to as the flexible zone. As shown in Figure 2-1, this may include on-street parking and/or bikeways in varying configurations. “Cycletracks”, also known as protected bikeways, may also be in the flexible zone (See Chapter 3 for more details on cycling facilities). Flexible zones may include street trees as shown in Figure 2-3 below, landscaped areas, or other design elements.

*Figure 2-3. Trees in flexible zone in Redwood City. (Credit: EOA)*

Medians may provide a physical barrier to separate vehicles traveling in opposite directions. Typical streets have a high point (crown) in the middle and slope out towards the edges. For a median that is at the high point of the street, GSI integration into the median would usually require a complete street redesign and regrading to direct runoff to the median. For streets with a low point in the middle (reverse crown), medians may have their own curb and gutter and drainage system. Medians may also occur between travel or parking lanes and a cycletrack (See Chapter 3 for more details on cycling facilities). Figure 2-4 shows a GSI measure GSI measure in a depressed median which treats stormwater collected upstream and directed to the facility.

*Figure 2-4. GSI measure in a depressed median in Paso Robles. (Credit: SvR Design and Cannon Engineering)*

## 2.1.2 Street Functional Classification

Most Santa Clara County streets are considered urban streets, in accordance with the definition of “urban area” in the American Association of State Highway and Transportation Officials (AASHTO) Green Book[9], which is defined as places with a population of 5,000 or more. In the Green Book, AASHTO identifies four main functional street classifications in urban areas – principal arterials (main movement), minor arterials (distributors), collectors, and local roads. Note: these street typologies are the standard primarily car-oriented ones that have been in use for decades, but with the advent of Complete Street designs and policies, other types of street typologies are also starting to be defined and used in urban environments[10]. See the NACTO Urban Street Guide and Chapter 3 for more information and definitions of bikeway facilities. The California Department of Transportation’s Highway Design Manual (HDM)[11] is often used by municipal engineers to design roadway, bikeway and sidewalk facilities in the State. Sections of the HDM are cited in this Handbook.

### *Principal Arterials*

Principal arterials carry the highest volumes of motor vehicles in urban areas. They carry most of the motor vehicle trips to and from major urban areas and most of the traffic through urban centers[12]. A typical arterial has 2-6 lanes of traffic and carries 10,000-50,000 vehicles per day (VPD). Examples of principal arterials in Santa Clara County include El Camino Real, Sunnyvale-Saratoga Road, Homestead Road, Pruneridge Avenue, Wolfe Road, Stevens Creek Boulevard, De Anza Boulevard, Los Gatos Boulevard, Capitol Avenue, Blossom Hill Road, Story Road, King Road, and Tully Road.

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[9] AASHTO, 2001

[10] www.changelabsolutions.org/sites/default/files/CompleteStreets_ComprehensivePlan_20141103.docx

[11] CA DOT, 2018

[12] AASHTO 2001

*Figure 2-5. Examples of principal arterials in Santa Clara County: El Camino Real, , De Anza Blvd, and Capitol Avenue. (Credit: Google Earth - principal arterials are highlighted with double yellow lines.)*

## Minor Arterials

Minor arterials act as distributors in urban areas and provide service for moderate length trips. Motor vehicle traffic volumes on minor arterials are medium to high. Similar to principal arterials, minor arterials may have on-street parking and a median, but lanes may be narrower and the demand for on-street parking may be higher, depending on the land use. Minor arterials often have standard striped Class II bike lanes but can also be installed with buffered Class II bike lanes, Class I or IV facilities to provide additional protection. Examples of minor arterials in Santa Clara County are Camden Avenue, Trimble Road, Tasman Drive, Winchester Boulevard, Santa Clara Street, Oakland Road, and Campbell Avenue.

*Figure 2-6. Examples of minor arterials in Santa Clara County: Camden Ave, Tasman Drive, and Campbell Ave. (Credit: Google Earth - minor arterials are shown as single yellow lines.)*

## Collector Streets

Collector streets connect neighborhoods or areas of homogenous land use to arterials. In addition to connecting arterials to local streets they provide traffic circulation within neighborhoods and small areas. Typically, collectors have 2-4 lanes of motor vehicle traffic and carry lower traffic volumes than arterials. On smaller streets, the outer lanes may be used as shoulders, bike lanes or parking. Collectors have an average volume of 1,000-10,000 VPD[13]. Bike facilities for collector streets can range from Class III bike routes and bicycle boulevards (maximum of 3,000 VPD recommended[14]) to Class I, II or IV facilities depending on the space available, average traffic speeds and VPD.

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[13] City of San Mateo, 2015

[14] City of Emeryville, 2012

*Figure 2-7. Examples of collector streets in Santa Clara County: Almond Ave, Lincoln Ave, and S Mary Ave. (Credit: Google Earth - collectors are shown either as single or double white lines.)*

### *Local Street*

Local streets are designed to only provide access to their immediate land uses. Typically, local streets have two lanes of traffic and have a load of 400-2000 vehicles per day[15]. Bikeways are usually Class III bike routes or bike boulevards.

*Figure 2-8. Examples of local streets in Santa Clara: Atlanta Ave, Boxwood Drive, and Bancroft Way. (Credit: Google Earth - local streets are shown as single white lines)*

## 2.1.3 Cycling Infrastructure Typologies

There are several types of cycling-related infrastructure that may be integrated with GSI:

- Roadways
- Bikeways
- Intersection Treatments
- Sidewalks (where allowed by the local jurisdiction)
- Bridges and Ramps
- Cycle Parking Areas

According to Chapter 1000 of the HDM, all roadways, except those that are signed “Bicycles Prohibited” such as most freeways, are legal for cyclists to use[16]. Roadways that are not signed as bikeways are to be shared by motor vehicles and cyclists with both users having legal use of the facility. Within the category of bikeways, there are four classes in California:

- Class I – Paths/Trails

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[15] AASHTO, 2001 (pg. 468)

[16] CA DOT, 2018

- Class II – Lanes
- Class III – Routes
- Class IV – Protected

### Class I Bikeways (Paths/Trails)

Class I bikeways are bicycle paths or trails that are non-vehicular, off-street facilities. The paths can be for bicycles only or designed as a multi-use path for pedestrians as well. The City of San Jose has 60 miles of Class I bikeways.

*Figure 2-9. Guadalupe River Trail in San Jose (Class I bikeway). (Credit: City of San Jose)*

### Class II Bikeways (Lanes)

Class II bikeways are signed and striped travel lanes for one-way bicycle travel on a street or highway and should have pavement markings indicating the facility. They are usually on collector and arterial roadways with medium to high levels of motor vehicle traffic where dedicated space for cyclists provides additional protection from higher speed vehicles. The lane is for the sole use of bicycles except when vehicles need to cross the lane to enter a parking lane or for turning movements. An example from the City of Palo Alto with green treated pavement is shown in Figure 2-10 below.

*Figure 2-10. Class II bicycle lane with green pavement in Palo Alto. (Credit: Palo Alto Patch)*

Since standard Class II bicycle lanes do not have any separation from the motor vehicle travel lane other than a stripe, an enhanced type of Class II facility was developed to provide a separation zone. These bikeways are called "buffered bicycle lanes" and have a striped separation area (typically 3 feet wide) between the motor vehicle lane and the bicycle lane. Figure 2-11 shows a buffered bike lane.

*Figure 2-11. Class II buffered bicycle lane in Mountain View. (Credit: www.safemountainview.org)*

## Class III Bikeways (Routes)

Class III bikeways are roadways designed for shared use with bicycles and motor vehicles typically on low-volume roadways, designated by signage, also known as a bicycle route. Bike routes use signage to indicate the facility. Enhanced bicycle routes are sometimes known as bicycle boulevards or bicycle priority streets with additional pavement markings and/or special signage. A signed bike boulevard from the City of Palo Alto is shown below in Figure 2-12.

*Figure 2-12. Class III bicycle boulevard in Palo Alto. (Credit: https://bikeaway.tumblr.com/post/30365628672/bay-area-again-tunitas-creek-old-la-honda-and)*

## Class IV Bikeways (Cycletracks)

The newest addition to the list of California bikeways is the Class IV bikeway, also known as a cycletrack or separated or protected bikeway/lane (this Handbook uses the term “cycletrack”). Class IV bikeways are separated from vehicle traffic by curbs, parked vehicles or other physical barriers such as railings, walls, planters or landscaped areas. Cycletracks provide an increased level of separation with a physical barrier to discourage motor vehicles from crossing into the bikeway.

The number of separated bikeway facilities in the US has grown rapidly since 2010 and increasingly is becoming the most popular type of facility with the public for the increased safety and separation that the facility provides. Surveys from around the country show that the majority of cyclists prefer riding in a separated bikeway and that certain segments of the population (older, younger and new adult riders) are more willing to consider cycling when separated bikeways are provided.

Figure 2-13 shows a contra-flow cycletrack facility in San Francisco with raised medians, parked vehicles and striping for separation. Contra flow bikeways are sometimes installed on one-way motor vehicle streets when there is extra capacity and a vehicle travel lane can be replaced with a bikeway where cyclists ride in the opposite direction of vehicle travel. A buffered bike lane is provided on the other side.

Figures 2-14 and 2-15 display before and after images of a Class II bike lane converted to a Class IV cycletrack in Australia. The new facility protects cyclists with parked cars and trees.

*Figure 2-13. Cycletrack in San Francisco with curbs and parking lane barrier. (Credit Google Street View)*

*Figure 2-14. Before: standard unprotected bicycle lane in Melbourne, Australia (Credit: Google Street View)*

*Figure 2-15. After: cycletrack with raised median, street trees & parked cars. (Credit: Google Street View)*

## 2.2 GSI Measures

Integrating GSI with public streets, parks and parking lots consists of incorporation of stormwater treatment measures into public spaces. The benefits, siting and design considerations related to installing common GSI measures in streets, parks and parking lots are described in the following sections. Additional information on the design and sizing of these GSI measures is provided in Chapter 6 of the SCVURPPP C.3 Stormwater Handbook.

### *Nomenclature*

There are three main categories of LID treatment measures that can be constructed in public spaces: (1) bioretention, (2) pervious pavement, and (3) infiltration facilities. For the purposes of this GSI Handbook, the following terms for GSI measures are used:

- Bioretention/Bioinfiltration
    - Stormwater Planter
    - Stormwater Curb Extension
    - Stormwater Tree Well Filter
- Pervious Pavement
- Infiltration Facilities
    - Infiltration Trench
    - Dry Well
    - Subsurface Infiltration System

### *Function*

All GSI measures slow and/or reduce the flow of runoff and associated pollutants to the storm drain system by capturing and storing urban runoff, removing pollutants via filtration, and then discharging treated water to the storm drain system or to underlying soils via infiltration. Reducing the flow to local storm drains and receiving water can help reduce local flooding, reduce erosion and sedimentation, and partially restore the natural hydrologic cycle[17]. Treating urban runoff with GSI measures reduces the pollutant load to receiving waters, which ultimately leads to healthier creeks and San Francisco Bay and meets MRP requirements to reduce pollutants of concern (POC) loading to the Bay. Additionally, reducing the flow to the storm drain system may reduce the size of the pipe needed for a project or the amount of underground storm drain infrastructure needed[18].

### *Siting*

GSI measures may be used in a multitude of locations along the public right-of-way and may require different edge controls depending on the type of adjacent hardscape or structure. For example, GSI measures may be situated at the following right-of-way locations:

- With roadway on either or both side(s)
- Between the curb and roadway (no parking)
- Between the curb and sidewalk
- Between the sidewalk and parking/step-out zone

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[17] PWD, 2011

[18] PWD, 2011

- Adjacent to landscaping and sidewalk
- Between sidewalk and parking (on-street or lot)

The approach to siting in parking lots, parks, plazas, and other public rights-of-way is discussed in Section 2.3

### *Edge Controls*

Edge controls are used to define and stabilize the edge of GSI measures and prevent water stored in the GSI measure from migrating laterally into an adjacent compacted soil layer or other materials. They also prevent engineered, compacted soil and gravel layers from migrating laterally or collapsing into adjacent, uncompacted bioretention soil. During the design phase, a licensed engineer should design the edge controls to address site-specific conditions. The designer must ensure that the pavement edges will be restrained and that water will be contained in the GSI measure as needed to protect adjacent pavement sections or structures. Designer notes should specify minimum edge control embedment depths to prevent this lateral seepage[19]. Typical edge control strategies include using an impermeable liner, metal paver, deepened concrete curb and/or concrete band to provide protection. Deepened curb depth will depend on the pavement section, which varies based on the street type category. Details are provided in Part 2 of this Handbook. Alternative edge control materials may be used, provided the material meets structural requirements for loading conditions, serves as a water barrier between the facility and adjacent pavement sections (as applicable), and complies with local accessibility requirements[20].

## 2.2.1 Bioretention

Bioretention areas are GSI measures that consist of a ponding area, mulch layer, plants, and biotreatment soil media[21], underlain by drain rock and an underdrain, if required. A bioretention area can be any size or shape. Where sites have underlying soils that are more permeable and infiltration is the primary form of treatment, the term bioinfiltration may be used to describe the system. More details on bioretention systems are provided in Section 6.1 of the C.3 Handbook. Types of bioretention systems in the streetscape include:

1. Stormwater Planter
2. Stormwater Curb Extension
3. Stormwater Tree Well Filter

The term used for a given bioretention system depends on its location in the streetscape and the primary type of plants used. Stormwater planters and stormwater curb extensions typically use small plants while trees are the focus of stormwater tree well filters.

For more information on Bay Area projects that have included bioretention as a GSI measure, see the examples in Chapter 6: Sections 6.1, 6.2, 6.4, 6.6, 6.8 and 6.9.

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[19] SFPUC, 2016

[20] SFPUC, 2016

[21] Bioretention systems should use biotreatment soil media that meets the requirements in the updated BASMAA Biotreatment Soil Media specification approved in 2016 and as posted on the Water Board website: www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/stormwater/MRP/C3.shtml

## Stormwater Planter

*Figure 2-16. Stormwater planter on Hacienda Avenue in Campbell. (Credit: EOA)*

A stormwater planter is a bioretention facility in the public right-of-way. They are designed to have a flat bottom and often have vertical (typically concrete) sides. However, depending on the amount of space that is available, they can also have sloped sides as shown in Figure 2-16.

### Benefits

- Stormwater planters can be installed as a physical buffer to divide pedestrians and/or cyclists from vehicular traffic, increasing safety. For example, a stormwater planter can be installed between a cycle track and the traffic lane.
- Stormwater planters can fit between existing features in the parkway zone such as driveways, signs, and street furnishings.
- Stormwater capacity can be increased while maintaining space for pedestrian activity by using grates or boardwalks to span portions of the planter.
- Stormwater planters can fit into leftover space.
- Stormwater planters can create aesthetic improvements to public spaces.
- Stormwater planters can be used to address surface flow constraints caused by speed tables, speed humps or bumps.

### Potential Locations

- In the parkway zone
- In the flexible zone to separate the bike lane from parking and/or the travel lane
- In a median of a street with a reverse crown

### *Design Considerations*

- Sloped sides (at a maximum of 3:1 slope) can be challenging to incorporate in a limited right-of-way width.
- The depth from the top of the curb or pavement adjacent to the system and the surface of the biotreatment soil media can vary. Systems with a differential depth over 12 inches may require the use of fencing, railings or physical barriers to avoid trip and fall hazards for pedestrians. The factors leading to deep systems are the minimum ponding depth, the depth of the storm drain system, type and depth of inlets and outlets. Sloped sides can also be used to mitigate a deep system, where space allows.
- Stormwater planters add a landscape amenity to the streetscape that will require maintenance to ensure that the plants and shrubs are healthy and the surrounding area is free of trash or debris that may impede the flow in and out of the system.
- Narrow sidewalks may limit space for stormwater planters.
- If a stormwater planter is designed adjacent to on-street parking, a transit stop, loading zone or other location where a connection is needed from the sidewalk to the street, a pathway should be provided across the planter for pedestrians and delivery of goods. A curb ramp may also be necessary for delivery equipment. Crossings are typically 6 feet wide[22] and can take the form of pavement interrupting a long stormwater planter or a pedestrian bridge over the planter. Crossings may be placed every 35-70 feet depending on pedestrian volume[23]. Otherwise, pedestrian traffic through the planter can compact biotreatment soil, impeding infiltration, and damage plants.
- If a stormwater planter is designed adjacent to on-street parking or loading/unloading areas, a paved “step-out zone” should be provided for door swings and passengers entering and exiting vehicles. The width of step-out zones varies by municipality, but can be 12-36 inches wide including roadway curb[24] or 48-inches wide for accessibility compliance. Step-out zones will need to be wider in a handicapped parking zone. This area may be paved with traditional concrete or pervious pavement. Flush curbs can also be part of a step-out zone. Change areas to “No Parking” where appropriate.
- Consider the types and volume of vehicles, taxis, bicycles, transit and pedestrians that will be loading/unloading in the area and use/demand of for-hire vehicles from transportation network companies (TNCs), such as Uber, Lyft etc., and resulting needs for curb cuts, pedestrian ramps, ADA needs, bridges or paths between planters and the width of those pathways for pedestrians and goods movement. Where possible and helpful, use geofencing[25] (a virtual perimeter defined around a specific geographic location) to position locations for the pick-up/drop-off of passengers of TNCs, autonomous vehicles and taxis, etc., away from planter locations or locations where pedestrian or goods movement is restricted, congested or more difficult. Consider working with any business improvement districts to access TNC data and coordinate efforts/designs. Curbside access fees and management programs[26] can also be considered.
- Vegetation height: consider how various plant species will grow over time and ‘soften’ the edges[27] of the system. The locations used for plantings within stormwater planters can be chosen to avoid

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[22] DDOT, 2014b
[23] DDOT, 2014b
[24] PWD, 2011
[25] https://nacto.org/tsdg/curb-appeal-whitepaper/
[26] https://nacto.org/publication/bau/curbside-management/
[27] SMCWPPP, 2009

sight line issues and reduce maintenance. Use a variety of plants and groundcovers with most that will grow at least 1 foot in height above the planter's walls and not exceed 4 feet in height or the height determined to not impede pedestrian, cyclist and motorist visibility requirements.

- Existing above ground or underground utilities or street fixtures may affect the location of the planter.
- Planters to be installed between a building edge and curb should be designed with geotechnical considerations to prevent damage or settling of building foundations.
- Planters should be designed with deep curbs where appropriate to protect pavement sections and prevent undermining of the street caused by aggregate base failure.
- Planters should be designed with considerations for emergency access and equipment. For example, avoid placing a treatment area where it may impede access to a fire department connection located in front of a building. Coordinate with your local fire department on design details.
- If stormwater planters are below the sidewalk grade, consider providing a low fence or curb for pedestrian safety. This will prevent tripping hazards and trampling of the system, which over time will compact the biotreatment soil, reduce its infiltration rate, and damage plants. Typical fence heights are 18-36 inches. Surrounding curbs may be designed at a minimum of 4 inches high and 6 inches wide[28].
- Stormwater runoff can enter the planter from the sidewalk by sheet flow, trench drains, slot drains, bubble ups, pervious pavement underdrains or curb cuts.
- Stormwater runoff can enter the planter from the street side of the curb through covered trench drains or by sheet flow (flush curb). Curb cuts can be used if there is no on-street parking (i.e. planter extends to street curb because there is no step out zone needed). If trench drains or curb cuts are used, the gutter should be molded near the opening to direct runoff into the planter.
- When considering street trees, allow for sufficient rooting space and soil volumes as appropriate to tree size at maturity. Do not "sandwich" trees between planters with edge controls that will restrict rooting space.
- Edge controls to prevent failure of pavement edge, migration of compacted subsurface material from the roadway or sidewalk into biotreatment soil media, or infiltration of stormwater into compacted subsurface material are discussed below.

For stormwater planters located within 5 feet of the roadway face of curb, the District of Columbia[29] and County of San Diego[30] require that the side adjacent to the roadway be lined with an impermeable liner. Similarly, for bioretention located within 10 feet of a structure, both agencies require the side adjacent to the structure to be lined to protect building foundations and keep water intrusion away from the building side of the system. If needed, the bottom of the system can be lined and/or sloped away from the building at 2% to 5% depending on the distance from the building[31] and other factors. The location of the underdrain can be set at the bottom of the sloped area, if needed.

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[28] SMCWPPP, 2009

[29] DDOT, 2014b

[30] County of San Diego, 2016

[31] See California Building Code section 1804.3 – positive drainage away from foundations required

Bioretention planter walls should extend at least to the bottom of the biotreatment soil media layer, or deeper, depending on structural requirements and the needs of tree roots to grow beyond the perimeter of the system. Footing or lateral bracing should be provided for all planter walls unless the designer demonstrates that the proposed wall design meets loading requirements. However, planter walls extending more than 36 inches below adjacent load-bearing surfaces, or when located adjacent to pavers, must always have footings or lateral bracing. Footings and lateral bracing should be designed to withstand anticipated loading assuming no reactive forces from the uncompacted bioretention soil within the facility.[32] The City of Portland recommends that the curb of a stormwater planter be designed to have a 1:6 (H:V) slope (i.e., curb batter) and a 4-inch minimum height from top of the curb to the top of the sidewalk (see Figure 2-17).[33]

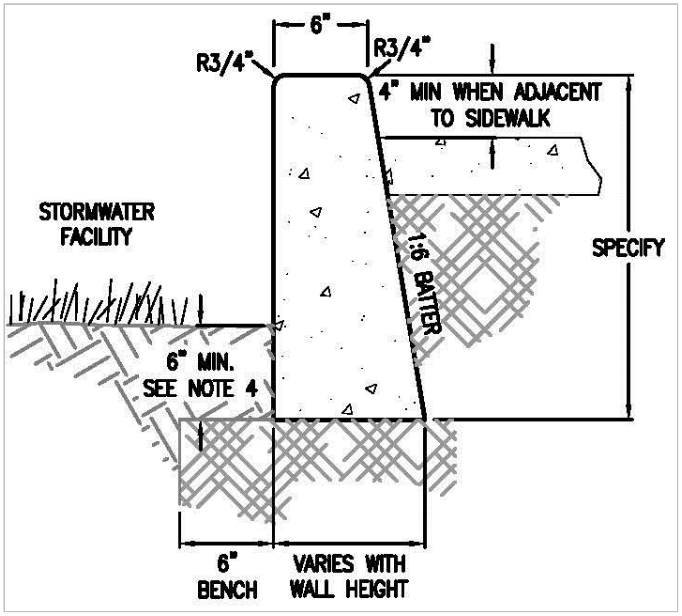

*Figure 2-17. Stormwater planter curb detail at sidewalk interface (Note 4: If a liner is used refer to lined systems). (Courtesy of Portland 2016)*

An engineered edge control may not always be necessary for bioretention facilities. When there is adequate space, the side slope of a bioretention stormwater planter can be laid back such that the underlying soil is stable and can function as an edge control for the GSI measure[34] (Figure 2-18). This case may occur when one side of a GSI measure is adjacent to uncompacted soil such as in a park or planting strip.

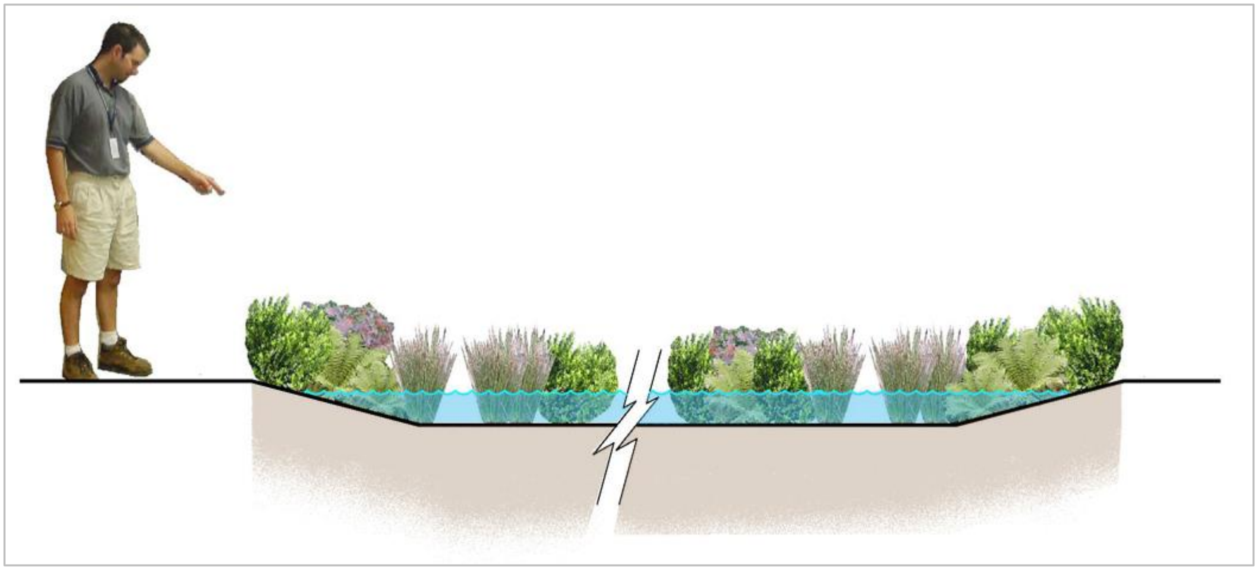

*Figure 2-18. Stormwater planter with sloped sides, conceptual example. (Courtesy of SMCWPPP)*

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[32] SFPUC, 2016

[33] Portland, 2016

[34] SFPUC, 2016

Figure 2-19 shows a stormwater planter with vertical sides in El Cerrito, and Figures 2-20 and 2-21 provide conceptual examples from Washington D.C.'s District Department of Transportation (DDOT) and the Philadelphia Water Department (PWD).

*Figure 2-19. Stormwater planter with vertical sides, step-out zone and on-street parking in El Cerrito. (Credit: EOA)*

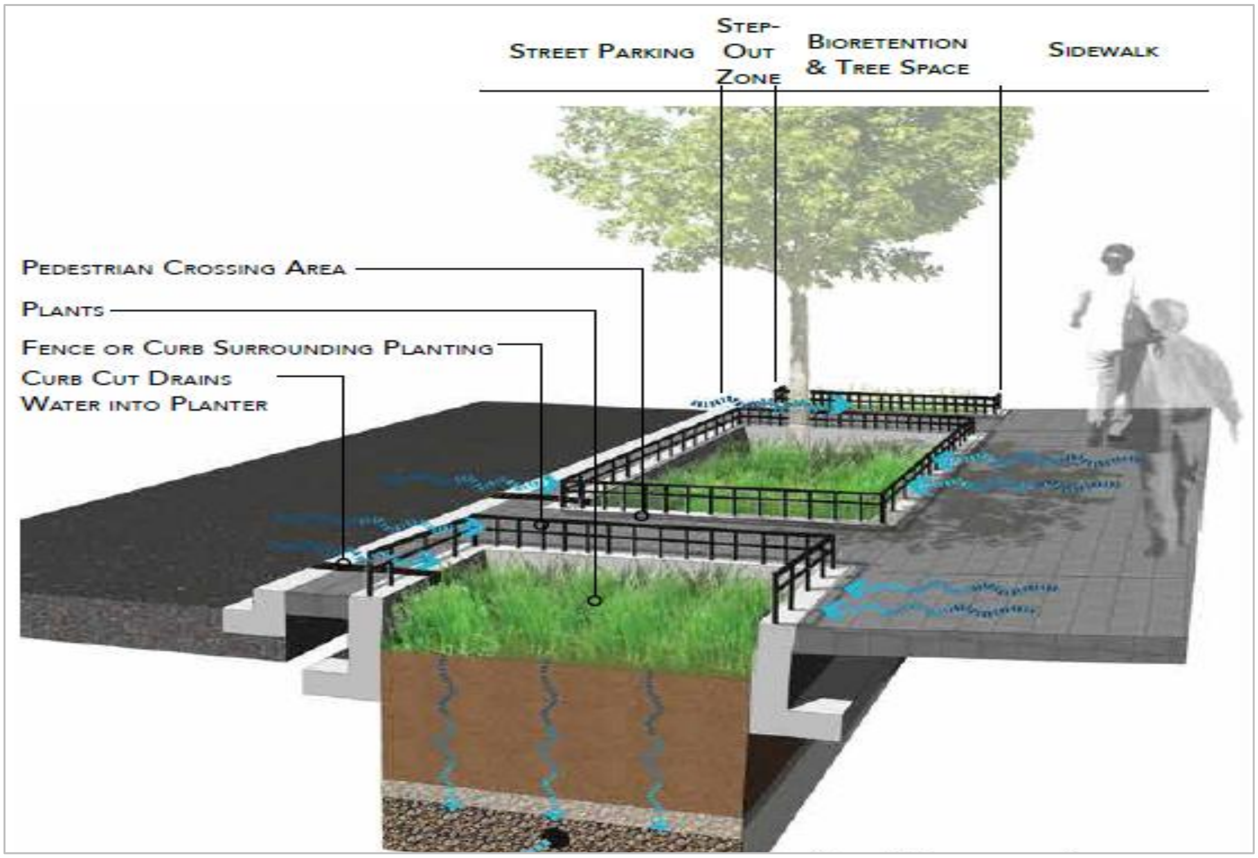


Figure 2-20. Conceptual stormwater planter with vertical sides. (Courtesy of DDOT)

Figure 2-21. Conceptual stormwater planter with vertical sides. (Courtesy of PWD)

## Stormwater Curb Extension

A stormwater curb extension (curb out, bulb out, or bump out) is a type of bioretention system that extends into the roadway (Figure 2-22). Stormwater curb extensions may be installed midblock or at an intersection.

*Figure 2-22. Stormwater curb extension in Southgate neighborhood, Palo Alto. (Credit: EOA)*

### Benefits

- Can be used in a variety of street types and land use classifications.
- Narrows the street, resulting in speed reduction and traffic calming.
- Increases pedestrian safety by shortening pedestrian crossing distance when constructed at intersections and/or crosswalks.
- Maintains sidewalk width in high-volume pedestrian areas.
- Can be constructed by adding a new curb that extends into the street and where desired leaving untouched the existing curb and parkway zone. This can be important where existing street trees, utilities or other infrastructure that are in the parkway or pedestrian zone need to be protected. However, widening the stormwater curb extension into the parkway zone where possible, can greatly increase the effectiveness and hydraulic sizing of the measure by increasing the square footage of basin area.
- Existing curb extensions can also be retrofitted into stormwater curb extensions by excavating the site and installing the necessary inlets, plants, biotreatment soil media, underdrains etc.

### Potential Locations

- Intersections
- Midblock
- In between on-street parking spots

- In no-parking zones
- At the topographic low point such as the bottom of a hill or low point on a block

Curb extensions may start in the parkway area of the sidewalk and will extend into the flexible zone of the street. See examples in Figures 2-23 and 2-24.

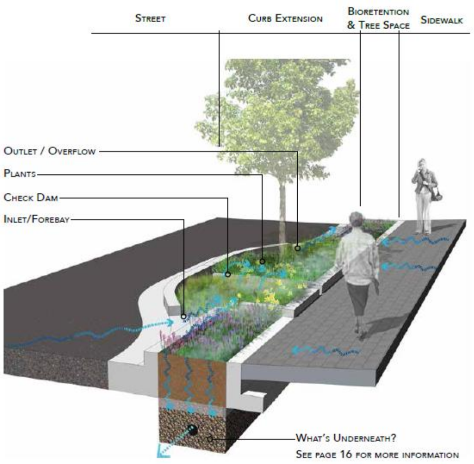
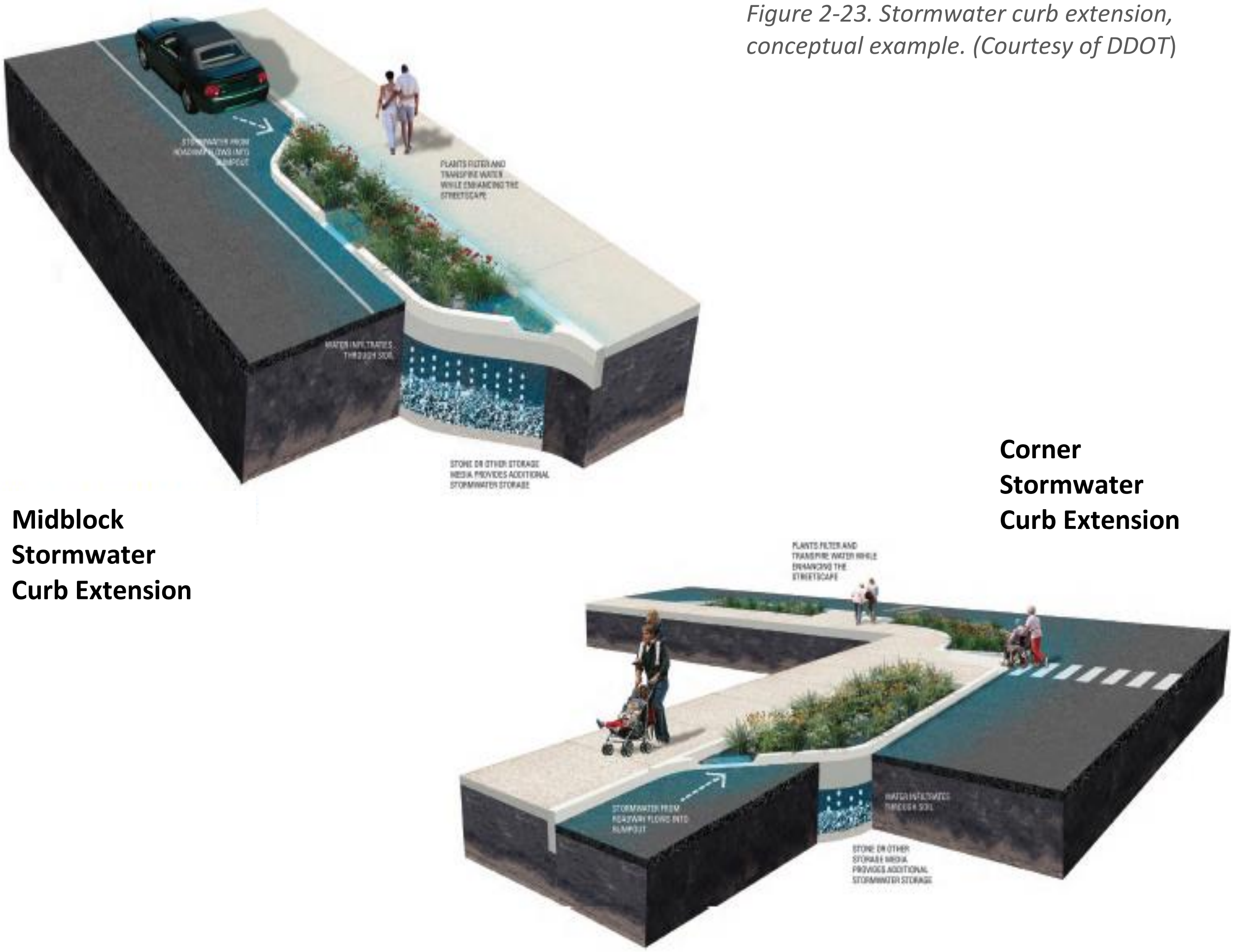


*Figure 2-23. Stormwater curb extension, conceptual example. (Courtesy of DDOT*)



**Midblock Stormwater Curb Extension**

**Corner Stormwater Curb Extension**

*Figure 2-24. Conceptual examples of midblock (top left) and corner (bottom right) stormwater curb extensions. (Courtesy of PWD)*

### *Design Considerations*

- Consider using stormwater curb extensions in areas with wide roadways or no-parking areas (excluding loading zones, transit stops, etc.).
- Conduct community outreach to resolve potential conflicts with residents and businesses over parking or other concerns.
- Ensure that corner stormwater curb extensions accommodate vehicle turning widths[35]. Refer to Exhibit 2-2 AASHTO Green Book[36] for minimum turning radii of different vehicles. Coordinate early in the design process with the Fire Department to ensure they are comfortable with the curb extensions. If necessary, use cones to demonstrate the dimensions of the curb extension and have the fire department drive their trucks around corners.
- Corner curb extension plantings must be chosen to maintain line of site for vehicles. Corner curb extensions and midblock extensions that will also serve as pedestrian crossings need to be designed with ADA compliant ramps and landings at cross walks. If midblock stormwater curb extensions are not intended to be used as pedestrian crossings, they should be designed to discourage such crossings[37].
- Consider bicycle usage and avoid conflicts with bicycle routes. Curb extensions should not extend into bicycle lanes.
- Stormwater curb extensions have a lower grade than traditional landscaping, and if cars enter the facility accidentally, they have the potential to get stuck and/or have damage to the underside of the vehicle. Consider including bollards or other barriers specific for stormwater curb extensions.
- Consider the maximum potential drainage area by selecting the topographically lowest point of the curb/flow line (e.g., midblock locations may not be as effective for stormwater capture and treatment as end-of-block locations).
- In areas with limited street lighting, consider installing light reflectors on curbs of the extension adjacent to the travel lane to increase visibility at night.
- Traditional curbs or flush curbs can be used to protect the bioretention area from street traffic. (A deeper curb may be needed for structural stability – see details in Part 2 of this Handbook.)
- Since curb extensions are typically not in the pedestrian zone, a barrier on the sidewalk side may not be needed unless required for pedestrian trip and fall hazards, or if excessive wear and tear from pedestrian cut-through traffic is affecting the vegetation or compacting soils. Additionally, if high vehicle speeds are occurring in the roadway, barriers such as rigid bollards or raised planter containers can be used in addition to red curbs, curb reflectors or flexible bollards.
- Stormwater runoff can enter the curb extension from sidewalks and roadways through curb cuts or a flush curb. See Figure 2-22.
- Pavement at intersections or midblock locations may need to be substantially regraded to match the outer curb of the stormwater curb extension or to meet ADA requirements, which may add significant cost to the project.

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[35] PWD, 2011
[36] https://store.transportation.org/item/collectiondetail/180
[37] PWD, 2011

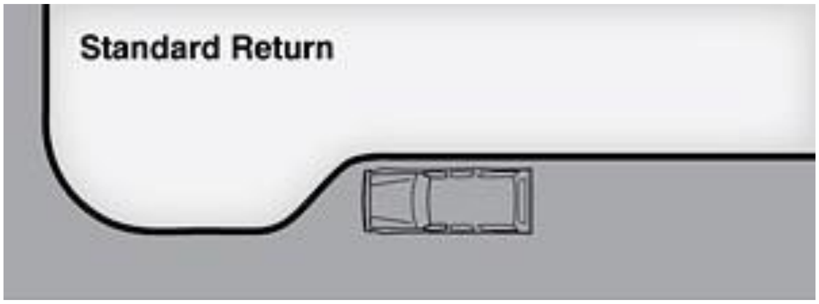

*Figure 2-25. Standard bulb-outs with inner/outer curb radii of 20' and 10' to enable street sweeping machinery to sweep entire curb line. (Courtesy of San Francisco Better Streets Plan December 2010* [38]*)*

- Edge controls to prevent failure of pavement edge, migration of compacted subsurface material from the roadway or sidewalk into biotreatment soil media, or infiltration of stormwater into compacted subsurface material are discussed in Section 2.2. An important issue to consider with an open, vegetated GSI measure like a stormwater curb extension is the capture of trash. If possible, design GSI measures so that litter is left on the street for street sweeping or concentrated in one part of the system for easier collection either manually or with a vactor truck. Systems with many curb cuts will distribute litter over a large area necessitating more expensive manual collection.
- Curb extensions should be designed to allow street sweepers to adequately clean the street area around the GSI measure (i.e., the extended curb should have a smooth, curved transition to the existing street curb) (Figure 2-25). If the system is not designed properly, street sweeper vehicles will not be able to pick up litter and debris near the inlets of stormwater curb extensions which could cause blockages. Figures 2-26 and 2-27 provide examples of properly and improperly designed stormwater curb extensions.

*Figure 2-26. Effective curb radius for a street sweeper in San Francisco.* (Credit: EOA)

*Figure 2-27. Ineffective curb radius for street sweeper in Emeryville. (Credit: EOA)*

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[38] SF Planning Department, 2010

## Stormwater Tree Well Filter

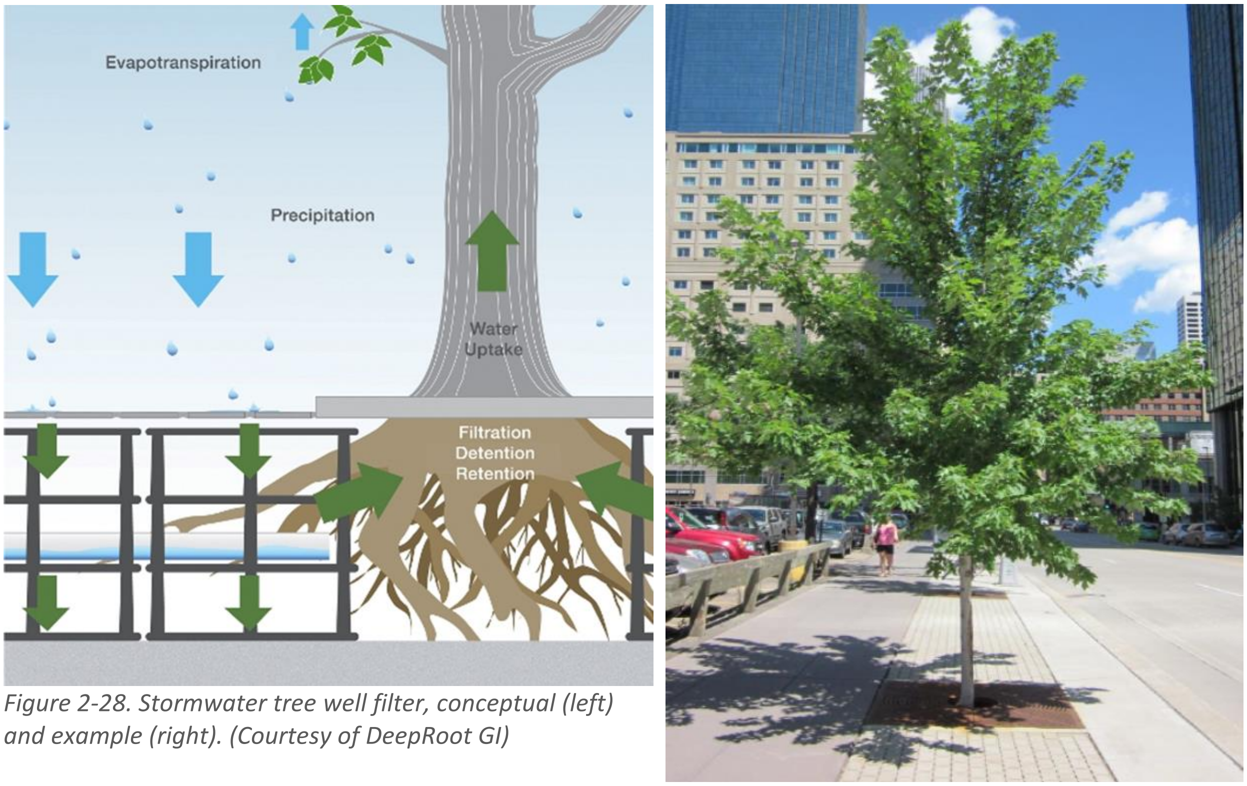

*Figure 2-28. Stormwater tree well filter, conceptual (left) and example (right). (Courtesy of DeepRoot GI)*

A stormwater tree well filter (Figure 2-28) is a type of bioretention system consisting of an excavated pit or vault that can be filled with biotreatment soil media, planted with a tree and other vegetation, and underlain with drain rock and an underdrain, if needed[39]. Stormwater tree well filters can be constructed in series and linked via a subsurface trench or underdrain. A stormwater tree well filter can require less dedicated space than other bioretention areas. They can use suspended pavement systems to provide underground treatment area and rootable soil volumes for the tree roots. Where desired soil volumes are unattainable, consider using shrubs in lieu of trees. For more information on design and sizing of stormwater tree well filters, refer to Section 6.3 of the SCVURPPP C.3 Stormwater Handbook.

## Benefits

- Space: Stormwater tree well filters with suspended pavement systems are especially useful in settings between existing sidewalk elements where available space is at a premium.
- Space: The design with suspended pavement systems and recommended soil volumes can allow trees to thrive in small spaces that wouldn't normally permit street trees to grow. The size of the tree should be dictated by the amount of soil volume provided.
- Sizing: Systems can store large volumes of water with minimal above-ground space requirements.
- Energy: Shade provided by the tree reduces the heat island effect and provides a more aesthetically pleasing streetscape environment.

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[39] For the purposes of this Handbook, the term "stormwater tree well filter" refers to systems that use biotreatment soil media per the Bay Area regional specifications. Proprietary tree well filters that use manufactured media with high flowrates are not covered in this section. Refer to Section 6.3 of the C.3 Stormwater Handbook for more information.

- Groundwater Recharge: Unlined systems promote infiltration.
- Aesthetics: Stormwater tree well filters with suspended pavement systems and adequate soil volumes can replace existing street trees with minimal changes to the street's aesthetic.
- Safety: Since the bulk of the system can be housed below hardscape, there is minimal interaction between pedestrians and the biotreatment soil media, minimizing tripping hazards and maintenance due to soil compaction.

## Potential Locations

- In the pedestrian, parkway and/or flexible zones as part of an integrated street landscape or in series as part of a chain of hydraulically connected wells in a tree trench
- In a midblock curb extension
- Medians
- Traffic circles
- Parking lots

*Figure 2-29. Stormwater tree well filter, conceptual example. (Courtesy of PWD)*

*Figure 2-30. Stormwater tree well filter trench, conceptual example. (Courtesy of PWD)*

*Figure 2-31. Stormwater tree well filter conceptual examples: modular suspended pavement system (left), column suspended pavement system (right). (Courtesy of PWD)*

## Design Considerations

- Stormwater tree well filters must be designed with enough soil volume to ensure that tree roots can expand and grow without lifting sidewalks or other pavement (see Section 3.6.6).

- Suspended pavement systems with structural soils, structural columns or structural cells to allow unimpeded tree root growth should be considered (see Section 3.6.7).
- Trees known to have shallow surface root growth and large surface root flare should not be planted to avoid lifting the sidewalk. Trees with deeper root growth will be easier to maintain.
- Designers should consult the SCVURPPP C.3 Stormwater Handbook, Appendix D (Plant List and Planting Guidance for Landscape-Based Stormwater Measures) for appropriate trees. Cities may also have a list of acceptable street trees for planting in the public right-of-way. The recessed surface of the tree well may be a pedestrian safety hazard and require additional design considerations to prevent pedestrians from stepping into the tree well such as grates or perimeter fencing.
- Load limits on the tree well filter should be considered if it is beneath hardscape. Vehicle loads from maintenance vehicles or vehicles parking on sidewalks could damage the hardscape or the stormwater tree well filter. Structural systems also need to meet seismic requirements.
- To reduce maintenance and inlet blockage: consider tree species that have less leaf litter, install devices that capture leaves and litter or devices that keep leaves and litter in the gutter area to allow street sweepers to collect leaves and litter. (See also Sections 3.6.4 and 3.7)
- Stormwater tree well filters should be designed and constructed to protect adjacent pavement structures and roadways from water intrusion and damage by including root barriers, waterproof liners, structural barriers etc.
- Tree placement, height, form and low-level limb trimming shall consider present and future lines of sight for vehicle operators, cyclists and pedestrians.
- Design systems to include vehicle overhang space.
- If stormwater tree well filters are below the sidewalk grade, provide perimeter fencing or horizontal grate for pedestrian safety.
- Stormwater runoff enters the tree well filter from the sidewalk by sheet flow.
- Stormwater runoff enters the tree well filter from the street side of the curb through covered trench drains if there is a step-out zone.
- If the tree well filter is designed as a midblock curb extension, it will require a curb or barrier to protect the tree from vehicles. In this configuration, stormwater runoff enters the tree well filter through curb cuts. The same constraints and considerations as regular midblock stormwater curb extensions apply, with the added constraint of locating trees to avoid blocking sightlines.
- For stormwater tree well filters proposed at sites with overhead power lines, the landscape architect must consider the mature height of selected trees to avoid future conflicts with the power lines.
- The volume of soil in the stormwater tree well filter should be large enough to support a mature tree. If more room is needed for tree root growth, see Section 3.6.7 for a full discussion of structural support options including use of suspended pavement systems.
- Edge controls to prevent failure of pavement edge, migration of compacted subsurface material from the roadway or sidewalk into biotreatment soil media, or infiltration of stormwater into compacted subsurface material are discussed below.

Stormwater tree well filters may require additional structural elements to support the sidewalk above the uncompacted engineered soil mix. These structural support strategies are discussed in more detail in Section 3.6 Landscape Design. For tree well filter designs, the District of Columbia[40] distinguishes between suspended pavements and structural cells**.** Suspended pavements include structural slabs that span between structural supports that allow uncompacted growing soil beneath the sidewalk, and commercially available structural systems. Structural cells are commercially-available structural grids placed subsurface that support the sidewalk and are filled with soil. One manufacturer of structural grid systems, DeepRoot Inc., recommends that a minimum of 30 inches of biotreatment soil media be placed within these structural supports.[41]

## 2.2.2 Pervious Pavement

Pervious pavement is hardscape that allows water to pass through its surface into a storage area filled with gravel prior to infiltrating into underlying soils. Types of pervious pavement include pervious concrete, porous asphalt, porous rubber, permeable interlocking concrete pavers, permeable pavers, and grid pavement. Pervious pavement does not require a dedicated surface area for treatment and allows a site to maintain its existing hardscape. Therefore, pervious pavement is often used where bioretention measures are not feasible due to space constraints or there is a need to maintain hardscape, such as in streets and parking areas. Figure 2-32 demonstrates the use of pervious pavement in a residential street crosswalk along a bike boulevard. For more information on design and sizing of pervious pavement systems, refer to Sections 6.10 and 6.11 of the SCVURPPP C.3 Stormwater Handbook.

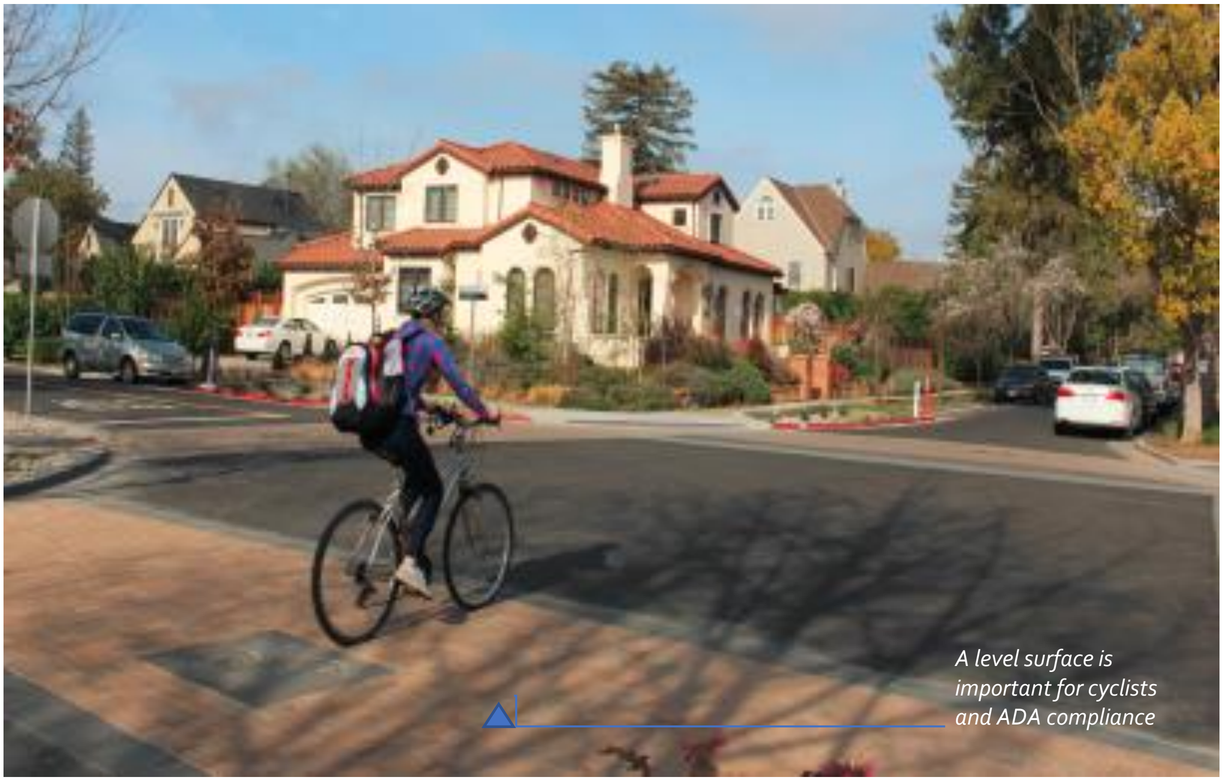

*Figure 2-32. Cyclist on pervious pavement crosswalk in Southgate Neighborhood, Palo Alto. (Credit: City of Palo Alto)*

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[40] DDOT, 2014

[41] DeepRoot Inc., 2017

### *Benefits*

- Pervious pavement provides the structural support and stability of a traditional hardscape surface, but acts as a pervious surface allowing stormwater infiltration.
- Pervious pavement can reduce the size of other stormwater control measures and work in urban locations with limited space for treatment.
- Pervious pavement can alleviate local ponding by allowing water to infiltrate instead of collecting on the surface.
- Pervious pavement can be used to direct stormwater to roots of trees and other plants.

### *Design Considerations*

- As infiltration of stormwater into the underlying native soil is a required element in the design of pervious pavement, the saturated hydraulic conductivity (Ksat) of the soil is a key design metric affecting cost and performance of the system and should be determined as early as possible in the project scoping through the use of on-site double ring infiltrometer testing or other similar methods.
- Designers must consider traffic loading and volume conditions when designing pervious pavement to ensure that the selected pavement has the necessary load bearing capacity. The design will be different if it is used in the sidewalk realm, the on-street parking and bike lane zone (flexible zone), with suspended pavement, or travel lanes in low volume/speed areas. See guidelines from the Interlocking Concrete Pavement Institute.[42]
- Sites with longitudinal slopes exceeding 5% may have potential limitations. In some locations, a sloped pervious pavement surface may be accommodated by providing check dams in the aggregate layer.
- Underground utilities need to be assessed early and with field verification to prevent major design changes later.
- Trees need to be protected if their roots extend under existing impervious surfaces that will be replaced as part of the project. Additionally, if the roots of large trees will be exposed to increased water infiltration, they can be affected negatively.
- Replacing existing impervious concrete and asphalt surfaces with pervious surfaces would require that existing sub-base be replaced with the structural section for pervious pavement to be effective. Replacement may also include additional sub-drains. Ensure that pervious pavement subgrades are properly prepared and graded to have a level surface. Differential settling of pavement can be hazardous for pedestrians, wheelchair users, and cyclists.
- Utility boxes within pervious pavement may need collars or additional support.
- Pervious pavement can be designed and constructed, if needed, with waterproof liners, structural barriers, compacted native soil, etc. on the sides only (not the bottom, since infiltration into underlying soils must not be obstructed) to protect adjacent impervious pavement systems from water intrusion and possible structural degradation.
- The designer may include an impermeable liner or a deepened concrete curb as the edge control for pervious pavement. When a deepened curb is used as an edge control for pervious pavement, the curb should be 6 inches wide. If the pervious pavement is adjacent to a sidewalk or landscaping, the curb should extend to the depth of pervious pavement section. When adjacent to a roadway, the concrete embedment should extend a minimum of 2 inches below

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[42] https://www.icpi.org/newsroom/icpi-releases-fifth-edition-manual-permeable-interlocking-concrete-pavement

impervious pavement base.[43] Deeper edge controls will restrict the rooting zone for street trees; therefore locate street trees with sufficient spacing for root development.

- For deep pavement sections, edge controls do not need to extend more than 12 inches below the wearing course (i.e, upper layer), provided that requirements for the wearing course at the interface with impervious pavements are satisfied.[44]

Benefits, potential locations, and general design considerations specific to the different types of pervious pavement is provided in the remainder of this section. Part 2 of this GSI Handbook provides additional design guidelines.

## *Porous Asphalt, Pervious Concrete and Porous Rubber*

Porous asphalt and pervious concrete (Figure 2-33) are similar to traditional asphalt and concrete, but do not include fine aggregates in the mixture, allowing water to pass through the surface. Porous rubber (Figure 2-34) can be made of poured-in-place material or pre-fabricated rubber pavers.

### *Additional Benefits*

- Porous asphalt pavement can increase safety by reducing vehicle hydroplaning.
- Porous asphalt and pervious concrete are lower in cost per square foot than pavers.
- As shown in Figure 2-34, porous rubber can be used around trees as a more flexible material, preventing root damage. Porous rubber can also be used as cushioning material to increase safety in playground areas.

*Figure 2-33. Conceptual examples of porous asphalt (top left) and pervious concrete (top right), and photographs of porous asphalt (bottom left) and pervious concrete (bottom right). (Courtesy of PWD (top) and DDOT (bottom)*

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[43] SFPUC, 2016.
[44] SFPUC, 2016.

*Figure 2-34. Porous rubber example. (Courtesy of DDOT)*

### *Potential Locations*

- Sidewalk, all zones
- On-street parking zone of street
- Parking lot surfaces
- Cross walks
- Travel lanes if low volume/speed areas (alleys, access streets)
- Bike paths and cycle tracks
- Playgrounds and parks

### *Additional Design Considerations*

- Similar to traditional concrete/asphalt, porous asphalt and pervious concrete are poured in place and can be more difficult to repair than pervious pavers which can be removed and replaced easily. Pervious concrete is also available in precast slabs that are more easily installed and replaced.
- Design pervious pavement to be ADA compliant (e.g., no tripping hazard or excess vibration for wheelchairs) when used in the pedestrian zone of the sidewalk or crosswalks. Given the similarity to asphalt and concrete, there should be no issues with sidewalk areas being ADA compliant.

## *Permeable Interlocking Concrete Pavers (PICP) and Permeable Pavers (PP)*

Permeable interlocking concrete pavers (PICP) allow water to pass through the joint spacing between solid pavers (Figure 2-35). Permeable pavers (PP) allow water to pass through the paver itself and therefore have narrower joints (Figure 2-36).

### *Additional Benefits*

- PICP and PP are easy to repair as small portions can be removed and replaced.
- PICP and PP are available in a variety of colors and can be used to distinguish different road features such as parking areas or crosswalks, or to indicate that the area is treating stormwater.
- PICP and PP can be laid out in a variety of patterns and colors, improving the aesthetics of a site or fitting with the surrounding area.

### *Potential Locations*

- Crosswalks
- Sidewalk, all zones, however, using PICPs in the parkway zone of a sidewalk eliminates many of the concerns regarding ADA compliance and pedestrian tripping hazards. Refer to Figure 2-1 for zone identifications.
- Plazas
- Parking lot surfaces
- On-street parking zone
- Travel lanes if low volume/speed areas (alleys, access streets).
- Driveways
- Bike paths and cycle tracks
- Parks

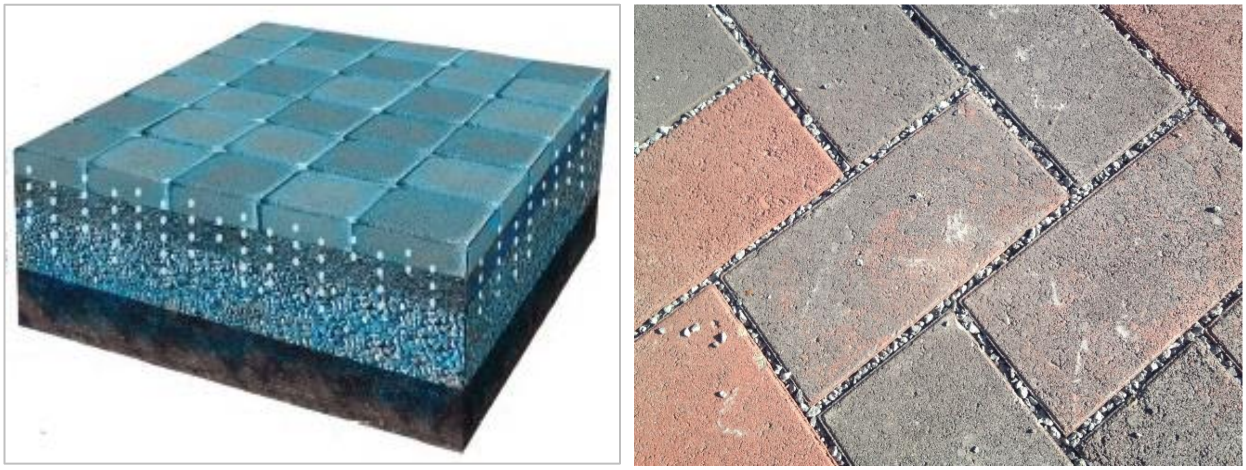

*Figure 2-35.Permeable interlocking concrete pavers conceptual example (left) and Allston Way in Berkeley (right). (Courtesy of PWD (left) and EOA (right))*

*Figure 2-36. Permeable pavers at Fire Station 21 in San Jose (left) and in a crosswalk in Palo Alto (right). (Courtesy of Pacific Interlock Pavingstone & the City of Palo Alto)*

### Additional Design Considerations

- PICP and PP may have higher installation costs than other pervious pavement as subgrades must be properly constructed to reduce the potential for differential settlement[45]. In areas with soils that have low permeability, drain pipes may be required below the permeable surfaces to carry runoff to an inlet to prevent differential settlement. Differential settling of pavement, especially permeable pavers, can be hazardous for pedestrians, wheelchair users, and cyclists.
- Designers must consider traffic loading and volume conditions when designing PICP and PP to ensure that the pavement has the necessary load bearing capacity. The design will be different if it is used in the sidewalk realm, the on-street parking and bike lane zone (flexible zone), with suspended pavement, or travel lanes in low volume/speed areas. PICP and PP are typically recommended for travel lanes with low traffic speeds and volumes. However, successful examples employed across entire streets exist. An example of a curb-to-curb PICP installation in the Bay Area is on Allston Way in the City of Berkeley – see Section 6.5 for more details.
- When PICP and PP are used in walkways (sidewalk pedestrian zone and cross walks) they must be designed to be ADA compliant and must not be a tripping hazard[46] or cause excess vibrations for wheelchairs[47]. With narrower joints, PP may have fewer ADA compliance issues.
- Concerns are typically raised by pedestrians, bicyclists and skateboarders regarding the potential for tripping, having wheels caught in the locking spaces, and vibrations. Actual installations such as the one in Berkeley on Allston Way (see the case study in Section 6.5) have shown these concerns can be mitigated by the type of permeable paver chosen.
- Municipal codes that do not allow permeable pavers in bikeways may need to be revised.

## Grid Paving

Grid paving is a mostly pervious surface (e.g., grass or gravel) with concrete or plastic grids that provide structural support in areas that receive occasional light traffic such as in parking lots.

*Figure 2-37. Grid paving in a parking lot in Napa (Left) and in a parking lot in Cupertino (Right). (Credit: EOA and Cupertino)*

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[45] SMCWPPP, 2009

[46] SMCWPPP, 2009

[47] San Mateo, 2015

### *Additional Benefits*

- Grid paving looks and acts like pervious landscaping, but still provides structural support for occasional light use.
- Grid paving may also allow for low grasses to grow within the openings and blend in with other landscaping in the area.

### *Potential Locations*

- Emergency vehicle access lanes
- Parking lots
- Play fields in parks

### *Additional Design Considerations*

- Grid paving should not be used in areas with high vehicle traffic volume, as frequent and/or heavy loads may over time degrade the system.
- Grid paving intended to be used with turf may not be a viable choice due to irrigation needs.
- Ensure that the grid paving and subgrades are properly prepared and graded to have a level surface.
- Grid paving may be designed and constructed, if needed, with waterproof liners, structural barriers, compacted native soil, etc. on the sides only to protect adjacent impervious pavement systems from water intrusion and possible structural degradation. There should be no liner on the bottom of the aggregate (See details in Part 2).
- As with other types of pervious pavement, the designer may include an impermeable liner or a deepened concrete curb as an edge control. When a deepened curb is used as an edge control, the curb should be 6 inches wide. If the grid paving is adjacent to a sidewalk or landscaping, the curb should extend to the depth of the grid paving section. When adjacent to a roadway, the concrete embedment should extend a minimum of 2 inches below impervious pavement base.[48] Deeper edge controls will restrict the rooting zone for street trees; therefore locate street trees with sufficient spacing for root development.
- For deep pavement sections, edge controls do not need to extend more than 12 inches below the wearing course (i.e, upper layer) provided requirements for the wearing course at the interface with impervious pavements are satisfied.[49]

## 2.2.3 Infiltration Devices

Infiltration devices are designed to infiltrate stormwater runoff directly into the subsurface and, as designed, bypass the natural groundwater protection afforded by surface soil. These devices include dry well and deep infiltration wells, infiltration trenches, and subsurface infiltration systems, which are all discussed in this section. Infiltration devices generally require pretreatment and can only be used in moderately- to well-draining soils. Infiltration devices must maintain a minimum 10-foot vertical separation between the bottom of the device and the seasonal high groundwater level. For more information on design and sizing of infiltration devices, refer to SCVURPPP C.3 Stormwater Handbook Sections 6.4 and 6.5 and Appendix A.

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[48] SFPUC, 2016

[49] SFPUC, 2016

## Infiltration Trench

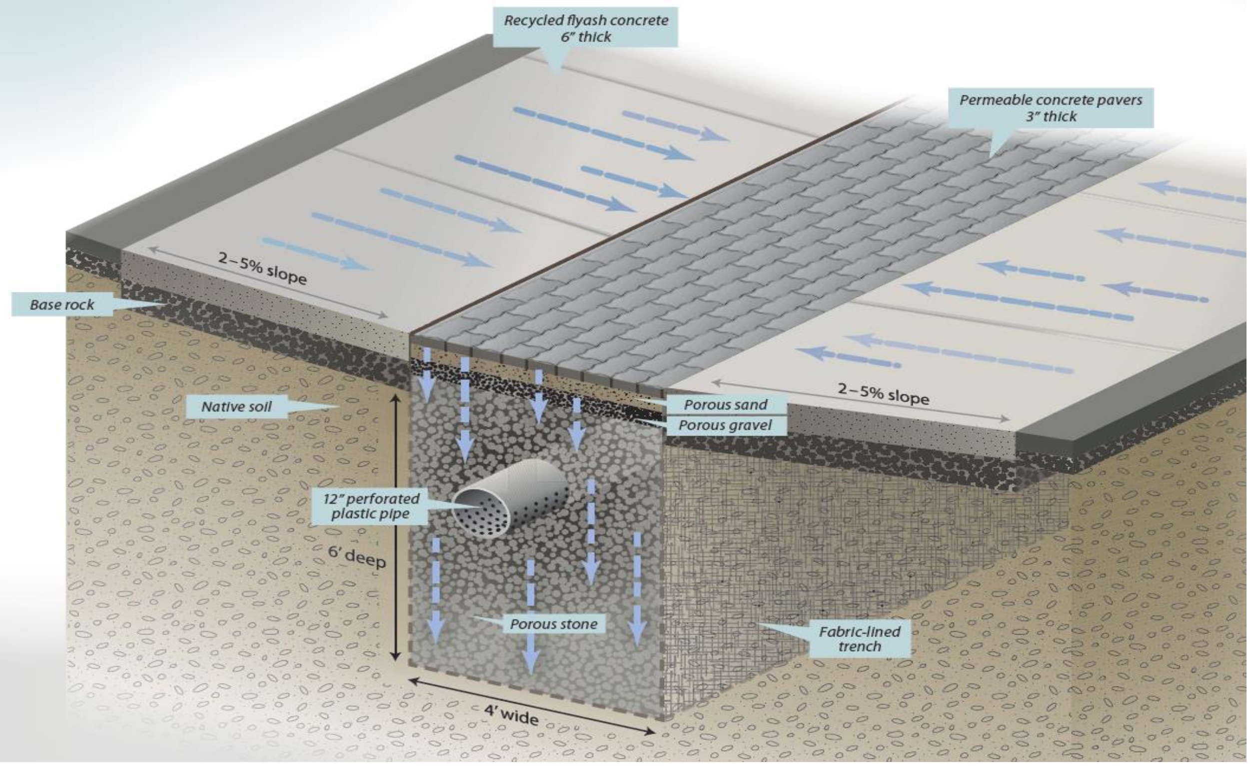

*Figure 2-38. Infiltration trench, conceptual example. (Courtesy of City of San Jose, Martha Gardens Green Alleys Fact Sheet)*

A stormwater infiltration trench is a shallow, excavated trench backfilled with a stone aggregate, and lined with a filter fabric. Typically, trenches are used with well-draining soils; a minimum soil permeability of 0.5 inches per hour is recommended. As a GSI measure, infiltration trenches can be designed with pervious pavement overlying the trench.

### Benefits

- Infiltration into underlying soils effectively removes pollutants and reduces discharge to storm drainage system.

### Applicable Locations

- Streets with low traffic speed/volume such as alleys and access roads (e.g., an infiltration trench designed with pervious pavement on top, such as that shown in Figure 2-38).
- In the on-street parking zone, or flexible zone, with pervious pavement on top.
- In parking lots, along the edge of the lot or in an adjacent landscaped area with stone aggregate at the surface.

### Design Considerations

- Santa Clara County has few sites with well-draining soils, limiting the use of infiltration trenches. Trenches must be able to store and infiltrate the water quality design volume of runoff within 72 hours.

- A minimum 10-foot vertical separation must be maintained between the bottom of an infiltration trench and the seasonal high ground water level. The Santa Clara Valley Water District (Valley Water) requires a 30-foot separation in some areas.[50]
- A horizontal separation between the trench and building foundations may need to be provided as well. Consult the California Building Code for general requirements; some municipalities may have stricter requirements.
- Infiltration trenches with underdrains that are located in the public right-of-way should be sited to allow safe access to underdrain clean-outs.
- Infiltration trenches located in alleys or along low-traffic volume streets are typically designed with pervious pavement on top and should follow the design considerations for pervious pavement.

### *Dry Well*

A dry well is a structure that allows infiltration into underlying soils while using minimal to no above ground surface area. They are typically constructed of a pipe approximately 3 feet wide and 20 to 50 feet deep, containing perforation at various locations along the pipe and/or at the bottom (Figure 2-39). Dry well infiltration columns can extend deep into the ground, beyond soils with low permeability that may be located near the surface, into soils with higher permeability. Dry wells usually require pretreatment, which can be done with bioretention, sand or other filter media, or proprietary treatment devices. They can also be used in conjunction with bioretention measures to increase infiltration capacity or provide hydromodification control.

Valley Water has worked with SCVURPPP to establish guidelines for stormwater infiltration devices such as dry wells, including horizontal setbacks, vertical separation from seasonally high groundwater, and pretreatment requirements, to prevent groundwater contamination. The guidelines are described in the SCVURPPP C.3 Stormwater Handbook, Appendix A, Table A-1. If the guidelines are not met by the project design, review and approval by Valley Water is required.

*Figure 2-39. Conceptual example of a dry well located in a street and a dry well located in a bioretention area in a corporation yard in Elk Grove, CA. (Courtesy of PWD and the City of Elk Grove)*

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[50] See SCVURPPP 2016, Appendix A, Table A-1, for SCVWD Guidelines for Stormwater Infiltration Devices.

### Benefits

- Dry wells are useful for small spaces since they typically have small footprints.
- Dry wells have the potential of capturing and infiltrating a large volume of stormwater runoff that can recharge groundwater and add to water supplies.
- Dry well can penetrate layers of poorly infiltrating soils and allow water to reach more permeable soil layers.

### Applicable Locations

- Parkway zone of the sidewalk
- Parking lots
- In or adjacent to bioretention areas

### Design Considerations

- Dry wells should be used with caution due to the concern that they can provide a conduit for pollutants to enter groundwater. They should be constructed with a pretreatment system, such as a bioretention area, sand or other filter media, or proprietary treatment device. If a bioretention area is used as pretreatment, reduction of sediment may need to be handled in a forebay or settling chamber of the dry well[51]
- Dry wells may be considered by the U.S. EPA as Class V injection wells. Dry wells may need to be registered with the EPA and have operation and destruction requirements.[52]
- Dry well installation must be reviewed and approved by Valley Water.
- Manhole locations should be placed to allow easy access by municipal maintenance staff for cleaning and maintenance if required.
- Dry wells located in the public right-of-way should be sited to allow safe access to maintenance ports..

## Subsurface Infiltration System

Subsurface infiltration systems, also known as infiltration galleries, are underground vaults or pipes that store and infiltrate stormwater. Storage can take the form of large-diameter perforated metal or plastic pipe, or concrete arches, concrete vaults, plastic chambers or crates with open bottoms. These systems allow infiltration into surrounding soil while preserving the land surface above parking lots, parks and playing fields. A number of vendors offer prefabricated, modular infiltration galleries in a variety of material types, shapes and sizes. Most of these options are strong enough for heavy vehicle loads and can be reinforced if needed. An example of a subsurface retention/infiltration system being installed under a parking lot is provided in Figure 2-40.

Another type of subsurface infiltration system is an exfiltration basin or trench, which consists of a perforated or slotted pipe laid in a bed of gravel. It is similar to an infiltration basin or trench with the exception that it can be placed below paved surfaces such as parking lots and streets. Stormwater runoff

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[51] For more information on the dry well and bioretention area installed in Elk Grove as shown in Figure 2-39, go to the following website: www.elkgrovecity.org/city_hall/departments_divisions/public_works/dry_well_project___prop_84/elk_grove_dry_well_project/

[52] Refer to SCVURPPP 2016, Appendix A, and Cal/EPA Office of Environmental Health Hazard Assessment Fact Sheet at: www.waterboards.ca.gov/board_reference/2014fall/docs/dry_wells_fs.pdf)

is temporarily stored in perforated pipe or coarse aggregate and allowed to infiltrate into the trench walls bottom for disposal and treatment.

### *Benefits*

- Subsurface facilities can be located beneath at-grade features, allowing a variety of uses above.
- Subsurface infiltration systems can have large drainage areas and the potential for capturing and infiltrating a large volume of stormwater runoff that can recharge groundwater and add to water supplies.

*Figure 2-40. Photo of subsurface retention/infiltration system installation under a parking lot. (Credit: Contech)*

### *Applicable Locations*

- Parks
- Playing fields
- Parking lots

### *Design Considerations*

- Pretreatment of runoff to remove sediment and other pollutants is typically required to maintain the infiltration capacity of the facility, reduce the cost and frequency of maintenance, and protect groundwater quality.
- Systems are not appropriate for use with poorly infiltrating soils. A minimum soil permeability of 0.5 inches per hour is recommended.
- A minimum vertical separation of 10 feet between the bottom of the facility and seasonal high groundwater is required.
- Design should consider potential for standing water and mosquito production.
- A “subsurface fluid distribution system” is considered a Class V injection well that is regulated by EPA’s Underground Injection Control Program[53]. These systems are “authorized by rule” and do

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[53] See EPA Region 9’s website: https://www.epa.gov/uic/underground-injection-control-regulations-and-safe-drinking-water-act-provisions

not require a permit if they do not endanger underground sources of drinking water and comply with federal UIC requirements. Valley Water guidelines for stormwater infiltration devices (C3 Handbook[54], Appendix A) also apply when siting any subsurface infiltration system.

- Consider placing the system access, monitoring and maintenance systems in areas that do not require full street closure for inspections and maintenance in the future.

## 2.3 Identifying Potential GSI Sites

This section contains guidance on identifying opportunities for GSI in public areas, and for evaluating public parking lots, parks, plazas, streets, and other public rights-of-way for potential GSI retrofits. As mentioned previously, siting GSI measures in public projects is generally more difficult than the design of stormwater control measures in new and redevelopment (C.3) projects because GSI measures in public projects are typically installed as retrofit projects and must fit into a space with numerous functions and constraints. Therefore, this section of the GSI Handbook address considerations for parcel-based public retrofit projects not covered in the C.3 Handbook, and provides extensive detail for siting in the public right-of-way.

### 2.3.1 Identifying Opportunities in Public Projects

Similar to regulated projects, redeveloping streets, parking lots and parks can be more costly than new development, and “greening” a street may be more expensive than performing regular street maintenance and/or replacement. However, the additional costs associated with GSI can have additional benefits aside from stormwater treatment such as air quality improvements, increased durability of pavement, reductions in ponding and flooding, enhanced transportation options, upgraded traffic safety, and higher property values. Over the long term, GSI may reduce overall infrastructure costs by extending the life of traditional gray stormwater infrastructure, reducing the need for upsizing of stormdrain pipes, increasing system-wide climate change resilience, or replacing the need/existence of gray infrastructure entirely in some locations.

The most cost-effective method of implementing GSI is to leverage planned projects; for example:

- Capital Improvement Projects (CIP) that have been planned and budgeted but may not have been fully designed, such as:
    - Street and sidewalk/curb renovation/replacement projects
    - Road diets (vehicle lane reduction and/or narrowing)
    - Planned traffic or pedestrian safety improvements (such Safe Routes to School)
    - Multi-modal modifications (addition of, or changes to, street facilities)
    - Public transportation facility improvements
    - Urban forestry projects
    - Park projects
    - Car and bicycle parking projects
    - Street retrofits for beautification or urban greening
    - Cycling safety improvements such as Safe Routes to Transit projects
    - Storm drain improvement projects

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[54] SCVURPPP 2016

- Planned utility maintenance or relocation which requires removal and replacement of hardscape in the right-of-way.
- Public school redevelopment projects.
- Partnerships with private redevelopment projects that replace hardscape in the public right-of-way.

When evaluating planned projects for GSI suitability, consider the following aspects that would make a site amenable to landscaped GSI (stormwater planters, curb extensions and/or tree well filters):

- Sites with minimal site constraints (e.g., low parking demand and large right-of-way space) are ideal. Major site constraints can minimize the space available to construct a GSI measure.
- Existing, planted or unplanted medians provide an ideal opportunity for landscaped GSI measures if stormwater can be directed into the median.
- Existing landscaping can be regraded and planted as a GSI measure.
  - Long, uninterrupted stretches of landscaping
  - Planting strips in the parkway zone of the sidewalk
  - Areas where existing tree roots will not be disturbed
  - Small, inefficient, hard to maintain or underutilized landscaped areas adjacent to roadways or other impervious surfaces
- Excess, under-utilized or inefficiently used hardscape areas can be resized or reconstructed for reduced demand, which would provide space for GSI measures.
  - Excessively wide roadways or sidewalks
  - Under-utilized on-street parking - sometimes found in non-commercial and lower density residential areas such as industrial zones and some single family neighborhoods, or where sufficient off-street parking exists or is being provided in a new development project. Permit parking programs can also free up on-street space.
  - Red curb (no parking) areas
  - The triangular intersection of non-right-angle streets
  - Traffic circles on flat streets with slopes less than 5%
  - Parking lots with large drive aisles, parking stalls
- Street and outdoor public spaces in areas that have active and willing stakeholders, owners, or neighbors can help provide advocacy or funding for a project. Business and neighborhood improvement districts would be ideal partners.

### 2.3.2 Approach for Siting GSI in Parking Lots

When retrofitting GSI measures into public parking lots, the lot size and parking space configuration will play a role in determining the potential for and the type and location of GSI measures. Small parking lots are the most difficult to retrofit because there is a high demand for available space[55]. Larger parking lots may be oversized and provide flexibility for redesign. Other considerations include the size of the drive aisles, whether the parking lot is internally draining (i.e. runoff is managed within the lot and does not flow off-site), whether it has angled parking or 90-degree parking, and whether there are center

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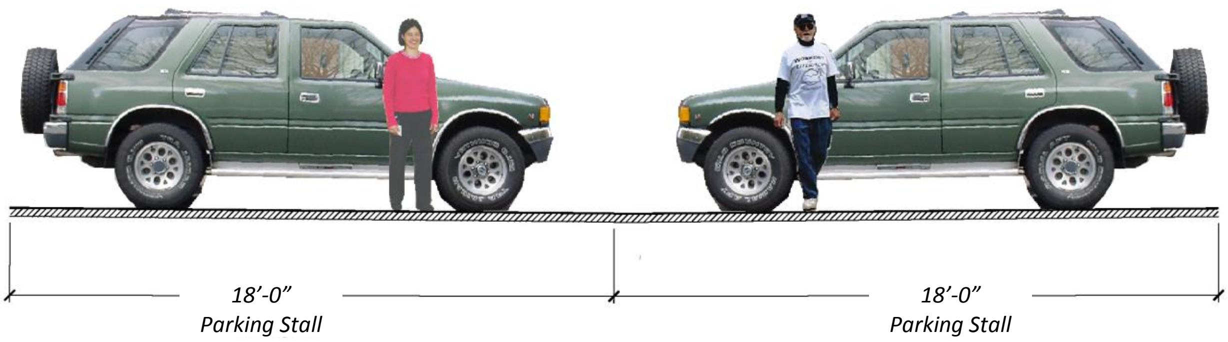
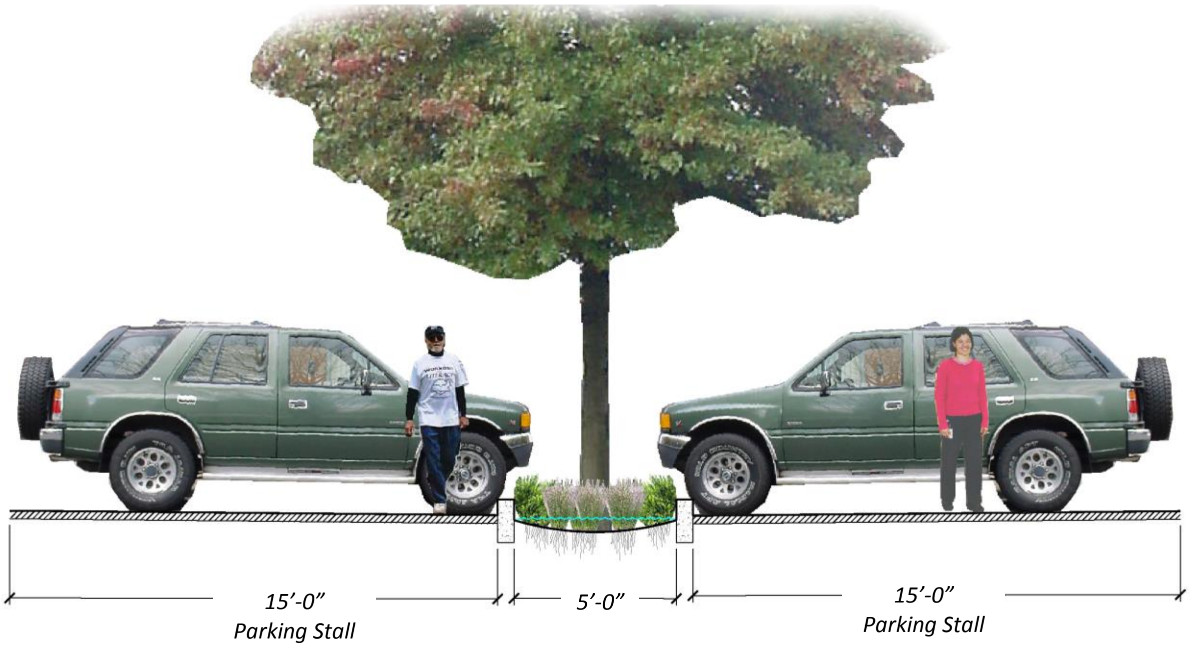
[55] SMCWPPP, 2009

medians or landscape islands. The following are tips for evaluating parking lots for potential GSI retrofits:

- Look for opportunities to replace vestigial hardscape (i.e., leftover space). For example, the triangular space in front of and to the side of angled parking can be converted to GSI while maintaining the existing parking volume.
- Consider reducing parking stall dimensions. Shorten and/or narrow parking stalls and shorten drive/back-up aisles as shown in Figures 2-41 and 2-42. This creates space in the parking lot for GSI measures. Implementation may require revisions to the municipal code or other documents that identify the parking requirements.



*This typical cross section illustrates a conventional parking lot condition with 18-foot-long parking stalls.*



*This cross section shows how a 15-foot-long parking stall can create room for landscaping used for stormwater management. Note that the parked cars in both scenarios fit within the reduced length parking stalls.*

*Figure 2-41. Conceptual tree layout in parking lot. (Courtesy of SMCWPPP)*

- Consider a shift from angled parking to parallel parking to create space for GSI measures, as shown in Figure 2-42.
- Use wheel stops to allow overhang areas to be used for GSI measures as shown in Figure 2-41.
- Look to landscaped areas on the perimeter of a parking lot for opportunities to site GSI.
- Consider using pervious pavement in parking stalls and/or drive aisles.
- Consider using an infiltration trench at the drainage low point or along a valley gutter.

Additional guidance for siting and design of GSI measures in parcel-based areas such as parking lots can be found in the C.3 Stormwater Handbook.

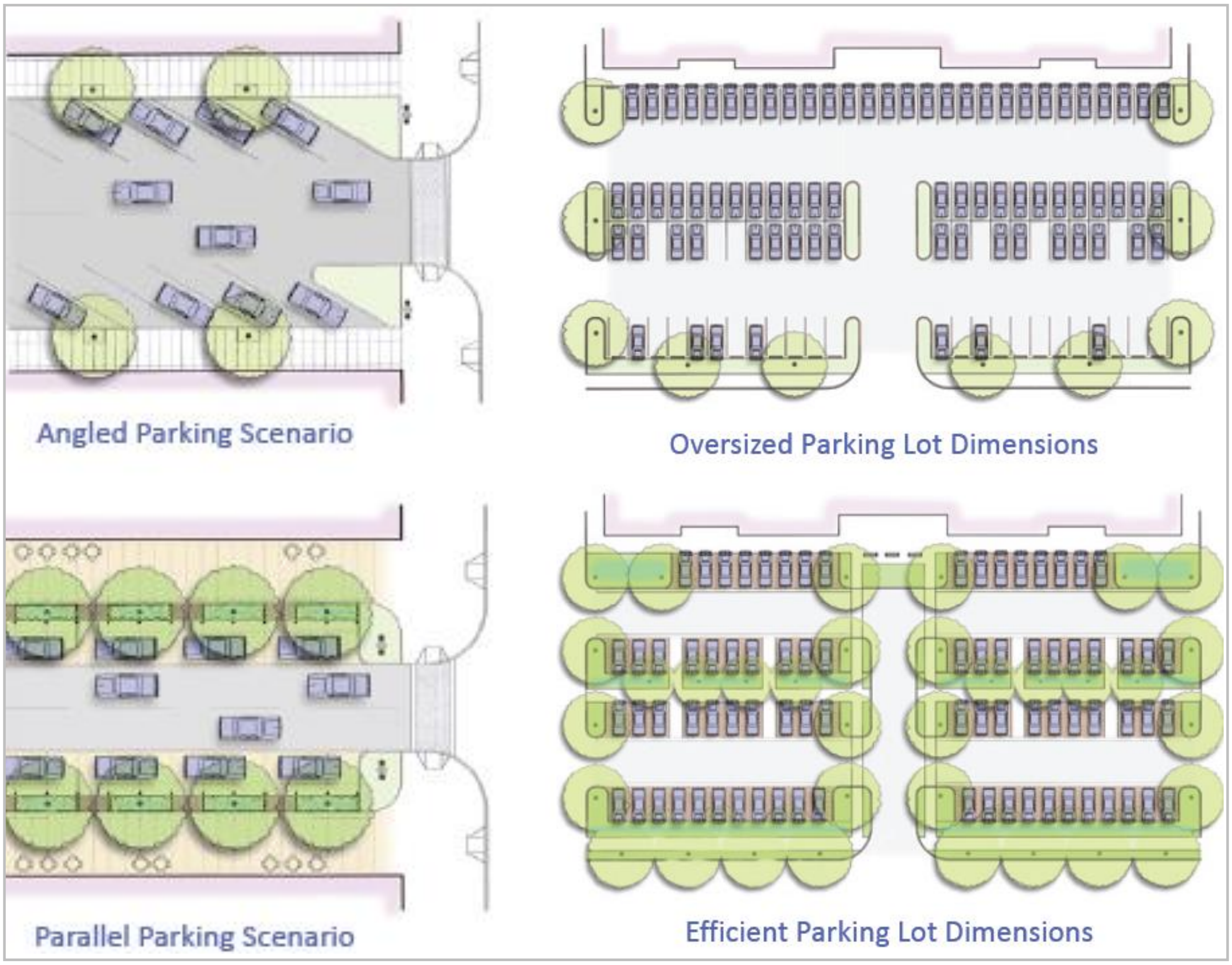


*Figure 2-42. Parking layouts allowing for GSI installation. Conceptual examples from the SMCWPPP Sustainable Green Streets and Parking Lots Design Guidebook. (Courtesy of SMCWPPP)*

## 2.3.3 Approach for Siting GSI in Parks, Plazas and Other Outdoor Areas

GSI projects can be combined with public art projects or improvements to public spaces in parks and plazas. Parks may also be used as an off-site area for treating stormwater runoff from a street. For example, if there is a street where GSI measures cannot be effectively added due to constraints, but there is a park downstream, it may be possible to direct the street runoff to the park for treatment. This opportunity is most likely to occur with streets in residential neighborhoods adjacent to public parks.

Parks can also be used for larger regional GSI projects. In these projects, runoff from upstream areas can be directed into a park or open space for treatment, either using surface or subsurface treatment facilities.

Section 3.1 of this Handbook provides additional discussion of integrating GSI measures in Parks and Sections 6.7 through 6.9 of this Handbook provide example GSI park projects. The C.3 Stormwater Handbook is also a useful resource for siting and design of GSI measures in parcel-based areas such as public parks. In addition, there is the National Recreation and Park Association Resource *Guide for Planning, Designing and Implementing Green Infrastructure in Parks*, which identifies the following park amenities for evaluation of incorporating GSI measures: active recreation areas, passive recreation areas and trails, natural areas, park entrances and parking areas.

## 2.3.4 Approach for Siting GSI in Public Rights-of-Way

This section of the Handbook provides guidance on factors to consider when evaluating GSI measure integration in public streets and small outdoor areas in the public right-of-way.

The first consideration is the street typology, which is a combination of the street's functional classification (discussed in Section 2.1.2) and the primary surrounding land uses. By characterizing streets, assumptions can be made about the types of GSI measures and placement typically suitable for particular classifications. After streets are characterized, the presence of other right-of-way components and site-specific conditions will determine the appropriate GSI measures, locations and design elements. These concepts are summarized in Table 2-1 and described in the text below.

*Table 2-1. Summary of Siting Considerations*

| Street Characterization | Site Conditions |
|---|---|
| • Street Functional Classification<br>○ Local<br>○ Collector<br>○ Principal<br>○ Arterial<br>• Land Use Type<br>○ Low Density Residential<br>○ High Density Residential<br>○ Commercial<br>○ Industrial<br>○ Parking Lot<br>• Other Right-of-Way Components<br>○ Pedestrian Facilities<br>○ Bikeways/Cycling Facilities<br>○ Truck/freight routes<br>○ Buildings/Furnishings | • Local gradients, topology and contributing drainage area – both on-street and off-street<br>• Location, type and depth of storm drain system<br>• Subterranean soil and other conditions<br>• Street trees and other vegetation<br>• Type, depth and location of existing above ground and below ground utilities<br>• Road and right-of-way width<br>• Parkway and sidewalk width |

### *Street Functional Classification*

A description of local, collector, principal, and arterial street types is provided in Section 2.1.2. This section focuses on considerations for GSI specific to each street type.

Principal arterials in Santa Clara County are often wide rights-of-way, include under-utilized on-street parking, wide shoulders, and have medians separating the two directions of traffic. These wide roadways provide opportunities for narrowing or reducing travel lanes in the roadway or removing on-street parking, which provides space to easily integrate any of the GSI measures. For example:

- Locations with wide shoulders where parking is not allowed, where parking is underutilized and/or where there is re-purposable roadway capacity can be retrofitted with GSI measures such as bioretention or bikeways with pervious pavement. Class I or IV bikeways are recommended for the best level of safety.
- Medians can be removed, shifting traffic to the roadway centerline, and providing space for GSI measures along the outer edges of the roadway.

GSI sites along minor arterials may require more consideration be paid to specific space demands and surrounding land use, but all GSI measures can be easily integrated into a minor arterial site.

For collector streets and local streets with small rights-of-way, land use must be considered when determining applicability of GSI integration, as space may be limited and demand may vary across land uses.

### *Land Use Type*

To better evaluate the types of GSI measures that can be implemented in a particular street, land use is one factor that should be taken into consideration. For example, using stormwater curb extensions on a local street in a low-density residential area may be more feasible than in a high-density neighborhood where more demands may be placed on limited right-of-way. Stormwater curb extensions are recommended where there is space in the street or where GSI measures are desired or are most practical as determined by the municipality using many factors such as low demand for on-street parking.  Other non-land use factors to consider are transit, pedestrian and bicycle infrastructure, car-ownership levels, permit parking programs, cost-effectiveness of construction, pollutant loading etc.

Recommend GSI measures for eight combinations of street type and land use are provided in Table 2-2. More siting and design considerations related to specific GSI measures can be found in Section 2.2.

As examples of how land use can assist in determining locations for GSI measures in the streetscape, four land use types and the associated street typologies commonly found in the County are discussed in more detail below: low-density residential, high-density residential, commercial, and industrial with recommendations for GSI measures for each land use type. Individual municipalities may want to expand or refine their defined street classifications given specific characteristics within their jurisdiction and how these are paired with additional land use types. For example, adding a separate category of “Local – Alley” or “Collector – Mixed Use”, or distinguishing between “Local – Commercial Downtown” and “Local – Commercial”.

*Table 2-2. Summary of recommended GSI measures for various land uses and road types.*

*Legend:* ☒ = Not Recommended ○ = Potential ☑ = Recommended

| **Street Type:** | **Local Streets** | | | | **Collectors** | **Minor Arterials** | **Principal Arterials** | **Parking Lots** |
|---|---|---|---|---|---|---|---|---|
| **Land Use Type:** | **Alley** | **Low Density Residential** | **High Density Residential** | **Commercial** | **Commercial** | **Commercial/ Industrial** | **Commercial/ Industrial** | |
| **Stormwater Planter** | ○ | ☑ | ☑ | ☑ | ☑ | ☑ | ○ | ☑ |
| **Stormwater Curb Extension: Midblock** | ☒ | ☑ | ○ | ○ | ☑ | ○ | ○ | ☒ |
| **Stormwater Curb Extension: Corner** | ☒ | ☑ | ☑ | ☑ | ☑ | ○ | ☒ | ☒ |
| **Stormwater Tree Well Filter** | ☒ | ☑ | ☑ | ☑ | ☑ | ○ | ○ | ☑ |
| **Pervious Pavement** | ☑ | ☑ | ☑ | ☑ | ☑ | ○ | ☒ | ☑ |
| **Infiltration Trench** | ☑ | ○ | ○ | ○ | ☒ | ☒ | ☒ | ☑ |
| **Dry Well/Infiltration Well** | ☑ | ○ | ○ | ○ | ☒ | ☒ | ☒ | ☑ |
| **Subsurface Infiltration System** | ☒ | ☒ | ☒ | ☒ | ☒ | ☒ | ☒ | ☑ |
| **Land Use Type Characteristics:** | Narrow roadway; no sidewalks; consider heavy loads and passage of garbage trucks. | Low to moderate demand for street parking; Light pedestrian traffic; moderate vehicle traffic; sidewalks of varying sizes; driveways and underground utilities may be limitations. | Moderate to high demand for street parking; moderate pedestrian traffic; moderate vehicle traffic; sidewalks of varying sizes; driveways and underground utilities may be limitation. | Moderate to high pedestrian traffic; sidewalks likely to be wide; moderate to high parking demand; underground utilities may be limitation. | Moderate to high pedestrian traffic; sidewalks likely to be wide; moderate to high parking demand; underground utilities may be limitation; may be able to reduce width of roadways. | Low pedestrian traffic; high vehicle traffic; possible opportunity for road diet; pervious pavement may only be possible in sidewalk areas. | Low pedestrian traffic; high vehicle traffic; medians are possible locations for GSI; heavy vehicles, sediment loads and large turning radii may limit GSI options. | Lighter traffic loads and volumes; more flexibility on space and design; tree soil volumes; have fewer utility conflicts. |

**Low-Density Residential** areas are residential areas populated with detached, single family homes. Often with less competition for space in the right-of-way (e.g., under-utilized on-street parking, less utility coordination), low-density residential areas are the most flexible land use for incorporating GSI, but may have low pollutant loads.

The availability of space allows many of the different types of GSI measures to be implemented in low density residential areas:

- Stormwater curb extensions can be placed midblock or at intersections.
- Stormwater planters can be placed in the sidewalk parkway zone. Consider planters with sloped sides and less concrete that may offer a softer design if space allows[50].

| | **Local – Low-Density Residential** |
|---|---|
| **Stormwater Planter** | ☑ |
| **Stormwater Curb Extension: Midblock** | ☑ |
| **Stormwater Curb Extension: Corner** | ☑ |
| **Stormwater Tree Well Filter** | ☑ |
| **Pervious Pavement** | ☑ |
| **Infiltration Trench** | ○ |
| **Dry Well** | ○ |
| **Subsurface Infiltration System** | ☒ |

**☒ = Not Recommended**
**○ = Potential ☑ = Recommended**

- Where there are existing street trees, there are several options. Work with certified arborists and other related staff or consultants to assess and approve an option:
  - If the existing trees are deemed valuable, modify the areas around existing trees to turn them into stormwater tree well filter trees. This can be challenging with large existing trees as roots may be extensive, and hand digging, air spading or other methods of carefully working around existing trees may be needed.
  - Existing underperforming street trees can be removed and new stormwater tree well filters can be planted in the same location to maintain the existing aesthetic while providing additional benefits in the form of stormwater treatment.
  - Leave valuable existing trees alone and plant new stormwater tree well filters sufficiently far away to allow for future growth and to protect existing tree roots.

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[50] NACTO, 2017

| | Local – High-Density Residential |
|---|---|
| **Stormwater Planter** | ☑ |
| **Stormwater Curb Extension: Midblock** | ○ |
| **Stormwater Curb Extension: Corner** | ☑ |
| **Stormwater Tree Well Filter** | ☑ |
| **Pervious Pavement** | ☑ |
| **Infiltration Trench** | ○ |
| **Dry Well** | ○ |
| **Subsurface Infiltration System** | ☒ |

**☒ = Not Recommended**
**○ = Potential ☑= Recommended**

**High-Density Residential** areas are mainly populated with attached single family homes, multi-family dwelling units and mixed use buildings. There is usually a high demand for on-street parking and a high density of driveways, limiting the amount of right-of-way that can be converted to GSI. High density residential areas along local streets will likely have less space available for GSI measures than collector streets, but can still incorporate GSI where feasible and desirable:

- In narrow streets, pervious pavement can be installed in the parking zone, sidewalk or in the entire street if underlying soils are permeable.
- Even when on-street parking is in high demand, a stormwater curb extension can be integrated at an intersection in a no-parking zone or in between driveways where the curb length is shorter than the length of a standard vehicle.
- Where there are existing street trees, there are several options. Recommendations are provided in the low-density residential areas discussion above.

**Commercial** areas frequently have a high demand for space. On-street parking, pedestrians, business appurtenances (e.g., sidewalk café seating, sidewalk sales) street trees, utilities, and bicycle lanes all compete for space in the right-of-way and limit the available space for GSI measures and GSI implementation. In addition, commercial areas have specific design considerations, such as maintaining a continuous, wide pedestrian path with limited driveway interruptions and broad canopy, high-branching trees, and providing safe facilities for pedestrians and bicycles[51]. How and where businesses receive commercial deliveries should also be taken into consideration. Potential locations to consider for GSI in commercial streetscapes include:

- Depending on the functional street type, commercial streets may be able to accommodate GSI measures by narrowing the roadway or by converting angled on-street parking to parallel parking or by replacing a few spaces with a stormwater curb extension.

| | Local – Commercial | Collector – Commercial |
|---|---|---|
| **Stormwater Planter** | ☑ | ☑ |
| **Stormwater Curb Extension: Midblock** | ○ | ☑ |
| **Stormwater Curb Extension: Corner** | ☑ | ☑ |
| **Stormwater Tree Well Filter** | ☑ | ☑ |
| **Pervious Pavement** | ☑ | ☑ |
| **Infiltration Trench** | ○ | ☒ |
| **Drywell** | ○ | ☒ |
| **Subsurface Infiltration System** | ☒ | ☒ |

**☒ = Not Recommended**
**○ = Potential ☑= Recommended**

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[51] City of San Diego, 2014

- GSI measures could be implemented in excessively wide sidewalks instead of the roadway to preserve existing roadway conditions.
- For local commercial streets with narrow roadways and narrow sidewalks, GSI can be implemented by installing pervious pavement in the sidewalk, parking zone, or even in the roadway.
- Stormwater curb extensions at intersections can shorten pedestrian crossing distances and shield waiting pedestrians from vehicular traffic. These measures can increase safety and aesthetics, which may be desired to encourage pedestrian traffic in these commercial zones.
- Where there are existing street trees, there are several options. Recommendations are provided in the low-density residential areas discussion above.

| | Minor Arterial | Principal Arterial |
|---|---|---|
| **Stormwater Planter** | ☑ | ○ |
| **Stormwater Curb Extension: Midblock** | ○ | ○ |
| **Stormwater Curb Extension: Corner** | ○ | ☒ |
| **Stormwater Tree Well Filter** | ☑ | ○ |
| **Pervious Pavement** | ○ (sidewalk) | ☒ |
| **Infiltration Trench** | ☒ | ☒ |
| **Dry Well** | ☒ | ☒ |
| **Subsurface Infiltration System** | ☒ | ☒ |

**☒ = Not Recommended**
**○ = Potential ☑= Recommended**

**Industrial** areas can be divided into light and heavy industrial and can be on many different types of streets from local to arterial.

Heavy industrial areas with manufacturing may have an added barrier to GSI of soil contamination or heavy sediment loading in the street. Sediment loads may restrict the use of infiltration facilities. Additional investigations and potential clean-up activities would need to take place before incorporating GSI.

Light industrial, such as industrial office parks, have similar opportunities for GSI as other land use types. Generally, the demand for space varies by business/operating hours. Considerations for GSI in industrial streetscapes include:

- For industrial office parks with on-site parking, on-street parking may have low demand, which frees up space for GSI implementation. In industrial areas with limited on-site parking, heavy vehicles may park in the sidewalk zones, or use that area for loading and unloading of materials, which could restrict the use of pervious pavement or other GSI measures in that area.
- Turning movements of large vehicles could impede the use of stormwater curb extensions at intersections.
- Where there are existing street trees, there are several options. Recommendations are provided in the low-density residential areas discussion above.

## *Other Right-of-Way-Components*

There are other components to consider when assessing a street's functionality and potential for GSI. Current conditions as well as future plans for the street should be taken into account.

For example, stormwater curb extensions may not be appropriate for installation at an intersection on an identified truck route. However, stormwater curb extensions at an intersection would be beneficial in an area of high pedestrian traffic. A cycletrack could be utilized to provide both GSI measures and a new bikeway if it has been identified in a Bicycle Master Plan. Other examples are provided below.

*Pedestrian Usage*. Note pedestrian circulation and use. In areas with high pedestrian volume, designers should consider implementing GSI measures in the roadway such as at intersections (i.e. corner stormwater curb extensions), instead of in the sidewalk, which may impede the flow of pedestrians. Underground suspended pavement systems can also be used to provide additional stormwater treatment area for stormwater tree well filters without reducing sidewalk areas for pedestrians, see Section 3.4. GSI measures could still work in sidewalk areas with high pedestrian traffic, as long as a clear path of travel of a desirable width is maintained. In fact, trees and landscaped GSI treatments can make an area a more desirable place to walk. Also refer to Section 3.4 for pedestrian facility information and more details on GSI measure integration

*Bikeways*. Identify any official (marked) or unofficial bikeways (routes used by cyclists). Any GSI measures considered for the on-street parking area, or flexible realm, should not interfere with bicycle traffic. If no bikeway exists at a site with heavy bicycle traffic, designers should consider integrating a bikeway into the design. Also refer to Section 3.3 for cycling facility information and more details on GSI measure integration.

*Truck/freight routes.* It may not be feasible to install stormwater curb extensions at the intersection on an identified truck route because of curb radii limitations for turning movements of large vehicles.

*Emergency vehicle routes*. In some instances identifying emergency vehicle routes may lead to ideal placement of GSI measures (e.g., grid pavers in emergency access lane only) or rejection of GSI measures (e.g., stormwater curb extensions at an intersection that would limit the turning radius of a fire truck should not be installed on a street with a fire station).

*Transit Routes*. Identify any overlapping transit routes and stops. Designers should not place GSI measures anywhere in the road or sidewalk that would interfere with normal transit flow and use. GSI measures should be used to enhance environments for people who walk and bike.

*Building/Furnishings*. Commercial districts, pedestrian-oriented retail land uses and higher density areas often have increased competition for space – especially when the distance from the building edge to the the flexible zone is narrower than desirable and pedestrian volumes are high. On the sidewalk, pedestrian traffic, transit stop furnishings (e.g., benches) and sidewalk furnishings related to business types (e.g., outdoor restaurant seating, retail signage, bicycle parking) compete for space. Pervious pavement in the parkway would not need to compete for space that a stormwater planter would need. Street trees and stormwater tree well filters in these locations may need to take advantage of suspended pavement systems to provide the room necessary for tree roots and bioretention sizing.

## *Site Conditions*

Considerations for site conditions when determining the appropriate GSI measures, locations and/or design elements in street projects are described below.

*Local gradient, topology, and contributing drainage areas.* Determine the local gradient of the contributing street section and adjacent private property that may be draining to the street section to determine the drainage area of a proposed GSI site. The GSI sites under consideration should include large drainage areas to GSI measures to maximize stormwater treatment where feasible. Streets with a slope greater than 5% are generally not suitable for GSI, or will require additional design strategies to make GSI integration possible[52]. Placing GSI measures at low points in the drainage area and at other locations where existing drainage infrastructure often exists, such as at intersections, can maximize the tributary area and effectiveness of the system.

*Location, type and depth of storm drain system*. Overlay the storm drain system over site candidates to identify the intersection of GSI measure location opportunities with storm drain system components in the area such as drainage inlets, location of manholes, direction of flow in pipes and final discharge locations. If an underdrain is necessary due to soil conditions or groundwater table, ideally, it would connect to an existing storm drain line.

*Subterranean soil and other conditions.* Identify the underlying soils infiltration rate. Determine the depth to first groundwater from the SCVURPPP C.3 Stormwater Handbook Appendix A, Figure A-1 (Depth to First Groundwater for the Santa Clara Basin) and soil type from Appendix B, Figure B-1 (Soil Texture and Mean Annual Precipitation and Depths for the Santa Clara Basin). Poorly-draining soils or high groundwater tables limit infiltration and require the use of an underdrain. If you have a known pollution source or contamination plume or a sensitive groundwater resource, groundwater quality protection must be considered when choosing GSI measures.

*Street trees and other vegetation.* Identify the species, age, health, value, condition, location, height, root structure, rootable soil volume and irrigation system of existing trees and surrounding pavement quality at the locations where GSI measures may be installed. Consider converting existing trees to Stormwater Tree Well Filters, where appropriate and possible. It may not be possible to convert existing trees depending on the factors described above such as the species and condition of the trees. Existing trees that have acclimated to certain conditions may not tolerate a major change in those conditions. For example, existing trees with extensive impervious surfaces around them may be impaired by a large increase in water flowing to their roots when the pavement is removed.

*Type, depth and location of existing above ground and below ground utilities.* Identify existing utilities in the area to avoid and/or plan for potential conflicts. More information on this is provided in Section 4.6 of this Handbook.

*Road width*. Consider the width of traffic lanes. AASHTO provides standard lane widths in the Green Book[53] for the four functional street classifications, but consult municipal code for minimum allowable widths. Determine if travel lanes can be reduced. Narrowing travel lanes provides space for GSI measures and/or bicycle lanes in the roadway. Implementation may require revisions in the municipal code. Unnecessary travel lanes (i.e., redundant lanes, right turn lanes, or center turn lanes on quiet streets) can be removed and replaced with landscaped GSI measures. NACTO provides additional information and guidance on road and travel lane width with safety issues[54].

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[52] NACTO, 2017

[53] AASHTO, 2001

[54] NACTO, 2017

*Sidewalk Width.* As discussed in Section 2.1 and shown again in Figure 2-43 below, the sidewalk is divided into four zones. At least two of these zones, the building interface zone and the pedestrian zone, likely have minimum design widths in a municipal code (and possibly varying depending on adjacent land use and other factors), and the pedestrian path of travel (sidewalk) must meet ADA requirements. Once those minimum widths have been identified the remaining area - the parkway and step out zone - can be considered for GSI measures including stormwater planters. The building interface zone and pedestrian zone may also be considered for suspended pavement systems if needed. If the sidewalk is narrow then pervious pavement in all areas of the sidewalk may be an option or stormwater curb extensions that utilize space in the street can be used.

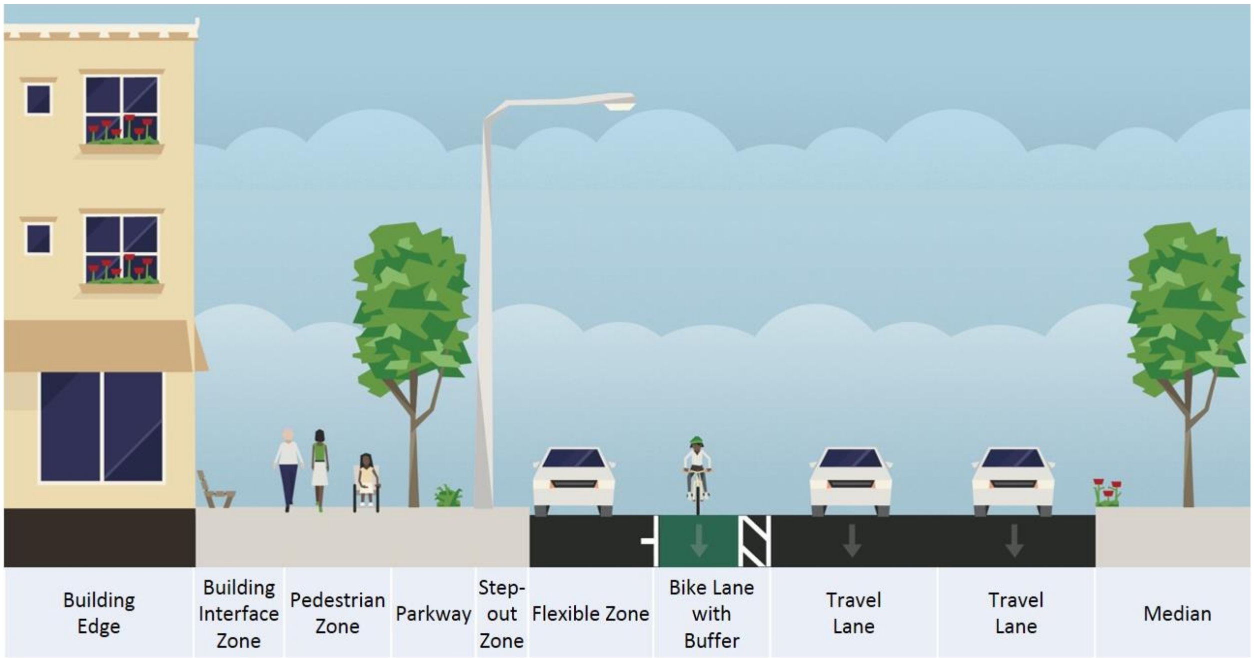

*Figure 2-43. Street and sidewalk cross section, conceptual example. (courtesy of Streetmix.net)*

# CHAPTER 3

# Design Guidance for GSI Measures

*This chapter discusses integration of GSI measures into the urban landscape including considerations for pedestrian and cyclist infrastructure, safety and accessibility, resolving utility conflicts, landscape design, urban forestry, maintenance considerations during design, and design for full trash capture benefits.*

As discussed previously, there may be special design considerations that need to be taken into account when designing stormwater treatment measures in public parcels and the public right-of-way. This chapter includes additional design considerations for public parcels and those unique to street design, including integration of GSI measures with pedestrian and cyclist infrastructure, safety and accessibility, resolving utility conflicts, landscape and street tree design, maintenance considerations and trash capture.

Typical details and design specifications for the stormwater control measures and utilities can be found in Part 2 of the Handbook.

## 3.1 Integration of GSI with Parks, Plazas and Public Outdoor Areas

A variety of public areas including parks, public plazas, and parklets can be designed to incorporate GSI. Public landscapes can contain GSI measures to capture and treat local runoff and/or may also capture and treat runoff from off-site areas. This section will focus primarily on park projects - new parks, park retrofit projects, and regional projects.

Options for incorporating GSI measures into park projects include the following:

- Drain basketball or tennis court surfaces to surrounding landscaping or use pervious pavement
- Pave walkways and plazas with pervious pavement, or drain to adjacent landscaping
- Use porous rubber safety surfacing in playgrounds to allow infiltration or drain runoff from non-porous safety surfaces to a bioretention area
- Install a subsurface infiltration system, such as an infiltration gallery, below the park
- Replace traditional plant vegetation surrounding park buildings with bioretention areas
- Incorporate green roofs on park buildings
- Utilize rainbarrels or cisterns for rainwater capture from roofs of building structures in the park, e.g., restrooms or community centers
- Construct playing field and open spaces that are depressed to collect and/or retain stormwater during large storms

New parks have a lot of potential for GSI. They can handle the stormwater on-site with GSI measures and can serve as locations for treating runoff from other parts of a jurisdiction. A local example of a new park that incorporates multiple types of GSI is Commodore Park in San Jose, which is described as a case study in Section 6.7. The athletic fields along El Camino Real at Stanford University, which are dry most of the year but provide storage for flood control if needed, are another local example.

Retrofits of existing parks also have great potential for GSI but can be limited by existing constraints such as mature trees, buildings, grading and utilities. The Stevens Creek Corridor Park project in Cupertino (see Section 6.9) consisted of retrofitting an existing park with GSI measures and restoring a section of the creek running through the park by removing hardened embankments and reestablishing vegetation in the riparian corridor.

Regional GSI park projects are those that capture and use or treat runoff from a relatively large off-site drainage area.  Facilities for flood control, groundwater recharge, and rainwater harvesting for irrigation or toilet flushing can also be integrated into these designs. For example, the Sun Valley Park project in the City of Los Angeles and Tanner Springs Park in Portland (see Figure 3-1 below) incorporate several of these features. The City of Santa Monica also has built large rainwater harvesting systems and other GSI systems in parks. In the Bay Area, the San Mateo County Stormwater Resource Plan identified three regional projects for stormwater capture and infiltration in parks: Orange Memorial Park in South San Francisco, Twin Pines Park in Belmont, and Holbrook-Palmer Park in Atherton[64].

*Figure 3-1. Subsurface infiltration gallery in Sun Valley Park, LA. (Left) and Tanner Springs Park in Portland (Right). (Credit: Los Angeles County Flood Control District and Museum of the City, Portland)*

In addition to stormwater capture and treatment, incorporating GSI measures into park projects has numerous benefits including safety, noise reduction, aesthetic landscaping improvements, and education and outreach. GSI measures can improve safety by preventing flooding on play surfaces (basketball courts, play fields, and playgrounds).  Replacing traditional pavement on sports courts with pervious pavement can increase sound attenuation, thereby reducing noise pollution for neighbors[65]. GSI measures in parks can also be used to educate the community about stormwater quality. Educational signage at a GSI measure describing what the project is and why it was constructed can

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[64] See: http://ccag.ca.gov/srp/

[65] See City of Lancaster's experience with playground retrofits: www.saveitlancaster.com/local-projects/parks/

encourage interest and help preserve the GSI measure from inadvertent damage. Community engagement during the project development and construction, for example using volunteers to complete a project, can also help with preservation of the GSI Measure.

Early community input and significant public outreach on traditional and social media helps develop public support for GSI projects. Since parks are focal points in communities, volunteers can be used to maintain GSI measures. Including volunteers from the community can cut maintenance costs and provide opportunities for community outreach and education. Volunteers who assist in maintenance become stewards for the project and can cultivate community support for future GSI projects.

Additional considerations and site design practices for integrating GSI into parks can be found in the National Recreation and Park Association *Resource Guide for Planning, Designing and Implementing Green Infrastructure in Parks*.[66]

## 3.2 Integration of GSI with Roadway Design

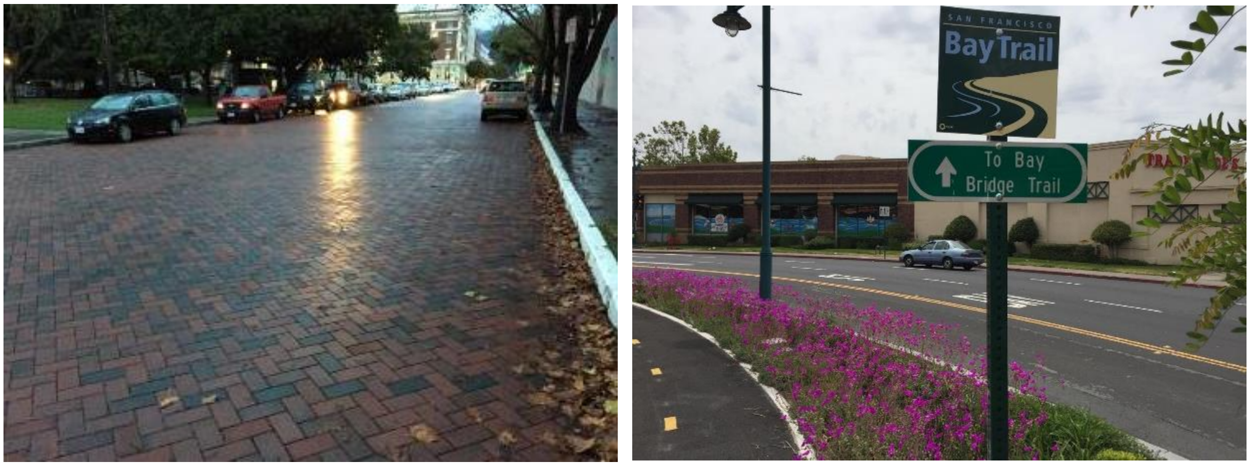

*Figure 3-2. Pervious pavement, Berkeley (left) and cycletrack, Emeryville (right). (Credit: EOA)*

Municipalities can take a variety of steps to ensure that consideration of GSI measures is a part of a roadway project planning process. Section C.3.j of the MRP requires municipalities to evaluate all appropriate public projects for opportunities to incorporate GSI measures. In order to institutionalize and solidify the role of GSI measures in roadway design, street and transportation design standards should be updated to include GSI measures. Policies adopting, promoting or requiring GSI measure implementation in streets projects can assist in the design process and provide a rationale for including GSI measures in projects when describing the project to elected officials and members of the public. Municipalities can also adopt rating systems such as Envision and Greenroads to assist in the planning and design process and to measure results. The Hacienda Avenue Green Street Improvement Project in Campbell is the first GSI project in the Bay Area to achieve a Greenroads certification.

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[66] NRPA, 2017

Greenroads® Summary
West Hacienda Avenue
Campbell, CA, USA

| Total Score* | 43 |
|---|---|
| Project Requirements | 11/11 |
| Environment & Water | 9/21 |
| Access & Equity | 11/30 |
| Construction Activities | 4/14 |
| Materials & Resources | 13/20 |
| Pavement Technologies | 0/20 |
| Custom Credits | 6/10 |

*Does not include Project Requirements

*Figure 3-3. Hacienda Ave. project with Greenroads certification. (Credit: Greenroads.org)*

There are several standard engineering design manuals that roadway designers in California rely on and in some cases must follow. These include the American Association of State and Highway Transportation Officials (AASHTO) "Policy on Geometric Design of Highways and Streets" (also known as the "Green Book")[67], the Caltrans Highway Design Manual (HDM)[68], and the California version of the national Manual on Uniform Traffic Control Devices (CAMUTCD)[69]. In addition, some jurisdictions have adopted local standards such as the City of San Jose's "Geometric Design Guidelines"[70]. These standards may not fully address green stormwater infrastructure in the roadway. Local street tree and urban forestry guidelines may also be used to supplement the standard design manuals.

The National Association of City Transportation Officials (NACTO) has created several design guides over the last ten years with the aim of incorporating all modes of transportation and green infrastructure into roadway design. NACTO's *Urban Street Design Guide*[71] and *Urban Street Stormwater Guide*[72] align cutting edge complete streets principles with comprehensive green drainage designs. This section of the GSI Handbook will summarize some of the design guidance from NACTO and other guidelines from around the U.S. which aim to incorporate green infrastructure into roadway design.

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[67] AASHTO, 2001
[68] CA DOT, 2018
[69] CA DOT, 2014
[70] San Jose, 2010
[71] NACTO, 2013
[72] NACTO, 2017

*Figure 3-4. NACTO Urban Street Design Guide and Urban Street Stormwater Guide. (Courtesy of NACTO)*

## 3.2.1 Lane Width Recommendations

One of the first design parameters that must be established when planning and designing a roadway design project to incorporate GSI measures is lane widths. Establishing lane widths sets the baseline for the rest of the project. Overly wide vehicle travel lanes reduce space for green stormwater infrastructure or other roadway uses. A summary of the NACTO recommendations is provided here:

- Ten-foot lane widths in urban areas improve street safety without impacting traffic operations.
- Truck or transit routes can use one travel lane of 11 feet in each direction.
- Narrower travel lanes (9–9.5 feet) can be effective as through lanes in conjunction with a turn lane.
- Wider lanes correlate with higher speeds and are more appropriate for highway designs – not urban roadways with multi-modal goals.

Cities may need to reevaluate and change their design standards to allow for reduced lane widths in order to accommodate green stormwater infrastructure.

## 3.2.2 Diverters/Closures

Projects that include partial or complete closures of segments of a street to motor vehicles are an excellent opportunity for incorporating GSI measures.

- Partial closures allow limited vehicle turning movements through an intersection – usually right turns only – while allowing full through movements for non-motor vehicles.
- Full closures allow only non-motor vehicle through movements, effectively turning the roadway into a dead-end for motor vehicles. Some full closures allow for emergency vehicle through movements for public safety access and efficiency of routing.
- Impervious pavement can be converted to pervious pavement – especially where traffic loads and/or volumes are reduced by the closure.
- Extra space freed up by the closure can be converted to landscaped GSI measures such as stormwater planters, stormwater curb extensions or stormwater tree well filters.
- Landscaped areas can also be used for placemaking and other infrastructure opportunities such as mini-parks, bicycle parking.
- Closures on transit priority corridors can free up space for amenities such as bus stops, stations and shelters.
- Access to neighboring properties through driveways may need to be taken into account.

*Figure 3-5. Traffic diversion with complete motor vehicle closure on Catalina Island. (Credit: LAecovillage.org)*

Figure 3-5 illustrates a combination of many design features that can be accommodated through the use of a complete closure. This concept is located on a bicycle priority street where traffic speeds and volumes are reduced. Diverting the motor vehicle traffic off the bicycle boulevard increases safety and comfort for cyclists. The stop controlled intersection and green pavement markings are important for creating safety for cyclists crossing the intersection diagonally into the closure area.

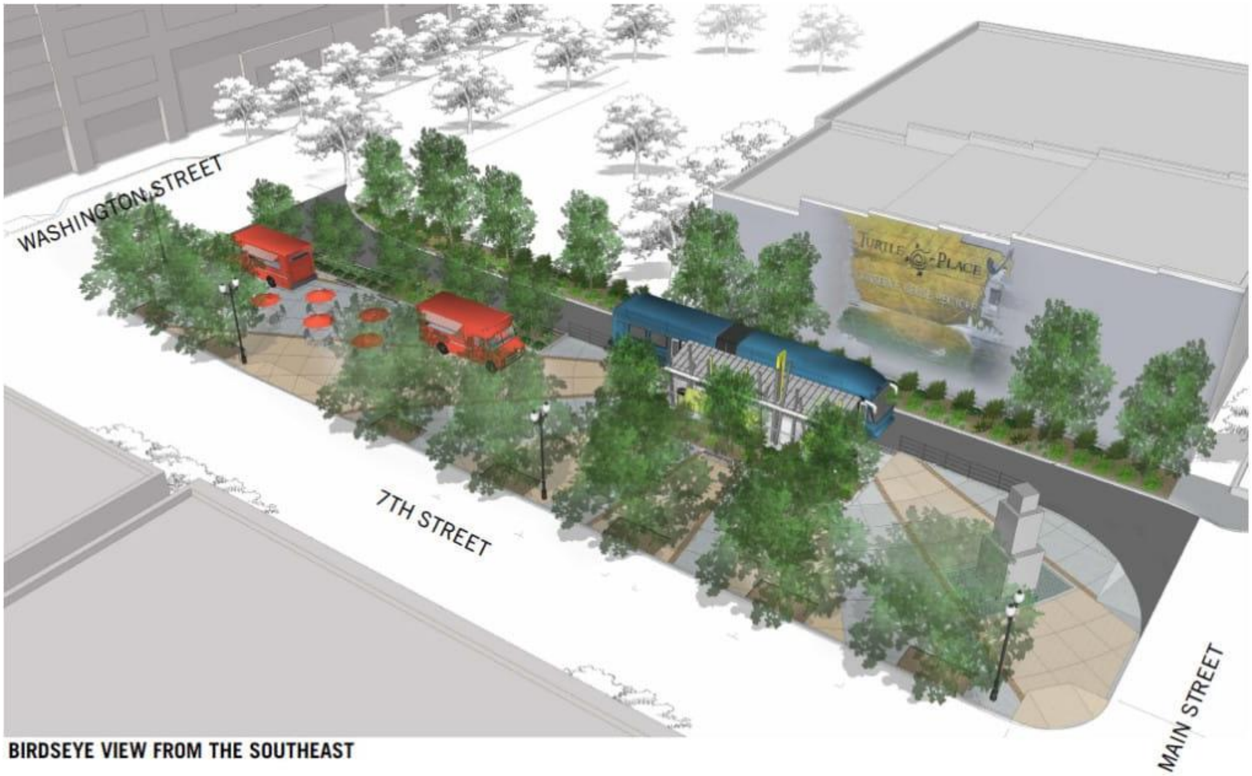

*Figure 3-6. Partial closure concept preventing private motor vehicles in Vancouver, CA. (Credit: Columbian.com)*

*Figure 3-7. Example of full closure concept. (Courtesy of City of Emeryville)*

Figure 3-6 depicts a partial closure concept that allows access for public transit, bicycles and pedestrians, but not private motor vehicles. GSI measures could be installed in the landscaping and pavement areas.

Figure 3-7 illustrates a full closure concept that allows emergency vehicle access and permits residents to enter their parking garage parking access. Permeable pavers are indicated as a GSI Measure. The landscape areas could also be used for bioretention.

## 3.3 Integration with Cycling Facilities

Cyclists benefit from GSI-cycling facility integration in several ways:

- Some GSI systems can provide physical separation from motor vehicles.
- Trees in GSI systems can provide protection from sun and rain and cool pavements.
- Stormwater planters and curb extensions can calm traffic and add aesthetic value.
- Pervious pavements can reduce hydroplaning and noise.

### 3.3.1 Class I Bikeways (Paths/Trails) and GSI

Bicycle paths are easy targets for GSI integration since they typically have landscaping on at least one side of the path or trail that could be used for a GSI measure. They do not carry vehicle loads, besides the occasional maintenance vehicle and can use pervious pavements without a deep structural aggregate base.

### 3.3.2 Class II Bikeways (Lanes) and GSI

The primary way to integrate GSI into a Class II bicycle lane project is to use pervious pavement in the bicycle lane. See the pervious pavement guidance in Section 2.2.2 for more information. If areas outside of the bicycle lane can be included in the project scope, then stormwater curb extensions, stormwater planters or tree filters are also possible GSI measures to consider. Other benefits of pervious pavements in bicycle facilities are:

- Lower cost – when using a life cycle analysis process, permeable interlocking concrete pavers can be less expensive than standard asphalt paving.
- Lower carbon footprint – pavers can provide a lower carbon footprint than standard asphalt.
- Avoidance of thermoplastic striping pollution – integrated color pavers can be used instead of asphalt with thermoplastic striping that typically crumbles into micro-plastic pieces over time.
- Ease of maintenance – over time asphalt can form potholes and other pavement problems. Permeable pavers can be replaced when damaged and when properly constructed can maintain a level and smooth surface longer than standard asphalt.
- Comfort and reduced noise – permeable pavers are a smooth and quiet surface for roadway users. Cyclists and others are often surprised at the smoothness of permeable paver surfaces.
- Avoidance of hydroplaning – pervious pavements infiltrate water quickly avoiding the problem of hydroplaning which can be a safety concern for cyclists.

### 3.3.3 Class III Bikeways (Routes) and GSI

Similar to bicycle lanes, bicycle route projects are limited to pervious pavement measures unless the whole right-of-way is being proposed for improvements.

### 3.3.4 Class IV Bikeways (Cycletracks) and GSI

Cycletrack projects provide an excellent opportunity for GSI integration because the separation between the motor vehicle travel lanes and the cycletrack frees up space that can be used for treating runoff from adjacent impervious pavement surfaces. Just as stormwater curb extensions function as both a pedestrian safety feature and a location for stormwater treatment, cycletracks can provide the dual function of protecting cyclists and improving water quality. Three reference manuals have gained national attention recently for providing guidance on the design of separated bikeways integrated with GSI designs:

1. Massachusetts Department of Transportation (massDOT) Separated Bicycle Lane Planning & Design Guide (2015)[73]
2. NACTO Urban Street Stormwater Guide (2017)[74]
3. FHWA Separated Bicycle Lane Planning & Design Guide (2013)[75]

Images and design guidance from the three guides are provided and described in the following sections.

*Figure 3-8. Guides with stormwater and separated bike lane information: (Credit: massDOT, NACTO & FHWA)*

## Cycletrack Typologies

There are several design features of cycletracks that impact the opportunity for GSI integration. The type of separation from the roadway, the pavement height, the travel direction of cyclists, the curb height, the travel direction related to motor vehicle travel, the location of the bikeway on the street, and whether there is a nearby storm drain system all play a role in determining the potential for and type of GSI measures to be considered. Details related to these features are listed below:

**Separation from roadway**

Raised curb
Standard planter
Stormwater planter
Stormwater tree well filter
Raised planter
Motor vehicle parking lane
Bicycle parking corral
Bicycle sharing station
Other barrier (fence, median, bollard, etc.)

**Pavement height**

Road level
Intermediate level
Sidewalk level

**Travel direction of cyclists**

One way
Two way

**Curb height**

Raised curb
Flush curb
Intermediate curb
Sidewalk curb

**Travel direction related to motor vehicle travel direction**

Contraflow
Same flow direction

**Location of bikeway on street**

Right side
Left side

**Drainage system**

Stormwater system in planter (typically with overflow drain)
Pervious pavement in bikeway
Inlet within bikeway
Inlet within bikeway and curb cut for roadway drainage

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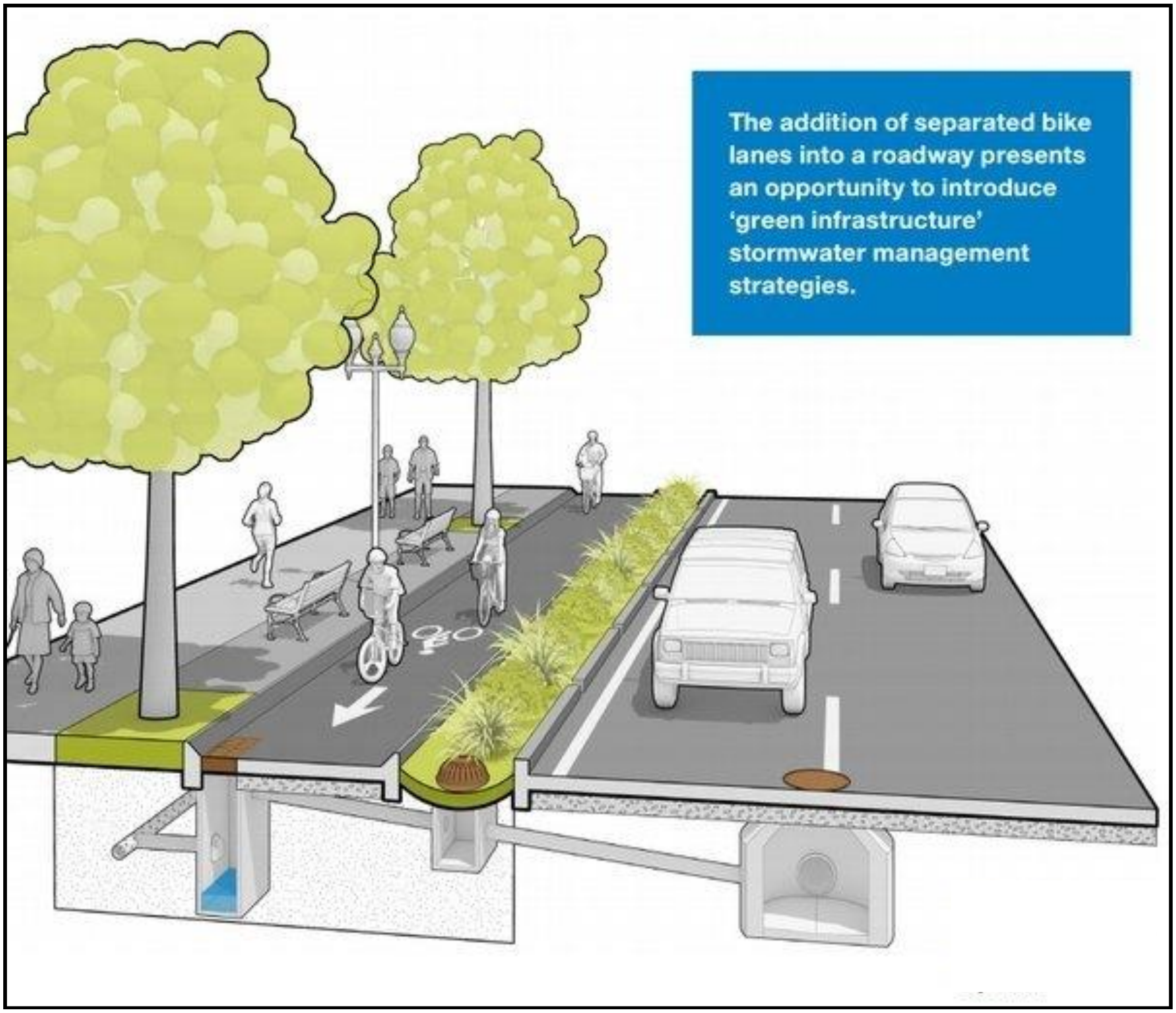
[73] MassDOT, 2015
[74] NACTO, 2017
[75] FHWA, 2013

## *GSI Integrated Cycletracks*

Cycletracks providing GSI measures come in four varieties:

1. Stormwater Planter with Cycletracks
2. Stormwater Tree Well Filter with Cycletracks
3. Pervious Pavement with Cycletracks
4. Combinations of the above features

Figure 3-9 illustrates a cycletrack combined with a stormwater planter. It provides the highest level of safety for cyclist on an urban roadway with full separation from motor vehicles, room for street trees, separation and safety for pedestrians and stormwater treatment in the landscaped strip separating cyclists from cars.



The addition of separated bike lanes into a roadway presents an opportunity to introduce 'green infrastructure' stormwater management strategies.

*Figure 3-9. Cycletrack with stormwater planter. (Courtesy of massDOT)*

Figure 3-10 illustrates a stormwater tree well filter and cycletrack which integrates urban forestry with GSI and cycling by using stormwater tree well filters to separate motor vehicles and cyclists. Adding the use of suspended pavement systems can increase the soil volume by allowing for uncompacted soil to be placed under the bikeway, under the sidewalk or under the parking lane. Stormwater runoff can be treated in the open landscaped strips and/or under the pavement in an underground bioretention area with biotreatment soil media.

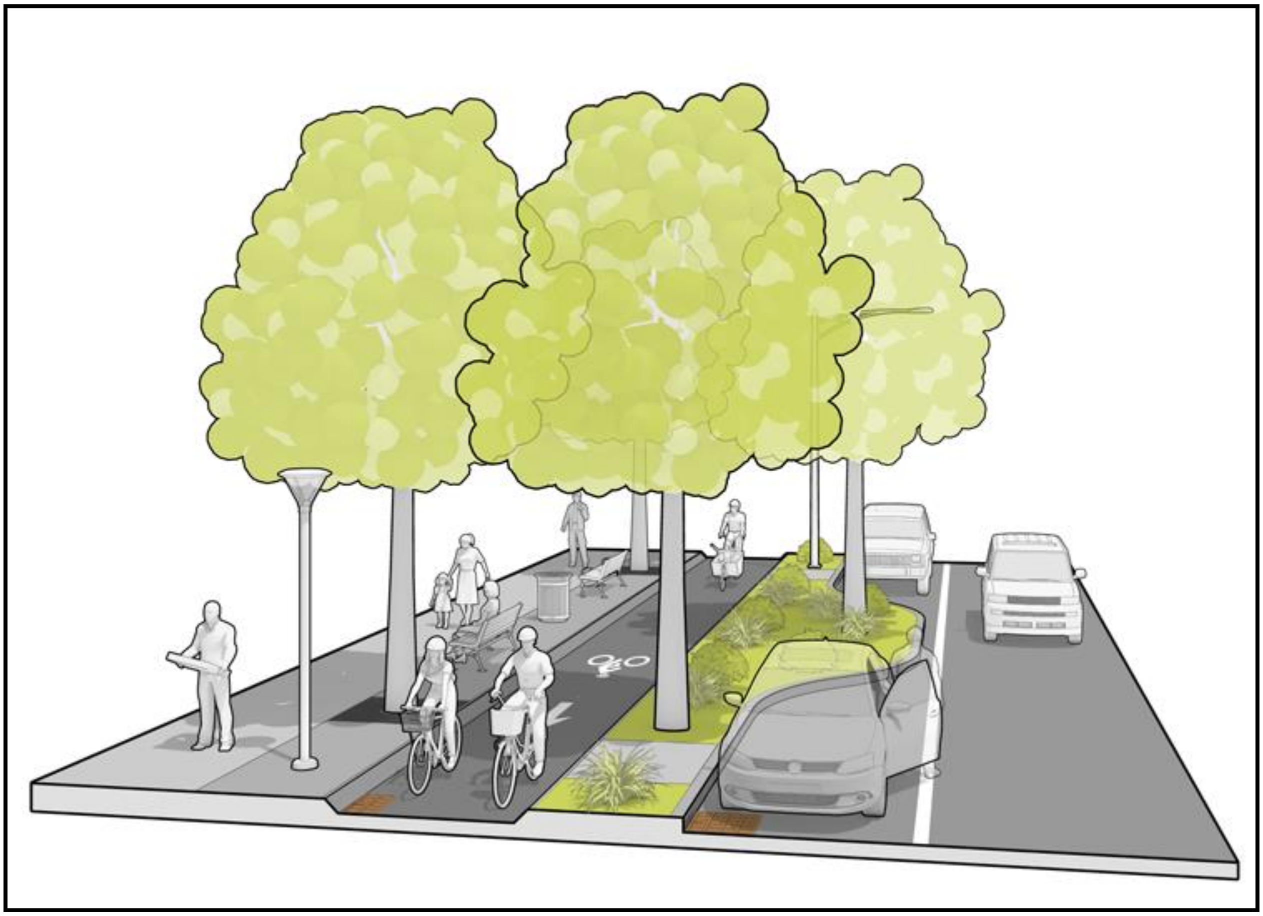


*Figure 3-10. Cycletrack with parking and stormwater tree well filters. (Courtesy of massDOT)*

Figures 3-11 illustrates the use of pervious pavement on a cycletrack which can improve the durability of the bikeway while allowing stormwater to infiltrate through the surface instead of running off into a landscaped area. For locations where soils are sufficiently permeable and where finding adequate space for stormwater planters may be difficult, pervious pavement cycletracks can be a good option. Figure 3-12 shows an example of pervious pavement usage on a Class III bikeway. While technically not a cycletrack because motor vehicles operate on the facility, the example shows similar design features.

*Figure 3-11. Two-way street level cycletrack with pervious pavement in Indianapolis. (Courtesy of NACTO Urban Stormwater Guide[76])*

Figure 3-12 also shows how bikeways can be combined with street trees and Silva Cells to provide a generous area for cyclists, pedestrians and urban forestry.

*Figure 3-12. One-way, class III bikeway with pervious pavement and Silva Cells for street tree planting in Bothell, WA. (Courtesy of DeepRoot GSI, LLC)*

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[76] NACTO, 2017

Paving roughness is often a concern of cyclists before a project with pervious pavement has been constructed, but the post-construction experience has generally exceeded expectations. The Berkeley pervious pavement project on Allston Way also had this experience with skateboarders, wheelchair users, cyclists and pedestrians generally expressing satisfaction with the pervious pavement surface smoothness. In fact, during a rain event, pervious pavement can provide a safer surface than traditional paving, as the water does not pond and contribute to hydroplaning.

Figure 3-13 provides an example of a cycletrack in Seattle with a suspended pavement system providing soil volume and stormwater treatment for the trees on either side of the facility.

*Figure 3-13. One-way, raised cycletrack with a suspended pavement system in Seattle (stormwater tree well filter with cycletrack). (Courtesy of DeepRoot GSI, LLC)*

## *Missed GSI Integration Opportunities with Cycletracks*

The cycletrack from Montreal in Figure 3-14 is an example of a standard cycletrack that could have included GSI systems. Options for GSI include: pervious pavement in the bikeway and sidewalk, bioretention landscaping in the area separating motor vehicles from the bikeway and/or bioretention in the area behind the adjacent sidewalk through the use of trench drains or relocation of the sidewalk.

*Figure 3-14. Cycletrack in Montreal on Chemin de la Côte Sainte Catherine with landscaping behind the adjacent sidewalk that could have been used for GSI measures. (Credit: dandyhorsemagazine.com)*

Raised planter boxes such as those in Figure 3-15 are often used instead of in-ground stormwater planters. The main reason for this is cost and flexibility. These treatments may be used as temporary measures to test cycletrack feasibility, but for permanent facilities, in-ground landscaping with curbs, curb cuts, boulders and/or other landscape features can provide a vertical barrier and GSI functions. Spaces between vehicles can be provided for motorists to exit.

*Figure 3-15. Moveable raised planter boxes can be used to test a new cycletrack installation such as this one in Vancouver on Hornby Lane. (Credit: https://commons.wikimedia.org)*

## 3.3.5 Cycling and Green Street Integration Approaches and Strategies

There are many projects in which it's possible to include GSI measures and improve cycling facilities at the same time. Some approaches to this topic are described below with specific strategies for including GSI in the project and corresponding examples of schematics, completed projects or possible retrofit opportunities.

### *Opportunistic Approach*

As various projects come through the preliminary design phase, those that are not specifically intended to implement GSI measures may still be analyzed for GSI implementation opportunities. This section relates to cycling facilities, but other programs and projects may also be analyzed in a similar way.

When possible, add GSI to a project where the primary focus is on improving cycling. There are many types of cycling infrastructure projects where GSI may increase the value of a project and/or can be added without significant modifications or cost. Sometimes GSI can even reduce the cost of the project by eliminating gray infrastructure components that are not needed when GSI is integrated into the design. Some of the most common integrated project opportunities are listed here:

- Reduction of excess impervious surface
- Street retrofits for beautification or urban greening
- Multi-modal modifications
- New roadway construction
- Public transportation facility Improvements

Excess impervious surface along existing streets can be converted to bikeways and include GSI measures. Urban greening projects can likewise reconsider the volume of traffic needed on a street and make changes to travel lanes such as striping that yields space on the side of the roadway for GSI measures. Tree planting projects can be modified to use tree filter systems and curb extensions to provide additional soil volume for the trees and can be used for traffic calming or roadway diverters.

Retrofits of existing roadways to increase multi-modal access can include GSI measures such as pervious pavement while new roadways provide an opportunity to take a holistic approach to roadway design to incorporate GSI measures and bicycle and pedestrian infrastructure.

## *Example Opportunistic Strategy*

Figure 3-16 provides an example of a cycletrack bend-out design that provides space for GSI measures in the resulting island area. This design was not intended as a GSI Measure, but any new paved area can be considered for stormwater treatment.

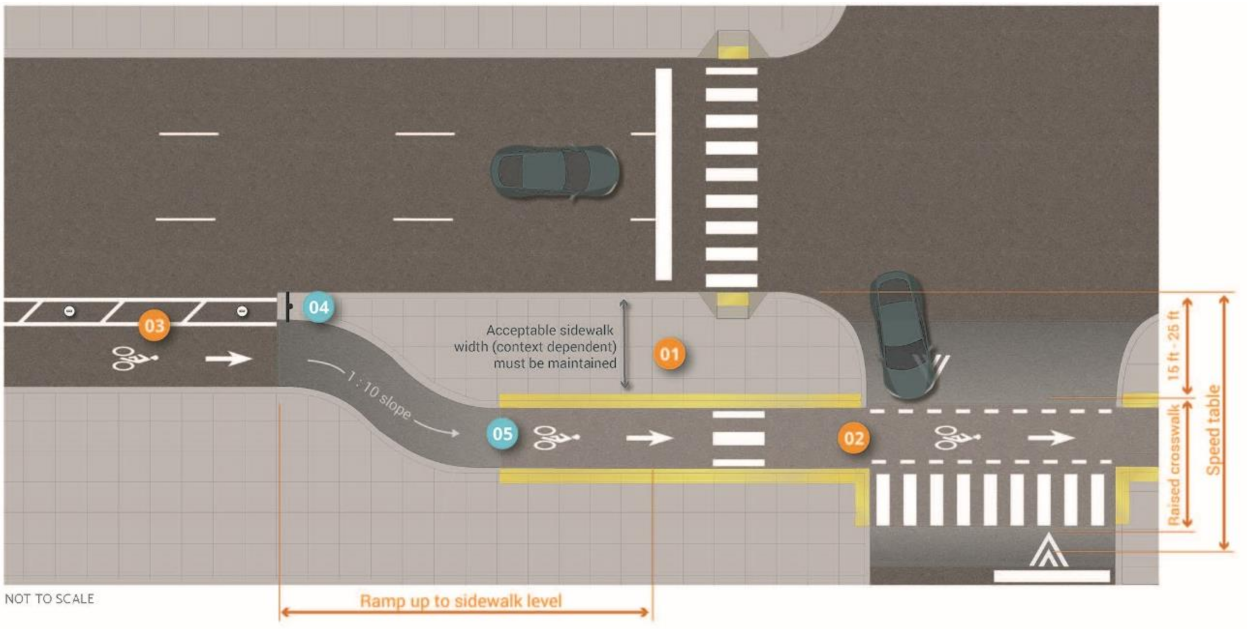

*Figure 3-16. Cycletrack with bend out design. (Courtesy of FHWA Separated Bike Lane Guide)*

## *Bicycle Plan Approach*

Bicycle Plans typically include a list of projects that the municipality plans to implement to enhance connectivity and provide greater access for bicyclists. A jurisdiction with an existing or proposed Bicycle Plan can integrate GSI measures into project descriptions in the plan and incorporate GSI policies into plan goals, policies, objectives and/or design standards. Bicycle projects often necessitate modifications to streets to add multi-modal functionality. These projects can be combined with GSI measures during the planning, development, or update process if addressed early on. Other municipal documents that can have bicycle-related GSI measures added include Urban Design Guidelines, Zoning Ordinances, General Plans, Climate Action Plans, Complete Streets Plans, and Sustainable Transportation Plans.

Typical cycling infrastructure projects in a Bicycle Plan that are good candidates for GSI measure inclusion include:

- Road diets
- Cycling safety improvements
- Bicycle parking area improvements
- Motor vehicle volume reduction on bikeways

## *Example Bicycle Plan Strategy*

In 2014, the City of Emeryville received a $500,000 grant from the Alameda County Transportation Commission to install a Class IV bikeway identified in the City's Bicycle Plan by removing a motor vehicle travel lane on Christie Ave, thus closing a critical gap in the SF Bay Trail. The separation between the motor vehicle roadway and the cycletrack is a stormwater planter (see Figure 3-17). The GSI element of the project gave it an added benefit that provided an edge over other projects when applying for the grant.

*Figure 3-17. Stormwater planter between cycletrack and roadway in Emeryville. (Credit: EOA)*

## *Workforce Development Approach*

Green jobs are a powerful and popular motivator for capital improvement projects. The public sometimes values employment opportunities over water quality objectives, so highlighting the green jobs aspect of any capital improvement project can improve the public's appreciation of it. Some projects types to consider for this approach are:

- Multi-benefit projects
- Urban forestry projects

## *Example Workforce Strategy*

Prince Georges County, Maryland has developed a 30-year public private partnership to create green jobs by constructing GSI measures. In the marketing of the program, green job creation and GSI installation are the primary goals, even though the funding for program comes from leveraging the County's stormwater fee. Cycling infrastructure improvements could be a part of the plan, integrating another benefit to the program and increasing its popularity. When the street is being torn up to add GSI measures, it can be an opportune time to also add cycling infrastructure.

### 3.3.6 Cycling and GSI Integration Design Tools

The City of San Diego developed an Urban Greening Plan for the City Heights section of the City[77]. Part of the plan includes several matrices of components for retrofitting streets. Figures 3-18 and 3-19 provide the matrices for cycling elements and stormwater elements. The matrix for each type of street element organizes in a concise and visual manner many of the tools that are available to the designer for improving cyclist and stormwater infrastructure. Combining the tools from both provides an excellent starting point for the early stage of project design.

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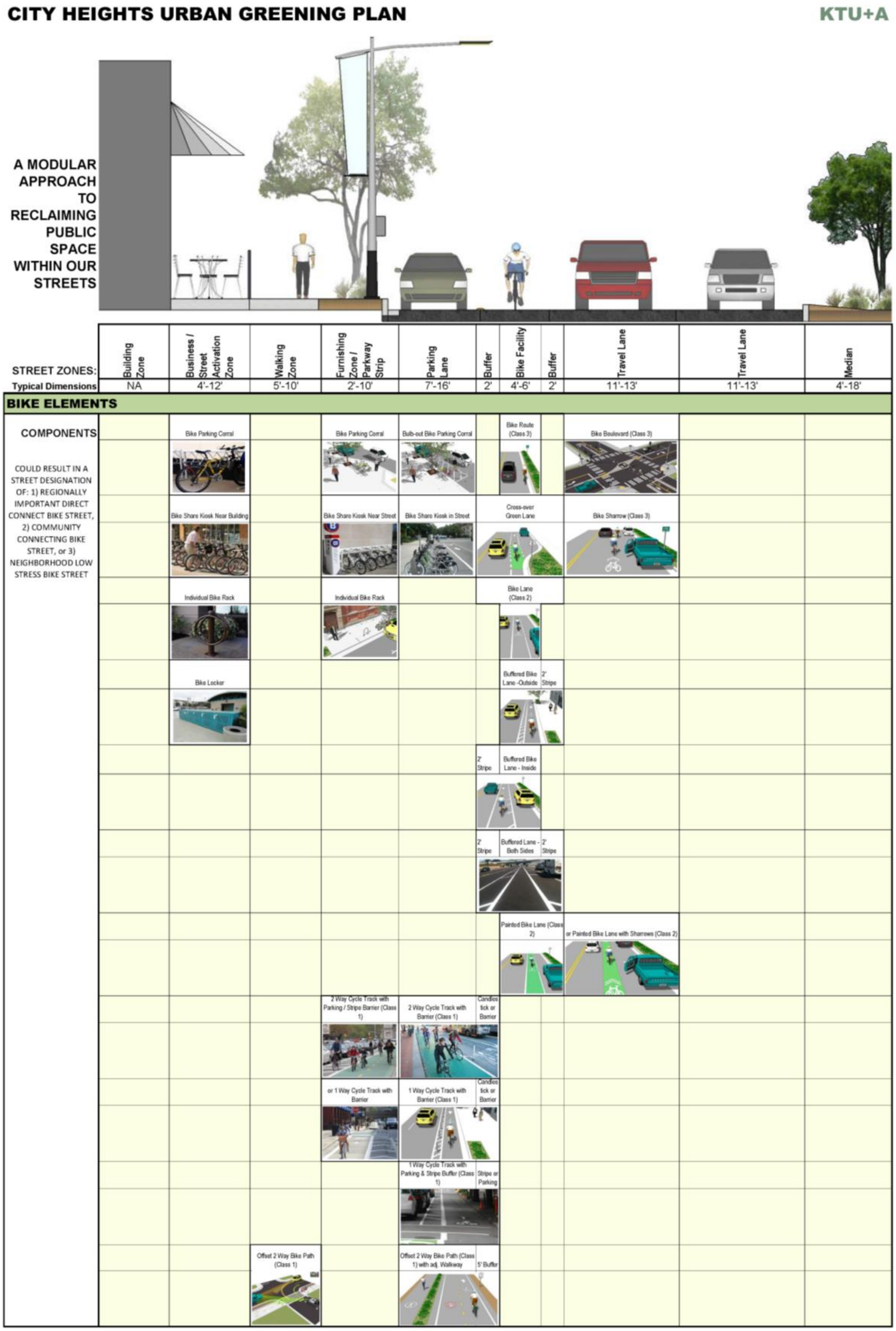
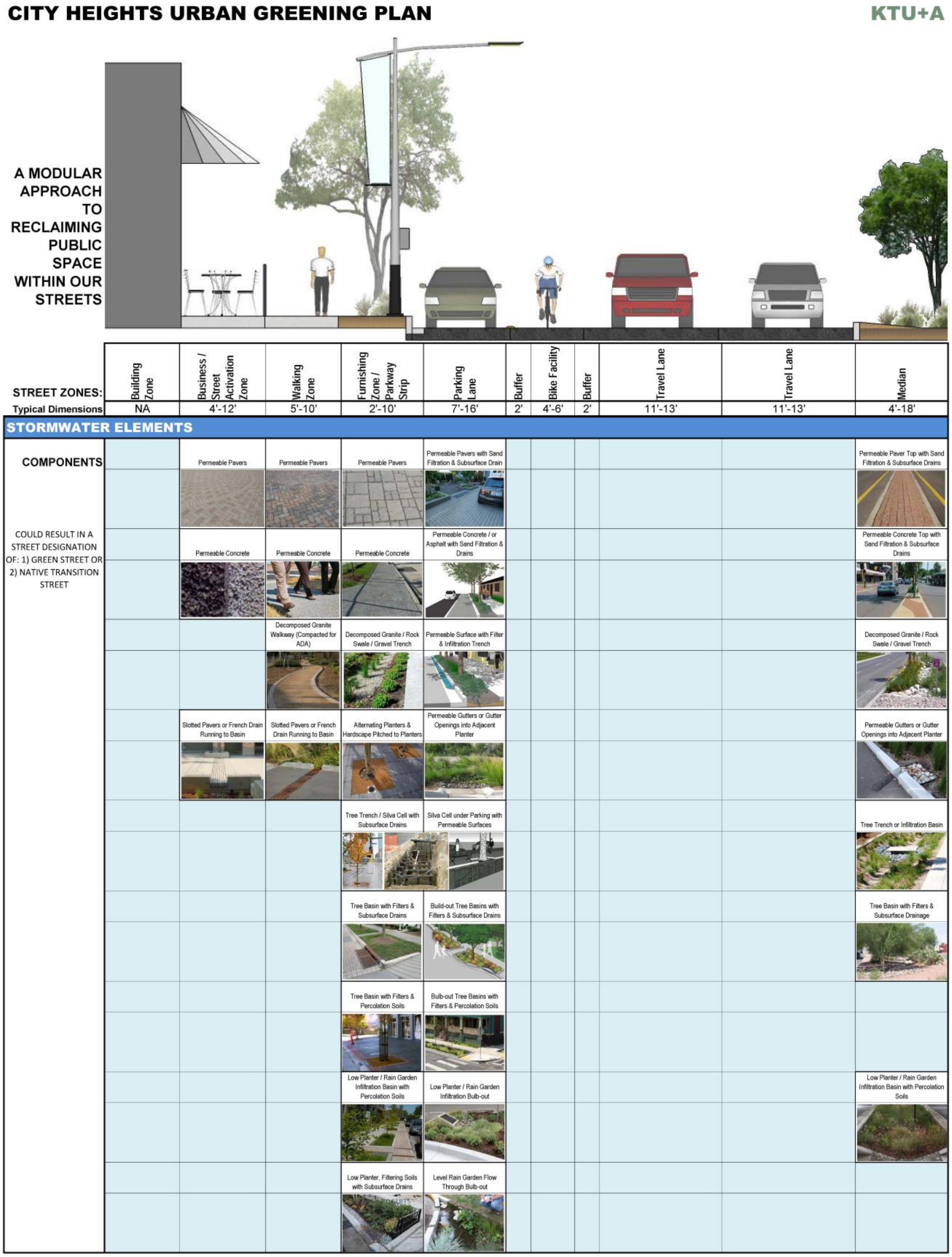
[77] City of San Diego, 2014



| STREET ZONES: | Building Zone | Business / Street Activation Zone | Walking Zone | Furnishing Zone / Parkway Strip | Parking Lane | Buffer | Bike Facility | Buffer | Travel Lane | Travel Lane | Median |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Typical Dimensions | NA | 4'-12' | 5'-10' | 2'-10' | 7'-16' | 2' | 4'-6' | 2' | 11'-13' | 11'-13' | 4'-18' |
| **BIKE ELEMENTS** | | | | | | | | | | | |
| COMPONENTS | | Bike Parking Corral | | Bike Parking Corral | Bulb-out Bike Parking Corral | | Bike Route (Class 3) | | Bike Boulevard (Class 3) | | |
| COULD RESULT IN A STREET DESIGNATION OF: 1) REGIONALLY IMPORTANT DIRECT CONNECT BIKE STREET, 2) COMMUNITY CONNECTING BIKE STREET, or 3) NEIGHBORHOOD LOW STRESS BIKE STREET | | Bike Share Kiosk Near Building | | Bike Share Kiosk Near Street | Bike Share Kiosk in Street | | Cross-over Green Lane | | Bike Sharrow (Class 3) | | |
| | | Individual Bike Rack | | Individual Bike Rack | | | Bike Lane (Class 2) | | | | |
| | | Bike Locker | | | | | Buffered Bike Lane -Outside | 2' Stripe | | | |
| | | | | | | 2' Stripe | Buffered Bike Lane - Inside | | | | |
| | | | | | | 2' Stripe | Buffered Lane - Both Sides | 2' Stripe | | | |
| | | | | | | | Painted Bike Lane (Class 2) | | or Painted Bike Lane with Sharrows (Class 2) | | |
| | | | | 2 Way Cycle Track with Parking / Stripe Barrier (Class 1) | 2 Way Cycle Track with Barrier (Class 1) | Candlestick or Barrier | | | | | |
| | | | | or 1 Way Cycle Track with Barrier | 1 Way Cycle Track with Barrier (Class 1) | Candlestick or Barrier | | | | | |
| | | | | | 1 Way Cycle Track with Parking & Stripe Buffer (Class 1) | Stripe or Parking | | | | | |
| | | | Offset 2 Way Bike Path (Class 1) | | Offset 2 Way Bike Path (Class 1) with adj. Walkway | 5' Buffer | | | | | |

*Figure 3-18. City Heights Urban Greening Plan – Bike Elements. (Courtesy of City of San Diego and KTU+A)*



| STREET ZONES: | Building Zone | Business / Street Activation Zone | Walking Zone | Furnishing Zone / Parkway Strip | Parking Lane | Buffer | Bike Facility | Buffer | Travel Lane | Travel Lane | Median |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Typical Dimensions | NA | 4'-12' | 5'-10' | 2'-10' | 7'-16' | 2' | 4'-6' | 2' | 11'-13' | 11'-13' | 4'-18' |
| **COMPONENTS** |  | Permeable Pavers | Permeable Pavers | Permeable Pavers | Permeable Pavers with Sand Filtration & Subsurface Drain |  |  |  |  |  | Permeable Paver Top with Sand Filtration & Subsurface Drains |
| COULD RESULT IN A STREET DESIGNATION OF: 1) GREEN STREET OR 2) NATIVE TRANSITION STREET |  | Permeable Concrete | Permeable Concrete | Permeable Concrete | Permeable Concrete / or Asphalt with Sand Filtration & Drains |  |  |  |  |  | Permeable Concrete Top with Sand Filtration & Subsurface Drains |
|  |  |  | Decomposed Granite Walkway (Compacted for ADA) | Decomposed Granite / Rock Swale / Gravel Trench | Permeable Surface with Filter & Infiltration Trench |  |  |  |  |  | Decomposed Granite / Rock Swale / Gravel Trench |
|  |  | Slotted Pavers or French Drain Running to Basin | Slotted Pavers or French Drain Running to Basin | Alternating Planters & Hardscape Pitched to Planters | Permeable Gutters or Gutter Openings into Adjacent Planter |  |  |  |  |  | Permeable Gutters or Gutter Openings into Adjacent Planter |
|  |  |  |  | Tree Trench / Silva Cell with Subsurface Drains | Silva Cell under Parking with Permeable Surfaces |  |  |  |  |  | Tree Trench or Infiltration Basin |
|  |  |  |  | Tree Basin with Filters & Subsurface Drains | Build-out Tree Basins with Filters & Subsurface Drains |  |  |  |  |  | Tree Basin with Filters & Subsurface Drainage |
|  |  |  |  | Tree Basin with Filters & Percolation Soils | Bulb-out Tree Basins with Filters & Percolation Soils |  |  |  |  |  |  |
|  |  |  |  | Low Planter / Rain Garden Infiltration Basin with Percolation Soils | Low Planter / Rain Garden Infiltration Bulb-out |  |  |  |  |  | Low Planter / Rain Garden Infiltration Basin with Percolation Soils |
|  |  |  |  | Low Planter, Filtering Soils with Subsurface Drains | Level Rain Garden Flow Through Bulb-out |  |  |  |  |  |  |

*Figure 3-19. City Heights Urban Greening Plan - Stormwater Elements. (Courtesy of City of San Diego and KTU+A)*

# 3.4 Integration with Pedestrian Facilities

*Figure 3-20. Pervious pavement, Allston Way, City of Berkeley (left); stormwater curb extension, Hacienda Avenue, City of Campbell (right). (Credit: EOA)*

Over the last 30 years in the U.S., the safety of pedestrians and their access to transportation facilities and services has grown tremendously. Implementation of Title II and Title III of the Americans with Disabilities Act of 1990 (ADA) deeply changed the sectors of public transportation services accommodation and transportation facility design respectively. Similarly, a major tenet of the "complete streets" movement is the accommodation of all modes of travel in a safe, convenient and comfortable manner. Finally, the addition of green stormwater infrastructure and water quality concerns is a third wave of change in the transportation sector design realm. This section of the GSI Handbook deals with some of the issues that arise at the intersection of design for GSI and pedestrian facilities, services, and access. The images above from Berkeley and Campbell display successful pervious pavement and stormwater curb extension projects designed with the needs of all members of society in mind.

As roadway designs move towards multi-modal transportation systems, pedestrian facilities often benefit; but safety and accessibility of those systems in relation to GSI is a new field that needs attention. When roadway designers attempt to re-think how streets and sidewalks are designed, constructed, operated and maintained to incorporate sustainable stormwater systems, ADA requirements and the needs of pedestrians should be thoroughly considered. For example, public transportation service providers can consider GSI in the design of bus stops and transit hubs.

Transportation engineers typically use a model called level of service (LOS) to determine the effectiveness of roadway design. The LOS model only accounts for the delays caused to vehicles at an intersection. A new model for determining the effectiveness of a roadway design is the vehicle miles traveled (VMT) per capita model. This takes into account other modes of transportation that move people such as public transportation, walking and cycling. VMT levels are lower in communities that are more walkable and compact and in communities that have strong public transportation systems[78]. VMT per capita data can be used to track effects of implemented policies and strategies. The images in Figure 3-21 are a classic visualization of how much space single-occupancy automobiles use in our cities compared with cycling or transit and the efficiency of other modes of travel for humans:

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[78] www.transportation.gov/mission/health/vmt-capita 2/2/2016

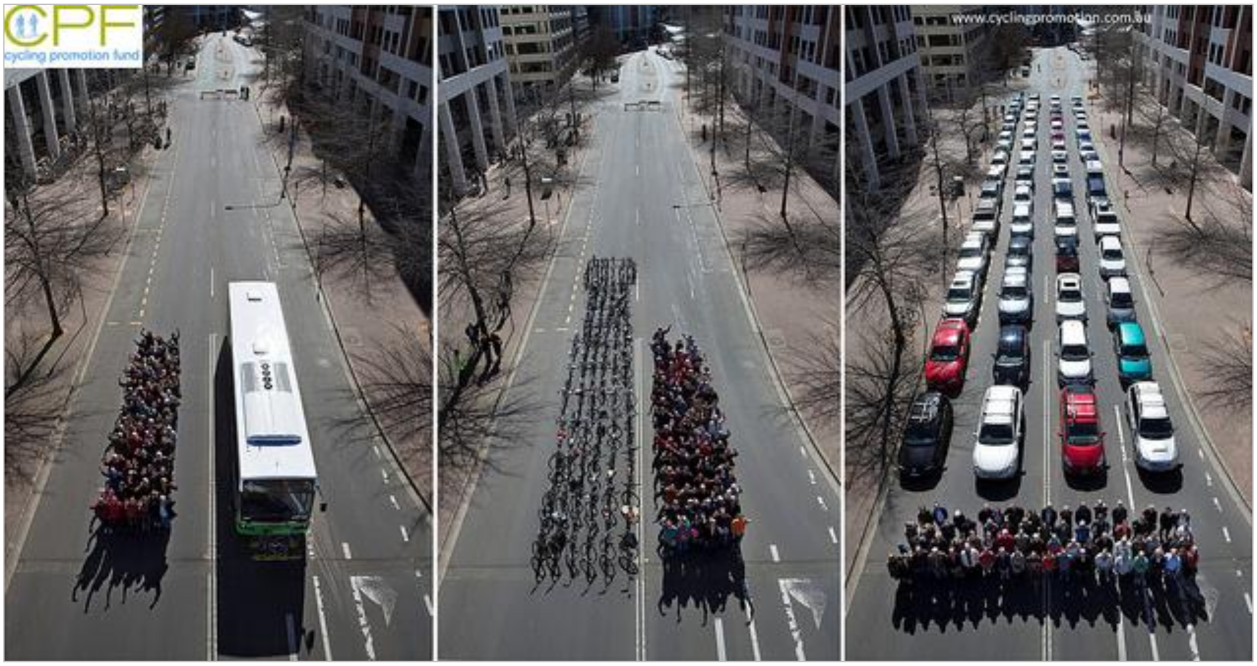

*Figure 3-21. Comparison of pedestrians in various modes of transportation. (Credit: Cycling Promotion Fund)*

Everyone becomes a pedestrian at some point in their day. Pedestrians, both walking and rolling should be accommodated in that mode of travel. Guidance for these situations and others is provided below.

There are many resources for developing a basis of design for pedestrian facilities, but ones that address the integration of stormwater and pedestrian systems are few. As described in Section 3.2, NACTO has created two design guides that provide guidance on the combining of active transportation systems and stormwater techniques (the Urban Street Design Guide and Urban Street Stormwater Design Guide[79]). Other resources include the Federal ADA design manual[80], CAMUTCD[81], AASHTO “Green Book”[82], and local design standards.

## 3.4.1 Pedestrian Infrastructure Typologies

It is important to consider the many types of pedestrian facilities that can be reimagined through a complete/green street lens:

- Sidewalks
- Roadway shoulders
- Paseos, plazas and parklets
- Public transit boarding areas
- Intersection treatments
- Midblock crossings
- Alleys, lanes, trails and multi-use paths
- Pedestrian-only streets and woonerfs

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[79] NACTO, 2013 and NACTO, 2017
[80] Department of Justice, 2010
[81] CA DOT, 2014
[82] AASHTO, 2001

- Bridges, stairs, ramps, stoops and elevators
- Building entrances, parking lots and driveways

Including GSI in some of the infrastructure types listed above may or may not require significant design changes; however, anywhere that exterior pavement and landscaping are installed there is typically an opportunity to consider modifications to a standard gray infrastructure design. Under some circumstances, integration with GSI can cost less than using gray infrastructure alone.

Some examples of green stormwater infrastructure measures implemented on a typical streetscape are shown in Figure 3-22 from the City of Wichita.

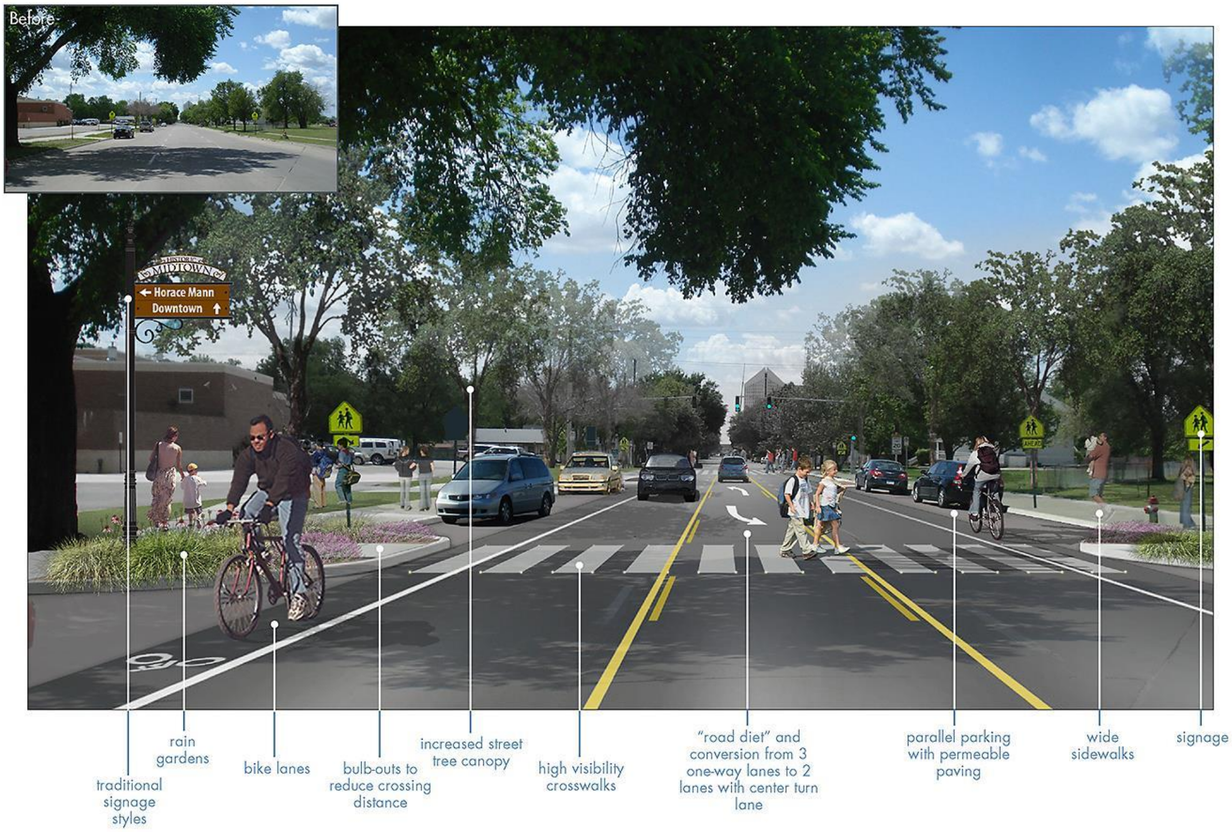


*Figure 3-22. Midtown Wichita, 2013, before and after streetscape visualization. (Credit: aslacentralstates.org)*

## 3.4.2 Integrating Stormwater Curb Extensions and Pedestrian Facilities

All of the concepts shown in Figure 3-22 have an impact on the pedestrian realm, but for integration with GSI, the combination of "bioretention" within the "bulb-out" (termed a "stormwater curb extension" in this Handbook) is possibly the most commonly used system in the San Francisco Bay Area. Stormwater curb extensions are popular for effectively addressing both pedestrian safety and GSI, since they reduce the street crossing distance, provide better visibility for people in crosswalks and create space for a landscape area. Instead of installing a typical mounded-up landscaped area, the landscaped area can be depressed and with some additional design modifications, become a bioretention system. Most of the streets in the Bay Area are crowned in the center of the street with the gutters on the outside edges so curb extensions are located where stormwater naturally flows. A stormwater curb extension can also be one of the easiest and lowest cost measures for retrofitting existing street drainage systems due to the minimal amount of new concrete forming needed and the relatively small footprint of the system. Therefore, this section of the GSI Handbook will focus primarily on stormwater curb extensions: different types, design parameters, and various factors to consider when locating, constructing and maintaining them.

## *Curb Extension Typologies*

Curb extensions come in a large variety of shapes, sizes and styles. Some of the many criteria that define curb extension designs include location, curb ramp design, curb design, signalization and traffic control, drainage design, crosswalk height, hardscape surface type, and landscaped surface type. Examples of each of these criteria are listed below:

### Location

- Midblock
- Intersection
- Gateway (At intersection of residential and collector/arterial)
- Transit Stop

### Ramp Design

- Single curb ramp
- Dual curb ramp

### Curb Design

- Raised curb
- Flush curb
- Rolled curb
- Angled curb

### Signalization and Traffic Control

- Uncontrolled
- Stop controlled
- Signalized
- Pedestrian activated signal (walk signal is not default)
- Automatic crossing signal (walk signal is default)
- Pedestrian detection activated signal (microwave detection)

### Drainage Design

- Trench drain through curb extension
- Curb cut or inlet into stormwater treatment system
- Standard drain inlet or catch basin

### Crosswalk Height

- Raised crossing
- Street level crossing

### Hardscaped Surface

- Pervious pavement
- Impervious

### Landscaped Surface

- Non-stormwater treatment landscape
  - Street tree
  - Small plants
  - Turf
  - Synthetic turf
- Stormwater treatment landscape
  - Tree filter
  - Small plant bioretention
  - Turf bioretention

Six examples of different types of curb extensions are shown in Figures 3-23 to 3-28.

*Figure 3-23. Signalized intersection with dual-ramp, raised curb, street-level crossing, impervious hardscape, and standard curb extension in San Francisco. (Credit: Google Street View)*

*Figure 3-24. Uncontrolled midblock crossing with raised curb, street-level crossing, non-functional turf landscape, and standard curb extension in British Columbia. (Credit: Richard Drdul, Wikimedia)*

*Figure 3-25. Stop-controlled intersection with dual-ramp, raised crossing, and stormwater curb extension in San Francisco. (Credit: EOA)*

*Figure 3-26. Partial stop-controlled T-intersection with flush curb, single-ramp, street-level crossing, and stormwater curb extension in Campbell (Credit: EOA)*

*Figure 3-27. Stop-controlled intersection with dual ramp, raised curb, street-level crossing, and standard curb extension with trench drain in Emeryville. (Credit: Google maps)*

*Figure 3-28. Midblock transit stop with pervious pavement and stormwater curb extension in Castro Valley. (Credit: Google Street View)*

From the stormwater perspective, two of the most important criteria are underlying soil permeability and catchment area. Adding these criteria to those for standard curb extensions will begin to shape the size of the stormwater curb extension needed and hence the feasibility and final design of the stormwater curb extension system for each street situation.

### *Pedestrian Benefits of Stormwater Curb Extensions*

There are several benefits of standard curb extensions for pedestrians:

- Physical separation of pedestrians from street
- Maintains full sidewalk area
- Shortened unprotected crossing distances at intersections
- Slower motor vehicles and calming of traffic

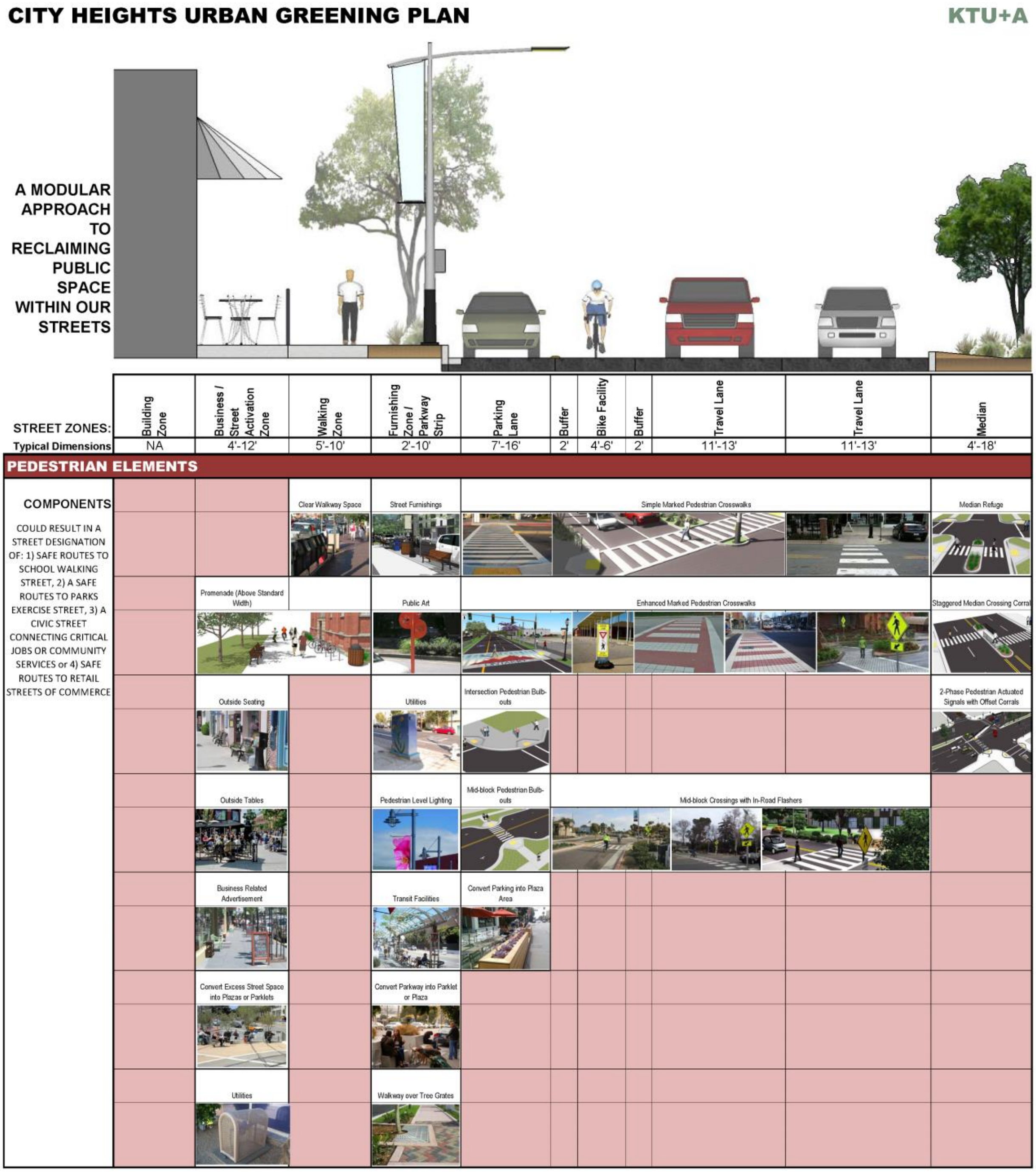
Integrating GSI into a standard curb extension adds these benefits for pedestrians:

- Shade from tree filters
- Cooler pavement from pervious pavement
- Cooler air from biotreatment landscapes
- Urban greening and improvement of the street environment

## 3.4.3 Pedestrian and Green Street Integration Approaches and Strategies

The City of San Diego put together several matrices of components for retrofitting streets. Figures 3-29 and 3-30 contain the matrices for pedestrian elements and stormwater elements. The matrix for each type of street element organizes in a concise and visual manner many of the tools that are available to the designer for improving pedestrian and stormwater infrastructure. Combining the tools from both provides an excellent starting point for the early stage of project design.

Different approaches to integrate GSI with pedestrian infrastructure are discussed in this section. For each approach, a corresponding example of a strategy to achieve the GSI integration is described. The costs for each approach and strategy will vary depending on the extent of integration and cost calculation methodology (e.g., capital cost vs. life-cycle analysis).



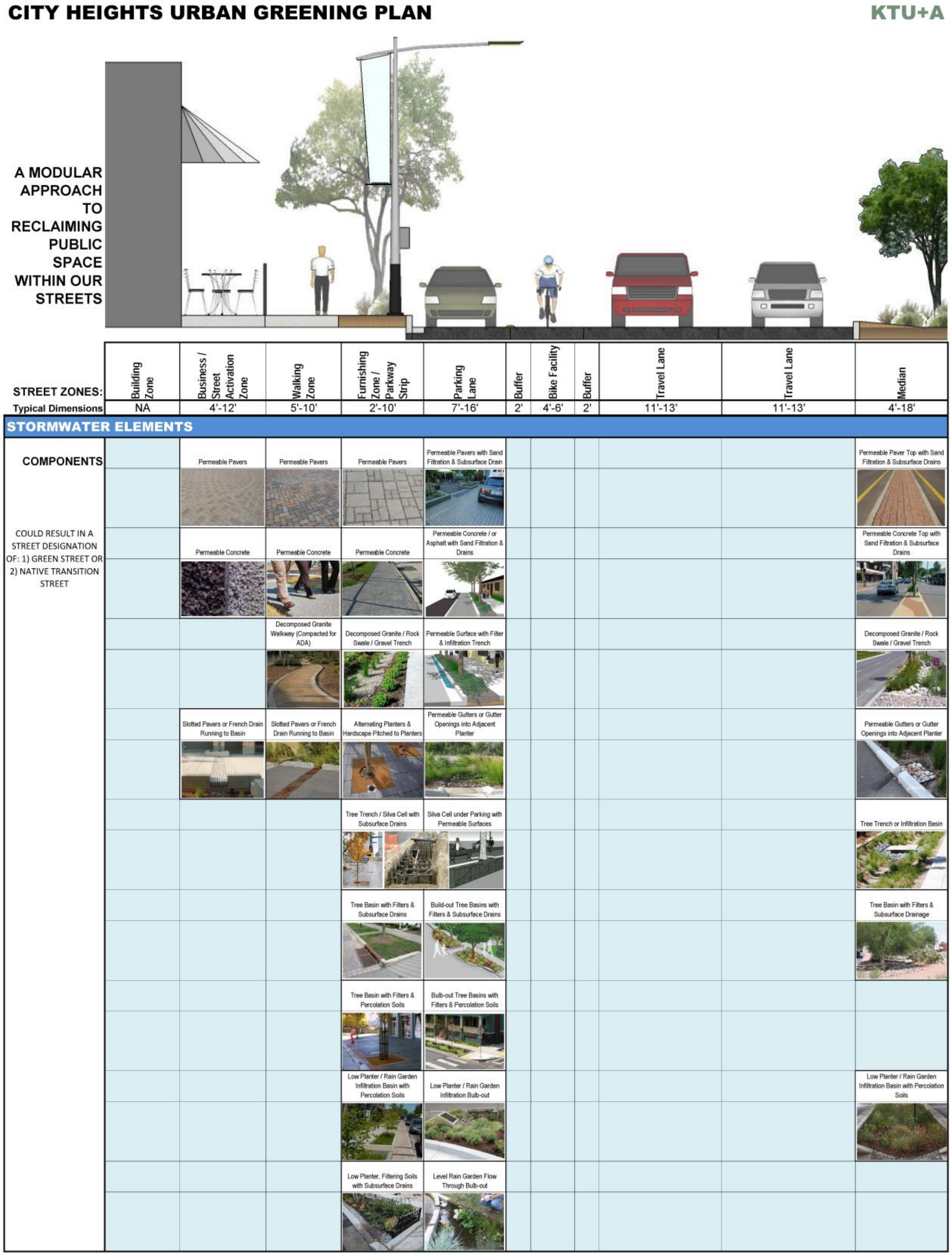
**CITY HEIGHTS URBAN GREENING PLAN**

**KTU+A**

**A MODULAR APPROACH TO RECLAIMING PUBLIC SPACE WITHIN OUR STREETS**

| STREET ZONES: | Building Zone | Business / Street Activation Zone | Walking Zone | Furnishing Zone / Parkway Strip | Parking Lane | Buffer | Bike Facility | Buffer | Travel Lane | Travel Lane | Median |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Typical Dimensions** | NA | 4'-12' | 5'-10' | 2'-10' | 7'-16' | 2' | 4'-6' | 2' | 11'-13' | 11'-13' | 4'-18' |
| **PEDESTRIAN ELEMENTS** | | | | | | | | | | | |
| **COMPONENTS**<br>COULD RESULT IN A STREET DESIGNATION OF: 1) SAFE ROUTES TO SCHOOL WALKING STREET, 2) A SAFE ROUTES TO PARKS EXERCISE STREET, 3) A CIVIC STREET CONNECTING CRITICAL JOBS OR COMMUNITY SERVICES or 4) SAFE ROUTES TO RETAIL STREETS OF COMMERCE | | | Clear Walkway Space | Street Furnishings | Simple Marked Pedestrian Crosswalks | | | | | | Median Refuge |
| | | Promenade (Above Standard Width) | | Public Art | Enhanced Marked Pedestrian Crosswalks | | | | | | Staggered Median Crossing Corral |
| | | Outside Seating | | Utilities | Intersection Pedestrian Bulb-outs | | | | | | 2-Phase Pedestrian Actuated Signals with Offset Corrals |
| | | Outside Tables | | Pedestrian Level Lighting | Mid-block Pedestrian Bulb-outs | Mid-block Crossings with In-Road Flashers | | | | | |
| | | Business Related Advertisement | | Transit Facilities | Convert Parking into Plaza Area | | | | | | |
| | | Convert Excess Street Space into Plazas or Parklets | | Convert Parkway into Parklet or Plaza | | | | | | | |
| | | Utilities | | Walkway over Tree Grates | | | | | | | |

*Figure 3-29. City Heights Urban Greening Plan Modular Approach – Pedestrian Elements. (Courtesy of City of San Diego and KTU+A)*



| STREET ZONES: | Building Zone | Business / Street Activation Zone | Walking Zone | Furnishing Zone / Parkway Strip | Parking Lane | Buffer | Bike Facility | Buffer | Travel Lane | Travel Lane | Median |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Typical Dimensions | NA | 4'-12' | 5'-10' | 2'-10' | 7'-16' | 2' | 4'-6' | 2' | 11'-13' | 11'-13' | 4'-18' |
| **STORMWATER ELEMENTS** | | | | | | | | | | | |
| COMPONENTS | | Permeable Pavers | Permeable Pavers | Permeable Pavers | Permeable Pavers with Sand Filtration & Subsurface Drain | | | | | | Permeable Paver Top with Sand Filtration & Subsurface Drains |
| COULD RESULT IN A STREET DESIGNATION OF: 1) GREEN STREET OR 2) NATIVE TRANSITION STREET | | Permeable Concrete | Permeable Concrete | Permeable Concrete | Permeable Concrete / or Asphalt with Sand Filtration & Drains | | | | | | Permeable Concrete Top with Sand Filtration & Subsurface Drains |
| | | | Decomposed Granite Walkway (Compacted for ADA) | Decomposed Granite / Rock Swale / Gravel Trench | Permeable Surface with Filter & Infiltration Trench | | | | | | Decomposed Granite / Rock Swale / Gravel Trench |
| | | Slotted Pavers or French Drain Running to Basin | Slotted Pavers or French Drain Running to Basin | Alternating Planters & Hardscape Pitched to Planters | Permeable Gutters or Gutter Openings into Adjacent Planter | | | | | | Permeable Gutters or Gutter Openings into Adjacent Planter |
| | | | | Tree Trench / Silva Cell with Subsurface Drains | Silva Cell under Parking with Permeable Surfaces | | | | | | Tree Trench or Infiltration Basin |
| | | | | Tree Basin with Filters & Subsurface Drains | Build-out Tree Basins with Filters & Subsurface Drains | | | | | | Tree Basin with Filters & Subsurface Drainage |
| | | | | Tree Basin with Filters & Percolation Soils | Bulb-out Tree Basins with Filters & Percolation Soils | | | | | | |
| | | | | Low Planter / Rain Garden Infiltration Basin with Percolation Soils | Low Planter / Rain Garden Infiltration Bulb-out | | | | | | Low Planter / Rain Garden Infiltration Basin with Percolation Soils |
| | | | | Low Planter, Filtering Soils with Subsurface Drains | Level Rain Garden Flow Through Bulb-out | | | | | | |

*Figure 3-30. City Heights Urban Greening Plan Modular Approach – Stormwater Elements. (Courtesy of City of San Diego and KTU+A)*

## Opportunistic Implementation

When possible, add GSI to a project where the primary focus is related to a specific type of pedestrian facility. There are many types of pedestrian infrastructure projects where GSI may increase the value of a project and/or can be added without significant modifications or cost. Sometimes GSI can even reduce the cost of the project by eliminating gray infrastructure components that are not needed when GSI is integrated into the design. Some of the most common pedestrian-related project types are listed here:

- Street retrofits for beautification or urban greening
- Pedestrian safety improvements, such as for Safe Routes to School
- Road diets (vehicle lane reduction and/or narrowing)
- Public transportation facility improvements
- Roadway and sidewalk construction or rehabilitation
- Street tree planting and maintenance projects
- Park construction and upgrade projects
- Car and bicycle parking projects with pedestrian passage elements

### *Example Strategy*

A parking lot for cars is being upgraded to comply with ADA requirements. As part of the non-C.3-regulated project, it has been determined that the landscaping may also need replacement. Several sections of the parking lot, near the low points in the respective sub-drainage areas, are found to be easily retrofitted with stormwater planters and stormwater tree well filters. The project will work around any existing trees that are determined to be in good condition and high performing. Figure 3-31 provides two examples of parking lots that could be retrofitted by adding low cost bioretention features to the ADA project. An additional consideration would be to substitute Bay-Friendly landscaping for turf which typically lowers the maintenance cost by 50%. The new design should take into consideration the existing trees and work around and with them where possible to incorporate their benefits.

*Figure 3-31. Parking lots that could be easily retrofitted with GSI measures in El Cerrito & Emeryville (Credit: EOA)*

## Plan Integration

A jurisdiction with a Pedestrian Plan or ADA Compliance Plan can integrate GSI measures into any project descriptions in the plan and incorporate GSI policies into goals, objectives and design standards. Multi-modal modifications (addition of, or changes to, street facilities) to streets called out in the Pedestrian Plan can be combined with GSI measures during the planning process. Other municipal documents that can have pedestrian-related GSI measures added include Urban Forest Master Plans, Urban Design Guidelines, Zoning Ordinances, General Plans, Climate Action Plans, Sustainable Transportation Plans and Park Master Plans.

*Example Strategy:*
Stacking benefits of GSI with pedestrian improvements in integrated systems can yield results greater than the parts individually. For example, planting street trees in the right location in a GSI design can shade pedestrian walkways and simultaneously reduce potable water irrigation by utilizing stormwater from the street. Visualized renderings of street retrofits are an effective way of communicating to the public and decision-makers the benefits of an integrated complete and green street. Figure 3-32 from the City of Philadelphia's Water Department (PWD) Green Street Manual[83] provides before and after images of an urban arterial street with the addition of stormwater curb extensions and tree filters.

*Figure 3-32. Street visualization with addition of stormwater curb extensions & tree filters. (Courtesy of PWD)*

## Water Quality Goals

Pedestrian infrastructure and water quality goals, such as reduction of PCB and mercury concentrations, can be utilized together in prioritization mechanisms for projects to comply with the Municipal Regional Stormwater Permit (MRP)[84].

*Example Strategy:*
A private, regulated project in Emeryville needed to use alternative compliance to meet the MRP requirements. In working with the City to find suitable locations, old industrial properties were of interest as projects in old industrial areas can obtain higher PCB load reduction crediting. Pedestrian infrastructure in old industrial areas is often substandard and can be integrated with GSI measures to provide a site with multiple benefits for the alternative compliance project. Figure 3-33 displays one of the initial locations that was evaluated. The sidewalk clear width could be improved in combination with GSI measures such as stormwater tree well filters or stormwater curb extensions. Large street trees in good condition would be avoided and other locations such as behind the sidewalk in the street and adjacent to the fire hydrant where a young tree is located were proposed for GSI measures.

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[83] Philadelphia, 2014
[84] CA RWQCB, 2015

*Figure 3-33. Sidewalk with potential for widening and installation of stormwater tree well filters in Emeryville. (Credit: Google Street View)*

## Traffic Calming

Increasing pedestrian safety can also be achieved by reducing vehicle speeds, also referred to as "traffic calming". The NACTO guide[85] (See Section 3.2) recommends using various types of curb extensions to reduce speed. These can take the form of transit stops, chicanes, pinchpoints and gateways. Figure 3-34 provides graphical illustrations of each of these four measures.

*Example Strategy:*

Use curb extension concepts in Safe Routes to School, transit and parks projects. Any type of curb extension can also be converted to a stormwater curb extension as demonstrated in Figure 3-35 (identified as such with curb cuts). Additionally, pervious pavement can be used for the non-landscaped portion of a curb extension such as at a transit stop.

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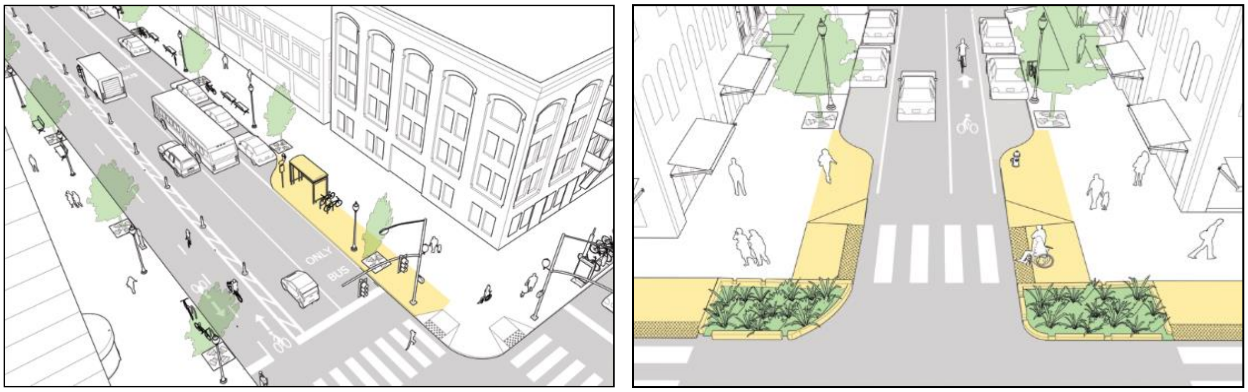
[85] NACTO, 2013

Chicane

Pinchpoint



Bus Curb Extension

Gateway

*Figure 3-34. Traffic calming strategies with potential for GSI integration. (Courtesy of NACTO's Urban Street Design Guide)*

*Figure 3-35. Laurel Elementary School, City of San Mateo, Safe Routes to School project includes stormwater curb extension. (Credit: EOA)*

### 3.4.4 ADA Issues in GSI Design

From an ADA perspective, the most important features of a pedestrian facility are the ability of all pedestrians – both walking and rolling – to access the system easily and safely. Considerations for design of green streets to accommodate pedestrians and ADA requirements include:

- Safety
    - Intersection and driveways
        - Warning and detection systems
        - Roadway crossings
        - Signal and crossing device location
    - Landscapes
        - Excessive system ponding depth
        - Prevention of tree root pavement heaving
        - Slopes within unprotected stormwater planters as trip and fall hazards
    - Pavement quality
        - Paving roughness and slope
        - Paving joint gaps/space
    - Path of travel
        - From on-street parking lane to sidewalk
        - From parking area in parking lot to sidewalk or building entrance
    - Low light situations
        - Excessive distance to existing lights
        - Lack of lighting infrastructure
        - Low wattage lighting
        - Upturned or other lighting directed away from the system
    - Vision impaired communities
        - Grade changes around bioretention areas
        - Grade changes within bioretention areas
        - Fencing and curbing around stormwater planters
        - Systems in the vicinity of senior housing or other possibly vision-impaired residential communities
- Accessibility
    - Vehicle and cycle parking
    - Vehicle and cycle loading and unloading
    - Public transit loading and unloading
    - Sidewalk clear widths
    - Curb ramp grades, length and interface with street

As landscapes are one of the primary features of GSI measures, there are several landscape related issues that can complicate the safety and access of pedestrians in integrated systems. For pedestrians exiting vehicles on roadways, a clear path of travel must be provided that is safe and close by. Specific design considerations for stormwater planter ADA issues are provided in Section 2.2.1.

A key issue concerning pervious pavements and pedestrian infrastructure is compliance with ADA standards. Considerations include paving roughness and slope and paver joint gaps. Experience in the Bay Area with various types of pervious pavements shows that, with proper selection of pavement material and design, these paving systems can comply with ADA and also provide stormwater benefits. Specific design considerations for pervious pavement ADA issues are provided in Section 2.2.2.

## 3.5 Utility Coordination

Utilities will often be present near proposed GSI measures locations within the public right-of-way, especially along existing streets. Some utilities may be found in the sidewalk realm in the parkway (e.g., streetlights and fire hydrants) or under the sidewalk in the walking zone. Other utilities run under the flexible realm of the street between the travel lanes and sidewalk curb or in medians. Joint trenches are often used for undergrounding of utilities. Vaults for utilities can take up considerable space and have lines coming in and out, often to the main lines under the flexible realm. Utilities may also be encountered as they extend laterally, across the sidewalk to private property. Utilities to look for include the following:

- Power lines and poles (underground and overhead)
- Communication lines and poles
- Internet and fiber-optic lines
- Gas lines laterals and meters
- Water mains, laterals, meters, valves, backflow preventers, and cathodic protection
- Sewer mains, service laterals, cleanouts, manholes, vaults and valves
- Streetlights, traffic signals, loop detectors, boxes and vaults
- Fire hydrants
- Joint trenches, transformers, vaults and boxes
- Irrigation meters, controllers, backflow preventers, sprinkler heads, and lines
- Storm drain catch basins, trench drains, inlets, pipes, cleanouts and manholes

In addition, typical right-of-way fixtures which may need to be relocated for the GSI design include:

- Parking meters
- Bicycle racks
- Street signs
- Street furniture

There are a number of concerns that must be addressed when considering GSI and utility coordination. However, the presence of utilities does not necessarily mean that GSI at a given location is infeasible.

One concern is the possibility of unexpectedly finding utilities during the construction phase. Conflicts can be costly for a project, both monetarily and in terms of scheduling. Identifying and planning for existing utilities prior to construction can prevent costly setbacks later. The first step in controlling for utility conflicts is to properly identify existing utilities when prioritizing potential GSI sites. Utilities can be found via as-built plans, site surveys, pot-holing, utility maps, and communication with utility companies.

Once a site has been selected, confirming the exact location, depth and (if possible) condition of utilities during the design phase can prevent redesigns or delays during construction. These existing utilities should be included on the site plan drawings. Note that the location, depth and dimensions shown on a plan may differ from the actual utility conditions at the site. It is often the case that older neighborhoods will have more differences between available utility plans and existing conditions, including abandoned utilities. The construction contractor will need to verify locations and depths at start of construction[86] and construction drawings should provide notification that the contractor should stop work and contact the appropriate parties when unanticipated utility locations or conditions are encountered[87]. The potential impact of a utility conflict to the project's design performance, cost, and schedule should be carefully evaluated during the planning and design development phases[88].

Utility agencies should be brought in as early as possible in the project and continue to be involved in the process from design phase through construction. The general approach when utilities are encountered is described in Section 3.5.1. Specific design guidance for individual utilities is described in Sections 3.5.2 through 3.5.7.

Another concern is how future maintenance on a buried utility located within a GSI measure footprint will be impacted. If a utility line needs to be accessed, the GSI measure may be temporarily disturbed or damaged. In discussions with utility agencies, it should be determined in advance who will be responsible for repairing and restoring the GSI measure to working condition, and how the utility owner will be informed that the area is a GSI measure and not traditional landscaping or hardscape. One common perception is that maintenance work on a utility within the footprint of a GSI measure will be more costly in the future, however, this is not necessarily the case. The SMCWPPP GI Design Guide[89] asserts that the use of pervious pavers and low-expenditure landscape stormwater facilities may actually "reduce the need for cutting and replacing concrete and asphalt and improve access to underground utilities". Utility providers and agencies could also develop new strategies that reduce the area of disturbance in the future or minimize the impact when a utility needs to be removed or replaced. These strategies include:

- Adding tracer wire on top of utility lines
- Replacing lines concurrently with the GSI and encasing the line in a larger conduit or adding a second conduit for future use
- Leaving a long segment of fiber that could be pulled at a later date

Another potential issue with having utilities within GSI measures is the migration of infiltrated stormwater along preferential flow paths within utility bedding and/or backfill material instead of moving vertically through the biotreatment soil and exiting the GSI measure through infiltration into native soils or an underdrain system. Also, requirements for utility protection are typically met through specified minimum depth for bedding and cover, which may conflict with the GSI measure location and sizing. These issues can often be addressed through design specifications such as impervious liners, anti-seep collars and utility sleeves.

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[86] SFPUC, 2016

[87] PWD, 2011

[88] SMCWPPP, 2019

[89] SMCWPPP, 2009

## 3.5.1 Approach to Utility Coordination

Existing utilities should not be disturbed whenever possible, but in an urban high-density residential or commercial area it is likely that this will not always be possible. For utilities identified and located at a proposed GSI site, there are four steps that a designer may take to work with the interfering utility:

Step 1 – Avoidance
Step 2 – Acceptance
Step 3 – Mitigation
Step 4 – Replacement[90]

Some utilities may not be allowed to be anywhere near standing water, while it may be acceptable for others if housed in a protective sleeve. It is necessary to with the utility provider to determine whether the specific interfering utility needs to be avoided completely. Allowances for specific utilities are included in Sections 3.5.2 to 3.5.7. However, it is important to identify and confirm all jurisdictional and utility owner standards and requirements for a specific site early in the design process.

Pre-design investigation includes finding the utilities by calling USA North (dial 811), and using pot-holing and/or sub-surface penetrating radar. The utility companies should be informed in advance about the project. They may have utility plans, specifications and/or typical line depths/coverage information.

### *Step 1 – Avoidance*

The least difficult strategy to implement is avoidance, meaning avoid the utility by relocating a GSI Measure, providing setbacks and clearances, or selecting a different GSI measure that might be better suited for the proposed site. Avoidance can also mean that the dimensions of a GSI measure are reduced in order to provide an adequate setback from utilities. Chapter 4 *Sizing Methodology* provides guidance for determining if a GSI measure with reduced dimensions still meets required sizing criteria.

If a proposed GSI measure will overlap or approach an existing utility, determine if a vertical or horizontal buffer can be maintained. This buffer may manifest as a specific depth of soil above the utility or a horizontal setback from the utility. For example, PWD recommends a horizontal setback of at least two feet from existing lighting poles, utility poles and underground utilities. Typical setbacks for individual utilities are provided in Sections 3.5.2 through 3.5.7. Buffers should also be provided for overhead wires, if stormwater tree well filters are the GSI measure, by selecting trees with anticipated mature tree heights lower than the wire heights. The designer should communicate with the utility owner to determine the appropriate distance to prevent disturbing the utility.

Sites with utility vaults should be avoided. If a vault is constructed or relocated because of a conflict, it should be located outside the GSI Measure's footprint.

### *Step 2 – Acceptance*

In some cases, the presence of an existing utility at the site of a planned GSI measure may not preclude the GSI measure from being built and treating the required stormwater volume. It may be possible to provide sufficient clearance between the GSI measure and utility and/or to protect the utility in place.

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[90] SMCWPPP, 2009

There are two main ways to separate the GSI measure from the utility: encasing the GSI measure and encasing the utility.

For permeable pavement facilities, SFPUC[91] recommends utility crossings be below the bottom of the structural pavement section whenever possible. If utilities encroach into this section, the engineer needs to confirm that the structural integrity of the pavement can be maintained over the utility.

## *Encasing the Stormwater Control Measure*

Some GSI measures can be encased in a concrete box or lined with a waterproof membrane on the sides and bottom as needed. For GSI measures that promote infiltration and have utilities located to the side, the bottom may be left open, and concrete or an impermeable membrane provided along the sides. Deeper curb profiles can be used for curb extensions to direct stormwater infiltration downward rather than laterally into adjacent utility trenches or road bed[92]. Where utilities are located below a proposed GSI measure, an impermeable liner can be placed over the utility's soil or engineered fill along the length of the utility and for a certain width on either side to prevent preferential flow of infiltrated stormwater water along the utility. SFPUC finds this method only acceptable when the facility does not include an underdrain or when the liner can be located below the invert of the underdrain[93].

## *Encasing the Utility*

If the utility can be protected in place within the GSI measure, there are additional considerations for future construction and maintenance if the utility remains within the GSI measure footprint. As discussed above, coordination with the utility provider will be needed to determine who is responsible for repairing and restoring the GSI measure to working condition and to provide information that the area is a GSI measure and not traditional landscaping or hardscape. One approach is to house the utility pipe within a larger carrier pipe or sleeve product, allowing the utility pipe to be replaced in the future without significant impact to the overlying GSI measure[94].

If a utility is located within or below a GSI measure and infiltration is used to treat stormwater, the utility provider should be consulted to determine the appropriate type of protection for the utility. The following are options for protecting utilities.

***Sleeve/casing***. A larger carrier pipe or split sleeve product is a protective encasement that surrounds a utility pipe or line. The sleeve protects the pipe from impact during construction and future trenching, excavation, and landscape activities. Additionally, sleeves can be used to seal the utility from the infiltrated stormwater and/or protect the infiltration GSI measure from sewer lateral leakages[95]. The utility should, at a minimum, be sleeved the entire length within the infiltration GSI measure. Example sleeves include plastic pipe or stainless steel split sleeve products.

***Insulating wrap.*** An insulating wrap may be sufficient to provide impact and water protection for existing shallow utility service lines that are remaining in place within infiltration GSI measure[96].

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[91] SFPUC, 2016
[92] SMCWPPP, 2009
[93] SFPUC, 2016
[94] SFPUC, 2016
[95] SFPUC, 2016
[96] SFPUC, 2016

***Impervious waterstops.*** Impervious waterstops, such as anti-seep collars, may be used where the utility enters and exits the GSI measure. This prevents infiltrated stormwater from traveling along the utility bedding or backfill and exiting the GSI measure where the utility enters or exits the GSI measure.

***Utility trench dam.*** If utilities are located under infiltration GSI measures, a utility trench dam is placed outside the footprint of the GSI measure to prevent preferential flow along the utility trenches. Flow in a utility trench may cause downstream damage by undermining the utility bedding material and causing a pipe to sag or deflect more than the industry allowable tolerance.

### *Step 3 – Mitigation*

Mitigation requires the design of the GSI measure to be significantly altered to mitigate concerns about the proximity to the utility. As a result, the volume of stormwater that a GSI measure will be able to treat may be reduced. Additional design aspects that may need to be altered include moving key features of the GSI measure (check dams, inlets, outlets, trees, etc.) to avoid conflict.

Chapter 4 *Sizing Methodology* provides guidance for determining if a significantly altered GSI measure still meets the required sizing criteria, or what percentage of stormwater runoff will be treated with the modified design.

The agency can evaluate the benefit for receiving a partial credit, if allowed, for pollutant removal and other environmental, safety, and visual appearance benefits of the GSI measure against the cost of constructing the modified GSI measure.

### *Step 4 – Relocation and Replacement*

In dense urban areas, it may be impossible to avoid or protect an existing utility. As a last resort, it may be necessary to relocate and replace the utility to establish a functional treatment area size. Gravity lines (e.g., sanitary sewer and storm drain systems) will typically be the most difficult to relocate or replace. Though relocation and replacement is typically the most difficult to implement and the most costly option, planned utility maintenance or replacement may be leveraged to plan GSI locations. Additionally, abandoned utilities should be removed to provide more space for the GSI measures. Any changes to utilities should be coordinated with the utility owner.

Depending on the utility, only a few features may need to be relocated, such as a shutoff valve or vault, while main utility lines may be allowed to remain within a GSI measure. Sections 3.5.2 through 3.5.7 provide additional guidance on coordination with specific utilities: communication/power, gas, water and sewer, street lights and fire hydrants.

## 3.5.2 Communication/Power

Communication utilities include telephone, cable and internet providers. There are typically multiple private companies in a jurisdiction with which coordination may be required. In most cities within Santa Clara County, electric lines are owned by PG&E. The infrastructure for these utilities can also include poles, vaults and manholes.

To avoid conflicts with the “wet” utilities, communication utilities are often located underneath the sidewalk and require sweeps instead of bends. Unless the provider installed a large duct bank, these utilities are generally possible to relocate if necessary. They are typically allowed to run through GSI measures with utility company acceptance. Washington D.C.'s District Department of Transportation (DDOT)[97] provides the following specific design details:

- Communication and electric lines are allowed to run through GSI measures when in concrete conduit.
- Communication and electric lines must have a minimum 6 inches vertical clearance and 2 inches horizontal clearance if not in concrete conduit.
- Utility poles may be located in permeable pavement facilities, but may not be located within bioretention unless additional stabilization is provided for the pole.
- Manholes may be located in permeable pavement facilities, but may not be located within bioretention.

Communication/power utility clearance examples from DDOT and City of Philadelphia Water Department (PWD) are provided in Table 3-1.

*Table 3-1. Communication/Power Utility Clearance Examples*

| | DDOT | PWD |
|---|---|---|
| **Allowed in GSI Measure** | Yes – concrete conduit required | Yes – specific design requirements subject to requirements of each utility owner |
| **Horizontal Clearance** | > 2 inches | 3 feet (general utility setback) |
| **Vertical Clearance** | > 6 inches | 6-18 inches (general utility setback) |

### 3.5.3 Natural Gas

Gas lines in Santa Clara County are owned by PG&E. There are GSI measures installed in the Bay Area that have gas lines running through them. Therefore, there is a precedent for the utility company to accept the utility in a GSI Measure. DDOT provides the following specific design details for gas lines that were also adopted by the County of San Diego:

- Gas lines within 6 inches of a GSI measure must have a protective fiberglass reinforced plastic shield installed around the pipe.
- Gas lines within the GSI measure must have a protective shield (e.g., fiberglass reinforced plastic) and sleeve (e.g., PVC or other plastic) installed that extends at least 9 inches on either side of the area in conflict.
- Maintain a minimum of 12 inches separation from underdrains to gas facility.

Gas utility clearance examples from DDOT, San Diego County, and PWD are provided in Table 3-2.

*Table 3-2. Gas Utility Clearance Examples*

| | DDOT & San Diego County | PWD |
|---|---|---|
| **Allowed in GSI Measure** | Yes – shield + sleeve required | Yes – specific design requirements subject to requirements of each utility owner |
| **Horizontal Clearance** | > 6 inches | 3 feet (general utility setback) |
| **Vertical Clearance** | > 12 inches from underdrain | 6-18 inches (general utility setback) |

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[97] DDOT, 2014b

### 3.5.4 Water

Water distribution systems may be operated by the municipality or leased and operated by one or more private water companies, such as the San Jose Water Company or Cal Water. There are some municipalities that do not allow water mains to run through GSI measures (SFPUC and the City of Denver) and others that allow water mains or service lines when a sleeve is installed (DDOT and San Diego County). DDOT requires a minimum 12 inches of cover between the bottom of a GSI measure and a water main. San Diego County requires GSI measure impermeable liners to be properly sealed where penetrated by water service laterals.

Water utility clearance examples from DDOT, San Diego County, SFPUC, and the City of Denver are provided in Table 3-3.

*Table 3-3. Water Utility Clearance Examples*

| | DDOT & San Diego County | SFPUC | City of Denver |
|---|---|---|---|
| **Allowed in GSI Measure** | Yes | No | No<br>Service lines < 2.5 inches may be allowed if sleeved |
| **Horizontal Clearance** | Not specified | N/A | Not specified |
| **Vertical Clearance** | > 12 inches | A/A | Not specified |

Recycled water distribution systems currently deliver water for non-potable use from a wastewater treatment plant to specific users. Considerations for GSI design near these types of systems are similar to those for water distribution systems. In Santa Clara County, the distribution system may be operated by one of the three wastewater treatment plants that produce recycled water (Sunnyvale Water Pollution Control Plant, San Jose/Santa Clara Water Pollution Control Plant, or Palo Alto Regional Water Quality Control Plant) or a recycled water purveyor such as the South Bay Water Recycling program or the City of Mountain View.

### 3.5.5 Sewer and Storm Drain

Sanitary sewer and storm drain systems are owned and operated by municipal departments or sanitary districts that may be separate from the municipal department that is planning and implementing GSI measures. Therefore, ongoing coordination is necessary with these potentially “in-house” utility owners. Most sanitary and storm sewer mains cannot be relocated except at great expense.

For some of the references used to research utility coordination resolution for this Handbook, the agencies, such as the City/County of San Francisco, have combined sanitary and storm sewer systems. Therefore, the allowed utility clearance for sanitary sewer systems and separate storm sewer systems were not reported separately. For example, Washington DC has a combined sewer system that allows the following:

- A minimum of 12 inches of cover is required between the bottom of GSI measures and sewer main or sewer lateral.

- When less than 5 feet vertical clearance is provided between the bottom of a GSI measure and sanitary sewer main, an impermeable liner shall be used at the bottom of the GSI facility to a horizontal distance at least 3 feet beyond the sewer main.
- Concrete collars shall be provided around surface structures (cleanouts, valve boxes, etc.) within GSI measures. The top of the concrete collar shall be above ponding depth.

Sanitary sewer utility clearance examples from DDOT (combined sewer system) and San Diego County (separate sewer system) are provided in Table 3-4.

*Table 3-4. Sanitary Sewer Utility Clearance Examples*

| | DDOT & San Diego County |
|---|---|
| **Allowed in GSI Measure** | Yes |
| **Horizontal Clearance** | Not specified |
| **Vertical Clearance** | >5 feet or impermeable liner at the bottom of GSI Measure |

The *Asset Protection Standards* developed by SFPUC (2017) for projects in the public right-of-way can also be referenced for standards to protect existing water assets.

## 3.5.6 Street Lights

Coordination with street lights may be necessary when a GSI measure is located in the sidewalk parkway realm. Street light poles are allowed in permeable pavement if they conform with minimum utility setback and protection measures (SFPUC). Street light pole foundations may be deeper than the GSI measure and as such these can allow for water intrusion and a solid liner would not be feasible. When the GSI measure is under construction, these poles will need to be stabilized as their foundation is exposed and potentially unstable until after the GSI measure is in place. DDOT allows street light conduits and poles to run through bioretention areas as long as shrubs or plants do not block access to transformer base openings. SFPUC requires a 6-inch concrete border as horizontal clearance.

*Table 3-5. Street Light Utility Clearance Examples*

| | DDOT& San Diego County | SFPUC |
|---|---|---|
| **Allowed in GSI Measure** | Yes | Yes |
| **Horizontal Clearance** | Not specified | 6 inches concrete border |
| **Vertical Clearance** | Not specified | Not specified |

## 3.5.7 Fire Hydrants

Coordination with the local Fire Department is required if an existing fire hydrant is located at a proposed GSI site. Fire hydrants are not allowed in bioretention facilities, but DDOT and San Diego County allow hydrants in pervious pavement as long as there is a 10-foot clearance longitudinally along a street and 4 feet into the street. However, designers of GSI measures should be aware of the thrust-blocks that keep the hydrant in place. These thrust-blocks are below the sidewalk and are essential for providing resistance to the high pressure flows that are associated with the hydrant and should not be compromised. Along the sidewalk side, there must be a 3-foot clearance around hydrants.

Fire hydrant utility clearance examples from the DDOT, San Diego County, SFPUC, and the City of Portland are provided in Table 3-6.

*Table 3-6. Fire Hydrant Utility Clearance Examples*

| | DDOT & San Diego County | SFPUC | City of Portland |
|---|---|---|---|
| **Allowed in GSI Measure** | No, except pervious pavement | Not in bioretention | No |
| **Horizontal Clearance** | Sidewalk 3 feet<br>Street: 10 feet longitude<br>4 feet into street | N/A | Minimum 5 feet clearance to outside edge of stormwater facility |
| **Vertical Clearance** | N/A | N/A | N/A |

# 3.6 Landscape Design

Design elements related to sustainable landscape principles, GSI plant and tree selection, planting, and location, soil and mulch considerations, and soil volume recommendations are discussed in this section. Examples of GSI landscape designs are shown in Figure 3-36.

*Figure 3-36. Examples of GSI landscape designs. (Credit: Cities of Palo Alto and San Jose and Urban Rain Design)*

## 3.6.1 Sustainable Landscape Principles

Green stormwater infrastructure measures paired with sustainable landscaping practices create beneficial symbiotic relationships. Using California natives and other climate-appropriate non-invasive plants in GSI measures can create sustainable landscapes where water quality improvements and many other benefits may be achieved. In light of the recent and future projected droughts and diminishing water supplies, turf and other plants with high water demand should not be the plants of choice for stormwater landscapes. Three programs in the Bay Area address various aspects of sustainable landscaping: the South Bay Green Gardens Program[98], the San Francisco Estuary Institute's (SFEI) Resilient Landscape Program[99] and Rescape California's Bay-Friendly Landscaping Program[100]. The newest of these is SFEI's Resilient Landscapes Program which integrates historical ecology, cultural landscaping, integrative geomorphology, landscape ecology, wetland science, climate adaptation and sustainability principles. Table 3-7 presents twelve principles with example strategies gleaned from each of the three programs.

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[98] www.southbaygreengardens.org

[99] www.sfei.org/cb

[100] www.rescapeca.org

*Table 3-7. Sustainable Landscape Principles and Example Strategies*

| Principle | Example Implementation Strategy |
|---|---|
| **Design Local** | Use climate-appropriate plants and know the historic ecology |
| **Construct Smart** | Recycle construction debris; purchase and use recycled products |
| **Reduce Energy** | Employ shade trees, efficient lighting, and locally sourced materials |
| **Smart Irrigation** | Install weather-based controllers and efficient water emitters |
| **Restore the Soil** | Loosen soils, amend with compost, and apply wood mulch |
| **Work with Nature** | Leverage native soil properties; practice IPM; design for maintenance |
| **Increase Habitat** | Plant food-producing flora for native insects, fauna, and pollinators |
| **Use Resources Wisely** | Harness recycled water, rainwater, graywater, wind and solar resources |
| **Protect Air & Water** | Clean air and runoff with stormwater tree well filters |
| **Provide Beauty** | Design aesthetically pleasing landscapes valued by the public |
| **Value Diverse Perspectives** | Partner with indigenous peoples and gain knowledge of world cultures |
| **Nurture the Urban Forest** | Provide large rootable soil volumes and healthy soils for trees |

## 3.6.2 Plant Selection

General guidelines on plant selection for GSI measures are presented in this section. Additional information is provided in Appendix D of the SCVURPPP C.3 Stormwater Handbook.

### *Role of Plants*

Plants and soil microorganisms are vital parts of green stormwater infrastructure systems. Vegetation provides many benefits for a stormwater landscape:

- Penetration of soil by plant roots, increasing permeability
- Food for soil organisms
- Nutrient and metal uptake & volatilization
- Habitat and food for flora and fauna
- Restoration of soil, increasing water retention and sequestering carbon
- Evapotranspiration of water, cooling the air

### *Desired Plant Qualities*

Well designed, constructed and maintained stormwater landscapes should, where feasible, use plants that have the following qualities:

- Drought tolerant with minimal irrigation needs (low or very low per WUCOLS[101])
- Tolerant of well-drained soils as well as periodic flooding
- Native or adapted to California climates
- Thrive without synthetic fertilizer or pesticides
- Non-invasive species in California[102]
- Low maintenance needs
- Provide uptake of pollutants

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[101] Water Use Classification of Landscape Species - http://ucanr.edu/sites/WUCOLS/

[102] www.cal-ipc.org

## *Plant Palette, Characteristics and Function*

Typical plant varieties seen in bioretention systems are rushes, sedges, bunch grasses, and fescues - some of which are California natives while others may be climate appropriate non-invasive plants from other parts of the world. Examples of green stormwater infrastructure plants and landscape designs are presented in Figure 3-37.

When selecting plants in a street environment, consider the site and the following factors:

- The amounts of solar exposure and heat that plants will experience differs based on site location, e.g., on the north side of a tall building versus the south side of buildings with no trees.
- Rock mulch absorbs and retains solar radiation more than wood mulch, thereby increasing the ambient temperature in a landscape. Plants may need to be more heat tolerant if that type of mulch is used.

- Different parts of a system can provide different planting opportunities for more plant species variety. Some plants do well in the basin (or ponding area) while others thrive on banks or in upland planting areas.

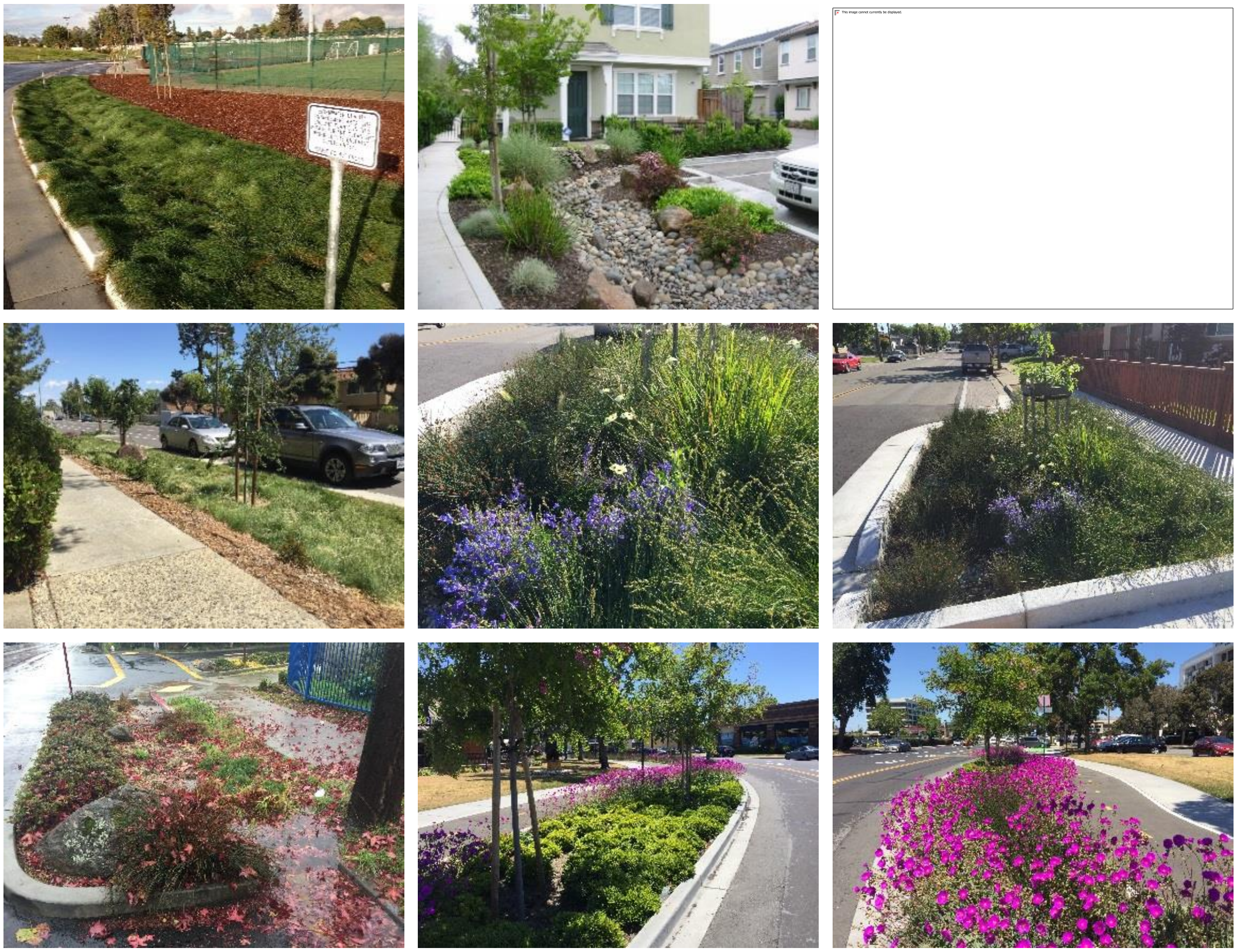

*Figure 3-37. Examples of green stormwater infrastructure plants and landscape designs. (Credit: EOA)*

- The plants in C.3 Handbook Appendix D have mostly been chosen for being low-maintenance, hardy plants. Many can survive without irrigation depending on the local climate and some can even stay green during a drought. Plants were chosen that do not require frequent trimming when properly placed and designed and do not need to be replanted every year. Where possible, California natives and other climate appropriate for the Bay Area plants were selected.
- The reproduction system of the plant (i.e. rhizomatous roots, seed, clumping, etc.) has effects on plant maintenance, growth, and spread through the system over time, including the possible dominance of one plant over others with less aggressive reproduction.
- The life expectancy of the plant affects maintenance needs. While perennials are generally specified, some have longer lifespans than others and can be planned for replacement in maintenance projections.
- Thorns, burrs, fruit and other aspects of a plant may create issues for the public and/or maintenance crews.
- Some plants can survive without irrigation systems, but may be dormant in the dry season, creating an aesthetic similar to the hills of the Bay Area that are golden in the summer and green in the winter (see Figure 3-38).

*Figure 3-38. "Dry season" aesthetic. (Credit: EOA)*

- Artificial turf, synthetic turf and artificial grass systems vary in quality, durability and cost and have advantages and disadvantages when compared with natural grass and turf landscapes. No mowing or irrigation is required, which can reduce those short-term maintenance costs, but long-term maintenance costs can be different when repairs of the system are needed. These systems are sometimes installed with impervious underground barriers preventing infiltration and they can have negative water quality impacts from plastic particles migrating into water bodies. The reduced short term maintenance burden, higher upfront costs, and other features of these systems should be analyzed with a cost-benefit and life-cycle analysis and compared with similar analyses of natural turf and grass systems.

Note that some less frequently specified plants may not be readily available at all times of the year and, depending on the project size, large quantities of some plants may require more time for the nursery to acquire. Plant disease and other vector quarantines can also affect availability and transportation of some plant stock. Therefore, it is recommended to check on plant availability well in advance of when installation is planned.

## 3.6.3 Plant Spacing and Location

General guidance on plant spacing and location is presented in this section. Appendix D of the C.3 Stormwater Handbook provides additional guidance, including recommended spacing of plants depending on the spread and height of the plant at maturity.

Plants should be spaced so that trimming is minimized and they do not impact the use of adjacent surfaces. Crowding with other plants should be avoided, but a fully planted landscape is the goal with minimal amounts of mulch being visible when the plants are mature. Consider how trees and shrubs will shade out other plants as they mature and grow in size. The C.3 Stormwater Handbook plant list divides planting locations into three zones:

- Basin
- Banks
- Upland

Figure 3-39 is an example of a landscape with the three zones. Plants are identified for these zones based on water needs and ability to withstand short periods of inundation. The location of the inlet and overflow as well as the longitudinal and lateral slopes of the system can also effect the basin, bank and upland sites of the system since the ponding (inundation) area is created by those factors. In Figure 3-39, the inlet and overflow are located in the same area indicated by the "Basin Plants" label and arrow.

*Figure 3-39. Landscape in El Cerrito with three zones: basin, bank, upland. (Credit: EOA)*

Figure 3-40 shows three examples of landscapes with multiple zones.

*Figure 3-40. Landscapes with multiple planting zones in Emeryville, El Cerrito, and Campbell. (Credit: EOA)*

Avoid locating plants in spaces that they will outgrow and cause functional issues such as the situation in Figure 3-41 where the mature plant is blocking the inlet and needing frequent trimming.

*Figure 3-41. Example of a mature plant located in the wrong place blocking an inlet in Castro Valley. (Credit: EOA)*

## 3.6.4 Tree Planting and Selection

Trees should only be planted in bioretention systems when the tree species is appropriate for sandy soils (or where adjacent clayey soils can be utilized and accessed by tree roots) and sufficient soil volumes and space are provided for the tree to reach mature size without causing problems with surrounding infrastructure, pavement, and buildings. Overhead utilities, such as high voltage lines that must be kept clear of tree growth, and other infrastructure can also reduce space for trees or limit the list of tree species for selection to smaller stature types. The design of the system and tree species selected should also be carefully considered for future irrigation needs (especially with large tree species, as irrigation demand may increase as the tree grows, possibly causing problems in a future drought scenario.) Hybrid systems that are able to use different soil types in different sectors of the landscape can also assist in providing water retaining soils for large trees.

Retrofitting or modifying existing trees into stormwater tree well filters can be done, but there are many design and construction issues, so consult with your arborist before attempting that strategy. Similarly, if a GSI measure is proposed for a location adjacent to an existing tree of value, discuss impacts to and protection measures for the tree with your arborist.

Various aspects of the aesthetics of the tree species should also be taken into account such as fall foliage, color, fruit/seed characteristics, shade type and tree shape. Some trees drop leaves very slowly and may therefore appear to be dying but are in fact healthy. Oak trees are often, but not always, in this category with one example shown in Figure 3-42.

*Figure 3-42. Young oak tree before leaf drop in Campbell.* *(Credit: EOA)*

*Figure 3-43. London plane tree leaves blocking a stormwater curb extension inlet in Emeryville.* *(Credit: EOA)*

High volumes of leaf drop in a short period of time can create inlet blockages in GSI measures, so leaf collection via street sweepers, manual collection or accommodation for degradation of leaves within the GSI landscape needs to be assessed and/or incorporated into the design before large broadleaf deciduous trees (such as the London Plane or Sycamore) are selected for streetscapes with GSI systems. Figure 3-43 shows an example of a stormwater curb extension with leaf blockage and the inability of the street sweeper to collect the leaves from the upstream London Plane trees due to the 90 degree angle of the curb extension. Other species of trees such as the Brisbane Box (native to Australia but commonly planted in the Bay Area) are broadleaf evergreens (having longer living, large waxy leaves), and therefore drop their leaves slowly, possibly creating fewer GSI measure maintenance and blockage problems. Coniferous evergreen trees generally have needles or other smaller leaf growth that is also dropped gradually. Another category of tree type is coniferous deciduous. An example of that tree type is the

Dawn Redwood (native to China but also commonly planted in the Bay Area). Its soft leafy needles drop every autumn but are smaller in size.

### 3.6.5 Benefits of Street Trees Related to Roadways

Trees can be a powerful tool in the stormwater landscape design kit. If a healthy and large urban forest with significant canopy coverage is a goal in the jurisdiction, integrating trees and stormwater treatment can be a significant aspect of a GSI Plan and program. Here are some of the benefits ascribed to trees:

- Moderate the urban climate reducing heat-related stress and energy usage
- Intercept water before it hits impervious surfaces
- Mitigate air pollution from vehicles
- Sequester carbon from fossil fuel combustion
- Improve the public's perception of the road and sidewalk
- Increase walking and cycling activity
- Increase community health
- Provide shade for public events on roadways
- Add beauty to the urban environment
- Reduce frequency of neighborhood crime[103]
- Provide habitat for birds and other animals
- May provide treatment without increasing maintenance load

The last item in the list is an important one to consider. Using stormwater tree well filters as a jurisdiction's primary GSI measure may be a better option than using bioretention with small plants only. If, over the long term, many new stormwater landscapes with small plants are added to blocks of roadways in the municipality, the large amounts of new landscaping will likely result in an increase in maintenance costs. However, if new trees are planted using stormwater tree well filter designs, the net increase in landscape maintenance costs may be minimal as the trees can provide multiple ecosystem services.

Other benefits of stormwater tree well filters (especially when paired with suspended pavement systems) are that they don't have to take up parking locations on the street and they can prevent sidewalk heaving from tree roots, reducing trip and fall hazards. Both of these benefits are popular with residents and can reduce maintenance costs and liability expenses for the jurisdiction.

Figure 3-44 shows a schematic of how, on a somewhat typical urban street block 400 feet in length and 50 feet in width (from curb to curb), two large species trees per side of the street may be used to treat all the MRP-required runoff from the roadway when planted with sufficient rootable soil volumes using suspended pavement systems or other similar means. The roadway runoff can be treated in the parkway strip and under the sidewalk in the underground bioretention area provided by the suspended pavement system (see Section 3.6.6 for more information on tree root soil volumes.)

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[103] Donovan and Preston, 2012

*Figure 3-44. Example schematic of a 400 foot long block with two stormwater tree well filters in the parkway strip, using suspended pavement systems under the sidewalk to provide sufficient soil volumes and stormwater treatment area for the runoff from one side of a typical 50 foot wide roadway.* (Credit: EOA and DeepRoot GSI LLC)

## 3.6.6 Minimum Soil Volume Recommendations

Rootable soil volume is one of the most important metrics to use for achieving street tree health and growth. At the average sidewalk planting site, street trees are dropped into holes with 30-100 cubic feet of soil volume for roots to grow in. Around the hole is compacted soil to support sidewalks and perhaps a planting strip with soil that is often similarly compacted during the building or roadway construction process. This tiny hole with compacted soil all around it is woefully inadequate for tree growth and explains why so many trees either die, become stunted, or heave adjacent sidewalks and curbs in order to find places to grow. In order to thrive, trees need soil that can provide oxygen, water, nutrients, microbial life and structural support.

More and more jurisdictions around the world are realizing that a minimum volume of soil must be provided in order to allow the tree to grow without destroying surrounding infrastructure. Sidewalks lifted by roots are tripping hazards which can result in expensive lawsuits for municipalities. Therefore many municipalities across North America have developed standards that require the provision of minimum amounts of soil volume at the time of planting based on the size of the tree species at maturity[104], space available and/or other metrics. A Bay Area example of a new street tree planting requirement can be found in the City of Emeryville, which requires a minimum of 600, 900, and 1200 cubic feet of soil volume per new tree for small, medium and large species, respectively.

In this way, the long-term growth of a tree is planned for and does not become a liability for the municipality. In fact, if proper planting standards are met and strategic pruning is provided, trees can yield a net positive triple bottom line benefit instead of a negative one – even with the increased up-front costs of providing more soil volume for a new tree. In one study[105], the costs and benefits of planting trees in the standard way were compared with the costs and benefits of planting trees with

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[104] www.deeproot.com/blog/blog-entries/soil-volume-minimums-organized-by-stateprovince

[105] MacDonagh, 2015, (http://ww1.prweb.com/prfiles/2011/04/06/8281436/SilvaCellLifecycleAnalysis.pdf)

increased soil volumes and then the results were modeled over a 50-year period. In the standard case, the model assumed that the trees would be replanted three times over the 50-year period using an average street tree life expectancy of 13 years. The model yielded a net cost of $3,094 per tree, compared to a net benefit of $25,427 per tree in the alternative case with increased soil volumes, over the 50-year period. This is in spite of the much higher upfront costs for the new tree with more soil volume. The study used a cost of $1,000 per standard new tree and $14,000 per tree with increased soil volume using suspended pavement systems to provide the increase. The study shows that large species trees that are planted correctly at the beginning of their lives will reap long-term benefits far surpassing the upfront costs.

## 3.6.7 Strategies for Achieving Larger Soil Volumes

Larger soil volumes can be achieved using open landscaped areas such as planting strips (as long as the soil is not overly compacted and is a good quality soil to a depth of at least three feet), suspended pavement systems, tree trenches, or structural soils.

Suspended pavement systems are techniques for providing the structural requirements of a surface such as a sidewalk while simultaneously providing uncompacted soil for tree root growth. The area under the sidewalk, or other paved surfaces such as parking lots or parking lanes of a roadway, can be supported with structural cells (such as a product called Silva Cells) or an engineered soil mix called structural soil. The image in Figure 3-45 from the Ada County Highway District Stormwater Design Guidelines (from Boise, Idaho)[106] shows a cross section for a street tree design with a suspended pavement system installed adjacent to the tree.

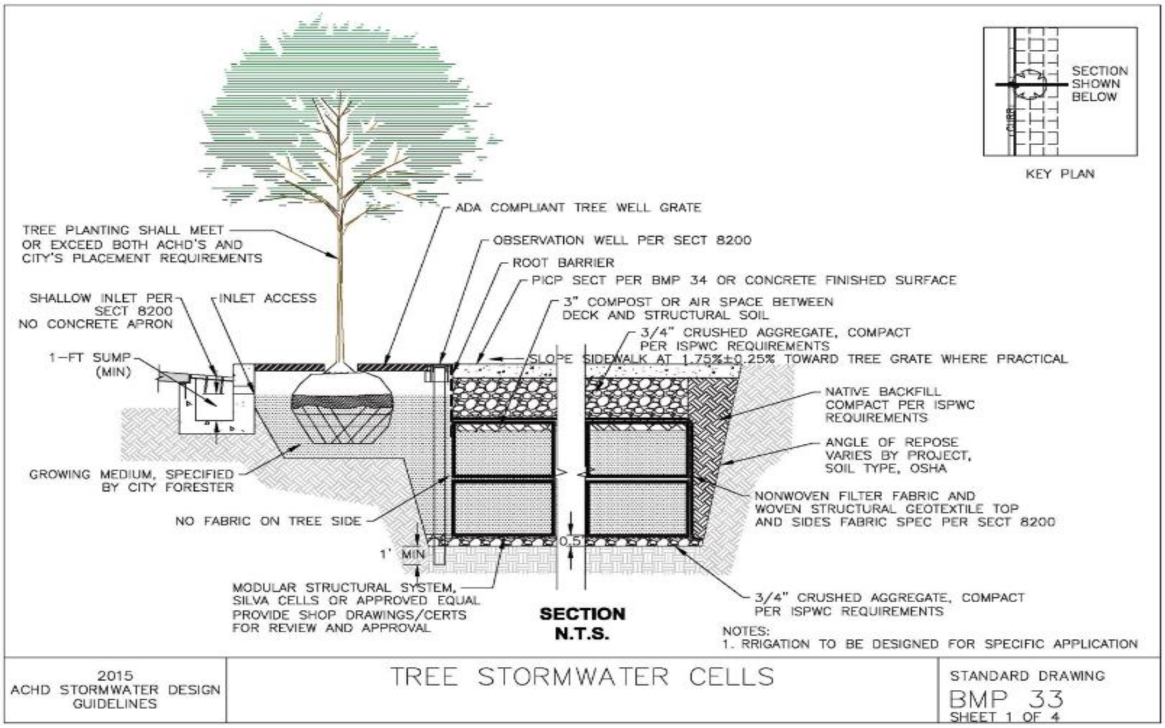

*Figure 3-45. Suspended pavement system installed under sidewalk. (Courtesy of Ada County Highway District Stormwater Design Guidelines)*

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[106] Ada County Highway District, 2015

The strategies for small, medium and large species of trees shown in Figure 3-46 are taken from DDOT's Greening DC Streets Manual[107].

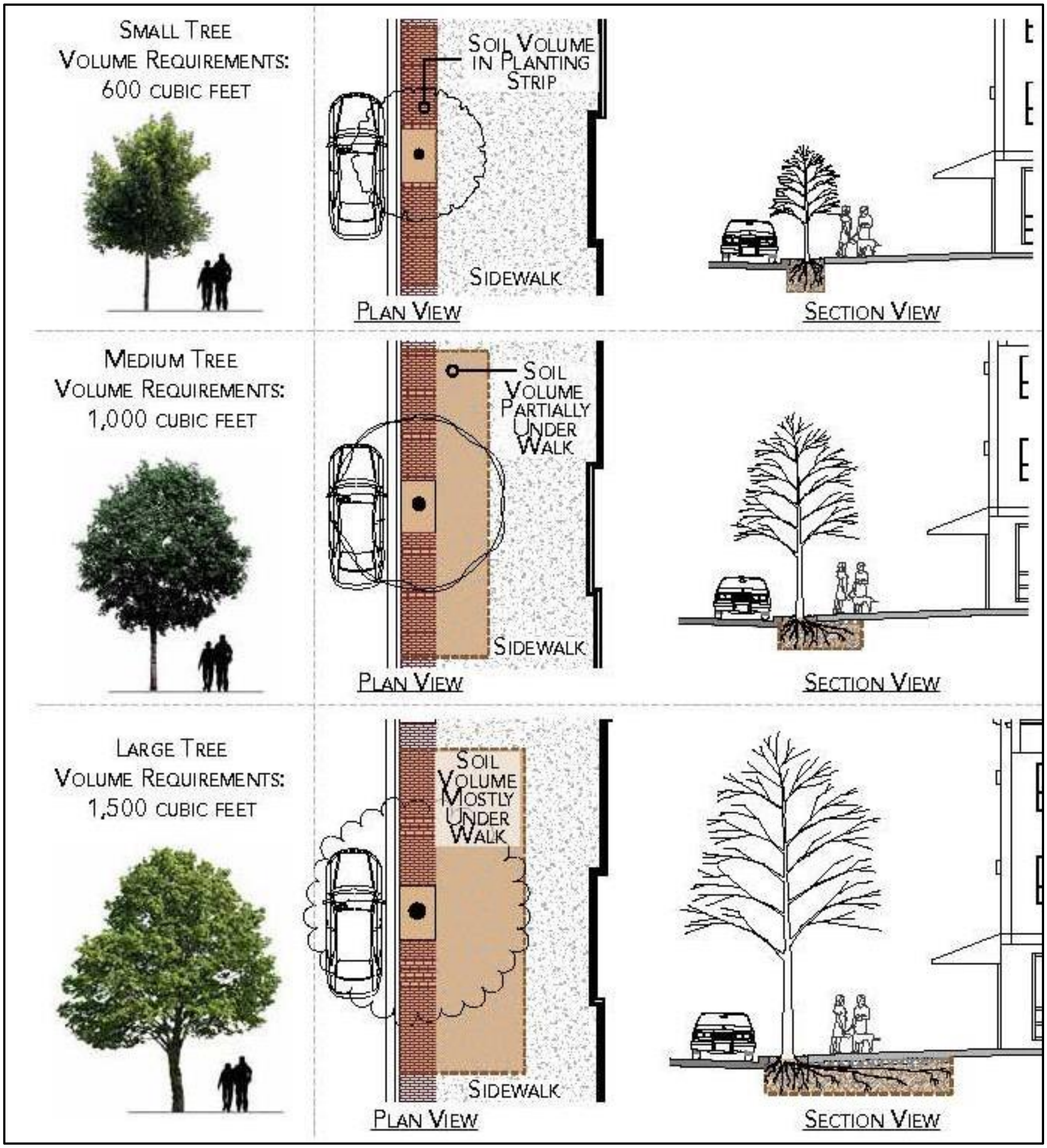

*Figure 3-46. Strategies for small, medium and large tree species. (Courtesy of DDOT)*

An additional strategy used to provide trees with adequate soil volumes is to plant trees in places where there are adjacent landscaped areas. Adjacent landscaped areas could be stormwater curb extensions, stormwater planters, non-stormwater planter strips, or private property areas between the sidewalk

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[107] DDOT, 2014a

and a building or parking lot. If the adjacent areas are separated from the tree planting location by impervious surfaces such as sidewalks, then suspended pavement methods can be used to provide an uncompacted soil "bridge" between the two landscaped areas allowing roots to grow through and under that pavement to the adjacent landscaped area. This strategy can be even more important if the adjacent landscaped area contains a clayey soil with good water retention compared to the sandy biotreatment soil media in stormwater bioretention areas. With the expectation of recurrent droughts in the future, clayey soils will be a key way that trees can access a source of water during the dry season. Irrigation with potable water and other types of water such as recycled water, harvested rainwater and graywater, can provide some or all of that need, but it may be limited and needed for other purposes. Resilient stormwater treatment landscapes are not dependent on irrigation alone.

Finally, additional soil volumes can be provided under pervious pavement systems. Pervious pavement allows the runoff to enter the suspended pavement system without a network of inlet pipes and distributes the flow more evenly. The bike route example in Figure 3-47 illustrates locations where suspended pavement systems can be integrated into a project. (For more information on the various types of integrated GSI-bikeways see Section 3.3.) This bikeway project is designed for shared use with bicycles and motor vehicles and includes trees and permeable pavers with suspended pavement systems in two locations:

1. Suspended pavement systems under pervious pavement with vehicular traffic
2. Suspended pavement systems under the sidewalks adjacent to the tree planting areas

Additional structural soil or suspended pavement systems could have also been installed under the sidewalk on the right side of the photo below to bridge between tree planting areas and landscaping to the right behind the sidewalk.

*Figure 3-47. Trees planted with Silva Cells and pervious pavement in a shared use bikeway in Bothell, Washington. (Courtesy of DeepRoot GSI, LLC)*

Figure 3-48 provides an example from Seattle of a stormwater tree well filter combined with a cycletrack. The project included Silva Cells under the pavement of the Class IV bikeway with two rows of trees on either side of the bikeway.

*Figure 3-48. Stormwater tree well filter with suspended pavement and cycletrack in Seattle. (Courtesy of DeepRoot GSI, LLC)*

## 3.6.8 Biotreatment Soil Media (BSM)

BSM is an engineered media used in landscape-based GSI measures. Per the MRP, BSM is comprised of two components -- 30-40% compost and 60-70% sand -- that meet standard regional specifications. The purposes of the BSM are to provide healthy plant growth and to infiltrate runoff and filter pollutants from runoff at a controlled rate.

Suppliers of BSM can provide a verification letter that the material meets the requirements of the MRP for healthy plant growth and permeability. The BSM specification was updated in 2016 as part of a BASMAA regional project, and approved by the Regional Water Board. SCVURPPP has created guidance, vendor lists and product verification checklists to assist municipal staff and others with the BSM procurement, submittal and approval process. These materials, as well as the updated BSM specification, are provided in Appendix C of the SCVURPPP C.3 Stormwater Handbook.

BSM should be installed in two approximately 10” deep lifts (totaling the minimum 18” deep layer required by the MRP and taking settling into account) using only boots or water for compaction. Do not use mechanical systems which typically over compact the BSM and reduce permeability. Expect additional settling of 1-2” in the final grade that can be accommodated with mounding, extra mulch or extra BSM before the plants are installed.

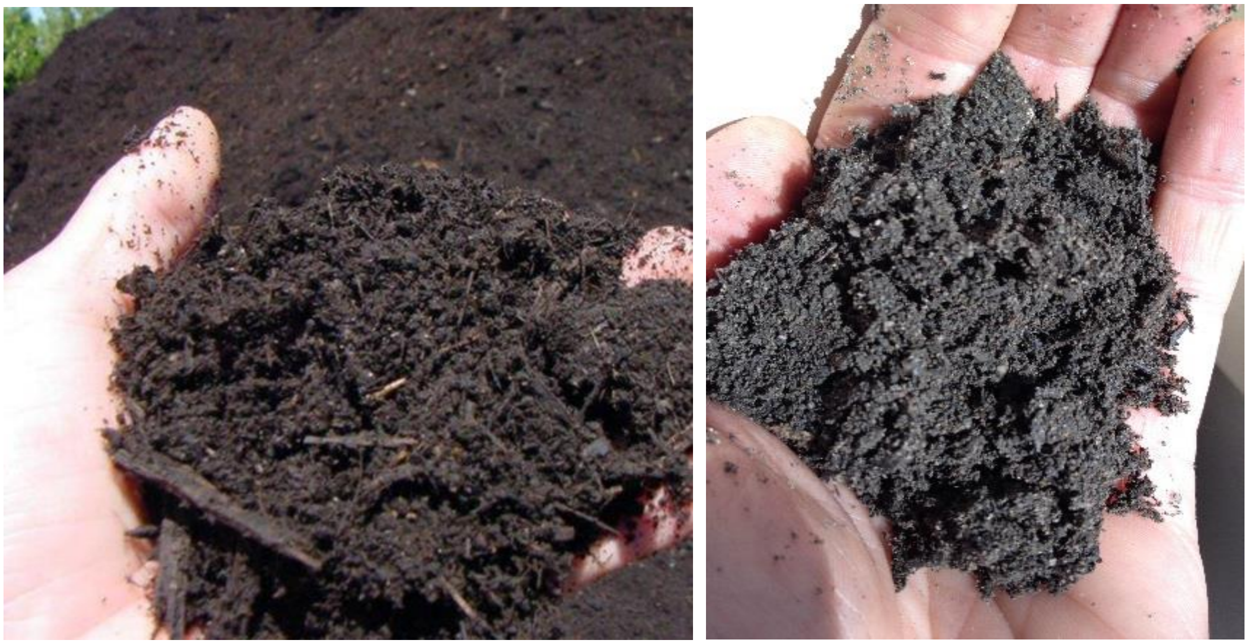

*Figure 3-49. Compost (left) mixed with sand produces the mix (right) in the Biotreatment Soil Media. (Credit: EOA)*

## 3.6.9 Use of Mulch in Stormwater Landscapes

Stormwater landscapes have special needs for mulch and the type of mulch most suitable can vary depending on the design of the system. Mulch is important in stormwater landscapes primarily to protect the BSM from erosion when runoff enters the facility. Applying three inches of wood or rock mulch over all exposed soil areas is required by California law (the Water Efficient Landscape Ordinance[108]) in most new landscapes because it has many benefits:

- Reduces the growth of unwanted plants
- Regulates soil temperature and evaporation
- Decreases the need for watering of plants
- Adds aesthetic value
- Protects soil from erosion by wind and water forces

### *Wood Mulch*

In general, wood mulch is recommended where it can be accommodated because of these benefits:

- Adds organic matter to the soil

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[108] www.water.ca.gov/wateruseefficiency/landscapeordinance/

- Provides nutrients for soil microorganisms and plants
- Creates demand for locally produced recycled material such as tree trimmings
- Improves soil structure
- Increases soil water retention
- Absorbs rainwater and releases it slowly
- Keeps organic materials out of landfills

The best types of wood mulch are:

- Varied in particle size and section of tree to knit together and stay in place during rain events
- Composted or aged for 3-6 months
- Comprised of whole and partial wood pieces - branches, twigs and leaves - not just bark
- Recycled from urban tree trimmings
- Produced locally (and kept within a quarantine zone, if applicable)

The type of wood mulch that best meets these attributes is composted or aged tree trimming mulch. This mulch is also referred to as composted or aged arbor mulch. The twigs, branches, leaves and pieces of wood that result from shredding or chipping tree trimmings create a mulch with a variety of particle sizes and types of wood – both green and woody. Aging or composting the arbor mulch in a pile for a few months allows the decomposition process to begin, inoculating the mulch with beneficial organisms and possibly reducing or eliminating some of any plant diseases or weeds that may have been in the feedstock material. Keeping the mulch local also reduces the export or import of any problems into or out of the region. Composting can also help the wood absorb water making it heavier and less likely to float. When ponding does occur, the arbor mulch tends to hold together better than bark mulches and not float downstream because of the varied particle size. Figures 3-50 and 3-51 show images of fresh arbor mulch and composted/aged arbor mulch.

*Figure 3-50. Freshly shredded arbor mulch. (Credit: [http://www.southernpeony.com](http://www.southernpeony.com))*

*Figure 3-51. Aged/composted arbor mulch. (Credit: Google Search Images)*

Another type of recommended mulch comes out of the commercial composting process. When the finished compost is screened larger particles are left behind and can be sold as “overs”. This can be a good option, but trash particles can also be left behind in the screening process, so check for contaminants in the mulch. Figure 3-52 provides a photo of clean overs from a screened compost.

*Figure 3-52. Clean overs from screened compost. (Credit: EOA)*

While the following types of mulch can be beneficial for decorative landscapes, they don’t work well in bioretention systems and generally are products from industrial forest operations that are not as sustainable as locally-sourced urban landscape maintenance-generated materials:

- “Micro-bark” mulch is made of small, uniform pieces of wood from the bark section of a tree, and can easily float and move downstream with even small rain events.

- Large bark mulch does not float or move as readily as micro-bark mulch, but because of the large particle size, it does not cover the soil.
- “Gorilla hair” mulch, which is a shredded redwood bark mulch, has been criticized for flammability and does not cover exposed soils effectively.

Finally, there is a type of decorative mulch that is made of recycled materials and works well in many landscapes, but is not recommended for bioretention systems. These mulch products are typically chipped recycled dimensional lumber from construction and demolition sites or are sourced from other recycled wood such as pallets. These mulches are usually very dry and are sometimes screened to be somewhat uniform in particle size; therefore, they do not perform well in ponding situations. They are often colorized for aesthetic purposes as shown in Figure 3-53.

*Figure 3-53. Decorative recycled wood mulch with colorized options. (Credit: Doitbest.com)*

## Rock Mulch

The benefits are of rock mulch are best described in comparison to wood mulch:

- Does not biodegrade
- Stays in place – depending on aggregate size and flow velocity
- Does not float
- Can be washed and therefore generally does not contain contaminants or other elements that can negatively affect the landscape
- Can act as a weed barrier when a sufficient depth of smaller aggregate rock is used

The best types of rock mulch are:

- Clean, washed small to medium sized aggregates such as pea gravel, small river rock and crushed angular granite or other inert and hard aggregates
- Clean, washed large cobble (but only where needed for functional purposes)

In some situations, rock mulch may be a better means of erosion and plant protection than wood mulch. There are various types of rock mulches that can be used for different needs in a stormwater landscape. As shown in Figure 3-54, two types of rock mulch are typically used. Larger rock or cobble is used at the inlet or under downspouts to reduce the velocity and erosivity of incoming flows; while smaller rock or gravel should be installed around plantings to reduce unwanted plant growth and evaporation of water in the soil. Smaller sized rock mulch is also easier to work with when performing weeding. The smaller rock should be installed in a 3-inch depth to form a protective layer over the soil. Sharp edged stone such as lava rock is not recommended due to the maintenance difficulties of hand weeding around an abrasive material.

*Figure 3-54. Rock and cobble mulch with temporary blockage of inlet during plant establishment in San Francisco. (Credit: EOA)*

## *Mulch Challenges*

Both types of mulch can create challenges, such as:

- Wood mulch can float, causing blockages, maintenance, and clean up issues
- Some wood mulches may contain weeds, seeds, pathogens, fertilizers, pesticides or other problematic substances
- Rock mulch can increase soil and ambient temperatures in warmer climates stressing some plants and increasing evaporation
- Rock mulch does not contribute nutrients to the soil and can impede weeding activity
- Larger rocks can compact soil reducing permeability, soil oxygen levels and root penetration
- Both types of mulch can be scattered onto sidewalks by dogs, cats and other animals

Figure 3-55 shows an overflow riser covered in wood mulch that has floated downstream from its original location and may be of the decorative type shown in 3-52. The movement of the mulch can create maintenance and operational issues since the mulch can clog the overflow riser, restrict outflows of the system, and possibly back up the flow into upstream areas causing localized flooding.

*Figure 3-55. Mulch covering overflow drain. (Credit: City of San Jose)*

*Figure 3-56. Mulch distributed after storm event overflow. (Credit: EOA)*

The worst case scenario occurs when an in-line type of system (see page 3-64) is undersized, overwhelmed during a large storm and/or uses the wrong type of wood mulch in the system. In these circumstances, mulch can become a mess to clean up, as shown in Figure 3-56. Solutions may include installing a new catch basin upstream to cut off large flows, trying other types of wood mulch, or removing and replacing wood mulch with rock mulch.

When selecting rock mulch, the location of the system and surrounding land use needs to be taken into account. Parks, schools and other locations where children may be playing near stormwater systems are not recommended sites for any installations of rock mulch larger than gravel due to the safety concerns of larger rock being thrown and injuring people or damaging vehicles or structures. Splash blocks made of plastic or concrete that are too heavy to be thrown can be used in place of the large rock for erosion control. Figure 3-57 shows an example school site with rock cobble that should be exchanged for a splash block.

*Figure 3-57. Rock cobbles under roof leader at school site in Emeryville. (Credit: EOA)*

## *Design Considerations for Mulch*

As discussed above, problems with wood mulch can occur when pieces of mulch float in a rain event and move towards the outlet or overflow system.  Mulch can clog the overflow riser, cause a blockage in downstream pipes, or create a mess that requires cleanup after a large storm. Migration of the mulch exposes the BSM to erosion and can allow unwanted plants to grow.

The best way to deal with the issue of “floating mulch” is to consider the design of the system and fit the mulch type to those needs. Wood mulch works best in green street systems that are “off-line”. An off-line system is the type where all the runoff from the drainage area does not need to flow through the system to get to an overflow. Figure 3-58 shows a series of “off-line” stormwater planters that each have an overflow drain within them. This system allows runoff to continue down the street to the next cell or storm drain in larger storms. This means that large storms do not “push” the wood mulch towards the overflow with as much force.

*Figure 3-58. Stormwater planter with off-line flow design reducing mulch problems in El Cerrito. (Credit: EOA)*

Stormwater curb extensions (such as the one in Figure 3-59) on the other hand, typically are designed as an “in-line” system where <u>all runoff</u> flows through the system to an overflow, underdrain, infiltration zone and/or outlet to continue downstream. If your design must use this type of system, and the treatment area is undersized or on the smaller end, then consider rock mulch in the flow line or throughout the whole system. If rock mulch is not desired or is not an option for some or all of the system, other possible solutions include using plants, curbs, splash blocks, boulders or other means to slow, redirect, block or otherwise reduce the erosivity and velocity of stormwater flows through the system. Different types of overflow risers, screens and covers (such as in Figure 3-60) can be used to keep mulch from blocking the outlet and/or flowing out of the system into the underground pipes.

Figure 3-59 shows an example of a stormwater curb extension with a flat concrete splash pad at the inlet followed by rock cobble mulch transitioning to smaller sized rock gravel mulch in the rest of the system. The splash pad collects sediment and trash with the large cobble reducing flow velocity. While this type of system with rock mulch are good for high flow situations, weeds will often grow between large cobbles. Removing weeds between large rock cobbles can require labor intensive movement of the cobbles in order to reach the base and roots of the weeds. Some systems of this design have the cobbles laid into a concrete pad instead of loose over soil. This removes the weed problem but increases impervious surface within the system and can make sediment removal difficult when the sediment builds up between the crevices of the cobbles. Strategic use and location of sturdy established plantings may be a better option than rock cobble where feasible and the system is properly sized for the catchment area being treated.

*Figure 3-59. Stormwater curb extension with in-line flow design using rock cobbles & rock mulch in San Francisco. (Credit: EOA)*

Similarly, if the system has a swale or conveyance on the surface for water to reach an overflow, a combination of rock mulch in the basin flow line with wood mulch on the slopes and upland areas can be effective. Figure 3-60 shows an example of this type of mulch combination in a park setting.

*Figure 3-60. Rock mulch used within the basin and flow-line in a park in Emeryville. (Credit: EOA)*

*Figure 3-61. Beehive overflow riser cover in Union City. (Credit: EOA)*

The type of overflow riser cover and grate can also be useful for reducing mulch problems. Domed or beehive grates on overflows are generally better than flat open box-grates for reducing mulch problems since they are less likely to be completely covered over with mulch. However, in the past, they have only been available in sizes smaller than the flat box-grate drains. A large overflow grate and inlet are easier to access for maintenance issues such as for cleaning of pipes. Larger diameter beehive grates and inlets are now being installed such as the one shown in Figure 3-61 that should resolve that issue. If mulch issues are not a problem and maintenance access is important, then a large flat box-grate may be the better option.

## *Plant Establishment Period and Mulch Options*

Another issue to consider related to mulch is the plant establishment period. Plant establishment periods and related maintenance guarantees should be included in construction contracts that are sufficient in duration to reach through the first rainy season. When possible, the best timing for completion of a GSI system may be in the summer so that plants will have enough time to grow and stabilize before the first rains appear in the fall, but this can vary by locale. Summers in hotter areas can be a stressful time for new plants. Special care is needed to help young plants survive during the first few months of a new system and wood mulch can assist young plants by keeping soil cool. However, if a rain event occurs before the new plants have established anchoring roots, they can be washed away or the soil around them can be eroded if there is no protection. Here are some options for the plant establishment period:

1. Mulch – either rock or wood – can be installed with no protection in off-line systems.
2. Biodegradable jute or hemp-based fiber netting products work best when installed over wood mulch and decompose over time so that they are not required to be removed after plant establishment.
3. During the rainy season, temporary inlet blockage with sand/gravel bags or wattles can be used. However, this inlet blockage system only works if gravity will divert runoff around the system (as shown in Figure 3-62); otherwise flooding can result.
4. Outside of the rainy season, rock or wood mulch can be used without protection if the system is adequately sized and protection is readily available if a rain event is predicted.

Figure 3-62 shows a system with rock cobble and jute netting for protection of new plantings (that would have worked even better with mulch underneath it). Once the netting biodegrades and/or the plants are established, additional mulch can be installed on top.

*Figure 3-62. Jute netting holding soil and mulch in place in San Mateo. (Credit: EOA)*

Figure 3-63 shows a system with gravel bags blocking the inlet. This protection strategy works in this location because the street has sufficient longitudinal slope and minimal cross slope allowing runoff to bypass the system and continue down the street to the next inlet. The bags were removed after the plant establishment period.

*Figure 3-63. Gravel bags protect a stormwater curb extension during plant establishment in San Francisco. (Credit: EOA)*

## 3.7 Maintenance Considerations for Design

Maintenance is essential for proper and effective operation of GSI measures. Neglect of GSI measures can result in localized flooding, erosion, vector control problems, and system inefficiencies or failures. During the design phase of GSI measures in the public right-of-way, it is important to consider the short and long term maintenance requirements and how maintenance will be conducted in the GSI measure locations. The ease or difficulty of maintenance may influence the location or type of GSI measure that is constructed. GSI measures in the public right-of-way pose different maintenance challenges compared with parcel-based measures because of the possibility of needing to work in high traffic areas and safety concerns for workers. It is important to consider having safe access by maintenance crews to GSI measures located near or in the street. Another consideration is the inconvenience maintenance activities may have to pedestrian, cyclist or vehicle throughways; for example, whether a traffic lane, bikeway, parking area or sidewalk needs to be closed to perform maintenance. If closures do need to occur, the location may dictate when maintenance activities are scheduled (e.g. mid-day to avoid rush hour times, early morning to avoid commercial area business hours, etc.).

As discussed in previous sections, there is competition of uses in the public right-of-way which leads to limited space for siting GSI measures. This may also mean constraints on the type of equipment that could be used for maintaining GSI measures. The use of certain equipment may not be possible, which may mean more time-consuming and labor-intensive maintenance activities. In some specific instances, confined space entry may be a concern.

The operation of a street sweeper is a specific consideration when designing curb extensions. San Francisco Better Streets[109] recommends a standard return of inner/outer curb radius of 20 feet and 10 feet to enable street sweeping machines to sweep the entire curb line. This may be reduced to 15 feet and 10 feet inner/outer curb radius if needed and compatible with the agency's street sweeper. NACTO[110] states curb extensions are typically angled between 30 and 60 degrees relative to the curb line to allow for street sweeping along the curb edge and steeper angles will usually require hand-sweeping.

Different types of street sweepers should be considered for the various types of GSI measures. Regenerative air and vacuum sweepers are best for pervious pavement systems but need to be calibrated for the paving system used. If aggregate is used in paver joints the vacuum strength of the sweeper will need to be reduced to minimize the amount of aggregate that is taken up by the sweeper. Standard sweepers are fine for stormwater curb extensions and stormwater planters where the main function of the sweeper is to remove as much as possible of the sediment and litter that collects in the gutter pan upstream of the system.

*Figure 3-64. Litter needing manual collection in a stormwater planter in the City of San Mateo. (Credit EOA)*

The design of GSI measures and integration with litter collection is an evolving area. GSI measures are generally designed to allow litter into the system through one or more curb cuts on the street surface, typically in the gutter pan area. The downside of this design is that litter that may have previously been collected by street sweepers must now be picked up manually by maintenance crews or volunteers.

The more curb cuts that are installed, the greater the distribution of litter over a larger area, therefore requiring more labor to collect. While multiple curb cuts/inlets can allow for reduced erosion and better distribution of flows throughout the system, the litter problem remains an issue as shown in Figure 3-64.

New integrated litter/GSI designs are being developed using catch basins with collector

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[109] SF Planning Department, 2010
[110] NACTO , 2017

pipe screens, forebays with trash capture devices, automatic retractable screens over curb cuts, and other design approaches.

Mulch replacement, sediment removal and weeding are three of the top maintenance tasks for GSI measures. The design of the system will affect the frequency and difficulty of these tasks. See Sections 3.6.2 and 3.6.9 for more information on maintenance considerations related to plants and mulch.

In some cases, GSI measures can reduce maintenance loads as compared with gray infrastructure or typical landscaping. For example, the use of Bay-Friendly Landscaping practices has been shown to reduce maintenance costs by 50% as compared with turf and other typical landscapes[111]. Increasing the soil volume for tree roots can help prevent pavement heaving, thereby avoiding associated maintenance costs while also providing space for stormwater treatment in an integrated stormwater tree well filter design.

The scheduling and staffing requirements for maintenance of GSI measures will affect the maintenance costs. When evaluating the costs of GSI measures as compared to standard “gray” infrastructure (e.g., pervious pavers versus asphalt), it is important to consider the complete life cycle cost (construction plus maintenance over the life of the facility). An example of this kind of calculation was done by the City of Berkeley comparing the life cycle costs of a roadway constructed and maintained using standard impervious asphalt and a roadway constructed and maintained using concrete permeable pavers. Their calculations showed that over the longer life span of the permeable pavers (approximately 50-60 years) the asphalt roadway (with a typical lifespan of 15 years) would cost more to construct, replace, and maintain.

## 3.8 Trash/Litter Capture Guidance

Certain types of GSI measures, when designed to meet specific criteria, can qualify as “multi-benefit treatment systems” to achieve State trash reduction requirements outlined in the State Water Board Trash Policy Amendments[112] adopted by the State Water Board in April 2015. Certified Multi-Benefit Trash Treatment Systems include bioretention facilities, capture and use systems, detention basins, infiltration trenches/basins, and media filters that are designed to trap trash in accordance with the Trash Amendments. Fact sheets with information on the design criteria and installation and maintenance requirements are available on the State Water Board’s website[113]. SCVURPPP representatives, working through CASQA, are continuing to work with State Water Board staff to refine the fact sheets to clarify the specific design requirements for each type of treatment system.

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[111] StopWaste.org

[112] SWRCB, 2015. The “Trash Amendments” apply to all Phase I and II permittees under the NPDES MS4 permits. See https://www.waterboards.ca.gov/water_issues/programs/stormwater/trash_implementation.html

[113] https://www.waterboards.ca.gov/water_issues/programs/stormwater/docs/trash_implementation/mbts_coversheet_05aug19.pdf

# CHAPTER 4

# Sizing Methodology for GSI Measures

*This chapter reviews standard sizing methodology detailed in the C.3 Stormwater Handbook and discusses alternative sizing methodology for GSI measures in the public right-of-way.*

MRP Provision C.3.d specifies minimum hydraulic sizing requirements for stormwater treatment measures at regulated projects. Regulated projects must treat the water quality design flow or volume (“C.3.d” amount) of stormwater runoff through infiltration or biotreatment. Certain regulated projects must also meet the sizing requirements for hydromodification management (HM) in Provision C.3.g, depending on the location and amount of impervious surface created and/or replaced on the site.

As discussed previously, GSI measures described in this Handbook are geared towards non-regulated projects. MRP Provision C.3.j.i.(2)(g)[79] states that GSI measures should be designed to meet the same treatment and HM sizing requirements (if applicable) as regulated projects. However, if GSI measures cannot be designed to meet the standard sizing requirements due to constraints in the public right-of-way or other factors, an agency may still wish to construct the measure to achieve other benefits (e.g., urban greening, reduced local flooding, integration with pedestrian safety features, etc.). To address this situation, the Provision allows Permittees to collectively “propose a single approach with their Green Infrastructure Plans for how to proceed should project constraints preclude fully meeting the C.3.d requirements”.

## 4.1 Standard Sizing Methodology

Chapter 5 of the C.3 Stormwater Handbook[80] contains detailed procedures for how to size specific stormwater treatment measures using volume-based sizing criteria, flow-based sizing criteria, or a combination flow and volume approach, consistent with Provision C.3.d. The chapter also describes a simplified sizing method for biotreatment in which the surface area of the treatment measure is equal to 4% of the contributing impervious area, i.e., a sizing factor of 0.04[81].

GSI measures in the public right-of-way should be located and sized to treat the C.3.d volume and/or flow of runoff from the contributing impervious surface area in (i.e., street and sidewalk) where possible. Similarly, for GSI measures in parking lots and public parks, every attempt should be made to locate and size GSI measures to treat the C.3.d amount of runoff from the contributing impervious surface areas. Consideration should be given to the feasibility of treating impervious surface area from adjacent parcels, even if privately owned.

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[79] CA RWQCB, 2015

[80] SCVURPPP, 2016

[81] This sizing factor is based on a permeability of 5 inches per hour (in/hr) through the biotreatment soil media and a rainfall intensity of 0.2 in/hr, as specified in MRP Provision C.3.d.

If site constraints prevent locating and sizing GSI measures in the public right-of way to meet C.3.d requirements, the alternative sizing methodology described in Section 4.2 may be used.

# 4.2 Alternative Sizing Methodology for Street Projects

## 4.2.1 Alternative Sizing Approach

Recognizing that GSI in the public right-of-way may not be able to meet the standard sizing methodology due to constraints such as lack of space, utility conflicts, or other factors, the MRP allows non-regulated green street projects with documented constraints to use an alternative sizing methodology. BASMAA has developed regional guidance for alternative sizing, based on a hydrologic modeling analysis, with sizing curves for the minimum bioretention surface area needed to provide treatment of 80% of annual runoff (per C.3.d) and design approaches to use when the C.3.d sizing requirements cannot be met[82].

Using model results for 10 rain gauges across the Bay Area, the BASMAA GI Facility Sizing Report[83] provides an equation to calculate the minimum bioretention sizing factor to meet C.3.d requirements, based on the mean annual precipitation of the project site:

$$\text{Sizing Factor} = 0.00060 \times MAP + 0.0086$$

Where:

*Sizing Factor* is the ratio of the surface area of the bioretention facility to the impervious area contributing runoff

*MAP* is the mean annual precipitation of the project site.

Based on this equation, green street bioretention facilities in some areas of Santa Clara County can be sized with as low as a 2% sizing factor and still meet the C.3.d sizing requirements.

If a green street opportunity is constrained such that the minimum sizing factor cannot be achieved, undersized green infrastructure measures may still be worth constructing to provide some water quality, runoff reduction, urban greening, or other benefits. The sizing curves in the BASMAA guidance can be used to determine what percentages of the C.3.d volume are treated in smaller facilities.

## 4.2.2 Guidance on Applying the Alternative Sizing Approach for Green Street Projects

BASMAA's regional guidance describes how to use the modeling results and what design approaches to use in specific situations when the C.3.d sizing requirements cannot be met. The regional guidance includes the following recommendations for sizing GSI measures in green street projects:

1. Bioretention facilities in street projects should be sized as large as feasible and meet the C.3.d sizing requirements where possible. Constraints in the public right-of-way may affect the size of these facilities and warrant the use of smaller sizing factors. Bioretention facilities in street projects may use the sizing curves in the BASMAA GI Facility Sizing Report to meet the C.3.d

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[82] BASMAA, 2019

[83] BASMAA, 2017a

criteria. Local municipal staff involved with other assets in the public right-of-way should be consulted to provide further guidance to design teams as early in the process as possible.

2. GSI measures in street projects smaller than what would be required to meet the Provision C.3.d Amount may be appropriate in some circumstances. As an example, it might be appropriate to construct a GI measure where a small proportion of runoff is diverted from a larger runoff stream. Where feasible, such facilities can be designed as "off-line" facilities, where the bypassed runoff is not treated or is treated in a different facility further downstream. In these cases, the proportion of total runoff captured and treated can be estimated using the BASMAA GI Facility Sizing Report. In cases where "in-line" bioretention systems cannot meet the C.3.d criteria, the facilities should incorporate erosion control as needed to protect the facility from high flows. See Figures 4-1 and 4-2 below for illustration of the in-line and off-line concepts.
3. Pollutant reduction achieved by GSI measures in street projects can be estimated in accordance with the Interim Accounting Methodology[84] or the applicable Reasonable Assurance Analysis[85].

*Figure 4-2: Off-line system in El Cerrito where low flow is diverted to the sidewalk planter and high flows continue down the gutter.*

*Figure 4-1: In-line system in Berkeley/Albany where low and high flows enter the system and overflows exit through a drain within the system.*

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[84] BASMAA, 2017b. The Interim Accounting Methodology for TMDL Loads Reduced Report describes the methodology that is being used to demonstrate progress towards achieving the PCB and mercury load reductions required during the term of MRP 2.0. The methodology is based on the conversion of land use from a higher to a lower PCB or mercury loading rate during the redevelopment of a parcel.

[85] A Reasonable Assurance Analysis (RAA) is a methodology used to demonstrate that implementation of pollutant control measures (such as GSI facilities) over a specified time period will meet required pollutant load reductions associated with a TMDL. SCVURPPP is in the process of conducting an RAA associated with the PCB and mercury TMDLs; the RAA is scheduled to be completed in 2020.

If it is determined that GSI measures in a green street project are unable to be designed to meet the C.3.d sizing requirements, the following steps can be taken:

- Document the project constraints that preclude meeting the C.3.d sizing requirements. For example, if an underground utility is preventing installation at the appropriate depth, or the sidewalk planter area is inadequate for ideal sizing, or heritage trees and their root structures conflict with the desired GI location, document those constraints.
- Use the sizing charts from the BASMAA GI Facility Sizing Report to determine the smallest facility size that will meet the C.3.d sizing requirements.
- If the minimum facility size is still infeasible, identify possible variations from the standard design. For example, determine whether the depth can be adjusted only in the area where a utility conflict exists. Using this alternative design, estimate the percent of the C.3.d volume that will be treated. Evaluate the cost-effectiveness of installing the GI measure given the other benefits realized (e.g., pedestrian safety, traffic calming, reduced local flooding, etc.) and the amount of pollutant removal achieved.

# CHAPTER 5

# Post-Construction Maintenance

*This chapter provides guidance on tracking GSI installation, typical inspection frequencies, and maintenance of GSI measures.*

As part of a municipality's development project approval and sign-off process for C.3 regulated projects, a maintenance agreement or other assurance mechanism that commits the owner to long-term maintenance of the stormwater control measures must be implemented. The regulated projects and associated stormwater control measures are tracked in a data management system, as required by the MRP. The C.3 Stormwater Handbook provides recommended inspection frequencies and what to inspect for each type of stormwater control measure.

GSI measures installed in the public right-of-way are typically public, non-regulated projects. Therefore, a maintenance agreement with the property owner is not usually required. However, an internal agreement among municipal departments may be needed to assign responsibility for maintenance. A maintenance agreement or memorandum of understanding (MOU) may also be needed between the agency that designed and built the GSI measure(s) and the utility providers (PG&E, Cal Water, San Jose Water Company, West Valley Sanitation District, etc.) that will be responsible for replacing it if they do work within the GSI measure(s).

Like stormwater control measures on regulated projects, GSI installations need to be maintained and tracked in a data management system. Agencies will need to develop a system for tracking where GSI measures are installed and assign inspection and maintenance responsibility to appropriate municipal staff. Staff responsible for inspection and maintenance should be trained to identify GSI measures and understand maintenance differences between GSI measures and landscape areas or impervious concrete/asphalt.

Although the GSI measures discussed in this Handbook are focused on non-regulated projects, the inspection and maintenance recommendations provided in Section 8.2 of the C.3 Stormwater Handbook are applicable[8]. Some specific considerations for GSI measures are provided below.

## 5.1 Inspection and Maintenance Frequency

In order to ensure that GSI measures continue to function properly and are effective for pollutant removal, it is recommended that GSI measures be inspected and maintained with at least the same frequency as regulated project stormwater treatment and HM measures. Inspection and maintenance schedules will change over time. For example, more frequent care and irrigation maybe necessary while establishing vegetation in a bioretention area (e.g., stormwater planter or curb extension). Once vegetation is established, maintenance requirements for the GSI measure may be reduced. Maintenance requirements and timing will also vary depending on the types of plants and/or trees planted in the GSI

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[8] SCVURPPP, 2016

measure. Knowledgeable staff or landscape professionals should be consulted to determine the appropriate time of year for pruning and plant replacement. Maintenance frequency and activities can also be dependent on available access in the public right-of-way and other site-specific conditions.

Maintenance frequencies may also depend on standards of care expectations. For example, a higher level of maintenance, including trash removal and weeding, may be expected in commercial districts than residential neighborhoods. Maintenance and inspection frequencies may also vary among the typical components of a GSI measure (i.e. surface, vegetation and subsurface maintenance).

Recommended minimum inspection frequencies from the C.3 Stormwater Handbook for the GSI measures identified in this Handbook are provided in Table 5-1.

*Table 5-1. Recommended Inspection Frequencies for GSI measures*

| GSI Measure | Inspection Frequency |
|---|---|
| **Bioretention Areas (including stormwater planters, stormwater curb extensions and bioinfiltration areas)** | • Quarterly general inspections<br>• Annual inspection before rainy season for wet weather functionality<br>• Annual inspection after rainy season and/or after large storm events for damage or maintenance issues.<br>• If installed adjacent to a building foundation, the building should also be inspected. |
| **Stormwater Tree Well Filters** | • Twice a year inspections<br>• Annual inspection before rainy season for wet weather functionality<br>• Inspect after storm events for damage or maintenance issues |
| **Infiltration Trenches** | • Annual inspection<br>• Inspect after large storm events for damage or maintenance issues |
| **Infiltration Dry Wells** | • Follow recommended inspection and maintenance frequencies if using proprietary devices. |
| **Pervious Pavement** | • Inspect two to four times a year<br>• Two to four times annually conduct preventative surface cleaning |

## 5.2 Maintenance Activities

Typical maintenance activities for GSI measures identified in this Handbook are provided in Table 5-2.

Access to treatment facilities in the street right-of-way is a maintenance consideration that should be addressed during the planning and design phases of the project (see Section 3.7). While personnel are conducting maintenance, traffic may need to be diverted around the area and traffic safety protocols should be followed.

Some agencies are requiring a maintenance period in construction contracts (up to 2 years after construction) before a bioretention project is accepted as complete, to cover maintenance during the plant establishment period and to ensure that the system performs correctly in the first rainy season(s).

For permeable pavement projects, an agency may consider requiring the contractor installing the permeable pavement to be responsible for pavement maintenance over a specified time period (e.g., three years of use). Maintenance tasks would include repairing cracked pavers and vacuum sweeping[9].

*Table 5-2. GSI Measure Maintenance Activities*

| GSI Measure | Maintenance Activities |
|---|---|
| **Bioretention and Stormwater Tree Well Filters** | • Pruning<br>• Weeding and removing invasive vegetation<br>• Replacing mulch and biotreatment soil media<br>• Watering<br>• Replacing plants<br>• Remove trash/debris<br>• Remove accumulated sediment<br>• Fixing or replacing flow dissipaters (e.g., cobbles, splash blocks)<br>• Cleaning inlets/outlets<br>• Flushing pipes<br>• Regrade soil surface where needed<br>• Repair concrete/masonry |
| **Pervious Pavement** | • Surface cleaning using vacuum sweeper or power washer<br>• Remove trash/debris<br>• Remove accumulated sediment<br>• Cleaning underdrain outlets or cleanouts<br>• Replace broken or damaged pervious pavement<br>• Replace aggregate in joints |
| **Infiltration Trenches** | • Remove trash/debris<br>• Weeding<br>• Cleaning inlets/outlets<br>• Flushing pipes<br>• Surface cleaning using vacuum or street sweeper if pervious pavement overlays infiltration trench |

## 5.3 Maintenance Staff Training

Typical maintenance activities for GSI measures may differ from standard landscape maintenance practices. Maintenance crews should be informed of the purpose of the facility and trained on what steps must be taken to maintain functionality. Project managers should make sure that maintenance activities and roles are clearly defined.

Interdepartmental coordination may be required to involve maintenance staff in the process and make sure that they have the skills and knowledge to prevent damage to the system. A well-trained maintenance crew can be a valuable asset by providing additional eyes on the facility to augment scheduled inspections.

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[9] NACTO, 2017

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# CHAPTER 6

# Example Green Stormwater Infrastructure Applications

*This chapter presents examples of GSI projects in different public settings.*

This chapter describes nine example GSI projects located in Santa Clara County and other Bay Area cities in which GSI measures are integrated into residential streetscapes, commercial streetscapes, parking lots and parks. These example projects illustrate how various GSI measures can fit into different types of public spaces and provide lessons learned for design and construction of GSI measures.

## 6.1 Hacienda Avenue Green Street Improvement Project

### *(Hacienda Avenue, Campbell)*

This project was located on a high-capacity collector street in a mostly low-density residential area and involved retrofitting 63 biotreatment areas (stormwater planters) within the sidewalk parkway.

The goals of the project were to reconstruct the asphalt pavement, increase pedestrian and cyclist safety, improve connectivity between neighborhoods, install better lighting, encourage active transportation along the improved linear parkway connecting to the Los Gatos Creek County Park and Trail, and reduce the roadway footprint. The pavement width on Hacienda Avenue was reduced from 65-70 feet to 52 feet, accommodating 11-foot vehicle lanes, parking lanes, and new bike lanes. The project was completed in November 2015.

### *Key Elements*

- The project addressed 1.1 miles of road with an 18-acre drainage area.
- The original roadway had a very wide right-of-way, no cycling facilities, and discontinuous sidewalks.
- 63 stormwater planters were installed along both sides of the street for a total surface area of 26,000 sq. ft.
- New bulb-outs at intersections calm traffic and improve pedestrian safety by reducing crosswalk distance.
- The area has highly infiltrative underlying soils, so stormwater planters did not need underdrains.
- A flush curb along the length of the roadway allows runoff to sheet flow into the stormwater planters.
- Roadway pavement was reconstructed with in-place recycled material.
- 60 new street trees were installed in tree wells in parking lanes to reduce the roadway heat island effect.

- Bay-Friendly low maintenance and drought resistant landscaping was used in the stormwater planters.
- Continuous sidewalks were added on both sides, separated from the roadway by planting areas.
- The project earned the Greenroads Silver Certification (Score of 43) and is a Bay-Friendly Rated Landscape (Score of 97).

### *Additional Benefits*

- Reduced localized flooding
- Energy efficient, durable LED street lighting
- New bike lanes and improved bus stops
- Educational signage

### *Project Outcomes and Lessons Learned*

- Reduced roadway width required driveway extensions. Construction activities were coordinated with property owners to minimize access disruptions.
- Construction of stormwater planters required lowering of sewer and underground utility service laterals. Utility relocation work was completed before street work to minimize potential delays.
- Stormwater planters were constructed directly above native soils without media fabric along the bottom. Underdrains were not required due to highly infiltrative underlying soils**.** An overflow system connects to the storm drain system. Stormwater planters were lined along the sides to prevent engineered soil from mixing with native soil.
- Cobbles found in the roadway subgrade and stormwater planter areas were crushed onsite for use in the roadway base. Excessive size and quantity of cobblestones meant adding a rock crushing process and two weeks of roadway closure.
- Full depth reclamation (FDR) approach saved the City half the cost of the conventional alternative to remove and replace the old street. FDR is the process of constructing a roadway by recycling the existing roadway materials.

*Figure 6-1. Hacienda Avenue before and after improvement project. (Credit: City of Campbell)*

*Figure 6-2. Stormwater planter along Hacienda Avenue with connection to a tree well filter. (Credit: EOA)*

*Figure 6-3. Stormwater curb extension at an improved intersection. (Credit: EOA)*

## 6.2 Southgate Neighborhood Green Street Project

*(Southgate Neighborhood, Palo Alto)*

This project is located on local, narrow streets in a low density residential area with on-street parking. It involved retrofitting 16 biotreatment areas into the sidewalk parkway (stormwater planters) and in corner curb extensions and permeable concrete pavers in the crosswalks at one intersection and in a pedestrian walkway.

The Southgate Neighborhood Storm Drain Improvement and Green Street Project was a partnership between the Southgate Neighborhood residents and the City of Palo Alto to help alleviate localized drainage issues while providing opportunities for improved water quality. In addition, the project integrated elements of the City of Palo Alto Bicycle and Pedestrian Transportation Plan to allow for traffic calming and safer pedestrian and bicycle access for the neighborhood.

### *Key Elements*

- Two types of biotreatment areas were used – some with underdrains and some with infiltration columns – for a total surface area of approx. 3,200 sq. ft.
- Permeable pavers were used in one crosswalk and along a pedestrian walkway (“paseo”), covering approx. 3,200 sq. ft.
- Stormwater planter designs minimized the impact to mature trees.
- Stormwater curb extensions at corners were also utilized for traffic calming and to minimize parking loss.
- Project included new storm drain inlets, pipelines, and pavement resurfacing in some areas.

*Figure 6-4. Southgate Neighborhood project bioretention areas and pervious pavement on crosswalks. (Credit: City of Palo Alto)*

### *Project Outcomes and Lessons Learned*

*Figure 6-5. Localized ponding before green stormwater infrastructure upgrades in the Southgate Neighborhood. (Credit: Palo Alto)*

- Utility conflicts, existing trees, and flat slope affected the shape of some biotreatment areas.
- A shallow aggregate layer was used in biotreatment areas with underdrains due to conflicts with the storm drain system.
- Use of infiltration columns allows storm-water to infiltrate into a porous soil layer.

- Early community outreach helped shape the streetscape design to address rideability along the bike route and concerns regarding potential reductions in on-street parking.
- Early coordination with the City Arborist on street trees and coordination with other city projects within the neighborhood were keys to success.
- Potholing was used to identify potential utility conflicts; however, more utility relocations occurred than anticipated.
- Sand layers below the concrete interlocking pavers enhance pollutant removal and protect groundwater quality.
- Installation of concrete bands prevents paver migration in crosswalks.

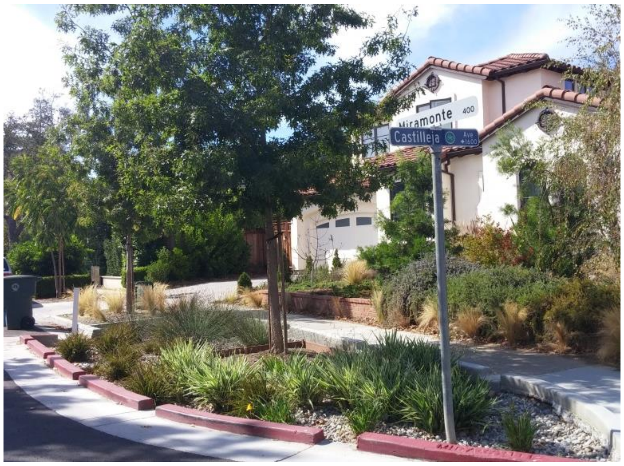

*Figure 6-6. Stormwater curb extension at the corner of Castilleja and Miramonte in the Southgate Neighborhood. (Credit: EOA)*

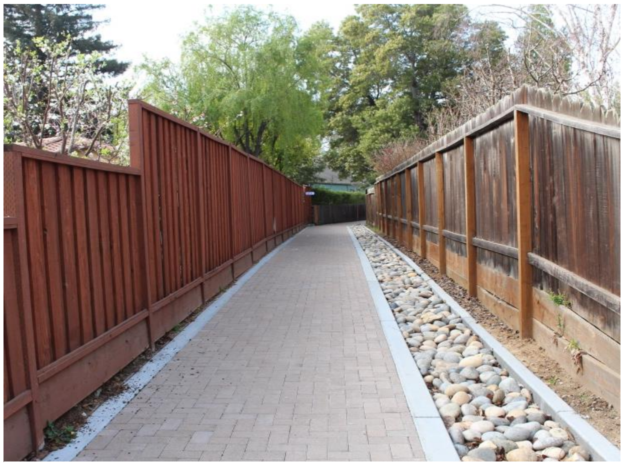

*Figure 6-7. A paseo with permeable pavers and an infiltration trench connects Southgate Neighborhood to El Camino Real. (Credit: EOA)*

## 6.3 Martha Gardens Green Alleys Project

### *(Martha Gardens Neighborhood, San Jose)*

This project is located on an alley in a mixed use (i.e., residential and commercial) area and involved installing an infiltration trench with pervious pavement.

Three residential alleys in the Martha Gardens neighborhood near downtown San Jose, which were previously covered with deteriorated asphalt and bare soil, now feature pervious pavement and concrete made from recycled content. A trench constructed underneath the pervious pavement collects and infiltrates stormwater runoff. The project improves drainage and aesthetics while adding stormwater storage, infiltration, and filtration to remove pollutants.

### *Key Elements*

- Three residential alleys totaling over 35,000 square feet have been replaced with concrete made from recycled fly ash and permeable pavers.
- Aggregate-filled trench beneath pavers stores and infiltrates runoff to reduce flows to the storm drain system.
- A layer of porous sand above the aggregate provides additional filtration of pollutants.
- The infiltration trench is 4 ft. wide by 6 ft. deep, and is fabric-lined on the sides.

*Figure 6-8. Pervious pavement over infiltration trench in Martha Gardens Alley. (Credit: San Jose)*

### *Project Outcomes and Lessons Learned*

*Figure 6-9. Unpaved surfaces & poor pavement prevented street sweeping and caused ponding in this area before project installation. (Credit: San Jose)*

- Street sweeping is restored (previously not feasible due to poor pavement).
- Improved pavement is pedestrian and cyclist friendly and provides proper drainage in areas with localized flooding prior to the project.
- Lighter colored paving absorbs less sunlight and lowers temperatures.
- The City created a “Green Streets Blue Bay” medallion for installation on the street, as well as a fact sheet and video for public outreach.
- A block party was held to celebrate project completion.
- The project provides benefits to an area considered a disadvantaged community.

## *Operation and Maintenance*

- City staff performs wet-weather inspections for clogging, ponding, and other conditions in need of maintenance.
- The City specifies use of regenerative air street sweepers within the alleys to maintain the permeability of the pavers.

## 6.4 El Cerrito Green Streets Pilot Project

### *(San Pablo Avenue, El Cerrito)*

This project is located on a major arterial street in a commercial area and involved retrofitting 19 biotreatment areas (stormwater planters) in the sidewalk parkway.

The El Cerrito Green Streets Pilot Project consisted of installing a series of stormwater planters at two locations along San Pablo Avenue in the City of El Cerrito as part of a street improvement project. The project also included water quality monitoring and community education. The purpose of this pilot project was not only to improve water quality, but also to promote the public's awareness of stormwater pollution, and expand local governments' existing stormwater management strategies to include green stormwater infrastructure approaches.

*Figure 6-10. Cells in construction at Madison site. (Credit: El Cerrito)*

*Figure 6-11. Biotreatment areas after planting at Eureka site. (Credit: El Cerrito)*

### *Key Elements*

- Installed stormwater planters by retrofitting about 750 linear feet of City-owned sidewalk in a commercial area along a Caltrans-owned route.
- The estimated total treatment volume of the stormwater planters is 20,700 cubic feet (minimal infiltration).
- Underdrains are plumbed to the existing storm drain system.
- Depressed stormwater planters receive runoff from the street and sidewalk through curb cuts.
- The City's outreach program engaged multiple target audiences throughout the project using video podcasts, interpretive signage in multiple languages, and educational pamphlets.

### *Project Outcomes and Lessons Learned*

- Stormwater planters are set back from the curb to allow pedestrians to step into or out of parked cars. Grate-covered inlets transport runoff to the treatment cells.
- Existing wide sidewalk made siting possible.
- During construction, a water main was uncovered and designs had to be adjusted.
- Water quality monitoring results show stormwater planters are successful in reducing pollutant concentrations for most pollutants analyzed.

- Poor water conveyance through some curb cuts was identified in monitoring and is attributed, in part, to the location of plantings in the stormwater planter with respect to curb cuts.
- Outreach program reached more than 50 local stakeholders.
- Plants in stormwater planters are thriving, adding aesthetic value that has been well received by the local community.

## *Operation and Maintenance*

- The City maintenance staff continues landscape maintenance of the stormwater planters using Bay Friendly techniques covered at a training session.

*Figure 6-12. Completed stormwater planters along San Pablo Ave. (Credit: EOA)*

# 6.5 Allston Way Green Street Project

## *(Allston Way, Berkeley)*

This project is located on a collector street in a commercial area and involved installing pervious pavement (interlocking concrete pavers) for the entire street including on-street parking and travel lanes.

The Allston Way project replaced aging asphalt pavement within a one block area (29,145 square feet) with pervious pavement. The project is also intended to function as a demonstration for future green stormwater infrastructure projects. It is the first public street in the Bay Area to install interlocking concrete pavers from curb to curb. Joint space filled with aggregate between the pavers allows rainwater to infiltrate.

### *Key Elements*

- Interlocking concrete pavers are installed in a herringbone pattern across the full width of Allston Way.
- Design challenges included clay soils and the street's 3% longitudinal slope.
- An underdrain was installed 6 inches above the sub-base to create some detention storage and allow infiltration into clay soil.
- Yellow pavers were used in crosswalks and centerlines (instead of thermoplastic striping).

*Figure 6-13. Pervious pavement installed in Allston Way, Berkeley. (Credit: URS)*

*Figure 6-14. Cyclist travels the new roadway. (Credit: Berkeley)*

### *Project Outcomes and Lessons Learned*

- Post-installation monitoring shows infiltration rate is better than estimated prior to project, and initial data show the project is effective in reducing pollutants and peak flows.
- A roadway location with few driveways was selected so that the road could be closed for 3 months continuously during construction as installment in sections would be less economical.
- Reduced required excavation depth from 41 to 29 inches by altering design to include an 8-inch cellular confinement for the aggregate base to increase structural stability and strength. This saved time, off-haul cost, carbon emissions, and minimized risk to underlying utilities.

- Initial community concerns came from cyclist, wheelchair and skateboarding communities regarding street roughness. However, these communities did not report problems after installation. Today, many wheeled users travel the new ADA-compliant roadway daily.
- City Forestry Department is monitoring street tree health for signs of change or improvement.

## *Operation and Maintenance*

- Maintenance plan and procedure manuals were created by the project consultants.
- Long-term cost of permeable interlocking concrete pavement estimated to be almost the same as a traditional pavement (<2% difference in 40-year life-cycle cost analysis).

## 6.6 Donnelly Avenue Rain Garden and Curb Extension

*(Donnelly Avenue, Burlingame)*

This project was a retrofit of an existing public parking lot in a commercial area and involved installing biotreatment areas in the form of a midblock curb extension and a stormwater planter at the perimeter of the parking lot. The parking lot, located behind a shopping district, had multiple driveways, angled parking within the lot, and on-street parking along the perimeter adjacent to Donnelly Avenue.

The parking lot was reconfigured to have only two entrances and 90-degree parking stalls with no loss of parking spaces. The stormwater planter was installed along the perimeter of the lot between the parking lot and sidewalk. The midblock stormwater curb extension was installed in the on-street parking zone of the street with no loss of street parking spaces due to the removal of two parking lot driveways.

*Figure 6-15. Configuration of lot before the project. (Credit: Google Earth)*

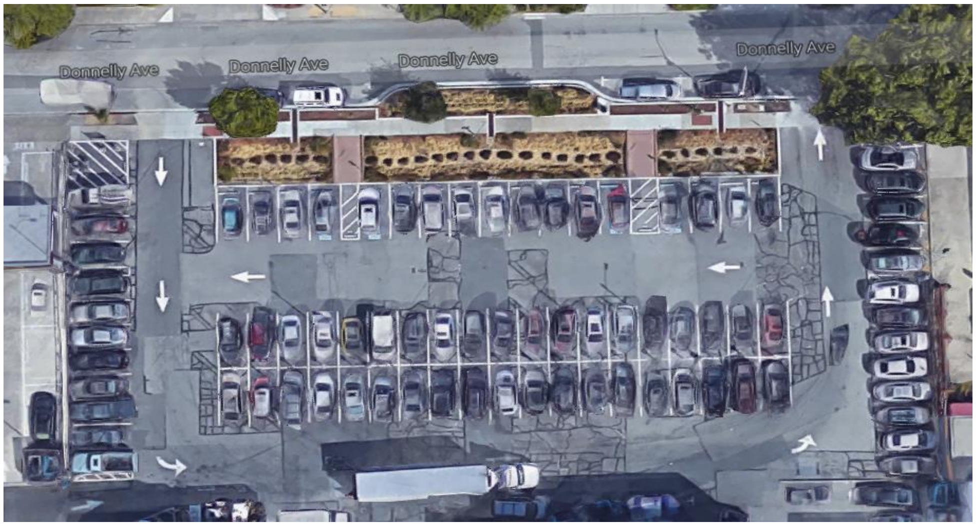

*Figure 6-16. Configuration after project. (Credit: Google Earth)*

## *Key Elements*

- The project captures runoff from commercial buildings and the parking lot.
- The GSI measures were designed for almost twice the required C.3.d treatment volume.
- Midblock curb extension captures runoff from the street and parking stalls.
- Landscaping includes California native plants and trees.
- Lights needed to be relocated.
- Boardwalks are installed over the stormwater planter in two locations to allow pedestrians to travel from the sidewalk to the parking lot.
- The stormwater planter is designed with an infiltration column and no underdrain.
- An interpretive sign was installed to educate the public.

*Figure 6-17. Bioretention area between parking lot and sidewalk features native California plants. (Credit: Burlingame)*

## *Project Outcomes and Lessons Learned*

- Erosion occurring along the edge of the stormwater planter was deterred by adding a one foot wide rock strip.
- Stormwater flow was able to carry pea gravel out of the midblock curb extension into the gutter. Heavier material such as rock cobble is recommended in areas that may experience high flow rates.
- Some plants have longer lead times for ordering. Check on plant availability during the design phase.[10]
- If special qualifications for the contractor are necessary, they should be included in the project specifications during the bidding process.

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[10] This lesson has been learned on other projects as well. Some less frequently specified plants may not be readily available at all times of the year. Depending on the project size, large quantities of some plants may require more time for the nursery to acquire. Plant disease and other vector quarantines can also affect availability and transportation of some plant stock.

## 6.7 Commodore Park

### *(North Jackson and Commodore Drive, San Jose)*

This project involved creation of a new park on a City-owned parcel in a residential area that utilized landscape and pervious pavement to avoid using a conventional drainage system. The park was constructed in November 2013 and includes two play areas, an adult fitness area, a native turf area with passive drainage, a porous asphalt parking lot, a landscaped area, a pervious colored-concrete walkway and permeable pavers in the picnic and plaza area.

### *Key Elements*

- Geotechnical investigation revealed the site has gravelly-clay soil that drains well.
- Each of the pervious pavement sections was designed to have a deeper sub-base than normal to act as a reservoir to store stormwater runoff for infiltration.
- Each of the pervious pavement areas is self-treating and treats some runoff from adjacent areas.
- Different types of pervious pavement (porous asphalt, permeable interlocking pavers, colored pervious concrete and porous rubber surfacing) were used for the parking area, plaza, walkways and play areas.
- Drought tolerant landscaping was incorporated in the park.

### *Project Outcomes and Lessons Learned*

- The park does not have a conventional drainage system which is expected to reduce long term operation and maintenance costs.
- The reduced construction costs for a conventional drainage system offset the GSI measure costs.

*Figure 6-18. The park contains porous rubber surfacing in the play area and pervious concrete in walkways. (Credit: San Jose)*

*Figure 6-19. Vegetated buffer areas play a role in the park's green stormwater infrastructure design. (Credit: San Jose)*

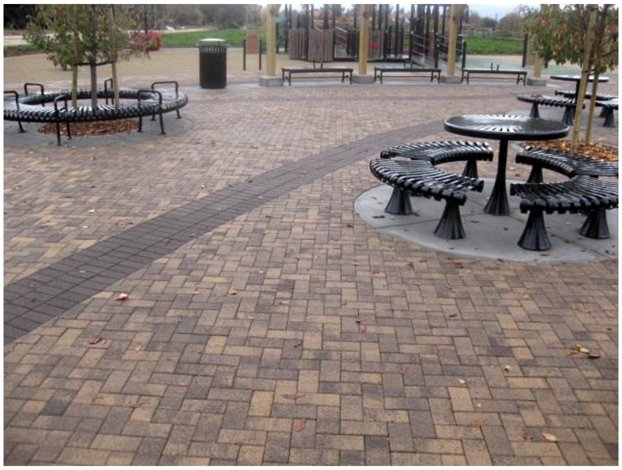

*Figure 6-20. Close-up of permeable pavers in the plaza area. (Credit: San Jose)*

*Figure 6-21. Commodore Park integrates various types of pervious pavement and vegetated areas into a beautiful and functional park. (Credit: San Jose)*

## 6.8 Creekside Sports Park

*(University Avenue, Los Gatos)*

This project redeveloped a previous commercial business corporation yard into a new sports park that incorporated synthetic turf, pervious pavement, and biofiltration areas. The sports park was completed in October 2012.

### *Key Elements*

- Infiltration occurs beneath the synthetic turf.
- No regular irrigation is required on the field.
- Porous asphalt was installed in the parking lot.
- Trenches were created in the aggregate below the porous asphalt and the synthetic turf to direct infiltrating water away from the nearby Los Gatos Creek bank.
- Permeable pavers were used for the picnic area.
- Biofiltration areas were placed along the perimeter of the area in two places.
- Provisions for a future Electric Vehicle charging station are an additional benefit.

*Figure 6-22. Park site before and after project. (Credit: Los Gatos)*

### *Operation and Maintenance*

- The Town has a stormwater facilities maintenance and operation plan.
- Maintenance activities include periodic flushing of perforated underdrains via cleanouts, vegetation weeding and replacement, irrigation inspection, soil media inspection and trash collection.
- Maintenance of the pervious pavement includes debris removal, surface washing, checking paver joints for porosity and vacuum-truck sweeping.
- No mowing is required for the synthetic turf which reduces the additional maintenance time needed for this new town park.

*Figure 6-23. Synthetic turf design allows infiltration on site. (Credit: EOA)*

*Figure 6-24. Porous asphalt collects and infiltrates runoff in the parking lot. (Credit: EOA)*

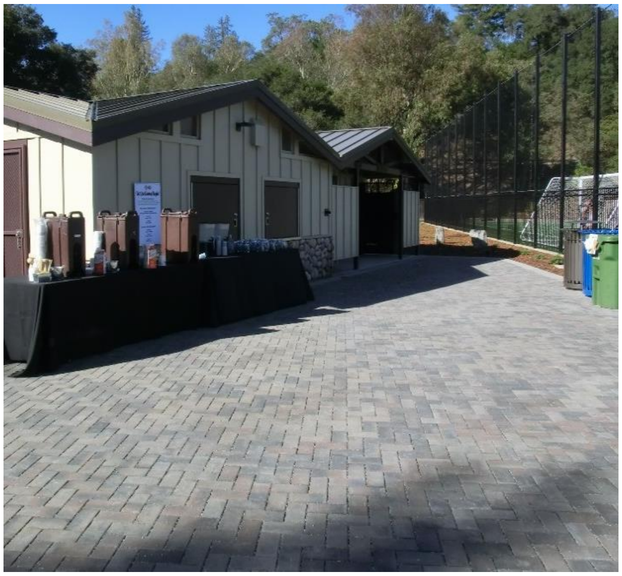

*Figure 6-25. Permeable pavers are used in park plazas, walkways, and picnic areas. (Credit: EOA)*

# 6.9 Stevens Creek Corridor Park and Restoration Project

## *(Stevens Creek Corridor, Cupertino)*

This was a creek restoration project in a mixed-use area that also included installation of a new pervious pavement trail and parking lot and bioretention areas to capture runoff from neighboring off-site areas (i.e., golf course and parking lot). The primary goal of the project was to restore Stevens Creek with a related goal to reduce impervious cover. The project restored 2,250 feet of creek channel and removed 3.4 acres of impervious surface. The project, completed in July 2014, included creek restoration, enhanced habitat for rare species, extensive new public open space, environmental education areas, and a completed trail connection.

### *Key Elements*

- In-stream creek restoration included removing concrete lining of the channel. All of the removed concrete was recycled. New channel stabilization was constructed entirely of natural materials, many harvested from the site.
- Pervious concrete paving was used for the trail. A special paving and subgrade design was used where the trail came near existing trees to protect the tree root systems.
- A new parking lot was constructed of recycled plastic geocells backfilled with soil, native grasses and meadow plants, and supported by drain rock placed underneath. Parking lot drive aisles were constructed of porous concrete.
- Two bioretention areas capture runoff from the nearby golf course and paving that previously went directly to the creek.
- A new orchard entryway infiltrates runoff from impervious roof and paving at the community pool complex.
- Over 1.25 acres of new restoration plantings were installed using native plants grown from locally-collected cuttings and seeds. Advanced planning allowed for several years of native tree growth prior to planting.
- Among the project’s unique aspects were the presence of federally-threatened Central California Coast steelhead in the creek year-round, and the significant barriers to fish passage in the creek channel to be removed.

### *Project Outcomes and Lessons Learned*

- The restored creek and the native restoration areas have created an excellent outdoor education venue. A new water access area at the edge of the creek provides a spot for the school groups and City Naturalist programs to provide education about ecosystems, natural sciences, and the value of healthy creeks and water quality.

### *Operation and Maintenance*

- The project was designed for low-cost operation and maintenance by accommodating natural processes.
- The pervious concrete trail is made of highly durable material and requires minimal maintenance.

*Figure 6-26. Parking bays contain recycled plastic geocells that support vehicle weight. Drain rock is below. (Credit: Cupertino)*

*Figure 6-27. The plantable geocells are backfilled with special soil. During heavy rains, excess water flows to bioretention areas in center. (Credit: Cupertino)*

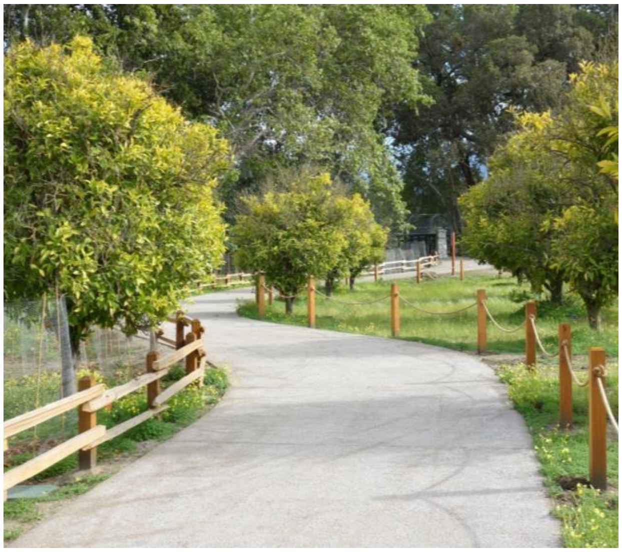

*Figure 6-28. The park includes a pervious concrete bike path and walkway. (Credit: Cupertino)*

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