Low Impact Development Manual for Southern California:

Technical Guidance and Site Planning Strategies

Southern California Stormwater Monitoring Coalition
California LID Evaluation and Analysis Network
(SMC CLEAN)

May 2019

Original (2010) Developed by:
The Low Impact Development Center, Inc.
Prepared for: The Southern California Stormwater Monitoring Coaltion in cooperation with the State Water Resources Control Board

Updated (2019) by SMC CLEAN:
Daniel Apt (Olaunu)
J. Michael Trapp, PhD (Michael Baker International)
Matt Yeager (Riverside County Flood Control and Water Conservation District)
Jeanne BenVau (Michael Baker International)

Table of Contents

Abbreviations ..... **i**

Glossary ..... **iii**

Executive Summary ..... **vii**

How to Use This Manual ..... **ix**

Nomenclature ..... **xi**

Section 1 The Impacts of Development and How LID Can Help **1-1**
Land Development Effects 1-2
Considerations and Challenges 1-3
Hydrologic Cycle Effects 1-5

Section 2 The LID Site Planning and Design Process **2-1**
Step 1: Conduct Site Assessment 2-5
LID Site Assessment – *Existing Hydrology* 2-8
LID Site Assessment – *Topography* 2-9
LID Site Assessment – *Soils and Geology* 2-10
LID Site Assessment – *Vegetation* 2-16
LID Site Assessment – *Ecoregion* 2-17
LID Site Assessment – *Sensitive and Restricted Areas* 2-18
LID Site Assessment – *Existing Development* 2-19
LID Site Assessment – *Contamination* 2-20
Step 2. Define Goals 2-21
Regulatory Goals 2-21
Environmental Stewardship 2-22
How Much is Enough? 2-22
Step 3: Implementing LID Principles 2-23
Maximize Natural Infiltration Capacity 2-24
Preserve Existing Drainage Patterns and Time of Concentration 2-24
Protect Existing Vegetation and Sensitive Areas 2-25
Minimize Impervious Area 2-26
Disconnect Impervious Areas 2-27
Minimize Construction Footprint 2-30
Revegetate Disturbed Areas 2-31
Implement Source Control Measures 2-34
Step 4: Use LID Structural BMPs to Mitigate Remainder of Impacts 2-38
Bioretention 2-49
Pervious Pavement 2-69
Capture and Reuse 2-99
Green Roofs 2-111
BMP Factsheets 2-117
Downspout Disconnection 2-118
Soil Amendments 2-120
Vegetated Filter Strips 2-122
Vegetated Swales 2-124
Infiltration Basins 2-127
Infiltration Trenches 2-129
Dry Wells 2-131
Dry Ponds 2-133
Constructed Wetlands 2-135
Media Filters 2-137
Proprietary Devices 2-140
Step 5: Evaluate Overall LID Site Plan & Design 2-143

Section 3 Case Studies **3-153**
Case Study 1: Commercial Retrofit 3-153
Case Study 2: Residential Retrofit 3-155
Case Study 3: Commercial Design 3-158
Case Study 4: Residential Development 3-161

References **3-163**
Southern California Master Plant List 8
General Plant List 17
Bioretention Plant List 26
Vegetated Roof Plant List 29

List of Figures

Figure 1-2. Urban influences on stormwater runoff. 1-3
Figure 1-1. The Hydrologic Cycle. 1-5
Figure 2-1. The LID Site Planning and Design Process 2-1
Figure 2-2. Use of the LID Site Design Process to Maintain or Restore Hydrologic Function. 2-3
Figure 2-3. Municipal Retrofit Flow Chart. 2-4
Figure 2-4. Hydrologic Groups for Southern California Soil Series 2-11
Figure 2-5. USDA Ecoregion Sections of Southern California..... 2-18
Figure 2-6. Grand Hope Park with Downtown Los Angeles in the background..... 2-26
Figure 2-7. Commercial site showing directly connected impervious areas..... 2-28
Figure 2-8. Commercial area in which impervious surfaces have been disconnected..... 2-28
Figure 2-9. Bioretention Cell in Parking Lot, OC Public Works, Orange, CA. 2-50
Figure 2-10. Single-Family Residential Lot Drainage Schematic. 2-53
Figure 2-11. Roof downspout draining to bioretention cell. 2-53
Figure 2-12. Planter box capturing roof runoff. 2-54
Figure 2-13. Parking Lot Bioswale, San Diego County, CA..... 2-55
Figure 2-14. Linear Bioretention, Downey, CA 2-56
Figure 2-15. Bioretention cell for street/yard drainage, Downey, CA. 2-57
Figure 2-16. Bioretention cell for street/yard drainage, Los Angeles, CA..... 2-59
Figure 2-17. Curb cut directing water from a parking lot into a bioswale..... 2-59
Figure 2-18. Positive Overflow Device: Domed Riser..... 2-63
Figure 2-19. Inlet Structure, County of San Diego, CA..... 2-64
Figure 2-20. Detailed cross-section of a parking lot bioretention cell. 2-64
Figure 2-21. Newly Planted Bioretention Cell in El Monte, CA..... 2-67
Figure 2-22. Cross-section showing design components of permeable pavement with subsurface infiltration bed..... 2-69
Figure 2-23. Water quality benefits of pervious pavement with subsurface infiltration..... 2-71
Figure 2-24. OC Public Works Parking Lot, City of Orange CA..... 2-75
Figure 2-25. Pervious Paver Parking Stalls, Redlands, CA..... 2-75
Figure 2-26. Pervious Paver Driveway, Chino, CA..... 2-76
Figure 2-27. Pervious Concrete Sidewalk, Frontier Project, Rancho Cucamonga, CA..... 2-76
Figure 2-28. Pervious asphalt basketball court at 2nd Ward Neighborhood Park in Upper Darby, PA..... 2-77
Figure 2-29. Pervious asphalt street in residential neighborhood in Portland Oregon. 2-78
Figure 2-30. Pervious paver parking edge in residential neighborhood in Portland Oregon..... 2-78
Figure 2-31. Porous friction course over traditional asphalt. 2-79
Figure 2-32. Close-up showing pervious asphalt pavement atop a stone infiltration/storage bed. 2-80
Figure 2-33. Pervious asphalt parking lot at Flinn Springs County Park in El Cajon, CA..... 2-80
Figure 2-34. Pervious concrete in Cerritos, CA. 2-81
Figure 2-35. Pervious concrete parking areas, Haas Automation, Inc., Oxnard, CA. 2-82
Figure 2-36. Turfstone™ Pavers..... 2-83
Figure 2-37. TurfstoneTM Driveway. 2-84
Figure 2-38. Checker Block® Shoulder. 2-84
Figure 2-39. NetPave® 50. 2-85
Figure 2-40. Permapave. 2-85
Figure 2-41. Uni Eco-stone® Pavers. 2-86
Figure 2-42. Acker-Stone Aqua-Via 2-86
Figure 2-43. Aqua Bric® Type 4 (ADA Compliant). 2-87
Figure 2-44. SF RimaTM Paving Stones at the 2-87
Figure 2-45. Reinforced turf used as overflow parking area..... 2-88
Figure 2-46. Settling Basin with Weir to Filter Underdrain Flow from a Pervious Asphalt Parking Lot in San Diego County..... 2-89
Figure 2-47. Pervious concrete parking lot with river stone edge treatment. 2-92
Figure 2-48. Example detail of an overflow device from a pervious asphalt system..... 2-93
Figure 2-49. Earthen berms separate terraced infiltration beds. 2-94
Figure 2-50. Open-graded, clean, coarse aggregate for infiltration beds..... 2-95

Figure 2-51. Water on Porous Asphalt.....2-96
Figure 2-52. Cisterns used for irrigation.....2-99
Figure 2-53. Outdoor Cistern with Overflow Directed to Pervious Area 2-100
Figure 2-54. Residential rain barrel in Los Angeles.....2-102
Figure 2-55. Large-scale residential system in Los Angeles, CA. 2-103
Figure 2-56. Schematic of Outdoor Underground Cistern with Overflow Directed to Pervious Area 2-104
Figure 2-57. Large cistern for vegetated roof plaza maintenance. 2-105
Figure 2-58. Six (6) 1,000 gallon cisterns at U.S EPA headquarters provide water for irrigation.....2-105
Figure 2-59. Rainstore™ unit beneath brick pavers on a vegetated rooftop plaza. 2-106
Figure 2-60. Rainstore™ units used as the storage element underneath a brick pathway atop a vegetated rooftop plaza. 2-106
Figure 2-61. Demonstration vegetated roof project at EuroAmerican Growers in Bonsall, CA. 2-111
Figure 2-62. Vista Hermosa Park Ranger Station, Los Angeles.....2-113
Figure 2-63. Premier Automotive Headquarters, Irvine. 2-113
Figure 2-64. Green Roof Schematic 2-115
Figure 2-65. Downspout disconnection into vegetated area.....2-118
Figure 2-66. Soil Amending Process. 2-120
Figure 2-67. Filter strip used as pretreatment for highway runoff. 2-122
Figure 2-68. A vegetated swale with curb cuts in Playa Vista, California. 2-124
Figure 2-69. A vegetated swale with curb cuts in Playa El Monte, California.....2-124
Figure 2-70. Infiltration basin.....2-127
Figure 2-71. Infiltration Trench. 2-129
Figure 2-72. Schematic of a dry well.....2-131
Figure 2-73. Dry pond. 2-133
Figure 2-74. Dominguez Gap Wetlands, LA County.....2-135
Figure 2-75. Surface media filter. 2-137
Figure 3-1. *Retrofit of an existing commercial site.* 3-154
Figure 3-2. *Existing residential subdivision.* 3-156
Figure 3-3. LID retrofits to an existing residential lot. These retrofits are to be applied 3-157
Figure 3-4. *Existing commercial development.* 3-160
Figure 3-5. *Proposed retrofits and addition to existing commercial development.* 3-160
Figure 3-6. *Residential subdivision design.* 3-162

List of Tables

Table 2-1. Necessary Data Collection for Site Assessment. 2-6
Table 2-2. Ideal Soil Properties for Infiltration and Pollutant Removal. 2-15
Table 2-3. Examples of LID Principles and Where Within a Project Lifecycle They Can Be Implemented. .. 2-23
Table 2-4. Available Techniques to Preserve Natural Infiltration Capacity. 2-24
Table 2-5. Available Techniques to Help Preserve Existing Drainage Patterns 2-25
Table 2-6. Available Techniques to Protect Existing Vegetation and Sensitive Areas 2-25
Table 2-7. Available Techniques to Minimize Impervious Surfaces. 2-27
Table 2-8. Available Techniques to Disconnect Impervious Areas. 2-29
Table 2-9. Available Techniques to Minimize the Construction Footprint. 2-30
Table 2-10. Pollutants in Stormwater. 2-35
Table 2-11. BMP Functions of the LID BMPs Discussed in this Manual. 2-39
Table 2-12. Structural BMP Performance – Hydrologic Impacts. 2-40
Table 2-13. Environmental Benefits of Structural BMPs. 2-41
Table 2-14. Structural BMP Performance – Influent/Effluent Water Quality. 2-43
Table 2-15. International Structural BMP Performance – Influent/Effluent Water Quality.[1] 2-45
Table 2-16. Structural BMP Site Suitability Criteria. 2-46
Table 2-17. Maintenance Considerations for LID Structural BMPs. 2-47
Table 2-18. Southern California Bioretention BMP Unit Costs 2-50
Table 2-19. National Bioretention BMP Unit Costs 2-51
Table 2-20. Bioretention Soil Medium Specification. 2-61
Table 2-21. Water Quality Benefits of Pervious Pavement With a Subsurface Infiltration Bed. 2-72
Table 2-22. San Diego COC Phase I – Pervious Pavement Costs. 2-73
Table 2-23. San Diego COC Phase II – Pervious Pavement Costs. 2-74
Table 2-24. Open Area Percentage of Several Commonly Used Paver Products. 2-83
Table 2-25. Minimum Pervious Asphalt Pavement Thickness Required to Bear Structural Load on Poor Subgrade with CBR 2. 2-91
Table 2-26. Minimum Total Pervious Asphalt Pavement Thickness Required to Bear Structural Load on Various Subgrades. 2-91
Table 2-27. Typical Domestic Daily per Capita Water Use. 2-107
Table 2-28. Minimum Water Quality Guidelines and Treatment Options for Stormwater Reuse. 2-108
Table 2-29. Filter Strip BMP Unit Costs 2-122
Table 2-30. Vegetated Swale BMP Unit Costs 2-125
Table 2-31. Commonly Used Models for LID Design 2-152

Appendices

Appendix A: LID Nomenclature and Requirements Comparison

Table A-1. BMP-related nomenclature used in California municipal permits found in the definitions or glossary section of the permit.
Table A-2. California regional BMP media terminology and requirements
Table A-3. California regional Hydromodification requirements
Table A-4. California Regional Site Design Requirements
Table A-5. California Regional LID or Water Quality Requirements

Appendix B: Southern California Ecoregions and Vegetation

Table B-1. Climate and Vegetation of the Southern California Coast Ecoregion.
Table B-2. Climate and Vegetation of the Southern CA Mountains and Valleys Ecoregion.
Figure B-1. Coastal Scrub
Figure B-2. Chaparral
Figure B-3. Grassland
Figure B-4. Oak Woodland
Figure B-5. Riparian Woodland.
Figure B-6. Pinyon-Juniper Woodland.
Figure B-7. Pine Forest
Figure B-8. Creosote Bush Scrub
Figure B-9. Joshua Tree Woodland
Table B-3. Southern California Master Plant List
Table B-4. General Plant List
Table B-5. Bioretention Plant List
Table B-6. Vegetated Roof Plant List

Appendix C: California Planning and Regulatory Framework for LID

Figure C-1. LID and CEQA for a Municipality's Development Plan
Figure C-2. LID in the CEQA Process.

Appendix D: LID, LEED, and the Sustainable Sites Initiative

Table D-1. LEED for New Construction Credit Options
Table D-2. LEED for Neighborhood Development Credit Options
Table D-3. Sustainable Sites Initiative Prerequisite and Credit Options

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
BMP	Best Management Practices
BSM	Bioretention Soil Media
Cal/EPA	California Environmental Protection Agency
CASQA	California Stormwater Quality Association
CEC	Cation Exchange Capacity
CEQA	California Environmental Quality Act
COC	County Operations Center
DFG	State Department of Fish and Game
Ep	Erosion Potential
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
HAS	Hydromodification Analysis Study
HCC	Hydromodification Control Criteria
HCOC	Hydrologic Conditions of Concern
HEC	U.S. Army Corps of Engineers, Hydrologic Engineering Center
HM	Hydromodification
HSG	Hydrologic Soil Group
HSPF	Hydrologic Simulation Program – FORTRAN
LEED	Leadership in Energy and Environmental Design
LGC	California Local Government Commission
LID	Low Impact Development
MPO	Metropolitan Planning Organization
MS4	Municipal Separate Storm Sewer System
NJ DEP	New Jersey Department of Environmental Protection
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
OPC	Ocean Protection Council
OPR	State Office of Planning and Research
RWQCB	Regional Water Quality Control Board
SHWT	Seasonal High-Water Table
SLAMM	Source Loading and Management Model
SUSMP	Standard Urban Stormwater Mitigation Plan
SWMM	Storm Water Management Model
SWQDv	Stormwater Water Quality Design Volume
TAPE	Technology Evaluation Protocol – Ecology
TBL	Triple Bottom Line
TSS	Total Suspended Solids
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WERF	Water Environment Research Foundation
WQMP	Water Quality Management Plan
WSS	Web Soil Survey

Glossary

Biofiltration	Strucutral stormwater control practices that detain and biofilter runoff using specific vegetation, mulch, bioretention soils media, aggregate rock, and underdrains. Treatment occurs through filtration, adsorption, ion exchange, biological uptake of pollutants, and in some cases evapotranspiration.
Bioretention	Structural stormwater control practices that biofilter and retain runoff using specific vegetation, mulch, bioretention soils media, aggregate rock, and some cases underdrains. Treatment occurs through filtration, biological uptake of pollutants, adsorption, ion exchange, infiltration and in some cases evapotranspiration.
Caliche	Layer of soil in which the soil particles have been cemented together by lime (calcium carbonate, $CaCO_3$).
Capture and use system	System of devices designed t collect and store rainwater runoff from impervious surfaces for later use.
Constructed Wetlands	Shallow, engineered vegetated systems designed to provide stormwater detention and pollutant removal. A permanent pool of water is present throughout the year or during the wet season in arid climates.
Corrosive soils	These soils are characterized by: high moisture content, high dissolved salts, and high acidity.
Cylinder or double-ring infiltrometers	A method of determining the infiltration rate of soils using metal cylinders to prohibit the horizontal percolation of water. These devices typically provide a direct reading of the infiltration rate.
Downspout Disconnection	Redirection of stormwater from a new or existing downspout to a vegetated area (e.g. a swale or planter box) or a collection system (e.g. a rain barrel or cistern).
Dry Pond	A constructed basin designed to collect and detain a water quality volume of stormwater for a set period of time, normally 24 to 72 hours, before discharging the runoff.
Dry Swale	A vegetated swale that incorporates bioretention features which provide infiltration and water quality treatment while conveying larger flows to supplemental storage BMPs.
Dry Wells	Underground storage facility used to capture and infiltrate runoff from downspouts or small impervious areas. Typical dry wells include a vertical shaft with a collection chamber on top and a gravel percolation bed below designed to percolate storm water runoff.
Ecoregion	Large area of land or water that contains a geographically distinct assemblage of natural communities that: share a large majority of their species and ecological dynamics, share similar environmental conditions, and interact ecologically in ways that are critical for their long-term persistence.

Evapotranspiration	The loss of water from the soil by evaporation and by transpiration from the plants growing in the soil.
Extensive green roof	Green roof 2 to 6 inches in thickness, are the design most often used for stormwater management.
Fragipan	Dense subsurface soil layers that severely restrict water flow and root penetration.
Green Roofs	Vegetated roof systems that filter, absorb, and retain or detain the rain that falls upon them. Green roofs are comprised of a layer of soil media planted with vegetation.
Hydromodification	Changes in natural watershed hydrologic processes and runoff characteristics (i.e., interception, infiltration, overland flow, and groundwater flow) caused by urbanization or other land use changes that result in increased stream flows and sediment transport. In addition, alteration of stream and river channels, such as stream channelization, concrete lining, installation of dams and water impoundments, and excessive streambank and shoreline erosion are also considered hydromodification, due to their disruption of natural watershed hydrologic processes.
Infiltration Basins	Shallow impoundments designed to collect and infiltrate stormwater.
Infiltration Trenches	Narrow trenches that have been back-filled with stone and used to infiltrate stormwater.
Intensive green roofs	Green roofs with soil media greater than 6 inches thick and may be comprised of a wide arrange of vegetation including shrubs and trees.
Low Impact Development (LID)	Storm water management practices in land development with the primary intent to mimic pre-development hydrology and minimize impacts on the natural environment. Low Impact Development techniques include conserving natural systems and hydrologic functions by managing rainfall at the source using design techniques that infiltrate, filter, store, evaporate, and detain runoff.
Lysimeters	Devices used to measure the amount of actual evapotranspiration which is released by plants. By recording the amount of precipitation that an area recieves and the amount lost through the soil, the amount of water lost to evapotranspiration can be calculated y
Media Filters	Flow-through system designed to improve water quality from impervious drainage areas by slowly filtering runoff through a media such as sand or a membrane designed to remove pollutants. modifications.
Municipal Separate Storm Sewer System	Conveyance or system of conveyances that is: owned by a state, city, town, village, or other public entity that discharges to waters of the U.S., designed, or used to collect or convey stormwater (e.g., storm drains, pipes, ditches), not a combined sewer, not part of a sewage treatment plant.

Pervious Pavement	Pavement with voids that allow flows to be passed to a gravel/sand bed below the pavement for storage, treatment, or infiltration.
Pervious Pavers	Interlocking units (often concrete) that provide some portion of surface area that may be filled with a pervious material such as gravel.
Planter Boxes	Constructed “green space” feature that provides a soil/plant mixture designed to provide stormwater capture and treatment.
Proprietary Devices	Stormwater management systems that are modular and/or premanufactured and are sold or distributed by a company for the purpose of the removal and/or treatment of stormwater pollutants.
Reinforced turf	Interlocking structural units that contain voids or areas for turf grass growth and are suitable for traffic loads and parking.
Soil Amendments	Compost, as well as other soil conditioners and fertilizers as appropriate for specific site conditions.
Sprinkler infiltrometers	Device used to measure soil infiltration and runoff using a portable rainfall simulator.
Vegetated Filter Strips	Bands of dense, permanent vegetation with a uniform slope designed to provide water quality treatment for an adjacent runoff source (i.e., impervious area) by allowing pollutant filtering and settling and stormwater infiltration.
Vegetated Swales	Broad, shallow channels with heavy vegetation designed to convey and either filter or infiltrate stormwater runoff.

Executive Summary

This manual was first developed in 2010 by the Low Impact Development Center, Inc,. for the Southern California Stormwater Monitoring Coalition (SMC). Funding for the manual was provided by grant funding from the State Water Resources Control Board (SWRCB), with matching funds from the SMC. In 2010 LID was relativelyl new in California and the purpose of the manual was to provide a resource for jurisdictions, deisgners, contractors, and maintence personnel about LIDnconcepts and implementation techniques. As LID has evolved in California over the past 9 years there was a need to update the manual to reflect this evolution. The manual updates in 2019 focused on minor modifications to integrate lessons learned regarding implementation of LID in Southenr California.

Southern California is facing increased demands from urbanization, which can create adverse impacts to water quality and quantity. Urban areas can discharge polluted runoff and degrade streams, rivers, and alluvial channels. The Los Angeles Region was found to have the greatest number of toxic stream and river sites between 2008 and 2012 by the state-wide Surface Water Ambient Monitoring Program (SWAMP) (SWRCB 2014). Water pollution not only impacts the recreational use and aquatic health of water bodies, but also adds significant cost to cities as they are required to reduce pollution to comply with state and federal water quality regulations. The Southern California region, under the jurisdiction of three California Regional Water Quality Control Boards (RWQCB), is faced with rapid population growth and continuous budget constraints. The region will meet the challenge of improving receiving water quality by implementing Low Impact Development (LID) stormwater techniques.

Worldwide, stormwater is increasingly being managed through the strategies and principles of LID. LID is defined as storm water management practices in land development conducted to minimize impacts on the natural environment. LID techniques include conserving or mimicking natural systems and hydrologic functions by managing rainfall at the source using design techniques that infiltrate, filter, store, evaporate, and detain runoff. It is an innovative approach to urban stormwater management that does not rely solely on conventional end-of-pipe structural methods; rather, it strategically integrates stormwater controls into the urban landscape. Targeted watershed goals and objectives can be addressed through the use of structural and non-structural LID techniques in order to reduce the discharge of pollutants and the effects of changes to runoff patterns caused by land use modifications (hydromodification).

Land developments in Southern California that drain to the Pacific coast and to inland waters and reservoirs have generated significant increases in stormwater runoff volume, which in turn has contributed to the discharge of pollutants into receiving waters, degraded aquatic habitat, impacted recreational use of these waters, and interfered with their use as water supply (SCCWRP 2007; California Department of Water Resources 2009). Implementing LID for new development projects will reduce water quality degradation, but may not be sufficient to account for the existing land disturbance. However, incorporating LID in redevelopment projects can replicate pre-project hydrology and enhance a site's hydrologic function. LID systems function as part of the ecosystem to increase water quality downstream, but note that developed areas with water quality degradation may take longer to respond to incremental implementation of LID, even 50 to 100 years.

Hydromodification has been identified as a leading source of water quality impairment in the United States (USEPA 2017). Hydrologic modifications change a site's runoff and sediment transport characteristics, diminishing infiltration, interception, and evapotranspiration, thereby altering the distribution and flow of water across a site. LID is a design strategy that utilizes decentralized, small-scale source control structural and/or non-structural stormwater practices to meet technical requirements of federal, state, and local government stormwater management regulations, as well as natural resource protection and restoration goals. This approach can be used as an alternative or enhancement for conventional end-of-pipe stormwater pond technology. This alternative tool is important because it has the potential to lessen the energy impacts of large concentrated volumes of runoff from conventional end-of-pipe approaches on receiving waters and to reduce the development footprint and long-term maintenance considerations for end-of-pipe facilities. LID has also been used to meet targeted regulatory and resource protection

objectives. LID addresses hydromodification through the use of “customized” small-scale source controls that allow the designer to select BMPs that best meet the watershed goals and objectives. This approach also allows for the creation of treatment trains, which use a system of different techniques to provide multiple opportunities to reduce pollutant loads.

This LID Manual is to serves as a resource to guide jurisdictions, designers, contractors, and maintenance personnel in the development of design, construction, and maintenance standards and specifications, as well as codes and ordinances, which can support their water quality management and regulatory compliance programs.

How to Use This Manual

This manual provides site planning and design guidance, but given the varying site conditions and regulations throughout the region, individual sites must adapt the guidance to meet the requirements of their particular site. The recommendations in this manual are not intended to supersede local regulations. The manual presents strategies and techniques in a format that will facilitate dialogue between developers, engineers, and local governments to encourage adaptation and integration of these strategies and techniques into local regulatory and watershed protection programs.

In summary, this is a manual of practice for LID that provides:

- Details on how to use LID Principles and LID Best Management Practices (BMPs) to reduce the impacts of land development or re-development on water resources at the project level.
- Guidance for municipalities, land use planners, land developers, consultants, design professionals who prepare stormwater engineering plans and specifications, and others in private industry and public service.
- A site planning and design reference that will facilitate the implementation of LID for projects in Southern California. It is designed to complement the Stormwater BMP Manual(s) that have been developed and are maintained by the California Stormwater Quality Association (CASQA).
- A tool that can be applied at the site level for the development of integrated water and stormwater management regulatory compliance and resource protection programs.

The Manual is structured as follows:

Executive Summary
Provides an overview of the Manual's structure and objectives.

Section 1: The Impacts of Development and How LID Can Help
Describes how LID can be used to address major water quality and regional environmental challenges.

Section 2: The LID Site Planning & Design Process

Step 1: Assess Site
- Outlines the data to be collected prior to site design and directs the user to data resources.

Step 2: Define Goals
- Describes how LID fits into the regulatory environment and how it can be used in green infrastructure.

Step 3: Implement LID Principles (LID Site Planning & LID Site Design) & Evaluate
- Presents site planning strategies to minimize the generation of stormwater runoff.

Step 4: Use LID Structural BMPs to Mitigate Impacts
- Discusses the selection and application of LID BMPs to address unavoidable stormwater runoff.

Step 5: Evaluate Overall LID Site Plan & Design
- Identifies methods for assessing the successful application of LID for a given site. Discusses the use of modeling methods to evaluate LID designs.

Section 3: Case Studies
Presents case studies showing how LID is applied in various contexts.

Appendix A: Ecoregions and Lists of Plants Suitable for LID in Southern California
Provides lists of plants suitable for general landscaping, bioretention, and green roofs in Southern California.

Appendix B: California Planning and Regulatory Framework for LID
Discusses how LID fits into California's regulatory environment.

Appendix C: LID, Leadership in Energy and Environmental Design (LEED), and the Sustainable Sites Initiative
Details how LID can be used to achieve LEED or Sustainable Sites Initiative Certification.

Nomenclature

LID BMP Terminology

LID BMP design requirements found in ten California Municipal Storm Sewer System (MS4) permits (MS4 Permits) were largely developed independently, and as a result, different terminology and specifications were adopted in the regional permits. Definitions relevant to LID BMPs, such as “biofiltration” or “green infrastructure” vary from permit to permit or were not defined at all within the permit glossary. Appendix D lists LID BMP terminology and definitions used in California regional water board regions can be found in Table in Appendix A.

BMP terminology varies widely across MS4 Permits. For example, “biofiltration” was defined broadly except by the Los Angeles permit which defined biofiltration as having an underdrain and the ability to treat 1.5 times the storm water quality design volume of the site. “Green infrastructure” tended to have a common definition that describes it as infrastructure that mimics natural systems with a focus on infiltration, evapotranspiration, or use. The San Francisco Public Utilities Commission (SFPUC) expanded the green infrastructure definition to include pollution reduction, flood protection, and habitat. Most Regional Water Quality Control Boards separate new development into categories based on size and sometimes location. Land development projects that require more stringent BMP and hydromodification standards are called “Priority Development Projects,” or “Regulated Projects.” Most often BMP terminology was not explicitly defined within the permit, most likely due to the variability and complexity of BMP designs.

The primary goal of Low Impact Development is to preserve or restore a site’s predevelopment hydrology. LID should be approached with specific steps, begininning with preventative steps that prevent the increase of the volume and velocity of stormwater from a site through LID site planning (minimizing the generation of runoff) and LID site design (e.g. designing pervious surfaces). After the preventative steps are taken, mitigation steps use structural LID measures (e.g. bioretention) to mitigate the impacts of the development.

Site Design Requirements

Site Design requirements focus primarily on the function of LID BMPs on a site; such as conserving natural areas, using permeable materials, and minimizing soil compaction. Regional site design requirements retain the same general focus, but vary in requirement details, as seen in Table (Appendix A). Some permits provide only a few broad requirements, such as minimizing impervious surface area and controlling runoff from impervious surfaces, whereas others outline ten or more practices.

LID or Water Quality Sizing Requirements

LID (also called Water Quality) sizing requirements are based primarily on the volume of water to be retained on site for a specified storm size or the amount of runoff flow to be treated by a biofilter or biotreatment BMP. Table lists permit requirements for LID sizing . Permits list either volume design criteria, flow design criteria, or both, such as these examples:

- Volume retainment design criteria:
    - 80% or more annual runoff
    - 95th percentile, 24-hour storm
    - 85th percentile storm event
    - 0.75-inch, 24-hour rain event
    - Rainfall intensity of 0.2 inch of rainfall per hour
- Flow hydraulic design basis:
- 10 percent of the 50-year peak flow rate
- Runoff resulting from at least 0.2 inches per hour intensity

- Runoff resulting from two times the 85th percentile rain event

Hydromodification Requirements

Hydromodification requirements in Southern California address increases in the volume and velocity of stormwater runoff caused by land development. Hydromodification requirements vary across permit regions. For example, the percent difference of runoff conditions allowed from predevelopment hydrology ranges from five to twenty percent. Table Appendix A compares the hydromodification permit language. A summary of key requirements is outlined below:

- Post-project runoff not to exceed pre-project water balance
    - Up to 85th percentile storm event
    - Up to 2-year frequency storm
    - Up to 2-year, 24-hour storm
    - Up to 10-year, 24-hour storm
    - Post- project runoff shall not exceed estimated pre-project rates and durations
    - The maximum flow rate of runoff for each hour of a storm event, as determined from the local historical rainfall record that achieves approximately the same reduction in pollutant loads and flows as achieved by mitigation of the 85th percentile hourly rainfall intensity multiplied by a factor of two
- Post development conditions of sediment transporting flows in receiving waters
    - Approximate the pre-project erosive effect
    - Not cause an increase in the erosion potential
    - Have an Erosion Potential value of 1
    - Avoid critical sediment yield areas, allow critical coarse sediment to be discharged to receiving waters, such that there is no net impact to the receiving water
- Maintain evapotranspiration volume and rate
    - At pre-development levels
- Maintain infiltration to support baseflow and interflow to wetlands and surface waters, and deep vertical infiltration to groundwater
    - At pre-development levels
- Maintain chemical attenuation through sequestration, degradation, and rate of chemical delivery to receiving waters
    - At pre-development levels

Characterizing Bioretention Soil Media

Bioretention soil media design (such as depth, infiltration rate, and composition) is a key part of bioretention and biofiltration functionality. However, since bioretention soil media terminology and requirements have been established independently across the California water board regions, different specifications and terminology have developed in different regions. Table in Appendix A outlines bioretention soil media requirements by permit.

Bioretention soil media specifications are found either directly in the stormwater permit, or in separate referenced documents such as guidance manuals or BMP fact sheets. When outlining BMP design specifications, California permits either:

- Included specific BMP media requirements within the permit
- Referred to an older permit version that included requirements
- Dedicated a separate appendix for BMP design specifications
- Referred to a separate guidance document or manual for BMP design

Some documents outlined specific requirements such as minimum media depth, infiltration rate, and media type, whereas other documents outlined general BMP design requirements and deferred to individual project proponents to create BMPs to meet those standards. Those documents that do specify BMP media composition and/or depth tended to include one or more of the following requirements:

- Minimum media depths ranging from required depths of 18 to 24 inches; 36 inches of media is recommended if possible
- Minimum infiltration rate of 5 to 12 inches per hour
- Planting media consisting of 60 to 80% fine sand and 20 to 40% compost
- Minimum subsurface gravel depth of 12 inches

Section 1 The Impacts of Development and How LID Can Help

The primary goal of Low Impact Development is to preserve or restore a site's predevelopment hydrology. There are many potential benefits associated with the use of LID practices. Using LID for stormwater management provides multiple environmental, economic, and social benefits, in addition to providing hydrologic and water quality improvements as identified below. One of the advantages of LID practices is the ability to integrate vegetated LID features, such as bioretention, as part of the overall landscaping for a site, which essentially turns non-functional landscaping into functional landscaping serving a stormwater purpose. This approach can be implemented for new or retrofit applications and in many cases, areas allocated for landscaping can accommodate vegetated LID practices without allocating additional space for LID features. Integrating LID into landscaping should consider the amount of vegetation planned for a development, associated water needs, as well as maintenance considerations.

Potential Environmental Benefits

- Improved water quality
- Runoff volume and rate reduction
- Groundwater recharge/water supply
- Terrestrial and aquatic habitat preservation
- Habitat creation
- Enhanced soil health
- Reduced potable water and energy demand through stormwater capture and use
- Improved air quality
- Carbon sequestration
- Climate resiliency
- Recycling and beneficial reuse
- Reduction in urban heat island effect

Potential Economic Benefits

- Reduced construction and maintenance costs (see SPU Cost-Benefit Analysis in *References and Resources* below)
- Reduction in drainage and flood control infrastructure
- Land space reduction for BMPs
- Reduction of potable water demand
- Increased water supply through direct use and/or groundwater recharge
- Increased land values[1]
- Improved marketability
- Reduced energy and water supply costs

Potential Social Benefits

- Improved aesthetic value
- Provides "green job" opportunities
- Educational opportunities
- Health benefits (associated with additional green space)
- Recreational benefits (associated with green spaces)
- Sound reduction (green roofs and vegetated LID)
- Traffic calming (associated with green streets)

Examples of where multiple benefits have been realized in LID with a more balanced approach include:

- Green streets – Improved water quality, traffic calming, increased land values, improved aesthetics, sound reduction, education, carbon sequestration, urban heat island reduction, etc.
- Green roofs - Runoff volume and rate reduction, habitat creation, improved air quality, energy cost reduction, icreased land values, aesthetics, recreation, sound reduction, etc.
- Porous pavement - Runoff volume and rate reduction, groundwater recharge, land space reduction, improved marketability (pavers), education, enhanced soil health, etc.

[1] See CA LID Portal Toolbox – LID Economics https://www.casqa.org/resources/lid/toolbox

Land Development Effects

Land development adds impervious surfaces such as rooftops, roads, and parking lots to the natural environment. As a result, the quantity and velocity of runoff increases, the amount of water that infiltrates to groundwater decreases, and pollutants deposited on the impervious surfaces are washed into stormwater conveyance systems and water bodies.

Typical alterations due to development may include:

- Increased imperviousness
- Increased runoff volume
- Reduced infiltration/groundwater recharge
- Introduction of new pollutants into watershed
- Increased pollutant concentrations
- Impacts to streams and channel banks

As a result of expansive development, the current hydrologic cycle in Southern California bears little resemblance to the natural system of a century ago. For example, in the 1920's approximately 95 percent of rainfall in Los Angeles was either infiltrated or evaporated, but that has dropped to approximately 50 percent as result of urban development (Green 2007). The amount of rainfall infiltrated or evaporated has likely increased since 2007 with the integration of LID and green infrastructure in Los Angeles since then. Although it may not be feasible to restore natural hydrology in much of Southern California due to the integration of managed stormwater systems with significant flood control and stormwater infrastructure in many locations, LID can assist in reducing the impacts on this infrastructure through retention and reducing velocities of stormwater discharging from sites. Additionally, integration of LID has the advantage of retention of pollutants and helping to restore the water quality of our receiving waters as well as assisting in restoring or preserving a more natural hydrology onsite. Additionally, LID provides the opportunity to help achieve better integrated water resource planning through LID site designs, stormwater capture and use, recharge of groundwater, and more functional and sustainable landscapes.

The primary goal of LID is to preserve a site's predevelopment hydrology. The effects of changes to runoff patterns caused by land surface modifications, or hydromodification, can be reduced through the use of site planning and design (non-structural) and the use of structural techniques l that store, infiltrate, evaporate, and detain runoff. Achieving site design goals and meeting hydromodification regulations often requires consideration design for detention of the larger storm events (up to the 10-year event), beyond LID design storm, that play a significant role in hydromodification, in addition to the smaller storms that are largely responsible for deteriorating water quality. Land use modifications may impact every aspect of site development and affect the hydrologic response of the site.
Error! Reference source not found. Figure 1-2 illustrates effects of development on surface runoff. The hydrologic response of a site is affected by every aspect of site development. Connected impervious areas and soil compaction characteristic of developed sites can cause runoff to be generated from even small amounts of rainfall. This results in an increase in volume and velocity of runoff, thereby increasing generation of sediment and suspended solids resulting from erosion of exposed soil and receiving streams downstream of development.

Both LID and conventional stormwater management techniques attempt to control rates of runoff using accepted methods of hydrologic and hydraulic analysis, but conventional approaches typically include only the hydrologic components of precipitation, runoff conveyance and storage capacity. LID site design recognizes the significance of other components of the hydrologic cycle as well. How these other hydrologic components are taken into account will depend on the data available and purpose of the design. There are many site design techniques that allow the site planner/engineer to create stormwater control mechanisms that function in a manner similar to that of natural control mechanisms. If LID techniques can be used for a particular site, the net result will be to more closely mimic the watershed's natural hydrologic functions or the water balance between runoff, infiltration, storage, groundwater recharge, and evapotranspiration. With the LID approach, receiving waters may experience fewer negative impacts in the volume, frequency, and quality of runoff, so as to maintain base flows and more closely approximate predevelopment runoff

conditions. In Southern California in the natural environment much of the smaller storm events evapotranspire through native vegetation and there is minimal infiltration, which is a consideration in the integration of LID and helping to restore and preserve hydrology for a site. Vegetated LID systems can help to mimic this evapotranspiration as even with biofiltration systems with underdrains a significant volume of stormwater is retained through evapotranspiration.

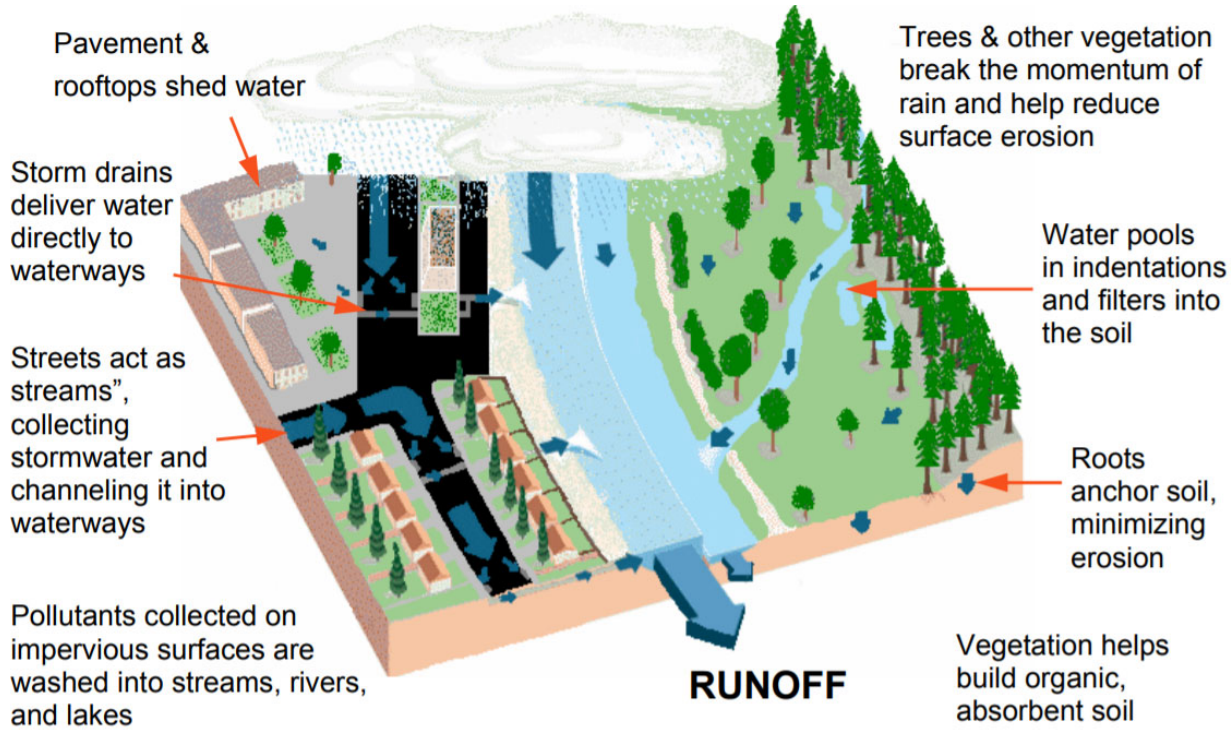

Figure 1-1. Urban influences on stormwater runoff.

Source: California Water & Land Use Partnership 2012

Considerations and Challenges

LID is one of the primary tools in the stormwater management tool box. However, regional solutions to stormwater management can also provide additional benefits such as groundwater recharge and water supply. Understanding the goals of a stormwater management strategy including those beyond water quality and hydrology will help to identify if an LID approach, regional approach, or other approach is appropriate. In Southern California, due to frequent drought and potentially the effects of climate change, capture and use of stormwater is strategy that is often considered. Capture and use of stormwater can be implemented on a regional or distributed scale with use of LID systems; however, there are limitations and barriers to implementation of capture and use in California[2].

LID also presents opportunities as a tool in the stormwater management tool box. As multiple benefits are evaluated and integrated with watershed planning and specific watershed improvement projects, approaches for identification and quantification of credits for water quality, water conservation or supply

[2] See Strategy to Optimize Resource Management of Stormwater (STORMS) Projects 1a Promote Stormwater Capture and Use and 1b Identify and Eliminate Barriers to Stormwater Capture and Use Product 1–Final Report: Enhancing Urban Runoff Capture and Use April 10, 2017

augmentation, and hydromodification reduction that can be achieved should be evaluated. Water quality credit and trading programs offer an opportunity for more rapid achievement of water quality improvement goals and the ability to use free market forces to help drive building stormwater capture capacity in a watershed. Water quality credit generating facilities can occur on a regional and/or distributed scale and LID as well as regional stormwater systems offer opportunities for generation and sale of water quality credits. In addition to water quality credits, water supply, and hydromodification, other credits are potentially available that could make a stormwater project more attractive and sustainable. Carbon sequestration credits with the integration of LID vegetated systems offer an opportunity to potentially bank credits while achieving water quality and hydrologic goals as well. Climate resiliency credits may also be appropriate for the implementation of LID vegetated systems.

Implementation of LID can also be encouraged with incentive programs. Many municipalities have implemented LID incentive programs, which are variously based on a stormwater fee discount or credit, development incentives such as waiver of permit fees, rebates on installations, installation financing, and/o awards and recognition programs. LID incentive programs reduce the impact and burden on municipalities for achieving water quality goals. Incentive programs can also be coupled with water quality credits.

Regulations do affect the configuration and placement of LID systems. An example of this is with the Waters of the United States (WOTUS) rule with the definitions of “intermittent” and “ephemeral” streams that may affect placement of LID systems in California. Another example is MS4 permit sizing requirements.

LID also presents some significant challenges with the two most difficult being retrofit constraints and ensuring maintence is adequately perfromed. Integration of LID in the urban environment in a retrofit or redevelopment situation presents many challenges. Within the built urban environment there are significant space limitations both on the surface and underground with underground utilities. LID systems do require some space and that space may not be available in the urban environment. Additionally, structures in the urban environment need to be protected and infiltration of water adjacent to structures is not feasible. Even if space is available for implementing LID systems space may not be available to perform maintenance on the LID system. Urban environments also present challenges with pedestrians and homelessness that may affect the ability to implement these systems. Southern California also presents challenges with drought and feasiibity of some plants and the need for irrigation of some vegetated LID systems.

The other primary challenge for LID is maintenance. Many LID structural measures are both engineered and vegetated systems and so proper education and training is necessary to ensure adequate maintenance and function of these systems. As distributed BMPs, LID requires a number of smaller systems as opposed to regional or centralized structural BMPs, which may result in an increased amount of maintenance cost. Proper construction of LID systems can also be challenging as minor modifications in construction as well as lack of protection of the location of LID systems during construction can also have a significant impact on their performance. Contractors and those installing LID systems should be properly trained about LID systems, so they understand their purpose and design and how to best protect LID system locations during construction. Inspections during construction, at completion of construction for commissioning of LID systems, and during operation to evaluate the need for maintenance also pose specific challenges. Inspectors need to be properly trained regarding LID systems, what information they should have during an inspection, and what they should be looking for depending on the type of inspection being performing.

Hydrologic Cycle Effects

A consideration when evaluating how to reduce and mitigate the impacts of stormwater is the pattern of rainfall in the watershed. The Southern California region experiences strong seasonal rainfall variation, with the wet season typically extending from October through April and virtually no rain from May through October. The region's diverse topography and climatic zones results in a high degree of regional variation in total rainfall and storm size. Annual rainfall totals can vary greatly from year to year. These variations will affect the feasibility, effectiveness and as a result the selection of various LID practices. In addition to evaluating local climatic conditions in LID selection and sizing for stormwater benefits, it is necessary to understand the local hydrologic cycle in order to mimic the natural hydrologic function of a site (Figure 1-1).

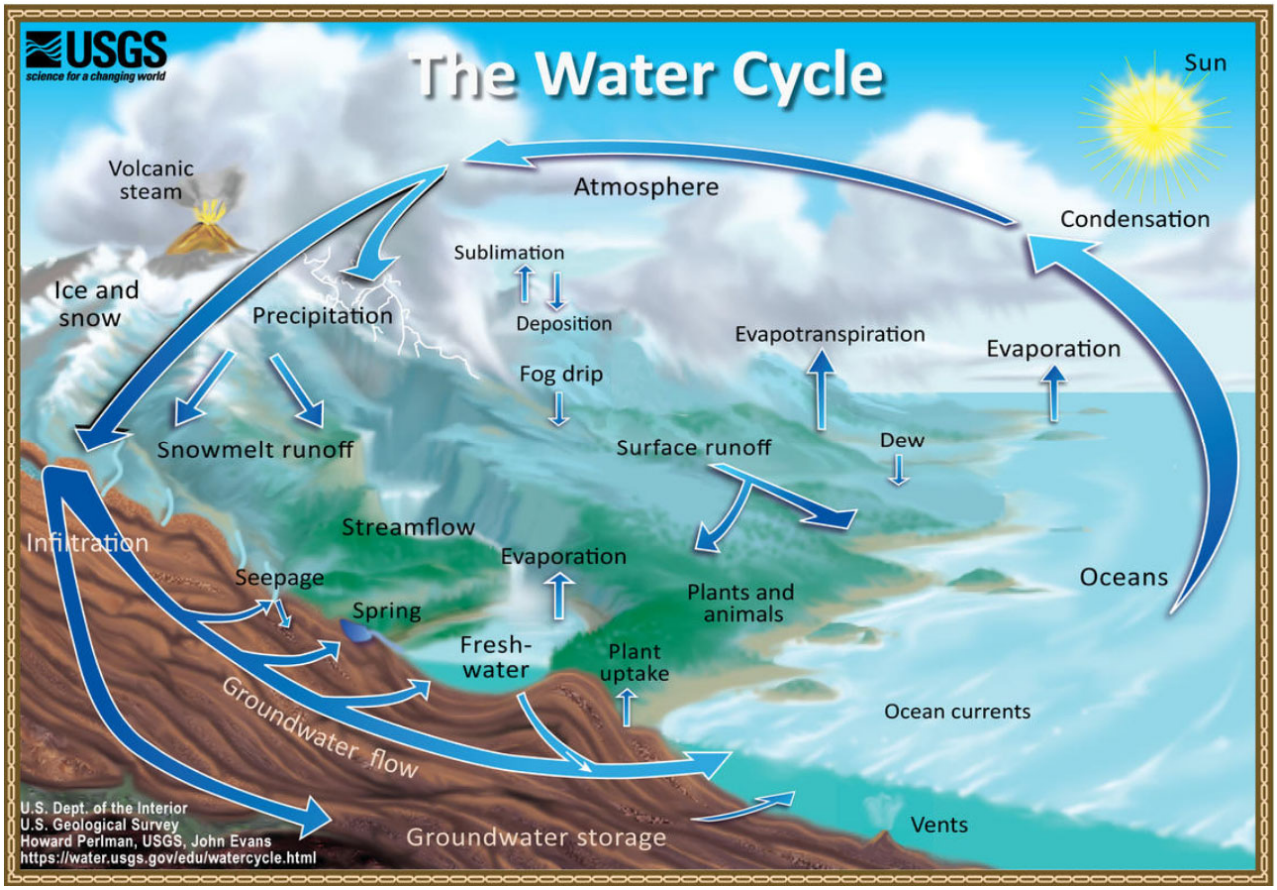

Figure 1-2. The Hydrologic Cycle.

Source: USGS 2019

Hydrologic cycles in the various regions of Southern California have difference rates of water transfer fluxes based on the amount of precipitation received. For example, in the northern part of Southern California, Pasadena receives 20 inches per year, while San Diego in the southwest receives just 10 inches. Los Angeles falls in the middle, averaging 15 inches per year. The low rainfall and high population of Southern California have led to increasing concern over water importation, and increased efforts to manage groundwater resources and promote groundwater recharge (EMWD 2005; OCWD 2015).

Section 2 The LID Site Planning and Design Process

This manual establishes a framework for the LID site planning and design process. LID cannot be effectively implemented as an afterthought, with a few BMPs placed on an otherwise conventionally designed site. Proper implementation of LID techniques involves specialized site planning methods which are intended to be integrated into the overall site design. On a LID project, consideration of hydrologically important natural resources such as soils, vegetation, and flow paths will influence the placement of buildings and paved surfaces, and as such LID needs to be considered at the earliest planning stages of a project. The below figure outlines the general steps to LID Site Planning and Design (Figure 2-1).

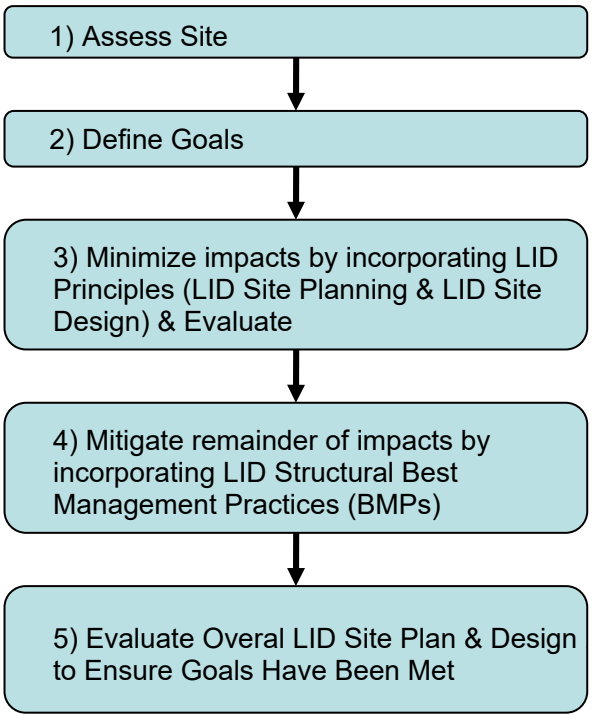

Figure 2-1. The LID Site Planning and Design Process

A common misstep of developers and engineers is to wait until the final stages of development planning and design to attempt to incorporate LID, which often ends up requiring the loss of planned building space – or a costly re-design of the site. When LID is considered from the beginning, many designs can adequately meet the requirements for a project without significant loss of building space.

LID Planning

The process of planning a LID project, as outlined in Figure 2-1, begins with a comprehensive understanding of the unique features of the site to be developed, which will guide the development of goals for the site. This is the LID site planning for the site, which can be used for new development, redevelopment as well as in a retrofit scenario where the integration of LID is the main purpose of the project. Site planning, developing site goals, and site design is different for retrofit of a site, but this same process can be used only with consideration of different constraints that retrofit of a site presents. The next step is identification of the goals for a site which may emanate from regulatory requirements (i.e., MS4 Permit) or other drivers (e.g., LEED) for integration of LID into a site. Retrofit of a site with LID may include its own drivers that include regulatory drivers such as Total Maximum Daily Loads or watershed planning requirements other drivers such as water quality credit and trading, sustainability goals, or funding drivers such as bonds or grants. Next, LID site planning is performed for the site that includes a process to guide the creation of a site plan that works with the site's natural features and minimizes the generation of runoff,

through proper site layout to assist in maintaining the natural hydrologic functions of a site. Site planning should also be performed in a retrofit scenario to identify if the site can be replanned to meet the retrofit goals. Site design elements to reduce and disconnect impervious areas are then integrated. Site design elements may also be able to be integrated in a retrofit scenario. Once a sound site plan has been created that integrates LID site planning techniques and LID site designs, the site should be evaluated towards meeting the site goals. This will help to identify the volume of stormwater that needs to be managed by structural LID BMPs, which are then included to address the remaining stormwater runoff to achieve the identified site goals. The overall site plan with the LID Site Planning and LID Site Design and the LID structural BMPs is then evaluated to ensure that the goals identified for the site have been met.

In many cases the LID Site Design Process can take place in a linear fashion, in some cases steps three through five can be an iterative process, where site planning and design (non-structural) and structural design elements are added and adjusted in response to the modeling results until the project goals are met.

One of the primary goals of LID are to maintain or restore hydrologic function. The below chart outlines the process for designing LID to meet this goal (Figure 2-2).

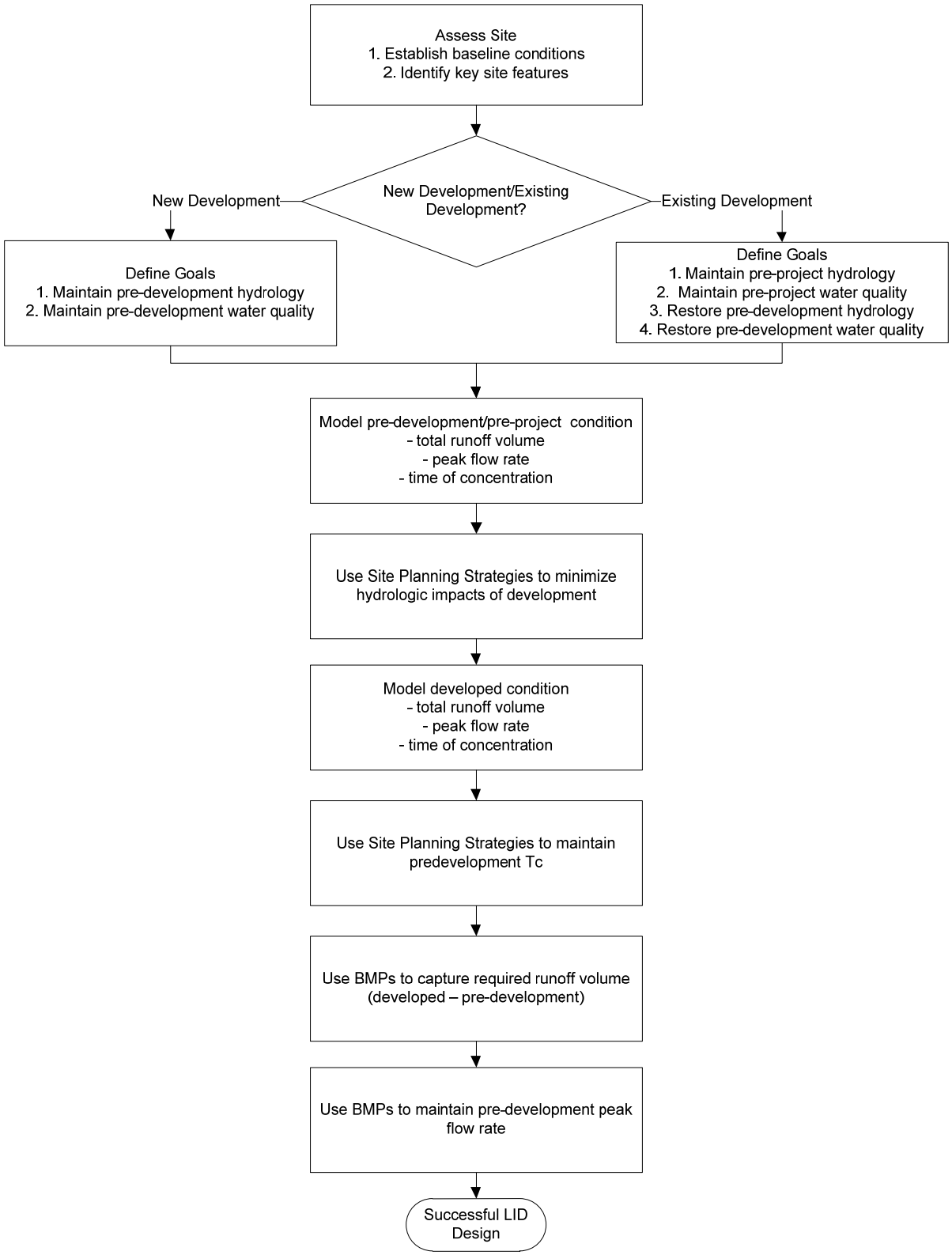

Figure 2-2. Use of the LID Site Design Process to Maintain or Restore Hydrologic Function.

Source: The Low Impact Development Center, Inc.

This LID site planning and design process is adaptable to a wide range of sites, economic constraints, and regulatory requirements, including those associated with new development, redevelopment, and retrofits, which may be subject to a variety of water quality, water quantity, and other requirements (Figure 2-3). These factors drive the site plan and design and guide the selection of the most appropriate practices and structural BMPs for the site.

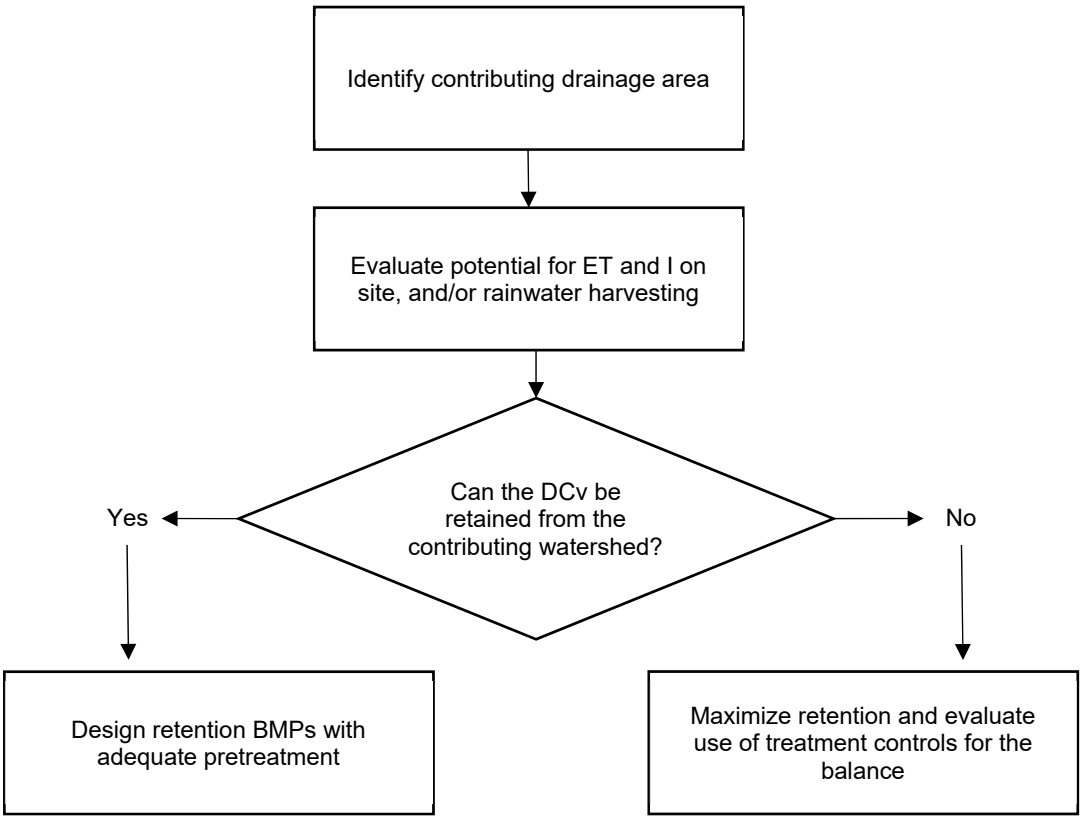

Figure 2-3. Municipal Retrofit Flow Chart.

The LID Site Planning and Design Process can be expected to require the balancing and rebalancing of a myriad of requirements placed on today's development projects in addition to those for water quality and water quantity, from the Americans with Disabilities Act requirements to xeriscaping requirements. Through the LID Site Planning and Design Process, the project professional must search for a balance that meets all requirements within the project budget.

Economics of LID

The economics of LID are influenced by many factors, and the costs to implement LID will likely be a key factor in the level of LID implementation. New development projects are expected to provide the most economical opportunities for LID implementation. In new development, LID can be integrated into a project from its initiation when there are usually fewer project constraints and where LID features may be used in lieu of conventional, non-LID features, potentially at savings to the project. Redevelopment and retrofit projects are expected to present more constraints to LID implementation, and these constraints are expected to make LID implementation on these types of projects costlier than in new development.

The economics of LID implementation in any given situation warrants evaluation of capital and lifecycle costs as well as the value of the multiple benefits that LID features provide. The capital cost analysis should include not only the cost to implement LID features, but also the potential savings in other features resulting from LID implementation. For example, a pervious paver parking lot may cost more to implement than a conventional asphalt concrete parking lot, but these costs may be offset by a reduction in storm drain costs or structural control BMP costs made possible by the runoff reduction provided by the LID BMP. The lifecycle cost analysis should include not only the operation and maintenance costs, but also the potential savings in energy use and replacement costs. In the previous example, a pervious paver parking lot may have a life two to three times the life of an asphalt concrete parking lot, resulting in replacement savings. Perhaps the most complicated economic factor associated with LID is appropriately valuing the other multiple benefits of LID for a development site. A triple bottom line (TBL) sustainability analysis can be performed to evaluate the value of the multiple benefits that LID provides. Guidance for performing a TBL analysis for stormwater and LID can be found at the California LID Portal.

Step 1: Conduct Site Assessment

A comprehensive site assessment is a fundamental starting point in the development of a LID site plan. The site assessment will be a compilation of data from a variety of sources. These sources range from on-site visual inspection to professional surveys with a certified survey team to take accurate measurements onsite and geotechnical investigations and reports. The most important component of the site assessment process is the evaluation of the existing soils and drainage on-site and how they relate to the selection of specific LID practices.

The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Web Soil Survey (WSS) is a common starting reference for the preliminary investigation of site suitability for LID. Soil Surveys include a plethora of planning level information for a site, from soil types to hydrologic soils groups. This resource can be used to develop a preliminary understanding of how LID would be best applied to the site. After the preliminary assessment of site soils has suggested the general site layout, then a site-specific geotechnical evaluation of soils is warranted. By conducting a geotechnical evaluation of site soils early in the LID Design Process, decisions regarding specific LID measures can be made with a higher degree of certainty, potentially reducing the number of iterations required to integrate LID into the site design.

The objective of the site assessment is a detailed site map, showing all of the data collected. This map will guide the selection and placement of site development features (roads, parking lots and structures) using LID site planning and LID site design techniques (non-structural BMPs), and structural BMPs.

The following list represents the foundation data for a comprehensive site assessment:

- Hydrology
- Topography
- Soils
- Geology
- Vegetation
- Eco-region
- Sensitive and Restricted Areas
- Existing Development
- Contamination
- Geological Considerations
- Receiving water quality concerns (303 (d) or other)
- Utility locations (existing developed sites)

Table 2-1 outlines each of the site assessment elements, what specific data should be collected and sources for the data of interest. Additional detail can be found in the sub-sections that follow.

Depending on the complexity of the site, a team of specialists may be required in order to conduct a thorough site assessment. These professionals may include: geotechnical engineers, surveyors, soil scientists, and restoration ecologists.

Table 2-1. Necessary Data Collection for Site Assessment.

Factor	Data of Interest	Data Sources	Development Stage
Hydrology	• Streams and receiving waters • Floodplains • Flow paths • Upslope drainage • Connection to existing drainage	• Geographic Information Systems (GIS) maps • Professional property survey • National Atlas • FEMA Map Service Center	• Hydrology Study (usually prior to CEQA)
Topography	• 1' contours • Elevations of existing curbs and gutters	• Professional property survey • GIS maps • As-built drawings	• Phase One site assessment (usually part of due diligence)
Soils & Geological Considerations	• Hydrologic Soils Group • Soil texture • Impermeable or restrictive layers • Depth to bedrock • Depth to groundwater • Infiltration rate • Landslide potential	• NRCS soil maps • Professional soil testing • Assessment by geotechnical engineer	• Phase One site assessment • Geotechnical Report (usually prior to CEQA and included in CEQA document; often part of WQMP but best done earlier)
Vegetation	• Existing cover • Existing plant communities • Well-established trees	• GIS maps • Professional site survey	• Biological report (almost always done before CEQA and included in the circulated CEQA document)
Ecoregion	• Ecoregion	• USDA Forest Service • USEPA	• Biological reports
Sensitive and Restricted Areas	• Wetlands • Streamside Management Areas • Watercourse and Lake Protection Zones • Floodplains • Established trees • Intact forest • Habitat for threatened or endangered species • Easements • Underground storage tanks • Underground utilities	• Local County/City • California EPA • Deed search • Site survey	• Biological report • Jurisdictional delineation (almost always done before CEQA document prepared) • Special surveys (vireo, fairy shrimp, etc.) almost always done before CEQA document is prepared • Phase One

Factor	Data of Interest	Data Sources	Development Stage
Existing Development	• Buildings • Paved areas • Landscaped areas • Utilities	• As-built site plans • Site Survey	• Many venues for gathering this information
Contamination	• Brownfield designation • Abandoned landfills • Groundwater contamination	• Local County/City • USEPA • California EPA • California Department of Toxic Substances Control	• Phase One
Receiving Water Quality Concerns	• 303(d) Listings • TMDLs • Hydromodification Conditions of Concern • Bioassessment Data	• State 303(d) List • Basin Plan • Hydromodification Management Plans • Bioassessment Monitoring	• Receiving Water Impacts Evaluation
Utility Locations (Existing Developed Sites)	• Locations of existing utilities	• Existing facility as-builts • Utility agencies • Dig Alert • Utility Mapping (Use of Ground Penetrating Radar)	• Existing utilities report • Existing facility as-builts

Source: The Low Impact Development Center, Inc.; Modified 2019 by SMC CLEAN

LID Site Assessment – *Existing Hydrology*

One of the key pieces of the site assessment will be to map the site's existing hydrology. The map should include:

- Onsite streams and other water bodies
- Existing flow paths
- Floodplains
- Depth to groundwater
- Connections to and routing of existing storm drain systems
- Receiving waters
- Upslope drainage

Much of this information may be available from city and county municipal agencies. Where such data is not available, the site will need to be mapped by a qualified professional.

Existing flow paths and upslope drainage concerns can be assessed by examining topographic maps of the site. Topographic maps can either be obtained through the United States Geological Survey (USGS) website, as discussed in the next section or based on site specific surveys performed for the site.

Information on depth to groundwater can be found in the Natural Resources Conservation Service (NRCS) Web Soil Survey.

One of the best ways to get a sense of how water moves on the site is to visit during a heavy rain and taking note of where the water flows, or looking for evidence of channeling, rills, or sediment deposition.

Additionally, the site should be placed in the context of the larger watershed. Identify any special concerns in the watershed. Find out whether the receiving waters are listed as impaired under section 303(d) of the Clean Water Act. The list is maintained by the State Water Resources Control Board (http://www.waterboards.ca.gov/water_issues/programs/tmdl/docs/303dlists2006/epa/state_usepa_combined.pdf). If the receiving water is listed, the development may be subject to additional regulatory requirements.

Resources

USDA NRCS Web Soil Survey: http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

USGS National Water Information Service: http://water.usgs.gov/nwis

Guidance for performing a TBL analysis for stormwater and LID can be found at the California LID Portal.

Clean Water Act Section 303(d) list:
http://www.waterboards.ca.gov/water_issues/programs/tmdl/docs/303dlists2006/epa/state_usepa_combined.pdf.

LID Site Assessment – *Topography*

The topography of the site defines both the location and capacity requirements for potential LID implementations. The topography of upstream and downstream sites should also be considered with respect to any potential contribution to the total runoff generated during a storm event.

To design effective LID into new or existing sites requires a careful analysis of the topography and how and where stormwater runoff will concentrate and flow. Visiting the site during a storm event can provide an enormous amount of information regarding areas of concentration and flow. In the event preliminary data cannot be found, a topographic survey should be ordered prior to proceeding with the design phase of the project.

To be able to perform a detailed topographic site analysis, the following information must be acquired and evaluated:

- A detailed site topographic map showing the smallest contour interval possible; a contour map showing the contours at a 1-foot interval is preferred. For initial planning and scoping purposes, additional intervals can be interpolated from maps with larger intervals if necessary. If possible, try to obtain as-built drawings that may exist from previous construction.
- The location and elevation of existing drainage or stormwater structures, including the elevation of the rim of the structure where stormwater enters and the inverts of drainage pipes entering or exiting the structure.
- Elevation of all curbs and gutters on the site. The drawing should show top of curb and bottom of curb elevations. High and low points of walkways, driveways, and parking areas should also be noted.
- Location of drainage swales on the site. Indicate the flow direction in the channel for reference.

Check with the property owner and/or city/county offices for as-built drawings that might be available.

The local county GIS office may have a topography layer available that could provide working information, but keep in mind this data is typically not survey-quality data and should only be used for preliminary evaluation of the contributing watershed for your site LID BMPs.

USGS 1:24,000 Quad maps can be used to calculate the contributing watershed on larger sites.

Resources

USGS Topographic Maps: https://www.usgs.gov/products/maps/topo-maps

LID Site Assessment – *Soils and Geology*

As many LID BMPs are designed to infiltrate runoff, understanding the site's soil characteristics will help focus efforts on measures that are most appropriate for managing stormwater on the site. This section describes considerations for assessing the site's soils that will help inform the placement of buildings and paved areas and suggest the most suitable BMPs and where they would be best placed.

Failure to understand the characteristics and capabilities of the specific site soils results in poorly functioning LID designs. Proper understanding of the analysis and application of soil type and its capacity to infiltrate stormwater and mitigate pollutants is imperative to the success of any LID implementation.

The following is a summary of soil considerations that should be assessed for the site. Additional information on each of these is provided below:

- Initial Soils Assessment
    - Hydrologic Soils Group

- On-Site Soils Assessment
    - Measured infiltration rates
    - Trench / Boring Logs
    - Depth to or presence of limiting soil types, i.e. expansive soils, caliche, fragipan, corrosive soils
- Geologic Assessment
    - Depth to bedrock
    - Depth to water table
    - Susceptibility to landslides

Initial Soils Assessment

Information regarding a site's hydrologic soils group can generally be gathered from available regional soils studies and may *only* be used as a preliminary source for soil characterization and early planning. When this information is used to estimate infiltration rates or BMP sizes, as well as the use of a safety factor based on jurisdictional design guidance is appropriately applied – and can usually be reduced once on-site testing has been completed. Site specific soil testing, by a qualified civil or geotechnical engineer, is essential before preliminary and final design and implementation of LID projects in order to confirm soil properties including infiltration capacity and should be done as early in the design process as possible.

The NRCS has compiled soils data on the USDA website. The online soil survey is called the Web Soil Survey and can be viewed at the following URL: http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm.

In the event the WSS is unable to provide a soil map for the site of interest, which is often the case in areas of urban development, soil maps may be available from state or municipal government agencies. The local NRCS office may have access to published printed soil survey data which has not yet been posted online.

Soil series are assigned a Hydrologic Soil Group (HSG) rating, A through D, which describes the physical drainage and textural properties of each soil type and is useful for stormwater, wastewater, and other applications. This HSG rating is usually based on a range of permeability, as well as certain physical constraints such as soil texture, depth to bedrock, and seasonal high water table (SHWT). Soil types assigned an HSG Group A classification are very well drained and highly permeable (sand, loamy sand, sandy loam); Group D soils (clay loam, silty clay loam, sandy clay, silty clay, clay) are poorly drained and often situated in a valley bottom or floodplain. HSG-rated B and C soils offer good (B; silt loam, loam) to fair (C; sandy clay loam) drainage characteristics (USDA 1986). The heavier D soils have little if any infiltration potential during rainfall events and produce much greater surface runoff in response to rainfall. Many soils in Southern California are classified with an HSG rating of C or D, which are usually not especially

conducive to and will limit applicability of infiltration practices. In fact, data for the six counties covered by Regional Boards 4, 8, and 9 indicates that 3% of the soils are classified as A, 17 percent of soils are classified as B, 30 percent as C, 33 percent as D, and 16 percent as Urban Soils (see 6). It should be noted that the permeability ranges listed for the HSG ratings are based on the minimum rate of infiltration obtained for bare soil after prolonged wetting. (USDA 1986). Figure 6 identifies that infiltration of stormwater may be challenging in many areas with the majority of soils in Southern California being HSG Group C and D.

These NRCS soil maps can be used to identify areas with potentially high infiltration rates (HSG Group A and B), which are potential areas for locating infiltration-based BMPs. Where possible, buildings and paved surfaces should be sited on less permeable soils.

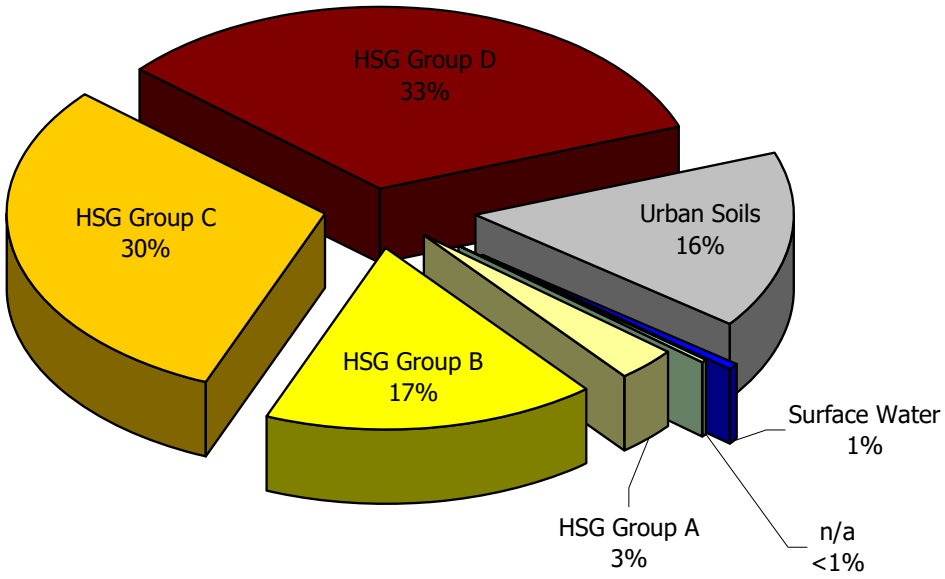

Figure 2-4. Hydrologic Groups for Southern California Soil Series

Source: USDA NRCS U.S. General Soils Map (STATSGO)

Although initial soils information may be estimated using regional soils studies (typically using web-based or GIS data), in most cases this will not be an adequate replacement for on-site analysis. Additionally, it is important to adequately understand and characterize the infiltration capacity of the entire soil profile, as deeper soils may be more limiting to infiltration than surface soils.

On-Site Soils Assessment

Infiltration Testing

Infiltration tests should be performed in areas where infiltration-based BMPs are proposed and typically a minimum infiltration rate of 0.5 inch per hour is required. A variety of field testing techniques can be used to determine infiltration rate, including sprinkler infiltrometers, cylinder or double-ring infiltrometers, and lysimeters. Appropriate techniques should be selected based on the method of stormwater being considered and local design guidance should be consulted to identify approved methods for infiltration test. Single or double ring infiltrometer tests are preferred for the design of stormwater retention facilities (Riverside County 2011/ Orange County TGD 2017). The standard US Public Health Service percolation test used to design septic drain fields is not recommended for LID BMP studies.

Trench / Boring Logs

Once potential building and BMP locations have been identified, a qualified soil scientist or geotechnical engineer should dig test pits to gather more detailed information on the soils present at these locations. Test pits are required to confirm the types of soils present onsite, and will uncover the presence of soil layers that may impede infiltration, such as caliche or fragipan. Test pits will also determine the depth to bedrock and will help to establish the high groundwater elevation.

In developed sites being evaluated for redevelopment or retrofits, soil bulk density should be measured in a number of areas to determine the level of soil compaction, which can dramatically impede the movement of water into the soil.

Other Limiting Factors

Many of the soils in Southern California contain fairly shallow, moderately cemented restrictive layers of lithic or paralithic bedrock. These restrictive layers will limit the applicability of infiltration designs. Another likely challenge to infiltration is a type of soil known as caliche, which is found in many areas of the region. Caliche is a layer of soil in which the soil particles have been cemented together by lime (calcium carbonate, $CaCO_3$). It is usually found as a light-colored layer in the soil or as white or cream-colored concretions (lumps) mixed with the soil. Layers will vary in thickness from a few inches to several feet, and there may be more than one caliche layer in the soil.

Caliche is also problematic for vegetation in at least three ways. First, the caliche layer can be so tight that roots cannot penetrate through it. The result is that plants have only the soil above the caliche to use as a source of nutrients and water and normal root development is restricted. Second, the same conditions that restrict root penetration also reduce water movement. Water applied to the soil cannot easily move through the profile if a restrictive caliche layer is present. The restricted water penetration can contribute to problems arising from inadequate root aeration and can lead to accumulations of salt in the soil surface. Both problems, lack of aeration and salt accumulation, reduce the vigor of growing plants. Third, the pH and free calcium carbonate in a caliche soil are often high enough to cause iron to become unavailable for plants. The symptoms of iron deficiency are a yellowing of the youngest plant leaves while the veins in the leaves remain green. Iron deficiencies are further aggravated by the water saturation of the soil.

In some cases, near-surface caliche layers can be broken apart through mechanical means during site grading. This is typically accomplished by deep ripping, a process that involves using a bulldozer to drag a long time through the soil on a checkerboard pattern. This process may remove the water penetration restriction, but may not mitigate the other challenges associated with caliche soils.

Many areas in Southern California have soils that are corrosive to metals and concrete. These soils are characterized by: high moisture content, high dissolved salts, and high acidity. Caltrans has established the following criteria for corrosive soils (Caltrans 2018b):

- Chloride concentration ≥ 500 ppm,
- Sulfate concentration ≥ 2,000 ppm, or
- pH ≤ 5.5

If one or more of these conditions is met, the site may require corrosion mitigation prior to the installation of any underground BMPs.

Pollutant Removal

Unpaved surfaces provide both infiltration and pollutant removal functions. Soils have a high capacity to remove soluble and insoluble pollutants from stormwater. Many factors influence a soil's pollutant removal capacity. Fully understanding soil pollutant removal involves a detailed understanding of hydrology, soils physics and chemistry, aquatic chemistry, biology, and botany. Factors that influence pollutant removal include the quality of the infiltrating water, and soil characteristics such as pH, mineral content, organic matter content, oxidation-reduction potential (redox), as well as the soil flora and fauna at the surface and in the subsurface.

Soil provides the medium for decomposition of organic material that is deposited on the land surface. Soil is the habitat for a vast spectrum of micro- and macro-organisms that form a natural recycling system. The rhizosphere (the rooting zone) includes roots, viruses, bacteria, fungi, algae, protozoa, mites, nematodes, worms, ants, maggots, other insects and insect larvae (grubs), earthworms and rodents. Processed nutrients in the rhizosphere are in turn used by the vegetative systems that develop on the soil mantle. When precipitation is infiltrated, pollutants from surface activities move into this soil treatment system, which effectively and efficiently breaks down most non-point source pollutants (biologically), removes them from the stormwater by cation exchange (chemically), and/or physically filters them through soil particles.

One important measure of chemical pollutant removal potential is cation exchange capacity (CEC), which describes the soil's ability to adsorb positively charged ions. A soil's CEC is a function of its clay and organic contents. Soils with a CEC of at least 10 milliequivalents per 100 grams are very efficient as a treatment medium, and offer the best opportunity to reduce or completely remove most common stormwater pollutants, such as phosphorus, metals and hydrocarbons. Non-point source pollutants that are solutes (dissolved), such as nitrate, are the exception. Nitrates typically move with the infiltrating rainfall and do not undergo significant reduction or transformation, unless an anaerobic environment with the right class of microorganisms is encountered.

Nutrients are a water quality issues in many Southern California watersheds. When integrating LID features such as bioretention or biofiltration in these watersheds BSM should have a lower content of nutrients as to not export nutrients and exacerbate nutrient issues in the nutrient impaired watershed. Phosphorus is a key pollutant of concern in many watersheds. Soils can act as either a source or a sink for certain forms of phosphorus, depending on their innate phosphorus content, measured by the P-index (Hunt et al. 2006). This can be of particular concern when soil is used as a pollutant filter, such as in bioretention. Use of high P-index soils in bioretention can lead to the bioretention cell exporting rather than removing certain forms of phosphorus. Where nutrients are a concern in a watershed BSMs should be tested for the makeup of the material specific to the identified BSM specification as well as tested with stormwater to identify if nutrient export occurs. The San Diego County BSM specification (San Diego County 2014) should be referenced for a BSM that has a reduced nutrient content. For more information see: https://www.sandiegocounty.gov/content/dam/sdc/dpw/WATERSHED_PROTECTION_PROGRAM/susmppdf/lid_appendix_g_bioretention_soil_specification.pdf.

Several proprietary biofiltration systems have been tested following the Technology Assessment Protocol – Ecology and have demonstrated Phosphorus removal exceeding 50% as well as removal of TSS and dissolved copper and dissolved zinc. Where nutrients are a pollutant of concern, these systems should be considered as alternatives to standard biofiltration specifications that include the use of compost. For more information see: https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Emerging-stormwater-treatment-technologies

Table 2-2 summarizes the ideal soil properties for infiltration and pollutant removal. It is important to note that LID principles can be adapted to any site soil conditions. This table is intended only to facilitate the identification of areas where infiltration BMPs would be best suited, and to flag any special soil conditions that may need to be considered.

Table 2-2. Ideal Soil Properties for Infiltration and Pollutant Removal.

Property	Ideal range for infiltration/ pollutant removal
USDA textural classification	Sand, loamy sand, sandy loam, or loam
HSG	A or B
Infiltration rate	0.5 in/hr
CEC	> 10 milli-equivalents/100 grams
Organic Content	1.5 – 10%
P-index	< 25
pH	5.5-7.5
Depth to impermeable layers	> 5 feet
Depth to groundwater	> 10 feet

Source: The Low Impact Development Center, Inc.

Geologic Assessment

The primary geologic factors that influence selection and placement of LID BMPs are the depth to bedrock and the water table, and susceptibility to landslides. The depths to bedrock and the water table can be easily obtained as part of the site soils assessment described above.

Landslides

Southern California's physiography makes certain areas prone to landslides. Landsliding is a form of mass wasting, or gravity-caused erosion, and is a natural process which occurs readily in certain earth materials. The action of landsliding is heavily influenced by the saturation of soil and rock masses and is, to the dismay of thousands of its residents, a natural process on California's hill slopes.

LID design in areas prone to landslides, especially those that utilize infiltration, should be given careful consideration and should be subject to review by a licensed civil or geotechnical engineer. Since soil saturation is a primary cause of landslides, infiltration should be limited in areas of high landslide risk. Local construction best practices should also be considered when implementing LID in an area that is subject to landslides.

More information on site soil suitability and soil assessment methods can be found in Section VII.4.1. of the Orange County Technical Guidance Document (Orange County Public Works 2013).

Resources

California Department of Transportation. 2018. *Corrosion Guidelines*.
http://www.dot.ca.gov/des/QualitySystem/documents/mets/osm/cg/CG_MANUAL.pdf

California Department of Conservation – California Geological Survey https://www.conservation.ca.gov/cgs.

California GeoTour: An Index to On-line Geologic Field Trip Guides of California
https://www.conservation.ca.gov/cgs/california-geotour.

NRCS Web Soil Survey Website: http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

SDC. 2014 – County of San Diego Low Impact Development Handbook, Appendix G. https://www.sandiegocounty.gov/content/sdc/dpw/watersheds/susmp/lid.html

USGS Education – California: Geography, Geology, Hazards, and Natural History Information http://education.usgs.gov/california/resources.html

USGS – Landslide Hazards Program http://landslides.usgs.gov/

USGS – Landslide Types and Processes http://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

USGS – National Geologic Map Database http://ngmdb.usgs.gov/

LID Site Assessment – *Vegetation*

Knowledge of the plant communities occurring onsite is a factor in developing a site design that is well-integrated into the natural environment. Although development pressures have removed or strongly modified much of the natural vegetation in the area, ongoing development, redevelopment, and restoration efforts may present opportunities to protect and/or recapture some of the region's native plant communities.

When a site is disturbed by either natural events or human intervention, invasive species have the opportunity to gain a toe hold and dominate indigenous plant communities. Invasive species are plants that have been recently introduced and have the ability to thrive beyond their range of natural dispersal. Typically, invasive species are characterized as adaptable, aggressive and have a high reproductive capability. These characteristics allow them to monopolize the limited resources available after a site disturbance has occurred and to outcompete native plant species. It is critical to identify these invaders during site assessment and, as part of the plant community restoration plan, to minimize the introduction and establishment of invasive plants into the landscape. Where a site is completely dominated by invasives, it may be possible to restore native vegetation into the planned landscaping. A qualified restoration ecologist should be consulted to create an appropriate restoration plan.

Southern California's natural vegetation reflects the region's climate and diverse topography and soils. The structure and function of the area's natural plant communities are strongly influenced by drought, seasonal flooding, elevation, slope and aspect, geological variation, fire history, and unique occurrence of the Santa Ana winds. The vegetation exhibits high levels of species diversity and endemism and provides habitat for a great range of animals.

A site assessment should include a survey of existing vegetation onsite, identifying:

- Existing or historical plant communities
- Existing invasive species
- The presence/location(s) of dense/native plant cover
- The presence/location(s) of well-established trees

Appendix B includes important characteristics of several major plant communities in Southern California to help in identifying native plant cover versus invasive species (Bornstein, Fross, and O'Brien 2005; Lenz and Dourley 1981; Las Pilitas Nursery 2018). Sections and tables in Appendix B include:

- Southern California Ecoregions (Table)
- Climate and Vegetation of Southern California Mountains and Valleys (Table B-2)
- Major plant communities of Southern California
- Southern California Master Plant List (Table)
- General Plant List (Table)
- Bioretention Plant List (Table B-5)

Vegetated Roof Plant List (

- Table B-6)

LID Site Assessment – *Ecoregion*

Ecoregions and Native Plant Communities

Landscaping within a LID project can be modeled on native plant communities found within an area's ecoregion. According to the World Wildlife Fund, an ecoregion is a "large area of land or water that contains a geographically distinct assemblage of natural communities that:

- share a large majority of their species and ecological dynamics;
- share similar environmental conditions, and;
- interact ecologically in ways that are critical for their long-term persistence."

Ecoregions can be described at a variety of spatial scales and further delineated into different subregions, such as provinces and sections. Two ecological subregions occur within the jurisdictions of Regional Water Quality Control Boards 4, 8 and 9, and have direct significance to this manual (USDA 1997):

1. **Southern California Coast**
2. **Southern California Mountains and Valleys**

In addition to the above subregions, large portions of Los Angeles, San Bernardino, Riverside, and San Diego Counties fall within three other ecoregions to the east:

1. Mohave Desert
2. Sonoran Desert
3. Colorado Desert

The ecoregions for the three RWQCB Regions in the project area are very broadly outlined; they can be further subdivided into sections and subsections within the hierarchical framework of ecoregions. Individual subsections have characteristic topography, soils, climate, and associated vegetation types.

Understanding the unique elements in a specific ecoregion where the BMP is located will inform the choices of plant materials incorporated into the BMP. This consideration will enhance the survival and sustainability of the selected plant material as well as provide habitat and cover for native wildlife. Appendix B includes additional ecoregion, climate and vegetation information.

The map below outlines the USDA ecoregions in Southern California (Figure 2-5).

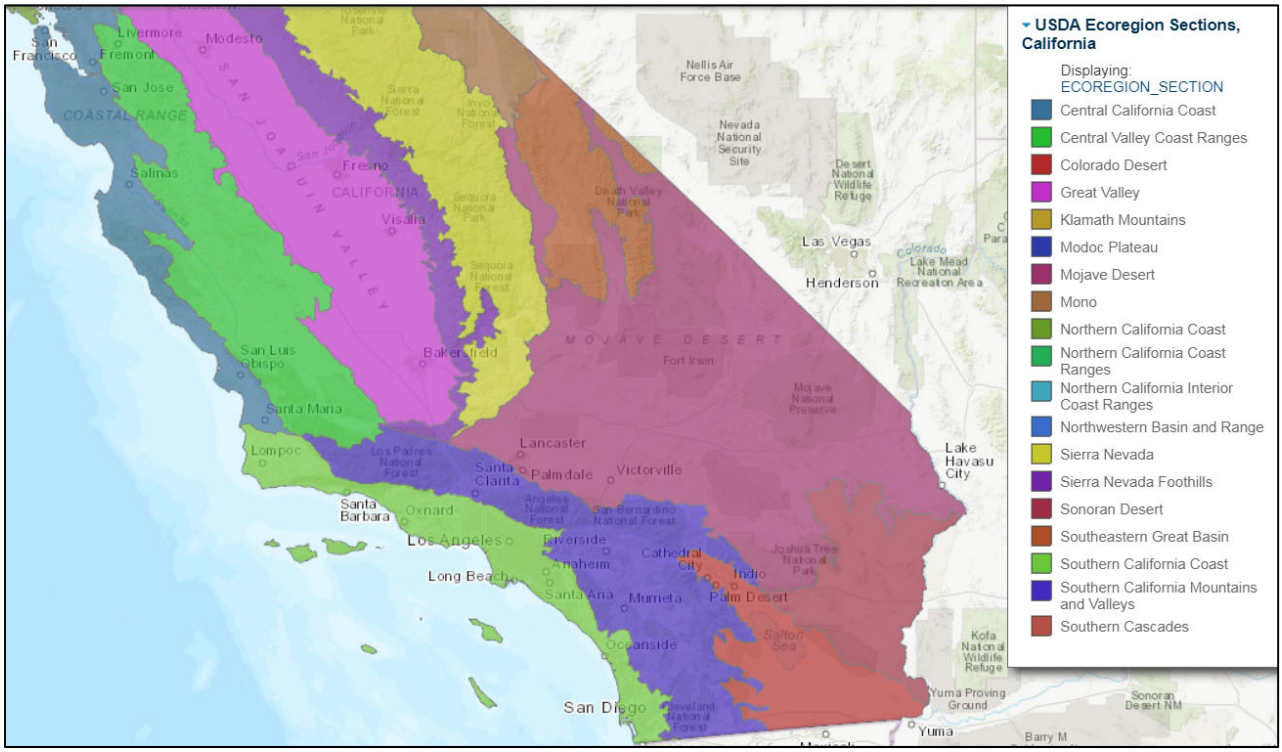

Figure 2-5. USDA Ecoregion Sections of Southern California

Source: Data Basin 2019

LID Site Assessment – *Sensitive and Restricted Areas*

Mapping of all sensitive and restricted areas on the site is required as part of the site planning and layout. Conservation easements that have been dedicated on the site will require special attention since these areas may fall under the control of regulatory agencies, such as the United States Army Corps of Engineers (USACE) or the State Department of Fish and Game.

Work that would affect the natural function of areas of environmental interest is often regulated by Federal or State agencies and must be identified and delineated. Additionally, several jurisdictions in Southern California have completed Multiple Species Habitat Conservation Plans, which identify key species and their associated habitats and may set requirements for conservation or mitigation.

Other types of easements and rights of way should also be identified prior to the selection of LID practices. Access easements can be established for sub-grade, on-grade and aerial utilities, and will dictate specific limitations to potential locations of LID BMPs.

Required Information

The following sensitive and restricted areas should be identified and delineated on the project site plan:

- Streamside Management Areas / Watercourse and Lake Protection Zones
  - http://www.swrcb.ca.gov/water_issues/programs/nps/encyclopedia/2b_sma.shtml
- Floodplains
  - Contact appropriate local agency for flood hazard areas
- Habitat for threatened or endangered species
  - Local Multi Species Habitat Conservation Plan or equivalent
  - http://www.dfg.ca.gov/habcon/
- Environmental easements on the property such as woodland, wetland, farmland, scenic areas, historic areas, wild and scenic rivers and other undisturbed natural areas that have been recorded as perpetual conservation easements in the property deed
- Location of buried storage tanks and utilities
  - As-built plans
  - Utility companies

Resources

California Watershed Assessment Manual http://www.cwam.ucdavis.edu/

California Regional Water Quality Control Board Region 4 – Los Angeles
http://www.waterboards.ca.gov/losangeles/

California Regional Water Quality Control Board Region 7 – Colorado
http://www.waterboards.ca.gov/coloradoriver/

California Regional Water Quality Control Board Region 8 – Santa Ana
http://www.waterboards.ca.gov/santaana/

California Regional Water Quality Control Board Region 9 – San Diego
http://www.waterboards.ca.gov/sandiego/

State of California Conservation Easements Registry http://easements.resources.ca.gov/

LID Site Assessment – *Existing Development*

On sites which are being redeveloped or retrofit with LID, it will be necessary to obtain detailed maps of the existing development on the site. Typical site surveys that are used in the design of the project will inherently contain most of the required information, and any non-standard information can be easily gathered by the surveyor. The existing topography (as described in the sections above) should also be included in the maps of the existing development. As-built site plans can also be obtained when available, but it should be noted that as-built drawings should be field-checked to ensure that they accurately reflect the site as it currently exists. The information listed below will be used to select possible locations for LID BMPs on the site and can identify opportunities for reduction of impervious surfaces.

The following features should be identified and delineated on the project site plan:

- Buildings and foundations
- Parking areas, including the number and layout of parking spaces
- Driveways
- Vehicular access roads
- Paved sidewalks and paths
- Turf
- Landscaped areas

- Underground utilities, such as electric, gas, water, sewer, stormwater, telephone and cable TV
- Underground storage tanks

LID Site Assessment – *Contamination*

Potential soil and groundwater contamination should be considered on all redevelopment sites. Sites with existing soil contamination are called brownfields. Identified brownfields and former agricultural sites are managed by the USEPA, California Environmental Protection Agency (Cal/EPA), and the CA Department of Toxic Substances Control. Each of these agencies maintains lists of known brownfields. For preliminary investigation, the following websites can provide information on known brownfield sites:

- EPA Brownfield Website: http://www.epa.gov/brownfields
- CA Department of Toxic Substances Control links:
    - http://www.dtsc.ca.gov/SiteCleanup/Brownfields/,
    - http://www.dtsc.ca.gov/SiteCleanup/Cortese_List.cfm

Site contamination can be an issue in the redevelopment of urban, industrial and agricultural sites. Urban soils may be contaminated with lead deposited by vehicle exhaust or deteriorating paint. Industrial sites may be contaminated with a variety of chemicals, and may have been subject to intentional or unintentional dumping, resulting in soil or groundwater contamination. Former agricultural sites may be contaminated with pesticides or other chemicals, or may have high concentrations of mineral salts or nutrients. All redevelopment sites must be investigated for underground storage tanks, abandoned landfills, or other sources of groundwater contamination.

Brownfields require an approach to LID that is somewhat different from the common emphasis on infiltration, which could mobilize pollutants in the soil, contaminating groundwater. Rather, the emphasis on brownfield sites should be on minimizing the generation of runoff via source control, detention of runoff to reduce peak flows, and the treatment of runoff prior to discharge. Keep in mind that contaminated soil is often capped prior to redevelopment, creating a high degree of site impermeability, which can be expected to generate a large volume of runoff.

Use of planning strategies and BMPs that prevent the generation of stormwater can be especially beneficial on sites with contaminated soils, as they reduce the volume of stormwater that must be stored and treated. Where applicable and feasible, green roofs, which retain rooftop rainfall, can greatly reduce runoff volume, as can capture and reuse strategies that do not involve contact with the soil. Maximizing vegetative cover will reduce runoff volumes, promote evapotranspiration, prevent erosion of contaminated soil during storm events, and may provide pollutant removal via phytoremediation. Locating buildings and other paved surfaces on contamination hotspots will help to prevent infiltration through those areas.

BMPs commonly used for infiltration, such as bioretention or permeable pavements, should be lined with clean soil or an impermeable barrier, and equipped with underdrains to discharge treated stormwater into the storm sewer. This will allow the use of these BMPs to store and treat stormwater runoff, but prevent contact between stormwater and the contaminated soil.

Resources

USEPA. 2016. *Stormwater Guidelines for Green, Dense Redevelopment*. https://www.epa.gov/smartgrowth/stormwater-guidelines-green-dense-redevelopment.

USEPA. 2008. *Case Studies for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas*. http://www.epa.gov/nps/lid/

USEPA. 2008. *Design Principles for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas*. http://www.epa.gov/nps/lid/

Step 2. Define Goals

LID can address both regulatory requirements and broader issues of environmental stewardship. Once you have a clear understanding of the site conditions and constraints, you can clearly define the project's goals for incorporating LID techniques. These goals may be imposed by local, state, or federal regulations, or may be the result of a desire to handle the site's stormwater in an environmentally responsible manner. A well-defined set of goals will inform the site design and selection of BMPs for the project.

Regulatory Goals

Regulatory requirements governing stormwater management on land development projects often include minimum requirements for implementation of LID. Since these requirements vary depending on the local National Pollutant Discharge Elimination System (NPDES) permit, the first step in defining a project's goals should be to evaluate the local regulatory requirements for the project.

Common Regulatory Requirements

- Water Quality Requirements, e.g.:
  - Treat the 85th percentile runoff volume
  - Treat the runoff flow rate generated by a rainfall intensity of 0.2 in/hr

- Hydromodification Requirements, e. g.:
  - Reduce/Match peak runoff discharge rate (pre-development and post-development)
  - Hydrograph matching (pre-development and post-development)
  - Flow duration control

LID to Help Meet Water Quality Requirements

Incorporation of LID Principles (described in Step 3) into a project will help reduce the runoff volume and peak rate, which will reduce treatment requirements. LID BMPs (described in Step 4) can be selected, sized and implemented to treat polluted runoff.

LID to help meet Hydromodification Requirements

Incorporation of LID Principles (described in Step 3) into a project will help reduce the runoff volume and peak rate, which will reduce the capture volume required for hydromodification mitigation. LID BMPs can then be implemented to address the remaining hydromodification requirements. Where LID infiltration or capture/reuse BMPs are feasible, they will most effectively meet hydromodification requirements as they remove runoff from the system. LID filtration BMPs can also be used to address hydromodification, but the design approaches provided in Step 4 herein may need to be modified to limit outflow from the BMP to meet the regulatory requirements.

LID vs Flood Control

The primary purpose of LID is to preserve a site's predevelopment hydrology. Achieving this goal often requires consideration of the larger, less-frequent storm events that play a significant role in hydromodification, in addition to the small, frequent storms that are largely responsible for water quality. It is important to note that under predevelopment conditions, site runoff will occur during large storms. This runoff plays an important role in the geomorphology of receiving waters, reshaping channels and supplying sediment and nutrients. LID is not intended to interfere with these large, channel forming events; rather it is intended to prevent degradation due to excessive discharge of highly polluted runoff from small, frequent storms.

Many communities have long had specific requirements for flood control. Flood control and stormwater management requirements may be set forth by different municipal departments or even different agencies, but nonetheless, these requirements often have similarities that can simultaneously be addressed by applying the LID techniques. Similarly, agencies may have landscaping requirements or green space preservation requirements that can be related to LID.

Environmental Stewardship

In addition to meeting the minimum regulatory requirements, implementing LID measures as described in this manual promotes Environmental Stewardship, which can add to the desirability / marketability of a project.

Benefits of Environmental Stewardship through LID

- Achieve LEED certification (details are included in Appendix C)
- Achieve Sustainable Sites Initiative certification (details are included in Appendix C)
- Maintain or restore water balance
- Protect habitat
- Preserve or create green space
- Harvest rainwater for reuse

How Much is Enough?

The goal evaluation process will define the level of LID implementation required for most projects. Due to the variables associated with the factors that define LID goals for a project, it is not possible for this manual to provide a single answer regarding the required extent of LID implementation. Furthermore, what may be considered an acceptable level of LID implementation in one area may be quite different acceptable levels in other areas.

Once the goals for LID implementation are determined for a project, the LID BMP can be compared to the regulations and metrics from Southern California jurisdictions found in Tables A-1 through A-4 (Appendix A). The tables in Appendix A cover commonly used LID terminology and summarize regulations and guidance for LID site design, water quality, hydromodification, and BMP media.

Step 3: Implementing LID Principles

Introduction

Once the site assessment has been performed and goals for implementing LID on the project have been defined, specific LID strategies can be selected and implemented to address the potential impacts of development discussed in Section 1 of this manual.

LID strategies can be broadly divided into two types:

- **LID Non-Structural Principles** inclusive of LID Site Planning & LID Site Design that **minimize** the causes (or drivers) of project impacts, and
- **LID Structural BMPs** that help **mitigate** unavoidable impacts.

Incorporating LID Non-Structural Principles through LID Site Planning and LID Site Design at the beginning of the development planning process is the most cost effective way to implement LID successfully. When properly done, such measures can greatly reduce the extent of impacts that must be mitigated with LID structural BMPs. As such, a project proponent should exhaust all available and applicable measures to minimize impacts, before moving on to mitigating the remaining impacts with LID structural BMPs. Once LID site planning and LID site design have been incorporated into a site the site plan should be evaluated towards meeting the site goals. This will help to identify the volume of stormwater that needs to be managed by LID structural BMPs. The site plan with the LID site planning and LID site design should be evaluated using the methods identified in Step 5 Evaluate Overall LID Site Plan and Design to ensure goals have been met before integration of LID Structural BMPs.

It is important to note that LID Principles apply to each of the phases of a project, including: planning, design, construction and occupation (Table 2-3).

Table 2-3. Examples of LID Principles and Where Within a Project Lifecycle They Can Be Implemented.

Phase	LID Principles (minimization)	LID Principles/ Structural BMPs (mitigation)
Planning	• Preserve natural infiltration capacity • Preserve existing drainage patterns • Protect existing vegetation and sensitive areas	N/A
Design	• Minimize impervious area • Disconnect impervious areas	• Infiltration BMPs • Capture/Reuse BMPs • Filtration BMPs
Construction	• Minimize construction footprint • Minimize unnecessary compaction • Minimize removal of native vegetation and trees	• Revegetate disturbed areas
Occupation	• Implement source control BMPs	• Maintain BMPs appropriately

Source: The Low Impact Development Center, Inc.

Step 3 in this manual provides examples of LID Principles inclusive of LID site planning and LID site design and how they can be incorporated into a project. The use of these strategies will help to maximize the effectiveness of the LID implementation, further improving and integrating stormwater management into the site. A LID project should attempt to incorporate each of these strategies to the extent appropriate, however the unique combination of features of the project site, as determined by the site assessment, will help inform the selection process. Creating a site plan that works with the site's natural features will generate a more hydrologically functional site and result in a site design that more closely

mimics its predevelopment hydrograph, which in turn will help reduce the requirement for mitigation measures.

The simplest way to maintain the predevelopment hydrologic function of a site is to minimize the development footprint, preserving existing topography and drainage patterns. However, many development projects involve complete landform manipulation, where the entire site is cleared and graded. On such sites, where such grading is unavoidable, predevelopment hydrologic function can be reproduced with a proper mix of design strategies, especially minimizing impervious area, and the use of supplemental BMPs to store and treat excess runoff.

Maximize Natural Infiltration Capacity

A key component of LID is taking advantage of a site's natural infiltration and storage capacity (Table 2-4). This will limit the amount of runoff generated, and therefore the need for mitigation BMPs. The site soils/geology assessment described previously in this manual will help to define areas with high potential for infiltration and surface storage (Page 2-10).

These areas are typically characterized by:

- Hydrologic Soil Group A or B soils
- Mild slopes or depressions
- Historically undeveloped areas

Table 2-4. Available Techniques to Preserve Natural Infiltration Capacity.

Phase	Available Techniques
Planning	• Avoid placing buildings or other impervious surfaces on highly permeable areas. • Cluster buildings and other impervious areas onto the least permeable soils.
Design	• Where paving of permeable soils cannot be avoided, loss of infiltration capacity can be minimized by using permeable paving materials.
Construction	• Minimize construction footprint • Minimize unnecessary compaction
Occupancy	N/A

Source: The Low Impact Development Center, Inc.

Preserve Existing Drainage Patterns and Time of Concentration

Integrating existing drainage patterns into the site plan will help maintain a site's predevelopment hydrologic function. Preserving existing drainage paths and depressions will help maintain the time of concentration and infiltration rates of runoff, decreasing peak flows. The best way to define existing drainage patterns is to visit the site during a rain event and to directly observe runoff flowing over the site. If this is impossible, drainage patterns can be inferred from topographic data, though it should be noted that depression micro-storage features are often not accurately mapped in topographic surveys. Analysis of the existing site drainage patterns during the site assessment phase of the project can help to identify the best locations for buildings, roadways, and stormwater BMPs (Table 2-5).

Table 2-5. Available Techniques to Help Preserve Existing Drainage Patterns and Increase the Time of Concentration.

Phase	Available Techniques
Planning	• Avoid channelization of natural streams • Establish set-backs and buffer areas from natural streams. • Where natural streams will be converted to engineered streams, provide sinuosity to increase the time of concentration. • Minimize mass grading of project site to avoid elimination of small depressions, which can provide storage of small storm volumes.
Design	• Avoid channelization of natural streams. • When designing channels, use mild slopes and increase channel roughness to extend time of concentration • When possible, use pervious channel linings to maximize opportunity for infiltration.
Construction	• Minimize construction footprint
Occupancy	N/A

Source: The Low Impact Development Center, Inc.

Minimize site grading that eliminates small depressions, which can provide storage of small storm volumes. Where possible, add additional depression "micro" storage throughout the site's landscaping. Mild gradients can be used to extend the time of concentration, which reduces peak flows and increases the potential for additional infiltration. While of course risk of serious flooding must be minimized, the persistence of temporary "puddles" during storms is beneficial to infiltration. If a site is visited during dry weather, these areas can sometimes be identified by looking for surficial dried clay deposits.

Protect Existing Vegetation and Sensitive Areas

A thorough site assessment will identify any areas containing dense vegetation or well-established trees (Table 2-6). When planning the site, avoid disturbing these areas. Soils with thick, undisturbed vegetation have a much higher capacity to store and infiltrate runoff than do disturbed soils. Reestablishment of a mature vegetative community can take decades. Sensitive areas, such as wetlands, streams, floodplains, or intact forest, should also be avoided. Development in these areas is often restricted by federal, state and local laws.

Table 2-6. Available Techniques to Protect Existing Vegetation and Sensitive Areas

Phase	Available Techniques
Planning	• Establish set-backs and buffer zones surrounding sensitive areas • Incorporate established trees into site layout
Design	• Design site to deter human activity within sensitive areas (i.e. fences, signs, etc.)
Construction	• Provide and maintain highly visible flagging and/or fencing around sensitive areas or vegetation that is to be protected.
Occupancy	• Establish use/access restrictions to sensitive areas

Source: The Low Impact Development Center, Inc.

Vegetative cover can also provide additional volume storage of rainfall by retaining water on the surfaces of leaves, branches, and trunks of trees during and after storm events. This capacity is rarely considered, but on sites with a dense tree canopy it can provide additional volume mitigation.

Minimize Impervious Area

One of the principal causes of environmental impacts due to development is the creation of impervious surfaces. Impervious cover can be minimized through identification of the smallest possible land area that can be practically impacted or disturbed during site development. The below photo is an example of minimizing impervious cover through building skyscrapers (Figure 2-6).

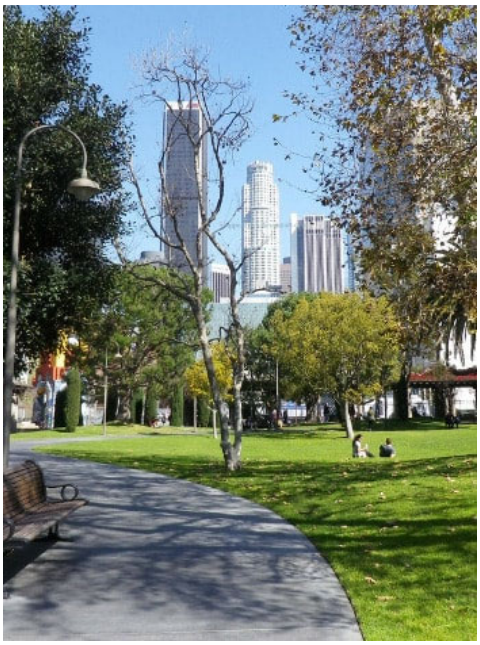

Figure 2-6. Grand Hope Park with Downtown Los Angeles in the background.

Source: Downtown Center Business Improvement District 2019

Below is a partial list of techniques that can reduce the amount of impervious area that will be created as part of a project (Table 2-7).

Table 2-7. Available Techniques to Minimize Impervious Surfaces.

Phase	Available Techniques
Planning	• Build vertically rather than horizontally – add floors to minimize building footprint. • Cluster development to reduce requirements for roads and preserve green space. • Minimize lot setbacks (which in turn minimize driveway lengths) • Reduce road widths to minimum necessary for emergency vehicles
Design	• Install sidewalks on only one side of private roadways • Use alternative materials such as permeable paving blocks or porous pavements on driveways, sidewalks, parking areas, etc. • Create smaller parking spaces intended for compact cars.
Construction	• Minimize unnecessary compaction. The infiltrative capacity of soils can be greatly reduced when they are compacted, often to the point that they perform similarly to impervious surfaces.
Occupancy	N/A

Source: The Low Impact Development Center, Inc.

It is important to note that local laws and ordinances may dictate minimum requirements for road widths or building setbacks that cannot be reduced due to public health and safety concerns. In certain situations, it may be possible to achieve changes to codes and ordinances. Additional information can be found in the EPA Green Infrastructure Municipal Handbook, which is accessible online at: https://www.epa.gov/green-infrastructure/green-infrastructure-municipal-handbook.

Additionally, the concepts of new urbanism and smart growth should be considered in reducing impervious surfaces an as an overall approach that integrates concepts to reduce impervious surfaces with LID site planning from a different perspective. The Light Imprint Handbook should be consulted for approaches of new urbanism that creates compact, walkable, and mixed-use neighborhoods that has a tool box of techniques to reduce impervious cover and manage stormwater. For more information see: http://lightimprint.org/.

Disconnect Impervious Areas

Runoff from 'connected' impervious surfaces commonly flows directly to a stormwater collection system with no opportunity for infiltration into the soil. For example, roofs and sidewalks commonly drain onto parking lots, and the runoff is conveyed by the curb and gutter to the nearest storm inlet (Figure 2-7). Runoff from numerous impervious drainage areas may converge, combining their volumes, peak runoff rates, and pollutant loads.

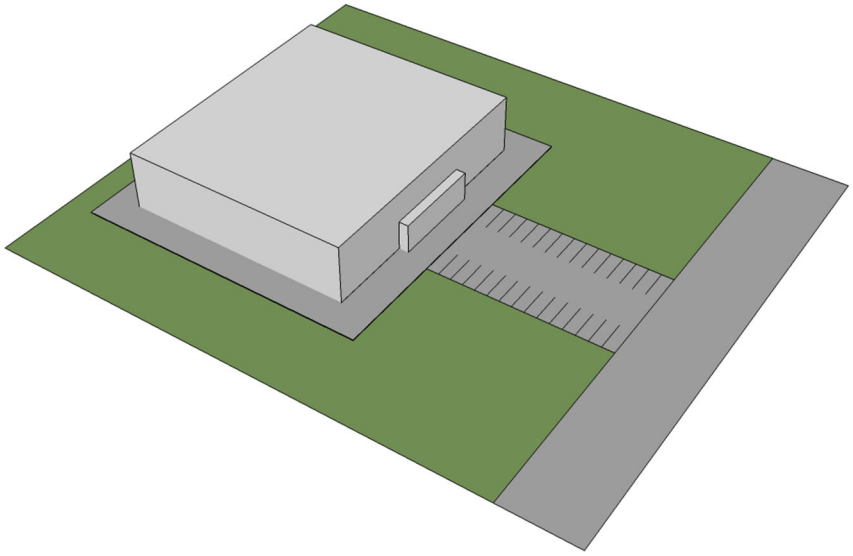

Figure 2-7. Commercial site showing directly connected impervious areas.

The roof drains to the sidewalk, which drains to the parking lot, and then directly onto the street.
Source: The Low Impact Development Center, Inc.

Disconnecting impervious areas from conventional stormwater conveyance systems allows runoff to be collected and managed at the source or redirected onto pervious surfaces such as vegetated areas. An example of an impervious area disconnect would be the installation of landscape areas upstream of storm drains to intercept or eliminate flows from impervious areas (Figure 2-8).

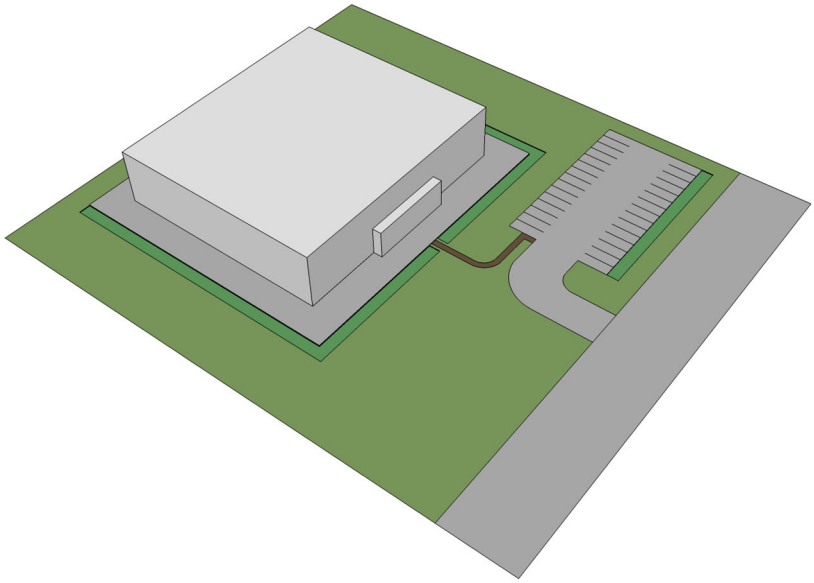

Figure 2-8. Commercial area in which impervious surfaces have been disconnected.

Runoff from the roof and sidewalk are captured by bioretention cells. Sidewalks are separated from the parking lot by a large vegetated area. The parking lot drains to a bioretention cell rather than directly to the street.
Source: The Low Impact Development Center, Inc.

Irrigation runoff must be prevented from reaching the storm drain from these landscaped areas otherwise sediment, nutrients, and other pollutants could be transported. Installing landscaping or other pervious areas can reduce the amount of directly connected impervious area, and will reduce the peak discharge rate by increasing the time of concentration , maximize the opportunity for infiltration by reducing the velocity of flows and providing for greater contact time with the soil, and maximize the opportunity for evapotranspiration during transport.

Disconnection practices may be applied in almost any location, but impervious surfaces must discharge into a suitable receiving area for the practices to be effective. Information gathered during the site assessment will help inform the determination of appropriate receiving areas. Typical receiving areas for disconnected impervious runoff include landscaped areas and/or other LID Mitigation BMPs (i.e. filter strips or bioretention). Runoff must not flow toward building foundations or be redirected onto adjacent private properties. Setbacks from buildings or other structures may be required to ensure soil stability. Consult with the project geotechnical engineer to identify areas where infiltration can be accommodated.

It is important to remember that water flows downhill; therefore, receiving areas must be located down gradient from runoff discharges. In a residential setting, this could mean that roof runoff discharges to either the front yard or the back yard, depending on the site configuration. As compared to conventional development, some potential techniques for redirecting flows to vegetated areas may require local design standards to be revisited. The below table outlines techniques used to disconnect impervious areas (Table 2-8).

Table 2-8. Available Techniques to Disconnect Impervious Areas.

Phase	Available Techniques
Planning	• Plan site layout and mass grading to allow for runoff to be directed into distributed permeable areas such as landscaping, recreational areas, medians, parking islands, planter boxes, etc. • Avoid channelization of natural on-site streams
Design	• Provide permeable areas within medians and parkways that are designed to accept runoff from adjacent areas (i.e. via curb cuts). • Construct roof downspouts to drain to pervious areas such as planter boxes or adjacent landscaping. • Use permeable paving materials such as paving blocks or porous pavements on driveways, sidewalks, parking areas, etc.
Construction	N/A
Occupancy	N/A

Source: The Low Impact Development Center, Inc.

Minimize Construction Footprint

Minimizing the amount of site clearing and grading can dramatically reduce the overall hydrologic impacts of site development. This applies primarily to new construction, but the principles can be adapted to retrofit and infill projects as well. The below table outlines techniques used to minimize construction footprints (Table 2-9).

Table 2-9. Available Techniques to Minimize the Construction Footprint.

Phase	Available Techniques
Planning	• Many of the planning techniques identified in the above sections will help minimize the construction footprint.
Design	N/A
Construction	• Minimize the size of construction easements. • Locate material storage areas and stockpiles within the development envelope. • Limit ground disturbance outside of areas that require grading. • Identify and clearly delineate access routes for the movement of heavy equipment. • Establish and delineate vegetation and soil protection areas.
Occupancy	N/A

Source: The Low Impact Development Center, Inc.

Soil compaction resulting from the movement of heavy construction equipment can reduce soil infiltration rates by 70-99% (Gregory et al. 2006). Even low levels of compaction caused by light construction equipment can significantly reduce infiltration rates. In addition, compaction can destroy the complex network of biota in the soil profile that support the soil's ability to capture and mitigate pollutants. Soil compaction severely limits the establishment of healthy root systems of plants that may be used to revegetate the area. For these reasons, it is very important to avoid unnecessary damage to soils during the construction process. The use of clearly defined protection areas will help to preserve the existing capacity of the site to store, treat and infiltrate stormwater runoff.

Establish Vegetation and Soil Protection Areas

Vegetative protection areas (e.g. stream, river, lake and other watercourse buffers, vegetation protection areas, existing trees) should be clearly delineated with highly visible fencing materials to prevent incursion of equipment or the stockpiling of materials during construction. Tree trunks should be sheathed during construction to prevent or minimize damage to the bark.

Use of Mulch and Load Distributing Matting

Mulch blankets can be used to protect soil from compaction during construction. The use of timbers or other types of load distributing materials can also be used to limit the effect of heavy equipment movement on the site.

Pre / Post Construction Soil and Plant Treatments

Consideration should be given to pre-construction treatment of the soil to mitigate the stresses on existing shrubs and trees. This can include soil aeration and specific fertilization protocols that would encourage plant vitality. A local restoration ecologist should be engaged well in advance of the start of construction to develop a plan based on specific site conditions since some of these practices are carried out prior to construction.

Inspection Guidelines and Procedures

Management of soil, water, and vegetation protection measures during the construction process will only be effective if it is carefully implemented and meticulously policed during all phases of construction. Even if overlooked for a single day, significant damage can be done. The cost of damage remediation will be far greater than the cost of avoiding it. Areas intended for infiltration should be treated especially carefully. Avoid the use of heavy machinery or discharge of sediment-laden runoff in these areas.

Techniques implemented on the construction site to minimize the construction footprint should be included in the project documentation and contractors working on the project should review and agree to comply with them while working on the jobsite. Construction site inspections should include inspection of such protocols to ensure they are maintained throughout construction.

Revegetate Disturbed Areas

Increasing plant cover protects the soil and improves the ability of the site to retain stormwater, minimize runoff, and help to prevent erosion. Xeriscape landscaping, the use of native and/or drought-tolerant plant species, reduces the amount of irrigation water required and the chance of irrigation runoff, which can transport pollutants. Landscaping can be paired with rainwater harvest and use to further reduce the irrigation water burden. Plants provide multiple benefits for downstream water quality. First, the presence of a plant canopy (plus associated leaf litter and other organic matter that accumulates below the plants) can intercept rainfall, which reduces the erosive potential of precipitation. With less eroded material going to receiving waters, turbidity, chemical pollution, and sedimentation are reduced. Second, a healthy plant and soil community can help to trap and remediate chemical pollutants and filter particulate matter as water percolates into the soil. This occurs through the physical action of water movement through the soil, as well as through biological activity by plants and the soil microbial community that is supported by plants. Third, thick vegetative cover can maintain and even improve soil infiltration rates in the upper soil layer.

When re-vegetating areas that will not be landscaped as part of the project, preference should be given to native vegetation, which is uniquely suited to the local soils and climate. However, consideration of the location of the plants in the landscape with regards to wildfire safety can sometimes make the use of native species unsuitable. Information about typical native species occurring in common local vegetative communities can be found in LID Site Assessment – Vegetation section of this manual. Additional information can be found by contacting local Master Gardeners or seeking the advice of local plant nurseries, which will have specific knowledge of plants suitable for your particular application. The Las Pilitas Nursery in Santa Margarita has compiled a detailed database of California native plants which is accessible online at: http://www.laspilitas.com/comhabit/california_communities.html. The website can be used to aid in determining the correct plant communities by searching by either ZIP code or town. In cases where use of native vegetation is impractical or impossible, use of non-natives adapted to similar climate regimes, such as the Mediterranean, may be appropriate. Appendix B can help with selection of plant species suitable for Southern California. This strategy will maximize the successful establishment of plantings, and minimize the need for supplemental irrigation.

Soil Stockpiling and Site Generated Organics

The regeneration of disturbed topsoil can take years under optimal conditions, and sometimes can take many decades (Brady and Weil 2008). Proper stockpiling, storage, and reapplication of disturbed topsoil can greatly accelerate this process. Improper soil storage and restoration can significantly decrease the biological activity of the soil, decrease the successful establishment of plantings, and increase the ability of undesirable invasive species to dominate the disturbed landscape.

Soil stockpiling and the use of in situ grubbed plant material and duff as mulch or soil amendments should be encouraged. This will reduce the need for importation of top soil to improve soil quality and will encourage reestablishment of soil flora and fauna after site disturbance. Successful soil stockpiling and reuse begins in the early stages of project planning.

The use of topsoil harvested from the local site can improve the productivity and rate of re-vegetation of a disturbed site. In addition to stockpiled soil, vegetative material grubbed from the site and free of invasive species can be tilled back into the soil to increase organic content.

Restoration of disturbed areas using native soils which have been properly stockpiled during the construction phase of the project is the preferred method of post construction soil restoration. Proper assessment of the site during the pre-construction phase of the project is critical to maintaining soil quality, both structural and biological, during the period the soil is stockpiled. Determination of the volume of soil to be stockpiled and designating an area large enough on site to accommodate the stockpiled soil should be considered early in project design.

Consideration must be given to maintenance of the flora and fauna present in the stockpiled soil in addition to its physical condition. Improper storage such as soil that is too wet or stockpiled to deeply, can render what were active biological soil communities sterile. This will severely impact the ability of the soil to support a healthy plant community. If necessary, a local soil scientist familiar with regional soils can provide testing services to evaluate soil condition prior to and after construction and recommend appropriate remediation steps to restore the soil's predevelopment ability to infiltrate stormwater runoff and support a healthy plant community.

Additional information about the impact of soil stockpiling can be found in the following document which was prepared for the District 11 office of the California Department of Transportation.

Restoration in the California Desert – http://www.sci.sdsu.edu/SERG/techniques/topsoil.html

Firescaping

Fire is a part of the ecosystems of Southern California. Over the years, wildfires have repeatedly destroyed homes and caused loss of life. In response to this natural phenomenon, extensive research has been done and, in the interest of public safety, guidelines have been codified into law. When considering any planting or re-vegetation plan consideration must be given to minimizing the risks of fire with proper plant selection and maintenance. Keep in mind that all plants are flammable given the right conditions; selection and maintenance of plants to mitigate flammability go hand in hand. A plant with a low flammability rating which is allowed to accumulate dead wood or excessive levels of duff in and around the plant will elevate the risk of flammability significantly.

California law (Public Resources Code 4291) requires a minimum 100-foot space around homes on level ground to protect the structure and provide a safe area for firefighters. If a home is located on a slope, additional distance is required and plant spacing, selection, and design must be modified to maintain proper fire safety margins.

A four-zone system has been developed to create a maximum buffer around structures located in high risk wildfire zones. Each zone has very specific landscaping and management requirements to minimize flammability of the landscape.

The four zones are broken down as follows:

Zone One – The garden or clean and green zone
Zone Two – The greenbelt or reduced fuel zone
Zone Three – The transition zone
Zone Four – Native or Natural Zone / Open Space

The landscape plant selection and design for any bioretention or re-vegetation project should be compliant with the requirements of the specific zone in which it will be located. For assistance in determining the correct zone plant selection and spacing, contact your local fire department or insurance company for assistance. Additional resources are provided below for specific information about successful firescaping plant selection and design requirements.

Additional Information

California Department of Forestry and Fire Protection – http://www.fire.ca.gov

California Master Gardeners – http://camastergardeners.ucdavis.edu.

Center for Fire Research – http://firecenter.berkeley.edu

Xeriscape Landscaping

As water use, the frequency of drought, and the impact of organic waste generated from landscape management increase in California, methods to deal with these problems have been developed. The concept of xeriscape was originally developed by the Denver Water Department in 1978. The word was coined by combining the Greek word *xeros* ("dry") with landscape. Since 1978, the xeriscape has become a widely-accepted alternative to traditional landscape design in dry areas.

Xeriscape landscaping is a landscape design and plant selection scheme that is used to minimize required resources and waste generated from a landscape. Defined as “quality landscaping that conserves water and protects the environment” the principles of xeriscape should be employed in any project that creates or restores the landscape. Consulting local resources, such as your local county extension agent, Master Gardeners, Landscape Architects, or local garden centers and nurseries, will help to select plant material suitable for a specific geographic location.

Xeriscape landscaping is based on seven principles:

- Planning and design
- Soil analysis
- Appropriate plant selection
- Practical turf areas
- Efficient irrigation
- Use of mulches
- Appropriate maintenance

Xeriscape landscaping has many benefits which include:

- Reduced water use
- Decreased energy use
- Reduced heating and cooling costs resulting from optimal placement of trees and plants
- Minimal runoff from both stormwater and irrigation resulting in reduction of sediment, fertilizer and pesticide transport
- Reduction in yard waste that would normally be landfilled
- Creation of habitat for wildlife
- Lower labor and maintenance costs
- Extended life of existing water resources infrastructure.

A xeriscape-type landscape can reduce outdoor water consumption by as much as 50 percent without sacrificing the quality and beauty of your home environment. It is also an environmentally sound landscape, requiring less fertilizer and fewer chemicals. Xeriscape-type landscape is low maintenance, saving time, effort and money.

Additional Resources

California Department of Water Resources – Water Use & Efficiency

Low Impact Development Manual for Southern California:
Technical Guidance and Site Planning Strategies

https://water.ca.gov/Programs/Water-Use-And-Efficiency

CalRecycle Website: http://www.calrecycle.ca.gov/Organics/xeriscaping/

University of California Cooperative Extension, and California Department of Water Resources. 2000. *A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California*; California Department of Water Resources: Sacramento, CA. http://www.water.ca.gov/wateruseefficiency/docs/wucols00.pdf

Planning/ Inspection Guidelines

The quality and size of plant material should be clearly defined in the landscaping and re-vegetation plans and the establishment period for the re-vegetation and landscaping should be clearly identified, including any specific establishment guidelines. While native plants are typically the lowest maintenance option for re-vegetation and landscaping any post-installation maintenance required will be dictated by the characteristics of the selected plant community.

Implement Source Control Measures

The discharge of many common stormwater pollutants from a project site can be greatly minimized by practicing vigilant source control. The most common stormwater pollutant impairments in Southern California fall into ten categories:

- Suspended solids
- Oxygen demanding substances
- Nitrogen compounds
- Phosphorus
- Microbial pathogens
- Heavy metals
- Oil and grease
- Toxic organic compounds (e.g. pesticides)
- Trash

Table 2-10 provides additional details on the sources of these pollutants/indicators.

Table 2-10. Pollutants in Stormwater.

Pollutant	Origin	Discharge Source(s)	Location
Suspended Solids	• Small particles of clay, silt, sand, other soil materials, small particles of vegetation, and bacteria	Soil erosion Motor vehicles Building materials	Deposited on impervious surfaces
Oxygen demanding substances	• Natural origin • Excess biodegradable materials or waste discharge	Excess organic waste products such as lawn clippings and leaves	Landscaped areas
Nitrogen compounds	• Excess residential, agricultural, and commercial fertilizer use • Animal wastes • Plant decay • Atmospheric deposition	Turf grass Non-native ornamental landscapes	Highly managed landscapes in both residential and commercial developments
Phosphorus	• Excess fertilizer use • Decaying vegetation, such as lawn clippings and leaves • Present in animal waste	Maintained commercial and residential landscapes Golf courses	Highly managed landscapes in both residential and commercial developments
Microbial pathogens	• Present in animal waste	Runoff from areas where waste has been deposited	Landscaped and natural areas Trails and walkways
Heavy metals	• Released in vehicle emissions • Released by tire wear • Break pads • Leach from asphalt shingles	Motor vehicles Asphalt shingles	Driveways, roadways, highways, parking and storage lots Roofs
Oils and Grease	• Leaks or spills from motor vehicles	Motor vehicles	Driveways, roadways, highways, parking and storage lots
Toxic organic compounds	• Pesticides	Pesticides used for commercial, agricultural and residential applications	Runoff from treated landscapes and agricultural areas
	• Polycyclic aromatic hydrocarbons (PAHs)	Motor vehicle fuel leakage and spillage Asphalt pavement Asphalt roof runoff	Roads and parking lots Runoff from buildings with asphalt roofing materials (shingles, membrane and other types of roofs)
	• Solvents	Industrial, commercial and residential cleaners, degreasers and lubricants	
Trash	Non-biodegradable plastics and coated paper products. Depending on storm intensity, a large variety of debris that would be classified as trash can be mobilized.	Human activities	Parking lots and roadways Sidewalks Parks and recreation areas

Source: Davis and McCuen 2005

Suspended Solids

The largest source of suspended solids is soil erosion. Protecting and revegetating soil is the best practice for reducing total suspended solids (TSS). Implementation of industry standard erosion and sediment control measures during construction is a very effective method to control the transport of TSS on- and off-site during and after the construction process. Innovative Erosion and Sedimentation control practices, such as compost socks and compost berms, have become widely accepted as effective TSS control practices.

Proper site design, incorporating maximum vegetative cover and the appropriate use of mulching to minimize exposed soil, dramatically reduces the levels of TSS generated during and after construction. Pretreating for TSS prior to runoff entering other BMPs will significantly extend the functional lifespan of the BMP.

Oxygen demanding substances

High levels of organic material in runoff increase the population of aerobic microorganisms, resulting in reduced dissolved oxygen content. Typical levels of biodegradable organic compounds do not contribute a major oxygen demand in runoff. Properly disposing of organic materials can help minimize the creation of oxygen demanding substances.

Nitrogen compounds / Phosphorus

High levels of nutrients, such as nitrogen and phosphorus, in runoff contribute to eutrophication in receiving waters. Although runoff from agricultural fields and feed lots is a major source of these pollutants, urban areas with improperly managed landscapes can also be substantial sources. The nutrient content in runoff can be reduced at the source by limiting application of fertilizers to landscaped areas to the minimum necessary. Measures that lower nutrient runoff potential by limiting fertilizer application and reducing the requirement for supplemental application include the use of conservation design principles, the reduction of high maintenance turf grass, and integration of native plants into the landscape.

Microbial pathogens

The primary source of microbial pathogens is feces from wild and domestic animals. Domestic animal feces should be managed with a combination of public awareness and municipal regulation requiring owners to remove waste left by their pets. At moderate levels, microbial pathogens can be mitigated by naturally occurring biota found in bioretention cell soils.

Heavy metals, oil, and grease

Automobiles, trucks, and buses are the primary source of heavy metals, oils, and grease found in urban settings. Source control for automotive sources includes fixing leaks, performing maintenance in covered/appropriate areas, and washing vehicles in landscaping.

Toxic organic compounds

Toxic organic compounds are found in pesticides used on high maintenance landscapes. The proper selection, application, and timing of application of pesticides can be the most effective way to control the source of pesticide toxicity. In the event levels of these pollutants are found that exceed EPA standards, appropriate local or state agencies should be contacted. If the source of the pollutants can be identified, it should be remediated by trained personnel.

Trash/floatables

Trash is found anywhere there is a human presence. Providing trash cans with lids at convenient locations and installing educational signs can help to prevent trash and floatables from entering the system. Conventional stormwater conveyance infrastructure can be retrofitted with devices to intercept trash and floatables at multiple locations within a drainage area. This reduces the maintenance required by concentrating the trash in fewer locations on the site, where it can be removed during scheduled maintenance of the facility.

Resources

Calflora Database: http://www.calflora.org/

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment. Section 4 – Source Control BMPs.* https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf

Inland Empire Regional Composting Authority: http://www.ierca.org

Munz, P. A. 2004. *Introduction to California Desert Wildflowers*. Berkeley: University of California Press.

Step 4: Use LID Structural BMPs to Mitigate Remainder of Impacts

For many projects, it will not be possible to completely meet the minimum goals for the project with LID Principles (LID Site Planning & LID Site Design Principles) alone. In such cases, LID Structural BMPs can be implemented to mitigate remaining project impacts. It should be noted that although such LID Structural BMPs may be necessary to meet the goals, the vigilant implementation of LID Principles (LID Site Planning & LID Site Design Principles) can significantly reduce the required size of such mitigation LID Structural BMPs.

This chapter provides descriptions, basic design guidance, and selection criteria for the most commonly used LID Structural BMPs. Detailed information on the five primary LID Structural BMPs used in LID (Bioretention, Capture/Reuse, Permeable Pavement, Vegetated Roofs, and Soil Amendments) is provided. Permeable Pavement and Vegetated Roofs are considered LID Site Design BMPs as they reduce the amount impervious surface but are included in this section for ease of reference. Other structural BMPs are also described briefly, and links are provided to more detailed sources of information.

The LID Structural BMPs discussed in this manual can be divided into two broad types based on how they function. LID Structural BMPs are either retention BMPs or non-retention BMPs; with the first comprised of BMPs that retain runoff onsite either via infiltration, evapotranspiration, or capture and use, and the latter being comprised of BMPs that filter or treat runoff and allow it to discharge offsite. Depending on any site constraints identified in the LID Site Assessment (Section 1 in this Manual), many LID Structural BMPs can be configured to function as either type or can be grouped together in a treatment train configuration. Below is a summary list of various common types of structural BMPs (Table 2-11).

Table 2-11. BMP Functions of the LID BMPs Discussed in this Manual.

BMP	Capture and Reuse	Infiltration	Filtration
Bioretention (infiltration design)		✓	✓
Bioretention (filtration design)			✓
Porous Pavement (infiltration design)		✓	✓
Porous Pavement (filtration design)			✓
Capture/Reuse	✓		✓*
Vegetated Roofs			✓
Soil Amendments		✓	✓
Downspout Disconnection		✓	✓
Filter Strips			✓
Vegetated Swales			✓
Infiltration (Retention) Basins		✓	✓
Infiltration Trenches		✓	✓
Dry Wells		✓	✓
Dry Ponds (Extended Detention Basins)			✓
Constructed Wetlands			✓
Wet Ponds			✓
Media Filters / Filter Basins			✓
* depends on design			
Many filtration BMPs can result in substantial runoff reduction via infiltration or evapotranspiration.			

Source: The Low Impact Development Center, Inc.

The selection of an appropriate set of structural BMPs for a given site should be based on the project goals and site capabilities and constraints. Several factors must be taken into account:

- LID goals (peak flow reduction, storage volume needed, pollutant removal)
- Site configuration (e.g. space available)
- Site constraints (e.g. slopes, depth to groundwater)
- Operation and maintenance requirements
- Cost

The following tables can be used to compare structural BMPs. Table 2-12 outlines the hydrologic impacts of 17 different types of structural LID BMPs.

Table 2-12. Structural BMP Performance – Hydrologic Impacts.

BMP	Volume Reduction	Peak Flow Reduction	Groundwater Recharge
Bioretention (infiltration design)	●	●	●
Bioretention (filtration design)	○	●	○
Porous Pavement (infiltration design)	●	●	●
Porous Pavement (filtration design)	○	●	○
Capture/Reuse	◉	○	○
Vegetated Roofs	○	●	○
Soil Amendments	◉	◉	◉
Downspout Disconnection	◉	◉	◉
Filter Strips	◉	○	◉
Vegetated Swales	◉	○	◉
Infiltration (Retention) Basins	●	●	●
Infiltration Trenches	◉	○	◉
Dry Wells	◉	○	◉
Dry Ponds (Extended Detention Basins)	○	●	○
Constructed Wetlands	◉*	●	○
Wet Ponds	◉*	●	○
Media Filters / Filter Basins	○	◉	○

Key: ● High effectiveness ◉ Medium effectiveness ○Low effectiveness

Rankings are qualitative.

- "High effectiveness" means that one of the BMP's primary functions is to meet the objective.
- "Medium effectiveness" means that a BMP can partially meet the objective but should be used in conjunction with other source controls.
- "Low effectiveness" means that the BMP provides minimal benefit to the objective and another BMP should be used if that objective is important.

* Wetlands and wet ponds constructed on soils with high permeability are difficult to keep saturated during Southern California's extended dry season. For this reason, they are rarely used, and only on highly impermeable soils.

Source: adapted from WERF 2006.

Different types of structural BMPs provide different environmental benefits based on the design and function of the LID BMP. Table 2-13 outlines the environmental benefits of 15 types of LID BMPs.

Table 2-13. Environmental Benefits of Structural BMPs.

BMP	Runoff Quality Enhancement	Water Conservation (Recharge/Reuse)	Heat Island Reduction	Energy Conservation	Air Pollution Reduction	Habitat
Bioretention	✓	✓	✓		✓	✓
Permeable Pavement	✓	✓				
Capture/Reuse	✓	✓				
Vegetated Roofs	✓		✓	✓	✓	✓
Soil Amendments	✓	✓				✓
Downspout Disconnection		✓				
Filter Strips	✓	✓	✓			
Vegetated Swales	✓	✓	✓		✓	
Infiltration (Retention) Basins	✓	✓				
Infiltration Trenches	✓	✓				
Dry Wells	✓	✓				
Dry Ponds (Detention Basins)	✓					
Constructed Wetlands	✓		✓		✓	✓
Wet Ponds	✓					✓
Media Filters/Filter Basins	✓					

Source: adapted from WERF 2006.

Different structural BMP designs remove different pollutants at varying efficiencies. Table 2-14 shows pollutant levels in the influent and effluent of 15 types of LID BMPs.

Table 2-14. Structural BMP Performance – Influent/Effluent Water Quality[3].

BMP[4]	Sediment (mg/L)	Nitrogen (mg/L)	Phosphorus (mg/L)	Metals – Zn (µg/L)	Oil and Grease (mg/L)	Bacteria (#/100mL)	Temp	Notes
Bioretention with underdrain	99.2/18.5‡‡	1.68/1.14†	0.61/0.16*	107/46*	30.8/2.5‡	641.5/86.5§	Moderate**	
Permeable Pavement with underdrain	xx/17.0††	xx/1.23††	xx/0.09††	xx/17††	xx/0.018‡‡	No data	Moderate	
Vegetated Filter Strips	114/27.6§§	1.12/0.66‡‡	0.38/0.86§§	355/79§§	No data	No data	Low	
Vegetated Swales	114/58.9§§	No data	0.38/0.62§§	355/96§§	No data	13,492/5,947§	Low	
Dry Ponds	114/46.6§§	0.96/0.98‡‡	0.38/0.28§§	355/136§§	2.72/2.54‡‡	2,218/1,741§	Poor	
Constructed Wetlands	37.8/17.8††	2.12/1.15††	0.27/0.14††	47/31††	No data	2,097/257§	Poor**	
Wet Ponds	114/11.8§§	2.29/1.46‡‡	0.38/0.54§§	355/37§§	0.82/0.88‡‡	2,693/446.4§	Poor**	
Media Filters / Filter Basins	114/11.3§§	No data	0.38/0.25§§	355/36§§	No data	1,820/541.3§	Poor	Includes Austin sand filter, Delaware sand filter, Multi-chambered treatment trains
Proprietary Devices	varies	varies	varies	varies	varies	varies	Poor	Performance is device-specific
Permeable Pavement without underdrain	N/A	N/A	N/A	N/A	N/A	N/A	Excellent	Infiltration practices are assumed to have zero discharge
Capture and Use	N/A	N/A	N/A	N/A	N/A	N/A	Excellent	Infiltration practices are assumed to have zero discharge
Dry Wells	N/A	N/A	N/A	N/A	N/A	N/A	Excellent	Infiltration practices are assumed to have zero discharge
Infiltration Basins	N/A	N/A	N/A	N/A	N/A	N/A	Excellent	Infiltration practices are assumed to have zero discharge

[3] When a substantial amount of data is collected for Southern California (i.e. through a BMP Submittal Tool) this table can be updated specific to Southern CA.
[4] BMPs with "N/A" values are designed to retain all flow and pollutants, it is assumed that all pollutants are retained in the BMP with zero discharge.

Table 2-14. Structural BMP Performance – Influent/Effluent Water Quality[3].

BMP[4]	Sediment (mg/L)	Nitrogen (mg/L)	Phosphorus (mg/L)	Metals – Zn (µg/L)	Oil and Grease (mg/L)	Bacteria (#/100mL)	Temp	Notes
Infiltration Trenches	N/A	N/A	N/A	N/A	N/A	N/A	Excellent	Infiltration practices are assumed to have zero discharge
Bioretention without underdrain	N/A	N/A	N/A	N/A	N/A	N/A	Excellent	Infiltration practices are assumed to have zero discharge
Key: *Davis 2007 §Clary et al. 2008 †Hunt et al. 2008 ‡Hong, Seagren, and Davis 2006 ***Teemusk and Mander, 2007 **Jones and Hunt 2008 §§Caltrans 2004 ††Geosyntec 2008 ‡‡ WERF 2016								

Source: Data assembled by The Low Impact Development Center, Inc.

Table 2-15 shows pollutant levels in the influent and effluent of 15 types of LID BMPs located internationally.

Table 2-15. International Structural BMP Performance – Influent/Effluent Water Quality.[1]

BMP	BMP Description	TSS In/Out (mg/L)	Nitrogen In/Out (mg/L)	Phosphorus In/Out (mg/L)	Total Zn In/Out (µg/L)	Total Cu In/Out (µg/L)	Fecal Coliform In/Out (MPN/100mL)
Bioretention		99.2/18.5	2.25/2.08	0.23/0.88	111.50/26.00	19.10/10.00	-
Composite		178.8/36.5	3.49/1.80	0.22/0.13	160.30/61.56	30.00/10.00	37,000/21,000
Detention Basin	Surface/grass-lined	129.0/49.6	1.70/2.10	0.16/0.14	151.00/58.25	23.30/12.00	12,000/7,100
Grass Strip		90.0/35.0	2.04/1.55	0.14/0.38	180.00/52.75	47.00/11.50	-
Grass Swale		67.5/46.7	1.50/1.60	0.10/0.25	110.00/61.40	24.05/17.33	22,000/17,000
LID[2]		87.5/82.0	-	-	-	-	-
Media Filter	Primarily sand filters	120.0/22.8	2.10/1.72	0.09/0.10	140.97/29.97	16.87/10.00	10,000/5,600
Porous Pavement		243.0/53.2	-	0.08/0.10	104.75/30.05	23.30/13.76	-
Retention Pond	Surface pond with a permanent pool	139.8/28.0	2.59/1.69	0.21/0.14	85.00/38.60	16.00/6.76	23,000/8,500
Wetland Basin	Basins with open water surface	75.9/31.0	2.00/1.82	0.10/0.08	85.50/33.07	11.74/6.00	23,000/7,200
Wetland Basin/ Retention Pond		110.3/29.6	2.26/1.75	0.17/0.11	85.00/37.00	14.20/6.58	23,000/8,500
Wetland Channel	Swales and channels with wetland vegetation	98.4/40.5	2.69/1.87	0.15/0.14	80.73/40.00	13.16/10.03	12,000/12,000

[1] BMP influent and effluent values account for the 75th percentile of the data. [2] Dashed (-) represent unavailable data. Source: WERF 2016.

Certain types of structural LID BMPs may not be feasible at certain sites based on site characteristics such as soil type, depth to groundwater, depth to bedrock, and site slope. Table 2-16 outlines the site characteristics suitable to certain BMP types.

Table 2-16. Structural BMP Site Suitability Criteria.

BMP	Soil HSG				Depth to groundwater		Depth to impermeable layer/bedrock		Slope			High Landslide Risk	Soil Contamination
	A	B	C	D	< 10'	> 10'	<5'	>5'	0-5%	5-15%	> 15%		
Bioretention	✓	✓				✓		✓	✓	✓if terraced			
Bioretention with underdrain			✓	✓	✓	✓	✓	✓	✓	✓ if terraced		✓	✓ with liner
Permeable Pavement	✓	✓				✓		✓	✓				
Permeable Pavement with underdrain			✓	✓	✓	✓	✓	✓	✓			✓	✓with liner
Capture/Reuse	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Vegetated Roofs	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Soil Amendments	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Downspout Disconnection	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Filter Strips	✓	✓	✓	✓		✓		✓	✓				
Vegetated Swales	✓	✓	✓	✓		✓		✓	✓	✓			
Infiltration (Retention) Basins	✓	✓	✓			✓		✓	✓				
Infiltration trenches	✓	✓	✓			✓		✓	✓				
Dry wells	✓	✓	✓			✓		✓	✓				
Dry ponds (detention basins)	✓	✓	✓			✓		✓	✓				✓ with liner
Constructed Wetlands		✓	✓	✓	✓	✓	✓	✓	✓				✓ with liner
Wet ponds		✓	✓	✓	✓	✓	✓	✓	✓	✓			✓ with liner
Media filters / Filter Basins	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Proprietary Devices	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Source: The Low Impact Development Center, Inc.

Another factor of LID design and planning is how much space is required for LID BMPs. Table 2-8 outlines average space requirements based on the upstream drainage area for eight types of LID BMPs.

Table 18. Typical Space Requirements for Stormwater LID Measures

Stormwater Quality Control Measure	% of Contributing Drainage Area
Retention	3-10
Rainwater Harvesting (Cistern)	0-10
Evapotranspiration (Green Roof)	1:1 of impervious area treated
Biofiltration	3-5
Dry Extended Detention Basin	1-3
Wet Detention Basin	1-3
Sand Filters	0-5
Cartridge Media Filter	0-5

Source: County of Los Angeles 2014.

Different types of LID structural BMPs require different types of maintenance at varying frequencies.The below table summarizes maintenance considerations for 16 types of LID structural BMPs (Table 2-17).

Table 2-17. Maintenance Considerations for LID Structural BMPs.

Source Control	Level of Effort	Frequency
Bioretention	**Minimal to Moderate:** Vegetation management required; occasional removal of captured debris	Semi-annual vegetation management, inspection
Permeable Pavement	**Moderate:** Rejuvenation may be needed (vacuum sweeper/power washing); vegetation management; pavement may have to be completely changed	Semi-annual vacuuming, inspection
Capture/Reuse	**Low:** No vegetation management; no removal of captured pollutants	Weekly emptying between storm events Semi-annual inspection
Vegetated Roofs	**Moderate:** Vegetation management	Semi-annual inspection Vegetation management
Soil Amendments	**Minimal:** No vegetation management; no removal of captured pollutants	Annual inspection
Downspout Disconnection	**Minimal:** No vegetation management; no removal of captured pollutants	Annual inspection
Filter Strips	**Low to Moderate:** Management of vegetation; occasional removal of captured pollutants	Weekly mowing Semi-annual inspection
Vegetated Swales	**Low to Moderate:** Minimal removal of captured pollutants; vegetation management	Weekly mowing Semi-annual inspection
Infiltration Basins	**Moderate to High:** Rejuvenation may be needed (scarifying surface/raking); possible removal of vegetation; removal of captured materials	Semi-annual inspection
Infiltration Trenches	**Low:** Removal of captured debris; periodic inspection	Semi-annual inspection

Source Control	Level of Effort	Frequency
Dry Wells	**Low:** Removal of captured debris; periodic inspection	Semi-annual inspection
Dry Ponds	**Moderate:** Removal of captured debris; vegetation management; periodic inspection	Weekly mowing Semi-annual inspection Sediment removal every 5-25 years
Constructed Wetlands	**High:** Management of vegetation; removal of floating debris and trash; sediment and vegetation removal; maintain water level during dry periods	Semi-annual inspection Vegetation management
Wet Ponds	**Moderate:** Removal of captured debris; vegetation management; mosquito control	Semi-annual inspection, debris removal, Annual vegetation harvesting
Media Filters	**Moderate:** Inspection and removal of captured debris; sediment removal.	Quarterly inspection, debris removal
Proprietary Devices	**Moderate:** Inspection and removal of captured debris; sediment removal.	Quarterly inspection, debris removal

Source: adapted from WERF 2006

Cost

In 2014, the National Cooperative Highway Research Program (NCHRP) published the Long-Term Performance and Life-Cycle Costs of Stormwater Best Management Practices report. The spreadsheet tools are intended to guide the determination of capital and maintenance costs for seven selected stormwater management practices that include:

1. Bioretention;
2. Dry detention;
3. Filter Strip;
4. Permeable Friction Course (PFC);
5. Sand Filter;
6. Swale;
7. Wet Pond;

By inputting values such as project location, drainage area, treatment volume, construction materials, and maintenance frequencies, the models will estimate BMP project costs.

Literature reviews, as well as surveys and interviews with Department of Transportation staff in all 50 states were used to develop the life-cycle cost models. The models can provide planning-level estimates of costs or site-specific costs depending upon the level of information that the user can provide. Each of the models contains default cost values from project research. Adding a few inputs (e.g., drainage area, rainfall, and treatment volume) will provide planning level capital, maintenance, and whole life costs. Using the models' default cost values provides general cost estimates as the cost factors are based on national averages and do not take into account regional or site-specific design factors.

The models provide location-specific cost estimates as a location adjustment factor can be entered to adjust for local costs. The BMP design components can be customized, allowing inputs that reflect geographic influences and individual site conditions. The models can also be used to provide varying degrees of specificity as each cost component can be provided by the user or a combination of default values and user provided values can be used.

The spreadsheet tools and report are available at the National Academies of Science, Engineering, and Medicine: http://www.trb.org/Publications/Blurbs/171471.aspx

Resources:

County of Los Angeles Department of Public Works. 2014. Low Impact Development Standards Manual. February 2014. https://dpw.lacounty.gov/ldd/lib/fp/Hydrology/Low%20Impact%20Development%20Standards%20Manual.pdf.

Geosyntec, 2008. *Overview of Performance by BMP Category and Common Pollutant Type, International Stormwater Best Management Practices (BMP) Database, 1999-2008.* http://www.bmpdatabase.org/Docs/Performance%20Summary%20June%202008.pdf

Water Environment Research Foundation (WERF). 2006. *Decentralized Stormwater Controls for Urban Runoff and Combined Sewer Overflow Reduction.* Report Number: 03SW3. Alexandria, VA: Water Environment Research Foundation. https://www.werf.org/a/ka/Search/ResearchProfile.aspx?ReportID=03-SW-3.

Water Environment Research Foundation (WERF). 2009. *User's Guide to the BMP and LID Whole Life Cost Models, Version 2.0*. Report Number: SW2R08. Alexandria, VA: Water Environment Research Foundation. http://stormwater.ucf.edu/wp-content/uploads/2016/06/SW2R08_Users-Guide-to-the-BMP-and-LID-Whole-Life-Cost-Models.pdf.

Water Environment Research Foundation (WERF). 2017. International Stormwater BMP Database 2016 Summary Statistics. http://www.bmpdatabase.org/Docs/03-SW-1COh%20BMP%20Database%202016%20Summary%20Stats.pdf.

Bioretention

Bioretention cells are small-scale, vegetated, shallow depressions that address pollutants contained in stormwater runoff by filtration through an engineered soil medium (Figure 2-9). Biological and chemical reactions in the soil matrix and root zone remove pollutants, and runoff volume is reduced through plant uptake and infiltration into the underlying subsoil. Where infiltration is impossible, bioretention cells are fitted with underdrains to discharge treated stormwater into the storm drainage system. Properly constructed bioretention cells replicate the hydraulic function of an undisturbed upland ecosystem. By intercepting, detaining, and infiltrating runoff, bioretention cells reduce the volume of stormwater flows and reduce on-site erosion. They may be designed on-line or off-line from the primary stormwater conveyance system.

Bioretention can be designed as an integrated landscape feature that improves water quality while reducing runoff quantity. Bioretention offers considerable flexibility in terms of how it can be integrated into a site, and can complement other structural management systems, such as porous pavement parking lots and infiltration trenches, as well as non-structural stormwater BMPs.

Bioretention vegetation serves to improve water quality and reduce runoff quantity. The plants absorb some pollutants, while microbes associated with the plant roots and soil degrade pollutants. In addition to filtering pollutants, the soil medium allows storage and, where feasible, infiltration of stormwater runoff, providing volume control. Soil media serve as a bonding surface for nutrients to enhance pollutant removal. Additional treatment capacity is provided by a surface mulch layer, which traps sediments that can carry high pollutant loads. The most successful bioretention cells mimic nature by employing a rich diversity of locally-adapted plant types and species, which provides them with good tolerance of pests, diseases, and other environmental stressors.

Figure 2-9. Bioretention Cell in Parking Lot, OC Public Works, Orange, CA.

Source: Olaunu

Cost

Bioretention cells often replace areas that would have been landscaped providing a functional landscape that is a more useful and cost efficient use of space. In addition, the use of bioretention can decrease the cost for stormwater conveyance systems on a site. Average bioretention BMP unit costs in Southern California are outlined in the below table (Table 2-18).

Table 2-18. Southern California Bioretention BMP Unit Costs

Design Activity or Product	Unit	Baseline Unit Cost
Mobilization	Each	$1,500
Clearing & Grubbing	Acre	$3,500
Planting Media	Square foot	$0.15
Pea Gravel	Cubic yard	$45
Gravel	Cubic yard	$36
Mulch	Cubic yard	$24
Slotted PVC Underdrain Pipe	Linear foot	$16
Excavation/Grading	Cubic yard	$11
Haul/Dispose of Excavated Material	Cubic yard	$24
Finish Grading	Square foot	$0.20
Bioretention Vegetation	Square foot	$0.35
Hydroseed	Square foot	$0.30
18" Square Trench	Each	$110
Dewatering	Day	$600
Inflow Structure(s)	Each	$850
Overflow Structure (concrete or rock riprap)	Each	$1,200
Metal Beam Guard Rail	Linear foot	$65

(W. Papac, personal communication, March 26, 2019)

Average bioretention BMP unit costs across the US are reflected in the below table (Table 2-19).

Table 2-19. National Bioretention BMP Unit Costs

Design Activity or Product	Unit	Baseline Unit Cost
Mobilization	Longitudinal section	10% to total cost
Clearing & Grubbing	Square yard	$0.96
Planting Media	Cubic yard	$43
Pea Gravel	Cubic yard	$129
Gravel	Cubic yard	$27
Mulch	Cubic yard	$71
Slotted PVC Underdrain Pipe	Linear foot	$8
Excavation/Grading	Bank cubic yard	$9
Haul/Dispose of Excavated Material	Cubic yard	$10
Finish Grading	Square yard	$2
Bioretention Vegetation	Square foot	$2
Hydroseed	Square foot	$0.08
18" Square Trench	Linear foot	$1
Dewatering	Day	$1,200
Inflow Structure(s)	Longitudinal section	$2,200
Overflow Structure (concrete or rock riprap)	Cubic yard	$125
Metal Beam Guard Rail	Linear foot	$58

(NCHRP 2014, Appendix E)

Benefits

- Reduced runoff volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Reduced runoff temperature
- Groundwater recharge (if soils are sufficiently permeable and no underdrain is placed underneath)
- Habitat creation
- Enhanced site aesthetics
- Reduced heat island effect
- Improved air quality
- Potential reduction in drainage and flood control infrastructure
- Increased land values
- Sound reduction
- Traffic calming

Limitations

- Terraced designs must be used on steep slopes
- Infiltration design requires sufficiently permeable soils, depth to groundwater and depth to impermeable layers
- Infiltration design should be located at least 100 feet from drinking water wells
- Maximum tributary area should be less than 5 acres
- Requires regular trash removal and maintenance of vegetation
- May require irrigation during dry periods

Potential LEED Credits:

Primary: Sustainable Sites – Rainwater management (3 Points) (LEED V4.1)

Water Supply Impacts

Water supply impacts vary and are associated with water needed for initial plant establishment and subsequent maintenance. Water will likely be needed for maintenance irrigation, unless the species chosen are adapted to the site's precipitation, soils, and microclimate, and have adequate conditions to survive and grow without supplemental irrigation. In these cases, the long-term supply impact is essentially neutral. For a retrofit project in which an existing "conventionally" landscaped area (e.g., turf or higher water-use plants) is replaced with bioretention, the water supply impact should be positive (i.e., less water is needed) compared to the existing developed condition. Detailed guidance on the irrigation needs of landscape plantings has been published by the California Department of Water Resources (UCCE/CDWR, 2000).

Applications

Bioretention can take many forms, from the simple residential "rain garden," to the "planter box" complete with underdrain and engineered filtering media. Bioretention is appropriate for use in commercial, institutional, residential, industrial, and transportation applications. The common forms of bioretention and potential applications are provided below.

Potential Applications

Residential	YES
Commercial	YES
High-density	LIMITED
Industrial	YES
Recreational/Institutional	YES
Highway/Road	YES
Parking Lots	YES

Residential

Residential settings often provide favorable conditions in which to incorporate bioretention (Figure **2-10**). Bioretention cells can be installed in lawn areas or locations that would otherwise have been landscaped. Roof drainage, driveway, street/sidewalk and yard drainage can be treated with bioretention.

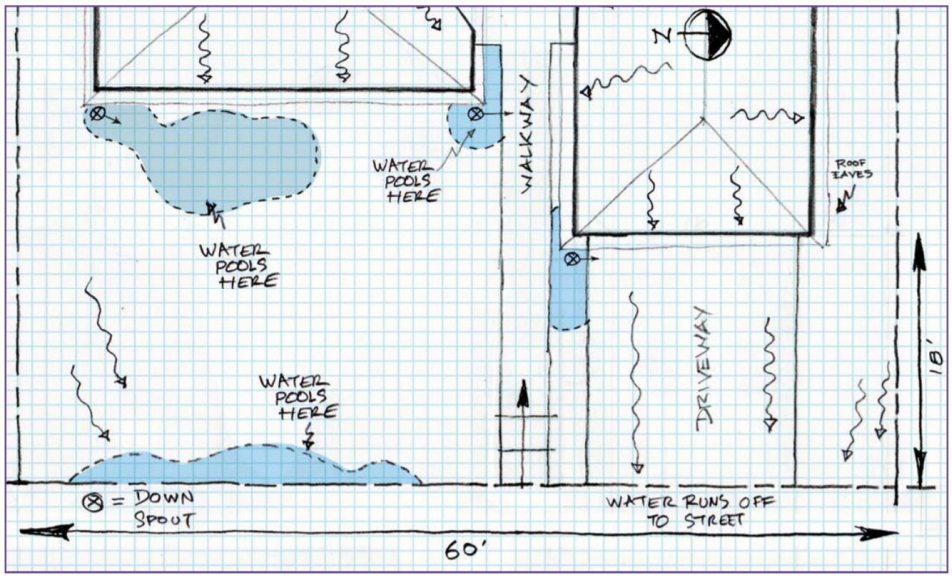

Figure 2-10. Single-Family Residential Lot Drainage Schematic.

Source: Sustainable Landscapes Program Partners 2018

A range of treatment train options are available in residential applications. Downspouts, for instance, can deliver stormwater directly to the surface of a bioretention cell or a landscaped yard, or a vegetated channel can be used as pretreatment for bioretention cell influent (Figure **2-11**).

Figure 2-11. Roof downspout draining to bioretention cell.

Source: Sustainable Landscapes Program Partners 2018

Planter Box

In urban settings, bioretention can be incorporated into planter boxes. As part of a disconnection strategy, roof downspouts may be directed to vegetated planter boxes to store and filter stormwater. Planter boxes offer “green space” in tightly confined urban areas that provide a soil/plant mixture suitable for stormwater capture and treatment.

Planter boxes are most commonly used in urban areas adjacent to buildings and along sidewalks (Figure 2-12). Locations close to roof downspouts are preferable when used a part of a disconnection program. Planter boxes may be constructed of any durable material. When built adjacent to buildings as a receptacle for downspout runoff, they are often constructed of the same material as the building. Otherwise they may be constructed of concrete to blend in with the sidewalk or metal when they are stand-alone units. Planter boxes constructed adjacent to buildings should be fitted with waterproofing membranes on the building side to prevent seepage of captured water into the building.

Figure 2-12. Planter box capturing roof runoff.

Source: The Low Impact Development Center, Inc.

Commercial – Parking Lot Landscaped Filter Basin (LFB)

Stormwater management and green space areas are limited in parking areas. In these situations, bioretention can create functional areas out of existing landscaping. Bioretention can be retrofit into existing parking lot islands, or designed into parking lot medians and perimeters (Figure 2-13).

Figure 2-13. Parking Lot Bioswale, San Diego County, CA

Source: Michael Baker International 2019a

- *Curbless Parking Lot Bioretention*
  A bioretention cell can be located adjacent to a parking area with wheel stops rather than curbs, allowing stormwater to flow as a distributed "sheet" of water over the parking lot edge and directly into the cell. Shallow grades must direct runoff at reasonable velocities.

- *Curbed Parking Lot Bioretention*
  Runoff can be directed along a parking lot island by using a curb and gutter. Once runoff reaches a low point along the curb perimeter, water enters the bioretention cell through a curb cut. If the runoff volume exceeds the ponding depth available, water will overflow the bioretention cell and enter a standard inlet.

Roadway

Bioretention cells can be used alongside roadways. Runoff is conveyed along the concrete curb until it reaches the end of the gutter, where it spills into the vegetated area. A photo of this type of arrangement is shown below (**Figure 2-14**).

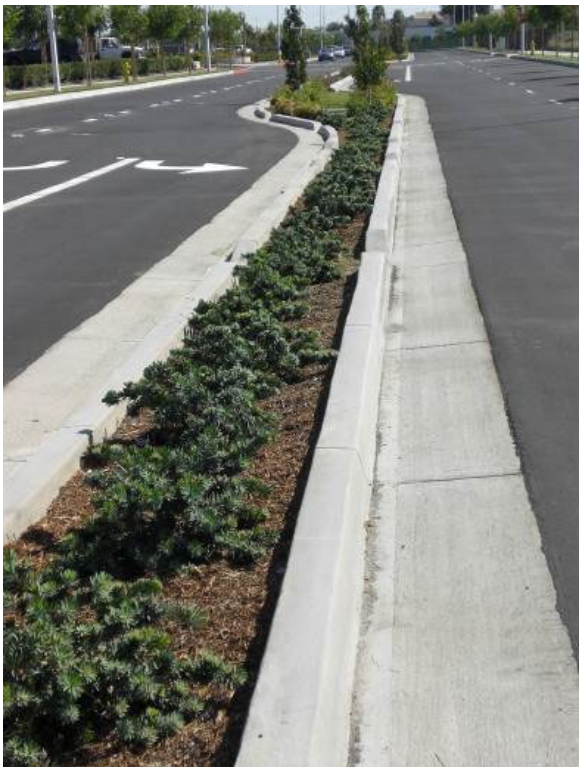

Figure 2-14**. Linear Bioretention, Downey, CA**

Source: Bill DePoto

Dry Swales

In addition to the common “cell” design, bioretention can be incorporated into vegetated swales (Figure 2-15). Such structures can be used to provide infiltration and water quality treatment while conveying larger flows to supplemental storage BMPs.

Figure 2-15. Bioretention cell for street/yard drainage, Downey, CA.

Source: Bill DePoto

Site Factors for infiltration designs

- Depth to water table: Ten (10)- foot minimum for infiltration[5]
- Depth to bedrock: Five (5)- foot minimum for infiltration
- Soil permeability: soils are typically required to have a minimum of 0.5 inches per hour for infiltration
- Feasibility on steeper slopes: medium

When working in areas with steeper slopes (up to 15%), it is critical to first verify that these BMPs are feasible. A geotechnical engineer should be consulted to evaluate the suitability of installing a bioretention cell on or near a steep slope, to identify the risk of creating an unstable condition; underdrains may be required for slope applications. When they do occur on slopes, bioretention cells should be terraced laterally along slope contours to minimize earthwork and provide level areas for infiltration.

Percolation tests should be performed by a qualified professional to verify soil permeability in the locations where bioretention cells are planned. If soils are found to have percolation rates less than 0.5 in/hour, bioretention cells should be fitted with underdrains and treated as filtration rather than infiltration practices.

Many local jurisdictions are developing standard specifications for the location, sizing, configuration, and/or maintenance of LID BMPs and such requirements where they exist should be used. Where local specifications for bioretention do not exist, the following guidelines can be used.

Building Setbacks

- Buildings with basements: 25 feet, down-gradient from foundation
- Buildings without basements: 5 feet

Planter box bioretention facilities can be placed adjacent to buildings if they are fit with waterproofing membranes adjacent to the building wall.

Pedestrian Traffic

Pedestrian traffic across bioretention cells causes compaction, decreasing the infiltration rate of the soil. Walking across bioretention cells should be discouraged by providing alternative pathways and by planting densely.

Pretreatment (may be necessary to help prevent clogging)

Pretreatment consists of sediment removal through a vegetated buffer strip, cleanout, stabilized inlet, water quality inlet, or sediment trap prior to runoff entry into the bioretention cell. Pretreatment of runoff should be provided wherever excessive sediment is likely to enter the bioretention cell and cause concern for decreased functionality of the BMP. Rooftop runoff may need little or no pretreatment.

Flow Entrance

Options:

- Water may enter via an inlet (e.g., flared end section) or trench drain
- Sheet flow into the facility over landscaped areas or level spreader
- Curb cuts with grading for sheet flow entrance
- Roof leaders with direct surface connection

Entering velocities must be non-erosive where concentrated runoff enters the bioretention cell – use inlet energy dissipaters such as rocks or splash blocks. The following figures show bioretention cells (Figure 2-16 and Figure 2-17).

[5] Varies by local LID BMP design permit requirements and minimum infiltration rates of the site

Figure 2-16. Bioretention cell for street/yard drainage, Los Angeles, CA.

Source: Bill DePoto

Figure 2-17**. Curb cut directing water from a parking lot into a bioswale.**

Source: Michael Baker International 2019b

Ponding Area

For most areas, maximum 3:1 side slopes or flatter are recommended to enhance safety and buffer the erosive force of incoming runoff. In planter boxes or other areas where vertical walls are necessary, use energy dissipators to control erosion.

Surface ponding depth is generally 6 to 12 inches. Drawdown times vary by jurisdiction but are generally in the range of 24-72 hours to minimize vector issues and prevent depletion of oxygen in the soil. Bioretention BMPs with an underdrain should ideally drain within a couple of hours; the design infiltration rate is typically between five and twelve inches per hour and the ponding depth is in the range of six to eighteen inches.

Bioretention Soil Medium/Volume Storage Bed

Bioretention soil medium (BSM) depth should be between 24 and 36 inches where only herbaceous plant species will be utilized. If trees and woody shrubs will be used, soil media depth may need to be increased, depending on plant species (especially in poorly drained sites). Provided they meet drainage criteria, native soils can be used as part of the soil medium.

The BSM is generally composed of: 60-80% sand, and 20-40% compost by volume (Table 2-20). The formula can be varied to some extent, but major changes may impact both hydraulic and pollutant removal performance and should be studied carefully. Engineered soil media meeting the specification described in Table 2-20 can be expected to have filtration rates ranging from five to twelve inches per hour. Proprietary biofiltration systems may have higher media filtration rates.

Table 2-20. Bioretention Soil Medium Specification.

Component	Properties
Sand	60 – 80% by weight
Characteristics	Free of wood, waste, coating such as clay, stone dust, carbonate, etc. or any other deleterious material
Specifications	Sand for bioretention should be analyzed by an accredited lab using #200, #100, #40, #30, #16, #8, #4, and 3/8 sieves and meet the gradation in Table H-1 of the Los Angeles County MS4 Permit.
Compost	20 – 40% by weight
Characteristics	Well decomposed, stable, weed free organic matter source derived from waste materials including yard debris, wood wastes, or other organic materials not including manure or biosolids meeting standards developed by the US Composting Council
Specifications	Compost for bioretention should be analyzed by an accredited lab using #200, ¼ inch, ½ inch, and 1 inch sieves and meet the gradation in Table H-2 of the Los Angeles County MS4 Permit. Compost quality should be verified via a lab analysis to be:
• Organic Matter	35 – 75% by dry weight
• Carbon and Nitrogen Ratio	15:1 < C:N < 25:1
• Maturity/Stability	Have dark brown color and a soil-like odor. Compost exhibiting a sour or putrid smell, containing recognizable grass or leaves, or is hot (120 F) upon delivery or rewetting is not acceptable.
• Toxicity (any one of the following properties)	NH4:NH3 < 3 Ammonium < 500 ppm, dry weight basis Seed Germination > 80% of control Plant trials > 80% of control Solvita® > 5 index value
• Nutrient Content	Total Nitrogen content 0.9% or above preferred. Total Boron should be <80 ppm, soluble boron < 2.5 ppm.
• Salinity	< 6.0 mmhos/cm
• pH	Between 6.5 and 8

Source: The Low Impact Development Center, Inc.

Surface Mulch or Organic Layer

- Acts as a filter for pollutants in runoff
- Protects underlying soil from drying and eroding
- Reduces likelihood of weed establishment
- Provides a medium for biological growth, decomposition of organic material, and adsorption and bonding of heavy metals

Two to three inches of shredded hardwood mulch (aged at least 6 months to 1 year), leaf compost, or other comparable product should be uniformly applied immediately after planting to prevent erosion, enhance metal removal, and aid plant establishment. Wood chips should be avoided as they tend to float during inundation periods.

Mulch or compost should not exceed 3 inches in depth so as not to restrict oxygen flow, and should not be placed directly against the stems or trunks of plants.

Plants

Proper plant selection is essential for bioretention areas to be effective. Typically, generalist plant species native to the area are best suited to the variable environmental conditions encountered in a bioretention cell, as they need to withstand a wide range of soil and moisture regimes. See the plant list in Appendix B for recommended species based on ecoregion. When designing the planting, it is important that plant species are located according to their tolerance of inundation and prolonged soil saturation; less tolerant species should be located at the higher elevations. It should be noted, however, that bioretention cells drain rapidly, and therefore do not develop anoxic soil conditions. Trees, shrubs, and herbaceous perennials may be used in a bioretention cell. They should be selected with other functions in mind (e.g., shade, screening versus clear views, color, etc.), in addition to suitability for bioretention and to the ecoregion. For bioretention cells that will have an underdrain, it is also important to select species that do not have invasive roots, which have a tendency to clog perforated drainage pipes. A landscape architect can help with plant selection and bioretention cell design.

Verify that candidate plants can tolerate snowmelt chemicals, if applicable (at high elevations).

In most cases, seed is not the preferred method for plant establishment in a bioretention cell. The fluctuating water levels make it difficult for the seed to readily establish, and the random nature of seeding may result in an undesirable plant layout for some situations. Instead, it is strongly recommended that containerized live plants be utilized: plugs or 1-gallon for herbaceous plants, 1- to 5-gallon for shrubs, and 5-gallon to 24-inch box for trees. Plant spacing depends on mature plant size and desired density of plant cover.

Plant species composition generally depends on how often water is expected to pond in the bioretention cell. For Southern California, species will likely need to be drought-tolerant plants that can handle occasional inundation during the rainy season.

Underdrain

In sections of Southern California with less-permeable soils (typically HSG Group C or D soils), underdrains are required to ensure adequate drainage. Underdrains are typically constructed of a 6” diameter perforated pipe connecting to an existing stormwater conveyance structure or outlet. The underdrain is preferably placed near the top of the gravel storage area to promote incidental infiltration and enhanced nitrogen removal. However, if underlying soils do not provide sufficient drainage, the underdrain may need to be placed lower in the gravel storage area (within 6 inches of the bottom) to prevent the unit from holding stagnant water for extended periods of time. Incidental infiltration is also an important factor in achieving the required pollutant load reduction (California RWQCB Los Angeles Region 2015).

Enhanced Nitrogen Removal

The underdrain can be placed several inches above the bottom of the bioretention cell, creating an extended detention zone that will provide an opportunity for enhanced nitrogen removal by denitrification (Hsieh, David, and Needleman 2007).

Overflow

Provide for the direct discharge of excess runoff during large storm events when the subsurface and surface storage capacity is exceeded. Where possible, peak flows exceeding the design capacity of the bioretention system should be routed around the system rather than through it so that the mulch and bioretention soil is not scoured.

Examples of outlet controls include domed risers, inlet structures, weirs, and similar devices (Figure 2-18, Figure 2-19, and Figure 2-20).

Figure 2-18**. Positive Overflow Device: Domed Riser**

Source: Macomb County Michigan Public Works Office

Figure 2-19. **Inlet Structure, County of San Diego, CA**

Source: Michael Baker International 2019c

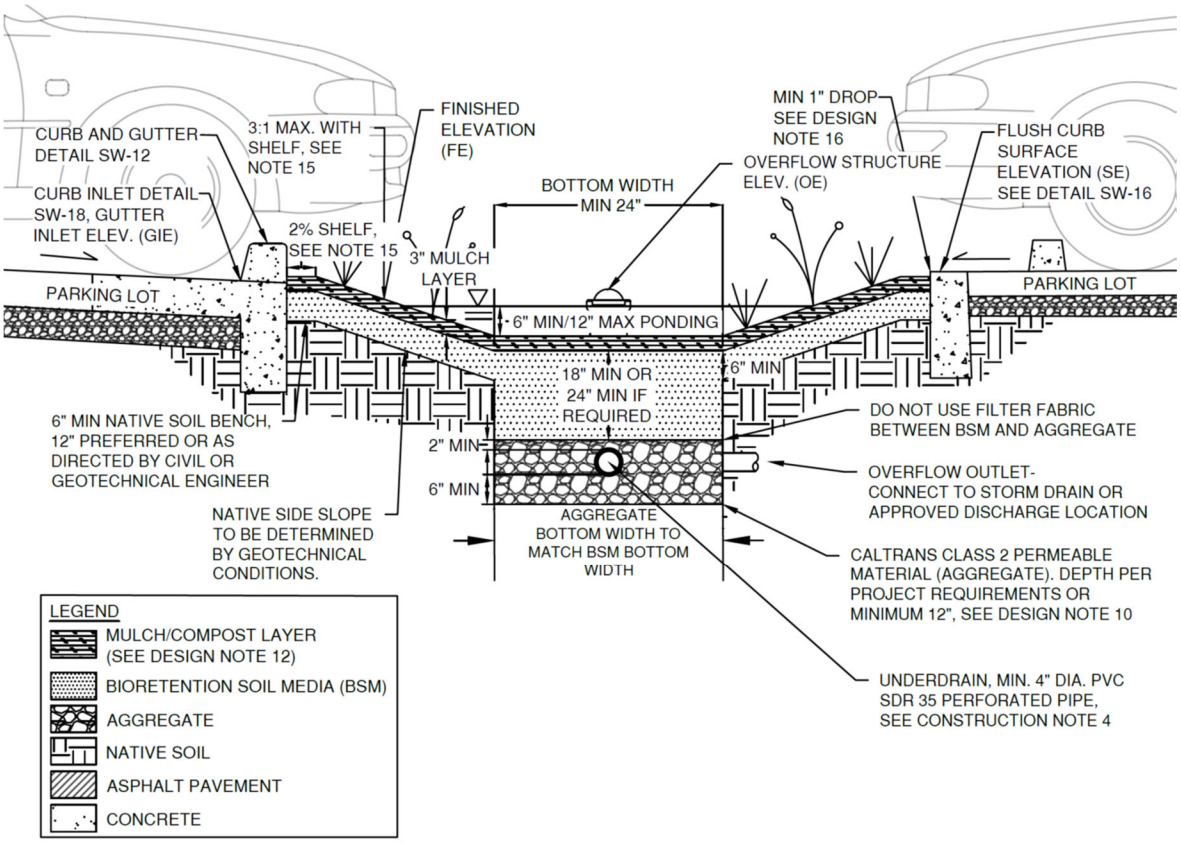

Figure 2-20. Detailed cross-section of a parking lot bioretention cell.

Source: CASQA/LIDI 2017

Sizing criteria for systems without underdrain

Surface area depends on storage volume requirements and permeability of the BSM and underlying native soil. Runoff volume is based on local regulatory requirements, such as a specific design storm (e.g. 2-year, 24-hour) or total runoff (85th percentile), and is calculated using one of the methods described in Step 5 of this manual, or by the method specified by local regulations. The total storage volume of a bioretention cell, V_{BMP}, accounts for both surface ponding and the available pore space within the soil medium.

Maximum Total Depth

The maximum total depth of the bioretention cell (ponding depth, BSM depth and gravel storage depth) is limited by the infiltration rate of the surrounding soil. This depth can be calculated using the following formula (RCFC & WCD 2006):

$$D_m(in) = \frac{t(hr) \times I(in/hr)}{s}$$

where I = site infiltration rate (in/hr)
s = safety factor, and
t = drawdown time (usually 48-72 hours).

The safety factor, s, accounts for uncertainty in the true site infiltration rate. If the infiltration rate is not based on onsite testing, use s = 10, for planning purposes only. Before finalizing design, conduct in situ double-ring infiltrometer tests to establish true infiltration rates, and use pits or borings to examine subsoils for restrictive layers. Then, a safety factor not less than s = 3 is to be applied.

This total depth can then be divided among the surface ponding depth and subsurface BSM depth:

$$D_m = D_p + D_b$$

where D_p = ponding depth, and
D_b = BSM depth.

Surface Area

The size of the bioretention cell is determined by calculating the area necessary to store the design volume at the maximum depth, taking into account the available storage volume within the BSM. The area of the bioretention cell can be calculated using the following formula, assuming that the bioretention cell is constructed with a level surface:

$$A(ft^2) = \frac{V_{BMP}(ft^3) \times 12(in/ft)}{D_p(in) + D_b(in) \times R_b}$$

where A = BMP surface area (ft^2)
V_{BMP} = BMP design volume (ft^3), and
R_b = BSM void ratio (usually about 0.3).

A four percent sizing factor is sometimes used as a general plan check, but bioretention sizing should be consistent with the local jurisdiction's regulations and requirements.

The total surface area needed may be divided into multiple cells. This configuration, for example, may be useful to collect runoff from both the front and back of a building.

Sizing criteria for systems with underdrain

In poor soils or other locations where infiltration is not feasible, bioretention cells are constructed with underdrains, and therefore serve as detention rather than retention systems. Where underdrains are used, maximum depth is not limited by the infiltration rate of the surrounding soil. The depth of the bioretention cell may be determined based on other design considerations, such as necessary storage volume, plant rooting depth, and pollutant removal performance. Typical values are given below:

Ponding depth	6 inches
BSM depth	24-36 inches

The total area required can then be calculated using the above equation for surface area.

Some LID design manuals allow for calculation of biofiltration systems as flow-based devices with a water quality flow rate calculation instead of a volume based calculation. Additionally, many MS4 permits require a 1.5 volume multiplier if a flow through design is used where infiltration is infeasible.

Construction Guidance

The following is a typical construction sequence. However, alterations will be necessary depending on design variations.

1. Install temporary sediment control BMPs as required by permitting authority.
2. Complete site grading, minimizing compaction as much as possible. If applicable, construct curb cuts or other inflow entrance, but provide protection so that drainage is prohibited from entering the construction area. Construct pretreatment devices (filter strips, swales, etc.) if applicable.
3. Stabilize grading, except within the bioretention area.
4. Excavate bioretention cell to proposed invert depth and scarify the existing soil surfaces. Do not compact soils.
5. Install perforated underdrain if applicable. The underdrain system shall be placed on a 3-ft wide bed of No. 57 aggregate, covered with 6 inches of No. 57 aggregate and topped with 2 inches of No. 7 aggregate.
6. Backfill bioretention cell with \BSM in 12-inch layers. Each layer should be compacted by saturating the bioretention cell.
7. Install automatic irrigation system if applicable.
8. Allow the BSM to settle for 24 hours.
9. Complete final grading to achieve proposed design elevations, leaving space for upper layer of compost or mulch as specified on plans.
10. Plant vegetation according to planting plan.
11. Apply mulch layer.
12. Install erosion protection at surface flow entrances where necessary.
13. Perform infiltration testing to verify system performance. Refer to the On-site Soil Assessment section on page 2-10 and 16 for additional details.

Figure 2-21. Newly Planted Bioretention Cell in El Monte, CA

Source: Bill DePoto

Maintenance Considerations

Properly designed and installed bioretention cells require some regular maintenance, most frequently during the first year or two of establishment.

Bioretention cells will require supplemental irrigation during the first 2-3 years after planting. Drought-tolerant species may need little additional water after this period, except during prolonged drought, when supplemental irrigation may become necessary for plant survival. Verify that the maintenance plan includes a watering schedule for the establishment period and in times of extreme drought after plants have been established.

While vegetation is being established, remove weeds by hand (weeding frequency should decrease over time, as plants grow).

Although plants may need occasional pruning or trimming, bioretention cells should generally not be mowed on a regular basis. Trim vegetation as necessary to maintain healthy plant growth. In some instances, where it is desired to maintain fast-growing, annual herbaceous plant cover, annual mowing may be appropriate.

Replace dead plants. If a particular species proves to be prone to mortality, it may need to be replaced with a different species that is more likely to succeed on this particular site.

Mulch should be re-applied when erosion is evident. In areas expected to have low metal loads in the runoff, mulch as needed to maintain a 2-3 inch depth. In areas with relatively high metal loads, replace mulch once per year.

Bioretention cells should be inspected at least two times per year for sediment buildup, trash removal, erosion, and to evaluate the health of the vegetation. If sediment buildup reaches 25 percent of the ponding depth, it should be removed, taking care to minimize soil disturbance. If erosion is noticed within the bioretention cell, additional soil stabilization measures should be applied. If vegetation appears to be in poor health with no obvious cause, a landscape specialist should be consulted.

An important concern for bioretention applications is their long-term protection and maintenance, especially if undertaken in multiple (adjacent) residential lots where individual homeowners provide maintenance. In such situations, it is important to provide management guarantees that ensure their long-term functionality (e.g., deed restrictions, covenants, and maintenance agreements).

Resources

CASQA/LIDI. 2017. CASQA/LIDI Bioretention Standard Designs and Specifications. https://www.casqa.org/resources/california-lid-portal/standard-lid-design-plans-specifications

City of Santa Barbara. 2008. *Stormwater Best Management Practices (BMP) Guidance Manual*. http://services.santabarbaraca.gov/CAP/MG110498/AS110499/AS110501/AI114484/DO114485/3.PDF

County of San Diego. 2014. *Low Impact Development Handbook.* https://www.sandiegocounty.gov/content/dam/sdc/pds/docs/LID_Handbook_2014.pdf

The Low Impact Development Center (LIDC). 2007. *Stormwater Urban Design Tools*. http://www.lid-stormwater.net/

Riverside County Flood Control and Water Conservation District (RCFC & WCD). 2006. *Riverside County Stormwater Quality Best Management Practice Design Handbook*. Riverside, CA. http://rcflood.org/downloads/NPDES/Documents/SA_WQMP/SA_BMP_Design_Handbook_July_2006.pdf

Sustainable Landscapes Program Partners. 2018. San Diego Sustainable Landscapes Guidelines A Watershed Approach to Landscaping. January 2018. https://sustainablelandscapessd.org/wp-content/uploads/SLP-Guidelines-Book-updated-January-2018.pdf.

University of California Cooperative Extension (UCCE) and California Department of Water Resources (CDWR). 2000. *A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California*. California Department of Water Resources: Sacramento, CA.

Pervious Pavement

Pervious pavement consists of a permeable surface course underlain by a storage reservoir consisting of a uniformly graded aggregate bed or premanufactured structural stormwater units (Figure 2-22). An optional filter layer with subdrains may be incorporated for installations on soils that do not support infiltration. The surface course may consist of pervious bituminous asphalt, pervious concrete, various types of permeable pavers, reinforced turf or gravel, or clear binder pavements.

Variations

1. Pervious Bituminous Pavement
2. Pervious Concrete
3. Permeable Pavers
4. Reinforced Turf/Gravel
5. "Clear" Binder Pavements

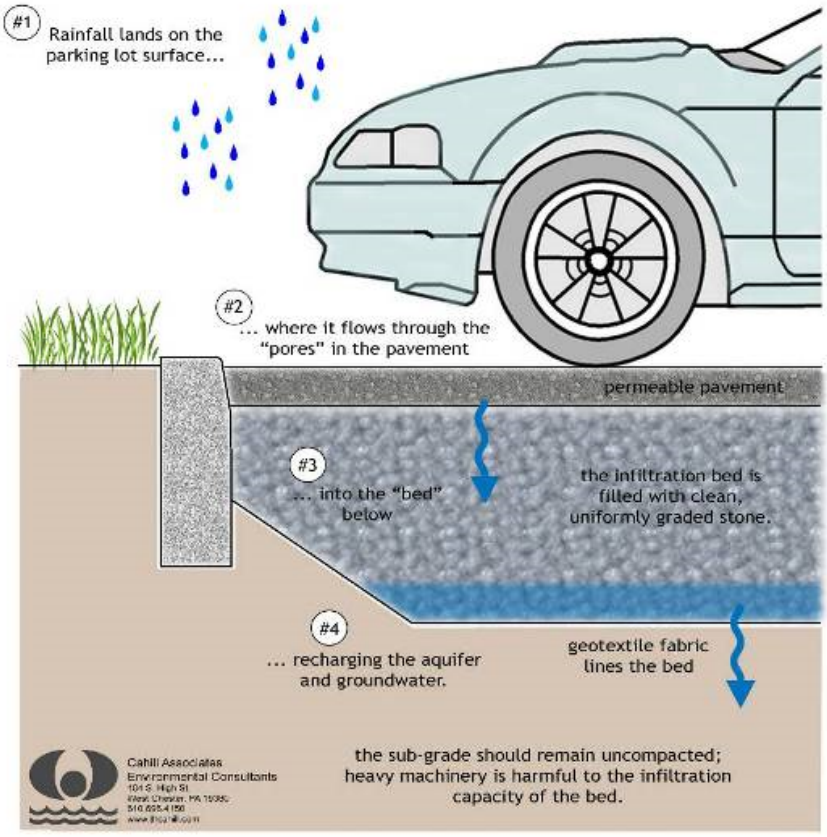

Figure 2-22. Cross-section showing design components of permeable pavement with subsurface infiltration bed.

Where infiltration is infeasible, underdrains can be fitted into the subsurface bed.

Source: Cahill Associates

Benefits

- Reduced runoff volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Reduced runoff temperature
- Groundwater recharge (if soils are sufficiently permeable and no underdrain is placed underneath)
- Reduced heat island effect
- Dual purpose

Limitations

- Should not be used to capture runoff from unpaved areas
- Should not be used in areas with high danger of pollutant spills
- Not suitable for high traffic areas
- Requires regular maintenance
- Not suitable for slopes greater than 3 percent

Water Quality

Pervious pavement systems are effective in reducing such pollutants as total suspended solids, metals, and oil and grease (Figure 2-23). The pervious pavement surface, the (optional) filter layer, and the underlying soils below the infiltration bed filter particulate pollutants. Pervious pavement systems will provide limited treatment of dissolved pollutants, such as nitrates.

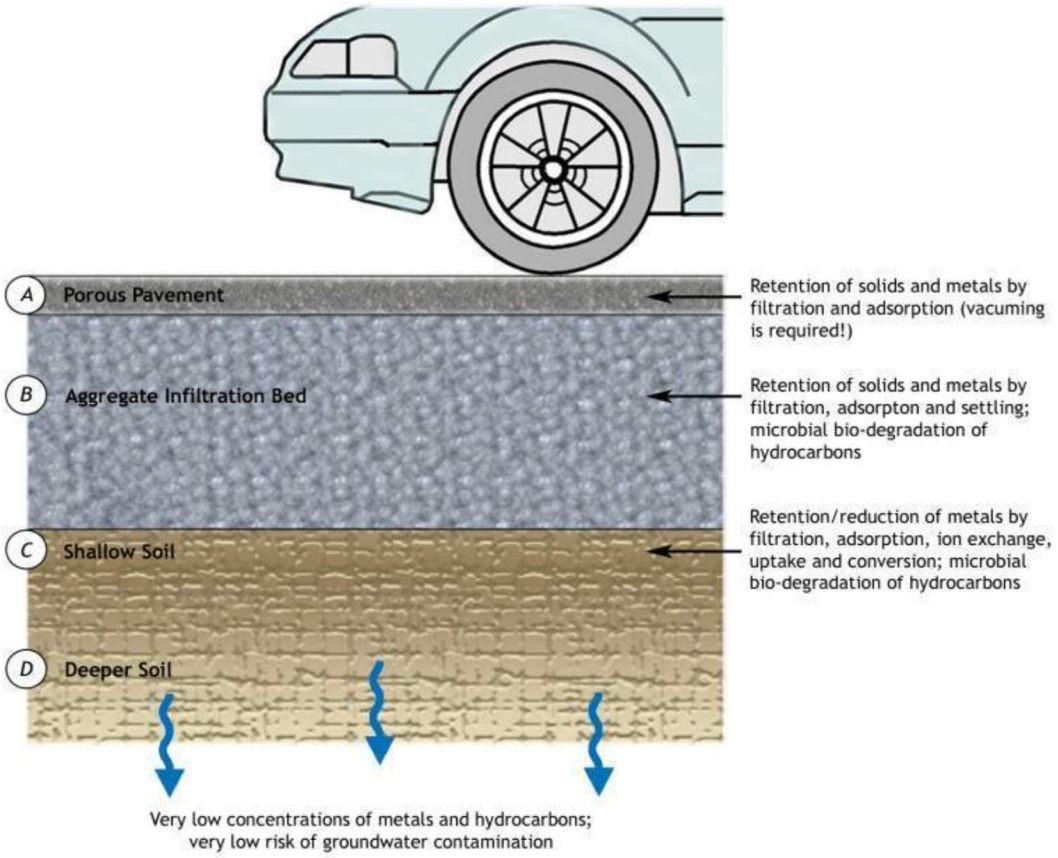

Figure 2-23. Water quality benefits of pervious pavement with subsurface infiltration.

Source: Cahill Associates

The following table outlines how each pervious pavement component retains or reduces certain pollutants (Table 2-21).

Table 2-21. Water Quality Benefits of Pervious Pavement With a Subsurface Infiltration Bed.

System Component	Mechanism(s)	Contaminants Retained/Reduced	References
Porous Pavement	Filtration and Adsorption	Total Suspended Solids (TSS), Heavy Metals, Hydrocarbons, COD, and De-icing Salt (less required, more retained) (Note: maintenance by vacuuming is required)	Ferguson 2005; Legret and Colandini 1999; Pagotto et al. 2000; Roseen et al. 2009
Infiltration Bed or filter layer	Filtration, Adsorption, Settling, Microbial Bio-Degradation	TSS, Metals, and Hydrocarbons, plus Total Organic Carbon, COD, Nitrogen	Legret and Colandini 1999; Newman et al. 2002; Pratt et al. 1999; Swisher 2002; Thelen and Howe 1978
Shallow Soil	Filtration, Adsorption, Ion Exchange, Microbial Bio-Degradation, Conversion, and Uptake (only with high plant activity)	Metals and Hydrocarbons, including PAHs	Barraud et al. 1999; Dierkes and Geiger 1999; Legret et al. 1999; Swisher 2002
Deeper Soil	Filtration, Adsorption, Ion Exchange, Conversion, and Uptake (only with high plant activity)	Metals and Hydrocarbons, plus Organics and Bacteria; Very Low Risk of Groundwater Contamination	Barraud et al. 1999; Boving et al. 2006; Dierkes 1998; Dierkes and Geiger 1999; Mikkelsen 1997; Pitt et al. 1994; Roseen et al. 2009

Peak Flow Rate Mitigation

Properly designed pervious pavement systems provide effective management of peak flow rates due to the provided storage reservoir.

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)
Other: Innovation & Design Process (1-4 Points)

Cost

The majority of added cost of a pervious pavement/infiltration system lies in the underlying stone bed and optional filter layer, which is generally deeper than a conventional bed and lined with non-woven geotextile. However, for new construction projects, this additional cost can be partially offset by the significant reduction in the required drainage infrastructure (i.e. inlets and pipes). Pervious pavement areas with subsurface infiltration beds can reduce or eliminate the need (and associated costs, space, etc.) for large detention basins. When these factors are considered, pervious pavement with infiltration has proven itself less expensive than the impervious pavement with associated traditional stormwater management. Recent installations have averaged between $2,000 and $2,500 per parking space, for the pavement and stormwater management systems.

- Pervious asphalt, with additives, is generally 10 to 20 percent higher in cost than standard asphalt on a unit area basis. Unit costs for pervious asphalt (w/o infiltration bed) range from about $1.75/SF to $3.50/SF.

- Pervious concrete, as a material, is generally more expensive than asphalt and requires more labor and experience for installation due to specific material constraints. Unit costs for 6-inch thick pervious concrete (w/o infiltration bed) section are typically between $6-7/SF.

- Permeable pavers vary in cost depending on type and manufacturer.

NOTE: The data provided is based on average market costs. For greater accuracy, a site and market specific cost estimate should be developed.

Table 2-22 and Table 2-23 summarize the costs associated with Phases I and II, respectively, of a pervious pavement demonstration project completed in 2005 at the San Diego County Operations Center (COC) in Kearny Mesa. Phase I included pervious asphalt, concrete, and pavers, while Phase II included only pervious asphalt (different mixes than in Phase I) and concrete.

Table 2-22. San Diego COC Phase I – Pervious Pavement Costs.

Pavement Replacement Square Foot Costs 2005						
	Demolition & Excavation	**Installation of Sub Base**	**Pavement Costs**	**Square Foot Costs***	**Annual Est. Square Foot Maintenance Costs**	**Comments**
Porous Asphalt	$ 2.75	$ 1.88	$ 1.87	$ 6.50	$ 0.04	18" – Excavation/Backfill 3" – Porous Asphalt
Standard Asphalt	$ 2.13	$ 1.04	$ 1.32	$ 4.49	$ 0.06	6" – Excavation/Backfill 6" – Asphalt
Porous Concrete	$3.19	$ 1.88	$ 6.34	$ 11.41	$ 0.02	18" – Excavation/Backfill 5-1/2" – Pervious Concrete
Standard Concrete	$ 1.51	$ -----	$ 3.42	$ 4.93	$ 0.01	No new base material 6" – Reinforced Concrete
Porous Pavers	$ 2.75	$ 1.88	$ 9.63	$ 14.26	TBD	18" – Excavation/Backfill 3" – Paver
*Square foot cost is based on actual cost received by the County of San Diego						

Source: Cahill Associates

Table 2-23. San Diego COC Phase II – Pervious Pavement Costs.

Pavement Replacement Square Foot Costs 2007						
	Demolition & Excavation	Installation of Sub Base	Pavement Costs	Square Foot Costs*	Annual Est. Square Foot Maintenance Costs	Comments
Porous Asphalt	$ 3.39	$ 3.40	$ 2.01	$ 8.80	$ 0.04	18-30" – Excavation/Backfill 3" – Porous Asphalt
Standard Asphalt	$ 2.13	$ 1.04	$ 1.32	$ 4.49	$ 0.06	6" – Excavation/Backfill 6" – Asphalt
Porous Concrete	$3.64	$ 3.40	$ 7.10	$ 14.14	$ 0.02	18-30" – Excavation/Backfill 5-1/2" – Pervious Concrete
Standard Concrete	$ 1.51	$ -----	$ 3.42	$ 4.93	$ 0.01	No new base material 6" – Reinforced Concrete
*Square foot cost is based on actual cost received by the County of San Diego						

Source: Cahill Associates

A permeable pavement project sized at 16,620 square feet located in Santa Ana cost $9.00 per square foot (Caltrans 2018a).

Applications

Pervious pavement is well-suited for parking lots, walking paths, sidewalks, playgrounds, plazas, tennis courts, and other similar uses. Pervious pavement can be used in driveways if the homeowner is aware of the stormwater functions of the pavement and willing to maintain it. Pervious pavement can be used in low-traffic roadways but should not be used on roadways carrying more than 25,000 vehicles per day. The thickness of the pervious pavement system works to distribute traffic loads and can decrease the need for compaction of the subsoil. Pervious pavement can also be layered on top of impermeable asphalt, where it can help to quickly remove water falling on the pavement surface, reducing splash and spray from vehicles. This reduces the amount of pollutants washed from vehicles, limiting water quality degradation. In areas where fire lanes are required to be impermeable, the impermeable surface should be sloped toward the pervious pavement. The reservoir layer should extend beneath the entire pavement surface.

Pervious pavements can be used in residential, commercial, institutional, and industrial applications in both urban and suburban environments. Pervious pavements have been widely applied in retrofit situations as existing standard pavements are replaced. Pervious pavements should not be used in industrial and commercial applications where pavement areas are used for material storage or the potential for surface clogging is high due to high traffic of construction vehicles.

Potential Applications

Residential	YES
Commercial	YES
High-Density	YES
Industrial	LIMITED
Recreational/Institutional	YES
Highway/Road	LIMITED

Parking Areas

The below figures show examples of how pervious pavers can be used in parking lots or driveways (Figure 2-24, Figure 2-25, Figure 2-26).

Figure 2-24. OC Public Works Parking Lot, City of Orange CA.

Source: Olaunu

Figure 2-25. Pervious Paver Parking Stalls, Redlands, CA.

Source: Jeff Endicott

Figure 2-26. Pervious Paver Driveway, Chino, CA.

Source: Jeff Endicott

Pervious Pavement Walkways

Pervious pavement, both as asphalt and concrete, can also be used in walkways and sidewalks (Figure 2-27). These installations typically consist of a shallow (8 in. minimum) aggregate trench that is sloped to follow the surface slope of the path. In the case of steeper surface slopes, the aggregate infiltration trench may be "terraced" into level reaches in order to maximize its infiltration capacity, at the expense of additional aggregate.

Figure 2-27. Pervious Concrete Sidewalk, Frontier Project, Rancho Cucamonga, CA.

Source: Olaunu

Playgrounds / Basketball / Tennis

The below figure demonstrates how recreational fields and courts can implement pervious pavement (Figure 2-28).

Figure 2-28. Pervious asphalt basketball court at 2nd Ward Neighborhood Park in Upper Darby, PA.

Source: Cahill Associates

Streets and Alleys

The below figures show residential streets with pervious pavement (Figure 2-29, Figure 2-30, Figure 2-31)

Figure 2-29. Pervious asphalt street in residential neighborhood in Portland Oregon.

Source: Cahill Associates

Figure 2-30. Pervious paver parking edge in residential neighborhood in Portland Oregon.

Source: Cahill Associates

Figure 2-31. Porous friction course over traditional asphalt.

Source: Caltrans

Variations

Pervious Bituminous Asphalt

Pervious bituminous asphalt pavement was first studied in the early 1970s by the Franklin Institute in Philadelphia and consists of standard bituminous asphalt in which the fines have been screened and reduced, allowing water to pass through small voids (Figure 2-32). Pervious asphalt is placed directly on the stone bed in a single 3 ½ to 4-inch lift that is lightly rolled to a finish depth of 2 ½ to 3-inches.

Figure 2-32. Close-up showing pervious asphalt pavement atop a stone infiltration/storage bed.

San Diego County Operations Center in Kearny Mesa, CA

Source: Cahill Associates

Because pervious asphalt is standard asphalt with reduced fines, it is similar in appearance to standard asphalt (Figure 2-33). Recent research in open-graded mixes for highway applications has led to additional improvements in pervious asphalt through the use of additives and higher-grade binders. Pervious asphalt is suitable for use in any climate where standard asphalt is appropriate.

Figure 2-33. Pervious asphalt parking lot at Flinn Springs County Park in El Cajon, CA.

Source: Cahill Associates

Pervious Concrete

Pervious Portland Cement Concrete, or pervious concrete, was developed by the Florida Concrete Association and has seen the most widespread application in Florida and other southern areas. Like pervious asphalt, pervious concrete is produced by substantially reducing the number of fines in the mix in order to establish voids for drainage. Like other types of pervious pavements, pervious concrete should always be underlain by a stone bed designed for stormwater management and should never be placed directly onto a soil bed.

While pervious asphalt is very similar in appearance to standard asphalt, pervious concrete has a coarser appearance than its conventional counterpart and a clean-swept finish cannot be achieved. Care must be taken during placement to avoid over-working the surface and creating an impervious layer. Pervious concrete has been proven to be an effective stormwater management BMP. Another potential advantage of pervious concrete is the option of introducing color to the mix. The industry now offers a variety of hues and tints that can allow a pervious concrete installation to better integrate with its adjacent landscape. Additional information pertaining to pervious concrete, including specifications, is available from the Florida Concrete Association (n.d) and the National Ready Mix Association (2019). The following photos show pervious pavement installations in Southern California (Figure 2-34, Figure 2-35).

Figure 2-34. Pervious concrete in Cerritos, CA.

Source: Bill DePoto

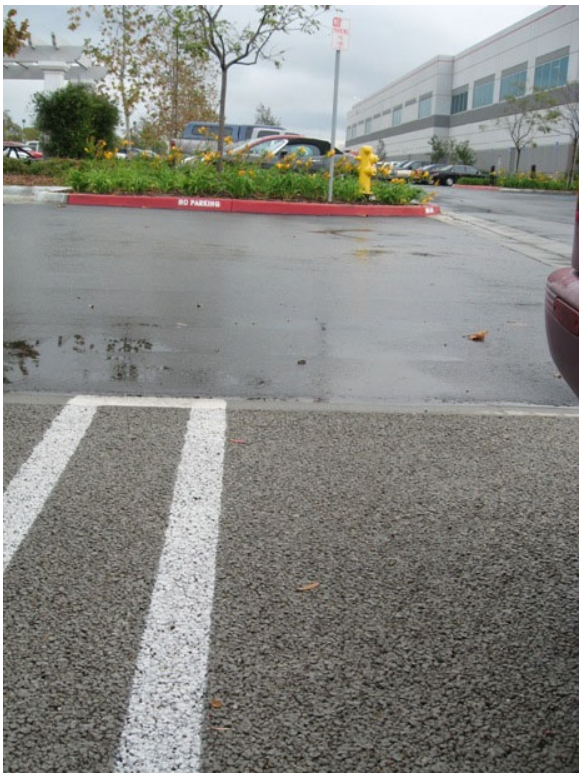

Figure 2-35. Pervious concrete parking areas, Haas Automation, Inc., Oxnard, CA.

Source: Lorraine Rubin

Permeable Pavers

Permeable pavers consist of interlocking units (often concrete) that provide some portion of surface area that may be filled with a pervious material such as gravel. These units are often very attractive and are especially well suited to plazas, patios, small parking areas, etc. (Figures 38 through 46). There are also products available that provide a fully permeable surface through the use of plastic rings/grids filled with gravel. A number of manufactured products are available, including (but not limited to): Aqua Bric (Orco Block); Turfstone; UNI Eco-stone; EP Henry ECO I Paver; Checkerblock; Netlon Gravel Pavement Systems; Permapave. Permeable pavers vary greatly in their design and resulting open area. Some designs offer relatively little open surface area where infiltration can take place. Table 2-24 lists the open area percentage of several commonly used paver products. This list is not exhaustive; there are many other paver products on the market.

Designers are encouraged to obtain paving system permeability data from the manufacturer of the paving stone being specified. The rates for clean systems (freshly installed) are expected to be quite high, and should be de-rated by applying a safety factor during design.

When used in parking lots or other applications involving pedestrians, ADA access standards must be considered. Options include selecting an ADA compliant block system, or paving ADA access areas with compliant, alternative surfaces such as AC or concrete.

Table 2-24. Open Area Percentage of Several Commonly Used Paver Products.

Paver Product	Open Area Percentage
Turfstone™	41
Checker Block®	75
Netpave® 50	85
UNI Eco-stone®	12
Acker-Stone Aqua-Via	9.3
PermaPave	Varies (depends on size of stone used as aggregate)
ORCO Aqua Brick® Paving Stones	10.6
Angelus SF Rima™ Paving Stones	10

Source: The Low Impact Development Center, Inc.

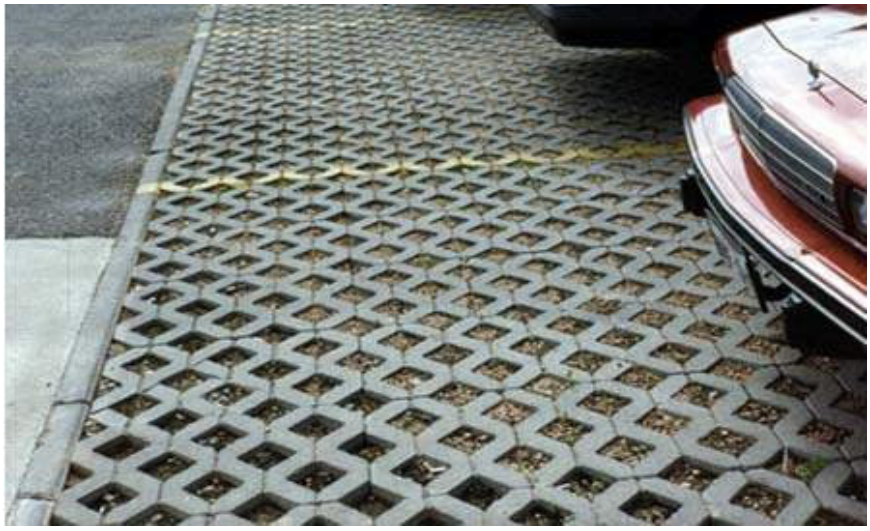

Figure 2-36. **Turfstone™ Pavers.**

Source: Interlocking Paving Systems, Inc.

Figure 2-37. TurfstoneTM Driveway.

Source: Nicolock

Figure 2-38. Checker Block® Shoulder.

Source: Nicolock

Figure 2-39. NetPave® 50.

Source: Rehbein Solutions, Inc.

Figure 2-40. Permapave.

Source: Permapave USA

Figure 2-41. Uni Eco-stone® Pavers.

Source: Interlocking Paving Systems, Inc.

Figure 2-42. Acker-Stone Aqua-Via

Source: Acker-Stone Industries

Figure 2-43. Aqua Bric® Type 4 (ADA Compliant).

Source: ORCO Block Co., Inc., Photography by RA Hanson

Figure 2-44. SF RimaTM Paving Stones at the

Persico Commercial Center in the City of Downy, CA

Source: Angelus Paving Stones

As products are always being developed, the designer is encouraged to evaluate the benefits of various products with respect to the specific application. Many paver manufacturers recommend compaction of the soil and do not include a drainage/storage area, and therefore, they do not provide optimal stormwater management benefits. A system with a compacted sub-grade will not provide significant infiltration. In LID applications, pavers are used with gravel beds or uncompacted subgrades. The entire system (paver, the joint fill, and subgrade) should be tested to provide reasonable estimates of performance.

Reinforced Turf

Reinforced Turf consists of interlocking structural units that contain voids or areas for turf grass growth and are suitable for traffic loads and parking. Reinforced turf units may consist of concrete or plastic and are underlain by a stone and/or sand drainage system for stormwater management (Figure 2-45).

Reinforced Turf is excellent for applications such as fire access roads (where permitted), overflow parking, and occasional use parking (such as at religious facilities and athletic facilities). Reinforced Turf is also an excellent application to reduce the required standard pavement width of paths and driveways that must occasionally provide for emergency vehicle access.

While both plastic and concrete units perform well for stormwater management and traffic needs, plastic units tend to provide better turf establishment and longevity, largely because the plastic will not absorb water and diminish soil moisture conditions. A number of manufactured products are available, including (but not limited to): Grasspave; Geoblock; Grassy Pave; Geoweb; Netlon Turf Pavement Systems. The designer is encouraged to evaluate and select a product suitable to the project.

Figure 2-45. Reinforced turf used as overflow parking area.

Source: Cahill Associates

Other

Other proprietary products are now available which are similar to pervious asphalt and concrete, but which utilize clear binders so that the beauty of the natural stone is visible, creating an aesthetically pleasing look. Some of these products are not suitable for vehicular traffic, and the material strength varies by product. The use of clear binder allows the designer the versatility of utilizing different colored aggregates to suit the application and appearance desired. Typical applications include: tree pits, walkways, plazas, and playgrounds. A number of products are available on the market today, including (but not limited to): Addapave TP, and Flexipave.

Design Guidance

A pervious pavement system consists of a pervious surface course underlain by a storage reservoir placed upon uncompacted subgrade to facilitate stormwater infiltration or upon a filter layer with subdrains. The storage reservoir consists of a stone bed of uniformly graded and clean-washed coarse aggregate, typically 1-1/2 to 2-1/2 inches in size. The pervious pavement may consist of pervious bituminous asphalt, pervious concrete, pervious pavers, or other types of pervious structural materials. A layer of nonwoven geotextile filter fabric can be used to separate the aggregate from the underlying soil, preventing the migration of fines into the bed. The porous pavement surface should be level if possible, and should not have a slope greater than 3%. Bed bottoms should always be level and uncompacted to allow for even and distributed stormwater infiltration. On sloped sites, beds should be constructed using a terraced design, as shown in. Many designs incorporate a river stone/rock edge treatment or inlets which are directly tied to the bed so that the stormwater system will continue to function despite the performance of the pervious pavement surface.

Pervious pavements are adaptable to various soil conditions. In sites with less permeable soils, pervious pavement systems can be fitted with underdrains to discharge stored runoff into the storm drainage system. In sites where soils are contaminated or with high groundwater tables, the storage reservoir can be lined to prevent exfiltration entirely.

When properly designed, pervious pavement systems provide effective management of stormwater volume and peak flow rates. The storage reservoir below the pavement surface can be sized to manage both direct runoff and runoff generated by adjacent areas, such as rooftops. Because the stone bed provides storage, outlet structures can be designed to manage peak flow rates with the use of weir and orifice controls Figure 2-46.

Figure 2-46. **Settling Basin with Weir to Filter Underdrain Flow from a Pervious Asphalt Parking Lot in San Diego County.**

Source: Michael Baker International 2019

Site Factors

1. Water Table Separation: Ten (10) feet (NOTE: Regional Boards and local agencies may have differing requirements.). Installations at sites with higher water tables may be lined to prevent exfiltration.
2. Bedrock Separation: Five (5) feet (NOTE: Regional Boards and local agencies may have differing requirements.).
3. Soil Permeability: Permeability of at least 0.5 in/hr is required for infiltration. Installations in less permeable soils can be fitted with underdrains.
4. Feasibility on Steep Slopes: Low**

** Infiltration beds may be placed on a mild slope (<3%) however subsurface layers should have level bottoms and be terraced along slopes.

The overall site shall be evaluated for potential pervious pavement/ infiltration areas early in the design process, as effective pervious pavement design requires consideration of grading.

Infiltration areas should be located within the immediate project area in order to control runoff at its source. Expected use and traffic demands shall also be considered in pervious pavement placement. An impervious water stop should be placed along infiltration bed edges where pervious pavement meets standard impervious pavements.

Sediment Control

Control of sediment is critical. Rigorous installation and maintenance of erosion and sediment control measures is required to prevent sediment deposition on the pavement surface or within the stone bed. The edges of the nonwoven geotextile lining may be folded over the edge of the pavement until the site is stabilized. The designer should carefully consider the site placement of pervious pavement to reduce the likelihood of sediment deposition. Surface sediment should be removed by a vacuum sweeper and should not be power-washed into the underlying bed.

Infiltration Bed

The underlying infiltration bed is comprised of clean, uniformly-graded aggregate with approximately 40 percent void space. American Association of State Highway and Transportation Officials (AASHTO) No.57 gravel is often used. Depending on local aggregate availability, both larger and smaller size aggregate have been used. The critical requirements are that the aggregate be uniformly-graded, clean-washed, and contain a significant void content. The depth of the bed is a function of stormwater storage requirements, site grading, and anticipated loading (in the case of pervious asphalt, see Table 2-25Table 2-25 and Table 2-26). Infiltration beds are typically sized to mitigate the increased runoff volume from the more frequent, small storm events.

If designed to infiltrate, the bed bottom is not compacted. The stone bed is placed in lifts and lightly rolled according to the specifications. The thickness of the pavement system acts to distribute the traffic load, compensating for the lack of compaction of the subsoil (Ferguson 2005).

Bed bottoms must be level or nearly level. Sloping bed bottoms will lead to areas of ponding and reduced stormwater distribution within the bed.

Table 2-25. Minimum Pervious Asphalt Pavement Thickness Required to Bear Structural Load on Poor Subgrade with CBR 2.

Traffic Category	Average ESAL per Day	Porous Asphalt Surface Course Thickness (in)	Aggregate Base Course Thickness (in)	Total Thickness (in)
Light (parking lots, residential streets)	1 10	4 4	6 12	10 16
Medium light (city business streets)	20 50	4.5 5	13 14	17.5 19
Heavy (highways)	1000 5000	6 7	20 22	26 29
CBR is California Bearing Ratio; ESAL is Equivalent Single Axle Load = 18,000 pounds				

Source: Ferguson 2005

Table 2-26. Minimum Total Pervious Asphalt Pavement Thickness Required to Bear Structural Load on Various Subgrades.

(aggregate base course + pervious asphalt surface course)

Traffic Load	Minimum Total Pavement Thickness (inches)		
	Subgrade CBR 6 to 9	Subgrade CBR 10 to 14	Subgrade CBR 15 or more
Light (ESAL 5 or less per day)	9	7	5
Medium light (1,000 vpd max., ESAL 6 to 20 per day)	11	8	6
Medium (3,000 vpd max., ESAL 21 to 75 per day)	12	9	7
vpd is vehicles per day; ESAL is 18,000 pounds			

Source: Ferguson 2005

While most pervious pavement installations are underlain by an aggregate bed, alternative subsurface storage products may also be employed. These include a variety of proprietary, interlocking plastic units that contain much greater storage capacity than aggregate.

In areas with poorly draining soils, infiltration beds below pervious pavement may be designed to slowly discharge to adjacent wetlands or bioretention areas. In this way, a pervious pavement installation may act as an alternative form of capture and reuse for landscape irrigation. Only in extreme cases (i.e. industrial sites with contaminated soils) will the aggregate bed need to be lined to prevent infiltration. The below figure shows a pervious concrete installation with a river stone edge treatment (Figure 2-47).

Figure 2-47. Pervious concrete parking lot with river stone edge treatment.

Flinn Springs County Park, El Cajon, CA

Source: Cahill Associates

Overflows

All systems should be designed with an overflow system. The specific design of these structures may vary, depending on factors such as rate and storage requirements, but it always must include positive overflow from the system. Below is an example detail of an overflow device from pervious asphalt (Figure 2-48).

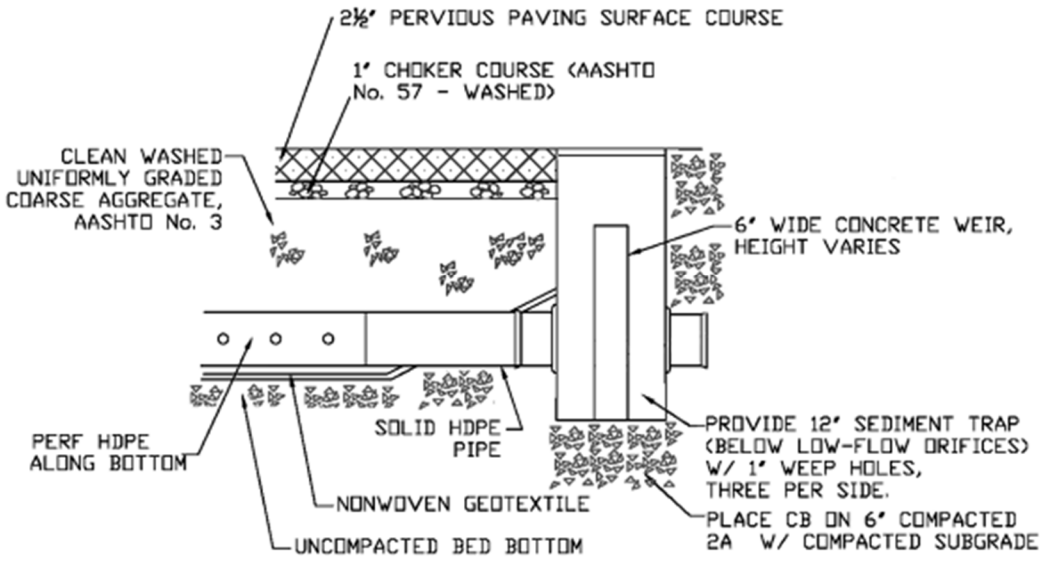

Figure 2-48. Example detail of an overflow device from a pervious asphalt system.

Source: Cahill Associates

Sizing Criteria

Surface area depends on storage volume requirements and permeability of the underlying native soil. Runoff volume is based on local regulatory requirements, such as a specific design storm (e.g. 2-year, 24-hour) or total runoff (85th percentile).

The permeable pavement area necessary to capture the design volume (V_{BMP}) is determined by calculating the area necessary to store the design volume at the maximum depth (b_{TH}), taking into account the available storage area within the gravel pore space. The depth of the gravel storage reservoir should not exceed 12 inches for either the infiltration or filtration designs (Riverside County 2010). The area can be calculated using the following formula:

$$A(ft^2) = \frac{V_{BMP}(ft^3)}{b_{TH}(in) \times R_g / 12(in/ft)}$$

where A = BMP surface area (ft^2)
V_{BMP} = BMP design volume (ft^3)
b_{TH} = reservoir depth (in), and
R_g = gravel void ratio (usually 0.4).

This calculation assumes a level pavement surface. The storage volume for a sloped surface would be significantly reduced.

Construction Guidance

Pervious pavement is most susceptible to failure difficulties during construction, and therefore it is important that the construction be undertaken in such a way as to prevent:

- Compaction of underlying soil
- Contamination of stone bed with sediment and fines
- Tracking of sediment onto pavement
- Drainage of sediment laden waters onto pervious surface or into constructed bed

Staging, construction practices, and erosion and sediment control must be taken into consideration when using pervious pavements.

1. Due to the nature of construction sites, pervious pavement and other infiltration measures should be installed toward the end of the construction period, if possible. Infiltration beds under pervious pavement may be used as temporary sediment basins or traps provided that they are not excavated to within 12 inches of the designated bed bottom elevation. Once the site is stabilized and sediment storage is no longer required, the bed is excavated to its final grade and the pervious pavement system is installed.

2. If designed to infiltrate, the existing subgrade under the bed areas shall NOT be compacted or subject to excessive construction equipment traffic prior to geotextile and stone bed placement.

3. Where erosion of subgrade has caused accumulation of fine materials and/or surface ponding, this material shall be removed with light equipment and the underlying soils scarified to a minimum depth of 6 inches with a York rake (or equivalent) and light tractor. Fine grading shall be done by hand. Bed bottoms must be level grade.

Earthen berms (if used) between infiltration beds shall be left in place during excavation (Figure 2-49). These berms do not require compaction if proven stable during construction.

Figure 2-49. Earthen berms separate terraced infiltration beds.

Source: Cahill Associates

Geotextile and bed aggregate shall be placed immediately after approval of subgrade preparation. Geotextile is to be placed in accordance with manufacturer's standards and recommendations. Adjacent strips of geotextile shall overlap a minimum of 18 inches. It shall also be secured at least 4 feet outside of the bed in order to prevent runoff or sediment from entering the storage bed. This edge strip shall remain in place until all bare soils contiguous to beds have been stabilized and vegetated. Once the site is fully stabilized, excess geotextile along bed edges can be cut back to the bed edge.

Clean (washed) uniformly-graded aggregate is placed in the bed in 8-inch lifts (Figure 2-50). Each layer shall be lightly compacted, with the construction equipment kept off the bed bottom as much as possible. Once bed aggregate is installed to the desired grade, a +/- 1 inch layer of choker base

course (AASHTO #57, or equivalent) aggregate shall be installed uniformly over the surface in order to provide an even surface for paving.

Figure 2-50. Open-graded, clean, coarse aggregate for infiltration beds.

Source: Cahill Associates

Install pervious pavement. Pervious concrete should be installed by an NRMCA Certified Installer (http://www.nrmca.org/certifications/pervious/). Permeable paver installers are certified by the Interlocking Concrete Pavement Institute (http://www.icpi.org/). After final pervious asphalt or concrete installation, no vehicular traffic of any kind shall be permitted on the pavement surface until cooling and hardening or curing has taken place, and in no case within the first 72 hours.

The full permeability of the pavement surface shall be tested by application of clean water over the surface, using a hose or other distribution device (Figure 2-51). Applied water shall infiltrate directly without puddle formation or surface runoff.

Figure 2-51. Water on Porous Asphalt.

Source: Fishbeck, Thompson, Carr & Huber, Inc.

Maintenance Considerations

- Prevent Clogging of Pavement Surface with Sediment
  - Vacuum pavement twice per year
  - Maintain planted areas adjacent to pavement
  - Immediately clean soil deposited on pavement
  - Do not allow construction staging, soil/mulch storage, etc. on unprotected pavement surface
  - Clean inlets draining to the subsurface bed twice per year

- Repairs
  - Surface should never be seal-coated
  - Inspect for pavement rutting/raveling on an annual basis (some minor ruts may occur in the pervious pavement from stationary wheel rotation)
  - Damaged areas less than 50 square feet can be patched with pervious or standard pavement
  - Larger areas should be patched with an approved pervious pavement

Properly installed and maintained pervious pavement has a lifespan comparable to impervious pavement types, and existing systems that are more than twenty years in age continue to function (Adams 2003). Because water drains through the surface course and into the subsurface bed, freeze-thaw cycles do not tend to adversely affect pervious pavement.

The primary goal of pervious pavement maintenance is to prevent the pavement surface and/or underlying infiltration bed from becoming clogged with fine sediments. To keep the system clean throughout the year and prolong its lifespan, the pavement surface should be vacuumed twice per year with a commercial cleaning unit. Inlet structures within or draining to the infiltration beds should also be cleaned out on a biannual basis.

Planted areas adjacent to pervious pavement should be well maintained to prevent soil washout onto the pavement. If washout does occur, it should be cleaned off the pavement immediately to prevent further clogging of the pores. Furthermore, if bare spots or eroded areas are observed within the planted areas, they should be replanted and/or stabilized at once. Planted areas should be inspected on a semi-annual basis. Trash and other litter that is observed during these inspections should be removed.

Superficial dirt does not necessarily clog the pavement voids. However, dirt that is ground in repeatedly by tires can lead to clogging. Therefore, vehicles should be discouraged from tracking or spilling excessive dirt onto the pavement. Furthermore, construction vehicles and hazardous materials carriers should be prohibited from entering a pervious pavement lot. Descriptive signage is recommended to maintain institutional memory of pervious pavement.

The use of pervious pavement must be carefully considered in areas where the pavement may be seal coated or paved over due to lack of awareness, such as individual home driveways. In those situations, a system that is not easily altered by the property owner may be more appropriate. Educational signage at pervious pavement installations may guarantee its prolonged use.

Vacuuming

Pervious pavement should be cleaned with a vacuum sweeper two times per year. Acceptable types of vacuum sweepers include the Elgin Whirlwind and the Allianz Model 650. Though much less effective than “pure” vacuum sweepers, regenerative air sweepers, such as the Tymco Model 210, Schwarze 348, Victory, and others, are sometimes used. These units contain a blower system that generates a high velocity air column, which forces the air against the pavement at an angle, creating a 'peeling’ or 'knifing' effect. The high-volume air blast loosens the debris from the pavement surface, then transports it across the width of the sweeping head and lifts it into the containment hopper via a suction tube. Thus, sediment and debris are loosened from the pavement and sucked into the unit. (Note: simple broom sweepers are not recommended for pervious pavement maintenance.)

If the pavement surface has become significantly clogged such that routine vacuum sweeping does not restore permeability, then a more intensive level of treatment may be required. Recent studies have proven the usefulness of washing pervious pavements with clean, low pressure water, followed by immediate vacuuming. Combinations of washing and vacuuming techniques have proved effective in cleaning both organic clogging as well as sandy clogging. Research in Florida found that a “power head cone nozzle” that “concentrated the water in a narrowly rotating cone” worked best. (Note: if the pressure of the washing nozzle is too great, contaminants may be driven further into the pervious surface.) Maintenance crews are encouraged to determine the most effective strategy of cleaning their pervious pavement installations.

For smaller installations, such as sidewalks, plazas, or small parking lots, “walk behind” vacuum units may prove most effective. Though these units can be loud and somewhat deleterious to the operator due to the lack of dust suppression, they are also relatively easy to operate and inexpensive. Examples of acceptable “walk behind” units include the Billy Goat models, the 5700 industrial-strength Scrubber by Tennant, and the sidewalk class vacuum sweepers made by Nilfisk, Advance, and Hako. If “walk behind” units are used, it is recommended that the scrub pressure be kept relatively low. The dirtiest areas may need to be power washed after scrubbing to get out the dirt that has been deeply ground in.

Restoration / Repairs

Because pervious pavement drains rapidly, potholes are extremely unlikely to occur, though settling might occur if a soft spot in the subgrade is not removed during construction. For damaged areas of less than 50 square feet, a declivity could be patched by any means suitable with standard pavement, with the loss of porosity of that area being insignificant. The declivity can also be filled with pervious mix or paver units. If an area greater than 50 SF is in need of repair, approval of patch type must be sought from either the engineer or owner. Under no circumstance is the pavement surface to ever be seal-coated. Required repair of drainage structures should be done promptly to ensure continued proper functioning of the system.

With minimal maintenance, pervious pavement can function effectively for well over 20 years. However, in the event that maintenance of the pervious pavement is neglected, and it becomes clogged over time, the owner should vacuum the lot until permeability is restored. (If the permeability of the lot cannot be restored, the pavement should be removed and replaced with a new pervious mix or pervious units.) Recent research has shown that one of the most effective ways of restoring pervious pavement is applying a pressurized dose of a non-toxic detergent cleaning solution, allowing adequate soak time, and then vacuuming with a high-performance unit. Once again, it is important to note that high pressure washing may drive contaminants further into the pervious surface and even into the underlying aggregate. It is therefore recommended that, prior to vacuum sweeping, a low performance pressure washer is used to get the solution to break the surface tension and reach into the pores.

Capture and Reuse

Capture/Reuse, commonly referred to as rainwater harvesting, is a centuries old practice of collecting rainwater that has recently gained prominence as a stormwater management practice. Capture/reuse systems collect and store rainwater from impervious surfaces for later use (Figure 2-52). The collected rainwater is ideal for non-potable applications, such as landscape irrigation, toilet flushing, and vehicle washing. Capture/reuse is a multi-benefit practice because it reduces stormwater discharge volumes while simultaneously reducing the demand for potable water.

Figure 2-52. Cisterns used for irrigation.

Source: R. D. Brodman, J. McCausland, Sunset Magazine

Rooftop runoff, because it often contains lower pollutant loads than surface runoff and provides accessible locations for collection, is the stormwater most often collected in capture/reuse systems. Roof downspouts are redirected to collection containers such as rain barrels, which typically range from 55 to 120 gallons, or cisterns, which can be several hundred to tens of thousands of gallons. Rain barrels are typically installed at outdoor residential locations; cisterns can be installed in residential and nonresidential locations, either indoors or out, and above or below grade (Figure 2-56).

Figure 2-53. Outdoor Cistern with Overflow Directed to Pervious Area

Source: SEMCOG

Capture/reuse serves to reduce the quantity of stormwater runoff by removing a volume of stormwater equal to the capacity of the collection tank. Capture/reuse can also be used as part of a treatment train by directing the overflow to a bioretention system to provide additional volume reduction and water quality treatment in instances where the quantity of runoff from a storm event exceeds the volume of the collection tank. When treatment such as filtration or disinfection is provided on capture/reuse systems it is intended to protect the collection tanks from fouling and/or to improve the quality of water for reuse applications.

Cost

A typical commercial 55-gallon rain barrel can retail for about $80 to $120. Additional costs are incurred for the hardware necessary to attach the barrel to the drainage system. Do-it-yourself kits may cost under $30. Cistern system prices vary by size and location of installation. Cisterns for residential applications may range in size from 100 gallons to 10,000 gallons. A cistern is expected to have a lifespan of 20-50 years, depending on site specifics and materials used. Cisterns can be prefabricated plastic, concrete or metal, or they can be cast-in-place concrete. In general, storage tanks can be expected to cost about one dollar per gallon of storage.

Benefits

- Reduced runoff volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Reduced potable water demand

Limitations

- Treats only rooftop runoff
- Must be monitored regularly to ensure that there is adequate storage capacity
- Regulatory obstacles may limit reuse opportunities
- If not installed correctly, may provide habitat for mosquitoes

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)
Other: Water Efficiency – Credit 1 “Water Efficient Landscaping” (1 Point)
Water Efficiency – Credit 2 “Innovative Wastewater Technologies” (1 Point)
Water Efficiency – Credit 3 “Water Use Reduction” (1-2 Points)
Innovation & Design Process (1-4 Points)

Water Supply Impacts

Per capita domestic indoor water use is 70 gallons per day (gpd); however, outdoor irrigation, especially in dry climates, can increase per capita usage to 165 gpd, meaning that outdoor irrigation can account for nearly 60% of demand. Similarly, other non-potable uses comprise a large percentage of water demand. Domestic toilet flushing accounts for 11% of water demand. In office buildings, toilet flushing accounts for 25% of demand, while cooling systems account for 23%. Non-potable uses consume a significant percentage of water from municipal systems. Capture/reuse offers the opportunity to reduce the demand on the potable water supply by offering an alternative source of water. Using capture/reuse as a stormwater management technique provides the opportunity to have a positive impact on water supply by matching the quality of the water supplied to the quality required for a given demand. Due to the limited and variable rainfall and extended dry seasons in many areas of the semi-arid southern California region, the benefits of integrating rainfall collection systems into domestic use systems must be weighed against the cost of implementing such systems. Constructing separate rainwater harvesting systems to be used solely for irrigation may be more practical economically.

Applications

Capture/reuse can be used in many applications from residential rain barrels to large-scale cisterns. Capture/reuse is appropriate for use in residential, commercial, high-density, institutional, residential, and industrial applications. The common forms of capture/reuse applications are provided below.

Potential Applications

Residential	YES
Commercial	YES
High-density	YES
Industrial	YES
Recreational/Institutional	YES
Highway/Road	NO

Passive Capture and Use Systems

Passive stormwater capture and use systems use gravity to disperse water rather than electric pumps and include rain barrels and gravity draining cisterns.

Residential
Rain barrels are most commonly used in residential settings (Figure 2-54, Figure 2-55). Simple diversions of roof downspouts to rain barrels allow roof runoff to be redirected away from sewers. The collected rainwater is most often used for outdoor water uses such as landscape irrigation or vehicle washing. A 55-gallon barrel will be filled by 0.5 inches of net runoff from 176 square feet of rooftop. Rain barrels are generally not fitted with water pumps; therefore discharge areas must be located down gradient from the rain barrel. This may limit the potential for a homeowner to use captured runoff for irrigation of landscaped areas that are upslope from the roof discharge point. Flow can be improved by raising the rain barrel on blocks.

It is important to note that atmospheric deposition is a significant source of pollution in runoff (Sabin et al. 2005). Captured roof runoff should never be used for potable uses and should not be used to irrigate vegetable gardens unless it is pretreated by filtration or settling.

Figure 2-54. Residential rain barrel in Los Angeles.

Source: LA Rainwater Harvesting Program

Figure 2-55. Large-scale residential system in Los Angeles, CA.

Source: Tree People

Active or Automated Capture and Use Systems

Active or automated stormwater capture and use systems typically include underground cisterns and other water storing devices located underground. These devices require a pump to move water to ground level and/or through an irrigation or plumbing system. For example, a large cistern system located below ground and connected to a spray irrigation system requires a pump system to provide adequate water pressure to the irrigation system. Figure 2-56 displays a schematic of a typical underground cistern with infiltration discharge and connection to landscaping irrigation.

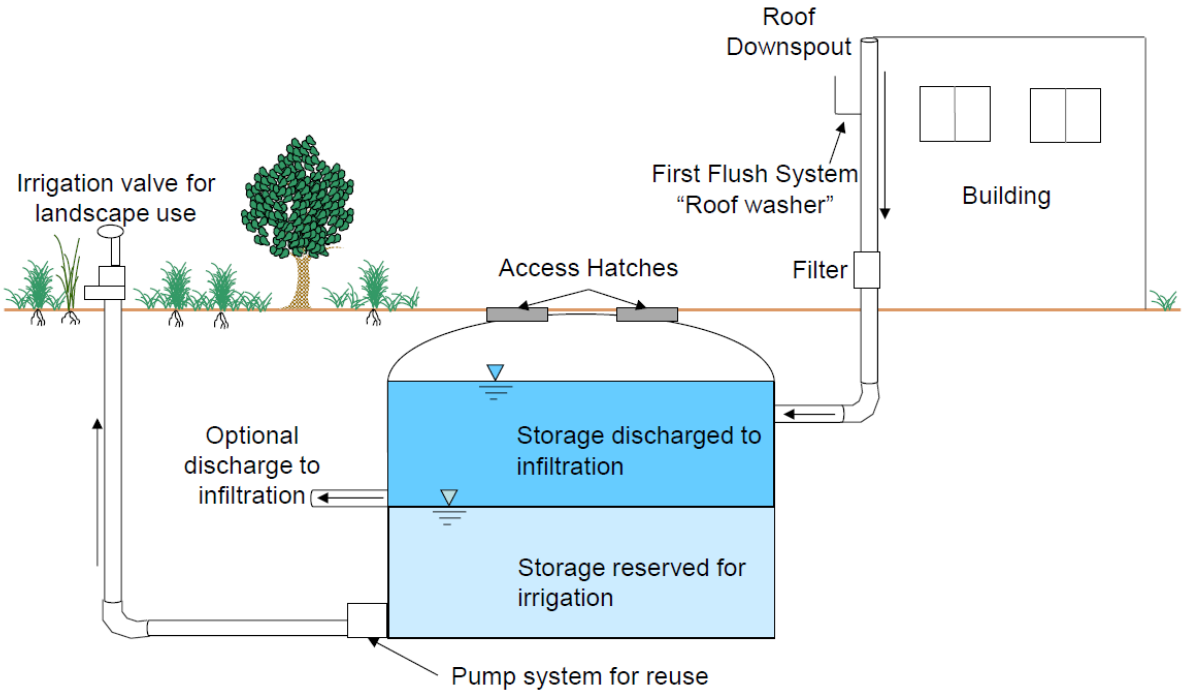

Figure 2-56. Schematic of Outdoor Underground Cistern with Overflow Directed to Pervious Area

Source: County of San Diego 2016.

Capture and use systems that connect to an indoor plumbing system, such as for flushing toilets, are subject to stringent plumbing water quality, pressure, and connection regulations.

Commercial

Capture/reuse systems for commercial settings can vary in size and may consist of cisterns with several thousand gallons of storage capacity (Figure 2-57, Figure 2-58). Because non-potable uses can constitute up to 85% of water demand in commercial buildings, commercial applications offer a large potential to use harvested rainwater for uses such as irrigation, toilet flushing, and cooling system makeup.

Figure 2-57. Large cistern for vegetated roof plaza maintenance.

Source: Cahill Associates

Figure 2-58. Six (6) 1,000 gallon cisterns at U.S EPA headquarters provide water for irrigation

Source: U.S. EPA

Storage Beneath Structure

Stormwater can be stored under hardscaped elements (such as paths and walkways) through the use of structural plastic storage units, such as RainTank, or other alternative manufactured storage products, and can supplement onsite irrigation needs (Figure 2-59, Figure 2-60). Designing a capture-reuse system in which runoff is stored under a hardscaped structure is best used in institutional or commercial settings. This type of subsurface storage is larger and more elaborate, typically requiring pumps to connect to the irrigation system.

Figure 2-59. Rainstore™ unit beneath brick pavers on a vegetated rooftop plaza.

Source: Cahill Associates

Figure 2-60. Rainstore™ units used as the storage element underneath a brick pathway atop a vegetated rooftop plaza.

Source: Cahill Associates

Design Guidance

Site Factors

- Water Table / Bedrock Separation: N/A
- Soil Permeability: N/A
- Feasibility on steeper slopes: N/A

Sizing

The sizing of capture/reuse systems is dependent upon the volume of water available for capture, comprised of the total area of the collection surface and rainfall; the associated demand for the harvested rainwater; and the space available for tank installation. In many instances the size of the collection container is a pre-determined design variable. For instance, rain barrels typically are available within a limited range of sizes; similarly, available lot or building space may determine the allowable dimensions of a cistern and thus the provided storage volume.

An analysis of precipitation and demand is required when trying to optimize the sizing of cisterns. Historical monthly or daily rainfall records should be examined to determine the amount, frequency, and seasonal variation of rainfall. Several years of data should be included to account for dry and wet years. Additionally, in Southern California it is often suggested to oversize the storage system to maximize the volume of rain captured during the rainy season. This allows some carryover in order to make water available in the dry season when little, if any, rainwater would be collected. The volume of water that can be collected from a given rain event can be calculated as:

V (gal) = Area of Collection Surface (ft^2) x Rainfall (in) / 12 in/ft x 0.8 (Capture Efficiency) x 7.48 gal/ft^3

Where captured rainwater can be practicably integrated into the sites water use supply, the specific potential end uses for the water need to be determined to provide an estimate of the daily or monthly water demands. For instance, toilet and urinal flushing impart a consistent daily demand on a water system while outdoor irrigation may be somewhat more episodic. The determined end uses will provide the daily drawdown rate. Comparing the drawdown rate to the predicted fill rate will determine proper cistern capacity. National averages for per capita residential water demand are provided below (Figure 2-25).

Table 2-27. Typical Domestic Daily per Capita Water Use.

Use	Gallons per Capita	% of Daily Total
Potable indoor uses		
• Showers	11.6	7.0%
• Dishwashers	1.0	0.6%
• Baths	1.2	0.8%
• Faucets	10.9	6.6%
• Other uses, leaks	11.1	6.7%
Subtotal	**35.8**	**21.7%**
Non-potable indoor uses		
• Clothes washers	15.0	9.1%
• Toilets	18.5	11.2%
Subtotal	**33.5**	**20.3%**
Outdoor uses	**95.7**	**58.0%**

Source: AWWARF 1999

Water Quality Treatment

Efficient operation and the intended end uses will determine the level of treatment needed in a capture/reuse system. Other than simple screening, water collected in rain barrels and used for residential irrigation does not typically require treatment. Little human health risk is presented when harvested rainwater is used for other non-potable uses (e.g., water closets, urinals, hose bibs), though such usage requires the installation of a dual plumbing system to keep potable water separated from harvested water. In these situations, screening and filtration to prevent particles and debris from traveling through the collection and plumbing system is typically sufficient. When harvested water is used for higher end contact uses, additional filtration and disinfection is required. As an example, typical water quality criteria for various end uses from the Texas Rainwater Harvesting Manual are provided in the table below (Figure 2-26). Detailed specifications and design guidance can be found through the American Rainwater Catchment Systems Association (http://www.arcsa.org).

Table 2-28. Minimum Water Quality Guidelines and Treatment Options for Stormwater Reuse.

Use	Minimum Water Quality Guidelines	Suggested Treatment Options
Potable indoor uses	• Total coliforms – 0 • Fecal coliforms – 0 • Protozoan cysts – 0 • Viruses – 0 • Turbidity < 1 NTU	• Pre-filtration – first flush diverter • Cartridge filtration – 3 micron sediment filter followed by 3 micron activated carbon filter • Disinfection – chlorine residual of 0.2 ppm or UV disinfection
Non-potable indoor uses	• Total coliforms < 500 cfu per 100 mL • Fecal coliforms < 100 cfu per 100 mL	• Pre-filtration – first flush diverter • Cartridge filtration – 5 micron sediment filter • Disinfection – chlorination with household bleach or UV disinfection
Outdoor uses	N/A	• Pre-filtration – first flush diverter
*cfu – colony forming units *NTU – nephelometric turbidity units		

Source: The Low Impact Development Center, Inc.

The harvesting system must not be connected to the potable water supply system at any time. High levels of caution are needed to ensure the integrity of the separation between the potable system and the harvesting system.

System Design

All components of a capture/reuse system should be designed to minimize the introduction of pollutants and to provide treatment sufficient for the intended end uses.

Tank, Collection, and Distribution

When rainwater is collected from rooftops, gutters should be equipped with leaf screens with openings no larger than 1/2 inch across their entire length, including the downspout opening. The screens prevent debris from clogging the collection system and/or fouling the harvested water. For internal downspouts, the downspout opening should be screened. A first flush diverter may be used to allow the initial portion of runoff to bypass the collection tank. If additional primary filtration is desired, roof washers may also be used. Roof washers can act as first flush diverters and also contain filter media (e.g., sand, gravel, filter fabric) to provide removal of particulates that have passed through the leaf screens.

Rain barrels and cisterns should be constructed of materials rated for potable water use. Outdoor tanks should be constructed of opaque materials or otherwise shaded or buried to protect the harvested rainwater from direct sunlight. Tank overflows should be directed away from structures and to pervious areas to allow for infiltration whenever possible. Outdoor tanks should also contain adequate screening at each opening to prevent insects from entering the tank. Rain barrels and cisterns temporarily store stormwater and when properly designed and maintained there is less potential for breeding of mosquitoes and other pests than with conventional BMPs.

For non-potable indoor uses (where local codes and ordinances allow), additional treatment can be provided following the collection tank, even though it may not be necessary for public health reasons. Additional cartridge filtration can be provided to prevent suspended particles from entering pipes.

Separate piping without direct connection to potable water piping should be provided for capture/reuse systems. Dedicated piping should be color coded and labeled as harvested rainwater, not for consumption. Faucets supplied with non-potable rainwater should contain signage identifying the water source as non-potable and not for consumption.

Cross-contamination

When make-up water is required to be provided to the capture/reuse system from the municipal system, steps should be taken to prevent cross-contamination. Cross-contamination measures for capture/reuse systems will be similar to those for reclaimed and greywater systems. The make-up supply to the cistern is the point of greatest risk for cross-contamination of the potable supply. A backflow prevention assembly on the potable water supply line, an air gap, or both must be provided to prevent collected rainwater from entering the potable supply. Contact local water system authorities to determine specific requirements. The designated dual piping system is also part of the cross-contamination prevention measures.

Construction

Cisterns are typically prefabricated, made of plastic, metal, or concrete. They can also be cast-in-place. A variety of containers are used for rain barrels. Positive outlet for overflow should be provided a few inches from the top of collection tank and should be sized to safely discharge excess volume when the tank is full. When cisterns are installed below grade, observation risers should rise at least 6 inches above grade.

Maintenance

When cisterns are used for non-potable indoor uses, a municipal inspection should occur during installation. Annual municipal inspections of the backflow prevention systems are also recommended. For a property owner, the operation and maintenance of a rainwater harvesting system is similar to a private well. Annual water quality testing is recommended when captured rainwater is provided for indoor uses. Regular inspection and replacement of treatment system components such as filters or UV lights is also recommended.

Maintenance Schedules:

Rain Barrel Maintenance
- Inspect rain barrels four times per year, and after major storm events.
- Remove debris from screens as needed.
- Replace screens, spigots, downspouts, and leaders as needed.

Cistern Maintenance
- Flush cisterns annually to remove sediment.
- For buried structures, vacuum removal of sediment is required.
- Brush the inside surfaces and thoroughly disinfect twice per year.

Resources

Ben-Horin, E. 2007. *Rainwater as a Resource: A Report on Three Sites Demonstrating Sustainable Stormwater Management*. Los Angeles, CA: Tree People. http://www.invisiblestructures.com/wp-content/uploads/2016/04/Rainwater_as_a_Resource.pdf.

County of San Diego. 2016. County of San Diego BMP Design Manual for Permanent Site Design, Storm Water Treatment and Hydromodification Management. February 2016.

Natural Resources Defense Council. 2006. *Building Green – CaseStudy, NRDC's Santa Monica Office*. http://www.nrdc.org/buildinggreen/casestudies/nrdcsm.pdf

Pacific Institute. 2003. *Waste Not, Want Not: The Potential for Urban Water Conservation in California*. http://www.pacinst.org/reports/urban_usage/waste_not_want_not_full_report.pdf

Green Roofs

Green roofs are vegetated roof systems that filter, absorb, and retain or detain the rain that falls upon them. Green roofs are comprised of a layer of soil media planted with vegetation. Extensive green roofs, defined as those systems 2 to 6 inches in thickness, are the design most often used for stormwater management. Other structural components are incorporated into green roof systems including waterproofing, synthetic insulation, and fabrics.

Intensive green roofs are less commonly used as a dedicated stormwater management practice. The soil media is greater than 6 inches thick and they can be comprised of a wide arrange of vegetation including shrubs and trees.

Rain that falls onto green roofs is returned to the atmosphere either by evaporation or transpiration by plants, which remove the water from the soil media. When the soil media becomes saturated, the excess water percolates through to the drainage layer and is discharged through the roof downspouts. Green roofs can provide high rates of rainfall retention and decrease the peak flow rate because of the temporary soil storage that occurs during discharge events. The following figure shows a demonstration vegetated roof project (Figure 2-61).

Figure 2-61. Demonstration vegetated roof project at EuroAmerican Growers in Bonsall, CA.

Source: Technical Advisory Committee

Cost

The cost for green roofs will be influenced by the depth of the soil media, the number and type of additional structural components in the design, the vegetation selected, and the need for structural roof modifications. While green roofs have typically been one of the more costly LID practices, costs have continued to decrease with increasing rates of adoption. In addition, the use of green roofs can decrease the cost for stormwater conveyance systems on a site and increase the cooling efficiency of the building. Green roofs cost approximately $5 to $10 per square foot for new roof construction, but can cost up to $25 per square foot for retrofits.

Benefits

- Reduced runoff volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Reduced runoff temperature
- Habitat creation
- Enhanced site aesthetics
- Reduced building energy use
- Recreational benefits
- Sound reduction
- Improved air quality
- Reduction in urban heat island effect
- Land space reduction for BMPs
- Increased land values
- Increased roof lifespan

Limitations

- Captures and treats only rooftop runoff
- Not suitable for steep roofs (> 30 degrees)
- Heavier than conventional roofs, may require additional support
- Require occasional vegetation management, and may require supplemental irrigation during droughts

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1 Point)
Other: Sustainable Sites – Credit 7 “Landscape & Exterior Design to Reduce Heat Islands” (1 Point)

Water Supply Impacts

Impacts vary and are associated with water needed for initial plant establishment and subsequent maintenance, but in general should be minor. When needed, subsurface irrigation should be used to minimize evaporative losses. Detailed guidance on the irrigation needs of landscape plantings has been published by the California Department of Water Resources (UCCE/CDWR 2000).

Applications

Green roofs have a wide variety of applications for a number of land uses but are most common in urban/high-density, institutional, commercial, and industrial applications. Potential applications are provided below.

Potential Applications

Residential	YES
Commercial	YES
High-density	YES
Industrial	YES
Recreational/Institutional	YES
Highway/Road	NO

The following figures show examples of vegetated roofs in Southern California (Figure 2-62, Figure 2-63).

Figure 2-62. Vista Hermosa Park Ranger Station, Los Angeles.

Source: Greenroofs.com

Figure 2-63. Premier Automotive Headquarters, Irvine.

Source: Roofscapes, Inc.

Design Guidance

Site Factors

- Water Table / Bedrock Separation: N/A
- Soil Permeability: N/A
- Feasibility on steeper slopes: N/A

Green roofs are most often applied to buildings with flat roofs, but roofs with slopes up to 30° can be accommodated with the use of mesh, stabilization panels, or battens. Slopes greater than 30° may also be accommodated with specialized designs. Green roofs will not cover the entire roof area because of the need to reserve space for heating ventilation and air condition (HVAC) systems and areas for roof access and maintenance. Typically 50 to 80 percent of the total roof area will be covered by the green roof.

The load carrying capacity of the roof will also influence the suitability of a green roof. The wet weight of the green roof measures the fully saturated vegetation, soil media, and membrane layers. Extensive green roof wet weight is approximately 6 to 7 pounds per square foot per inch of depth. Green roofs typically incorporate very drought-tolerant plants and utilize coarse engineered media with high permeability. A typical profile would include the following layers:

- Vegetation layer
- Engineered growth media
- Separation geotextile
- Semi-rigid plastic geocomposite drain or mat (typical mats are made from non-biodegradable fabric or plastic foam)
- Root barrier (optional)
- Waterproofing membrane

A waterproof membrane is needed to prevent water migration from the green roof to the structural roof. An optional root barrier may also be installed to prevent root damage of the waterproof membrane. Insulation, if included in the roof covering system, may be installed either above or below the primary waterproofing membrane. Figure 2-64 shows layers and materials present in a typical vegetated roof.

Plant Selection

Plants should be selected which will create a healthy, drought-tolerant roof cover. In general, selected plants should be:

- Native or adapted species tolerant of extreme climate conditions (e.g., heat, drought, wind);
- Low-growing, with a range of growth forms (e.g., spreading evergreen shrubs or subshrubs, succulents, perennials, self-seeding annuals);
- Possessive of a shallow root system without the chance of developing a deep taproot; and
- Long lived or self-propagating, with low maintenance and fertilizer needs.

A variety of species and growth forms may be considered for a single roof project to ensure survival and plant growth. In addition, because many perennials and annuals are dormant during part or all of the rainy season, evergreen and cool-season plants should be included to help with rainfall interception and evapotranspiration during the seasons when rains typically occur.

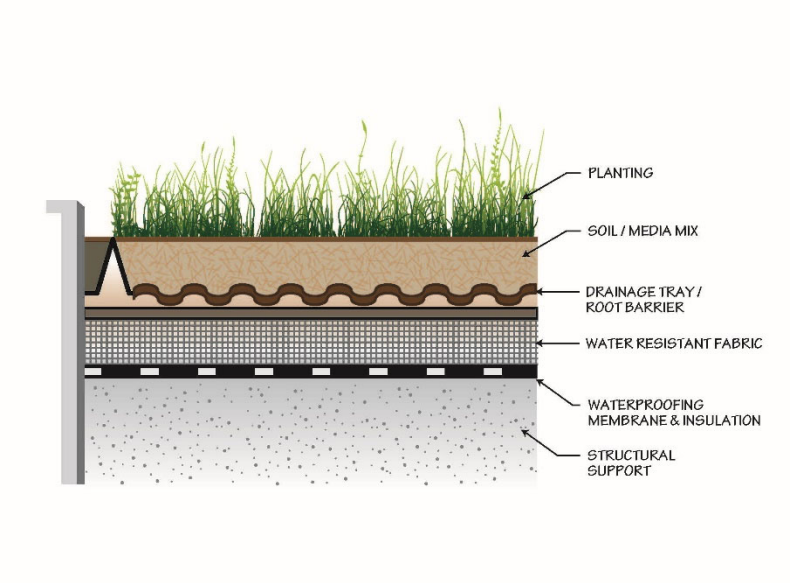

Figure 2-64. Green Roof Schematic

Source: RBF Consulting

Construction Guidance

The following is a typical construction sequence. However, alterations will be necessary depending on design variations.

1. Install waterproof membrane and visually inspect. The waterproofing should be tested for water tightness by the roofing applicator.
2. Install slope stabilization measures for pitched roofs.
3. If the waterproofing materials are not root-fast, install a root-barrier layer.
4. Lay out key drainage components, including drain access chambers, internal drainage conduit, confinement border units, and isolation frames (for rooftop utilities, hatches, and penetrations).
5. Install walkways and paths (for maintenance or projects with public access).
6. Install the drainage layer. Depending on the variation type, this could be a geocomposite drain, mat, or drainage media.
7. Cover the drainage layer with the separation fabric (in some assemblies, the separation fabric is pre-bonded to a synthetic drainage layer).
8. Install sub surface irrigation capillary matting and supply lines according to design.
9. Install the growth media layer on top of the capillary matting using crane lifted supersacks.
10. Install the plant layer from cuttings, plugs, seed, or pre-grown mats, according to spacing or seeding rate specified by green roof designer.
11. Provide protection (e.g., UV-degradable erosion control netting) from wind disruptions as warranted by the project conditions and plant establishment method.
12. Overhead irrigation should be provided during the plant establishment for a period determined by the green roof designer until plants are fully established.

Maintenance Considerations

The maintenance schedule should include the following activities.

1. In the arid southwest, regular to periodic irrigation will likely be required.
2. During the plant establishment period, weeding, fertilization (if needed), and infill planting is recommended every three to four months. Thereafter, only two visits per year for inspection and light weeding should be required.
3. Drainage outlets should be inspected periodically to verify that they drain freely and are not clogged with debris.
4. The waterproof membrane should be inspected periodically for drainage or leaks. It is also possible to include a leak detection system in the green roof design.

Resources

Hutchinson, D., P. Abrams, R. Retzlaff, and T. Liptan. 2003. *Stormwater Monitoring Two Ecoroofs in Portland, Oregon, USA*. City of Portland Bureau of Environmental Services. http://www.portlandonline.com/shared/cfm/image.cfm?id=63098

City of Portland. 2006. *2006 Stormwater Management Facility Monitoring Report Summary*. https://www.portlandoregon.gov/bes/article/148928.

BMP Factsheets

The following factsheets cover several additional structural BMPs that are commonly used in LID designs. These structural BMPs are in widespread use, and many local sources of design guidance already exist. Therefore, the factsheets provide a brief description of the practice, its benefits and limitations, and links to more detailed information.

Downspout Disconnection

Downspout disconnection refers to the redirection of stormwater from an existing downspout to a vegetated area (e.g. a swale or planter box) or a collection system (e.g. a rain barrel or cistern) (Figure 2-65). The collected water can be used for onsite landscaping. Downspout disconnections are typically used in residential, commercial, and industrial applications.

Water quality benefits are gained from disconnection practices because a percentage of the overall stormwater volume infiltrates into pervious areas or is lost through evapotranspiration. Disconnection practices decrease the total volume of stormwater discharged to receiving water bodies. Therefore, the reduction in pollutant and nutrient loading attributed to disconnection is dependent upon the reduction in stormwater volume. In addition, the impact of disconnection on stormwater volume and peak discharge is dependent upon the area to which the stormwater is directed.

Figure 2-65. Downspout disconnection into vegetated area.

Source: Prince George's County, MD Department of Environmental Resources

Benefits

- Reduced peak discharge rate
- Reduced runoff volume
- Reduced TSS
- Reduced pollutant loading
- Reduced runoff temperature

Limitations

- Runoff must not flow toward building foundations or onto adjacent private property.
- Discharge areas must be large enough to infiltrate runoff (typically 10% of contributing roof area)

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)
Other: Water Efficiency – Credit 1 “Water Efficient Landscaping” (1-2 Points)
Innovation & Design Process (1-4 Points)

Design Guidance

Direct downspout disconnections away from buildings. Ensure that the ground slopes away from the discharge point. Use spashblocks, rocks, or flagstones at the end of downspouts to direct runoff and control erosion. As a rule of thumb, the discharge area should be 10% of the roof area draining to the downspout (Portland Bureau of Environmental Services 2010). For low permeability soils (HSG C and D), a greater discharge area may be required. In large storm events, discharge areas may be subjected to high flows, and potentially to temporary submergence. Select landscape materials that are not easily eroded or transported. Preference should be given to rock or stone groundcovers over wood mulch.

Resources

California Stormwater Quality Association. 2003. *Roof Runoff Controls, SD-11*. California Stormwater BMP Handbook New Development and Redevelopment.
https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf.

County of San Diego. 2014. *Low Impact Development Handbook.*
https://www.sandiegocounty.gov/content/dam/sdc/pds/docs/LID_Handbook_2014.pdf.

Soil Amendments

The ability of existing soils to absorb, infiltrate and remove pollutants from stormwater can be improved by the application of soil amendments. These include compost, as well as other soil conditioners and fertilizers as appropriate for specific site conditions. Soil amendments can change the physical, chemical and biological characteristics of the soil, restoring degraded soils and improving naturally poor soils. Soil amendments reduce bulk density and increase cation exchange capacity, enhancing the soil's ability to hold water, increasing infiltration rates, and improving nutrient retention and pollutant removal. The below photo shows the soil amending process (Figure 2-66).

Figure 2-66. Soil Amending Process.

Source: U.S. EPA

Cost

Costs associated with soil amending include the amendments themselves and their application. These costs are generally on the order of $1-3 per square foot.

Benefits

- Reduced runoff volume
- Reduced peak discharge rate
- Groundwater recharge
- Reduced TSS
- Reduced pollutant loading
- Habitat creation
- Enhanced site aesthetics

Limitations

- Not recommended for slopes steeper than 3:1

Potential LEED Credits:

Primary: N/A
Other: Innovation & Design Process (1-4 Points)

Water Supply Impacts
Soil amendments increase the ability of the soil to hold water, and therefore may decrease the need for irrigation during dry periods.

Design Guidelines

Amendments can be applied by topdressing or tilling into the upper soil layers. The most appropriate amendments and application rates are determined through soil testing.

Maintenance
Soil should be planted and mulched after installation. No part of the site should have bare soil exposed. Compaction of amended soils should be avoided.

Amended soils should be inspected annually for signs of compaction, waterlogging, loss of vegetated cover, or erosion. Routine infiltration testing can be used to pinpoint potential problem areas. In areas where remediation is needed, soil samples may help to diagnose specific deficiencies in the soil. Corrective actions include application of additional amendments and mechanical aeration.

Links to Detailed Information

County of San Diego. 2014. *Low Impact Development Handbook.* https://www.sandiegocounty.gov/content/dam/sdc/pds/docs/LID_Handbook_2014.pdf.

Inland Empire Regional Composting Authority. *General Landscaping Information*. http://www.ierca.org/docs/GeneralLandscape.pdf

Low Impact Development Center, Inc. *Soil Amendments*. http://www.lid-stormwater.net/soilamend_home.htm

University of California Cooperative Extension (UCCE) and California Department of Water Resources (CDWR). 2000. *A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California*. Sacramento, CA: California Department of Water Resources.

Vegetated Filter Strips

Filter strips are bands of dense, permanent vegetation with a uniform slope designed to provide water quality treatment for an adjacent runoff source (i.e., impervious area) by allowing pollutant filtering and settling and stormwater infiltration (Figure 2-67). They are also commonly used as pretreatment for other BMPs.

Figure 2-67. Filter strip used as pretreatment for highway runoff.

Source: Michael Baker International

Costs

Table 2-29. Filter Strip BMP Unit Costs

Design Activity or Product	Unit	National Baseline Unit Cost
Mobilization	Longitudinal section	10% to total cost
Clearing & Grubbing	Square yard	$0.96
Excavation/Grading	Cubic yard	$69
Haul/Dispose of Excavated Material	Cubic yard	$10
Hydroseed	Square foot	$0.08
Traffic Control	Linear foot	$12
Signage, Public Education Materials, etc.	Each	$77

(NCHRP 2014, Appendix E)

Benefits

- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Enhanced site aesthetics
- Reduced phosphorus (high efficiency)
- Reduced metals (medium efficiency)

Limitations

- Must be sited adjacent to imperviousness surfaces
- Requires regular inspection and maintenance to maintain sheet flow
- Relatively large footprint, may not be suitable for highly urban areas
- Must be used in conjunction with additional BMPs to provide volume storage and peak flow reduction.

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Other: Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Innovation & Design Process (1-4 Points)

Resources

California Department of Transportation. 2008. *Caltrans Treatment BMP Technology Report*. April 2008, CTSW-RT-08-167.02.02.
http://www.dot.ca.gov/hq/env/stormwater/annual_report/2008/annual_report_06-07/attachments/Treatment_BMP_Technology_Rprt.pdf

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-31: Vegetated Buffer Strip.
https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*.
http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf

County of San Diego. 2014. *Low Impact Development Handbook.*
https://www.sandiegocounty.gov/content/dam/sdc/pds/docs/LID_Handbook_2014.pdf

National Cooperative Highway Research Program. 2014. Long-Term Performance and Life-Cycle Costs of Stormwater Best Management Practices. Transportation Research Board of the National Academies.

Vegetated Swales

Vegetated swales are broad, shallow channels designed to convey and either filter or infiltrate stormwater runoff (Figure 2-68, Figure 2-69). The swales are vegetated along the bottom and sides of the channel and are used to reduce stormwater volume through infiltration, improve water quality through infiltration and vegetative filtering, and reduce runoff velocity by increasing flow path lengths and channel roughness.

Figure 2-68. A vegetated swale with curb cuts in Playa Vista, California.

Source: Keith Linker

Figure 2-69. A vegetated swale with curb cuts in Playa El Monte, California.

Source: Bill DePoto

Costs

Table 2-30. Vegetated Swale BMP Unit Costs

Design Activity or Product	Unit	National Baseline Unit Cost
Mobilization	Longitudinal section	10% to total cost
Clearing & Grubbing	Square yard	$0.96
Excavation/Grading	Cubic yard	$69
Dewatering	Day	$1,200
Haul/Dispose of Excavated Material	Cubic yard	$10
Inflow Structure(s)	Longitudinal section	$2,200
Overflow Structure (concrete or rock riprap)	Cubic yard	$125
Hydroseed	Square foot	$0.08
Metal Beam Guard Rail	Linear foot	$58
Signage, Public Education Materials, etc.	Each	$77

(NCHRP 2014, Appendix E)

Benefits

- Reduced stormwater volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Enhanced site aesthetics
- Reduced phosphorus (moderate efficiency)
- Reduced metals (moderate efficiency)
- Increases time of concentration

Limitations

- Not applicable for steep slopes
- Requires regular vegetation maintenance and trash removal
- Not suitable for areas with highly erodible soils
- Should not be located under trees which may drop leaves or needles, impeding flow
- Must be used in conjunction with additional BMPs to provide volume storage and peak flow reduction.

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)
Other: Sustainable Sites – Credit 7 “Landscape & Exterior Design to Reduce Heat Islands” (1-2 Points)
Water Efficiency – Credit 1 “Water Efficient Landscaping” (1-2 Points)
Innovation & Design Process (1-4 Points)

Links to Detailed Information

California Department of Transportation. 2008. *Caltrans Treatment BMP Technology Report*. April 2008, CTSW-RT-08-167.02.02.
http://www.dot.ca.gov/hq/env/stormwater/annual_report/2008/annual_report_06-07/attachments/Treatment_BMP_Technology_Rprt.pdf

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-30: Vegetated Swale.
https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*.
http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf

County of San Diego. 2014. *Low Impact Development Handbook.*
https://www.sandiegocounty.gov/content/dam/sdc/pds/docs/LID_Handbook_2014.pdf

Infiltration Basins

Infiltration basins are shallow impoundments designed to collect and infiltrate stormwater (Figure 2-70). Collected stormwater temporarily ponds on the surface of the basin, then infiltrates. Pollutant removal is accomplished by natural mechanisms within the soil including filtration, absorption and adsorption, and chemical and biological uptake. Siting is constrained by available land and the infiltration capacity of the soils.

Figure 2-70. Infiltration basin.

Source: March Joint Powers Authority

Benefits

- Reduced stormwater volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Increased groundwater recharge

Limitations

- Requires large pervious area
- Not suitable on fill sites or steep slopes
- Risk of groundwater contamination in very coarse soils
- High potential for clogging; functioning is difficult to restore
- Requires regular maintenance

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)
Other: Innovation & Design Process (1-4 Points)

Links to Detailed Information

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-11: Infiltration Basin. https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*. http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf.

County of San Diego. 2014. *Low Impact Development Handbook.* https://www.sandiegocounty.gov/content/dam/sdc/pds/docs/LID_Handbook_2014.pdf.

Infiltration Trenches

Infiltration trenches are narrow trenches that have been back-filled with stone (Figure 2-71). They collect runoff during a storm event, store it in the void spaces in the stone, and release it into the soil by infiltration. Pretreatment, often with filter strips, is required to prevent sediment buildup and ensure effective infiltration. Infiltration trenches can drain areas up to 10 acres. They are not recommended downstream of erodible areas, on steep slopes, or in areas where pollutant spills are likely. Infiltration trenches must be set back 10 feet from the seasonal high groundwater table, 5 feet from any impermeable soil layers or bedrock, and out of tree drip lines. Infiltration trenches can be prone to clogging with sediment and require pretreatment as well as regular observation and maintenance to ensure proper functioning.

Figure 2-71. Infiltration Trench.

Source: Michael Baker International

Benefits

- Reduced stormwater volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Increased groundwater recharge

Limitations

- The longitudinal slope of the trench should not exceed 3%
- High potential for clogging; functioning is difficult to restore
- Risk of groundwater contamination in very coarse soils
- Requires regular maintenance
- Low removal of dissolved pollutants
- Some configurations may meet the definition of EPA Class V injection wells, and must be registered with EPA Region 9. Regulations vary by jurisdiction. Details are available at: http://www.epa.gov/region09/water/groundwater/uic-classv.html

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)
Other: Innovation & Design Process (1-4 Points)

Links to Detailed Information

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-10: Infiltration Trench.
https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*.
http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf

County of San Diego. 20014. *Low Impact Development Handbook.*
https://www.sandiegocounty.gov/content/dam/sdc/pds/docs/LID_Handbook_2014.pdf

Dry Wells

A dry well is an underground storage facility used to capture and infiltrate runoff from downspouts or small impervious areas (Figure 2-72). Dry wells can be used on steep slopes, where many other BMPs cannot, provided the slope is stable and not subject to landslide risk. They have a very small footprint, and can be used in tight spaces. Dry wells are typically used in residential or other small-scale applications.

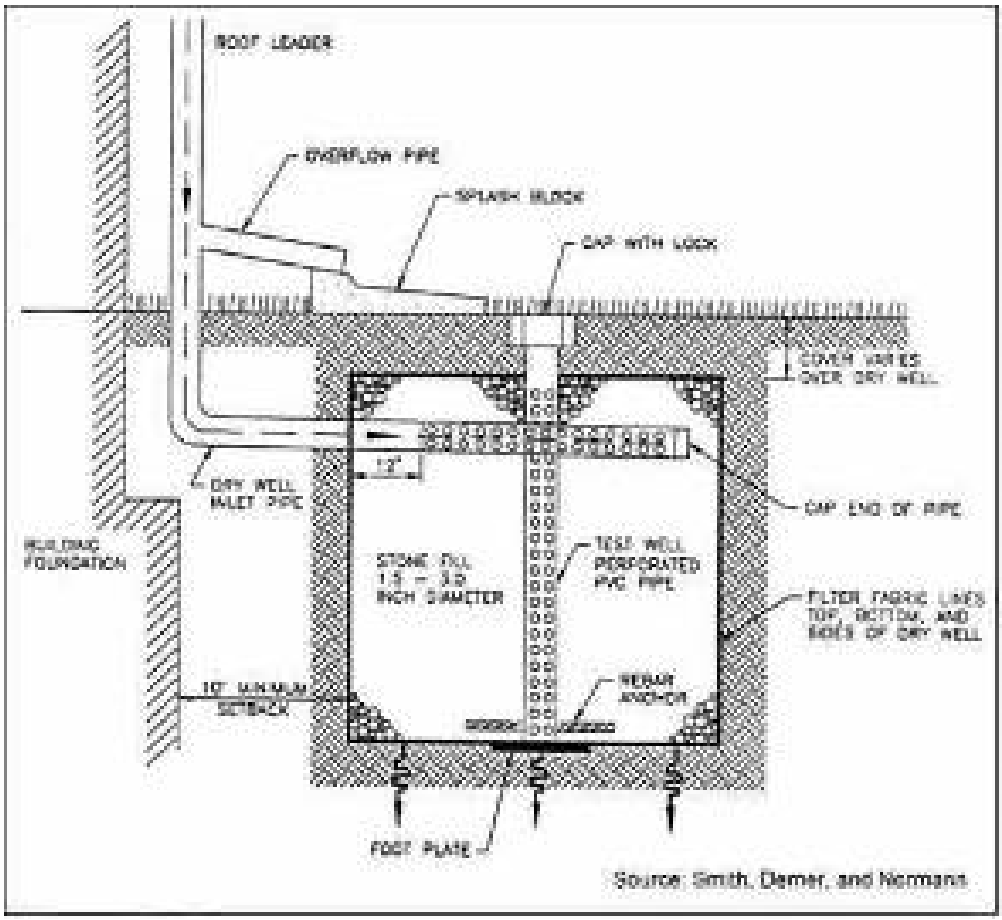

Figure 2-72. Schematic of a dry well.

Source: Stormwater Management for Maine 1995. (UFC Manual).

Benefits

- Reduced peak discharge rate
- Reduced runoff volume
- Reduced TSS
- Reduced pollutant loading
- Reduced runoff temperature

Limitations

- Requires HSG Group A or B soils
- Not suitable for high sediment loads

- Dry wells meet the definition of EPA Class V wells, and must be registered with EPA Region 9. Regulations vary by jurisdiction. Details are available at: http://www.epa.gov/region09/water/groundwater/uic-classv.html

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)
Other: Innovation & Design Process (1-4 Points)

Links to Detailed Information

County of San Diego. 2014. *Low Impact Development Handbook.*
https://www.sandiegocounty.gov/content/dam/sdc/pds/docs/LID_Handbook_2014.pdf

Dry Ponds

Dry ponds, also known as extended detention basins, are designed to collect and detain a water quality volume of stormwater for a set period of time, normally 24 to 72 hours, before discharging the runoff (Figure 2-73). Dry ponds do not maintain a permanent pool, emptying completely between rain events. Water quality improvements are gained from sedimentation and peak flow attenuation.

Figure 2-73. Dry pond.

Source: Michael Baker International

Benefits

- Reduced TSS
- Reduced pollutant loading

Limitations

- Requires tributary area greater than 5 acres
- Outlets of detention systems may clog easily if not properly designed and maintained
- Requires large dedicated area
- Low ability to reduce runoff volume

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)
Other: N/A

Links to Detailed Information

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-22: Extended Detention Basin.
https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*.
http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf

County of San Diego. 2014. *Low Impact Development Handbook.*
https://www.sandiegocounty.gov/content/dam/sdc/pds/docs/LID_Handbook_2014.pdf

Constructed Wetlands

Constructed wetlands are shallow, engineered vegetated systems designed to provide stormwater detention and pollutant removal (Figure 2-74). Natural wetlands *should not* be used to treat stormwater.

Figure 2-74. Dominguez Gap Wetlands, LA County.

Source: Raphael D. Mazor, Southern California Coastal Water Research Project

Benefits

- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Reduced runoff temperature
- Habitat creation
- Enhanced site aesthetics

Limitations

- Requires year-round base flow
- Requires large footprint
- Not suitable for steep slopes
- Requires careful design, maintenance and monitoring to prevent vector infestation
- Safety concerns where there is public access
- Dense plantings may restrict access for maintenance

Links to Detailed Information

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-21: Constructed Wetlands.
https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*.
http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf

USEPA – Guiding Principles for Constructed Wetlands
http://www.epa.gov/owow/wetlands/pdf/constructed.pdf

Media Filters

A media filter is a flow-through system designed to improve water quality from impervious drainage areas by slowly filtering runoff through a media such as sand (Figure 2-75). It consists of one or more sedimentation and filtration chambers or areas to treat runoff. Pollutant removal in media filters occurs primarily through straining and sedimentation. Treated effluent is collected by underdrain piping and discharged. Surface and underground media filters function similarly.

Types of non-vegetated Media Filters

- Bed Filters – Includes conventional Delaware and Austin sand filter designs as well as horizontal flow bed filters.
- Modular Cartridge based filters – Typically proprietary and available in a range of configurations including radial flow, upward flow and fluidized bed filters with customizable media.
- Powered filtration systems – Utilize a range of media and are often designed as parallel systems with backwash capabilities.
- Catch Basin inserts – Typically designed with shallow media beds (<2") very high hydraulic loading rates (> 10 gpm/ft^2) and very low contact time (<5 sec) at design flow rates.

Figure 2-75. Surface media filter.

Source: Portland BES

Benefits

- Most media filters can be located below ground and can support H20 loading. Therefore they require no dedicated site area.
- No potable water demand
- Pollutant sequestration. Pollutants are stored out of contact with the public, wildlife, groundwater, soil or vegetation.

- Spill protection
- Filter media can be customized to target specific pollutants of concern
- Modular, standardized design can reduce construction errors

Limitations

- Very low runoff volume reduction capability
- Low ability to remove dissolved pollutants
- May require confined space entry for maintenance
- May require cooperation with vendor for replacement media or cartridges
- Maintenance of underground filters is easily neglected, and can lead to system failure
- Designs that maintain permanent standing water may create vector concerns

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Other: N/A

Application

Where landscape based BMPs are infeasible, especially on retrofit projects due to space limitations or pre-existing structures and grading, filtration can be provided in a modular, non-vegetated format to provide important pollutant reduction benefits.

Filter Performance and Design

The performance of any media filter is governed primarily by four factors:

- Hydraulic Loading Rate – The application rate of untreated water to the surface of the filter media usually expressed as a flow rate per filter surface area. i.e. gpm/ft2
- Filter Media Gradation – A finer media gradation reduces hydraulic conductivity and increases the capture efficiency for fine particulate pollutants. Finer media also has a greater surface area which increases sorption rates for chemically active media. A more homogenous media gradation increases voids volume in a media bed. Finer media is more susceptible to surface clogging.
- Residence Time – Residence time is a function of media gradation, hydraulic loading rate and the media bed depth and configuration. A longer residence time generally improves pollutant removal performance.
- Media Chemical properties – Filter media can be inert (i.e. perlite) or can be selected to target specific pollutants of concern (i.e. activated carbon for trace organics). Chemically active options may be organic, mineral or synthetic or a combination of types. Media should be selected with consideration of the type and load of pollutants requiring removal.

Given the tremendous variability and the proprietary nature of many media filter designs, observed media filter performance varies widely. Sand filters following CASQA handbook guidance are generally accepted as effective stand-alone treatment systems for most common stormwater pollutants. At least three peer reviewed field monitoring protocols have been developed for the express purpose of identifying those stormwater treatment system designs that demonstrate comparable performance and that operational feasibility. Initial laboratory or bench scale performance evaluation is useful for refining filter design and operation characteristics, but in-field performance verification following one of the following protocols is essential. Media filter designs that have been accepted by the following programs may be considered for use where bioretention facilities are infeasible.

- Sacramento Stormwater Quality Partnership – "Investigation of Structural Control Measures for New Development"
- Washington State Department of Ecology – "Technology Assessment Protocol – Ecology" (TAPE), General Use Level Designation
- Technology Assessment Reciprocity Partnership (TARP) – "Protocol for Stormwater Best Management Practice Demonstrations," Final Certification

Resources

Caltrans, 2004. BMP Retrofit Pilot Program – Final Report. Report ID: CTSW – RT – 01 – 050. California Department of Transportation, Sacramento, CA. http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/_pdfs/new_technology/CTSW-RT-01-050.pdf

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*. http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf

County of San Diego. 2014. *Low Impact Development Handbook.* https://www.sandiegocounty.gov/content/dam/sdc/pds/docs/LID_Handbook_2014.pdf

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-40: Media Filter. https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf

City of Sacramento. 2014. *Comprehensive Protocol for Performance Evaluation of Proprietary Stormwater Control Products.* http://www.beriverfriendly.net/docs/files/File/NewDev/PropDevices-%20Protocol_revised-Mar2014.pdf.

Technology Acceptance and Reciprocity Partnership (TARP). 2001. *The Technology Acceptance Reciprocity Partnership Protocol for Stormwater Best Management Practice Demonstrations.* https://www.mass.gov/files/documents/2016/08/rd/swprotoc.pdf

Washington State Department of Ecology. 2018. *Emerging stormwater treatment technologies (TAPE).* https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Emerging-stormwater-treatment-technologies.

Proprietary Devices

Proprietary devices are available in a wide range of designs and are designed to provide a wide range of hydrologic and water quality benefits. Proprietary devices include:

- Rainwater harvesting systems
- Green roof systems
- Subsurface infiltration and detention
- Permeable paving systems (paving blocks as well as new large precast concrete sections)
- Biofilters
- Media filters
- Hydrodynamic separators
- Inserts
- Trash control systems

Most proprietary devices are modular and premanufactured, which allows for a level of quality control that can be difficult to achieve with conventional landscape-based systems that are constructed on site. Manufactured devices can often provide similar benefits as their conventional counterparts in a considerably smaller footprint due to optimized flow patterns, engineered filter media and/or subterranean installation. Given the diversity of manufactured stormwater management system designs, sizing approaches, and operation and maintenance demands it is more informative to look at characteristics and capabilities of devices individually rather than as a generalized group.

Benefits

- Remove trash, debris, sediment, and/or oils
- Wide variety of functionality and designs
- Good retrofit capability
- Can be used for pre-treatment of stormwater
- Modular and premanufactured designs can allow for a higher level of quality control than BMPs constructed on site

Limitations

- Provide limited water quality treatment
- Do not attenuate peak flows or volume
- Some devices permit permanent pools of standing water, which can provide a breeding area for mosquitoes
- Maintenance of underground devices is easily neglected, and can lead to system failure

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)
Other: N/A

Proprietary Device Verification Programs

With regard to water quality impacts, there are two primary verification programs that have developed testing protocols and performance verification programs for manufactured treatment devices; New Jersery Department of Environmental Protection (NJ DEP) and The Washington State Department of Ecology (Ecology).

NJ DEP program evaluates and certifies manufactured treatment devices and requires laboratory testing of media filters and hydrodynamic separators for adequate removal of TSS. This laboratory testing also evaluates suitability for online configuration where flow rates in excess of the treatment capacity of the system can be safely routed through the system. The potential of hydrodynamic separators to release previously captured pollutants is also assessed and a maximum sediment storage capacity is identified. Mass load capacity of filtration devices is also assessed. Once laboratory tests are completed, results are

submitted to an independent auditor for peer review and a verification report is authored. If the verified results satisfy the NJ DEP program goals, a certification is issued for the manufactured treatment device.

Program information and a list of verified and certified technologies can be found on the NJ DEP web site at: https://www.nj.gov/dep/stormwater/treatment.html.

Ecology program evaluates emerging stormwater treatment technologies and relies on the Technology Evaluation Protocol – Ecology (TAPE) to guide field testing of both proprietary and non-proprietary stormwater treatment systems. Ecology has established treatment standards for TSS, dissolved zinc and dissolved copper, phosphorus and oil and grease. Experimental technologies that successfully complete testing following the TAPE and meet the performance standards are issued a General Use Level Designation which summarizes testing results, sizing and design conditions and operation and maintenance guidance.

The current TAPE and list of approved technologies can be found on the Ecology web site at: https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Emerging-stormwater-treatment-technologies.

Both programs have been referenced by local jurisdictions throughout the United States, including in Southern California, as providing objective performance data and design requirements for innovative stormwater technologies. Such local policy typically requires that the approved design hydraulic loading rate not be exceeded on local projects and that other conditions of design, operation and maintenance be met. It should be noted that neither the NJ DEP program nor the Ecology program differentiate between LID and non-LID technologies. For example, biofiltration systems would be considered media filters under the NJ DEP testing program and the Ecology program evaluates water quality performance without regard to the classification or unit processes active in a particular system. Therefore, suitability of a particular system must be assessed given local permit requirements. For example, while some non-vegetated media filters may be able to provide similar performance to biofiltration, they may not be acceptable as LID technologies. It is also important to match the pollutants of concern on a particular site with the pollutants evaluated by a verification program. For example, in a nutrient impaired watershed the Ecology phosphorus treatment standard is more relevant than the NJ standard for TSS removal.

Volume Reduction and Detention Technologies

Runoff reduction capability is not a criteria for approval of innovative treatment systems in either program, although it may be noted. However, there are numerous examples of proprietary volume reduction and detention technologies. Cisterns and automated rainwater harvesting systems are typically packaged proprietary systems. Subsurface infiltration systems are ubiquitous in Southern California. Subsurface infiltration systems are typically comprised of perforated pipes, plastic chambers, precast concrete vaults or vertical drywell shafts. Where site conditions preclude infiltration, most of these same systems can serve as detention systems when provided without perforations or with an impermeable liner. Rather than relying on pollutant removal performance verification programs for these systems, structural analysis for subsurface systems and assessment of suitability given local geotechnical considerations should be undertaken.

Proprietary Devices as Pretreatment

Infiltration and detention systems should be designed to include upstream pretreatment devices to intercept stormwater pollutants. Pretreatment extends the useful life of infiltration and detention systems by preventing solids from occluding infiltrating surfaces or occupying void spaces within a detention system. Pretreatment also greatly simplifies maintenance since captured pollutants are contained in the pretreatment BMP rather than distributed throughout the downstream infiltration or detention system. Preferably, a pretreatment system utilizing filtration through plants and soil or engineered filter media would be specified as pretreatment. However, at a minimum a hydrodynamic separator meeting NJ DEP and/or Ecology standards and providing trash capture and spill storage capacity should be used as pretreatment.

Resources

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-50: Water Quality Inlet. https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet MP-50: Wet Vault. https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf

City of Sacramento. 2014. *Comprehensive Protocol for Performance Evaluation of Proprietary Stormwater Control Products.* http://www.beriverfriendly.net/docs/files/File/NewDev/PropDevices-%20Protocol_revised-Mar2014.pdf.

Step 5: Evaluate Overall LID Site Plan & Design

A successful LID site plan and design must meet the goals that have been laid out at the beginning of the design process. Assessment of the level to which these goals have been met has both quantitative and qualitative elements.

LID centers on the goal of mimicking the predevelopment hydrology of a site, including volume, flow, and time of concentration of the runoff hydrograph. A successful LID site plan and design will have the following attributes:

- Runoff should be captured and treated where it is generated. Therefore, every impervious surface should be associated with a dedicated structural BMP or set of structural BMPs to capture and treat the runoff from that surface.

- No runoff should be discharged untreated, with the exception of excess runoff from events greater than the 85th percentile storm event or design storm.

- Excess stormwater relative to predevelopment conditions should be captured and held onsite to the maximum extent practicable. The exact level of capture that is warranted will depend on the site's predevelopment hydrology, and the level of infiltration that can be achieved will depend on the site's soils.

- Predevelopment peak discharge rates should be maintained.

- The predevelopment time of concentration should be maintained. Flow paths should be as long as possible, flow surfaces should be roughened. This will prevent increases in the peak flow rate.

- Environmentally sensitive site features should be preserved.

- A designer should try to optimize the siting of buildings and paved areas in places that will have minimal impact on the site's hydrology. The design should avoid developing the most permeable soils, instead taking advantage of these areas for infiltration.

LID Hydrologic Analysis
The purpose of this section is to provide technical guidance on the estimation and control of stormwater runoff quality and quantity. A general overview of hydrograph methods used for designing BMPs, and a description of some of the more common computerized modeling methods and analysis is provided.

When assessing the structural BMPs that can be used to meet stormwater control objectives for a new or redevelopment project, the stormwater designer will need to adequately simulate various stormwater runoff scenarios. The hydrologic analysis includes estimating design storm characteristics (e.g., frequency, intensity, duration, and quality of runoff) with and without stormwater BMP controls. The type of calculations and models utilized in the hydrologic analyses is integral to appropriately simulating the pre- and post- design conditions and determining whether a successful design has been developed.

Background on Modeling LID

Stormwater modeling has its origin in the design of flood control facilities, which focused on protection of public property and safety. Changes in stormwater management, primarily related to environmental objectives, have necessitated that models be expanded to include a broader array of modeling capabilities. Additionally, conventional modeling focuses on the large storm events, whereas environmental objectives are often focused on the smaller events, which have the greatest influence on pollutant transport and channel geomorphology.

With the increasing use of LID as a stormwater mitigation approach, the peak flow rate and volume runoff benefits of LID need to be adequately accounted for in the selected modeling approach. There are multiple models that are capable of simulating stormwater runoff characteristics.

Commonly Used Models for LID Design

- California Stormwater BMP Handbook Approach
- Rational Method
- TR-20/TR-55
- HEC-1
- HSPF
- SWMM
- SLAMM

There have been many methodologies developed to estimate the total runoff volume, the peak flow rate of runoff, and the runoff hydrograph from land surfaces under a variety of conditions. This section describes some of the methods that are most commonly used for stormwater design. When selecting a modeling approach, match the tool to the scope, complexity, and size of the project while considering the conditions of the receiving waters and runoff conveyance system.

California Stormwater BMP Handbook Approach

Source: California Stormwater Quality Association

Storm Simulation Type: Continuous

Stormwater Analysis Capability: Volume, Flow

Description: The California Stormwater BMP Handbook Approach is based on an application of the STORM model, developed by the U.S. Army Corps of Engineers, to California. Both volume-based and flow-based BMP sizing curves are provided for representative areas throughout the state and require only the calculation of a composite runoff coefficient for the proposed site.

Typical Use: Primarily used for site-scale sizing of water quality BMPs.

Advantages: This approach is easy to apply and does not require the use of sophisticated models. Calculations are based on commonly available project information. The approach is often approved for use in California NPDES permits.

Resources:

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. Section 5, Treatment Control BMPs. https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf.

The Rational Method

Source: Kuichling 1889

Storm Simulation Type: Single event

Storm Analysis Capability: Flow

Description: The rational formula calculates the peak flow rate as a function of the rainfall intensity (for a specific design return period and time of concentration (T_c)), the watershed area, and the runoff coefficient.

Typical Use: Estimating peak runoff rates from relatively small (200 acre) developed drainage areas. The Rational Method is commonly used to estimate runoff rates from large storm events for the design of conventional stormwater infrastructure (e.g., pipes) for flood management.

Advantages: Simple calculations that do not require intensive labor or software. Input values are readily available and can be adjusted to improve estimates.

Disadvantages: While the calculations are simple, peak runoff rate estimates are highly sensitive to estimates of the T_c. Additionally, the Rational Method is unable to accommodate for storage in the drainage area.

Recommendation: Can be used to size BMPs for water quality improvement. Manipulation of runoff coefficients can be conducted to simulate storage and infiltration processes, but considerable error may be introduced.

TR-55 / TR-20

Source: The U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS)

Storm Simulation Type: Single event

Description: "Technical Release 55 (TR-55) presents simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs. These procedures are applicable to small watersheds, especially urbanizing watersheds, in the United States." (NRCS, 1986) TR-55 uses the runoff curve number method and unit hydrographs to convert rainfall into runoff estimates.

Typical Use: Used for both watershed/basin planning as well as project scale calculations.

Advantages: The advantage of applying TR-55 and TR-20 is the convenience of tables and input parameters included for a wide range of soil and land use conditions. TR-55 is the most widely used approach to hydrology.

Disadvantages: While simple to use, runoff estimates are highly sensitive to estimates of the Tc and curve numbers.

Recommendation: Can be effectively used to model LID BMPs for single event storms. User must be aware of uncertainty related to input parameters.

HEC-1

Source: U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC)

Storm Simulation Type: Single event

Stormwater Analysis Capability: Flow

Description: HEC-1 is designed to simulate the surface runoff response of a drainage basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. Each component provides simulation of a rainfall-runoff process. The result of the modeling process is the computation of streamflow hydrographs at desired locations in the river basin.

Typical Use: Primarily used to design conventional detention basins for flood control.

Advantages: The ability to simulate system routing and storage provides some improvement over use of the Rational Method.

Disadvantages: May be complex for most users without appreciable benefit over TR-55, which is easier to use.

Recommendation: Can be used to simulate LID BMPs, but TR-55 would be a better option.

HSPF- Hydrologic Simulation Program – FORTRAN

Source: U.S. Environmental Protection Agency

Storm Simulation Type: Continuous simulation

Stormwater Analysis Capability: Water Quality and Flow

Description: The HSPF model simulates of water quantity and quality runoff from mixed land use watersheds. Using continuous simulation of rainfall-runoff processes, the model generates hydrographs, runoff flow rates, sediment yield, and pollutant washoff and transport. HSPF includes consideration of infiltration, subsurface water balance, interflow, and base flow.

Typical Use: Traditional use for conventional flood control and water quality treatment. Increasingly, models based on HSPF are being utilized to estimate emerging stormwater management practices such as LID.

Advantages: Models most processes that would concern LID BMP design. Capable of simulating a wider range of hydrologic responses through continuous simulation.

Disadvantages: HSPF is a complex model and requires a user familiar with the software. Also requires significant input data.

Recommendation: If the model is available and calibrated to the local conditions, then HSPF or an HSPF-based model would be appropriate. The LID designer should consider whether a simpler model (e.g., TR-55) would be sufficient.

Storm Water Management Model (SWMM)

Source: U.S. Environmental Protection Agency

Storm Simulation Type: Single event and continuous simulations

Stormwater Analysis Capability: Water quality and flow

Description: SWMM is an urban stormwater model developed and maintained by the EPA. SWMM is applied to stormwater simulations including urban runoff, flood routing, and flooding analysis. The model provides continuous simulation of rainfall-runoff processes (peak flow, rate, duration) and associated pollutant washoff and transport. SWMM also includes flow routing capabilities for open channels and piped systems.

Typical Use: Predominantly used to design conventional stormwater facilities for flood control and conveyance. Used both at watershed- and parcel- level analysis. Some users have modified SWMM to better simulate LID practices and processes.

Advantages: SWMM provides ability to simulate water quality and flow, routing, and storage functions. Accounts for rainfall patterns and characteristics through continuous simulations. Can be modified to better meet user needs.

Disadvantages: Requires significant data input and user familiarity. Increase in variables, while providing an opportunity for more accurate simulations, can also create increased error due to the need to estimate multiple parameters.

Recommendation: Can be effectively used to model LID BMPs but user should determine whether a simpler method would be satisfactory.

SLAMM (Source Loading and Management Model)

Source: PV & Associates

Storm Simulation Type: Continuous

Stormwater Analysis Capability: Water Quality

Description: SLAMM was developed to better understand the relationships between sources of runoff pollutants and runoff quality. It has been continually expanded and includes a variety of water quality control practices (infiltration, detention ponds, porous pavement, street cleaning, catch basin cleaning, and landscaped swales).

Typical Use: SLAMM is mostly used as a planning tool, to better understand sources of urban runoff pollutants and their control. Special emphasis has been placed on small storms, where most pollutant transport occurs.

Advantages: One of its most important features is its ability to consider many stormwater controls (affecting source areas, drainage systems, and outfalls) together, for a long series of rains. SLAMM can be effectively used in conjunction with drainage design models to incorporate the mutual benefits of water quality controls on drainage design.

Disadvantages: As a water quality model, SLAMM cannot predict stormwater runoff characteristics associated with LID.

Recommendation: Can be used if coupled with an appropriate runoff model.

Selecting the Appropriate Model to Evaluate Your LID Site Plan & Design

All of the models described in the preceding section can be utilized for evaluation of an LID site plan and design. The appropriate computational methods depend on the type of information required and the size of the drainage area to be analyzed. In selecting the appropriate procedure, consider the scope and complexity of the problem, the available data, and the acceptable level of error. Consider the stormwater runoff objective (e.g., volume, peak rate, flow frequency/duration, water quality), then select the appropriate model.

Single Event versus Continuous Simulation Model

A continuous simulation model has considerable advantages over the single event-based methods. A continuous simulation model is capable of simulating a wider range of hydrologic responses than the single event models. Single event models cannot take into account storm events that may occur just before or just after the single event (the design storm) that is under consideration. Event- based modeling has a place, however, especially in the design of small projects (typically less than 200 acres), where resources are limited.

Continuous runoff models are able to simulate a continuous long term record of runoff and soil moisture conditions. Finally, single event models do not allow for estimation and analyses of flow durations, which may be necessary to determine acceptable discharges to streams.

Table 2-31 further describes the differences between these models.

Table 2-31. Commonly Used Models for LID Design

	CA BMP Handbook	Rational Method	TR-55/TR-20	HEC-1	HSPF	SWMM	SLAMM
Simulation Type	Continuous	Single event	Single event	Single event	Continuous	Single Event/ Continuous	Continuous
Runoff Volume	Yes	No	Yes	Yes	Yes	Yes	No
Peak Discharge	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Water Quality	No	No	No	No	Yes	Yes	Yes
Flow Routing	No	No	Yes	Yes	Yes	Yes	Yes
Storm Events	Small	Large	All	Large	All	All	Small
Overall Complexity	Low	Low	Moderate	Moderate	High	High	High
Appropriatenes s for LID	Moderate	Moderate	High	Moderate	High	High	High

Source: The Low Impact Development Center, Inc.

Section 3 Case Studies

Case Study 1: Commercial Retrofit

Retrofit existing commercial site with green roofs, permeable pavement, and bioretention.

Location: San Diego
Total Site Area: 2.81 acres

Existing Conditions
Total impervious area: 1.65 ac

- buildings: 0.39 ac
- parking: 0.99 ac
- walkways: 0.26 ac

Landscaped areas (turf): 1.16 ac

Existing soils: Gravel pit, Hydrologic Soil Group A, Infiltration rate: 13 in/hr, based on NRCS Web Soil Survey (http://websoilsurvey.nrcs.usda.gov). Soil profiles and infiltration rates should be measured in the field prior to finalization of design.

Weighted runoff coefficient: 0.54
Composite curve number: 78

Predevelopment Condition
Land cover: California sagebrush
Curve number: 35

Analysis
Using the California Stormwater BMP Handbook approach, the required storage volume for 85% capture would be 3,979 cubic feet.

Using the TR-55 approach, the required storage volume to restore predevelopment hydrologic performance for the 10-year, 24 hour storm would be 11,224 cubic feet.

Suggested BMPs:

1. Retrofit existing buildings with extensive green roofs. Cover 75% of each roof's surface, leaving room for HVAC and other equipment. This would reduce the site composite curve number to 69, and reduce the required storage volume to 5,153 cubic feet.
2. The remaining impervious area can be treated by incorporating 6,800 square feet of permeable pavement into existing parking areas. The permeable pavement would be underlain by a 1-foot-deep gravel storage bed. This is well below the 5.2-foot maximum storage depth to ensure drainage within 48 hours on this soil, providing 2,736 cubic feet of storage.

Landscaped areas cannot be drained to permeable pavement. Runoff from these areas can be captured by surrounding existing drains with small bioretention cells. Assuming a typical 1.4-foot depth of storage, based on 6 inch ponding depth and 2.5 foot media depth, 1,940 square feet of bioretention would provide an additional 2716 cubic feet of storage. The following figure shows the plan view of an existing commercial site (Figure 3-1).

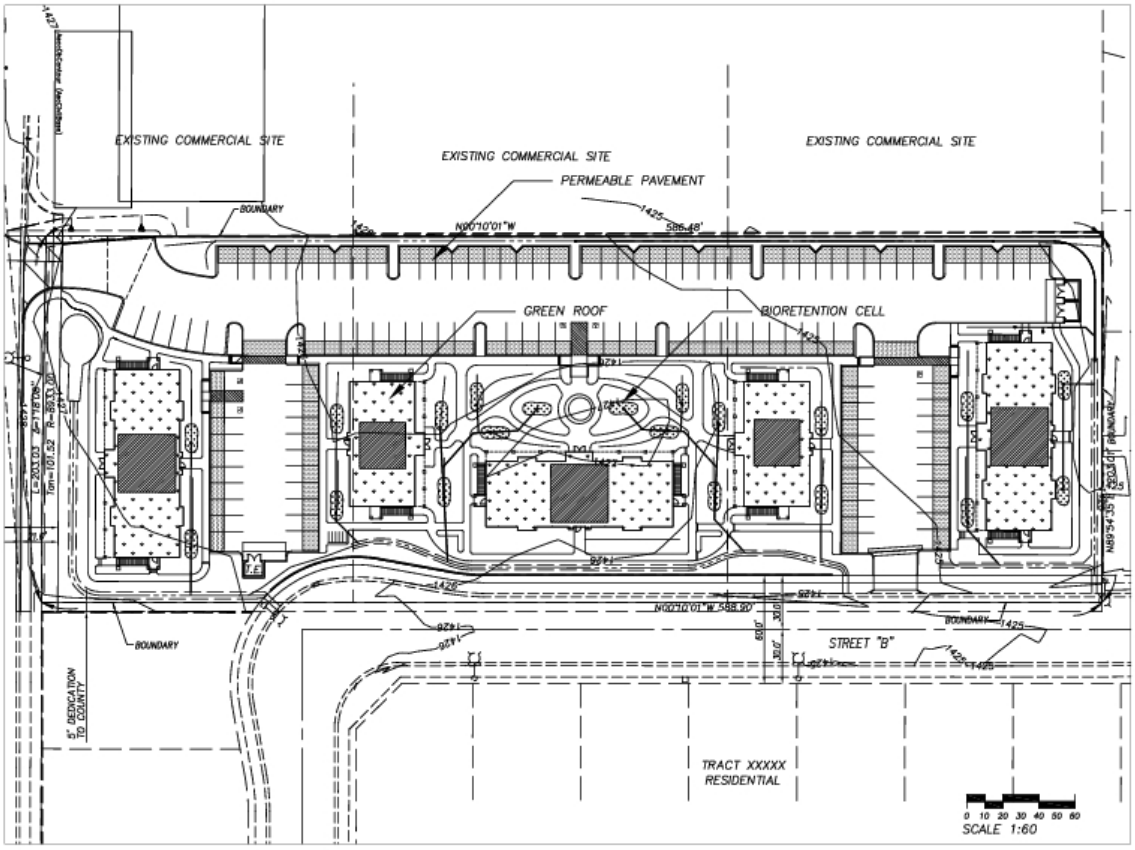

Figure 3-1. ***Retrofit of an existing commercial site.***

Source: The Low Impact Development Center, Inc.

Case Study 2: Residential Retrofit

Retrofit existing residential development with permeable pavement, bioretention, and rain barrels.

Location: Ventura
Total site area: 14.7 acres

Existing Conditions
Total impervious area: 6.9 ac

- houses: 1.3 ac
- driveways: 1.1 ac
- sidewalks: 1.0 ac
- roads: 3.0 ac

Landscaped areas (turf): 7.7 ac

Existing soils: Mocho loam and Pico sandy loam, Hydrologic Soil Group B, average infiltration rate: 2.6 in/hr, based on NRCS Web Soil Survey (http://websoilsurvey.nrcs.usda.gov). Soil profiles and infiltration rates should be measured in the field prior to finalization of design.

Weighted runoff coefficient: 0.49
Composite curve number:

Predevelopment Condition
Land cover: California sagebrush
Curve number: 35

Analysis
Using the California Stormwater BMP Handbook Approach, the required storage volume for 85% capture would be 39,949 cubic feet.

Using the TR-55 approach, the required storage volume to restore predevelopment hydrologic performance for the 10-year, 24 hour storm would be 127,304 cubic feet.

Suggested BMPs:

1. Replace existing sidewalks with permeable pavement, underlain by a 2-foot gravel storage layer. This would provide 55,187 cubic feet of storage.
2. Retrofit each house with two 55-gallon rain barrels. This would provide 834 cubic feet of storage.
3. Build two bioretention cells on each lot, totaling 580 square feet per lot, assuming a 6-inch ponding depth, and 30-inch media depth. This would provide 45,493 cubic feet of storage.
4. Convert existing swale to bioretention, 10,206 square feet, assuming a 6-inch ponding depth, and a 30-inch media depth. This would provide the remaining 14,033 cubic feet of storage.

The following figures show the plan view of an existing residential subdivision and proposed LID retrofits (Figure 3-2, Figure 3-3).

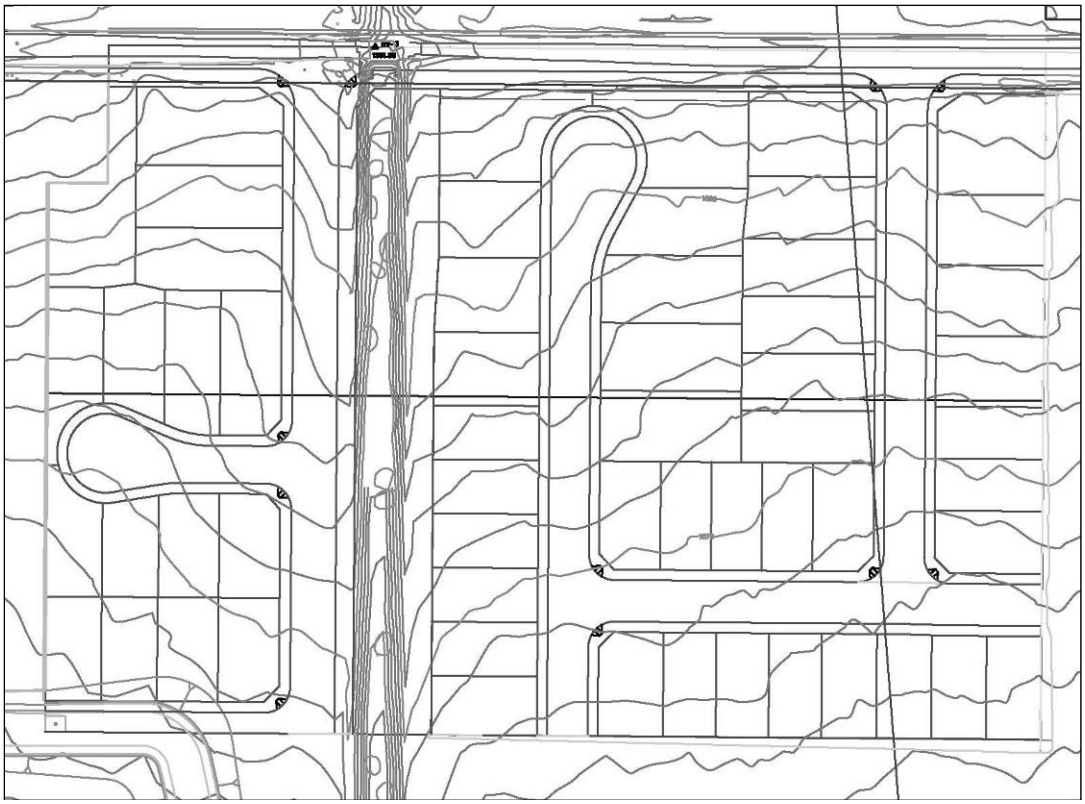

Figure 3-2. ***Existing residential subdivision.***

Source: The Low Impact Development Center, Inc.

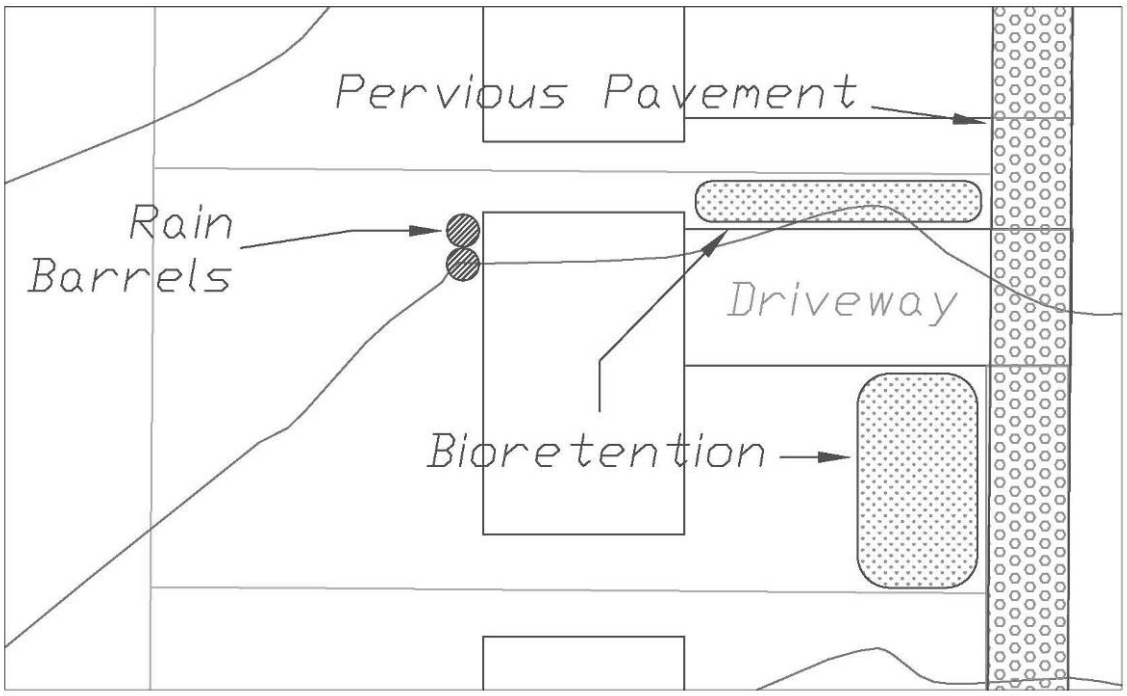

Figure 3-3. LID retrofits to an existing residential lot. These retrofits are to be applied to each lot in the subdivision.

Source: The Low Impact Development Center, Inc.

Case Study 3: Commercial Design

Retrofit an existing commercial warehouse with green roof, permeable pavement, and bioretention, and reduce the impact of a planned expansion.

Location: Riverside
Total site area: 52.9 acres

Existing Conditions
Total impervious area: 21.6 ac

- Existing building: 11.8 ac
- Existing parking: 9.8 ac

Undeveloped area: 31.3 ac

Existing Hydrology: Existing ephemeral stream running through site. Depth to groundwater: high (> 2m). Site is within a braided channel and floods frequently.

Topography: Site has a steady, 2-5% slope running northwest to southeast. Stream runs transverse to the slope in the eastern half of the site.

Existing soils: Soboba stony loamy sand, psamments, and fluvents, Hydrologic Soil Group A, average infiltration rate: 16 in/hr. Soil is very coarse, but frequently floods. No restrictive layers. Soils data is based on NRCS Web Soil Survey (http://websoilsurvey.nrcs.usda.gov). Soil profiles and infiltration rates should be measured in the field prior to finalization of design.

Existing vegetation: California sagebrush

Ecoregion: Los Angeles Plain

Sensitive and restricted areas: There is a stream running through the site, blocking the natural area for the addition.

Existing development: existing building (513,361 sf), two parking areas (55,606 sf in front, 360,644 sf loading area behind building)

Contamination: no known contamination issues

Landslide Potential: low

Proposed Addition
Warehouse addition: 146,711 sf
Parking lot: 50,687 sf
Loading area: parking for 210 tractor trailers

Design Approach
Design addition using LID Site Design Strategies to minimize hydrologic disturbance.

- Maximize Natural Infiltration Capacity
- Preserve Existing Drainage Patterns
- Protect Existing Vegetation and Sensitive Areas

Avoid development within riparian corridor. Place new building and parking areas to the east of the stream, with a bridge connecting the two areas.

- Minimize Impervious Area

- Reduce the size of the tractor trailer parking area by creating a two-story parking structure.
- Disconnect Impervious Areas and Downspouts
- Separate front parking area from building. Isolate roof runoff from loading area.

Weighted runoff coefficient: 0.52
Composite curve number, developed site: 75
Composite curve number, predevelopment (before ALL development): 35

Analysis
Using the California Stormwater BMP Handbook Approach, the required storage volume for 85% capture would be 67,153 cubic feet.

Using the TR-55 approach, the required storage volume to restore predevelopment hydrologic performance for the 10-year, 24 hour storm would be 193,785 cubic feet.

Suggested BMPs:
1. Retrofit existing building with extensive green roof. Cover 75% of roof's surface, leaving room for HVAC and other equipment. This would reduce the site composite curve number to 69, and reduce the required storage volume to 84,421 cubic feet.
2. Harvest rainwater from the roof of the new building, stored in cisterns under the building – 38,023 cubic feet.
3. Install pervious pavement with 6-inch gravel storage layer in front parking lots – 21,572 cubic feet.
4. Surround perimeter of existing and proposed loading areas with bioretention:
    a. 10 feet x 1,350 ft, 6 inch ponding depth, 30-inch media for existing loading area – 18,562 cubic feet.
    b. 10 feet x 743 ft, 6 inch ponding depth, 30-inch media for proposed loading area/ truck parking – 10,220 cubic feet.

Bioretention has an excellent capacity to trap and remove any oil, grease or other pollutants resulting from high truck traffic in these areas. The following figures show an overview of an existing commercial development and proposed retrofits (Figure 3-4, Figure 3-5).

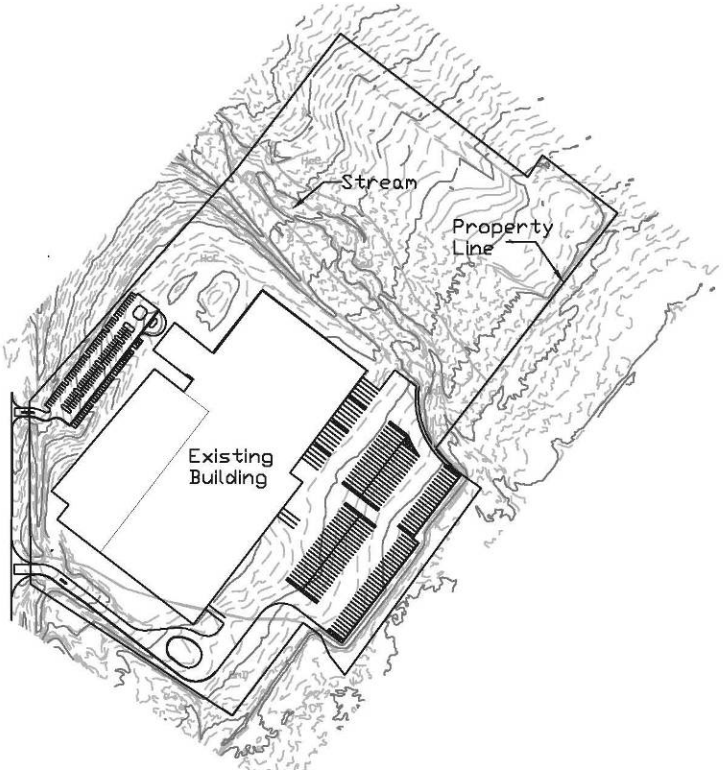

Figure 3-4. ***Existing commercial development.***

Source: The Low Impact Development Center, Inc.

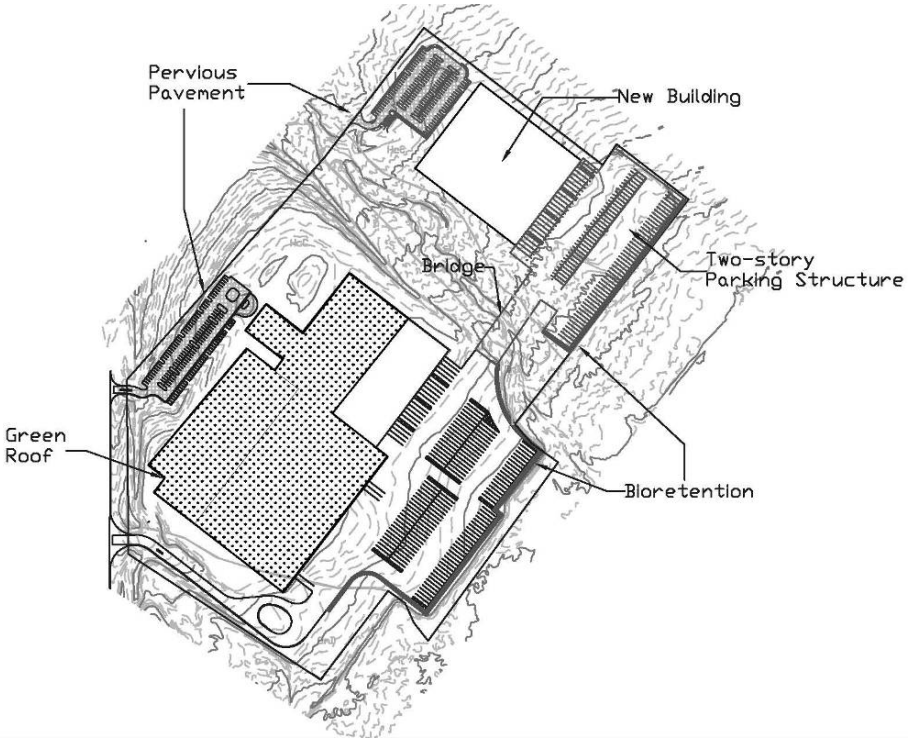

Figure 3-5. ***Proposed retrofits and addition to existing commercial development.***

Source: The Low Impact Development Center, Inc.

Case Study 4: Residential Development

Design a 118-lot residential subdivision on an undeveloped parcel (Figure 3-6).

Location: Riverside
Total site area: 44.4 acres

Existing Conditions

Existing Hydrology: No waterbodies are present onsite. Depth to groundwater: high (> 2m).

Topography: Site is sloped from west to east. The northwestern quadrant slopes steeply to the south and east (5-8% slopes). A smaller hill is present in the southeast corner, sloping north and west. The low area between these hills slopes gently from west to east, with a slope of 1-2%.

Existing soils:

- 60% Cortina gravelly coarse sandy loam, 2-5% slopes, HSG A
- 34% Arbuckle gravelly loam, 8-15% slopes, HSG B
- 3% Ysidora gravelly very fine sandy loam, 8-25% slopes, eroded, HSG C

No restrictive layers. Soils data is based on NRCS Web Soil Survey (http://websoilsurvey.nrcs.usda.gov). Soil profiles and infiltration rates should be measured in the field prior to finalization of design.

Existing vegetation: California sagebrush

Ecoregion: Los Angeles Plain

Sensitive and restricted areas: The slope on the northwestern side of the site is fairly steep, with poorly draining, eroded soils, and should therefore be avoided.

Existing development: none

Contamination: no known contamination issues

Landslide Potential: low

Proposed Development

Design Approach
Design subdivision using LID Site Design Strategies to minimize hydrologic disturbance.

- Maximize Natural Infiltration Capacity
- Preserve Existing Drainage Patterns

Development is focused on level ground to avoid disturbance of natural drainage patterns

- Protect Existing Vegetation and Sensitive Areas
- Avoid developing on steep, eroded slopes
- Minimize Impervious Area

The subdivision is designed with small lots concentrated on one part of the site. Lots are centered around a large communal park to provide recreational opportunities. Minimal road widths are used (40 feet, including sidewalks on one side).

- Disconnect Impervious Areas and Downspouts

Roof downspouts are connected to rain barrels. Driveways use permeable pavement to avoid discharge onto roads. Sidewalks are fitted with permeable pavement to capture street runoff.

Weighted runoff coefficient:
Composite curve number, predevelopment: 36
Composite curve number, developed site: 51

Analysis
Using the California Stormwater BMP Handbook approach, the required storage volume for 85% capture would be cubic feet.

Using the TR-55 approach, the required storage volume to restore predevelopment hydrologic performance for the 10-year, 24 hour storm would be 21,121 cubic feet.

Suggested BMPs:
1. Install one 55-gallon rain barrel at each house – 841 cubic feet
2. Install pervious pavement with 1-foot gravel storage layer in driveways – 11,500 cubic feet
3. Install pervious pavement with 1-foot gravel storage layer on sidewalks – 11,193 cubic feet

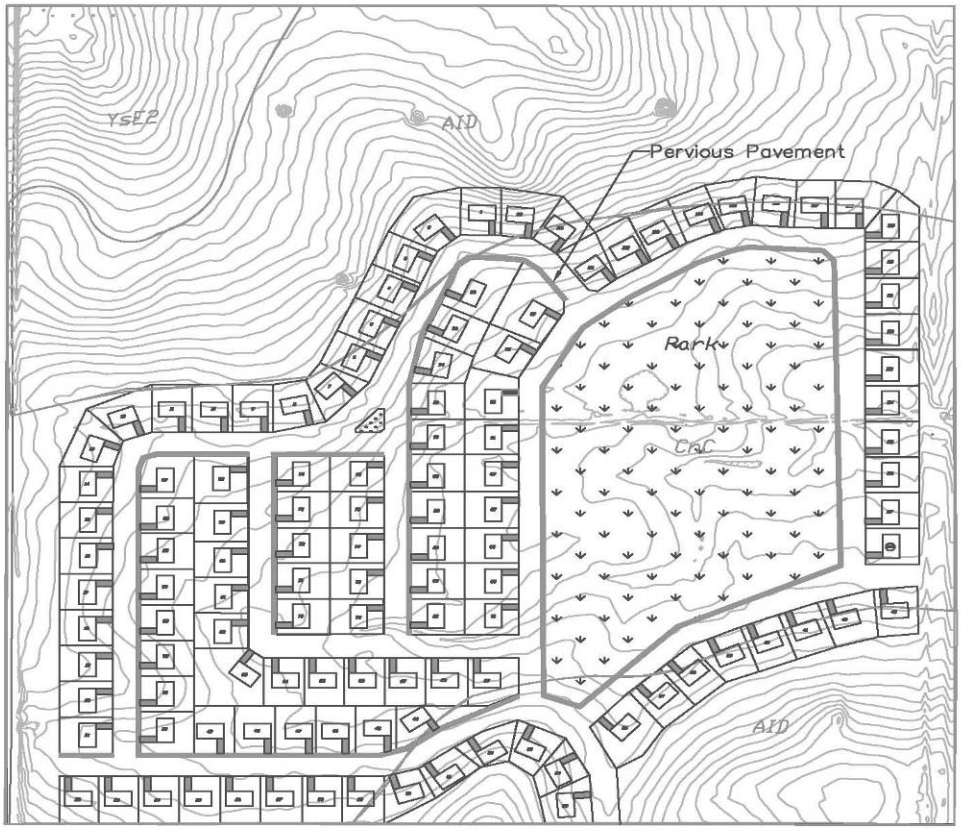

Figure 3-6. ***Residential subdivision design.***

Source: The Low Impact Development Center, Inc.

References

Adams, M. 2003. “Porous Asphalt Pavement with Recharge Beds: 20 Years & Still Working.” *Stormwater*, 4:24-32. https://www.icpi.org/resource-library/technical-papers/porous-asphalt-pavement-recharge-beds-20-years-still-working.

AWWARF (American Waterworks Association Research Foundation). 1999. *Residential End Uses of Water*. Denver, CO: AWWARF.

Barraud, S., Azzout, Y., Cres, F.N., Chocat B. 1999. “Selection Aid of Alternative Techniques in Urban Storm Drainage — Proposition of an Expert System.” *Water Science and Technology* 39, (4): 241-248. https://www.sciencedirect.com/science/article/pii/S0273122399000694.

Ben-Horin, Edith. 2007. *Rainwater as a Resource: A Report on Three Sites Demonstrating Sustainable Stormwater Management*. Los Angeles, CA: Tree People. http://www.invisiblestructures.com/wp-content/uploads/2016/04/Rainwater_as_a_Resource.pdf.

Bornstein, C., D. Fross, and B. O’Brien. 2005. *California Native Plants for the Garden*. Los Olivos, CA: Cachuma Press.

Boving, T.B., Stolt, M.H., Augenstern, J., Brosnan, B. 2006. “Porous Pavement and Water Quality: Investigation of a Parking Lot and Its Potential Impact on Subsurface Water.” Washington, DC: The National Academies of Sciences, Engineering, and Medicine. https://trid.trb.org/view/793302.

Brady, N.C. and Weil, R.R. 2008. *The Nature and Properties of Soil*, 14 ed. Upper Saddle River, NJ: Prentice-Hall.

Cahill, T. 1993. *Porous Pavement with Underground Recharge Beds, Engineering Design Manual*. West Chester Pennsylvania: Cahill Associates.

———. 1994. “A Second Look at Porous Pavement/Underground Recharge.” *Watershed Protection Techniques* 1:76-78.

Cahill, T., M. Adams, and C. Marm. 2003. *Porous Asphalt: The Right Choice for Porous Pavements*. Hot Mix Asphalt Technology.

Calflora. n.d. “Information on Wild California Plants.” http://www.calflora.org/

California Department of Conservation. 2018. “California Geological Survey.” https://www.conservation.ca.gov/cgs

———. 2018. “The California Geotour: An Index to Online Geologic Field Trip Guides of California.” https://www.conservation.ca.gov/cgs/california-geotour.

California Department of Water Resources. 2009. *California Water Plan Update 2009 Integrated Water Management.* https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Water-Plan-Updates/Files/Update-2009/Water-Plan-Update-2009-Volume-1.pdf.

———. 2019. “Water Use & Efficiency.” https://water.ca.gov/Programs/Water-Use-And-Efficiency/.

California Master Gardeners. 2019. “Advice to Grow By ... Ask Us!” http://camastergardeners.ucdavis.edu.

California RWQCB (Regional Water Quality Control Board) Los Angeles Region. 2015. Order No. R4-2012-0175 as Amended by State Water Board Order WQ 2015-0075 and Los Angeles Water Board Order R4-2012-0175-A01 NPDES Permit No. CAS004001.

———. 2019a. Region 4 – Los Angeles. http://www.waterboards.ca.gov/losangeles/

———. 2019b. Region 7 – Colorado. http://www.waterboards.ca.gov/coloradoriver/

———. 2019c. Region 8 – Santa Ana. http://www.waterboards.ca.gov/santaana/

———. 2019d. Region 9 – San Diego. http://www.waterboards.ca.gov/sandiego/

California Water & Land Use Partnership. 2012. “How Urbanization Affects the Water Cycle.” https://www.coastal.ca.gov/nps/watercyclefacts.pdf.

CalRecycle (California Department of Resources Recycling and Recovery). 2019. “Establishing a Water Efficient Landscape.” https://www.calrecycle.ca.gov/organics/xeriscaping.

Caltrans (California Department of Transportation). 2004. *BMP Retrofit Pilot Program – Final Report*. Report ID: CTSW – RT – 01 – 050. http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/_pdfs/new_technology/CTSW-RT-01-050.pdf.

———. 2008. *Caltrans Treatment BMP Technology Report*. CTSW-RT-08-167.02.02. http://www.dot.ca.gov/hq/env/stormwater/annual_report/2008/annual_report_06-07/attachments/Treatment_BMP_Technology_Rprt.pdf.

———. 2018a. Contract Cost Data. Accessed March 26, 2019. http://sv08data.dot.ca.gov/contractcost/results.php?item=permeable+pavement&ob=2&DISTRICT%5B%5D=07&DISTRICT%5B%5D=08&DISTRICT%5B%5D=11&DISTRICT%5B%5D=12&Year%5B%5D=y2019&Year%5B%5D=y2018&Year%5B%5D=y2017&min=&max=&minU=&maxU=&unit=none&start=Search.

———. 2018b. *Corrosion Guidelines*. http://www.dot.ca.gov/des/QualitySystem/documents/mets/osm/cg/CG_MANUAL.pdf.

CASQA (California Stormwater Quality Association). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment.* https://www.casqa.org/sites/default/files/BMPHandbooks/BMP_NewDevRedev_Complete.pdf.

———. 2017. CASQA/LIDI Bioretention Standard Designs and Specifications. https://www.casqa.org/resources/california-lid-portal/standard-lid-design-plans-specifications.

CDFW (California Department of Fish and Wildlife). 2018. *California Wildlife Habitat Relationships System*. https://www.wildlife.ca.gov/Data/CWHR/Wildlife-Habitats.

Center for Fire Research. 2019. “Berkeley Forests.” Accessed March 12, 2019. http://firecenter.berkeley.edu.

City of Portland. 2001. Office of Planning & Development Review. *Rainwater Harvesting – ICC – RES/34/#1 & UPC/6/#2: One & Two Family Dwelling Specialty Code: 2000 Edition; Plumbing Specialty Code: 2000 Edition*, March 13, 2001.

———. 2006. *2006 Stormwater Management Facility Monitoring Report Summary*. https://www.portlandoregon.gov/bes/article/148928.

City of Sacramento. 2014. *Comprehensive Protocol for Performance Evaluation of Proprietary Stormwater Control Products.* http://www.beriverfriendly.net/docs/files/File/NewDev/PropDevices-%20Protocol_revised-Mar2014.pdf.

City of Santa Barbara. 2008. *Stormwater Best Management Practices (BMP) Guidance Manual*. http://services.santabarbaraca.gov/CAP/MG110498/AS110499/AS110501/AI114484/DO114485/3.PDF.

Clary, J., J.E. Jones, B.R. Urbonas, and M. Quigley, 2008. "Can stormwater BMPs remove bacteria? New findings from the International BMP Database." *Stormwater*, May 2008. https://www.researchgate.net/publication/228871815_Can_Stormwater_BMPs_Remove_Bacteria_New_Findings_from_the_International_Stormwater_BMP_Database.

County of Los Angeles. 2009. Department of Public Works. *Stormwater Best Management Practice Design and Maintenance Manual*. http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf.

———. 2014. Department of Public Works. *Low Impact Development Standard Manual*. https://dpw.lacounty.gov/ldd/lib/fp/Hydrology/Low%20Impact%20Development%20Standards%20Manual.pdf.

Data Basin. 2019. USDA Ecoregion Sections, California. Accessed March 29. https://databasin.org/datasets/81a3a809a2ae4c099f2e495c0b2ecc91.

Davis, A. P. and R. H. McCuen. 2005. *Stormwater management for smart growth.* New York: Springer Science+Business Media.

Davis, Allen P., 2007. "Field performance of bioretention: water quality." *Environmental Engineering Science* 24(8):1048-1063.

Deutsch, B., H. Whitlow, M. Sullivan, and A. Savineau. 2005. *Re-Greening Washington, DC: A Green Roof Vision Based on Quantifying Stormwater and Air Quality Benefits*. Casey Trees Endowment Fund and Limno-Tech, Inc., Washington, DC.

Dierkes, Carsten. 1998. "Decontaminating Effects of Soil-Passages for the Infiltration of Highway Runoff." Essen, Germany: University of Essen. https://hydrocon.com.au/wp-content/uploads/2013/05/dierkes-12ejw-prefailles.pdf.

Dierkes, C., and Geiger, W.F. 1999. "Pollution retention capabilities of roadside soils." *Water Science and Technology* 39 (2): 201-208. https://www.sciencedirect.com/science/article/pii/S0273122399000244.

Downtown Center Business Improvement District. 2019. "Grand Hope Park @ FIDM." Accessed March 13. https://www.downtownla.com/explore/getting-around/find-a-business/businesses/grand-hope-park-fidm.

EMWD (Eastern Municipal Water District). 2005. *2005 Urban Water Management Plan*. https://water.ca.gov/LegacyFiles/urbanwatermanagement/2005uwmps/Eastern%20MWD/UWMPFinal.pdf.

Ferguson, B. 2005. *Porous Pavements*. Boca Raton, Florida: CRC Press.

FISRWG (Federal Interagency Stream Restoration Working Group). 1998. *Stream Corridor Restoration: Principles, Processes, and Practices.* GPO Item No. 0120-A; SuDocs No. A 57.6/2: EN 3/PT.653. ISBN-0-934213-59-3.

Florida Concrete and Products Association. N.d. *Construction of a Portland Cement Pervious Pavement*. Orlando, Florida: Florida Concrete and Products Association.

Förster, J. 1999. "Variability of Roof Runoff Quality," *Water Science and Technology* 39(5):137-144.

Geosyntec. 2008. *Analysis of Treatment System Performance, International Stormwater Best Management Practices (BMP) Database, 1999-2008.* http://www.bmpdatabase.org/Docs/Performance%20Summary%20June%202008.pdf.

Grant, G., L. Engleback, and B. Nicholson. 2003. *Green Roofs: Their Existing Status and Potential for Conserving Biodiversity in Urban Areas, Report Number 498*. English Nature Research Reports.

Green, D. 2007. *Managing Water: Avoiding Crisis in California*. Berkeley, CA: University of California Press.

Gregory, J., M. Dukes, P. Jones, and G. Miller. 2006. "Effects of urban soil compaction on infiltration rate." *Journal of Soil and Water Conservation* 61:117-124.

Hinman, C. 2005. *Low Impact Development – Technical Guidance Manual for Puget Sound*. Puget Sound Action Team. http://www.psp.wa.gov/downloads/LID/LID_manual2005.pdf.

———. 2007. *Maintenance of Low Impact Development Facilities*. Puget Sound Action Team.

Hong, E., E.A. Seagren, and A.P. Davis. 2006. "Sustainable oil and grease removal from synthetic stormwater runoff using bench-scale bioretention systems." *Water Environment Research*, 78(2):141-155.

Hossain, M., L.A. Scofield, and W. R. Meier, Jr. 1992. "Porous Pavement for Control of Highway Runoff in Arizona: Performance to Date." *Transportation Research Record* 1354:45-54.

Hsieh, C.-h., and A.P. Davis. 2005. "Evaluation and Optimization of Bioretention Media for Treatment of Urban Stormwater Runoff." *Journal of Environmental Engineering*, 131(11), 1521-1532.

Hsieh, C.-h., A.P. Davis, and B.A. Needleman. 2007. "Nitrogen Removal from Urban Stormwater Runoff Through Layered Bioretention Columns." *Water Environment Research*, 79(12), 2404-2411.

Hunt, W.F., A.R. Jarrett, J.T. Smith, and L.J. Sharkey. 2006. "Evaluating Bioretention Hydrology and Nutrient Removal at Three Field Sites in North Carolina." *Journal of Irrigation and Drainage Engineering*, 132(6): 600-608.

Hunt, W.F., J.T. Smith, S.J. Jadlocki, J.M. Hathaway, and P.R. Eubanks. 2008. “Pollutant removal and peak flow mitigation by a bioretention cell in urban Charlotte, N.C.” *Journal of Environmental Engineering*, 134(5):403-408.

Hutchinson, D., P. Abrams, R. Retzlaff, and T. Liptan. 2003. *Stormwater Monitoring Two Ecoroofs in Portland, Oregon, USA*. City of Portland Bureau of Environmental Services. http://www.portlandonline.com/shared/cfm/image.cfm?id=63098.

ICPI (Interlocking Concrete Pavement Institute). 2019. “Interlocking Concrete Pavement Institute.” http://www.icpi.org/.

Inland Empire Regional Composting Authority. n.d. *General Landscaping Information*. http://www.ierca.org/docs/GeneralLandscape.pdf.

Inland Empire Utilities Agency. 2019. “Inland Empire Utilities Agency Municipal Water District.” http://www.ieua.org.

Jackson, N. 2003. *Porous Asphalt Pavements*. Information Series 131, Lanham, Maryland: National Asphalt Pavement Association.

Jones, M.P. and W.F. Hunt. 2008. “The effect of bioretention on runoff temperature in trout sensitive waters.” Paper Number: 084072. Presented at: 2008 ASABE Annual International Meeting, June 29–July 2, 2008, Providence, Rhode Island.

Kandhal, P. S. 2002. *Design, Construction, and Maintenance of Open-Graded Asphalt Friction Courses.* Information Series 115, Lanham, Maryland: National Asphalt Pavement Association.

Kandhal, P. S., and R. B. Mallick. 1998. *Open-Graded Asphalt Friction Course: State of the Practice*. Report No. 98-7, Auburn, Alabama: Auburn University National Center for Asphalt Technology.

———. 1999. *Design of New-Generation Open-Graded Friction Courses*. Report No. 99-2, Auburn, Alabama: Auburn University National Center for Asphalt Technology.

Kuichling, E. 1889. “The Relation Between Rainfall and the Discharge of Sewers in Populous Districts.” *Transactions ASCE* 20(402):1-60.

Las Pilitas Nursery. 2018. *Habitats of California*. http://www.laspilitas.com/comhabit/habitat.htm

Legret, M. and Colandini, V. 1999. “Effects of a Porous Pavement with Reservoir Structure on Runoff Water: Water Quality and Fate of Heavy Metals.” *Water Science and Technology* 39 (2) 111-117.

Legret, M., Micollet, M., Miloda, P., Colandini, V., and Raimbault, G. 1999. “Simulation of heavy metal pollution from stormwater infiltration through a porous pavement with reservoir structure.” *Water Science and Technology* 39 (2) 1999: 119-125.

Lenz, L., and J. Dourley. 1981. *California Native Trees & Shrubs: For Garden & Environmental Use in Southern California and Adjacent Areas.* Claremont, CA: Rancho Santa Ana Botanic Garden.

Lindsey, G., L. Roberts, and W. Page. 1992. “Inspection and Maintenance of Infiltration Facilities.” *Journal of Soil and Water Conservation*, 47(6): 481-486.

Liptan, T. and E. Strecker. 2003. *Ecoroofs (Green Roofs) – A More Sustainable Infrastructure*. Proceedings from the National Conference on Urban Stormwater: Enhancing Programs at the Local Level, Chicago, IL, February 17-20, 2003.

Low Impact Development Center. 2007a. *Stormwater Urban Design Tools*. http://www.lid-stormwater.net.

———. 2007b. *Soil Amendments*. http://www.lid-stormwater.net/soilamend_home.htm.

Mallick, R. B., P. S. Kandhal, L. A. Cooley Jr., and D. E. Watson. 2000. *Design, Construction and Performance of New-Generation Open-Graded Friction Courses*. Report No. 2000-01. Auburn, Alabama: Auburn University National Center for Asphalt Technology.

McCuen, Richard H. 1998. *Hydrologic Analysis and Design*, 2nd edition. Upper Saddle River: Prentice Hall.

Michael Baker International. 2019a. "Parking Lot Bioswale in San Diego County." Electronic JPG file.

Michael Baker International. 2019b. "Curb Cut Directing Water from a Parking Lot into a Bioswale." Electronic JPG file.

Michael Baker International. 2019c. "Inlet Structure, County of San Diego, CA." Electronic JPG file.

Michael Baker International. 2019d. "Settling Basin with Weir to Filter Underdrain Flow from a Pervious Asphalt Parking Lot in San Diego County." Electronic JPG file.

Mikkelsen, P.S. 1997. "Design of stormwater infiltration trenches based on uncertain information." New York, NY: American Society of Civil Engineers.

Minnesota Pollution Control Agency. 2006. *Minnesota Stormwater Manual*. http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html.

Munz, P. A. 2004. *Introduction to California Desert Wildflowers*. Berkeley: University of California Press.

National Ready Mixed Concrete Association. 2019. "National Ready Mized Concrete Assoication Home Page." https://www.nrmca.org/.

Natural Resources Defense Council. 2006. *Building Green – CaseStudy, NRDC's Santa Monica Office*. http://www.nrdc.org/buildinggreen/casestudies/nrdcsm.pdf.

NCHRP (National Cooperative Highway Research Program). 2014. Long-Term Performance and Life-Cycle Costs of Stormwater Best Management Practices Report 792. Transportation Research Board of the National Academies.

Newman, A.P., Pratt, C.J., Coupe, S.J., Cresswell, N. 2002. "Oil bio-degradation in permeable pavements by microbial communities." *Water Science Technology* 45 (7): 51-56.

NRCS (Natural Resources Conservation Service). 1986. *Urban Hydrology for Small Watersheds*. Washington, DC: USDA.

———. 2017. Web Soil Survey Website. http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm.

OCWD (Orange County Water District). 2015. *Groundwater Management Plan 2015 Update*.

https://www.ocwd.com/media/3503/groundwatermanagementplan2015update_20150624.pdf.

Orange County Public Works. 2013. Technical Guidance Document (TGD) For the Preparation of Conceptual/Preliminary and/or Project Water Quality Management Plans (WQMPs). http://www.ocpublicworks.com/civicax/filebank/blobdload.aspx?blobid=38765.

Orange County Watersheds. 2019. "OC Watershed". http://www.ocwatersheds.com/

Pacific Institute. 2003. *Waste Not, Want Not: The Potential for Urban Water Conservation in California*. http://www.pacinst.org/reports/urban_usage/waste_not_want_not_full_report.pdf.

Pagotto, C., Legret, M., and Le Cloirec, P. 2000. "Comparison of the hydraulic behaviour and the quality of highway runoff water according to the type of pavement." *Water Research Volume* (34) 18: 4446-4454.

Paine, J. E. 1990. *Stormwater Design Guide, Portland Cement Pervious Pavement*. Orlando: Florida Concrete and Products Association.

Pennsylvania Department of Environmental Protection. 2006. *Pennsylvania Stormwater Best Management Practices Manual.* http://www.depgreenport.state.pa.us/elibrary/GetFolder?FolderID=4673

Pitt, Robert, Clark, Shirley, and Parmer, Keith. *Potential Groundwater Contamination from Intentional and Nonintentional Stormwater Infiltration*. Cincinnati, Ohio: Risk Reduction Engineering Laboratory Office Of Research and Development. https://books.google.com/books?hl=en&lr=lang_en&id=klzoGxF9GvUC&oi=fnd&pg=PP2&dq=Pitt+stormwater&ots=mdzghR6WZr&sig=OZ_UQocp1w5b8-81o1vWbfacTrc#v=onepage&q=Pitt%20stormwater&f=false.

Pratt, C.J., Newman, A.P., and Bond, P.C. 1999. "Mineral oil bio-degradation within a permeable pavement: Long term observations." *Water Science and Technology* (39) 2: 103-109. https://www.sciencedirect.com/science/article/pii/S027312239900013X.

RCFC & WCD (Riverside County Flood Control and Water Conservation District). 2006. *Riverside County Stormwater Quality Best Management Practice Design Handbook*. Riverside, CA. http://rcflood.org/downloads/NPDES/Documents/SA_WQMP/SA_BMP_Design_Handbook_July_2006.pdf.

Riverside County. 2010. Riverside County BMP Design Handbook: Draft 2010 updates.

———. 2011. Riverside County – Low Impact Development BMP Design Handbook – Appendix A – Infiltration Testing. http://rcflood.org/downloads/NPDES/Documents/LIDManual/Appendix%20A_Infiltration_Testing.pdf.

Roseen, RM., Briggs, J., Ballestero, TP., Pochily, J. 2009. *UNHSC Design Specifications for Porous Asphalt Pavement and Infiltration Beds*. Durham, NH: University of New Hampshire Stormwater Center. https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/pubs_specs_info/unhsc_pa_spec_10_09.pdf.

Sabin, L.D., J.H. Lim, K.D. Stolzenbach, and K.C. Schiff. 2005. "Contribution of trace metals from atmospheric deposition to stormwater runoff in a small impervious urban catchment." *Water Research* 39(16):3929-37.

San Diego County. 2014. *Low Impact Development Handbook.* https://www.sandiegocounty.gov/content/dam/sdc/pds/docs/LID_Handbook_2014.pdf.

———. 2016. County of San Diego BMP Design Manual for Permanent Site Design, Storm Water Treatment and Hydromodification Management.

Sawyer, J. O. and T. Keeler-Wolf. 2005. *A Manual of California Vegetation*. California Native Plant Society. http://davisherb.ucdavis.edu/cnpsActiveServer/intro.html.

SCCWRP (Southern California Coastal Water Research Project). 2007. "Watershed and Land Use Storm Water Pollutant Loading Data for the Greater Los Angeles Area." Greater Los Angeles Area, CA: Southern California Coastal Water Research Project. http://archive.sccwrp.org/Data/SearchAndMapData/DataCatalog/2007StormWaterLoading.aspx.

Smith, D. R. 2001. *Permeable Interlocking Concrete Pavements: Selection, Design Construction, Maintenance,* 2nd ed., pp 1-29. ICPI Interlocking Concrete Pavement Institute.

State of California Conservation Easements Registry. 2007. Conservation Easements Registry. http://easements.resources.ca.gov/.

Sustainable Landscapes Program Partners. 2018. San Diego Sustainable Landscapes Guidelines: A Watershed Approach to Landscaping. https://sustainablelandscapessd.org/wp-content/uploads/SLP-Guidelines-Book-updated-January-2018.pdf.

Swisher, David. 2002. "Chemical and Hydraulic Performance of a Porous Pavement Parking Lot with Infiltration to Ground Water." State College, PA: Pennsylvania State University. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.366.558&rep=rep1&type=pdf.

SWRCB (State Water Resources Control Board). 2014. *Trends in Chemical Contamination, Toxicity and Land Use in California Watersheds: Stream Pollution Trends (SPoT) Monitoring Program Third Report - Five-Year Trends 2008-2012*. https://www.waterboards.ca.gov/water_issues/programs/swamp/docs/workplans/spot_%20fourteen_rpt.pdf.

Tappeiner, W. J. 1993. *Open-Graded Asphalt Friction Course.* Information Series 115. Lanham, Maryland: National Asphalt Pavement Association.

TARP (Technology Acceptance and Reciprocity Partnership). 2003. *The Technology Acceptance Reciprocity Partnership Protocol for Stormwater Best Management Practice Demonstrations.* https://www.mass.gov/files/documents/2016/08/rd/swprotoc.pdf.

Teemusk, A. and Mander, U. 2007. "Rainwater runoff quantity and quality performance from a greenroof: The effects of short-term events." *Ecological Engineering* 30: 271-277.

Tennis, P. D., M. L. Leming, and D. J. Akers. 2004. *Pervious Concrete Pavements*. Portland Cement Association, Skokie, IL, and National Ready Mixed Concrete Association, Silver Spring, MD.

Texas Rainwater Harvesting Evaluation Committee. 2006. *Rainwater Harvesting Potential and Guidelines for Texas, Report to the 80th Legislature*, Texas Water Development Board, Austin, TX, November 2006.

Thelen, E. and L. F. Howe. 1978. *Porous Pavement*. Philadelphia: Franklin Institute Press.

Tullock, R. J., Coleman, N. T., and Pratt, P. F. 1975. “Rate of Chloride and Water Movement in Southern California Soils.” *Journal of Environmental Quality* 4: 127-131.

UCCE/CDWR (University of California Cooperative Extension and California Department of Water Resources). 2000. *A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California*. Sacramento, CA: California Department of Water Resources. http://www.water.ca.gov/wateruseefficiency/docs/wucols00.pdf.

University of California, Davis. 2005. *California Watershed Assessment Manual*. http://www.cwam.ucdavis.edu/

USDA (US Department of Agriculture). 1986. *Urban Hydrology for Small Watersheds, Technical Release 55*. Washington, DC: USDA Soil Conservation Service.

———. 1997. *Ecological Subregions of California: Section and Subsection Descriptions.* Washington, DC: USDA Forest Service, Natural Resources Conservation Service, and Bureau of Land Management. https://www.fs.usda.gov/treesearch/pubs/48672.

USEPA (U.S. Environmental Protection Agency). 1993. Office of Water. *Xeriscape Landscaping: Preventing Pollution and Using Resources Efficiently* (EPA-840-B-93-001). USEPA: Washington, DC. http://www.epa.gov/nscep/.

———. 2008. *Design Principles for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas*. https://archive.epa.gov/greenbuilding/web/pdf/swdp0408.pdf.

———. 2016. *Stormwater Guidelines for Green, Dense Redevelopment*. Accessed January 23, 2019. https://www.epa.gov/smartgrowth/stormwater-guidelines-green-dense-redevelopment.

———. 2017. National Water Quality Inventory: Report to Congress. EPA 841-R-16-011. https://www.epa.gov/sites/production/files/2017-12/documents/305brtc_finalowow_08302017.pdf.

———. 2018. “Wetlands Protection and Restoration.” http://www.epa.gov/owow/wetlands/pdf/constructed.pdf.

U.S. Green Building Council. 2019. “Introduction to LEED v4.1 for Design and Construction”. Accessed January 22, 2019. https://www.usgbc.org/education/sessions/introduction-leed-v41-design-and-construction-12082659.

———. 2016. Landslide Types and Processes. http://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html.

———. 2019. “The Water Cycle (Natural Water Cycle).” https://www.usgs.gov/media/images/water-cycle-natural-water-cycle.

———. 2019. National Geologic Map Database. http://ngmdb.usgs.gov/.

———. n.d.a. Landslide Hazards Program. https://www.usgs.gov/natural-hazards/landslide-hazards.

———. n.d.b. “Resources for Teachers.” http://education.usgs.gov/california/resources.html.

Vingarzan, R. and B. Taylor. 2003. *Trend Analysis of Ground Level Ozone in the Greater Vancouver / Fraser Valley Area of British Columbia*. Environment Canada – Aquatic and Atmospheric Sciences Division.

Washington State Department of Ecology. 2008. “Emerging stormwater treatment technologies (TAPE).” https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Emerging-stormwater-treatment-technologies.

WERF (Water Environment Research Foundation). 2006. *Decentralized Stormwater Controls for Urban Runoff and Combined Sewer Overflow Reduction.* Report Number: 03SW3. Alexandria, VA: Water Environment Research Foundation. https://www.werf.org/a/ka/Search/ResearchProfile.aspx?ReportID=03-SW-3

———. 2009. *User’s Guide to the BMP and LID Whole Life Cost Models, Version 2.0*. Report Number: SW2R08. Alexandria, VA: Water Environment Research Foundation. https://www.werf.org/a/ka/Search/ResearchProfile.aspx?ReportId=SW2R08.

———. 2017. International Stormwater BMP 2016 Summary Statistics. http://www.bmpdatabase.org/Docs/03-SW-1COh%20BMP%20Database%202016%20Summary%20Stats.pdf.

Western Riverside County Regional Conservation Authority. 2003. *Multiple Species Habitat Conservation Plan*. http://www.wrc-rca.org/about-rca/multiple-species-habitat-conservation-plan/.

Appendix A: LID Nomenclature and Requirements Comparison

Starting with the San Diego MS4 Permit (Order No. R9-2007-0001), adopted on January 24, 2007, municipal permits within Southern California have contained specific LID and hydromodification requirements. Prior to this adoption, most of the MS4 Permits in Southern California contained requirements for new and redevelopment that were effectively essential components of LID. LID requirements in new MS4 permits apply to specified categories of new development and redevelopment projects. The Permittees were tasked with the responsibility of developing design and maintenance criteria and establishing minimum standards for the use of LID practices. They were also required to develop manuals or technical guidance for municipal employees and private sector practitioners involved with the implementation of LID practices. Table 32 below identifies language from the Southern California MS4 Permits related to LID requirements and the nomenclature used in permit language.

Table A-1. BMP-related nomenclature used in California municipal permits found in the definitions or glossary section of the permit.

Regional Board	Date of Permit	Nomenclature	Definition/Description
Central Coast[1]	May 3, 2012	Biofiltration	"Any structural or non-structural method, technique, or process that relies on biological and biochemical processes in soil media and vegetation to remove pollutants and/or solids from polluted stormwater runoff" (page B-1).
Los Angeles – Los Angeles County[2]	Sept 8, 2016	Biofiltration	"A LID BMP that reduces storm water pollutant discharges by intercepting rainfall on vegetative canopy, and through incidental infiltration and/or evapotranspiration, and filtration. As described in the Ventura County Technical Guidance Manual, studies have demonstrated that biofiltration of 1.5 times the storm water quality design volume (SWQDv) provides approximately equivalent or greater reductions in pollutant loading when compared to bioretention or infiltration of the SWQDv. Incidental infiltration is an important factor in achieving the required pollutant load reduction. Therefore, the term "biofiltration" as used in this Order is defined to include only systems designed to facilitate incidental infiltration or achieve the equivalent pollutant reduction as biofiltration BMPs with an underdrain (subject to Executive Officer approval). Biofiltration BMPs include bioretention systems with an underdrain and bioswales" (Page A-3).
San Diego[3]	Nov 18, 2015	Biofiltration	"Practices that use vegetation and amended soils to detain and treat runoff from impervious areas. Treatment is through filtration, infiltration, adsorption, ion exchange, and biological uptake of pollutants" (Page C-2).
San Francisco[4]	Nov 19, 2015	Green Infrastructure	"Infrastructure that uses vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a city or county, green infrastructure refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, green infrastructure refers to stormwater management systems that mimic nature by soaking up and storing water" (page 147).

Regional Board	Date of Permit	Nomenclature	Definition/Description
Central Coast[1]	May 3, 2012	Green Infrastructure	"Any of a variety of technologies or practices that use natural systems (such as vegetation or infiltration) or engineered systems (such as bioswales or rain gardens) which mimic natural systems, to manage stormwater" (page B-3).
Santa Ana – San Bernadino[5]	Jan 29, 2010	Green Infrastructure	"Generally refers to technologically feasible and cost-effective systems and practices that use or mimic natural processes to infiltrate, evapotranspire, or use stormwater or runoff on the site where it is generated. Green infrastructure is used interchangeably with low impact development (LID). See LID." (page 111).
Santa Ana – Riverside[7]	Jan 29, 2010	Green Infrastructure	"Generally refers to technologically feasible and cost-effective systems and practices that use or mimic natural processes to infiltrate, evapotranspire, or reuse stormwater or runoff on the site where it is generated. This is a concept that highlights the importance of the natural environment in decisions about land use planning. In particular there is an emphasis on the "life support" functions provided by a network of natural ecosystems, with an emphasis on connectivity to support long term sustainability. (Also see Low Impact Development.)" (Appendix 4, page 4)
Los Angeles – Los Angeles County[2]	Sept 8, 2016	Bioretention	"A LID BMP that reduces storm water runoff by intercepting rainfall on vegetative canopy, and through evapotranspiration and infiltration. The bioretention system typically includes a minimum 2-foot top layer of a specified soil and compost mixture underlain by a gravel-filled temporary storage pit dug into the in-situ soil. As defined in this Order, a bioretention BMP may be designed with an overflow drain but may not include an underdrain. When a bioretention BMP is designed or constructed with an underdrain it is regulated in this Order as biofiltration" (page A-3).
Los Angeles – Los Angeles County[2]	Sept 8, 2016	Bioswale	"A LID BMP consisting of a shallow channel lined with grass or other dense, low-growing vegetation. Bioswales are designed to collect storm water runoff and to achieve a uniform sheet flow through the dense vegetation for a period of several minutes" (page A-3).
Los Angeles – Los Angeles County[2]	Sept 8, 2016	Flow-through treatment BMPs	"Flow-through treatment BMPs include modular, vault type "high flow biotreatment" devices contained within an impervious vault with an underdrain or designed with an impervious liner and an underdrain" (page A-8).
Los Angeles – Los Angeles County[2]	Sept 8, 2016	Infiltration BMP	"A LID BMP that reduces storm water runoff by capturing and infiltrating the runoff into in-situ soils or amended on-site soils. Examples of infiltration BMPs include infiltration basins, dry wells, and pervious pavement" (page A-9).
San Francisco[4]	Nov 19, 2015	Infiltration Device	"Any structure that is deeper than wide and designed to infiltrate stormwater into the subsurface, and, as designed, bypass the natural groundwater protection afforded by surface soil. These devices include dry wells, injection wells, and infiltration trenches (includes French drains)" (page 148).
State-wide Phase II[18]	Feb 5, 2013	Pervious Pavement	"Pavement that stores and infiltrates rainfall at a rate that exceeds conventional pavement." (Attachment I, page 11).

Regional Board	Date of Permit	Nomenclature	Definition/Description
Central Coast[1]	May 3, 2012	Priority Development Project	"Any new development or redevelopment project meeting the applicability criteria pursuant to Section J.4 (Parcel-Scale Development: Requirements for Priority Development Projects) of this Order. The April 2010 version of the SWDS refers to these projects as Priority Projects" (page B-5).
Colorado River Basin[10]	Jun 20, 2013	Priority Development Projects	"Discretionary New Development and Redevelopment Projects that fall into any of the categories listed in Section F.1.c.iii of this MS4 Permit" (page 77).
Los Angeles – Los Angeles County[2]	Sept 8, 2016	Planning Priority Projects	"Those projects that are required to incorporate appropriate storm water mitigation measures into the design plan for their respective project. (see permit for full definition)" (page A-14).
San Francisco[4]	Nov 19, 2015	Regulated Projects	"Development projects as defined in Provision C.3.b.ii" (page 150).
San Diego[3]	Nov 18, 2015	Priority Development Projects	"New development and redevelopment projects defined under Provision E.3.b of Order No. R9-2013-0001, as amended by Order Nos. R9-2015-0001 and R9-2015-0100" (page C-9).
Los Angeles – Long Beach[15]	Sept 8, 2016	New Development Projects	"New Development projects subject to conditioning and approval by the City of Long Beach for the design and implementation of post-construction controls to mitigate storm water pollution, prior to completion of the project(s)" (page 61).
Santa Ana – San Bernardino[5]	Jan 29, 2010	WQMP	Water Quality Management Plan
Los Angeles – Los Angeles County[2]	Sept 8, 2016	SUSMP	Standard Urban Stormwater Mitigation Plan
San Francisco[21]	Nov 19, 2015	SCP	Stormwater Control Plan
San Diego[12]	Nov 18, 2015	SWQMP	Storm Water Quality Management Plans
Central Coast[1]	May 3, 2012	SWCP	Stormwater Control Plan
Colorado River Basin[10]	Jun 20, 2013	WQMP	Water Quality Management Plan

Table A-2. California regional BMP media terminology and requirements

Region	Document	Terminology Used	Soil Media Requirements
San Francisco	San Francisco Bay Region MS4 Permit (Appendix L) [8]	Biotreatment soil media	"Soils for biotreatment or bioretention areas shall meet two objectives: 1) Be sufficiently permeable to infiltrate runoff at a minimum rate of 5" per hour during the life of the facility, and 2) have sufficient moisture retention to support healthy vegetation." (Page L-1)

Region	Document	Terminology Used	Soil Media Requirements
Santa Ana – San Bernardino	Model WQMP [9], Technical Guidance Document [11]	BMP Performance Criteria	"LID BMPs must be designed to: • Retain, on-site, (infiltrate, harvest and use, or evapotranspire) stormwater runoff as feasible up to the Design Capture Volume, and • Recover (i.e., draw down) the storage volume as soon as possible after a storm event (see criteria for maximizing drawdown rate in the TGD Appendix XI), and, if necessary • Biotreat, on-site, additional runoff, as feasible, up to 80 percent average annual capture efficiency cumulative, retention plus biotreatment) • NOC Permit Area only – retain or biotreat, in a regional facility, the remaining runoff up to 80 percent average annual capture efficiency • (cumulative, retention plus biotreatment, on-site plus off-site), and, if necessary • Fulfill alternative compliance obligations for runoff volume not retained or biotreated up to 80 percent average annual capture efficiency using treatment • controls or other alternative approaches as described in Section 7.II-3." (Page 7.II 2-10)
Los Angeles County	Los Angeles Region MS4 Permit – Los Angeles County (Appendix H)[2]	Planting/Storage Media	"The planting media placed in the cell should achieve a long-term, in-place infiltration rate of at least 5 inches per hour. Higher infiltration rates of up to 12 inches per hour are permissible. Bioretention/biofiltration soil shall retain sufficient moisture to support vigorous plant growth. Planting media should consist of 60 to 80% fine sand and 20 to 40% compost. Sand should be free of wood, waste, coating such as clay, stone dust, carbonate, etc. or any other deleterious material. All aggregate passing the No. 200 sieve size should be non-plastic. Sand for bioretention should be analyzed by an accredited lab using #200, #100, #40, #30, #16, #8, #4, and 3/8 sieves." (Page H-3)
Central Coast	Central Coast Region MS4 Permit [1]	Biofiltration Soil Media	"If using a soil layer to cleanse or filter stormwater (e.g., bioretention with underdrain, planter box), the system shall be designed to have a stormwater runoff surface loading rate not exceeding 5 inches/hour and a minimum soil depth of 24 inches. The planting and soil media for biofiltration systems shall be designed to sustain healthy, vigorous plant growth and maximize stormwater runoff retention and pollutant removal. The system shall meet the design specifications for biofiltration systems, as documented in the City of Los Angeles Low Impact Development Handbook, updated versions of the City of Los Angeles Low Impact Development Handbook, or an equivalent source." (Page 64)

Region	Document	Terminology Used	Soil Media Requirements
San Diego	County of San Diego BMP Design Manual (Appendices B and E) [12]	Media	*"Infiltration Basin*: Use the sizing worksheet (Appendix B.4) to determine if full infiltration of the DCV is achievable based on the infiltration storage volume calculated from the surface ponding area and depth for a maximum 36-hour drawdown time. (Appendix E, page E-56). *Bioretention*: A minimum of 3 inches of well-aged, shredded hardwood mulch that has been stockpiled or stored for at least 12 months is provided. Mulch must be non-floating to avoid clogging of overflow structure. Media maintains a minimum filtration rate of 5 in/hr over lifetime of facility. A minimum initial filtration rate of 10 in/hr is recommended. Media is a minimum 18 inches deep, meeting either of these two media specifications: City of San Diego Low Impact Development Design Manual (page B-18) (July 2011, unless superseded by more recent edition) or County of San Diego Low Impact Development Handbook: Appendix G -Bioretention Soil Specification (June 2014, unless superseded by more recent edition)" (Appendix E, pages E-63 – E-64).
Santa Ana – Riverside	Riverside County Design Handbook for LID BMPs [22]	Engineered Soil Media	"While the 18-inch minimum engineered soil media depth can be used in some cases, it is recommended to use 24 inches or a preferred 36 inches to provide an adequate root zone for the chosen plant palate" (page 2).
Santa Ana – Orange County	Orange County Technical Guidance Document BMP Fact Sheets [23]	Soil	"The minimum soil depth is 2 feet (3 feet is preferred) … The bioretention area should be covered with 2-4 inches (average 3 inches) or mulch at the start and an additional placement of 1-2 inches of mulch should be added annually" (page XIV-52).
Los Angeles – Long Beach	Long Beach LID BMP Design Manual [24]	Planting Soil	"Where applicable, biofiltration BMPs shall be constructed with a minimum planting soil depth of 2 feet (3 feet preferred) and topped with 3 inches of mulch" (page 45).
Los Angeles – Ventura	Ventura County Technical Guidance Manual [17]	Filtration Media	*"Bioretention*: 2"-4" mulch, 2' minimum planting mix (3' preferred)." (Page 6-34)
State-wide Phase II	Phase II MS4 Permit [18]	Planting Medium, Subsurface drainage/storage (gravel) layer	"Minimum planting medium depth of 18 inches. The planting medium must sustain a minimum infiltration rate of 5 inches per hour throughout the life of the project and must maximize runoff retention and pollutant removal. A mixture of sand (60%-70%) meeting the specifications of American Society for Testing and Materials (ASTM) C33 and compost (30%-40%) may be used. Subsurface drainage/storage (gravel) layer with an area equal to the surface area and having a minimum depth of 12 inches." (Page 54).

Region	Document	Terminology Used	Soil Media Requirements
State-wide Construction	Construction General Permit [19]	-	*Soil media depth not listed*

Table A-3. California regional Hydromodification requirements

Region	Document	Hydromodification Requirements Summary
Central Coast	Central Coast Regional MS4 Permit [1]	"Using methodology developed through the Central Coast Water Board Joint Effort for Hydromodification Control, the Permittee shall derive and apply post-construction numeric criteria for controlling stormwater runoff… 1. Surface Runoff – Maintain runoff volume, rate, duration, and surface storage at pre-development levels; 2. Groundwater Recharge and Discharge – Maintain infiltration to support baseflow and interflow to wetlands and surface waters, and deep vertical infiltration to groundwater at pre-development levels; 3. Sediment Processes – Maintain hillslope (rilling, gullying, sheetwash, creep, and other mass movements); riparian (bank erosion); and channel (fluvial transport and deposition) processes within natural ranges; 4. Chemical Processes – Maintain chemical attenuation through sequestration, degradation, and rate of chemical delivery to receiving waters at predevelopment levels; and 5. Evapotranspiration – Maintain evapotranspiration volume and rate at predevelopment levels" (Page 62).
San Diego	San Diego Regional MS4 Permit [3]	• "Post-project runoff conditions (flow rates and durations) of Priority Development Projects must not exceed pre-development runoff conditions by more than 10 percent." (Page 98) • "Each Priority Development Project must avoid critical sediment yield areas… implement measures that allow critical coarse sediment to be discharged to receiving waters, such that there is no net impact to the receiving water." (Page 98)
Santa Ana – San Bernardino	Santa Ana Regional MS4 Permit- San Bernardino [5]	"A development/redevelopment project does not cause a HCOC if it causes no adverse downstream impacts on the physical structure, aquatic, and riparian habitat and any of the following conditions is met: and any of the following conditions is met… The post-development site hydrology (including runoff volume, velocity, duration, time of concentration) is not significantly different from predevelopment hydrology for a 2- year return frequency storm. A difference of 5% or less is considered insignificant" (Page 86).

Region	Document	Hydromodification Requirements Summary
San Francisco	San Francisco Regional MS4 Permit [4]	• "Stormwater discharges from HM Projects shall not cause an increase in the erosion potential of the receiving stream over the pre-project (existing) condition. Increases in runoff flow and volume shall be managed so that post- project runoff shall not exceed estimated pre-project rates and durations…" (Page 33). • "For Alameda, Contra Costa, San Mateo, and Santa Clara Permittees, and the City of Vallejo, HM controls shall be designed such that post-project stormwater discharge rates and durations match pre-project discharge rates and durations from 10 percent of the pre-project 2-year peak flow up to the pre-project 10-year peak flow. For Fairfield-Suisun Permittees, HM controls shall be designed such that post-project stormwater discharge rates and durations shall match from 20 percent of the 2-year peak flow up to the pre-project 10-year peak flow." (Page 34). • "Permittees shall use, or shall cause to be used, a continuous simulation hydrologic computer model to simulate pre-project and post-project runoff, or sizing factors or charts developed using such a model, to design onsite or regional HM controls." (Page 34).
Los Angeles County	Los Angeles Region MS4 Permit – Los Angeles County [2]	"Projects disturbing an area greater than 1 acre but less than 50 acres: 1. The runoff flow rate, volume, velocity, and duration for the post-development condition do not exceed the pre-development condition for the 2-year, 24-hour rainfall event. 2. The Erosion Potential (Ep) in the receiving water channel will approximate 1, as determined by a Hydromodification Analysis Study and the equation presented in Attachment J. Alternatively, Permittees can opt to use other work equations to calculate Erosion Potential with Executive Officer approval. (Page 106-107) Projects disturbing 50 acres or more: 1. The runoff flow rate, volume, velocity, and duration for the post-development condition does not exceed the pre-development condition for the 2-year, 24-hour rainfall events. These conditions must be substantiated by hydrologic modeling acceptable to the Regional Water Board Executive Officer, or 2. The Erosion Potential (Ep) in the receiving water channel will approximate 1, as determined by a Hydromodification Analysis Study and the equation presented in Attachment J." (Page 107).
Santa Ana – Riverside	Santa Ana Riverside MS4 Permit [7]	"Order No. WQ-2000-11 required that Urban Runoff generated by 85th percentile storm events from specific types of development categories be infiltrated, filtered or treated." (page 29)

Region	Document	Hydromodification Requirements Summary
Santa Ana – Orange County	Santa Ana Orange County Regional MS4 Permit[6]	"The project does not have a hydrologic condition of concern if any one of the following conditions is met: a) The volumes and the time of concentration of storm water runoff for the post-development condition do not significantly exceed those of the pre-development condition for a two-year frequency storm event (a difference of 5% or less is considered insignificant). This may be achieved through site design and source control BMPs. b) All downstream conveyance channels that will receive runoff from the project are engineered, hardened and regularly maintained to ensure design flow capacity, and no sensitive stream habitat areas will be affected. c) The site infiltrates at least the runoff from a two-year storm event. The permittees may request for a variance from these criteria, based on studies conducted by the Storm Water Monitoring Coalition, Southern California Coastal Water Research Project, or other regional studies. Requests for consideration of any variances should be submitted to the Executive Officer." (Page 57).
Los Angeles – Long Beach	City of Long Beach MS4 Permit [15]	"Minimize the percentage of impervious surfaces on land developments by minimizing soil compaction during construction, designing projects to minimize the impervious area footprint, and employing Low Impact Development (LID) design principles to mimic predevelopment hydrology through infiltration, evapotranspiration and rainfall harvest and use." (page 61)
Los Angeles – Ventura	Ventura County MS4 Permit [16]	• "Hydromodification control in natural drainage systems shall be achieved by maintaining the Erosion Potential (Ep) in streams at a value of 1, unless an alternative value can be shown to be protective of the natural drainage systems from erosion, incision, and sedimentation that can occur as a result of flow increases from impervious surfaces, and damage stream habitat (see Attachment "E" -Determination of Erosion Potential) • Hydromodification control may include one, of a combination of on-site, regional subregional hydromodification control BMPs, LID strategies, or stream restoration measures, with preference given to LID strategies and hydromodification control BMPs. Any in-stream restoration measure shall not adversely affect the beneficial uses of the natural drainage systems." (Pages 59-60).
State-wide Phase II	Phase II MS4 permit [18]	• "Post-project runoff shall not exceed estimated pre-project flow rate for the 2- year, 24-hour storm in the following geomorphic provinces: Coast Ranges, Klamath Mountains, Cascade Range, Modoc Plateau, Basin and Range, Sierra Nevada, Great Valley. • Post-project runoff shall not exceed estimated pre-project flow rate for the 10- year, 24-hour storm in the following geomorphic provinces: Transverse Ranges, Peninsular Ranges, Mojave Desert, Colorado Desert." (Page 56)

Region	Document	Hydromodification Requirements Summary
State-wide Construction	Construction General Permit [19]	• "The discharger shall, through the use of non-structural and structural measures as described in Appendix 2, replicate the pre-project water balance (for this permit, defined as the volume of rainfall that ends up as runoff) for the smallest storms up to the 85th percentile storm event (or the smallest storm event that generates runoff, whichever is larger)… Volume that cannot be addressed using nonstructural practices shall be captured in structural practices and approved by the Regional Water Board. • For sites whose disturbed area exceeds two acres, the discharger shall preserve the pre-construction drainage density (miles of stream length per square mile of drainage area) for all drainage areas within the area serving a first order stream or larger stream and ensure that post project time of runoff concentration is equal or greater than pre-project time of concentration." (Page 35)

Table A-4. California Regional Site Design Requirements

Region	Document	Site Design Requirements Summary
San Diego[3]	San Diego MS4 Permit	"The following LID BMPs must be implemented at all development projects where applicable and feasible: a) Maintenance or restoration of natural storage reservoirs and drainage corridors (including topographic depressions, areas of permeable soils, natural swales, and ephemeral and intermittent streams); b) Buffer zones for natural water bodies (where buffer zones are technically infeasible, require project applicant to include other buffers such as trees, access restrictions, etc.); c) Conservation of natural areas within the project footprint including existing trees, other vegetation, and soils; d) Construction of streets, sidewalks, or parking lot aisles to the minimum widths necessary, provided public safety is not compromised; e) Minimization of the impervious footprint of the project; f) Minimization of soil compaction to landscaped areas; g) Disconnection of impervious surfaces through distributed pervious areas; h) Landscaped or other pervious areas designed and constructed to effectively receive and infiltrate, retain and/or treat runoff from impervious areas, prior to discharging to the MS4; i) Small collection strategies located at, or as close as possible to, the source (i.e. the point where storm water initially meets the ground) to minimize the transport of runoff and pollutants to the MS4 and receiving waters; j) Use of permeable materials for projects with low traffic areas and appropriate soil conditions; k) Landscaping with native or drought tolerant species; and l) Harvesting and using precipitation." (Page 93-94).

Region	Document	Site Design Requirements Summary
Central Coast	Central Coast Regional MS4 Permit [1]	"At a minimum, to implement LID design principles, the Permittee shall require Priority Development Projects to: i. Conserve natural areas, including existing trees, other vegetation, and soils; ii. Construct streets, driveways, sidewalks, or parking lot aisles to the minimum widths necessary, provided that public safety is not compromised; iii. Minimize the impervious footprint of the project, including: 1) Implementing measures to make development more compact (e.g., site layout 2) characteristics, densities, parking allocation, open space); and 3) Implementing measures to limit directly connected impervious area (e.g., 4) selection of paving materials, use of self-retaining areas). iv. Avoid excess grading and disturbance to soils; v. Concentrate development where soils are least permeable; vi. Minimize soil compaction to landscaped areas; vii. Minimize disturbances to natural drainages (e.g., natural swales, topographic depressions); viii. Disconnect impervious surfaces through distributed pervious areas; and ix. Direct runoff into cisterns or rain barrels for reuse, onto vegetated areas, or through infiltrative surfaces." (Page 60)
Los Angeles – Long Beach	City of Long Beach MS4 Permit [15]	"The City of Long Beach shall require all new development and redevelopment projects, referred to hereinafter as new projects, identified in Part VII.J.2-3 to control pollutants, pollutant loads, and runoff volume emanating from the project site by: (1) minimizing the impervious surface area and (2) controlling runoff from impervious surfaces through infiltration, bioretention and/or rainfall harvest and use." (Page 63).
Los Angeles County	Los Angeles Region MS4 Permit – Los Angeles County [2]	"Projects disturbing an area greater than 1 acre but less than 50 acres: • The project is designed to retain on-site, through infiltration, evapotranspiration, and/or harvest and use, the storm water volume from the runoff of the 95th percentile, 24-hour storm (Page 106-107) Projects disturbing 50 acres or more: • The site infiltrates on-site at least the runoff from a 2-year, 24-hour storm event" (Page 107).

Region	Document	Site Design Requirements Summary
Los Angeles – Ventura	Ventura County MS4 Permit [16]	"The Permittees shall implement a Planning and Land Development Program pursuant to part 4.E. for all New Development and Redevelopment projects subject to this Order to: a) Lessen the water quality impacts of development by using smart growth practices such as compact development, directing development towards existing communities via infill or redevelopment, safeguarding of environmentally sensitive areas, mixing of land uses (e.g., homes, offices, and shops), transit accessibility, and better pedestrian and bicycle amenities. b) Minimize the adverse impacts from storm water runoff on the biological integrity of Natural Drainage Systems and the beneficial uses of waterbodies in accordance with requirements under CEQA (Cal. Pub. Resources Code § 21100). c) Minimize the percentage of effective impervious surfaces on land developments to mimic predevelopment water balance through infiltration, evapotranspiration and reuse. d) Minimize pollutant loadings from impervious surfaces such as roof-tops, parking lots, and roadways through the use of properly designed, technically appropriate BMPs (including Source Control BMPs such as good housekeeping practices), Low Impact Development Strategies and Treatment Control BMPs. e) Properly select, design and maintain Treatment Control BMPs and Hydromodification Control BMPs to address pollutants that are likely to be generated, assure long-term function, and to avoid the breeding of vectors. f) Prioritize the selection of BMPs suites to remove storm water pollutants, reduce storm water runoff volume, and beneficially reuse storm water to support an integrated approach to protecting water quality and managing water resources in the following order of preference: 1) Infiltration BMPs 2) BMPs that store and reuse storm water runoff. 3) BMPs that incorporate vegetation to promote pollutant removal and runoff volume reduction and integrate multiple uses 4) BMPs which percolate runoff through engineered. soil and allow it to discharge downstream slowly 5) Approved modular/ proprietary treatment control BMPs that are based on LID concepts and that meet pollution removal goals" (Pages 53-54).

Region	Document	Site Design Requirements Summary
San Francisco	San Francisco Regional MS4 Permit [4]	"Site Design and Stormwater Treatment Requirements Require each Regulated Project to implement at least the following design strategies onsite: i. Limit disturbance of natural water bodies and drainage systems; minimize compaction of highly permeable soils; protect slopes and channels; and minimize impacts from stormwater and urban runoff on the biological integrity of natural drainage systems and water bodies; ii. Conserve natural areas, including existing trees, other vegetation, and soils; iii. Minimize impervious surfaces; iv. Minimize disturbances to natural drainages; and v. Minimize stormwater runoff by implementing one or more of the following site design measures: • Direct roof runoff into cisterns or rain barrels for reuse. • Direct roof runoff onto vegetated areas. • Direct runoff from sidewalks, walkways, and/or patios onto vegetated areas. • Direct runoff from driveways and/or uncovered parking lots onto vegetated areas. • Construct sidewalks, walkways, and/or patios with pervious pavement systems. • Construct driveways, bike lanes, and/or uncovered parking lots with pervious pavement systems. (Pages 19-20)"
Santa Ana – Orange County[6]	Santa Ana Orange County Regional MS4 Permit[6]	"The permittees shall incorporate LID site design principles to reduce runoff to a level consistent with the maximum extent practicable standard during each phase of priority development projects. The permittees shall require that each priority development project include site design BMPs during development of the preliminary and final WQMPs. The design goal shall be to maintain or replicate the pre-development hydrologic regime through the use of design techniques that create a functionally equivalent post-development hydrologic regime through site preservation techniques and the use of integrated and distributed micro-scale storm water infiltration, retention, detention, evapotranspiration, filtration and treatment systems as close as feasible to the source of runoff." (Page 54).

Table A-5. California Regional LID or Water Quality Requirements

Region	Document	LID or Water Quality Requirements Summary
San Diego[3]	San Diego MS4 Permit	• "Each Priority Development Project must be required to implement LID BMPs that are designed to retain (i.e. intercept, store, infiltrate, evaporate, and evapotranspire) onsite the pollutants contained in the volume of storm water runoff produced from a 24-hour 85th percentile storm event (design capture volume); • If a Copermittee determines that implementing BMPs to retain the full design capture volume onsite for a Priority Development Project is not technically feasible, then the Copermittee may allow the Priority Development Project to utilize biofiltration BMPs. Biofiltration BMPs must be designed to have an appropriate hydraulic loading rate to maximize storm water retention and pollutant removal, as well as to prevent erosion, scour, and channeling within the BMP, and must be sized to: [a] Treat 1.5 times the design capture volume not reliably retained onsite, OR [b] Treat the design capture volume not reliably retained onsite with a flow-thru design that has a total volume, including pore spaces and pre-filter detention volume, sized to hold at least 0.75 times the portion of the design capture volume not reliably retained onsite." (Page 97).
Central Coast	Central Coast Regional MS4 Permit [1]	• "Hydraulic Sizing Criteria for LID Systems – LID systems shall be designed to retain stormwater runoff equal to the volume of runoff generated by the 85th percentile 24-hour storm event, based on local rainfall data." (Page 64)

Region	Document	LID or Water Quality Requirements Summary
Colorado River Basin	Colorado River Basin MS4 Permit [10]	"Treatment Control BMPs shall be collectively sized to comply with the following numeric sizing criteria: a. Volumetric Treatment Control BMP design criteria. i. The 85th percentile 24-hour event determined as the maximized capture Storm Water volume for the project area, from the formula recommended in Urban Runoff Quality Management, Water Environment Federation Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998); or ii. The volume of annual runoff based on unit basin storage water quality volume, to achieve 80% or more volume treatment by the method recommended in California Stormwater Best iii. Management Practices Handbook – Industrial/Commercial (2003); or iv. The volume of runoff produced from a historical-record based reference 24-hour rainfall criterion for "treatment" that achieves approximately the same reduction in Pollutant loads achieved by the 85th percentile 24-hour runoff event; or… b. Flow-Based BMP design criteria i. The maximum flow rate of runoff produced from a rainfall intensity of 0.2 inch of rainfall per hour, for each hour of a storm event; or ii. The maximum flow rate of runoff produced by the 85th percentile hourly rainfall intensity (for iii. each hour of the storm event), as determined from the local historical rainfall record, multiplied iv. by a factor of two; or v. The maximum flow rate of runoff for each hour of a storm event, as determined from the local historical rainfall record that achieves approximately the same reduction in Pollutant loads and flows as achieved by mitigation of the 85th percentile hourly rainfall intensity multiplied by a factor of two." (Page 45-46).
Los Angeles – Long Beach	City of Long Beach MS4 Permit [15]	• "…The City of Long Beach shall require the project to retain on-site the stormwater quality design volume (SWQDv) defined as the runoff from: (a) The 0.75-inch, 24-hour rain event or (b) The 85th percentile, 24-hour rain event, as determined from the Los Angeles County 85th percentile precipitation Isohyetal map, whichever is greater. • Bioretention and biofiltration systems shall meet the design specifications provided in Attachment H to this Order unless otherwise approved by the Regional Water Board Executive Officer. • When evaluating the potential for on-site retention, the City of Long Beach shall consider the maximum potential for evapotranspiration from green roofs and rainfall harvest and use." (Page 63-64).

Region	Document	LID or Water Quality Requirements Summary
County of Los Angeles	Los Angeles Region MS4 Permit – Los Angeles County [2]	• "… Each Permittee shall require the project to retain on-site the Stormwater Quality Design Volume (SWQDv) defined as the runoff from: a) The 0.75-inch, 24-hour rain event or b) The 85th percentile, 24-hour rain event, as determined from the Los Angeles County 85th percentile precipitation Isohyetal map, whichever is greater. • Bioretention and biofiltration systems shall meet the design specifications provided in Attachment H to this Order unless otherwise approved by the Regional Water Board Executive Officer. • When evaluating the potential for on-site retention, each Permittee shall consider the maximum potential for evapotranspiration from green roofs and rainfall harvest and use." (Page 98).
Los Angeles – Ventura	Ventura County MS4 Permit [16]	• "Permittees shall require all New Development and Redevelopment projects identified in subpart 4.E.ll to control pollutants, pollutant loads, and runoff volume emanating from impervious surfaces through infiltration, storage for reuse, evapotranspiration, or bioretention biofiltration by reducing the percentage of Effective Impervious Area (EIA) to 5 percent or less of the total project area. • Impervious surfaces may be rendered "ineffective", and thus not count toward the 5 percent EIA limitation, if the storm water runoff from those surfaces is fully retained on-site for the design storm event specified in provision… If on-site retention is determined to be technically infeasible pursuant to 4.E.lll.2(b), an on-site biofiltration system that achieves equivalent storm water volume and pollutant load· reduction as would have been achieved by on-site retention shall satisfy the EIA limitation. An on-site biofiltration system that releases above the design volume shall achieve 1.5 times the amount of storm water volume and pollutant load reduction as would have been achieved by on-site retention and, thereby, shall satisfy the EIA limitation." (Page 56).

Region	Document	LID or Water Quality Requirements Summary
San Francisco	San Francisco Regional MS4 Permit [4]	"The Permittees shall require that stormwater treatment systems constructed for Regulated Projects meet at least one of the following hydraulic sizing design criteria: (1) Volume Hydraulic Design Basis – Treatment systems whose primary mode of action depends on volume capacity shall be designed to treat stormwater runoff equal to: a) The maximized stormwater capture volume for the area, on the basis of historical rainfall records, determined using the formula and volume capture coefficients set forth in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998), pages 175–178 (e.g., approximately the 85th percentile 24-hour storm runoff event); or b) The volume of annual runoff required to achieve 80 percent or more capture, determined in accordance with the methodology set forth in Section 5 of CASQA's Stormwater Best Management Practice Handbook, New Development and Redevelopment (2003), using local rainfall data. (2) Flow Hydraulic Design Basis – Treatment systems whose primary mode of action depends on flow capacity shall be sized to treat: a) 10 percent of the 50-year peak flow rate; b) The flow of runoff produced by a rain event equal to at least two times the 85th percentile hourly rainfall intensity for the applicable area, based on historical records of hourly rainfall depths; or c) The flow of runoff resulting from a rain event equal to at least 0.2 inches per hour intensity. (3) Combination Flow and Volume Design Basis – Treatment systems that use a combination of flow and volume capacity shall be sized to treat at least 80 percent of the total runoff over the life of the project, using local rainfall data." (Page 22).
Santa Ana – Orange County	Santa Ana Orange County Regional MS4 Permit[6]	"The permittees shall reflect in the WQMP and otherwise require that each priority development project infiltrate, harvest and re-use, evapotranspire, or bio-treat the 85th percentile storm event ("design capture volume"), as specified in Section XII.B.4.A.1, above. Any portion of the design capture volume that is not infiltrated, harvested and re-used, evapotranspired or bio-treated onsite by LID BMPs shall be treated and discharged in accordance with the requirements set forth in Section XII.C.7 and/or Section XII.E, below." (Page 54)
Santa Ana – San Bernardino	Santa Ana Regional MS4 Permit- San Bernardino [5]	"…Each priority development project to infiltrate, harvest and use, evapotranspire, or bio-treat the 85th percentile storm event ("design capture volume"), as specified in Section XI.D. 6 above. Any portion of the design capture volume that is not infiltrated, harvested, used, evapotranspired or bio-treated onsite by LID BMPs shall be treated and discharged in accordance with the requirements set forth in Section XI.E.1 0 and/or Section XI.G, below." (pg. 84)

References

California Regional Water Quality Control Board Central Coast Region. 2012. Order No. R3-2012-0005 NPDES Permit No. CA0049981 Waste Discharge Requirements for City of Salinas Municipal Storm Water Discharges Monterey County.

[2] California Regional Water Quality Control Board Los Angeles Region. 2016. Order No. R4-2012-0175 as amended by State Water Board Order WQ 2015-0075 and Los Angeles Water Board Order R4-2012-0175-A01 NPDES Permit No. CAS004001 Waste Discharge Requirements for Municipal Separate Storm Sewer System (MS4) Discharges Within the Coastal Watersheds of Los Angeles County, except those Discharges Originating from the City of Long Beach MS4.

[3] California Regional Water Quality Control Board San Diego Region. 2015. Order No. R9-2013-0001, As Amended by Order Nos. R9-2015-0001 and R9-2015-0100 NPDES No. CAS0109266 National Pollutant Discharge Elimination System (NPDES) Permit and Waste Discharge Requirements for Discharges from The Municipal Separate Storm Sewer Systems (MS4s) Draining the Watersheds Within The San Diego Region.

[4] California Regional Water Quality Control Board San Francisco Bay Region. 2015. Municipal Regional Stormwater NPDES Permit Order No. R2-2015-0049 NPDES Permit No. CAS612008.

[5] California Regional Water Quality Control Board Santa Ana Region. 2010. Order No. R8-2010-0036 NPDES No. CAS618036 National Pollutant Discharge Elimination System (NPDES) Permit and Waste Discharge Requirements For The San Bernardino County Flood Control District The County Of San Bernardino, And The Incorporated Cities Of San Bernardino County Within The Santa Ana Region.

[6] California Regional Water Quality Control Board Santa Ana Region. 2010. Order No. R8-2009-0030 NPDES No. CAS618030 as amended by Order No. R8-2010-0062 Waste Discharge Requirements for The County of Orange, Orange County Flood Control District and The Incorporated Cities of Orange County within the Santa Ana Region Areawide Urban Storm Water Runoff Orange County.

[7] California Regional Water Quality Control Board Santa Ana Region. 2010. Order No. R8-2010-0033 NPDES NO. CAS 618033 National Pollutant Discharge Elimination System (NPDES) Permit and Waste Discharge Requirements for The Riverside County Flood Control and Water Conservation District, the County of Riverside, And the Incorporated Cities of Riverside County Within the Santa Ana Region.

[8] California Regional Water Quality Control Board San Francisco Bay Region. 2015. Municipal Regional Stormwater NPDES Permit Order No. R2-2015-0074 NPDES Permit No. CAS612008.

Santa Ana Regional Water Quality Control Board (SARWQCB). 2011. Model Water Quality Management Plan (Model WQMP).

[10] California Regional Water Quality Control Board Colorado River Basin Region. 2013. Order No. R7-2013-001 NPDES No. CAS617002 Waste Discharge Requirement for Discharges from the Municipal Separate Storm Sewer System (MS4) within the Whitewater River Watershed Riverside County Flood Control and Water Conservation District, Owner/Operator County of Riverside, Owner/Operator Coachella Valley Water District, Owner/Operator and Incorporated Cities of Riverside County within the Whitewater River Basin, Owner/Operator.

[11] Orange County Public Works. 2011. *Technical Guidance Document BMP Fact Sheets.* http://cms.ocgov.com/gov/pw/watersheds/documents/wqmp/technical_guidance_document_(tgd)/technical_guidance_document_bmp_fact_sheets.asp.

[12] County of San Diego. 2016. *County of San Diego BMP Design Manual for Permanent Site Design, Storm Water Treatment and Hydromodification Management.*

https://www.sandiegocounty.gov/content/dam/sdc/dpw/WATERSHED_PROTECTION_PROGRAM/watershedpdf/County_BMPDM.pdf.

[13] Riverside County Flood Control and Water Conservations District. 2015. Whitewater River Region Water Quality Management Plan Guidance Document. http://rcflood.org/downloads/NPDES/Documents/WW_SWMP_WQMP/WWR_WQMP_Guidance_Jan15_2015.pdf.

[14] Cities and County of Riverside. 2012. Water Quality Management Plan A Guidance Document for the Santa Ana Region of Riverside County. http://rcflood.org/downloads/NPDES/Documents/SA_WQMP/SantaAnaWQMPGuidance.pdf.

[15] California Regional Water Quality Control Board Los Angeles Region. 2014. *California Regional Water Quality Control Board Los Angeles Region Order No. R4-2014-0024 NPDES Permit No. CAS004003 Waste Discharge Requirements for Municipal Separate Storm Sewer System (MS4) Discharges from The City of Long Beach.*

[16] California Regional Water Quality Control Board Los Angeles Region. 2010. *Order R4-2010-0108 NPDES Permit No. CAS004002 Waste Discharge Requirements for Storm Water (Wet Weather) and Non-Storm Water (Dry Weather) Discharges from the Municipal Separate Storm Sewer Systems within the Ventura County Watershed Protection District, County of Ventura and the Incorporated Cities Therein.* https://www.waterboards.ca.gov/losangeles/water_issues/programs/stormwater/municipal/ventura.html.

[17] Ventura Countywide Stormwater Quality Management Program. 2011. Ventura County Technical Guidance Manual for Stormwater Quality Control Measures. https://www.waterboards.ca.gov/losangeles/water_issues/programs/stormwater/municipal/ventura_ms4/VenturaTGM/Ventura%20Stormwater%20TGM%20Final%207-13-11.pdf.

[18] State Water Resources Control Board. 2013. Water Quality Order No. 2013-0001-DWQ National Pollutant Discharge Elimination System (NPDES) General Permit No. CAS000004 Waste Discharge Requirements (WDRS) for Storm Water Discharges from Small Municipal Separate Storm Sewer Systems (MS4S) (General Permit). https://www.waterboards.ca.gov/water_issues/programs/stormwater/phase_ii_municipal.html#phase.

[19] State Water Resources Control Board Division of Water Quality. 2012. Construction General Permit Fact Sheet. https://www.waterboards.ca.gov/water_issues/programs/stormwater/constpermits.shtml.

[20] California Regional Water Quality Control Board Santa Ana Region. 2010. *Order No. R8-2009-0030 NPDES No. CAS618030 As amended by Order No. R8-2010-0062 Waste Discharge Requirements for The County of Orange, Orange County Flood Control District and The Incorporated Cities of Orange County within the Santa Ana Region Areawide Urban Storm Water Runoff Orange County.*

[21] San Francisco Public Utilities Commission. 2018. Stormwater Management Requirements https://sfwater.org/index.aspx?page=1000.

[22] RCFCWCD (Riverside County Flood Control and Water Conservation District). 2012. *LID BMP Design Handbooks* “Bioretention Facilities.” http://www.floodcontrol.co.riverside.ca.us/NPDES/LIDBMP.aspx.

[23] Orange County. 2011. *Technical Guidance Document BMP Fact Sheets*. “Biotreatment BMP Fact Sheets (BIO).” http://www.ocwatersheds.com/gov/pw/watersheds/documents/wqmp/technical_guidance_document_(tgd)/technical_guidance_document_bmp_fact_sheets.asp

[24] City of Long Beach. 2013. Low Impact Development (LID) Best Management Practices (BMP) Design Manual. 2nd Edition. December 2013.

Appendix B: Southern California Ecoregions and Vegetation

The ecoregions for the three RWQCB Regions are very broadly outlined; they can be further subdivided into sections and subsections within the hierarchical framework of ecoregions. Individual subsections have characteristic topography, soils, climate, and associated vegetation types. Table provides details on the climate and vegetation of the Southern California mountains and valleys ecoregion.

Table B-1. Climate and Vegetation of the Southern California Coast Ecoregion.

Subsection	Mean Annual Temperature & Precipitation	Surface Water	Predominant Vegetation	Less Common Vegetation
Santa Ynez – Sulphur Mountains	45° – 60° F 18-30 in	Rapid runoff; all but larger streams dry in summer; no natural lakes	Coastal Oak Woodland; Montane Hardwood Forest; Chamise Chaparral; Mixed Chaparral	Coastal Scrub; Duneland; Grassland
Oxnard Plain – Santa Paula Valley	56° – 60° F 12-18 in with summer fog	Santa Clara River is perennial, Calleguas Creek is year-round; no natural lakes	Coastal Scrub	Saline Emergent Wetland; Grassland; Coastal Oak Woodland; Valley Foothill Riparian Woodland
Simi Valley – Santa Susana Mountains	52° – 62° F 16-20 in	Rapid runoff; streams dry in summer; no natural lakes	Coastal Scrub; Chamise Chaparral; Coast Oak Woodland	Valley Oak Woodland; Montane Hardwood Forest; Grassland; Valley Foothill Riparian Woodland; Montane Riparian Forest
Santa Monica Mountains	54° – 62° F 15-25 in	Rapid runoff; streams dry in summer; no natural lakes	Coastal Scrub; Chamise Chaparral; Mixed Chaparral	Coast Oak Woodland; Grassland; Valley Foothill Riparian Woodland; Montane Riparian Forest; Valley Oak Woodland
Los Angeles Plain	58° – 64° F 12-20 in with summer fog	Most streams dry in summer; no natural lakes	Coastal Scrub	Coast Oak Woodland; Chamise Chaparral; Mixed Chaparral; Valley Foothill Riparian Woodland; Saline Emergent Wetland; Duneland; Grassland
Coastal Hills	56° – 62° F 12-16 in with summer fog	Rapid runoff; mix of perennial and summer-dry streams; no natural lakes; some reservoirs	Coastal Scrub; Coast Oak Woodland	Chamise Chaparral; Mixed Chaparral; Valley Foothill Riparian Woodland; Grassland
Coastal Terrace	58° – 62° F 10-12 in with summer fog	Rapid runoff except for terraces with vernal pools; mix of perennial and summer-dry streams; no natural lakes	Coastal Scrub; Chamise Chaparral	Coast Oak Woodland; Saline Emergent Wetland; Torrey Pine Stands; Vernal Pools; Duneland; Grassland; Mixed Chaparral; Valley Foothill Riparian Woodland

Sources: USDA-FS, 1997, and CA-DFG, 2009

Table B-2. Climate and Vegetation of the Southern CA Mountains and Valleys Ecoregion.

Subsection	Mean Annual Temperature & Precipitation	Surface Water	Predominant Vegetation	Less Common Vegetation
San Raphael – Topatopa Mountains	45° – 60° F 18-30 in	Rapid runoff; rain except at higher elevations; all but larger & high-elevation streams dry in summer; no natural lakes	Chamise Chaparral; Mixed Chaparral	Coastal Oak Woodland; Coastal Scrub; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Jeffrey Pine Forest; White Fir Forest; Grassland; Wet Meadow
Northern Transverse Ranges	40° – 54° F 12-30 in	Rapid runoff; rain except at higher elevations; all but larger & high-elevation streams dry in summer; no natural lakes	Juniper Woodland; Jeffrey Pine Forest; Montane Hardwood Conifer Forest; Chamise Chaparral; Mixed Chaparral;	Coastal Scrub; Montane Hardwood Forest; Pinyon-Juniper Woodland; Montane Chaparral; Subalpine Conifer Forest; White Fir Forest; Grassland; Wet Meadow
Sierra Pelona – Mint Canyon	45° – 60° F 12-20 in	Rapid runoff; rain except at higher elevations; all but larger streams dry in summer; sag ponds along San Andreas Fault	Chamise Chaparral; Mixed Chaparral; Coastal Oak Woodland	Coastal Scrub; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Jeffrey Pine Forest; Juniper Woodland; Montane Chaparral; Grassland; Wet Meadow;
San Gabriel Mountains	45° – 60° F 20-30 in	Rapid runoff; rain except at higher elevations; all but larger streams dry in summer; sag ponds along San Andreas Fault	Chamise Chaparral; Mixed Chaparral	Jeffrey Pine Forest; Juniper Woodland; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Grassland; Montane Chaparral; Coastal Oak Woodland; Pinyon-Juniper Woodland; Wet Meadow
Upper San Gabriel Mountains	40° – 50° F 30-40 in	Rapid runoff; rain except at higher elevations; all but larger streams dry in summer; no natural lakes	Jeffrey Pine Forest	Lodgepole Pine Forest; Subalpine Conifer Forest; Montane Chaparral; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Coastal Oak Woodland; Juniper Woodland; Wet Meadow
Santa Ana Mountains	45° – 62° F 15-25 in	Rapid runoff; rain except at higher elevations; all but larger streams dry in summer; no natural lakes (but some drainage to Lake Elsinore)	Coastal Oak Woodland; Chamise Chaparral; Mixed Chaparral	Montane Hardwood Conifer Forest; Montane Hardwood Forest; Coastal Scrub; Jeffrey Pine Forest; Montane Chaparral; Grassland; Vernal Pools

Subsection	Mean Annual Temperature & Precipitation	Surface Water	Predominant Vegetation	Less Common Vegetation
San Gorgonio Mountains	45° – 60° F 20-30 in	Rapid runoff; rain except at higher elevations; all but larger streams dry in summer; no natural lakes	Chamise Chaparral; Mixed Chaparral; Jeffrey Pine Forest	Subalpine Conifer Forest; Montane Chaparral; Juniper Woodland; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Coastal Oak Woodland; Pinyon-Juniper Woodland; Coastal Scrub; Grassland
Upper San Gorgonio Mountains	40° – 50° F 30-40 in	Rapid runoff; much precipitation is snow; all but larger streams dry in summer; previously natural lakes replaced by reservoirs	Jeffrey Pine Forest	Mixed Chaparral; Subalpine Conifer Forest; Lodgepole Pine Forest; Juniper Woodland; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Montane Chaparral; White Fir Forest; Pinyon-Juniper Woodland; Wet Meadow; Alpine Meadow
Fontana – Calimesa Terraces	62° – 64° F 20-20 in	Rapid runoff (even from alluvial fans); all but larger streams dry in summer; Santa Ana River flows year-round; no natural lakes	Coastal Scrub; Grassland	Mixed Chaparral; Juniper Woodland; Valley Foothill Riparian Woodland
Perris Valley and Hills	58° – 64° F 10-16 in	Rapid runoff (except from floodplains and lake basins); all but larger streams dry in summer; sag ponds along Elsinore Fault Zone; reservoirs	Coastal Scrub; Grassland	Coastal Oak Woodland; Chamise Chaparral; Mixed Chaparral; Juniper Woodland; Vernal Pools
San Jacinto Foothills – Cahuilla Mountains	50° – 60° F 10-20 in	Rapid runoff (except from alluvial plains); all but larger streams dry in summer; no natural lakes	Coastal Oak Woodland; Coastal Scrub	Chamise Chaparral; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Mixed Chaparral; Montane Chaparral; Juniper Woodland; Jeffrey Pine Forest; Pinyon-Juniper Woodland; Grassland
San Jacinto Mountains	40° – 58° F 16-30 in	Rapid runoff (except from alluvial plains); rain except at higher elevations; all but larger streams dry in summer; no natural lakes	Jeffrey Pine Forest; Lodgepole Pine Forest; Mixed Chaparral	Coastal Oak Woodland; Juniper Woodland; Pinyon-Juniper Woodland; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Montane Chaparral; Chamise Chaparral; Subalpine Conifer Forest; White Fir Forest; Wet Meadow; Grassland
Western Granitic Foothills	55° – 62° F 14-20 in	Rapid runoff; all but larger streams dry in summer; no natural lakes	Coastal Oak Woodland; Chamise Chaparral; Mixed Chaparral; Coastal Scrub	Montane Hardwood Conifer Forest; Montane Hardwood Forest; Montane Chaparral; Grassland; stands of Tecate cypress

Subsection	Mean Annual Temperature & Precipitation	Surface Water	Predominant Vegetation	Less Common Vegetation
Palomar – Cuyamaca Peak	50° – 58° F 18-40 in	Rapid runoff; all but larger streams dry in summer; sag ponds along Elsinore Fault Zone; level of Lake Henshaw (natural) has been raised artificially; reservoirs	Chamise Chaparral; Mixed Chaparral	Coastal Oak Woodland; Grassland; Jeffrey Pine Forest; Montane Hardwood Conifer Forest; Subalpine Conifer Forest; White Fir Forest; Montane Chaparral; Coastal Scrub; stands of Cuyamaca cypress and Tecate cypress

Sources: USDA-FS, 1997, and CA-DFG, 2009

Major Plant Communities in Southern California

The following points briefly summarize important characteristics of several major plant communities in Southern California to help in identifying native plant cover versus invasive species. (Bornstein et al, 2005; Lenz and Dourley, 1981; Las Pilitas Nursery):

- Coastal Scrub:
    - primarily small to medium shrubs, subshrubs, or succulents
    - some species produce large green leaves with winter rains and small grayish leaves in summer; other species are drought-deciduous
    - annual precipitation is generally 10-20 inches
    - relatively narrow temperature range
    - plants can be somewhat sparsely distributed in the landscape
    - tend to be found in flat to moderately-sloped areas; slopes may be rocky
    - shallow to moderate soil depth

Figure B-1. Coastal Scrub

Source: © Marc Hoshovsky, California Department of Fish and Game

- Chaparral:
    - most extensive type of vegetation in California
    - primarily medium to large shrubs with thick, small, evergreen leaves; also contains fire-adapted annuals
    - can form dense thickets
    - many types of chaparral are recognized, depending on dominant species and combinations of species; this variation reflects different elevations, moisture levels, and soil types
    - annual precipitation is generally 12-35 inches, occurring in infrequent, heavy events
    - found on hills and lower mountain slopes in areas with generally mild winters; often on steep slopes that are very hot in summer
    - fairly drought-tolerant and adapted to fire; many shrub species can sprout from stumps following fire
    - shallow, usually well-drained, rocky soils

Figure B-2. Chaparral

Source: California Chaparral Institute

- Grassland:
    - comprises bunchgrasses, sedges, and annual and perennial wildflowers
    - merges with chaparral or oak woodland at higher elevations
    - annual precipitation is generally 6-20 inches
    - soils range from: deep alluvial fan and floodplain, to moderately deep upland with high organic matter, to low terrace land soils having moderately dense subsoils, to poorly drained valley basin soils
    - no longer abundant (largely replaced by agricultural land uses)
    - invasive exotic grasses and other herbs have impaired some remaining California grassland

Figure B-3. Grassland

Source: I. Anderson Center for Biological Diversity

- Coastal Oak Woodland:
    - discontinuous overstory of Coast Live Oak, other oak trees, or California Walnut
    - canopy coverage can vary, with a mix of shrubs and grasses occurring in the understory
    - annual precipitation is generally 15-25 inches with substantial runoff
    - soils are generally deep terrace land or upland soils

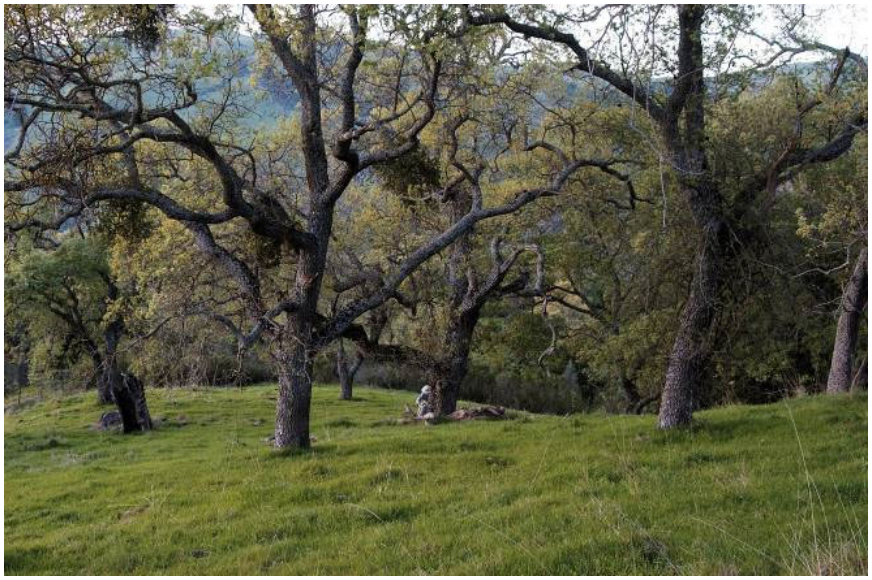

Figure B-4. Oak Woodland

Source: Daniel Griffin, University of Arkansas Tree-Ring Laboratory

- Riparian Woodland:
    - species composition varies with elevation
    - soils vary, depending on composition of materials deposited along waterways
    - plants generally require year-round presence of nearby surface water

Figure B-5. Riparian Woodland.

Source: V.L. Holland, Ph.D.; Biological Sciences Department, California Polytechnic State University

- Pinyon-Juniper Woodland:
    - consists of juniper on shallower slopes and pinyon pine on higher and steeper slopes in mountain regions
    - plant community may have a variety of other trees, shrubs, and succulents
    - annual precipitation is generally 10-30 inches

Figure B-6. Pinyon-Juniper Woodland.

Source: Joel Michaelson; Department of Geology, UC Santa Barbara

- Pine Forest:
    - lower montane coniferous forest, with a great number of potential species (canopy and understory)
    - elevation generally ranges from 5,000 to 8,000 feet
    - annual precipitation is generally 25-80 inches (much of it falls as snow)
    - deep upland soils with moderate to high acidity

Figure B-7. Pine Forest

Source: Joel Michaelson; Department of Geology, UC Santa Barbara

- Creosote Bush Scrub:
    - Open, sparse desert community dominated by Creosote bush and prickly pear cactus
    - elevation generally less than 3,500 feet
    - annual precipitation is generally 5-10 inches
    - alkaline soils

Figure B-8. Creosote Bush Scrub

Source: Carrie Tai

- Joshua Tree Woodland:
    - Desert community dominated by Joshua trees, shrubs and wildflowers
    - elevation generally ranges from 2,500 to 5,000 feet
    - annual precipitation is generally 5-10 inches
    - neutral soils

Figure B-9. Joshua Tree Woodland

Source: Carrie Tai

The plant lists included in this manual are intended to serve as a general guide for identifying plants likely to be suitable for use in LID. The lists a and associated references are not exhaustive and are not a substitute for the planting recommendations of a qualified landscape professional with knowledge of LID and following a site and design specific evaluation.

Table B-3. Southern California Master Plant List

Southern California Master Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Acalypha californica	California Copperleaf	evergreen shrub		✓	✓	✓	chaparral, scrub	✓	✓		✓ ✓				✓		
Achillea millefoilum *	Yarrow	herbaceous perennial	1-24	✓	✓	✓	Many	✓	✓	✓	✓ ✓	✓	✓	✓	✓	✓	✓
Adenostoma fasciculatum 'Nicolas'	Prostrate Chamise	groundcover	14-16, 18-24	✓	✓	✓	Chaparral	✓	✓	✓	✓ ✓			✓	✓		✓
Aesculus californica	California Buckeye	deciduous tree	4-10,12,14-24	✓	✓	✓	Woodland	✓	✓	✓	✓ ✓			✓	✓		✓
Agave deserti	Desert Century Plant	succulent	12-24	✓	✓	✓	Scrub	✓		✓	✓ ✓			✓	✓		✓
Agave shawii	Shaw's Century Plant	succulent		✓	✓		css	✓		✓	✓ ✓			✓	✓		✓
Ambrosia chamissonis	Sand Bur	sprawling perennial		✓			dunes	✓			✓ ✓						✓
Ambrosia pumila	San Diego Ambrosia	groundcover		✓	✓		dunes	✓	✓		✓ ✓	✓					✓
Amorpha fruticosa	False Indigobush	Deciduous shrub		✓	✓	✓	riparian	✓	✓	✓	✓		✓	✓	✓	✓	✓
Antigonon leptopus	San Miguel Coral Vine	climbing vine	12, 13, 18-24	✓	✓		chaparral, scrub	✓	✓			✓	✓				✓
Arbutus menziesii	Madrone	broadleaf evergreen tree	15-17, 19-24	✓	✓	✓	woodland, forest	✓	✓	✓	✓	✓	✓	✓	✓		✓
Arctostaphylos catalinae	Catalina Manzanita	broadleaf evergreen tree/shrub		✓	✓	✓	chaparral	✓	✓	✓	✓ ✓			✓	✓		✓
Arctostaphylos densiflora 'Howard McMinn'	McMinn Manzanita	broadleaf evergreen shrub	7-9, 14-21	✓	✓	✓	chaparral	✓	✓	✓	✓ ✓			✓	✓		✓
Arctostaphylos edmundsii 'Carmel Sur'	Carmel Sur Manzanita	groundcover	6-9, 14-24	✓	✓	✓	ocean bluffs	✓	✓	✓	✓	✓		✓	✓		✓
Arctostaphylos glauca	Bigberry Manzanita	broadleaf evergreen shrub		✓	✓	✓	chaparral	✓	✓	✓	✓ ✓			✓	✓		✓
Arctostaphylos 'Lester Rowntree'	Lester Rowntree Manzanita	broadleaf evergreen tree/shrub		✓	✓		chaparral	✓	✓		✓	✓			✓		
Arctostaphylos 'Pacific Mist'	Pacific Mist Manzanita	groundcover	7-9, 14-24	✓	✓		chaparral	✓	✓		✓	✓			✓		

Southern California Master Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Arctostaphylos uva-ursi 'Point Reyes'	Point Reyes Bearberry	groundcover	1-9, 14-24	✓		✓	woodland	✓	✓	✓	✓				✓		
Aristida purpurea	Purple Three-Awn	bunchgrass		✓	✓	✓	css, chaparral	✓	✓		✓ ✓				✓	✓	✓
Artemisia californica	California Sagebrush	evergreen subshrub	1-24	✓	✓		css, chaparral	✓	✓		✓ ✓				✓		✓
Artemisia californica 'Canyon Gray'	Canyon Gray Sagebrush	groundcover	1-24	✓	✓		css, chaparral	✓	✓		✓				✓		
Artemisia ludoviciana	Silver Wormwood	creeping perennial				✓	scrub	✓			✓				✓		✓
Artemisia pycnocephala	Beach Sagewort	herbaceous perennial	1-24	✓		✓	css, dune	✓	✓		✓	✓					✓
Atriplex lentiformis ssp. Breweri	Quail Bush	everg. or decid. shrub	1-24	✓	✓	✓	scrub	✓			✓ ✓				✓		
Baileya multiradiata	Desert Marigold	perennial	7-14, 18, 19		✓	✓	scrub, grassland	✓			✓ ✓	✓					✓
Baccharis pilularis 'Pigeon Point' or 'Twin Peaks'	Dwarf Coyote Bush	groundcover	1-3, 7-23	✓	✓	✓	css, chaparral	✓	✓		✓	✓			✓	✓	✓
Baileya multiradiata	Desert Marigold	perennial	7-14, 18, 19		✓	✓	scrub, grassland	✓			✓ ✓	✓					✓
Baccharis pilularis 'Pigeon Point' or 'Twin Peaks'	Dwarf Coyote Bush	groundcover	1-3, 7-23	✓	✓	✓	css, chaparral	✓	✓		✓	✓			✓	✓	✓
Baccharis pilularis ssp. consanguinea	Coyote Bush	woody perennial	5-11, 14-24	✓	✓		css, chaparral	✓	✓		✓ ✓				✓		
Bouteloua curtipendula	Side-oats Grama	bunchgrass		✓	✓	✓	scrub, woodland	✓			✓	✓			✓		✓
Brahea armata	Blue Hesper Palm	palm tree	10, 12-17, 19-24	✓	✓	✓	scrub	✓			✓	✓			✓		
Brahea edulis	Guadalupe Palm	palm tree	12-24	✓	✓		woodland	✓	✓		✓	✓			✓		
Calycanthus occidentalis	Spice Bush	decid shrub	4-9, 14-24	✓	✓	✓	woodland, forest	✓	✓			✓	✓		✓	✓	
Calystegia macrostegia 'Anacapa Pink'	Island Morning-glory	evergreen vine		✓	✓		css, chaparral	✓	✓			✓			✓		
Calocedrus decurrens	Incense Cedar	evergreen tree	2-12, 14-24	✓	✓	✓	forest	✓	✓		✓	✓			✓		
*Camissonia (Oenothera) cheiranthifolia **	Beach Evening Primrose	herbaceous perennial		✓			beach/dune	✓	✓		✓ ✓	✓			✓		✓
Carex pansa	California Meadow Sedge	creeping perennial		✓		✓	bluffs, strand	✓	✓	✓			✓	✓	✓	✓	
Carex parametricities	California Field Sedge	creeping perennial		✓	✓	✓	riparian	✓	✓	✓			✓	✓		✓	
Ceanothus arboreus	Island Ceanothus	broadleaf evergreen		✓	✓		css, chaparral	✓			✓	✓			✓		

Southern California Master Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
		tree/shrub															
Ceanothus crassifolius	Hoaryleaf Ceanothus	broadleaf evergreen shrub		✓	✓		chaparral	✓			✓ ✓				✓		
Ceanothus greggii ssp. Perplexans	Cupleaf Lilac	broadleaf evergreen shrub			✓	✓	chaparral	✓			✓ ✓				✓		
Ceonothus griseus 'Santa Ana'	Santa Ana Ceonothus	evergreen shrub		✓			chaparral	✓	✓			✓	✓		✓	✓	
Ceanothus griseus horizontalis 'Yankee Point'	Carmel Creeper	groundcover	5-9, 14-17, 19-24	✓	✓		css, forest	✓	✓		✓	✓			✓		
Ceanothus hearstiorum	Heart Ceanothus	groundcover		✓			css, forest	✓	✓		✓	✓			✓		
Ceanothus impressus	Santa Barbara Ceanothus	evergreen shrub		✓			chaparral	✓	✓		✓ ✓				✓		
Ceanothus maritimus	Maritime Ceanothus	groundcover		✓			css	✓	✓		✓	✓			✓		
Ceanothus megacarpus	Big Pod Ceanothus	evergreen shrub		✓	✓		css, chaparral	✓			✓ ✓				✓		
Ceonothus verrucosus	Wartystem Ceonothus	evergreen shrub		✓	✓		css, chaparral	✓			✓ ✓				✓		
Ceanothus 'Anchor Bay'	Anchor Bay Ceanothus	groundcover		✓	✓		css, forest	✓	✓			✓	✓		✓	✓	
Ceanothus 'Concha'	Concha Ceanothus	evergreen shrub		✓	✓		chaparral	✓			✓	✓			✓		
Calystegia macrostegia 'Anacapa Pink'	Island Morning-glory	evergreen vine		✓	✓		css, chaparral	✓	✓			✓			✓		
Ceanothus 'Ray Hartman'	Ray Hartman Ceanothus	evergreen shrub	5-9, 14-24	✓	✓		css, chaparral	✓			✓	✓			✓		
Cercidium floridum	Blue Palo Verde	deciduous tree	10-14, 18-20	✓	✓	✓	scrub	✓			✓ ✓				✓		
Cercis occidentalis	Western Redbud	deciduous shrub/tree	2-24	✓	✓	✓	chaparral, woodland	✓	✓		✓	✓			✓		
Cercocarpus betuloides	Western Mountain Mahogany	evergreen shrub/tree	6-24	✓	✓	✓	chaparral, woodland	✓			✓ ✓				✓		
Chilopsis linearis	Desert Willow	deciduous tree/shrub	7-14, 18-23	✓	✓	✓	riparian, scrub	✓			✓	✓	✓		✓	✓	
Cneoridium dumosum	Bushrue	evergreen shrub		✓	✓	✓	css, chaparral	✓	✓		✓ ✓				✓		
Cupressus forbesii	Tecate Cypress	evergreen conifer	8-14, 18-20	✓	✓	✓	chaparral, forest	✓			✓				✓		
Ceanothus hearstiorum	Heart Ceanothus	groundcover		✓			css, forest	✓	✓		✓	✓			✓		
Ceanothus impressus	Santa Barbara Ceanothus	evergreen shrub		✓			chaparral	✓	✓		✓ ✓				✓		

Southern California Master Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Ceanothus maritimus	Maritime Ceanothus	groundcover		✓			css	✓	✓		✓	✓			✓		
Ceanothus megacarpus	Big Pod Ceanothus	evergreen shrub		✓	✓		css, chaparral	✓			✓ ✓				✓		
Ceonothus verrucosus	Wartystem Ceonothus	evergreen shrub		✓	✓		css, chaparral	✓			✓ ✓				✓		
Ceanothus 'Anchor Bay'	Anchor Bay Ceanothus	groundcover		✓	✓		css, forest	✓	✓			✓	✓		✓	✓	
Ceanothus 'Concha'	Concha Ceanothus	evergreen shrub		✓	✓		chaparral	✓			✓	✓			✓		
Ceanothus 'Ray Hartman'	Ray Hartman Ceanothus	evergreen shrub	5-9, 14-24	✓	✓		css, chaparral	✓			✓	✓			✓		
Cercidium floridum	Blue Palo Verde	deciduous tree	10-14, 18-20	✓	✓	✓	scrub	✓			✓ ✓				✓		
Cercis occidentalis	Western Redbud	deciduous shrub/tree	2-24	✓	✓	✓	chaparral, woodland	✓	✓		✓	✓			✓		
Cercocarpus betuloides	Western Mountain Mahogany	evergreen shrub/tree	6-24	✓	✓	✓	chaparral, woodland	✓			✓ ✓				✓		
Chilopsis linearis	Desert Willow	deciduous tree/shrub	7-14, 18-23	✓	✓	✓	riparian, scrub	✓			✓	✓	✓		✓	✓	
Cneoridium dumosum	Bushrue	evergreen shrub		✓	✓	✓	css, chaparral	✓	✓		✓ ✓				✓		
Cupressus forbesii	Tecate Cypress	evergreen conifer	8-14, 18-20	✓	✓	✓	chaparral, forest	✓			✓				✓		
Dendromecon harfordii	Channel Island Bush Poppy	evergreen shrub	7-9, 14-24	✓	✓		chaparral	✓			✓ ✓				✓		
Dendromecon rigida	Bush Poppy	evergreen shrub	4-12, 14-24		✓	✓	chaparral	✓			✓ ✓				✓		
*Deschampsia caespitosa **	Tufted Hairgrass	perennial bunchgrass	1-24	✓	✓	✓	woodland, forest	✓	✓	✓	✓	✓	✓		✓	✓	
Dichelostemma capitatum	Wild Hyacinth	bulb	1-24	✓		✓	many	✓			✓ ✓				✓		✓
Distichlis spicata	Salt Grass	creeping perennial		✓		✓	beach/dune; marsh	✓	✓			✓	✓	✓	✓	✓	
Dudleya hassei	Catalina Live-forever	succulent		✓		✓	css	✓	✓	✓	✓ ✓				✓		✓
Dudleya pulverulenta	Chalk Dudleya	succulent		✓	✓	✓	css, chaparral	✓	✓		✓ ✓				✓		✓
Eleocharis montevidensis	Spike Rush	grass-like perennial		✓	✓	✓	many	✓	✓	✓				✓		✓	
Encelia californica	Coast Sunflower	evergreen subshrub		✓	✓		css, chaparral	✓	✓		✓ ✓				✓		

Southern California Master Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Encelia farinose	Incienso	evergreen subshrub		✓	✓	✓	chaparral, scrub	✓			✓ ✓				✓		
Epilobium californicum	California Fuchsia	herb perennial		✓	✓	✓	many	✓	✓		✓ ✓				✓		✓
Epilobium canum	Hoary California Fuchsia	herb perennial		✓	✓	✓	css, chaparral	✓	✓		✓ ✓				✓		✓
Eriogonum arborescens	Santa Cruz Island Buckwheat	evergreen shrub	14-24	✓	✓		css, chaparral	✓	✓		✓	✓			✓		
Eriogonum crocatum	Saffron Buckwheat	evergreen subshrub /herb perennial	12-24	✓	✓		css	✓			✓ ✓				✓		✓
Eriogonum fasciculatum	California Buckwheat	woody perennial	8, 9, 12-24	✓	✓	✓	many	✓	✓		✓ ✓				✓		
Eriogonum fasciculatum 'Dana Point'	Dana Point Buckwheat	groundcover	8, 9, 12-24	✓	✓		css	✓	✓		✓ ✓				✓		
Eriogonum grande var. rubescens	Red Buckwheat	evergreen subshrub	14-24	✓			beach/dune; css	✓	✓		✓	✓			✓		
Eriogonum parvifolium	Coastal Buckwheat	evergreen subshrub		✓			beach/dune; css	✓	✓		✓ ✓				✓		
Eriophyllum confertiflorum	Golden Yarrow	herbaceous subshrub		✓	✓		many	✓	✓			✓	✓		✓		✓
Eschscholzia californica	California Poppy	annual	1-24	✓	✓	✓	scrub	✓			✓ ✓				✓		✓
Euphorbia misera	Cliff Spurge	shrub		✓		✓	scrub	✓			✓						✓
Fallugia paradoxa	Apache Plume	semi-decid shrub	2-23	✓	✓	✓	scrub, woodland	✓			✓ ✓				✓		
Fragaria californica *	Woodland Strawberry	groundcover		✓	✓	✓	chap, forest		✓	✓		✓	✓		✓		
Fraxinus dipetala	California Ash	deciduous tree	7-24	✓	✓	✓	chap., woodland	✓	✓		✓ ✓	✓			✓		
Fremontodendron californicum	California Flannelbush; Fremontia	evergreen shrub	7-24	✓	✓	✓	chaparral, forest	✓			✓ ✓				✓		
Galvezia speciosa	Island Bush Snapdragon	evergreen shrub	14-24	✓	✓		css	✓	✓			✓			✓		
Grindelia stricta	Gum Plant	evergreen herb. perenn.		✓	✓		css, chap, beach	✓	✓		✓	✓			✓		
Helianthemum scoparium	Sun Rose	herbaceous subshrub		✓	✓	✓	css, forest	✓	✓		✓ ✓				✓		✓

Southern California Master Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Heteromeles arbutifolia	Toyon	broadleaf evergreen tree/shrub	5-9, 14-24	✓	✓	✓	chaparral	✓	✓		✓ ✓				✓		
Huechera maxima	Island Alum Root	evergreen perennial		✓		✓	css, chaparral		✓	✓	✓	✓			✓	✓	
Hyptis emoryi	Desert Lavender	semi-ever shrub		✓	✓	✓	scrub	✓	✓		✓ ✓				✓		
Iris douglasiana *	Douglas Iris	herbaceous perennial	4-9, 14-24	✓	✓	✓	grassland, forest	✓	✓	✓	✓	✓			✓	✓	
Isocoma menziesii var. menziesii	Menzies' Goldenbush	evergreen subshrub		✓			css, beach/dune	✓	✓		✓ ✓				✓		✓
Iva hayesiana	Hayes Iva	evergreen shrub		✓	✓	✓	css, marsh	✓	✓		✓ ✓				✓	✓	✓
Juncus patens	California Gray Rush	perennial rush	8-24	✓	✓	✓	riparian	✓	✓	✓	✓ ✓	✓	✓	✓	✓	✓	
Keckiella antirrhinoides	Yellow Bush Penstemon	semi-evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓ ✓				✓		
Lasthenia californica	California Goldfields	annual		✓	✓		css, woodland	✓	✓		✓ ✓	✓			✓		✓
Lepechinia fragrans	Fragrant Pitcher Sage	semi-evergreen shrub		✓	✓		chaparral	✓	✓		✓	✓			✓		
Leymus condensatus 'Canyon Prince'	Canyon Prince Wild Rye	bunchgrass		✓	✓	✓	css, chaparral, woodland	✓	✓		✓	✓			✓	✓	
Leymus triticoides 'Grey Dawn' *	Grey Dawn Creeping Wild Rye	creeping perennial grass		✓	✓	✓	css, chaparral, woodland	✓	✓	✓	✓	✓	✓			✓	
Linum lewisii *	Blue Flax	herbaceous perennial		✓	✓	✓	many	✓	✓	✓	✓	✓	✓	✓	✓		
Lonicera subspicata	Chaparral Honeysuckle	deciduous vine/shrub		✓	✓		chaparral	✓	✓		✓ ✓				✓		
Lotus scoparius	Deerweed	herbaceous perennial		✓	✓		chaparral	✓	✓		✓ ✓				✓		
Lyonothamnus floribundus ssp. Asplenifolius	Fern-leaved Catalina Ironwood	broadleaf evergreen tree	15-17, 19-24	✓	✓		chap., woodland	✓			✓ ✓				✓		
Mahonia nevinii	Nevin's Barberry	evergreen shrub	8-24	✓	✓	✓	css, chaparral	✓			✓ ✓	✓			✓	✓	
Malacothamnus fasciculatus	Chaparral Mallow	evergreen shrub		✓	✓		css, chaparral	✓			✓ ✓				✓		

Southern California Master Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Malosma laurina (Rhus laurina)	Laurel Sumac	evergreen shrub		✓	✓		css, chaparral	✓			✓ ✓				✓		
Mimulus cardinalis	Scarlet Monkeyflower	herbaceous perennial	4-24	✓	✓	✓	riparian	✓	✓	✓			✓	✓		✓	
Mirabilis californica	Wishbone Bush	perennial		✓		✓	chap., grassland	✓			✓	✓			✓		✓
Muhlenbergia rigens *	Deergrass	bunchgrass	4-24	✓	✓	✓	many	✓	✓		✓ ✓				✓	✓	
Myrica californica	Pacific Wax Myrtle	broadleaf evergreen tree/shrub		✓	✓		css, chaparral	✓	✓			✓	✓		✓	✓	
Nasella pulchra *	Purple Needlegrass	bunchgrass		✓	✓	✓	css, chaparral, woodland	✓	✓		✓ ✓				✓		✓
Opuntia littoralis	Coastal Prickly Pear	low-growing cactus		✓	✓		css, chaparral	✓			✓ ✓				✓		✓
Ornithostaphylos oppositifolia	Baja Bird Bush	evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓ ✓				✓		
Pinus coulteri	Coulter Pine	evergreen tree		✓	✓	✓	woodland, forest	✓			✓				✓		
Pinus sabiniana	Foothill Pine	evergreen conifer		✓	✓	✓	woodland	✓			✓ ✓				✓		
Pinus torreyana	Torrey Pine	evergreen conifer		✓	✓		woodland	✓			✓ ✓				✓		
Platanus racemosa	California Sycamore	deciduous tree	4-24	✓	✓		riparian	✓			✓ ✓	✓	✓		✓	✓	
Polypodium californicum	California Polypody	summer-dormant fern		✓	✓	✓	css, chaparral, woodland		✓	✓			✓	✓		✓	
Populus fremontii	Fremont Cottonwood	deciduous tree	7-24	✓	✓	✓	riparian	✓			✓	✓	✓		✓		
Prunus ilicifolia ssp. Ilicifolia	Hollyleaf Cherry	broadleaf evergreen tree/shrub	7-9, 12-24	✓	✓	✓	chap, woodland	✓	✓		✓ ✓				✓		
Quercus agrifolia	Coast Live Oak	broadleaf evergreen tree	7-9, 14-24	✓	✓		chap, woodland	✓			✓ ✓				✓		
Quercus chrysolepis	Canyon Live Oak	broadleaf evergreen tree	3-11, 14-24	✓	✓	✓	woodland	✓	✓		✓	✓			✓		
Quercus engelmannii	Engelmann Oak	broadleaf evergreen tree	7-9, 14-21	✓	✓		grassland, woodland	✓			✓ ✓				✓		
Quercus kelloggii	Black Oak	deciduous tree	5-9, 14-21	✓	✓	✓	woodland, forest	✓			✓	✓			✓		

Southern California Master Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Quercus lobata	Valley Oak	deciduous tree	4-9, 12-24	✓	✓	✓	grassland, woodland	✓			✓	✓			✓		
Rhamnus californica	Coffeeberry	evergreen shrub	4-9, 14-24	✓	✓		chap, woodland	✓	✓		✓	✓			✓		
Rhamnus californica 'Eve Case'	Coffeeberry	evergreen shrub	4-24	✓	✓		chap, woodland	✓	✓		✓	✓			✓		
Rhamnus crocea	Redberry	evergreen shrub	14-21	✓	✓		css, chaparral	✓	✓		✓ ✓				✓		
Rhamnus ilicifolia	Hollyleaf Redberry	evergreen shrub	7-16, 18-21	✓	✓	✓	chaparral, woodland, forest	✓	✓		✓ ✓				✓		
Rhus integrifolia	Lemonadeberry	evergreen shrub	8, 9, 14-17, 19-24	✓	✓		css, chaparral	✓	✓		✓ ✓				✓		
Rhus ovata	Sugar Bush	evergreen shrub	9-12, 14-24	✓	✓	✓	css, chaparral	✓	✓		✓ ✓				✓		
Ribes aureum var. gracillimum	Golden Currant	semi-deciduous shrub	1-24		✓	✓	chap., woodland	✓	✓		✓ ✓	✓			✓		
Ribes malvaceum 'Dancing Tassels'	Dancing Tassels Currant	deciduous shrub	6-9, 14-21	✓	✓	✓	chap., woodland	✓	✓	✓	✓	✓			✓		
Ribes speciosum	Fuchsia Flowering Gooseberry	deciduous shrub	8, 9, 14-24	✓	✓	✓	chap., woodland		✓	✓		✓	✓		✓	✓	
Ribes viburnifolium	Catalina Perfume	evergreen shrub	8, 9, 14-24	✓	✓	✓	css	✓	✓	✓	✓ ✓	✓			✓	✓	
Romneya coulteri	Matilija Poppy	clumping semi-evergreen perennial	4-12, 14-24	✓	✓		css, chaparral	✓	✓		✓				✓		
Romneya trichocalyx	Hairy Matilija Poppy	clumping semi-evergreen perennial		✓	✓	✓	css, chaparral	✓			✓ ✓				✓		
Rosa californica	California Wild Rose	semi-deciduous shrub		✓	✓	✓	riparian, woodland	✓	✓	✓		✓	✓		✓	✓	
Salix lucida ssp. Lasiandra	Lance-leaf Willow	deciduous tree		✓	✓	✓	many	✓	✓				✓	✓		✓	
Salvia apiana	White Sage	evergreen shrub		✓	✓		css, chaparral	✓			✓ ✓				✓		
Salvia cedrosensis	Cedros Island Sage	perennial		✓			scrub	✓	✓		✓ ✓				✓		✓
Salvia clevelandii	Cleveland Sage	evergreen shrub	8, 9, 12-24	✓	✓		css, chaparral	✓	✓		✓ ✓				✓		
Salvia greggii	Autumn Sage	woody perennial	8-24		✓	✓	grassland, woodland	✓	✓		✓ ✓	✓			✓		✓

Southern California Master Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Sporobolus airoides	Alkali dropseed	perennial bunchgrass	1-24	✓	✓	✓	many	✓			✓	✓	✓		✓	✓	
Symphoricarpos mollis	Creeping Snowberry	groundcover	4-24	✓	✓		chap., woodland		✓	✓	✓	✓			✓		
Trichostema lanatum	Woolly Blue Curls	evergreen shrub	14-24	✓	✓		chaparral	✓			✓ ✓				✓		
Umbellularia californica	California Bay Laurel	broadleaf evergreen tree	4-10, 12-24	✓	✓	✓	woodland, forest	✓	✓		✓ ✓	✓			✓	✓	
Venegasia carpesioides	Canyon Sunflower	semi-evergreen subshrub		✓	✓	✓	css, chaparral, woodland	✓	✓	✓		✓	✓	✓	✓	✓	
Washingtonia filifera	California Fan Palm	palm tree	8-24		✓	✓	desert oasis	✓	✓				✓		✓		
Yucca schidigera	Mohave Yucca	succulent	10-24	✓	✓	✓	scrub	✓			✓ ✓				✓		
Yucca whipplei	Our Lord's Candle	succulent	2-24	✓	✓	✓	css, chap., scrub	✓	✓		✓ ✓				✓		

[1] References: *California Native Plants for the Garden*. Carol Bornstein, David Fross, & Bart O'Brien. Cachuma Press (2005). *California Native Trees & Shrubs*. Lee W. Lenz & John Dourley. Rancho Santa Ana Botanic Garden (1981). *Plants of El Camino Real*. Tree of Life Nursery (2004). *Western Garden Book*. Kathleen Norris Brenzel, ed. Sunset Publishing (2007).

[2] Indicates region that species may be grown in, based on horticultural references. Verify the cold-hardiness of desired species, especially for higher elevations. Coastal region includes Sunset *Western Garden Book* zones 22 and 24; Intermediate region includes Sunset zones 3, 20, 21, and 23; Inland region includes Sunset zones 2, 18, and 19.

[3] Note that some native plants may not be permitted in certain fire fuel management areas, or are only permitted under specific planting and management conditions. Consult with appropriate county fire authority as to the applicability of a proposed plant species list.

[4] H = high (full sun); M = medium (partial shade); L = low (full shade)

[5] Refers to summer water needed after establishment. VL = very low (summer water every 4 weeks; two check marks indicates that species may acclimate to seasonal rainfall, especially if planted in its native region and conditions); L = low (summer water every 4 weeks); M = medium (summer water every 2-3 weeks); H = high (summer water every week; some species may require constant moisture)

* Can be used in a native meadow planting as a lawn substitute, for example: *Achillea millefolium, Camissonia cheiranthifolia, Deschampsia caespitosa, Fragaria californica, Iris douglasiana, Leymus triticoides 'Gray Dawn', Linum Lewisii, Muhlenbergia rigens, Nasella pulchra, Salvia sonomensis, Sisyrhynchium bellum*

** Several Sedum species may be used for vegetated roofs, including: *S. clavatum, S. hakonense, S. lineare, S. nussbaumerianum, S. repestre, S. spathulifolium*

Table B-4. General Plant List

General Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Trees																	
Aesculus californica	California Buckeye	deciduous tree	4-10, 12, 14-24	✓	✓	✓	woodland	✓	✓		✓ ✓				✓		
Arbutus menziesii	Madrone	broadleaf evergreen tree	15-17, 19-24	✓	✓		woodland, forest	✓	✓			✓	✓		✓		
Arctostaphylos catalinae	Catalina Manzanita	broadleaf evergreen tree/shrub		✓	✓		chaparral	✓	✓		✓ ✓				✓		
Arctostaphylos 'Lester Rowntree'	Lester Rowntree Manzanita	broadleaf evergreen tree/shrub		✓	✓		chaparral	✓	✓		✓	✓			✓		
Brahea armata	Blue Hesper Palm	palm tree	10, 12-17, 19-24	✓	✓	✓	scrub	✓			✓	✓			✓		
Brahea edulis	Guadalupe Palm	palm tree	12-24	✓	✓		woodland	✓	✓		✓	✓			✓		
Calocedrus decurrens	Incense Cedar	evergreen tree	2-12, 14-24	✓	✓	✓	forest	✓	✓		✓	✓			✓		
Ceanothus arboreus	Island Ceanothus	broadleaf evergreen tree/shrub		✓	✓		css, chaparral	✓			✓	✓			✓		
Cercidium floridum	Blue Palo Verde	deciduous tree	10-14, 18-20	✓	✓	✓	scrub	✓			✓ ✓				✓		
Chilopsis linearis	Desert Willow	deciduous tree/shrub	7-14, 18-23	✓	✓	✓	riparian, scrub	✓			✓	✓	✓		✓		
Cupressus forbesii	Tecate Cypress	evergreen conifer	8-14, 18-20	✓	✓	✓	chaparral, forest	✓			✓				✓		
Fraxinus dipetala	California Ash	deciduous tree	7-24	✓	✓	✓	chap., woodland	✓	✓		✓ ✓	✓			✓		
Lyonothamnus floribundus ssp. asplenifolius	Fern-leaved Catalina Ironwood	broadleaf evergreen tree	15-17, 19-24	✓	✓		chap., woodland	✓			✓ ✓				✓		
Myrica californica	Pacific Wax Myrtle	broadleaf evergreen tree/shrub	4-9, 14-24	✓	✓		css, chaparral	✓	✓			✓	✓		✓		
Pinus coulteri	Coulter Pine	evergreen tree		✓	✓	✓	woodland, forest	✓			✓				✓		
Pinus sabiniana	Foothill Pine	evergreen conifer		✓	✓	✓	woodland	✓			✓ ✓				✓		

General Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Pinus torreyana	Torrey Pine	evergreen conifer		✓	✓		woodland	✓			✓ ✓				✓		
Platanus racemosa	California Sycamore	deciduous tree	4-24	✓	✓		riparian	✓			✓ ✓	✓	✓		✓		
Populus fremontii	Fremont Cottonwood	deciduous tree	7-24	✓	✓	✓	riparian	✓			✓	✓	✓		✓		
Quercus agrifolia	Coast Live Oak	broadleaf evergreen tree	7-9, 14-24	✓	✓		chap., woodland	✓			✓ ✓				✓		
Quercus chrysolepis	Canyon Live Oak	broadleaf evergreen tree	3-11, 14-24	✓	✓	✓	woodland	✓	✓		✓	✓			✓		
Quercus engelmannii	Engelmann Oak	broadleaf evergreen tree	7-9, 12-24	✓	✓		grassland, woodland	✓			✓ ✓				✓		
Quercus kelloggii	Black Oak	deciduous tree	5-9, 14-21	✓	✓	✓	woodland, forest	✓			✓	✓			✓		
Quercus lobata	Valley Oak	deciduous tree	4-9, 12-24	✓	✓	✓	grassland, woodland	✓			✓	✓			✓		
Umbellularia californica	California Bay Laurel	broadleaf evergreen tree	4-10, 12-24	✓	✓	✓	woodland, forest	✓	✓		✓ ✓	✓			✓		
Washingtonia filifera	California Fan Palm	palm tree	8-24		✓	✓	desert oasis	✓	✓				✓		✓		
Shrubs																	
Acalypha californica	California Copperleaf	evergreen shrub		✓	✓	✓	chaparral, scrub	✓	✓		✓ ✓				✓		
Arctostaphylos densiflora 'Howard McMinn'	McMinn Manzanita	broadleaf evergreen shrub	7-9, 14-21	✓	✓		chaparral	✓	✓		✓ ✓				✓		
Arctostaphylos glauca	Bigberry Manzanita	broadleaf evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓ ✓				✓		
Arctostaphylos manzanita	Common Manzanita	evergreen shrub		✓	✓	✓	chaparral, forest, woodland	✓	✓		✓ ✓				✓		
Arctostaphylos otayensis	Otay Manzanita	evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓ ✓				✓		
Arctostaphylos refugioensis	Refugio Manzanita	evergreen shrub		✓	✓		chaparral	✓	✓		✓				✓		
Artemisia californica	California Sagebrush	evergreen subshrub	1-24	✓	✓		css, chaparral	✓	✓		✓ ✓				✓		
Atriplex lentiformis ssp. Breweri	Quail Bush	evergreen or deciduous shrub	7-14, 18, 19	✓	✓	✓	scrub	✓			✓ ✓				✓		
Calycanthus occidentalis	Spice Bush	deciduous shrub	4-9, 14-24	✓	✓	✓	woodland, forest	✓	✓			✓	✓		✓		
Ceanothus crassifolius	Hoaryleaf Ceanothus	broadleaf evergreen shrub		✓	✓		chaparral	✓			✓ ✓				✓		

General Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Ceanothus greggii ssp. Perplexans	Cupleaf Lilac	broadleaf evergreen shrub			✓	✓	chaparral	✓			✓ ✓				✓		
Ceonothus griseus 'Santa Ana'	Santa Ana Ceonothus	evergreen shrub		✓			chaparral	✓	✓			✓	✓		✓		
Ceanothus impressus	Santa Barbara Ceanothus	evergreen shrub		✓			chaparral	✓	✓		✓ ✓				✓		
Ceanothus megacarpus	Big Pod Ceanothus	evergreen shrub		✓	✓		css, chaparral	✓			✓ ✓				✓		
Ceonothus verrucosus	Wartystem Ceonothus	evergreen shrub		✓	✓		css, chaparral	✓			✓ ✓				✓		
Ceanothus 'Concha'	Concha Ceanothus	evergreen shrub		✓	✓		chaparral	✓			✓	✓			✓		
Ceanothus 'Ray Hartman'	Ray Hartman Ceanothus	evergreen shrub	5-9, 14-24	✓	✓		css, chaparral	✓			✓	✓			✓		
Cercis occidentalis	Western Redbud	deciduous shrub/tree	2-24	✓	✓	✓	chaparral, woodland	✓	✓		✓	✓			✓		
Cercocarpus betuloides	Western Mountain Mahogany	evergreen shrub/tree	6-24	✓	✓	✓	chap., woodland	✓			✓ ✓				✓		
Cneoridium dumosum	Bushrue	evergreen shrub		✓	✓	✓	css, chaparral	✓	✓		✓ ✓				✓		
Dendromecon harfordii	Channel Island Bush Poppy	evergreen shrub	7-9, 14-24	✓	✓		chaparral	✓			✓ ✓				✓		
Dendromecon rigida	Bush Poppy	evergreen shrub	4-12, 14-24		✓	✓	chaparral	✓			✓ ✓				✓		
Encelia californica	Coast Sunflower	evergreen subshrub		✓	✓		css, chaparral	✓	✓		✓ ✓				✓		
Encelia farinose	Incienso	evergreen subshrub		✓	✓	✓	chap, scrub	✓			✓ ✓				✓		
Eriogonum arborescens	Santa Cruz Island Buckwheat	evergreen shrub	14-24	✓	✓		css, chaparral	✓	✓		✓	✓			✓		
Eriogonum fasciculatum	California Buckwheat	woody perennial	8, 9, 12-24	✓		✓	many	✓	✓		✓ ✓				✓		
Eriogonum grande var. rubescens	Red Buckwheat	evergreen subshrub	14-24	✓			beach/dune, css	✓	✓		✓	✓			✓		
Eriogonum parvifolium	Coastal Buckwheat	evergreen subshrub		✓			beach/dune, css	✓	✓		✓ ✓				✓		
Fallugia paradoxa	Apache Plume	semi-deciduous shrub	2-23	✓	✓	✓	scrub, woodland	✓			✓ ✓				✓		
Fremontodendron californicum	California Flannelbush	evergreen shrub	7-24	✓	✓	✓	chap, forest	✓			✓ ✓				✓		

General Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Galvezia speciosa	Island Bush Snapdragon	evergreen shrub	14-24	✓	✓		css	✓	✓			✓			✓		
Heteromeles arbutifolia	Toyon	broadleaf evergreen tree/shrub	5-9, 14-24	✓	✓	✓	chaparral	✓	✓		✓				✓		
Hyptis emoryi	Desert Lavender	semi-evergreen shrub		✓	✓	✓	scrub	✓	✓		✓				✓		
Isocoma menziesii var. menziesii	Menzies' Goldenbush	evergreen subshrub		✓			css, beach/dune	✓	✓		✓				✓		
Iva hayesiana	Hayes Iva	evergreen shrub	10-13	✓	✓	✓	css, marsh	✓	✓		✓				✓		
Justicia californica	Chuparosa	semi-deciduous shrub		✓	✓	✓	scrub	✓	✓		✓	✓	✓		✓		
Keckiella antirrhinoides	Yellow Bush Penstemon	semi-evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓				✓		
Lepechinia fragrans	Fragrant Pitcher Sage	semi-evergreen shrub		✓	✓		chaparral	✓	✓		✓	✓			✓		
Mahonia nevinii	Nevin's Barberry	evergreen shrub	8-24	✓	✓	✓	css, chaparral	✓			✓	✓			✓		
Malacothamnus fasciculatus	Chaparral Mallow	evergreen shrub		✓	✓		css, chaparral	✓			✓				✓		
Malosma laurina (Rhus laurina)	Laurel Sumac	evergreen shrub		✓	✓		css, chaparral	✓			✓				✓		
Ornithostaphylos oppositifolia	Baja Bird Bush	evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓				✓		
Prunus ilicifolia ssp. Ilicifolia	Hollyleaf Cherry	broadleaf evergreen tree/shrub	7-9, 12-24	✓	✓	✓	chap., woodland	✓	✓		✓				✓		
Rhamnus californica	Coffeeberry	evergreen shrub	4-9, 14-24	✓	✓		chap., woodland	✓	✓		✓	✓			✓		
Rhamnus californica 'Eve Case'	Coffeeberry	evergreen shrub	4-24	✓	✓		chap., woodland	✓	✓		✓	✓			✓		
Rhamnus crocea	Redberry	evergreen shrub	14-21	✓	✓		css, chaparral	✓	✓		✓				✓		
Rhamnus ilicifolia	Hollyleaf Redberry	evergreen shrub	7-16, 18-21	✓	✓	✓	chaparral, woodland, forest	✓	✓		✓				✓		
Rhus integrifolia	Lemonadeberry	evergreen shrub	8, 9, 14-17, 19-24	✓	✓		css, chaparral	✓	✓		✓				✓		
Rhus ovata	Sugar Bush	evergreen shrub	9-12, 14-24	✓	✓	✓	css, chaparral	✓	✓		✓				✓		

General Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Ribes aureum var. gracillimum	Golden Currant	semi-deciduous shrub	1-24		✓	✓	chap., woodland	✓	✓		✓ ✓	✓			✓		
Ribes malvaceum 'Dancing Tassels'	Dancing Tassels Currant	deciduous shrub	6-9, 14-21	✓	✓	✓	chap., woodland	✓	✓	✓	✓	✓			✓		
Ribes speciosum	Fuchsia Flowering Gooseberry	deciduous shrub	8,9, 14-24	✓	✓	✓	chap., woodland		✓	✓		✓	✓		✓		
Ribes viburnifolium	Catalina Perfume	evergreen shrub	8,9, 14-24	✓	✓	✓	css	✓	✓	✓	✓ ✓	✓			✓		
Rosa californica	California Wild Rose	semi-deciduous shrub		✓	✓	✓	riparian, woodland	✓	✓	✓		✓	✓		✓		
Salvia apiana	White Sage	evergreen shrub		✓	✓		css, chaparral	✓			✓ ✓				✓		
Salvia clevelandii	Cleveland Sage	evergreen shrub	8,9, 12-24	✓	✓		css, chaparral	✓	✓		✓ ✓				✓		
Salvia leucophylla	Purple Sage	semi-evergreen shrub	8, 9, 14-17	✓	✓		css, chap	✓			✓ ✓	✓			✓		
Salvia mellifera 'Tera Seca'	Tera Seca Sage	semi-evergreen subshrub		✓	✓		css, chaparral	✓	✓		✓	✓			✓		
Sambucus mexicana	Mexican Elderberry	deciduous shrub/tree	1-24	✓	✓	✓	css, chaparral, woodland	✓	✓				✓	✓	✓		
Simmondsia chinensis	Jojoba	evergreen shrub	7-24	✓	✓	✓	scrub	✓			✓ ✓				✓		
Trichostema lanatum	Woolly Blue Curls	evergreen shrub	14-24	✓	✓		chaparral	✓			✓ ✓				✓		
Groundcovers, Vines, Succulents, Perennials, Annuals																	
Achillea millefoilum *	Yarrow	herbaceous perennial	1-24	✓	✓	✓	many	✓	✓	✓	✓ ✓	✓	✓	✓	✓		
Adenostoma fasciculatum 'Nicolas'	Prostrate Chamise	groundcover	14-16, 18-24	✓	✓		chaparral	✓	✓		✓ ✓				✓		
Agave deserti	Desert Century Plant	succulent	12-24	✓	✓	✓	scrub	✓			✓ ✓				✓		
Agave shawii	Shaw's Century Plant	succulent		✓	✓		css	✓			✓ ✓				✓		
Arctostaphylos edmundsii 'Carmel Sur'	Carmel Sur Manzanita	groundcover	6-9, 14-24	✓	✓		ocean bluffs	✓	✓			✓			✓		
Arctostaphylos hookeri 'Monterey Carpet'	Monterey Carpet Manzanita	groundcover		✓	✓		woodland		✓		✓	✓			✓		
Arctostaphylos uva-ursi 'Point Reyes'	Point Reyes Bearberry	groundcover	1-9, 14-24	✓		✓	woodland	✓	✓	✓	✓				✓		
Arctostaphylos 'Pacific Mist'	Pacific Mist Manzanita	groundcover	7-9, 14-24	✓	✓		chaparral	✓	✓		✓	✓			✓		

General Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	V L	L	M	H	General	Bioretention	Roof
Aristolochia californica	California Dutchman's Pipe	deciduous vine		✓	✓	✓	woodland		✓	✓	✓	✓	✓		✓		
Artemisia californica 'Canyon Gray'	Canyon Gray Sagebrush	groundcover	1-24	✓	✓		css, chaparral	✓	✓		✓				✓		
Artemisia ludoviciana	Silver Wormwood	creeping perennial	1-24			✓	scrub	✓			✓				✓		
Baccharis pilularis 'Pigeon Point' or 'Twin Peaks'	Dwarf Coyote Bush	groundcover	5-11, 14-24	✓	✓	✓	css, chaparral	✓	✓		✓	✓			✓		
Baccharis pilularis ssp. consanguinea	Coyote Bush	woody perennial	5-11, 14-24	✓	✓		css, chaparral	✓	✓		✓ ✓				✓		
Baccharis 'Centennial'	Centennial Desert Broom	groundcover	10-13		✓	✓	scrub	✓	✓		✓ ✓				✓		
Calystegia macrostegia 'Anacapa Pink'	Island Morning-glory	evergreen vine		✓	✓		css, chaparral	✓	✓			✓			✓		
Camissonia (Oenothera) cheiranthifolia *	Beach Evening Primrose	herbaceous perennial		✓			beach/dune	✓	✓		✓ ✓	✓			✓		
Ceanothus griseus horizontalis 'Yankee Point'	Carmel Creeper	groundcover	5-9,14-17, 19-24	✓	✓		css, forest	✓	✓		✓	✓			✓		
Ceanothus hearstiorum	Heart Ceanothus	groundcover		✓			css, forest	✓	✓		✓	✓			✓		
Ceanothus maritimus	Maritime Ceanothus	groundcover		✓			css	✓	✓		✓	✓			✓		
Ceanothus 'Anchor Bay'	Anchor Bay Ceanothus	groundcover		✓	✓		css, forest	✓	✓			✓	✓		✓		
Dichelostemma capitatum	Wild Hyacinth	bulb	1-24	✓		✓	many	✓			✓ ✓				✓		
Distichlis spicata	Salt Grass	creeping perennial		✓		✓	beach/dune, marsh	✓	✓			✓	✓	✓	✓		
Dudleya hassei	Catalina Live-forever	succulent		✓		✓	css	✓	✓	✓	✓ ✓				✓		
Dudleya pulverulenta	Chalk Dudleya	succulent		✓	✓	✓	css, chaparral	✓	✓		✓ ✓				✓		
Epilobium californicum	California Fuchsia	herbaceous perennial		✓	✓	✓	many	✓	✓		✓ ✓				✓		
Epilobium canum	Hoary California Fuchsia	herbaceous perennial		✓	✓	✓	css, chaparral	✓	✓		✓ ✓				✓		
Eriogonum crocatum	Saffron Buckwheat	evergreen subshrub / herbaceous perennial	12-24	✓	✓		css	✓			✓ ✓				✓		
Eriogonum fasciculatum 'Dana Point'	Dana Point Buckwheat	groundcover	8, 9, 12-24	✓	✓		css	✓	✓		✓ ✓				✓		

General Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Eriophyllum confertiflorum	Golden Yarrow	herbaceous subshrub		✓	✓		many	✓	✓			✓	✓		✓		
Eschscholzia californica	California Poppy	annual	1-24	✓	✓	✓	scrub	✓			✓ ✓				✓		
Fragaria californica *	Woodland Strawberry	groundcover		✓	✓	✓	chaparral, forest		✓	✓		✓	✓		✓		
Grindelia stricta	Gum Plant	evergr. herb. perennial		✓	✓		css, chap, beach	✓	✓		✓	✓			✓		
Helianthemum scoparium	Sun Rose	herbaceous subshrub		✓	✓	✓	css, forest	✓	✓		✓ ✓				✓		
Huechera maxima	Island Alum Root	evergreen perennial		✓		✓	css, chaparral		✓	✓	✓	✓			✓		
Iris douglasiana *	Douglas Iris	herbaceous perennial	4-9, 14-24	✓	✓	✓	grassland, forest	✓	✓	✓	✓	✓			✓		
Lasthenia californica	California Goldfields	annual		✓	✓		css, woodland	✓	✓		✓ ✓	✓			✓		
Linum lewisii *	Blue Flax	herbaceous perennial		✓	✓	✓	many	✓	✓	✓	✓	✓	✓	✓	✓		
Lonicera subspicata	Chaparral Honeysuckle	deciduous vine/shrub		✓	✓		chaparral	✓	✓		✓ ✓				✓		
Lotus scoparius	Deerweed	herbaceous perennial		✓	✓		chaparral	✓	✓		✓ ✓				✓		
Mirabilis californica	Wishbone Bush	perennial		✓		✓	chap, grassland	✓			✓	✓			✓		
Opuntia littoralis	Coastal Prickly Pear	low-growing cactus		✓	✓		css, chaparral	✓			✓ ✓				✓		
Romneya coulteri	Matilija Poppy	clumping semi-everg perennial	4-12, 14-24	✓	✓		css, chaparral	✓	✓		✓				✓		
Romneya trichocalyx	Hairy Matilija Poppy	clumping semi-everg perennial		✓	✓	✓	css, chaparral	✓			✓ ✓				✓		
Salvia cedrosensis	Cedros Island Sage	perennial		✓			scrub	✓	✓		✓ ✓				✓		
Salvia greggii	Autumn Sage	woody perennial	8-24		✓	✓	grassland, woodland	✓	✓		✓ ✓	✓			✓		
Salvia sonomensis *	Creeping Sage	perennial	7-9, 14-24	✓	✓	✓	chap., woodland	✓	✓		✓				✓		

General Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Salvia spathacea	Hummingbird Sage	perennial		✓	✓		many		✓	✓	✓ ✓				✓		
Satureja douglasii	Yerba Buena	evergr. herb. perennial	4-9, 14-24	✓	✓		chap., woodland		✓	✓	✓	✓	✓		✓		
Sisyrhynchium bellum *	Blue-eyed Grass	perennial	4-24	✓	✓	✓	many	✓	✓		✓ ✓				✓		
Sphaeralcea ambigua	Desert Mallow	woody perennial			✓	✓	scrub	✓	✓		✓				✓		
Symphoricarpos mollis	Creeping Snowberry	groundcover	4-24	✓	✓		chap, woodland		✓	✓	✓	✓			✓		
Venegasia carpesioides	Canyon Sunflower	semi-evergreen subshrub		✓	✓	✓	css, chap, woodland	✓	✓	✓		✓	✓	✓	✓		
Yucca schidigera	Mohave Yucca	succulent	10-24	✓	✓	✓	scrub	✓			✓ ✓				✓		
Yucca whipplei	Our Lord's Candle	succulent	2-24	✓	✓	✓	css, chap, scrub	✓	✓		✓ ✓				✓		
Grasses and Grass-like Plants															✓		
Aristida purpurea	Purple Three-Awn	bunchgrass		✓	✓	✓	css, chaparral	✓	✓		✓ ✓				✓		
Bouteloua curtipendula	Side-oats Grama	bunchgrass		✓	✓	✓	scrub, woodland	✓			✓	✓			✓		
Carex pansa	California Meadow Sedge	creeping perennial		✓		✓	bluffs, strand	✓	✓	✓			✓	✓	✓		
Deschampsia caespitosa *	Tufted Hairgrass	perennial bunchgrass	1-24	✓	✓	✓	woodland, forest	✓	✓	✓	✓	✓	✓		✓		
Juncus patens	California Gray Rush	perennial rush	8-24	✓	✓	✓	riparian	✓	✓	✓	✓ ✓	✓	✓	✓	✓		
Leymus condensatus 'Canyon Prince'	Canyon Prince Wild Rye	bunchgrass		✓	✓	✓	css, chap, woodland	✓	✓		✓	✓			✓		
Muhlenbergia rigens *	Deergrass	bunchgrass	4-24	✓	✓	✓	many	✓	✓		✓ ✓				✓		
Nasella pulchra *	Purple Needlegrass	bunchgrass		✓	✓	✓	css, chap, woodland	✓	✓		✓ ✓				✓		
Sporobolus airoides	Alkali dropseed	perennial bunchgrass	1-24	✓	✓	✓	many	✓			✓	✓	✓		✓		

General Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof

[1] References: *California Native Plants for the Garden*. Carol Bornstein, David Fross, & Bart O'Brien. Cachuma Press (2005). *California Native Trees & Shrubs*. Lee W. Lenz & John Dourley. Rancho Santa Ana Botanic Garden (1981). *Plants of El Camino Real*. Tree of Life Nursery (2004). *Western Garden Book*. Kathleen Norris Brenzel, ed. Sunset Publishing (2007).
[2] Indicates region that species may be grown in, based on horticultural references. Verify the cold-hardiness of desired species, especially for higher elevations. Coastal region includes Sunset *Western Garden Book* zones 22 and 24; Intermediate region includes Sunset zones 3, 20, 21, and 23; Inland region includes Sunset zones 2, 18, and 19.
[3] Note that some native plants may not be permitted in certain fire fuel management areas, or are only permitted under specific planting and management conditions. Consult with appropriate county fire authority as to the applicability of a proposed plant species list.
[4] H = high (full sun); M = medium (partial shade); L = low (full shade)
[5] Refers to summer water needed after establishment. VL = very low (summer water every 4 weeks; two check marks indicates that species may acclimate to seasonal rainfall, especially if planted in its native region and conditions); L = low (summer water every 4 weeks); M = medium (summer water every 2-3 weeks); H = high (summer water every week; some species may require constant moisture)
* Can be used in a native meadow planting as a lawn substitute, for example: *Achillea millefolium, Camissonia cheiranthifolia, Deschampsia caespitosa, Fragaria californica, Iris douglasiana, Leymus triticoides 'Gray Dawn', Linum Lewisii, Muhlenbergia rigens, Nasella pulchra, Salvia sonomensis, Sisyrhynchium bellum*

Table B-5. Bioretention Plant List

Bioretention Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	V L	L	M	H	General	Bioretention	Roof
Trees																	
Chilopsis linearis	Desert Willow	deciduous tree/shrub	7-14, 18-23	✓	✓	✓	riparian, scrub	✓			✓	✓	✓			✓	
Myrica californica	Pacific Wax Myrtle	broadleaf evergreen tree/shrub	4-9, 14-24	✓	✓		css, chaparral	✓	✓			✓	✓			✓	
Platanus racemosa	California Sycamore	deciduous tree	4-24	✓	✓		riparian	✓			✓ ✓	✓	✓			✓	
Salix lucida ssp. lasiandra	Lance-leaf Willow	deciduous tree		✓	✓	✓	many	✓	✓				✓	✓		✓	
Umbellularia californica	California Bay Laurel	broadleaf evergreen tree	4-10, 12-24	✓	✓	✓	woodland, forest	✓	✓		✓ ✓	✓				✓	
Shrubs																	
Amorpha fruticosa	False Indigobush	deciduous shrub		✓	✓	✓	riparian	✓	✓	✓			✓	✓		✓	
Calycanthus occidentalis	Spice Bush	deciduous shrub	4-9, 14-24	✓	✓	✓	woodland, forest	✓	✓			✓	✓			✓	
Ceonothus griseus 'Santa Ana'	Santa Ana Ceonothus	evergreen shrub		✓			chaparral	✓	✓			✓	✓			✓	
Iva hayesiana	Hayes Iva	evergreen shrub		✓	✓	✓	css, marsh	✓	✓		✓ ✓					✓	
Justicia californica	Chuparosa	semi-decid shrub	10-13	✓	✓	✓	scrub	✓	✓		✓	✓	✓			✓	
Mahonia nevinii	Nevin's Barberry	evergreen shrub	8-24	✓	✓	✓	css, chaparral	✓			✓ ✓	✓				✓	
Ribes speciosum	Fuchsia Flowering Gooseberry	deciduous shrub	8, 9, 14-24	✓	✓	✓	chap., woodland		✓	✓		✓	✓			✓	
Ribes viburnifolium	Catalina Perfume	evergreen shrub	8, 9, 14-24	✓	✓	✓	css	✓	✓	✓	✓ ✓	✓				✓	
Rosa californica	California Wild Rose	semi-deciduous shrub		✓	✓	✓	riparian, woodland	✓	✓	✓		✓	✓			✓	
Sambucus mexicana	Mexican Elderberry	deciduous shrub/tree	1-24	✓	✓	✓	css, chaparral, woodland	✓	✓				✓	✓		✓	
Groundcovers, Vines, Succulents, Perennials, Annuals																	
Achillea millefoilum	Yarrow	herbaceous perennial	1-24	✓	✓	✓	riparian	✓	✓	✓			✓			✓	

Bioretention Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	V L	L	M	H	General	Bioretention	Roof
Artemisia douglasiana	Mugwort	herbaceous perennial		✓	✓	✓	css, chaparral	✓	✓		✓	✓				✓	
Baccharis pilularis 'Pigeon Point' or 'Twin Peaks'	Dwarf Coyote Bush	groundcover	5-11, 14-24	✓	✓		css, forest	✓	✓			✓	✓			✓	
Ceanothus 'Anchor Bay'	Anchor Bay Ceanothus	groundcover														✓	
Huechera maxima	Island Alum Root	evergreen perennial		✓		✓	css, chaparral		✓	✓	✓	✓				✓	
Iris douglasiana	Douglas Iris	herbaceous perennial	4-9, 14-24	✓	✓	✓	grassland, forest	✓	✓	✓	✓	✓				✓	
Mimulus cardinalis	Scarlet Monkeyflower	herbaceous perennial	4-24	✓	✓	✓	riparian	✓	✓	✓			✓	✓		✓	
Polypodium californicum	California Polypody	summer-dormant fern		✓	✓	✓	css, chaparral, woodland		✓	✓			✓	✓		✓	
Satureja douglasii	Yerba Buena	evergr. herb. perennial	4-9, 14-24	✓	✓		chap., woodland		✓	✓	✓	✓	✓			✓	
Venegasia carpesioides	Canyon Sunflower	semi-evergreen subshrub		✓	✓	✓	css, chaparral, woodland	✓	✓	✓		✓	✓	✓		✓	
Grasses and Grass-like Plants																	
Aristida purpurea	Purple Three-Awn	bunchgrass		✓	✓	✓	css, chaparral	✓	✓		✓ ✓					✓	
Carex pansa	California Meadow Sedge	creeping perennial		✓		✓	bluffs, strand	✓	✓	✓			✓	✓		✓	
Carex praegracilis	California Field Sedge	creeping perennial		✓	✓	✓	riparian	✓	✓	✓			✓	✓		✓	
Deschampsia caespitosa	Tufted Hairgrass	perennial bunchgrass	1-24	✓	✓	✓	woodland, forest	✓	✓	✓	✓	✓	✓			✓	
Distichlis spicata	Salt Grass	creeping perennial		✓		✓	beach/dune, marsh	✓	✓			✓	✓	✓		✓	
Eleocharis montevidensis	Spike Rush	grass-like perennial		✓	✓	✓	many	✓	✓	✓				✓		✓	
Juncus patens	California Gray Rush	perennial rush	8-24	✓	✓	✓	riparian	✓	✓	✓	✓ ✓	✓	✓	✓		✓	
Leymus condensatus 'Canyon Prince'	Canyon Prince Wild Rye	bunchgrass		✓	✓	✓	css, chaparral, woodland	✓	✓		✓	✓				✓	
Leymus triticoides 'Grey Dawn'	Grey Dawn Creeping Wild Rye	creeping perennial grass		✓	✓	✓	css, chaparral, woodland	✓	✓	✓	✓	✓	✓			✓	
Muhlenbergia rigens *	Deergrass	bunchgrass	4-24	✓	✓	✓	many	✓	✓		✓ ✓					✓	

Bioretention Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Scirpus cenuus	Low Bulrush	grass-like perennial		✓	✓		marsh	✓	✓	✓			✓	✓		✓	
Sporobolus airoides	Alkali dropseed	perennial bunchgrass	1-24	✓	✓	✓	many	✓			✓	✓	✓			✓	

[1] References: *California Native Plants for the Garden*. Carol Bornstein, David Fross, & Bart O'Brien. Cachuma Press (2005). *California Native Trees & Shrubs*. Lee W. Lenz & John Dourley. Rancho Santa Ana Botanic Garden (1981). *Plants of El Camino Real*. Tree of Life Nursery (2004). *Western Garden Book*. Kathleen Norris Brenzel, ed. Sunset Publishing (2007).
[2] Indicates region that species may be grown in, based on horticultural references. Verify the cold-hardiness of desired species, especially for higher elevations. Coastal region includes Sunset *Western Garden Book* zones 22 and 24; Intermediate region includes Sunset zones 3, 20, 21, and 23; Inland region includes Sunset zones 2, 18, and 19.
[3] Note that some native plants may not be permitted in certain fire fuel management areas, or are only permitted under specific planting and management conditions. Consult with appropriate county fire authority as to the applicability of a proposed plant species list.
[4] H = high (full sun); M = medium (partial shade); L = low (full shade)
[5] Refers to summer water needed after establishment. VL = very low (summer water every 4 weeks; two check marks indicates that species may acclimate to seasonal rainfall, especially if planted in its native region and conditions); L = low (summer water every 4 weeks); M = medium (summer water every 2-3 weeks); H = high (summer water every week; some species may require constant moisture)

Table B-6. Vegetated Roof Plant List

Vegetated Roof Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Shrubs																	
Euphorbia misera	Cliff Spurge	shrub		✓		✓	scrub	✓			✓						
Iva hayesiana	Hayes Iva	evergreen shrub		✓	✓	✓	css, marsh	✓	✓		✓ ✓						
Groundcovers, Vines, Succulents, Perennials, Annuals																	
Achillea millefoilum	Yarrow	herbaceous perennial	1-24	✓	✓	✓	many	✓	✓	✓	✓ ✓	✓	✓	✓			
Adenostoma fasciculatum 'Nicolas'	Prostrate Chamise	groundcover	4-16, 18-24	✓	✓		chaparral	✓	✓		✓ ✓						
Ambrosia chamissonis	Sand Bur	sprawling perennial		✓			dunes	✓			✓ ✓						
Ambrosia pumila	San Diego Ambrosia	groundcover		✓	✓		dunes	✓	✓		✓ ✓	✓					
Antigonon leptopus	San Miguel Coral Vine	climbing vine	12, 13, 18-24	✓	✓		chap, scrub	✓	✓			✓	✓				
Artemisia californica	California Sagebrush	evergreen subshrub	1-24	✓	✓		css, chaparral	✓	✓		✓ ✓						
Artemisia ludoviciana	Silver Wormwood	creeping perennial	1-24			✓	scrub	✓			✓						
Artemisia pycnocephala	Beach Sagewort	herbaceous perennial	1-24	✓		✓	css, dune	✓	✓		✓	✓					
Baileya multiradiata	Desert Marigold	perennial			✓	✓	scrub, grassland	✓			✓ ✓	✓					
Baccharis pilularis 'Pigeon Point' or 'Twin Peaks'	Dwarf Coyote Bush	groundcover	5-11, 14-24	✓	✓	✓	css, chaparral	✓	✓		✓	✓					
Camissonia (Oenothera) cheiranthifolia	Beach Evening Primrose	herbaceous perennial		✓			beach/dune	✓	✓		✓ ✓	✓					
Dichelostemma capitatum	Wild Hyacinth	bulb		✓		✓	many	✓			✓ ✓						
Dudleya hassei	Catalina Live-forever	succulent		✓		✓	css	✓	✓	✓	✓ ✓						
Dudleya pulverulenta	Chalk Dudleya	succulent		✓	✓	✓	css, chaparral	✓	✓		✓ ✓						
Epilobium californicum	California Fuchsia	herbaceous perennial		✓	✓	✓	many	✓	✓		✓ ✓						
Epilobium canum	Hoary California Fuchsia	herbaceous perennial		✓	✓	✓	css, chaparral	✓	✓		✓ ✓						
Eriogonum crocatum	Saffron Buckwheat	evergreen subshrub	12-24	✓	✓		css	✓			✓ ✓						

Vegetated Roof Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	V L	L	M	H	General	Bioretention	Roof
		/ herbaceous perennial															
Eriophyllum confertiflorum	Golden Yarrow	herbaceous subshrub		✓	✓		many	✓	✓			✓	✓				
Eschscholzia californica	California Poppy	annual	1-24	✓	✓	✓	scrub	✓			✓ ✓						
Helianthemum scoparium	Sun Rose	herbaceous subshrub		✓	✓	✓	css, forest	✓	✓		✓ ✓						
Isocoma menziesii var. menziesii	Menzies' Goldenbush	evergreen subshrub		✓			css, beach/dune	✓	✓		✓ ✓						
Lasthenia californica	California Goldfields	annual		✓	✓		css, woodland	✓	✓		✓ ✓	✓					
Mirabilis californica	Wishbone Bush	perennial		✓		✓	chap., grassland	✓			✓	✓					
Opuntia littoralis	Coastal Prickly Pear	low-growing cactus		✓	✓		css, chaparral	✓			✓ ✓						
Salvia cedrosensis	Cedros Island Sage	perennial		✓			scrub	✓	✓		✓ ✓						
Salvia greggii	Autumn Sage	woody perennial	8-24		✓	✓	grassland, woodland	✓	✓		✓ ✓	✓					
Salvia mellifera 'Tera Seca'	Tera Seca Sage	semi-evergreen subshrub		✓	✓		css, chaparral	✓	✓		✓	✓					
Salvia sonomensis	Creeping Sage	perennial	7-9, 14-24	✓	✓	✓	chap., woodland	✓	✓		✓						
Sedum sp. **	Sedum	succulent		✓	✓	✓		✓			✓ ✓	✓					
Sisyrhynchium bellum	Blue-eyed Grass	perennial	4-24	✓	✓	✓	many	✓	✓		✓ ✓						
Sphaeralcea ambigua	Desert Mallow	woody perennial			✓	✓	scrub	✓	✓		✓						
Grasses and Grass-like Plants																	
Aristida purpurea	Purple Three-Awn	bunchgrass		✓	✓	✓	css, chaparral	✓	✓		✓ ✓						
Bouteloua curtipendula	Side-oats Grama	bunchgrass		✓	✓	✓	scrub, woodland	✓			✓	✓					
Nasella pulchra	Purple Needlegrass	bunchgrass		✓	✓	✓	css, chap, woodland	✓	✓		✓ ✓						

Vegetated Roof Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof

[1] References: *California Native Plants for the Garden*. Carol Bornstein, David Fross, & Bart O'Brien. Cachuma Press (2005). *California Native Trees & Shrubs*. Lee W. Lenz & John Dourley. Rancho Santa Ana Botanic Garden (1981). *Plants of El Camino Real*. Tree of Life Nursery (2004). *Western Garden Book*. Kathleen Norris Brenzel, ed. Sunset Publishing (2007).

[2] Indicates region that species may be grown in, based on horticultural references. Verify the cold-hardiness of desired species, especially for higher elevations. Coastal region includes Sunset *Western Garden Book* zones 22 and 24; Intermediate region includes Sunset zones 3, 20, 21, and 23; Inland region includes Sunset zones 2, 18, and 19.

[3] Note that some native plants may not be permitted in certain fire fuel management areas, or are only permitted under specific planting and management conditions. Consult with appropriate county fire authority as to the applicability of a proposed plant species list.

[4] H = high (full sun); M = medium (partial shade); L = low (full shade)

[5] Refers to summer water needed after establishment. VL = very low (summer water every 4 weeks; two check marks indicates that species may acclimate to seasonal rainfall, especially if planted in its native region and conditions); L = low (summer water every 4 weeks); M = medium (summer water every 2-3 weeks); H = high (summer water every week; some species may require constant moisture)

** Several Sedum species may be used for vegetated roofs, including: *S. clavatum, S. hakonense, S. lineare, S. nussbaumerianum, S. repestre, S. spathulifolium*

Appendix C: California Planning and Regulatory Framework for LID

Introduction

Low Impact Development has been implemented in California for more than a decade being primarily driven by requirements in MS4 permits, which are backed by USEPA. LID has been integrated into the California planning process at varying levels in different jurisdictions. Since the general plan is the foundation of the California planning process, and LID should be addressed in general plans, LID should also be addressed in subsequent steps in the planning process. LID should be integrated at the earliest stage of the land planning process.

Planning Framework for LID

LID and General Plans

Although California has a variety of regional plans, including Regional Blueprints adopted by Councils of Governments, the cornerstone of the California planning process is the general plan. According to Thomas Kent, in his text The Urban General Plan (1964), a general plan is "the official statement of a municipal legislative body which sets forth its major policies concerning desirable future physical development." The general plan process is defined by Government Code Sections 65000-66037, which delegate most local land use decisions to individual cities and counties across the state. Each county and incorporated city is required to adopt "a comprehensive long term general plan for physical development."

General plans include development goals and policies and lay the foundation for land use decisions made by planning commissions, city councils, or boards of supervisors. General plans must contain text sections and maps or diagrams illustrating the general distribution of land uses, circulation systems, open space, environmental hazard areas, and other policy statements that can be illustrated. The Government Code specifies that general plans must contain seven mandatory elements or components: circulation, conservation, housing, land use, noise, open-space, and safety. Local governments may also voluntarily adopt other elements addressing topics of local interest. Cities and counties could adopt an optional water element in their general plans, but few have done so. Instead, water has most often been partially addressed in either the mandatory conservation element or in optional natural resources or public facilities elements. Water is frequently addressed only in terms of water supply and/or water conservation.

LID and Zoning

California law establishes zoning as a regulatory mechanism to implement general plans. Zoning is adopted by ordinances and must be consistent with general plans. Under a zoning ordinance, development is required to comply on a lot-by-lot basis with specific enforceable standards. Zoning ordinances specify categories of land use and associated standards such as minimum lot size, maximum building heights, and minimum building setbacks. Zoning ordinances can include overlay zones that provide additional standards for specified areas such as historic districts, wetlands, and other areas deemed to require extra protection.

Traditional zoning is often referred to as Euclidian zoning after the United States Supreme Court decision that affirmed the legality of zoning to separate land uses. Separation of uses became widespread as zoning gained popularity. LID is not specifically addressed in traditional zoning, but some of the standards included in specific zones can provide significant barriers to implementations of LID practices.

The planning profession and many communities have approached zoning differently that provides more flexibility regarding building areas within particular zones combined with more stringent

regulation of design elements such as architecture, landscaping, and pedestrian-friendly circulation systems. This form of zoning can help to implement smart growth, as was made possible by the approval in 2004 of Assembly Bill 1268, which allowed the use of form-based codes in the state. Form-based codes provide the flexibility to address LID and, in fact, invite the inclusion of detailed LID design elements.

LID and Municipal Codes

In addition to zoning, municipalities also have a variety of other codes and ordinances that impact the amount of impervious cover and the implementation of LID practices. The Local Government Commission (LGC) conducted a Code Review in Ventura County. This review focused on two overarching questions:

1. Which code (or combinations of codes) drives creation or prevention of excess land disturbances and impervious cover at the regional, community, or neighborhood level?

2. Which aspects of the code (or combination of codes) drive creation or prevention of excess land disturbance and impervious surface at the parcel, lot, or site level (in particular, directly connected impervious surfaces)?

The analysis examined code impacts on several drivers of overall imperviousness in watersheds, including open space, infill and redevelopment, compact design use mix, streets and mobility, parking, and site planning and environmental design. Within each category, the review included an overview of the land development elements and how they are typically treated within codes and ordinances as well as sample language and discussion of its relevance. In addition to zoning codes, the review examined: the State Streets and Highway Code; building codes; circulation codes; County Fire Protection District codes, standards, and ordinances; open space and growth management ordinances; plumed watercourse setback ordinances; subdivision ordinances; water quality ordinances; transfer of development rights (TDR) programs; floodplain management regulations; land development standards; landscape standards; and local road standards.

The codes that have the most widespread impact on imperviousness and implementation of LID practices are the zoning codes, landscape codes, parking codes, and subdivision codes.

LID and the California Environmental Quality Act (CEQA)

LID and the Purpose of CEQA

The question of the relationship between CEQA and LID is similar to the questions that have been asked about the relationship between CEQA and the New Urbanist argument, as detailed by Cindy van Empel in her article, “CEQA and New Urbanist Development.”[6] Van Empel concluded that the problem is due to varying interpretations of CEQA, rather than with the structure of CEQA itself. CEQA’s primary purpose is, in part, to maintain a quality environment, with significant consideration given to preventing environmental damage (PRC §21000). As stated in the CEQA Guidelines (CCR §15002), the basic purposes of CEQA are to inform decision makers of environmental impacts, identify ways to reduce impacts, prevent environmental damage where feasible, and disclose to the public why an agency decides to approve a project in spite of its impacts. CEQA is essentially a disclosure law.

LID in CEQA Guidelines

As noted in the CEQA Guidelines, the ideal timeframe for CEQA implementation is as early in the planning process as possible to "enable environmental considerations to influence project

[6] van Empel, C., 2008. “CEQA and New Urbanist Development.” *The Environmental Monitor*, Association of Environmental Professionals, Winter 2008. Sacramento, CA.

program and design and yet late enough to provide meaningful information for environmental assessment" [CCR §15004(b)]. As general plan development is the earliest planning stage, LID should be incorporated into general plans in California. Any subsequent municipal planning must be consistent with a municipality's general plan. In the case that a planning document is inconsistent with the general plan, a general plan amendment must be adopted such that the general plan remains the consistent guiding document for planning in a municipality. Incorporation of LID into general plans would provide support for its principles at the foundational level of development planning, and would serve to link LID with CEQA Guidelines.

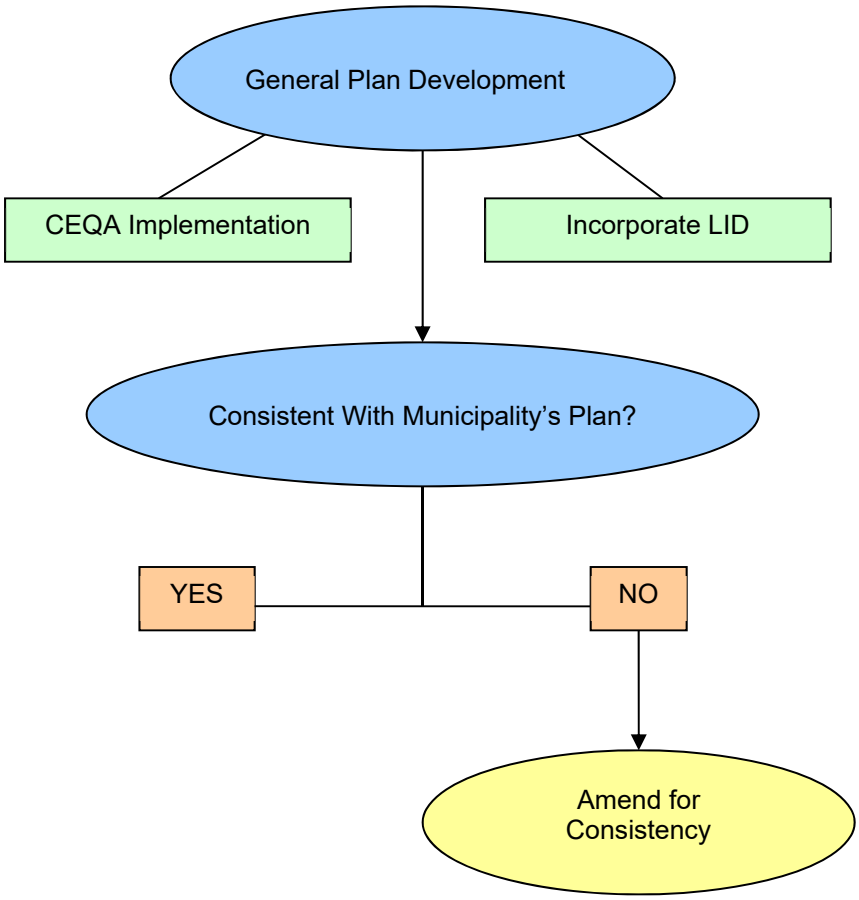

Figure C-1. LID and CEQA for a Municipality's Development Plan

Source: The Low Impact Development Center, Inc.

In order to support a municipality's preferred development pattern, it should establish significance thresholds that are consistent with general plan goals, objectives, and policies. Significance thresholds establish the framework for evaluation of impacts. They are similar to objectives or performance standards in that they provide a baseline measure against which proposals can be

compared. In most impact categories, municipalities and their departments establish their own significance criteria to reflect agency or municipality goals. The standard Initial Study Checklist, Appendix G of the CEQA Guidelines, indicates that the significance of an impact is a primary concern. The lead agency of a planning process is generally responsible for establishing significance thresholds that further its objectives and that are supported by substantial evidence (CCR §15064.7).

Recognition of LID in significance thresholds is another important means of incorporating LID into the planning process. If LID differs substantially from prevailing development policies, new significance thresholds will need to be established. Failure to create new significance thresholds that recognize LID will add time and expense to the development process in the form of additional CEQA review.

Policies and significance thresholds can be structured to require additional environmental review if a particular proposal does not comply with the general plan. Conversely, an agency can encourage a particular development pattern by minimizing the amount of environmental review needed for that development type. General plan policies, significance thresholds, and mitigation measures can be structured to support a preferred development type. The combination of general plan policies and adopted significance thresholds can greatly influence development patterns to favor those aligned with agency or municipality goals.

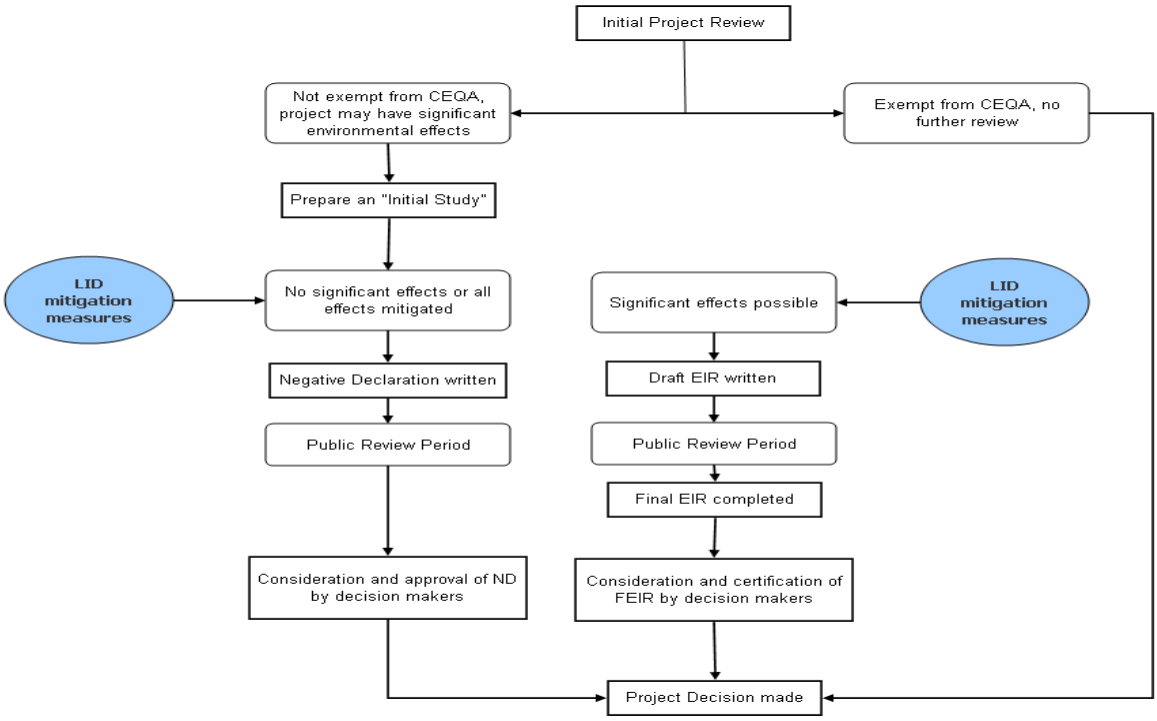

Figure C-2. LID in the CEQA Process.

Source: California Planning Guide: An Introduction to Planning in California; Governor's Office of Planning and Research, 2005

LID is Driven by Water Quality Regulation

LID in Water Boards' Strategic Plan

The use of LID measures in California is driven by water quality regulations and promoted by the Ocean Protection Council. The State Water Resources Control Board's formal adoption of its *Strategic Plan Update 2008-2012* restates the Board's vision of *"a sustainable California made possible by clean water and water availability for both human use and resource protection."* The update contains a sustainability principle and value that states, *"we commit to enhancing and encouraging sustainability within the administration of Water Board programs and activities by promoting water management strategies such as low impact development, considering the impacts of climate change in our decision-making, and coordinating with governmental, non-profit, and private industry, and business partners to further strategies for sustainability."*

In the *Strategic Plan Update,* the Water Boards have identified actions that they can realistically take in the next five years to implement these goals and objectives. Among these are:

- **Action 1.2.1.** Develop and adopt incentives and standard requirements, beginning with the general construction permit by December 2008, and water quality certifications by December 2009, that encourage or require local jurisdictions to implement LID/Green Infrastructure techniques that promote the infiltration, capture, and treatment of stormwater for reuse;

- **Action 1.2.2.** Establish a Low-Impact Development Center in the Central Coast Region by July 2009 to develop, deliver, and adapt (as needed) LID information, and to provide expertise that can be tailored to the needs of site-specific projects in the Central Coast Region. The LID Center will assist the Water Boards in identifying impediments to stormwater reuse and will be a pilot for longer range expansion of centers throughout the State; and

- **Action 1.2.3.** Collaborate with the State Water Board's Stormwater Advisory Task Force, the California Stormwater Quality Association, and other interested stakeholders to identify, prioritize for action, and begin to address by December 2010 impediments associated with the implementation of LID and stormwater reuse techniques. This includes working with the Department of Public Health and others to clarify existing regulations for stormwater reuse. If new regulations or guidance will take substantial time to develop, in the interim, clarify administratively what rules or practices local public health departments and Regional Water Boards should follow to facilitate stormwater reuse consistent with public health protection.

The Strategic Plan supports the determinations by the Board in Resolution No. 2008-0030 Requiring Sustainable Water Resources that state:

> ***Resolved 2****: Directs Water Boards' staff to require sustainable water resources management such as LID and climate change considerations, in all future policies, guidelines, and regulatory actions;*
>
> ***Resolved 3****: Directs State Water Board staff to identify policies and program areas to integrate climate change strategies and comply with the goals stated in Assembly Bill 32, based on the Water-Energy Climate Action Team process;*
>
> ***Resolved 4****: Directs Regional Water Boards to aggressively promote measures such as recycled water, conservation, and LID Best Management Practices where appropriate and work with Dischargers to ensure proposed compliance documents include appropriate, sustainable water management strategies; and*
>
> ***Resolved 7****: Directs Water Boards' staff to coordinate with partners from other government agencies, non-profit organizations, and private industry and business*

to further enhance and encourage sustainable activities within the administration of Water Board programs and activities.

Water Quality Grants Encourage LID

Not only are the State Water Resources Control Board and the Ocean Protection Council promoting LID through strategic plans and resolutions, they are structuring grant funding guidelines to facilitate construction of low impact development projects. Section 4 of Assembly Bill 739 (Statutes of 2007, Chapter 610, Laird) inserted language into the Public Resources Code specifying that funds shall be available *"for assistance in implementing low-impact development and other onsite and regional practices, on public and private lands, that seek to maintain predevelopment hydrology for existing and new development and redevelopment projects."*

Furthermore, the Stormwater Advisory Task Force, as part of its discussion of possible user stormwater grant program funds, considered evaluation of LID regulatory barriers and studies of how to implement LID on a watershed basis. The Task Force concluded that the focus should be on LID capital improvement projects in order to achieve something meaningful. However, up to 10% of the available grant funds will be allocated to finance the planning and monitoring necessary for successful design selection and implementation of capital projects. Integrated Regional Water Management Plans (IRWMPs) and watershed plans could be funded, as could studies to revise municipal ordinances, regulations, and site design standards to clearly allow and encourage the use of LID measures.

The Ocean Protection Council (OPC) has also taken action to use grant funds to help implement its June 2006 Five-Year Strategic Plan, **"A Vision for Our Ocean and Coast,"** the May 2008 Resolution of the California Ocean Protection Council Regarding Low Impact Development. The Council's Program Priorities for 2008-2010 (Ocean and Coastal Water Quality portion of Program Priorities) states, *"the OPC will initiate a competitive grant process to seek projects that address polluted runoff in various ways, including encouraging California communities to remove impediments to LID*." The OPC staff is in discussion with other state entities in an effort to increase the pool of funds available for projects to promote LID or reduce polluted runoff by other means.

Incorporating LID into the Planning Process

Start with the Ahwahnee Water Principles

The Ahwahnee Principles for Resource-Efficient Communities was written in 1991 by the California Local Government Commission and has served as a planning blueprint for the Smart Growth movement. The concept was for the principles to guide elected officials in developing compact, mixed use, walkable and transit-oriented communities as an alternative to existing urban and suburban sprawl patterns. The *Ahwahnee Principles for Economic Development* (1997) and the *Ahwahnee Water Principles* (2005) were added to expand upon and complement the original Ahwahnee Principles.

There are nine Community Principles and five Implementation Principles identified in the *Ahwahnee Water Principles.* These can be generally grouped into the following four categories, as stated in the four-page brochure created by the LGC to describe the Ahwahnee Principles:

1. Growing in a water-wise manner
2. Water-friendly neighborhood/site-scale planning and design strategies
3. Water conservation approaches to make the most efficient use of existing water supplies; and

4. A set of corollary guidelines that can help put the nine community principles into action through strategies for implementing practical steps to make the physical changes necessary to ensure water stability.

According to the *Ahwahnee Water Principles*:

- Natural resources such as wetlands, flood plains, recharge zones, riparian areas, open space, should be identified, preserved, and restored as valuable assets for such uses as flood protection and water quality improvement.
- Water holding areas, including creek beds, recessed athletic fields should be incorporated into urban landscapes.
- Landscaping should be designed to reduce water demand, retain runoff, and recharge groundwater.
- Permeable surfaces should be used for hardscape, with impervious surfaces minimized, so that land is available to absorb storm water, reduce polluted urban runoff, recharge groundwater and reduce flooding.
- Dual plumbing should be used to allow the use of greywater for landscape irrigation in new development.
- Community design should maximize use of recycled water for landscape irrigation, toilet flushing, and commercial/industrial uses, with purple pipe installed in new construction and redevelopment in anticipation of future recycled water use.
- Water conservation technologies for new construction and retrofit should be incorporated in new construction and redevelopment.
- Maximize locally available, drought-proof water supplies (i.e. groundwater treatment and brackish water desalination).

The Implementation Principles encourage the participation of water supply agencies, city and county officials, watershed councils, local agency formation commissions, special districts, and other stakeholders sharing watersheds to take advantage of the benefits of watershed-level planning. They note the importance of working with water supply agencies early in the planning and land use decision-making process in order to understand technology, demographics, and growth projections and incorporate them into the planning process. In addition, the Implementation Principles stress prioritization and implementation of multi-benefit and integrated projects before others and the importance of keeping the public informed and involved in the process from inception. Projects should be evaluated to inform and improve future plans and practices.

A list of the Ahwahnee Water Principles can be found at the LGC website: http://www.lgc.org/ahwahnee/h2o_principles.html.

Incorporating LID into General Plans

There are several viable methods of incorporating LID into general plans. One approach would involve amending existing general plan elements to incorporate LID principles, goals, and policies. Since water is most often addressed in the required conservation element, appropriate principles, goals, and policies could be added to this element. In a January 2008, report prepared for the Ocean Protection Council, entitled **"State and Local Policies Encouraging or Requiring Low Impact Development in California,"** The report recommends that a state LID statute should provide language for incorporating low impact development into the mandatory land use and conservation elements of general plans. In addition, since the land use element is the focus of local land use decisions, language on low impact development should also be added to the element. When water is addressed in another element, such as an optional natural resources or water element, LID language should be added to that element.

A second approach would be to develop a new water element. Few such optional elements have been adopted in California; however, the 2003 edition of the State of California General Plan Guidelines contains a detailed discussion of optional water elements. OPR stated,

> *"Given the importance of water to the state's future, a community would be well served to create a separate water element, in conjunction with the appropriate water supply and resource agencies, in which each aspect of the hydrologic cycle is integrated into a single chapter of the general plan. With recent law that requires land use decisions to be linked to water availability, a water element takes on increased importance."*

An optional element, such as a water element, can be amended at any time, which is important since LID is an evolving practice. To assist local governments in developing water elements, the LGC included a model water element as appendix to its July 2006 publication, *The Ahwahnee Water Principles, A Blueprint for Regional Sustainability*.

The model water element proposed by the LGC includes sample policies grouped into three sections: 1) Watershed protection and management; 2) Protecting and improving water quality; and 3) Managing supply and demand of water resources. The model element was designed to provide a policy framework to address the links between water and land use. It builds upon the Ahwahnee Water Principles.

Addressing LID Through Specific Plans

One of the most potentially useful planning tools to promote and facilitate LID may be the specific plan. A specific plan is a very flexible tool for systematically implementing general plans. Specific plans must be consistent with Section 65450-65457 of the Government Code. These provisions require that specific plans be consistent with the general plans of the jurisdictions that adopt them. The range of issues addressed and the area covered by specific plans is left to the discretion of the decision-making body of the city or county adopting the plan. Once a specific plan is adopted, all zoning regulations, all public works projects, and all subsequent subdivision and development must be consistent with the specific plan.

Section 65451 of the Government Code specifies the structure of a specific plan. The information that is to be presented by text and diagram includes the distribution, location and extent of land uses within the area covered by the plan. Specific plans also include:

> *"(2) The proposed distribution, location, and extent and intensity of major components of public and private transportation, sewage, water, drainage, solid waste disposal, energy, and other essential facilities proposed to be located within the area covered by the plan and needed to support the land uses described in the plan.*

In addition, the specific plans contain:

> *"(3) The Standards and criteria by which development will proceed, and standards for the conservation, development, and utilization of natural resources, where applicable," and*
>
> *"(4) A program of implementation measures including regulations, programs, public works projects, and financing measures necessary to carry out paragraphs (1), (2), and (3).*

Since specific plans are flexible and scalable by design, they can be used in different ways to implement LID. If adopted by resolution, a specific plan is a policy document. If adopted by

ordinance, a specific plan would be a regulatory document. An overlay specific plan could be adopted either by resolution or ordinance to address only the LID issue. Alternatively, a specific plan could be adopted to address the comprehensive development or redevelopment of a defined area and include LID requirements among the standards and implementation measures applicable to the area.

An example specific plan is being prepared for a portion of the City of San Bernardino as part of the Inland Empire Sustainable Watershed Program (IESWP), a Proposition 50 grant project funded through the CalFed Watershed Program of the California Department of Water Resources. This project, **"The Model Specific Plan for Watershed Sustainability"** was designed to "develop a guide for how urban planners can use land use design to create LID-friendly specific plans that implement LID at a community scale. This approach leverages the efficiency and opportunity of scale to streamline the MS4 storm water runoff permit compliance process.

The IESWP is a capacity building program to increase participation in watershed planning and management in the upper Santa Ana River watershed. It targets land use planners and decision-makers, the development community, and residents by providing products, resources, and forums that encourage the incorporation of watershed and low impact development approaches into the planning and development process.

Addressing LID Through Conditions of Approval

One method of addressing LID as early as possible in the planning process and of tracking implementation of LID practices would be to develop and apply both standard and non-standard conditions of approval. Most jurisdictions apply conditions of approval to the approval of development projects. These conditions often relate to a broad range of topics, including grading, drainage, landscaping, and water quality. Conditions of approval normally state what is to be done, who is to do it, when it is to be done, and who is responsible for determining compliance. Conditions are applied to discretionary planning permits and subdivision maps at different levels in the approval process and may be repeated at subsequent levels of approval when they would be informative to applicants or municipal staff.

Many jurisdictions have developed water quality conditions of approval. Such conditions often relate to pollution prevention during construction and planning for the installation of post-construction structural and non-structural water quality control measures.

New conditions of approval requiring consideration of, and planning for, implementation of low impact development measures could be added to the lists of conditions of approval. LID conditions of approval should be applied as early as possible in the project approval process and repeated at subsequent levels of approval to ensure compliance, timely implementation, and long-term maintenance.

LID and Municipal Codes and Ordinances

LID and Municipal Codes

Municipal codes can relate to low impact development in several ways. Cities and counties can adopt separate LID ordinances to require the use of LID principles in development projects and provide standards for the use of LID. An LID ordinance can specify when LID implementation plans are due and can specify compliance with criteria and standards in a manual or guidance document that can be updated as new information becomes available and as experience with implementation and maintenance of LID measures is gained.

Municipal codes may contain barriers to LID implementation. The magnitude of the barriers in existing ordinances will vary with the purpose of implementing LID measures. If the primary

purpose for implementing LID measures is to reduce runoff to improve water quality or to improve flood control, the barrier in existing ordinances may be less difficult to overcome than if the purpose is to achieve a broad watershed protection and enhancement goal.

Many types of codes and ordinances can influence the implementation of LID. Different codes may impact LID differently at different scales. At the site scale, building codes, landscape codes, parking codes, and zoning ordinances can influence site coverage, building dimension, parking requirements and landscaping. Parking codes have received special attention because vehicle parking is a major component of the built environment. These issues are discussed in detail in the January 2008 Tetra Tech analysis of **"State and Local Policies Encouraging or Requiring Low Impact Development in California**" and in an analysis of watershed-based planning strategies completed for Ventura County by the LGC.

New Ordinances to Facilitate LID

One direct way to use city and county codes to facilitate LID is to adopt specific LID ordinances to require the use of LID principles in development projects. This approach has been followed by the County of Los Angeles, which added a chapter to the Title 12 Environmental Protection of the Los Angeles County Code. This chapter is entitled LID Standards; its stated purpose is to require the use of LID principles in development projects. The chapter states, *"LID builds on conventional design strategies by utilizing every softscape and hardscape surface in the development to perform a beneficial hydrologic function by retaining, detaining, storing, changing the timing of, or filtering stormwater and urban runoff."* The ordinance requires that comprehensive LID plans that demonstrate compliance with an LID Standards Manual be submitted for review and approval by the Department of Public Works. It also specifies that urban and stormwater runoff quantity and quality control standards will be established in the LID Standards Manual that is to be updated and maintained by the Department of Public Works. For subdivisions, the LID plans must be approved prior to tentative map approval. For all other development, an LID plan must be approved prior to issuance of a grading permit or, where a grading permit is not required, prior to issuance of a building permit.

The Subdivision and Planning Zoning Titles of the Los Angeles County Code were amended to add reference to the Low Impact Development Title. In addition, the County adopted ordinances for green building and drought-tolerant landscaping. All three ordinances apply to all administrative and all discretionary projects.

Including LID in Stormwater Ordinances

LID can be included in new stormwater management ordinances or amended into existing ordinances. One example of this is the model developed by the Contra Costa County Clean Water Program for adoption by its member municipalities. This ordinance was adopted individually by the County of Contra Costa and the 19 cities and towns in the County after the San Francisco Bay Regional Water Quality Control Board added provision C.3 to the County's 1999 area-wide municipal NPDES permit in 2003. This provision is similar to the SUSMP provisions in other MS4 permits. The permittees began to implement provision C.3 in 2005.

This ordinance is a comprehensive stormwater management and discharge control ordinance. It incorporates LID by requiring that:

> *"Every application for a development project, including but not limited to a rezoning, tentative map, parcel map, conditional use permit, variance, site development permit, design review, or building permit that is subject to the development runoff requirements in the City's NPDES permit shall be accompanied by a stormwater control plan that meets the criteria in the most recent version of the Contra Costa Clean Water Program Stormwater C.3. Guidebook."*

The Guidebook contains step-by-step guidance for preparing the required Stormwater Control Plans. It also includes design procedures and calculation procedures, as well as guidance for the operation and maintenance of stormwater facilities.

Originally, the Stormwater Control Plan requirement applied, with some exceptions, to all developments that created one acre or more of impervious surface, including street and road projects and projects on previously developed sites that result in the addition or replacement of a combined total of one acre or more of impervious surface. Effective August 15, 2006, it applies, again with some exceptions, to all projects that create 10,000 square feet or more of impervious surface.

The Contra Costa County Clean Water Program created an LID approach to implementing the Regional Water Board's requirements for applicable new developments to:

- Design the site to minimize imperviousness, detain runoff, and infiltrate runoff where feasible;
- Cover or control sources of stormwater pollutants;
- Treat runoff prior to discharge from the site;
- Ensure runoff does not exceed pre-project peaks and durations; and
- Maintain treatment and flow-control facilities.

Removing Barriers to LID in Current Codes

Removing barriers to LID in existing codes, including zoning codes, is likely to be a time consuming process and vary from jurisdiction to jurisdiction. Perceived barriers to implementation of LID measures are often the result of the needs and experience of multiple departments within a municipality. These departments have promoted standards to facilitate achieving a variety of goals and responsibilities. Not all perceived barriers will need to be removed from existing codes. It may be easier, at least initially, to use overlay zones or specific plans to facilitate implementation of LID practices in both new development and redevelopment projects. As more experience is gained with implementation of LID, standards could be modified in consultation with the departments that promoted the standards that are perceived by stormwater managers to be barriers to LID.

CASQA as part of a Proposition 84 grant from the State Water Board with its grant Project partners (Central Coast Low Impact Development Initiative, UC Davis, Local Government Commission) assisted 25 California municipalities including some Southern California municipalities with removing barriers to LID implementation. The goal of the Project was to achieve tangible progress in protecting and improving the quality of California waterbodies by addressing barriers to LID and encouraging LID implementation through the update of local codes and ordinances and standards that regulate new and redevelopment projects, by providing training regarding LID, and by providing extensive LID resources to local communities to assist them with implementation of LID in their jurisdictions. The Project provided direct assistance to 25 California municipalities to integrate LID into local regulations for public and private new and redevelopment projects. Access to all of the LID resources provided as part of this Project are available to municipalities throughout the state on the California LID Web-Portal located at www.californialid.org.

Resources

California Regional Water Quality Control Board, San Diego Region. 2007. *Waste Discharge Requirements for Discharges of Urban Runoff from the Municipal Separate Storm Sewer Systems (MS4s) Draining the Watersheds of the County of San Diego, the Incorporated Cities of San Diego County, the San Diego Unified Port District, and the San Diego County Regional Airport Authority.* San Diego, CA.

California Regional Water Quality Control Board, Los Angeles Region. 2008. *Draft Ventura County Municipal Separate Storm Sewer System Permit (NPDES Permit No. CAS004002),* 29 April 2008. Los Angeles, CA.

City of Los Angeles Department of Public Works, Bureau of Sanitation (LA DPW). 2009. *Draft Stormwater Low Impact Development (LID) Ordinance*. http://www.lastormwater.org/Siteorg/download/pdfs/public_anncmnts/LID/Transmittal1.pdf

City of Los Angeles Department of Public Works, Bureau of Sanitation (LA DPW). 2010. Board Report No. 1, January 15, 2010. *Proposed Amendment to the Los Angeles Municipal Code (LAMC) to Include a Low Impact Development (LID) Ordinance – Response to Council Files No. CF 09-1554 (Gruel-Reyes Motion)*. http://www.lastormwater.org/Siteorg/download/pdfs/public_anncmnts/LID/SignedBrdRpt1.11.10.pdf

Local Government Commission. 2005. *Ahwahnee Water Principles*. Sacramento, CA. http://www.lgc.org/ahwahnee/h2o_principles.html

Project Clean Water. 2008. *Countywide Model SUSMP: Standard Urban Stormwater Mitigation Plan Requirements for Development Applications.* July 16, 2008 Draft. San Diego, CA.

Governor's Office of Planning and Research, State of California. 2005. *California Planning Guide: An Introduction to Planning in California*. Walsh, S. et al, December 2005 Edition. Sacramento, CA. http://www.opr.ca.gov/planning/publications/California_Planning_Guide_2005.pdf

Governor's Office of Planning and Research, State of California. 2008. *CEQA and Climate Change: Addressing Climate Change Through California Environmental Quality Act (CEQA) Review*, June 19. 2008. Sacramento, CA. http://www.opr.ca.gov/ceqa/pdfs/june08-ceqa.pdf

Kent, T. *The Urban General Plan*. 1964. Chandler Publishing Co. San Francisco, CA.

Local Government Commission. 2006. *The Ahwahnee Water Principles*: *A Blueprint for Regional Sustainability.* Corbett, J. et al, July 2006. Sacramento, CA. http://water.lgc.org/Members/tony/docs/lgc_water_guide.pdf

Parolek, D. G., K. Parolek, and P. C. Crawford. 2008. *Form-Based Codes A Guide for Planners, Urban Designers, Municipalities, and Developers*. John Wiley & Sons, Inc.

Stein, E. D., S. Zaleski. 2005. *Managing Runoff to Protect Natural Streams: The Latest Developments on Investigation and Management of Hydromodification in California*, Technical Report #475. Southern California Coastal Water Research Project, December 2005.

van Empel, C. 2008. "CEQA and New Urbanist Development." *The Environmental Monitor*, Association of Environmental Professionals, Winter 2008. Sacramento, CA.

Appendix D: LID, LEED, and the Sustainable Sites Initiative

LID practices can not only accomplish stormwater management goals but can also aid in obtaining LEED (Leadership in Energy and Environmental Design) certification. The systems are categorized by development type, and internally divided into credit categories. The credit name, number, and LEED point-worth are provided, as well as the credit's intent, requirements, options, and in some cases, potential strategies. Information about LEED V 4.1 can be found at: https://new.usgbc.org/leed-v41#bdc

Table D-1. LEED for New Construction Credit Options

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP
Sustainable Sites	5.1	Site Development, Protect or Restore Habitat	1	Appropriate native plant selection, protect sensitive areas
	5.2	Site Development, Maximize Open Space	1	Minimize construction footprint
	6.1	Stormwater Design, Quantity Control	1	Multiple LID BMPs
	6.2	Stormwater Design, Quality Control	1	Multiple LID BMPs
	7.1	Heat Island Effect, Non-roof	1	Shade from trees, light colored pervious paving
	7.2	Heat Island Effect, Roof	1	Vegetated roof
Water Efficiency	1.1	Water Efficient Landscaping, Reduce by 50%	2	Rain barrels, cisterns, select appropriate plant species
	1.2	Water Efficient Landscaping, No Potable Use or No Irrigation	4	Soil amendments, capture/reuse
	2.1	Innovative Wastewater Technologies, Reduce potable by 50%	2	Capture/reuse
	3.1	Water Use Reduction, 30% Reduction	2	Capture/reuse
	3.2	Water Use Reduction, 35% Reduction	3	Capture/reuse
	3.3	Water Use Reduction, 40% Reduction	4	Capture/reuse
	3.1	Material Reuse, 5%	1	Multiple LID BMPs
Materials & Resources	3.2	Material Reuse, 10%	1	Multiple LID BMPs
	4.1	Recycled Content, 10%	1	Multiple LID BMPs
	4.2	Recycled Content, 20%	1	Multiple LID BMPs
	5.1	Regional Materials, 10%	1	Multiple LID BMPs
	5.2	Regional Materials, 20%	1	Multiple LID BMPs
		Total Possible Points:	**22**	

Source: The Low Impact Development Center, Inc.

The LEED for Neighborhood Development Rating System integrates the principles of smart growth, urbanism, and green building to bring buildings together into a neighborhood, and relate the neighborhood to its larger region and landscape (Congress of New Urbanism et al, 2009). These standards have been assembled through collaboration among the Congress of New Urbanism, the U. S. Green Building Council, and the Natural Resources Defense Council. The

partnership created the rating system to encourage developers to revitalize existing urban areas, reduce land consumption, reduce automobile dependence, promote pedestrian activity, improve air quality, decrease polluted stormwater runoff, and build more livable, sustainable, communities for people of all income levels (Congress of New Urbanism et al, 2009). Credit categories relating to LID include: Smart Location & Linkage and Green Construction & Technology. The table below provides examples of LEED credits that LID can be used to address.

Table D-2. LEED for Neighborhood Development Credit Options

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP/Strategy
Smart Location & Linkage	8.1	Steep Slope Protection	1	Vegetated swales, native plants
	9.1	Site Design for Habitat or Wetland Conservation	1	Native plants, infiltration basins, dry ponds, constructed wetlands
	10.1	Restoration of Habitat or Wetlands	1	Restore vegetation
	11.1	Conservation Management of Habitat or Wetlands	1	Preserve existing vegetation and sensitive areas
Neighbor-hood Patter & Design	1.1	Compact Development	1-7	Minimize impervious areas
	6.1	Reduced Parking Footprint	2	Decrease size of parking spaces, pervious pavement
	7.1	Walkable Streets	4-8	Planting trees, curb bump-outs
	12.1	Access to Open Spaces	1	Minimize impervious areas
	13.1	Access to Active Spaces	1	Minimize impervious areas
	15.1	Community Outreach and Involvement	1	Informative signs on public LID structures, meetings
Green Construction & Technology	1.1	LEED Certified Green Buildings	1-3	Green roofs, cisterns, landscaping
	2.1	Energy Efficiency in Buildings	1-3	Green roofs, cisterns, landscaping
	3.1	Reduced Water Use	1-3	Cisterns, rain barrels
	6.1	Minimize Site Disturbance Through Site Design	1	Native vegetation preservation
	7.1	Minimize Site Disturbance Through Site Design	1	Minimizing construction footprint
	9.1	Stormwater Management	1-5	Vegetated swales

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP/Strategy
	10.1	Heat Island Reduction, Non-Roof	1	Shade from native trees, light colored pervious paving
	10.2	Heat island Reduction, Roof	1	Vegetated roof
		Total Possible Points:	**40**	

Source: The Low Impact Development Center, Inc.

The above tables display just some of the options for achieving LEED credit points through LID. There are many other points available under these systems as well as through the other seven rating systems that may be applicable to a given project. Some credit categories have prerequisites that must be met before credit certification can be achieved. The U.S. Green Building Council provides information about all of the LEED rating systems, listing all prerequisites, possible credits, and points.

The Green Building Certification Institute administers LEED certification for all commercial and industrial projects. The certification process begins with a determination of whether LEED is right for a project. The project must then be registered, signifying intent to develop a building which meets LEED certification requirements. Resources will be provided at this time that will assist with the application for certification. Application preparation will require a specific set of documents, depending on the desired credit or certification. Once all materials are assembled, the designated LEED Project Administrator is eligible to submit the application online.

Sustainable Sites Initiative

The Sustainable Sites Initiative, a partnership of the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center, and the United States Botanic Garden, has established Sustainable Sites Initiative Guidelines to certify sustainable landscapes. The Guidelines are modeled after the LEED program, and offer certification based on the use of prerequisites and credits for specific sustainable design practices. The Initiative is currently in its pilot phase. Ratings are based on a 250 point system. Projects can be awarded one to five stars, based on the number of credits earned. A minimum of 100 credits must be earned in order to be awarded one star. In addition to earning credits, projects must follow several prerequisites in order to qualify as sustainable sites. Up to 127 of these credits can be earned by following the LID Site Design Process described in this manual.

Table D-3. Sustainable Sites Initiative Prerequisite and Credit Options

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP/Strategy
Site Selection	Prerequisite 1.2	Protect floodplain functions		Protect sensitive areas
	Prerequisite 1.3	Preserve wetlands		Protect sensitive areas
	Prerequisite 1.4	Preserve threatened or endangered species and their habitats		Protect sensitive areas
	Credit 1.5	Select brownfields or greyfields for redevelopment	5-10	LID can be used on these sites
	Credit 1.6	Select sites within existing communities	6	LID can be used for redevelopment
	Credit 1.7	Select sites that encourage non-motorized transportation and use of public transit	5	LID can be used for redevelopment
Pre-Design Assessment and Planning	Prerequisite 2.1	Conduct a pre-design site assessment and explore opportunities for site sustainability		LID site assessment process
	Prerequisite 2.2	Use an integrated site development process		LID site planning strategies
Site Design – Water	Prerequisite 3.1	Reduce potable water use for landscape irrigation by 50 percent from established baseline		Plant adapted vegetation Capture/reuse
	Credit 3.2	Reduce potable water use for landscape irrigation by 75 percent or more from established baseline	2-5	Plant adapted vegetation Capture/reuse
	Credit 3.3	Protect and restore riparian, wetland, and shoreline buffers	3-8	Protect sensitive areas
	Credit 3.5	Manage stormwater on site	5-10	Multiple LID BMPs
	Credit 3.6	Protect and enhance on-site water resources and receiving water quality	3-9	Multiple LID BMPs
	Credit 3.7	Design rainwater/stormwater features to provide a landscape amenity	1-3	Multiple LID BMPs

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP/Strategy
	Credit 3.8	Maintain water features to conserve water and other resources	1-4	Multiple LID BMPs
Site Design – Soil and Vegetation	Prerequisite 4.2	Use appropriate, non-invasive plants		Revegetate disturbed areas
	Prerequisite 4.3	Create a soil management plan		Amend soils
	Credit 4.4	Minimize soil disturbance in design and construction	6	Minimize impervious areas Minimize construction footprint
	Credit 4.5	Preserve all vegetation designated as special status	5	Protect existing vegetation
	Credit 4.6	Preserve or restore appropriate plant biomass on site	3-8	Protect existing vegetation Revegetate disturbed areas
	Credit 4.7	Use native plants	1-4	Revegetate disturbed areas
Site Design – Soil and Vegetation	Credit 4.8	Preserve plant communities native to the ecoregion	2-6	Protect existing vegetation
	Credit 4.9	Restore plant communities native to the ecoregion	1-5	Revegetate disturbed areas
	Credit 4.10	Use vegetation to minimize building heating requirements	2-4	Vegetated roofs
	Credit 4.11	Use vegetation to minimize building cooling requirements	2-5	Vegetated roofs
	Credit 4.12	Reduce urban heat island effects	3-5	Minimize impervious areas Vegetated roofs Light-colored pervious pavement
Site Design – Materials Selection	Credit 5.2	Maintain on-site structures, hardscape, and landscape amenities	1-4	Minimize impervious areas
Site Design – Human Health and Well-Being	Credit 6.7	Provide views of vegetation and quiet outdoor spaces for mental restoration	3-4	Multiple LID BMPs
	Credit 6.8	Provide outdoor spaces for social interaction	3	Vegetated roofs

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP/Strategy
Monitoring and Innovation	Credit 9.2	Innovation in site design	8	LID Site Design Process
		Total Possible Points:	**127**	

Source: The Low Impact Development Center, Inc.

References and Resources

Congress of New Urbanism, Natural Resources Defense Council, and U.S. Green Building Council. 2009. *LEED 2009 for Neighborhood Development Rating System*. http://www.usgbc.org/DisplayPage.aspx?CMSPageID=148

Sustainable Sites Initiative. 2009. *The Sustainable Sites Initiative: Guidelines and Performance Benchmarks 2009*. http://www.sustainablesites.org/report

U.S. Green Building Council. 2009. *LEED 2009 for New Construction and Major Renovations Rating System*. http://www.usgbc.org/ShowFile.aspx?DocumentID=5546