California LID Evaluation and Analysis Network

(SMC CLEAN)

Phase I

Final Project Report

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EXECUTIVE SUMMARY

The mission of SMC CLEAN is to develop a thorough understanding of the effectiveness of LID BMPs in California both in the short term for use in calibration of watershed programs and the long term for modification of LID design, construction, and maintenance, through coordination with project partners and others performing LID monitoring. SMC CLEAN accomplishes this by serving as a clearing house for LID monitoring information, developing targeted LID research questions, performing targeted LID monitoring based on these questions, analyzing LID monitoring data, and providing recommendations for the design, construction, maintenance, and monitoring of LID in updates to the Southern California LID Manual to ensure that LID BMPs are implemented in the most effective manner.

This SMC CLEAN Project Report serves as the summary of SMC CLEAN Phase I. In furthering the mission of the SMC CLEAN this report provides an initial understanding of the effectiveness of LID BMPs in California, however more prevalently the report emphasizes the primary finding of SMC CLEAN Phase I, which is that currently there is a lack of existing data, monitoring data and meta data needed to perform the analysis necessary fora thorough understanding of the effectiveness of LID BMPs in California identified in the SMC CLEAN mission. A key finding of the SMC CLEAN Phase I and previous LID effectiveness evaluation work performed by the SMC and its partner agencies, is that long-term monitoring data for LID and GSI projects in Southern California are essential to truly understand the effectiveness of LID and GSI systems in Southern California. This report provides a pathway and process to obtain the monitoring data and meta data to perform the analysis needed to have a thorough understanding of the effectiveness of LID BMPs in California and achieve the SMC CLEAN mission. This pathway and process, identified in Section 5.5, serves as the primary recommendation and outcome of the SMC CLEAN Phase I and a plan for SMC CLEAN Phase II.

The SMC CLEAN project report is organized according to the five primary tasks of the SMC CLEAN Phase I project including:

- Task 1 - Form and coordinate a project Technical Advisory Committee
- Task 2 - Research existing data
- Task 3 - Implement initial monitoring procedures in a beta test phase
- Task 4 - Summarize all monitoring data, make recommendations, and update the LID Manual
- Task 5 - Ongoing collaboration with Project Partners

The report provides a summary of the efforts involved in and work products that resulted from each of the five SMC CLEAN Phase I tasks.

The initial work of the SMC regarding LID effectiveness was funded by a State Proposition 40 grant, and consistent with California Government Code Section 6219, the SMC CLEAN Project Report to the extent feasible is a document produced in plain, straightforward language, avoiding technical terms as much as possible, and using a coherent and easily readable style.

The primary findings and recommendations of the SMC CLEAN Phase I are:

Findings

- There is currently a lack of existing data, monitoring data and meta data needed to perform the analysis necessary for a thorough understanding of the effectiveness of LID BMPs in California.
- Very few organizations are conducting BMP performance monitoring or research across the SMC region.
- BMP performance monitoring that is being completed varies substantially in that different types of BMPs and configurations of BMPs are being monitored using a wide variety of monitoring plans/protocols with an inconsistent set of analytes.
- Meta data (e.g. design plans, inspection records, maintenance records) is not being collected for sites where BMP performance monitoring is being conducted, which can have significant effects on performance.
- Significant barriers exist for sharing unpublished BMP performance data for some organizations usually emanating from lack of understanding of what the data was stating as result of a number of reasons including: little or no data interpretation or processing, results not appearing to show the desired outcomes and hesitation regarding regulatory or public knowledge, or bureaucratic process.
- BMP performance monitoring data that has been performed by organizations is often kept in various locations including paper records, active or inactive databases, or other inaccessible locations that make data analysis and sharing difficult.
- BMP data compilation and sharing is important as analysis of individual BMP sites at specific locations are not representative of the performance of a type of BMP across the SMC Region.
- The lack of a centralized location for California specific BMP performance monitoring data and meta data is a barrier to performing analysis of a statistically significant data set over a long period of time to understand the performance of LID and GSI systems.

Recommendations

- A long-term study of at least 10 years is needed to allow for monitoring of a substantial amount of storm events. This will provide the data needed to conduct analyses to help understand how LID and GSI systems perform overtime and with a variety of factors, such as maintenance, that affect performance.
- There is a need for the development of a LID & GSI BMP data submittal tool so that there is a central repository for collected LID monitoring and meta data in Southern California. This

will allow for adequate data analysis to be performed to understand the primary elements that affect performance of LID & GSI BMPs in Southern California.

- An important element of any future work of the SMC focused on effectiveness of LID and GSI is to identify what the focus of future research should be. As part of the SMC CLEAN Phase I project, the focus was on bioretention and biofiltration as the most common LID and GSI BMP implemented in Southern California, however any future SMC work should identify if the scope of LID and GSI BMPs should go beyond bioretention/biofiltration to include other LID and GSI BMPs and if so, which targeted research questions should be answered for those BMPs.
- Many of the issues associated with the implementation of LID and GSI systems is the variety of different designs for the same LID or GSI system that make it difficult for contractors to construct these systems effectively. The SMC should evaluate the potential development of statewide LID & GSI BMP standards and specifications for California.
- Based on input from the SMC CLEAN TAC there is a desire to evaluate the development of a California LID & GSI BMP Testing and Certification Program. This effort should evaluate the need among MS4s, developers, regulators, academia, and manufacturers of proprietary LID & GSI BMP systems for the development of a California LID & GSI BMP Testing and Certification Program.
- Future state grants should specify that instead of individual grantees performing monitoring of their projects, entities such as the SMC CLEAN, SCCWRP, and SFEI should perform the monitoring using a standard monitoring protocol such as the SMC CLEAN Monitoring Protocol. This would allow a more consistent monitoring approach statewide resulting in comparable data, acquisition of needed monitoring data and meta data to evaluate the effectiveness of LID/GSI BMPs, and less burden on the grantee project proponents. Additionally, access to perform monitoring past the typical 3-year grant period should be included in the grant guidelines to have the ability for the monitoring entity obtain the needed long-term monitoring data and meta data to truly evaluate the effectiveness of LID/GSI BMPs in California.

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ACRONYMS AND ABBREVIATIONS

BMP	Best management practices
BSM	Bioretention soil media
CASQA	California Stormwater Quality Association
CLEAN	California LID Evaluation & Analysis Network
EPA	United States Environmental Protection Agency
GSI	Green Stormwater Infrastructure
LID	Low Impact Development
MS4	Municipal Separate Storm Sewer System
O&M	Operations and maintenance
SCCWRP	Southern California Coastal Water Research Project
SFEI	San Francisco Estuary Institute
SMC	Southern California Stormwater Monitoring Coalition
SWRCB	State Water Resources Control Board
TAC	Technical Advisory Committee
TKN	Total Kjeldahl Nitrogen
TPH	Total Petroleum Hydrocarbons
WQMP	Water Quality Management Plan

GLOSSARY

This draft glossary section will be modified specifically to the SMC CLEAN project.

Bioretention – Structural stormwater control practices that filter 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.

Biofiltration – Structural stormwater control practices that detain and filter 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.

Blue Roofs – Serve as a rooftop storage designed to reduce runoff peaks and volumes, also known as rooftop detention systems. Captured stormwater is held on the rooftop until the water either evaporates or is slowly metered out via flow restriction valves.

Evapotranspiration – The loss of water from the soil by evaporation and by transpiration from the plants growing in the soil.

Green Stormwater Infrastructure (GSI) - Constructed structural systems that are used to infiltrate, evapotranspire, treat, detain, and/or reuse stormwater. Green Stormwater Infrastructure uses natural processes for management of stormwater close to its source, thus reducing stormwater runoff and pollutant loading.

Green Roofs - Vegetated roof systems that filter, absorb, and retain or detain the rain that falls upon them. Green roofs are composed of a layer of soil media planted with vegetation.

Infiltration Basins - Basins designed to collect and infiltrate stormwater into the ground.

Infiltration Trenches - Narrow trenches that have been back-filled with stone that allow for stormwater to infiltrate into the ground.

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. LID is a comprehensive land development or retrofit approach that includes techniques to conserve and mimic natural hydrologic functions and reduce stormwater runoff and pollutants by managing rainfall, using a combination of LID site planning and LID site design techniques as well as LID structural systems or LID structural BMPs that infiltrate, filter, store, evaporate, and detain stormwater runoff.

Low Impact Development Site Planning - Evaluation and planning of a site with the primary planning principle of maintaining or restoring pre-development hydrology and minimizing the generation of runoff.

Low Impact Development Site Design – Design techniques to reduce and or disconnect impervious surfaces on a site including designing pervious functional surfaces such as green roofs and pervious pavement.

Low Impact Development Structural BMPs – Structural measures that retain or treat stormwater, usually the design capture volume.

Municipal Separate Storm Sewer System (MS4)[1] – 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, and 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 - "Green space" that provides a soil/plant mixture suitable for stormwater capture and treatment, usually associated with bioretention systems.

Soil Matrix - Bioretention soil matrix or biofiltration soil matrix is an engineered soil media for filtration of water and provides adsorption or absorption of pollutants and is made of mixture of fine sand and compost, which is based on a specific bioretention soil specification.

[1] The regulatory definition of an MS4 (40 CFR 122.26(b)(8)) is "a conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains): (i) Owned or operated by a state, city, town, borough, county, parish, district, association, or other public body (created to or pursuant to state law) including special districts under state law such as a sewer district, flood control district or drainage district, or similar entity, or an Indian tribe or an authorized Indian tribal organization, or a designated and approved management agency under section 208 of the Clean Water Act that discharges into waters of the United States. (ii) Designed or used for collecting or conveying storm water; (iii) Which is not a combined sewer; and (iv) Which is not part of a Publicly Owned Treatment Works (POTW) as defined at 40 CFR 122.2." (SWRCB 2013)

1 INTRODUCTION & BACKGROUND

The Stormwater Monitoring Coalition California LID Evaluation and Analysis Network (SMC CLEAN) is designed to understand the effectiveness of Low Impact Development (LID) and Green Stormwater Infrastructure (GSI) Best Management Practices (BMPs) in California. As LID and GSI continues to be the focus of stormwater permits and is increasingly implemented in California, an understanding of the effectiveness of the LID and GSI BMPs is needed. The SMC CLEAN has identified the key elements for a consistent approach to monitoring and determining the effectiveness of LID and GSI BMPs for pollutants of concern and for reduction in hydromodification impacts in California. The SMC CLEAN provides a comprehensive framework for understanding how design, soil matrix, construction/installation, maintenance, and other factors affect the performance of LID and GSI BMPs in California. The SMC CLEAN is focused on answering targeted research questions related to the effectiveness of LID and GSI BMPs in California and coordinates and collaborates with agencies and organizations which are engaged in efforts to monitor and understand the effectiveness of LID and GSI BMPs.

1.1 SMC LID Effectiveness Evaluation Background

The SMC identified a need for enhanced guidance and training to facilitate the implementation of LID techniques for projects in Southern California. In coordination with the SMC, the San Bernardino County Flood Control District (SBCFCD), applied for and was awarded funding under the State Proposition 40 Grant Program for the LID Guidance and Training Project ("LID Project") in 2006. The LID Project was funded with $600,000 from Proposition 40 grant funds, with approximately $500,000 in matching and additional monitoring funds provided by the SMC Member Agencies and the California Stormwater Quality Association (CASQA).

The LID Project envisioned a comprehensive plan to support effective implementation of LID in Southern California, as expressed in the 2008 SMC Agreement:

> "This Project will facilitate the implementation of Low Impact Development (LID) at the local government level. This is to be accomplished by a well-proven multiple step process that involves stakeholder, regulator, and design professionals in a collaborative effort that provides opportunities for feedback and adaptive management for the project. The project includes the selection and monitoring of a pilot project to show how LID can be used as an effective Best Management Practice (BMP) strategy. The project will also identify the best mechanisms by which to integrate LID into existing design, construction, and maintenance programs. The effectiveness of LID will be demonstrated by field monitoring and development of guidelines for design and life-cycle management. There will be a significant training component that will develop and communicate LID implementation information appropriate for the project watershed(s) and for other communities in the State."

The original 5-year scope of the LID project included:

- Define LID for Southern California

- Compile literature review and perform gap analysis
- Conduct pre and post manual training
- Develop the LID Manual
- Monitor to evaluate LID BMP effectiveness
- Develop feedback and update the manual based on monitoring findings

The SBCFCD led the project with the support of the SMC and a Technical Advisory Committee, which included training events, monitoring of LID BMPs and data evaluation, and the preparation of the LID Manual for Southern California. The LID Manual was posted on the California LID Portal (www.californialid.org) in April 2010. The SBCFCD submitted all the required final grant deliverables to the State Water Resources Control Board in 2010, including a technical memorandum with the monitoring data, evaluation, and recommendations.

Following the completion of the grant and after review of the Monitoring Technical Memorandum, the SMC determined that to fully achieve the purpose of the LID Project, substantially more monitoring data was needed for more BMPs over a longer time frame. The original grant-funded monitoring and evaluation was limited to the 3-year grant timeline, and further constrained by the very limited number of existing sites where field monitoring of LID BMPs could feasibly be conducted in the SMC Region. Therefore, the findings of the LID BMP monitoring technical memorandum were preliminary, and led to more questions. Although runoff volume and pollutant load reductions for constituents including total suspended sediments (TSS), several metals, pesticides, and nutrients were quantified for LID BMPs at the test sites, the data were quite variable, and confounding factors at the sites limited data interpretation. The strongest recommendations were for longer term studies to sample more events and suggestions for improvement of study designs to limit confounding factors.

Due to limited opportunities to work with existing LID BMP monitoring sites or to develop new pilot monitoring sites in the 3-year grant timeline, the monitoring budget for the LID Project was not fully expended. SMC partner funding originally included funds for monitoring in addition to the required grant matching funds. In 2011 and 2012, following the evaluation of the Monitoring Technical Memorandum, and realizing the growing need to better understand LID BMP effectiveness, the SMC developed an approach to reinitiate the LID monitoring and assessment tasks. The reinitiated project essentially picked up where the LID Project left off. The new project was scoped to: "review and revise the LID effectiveness monitoring program to incorporate new information or procedures, and to initiate the feedback and update process for the LID Manual and training materials."

The reinitiated project enhanced the approach to evaluate LID BMP effectiveness; which includes water quality monitoring of LID features, and extensive coordination and data collection from other LID implementation projects in southern California. The revised project scope included updates to the monitoring and LID BMP effectiveness evaluation tasks for the Project, to coordinate completion of revised Scope tasks, and coordinate with CASQA and stakeholders to update the LID Manual as appropriate, based on effectiveness results and to manage the project progress in coordination with the SMC. From 2013 to 2014, Dr. Matt Yeager, with the assistance from Daniel Apt and Scott Taylor of Michael Baker International, worked with the SMC members to develop a Scope of Work (SOW) for this project, funded from remaining SMC funds allocated to the overall project.

In the development of the Southern California LID Manual and associated tasks and the development of the later SOW to evaluate LID BMP effectiveness, the SMC recognized that LID concepts in Southern California are affected by differences associated with Southern California compared to the areas of the east coast where LID had been formulated and different from those areas such as the Pacific Northwest where LID has been successfully implemented. The primary difference is the overall semi-arid climate in Southern California, with its highly variable storm patterns. Overall the Mediterranean climate of Southern California is much dryer than other parts of the country where LID and GSI have been successfully implemented. However, there are also important regional differences within Southern California as the climate of the coastal plains, mountains, and deserts are very different and affect LID and GSI implementation. Additionally, in response to climate change, California is expected to experience longer periods of drought, a change in rainfall patterns with more intense storm events, less snowpack in higher elevations, and years of significantly higher rainfall with totals well above average. The variability in rainfall with some years being less than the average of 12 inches per year and some years being more than three times the average has a significant effect on how LID and GSI are implemented. With increasing variability in rainfall and changes in how California receives its precipitation (e.g. less snow pack), water supply is a primary concern that also affects LID and GSI. These differences support, why LID and GSI effectiveness be evaluated specifically for Southern California and not rely upon effectiveness studies performed in other parts of the country.

1.2 SMC CLEAN Phase I (2015-2020)

In August 2015, the SMC LID BMP Monitoring/Effectiveness project began with a consultant team that included Daniel Apt (project lead), Dr. Matt Yeager, and Dr. Michael Trapp. A Technical Advisory Committee (TAC) was formed and one of the first tasks was to brand the project. With input from the TAC the project was branded as the SMC California LID Evaluation and Analysis Network (SMC CLEAN). The tasks of the initial phase of the SMC CLEAN project included the following:

- Task 1 - Form and coordinate a project Technical Advisory Committee
- Task 2 - Research existing data
- Task 3 - Implement initial monitoring procedures in a beta test phase
- Task 4 - Summarize all monitoring data, make recommendations, and update the LID Manual
- Task 5 – Conduct ongoing collaboration with project partners

With input from the SMC CLEAN TAC the focus of the first phase of the SMC CLEAN project was to evaluate bioretention/biofiltration systems as the most common LID/GSI BMP being implemented in Southern California. Discussions with the SMC CLEAN TAC identified two primary needs to be addressed by the project. First, a short term need for a quantification of LID performance in southern California, needed to provide empirical data to calibrate estimates for compliance measures such as the recently developed watershed programs (i.e. EWMPs, WQIPs, etc.) and their associated watershed/water quality models [i.e. Reasonable Assurance Analysis (RAA), Reasonable Assurance Studies (RAS)]. The second is a long term need for a collaboration entity and clearinghouse of LID monitoring data in order to compile enough data to understand the effectiveness of various LID BMPs over time and understand how the differences in design, construction, and maintenance affect their performance. With LID and GSI BMPs being a significant portion of the portfolio of projects for watershed programs, collection and evaluation of LID and GSI effectiveness data is needed so the performance of these systems can be optimized to improve the likelihood of success in attaining and maintaining water quality objectives and waste load allocations. The following mission statement guided the SMC CLEAN project in addressing short- and long-term goals:

> The mission of SMC CLEAN is to develop a thorough understanding of the effectiveness of LID BMPs in California both in the short term for use in calibration of watershed programs and the long term for modification of LID design, construction, and maintenance, through coordination with project partners and others performing LID monitoring and serving as a clearing house for LID monitoring information, developing targeted LID research questions and performing targeted LID monitoring based on these questions, analysis of LID monitoring data, and recommendations for the design, construction, maintenance, and monitoring of LID in updates to the Southern California LID Manual to ensure that LID BMPs are implemented in the most effective manner.

A Work Plan was developed by the SMC CLEAN Consulting Team with input from the SMC CLEAN TAC and is provided in Appendix A. The Work Plan guided the implementation of the five tasks of the SMC CLEAN Project and identified how each task was to be performed. The structure of the SMC CLEAN Work Plan included mission, goals, and objectives of the project, an approach and work products for completion of the five project tasks, and a summary of the short-term and long-term targeted research questions. The goals identified in the Work Plan are related to the specific SMC CLEAN tasks. Each of the goals and related objectives are an expansion of the mission statement and include:

Goal #1: Development and Ongoing Facilitation of a Technical Advisory Committee to Assist in Accomplishing the SMC CLEAN Mission & Goals.

- Objective #1A: Identify Potential Research Questions
- Objective #1B: Develop Work Plan
- Objective #1C: Develop branding for the project

- Objective #1D: Ongoing coordination with consulting team and review comment of project products
- Objective #1E: Ongoing identification of Project Partners

Goal #2: Provide Ongoing Collaboration with Project Partners and Others Performing LID Monitoring and Serving as a Clearing House for LID Monitoring Information.

- Objective #2A: Ongoing collaboration with project partners to understand LID monitoring efforts and lessons learned.
- Objective #2B: Ongoing collaboration with project partners on potential future funding (i.e. grants) to make the SMC CLEAN project more robust and maximize the current funds allocated to the project.
- Objective #2C: Development of SMC CLEAN website for collaboration of project partners and a platform for the development of an LID Monitoring Clearing House
- Objective #2D: Evaluate development of an SMC CLEAN Online LID Data Submittal Tool/Clearing House

Goal #3: Development of Targeted LID Research Questions

- Objective #3A: Evaluate current LID monitoring data & LID research
- Objective #3B: Identify gaps in LID monitoring data
- Objective #3C: Identify Target LID Research Questions to answer short term need for use in calibration of watershed programs
- Objective #3D: Identify Target LID Research Questions to answer long term for modification of LID design, construction, and maintenance

Goal #4: Development of LID Monitoring Plan Elements

- Objective #4A: Development of Standard LID Project Data-Information List
- Objective #4B: Development of Standard LID/GSI Monitoring Protocol
- Objective #4C: Development of Data Sharing Protocol
- Objective #4D: Development of SMC CLEAN Database
- Objective #4E: Develop LID Operations Conceptual Model
- Objective #4F: Develop SMC CLEAN Monitoring Plan based on targeted LID research questions for short term and long term needs.

Goal #5: Perform Targeted LID Monitoring

- Objective #5A: Implement targeted LID monitoring to answer short term needs
- Objective #5B: Implement targeted LID monitoring to answer long term needs

Goal #6: Analyze LID Monitoring Data Collected

- Objective #6A: Analyze monitoring data to answer short term needs
- Objective #6B: Analyze monitoring data to answer long term needs

Goal #7: Make Recommendations & Update the Southern California LID Manual

- Objective #7A: Develop technical memorandum on bioretention/biofiltration performance for short term needs, for use in calibration of watershed programs and any associated recommendations for bioretention/biofiltration design, construction, maintenance, and monitoring
- Objective #7B: Develop technical memorandum on bioretention/biofiltration performance and associated recommendations for long term needs for modification of bioretention/biofiltration design, construction, maintenance, and monitoring.
- Objective #7C: Develop Standard Bioretention/Biofiltration Monitoring Design Plans and Specifications
- Objective #7D: Update the Southern California LID Manual to incorporate recommendations for bioretention/biofiltration design, construction, maintenance, and monitoring
- Objective #7E: Development SMC CLEAN Phase 1 Project Report

The following are some general challenges associated with the SMC CLEAN and evaluating the effectiveness of LID and GSI BMPs in California:

- Lack of existing data, monitoring data and meta data, in order to perform the analysis needed to have the thorough understanding of the effectiveness of LID and GSI BMPs.
- Monitoring LID and GSI BMPs in situ is challenging as most existing LID and GSI BMPs were not designed to be monitored.
- Multiple factors affect the performance of LID and GSI BMPs including design, construction, maintenance and lack of uniformity of LID and GSI BMP configuration and consistency in construction and maintenance present comparability problems.
- The potential for lack of precipitation in the arid Southern California climate with long periods of drought presents challenges with obtaining enough data over a defined monitoring periods.
- The lack of consistency in monitoring approaches makes comparing data challenging.
- The duration of monitoring is often too short which does not allow for understanding of the effectiveness of LID and GSI systems in various points in the systems operational lifetime.
- Funding to perform monitoring is often not available either locally or through statewide grants.
- Access to data if monitoring has been performed is not available due to logistics of housing data in local databases or restriction of access due to regulatory compliance concerns.

2 TASK 1: FORM AND COORDINATE A PROJECT TECHNICAL ADVISORY COMMITTEE

The purpose of the SMC CLEAN Technical Advisory Committee (TAC) was to provide technical expertise and input in the development and implementation of the SMC CLEAN Work Plan, targeted research questions, branding for the project, and subsequently implementation of the SMC CLEAN tasks and associated work products. The SMC CLEAN Consulting Team formulated the TAC, scheduled and facilitated TAC meetings, developed the Work Plan and schedule, coordinated with the TAC regarding branding of the SMC CLEAN Project, developed a project website, and developed procedures for TAC review of draft work products.

2.1 TAC Formulation and TAC Members

The formulation of the TAC included a request by the SMC CLEAN Consulting Team to the funding agencies of the SMC to identify appropriate members of the TAC. With input from SMC members, a list of potential TAC members representing LID experts and interests in the State of California was developed. The Consulting Team reached out to this list of people to identify their ability to serve on the TAC as well as an inquiry of other potential TAC members. The roster of the TAC was a result of this process. The TAC was formulated and first met in December 2015.

The make-up of the TAC included MS4s, regulatory agencies, the environmental community, the development community, the academic community, industry, and other LID experts that are engaged in the implementation and monitoring of LID in California. The TAC represents a good cross section of those experts involved in LID in California and represents a significant amount of the LID knowledge and experience in California. **Table 2-1** below provides a list of the SMC CLEAN TAC Members. Marc Rodabaugh initially and subsequently Arlene Chun of San Bernardino County Department of Public Works served as the contract manager for the project. **Table 2-2** below provides a list of the SMC CLEAN Interested Parties.

Table 2-1. SMC CLEAN TAC Members

TAC Member	Organization
Arlene Chun	San Bernardino County Department of Public Works
Marc Rodabaugh	San Bernardino County Department of Public Works
Chris Crompton	Orange County Public Works
Grant Sharp	Orange County Public Works
Jian Peng	Orange County Public Works
Ava Moussavi	Riverside County Flood Control and Water Conservation District
David Garcia	Riverside County Flood Control and Water Conservation District
Joanna Wisniewska	County of San Diego

TAC Member	Organization
Arne Anselm	Ventura County Watershed Protection District
Ivar Ridgeway	Los Angeles Regional Water Quality Control Board
Chris Lopez	Los Angeles Regional Water Quality Control Board
Adam Fischer	Santa Ana Regional Water Quality Control Board
Erica Ryan	San Diego Regional Water Quality Control Board
Brian Currier	CSUS Office of Water Programs
Darren Haver	UCCE
Scott Taylor	Michael Baker International
Jill Bicknell	SCVURP/EOA
Darla Elswick	LIDI/Consultant
Katie Day	Surfrider Foundation
Rick Wilson	Surfrider Foundation (Former Staff)
Eileen Alduenda	Council for Watershed Health
Ray Heimstra	Orange County CoastKeeper
Mark Grey	BIA/CICWQ
Ken Schiff	SCCWRP
Eric Stein	SCCWRP
Ashmita Sengupta	SCCWRP (Former Staff)
Nabiul Afrooz	SCCWRP (Former Staff)
Elizabeth Fassman-Beck	SCCWRP
Xavier Swamikannu	Consultant
Vaikko Allen	Contech
Gregor Patsch	2nd Nature (Former Staff)

Table 2-2. SMC CLEAN Interested Parties

Interested Person	Organization
Tracy Ingebrigtsen	Orange County Public Works
Jennifer Nowaczewski	Orange County Public Works
Harold Zamora	San Bernardino County Department of Public Works
Andrew Kleis	City of San Diego
Sumer Hasenin	City of San Diego
Sara Agahi	County of San Diego
Sheri McPherson	County of San Diego
Charles Mohrlock	County of San Diego
Jo Ann Weber	County of San Diego
Christopher Wolff	County of San Diego
David Laak	Ventura County Watershed Protection District
Alireza Rahmani	Los Angeles Regional Water Quality Control Board
Laurie Walsh	San Diego Regional Water Quality Control Board
Stanley Grant	UC Irvine/Virginia Tech
Matt Deines	UC Irvine
Richard Demerjian	UC Irvine
Pete Stauffer	Surfrider Foundation
Chris Solek	USACE
Michael Antos	SAWPA
Eric Bollens	Cloud Compli (Former Staff)

2.2 SMC CLEAN Work Plan Formulation

A Work Plan was developed by the SMC CLEAN Consulting Team with input from the SMC CLEAN TAC. The Work Plan guided the implementation of the five tasks of the SMC CLEAN Project and identified how each task was to be performed. The formulation of the Work Plan began in December of 2015 with the development of an annotated outline. Comments on the annotated outline were received from the TAC and a draft Work Plan was developed and provided to the TAC in May 2016. Comments were received on the Work Plan and revisions were made. Additional discussions and input on the Work Plan were received from the TAC and the Work Plan was finalized in August 2017, although work was already ongoing to implement the SMC CLEAN tasks including elements of the Work Plan. The Final SMC CLEAN Work Plan and is provided in Appendix A.

2.3 SMC Targeted Research Questions

As part of development of the SMC CLEAN Work Plan, the TAC identified that targeted research questions were needed to focus the work of SMC CLEAN. Completion of Work Plan Objective #1A Identify Potential Research Questions, resulted in collaboration with the TAC to help further define and articulate the details within the scope of work and Work Plan for the SMC CLEAN project. The specific research questions identified by the TAC for potential exploration are provided in the SMC CLEAN Targeted Research Questions provided in Appendix B.

Discussions with the SMC CLEAN TAC identified two primary needs associated with the project. The first was a short term need for a quantification of LID performance in Southern California, needed for use in providing empirical data to calibrate estimates for compliance measures such as the recently developed watershed programs (i.e. EWMPs, WQIPs, etc.) and their associated watershed/water quality models (i.e. RAA, RAS), and TMDLs. The second was more of a long term need to serve as collaboration entity and clearing house of LID monitoring data in order to understand the effectiveness of various LID BMPs overtime and understand how the differences in design, construction, and maintenance affect their performance. Completion of Work Plan Objectives #3C and #3D identified the following SMC CLEAN Targeted Research Questions:

<u>Objective 3C: Identify Target LID Research Questions to answer short term need for use in calibration of watershed programs</u>

- What are the pollution removal benefits of bioretention systems in Southern California?
    - Calculate/characterize the pollutant removal benefits of bioretention systems with underdrains.
    - Calculate/characterize the pollutant removal benefits of bioretention systems without underdrains.
    - If possible, discern whether changes in the bioretention soil matrix (BSM) being implemented in Southern California affects performance across pollutants.
- What are the hydrologic benefits of bioretention systems in Southern California?
    - Calculate/characterize the volume reduction of bioretention systems with underdrains.
    - Calculate/characterize the flow duration effects of bioretention systems.
    - Compare/evaluate the measured hydrologic benefits (volume and flow attenuation) with bioretention system design parameters.

Objective 3D: Identify Target LID Research Questions to answer long term for modification of LID design, construction, and maintenance

- How do specific bioretention designs/configurations affect pollutant removal and hydrologic performance?
  - What are the most common bioretention designs/configurations (isolate soil depth, aggregate depth, and underdrain configuration as the differentiating factors) being implemented in Southern California (identify maximum 3 configurations)?
- How do different bioretention plants affect pollutant removal and hydrologic performance?
  - How do systems with and without plants affect pollutant removal and hydrologic performance?
  - What are the effects of different plants as identified in studies by others?
- How does maintenance for bioretention systems affect pollutant removal and hydrologic performance?
  - What is the frequency of monitoring for an individual LID BMP that would need to be performed to identify the pollutant removal and hydrologic performance effects of maintenance of an individual LID BMP?
  - What type of maintenance records are needed to identify the pollutant removal and hydrologic performance effects of maintenance of an individual LID BMP?
  - Can preliminary conclusions be drawn regarding pollutant removal and hydrologic performance effects of maintenance with information currently being collected and if so, what are they?
- What kind of impacts are evident from improper construction of bioretention systems and how are these impacts affecting pollutant removal and hydrologic performance?
  - What are the typical construction errors that are seen with bioretention systems?
  - What are the qualitative impacts affecting pollutant removal and hydrologic performance of the typical construction errors that are seen with bioretention systems?
- What Southern California specific factors (i.e. climate) affect pollutant removal and hydrologic performance in comparison to bioretention data from project partners outside of Southern California?
  - What are the translators for Southern California of performance from bioretention studies performed elsewhere?
  - How do bioretention design parameters (soil depth, aggregate depth, and underdrain configuration) affect the translators?

2.4 Summary of TAC Meetings and Input

It was agreed at the first TAC meeting that the schedule of TAC meetings would be quarterly. Provided in Appendix C is summary of the SMC CLEAN TAC meetings including meeting agenda items, and key input provided.

3 TASK 2: RESEARCH EXISTING DATA

Research of existing data began at the beginning of the SMC CLEAN project. The methods to locate existing data are provided below. The primary findings of the research of existing data was that contrary to popular belief, there is not a significant amount of LID/GSI monitoring being completed by the SoCal stormwater community. Therefore, there is not much existing data which the SMC CLEAN project can leverage to answer the targeted research questions. The primary outcome of the SMC CLEAN through research of existing data is that there is currently a lack of existing data, monitoring data and meta data, in order to perform the analysis needed to have the thorough understanding of the effectiveness of LID and GSI BMPs. Additionally, access to data if monitoring has been performed is not available due to logistics of housing data in inaccessible local databases, lack of compilation of data, or restriction of access to data due to regulatory compliance concerns.

3.1 Background Literature Review

In 2007, a literature review was conducted as part of the initial phase of the LID Guidance and Training Project to support development of the LID Manual. SMC CLEAN Phase I reviewed additional and more recent literature (1999 – 2017) regarding the effectiveness of LID BMPs, including journal articles, agency reports, and graduate theses. The reviewed documents included four literature reviews, each of which independently summarized findings from 60 – 150 papers, and studies reporting results from field monitoring of BMPs (30), laboratory media performance testing (4), and hydrologic modeling of BMPs (3). Results from this review were used in developing the monitoring protocol discussed in Section 4, and for comparison of BMP performance.

3.2 Project Partners and SMC Members

The SMC CLEAN Consulting Team coordinated with SMC members and project partners to identify an obtain existing data to answer the SMC CLEAN targeted research questions. The following is a list of SMC members and project partners that were coordinated with to obtain existing data:

- County of Orange, OC Public Works
- County of San Diego Department of Public Works
- Riverside County Flood Control and Water Conservation District
- Los Angeles Green Streets Committee
- Council for Watershed Health
- Loyola Marymount University
- University of California Irvine
- University of California San Diego
- University of California South Coast Research and Extension Center

- Southern California Coastal Water Research Project

The following are the primary results of the coordination with SMC members and project partners to identify an obtain existing data:

1. Coordination with SMC members and other organizations revealed that surprisingly few were conducting BMP performance monitoring or research across the SMC region, including higher profile demonstration projects designed for monitoring.
2. Significant barriers existed for sharing unpublished data existed for some organizations. This seemed to be a consequence of a lack of understanding of what the data was saying as result of a number of reasons, including: little or no data interpretation or processing, results not appearing to show the desired outcomes and hesitation regarding the regulatory or public knowledge, or bureaucratic process.
3. Everyone believed that there was work being done by others.
4. Projects we isolated and had limited comparability across or within programs, including the type of BMP, methods used, parameters collected, and number and type of constituents analyzed.
5. Data was provided by member agencies for a total of six completed LID BMP monitoring programs. The specific BMPs monitored as part of each of these programs varied greatly in both number and BMP type including bio retention/infiltration, bio swales / strips, permeable pavement / concrete, and rain gardens. Below is a list of the projects and partners:

Table 3-1. SMC CLEAN Research Data Summary

Project Owner	Project Name	BMP Type	Number of BMPs	Number of Events
City of San Diego	Cabrio Heights	Bioretention	2	5
City of San Diego	43 and Logan	Curbside filtration	2	7
UCSD	SCRIPPS-ASBS	Bio-Media Filter	2	6
National City	A Avenue	Infiltration basins, bioretention basins	2	2
Riverside County	District Demonstration Site	Porous Asphalt/Concrete, bioretention, permeable pavers, planter box, bioswale	6	7

3.3 State Water Board and Grant Funding

The SMC CLEAN Consulting Team coordinated with the State Water Board to obtain existing data related to LID and GSI projects. A summary of this coordination is provided below:

1. Coordination with the SWRCB occurred to obtain data from monitoring that occurred from grant funded LID and GSI projects.
2. While recent grant programs required monitoring components to demonstrate that the funded BMPs were meeting the desired outcomes limited guidance on the level and methodologies provided very limited useable information to address TAC research questions.
3. Database structure made it difficult to search and find relevant information to the point that you almost had to know the project and files you were looking for to locate documents.
4. Documents were almost exclusively reports in flat PDFs which made extracting meta data, monitoring data, and performance results a manual process limited to text that was reported and often not able to be recreated due to gaps in information provided

3.4 International BMP Database

The SMC CLEAN Consulting Team also investigated obtaining existing data related to LID and GSI projects in the International BMP Database. A summary of this investigation is provided below:

1. Very limited number of BMPs were reported for the SMC region in the BMP data base. Most were older data and not "LID".
2. Almost all data in the database were part of the Caltrans BMP effectiveness program that did not include bioretention/biofiltration data.
3. Lessons could be gained on the program architecture to create or adopt a repository of data for SoCal to answer TAC research questions.

4 TASK 3: IMPLEMENT INITIAL MONTORING PROCEDURES IN A BETA TEST PHASE

The intent of this SMC CLEAN task was the development of monitoring guidance for LID and GSI projects and to implement monitoring the monitoring procedures in a beta test phase. Elements of this task included identification of new/continuing monitoring sites, coordination with project partners to improve evaluation of monitoring designs and results, and providing monitoring assistance to project partners.

4.1 SMC CLEAN Monitoring Guidance

Based on the results of the research of existing data with limited comparability across data sets and input from the SMC CLEAN TAC, monitoring guidance for LID and GSI systems was developed. The primary purpose of the BMP monitoring guidance recommendations was to build continuity and comparability with in and across SoCal monitoring programs. Three guidance documents were created. The first document was the SMC CLEAN Standard LID Project Data-Information List developed in 2016 and provided in Appendix D. The list of data/information was initially developed for use in the research of existing data requested and compiled for each of the LID projects data/information was being obtained for the SMC CLEAN project. The list comprises monitoring data as well as meta data so that analysis could be performed to answer the proposed SMC CLEAN targeted research questions. Based on coordination with the State Water Resources Control Board (SWRCB) this list may serve as a preliminary list of data-information required to be gathered associated with future LID/GSI grant projects.

The second guidance document is the SMC CLEAN LID-GI Monitoring Protocol developed in 2017 and provided in Appendix E. This document outlines the process of data collection for a specific LID or GSI project. It provides project management information, specific project information (meta data) to be collected, monitoring plan review recommendations, specific details on the data acquisition process including monitoring equipment, site set-up guidance, monitoring parameters for hydrology and water quality, and describes the intended use of the data collected. This document was also provided to the State Board for consideration to be included in future rounds of funding to increase the standardization of information obtained as part of their programs.

The third monitoring guidance document is Section 6 of the SMC CLEAN Construction, Inspection, Maintenance, and Monitoring Guidance Manual focused on LID Monitoring. This section includes a monitoring purpose, the SMC CLEAN Monitoring Protocol, SMC CLEAN Standard LID Project Data-Information List, alternative LID/GSI testing, standard designs for biofiltration monitoring based on the CASQA standard design plans for biofiltration systems, guidance on porous pavement monitoring, and other monitoring resources.

4.2 SMC Member LID Monitoring Support

The SMC CLEAN project provided both direct services as well as support to SMC member agencies throughout the duration of five-year project. These interactions ranged from strategies of implementation of new BMP monitoring programs to improving existing monitoring programs aimed at providing information to make management decisions or meeting grant requirements.

SMC CLEAN provided informal and formal consultations to member agency programs on the interpretation of performance data for reporting and on the incorporation of elements to assist in effective monitoring to BMP designs. Additionally, direct SMC CLEAN funds have been used to supplement SMC member agency's existing programs to conduct additional analysis of samples being collected in existing BMP monitoring programs to help create a more robust dataset, as well as contributing funds to buy equipment for research being collaboratively conducted by the University of California system and SMC member agency, Orange County, at their bioretention research site. Specific actions are further discussed under task 5 collaboration with project partners.

5 TASK 4: SUMMARIZE ALL MONITORING DATA, MAKE RECOMMENDATIONS, AND UPDATE THE LID MANUAL

Due to the lack of both water quality monitoring data and meta data for LID and GSI systems it was clear that a comprehensive evaluation of the effectiveness of LID and GSI systems in Southern California is not possible until this data could be collected and tracked for long periods of time. This monitoring is necessary to understand the effects of variability of designs, construction, maintenance, and other factors, and must be made accessible so analysis can be performed. Therefore, recommendations provided as part of this task are not based on the existing data collected or monitoring performed but are rather recommendations for improvements in LID and GSI construction, inspection, maintenance, and monitoring as well as a summary of the revisions to the SoCal LID Manual. Additionally, this section provides recommendations regarding the long-term LID/GSI effectiveness needs of the SMC and references the draft scope of work for Phase 2 of the SMC CLEAN.

5.1 Data Summary, Analysis, and Evaluation

The data collected though the historical existing data collection as well as the data collected as part of the SMC CLEAN Phase I project, relevant to biofiltration/bioretention systems, informed the data analysis that was performed. Over the course of the SMC CLEAN project the State Water Board and SCCWRP conducted a statewide synthesis of BMP performance data. The analysis presented here will build upon the findings presented in their final report to focus on LID effectiveness in SoCal. Similar data treatments to estimate effectiveness will be employed including:

1. Percent reduction based on paired influent/effluent concentrations
2. Effluent probability method focused on the cumulative frequency distribution of effluent concentrations to show the probability of effluent WQ thresholds being achieved.
3. Linear regression which quantifies the average (single storm) relationship between the influent and effluent of a BMP.
4. Quantile regression which is similar to the single storm relationship of linear regression but provides a least absolute deviation from specific percentiles of the influent-effluent distribution by examining the data over the course of the gradient of results.

Data Selection

Statewide BMP database, conducted through SMC CLEAN project, was used as the baseline for this analysis. SMC CLEAN BMP database was filtered to obtain data for bioretention BMPs in SoCal (R4, R8, and R9). In addition, the SMC CLEAN BMP data for bioretention BMPs was compared to the BMP International Database to obtain more information for the ones labeled with N/A as region, and to include any additional data for more recent years (2019 and 2020). Information from three local bioretention BMPs (located in R9) that have been monitored by Michael Baker International (MBI) was also added the database.

Data types selected for this project included general BMP information (name, location, owner, etc.), and monitoring information (flow and water quality data, year). Dissolved and total trace metals (Cu, Zn, Hg, and Pb), nutrients (nitrate, and total kjedahl nitrogen), bacteria (Enterococci), and organics (PCBs) were analyzed to investigate how effective bioretention BMPs in SoCal are at improving water quality and reducing runoff volume.

Statistical Analysis

This section provides description of some selected statistical tests and their data requirements being used for bioretention efficiency evaluations.

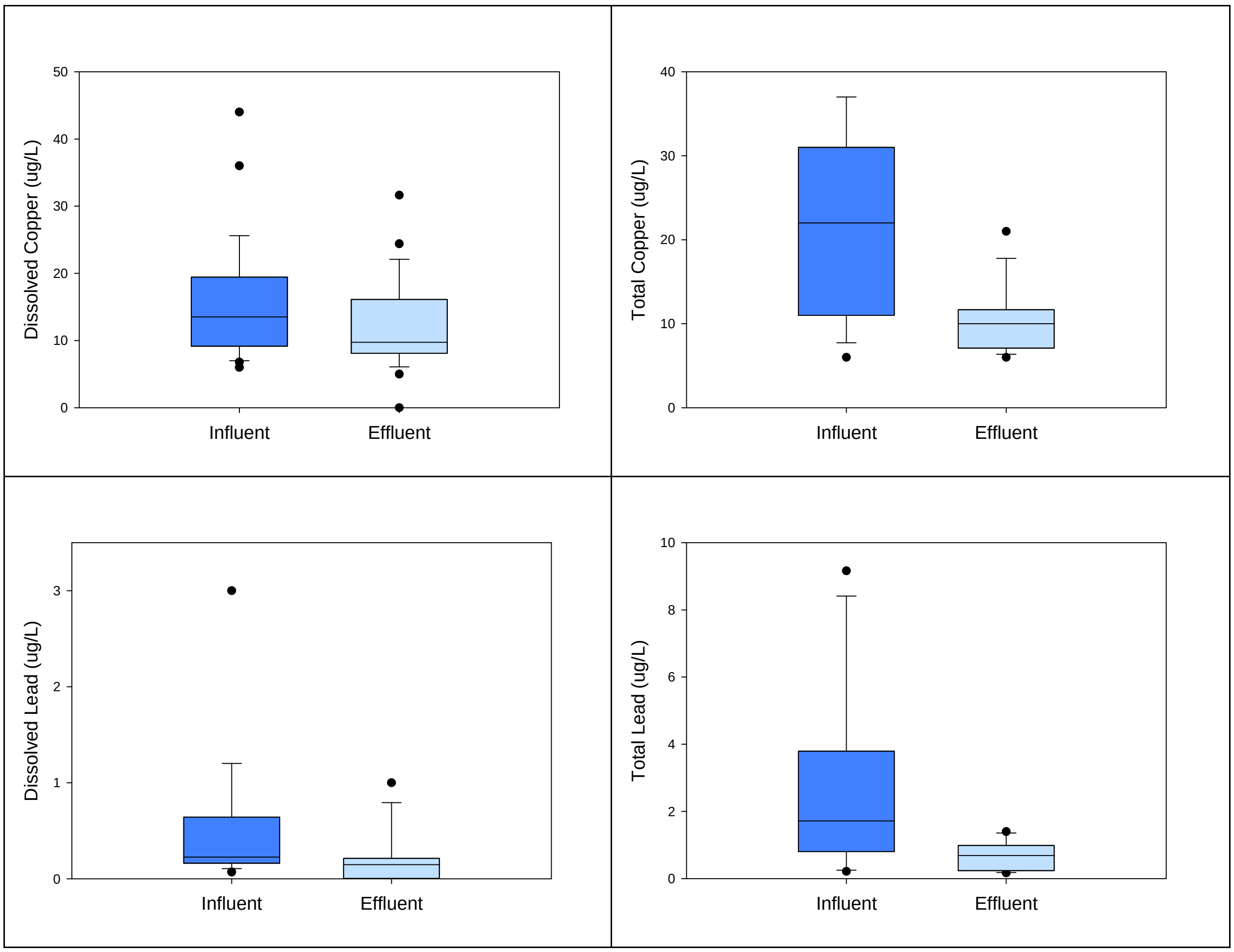
Table 5-1 summarizes basic statistics for measured parameters. As shown in Table 5-1, the number of paired samples for different parameter ranges from 1 to 29 samples. Regardless of assessment method, we set a minimum sample size of 10 measured pairs as a requirement to make robust estimates of effectiveness. Therefore, Mercury, PCBs, and TSS were excluded from further statistical tests and effectiveness analysis, due to lack of a minimum sample size of 10 measured pairs.

Table 5-1. Summary of Basic Statistics for Measured Parameters

Analyte	Unit	Count	Influent						Effluent					
			Min	Max	Average	Standard Deviation	Median	Coefficient of Variation (unitless)	Min	Max	Average	Standard Deviation	Median	Coefficient of Variation (unitless)
Dissolved Copper	ug/L	29	6	44	15.79	8.65	13.5	0.55	0	31.63	12.36	6.62	9.73	0.54
Total Copper	ug/L	15	6	37	20.71	10.41	22	0.50	6	21	10.55	3.74	10	0.35
Dissolved Lead	ug/L	18	0.07	3	0.50	0.67	0.23	1.33	0	1	0.19	0.26	0.15	1.37
Total Lead	ug/L	12	0.22	9.16	2.67	2.62	1.72	0.98	0	1.4	0.63	0.41	0.64	0.65
Dissolved Zinc	ug/L	27	5.8	168.4	64.57	41.56	64	0.64	0	76	23.49	20.19	14	0.86
Total Zinc	ug/L	15	15	150	74.80	40.31	70.67	0.54	8.1	77	28.29	19.20	21.93	0.68
Enterococci	MPN/100 mL	17	240	7000000	568836	1652300	17000	2.90	300	170000	46757	55916	9019	1.20
Nitrate-N	mg/L	13	0.18	2.8	0.62	0.74	0.34	1.18	0.18	3.56	1.00	0.90	0.73	0.90
Total Kjeldahl Nitrogen	mg/L	29	0.9	25.6	4.19	4.85	2.8	1.16	0.2	4.78	1.94	1.08	1.63	0.55
Total Mercury	ng/L	4	8.66	650	170.29	319.81	11.25	1.88	6	9.84	7.44	2.09	6.48	0.28
Total Mercury, <10 um	ng/L	1	8	8	8	N/A	8	N/A	6	6	6	N/A	6	N/A
Total PCBs	pg/L	3	3020	7600	5563.3	2331.7	6070	0.42	350	973.5	722.17	328.8	843	0.46
Total PCBs, <10 um	pg/L	1	1040	1040	1040	N/A	1040	N/A	620	620	620	N/A	620	N/A
Flow Volume	L	27	2.83	226441	54669	64541	21480	1.18	0	189429	40722	51942	12537	1.28

Box Plots

The box plots identified below are for bioretention/biofiltration systems that include an aggregate base, bioretention soil matrix, and bioretention plantings. Box plots compare the ranges of observed concentrations between influent and effluent samples for different water quality parameters, as well as flow volume. These plots enable a rapid, visual comparison of data for influent and effluent concentrations. If a median value (the central line in the box) is above or below the 25th and 75th percentiles of an adjacent box, the data sets are likely significantly different. Box plots also indicate the data symmetry and the presence of unusually high or low concentration values.



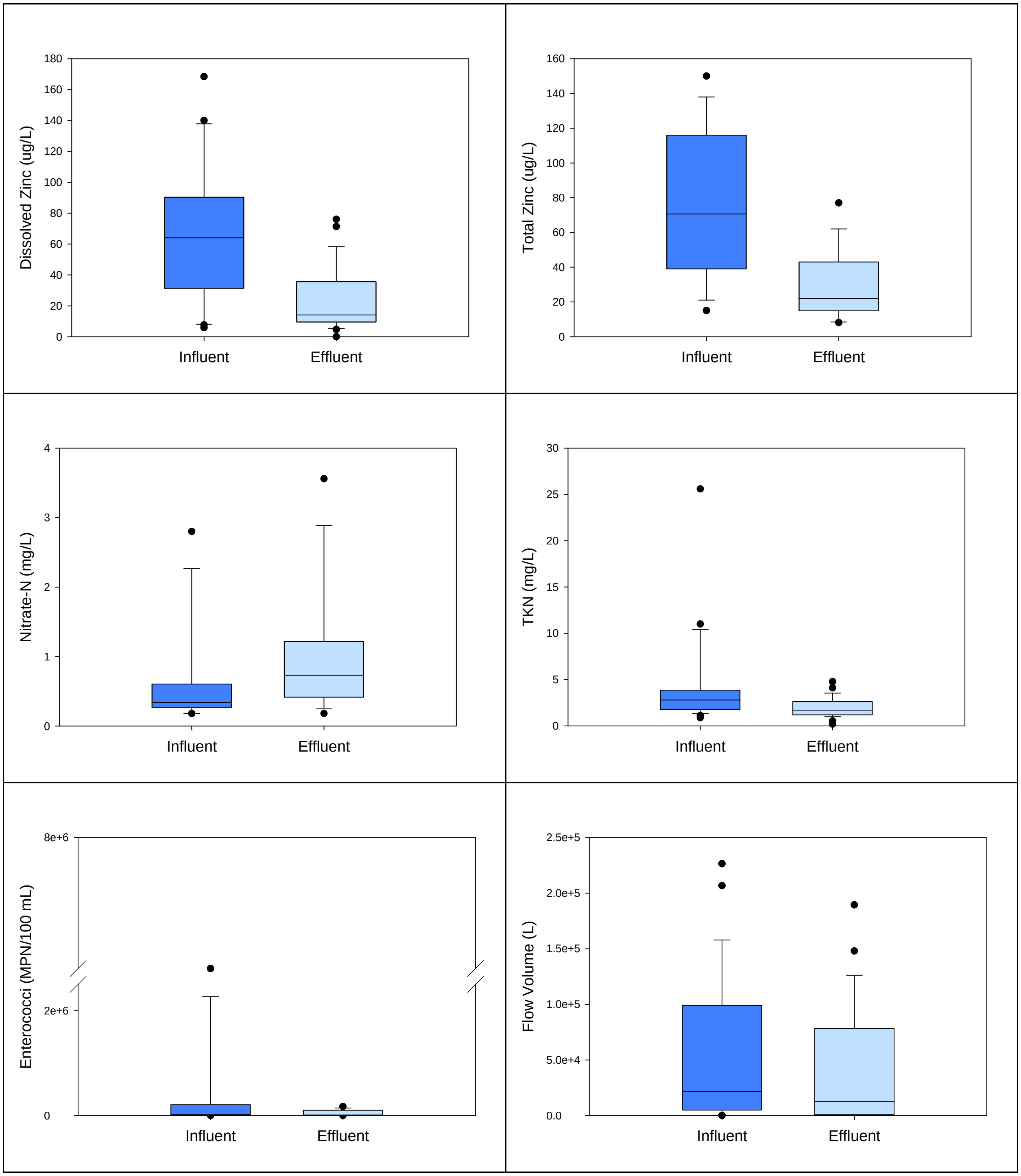


Figure 5-1. Box Plots for Measured Parameters

(the x-axis shows influent and effluent box groups and the y-axis shows the concentrations/flows)

Mann-Whitney comparison tests.

The Mann-Whitney test, also called the rank sum test, is a nonparametric test that compares two unpaired groups. Nonparametric tests are preferred when the values are not normally distributed, or the distribution is unknown or mixed (as in this case). The Mann-Whitney test was performed using SigmaPlot to test if the influent samples have significantly higher or lower concentrations/flow volumes than the effluent values. This test performs a hypothesis test of the equality of the two population medians and calculates the corresponding point estimate and confidence interval. The probability of these two medians being the same (within the confidence interval) is then calculated. The p-value is used to evaluate the test results: if the populations really have the same median, what is the chance that random sampling would result in medians as far apart (or more so) as observed in this set of observations? If the number of samples is small, the Mann-Whitney test has little power. P-values less than, or equal to, a level of 0.05 are usually used to signify a significant difference (indicating an error of 1 out of 20 cases). Table 5-2 summarizes Mann-Whitney test for comparison between paired data, using SigmaPlot. Except for Dissolved Copper, Enterococci and flow volume, all paired sample sets did indicate statistically significant differences for these numbers of samples, at the 0.05 level.

Table 5-2. Summary of Mann-Whitney Test for Paired Data

Analyte	Count	P value	Significant Difference Observes? (at level of 0.05)
Dissolved Copper	29	0.10	No
Total Copper	15	0.007	Yes
Dissolved Lead	18	0.014	Yes
Total Lead	12	0.039	Yes
Dissolved Zinc	27	<0.001	Yes
Total Zinc	15	<0.001	Yes
Enterococci	17	0.469	No
Nitrate-N	13	0.035	Yes
Total Kjeldahl Nitrogen (TKN)	29	0.004	Yes
Flow Volume	27	0.341	No

Making Estimates of Effectiveness

The analysis presented here was built upon the findings presented in the final SMC CLEAN report (BMP Performance Monitoring Data Compilation to Support Reasonable Assurance Analysis) to focus on BMP effectiveness in SoCal. Similar data treatments to estimate effectiveness were employed including:

1. Percent reduction based on paired influent/effluent concentrations
2. Effluent probability method focused on the cumulative frequency distribution of effluent concentrations to show the probability of effluent WQ thresholds being achieved.

3. Linear regression which quantifies the average (single storm) relationship between the influent and effluent of a BMP.
4. Quantile regression which is similar to the single storm relationship of linear regression but provides a least absolute deviation from specific percentiles of the influent-effluent distribution by examining the data over the course of the gradient of results.

The following sections discuss these analyses.

1. Percent Reduction

Percent reduction (PR) is a simple method to calculate BMP efficiency from a set of paired influent/effluent concentrations. PR is best to be calculated as flow-weighted event mean concentrations (EMCs). However, since corresponding flow volume data was not available for most of water quality concentrations in this study, the percent reduction was calculated as unity minus the ratio of the average effluent to average influent concentrations.

The following general equation (equation 1) is used for calculating BMP efficiency using this approach:

$$\text{BMP Efficiency (\%)} = 1 - \frac{Average\ Effluent\ Concentration}{Average\ Influent\ Concentration} \tag{1}$$

This PR approach, which is based solely on concentrations, have some value for evaluating samples where no flow weighted data is available or where the period of record does not include the storm volume. However, this method could be markedly underestimating the performance of the BMP and results in stating lower removal efficiency. When an influent concentration entering a bioretention BMP is high and much of the water is infiltrating into the ground, the overall load will be greatly reduced, yet not show up as such if the effluent concentration remains high. For this project, we estimated BMP effectiveness as the predicted difference between influent and effluent concentrations at the median influent concentration.

Table 5-3. Percent Reduction Summary

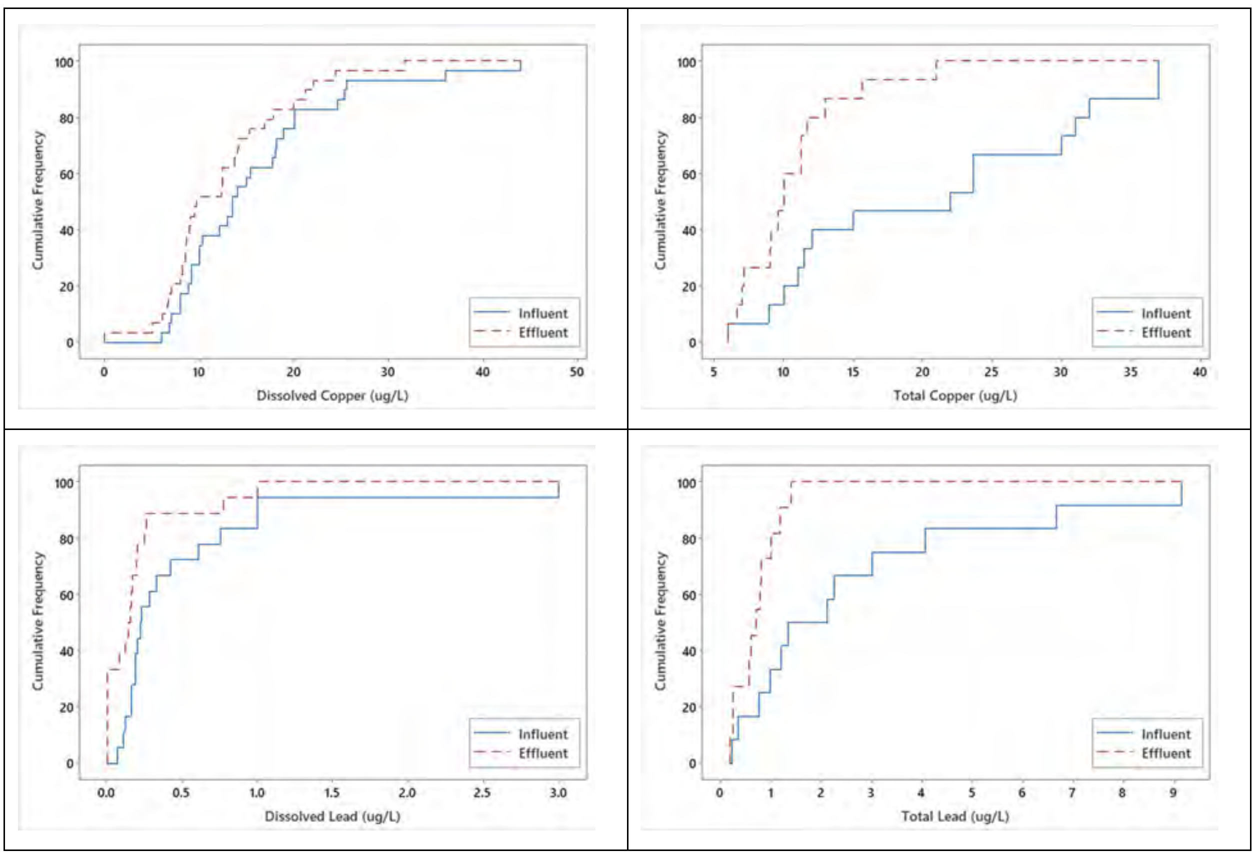
Analyte	Unit	Count	Influent Average	Effluent Average	Percent Reduction (%)
Dissolved Copper	ug/L	29	15.79	12.36	22%
Total Copper	ug/L	15	20.71	10.55	49%
Dissolved Lead	ug/L	18	0.50	0.19	62%
Total Lead	ug/L	12	2.67	0.63	76%
Dissolved Zinc	ug/L	27	64.57	23.49	64%
Total Zinc	ug/L	15	74.80	28.29	62%
Enterococci	MPN/100 mL	17	568836	46757	92%
Nitrate-N	mg/L	13	0.62	1.00	No Reduction
Total Kjeldahl Nitrogen (TKN)	mg/L	29	4.19	1.94	54%
Flow Volume	L	27	54669	40722	26%

2. Effluent Probability

The effluent probability method (EPM) provides a statistical view of influent and effluent concentrations, by calculation the cumulative frequency distribution of influent and effluent concentrations for a bioretention BMP. The EPM graphically illustrates the probability of occurrence (or exceedance) of influent or effluent concentrations in a stormwater BMP. EPM treats all storms equally and does not require paired data.

EPM plots are generated, using cumulative distribution functions (CDFs) in Minitab. EPM is sometimes referred as the most straightforward analysis and provides a clear, but qualitative picture of BMP effectiveness (EPA 2006). However, due to disconnection between paired influent and effluent data, there are limited inferences that can be made regarding BMP effectiveness over a particular concentration range.

To enable comparisons among assessment methods for this project, we estimated BMP effectiveness as the predicted difference between influent and effluent concentrations at the median influent concentration.



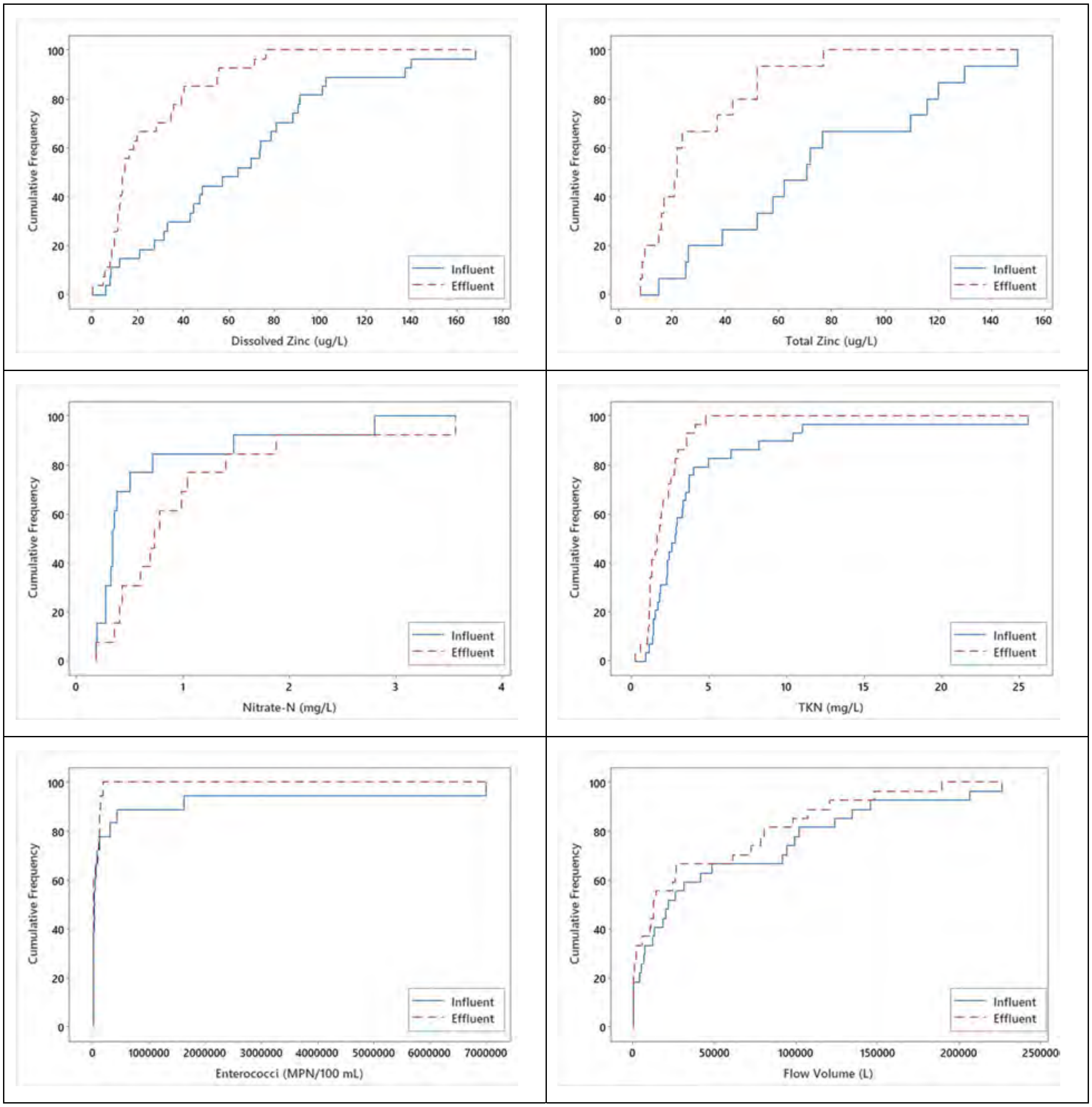
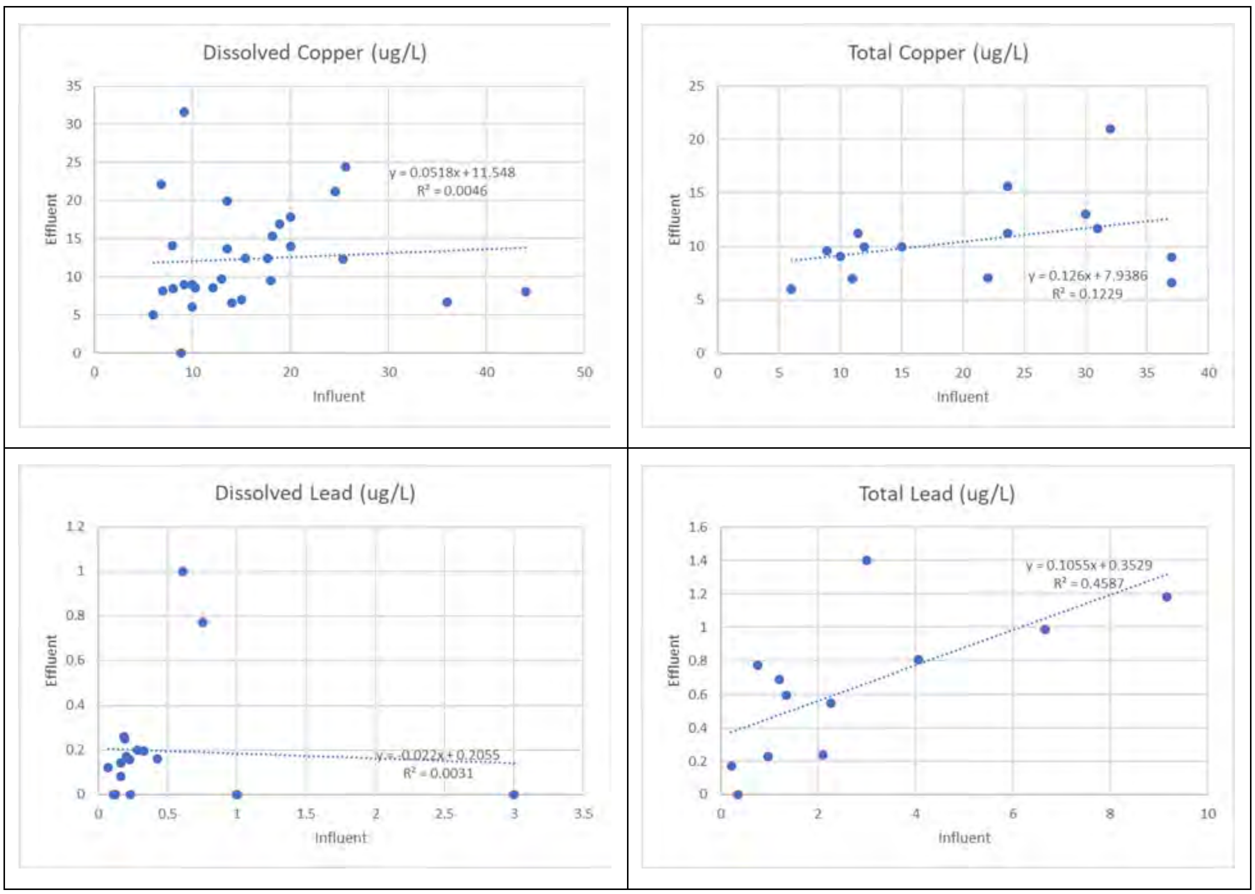


Figure 5-2. Effluent Probability for Measured Parameters

[the x-axis shows concentrations/flows, and y-axis shows the cumulative frequency distribution of influent and effluent concentrations/flows which essentially is the probability of occurrence (or exceedance) of influent or effluent concentrations/flows in a stormwater BMP]

3. Linear Regression

Linear regression (LR) assumes a linear relationship between the influent and effluent concentrations. One assumption for linear regression is that the both influent and effluent data are normally distributed or transformed to a distribution to achieve normality and homogeneity. Anderson-Darling (AD) p test for normality is a statistical test that complements the probability plots by indicating if the data are significantly different from the fitted normal distribution. If the calculated AD p test statistic is smaller than 0.05, the data are significantly different from a normal distribution. If the p-value is larger than 0.05, insufficient data are available to indicate they are different, and the observed data are usually assumed to be normally distributed (especially if the p-value is relatively large). AD test was performed for bioretention influent/effluent data and for all water quality parameters and flow volume, the results indicated that the data is not normally distributed (p-values < 0.05). Since data included zero values, log-transform was not applicable. Therefore, the data failed to meet assumptions for linear regression. Also as shown in Figure 5-3 small number of data points resulted in poor R^2 values and influenced slopes and intercepts. For this project, we estimated BMP effectiveness as the predicted difference between influent and effluent concentrations at the median influent concentration.



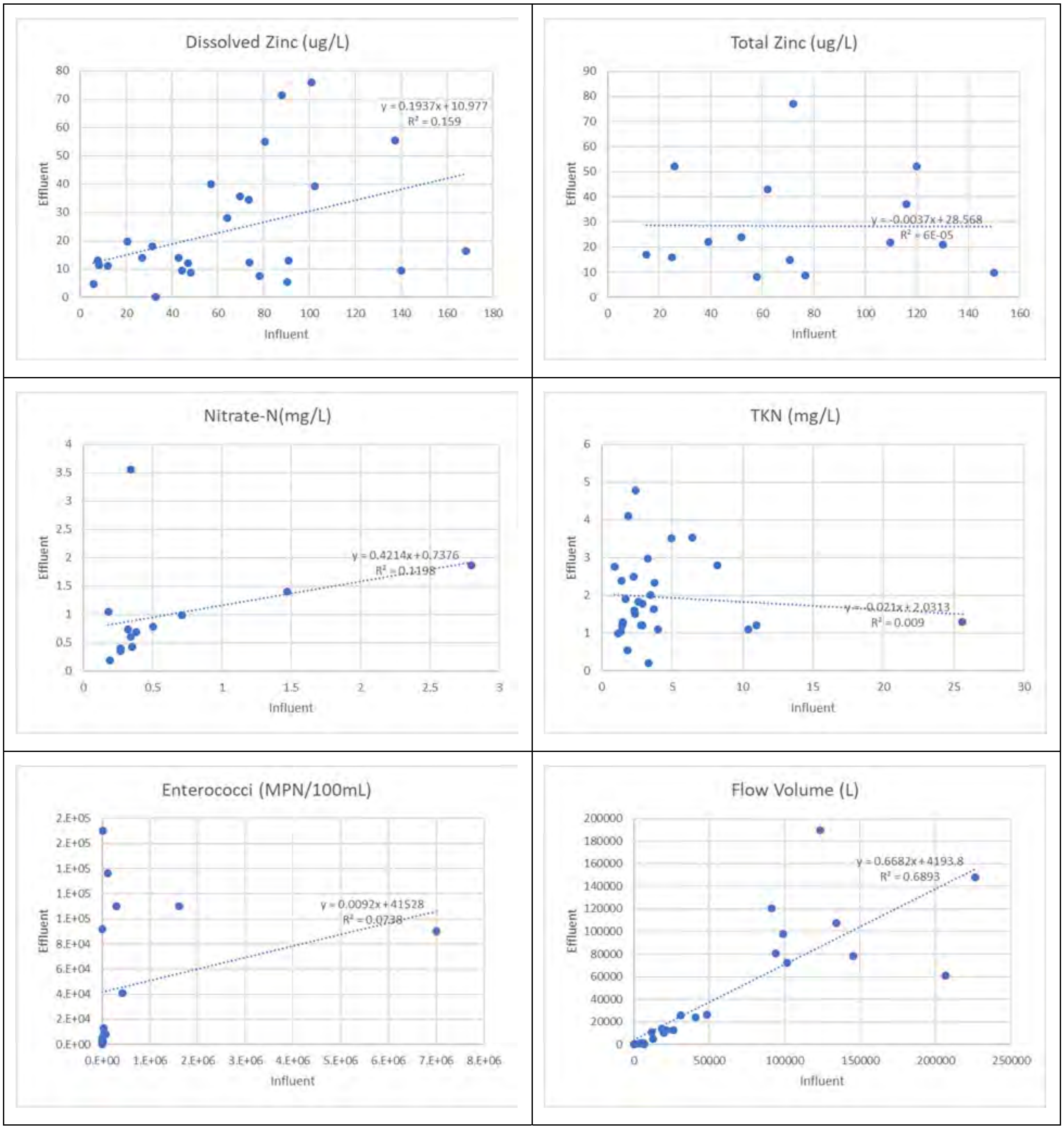


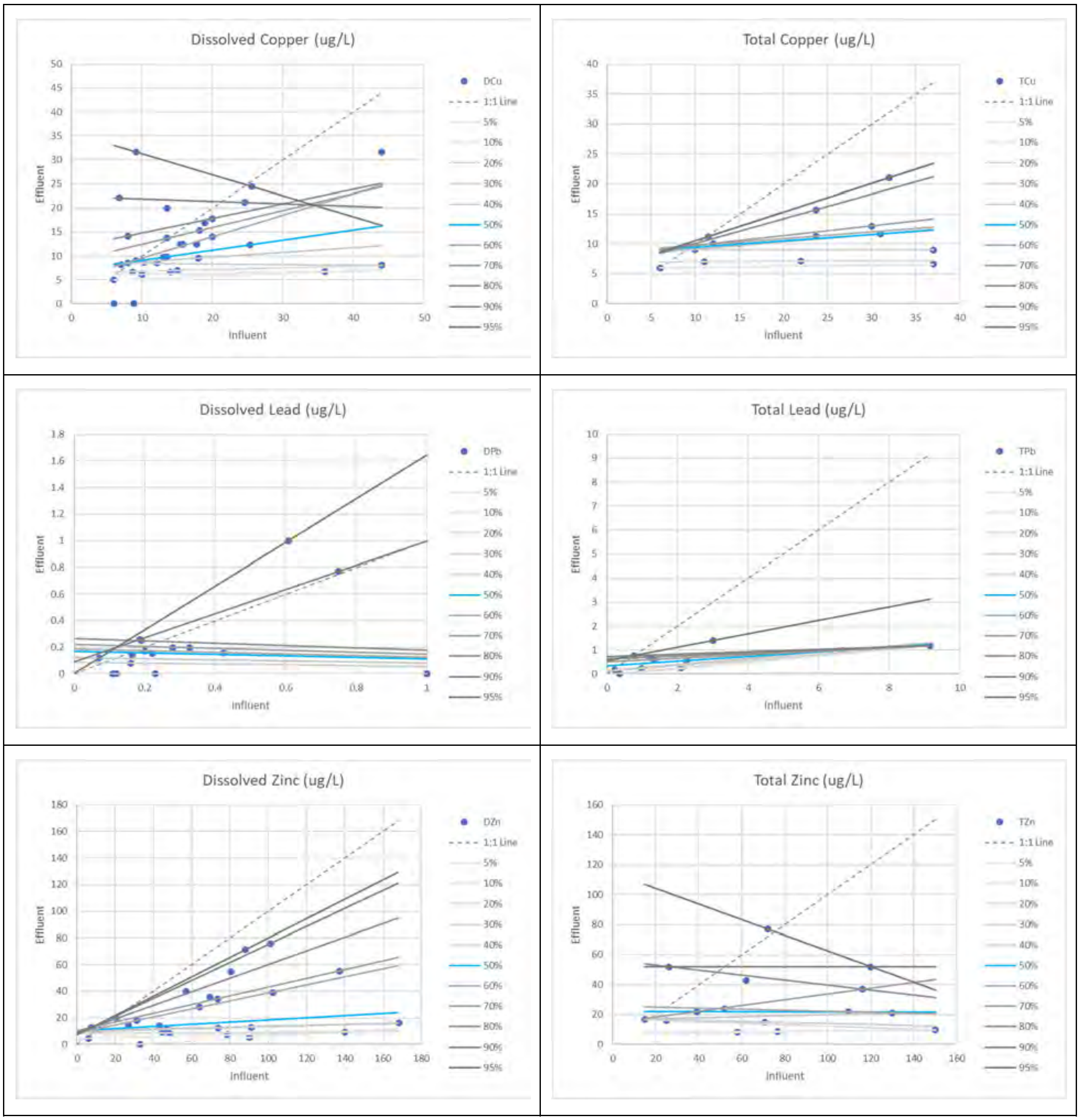
Figure 5-3. Effluent Probability for Measured Parameters

(the x-axis shows influent concentrations/flows and the y-axis shows effluent concentrations/flows)

4. Quantile Regression

Quantile regression (QR) is a statistical technique similar to the single storm relationship of linear regression but provides a least absolute deviation from specific percentiles of the influent-effluent distribution by examining the data over the course of the gradient of results. QR makes no assumptions about the distribution of the residuals. It also allows for exploring different aspects of the relationship between the dependent variable and the independent variables.

Quantile regression for BMP effectiveness is performed using macros in Excel, with quantiles desired from 5% to 95%. For this project, we estimated BMP effectiveness as the predicted difference between influent and effluent concentrations based on 50th percentile QR at the median influent concentration.



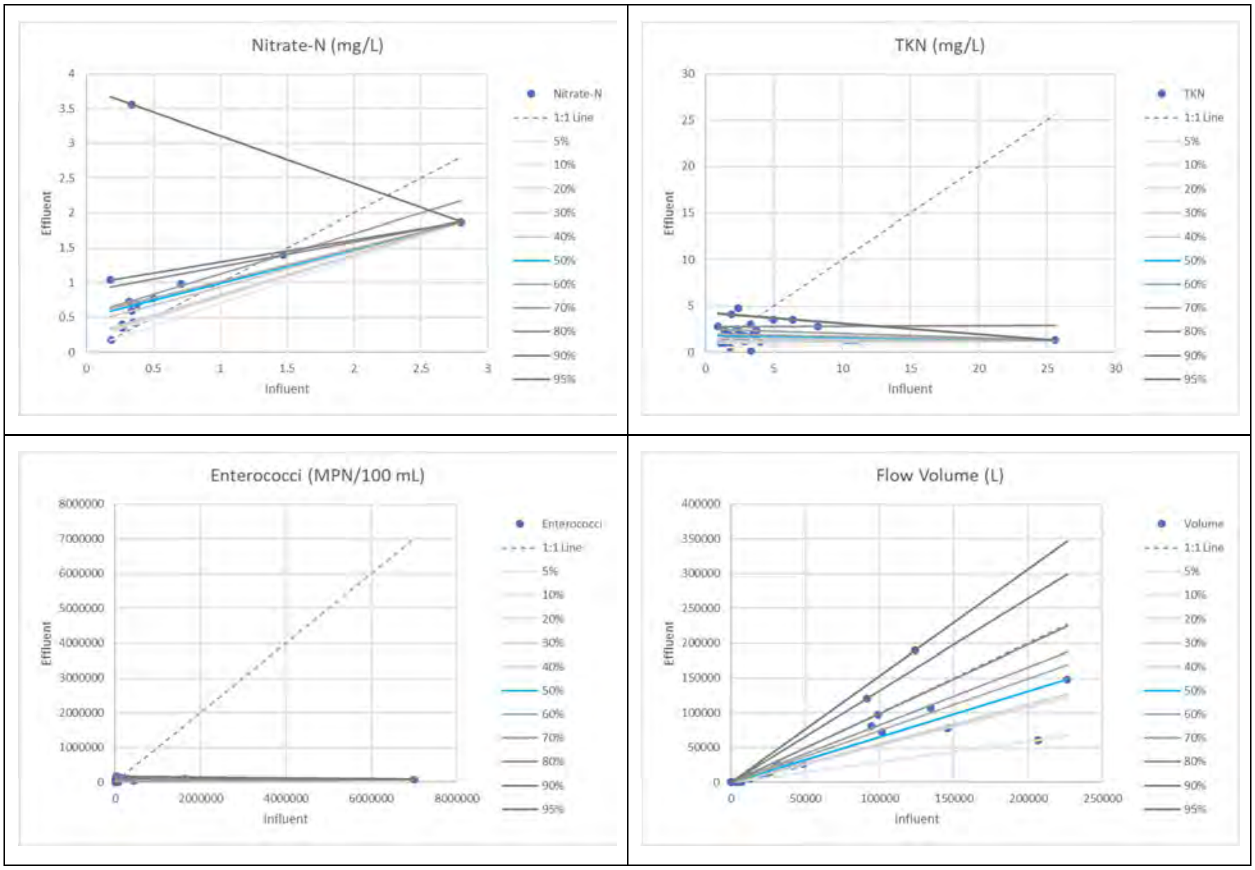


Figure 5-4. Quantile Regression Plots for Measured Parameters

(the x-axis shows influent concentrations/flows and the y-axis shows effluent concentrations/flows)

5.2 Discussion of Results & Monitoring Recommendations

For this project, we estimated BMP effectiveness as the predicted difference between influent and effluent concentrations at the median influent concentration value, for different parameters. The table below shows the results of the various methods discussed above for calculation of bioretention BMPs efficiency in SoCal. The four methods demonstrated vary widely in their estimates of percent removal depending on the select influent value, as well as assumptions of each method as discussed above. As discussed, QR method makes no assumptions about the distribution of the residuals. Therefore, we recommend utilizing QR method to estimate bioretention efficiency in SoCal.

Table 5-4. Summary of Estimated Bioretention Efficiency

Analyte	Unit	Influent (Median)	Estimated Bioretention Efficiency (%)			
			PR	EMP	LR	QR (50%)
Dissolved Copper	ug/L	13.5	21.7%	9.1%	9.3%	27.1%
Total Copper	ug/L	22	49.1%	46.2%	51.3%	51.3%

Dissolved Lead	ug/L	0.23	62.2%	16.7%	13.0%	31.7%
Total Lead	ug/L	1.72	76.4%	49.9%	69.0%	71.5%
Dissolved Zinc	ug/L	64	63.6%	40.3%	62.4%	75.5%
Total Zinc	ug/L	70.67	62.2%	40.0%	60.0%	68.9%
Enterococci	MPN/100 mL	17000	91.8%	0.0%	< 0%	56.6%
Nitrate-N	mg/L	0.34	N/A	46.4%	< 0%	< 0%
Total Kjeldahl Nitrogen	mg/L	2.8	53.6%	29.8%	29.6%	36.4%
Flow Volume	L	21480	25.5%	10.0%	13.7%	34.8%

Monitoring Recommendations

While this study provides important information about the overall performance of LID BMPs in Southern California, significant constraints regarding the production and amount of data needed to fully characterize and model performance limit the confidence ranges that can be provided. Thus, the most important recommendation of this study is to increase the amount of comparable monitoring data available in the SMC Geographical region to provide a larger sample size, that will be more likely to show a statistically significant relationship, if one exists, and provide the data needed for calibration of watershed programs. The SMC Monitoring Protocol provided in Appendix E, provides a template for all future monitoring projects to follow, which will assist in increasing the comparable monitoring data available. A larger sample size of comparable data is critical since the larger the sample size, the closer the sampling distribution of the mean would be to a normal distribution, which is an important assumption for some statistical methods such as linear regression. A p-value is also affected by sample size and the magnitude of effect. For non-parametric tests such as Mann-Whitney (which do not assume data is normally distributed) if the number of samples is small, the test has little power. In fact, if the total sample size is seven or less, the Mann-Whitney test will always give a p-value greater than 0.05 (meaning the influent and effluent data are not statistically different). For example, in this study, the maximum water quality parameter sample size available for bioretention BMPs in SoCal was 29 pairs of influent and effluent data (for TKN), which still did not pass the normal probability test. We recommend a minimum of 30 paired data for BMP efficiency analysis.

Additionally, for many of these systems there is limited information to answer the initial study questions set forth by the TAC. While this is certainly true for metadata required to analyze the more nuanced questions about design elements and maintenance, it was also true about more basic overall performance due to inconsistent analytes and lack of paired flow data. The absence of measured flow volume associated with inflow and outflow concentrations presents the biggest of these challenges and needs for a more comprehensive understanding of performance. This is because the "percent reduction" calculated from only the collection of the inflow and outflow concentrations represents only a partial accounting of the pollutant load removed, and is thus not recommended, as it does not account for the load removal associated with infiltration or field capacity of the matrix. Therefore, we recommend estimating the BMP efficiency for a particular pollutant with evaluating the load of the pollutant that is removed by a BMP. To be able to estimate BMP efficiency, flow volume measurements are needed. Total load can be calculated using the volume of water that is discharged from the BMP over a given period multiplied by the mean or average concentration of the pollutant. Also, BMP efficiency is dependent on the inflow load. Therefore, technically estimating BMP efficiency for different breakdowns of the flow loads will provide a better tool for evaluating BMP performance.

The monitoring recommendations identified in this section are consistent with a primary monitoring recommendation of increasing the amount of comparable monitoring data available in the SMC Geographical region. The recommendations of how to increase the amount of comparable monitoring data are provided in Section 5.5 below, which identifies the Long-term LID/GSI Effectiveness Needs of the SMC.

5.3 SoCal LID Manual Updates

The SoCal LID 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 relatively new in California and the purpose of the manual was to provide a resource for jurisdictions, designers, contractors, and maintenance personnel about LID concepts and implementation techniques. As LID has evolved in California over the past nine 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 Southern California. Updates focused on LID nomenclature, land development effects, considerations and challenges related to LID, and the LID site planning and site design process. The updated SoCal LID Manual is provided in Appendix F.

5.4 SMC CLEAN LID & GSI Construction, Inspection, Maintenance, and Monitoring Manual

Based on input form the SMC CLEAN TAC and experience of the Consulting Team there was a need for the development of guidance for construction, inspection, maintenance, and monitoring of LID and GSI systems for California. The Consulting Team developed with input from the SMC CLEAN TAC the 2019 SMC CLEAN LID & GSI Construction, Inspection, Maintenance, and Monitoring Manual, which is provided in Appendix G. The manual is a companion document to the LID Manual for Southern California and is designed to address these key implementation challenges in an effort to improve the effectiveness of LID BMPs and GSI as they are more widely implemented.

Numerous manuals have been developed to guide the implementation of LID BMPs in the Southern California region and nationwide in the past 10 – 15 years. These manuals provide information on site assessment, BMP selection and sizing, BMP designs, required/recommended materials, and recommended maintenance requirements. However, evaluations of implementation of these BMPs based on inspections suggests that LID BMPs are often constructed without due care with respect to siting, conformance with design standards, construction practices, materials used, and that inspection and maintenance are often not conducted as needed or required. In addition, it is challenging to conduct hydrologic and water quality monitoring for LID BMPs and GSI features, and there are very few existing datasets representative of southern California.

The audience for this manual is intended to be LID/GSI practitioners, land development planners and engineers, staff responsible to manage municipal drainage infrastructure, regulatory agency staff, consulting designers and engineers, contractors, maintenance staff, and asset managers.

This guidance manual focuses on structural LID BMPs and GSI with an emphasis on five key elements required to ensure effectiveness:

- Construction considerations
- Visual inspections
- Maintenance procedures
- Tracking the locations
- Condition and functionality of LID and GSI features over time through effective asset management, approaches and procedures to monitor their performance in removing pollutants and reducing changes in site hydrology

Improper implementation of these elements may lead to improper construction or maintenance, which can have detrimental effects on the functionality of the LID/GSI facilities.

LID/GSI construction incorporates site management, planning and scheduling, safety, the use of proper LID/GSI materials, BMP protection, and inspections. Safety protocols must be developed and followed to ensure the safety of staff on-site. Materials used for the construction of LID/GSI facilities must be based on design specifications and stored correctly to prevent contamination or damage. The LID/GSI area must be protected from soil compaction and stormwater run-on during construction. Existing vegetation must be protected from damage from construction equipment. Ongoing construction inspections should be conducted to determine whether the above-mentioned requirements are being met.

The purpose of LID/GSI monitoring is to determine whether or not the implemented BMP provides hydrologic and pollutant reduction benefits as expected based on its design and application. Targeted research questions must be created to guide the creation of a sampling and monitoring plan. Monitoring plans must be designed specifically for each LID/GSI facility.

Periodic visual inspections of LID/GSI measures will confirm whether BMPs are adequately maintained and are functioning as designed. Inspections include assessing whether maintenance is needed, and if so, what type of maintenance is required. Photographs are taken, and field sheets are completed to document the inspections.

Proper maintenance of LID/GSI measures is vital to ensure that these systems continue to function as they were designed. Lack of maintenance may cause the systems to have reduced capacity, clogging, short circuiting, or complete failure. General maintenance includes the correction of blockages to inlet and outlet structures, erosion on side slopes and bioretention inverts, burrows, emergence of excessive vegetation, graffiti or vandalism, and fence damage.

Verifying and tracking the design, proper installation, location and operating condition LID BMPs within a jurisdiction is crucial for managing maintenance and quantifying aggregate benefits.

Maintaining records of BMP metadata is also central to providing background information to jurisdiction staff. Data on LID/GSI facilities is valuable in the long-term as it allows jurisdictions to gauge the effectiveness of LID/GSI infrastructure over time. Data includes water quality monitoring data as well as meta data including design, inspection, maintenance data, and other data. GSI and publicly owned LID systems are a part of public infrastructure and so need to be properly managed as part of a public asset management systems. Effectively tracking private LID BMPs will help to understand the watershed area and volume of stormwater managed which will help with future stormwater management infrastructure planning and water quality standard compliance documentation. All current MS4 permits in Southern California require that post-construction BMPs be tracked and inspected. Development of an effective asset management program for LID BMPs therefore will be an essential part of ensuring LID BMPS are properly constructed and properly functioning.

5.5 Long-term LID/GSI Effectiveness Needs of the SMC

A white paper of the GSI/LID long-term effectiveness evaluation needs for the SMC was developed in 2019 to provide a direction for the future of GSI/LID evaluations for the SMC and the direction for Phase 2 of the SMC CLEAN. The white paper is provided in Appendix H and key elements of the white paper are provided below.

A key finding of the SMC CLEAN Phase I and previous LID effectiveness evaluation work performed by the SMC and its partner agencies, is that long-term monitoring and data for LID and GSI projects in Southern California is essential to truly understand the effectiveness of LID and GSI systems in Southern California. The primary need is for the collection, tracking, and access to monitoring and meta data (design, construction, maintenance, and inspection information) of LID and GSI systems in Southern California to understand the effectiveness of various LID and GSI BMPs with different designs and configurations as well as to understand how construction practices and maintenance activities may affect performance and effectiveness. Through collection, tracking, and access to monitoring data, an understanding of how best to conduct monitoring of these systems can be obtained. With the collection of LID and GSI systems monitoring and meta data analysis of this data can be performed so that design, construction, maintenance, and monitoring recommendations can be made so that LID and GSI BMPs are implemented and maintained in the most effective manner.

As implementation of LID and GSI, driven by MS4 Permit and water quality requirements, becomes ever more prevalent, a comprehensive and quantitative understanding of the effectiveness of LID and GSI in Southern California becomes more critical. The original emphasis on LID was focused in the Land Development sections of the MS4 Permits where permittees must ensure that new and redevelopment projects implement LID BMPs with sizing requirements designed to comply with volume-based retention standards instead of implementing conventional stormwater quality treatment devices. Most California Phase I MS4 permits now allow or require permittees to develop watershed management plans, which must ensure that discharges will achieve Water Quality Based Effluent Limits and not cause or contribute to exceedances of receiving water limitations. As these plans have been developed, LID in the form of GSI has been identified as a significant piece of the compliance schema. In Los Angeles County an analysis of the Watershed Management Plans

(WMPs) and Enhanced Watershed Management Plans (EWMPs) developed identified approximately 40% of the BMPs to meet compliance are based on implementation of LID and GSI systems. Due to constraints of land availability and the high cost of land acquisition, GSI is identified in most of these watershed management plans as a primary watershed control measure. As LID and GSI becomes more prevalent in the stormwater quality regulatory schema and stormwater programs, and serves as a fundamental tool for watershed and receiving water protection, understanding these systems' actual field performance becomes a requirement to demonstrate compliance.

The SMC's work to date shows that a quantitative understanding of the effectiveness of LID and GSI systems will require a significant amount of data, much more than currently available. The SMC should take a leading role in evaluating LID and GSI effectiveness, especially in southern California, while continuing to coordinate, and expand this coordination, with other organizations (e.g. universities) and initiatives performing monitoring and effectiveness evaluations. Additionally, water quality monitoring data and meta data describing designs, materials, construction procedures, inspections, and maintenance information should be sought from others that are implementing, inspecting, monitoring, and maintaining LID and GSI systems in Southern California to enhance the data set and support a more robust performance evaluation of different types of LID and GSI systems in Southern California. As the primary stormwater monitoring organization in southern California, the SMC should actively seek LID/GSI monitoring and meta data, and serve as a clearinghouse and coordination network for LID/GSI monitoring effectiveness information for Southern California and potentially all of California. It will also be essential for the SMC to reach out and engage with other initiatives and organizations performing LID/GSI monitoring and effectiveness evaluations using field and laboratory approaches, and in other regions, to gain the most comprehensive understanding of these systems.

To have a thorough understanding of the performance of LID and GSI BMPs a long-term study of 10 years is needed that will allow monitoring of a substantial amount of storm events and understand how LID and GSI systems perform overtime and to understand a variety of factors, such as maintenance, that affect performance. There is a significant need to quantitatively understand the performance of LID and GSI systems in Southern California so that specified designs will provide predictable water quality and hydrologic benefits. LID and GSI systems are complex, and performance is affected by numerous factors. Performance data for LID and GSI systems are difficult to obtain and therefore a long-term and more controlled monitoring approach is required. This need to quantitatively understand the performance of LID and GSI systems in Southern California requires significant work in several areas that are in line with the mission of the SMC and SMC CLEAN. Several key elements of this work include research focus, collaboration and communication, LID & GSI BMP Data Submittal Tool & Portal, LID & GSI BMP standards and specifications, California LID & GSI BMP Testing and Certification Program, monitoring plan & monitoring, data analysis & recommendations, and schedule, and are detailed in the white paper provided in Appendix H. A draft scope of work for the SMC CLEAN Long-Term Study (Phase 2) was developed as a precursor to the white paper and is provided in Appendix I.

6 TASK 5: ONGOING COLLABORATION WITH PROJECT PARTNERS

A significant amount of collaboration with project partners took place during the course of Phase I of the SMC CLEAN. Below are identified the project partners and a summary of the coordination and collaboration that took place over the course of Phase I of the SMC CLEAN.

<u>SMC Members</u>

6.1 County of Orange, OC Public Works

Collaboration with OC Public Works began with the start of the SMC CLEAN project with site visits and evaluation of the monitoring for the Glassell campus LID retrofit project. SMC CLEAN collaborated on the design of the biofilter research project and was introduced to the UC MRPI project through this collaboration. Additional collaboration included providing input on reconfiguration of some of the monitoring for the LID systems at the Glassell campus and obtaining monitoring data. Collaboration also included maintenance assessments performed by SMC CLEAN in collaboration with 2ndNature to be used in collaboration with monitoring data to evaluate maintenance effects on performance. Significant input has been provided by OC Public Works staff regarding the direction of the SMC CLEAN project.

6.2 City of San Diego, Transportation and Stormwater Department

The City of San Diego was one of the first SMC members to collaborate with the SMC CLEAN project in implementing a bio-retention evaluation study on two LID BMPs. This two-year study was funded through funded under a separate funding contract. The procedures developed and implemented during this project served as a proving ground and proof of concept for the BMP monitoring procedures developed as a SMC CLEAN work product.

6.3 County of San Diego Department of Public Works

The County of San Diego received several grants to build various LID demonstration projects at County facility including bio-retention, pervious pavement, bio-swales, and sub-surface wetlands. In 2019 the County coordinated with the SMC CLEAN team to adapt the SMC CLEAN monitoring protocols to 7 BMPs including inlet and outlet sampling locations to fulfil the 2 grant PAEP requirements over a five-year period. These studies were funded through funded under a separate funding contract.

6.4 County of Ventura Department of Public Agency

The County of Ventura received several grants to build two LID demonstration projects in residential areas including bio-retention, and sub-surface wetlands. In 2016, the County coordinated with the SMC CLEAN team to adapt the SMC CLEAN monitoring protocols. Sampling was conducted solely by County staff, but the SMC CLEAN team provided consulting on monitoring execution and reporting activities. These studies were funded through funded under a separate funding contract.

6.5 Riverside County Flood Control and Water Conservation District

Collaboration with OC Public Works began with the start of the SMC CLEAN project with site visits and evaluation of the monitoring for the RCFCWCD campus LID retrofit project. Collaboration included site visits of the RCFCWCD campus LID retrofit project, providing input on reconfiguration of some of the monitoring for the LID systems at the RCFCWCD campus, obtaining monitoring data, and performing analysis of the monitoring data. Collaboration also included maintenance assessments performed by SMC CLEAN in collaboration with 2ndNature to be used in collaboration with monitoring data to evaluate maintenance effects on performance. Significant input has been provided by RCFCWCD staff regarding the direction of the SMC CLEAN project.

6.6 San Bernardino Flood Control District and San Bernardino County Stormwater Program

SBFCD/San Bernardino County Stormwater Program have served as the contract manager for the SMC CLEAN contract. Significant input has been provided by SBFCD/San Bernardino County Stormwater Program staff regarding the direction of the SMC CLEAN project.

6.7 State Water Resources Control Board

SMC CLEAN collaboration with the State Water Resources Control Board began in early 2016 with attempting to obtain monitoring data associated with grant funded LID/GSI projects. Ongoing collaboration with the State Board included the development of statewide standards for data for GSI and LID, discussions about the potential for a statewide BMP data submittal tool, presentation of the SMC CLEAN Standard LID Project Data-Information List and SMC CLEAN LID/GI Monitoring Protocol, and SMC CLEAN targeted research questions and potential subsequent use for future grant funded projects. Collaboration also included providing input on the updates to the Prop 1 grant guidelines regarding monitoring of LID/GSI projects and recommendations for Prop 1 projects and future grants to instead of individual Prop 1 grantees performing monitoring of their projects, having entities such as the SMC CLEAN, SCCWRP, and SFEI perform the monitoring using a standard monitoring protocol such as the SMC CLEAN Monitoring Protocol, which would allow a more consistent monitoring approach statewide resulting in comparable data, acquisition of needed monitoring data and meta data for the SMC CLEAN, and less burden on the grantee project proponents. This recommendation included access to perform monitoring past the typical 3-year grant period to have the ability to obtain the needed long-term monitoring data and meta data.

6.8 Southern California Coastal Water Research Project

Collaboration with SCCWRP began at the beginning of the SMC CLEAN project including assistance in obtaining existing data, coordination with the SWRCB on GSI/LID data standards, and evaluation and scoping of an online BMP submittal tool. Significant input has been provided by SCCWRP staff regarding the direction of the SMC CLEAN project.

<u>Non-SMC Members</u>

6.9 Council for Watershed Health

Collaboration with the Council for Watershed Health (CWH) began in October 2015 with a discussion of obtaining LID/GSI monitoring data that the Council had collected. Monitoring data was provided but it did not include specific biofiltration data. Collaboration with CWH continued for the duration of the SMC CLEAN Phase I including plans to present on the SMC CLEAN project at the CWH Green Infrastructure Symposium in March 2020, until it was cancelled due to COVID-19.

6.10 China Sponge City Initiative

With the assistance of Dr. Jian Peng, OC Public Works collaboration with the China Sponge City initiative began in 2016. This collaboration included SMC CLEAN presentations at the International LID Conference in Beijing in 2016 and other China Sponge City conferences and meetings in 2016, 2017, and 2018, and visitation to China Sponge City monitoring sites, and the potential for future collaboration on LID/GSI monitoring with the China Sponge City initiative.

6.11 Loyola Marymount University

Collaboration with LMU began in early 2017 with a site visit to their Ballona Biofilter Monitoring Project with biofilters placed adjacent to Ballona Creek in Culver City. Data was obtained from LMU, but effluent data was collected as the systems were bioretention systems without the possibility of collecting effluent data. LMU also attended the May 22, 2017 SMC CLEAN TAC meeting and presented about their Ballona Biofilter Monitoring Project.

6.12 Los Angeles Green Streets Committee

A presentation was made by the SMC CLEAN Consulting Team about SMC CLEAN at the January 2016 meeting of the Los Angeles Green Streets Committee. The hope was to obtain existing data of Los Angeles green streets or potentially collaborate on future monitoring, of which neither materialized.

6.13 University of California MRPI

Collaboration with the UC Multicampus Research Programs and Initiatives (MRPI) research grant began with attendance of a mini conference at UC Riverside on May 4, 2017. The focus of the UC MRPI grant is on how urban stormwater can augment water supplies and minimize flood risk. The MRPI grant involves 5 Southern California UC campuses including UCI, UCLA, UCR, UCSB, and UCSD. The grant involves significant biofilter research. SMC CLEAN participation has included attendance to the weekly MRPI web meetings/conference calls, input on the research agenda related to biofilter monitoring, and input and participation on the OCPW biofilter cell research that is part of the UC MRPI project.

6.14 University of California Irvine

Coordination with UC Irvine began in October 2015 and included meetings with UC Irvine Facilities staff to identify if there were LID/GSI systems on campus that could eb monitored. Coordination also took place with the Civil Engineering Department, specifically Dr. Stanley Grant, about potential future collaboration regarding future monitoring of LID/GSI systems at the UCI campus, which lead in part to SMC CLEAN's participation in the University of California MRPI grant.

6.15 University of California San Diego - SCRIPPS

Collaboration with UCSD SCRIPPS began in January 2016 with a meeting and site visit regarding some biofilter type BMPs at the SCRIPPS site that had been monitored. Monitoring data was obtained, however the configuration of the biofilter type BMPs was not a conventional type of biofilter. SMC CLEAN continued to collaborate with SCRIPPS including an unsuccessful joint grant application for monitoring.

6.16 University of California South Coast Research and Extension Center

Collaboration with the UC South Coast Research and Extension Center began in early 2017 and included coordination on existing monitoring at the Center including urban landscape monitoring and bioswale monitoring as well as discussions and providing analysis about reconfiguration of a swale onsite to integrate a bioretention cell/biofilter for monitoring.

Appendix A

Work Plan

SMC California LID Evaluation & Analysis Network (SMC CLEAN)

Work Plan

Final

August 10, 2017

Introduction

This document constitutes the Work Plan for the Southern California Stormwater Monitoring Coalition California Evaluation and Analysis Network Project (SMC CLEAN). The Work Plan was developed by the SMC CLEAN Consulting Team with input from the SMC CLEAN Technical Advisory Committee (TAC). The Work Plan is designed to guide the implementation of the five tasks of the SMC CLEAN Project and identifies how each task will be performed.

Project Background

In 2006 the SMC, led by Dr. Matt Yeager, in collaboration with the California Stormwater Quality Association (CASQA) submitted a State Proposition 40 grant proposal for the LID Guidance and Training Project. The project grant submittal was successful and $600,000 of funding was awarded to complete the following Tasks 1) Compile and Evaluate Existing Information on LID BMP Effectiveness; 2) Coordinate with other Stakeholders; 3) Conduct Field Monitoring of LID Features; 4) Develop an LID Technical Manual with results of field monitoring. A technical advisory committee (TAC) was formed to guide the LID Project, which included representatives from the six coastal southern California Counties, the Santa Ana Regional Water Board, the development community, and other stakeholders. The TAC met over half a dozen times and provided significant comment on the development of the Southern California LID Manual. The duration of this initial phase of the project was from 2006 -2010, which culminated with posting of the Southern California LID Manual on the California LID Portal (www.californialid.org) in April of 2010.

In 2011 Dr. Yeager continued project coordination with the SMC to develop a revised approach to evaluate LID BMP effectiveness; an approach that includes water quality monitoring, and extensive coordination and data collection from other LID implementation projects in southern California. In 2011 and 2012 a draft revised Scope of Work was developed. The revised scope included updates to the monitoring and LID BMP effectiveness evaluation tasks for the Project, to coordinate completion of revised Scope tasks, and coordinate with CASQA and stakeholders to update the LID Manual as appropriate, based on effectiveness results and to manage the project progress in coordination with the SMC.

From 2013 to 2014, Dr. Yeager, with the assistance from Daniel Apt and Scott Taylor of RBF, worked with the SMC members to develop a Scope of Work (SOW) for this project, funded from remaining SMC funds allocated to the overall project. This project was discussed at length at SMC quarterly meetings, progressing from a project outline, to a draft SOW, to a final SOW which was reviewed and approved by the SMC in the fall of 2014. To support development of the SOW, a questionnaire was distributed to the SMC members and Municipal Separate Storm Sewer System (MS4) permittees to determine if local jurisdictions required effectiveness monitoring for LID BMP installations. Very few jurisdictions were found to require monitoring for LID BMPs and such monitoring was mostly limited to grant funded LID projects. Therefore, a key feature of this project is the development of a standard methodology for monitoring LID BMPs, so future monitoring data will be more comparable.

Project Overview

SMC CLEAN is designed to: understand the effectiveness of LID BMPs through the development of specific LID research questions; research existing LID monitoring data; develop a standard methodology for monitoring LID BMPs including coordination with other SMC projects concerned with monitoring methodology; coordinate ongoing LID monitoring; implement LID monitoring through the standard methodology and monitoring protocol developed; compile and analyze LID monitoring data; and develop recommendations and conduct a review and update of the Southern California LID Manual. The primary purpose of SMC CLEAN is to understand the effectiveness of various LID BMPs with different designs and configurations so that design, construction, maintenance, and monitoring recommendations can be made in an updated LID Manual to ensure that LID BMPs are implemented in the most effective manner.

As LID and green infrastructure (GI) become ever more prevalent in the stormwater management world a comprehensive and quantitative understanding of the effectiveness of LID and GI becomes more important. It has been almost 10 years since LID implementation requirements first started appearing in MS4 Permits in California. The emphasis on LID was focused in the Land Development sections of the MS4 Permits where permittees must ensure that new and redevelopment projects implement LID to comply with volume-based retention standards instead of implementing conventional stormwater quality treatment devices. LID site design and planning principles were also integrated into the MS4 permits. MS4 permits now require the development of LID ordinances requiring implementation of LID and a review and update of municipal codes and general plans to remove LID implementation barriers and to encourage LID implementation. Most current MS4 permits allow permittees to develop watershed management plans which must unsure that discharges will achieve Water Quality Based Effluent Limits and not cause or contribute to exceedances of receiving water limitations. As these plans have been developed, LID in the form of GI has been identified as a significant piece of the compliance schema. Due to constraints of land availability and the high cost of land acquisition, (GI) is identified in most of the watershed management plans as a primary watershed control measure. As LID and GI have become more prevalent in the stormwater quality regulatory schema, and serve as a fundamental tool for watershed and receiving water protection, understanding their true effectiveness becomes ever more relevant.

A main goal of SMC CLEAN is to coordinate with others evaluating the effectiveness of LID and those performing LID monitoring. The study will coordinate with partners to research and evaluate LID monitoring data. The types of LID BMPs to be evaluated and monitored will be identified. SMC CLEAN will perform analysis of this data and the aim is that the project will eventually serve as a clearinghouse and coordination network for LID monitoring effectiveness information for California.

There are however many challenges with LID monitoring and understanding the true effectiveness of LID BMPs. Many LID features were not designed to be monitored and so accurately obtaining data and understanding the effectiveness of the LID BMPs can be challenging. Improved standard LID BMP designs are needed that facilitate monitoring by incorporating features that provide access for flow instrumentation and influent/effluent sample collection. Existing LID monitoring efforts do not use consistent monitoring protocols or test for consistent suites of analytes. Development of a consistent monitoring protocol with a suggested standard set of analytes will support the development of LID effectiveness data that can be properly compared. The variety of design configurations for the same LID BMPs also poses a challenge for LID monitoring, however understanding how these design configurations affect BMP performance will be critical moving forward. Proper construction of LID designs is also an issue that needs to be considered. Finally, maintenance and its inconsistent implementation also poses a challenge for LID monitoring but understanding how maintenance of LID BMPs affects performance will be a critical piece to understanding the effectiveness of LID BMPs.

The following tasks have been developed to accomplish the primary purpose of the project of understanding of the effectiveness of LID BMPs. The tasks also consider that there is a significant amount of knowledge and experience in California regarding LID, that there are many partners evaluating the effectiveness of LID, that there is a significant amount of existing LID data available, as well as the LID monitoring challenges needs as identified above.

SMC CLEAN Mission, Goals, and Objectives

Discussions with the SMC CLEAN Technical Advisory Committee identified two primary needs associated with the project. The first is a short term need for a quantification of LID performance in Southern California, needed for use in providing empirical data to calibrate estimates for compliance measures such as the recently developed watershed programs (i.e. EWMPs, WQIPs, etc.) and their associated watershed/water quality models (i.e. RAA, RAS). The second is more of a long term need to serve as collaboration entity and clearinghouse of LID monitoring data in order to obtain enough data to understand the effectiveness of various LID BMPs overtime and understand how the differences in design, construction, and maintenance affect their performance. The following mission statement is intended to guide the SMC CLEAN project to address the short and long-term goals:

> The mission of SMC CLEAN is to develop a thorough understanding of the effectiveness of LID BMPs in California both in the short term for use in calibration of watershed programs and the long term for modification of LID design, construction, and maintenance, through coordination with project partners and others performing LID monitoring and serving as a clearing house for LID monitoring information, developing targeted LID research questions and performing targeted LID monitoring based on these questions, analysis of LID monitoring data, and recommendations for the design, construction, maintenance, and monitoring of LID in updates to the Southern California LID Manual to ensure that LID BMPs are implemented in the most effective manner.

The mission statement above was developed to better guide the SMC CLEAN project and based on the mission statement the following goals and associated objectives were developed. These goals are also related to specific tasks in the Work Plan that are identified below and provide more specifics. The goals and objectives are identified here as an expansion of the mission statement and so a snapshot of the project can be referenced in one location.

Goal #1: Development and Ongoing Facilitation of a Technical Advisory Committee to assist in accomplishing the SMC CLEAN Mission & Goals.

- Objective #1A: Identify Potential Research Questions
- Objective #1B: Develop Work Plan
- Objective #1C: Develop branding for the project.
- Objective #1D: Ongoing coordination with consulting team and review comment of project products
- Objective #1E: Ongoing identification of project partners

Goal #2: Provide Ongoing Collaboration with Project Partners and Others Performing LID Monitoring and Serving as a Clearing House for LID Monitoring Information.

- Objective #2A: Ongoing collaboration with Project Partners to understand LID monitoring efforts, lessons learned.
- Objective #2B: Ongoing collaboration with Project Partners on potential future funding (i.e. grants) to make the SMC CLEAN project more robust and maximize the current funds allocated to the project.
- Objective #2C: Development of SMC CLEAN Website for Collaboration of Project Partners and a platform for the development of an LID Monitoring Clearing House
- Objective #2D: Evaluate development of an SMC CLEAN Online LID Data Submittal Tool/Clearing House

Goal #3: Development of Targeted LID Research Questions

- Objective #3A: Evaluate Current LID Monitoring Data & LID Research
- Objective #3B: Identify Gaps in LID Monitoring Data
- Objective #3C: Identify Target LID Research Questions to answer short term need for use in calibration of watershed programs
- Objective #3D: Identify Target LID Research Questions to answer long term for modification of LID design, construction, and maintenance

Goal #4: Development of LID Monitoring Plan Elements

- Objective #4A: Development of Standard LID Project Data-Information List
- Objective #4B: Development of Standard LID/GI Monitoring Protocol
- Objective #4C: Development of Data Sharing Protocol
- Objective #4D: Development of SMC CLEAN Database
- Objective #4E: Develop LID Operations Conceptual Model
- Objective #4F: Develop SMC CLEAN Monitoring Plan based on targeted LID research questions for short term and long term needs.

Goal #5: Perform Targeted LID Monitoring

- Objective #5A: Implement targeted LID monitoring to answer short term needs
- Objective #5B: Implement targeted LID monitoring to answer long term needs

Goal #6: Analyze LID Monitoring Data Collected

- Objective #6A: Analyze monitoring data to answer short term needs
- Objective #6B: Analyze monitoring data to answer long term needs

Goal #7: Make Recommendations & Update the Southern California LID Manual

- Objective #7A: Develop technical memorandum on bioretention/biofiltration performance for short term needs, for use in calibration of watershed programs and any associated recommendations for bioretention/biofiltration design, construction, maintenance, and monitoring.
- Objective #7B: Develop technical memorandum on bioretention/biofiltration performance and associated recommendations for long term needs for modification of bioretention/biofiltration design, construction, maintenance, and monitoring.
- Objective #7C: Develop Standard Bioretention/Biofiltration Monitoring Design Plans and Specifications.
- Objective #7D: Update the Southern California LID Manual to incorporate recommendations for bioretention/biofiltration design, construction, maintenance, and monitoring.
- Objective #7E: Development SMC CLEAN Phase 1 Project Report

Task 1 - Form and Coordinate a Project Technical Advisory Committee

Technical Advisory Committee

The purpose of the Technical Advisory Committee is to provide technical expertise and input in the development and implementation of the SMC CLEAN Work Plan. The make-up of the TAC includes MS4s, regulatory agencies, the environmental community, the development community, the academic community, industry, and other LID experts that are engaged in the implementation and monitoring of LID in California. The TAC represents a good cross section of those experts involved in LID in California and represents a significant amount of the LID knowledge and experience in California. The TAC will help to identify potential research questions (Objective #1A), provide input on the development of the Work Plan (Objective #1B), assist with developing branding for the SMC LID Effectiveness Study (Objective #1C), review and provide comments on the Consultant Team work products (Objective #1D), assist with identification of project partners (Objective #1E), provide input on the development of targeted research questions (Goal #3), and attend the TAC meetings.

The Consultant will formulate the TAC, schedule and facilitate TAC meetings, develop the Work Plan) and schedule, coordinate with the TAC regarding branding of the SMC CLEAN Project, develop a project website, and development of procedures for TAC review of draft Consultant products. The formulation of the TAC included a request to the funding agencies of the SMC to identify appropriate members of the TAC. The Consulting Team reached out to this list of people to identify their ability to serve on the TAC as well as an inquiry of other potential TAC members. The current roster of the TAC was a result of this process. It was agreed at the first TAC meeting that the schedule of TAC meetings will be quarterly. The primary location of the TAC Meetings will be at SCCWRP and the Consultant will schedule these meetings at least one meeting in advance.

Branding of the SMC CLEAN (Objective #1C) took place with TAC input with ideas being suggested by the Consulting Team. The result of the branding discussion at the February 25, 2016 TAC Meeting and the name of the project going forward was identified as SMC CLEAN – California LID Evaluation & Analysis Network. SMC CLEAN will be used by the Consultant for all project materials. The branding of SMC CLEAN will also be used in the development of the project website. The website will include project information and potentially a data submittal tool and data sharing site for LID monitoring data. The website will be a resource for TAC members and interested parties regarding LID monitoring. The Consultant Team will also develop a procedure for TAC review of draft Consultant products that will developed in coordination with the TAC.

Objective 1A: Definition of Potential Research Questions

The first Objective #1A identified above is for in collaboration with the TAC is to work with the consulting team to define potential research questions which will help with Objective #1B of developing the Work Plan in that these questions will further define and articulate the details within the scope of work for the SMC CLEAN project that will provide the greatest benefit to the state of LID science in California. Specific research questions which have been identified by the TAC for potential exploration are as follows:

- What is the magnitude of pollution removal benefits of different forms of LID infrastructure?
- What is the mechanism by which the greatest benefit is achieved i.e. reduction in concentration or reduction in volume of stormwater?
- What is the expected range of performance for different pollutant / chemical / biological categories provided by LID treatment
- What are the benefits to different physical fractions during treatment? Is all benefit in the particulate form?
- How do different LID designs affect LID performance?
- How does the bioretention soil matrix affect bioretention performance?
- How does the plant pallet affect LID performance?
- How do the different climate zones in California affect LID performance?
- How does construction and construction sequencing affect LID performance?
- What are the effects of maintenance on LID performance?
- How do proprietary BMPs perform in the real-world setting compared to manufacturer specifications?

Through research and coordination performed by the SMC CLEAN Consulting Team and discussion of the potential research questions with the TAC with acknowledgement of the limited funding of the SMC CLEAN Project it was decided that the initial phase of the SMC CLEAN project would focus on bioretention/biofiltration as the most common LID BMP being implemented in Southern California. The initial approach of the SMC CLEAN project was more inclusive with data gathering and evaluation of other LID BMPs as well, and subsequent phases of the SMC CLEAN project, if funds are available, should implement the initial broader approach. The focus of the current phase of the SMC CLEAN project is to identify the pollutant removal and hydrologic effectiveness of bioretention/biofiltration BMPs. This decision and focus helped to guide the identification of the targeted research questions (Goal #3) which is discussed under Task 2.

Task 1 Work Products

- TAC Collaboration & Facilitation
- Potential Research Questions
- Work Plan
- Project Branding
- Ongoing identification of Project Partners

Task 2 - Research Existing Data

The primary purpose of this task is to explore and evaluate the existing literature, resources, and data to identify the SMC CLEAN targeted research questions (Goal #3). The first step for this goal is to identify and evaluate existing LID monitoring data and existing LID research regarding LID BMP performance (Objective #3A). A key component of this is the identification and compilation of sources of existing LID BMP monitoring data from local municipalities and organizations conducing LID monitoring, literature, and existing database sources. This information will be used to make preliminary characterization of LID of performance. Based on these findings data gaps will be determined (Objective #3B) and priorities and targeted research questions are to be identified to guide future project activities. These data gaps will be presented to the TAC to guide the development of a strategy to acquire additional information to evaluate the targeted research questions in a qualitative and/or quantitative manner or revise project objectives and expectations. Options to be considered could include initiation of new projects by stakeholders, supplementation of existing studies by this project, or inclusion of literature data or national BMP database from sources outside of the southern California.

The most promising sources of data for this project will come from stakeholders who have past and ongoing LID monitoring / evaluation projects. Outreach will be conducted to potential partners to introduce the project and its goals with the intentions of gaining support of the project and approval to share data with the research team. Organizations holding LID monitoring data and willing to contribute to the study will be asked to share complete data sets. Important to evaluating the performance of LID BMPs is not just monitoring data but also the meta data (i.e. design plans, maintenance information) associated with an LID monitoring projects so a standard LID project data-information list (Objective #4A) will be developed. To ensure a consistent approach to monitoring an obtaining comparable data a standard LID/GI monitoring protocol (Objective #4B) will also be developed for use by all SMC CLEAN LID monitoring. A data sharing protocol (Objective #4C) will be developed for use in this initial phase as well as the active data collection phase of the project.

All information gained will be compiled into a database (Objective #4D) and examined to understand where overlap exists to make site to site comparisons for LID performance. This matrix will also allow for a comparison of available data to requirements necessary to address the identified targeted research questions. These will be divided as applicable to the targeted research questions to answer short term need for use in calibration of watershed programs (Objective #3C) and the long-term questions for modification of LID design, construction, and maintenance (Objective #3D).

Data will first be characterized to estimate LID BMP performance and to develop a conceptual model of LID operations (Objective #4E) and a companion method for performance calculation. Performance calculations will be mass balance based and look to evaluate the TAC approved targeted LID research questions. Finally, based on the targeted research questions a monitoring plan (Objective #4F) will be developed for the SMC CLEAN Project.

Task 2 Work Products

- Research & Evaluate Current LID Monitoring Data
- LID Monitoring Database
- Identification of Gaps in LID Monitoring Data
- Targeted LID Research Questions to answer short term needs
- Targeted LID Research Questions to answer long term needs
- LID Operations Conceptual Model
- Standard LID Project Data-Information List
- Standard LID/GI Monitoring Protocol
- Data Sharing Protocol
- SMC CLEAN Monitoring Plan

SMC CLEAN Targeted LID Research Questions

Objective 3C: Identify Target LID Research Questions to answer short term need for use in calibration of watershed programs

To answer the short-term need for use in calibration of watershed programs the focus is two-fold, 1) verification and understanding the pollutant removal of LID systems and 2) understanding the hydrologic benefits of LID systems. Since bioretention systems (with and w/o underdrains) are the most commonly implemented LID BMPs in southern California, and with a need for a targeted focus of the initial phase of the SMC CLEAN it is proposed to focus on bioretention systems to answer this 2-part focus. Data availability is the primary criteria for the selection of BMPs to evaluate. Other LID data will be collected and evaluated to the extent feasible, however the focus of the initial phase of the SMC CLEAN project will be on bioretention systems. The watershed calibration will use information regarding bioretention systems to understand if 1) the assumed pollutant removal effectiveness associated with bioretention systems which is used to support water quality outcomes that are integrated into watershed plans is accurate and 2) are bioretention systems achieving one of the primary purposes of LID of mimicking pre-development (naturally occurring) hydrology for the drainage areas in which they are implemented. Watershed plans can then be modified to optimize bioretention size based on understanding of pollutant removal and hydrologic benefit. The questions below will be answered using data obtained from the SMC CLEAN project partners and with the data resulting from the monitoring to be performed as part of the project. With the 2-part focus of understanding the pollutant removal and hydrologic benefits of bioretention systems the following specific research questions have been identified to accomplish Objective 3C:

- What are the pollution removal benefits of bioretention systems in Southern California?
  - Calculate/characterize the pollutant removal benefits of bioretention systems with underdrains
  - Calculate/characterize the pollutant removal benefits of bioretention systems without underdrains.
  - If possible, discern whether changes in the bioretention soil matrix (BSM) being implemented in Southern California affects performance across pollutants.
- What are the hydrologic benefits of bioretention systems in Southern California?
  - Calculate/characterize the volume reduction of bioretention systems with underdrains.
  - Calculate/characterize the flow duration effects of bioretention systems.
  - Compare/evaluate the measured hydrologic benefits (volume and flow attenuation) with bioretention system design parameters.

The answers to the questions above should be completed by June of 2018 (2 wet seasons).

Objective 3D: Identify Target LID Research Questions to answer long term for modification of LID design, construction, and maintenance

To answer the long-term need to understand how the differences in design, construction, and maintenance affect LID performance the focus will be on gathering existing data not currently accessible (i.e. Prop 84 data) including the meta data (design, construction, and maintenance information) and evaluate how these elements effect pollutant removal and hydrologic performance. The focus of the long-term effort will be bioretention systems and will incorporate to the extent feasible research and monitoring being performed by project partners and evaluation of the meta data to understand what elements affect performance. Data collected and evaluated to date suggest that it is possible and perhaps likely that even with access to data sets not currently available the data and information may not yet exist to adequately answer the questions identified below. If the data and information to answer these questions cannot be obtained within the constraints of this project, then the priority focus of Objective 3D will be to identify critical data needs and to provide clear guidelines for LID data collection so that more robust data are generated from projects in the future. With better datasets, these questions can be more and more effectively addressed going forward. ensure that the standard LID data/information is generated for future LID projects so that the questions below can be answered in the long-term. The following specific research questions have been identified to accomplish Objective 3D, however these questions will take a longer time frame to answer and the SMC CLEAN project will establish a standard LID monitoring protocol and identify the process studies that would need to be performed and identify those that have been performed and are being performed to quantify the kinetics of removal processes in bioretention systems, both helping to answer the following long-term questions:

- How do specific bioretention designs/configurations affect pollutant removal and hydrologic performance?

- What are the most common bioretention designs/configurations (isolate soil depth, aggregate depth, and underdrain configuration as the differentiating factors) being implemented in Southern California (identify maximum 3 configurations)?

- How do different bioretention plants affect pollutant removal and hydrologic performance?
    - How do systems with and without plants affect pollutant removal and hydrologic performance?
    - What are the effects of different plants as identified in studies by others?
- How does maintenance for bioretention systems affect pollutant removal and hydrologic performance?
    - What is the frequency of monitoring for an individual LID BMP that would need to be performed to identify the pollutant removal and hydrologic performance effects of maintenance of an individual LID BMP?
    - What type of maintenance records are needed to identify the pollutant removal and hydrologic performance effects of maintenance of an individual LID BMP?
    - Can preliminary conclusions be drawn regarding pollutant removal and hydrologic performance effects of maintenance with information currently being collected and if so what are they?
- What kind of impacts are evident from improper construction of bioretention systems and how are these impacts affecting pollutant removal and hydrologic performance?
    - What are the typical construction errors that are seen with bioretention systems?
    - What are the qualitative impacts affecting pollutant removal and hydrologic performance of the typical construction errors that are seen with bioretention systems?
- What Southern California specific factors (i.e. climate) effect affect pollutant removal and hydrologic performance in comparison to bioretention data from project partners outside of Southern California?
    - What are the translators for Southern California of performance from bioretention studies performed elsewhere?
    - How do bioretention design parameters (soil depth, aggregate depth, and underdrain configuration) affect the translators?

Task 3 - Implement initial monitoring procedures in a beta test phase

The purpose of this task is to conduct monitoring activities needed to support the project research questions. A prioritized list of monitoring options will be created to fill the identified data gaps using existing data and information from ongoing projects identified in Task 2 and guidance from the TAC. Prioritization will be based on filling data gaps related to the highest priority questions with the goal of having representative and reproducible results within study sites and across multiple study sites.

Due to limited funds, priority will be given to existing projects that can be augmented. Based on needs and opportunities these efforts could include monitoring additional events, sampling/testing for additional analytes, monitoring receiving waters at sites within a project, or resampling a previously monitored site. Options for supporting this work include providing in-kind labor, providing funding for labor, or providing funds for lab / equipment. One other option could be the inclusion of additional stakeholder funding or other in-kind efforts from stakeholders.

Data will be collected according to the SMC CLEAN Monitoring Plan (Objective #4F) utilizing the Standard LID Project Data-Information List (Objective #4A) and the Standard LID/GI Monitoring Protocol (Objective #4B). The monitoring will include collecting data for the short-term needs (Objective #5A) and long term needs (Objective #5B).

Task 3 Work Products

- Implementation of targeted LID monitoring to answer short term needs
- Implementation of targeted LID monitoring to answer long term needs

Task 4 - Summarize all monitoring data, make recommendations, and update the LID Manual

Task 4A - Summarize and analyze of all monitoring data

The purpose of this task is to analyze and summarize existing and new monitoring data compiled during Tasks 2 and 3 and to answer the targeted research questions (Goal #3) based on the available information.

The SMC CLEAN database (Objective #4D) will be used for query of data for comparison to address the SMC CLEAN Targeted LID Research Questions (Goal #3). Using the database, inlet /outlet concentrations as well as volume reductions, pollution removal, and other pertinent meta data will be compared for the different bioretention/biofiltration systems monitored. Data from other LID BMPs besides bioretention/biofiltration systems that has been collected will also be evaluated to the extent possible. Event based data for each site will be calculated for end point metrics including percent removal and load reductions based on concentration and volume of influent vs. effluent. Effluent water quality will also be examined with respect to water quality objectives. These performance evaluations will be compared across the different bioretention/biofiltration systems monitored. Where possible other factors including design, environmental factors, rain event size vs design size, lifetime performance, and maintenance will be summarized. This information will be used to determine if qualitative or quantitative answers can be made for the SMC CLEAN Targeted LID Research Questions (Goal #3).and to identify management approaches which could be examined in future research.

As part of this analysis the LID conceptual model may need to be revised to identify how to control for/isolate each of the major study variables such as; design, soil matrix, construction vs installation, and BMP maintenance variability.

The SMC CLEAN Monitoring Plan (Objective #4F) and specific monitoring plans for each bioretention/biofiltration site and the design elements incorporated to facilitate monitoring will also be summarized. The site-specific monitoring plans will be examined to determine which elements are most effective at producing representative data and helping to answer management questions. The best elements will be used to make any modifications to the Standard LID/GI Monitoring Protocol (Objective

#4B). Also, an evaluation of event sample sets for statistical power will be conducted to determine recommended sampling events to characterize a site.

The analysis matrix of monitoring data to answer short term needs will accomplish Objective #6A, analysis of monitoring data to answer short term needs. Based on the compiled results, an expected performance range will be estimated for bioretention and biofiltration BMPs. This analysis matrix will provide real world empirical estimates of performance to guide the refinement of watershed models used to estimate pollutant concentrations in discharges, pollutant loads, and potentially to demonstrate compliance with permit requirements. These results will be compared to performance data from the literature and from BMP manufacturers in other areas.

The analysis matrix of monitoring data to answer long term needs will begin to accomplish Objective #6B, analysis matrix will be developed from monitoring data to answer long term needs. This will be a qualitative assessment of the performance of bioretention design elements and construction and maintenance. Here data will be examined to determine if measurable differences are observed from the data available. Performance under different antecedent conditions and performance over time will be examined. Longer term data needed to continue to characterize LID performance over time will be identified.

Task 4A Work Products

- Analysis matrix: monitoring data to answer short term needs
- Analysis matrix: monitoring data to answer long term needs

Task 4B - Make recommendations and update the LID Manual

The purpose of this task is to use the information and analysis developed in the other tasks to make recommendations and update the Southern California LID Manual. The first work product for this task is a technical memorandum on bioretention/biofiltration performance for short term needs, for use in calibration of watershed programs and any associated recommendations for bioretention/biofiltration design, construction, maintenance, and monitoring (Objective #7A). This memorandum will address the short term targeted LID research questions and will also provide any recommendations for the short term prior to the updates to the Southern California LID Manual being updated.

The second work product will be a technical memorandum on LID performance and associated recommendations for long term needs for modification of bioretention/biofiltration design, construction, maintenance, and monitoring (Objective #7B). This memorandum will identify any recommended modifications of bioretention/biofiltration design, construction, maintenance, and monitoring, based on data to date but will provide a document outside of the manual update, as it is likely that the long-term needs will not be able to be fully answered by this first phase of the SMC CLEAN Project.

The third work product will be the development of a set of Standard Bioretention/Biofiltration Monitoring Design Plans and Specifications (Objective #7C) for use by future bioretention/biofiltration monitoring projects. Information gathered through the implantation of the SMC CLEAN bioretention/biofiltration monitoring and the CASQA Standard Bioretention/Biofiltration Design Plans and Specifications will be used for developing this deliverable.

The updates to the LID Manual (Objective #7D) will include identification of the sections of the manual that will need to be updated and the LID monitoring data required to support the changes. Any recommendations based the technical memorandums as well as any recommendations based on any data evaluation performed for other LID BMPs besides bioretention/biofiltration BMPs will be integrated into the manual. The SMC CLEAN Project will coordinate with CASQA to post the updated Manual to the California LID Portal. The recommendations and updates to the Southern California LID Manual are expected to include the following based on the information, data, and analysis to date:

- Bioretention/Biofiltration Monitoring
    - Standard LID Project Data-Information List (Objective #4A)
    - Standard LID/GI Monitoring Protocol (Objective #4B)
    - LID Operations Conceptual Model (Objective #4E)
    - Standard Bioretention/Biofiltration Monitoring Design Plans and Specifications (Objective #7C)
- Any Bioretention/Biofiltration design and soil matrix recommendations
    - Bioretention/Biofiltration BMP design considerations
    - Hydrologic modeling/calculations
    - Site specific considerations
    - Soil matrix configurations
- Bioretention/Biofiltration Construction/Installation recommendations
    - Construction/installation specifications
    - Protocol to ensure Bioretention/Biofiltration features are installed as designed, including all specified materials.
    - Documentation required before final approval.
    - LID inspection frequencies (Plans, final grading, during construction)
- LID BMP Maintenance recommendations
    - O&M plan preparation, timing and responsibilities
    - LID elements to be inspected and maintained
    - Use available maintenance documentation to develop a consistent approach.
- Update approval/recordation process

This task will also include the preparation of Project Report for Phase 1 of the SMC CLEAN Project (Objective #7E). The project report will be developed to summarize the completion of all of the tasks, document the recommendations of the study, and the updates to the Southern California LID Manual. The report will be reviewed by the TAC and changes will be based on TAC comments to finalize the report. Findings and recommendations of the report will also be linked to the SMC Research Agenda.

Task 4B Work Products

- Technical memorandum on LID performance for short term needs and any associated recommendations for LID design, construction, maintenance, and monitoring.

- Technical memorandum on LID performance and associated recommendations for long term needs for modification of LID design, construction, maintenance, and monitoring.
- Standard Bioretention/Biofiltration Monitoring Design Plans and Specifications
- Updates to the Southern California LID Manual to incorporate recommendations for LID design, construction, maintenance, and monitoring.
- SMC CLEAN Phase 1 Project Report

Task 5 - Ongoing Collaboration with Project Partners

The primary purpose of this task is to collaborate with the project partners and obtain LID monitoring information and in the future help to coordinate LID monitoring using the Standard LID Project Data-Information List (Objective #4A) and the Standard LID/GI Monitoring Protocol (Objective #4B). Coordination will take place with the following project partners:

- Coordination with university project partners and identify opportunities for long-term collaboration.
- OCPW Glassel Campus LID Retrofit – Dr. Jian Peng
- RC Flood Control & Water Conservation District Campus LID Retrofit site
- UCCE site in Irvine (Darren Haver)
- UCI sites—Dr. Stanley Grant & Dr. Demerjian
- UCSD Scripps site-San Diego
- UCLA—Xavier Swamikannu and Institute of the Environment—internships
- Ballona Creek Bioretention Site/LMU – Dr. John Dorsey
- Council for Watershed Health
- City of Los Angeles
- CASQA
- Bay Area LID/Greenstreets Projects??
- Regional Boards
- SWRCB
- USEPA
- China Sponge City Initiative

Initial coordination with project partners will include identification of the LID with a focus on bioretention/biofiltration monitoring conducted or ongoing by the partner, identification of the LID data set available for analysis, and identification of future planned LID monitoring by the project partner Coordination also includes obtaining design plans (as-builts) for the LID BMPs that are being monitored. Since the initial approach of the SMC CLEAN project was more inclusive with data gathering and evaluation of other LID BMPs besides bioretention/biofiltration systems data has been collected from project partners regarding LID BMPs besides bioretention/biofiltration systems as well. Coordination may also include a site visit to the LID BMPs that are being monitored. It is expected that the level of effort for the Project Partners will be minimized to providing data and information about the LID BMPs. Coordination will also include obtaining information about potential future project funding such as grants as well as potentially teaming on grant pursuits (Objective 2B). Documentation of project coordination will be in the form of notes from each project partner coordination meeting and any site visits which will be provided to the TAC and interested parties. Project collaboration will also involve the development of the project website and platform for an LID monitoring clearing house and a place where LID monitoring project proponents can collaborate (Objective #2C). If feasible, due to locating funding for creation, an SMC CLEAN Online LID Data Submittal Tool/Clearing House (Objective #2D) will be developed. The SMC CLEAN Online LID Data Submittal Tool/Clearing House (Objective #2D) will be scoped out and funding will be sought for its development.

Task 5 Work Products

- Ongoing collaboration with Project Partners to understand LID monitoring efforts, lessons learned.
- Ongoing collaboration with Project Partners on potential future funding (i.e. grants)
- Development of SMC CLEAN Website for Collaboration of Project Partners and platform for the development of an LID/Data Submittal Tool Clearing House
- Scope and identification of potential funding sources for SMC CLEAN Online LID Data Submittal Tool/Clearing House
- SMC CLEAN Online LID Data Submittal Tool/Clearing House (If funding is located)

Appendix B

Targeted Research Questions

SMC California LID Evaluation & Analysis Network (SMC CLEAN)

Targeted Research Questions

August 8, 2017

SMC CLEAN Goals, and Objectives – From SMC CLEAN Work Plan

The following are the goals and objectives identified in the SMC CLEAN Work Plan, which are provided for reference. The focus of this document is Goal 3 and focus on Objectives 3C & 3D. Objective 1A is included for context.

Goal #1: Development and Ongoing Facilitation of a Technical Advisory Committee to assist in accomplishing the SMC CLEAN Mission & Goals.

- Objective #1A: Identify Potential Research Questions
- Objective #1B: Develop Work Plan
- Objective #1C: Develop branding for the project.
- Objective #1D: Ongoing coordination with consulting team and review comment of project products
- Objective #1E: Ongoing identification of project partners

Goal #2: Provide Ongoing Collaboration with Project Partners and Others Performing LID Monitoring and Serving as a Clearing House for LID Monitoring Information.

- Objective #2A: Ongoing collaboration with Project Partners to understand LID monitoring efforts, lessons learned.
- Objective #2B: Ongoing collaboration with Project Partners on potential future funding (i.e. grants) to make the SMC CLEAN project more robust and maximize the current funds allocated to the project.
- Objective #2C: Development of an SMC CLEAN Website for Collaboration of Project Partners and a platform for the development of an LID Monitoring Clearing House
- Objective #2D: Evaluate development of an SMC CLEAN Online LID Data Submittal Tool/Clearing House
- Objective #2E: Ongoing collaboration with the SWRCB and the GI/Data Standards Initiative

Goal #3: Development of Targeted LID Research Questions

- Objective #3A: Evaluate Current LID Monitoring Data & LID Research
- Objective #3B: Identify Gaps in LID Monitoring Data
- **Objective #3C: Identify Target LID Research Questions to answer short term need for use in calibration of watershed programs**
    - **Calibration of watershed models**
    - **Potential modification of watershed management programs**
- **Objective #3D: Identify Target LID Research Questions to answer long term for modification of LID design, construction, maintenance, and monitoring**

Goal #4: Development of LID Monitoring Plan Elements

- Objective #4A: Development of Standard LID Project Data-Information List
- Objective #4B: Development of Standard LID/GI Monitoring Protocol
- Objective #4C: Development of Data Sharing Protocol
- Objective #4D: Development of SMC CLEAN Database
- Objective #4E: Develop LID Operations Conceptual Model
- Objective #4F: Develop SMC CLEAN Monitoring Plan based on targeted LID research questions for short term and long term needs.

Goal #5: Perform Targeted LID Monitoring

- Objective #5A: Implement targeted LID monitoring to answer short term needs
- Objective #5B: Implement targeted LID monitoring to answer long term needs

Goal #6: Analyze LID Monitoring Data Collected

- Objective #6A: Analyze monitoring data to answer short term needs
- Objective #6B: Analyze monitoring data to answer long term needs

Goal #7: Make Recommendations & Update the Southern California LID Manual

- Objective #7A: Develop technical memorandum on bioretention/biofiltration performance for short term needs, for use in calibration of watershed programs and any associated recommendations for bioretention/biofiltration design, construction, maintenance, and monitoring.
- Objective #7B: Develop technical memorandum on bioretention/biofiltration performance and associated recommendations for long term needs for modification of bioretention/biofiltration design, construction, maintenance, and monitoring.
- Objective #7C: Develop Standard Bioretention/Biofiltration Monitoring Design Plans and Specifications.
- Objective #7D: Update the Southern California LID Manual to incorporate recommendations for bioretention/biofiltration design, construction, maintenance, and monitoring.
- Objective #7E: Development SMC CLEAN Phase 1 Project Report

Objective 1A: Definition of Potential Research Questions

The first Objective #1A identified in collaboration with the TAC potential research questions to help further define and articulate the details within the scope of work and work plan for the SMC CLEAN project. The specific research questions identified by the TAC for potential exploration are as follows:

- Understanding the range of performances under varying conditions and how ambient conditions affect performance
    - What is the mechanism by which the greatest benefit is achieved i.e. reduction in concentration or reduction in volume of stormwater?
    - What is the expected range of performance for different pollutant / chemical / biological categories experienced by LID treatment

- What are the benefits to different physical fractions during treatment? Is all benefit in the particulate form?
- How do the different climate zones in California affect LID performance?

- Understanding factors that influence performance (e.g. plants, soils, etc)
  - What is the magnitude of pollution removal benefits of different forms of LID infrastructure?
  - How do different LID designs affect LID performance?
  - How does the bioretention soil matrix affect bioretention performance?
  - How does the plant pallet affect LID performance?

- Understanding how implementation and management affects performance (installation, maintenance, real world)
  - How does construction and construction sequencing affect LID performance?
  - What are the effects of maintenance on LID performance?
  - Do proprietary BMPs perform in the real world setting compared to manufacturer specifications?

Identification of Targeted SMC CLEAN Research Questions

Discussions with the SMC CLEAN Technical Advisory Committee identified two primary needs associated with the project. The first is a short term need for a quantification of LID performance in Southern California, needed for use in providing empirical data to calibrate estimates for compliance measures such as the recently developed watershed programs (i.e. EWMPs, WQIPs, etc.) and their associated watershed/water quality models (i.e. RAA, RAS), and TMDLs. The second is more of a long term need to serve as collaboration entity and clearing house of LID monitoring data in order to understand the effectiveness of various LID BMPs overtime and understand how the differences in design, construction, and maintenance affect their performance. Objectives 3C & 3D below address these two needs respectively.

Objective 3C: Identify Target LID Research Questions to answer short term need for use in calibration of watershed programs

To answer the short-term need for use in calibration of watershed programs the focus is two-fold, 1) verification and understanding the pollutant removal of LID systems and 2) understanding the hydrologic benefits of LID systems. Since bioretention systems (with and w/o underdrains) are the most commonly implemented LID BMPs in Southern California and with a need for a targeted focus of the initial phase of the SMC CLEAN it is proposed to focus on bioretention/biofiltration systems to answer this 2-part focus. Data availability is the primary criteria for the selection of BMPs to evaluate. Other LID data will be collected and evaluated to the extent feasible, however the focus of the initial phase of the SMC CLEAN project will be on bioretention systems. The watershed calibration will use information regarding bioretention systems to understand if 1) the assumed pollutant removal effectiveness associated with bioretention systems which is used to support water quality outcomes that are integrated into watershed plans is accurate and 2) are bioretention systems achieving one of the primary purposes of LID of mimicking pre-development (naturally occurring) hydrology for the drainage areas in which they are implemented. Watershed plans can then be modified to optimize bioretention size based on understanding of pollutant removal and hydrologic benefit. The questions below will be answered using data obtained from the SMC CLEAN project partners and with the data resulting from the monitoring to be performed as part of the project. With the 2-part focus of understanding the pollutant removal and hydrologic benefits of bioretention systems the following specific research questions have been identified to accomplish Objective 3C:

- What are the pollution removal benefits of bioretention systems in Southern California?
    - Calculate/characterize the pollutant removal benefits of bioretention systems with underdrains
    - Calculate/characterize the pollutant removal benefits of bioretention systems without underdrains.
    - If possible, discern whether changes in the bioretention soil matrix (BSM) being implemented in Southern California affects performance across pollutants.
- What are the hydrologic benefits of bioretention systems in Southern California?
    - Calculate/characterize the volume reduction of bioretention systems with underdrains.
    - Calculate/characterize the flow duration effects of bioretention systems.
    - Compare/evaluate the measured hydrologic benefits (volume and flow attenuation) with bioretention system design parameters.

The answers to the questions above should be completed by June of 2018 (2 wet seasons).

Objective 3D: Identify Target LID Research Questions to answer long term for modification of LID design, construction, and maintenance

To answer the long-term need to understand how the differences in design, construction, and maintenance affect LID performance the focus will be on gathering existing data not currently accessible (i.e. Prop 84 data) including the meta data (design, construction, and maintenance information) and evaluate how these elements effect pollutant removal and hydrologic performance. The focus of the long-term effort will be bioretention systems and will incorporate to the extent feasible research and monitoring being performed by project partners and evaluation of the meta data to understand what elements are affect performance. Data collected and evaluated to date suggest that it is possible and perhaps likely that even with access to data sets not currently available the data and information may not yet exist to adequately answer the questions identified below. If the data and information to answer these questions cannot be obtained within the constraints of this project, then the priority focus of Objective 3D will be to identify critical data needs and to provide clear guidelines for LID data collection so that more robust data are generated from projects in the future. With better datasets these questions can be more and more effectively addressed going forward. ensure that the standard LID data/information is generated for future LID projects so that the questions below can be answered in the long-term. The following specific research questions have been identified to accomplish Objective 3D, however these questions will take a longer time frame to answer and the SMC CLEAN project will establish a standard LID monitoring protocol and identify the process studies that would need to be performed and identify those that have been performed and are being performed to quantify the kinetics of removal processes in bioretention systems, both helping to answer the following long-term questions:

- How do specific bioretention designs/configurations affect pollutant removal and hydrologic performance?
  - What are the most common bioretention designs/configurations (isolate soil depth, aggregate depth, and underdrain configuration as the differentiating factors) being implemented in Southern California (identify maximum 3 configurations)?
- How do different bioretention plants affect pollutant removal and hydrologic performance?
  - How do systems with and without plants affect pollutant removal and hydrologic performance?
  - What are the effects of different plants as identified in studies by others?
- How does maintenance for bioretention systems affect pollutant removal and hydrologic performance?
  - What is the frequency of monitoring for an individual LID BMP that would need to be performed to identify the pollutant removal and hydrologic performance effects of maintenance of an individual LID BMP?
  - What type of maintenance records are needed to identify the pollutant removal and hydrologic performance effects of maintenance of an individual LID BMP?
  - Can preliminary conclusions be drawn regarding pollutant removal and hydrologic performance effects of maintenance with information currently being collected and if so what are they?
- What kind of impacts are evident from improper construction of bioretention systems and how are these impacts affecting pollutant removal and hydrologic performance?
  - What are the typical construction errors that are seen with bioretention systems?
  - What are the qualitative impacts affecting pollutant removal and hydrologic performance of the typical construction errors that are seen with bioretention systems?
- What Southern California specific factors (i.e. climate) effect affect pollutant removal and hydrologic performance in comparison to bioretention data from project partners outside of Southern California?
  - What are the translators for Southern California of performance from bioretention studies performed elsewhere?
  - How do bioretention design parameters (soil depth, aggregate depth, and underdrain configuration) affect the translators?

Appendix C

Summary of the SMC CLEAN TAC Meetings

Table C-1. SMC CLEAN TAC Meetings Summary

No.	TAC Meeting Date	Meeting Agenda Items	Key TAC Input Provided
1	December 17, 2015	Introductions Project Overview TAC Participation/Expectations TAC Member Confirmation & ID Additional TAC Members Review/Discussion Draft Work Plan Outline Proposed Project Monitoring Sites & ID of Additional Sites Identification of Additional Project Partners Project Branding Project Resources Additional Funding Sources Next Meeting	Pollutant removal vs. water quality assessment: develop the right questions Develop standardized protocol for monitoring For additional members for the TAC, look for skill sets Priority on CA data, but use what is available and applicable Focus and customization of LID tracking tool Collectively look for a solution – what else needs to be done to answer the questions, get more funding, a possibility for comprehensive “branch” studies Funding sources: Prop 1, equipment manufacturers, EPA Future: standardized testing of the BMPs

2	February 25, 2016	Introductions Project Tasks Update Project Branding Work Plan Review & Discussion Next Steps Next Meeting	Need a consistent list of constituents Need to identify the performance differences for LID systems with and without vegetation Need to identify where are the data gaps Need to identify load reduction and volume reduction We need a better understanding of load reduction for watershed plans like the WQIP Need to start with a paper that Xavier and Ivar Ridgeway wrote regarding BMP performance Need to add the volume evaluation back in and have site specific data. The project cannot do everything and so need to have priorities Need to look at the DROPs program and evaluate how they are assessing performance Look at RCFC&WCD maintenance records along with their data Need to identify what the data gaps are and which data gaps we are going to fill We should be using the input criteria for the International BMP database Need to also evaluate permeable surfaces Need to stay away from evaluating vendor products Need to understand the adsorptive capacity of bioretention with and without underdrains and permeable pavement Need to gather data and focus on specific parameters so that effective recommendations can be made Need to also identify what metadata or other information needs to be collected (i.e. design elements, bioretention soil mix, plant pallet) so different LID configurations can be compared to other similar LID configurations. Need to also identify what are the next steps in the iterative process associated with Adaptive Management.

No.	TAC Meeting Date	Meeting Agenda Items	Key TAC Input Provided
3	May 25, 2016	Introductions OCPW Glassell Yard LID Retrofit Project Presentation & Tour Project Tasks Update Updated Work Plan Review & Discussion Next Steps - 2:55 Next Meeting	Develop project website Need identification of data gaps Develop conceptual LID monitoring plan
4	October 6, 2016	Introductions Project Tasks Update Standard LID Project Data-Information Request Targeted SMC CLEAN Research Questions Discussion & Finalization Next Steps Next Meeting	If constrained by annual budgets, or lack of rain, etc., can we stretch monitoring out over multiple seasons. Consider what kind of conditions (e.g. contaminated soils) should affect design/configuration decisions to maximize pollutant removal and hydrologic performance. Consider what information is needed to predict the major maintenance intervals (e.g., media replacement) that are necessary to maintain design performance. Consider level of construction management training and contractor oversight is necessary to achieve as-designed hydraulic function. Collapse tiers of monitoring parameters into those that are on 303-d as causing impairment from urban runoff and those supportive of understanding system function and water chemistry.

No.	TAC Meeting Date	Meeting Agenda Items	Key TAC Input Provided
5	February 17, 2017	Introductions SMC CLEAN Research/Monitoring Approach Draft SMC CLEAN Monitoring Protocol Potential LID Data Submittal Tool Discussion Next Steps Next Meeting	Develop costs estimates for research monitoring approach Develop final budget for monitoring task Implement research monitoring approach per budget Continue to research and obtain additional bioretention data Continue to collaborate with project partners Finalize research questions Define data analysis that will be performed based on finalized research questions
6	May 22, 2017	Introductions Ballona Biofilter Monitoring Presentation – John Dorsey, LMU Revised Draft SMC CLEAN LID/GI Monitoring Protocol Existing Monitoring & Stakeholder Collaboration Update Next Steps Next Meeting	Finalize Monitoring Protocol Finalize monitoring approach & associated costs for Define data analysis that will be performed
7	August 15, 2017	Introductions Final Work Plan Final SMC CLEAN LID/GI Monitoring Protocol SMC CLEAN Data Submittal Tool Existing Monitoring & Stakeholder Collaboration Update Next Steps Next Meeting	Continue with ongoing data compilation and evaluation Development of detailed data analysis methodology via Work Plan

8	January 22, 2018	Introductions Data Acquisition/Flow & SMC CLEAN Data Submittal Tool Maintenance & Inspection Protocols – Effects on Performance Proposed Monitoring with Maintenance Assessments Existing Monitoring & Stakeholder Collaboration Update Next Steps, Schedule, and Project Outcome Discussion Next Meeting	Once data is compiled compare local set of data to data outside of California. Develop a process for developing the BMP submittal tool including the following steps 1. Step 1: Identify the standard information to be collected 2. Step 2: Develop a scope for the data submittal tool 3. Step 3: Build the data submittal tool (to be developed in later phase of the SMC CLEAN project and once funds are identified) Develop guidance to standardize the way LID BMP data is collected, which would be one of the main outcomes of the project, similar to the Regional Monitoring Program Develop guidance to standardize the way LID BMP data is collected, which would be one of the main outcomes of the project, similar to the Regional Monitoring Program Develop standardized information and potentially a protocol for BMP inspections for public and private BMPs including Develop a standard inspection checklist Develop standard information to track maintenance performed Integrate standardized information for BMP inspections, inspection checklist, and standard info to track maintenance performed into the updated SMC LID Manual Evaluate OCPW Glassell campus and RC Flood campus to perform pre and post maintenance monitoring including BMP RAM Evaluate other public sites campus to perform pre and post maintenance monitoring including BMP RAM Scope out the entire SMC CLEAN project (study) including the elements that would occur in subsequent phases of the SMC CLEAN project.

No.	TAC Meeting Date	Meeting Agenda Items	Key TAC Input Provided
9	April 16, 2018	Introductions SMC LID Manual Proposed Project Deliverables Monitoring with Maintenance Assessments Update Existing Monitoring & Stakeholder Collaboration Update Next Meeting	Provide Scope of Long Term SMC CLEAN Study Provide SMC LID Manual Updates Provide SMC CLEAN Project Report
10	July 16, 2018	Introductions SMC LID Manual Status Update Bioretention Materials Evaluation Study Existing Monitoring & Stakeholder Collaboration Update Scope of Long Term SMC CLEAN Study Next Steps & Next Meeting	SMC LID Manual Updates should reflect what we have learned over the past near decade and the current regulatory conditions Determine if BSM is meeting full specifications is critical Expand audience of survey to designers and municipalities as well as suppliers
11	January 15, 2019	Introductions Updated SMC LID Manual Review Existing Monitoring & Stakeholder Collaboration Update BMP Submittal Tool Next Steps & Next Meeting	Update manuals based on comments Develop a detailed scope of work for the LID BMP Data Submittal Tool Coordinate the development of the tool scope with the SMC Regional Stream Monitoring Program Evaluate potential functional elements of the BMP Data Submittal Tool

No.	TAC Meeting Date	Meeting Agenda Items	Key TAC Input Provided
12	April 16, 2019	Introductions Updated SMC LID Manual Review Bioretention Materials Evaluation Study BMP Submittal Tool Scope Review Existing Monitoring & Stakeholder Collaboration Update	Include more of the history of the evolution of the manual and modify the cover to previously be for the SWRCB but now recognize it is an SMC CLEAN effort Include a more thorough definition of bioretention and biofiltration Include the negative/unintended aspects of LID as well as the benefits, flow affecting downstream habitat, maintenance. Include the aspect of approaching stormwater management from a regional perspective as well Need to reference all the complexities with implementation of LID up front in the manual: drought, regional capture and use, taking up the land, and what it means to implement LID in the urban environment Identify how WOTUS affects LID implementation Include a couple of examples where multiple benefits have been realized Should include info on proprietary BMPs optimization Add synthetic stormwater to the testing protocol Need to address long-term scope on how to maintain the submittal tool and database; need to ID where the funding for long term maintenance comes from Maybe the SWRCB would provide some funding for the tool

No.	TAC Meeting Date	Meeting Agenda Items	Key TAC Input Provided
13	July 16, 2019	Introductions Bioretention Materials Evaluation Study SMC CLEAN Phase I Remaining Schedule & Deliverables SMC CLEAN Webpage BMP Submittal Tool & BMP Regional Monitoring Update Existing Monitoring & Stakeholder Collaboration Update Next Meeting	Develop a broad survey to contractors, material suppliers, MS4 inspectors, and others to be identified to understand what type of materials we are seeing with construction of LID materials; survey could be broader in scope to help with scoping SMC CLEAN 2 Develop the next steps for the next phase of the SMC CLEAN (SMC CLEAN Phase 2); incorporate results of the survey; need to think about what the bigger picture is; develop a plan for to get to SMC CLEAN 2. Inclusive in this scope for SMC CLEAN 2: a. Identify the steps for development of a set of LID BMP standards and collaborating with ASTM, Greenbook. b. Evaluate the development of statewide specification. c. Identify the steps for the creation of an LID BMP testing and certification program d. Scope out what column testing of LID materials would be and integrate the age of the materials and how it affects pollutant removal and pollutant export. Identify any other elements/tasks that can be completed in this phase of SMC CLEAN that can serve as a foundation for SMC CLEAN 2. In collaboration with the BMP Regional Monitoring Program Ad Hoc Committee identify how the SMC CLEAN and new BMP Regional Monitoring Program fit together. In the update of the SMC CLEAN 2 SOW identify how the BMP Regional Monitoring Program and SMC CLEAN 2 fit together

No.	TAC Meeting Date	Meeting Agenda Items	Key TAC Input Provided
14	October 15, 2019	Introductions SMC LID-GI Long-Term Effectiveness Evaluation Needs White Paper Bioretention Materials Evaluation Study Survey SMC CLEAN Phase I Remaining Schedule & Deliverables Existing Monitoring & Stakeholder Collaboration Update Next Meetings	Develop Project Report Including: a. Data evaluation b. Preliminary evaluation of bioretention effectiveness c. Summary of SoCal SMC Manual Updates d. Summary of LID & GSI Construction, Inspection, Maintenance, and Monitoring Guidance Manual e. Scope of Long-Term SMC CLEAN Study f. Scope of the BMP Submittal Tool
15	March 10, 2020	Introductions Bioretention Materials Evaluation Study Survey Draft Project Report Annotated Outline SMC CLEAN Phase I Remaining Schedule Next Meeting: Date: TBD	State how we expect to use the report Link asset management in BMP submittal tool Put recommendations ins Executive Summary Need CA BMP database Need future guidance on how to apply data from other locations Provide training in June timeframe and need to promote the manuals
16	June 1, 2020	TBD	

Appendix D

Standard LID Project Data-Information List

SMC California LID Evaluation & Analysis Network (SMC CLEAN)

Standard LID Project Data-Information List

October 16, 2016

SMC CLEAN Standard LID Project Data-Information List

The following is the list of data/information that will be requested and compiled for each of the LID projects data/information is being obtained for the SMC CLEAN project. The list comprises monitoring data as well as meta data so that analysis can be performed to answer the proposed SMC CLEAN targeted research questions. Based on coordination with the State Water Resources Control Board (SWRCB) this list may serve as a preliminary list of data-information required to be gathered associated with future LID grant projects.

- Monitoring Data
    - Monitoring protocol
    - Monitoring parameters
        - Research question parameters (common 303-d constituents)
            - Bacteria – Enterococci, E. coli
            - Nutrients – TKN TN, TP, N+N, OP, NH4
            - Metals – Cu, Zn, Mn, Pb, Hg
            - Pesticides and herbicides
            - PCB
            - Trash
        - Water chemistry, surrogates, and system function
            - TSS / VSS / turbidity
            - Field parameters - pH, hardness, O2, Conductivity
            - DOC
            - Organics
    - Monitoring elements integrated into LID feature
    - Water quality data – inlet/outlet
    - Whole-storm water flow data – inlet/outlet
    - Draw down time/volume
    - Precipitation data
- Meta Data
    - Design plans and specifications
    - As-builts
    - Design storm, drainage area size, and sizing calculations
    - Drainage area land uses and percentages
    - Native soils information (including analysis of all inorganics measured in the water quality protocol), geotechnical report, infiltration tests
    - Engineered soil matrix information, soil matrix source
    - Plant information/list, plant source

- Mulch information/source
- Construction records, contractor information
- Maintenance protocols
- Maintenance records, maintenance contractor information
- Inspection records
- Data tracking protocols
- Data access information
- Data reporting protocols
- Other information being collected for each site and why it is being collected.

Appendix E

Monitoring Protocol

SMC CLEAN LID/GI Monitoring Protocol

This document outlines the process of data collection for a specific LID or green infrastructure project. It provides project management information, specific project information (meta data) to be collected, monitoring plan review recommendations, specific details on the data acquisition process including monitoring equipment, site set-up guidance, monitoring parameters for hydrology and water quality, and describes the intended use of the data collected. As much as possible, sample collection and analysis methods are standardized for comparability. However, do to different study needs, the recommended sampling frequency and schedule may vary substantially. Consequently, sampling schedules are included for three identified project types: Basic BMP Performance Verification; BMP Performance over Time, and Special BMP Studies (Tables 1, 2, and 3).

Basic BMP Performance Verification—for new BMP installations:

- To establish that the implemented BMP provides the hydrologic and pollutant reduction benefits as expected based on its design and application.
- To fulfill effectiveness assessment requirements for grant-funded BMPs;
- To support quantitative BMP effectiveness inputs to watershed management plans and impacts on receiving water quality;
- To support regional studies of bioretention BMP performance (such as the SMC CLEAN Project).

BMP Performance over Time:

- To evaluate the lifespan of bioretention media or otherwise predict major maintenance needs (e.g., media replacement) for common bioretention installations;
- To evaluate the performance implications of plant conditions and maintenance;
- To support cost-benefit evaluations.

Special BMP Studies:

- Proof-of-concept to evaluate new bioretention soil media types, new designs, or unique BMP arrangements;
- To evaluate the performance impacts of specific factors such as plant palette; construction practices; rainfall characteristics, or other;
- To evaluate pollutant fate and transport.

This data collection protocol is designed to ensure that monitoring data are adequate to evaluate the effectiveness of the aggregate of LID BMPs and are collected in a consistent manner to ensure that data from different LID BMP installations will be comparable. Improved understanding of the hydrologic and water quality benefits of LID BMPs will improve efforts to modify LID designs, specifications, and maintenance measures to optimize performance. Many individual LID BMPs should be monitored throughout all regional watersheds. Collectively, such data can be used to determine how effectively each class of LID BMPs reduce runoff volume and maintain or restore pre-project hydrologic parameters; how effectively they reduce pollutant loads and concentrations in runoff; what maintenance is required to ensure BMP performance over time; and what is the typical lifespan of bioretention media. Monitoring data collected, depending on the protocol options selected, will support evaluations of LID performance for individual projects, for multiple projects at small and large scales, and for various LID design approaches and implementation conditions. For example, monitoring for Basic BMP Verification or proof-of-concept studies for new designs or new bioretention media should be designed to stand alone since conclusions must be drawn from a single (or very few) installations.

This protocol is an integral part of a comprehensive project evaluation process. The process requires a complete project description and implementation records; stated objectives and management questions; a monitoring/sampling protocol; laboratory test methods, analytical procedures, and QA/QC procedures; data evaluation methods; and reporting specifications. The LID/GI monitoring is part of an iterative process as identified in Figure 1 on the following page. The effectiveness evaluation should be scaled to the scope and life expectancy of the project. Most LID BMPs are expected to function effectively for 10 – 20 years or longer if adequately maintained. If possible, prior to investing in full water quality monitoring, perform visual monitoring of at least one storm to identify any functional defects that may need to be corrected. A comprehensive evaluation will include documentation and evaluation of maintenance and performance over the life of the project BMP.

Pre-Monitoring Check

Before monitoring is scheduled to commence the basic functionality of the BMP must be checked. This Pre-Monitoring Check should verify:

- BMP built and sized per design;
- Preferred Construction Practices were used to minimize soil compaction or contamination;
- Correct BSM Materials used and installed correctly;
- Correct Elevations to ensure functionality;
- Inlet and Outlet in good condition
- Hydraulic Connectivity between BMP and inlet/outlet conveyance

Contributing Area Condition Evaluation

The condition of the area contributing runoff to the BMP must be evaluated periodically to verify the size of the area, the land use and use intensity, and the surface cover condition.

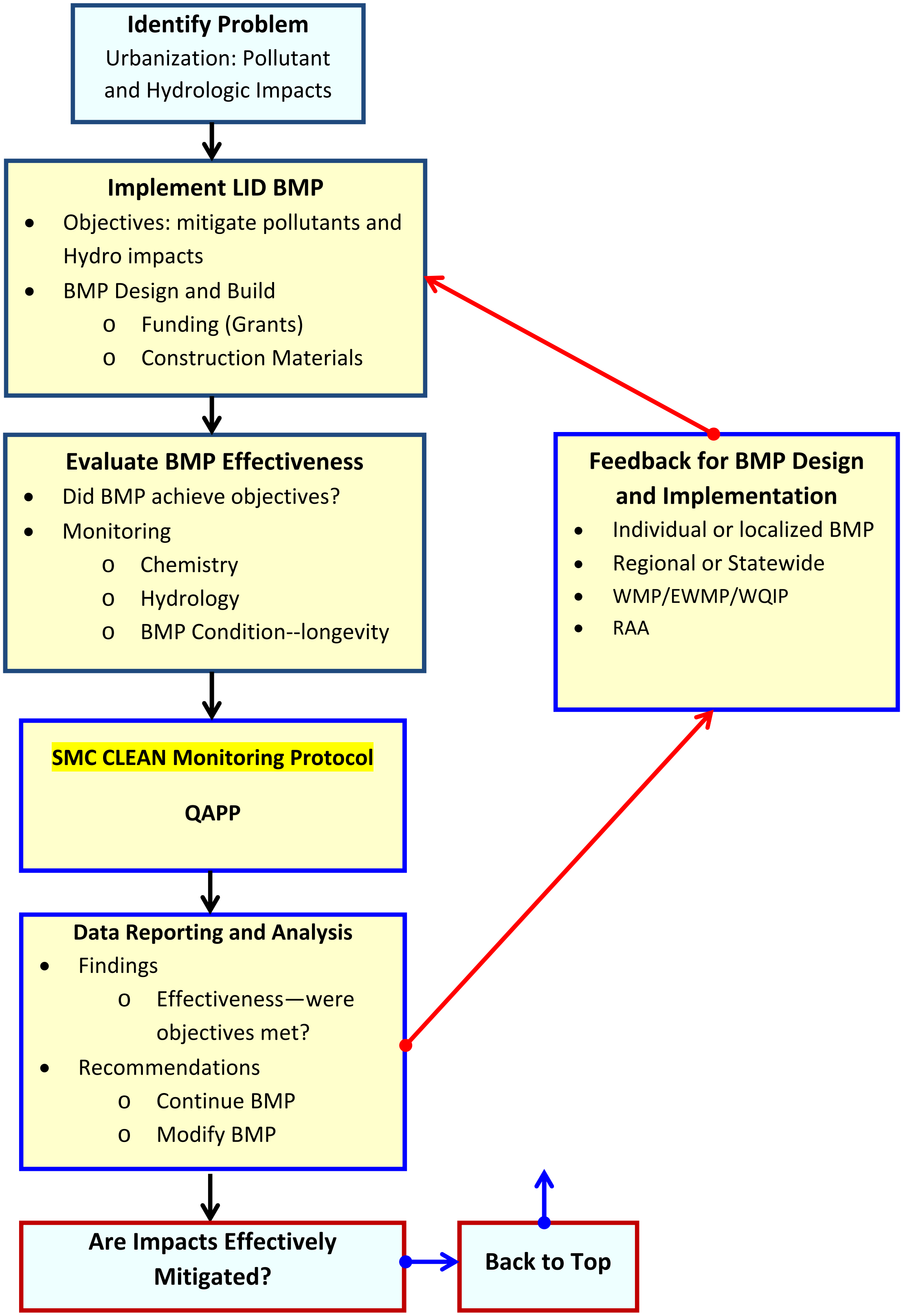
Plant Condition Assessment

The condition of the plants in the bioretention BMP must be periodically evaluated and documented, including consideration of the following parameters:

- Planted per Design
    - Plant type
    - Placement/spacing
- % Cover
- Irrigation system observations
- Maturity
    - Plant establishment date
- No Plants by Design

Maintenance Condition Tracking: Specific protocol to be developed

Figure 1: Iterative Process & LID/GI Monitoring



Monitoring/Sampling Frequency Options

<table>
<tr><th colspan="3">Table 1: Basic BMP Performance Verification</th></tr>
<tr><th>Year 1</th><th>Year 2</th><th>Year 3</th></tr>
<tr><td>Pre-monitoring check</td><td rowspan="3">3 events; early, mid, late season:
• Influent, effluent, hydrology
• Contributing area observations
• Plant condition observations
• Maintenance condition tracking</td><td rowspan="2">1 event:
• Influent, effluent, hydrology
• Contributing area observations
• Plant condition observations
• Maintenance condition tracking</td></tr>
<tr><td rowspan="1">2 events; early and mid/late season:
• influent samples;
• hydrology;
• contributing area observations;</td></tr>
<tr><td>Monthly plant condition observations</td><td>2 additional events required if significant BMP changes occur:
• Influent, effluent, hydrology
• Visual monitoring of contributing area
• Plant condition observations</td></tr>
</table>

<table>
<tr><th colspan="4">Table 2: BMP Performance over Time</th></tr>
<tr><th>Year 1</th><th>Year 2</th><th>Year 3 - 10[1]</th><th>Year 11 - 20[1]</th></tr>
<tr><td>Pre-monitoring check</td><td rowspan="2">3 events; early, mid, late season:
• Influent, effluent, hydrology
• Contributing area observations;
• Plant condition observations
• Maintenance condition tracking</td><td rowspan="2">2 events; early and mid/late season:
• Influent, effluent, hydrology
• Contributing area observations;
• Plant condition observations
• Maintenance condition tracking</td><td rowspan="2">2 events; early and mid/late season:
• Influent, effluent, hydrology
• Contributing area observations;
• Visual hydrologic function verification
• Plant condition observations
• Maintenance condition tracking</td></tr>
<tr><td rowspan="2">2 events; early and mid/late season:
• influent samples;
• hydrology;
• Contributing area observations;</td></tr>
<tr><td rowspan="4">3 events required after significant BMP changes occur:
• Influent, effluent, hydrology
• Contributing area observations;
• Plant condition observations
• Maintenance condition tracking</td><td>3 events required after significant BMP changes occur:
• Influent, effluent, hydrology
• Contributing area observations;
• Plant condition observations
• Maintenance condition tracking</td><td>2 events required after significant BMP changes occur:
• Influent, effluent, hydrology
• Contributing area observations;
• Plant condition observations
• Maintenance condition tracking</td></tr>
<tr><td>Monthly plant condition observations</td><td>[1]Evaluate data after year 5 and confirm or revise sampling frequency.</td><td>[1]Evaluate data after year 10 and confirm or revise sampling frequency.</td></tr>
<tr><td>First event after plant establishment:
• Influent, effluent, hydrology
• Contributing area observations
• Plant condition observations</td><td colspan="2" rowspan="2">Evaluate and revise schedule in response to any significant changes to BMP, major plant or structural failure, change, or replacement;

Evaluate and revise schedule with any significant changes in contributing area condition.</td></tr>
<tr><td rowspan="2">Maintenance condition tracking
(develop protocol with CWH)</td></tr>
<tr><td colspan="3">Older, established BMPs can begin monitoring using the Year 2 schedule.</td></tr>
</table>

Table 3: Special BMP Studies

Year 1	Year 2	Year 3	Beyond Year 3
Pre-monitoring check	**3 events; early, mid, late season:** • Influent, effluent, hydrology • Soil moisture • Contributing area observations • Maintenance condition tracking • Monthly plant condition observations	**3 events; early, mid, late season:** • Influent, effluent, hydrology • Soil moisture • Contributing area observations • Maintenance condition tracking • Monthly plant condition observations	**Evaluate study objectives and existing data; confirm or revise sampling frequency.** • Evaluate and revise schedule in response to any significant changes to BMP, major plant or structural failure, change, or replacement. • Evaluate and revise schedule with any significant changes in contributing area condition.
2 events; early and mid/late season: • influent samples; • Hydrology; • Soil moisture; • Contributing area observations; **In addition:** For studies requiring pollutant removal data to evaluate performance of bioretention soil media: • Collect effluent samples; For studies where pollutant removal is determined by volume of retention; • Ensure flow monitoring equipment is functional prior to each event		**2 additional events required if significant BMP changes occur:** • Influent, effluent, hydrology • Soil moisture • Contributing area observations • Monthly plant condition observations	
Monthly plant condition observations			

Integration of Monitoring into LID BMP Design

LID BMPs are inherently challenging to monitor due to their design as part of the landscape. There conveyance features are more subtle and distributed when compared to conventional BMPs which have defined inlet and outlet structures. Therefore, monitoring approaches should be considered and monitoring features should be integrated as part of the BMP design. LID BMP designs should be modified based on the type of monitoring that will be performed.

Project Description and Implementation

- Site drawings – Design plans, specifications, As-builts
- Design storm, drainage area size, and sizing calculations
- Drainage area land uses and percentages
- Historic site information
- Native soils information (including analysis of all inorganics measured in the water quality protocol), geotechnical report, infiltration tests
- Engineered soil matrix information, soil matrix source
- Plant information/list, plant source
- Mulch information/source
- Construction records, contractor information
- Maintenance protocols
- Maintenance records, maintenance contractor information
- Inspection records
- Data tracking protocols
- Data access information
- Data reporting protocols
- Other information being collected for each site and why it is being collected.

Monitoring Plan Review and Reporting

LID project monitoring plans should be consistent with the requirements of the agency requesting/requiring project monitoring and should be reviewed before being implemented. Some projects may have a monitoring plan review requirement imposed by the jurisdiction where the project has been implemented or by a regulatory agency (i.e. SWRCB) for a grant funded project or as part of a 401 Water Quality Certification or other regulatory requirement. For projects in the geographic scope of the SMC, projects can submit their LID monitoring plan to the SMC CLEAN project for review.

Monitoring data should be reported as specified by the jurisdiction approving the project and per applicable regulatory reporting requirements (e.g. CEDEN/SWAMP). For LID BMP projects in the geographic region of the SMC, LID monitoring and meta data will be submitted to the SMC CLEAN Data Submittal Tool.

<u>Required Monitoring Equipment</u>

Some or all of the following equipment will be required:

- data logger (a remote electronic measurement recorder)
- autosampler(s) with sample bottles and required accessories
- rain gauge
- weir(s) or flume(s)
- bubbler or pressure transducer
- area velocity meter or impeller
- Field meter (e.g. pH, EC, turbidity, DO) if available
- Soil moisture sensors (optional)

<u>Measurements</u>

Monitoring will include these measurements:

- Rainfall depth
- Temperature (?)
- Flow Rate[1]
    - Water level/depth
    - Flow velocity
    - Area-velocity
- Pollutant Concentration
- Soil Moisture (optional)

<u>Site Setup</u>

Develop BMP configuration schematic including:

- Contributing drainage area(s)
- Influent sampling point(s)
- Underdrain/effluent sampling point (s)
- Overflow/bypass sampling point(s)

Flow rate of water into and/or out of the selected LID BMP and pollutant concentration should be measured during runoff events at each point:

- Inflow
- Overflow
- Underdrain
- Bypass
- Vadose zone or within the bioretention soil media or gravel reservoir (optional)

[1] See flow monitoring guidance: http://www.openchannelflow.com/blog/isco-releases-7th-edition-of-its-flow-measurement-handbook

If all inlet/outlet points cannot be monitored, representative sites should be selected that allow for scaling or modeling of the entire BMP. Monitoring of flow from the underdrain (if present) and overflow/bypass is preferred to monitoring of the overflow/bypass alone.

If possible, projects should collect hydrologic and water quality data at the proposed BMP location before the BMP is installed. These projects should characterize the pre-BMP drainage area, instrument the location with flow rate measurement devices and autosamplers, collect flow-weighted composite samples, and analyze water samples for the same parameters to ensure comparability to samples collected after the BMP is installed.

Each sampling point for the LID BMP should be instrumented with a data logger, autosampler, and flow measurement devices. Tubing lines should be properly secured to the sampling location and protected within PVC conduit stretching from the sampler to the sample location to avoid damage to the lines. At the sampling location, tubing lines should be secured to the bottom of the flow pathway directly upstream of a metering weir (where possible). The weir will create sufficient head for an accurate water level measurement which can be used to calculate flow over the weir as well as provide a reservoir of storm water for collection through the autosampler tubing inlet strainer during lower flow periods of the hydrograph. If no weir is present, install the tubing lines to ensure that stormwater flow will not dislodge the equipment. Equipment checks should be conducted to ensure no blockages or tears will prevent proper measurements. The bubbler line should be secured, but allow bubbles to form at a continuous rate (1 bubble/sec) and sampling tubing lines lengths should be programmed to allow for proper head clearance, flushing time, and run time to collect samples. One rain gauge should be installed per BMP location to accurately measure the rainfall that occurs on the BMP drainage area. The preferable rain gauge is a tipping bucket gauge that interfaces directly with the data logger to allow direct comparison to flow data.

All sampling equipment should be placed in lockable security enclosures to deter theft and vandalism. Tubing lines and data cables should be protected with a PVC conduit from the elements and vandalism.

<u>Event Mobilization</u>

Prior to mobilization for a sampling event, weather/storm events should be tracked using multiple weather sources such as NOAA National Weather Service and Accuweather to estimate the event rainfall amount and arrival time of the storm event. Rainfall estimates should equal at least the project specific threshold to ensure adequate runoff to sample (0.25 inches suggested over 24 hrs.), and for effluent sampling, the antecedent dry period should be sufficient so that the BMP has completely drained water from previous rain events.

When event conditions are met, the sampling team should conduct a pre-event site visit to ensure the site is prepared for monitoring and the equipment remains properly installed, and begin sampling preparation procedures.

<u>Sampler Programming</u>

Composite samples

Minimum: collect a single volume-adjusted composite sample at the inlet and outlet/overflow which will represent the event mean concentration for the storm event.

Enhanced: collect a composite sample representing the "first flush" or rising limb of the hydrograph, and a composite sample representing the remaining flow for the event at the inlet and outlet/overflow.

Time-based

Based on the duration of the forecasted storm event autosamplers should be programmed to sample for up to 24 hrs. to provide a composite sample to represent the event mean concentration for the event. For a 24-hr. storm, tiered programming is recommended; where the first 12 discrete auto samples are collected every 30 minutes and the final 12 samples are collected at 1.5 hrs. For a storm event shorter than 24 hours the program should be appropriately scaled so that at least 75% of the storm is sampled.

Volume-based

Alternatively, autosamplers can be programmed for volume-weighted sampling by triggering samples based on a user-defined volume-to-sample quantity. In this case, a good estimate of flow rate and shape/timing of the hydrograph are needed. Adjustments are usually required based on experience from initial storm events. Underestimation of runoff will result in collection of additional samples and increased sample pacing which can backlog the autosampler tubing rinse/purge routine; backlogged samples then become time-weighted. Overestimation of runoff will result in collection of fewer samples and reduced representation of the event. Estimation of storm volumes and hydrographs can be improved by observing the monitoring site and instrumentation during the sampling event and adjusting pacing if needed. Hydrologic response of the BMP contributing area can also be better understood by monitoring and evaluating rainfall and flow only during storm event(s) prior to initiation of water quality sampling.

General setup

The autosampler should be programmed to conduct a triple rinse of the line, take a 1-liter water sample, and then purge the line.

The auto sampler/bubbler should be programmed to trigger sample collection based on a minimum flow/water level when water begins to overflow the weir. This can be done by setting a zero water level at ambient atmospheric pressures and setting the trigger to be the elevation of the top of the weir. Sample bottles should be then loaded into the auto sampler and iced for sample preservation prior to setting the sampler to standby.

Finally, all field meters should be calibrated/checked per manufacturer's instructions for in-situ instructions.

Grab Samples

Grab sampling may be required to collect samples for a specific parameter such as oil and grease or bacteria. Such grab samples should be collected during the estimated peak of a storm event in an area with representative flow. Collect water grab samples using a clean HDPE bottle. Once bottled, water samples are to be put on ice for rapid cooling to reduce biological activity. See USEPA *Industrial Stormwater Monitoring and Sampling Guide* (EPA-832-B-09-003; 2009) for grab sampling procedure.

If the use of autosamplers is not feasible, collect a composite sample by collecting 1-L grab samples using a time-based approach (e.g. 1 grab sample every 30 minutes for first 6 hours and 1 sample every 1.5 hours for remaining storm event duration) scaled to the project site and size of the storm event. Discrete samples are then combined in a single vessel to create the composite, or they can be composited by the laboratory.

Use field meter to measure temperature, pH, EC, DO, turbidity and other parameters at selected times during the storm event.

Sample Collection

Multiple trips to collect or retrieve the composite / grab samples may be required to ensure hold times are met (sampling collection times should be calculated based on the final sample of the composite). Composite samples for the rising, peak, and declining limbs of the hydrograph should be composited together in a clean vessel and homogenized prior to subsampling into containers for sample analysis. Personnel should wear disposable gloves to prevent sample contamination. One subsample should be used to collect in-situ measurements such as temperature, conductivity, pH, and dissolved oxygen.

Laboratory Preparation

Transport samples to a safe, dry, and clean area for preparation to ship to a contract laboratory for processing. Alternatively subsamples for dissolved species can be filtered using a 0.45 micron filter in the field where possible using a syringe filter. Samples requiring acid preservation should then have their pH adjusted to <2 as required.

Prepare Chain of Custody (COC) and field sheets for accurate documentation of the collection and processing of samples.

Laboratory Guidance

Common parameters that the contract laboratory should test for are listed below with their typical units and reporting limits from the 2015 Surface Water Ambient Monitoring Program:

Parameter	Analysis Method	Common Units	Target Detection Limit
	Conventional		
pH	SM 4500-H+	s.u.	N/A
Conductivity	SM 2510	µS/cm	2.5
Turbidity	EPA 180.1	NTU	1
Total Suspended Solids (TSS)	SM 2540-B	mg/L	2.0
Total Hardness	SM 2340-B	mg/L	1
	Bacteria		
Fecal Coliform	SM 9221-E	MPN/100 mL	2
Enterococcus	EPA 9000-1600	Colonies/100 mL	1
	Nutrients		
Total Phosphorus	SM 4500 – P E	mg/L	0.5
Total Kjeldahl Nitrogen	SM 4500-N	mg/L	0.5
	Metals – Total & Dissolved		
Cadmium	EPA 200.8(m)	µg/L	0.03
Copper	EPA 200.8(m)	µg/L	0.10
Lead	EPA 200.8(m)	µg/L	2
Zinc	EPA 200.8(m)	µg/L	0.70
	Organics		
Pesticides	EPA 625(m)	µg/L	0.005 - 0.2
	Hydrocarbons		
Total Petroleum Hydrocarbons (TPH)	EPA 625(m)	mg/L	0.5

Appendix F

Updated Southern California LID Manual

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

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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 85^{th} 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 85^{th} 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 I 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.

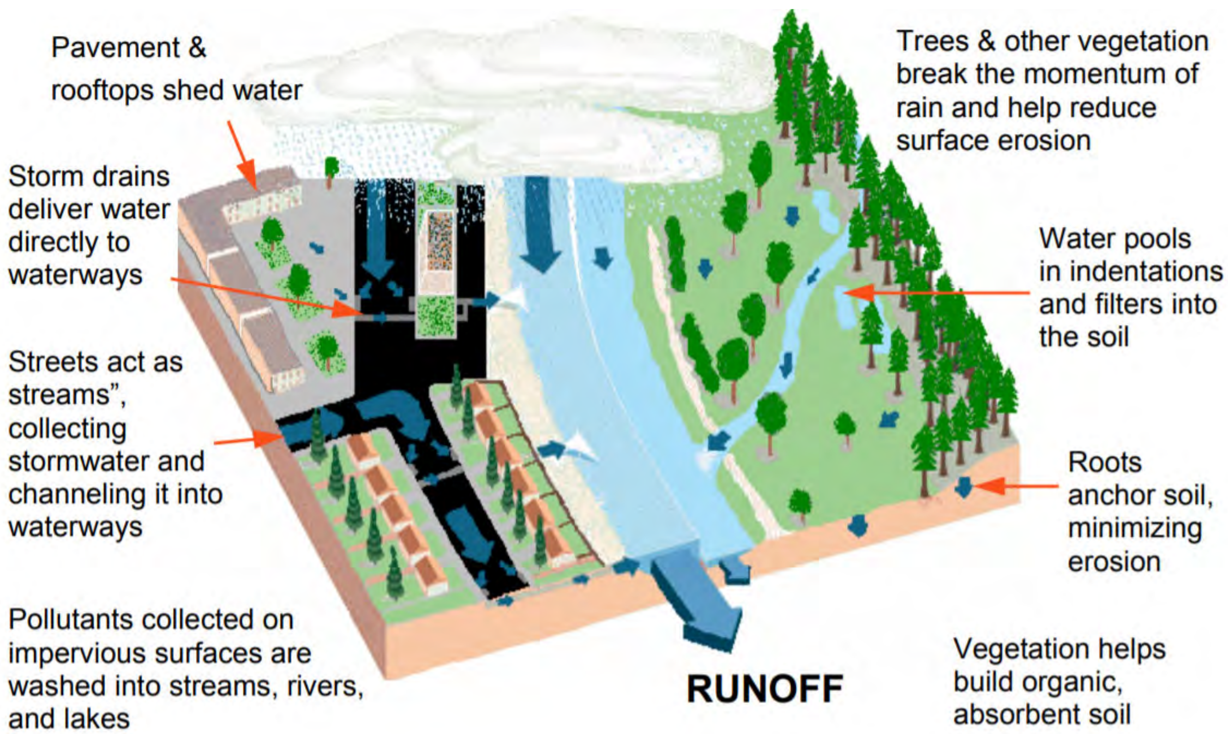

Figure 1-1. Urban influences on stormwater runoff.

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).

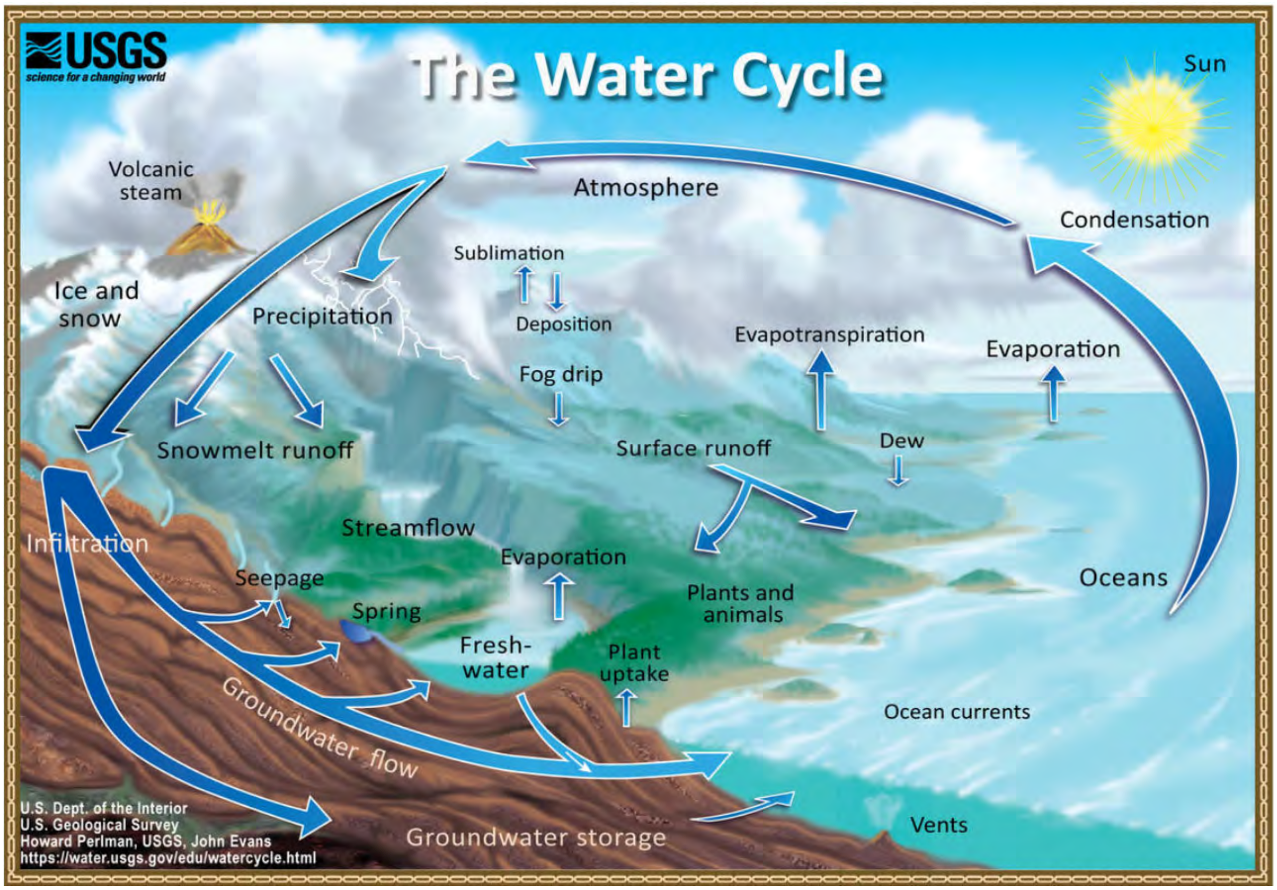

Figure 1-2. The Hydrologic Cycle.

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).

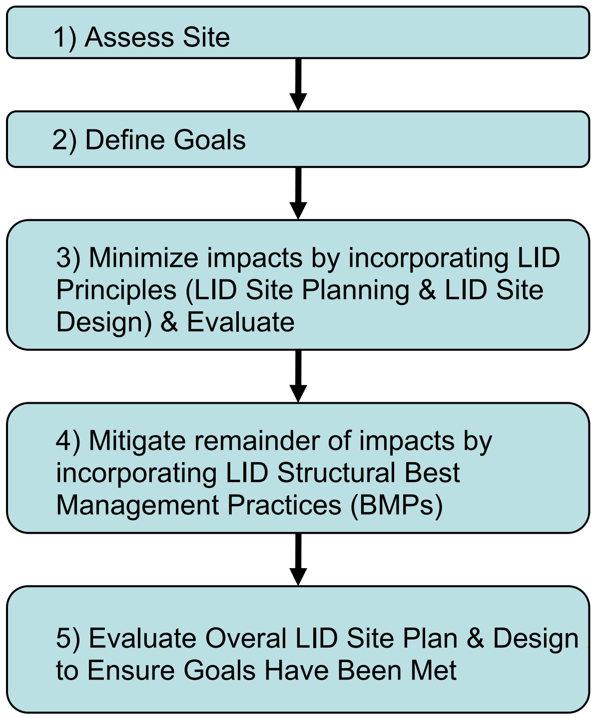

Figure 2-1. The LID Site Planning and Design Process

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.

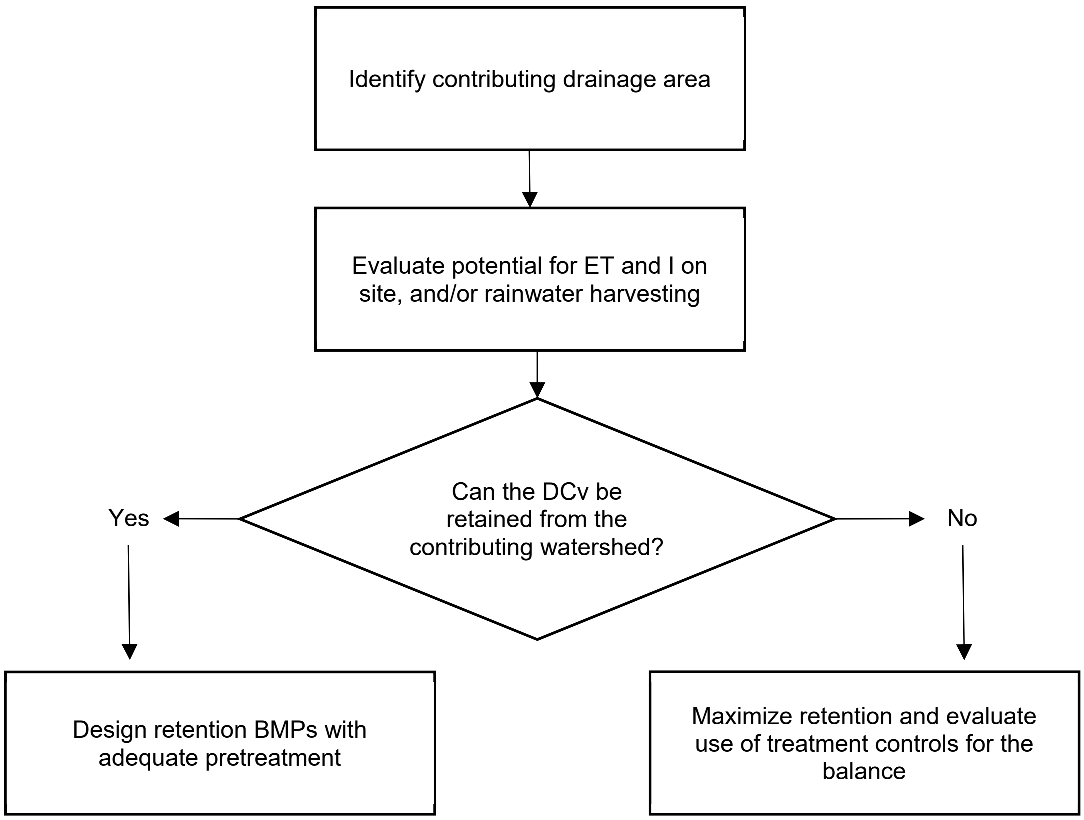

Figure 2-3. Municipal Retrofit Flow Chart.

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.

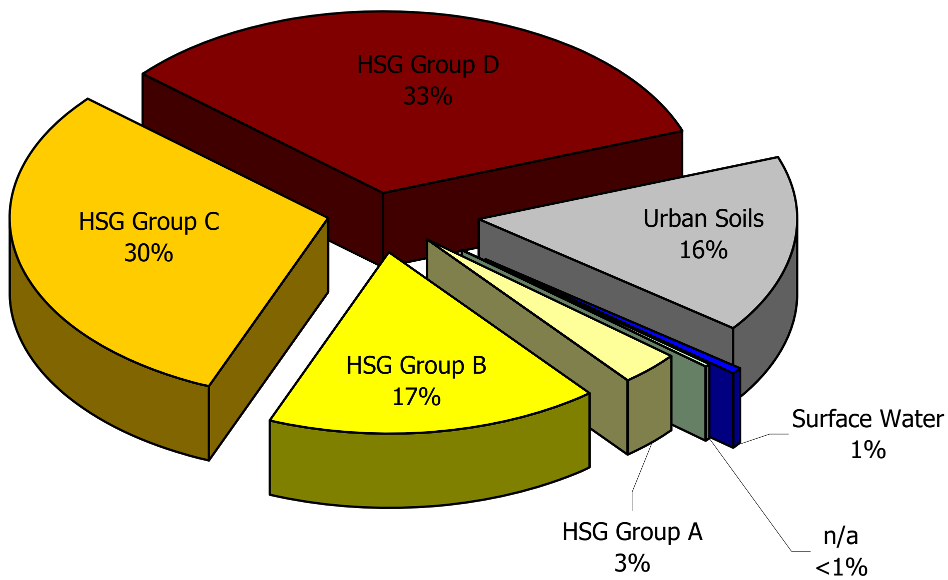

Figure 2-4. Hydrologic Groups for Southern California Soil Series

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).

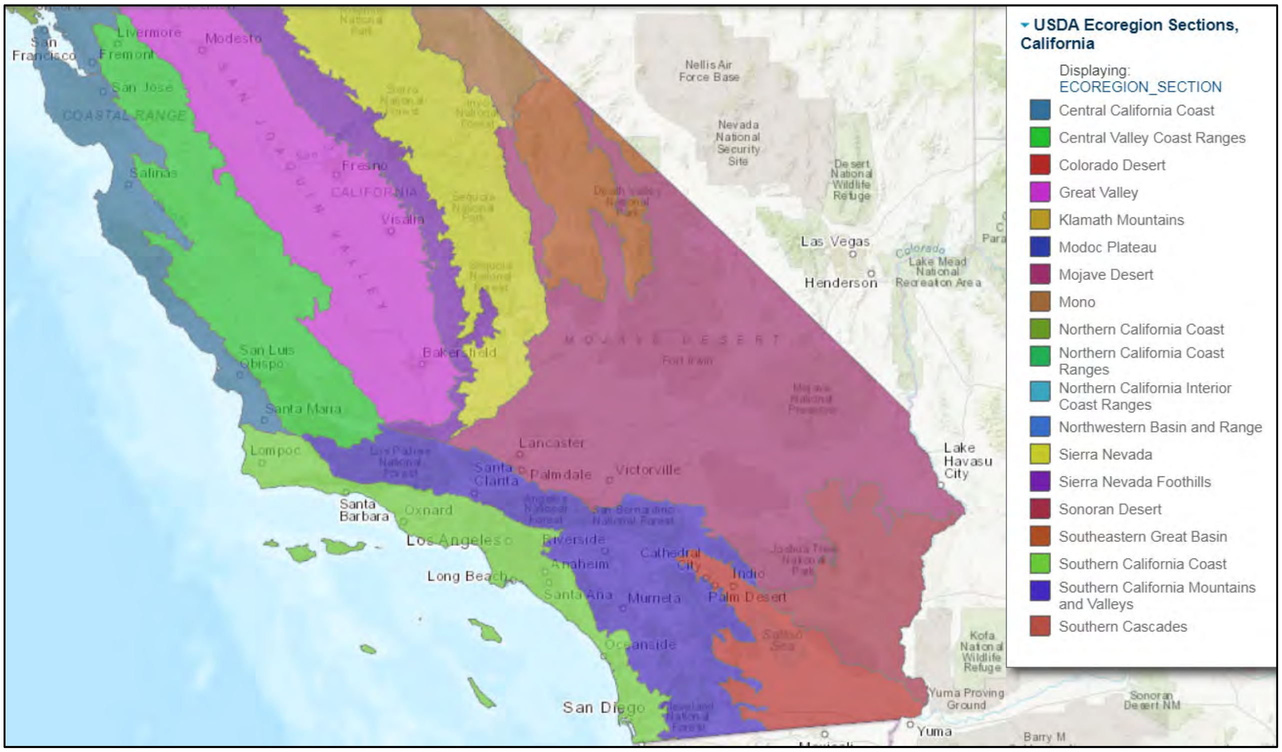

Figure 2-5. USDA Ecoregion Sections of Southern California

Source: Data Basin 2019

<u>LID Site Assessment – *Sensitive and Restricted Areas*</u>

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 85^{th} 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.

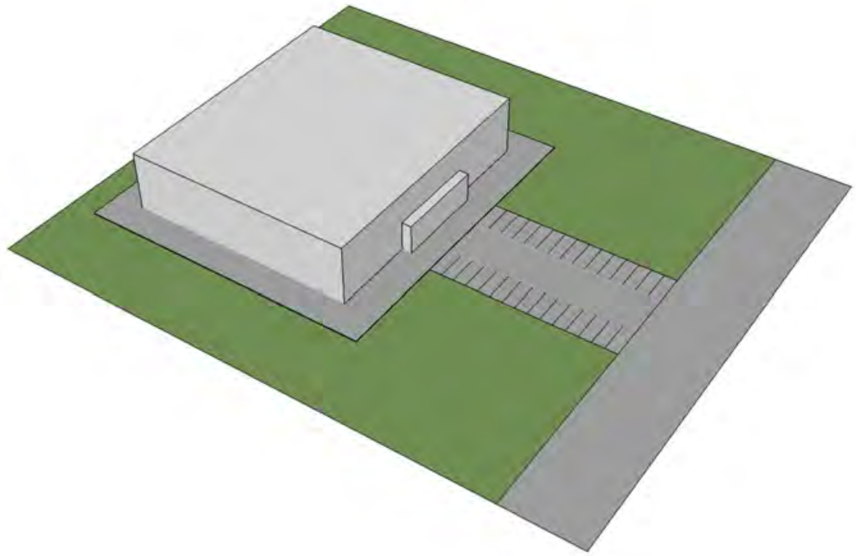

Figure 2-7. Commercial site showing directly connected impervious areas.

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).

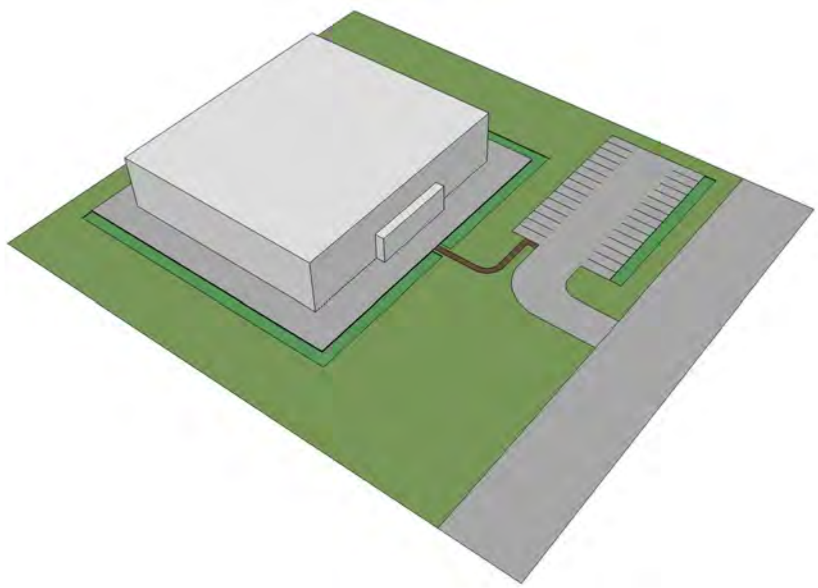

Figure 2-8. Commercial area in which impervious surfaces have been disconnected.

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 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.

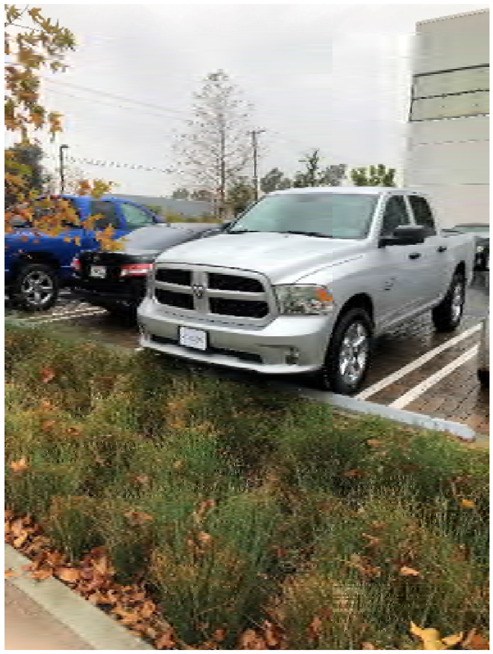

Figure 2-9. Bioretention Cell in Parking Lot, OC Public Works, Orange, CA.

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

<u>Residential</u>
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.

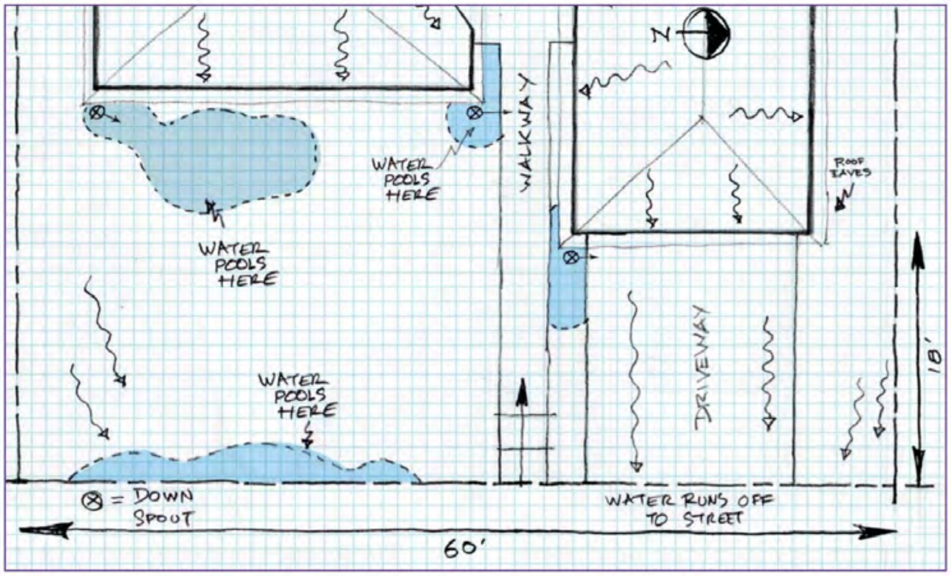

Figure 2-10. Single-Family Residential Lot Drainage Schematic.

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**).

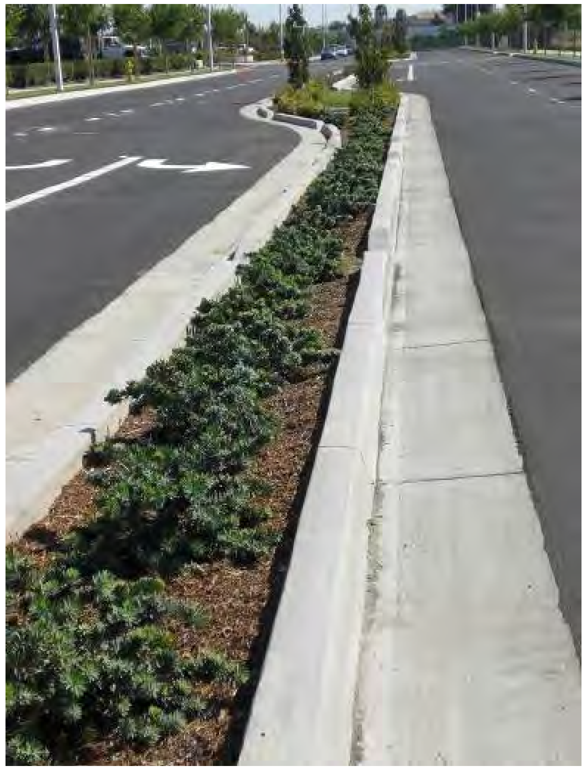

Figure 2-14***. Linear Bioretention, Downey, CA***

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

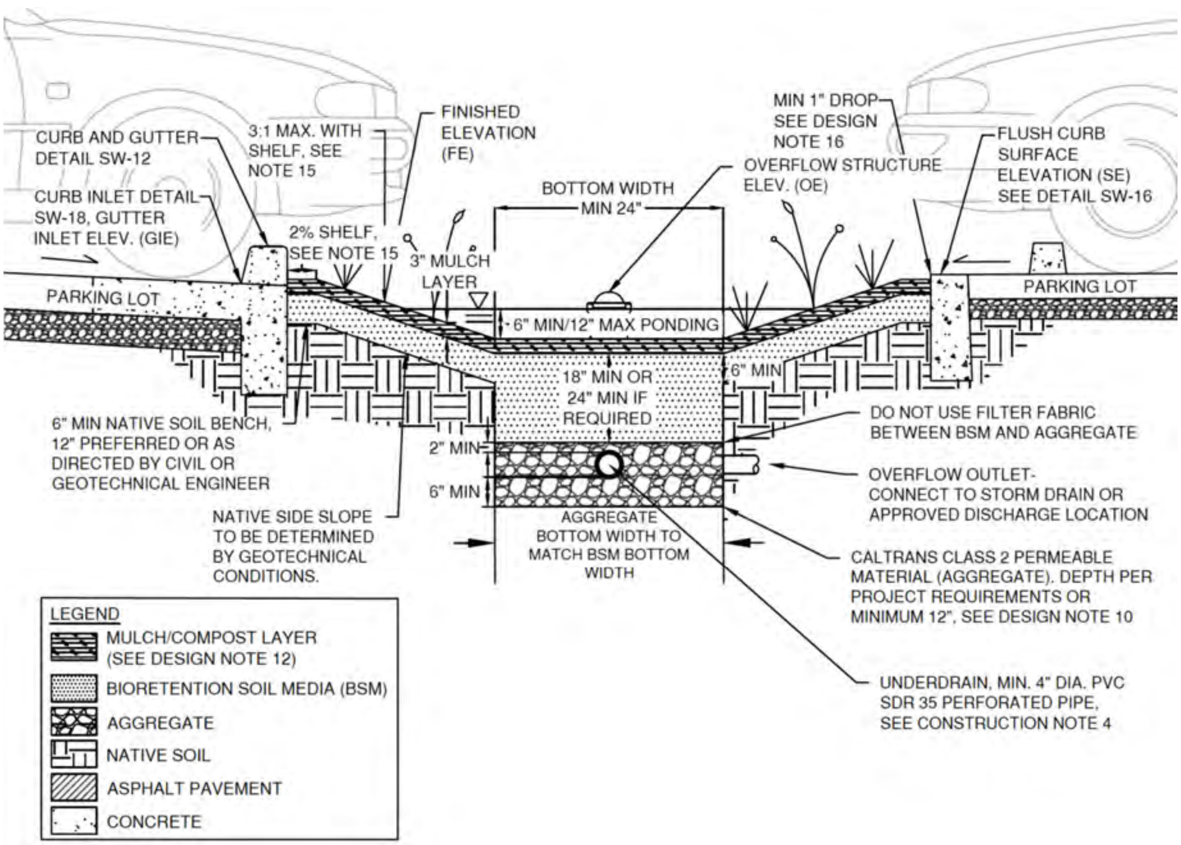

Figure 2-20. Detailed cross-section of a parking lot bioretention cell.

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).

<u>Resources</u>

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

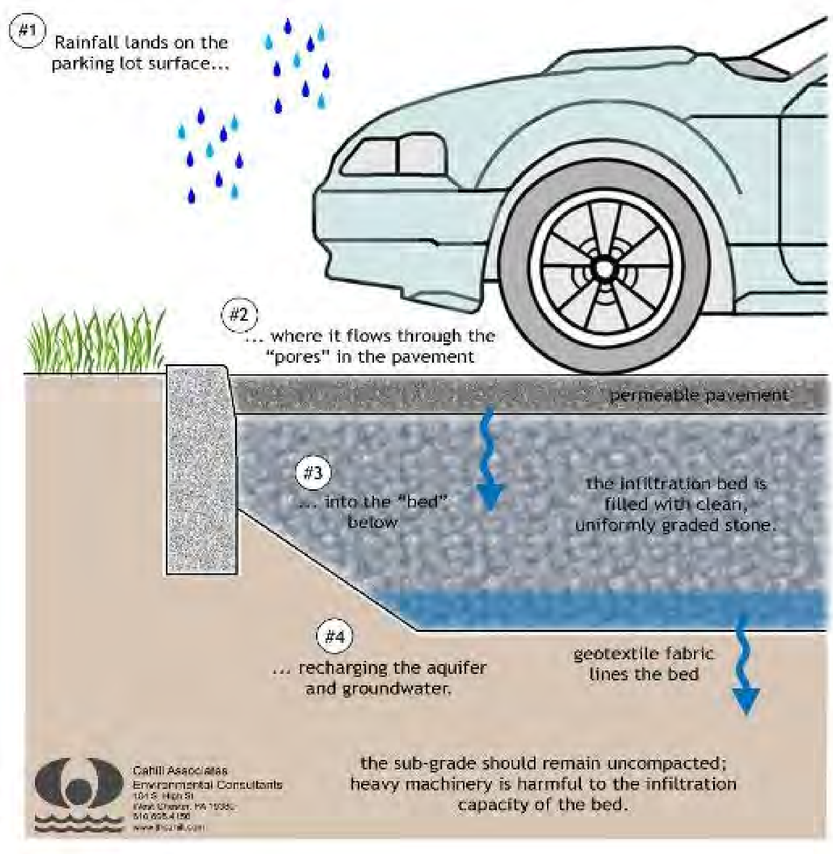

Figure 2-22. Cross-section showing design components of permeable pavement with subsurface infiltration bed.

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.

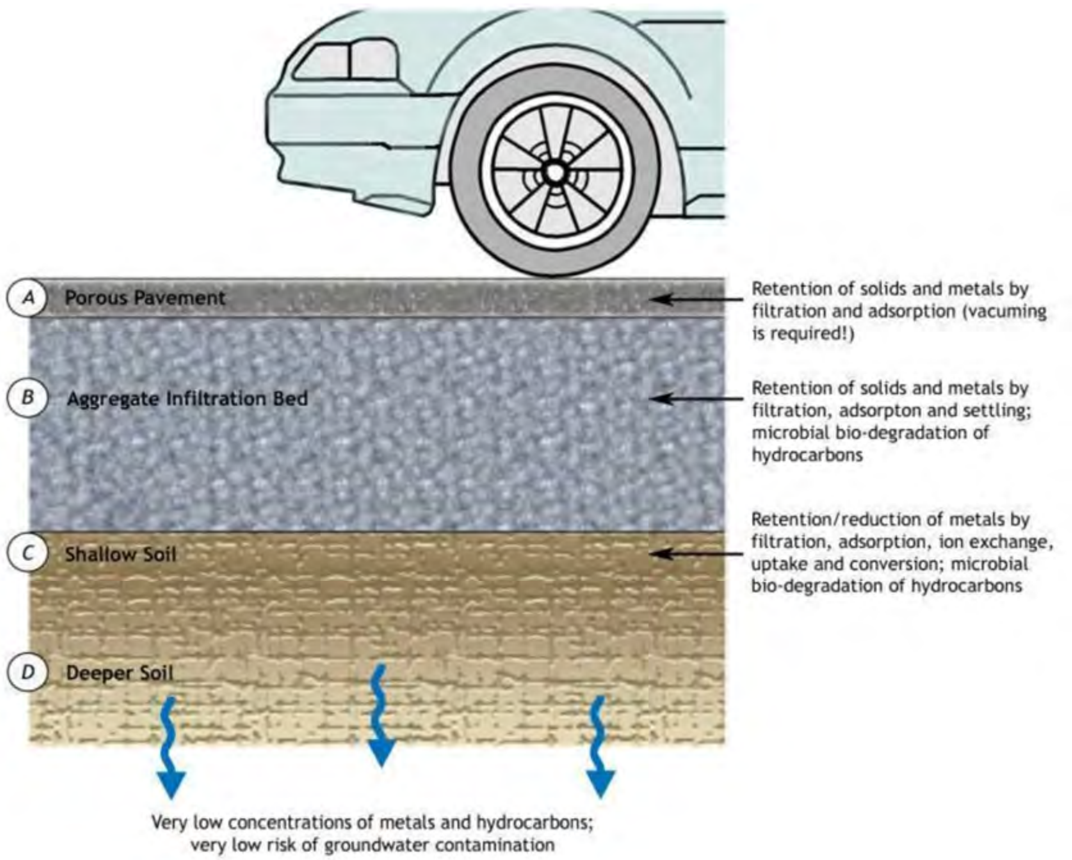

Figure 2-23. Water quality benefits of pervious pavement with subsurface infiltration.

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

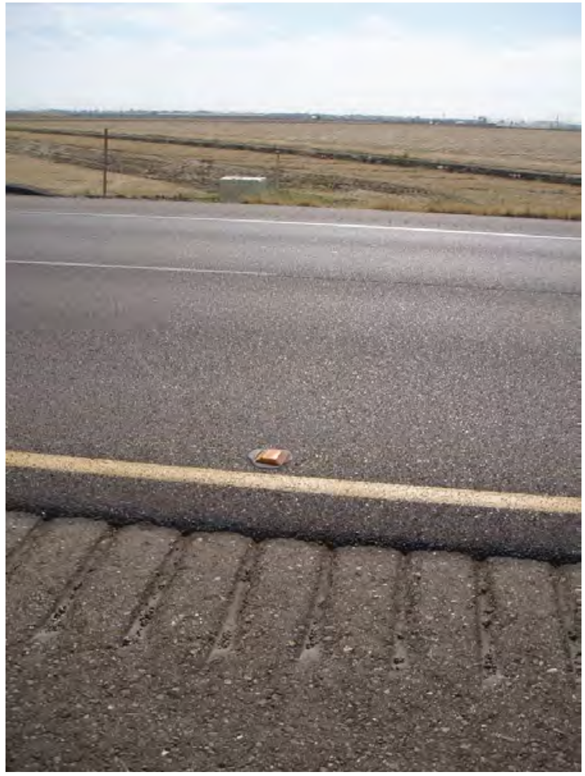

Figure 2-31. Porous friction course over traditional asphalt.

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).

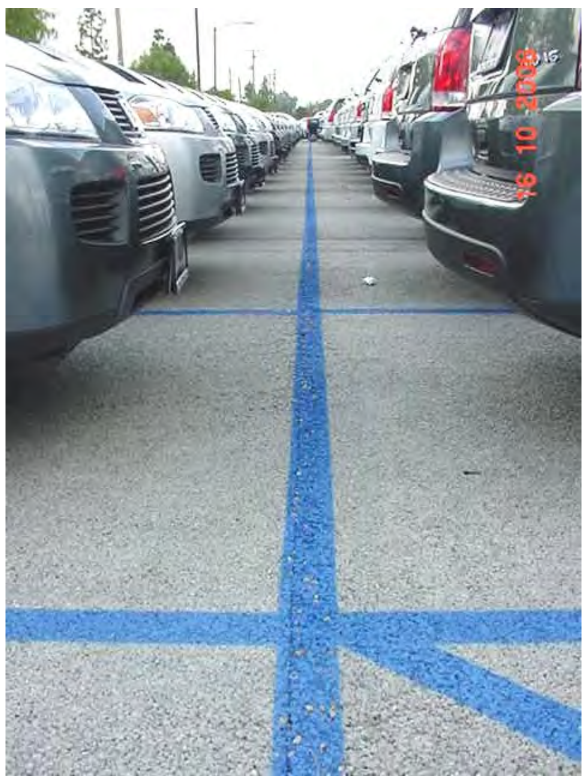

Figure 2-34. Pervious concrete in Cerritos, CA.

Source: Bill DePoto

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

Source: Lorraine Rubin

<u>Permeable Pavers</u>

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).

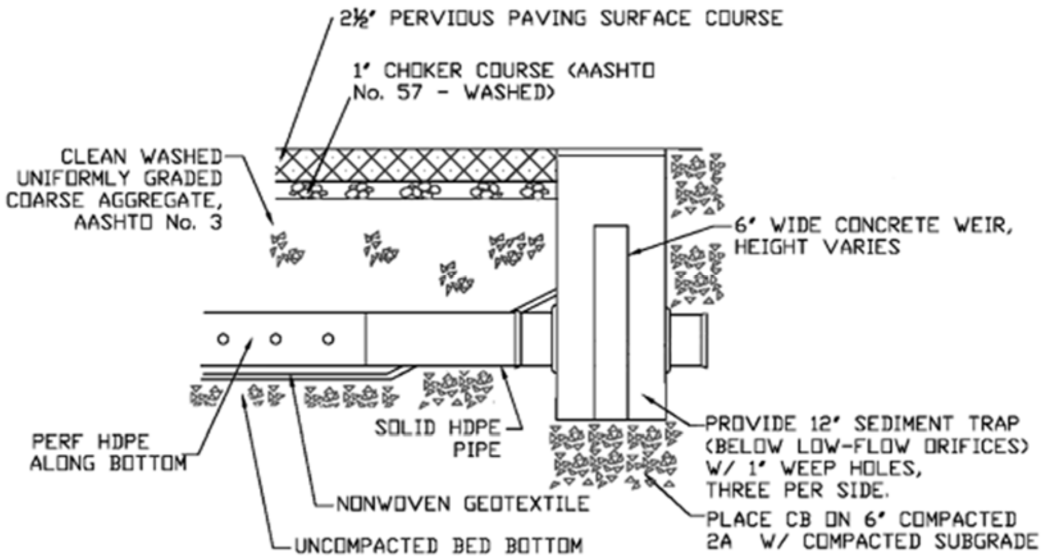

Figure 2-48. Example detail of an overflow device from a pervious asphalt system.

Source: Cahill Associates

<u>Sizing Criteria</u>

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:

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

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.

<u>Construction Guidance</u>

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.

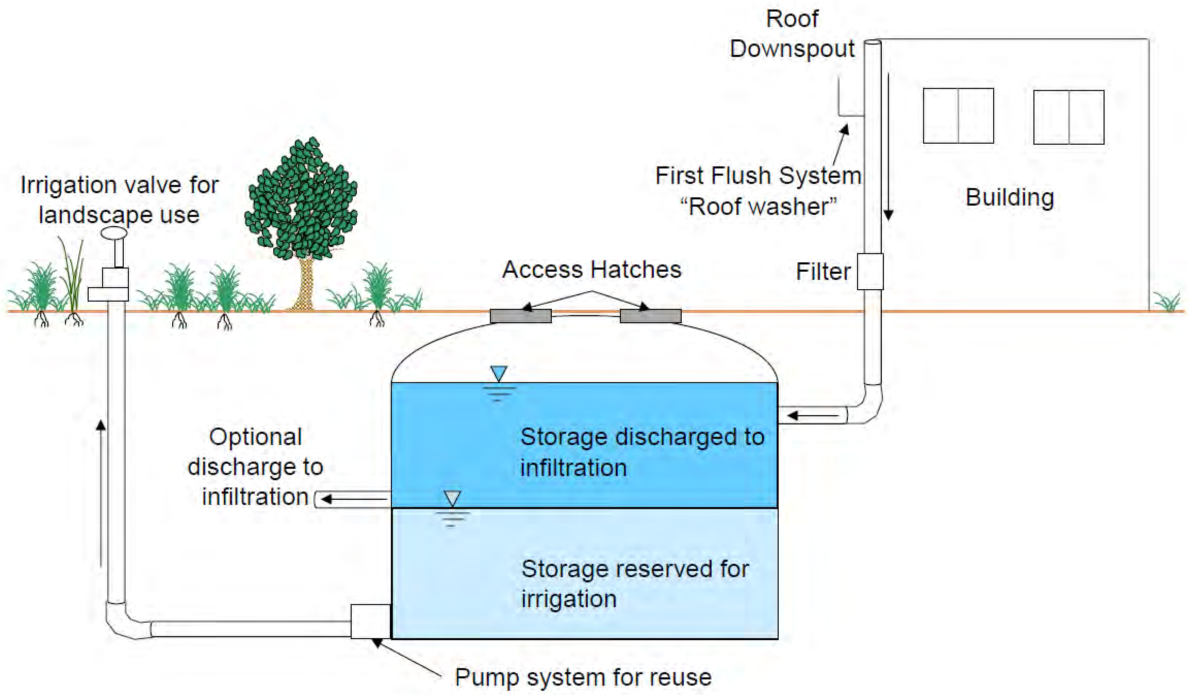

Figure 2-56. Schematic of Outdoor Underground Cistern with Overflow Directed to Pervious Area

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.

<u>Cross-contamination</u>
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.

<u>Maintenance Schedules:</u>

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.

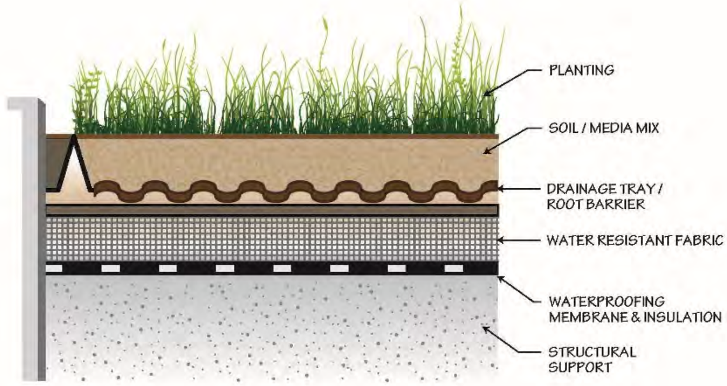

Figure 2-64. Green Roof Schematic

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.

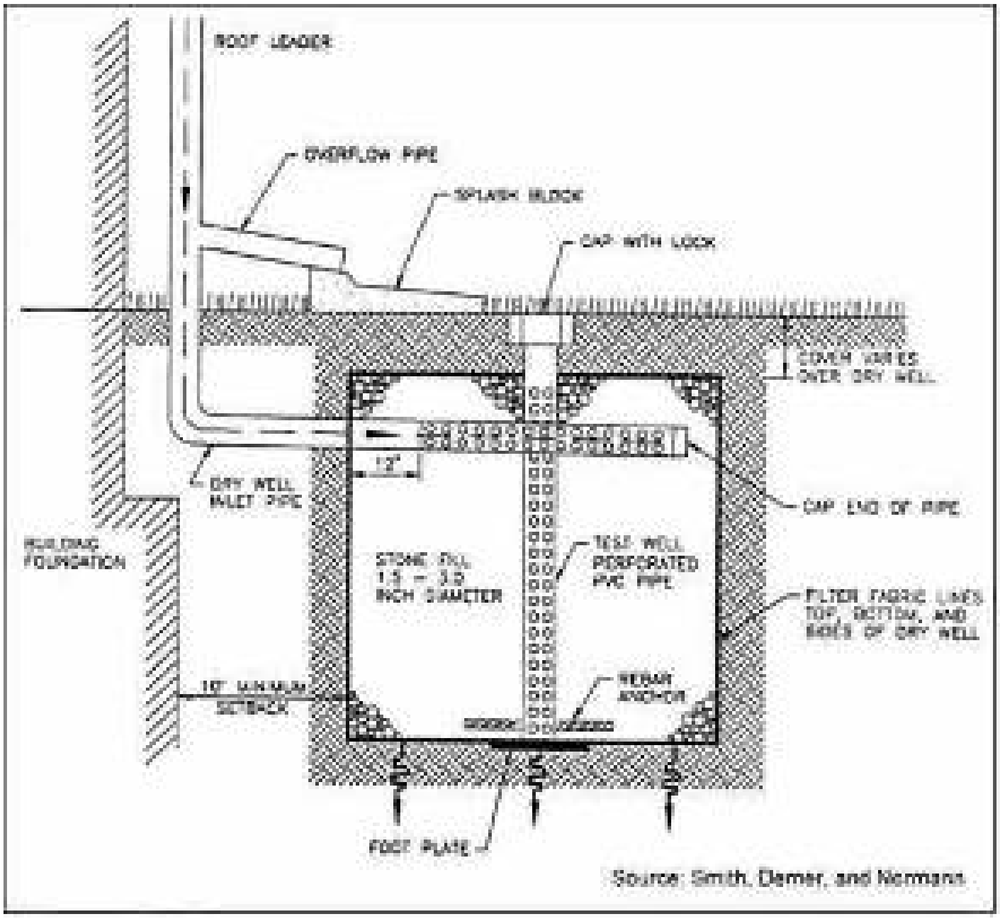

Figure 2-72. Schematic of a dry well.

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 Jersey 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.

<u>Background on Modeling LID</u>

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).

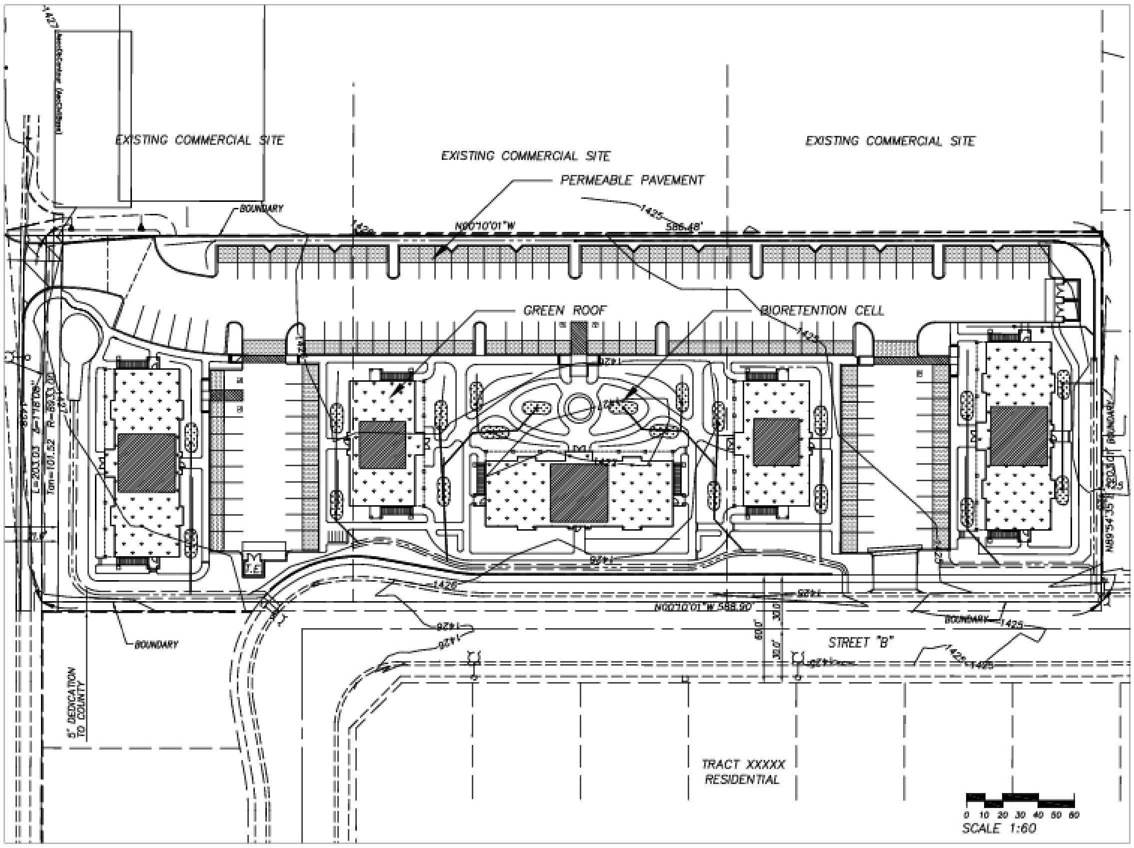

Figure 3-1. ***Retrofit of an existing commercial site.***

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).

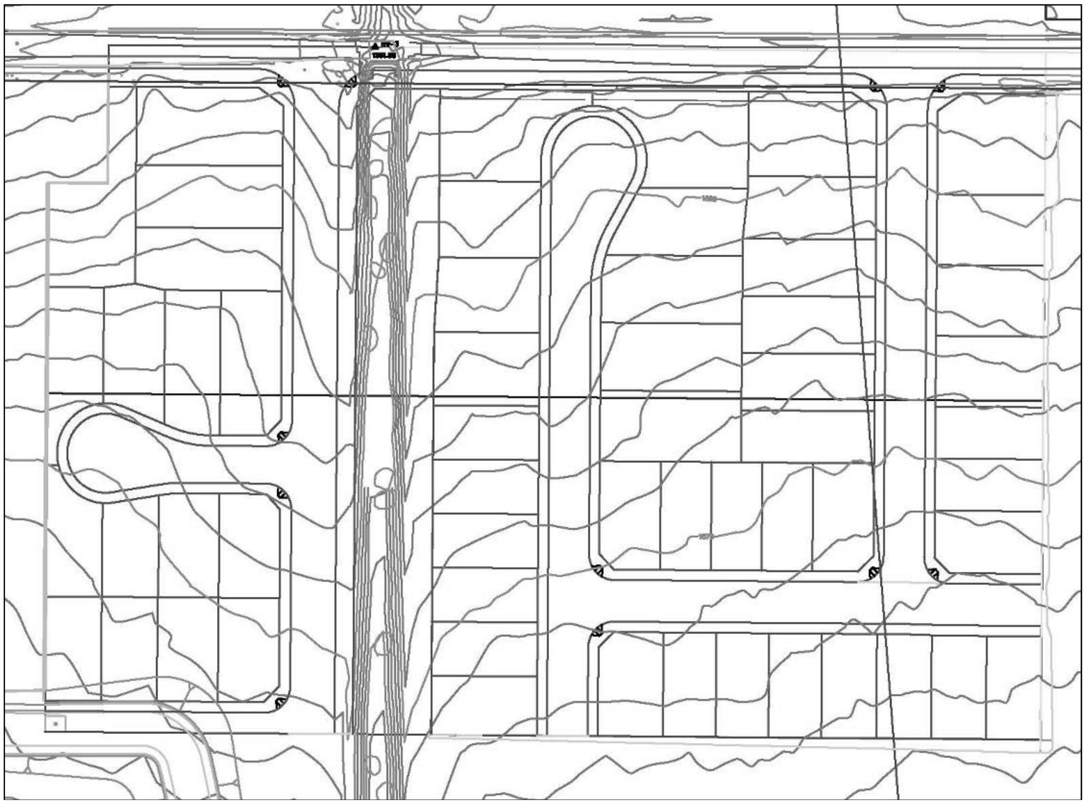

Figure 3-2. ***Existing residential subdivision.***

Source: The Low Impact Development Center, Inc.

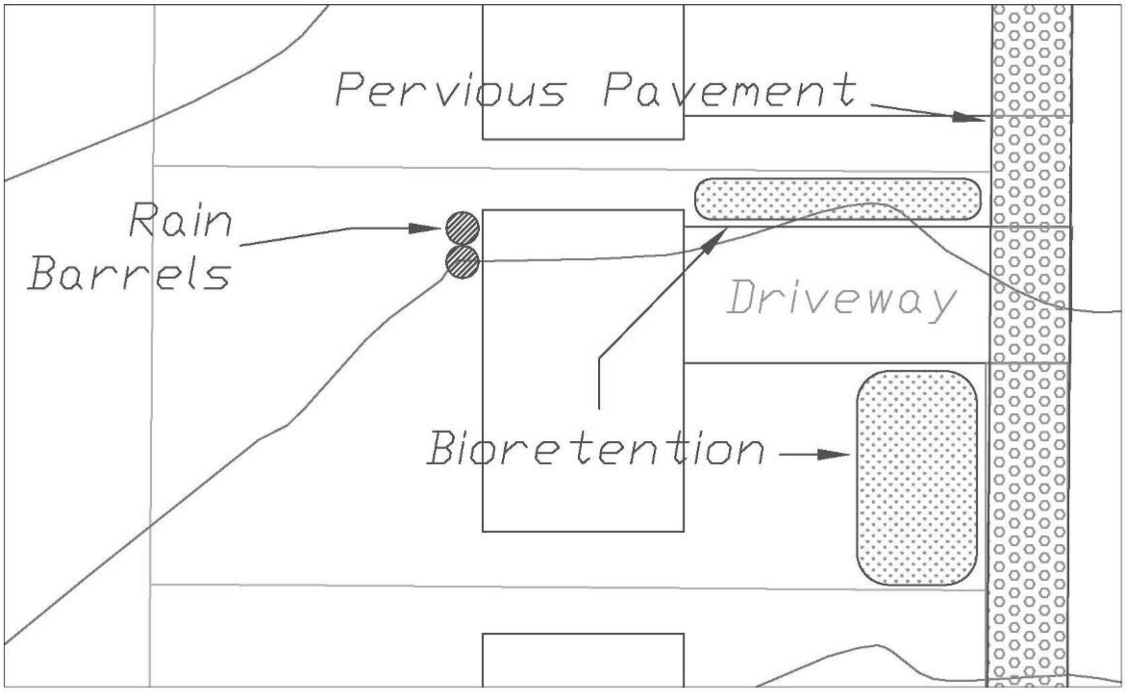

Figure 3-3. LID retrofits to an existing residential lot. These retrofits are to be applied to each lot in the subdivision.

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).

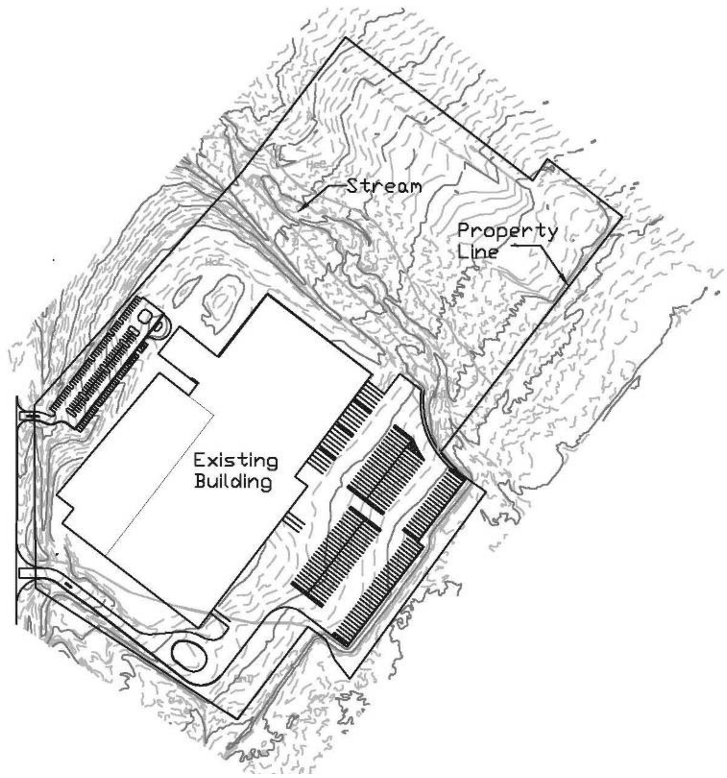

Figure 3-4. ***Existing commercial development.***

Source: The Low Impact Development Center, Inc.

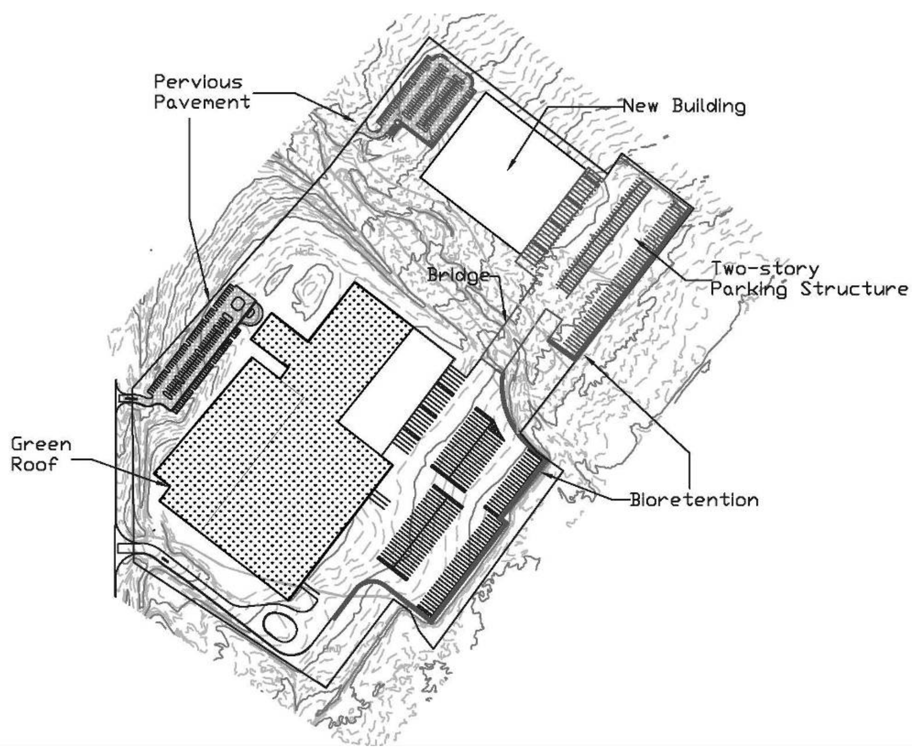

Figure 3-5. ***Proposed retrofits and addition to existing commercial development.***

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

<u>Analysis</u>
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

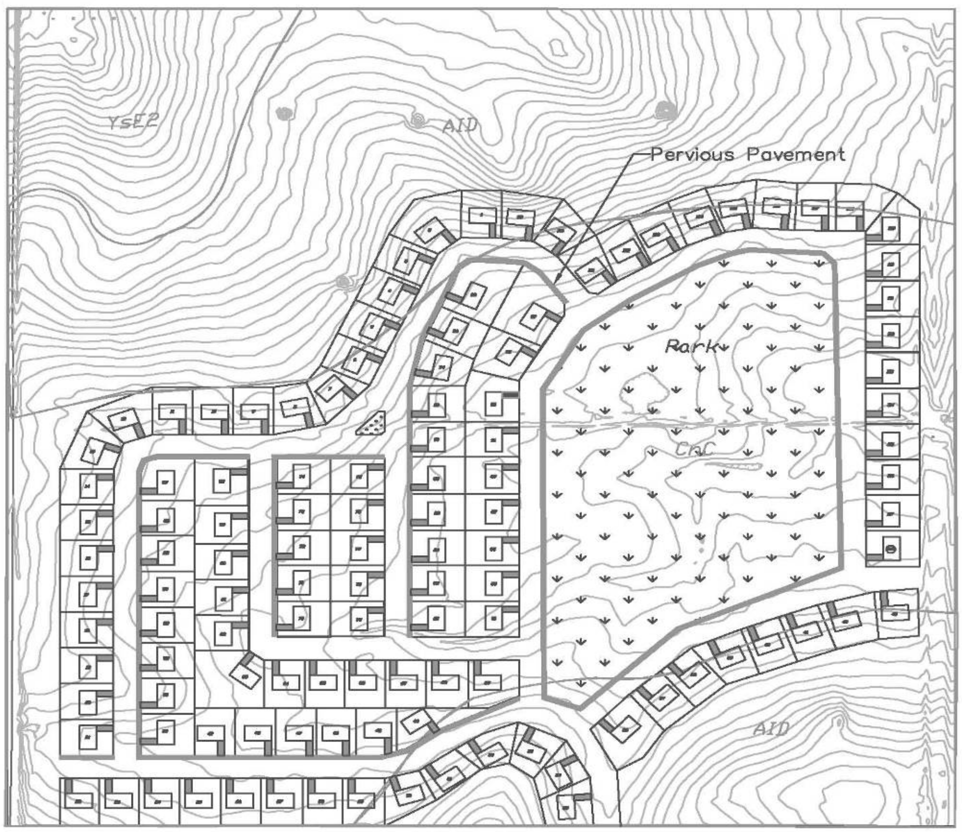

Figure 3-6. ***Residential subdivision design.***

Source: The Low Impact Development Center, Inc.

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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 85^{th} 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.II 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.III.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)

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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	deciduou s tree	4-9, 12-24	✓	✓	✓	grassland , woodland	✓			✓	✓			✓		
Rhamnus californica	Coffeeberry	evergree n shrub	4-9, 14-24	✓	✓		chap, woodland	✓	✓		✓	✓			✓		
Rhamnus californica 'Eve Case'	Coffeeberry	evergree n shrub	4-24	✓	✓		chap, woodland	✓	✓		✓	✓			✓		
Rhamnus crocea	Redberry	evergree n shrub	14-21	✓	✓		css, chaparral	✓	✓		✓ ✓				✓		
Rhamnus ilicifolia	Hollyleaf Redberry	evergree n shrub	7-16, 18-21	✓	✓	✓	chaparral, woodland , forest	✓	✓		✓ ✓				✓		
Rhus integrifolia	Lemonadeberr y	evergree n shrub	8, 9, 14-17, 19-24	✓	✓		css, chaparral	✓	✓		✓ ✓				✓		
Rhus ovata	Sugar Bush	evergree n shrub	9-12, 14-24	✓	✓	✓	css, chaparral	✓	✓		✓ ✓				✓		
Ribes aureum var. gracillimum	Golden Currant	semi-deciduou s shrub	1-24		✓	✓	chap., woodland	✓	✓		✓ ✓	✓			✓		
Ribes malvaceum 'Dancing Tassels'	Dancing Tassels Currant	deciduou s shrub	6-9, 14-21	✓	✓	✓	chap., woodland	✓	✓	✓	✓	✓			✓		
Ribes speciosum	Fuchsia Flowering Gooseberry	deciduou s shrub	8, 9, 14-24	✓	✓	✓	chap., woodland		✓	✓		✓	✓		✓	✓	
Ribes viburnifolium	Catalina Perfume	evergree n shrub	8, 9, 14-24	✓	✓	✓	css	✓	✓	✓	✓ ✓	✓			✓	✓	
Romneya coulteri	Matilija Poppy	clumpin g semi-evergre en perenni al	4-12, 14-24	✓	✓		css, chaparral	✓	✓		✓				✓		
Romneya trichocalyx	Hairy Matilija Poppy	clumpin g semi-evergre en perenni al		✓	✓	✓	css, chaparral	✓			✓ ✓				✓		
Rosa californica	California Wild Rose	semi-deciduo us shrub		✓	✓	✓	riparian, woodlan d	✓	✓	✓		✓	✓		✓	✓	
Salix lucida ssp. Lasiandra	Lance-leaf Willow	deciduo us tree		✓	✓	✓	many	✓	✓				✓	✓		✓	
Salvia apiana	White Sage	evergree n shrub		✓	✓		css, chaparral	✓			✓ ✓				✓		
Salvia cedrosensis	Cedros Island Sage	perennial		✓			scrub	✓	✓		✓ ✓				✓		✓
Salvia clevelandii	Cleveland Sage	evergree n 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	evergree n shrub	14-24	✓	✓		css	✓	✓			✓			✓		
Heteromeles arbutifolia	Toyon	broadleaf evergree n tree/shru b	5-9, 14-24	✓	✓	✓	chaparral	✓	✓		✓ ✓				✓		
Hyptis emoryi	Desert Lavender	semi-evergree n shrub		✓	✓	✓	scrub	✓	✓		✓ ✓				✓		
Isocoma menziesii var. menziesii	Menzies' Goldenbush	evergree n subshrub		✓			css, beach/du ne	✓	✓		✓ ✓				✓		
Iva hayesiana	Hayes Iva	evergree n shrub	10-13	✓	✓	✓	css, marsh	✓	✓		✓ ✓				✓		
Justicia californica	Chuparosa	semi-deciduou s shrub		✓	✓	✓	scrub	✓	✓		✓	✓	✓		✓		
Keckiella antirrhinoides	Yellow Bush Penstemon	semi-evergree n shrub		✓	✓	✓	chaparral	✓	✓		✓ ✓				✓		
Lepechinia fragrans	Fragrant Pitcher Sage	semi-evergree n shrub		✓	✓		chaparral	✓	✓		✓	✓			✓		
Mahonia nevinii	Nevin's Barberry	evergree n shrub	8-24	✓	✓	✓	css, chaparral	✓			✓ ✓	✓			✓		
Malacothamnus fasciculatus	Chaparral Mallow	evergree n shrub		✓	✓		css, chaparral	✓			✓ ✓				✓		
Malosma laurina (Rhus laurina)	Laurel Sumac	evergree n shrub		✓	✓		css, chaparral	✓			✓ ✓				✓		
Ornithostaphylos oppositifolia	Baja Bird Bush	evergree n shrub		✓	✓	✓	chaparral	✓	✓		✓ ✓				✓		
Prunus ilicifolia ssp. Ilicifolia	Hollyleaf Cherry	broadleaf evergree n tree/shru b	7-9, 12-24	✓	✓	✓	chap., woodland	✓	✓		✓ ✓				✓		
Rhamnus californica	Coffeeberry	evergree n shrub	4-9, 14-24	✓	✓		chap., woodland	✓	✓		✓	✓			✓		
Rhamnus californica 'Eve Case'	Coffeeberry	evergree n shrub	4-24	✓	✓		chap., woodland	✓	✓		✓	✓			✓		
Rhamnus crocea	Redberry	evergree n shrub	14-21	✓	✓		css, chaparral	✓	✓		✓ ✓				✓		
Rhamnus ilicifolia	Hollyleaf Redberry	evergree n shrub	7-16, 18-21	✓	✓	✓	chaparral, woodland, forest	✓	✓		✓ ✓				✓		
Rhus integrifolia	Lemonadeberry	evergree n shrub	8, 9, 14-17, 19-24	✓	✓		css, chaparral	✓	✓		✓ ✓				✓		
Rhus ovata	Sugar Bush	evergree n 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	VL	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	VL	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	VL	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	VL	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.

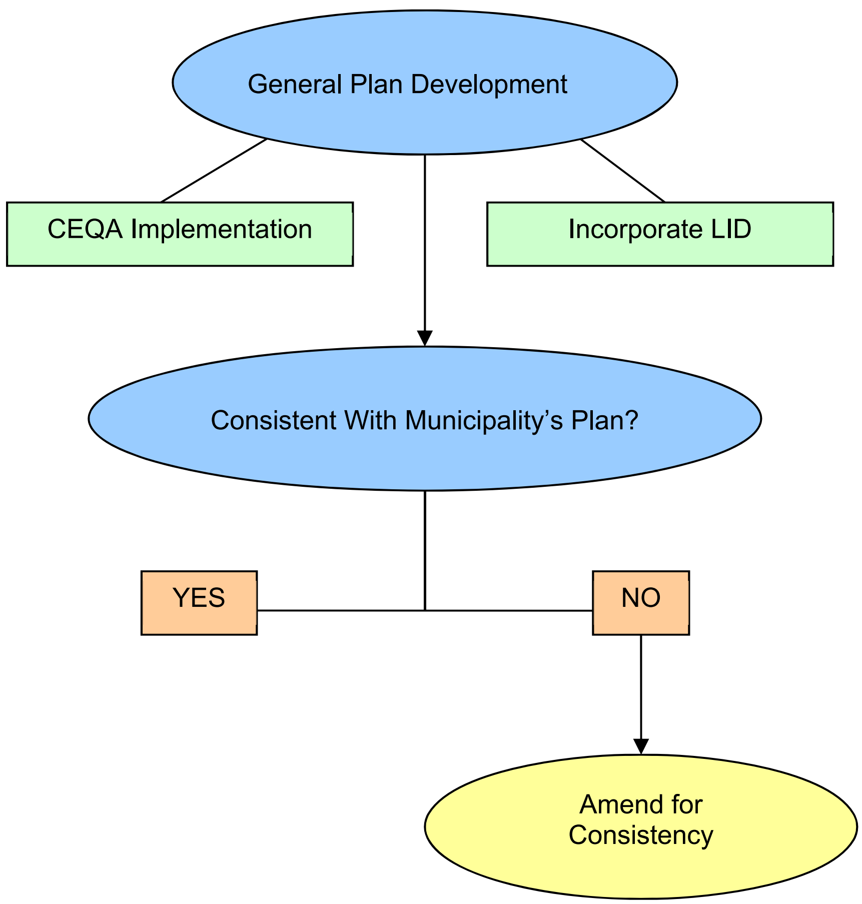

Figure C-1. LID and CEQA for a Municipality's Development Plan

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.

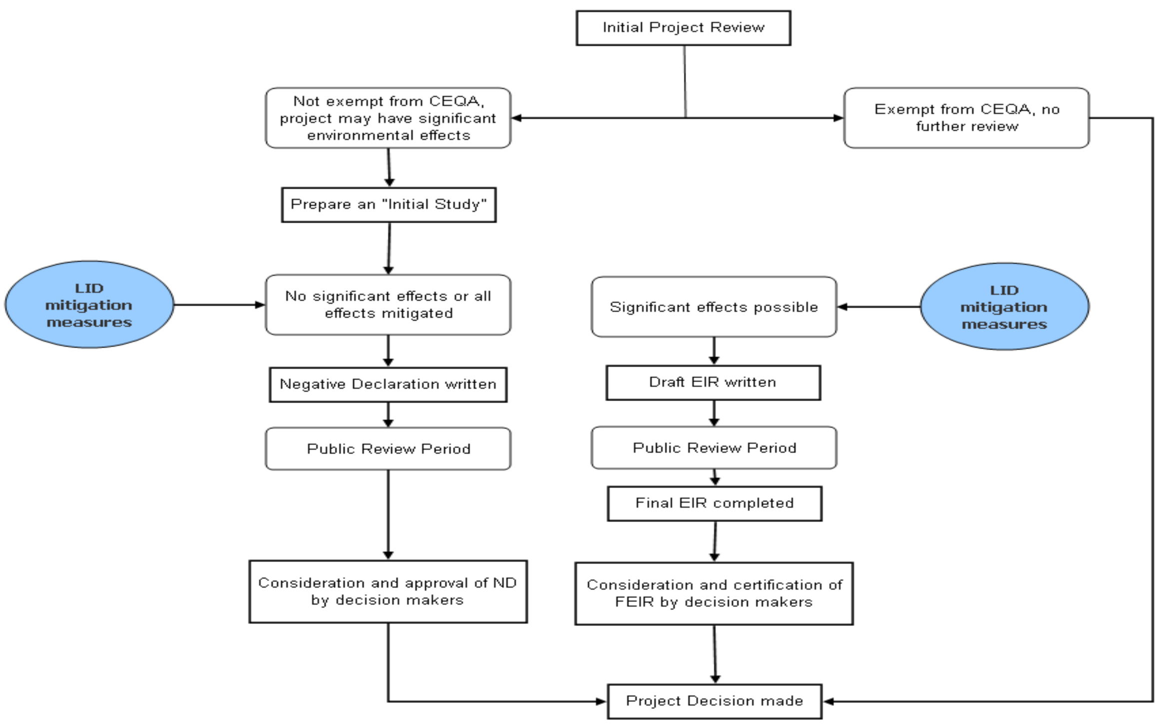

Figure C-2. LID in the CEQA Process.

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.

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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.

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Appendix G

LID & GSI Construction, Inspection, Maintenance, and Monitoring Guidance Manual

Low Impact Development &

Green Stormwater Infrastucture

Construction, Inspection, Maintenance, and Monitoring Guidance Manual

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

May 2019

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EXECUTIVE SUMMARY

Numerous manuals have been developed to guide the implementation of Low Impact Development (LID) Best Management Practices (BMPs) in the Southern California region and nationwide in the past 10 – 15 years. These manuals provide information on site assessment, BMP selection and sizing, BMP designs, required/recommended materials, and recommended maintenance requirements. However, an evaluation of implementation of these BMPs suggests that LID BMPs are often constructed without due care with respect to siting, conformance with design standards, construction practices, materials used, and that inspection and maintenance are often not conducted as needed or required. In addition, it is challenging to conduct hydrologic and water quality monitoring for LID BMPs and Green Stormwater Infrastructure (GSI) features, and there are very few existing datasets representative of southern California.

This manual is a companion document to the LID Manual for Southern California and is designed to address these key implementation challenges in an effort to improve the effectiveness of LID BMPs and GSI as they are more widely implemented. Detailed design guidance for LID practices is included elsewhere (see LID Manual for Southern California or a manual developed for the local jurisdiction). Regulatory requirements for stormwater management vary somewhat across the state and are established in the Municipal Separate Storm Sewer System (MS4) Permits issued by the Regional Boards. Further design, operation, and maintenance information is included in technical design manuals that have been created by the MS4 permittees to guide land developers in compliance with the applicable MS4 permit.

The audience for this manual is intended to be LID/GSI practitioners, land development planners and engineers, staff responsible to manage municipal drainage infrastructure, regulatory agency staff, consulting designers and engineers, contractors, maintenance staff, and asset managers.

This guidance manual focuses on structural LID BMPs and Green Stormwater Infrastructure (GSI) with an emphasis on five key elements required to ensure effectiveness:

- Construction considerations.
- Visual inspections.
- Maintenance procedures.
- Tracking the locations.
- Condition and functionality of LID and GSI features over time through effective asset management, approaches and procedures to monitor their performance in removing pollutants and reducing changes in site hydrology.

Improper implementation of these elements may lead to improper construction or maintenance, which can have detrimental effects on the functionality of the LID/GSI facilities.

LID/GSI construction incorporates site management, planning and scheduling, safety, the use of proper LID/GSI materials, BMP protection, and inspections. Safety protocols must be developed and followed to ensure the safety of staff on-site. Materials used for the construction of LID/GSI facilities must be based on design specifications and stored correctly to prevent contamination or damage. The LID/GSI area must be protected from soil compaction and stormwater run-on during construction. Existing vegetation must be protected from damage from construction equipment. Ongoing construction inspections should be conducted to determine whether the above-mentioned requirements are being met.

The purpose of LID/GSI monitoring is to determine whether or not the implemented BMP provides hydrologic and pollutant reduction benefits as expected based on its design and application. Targeted research questions must be created to guide the creation of a sampling and monitoring plan. Monitoring plans must be designed specifically for each LID/GSI facility.

Periodic visual inspections of LID/GSI measures will confirm whether BMPs are adequately maintained and are functioning as designed. Inspections include assessing whether maintenance is needed, and if so, what type of maintenance is required. Photographs are taken, and field sheets are completed to document the inspections.

Proper maintenance of LID/GSI measures is vital to ensure that these systems continue to function as they were designed. Lack of maintenance may cause the systems to have reduced capacity, clogging, short circuiting, or complete failure. General maintenance includes the correction of: blockages to inlet and outlet structures, erosion on side slopes and bioretention inverts, burrows, emergence of excessive vegetation, graffiti or vandalism, and fence damage.

Verifying and tracking the design, proper installation, location and operating condition LID BMPs within a jurisdiction is crucial for managing maintenance and quantifying aggregate benefits. Maintaining records of BMP metadata is also central to providing background information to jurisdiction staff. Data on LID/GSI facilities is valuable in the long-term as it allows jurisdictions to gauge the effectiveness of LID/GSI infrastructure over time. Data includes water quality monitoring sat as well as meta data including design, inspection, maintenance data, and other data (see Section 6.3). GSI and publicly owned LID systems are a part of public infrastructure and so need to be properly managed as part of a public asset management systems. Effectively tracking private LID BMPs will help to understand the watershed area and volume of stormwater managed which will help with future stormwater management infrastructure planning and water quality standard compliance documentation. All current MS4 permits in Southern California require that post-construction BMPs be tracked and inspected. Development of an effective asset management program for LID BMPs therefore will be an essential part of ensuring LID BMPS are properly constructed and properly functioning.

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ACRONYMS AND ABBREVIATIONS

BMP	best management practices
BSM	bioretention soil media
CASQA	California Stormwater Quality Association
CLEAN	California LID Evaluation & Analysis Network
EPA	United States Environmental Protection Agency
GSI	green stormwater infrastructure
LID	low impact development
MS4	Municipal Separate Storm Sewer System
O&M	operations and maintenance
SMC	Southern California Stormwater Monitoring Coalition
SWRCB	State Water Resources Control Board
TKN	Total Kjeldahl Nitrogen
TPH	Total Petroleum Hydrocarbons
WQMP	Water Quality Management Plan

GLOSSARY

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.

Biofiltration – Structural 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.

Blue Roofs – Serve as a rooftop storage designed to reduce runoff peaks and volumes, also known as rooftop detention systems. Captured stormwater is held on the rooftop until the water either evaporates or is slowly metered out via flow restriction valves.

Evapotranspiration – The loss of water from the soil by evaporation and by transpiration from the plants growing in the soil.

Green Stormwater Infrastructure (GSI) - Constructed structural systems that are used to infiltrate, evapotranspire, treat, detain, and/or reuse stormwater. Green Infrastructure uses natural processes for management of stormwater close to its source, thus reducing stormwater runoff and pollutant loading.

Green roofs - Vegetated roof systems that filter, absorb, and retain or detain the rain that falls upon them. Green roofs are composed of a layer of soil media planted with vegetation.

Infiltration basins - Basins designed to collect and infiltrate stormwater into the ground.

Infiltration trenches - Narrow trenches that have been back-filled with stone that allow for stormwater to infiltrate into the ground.

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. LID is a comprehensive land development or retrofit approach that includes techniques to conserve and mimic natural hydrologic functions and reduce stormwater runoff and pollutants by managing rainfall, using a combination of LID site planning and LID site design techniques as well as LID structural systems or LID structural BMPs that infiltrate, filter, store, evaporate, and detain stormwater runoff.

Low Impact Development Site Planning - Evaluation and planning of a site with the primary planning principle of maintaining or restoring pre-development hydrology and minimizing the generation of runoff.

Low Impact Development Site Design – Design techniques to reduce and or disconnect impervious surfaces on a site including designing pervious functional surfaces such as green roofs and pervious pavement.

Low Impact Development Structural BMPs – Structural measures that retain or treat stormwater, usually the design capture volume.

Municipal separate storm sewer system MS4[1] – 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, and 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 - "Green space" that provides a soil/plant mixture suitable for stormwater capture and treatment, usually associated with bioretention systems.

[1] The regulatory definition of an MS4 (40 CFR 122.26(b)(8)) is "a conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains): (i) Owned or operated by a state, city, town, borough, county, parish, district, association, or other public body (created to or pursuant to state law) including special districts under state law such as a sewer district, flood control district or drainage district, or similar entity, or an Indian tribe or an authorized Indian tribal organization, or a designated and approved management agency under section 208 of the Clean Water Act that discharges into waters of the United States. (ii) Designed or used for collecting or conveying storm water; (iii) Which is not a combined sewer; and (iv) Which is not part of a Publicly Owned Treatment Works (POTW) as defined at 40 CFR 122.2." (SWRCB 2013)

1 INTRODUCTION

The Low Impact Development (LID) land development approach aims to reduce stormwater runoff and pollutants by managing rainfall using a combination of site planning and design techniques and structural systems that infiltrate, filter, store, evaporate, and detain stormwater runoff. The LID Manual for Southern California (LID Manual) provides site planning and design guidance for land development projects for designers, engineers, planners, and municipal jurisdictions at different spatial scales. As a companion document to the LID Manual, this Construction, Maintenance, and Monitoring Manual includes methods and considerations beyond site planning and design of LID measures, with a focus on these critical implementation challenges:

- Proper construction of LID structural measures including considerations, challenges, and practices.
- Monitoring of LID features, including collecting and interpreting monitoring data, analyzing LID site performance with respect to effluent water quantity and quality.
- Performing visual inspections to confirm LID/green stormwater infrastructure (GSI) measures were built per plan requirements and are correctly maintained; and maintenance procedures.

LID Best Management Practices (BMP) siting and design guidance must be followed carefully when planning and constructing practices, including verifying use of specified materials and protecting soil infiltration capacity. Required inspection and maintenance procedures must be conducted throughout the life of the BMP. Where feasible, performance monitoring can demonstrate ongoing BMP effectiveness and achievement of regulatory and environmental protection goals. This guidance manual is focused on LID structural BMPs and is organized into five main elements:

- Construction considerations.
- Visual inspections.
- Maintenance procedures.
- Tracking of structural LID and GSI measures.
- Monitoring procedures.

1.1 Manual Overview

1. Introduction
2. LID Construction
3. LID Inspections
4. LID Maintenance
5. LID Asset Management
6. LID Monitoring
7. References

1.2 Importance of Proper LID Construction, Inspections, Maintenance, Asset Management and Monitoring

Correct design and construction of LID/GSI facilities is crucial for proper performance. Improperly constructed LID/GSI measures may result in a variety of problems, including poor stormwater infiltration, a reduction in the storage capacity of BMPs, and reduced efficiency in pollutant removal among other things. Poor drainage can result in flooding, standing water and mosquito breeding habitat as well as anoxic conditions that can lead to release of previously captured pollutants. Improper construction of curb cuts and other flow connectivity devices to the BMP may result in flows bypassing the BMP rendering them useless. Improperly constructed BMPs may even contribute pollutants to stormwater such as nitrate or phosphate from the improper use of compost or contribute sediment from BMP erosion (County of San Diego 2016).

Routine inspections of LID/GSI measures ensure that the measures function as designed and provide information on the type and frequency of necessary maintenance. Without routine inspection and maintenance, sediment, trash, and other debris can be trapped and accumulate in LID/GSI facilities, which can impede functionality and reduce capacity. Some LID/GSI measures may also have excess vegetation growth, which can block water from entering or infiltrating effectively. Overgrown vegetation, sediment, and other pollutants must be removed periodically throughout the life span of the BMP to maintain its capacity to process storm water and capture pollutants from every storm event. Alternatively, inadequate vegetation coverage can cause erosion issues in BMPs. Inspections are critical to identify potential problem areas and ensure the ongoing drainage and functionality of the facility (County of San Diego 2016).

Incorporating LID BMPs into a jurisdictional asset management plan is crucial for ensuring adequate tracking, inspection and maintenance. An asset management approach is also useful in documenting the costs, benefits and performance of LID systems, which can inform future stormwater management infrastructure planning. Water quality and hydrologic monitoring data for LID/GSI facilities is valuable in the long-term as it allows jurisdictions to gauge the effectiveness of LID/GSI infrastructure over time. GSI and publicly owned LID systems are a part of public infrastructure and so need to be properly managed as part of a public asset management systems. Effectively tracking private LID BMPs will help to understand the watershed area and volume of stormwater managed which will help with future stormwater management infrastructure planning and water quality standard compliance documentation. All current MS4 permits in Southern California also require that post-construction BMPs be tracked and inspected.

Accurate flow monitoring and water quality sampling data are vital to measuring the pollutant removal and hydrologic performance of LID/GSI measures. Monitoring flow at inlet, outlet and bypass points over time allows for the calculation of treated volume, volume reduction and bypass volume. Volume reduction through infiltration, evapotranspiration and harvest and use is a primary mechanism of LID/GSI measures and can be an important pollutant removal mechanism. The diverse shapes, sizes, and layouts of LID/GSI measures requires monitoring studies be site-specific and tailored to the configuration of the BMP and characteristics of the area. Monitoring studies and the development of targeted research questions help demonstrate whether a LID/GSI facility meets pollution or flow reduction requirements. Water quality sampling and flow monitoring are not typical requirements in MS4 permits so not all LID BMPs need water quality monitoring.

1.3 Training and Education

Training and education about different aspects of LID/GSI facilities are critical to proper BMP implementation and functioning. Site planning and design training are important as these inform proper selection, placement, and design of LID/GSI measures. Training for contractors will help ensure that contractors understand the purpose and intent of the LID/GSI measures and will guide the contractors on proper construction of structural LID/GSI measures. It is crucial to provide proper training and education to BMP maintenance staff since LID/GSI measures often require specialized maintenance to perform efficiently. Larger structural BMPs may be more complex to maintain and could require heavy equipment and special training (County of San Diego 2016).

Training is also required to properly perform both visual monitoring and water quality /flow monitoring of LID/GSI facilities. Training includes instruction on how to perform LID/GSI construction inspections, LID/GSI certificate of occupancy inspections, and the routine operations and maintenance inspections. For those performing water quality and flow monitoring of LID/GSI measures, training on monitoring protocols and specifics about LID/GSI monitoring will help ensure the data obtained during the monitoring process is effective.

LID/GSI education and training programs should identify the target audiences. Any LID/GSI training that is completed should be documented. LID/GSI training should integrate adult learning principles and be interactive with exercises and quizzes to engage the trainees. The effectiveness of training should also be evaluated with pre- and post- training surveys (County of Los Angeles Department of Public Works 2014).

2 LID CONSTRUCTION

This section identifies considerations that will help ensure LID/GSI structural measures are constructed per the design and perform as intended. Even minor modifications to the design or small elevation changes in elements of a LID/GSI measure can have significant effects on the overall performance and function of the system. Many contractors and subcontractors in California may not be familiar with LID/GSI measures and may inadvertently implement design and/or material modifications that affect overall function and performance. Construction inspections are a significant part of LID construction and details regarding construction inspections are provided in Section 3.1 below. It should be noted that there are also other programs and initiatives that provide guidance regarding the construction of LID and GSI including the San Francisco Public Utilities Commission Green Infrastructure Construction Guidebook (SFPUC 2018) and the National Green Infrastructure Certification Program (NGICP, 2019).

2.1 LID/GSI Site Management, Planning, & Scheduling

The development of site management goals is an essential step in the planning of a LID or GSI site. Site management goals are specific to each site but should evaluate the sections identified below including:

1. Protection of existing vegetation and trees.
2. Protection of LID system locations from construction activities and offsite stormwater run-on.
3. Effective erosion and sediment controls.
4. Identification and protection of existing utilities.
5. Protection of LID/GSI construction materials.
6. Protection of LID/GSI vegetation until established, and any other issues specific to the site.

The site management goals and the construction sequencing/schedule should be developed prior to the pre-construction coordination meeting(s) with the contractor and subcontractor(s) (Riverside County Flood Control and Water Conservations District 2015).

2.1.1 Construction Sequencing and Scheduling

Construction sequencing and scheduling is a critical component for the effective implementation of properly performing LID/GSI structural measures. Construction sequencing and scheduling will be different based on whether the LID/GSI site is a retrofit or new construction. With retrofits, in most cases only LID or GSI measures are newly constructed; therefore scheduling is not dependent on completion of other elements of construction.

For new developments construction, sequencing is essential; LID/GSI features should be installed at the end of construction when the surrounding site is complete to avoid the potential for construction materials to contaminate a newly constructed LID/GSI feature. If construction of LID/GSI features are not possible at the end of construction when the surrounding site is complete measures should be implemented to protect the LID/GSI measure locations including conveying stormwater around the

LID/GSI measure locations. Additionally, sequencing construction of LID/GSI BMPs at the end of new development construction tends to cause less conflict with other aspects of construction (Ventura Countywide Stormwater Quality Management Program 2011).

Construction scheduling of LID/GSI measures must consider lead times on specialized LID/GSI BMP materials including:

- Bioretention soil mix.
- Bioretention stone aggregate.
- Plants and Mulch.
- Impermeable liners.

2.1.2 Pre-Construction Coordination

Coordination prior to commencing construction of LID/GSI measures is critical to ensure proper installation and protection of LID/ GSI BMPs during construction. Pre-construction coordination meetings should cover in general all of the information provided in the LID Construction chapter of this manual, however the following subjects should be covered in detail:

- Safety and site management goals for the project.
- Construction documents (design plans) for the LID/GSI measures to be constructed.
- Proper construction sequencing and schedule for the project.
- Critical path/item checkpoints and verification.
- LID construction materials and process for substitutions.
- Communication protocols.

Consistent communication between the construction and design teams is essential for the successful implementation of LID/GSI projects. The contractor, subcontractors, and the designer should all be present in the pre-construction coordination meeting(s) and protocols for communication and for submitting and answering Requests for Information should be discussed during the pre-construction coordination meeting. The construction documents (design plans) should also be reviewed in detail during the pre-construction coordination meeting to allow the contractor or subcontractor to ask questions of the designer.

2.1.3 Construction Documents

The construction documents include the design plans that identify what to build and the specifications that identify how to build it. Construction documents may include the following, however critical must include items have been identified below:

1. Title page that includes the project name, location and designer information (must include).
2. Plan view sheet providing a geographical reference looking down on the project site (must include).

3. The plan view sheet should include a legend, topographic contours, and locations of existing features, proposed LID/GSI measures, utilities, vegetation, and property lines; and in some cases proposed erosion and sediment control BMPs.

4. Section view, also known as cross-sections, of each LID/GSI feature, which provide an overall view of all critical elements and detail views of the LID/GSI measure as seen if viewed across the critical elements (must include).

5. Longitudinal profiles may be provided in some cases to offer.

6. Longitudinal section pertains to a section along the long axis of a structure.

7. Standard details provide a detail view of critical elements such as a LID/GSI measure, and the appurtenant details such as a curb cut or overflow riser (must include).

8. Specifications provide written detailed information on materials used on a construction project as well as the proper technique required for installation/construction (must include).

2.2 Safety in and Around LID/GSI

Safety is of concern in the construction of LID/GSI measures, as many elements of construction of LID/GSI systems have hazards associated with them. Safety should be discussed as part of the pre-construction coordination meeting. Safety protocols should include:

- Plans to ensure the site is protected and secured with effective perimeter controls during and after site work hours.
- Traffic safety plan including vehicular, bicycle, and pedestrian plans as appropriate.
- Protocol directing staff to call "Dig Alert" before digging to locate utilities.
- Existing utility protection and marking.
- Identification and safety procedures for overhead power lines.
- Confined space identification, and procedures ensuring workers have proper training before entering.
- Protocols for all workers to wear Personal Protective Equipment (PPE) appropriate to their duties and proximity to other work.
- Schedules for frequent safety meetings to inform workers of and coordinate upcoming construction activities.
- Proper implementation of erosion and sediment controls including dust controls.
- Protocol that calls for the use of trench boxes or shoring in trenches over 4 feet deep.
- Instructions to divert stormwater away from trenches and around the site.

2.3 LID/GSI Materials

Use of the specified materials in the construction of LID/GSI measures is essential to LID/GSI performance and durability. It is important to source material before construction begins to ensure that the materials specified in the design plans are available. Lead times may affect the availability of materials such as bioretention soil, non-standard over flow structures, and trench drains. Any proposed changes to the specified materials should be coordinated with the designer (e.g. design engineer) of the project as identified in the pre-construction meeting. LID/GSI materials and a process for substitution of materials should be discussed in the pre-construction meeting. As part of the process the regulatory document such as a Water Quality Management Plan (WQMP) should be reviewed if changes of materials would deem the project non-compliant.

LID/GSI facilities in most cases infiltrate or filter stormwater; therefore, it is essential that the materials used for construction of LID/GSI facilities are clean. Using clean materials such as aggregates will help prevent pollutant export from LID/GSI facilities and prevent the potential for clogging from increased fine particles. All materials should be inspected prior to installation in a LID/GSI system.

Typical materials associated with construction of LID/GSI facilities include:

- Aggregate: Aggregate is washed to remove finer particle sizes. The American Associate of State Highway and Transportation Officials aggregate is used in permeable pavement systems for the aggregate base that provides structural support (particularly for flexible systems such as porous asphalt, pavers and grid systems) and water storage. The aggregate is also used as a drainage/water storage layer under bioretention media. Sand is classified as mineral aggregate ranging in size from 0.0625 mm to 2 mm. Sand is used as a typical component of bioretention media, drainage layers, filter layers under permeable pavement and other LID/GSI practices.
- Bioretention soil media (BSM): Many BSM specifications have been developed but they usually consist of fine sand and compost and sometimes sandy loam.
- Riprap: A mixture of rock sizes and is angular (fractured). Rip rap is used for energy dissipation.
- Mulch: Cover to prevent erosion and support soil retention, retain moisture, reduce weeds, and enhance plant growth. When used in ponding zones, mulch should be aged, stabilized, and non-floating, such as a specified composted wood mulch or coconut fiber. Gravel mulch may also be used when high flow velocities through the system are expected.
- Geotextile fabrics: Used for separation of adjacent native soils from a subgrade of LID/GSI systems. Geotextile fabrics should not be used in the invert of LID/GSI systems.
- Liners and Waterproofing membranes: Thin sheets of synthetic material that do not allow water to pass through. Liners and waterproofing membranes are used in biofiltration systems, bioretention planter boxes, green roofs, blue roofs, and to protect adjacent structures.

All GSI materials should be protected at the construction site prior to installation. Protection includes covering and perimeter control around stockpiles of LID/GSI construction materials. LID/GSI materials should not be delivered to the site until just before their construction: this will reduce the incidence of contamination of the LID/GSI system materials. Avoid placing LID/GSI construction materials in concentrated flow paths and or near catch basins.

2.4 Site Layout Survey and Utility Location

Site layout survey and utility locating is primarily associated with LID/GSI retrofit projects and re-development sites. Site layout survey and utility locating is often the first construction activity on site. Verification of how the proposed construction layout interacts with existing infrastructure is essential to efficient construction. Utilities should have been identified and located during the design process through several methods: record plans collected from utility providers, surveys providing locations of utility surface indications, and potholing to determine locations and depths of known critical utility lines that could significantly impact the project design (SFPUC 2018). Overhead, surface, and underground utilities should be evaluated for conflicts with the proposed LID/GSI features. Construction should not commence without a clear understanding of how utility conflicts are to be addressed. Locations of existing or unknown utilities should be identified with the use of as-builts, potholing, ground penetrating radar, or other similar method.

2.5 Geotechnical Investigations

Geotechnical investigations to determine infiltration rates, substrate composition, and depth to groundwater should be completed as part of the design phase of any LID/GSI feature. Accurate geotechnical investigations to understand infiltration rates are critical to those LID/GSI measures relying upon infiltration. Once excavation of the location of the LID/GSI features is complete infiltration testing should be completed to confirm the design infiltration rates. Infiltration tests should be performed at the depth of the invert of the LID/GSI system using an approved methodology by the approving jurisdiction. Common infiltration tests include a double ring infiltrometer test and a single ring infiltrometer test, or in drill hole permeability test. A factor of safety should be applied to all infiltration rates when determining the design infiltration rate. The factor of safety is at the discretion of the engineer and/or local jurisdiction based on the underlying soil type and expected sediment loading to the BMP.

2.6 Existing Vegetation and Tree Protection

Existing vegetation and trees provide hydrologic benefits by retaining stormwater discharge on site. It is therefore essential to protect existing vegetation and trees outside the area of disturbance of the project, especially since vegetation takes time to regrow. Trees are susceptible to damage from soil compaction near the root zone that may be caused by construction equipment. Tree branches may also be damaged by large overhead equipment such as excavators. Construction stormwater should be routed away from existing vegetation with gravel bags to avoid impacts to vegetation. Trees should be taped off at the drip line to warn on-site workers to avoid using construction equipment or storing equipment or materials too near the trees.

2.7 BMP Area Protection

As the surrounding site is constructed, it is critical to protect of the on-site locations where the LID/GSI measures will be implemented. It is important to protect the LID/GSI areas from compaction, sedimentation, and pollutants. Areas where LID/GSI measures will be constructed should be taped off and surrounded by gravel bags to prevent sedimentation and deposition of other pollutants.

LID/GSI locations should only be excavated when the site is ready for construction of the LID/GSI measure. If excavation of LID/GSI areas is necessary, a 6-inch layer of soil above the excavation depth should be left in place to help protect the future system. Whenever possible, machinery performing excavation for LID/GSI measures should be located adjacent to, not inside of, the LID/GSI BMP when in operation. When machinery must operate in the LID/GSI BMP due to size or location, the soils engineer should be consulted for strategies to minimize compaction and implement re-scarification of the compacted area.

Locations of future LID/GSI measures in many cases are in low depressed areas where stormwater naturally flows. These areas should not be used as temporary sediment basins during construction and construction stormwater should be conveyed around these areas if possible. Construction stormwater flows may carry fine sediment into the LID/GSI area which may reduce or eliminate the ability of these locations to infiltrate stormwater, negatively affecting the overall LID approach for the site. Additionally, the weight of the water may result in compaction of the area including the substrate, which would reduce or eliminate the infiltration capacity of the future LID/GSI measure.

2.8 Erosion and Sediment Controls

An effective combination of erosion and sediment controls are needed for construction sites, especially for the protection of future and existing LID/GSI measures. Erosion BMPs are designed to keep sediment from being mobilized by runoff, whereas sediment BMPs are designed to capture sediment from discharge off-site. The Erosion and Sediment Control Plan for the site should include specific protections for future locations of LID/GSI measures. The California Stormwater Quality Association (CASQA) Construction BMP Manual should be consulted for a full suite of construction site stormwater management BMPs (CASQA 2018a).

2.9 Bioretention Specifics

Although all of the above construction sections apply to bioretention systems, there are construction considerations specific to bioretention systems:

- Filter fabric is not to be used in the invert LID/GSI landscape features as it may cause long-term clogging and system failure.
- Ensure that the bioretention soil mix used is per the design specification and is not mixed on-site using native soils.
- Compaction of the bioretention soil mix should adhere to the compaction procedures identified in the BSM specifications. Do not use mechanical compaction equipment for BSM compaction.
- Verify BSM elevations per the design plans.
  - Ensure final grades are maintained upon completion of plant and mulch installation (if used).
  - Excess soil from planting should be exported or reincorporated to meet design contouring.
- Ensure bioretention plants adhere to the planting plan.
- Ensure bioretention plantings are protected until established enough to endure stormwater flows.

- Ensure a non-floating mulch is used such as aged compost or coconut fiber. Wood mulch will float and clog overflows.
- Ensure that overflow risers are not at the elevation of the bioretention system. They need to be raised to allow for ponding, otherwise stormwater will discharge out of the riser and not filtrate into the BSM.
- Ensure structural capacity of bioretention systems adjacent to streets and parking lots or other areas that have potential structural issues.
  - Because bioretention soil is not compacted, planter walls require proper structural support such as continuous footings or lateral bracing to maintain the structural integrity required for adjacent use loadings.
  - For side sloped-style bioretention systems maintaining a native soil bench adjacent to the bioretention system can help maintain structural support.
- For bioretention systems on greater than a 2% slope check dams should be integrated into the system. Check dams can be made of concrete, rock, or steel.
- Ensure energy dissipaters are integrated into the bioretention system at the inlets so that erosion does not occur. Concrete splash pads and cobble are effective energy dissipaters.

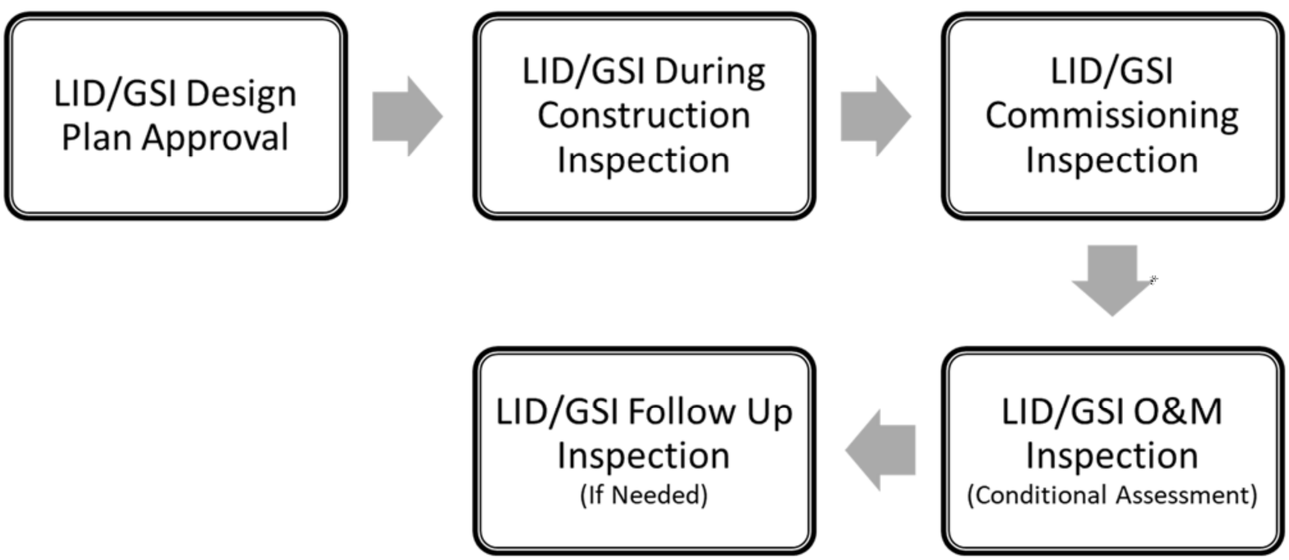
3 LID INSPECTIONS

Visual monitoring of LID/GSI measures in the form of inspections is an important element to ensure that LID/GSI measures have been constructed per the design plans and are effectively being maintained to ensure their proper function and performance. The following are the three types of inspections associated with LID/GSI measures:

- **During Construction –** Verify BMPs are being constructed in accordance with the approved design plans.
- **Commissioning/Construction Complete** - Verify BMPs were constructed in accordance with the approved design plans.
- **Operations and Maintenance (O&M) Inspections/Conditional Assessments** – Verify BMPs are present and functional, and that the area is well maintained.

Figure 3-1. LID/GSI Measures Process of Inspections below identifies the process of inspections for LID/GSI measures.

Figure 3-1. LID/GSI Measures Process of Inspections



3.1 Construction Inspections

Inspections during the construction of structural LID/GSI projects are critical to ensure that the LID/GSI measures are constructed per the approved design, with acceptable materials, and that proper construction procedures are implemented. BMP inspections are recommended at each stage of construction. At least one inspection should take place, but several inspections are optimal to observe the various stages of construction of a LID/GSI measure. The following are the stages of construction where construction inspections should occur using bioretention as an example:

1. Completion of initial excavation.
2. Placement of aggregate layer.
3. Placement of bioretention soil media.
4. Planting of bioretention plants.

Any changes or modifications to the BMPs that occur during construction should be documented as part of the as-built drawings for the project. LID/GSI projects construction inspections should:

- Verify the presence, location, footprint, type and configuration of each LID/GSI measure.
- Evaluate if the LID/GSI measure is built per the approved design plans including all constructed elements based on the stage of construction completion.
- Verify that the LID/GSI measure inlets, outlets, and invert are at the elevations identified in the design plans to ensure conveyance of inflows and outflows.
- Evaluate if the correct BMP materials are used for the LID/GSI measure and installed correctly.
- Identify if machinery performing excavation is adjacent to, and not inside of the LID/GSI measure footprint.
- Evaluate if the LID/GSI BMP area is being protected from construction traffic and debris to prevent compaction, sedimentation, and construction pollutants.
- Confirm the drainage area contributing runoff to the LID/GSI measure and evaluate the condition of the drainage area; including the land use and use intensity, status of surrounding construction, and the surface cover condition.
- Evaluate if proper construction sequencing is being implemented:
  - The LID/GSI BMP measure is one of the last items constructed onsite.
  - Excavation for LID/GSI BMPs is completed after adjacent construction is complete.
- Photographs of the LID/GSI measure.

3.2 Commissioning Inspections

After construction of a LID/GSI structural measure is complete, a commissioning inspection is performed as a final check to ensure the measures were built per design plans and, if any modifications occurred, that the changes are documented. This final check is similar to the commissioning of other infrastructure or buildings. The verification of structural LID/GSI measures, updates to reports, and records of a maintenance agreement may occur concurrently with project closeout or may be required prior to final construction completion based on local requirements.

Project close-out procedures for new and redevelopment sites typically include field verification that site design, source control and treatment control BMPs are designed, constructed and functional in accordance with the approved site plans. Documentation is submitted of the field verification, including tracking number, if applicable, and information on the type, location and maintenance responsibility of the BMPs.

Commissioning inspections should:

- Verify the LID/GSI measure existence, location, footprint, type and configuration.
- Evaluate if the LID/GSI measure is built and sized per the approved design plans including all constructed elements.
- Identify conveyance to the LID/GSI measure and that LID/GSI measure inlets, outlets, and invert are at the elevations identified in the design plans.
- Confirm the drainage area contributing runoff to the LID/GSI measure and evaluate the condition of the drainage area; include the land use and use intensity, if the surrounding construction is complete, and the surface cover condition in the drainage area.
- Identify if the overflow structure/outlet is at the proper elevation.
- Take photographs of the LID/GSI measure areas mentioned above.

Vegetation condition is assessed during commissioning inspections since plant installation is usually the last step in LID/GSI measures construction. The condition of the plants in bioretention, biofiltration, and bioswale type LID/GSI measures must be evaluated and documented, including observation of the following:

- If vegetation is planted per the specifications or an identified plant list.
- If the vegetation percentage coverage, placement, and spacing is consistent with the planting plan.
- If the proper mulch has been used.
- Whether the BMP is offline until vegetation is established.
- If the irrigation system is installed per the irrigation plan and is functioning properly.

3.3 Operation and Maintenance Inspections (Conditional Assessments)

Operations and maintenance (O&M) inspections also called conditional assessments, are typically performed on an annual basis to ensure the LID/GSI structural measures are adequately maintained and functioning. Additionally, some LID/GSI BMPs are required to be inspected after significant storm events, with a significant storm event varying by the location of the LID/GSI measure. LID/GSI structural measures are subject to sediment, trash, and other debris build up which can impede infiltration or biofiltration. Excess vegetation can reduce infiltration or biofiltration, while LID/GSI structural measures lacking proper vegetation density can cause erosion of sediment.

LID/GSI structural measures maintenance requirements are included in the LID/GSI O&M plan that is usually attached to the approved water quality compliance plan [e.g. WQMP, Standard Urban Stormwater Mitigation Plan]. Operation and maintenance inspections/conditional assessments should:

- Verify the existence, location, footprint, type and configuration of the LID/GSI measure.
- Evaluate if the LID/GSI measure is built and sized per the approved design plans including all constructed elements.
- Identify conveyance to the LID/GSI measure and verify LID/GSI measure inlets, outlets, and invert are at the elevations identified in the design plans.
- Confirm the drainage area contributing runoff to the LID/GSI measure and evaluate the condition of the drainage area; including the land use and use intensity and the surface cover condition in the drainage area.
- Identify if the overflow structure/outlet is at the proper elevation.
- Identify if any short circuiting is occurring.
- Identify if maintenance is needed per maintenance triggers in the O&M plan including:
  - Visible erosion, which may require energy dissipation or the addition of vegetation.
  - Vegetation
    - Observe if plants installed are per the specifications or from an identified plant list.
    - Observe if the vegetation percent coverage, placement, and spacing is consistent with the planting plan.
    - Observe if the proper mulch has been used and whether it needs replacement.
    - Observe if vegetation removal is required, such as invasive, woody, or dead vegetation.
  - Sediment accumulation in inlets and in the LID/GSI measure.
  - Presence of trash and/or debris.
  - Whether the capacity of the LID/GSI measure is reduced by sediment and vegetation.
  - Check infiltration rates with simple tests.
- Photographs of the LID/GSI measure.

A number of jurisdictions have created fact sheets that outline schedules for inspection activities for LID/GSI measures such as infiltration trenches, permeable pavement, and bioretention. O&M inspection activities during dry weather of common LID/GSI measures are listed below.

3.3.1 Permeable pavers/pavement

- Ensure the design infiltration rate is maintained for the majority of the BMP.
- Ensure sediment and debris have not accumulated and caused surface sealing.

3.3.2 Bioretention basin

- Ensure BMP is free of damage. Vegetated BMPs should be free of erosion or scouring.

- Remove significant sediment, trash, and/or debris accumulation.
- Ensure BMP inlets and outlets are free of obstructions. Obstructions may be caused by sediment, trash, and debris, or by excessive vegetation.
- Ensure BMP is free of standing water and unpleasant odors.
- Ensure vegetated BMPs maintain sufficient ground cover per the design. Vegetation should be healthy, but not overgrown.
- Infiltration Basin.
- Maintain vegetation, avoiding fertilizers, pesticides and herbicides.
- Remove debris and litter from basin.
- Check for ponding water, odor, and insects.
- Check for erosion and sediment accumulation in the basin.

3.4 Inspection Protocols

For all LID/GSI facility inspections, the following is a list of what can be completed in the office prior to a field inspection:

- Review water quality plan, design plans, specifications, and O&M plan.
- Determine the contributing drainage area of the BMP.
- Identify BMP type, configuration, location, and footprint.
- Review design specifications for BMP materials (construction inspection).
- Review plant specifications (certificate of occupancy/O&M inspection).
- Identify the O&M requirements and triggers (O&M inspection).

3.5 Inspection Checklists

Accurate and complete LID/GSI inspection forms are vital to maintaining precise LID/GSI maintenance and performance data over time. Example LID/GSI inspection and verification forms are included in Appendix A.

4 LID MAINTENANCE

Proper maintenance of LID/GSI measures is important to ensure that these systems continue to function as they were designed. Lack of maintenance may cause the systems to have reduced capacity, clogging, short circuiting, or complete failure. Performing effective maintenance of LID/GSI measures on a regular basis ensures they will continue to function properly, meet performance standards associated with their design, and provide pollutant removal and hydrologic benefits (Riverside County Flood Control and Water Conservation District 2011). This section identifies types of maintenance and some maintenance challenges associated with commonly implemented LID/GSI measures. It should be noted that there are also other programs and initiatives that provide guidance regarding the maintenance of LID and GSI including the San Francisco Public Utilities Commission Green Infrastructure Maintenance Guidebook (SFPUC 2018) and the National Green Infrastructure Certification Program (NGSICP 2019).

4.1 Maintenance Challenges

Maintenance of LID/GSI measures can present significant challenges that should be considered with the installation of LID/GSI measures and in planning for maintenance of existing measures. Some of these challenges are more overarching and others are more specific to certain LID/GSI measures and their associated elements.

<u>Maintenance Training</u>: Proper education and training of maintenance staff and crews is essential to proper function of LID and GSI systems and continues to be a significant challenge as some maintenance staff and crews may not be familiar with LID/GSI measures. In some cases, if LID/GSI measures are not maintained correctly, the performance of these systems can be diminished greatly. Effective and consistent training of maintenance personnel will help ensure long term functionality of LID/GSI measures.

<u>Distributed BMPs</u>: Another maintenance challenge is related to the nature of LID/GSI measures as distributed systems. As opposed to regional or centralized structural BMPs, LID/GSI measures are designed to manage stormwater at its source. Because of the LID/GSI approach, a larger number of smaller systems are integrated in specific drainage areas. An increased number of smaller LID/GSI systems results in an increased amount of maintenance responsibility and an increased cost associated with that maintenance. Additionally, more LID/GSI measure inspections need to be performed, which also results in higher costs. An increased number of LID/GSI measures within a jurisdiction can strain existing municipal budgets for both maintenance of LID/GSI measures in the public right-of-way and on inspections of LID/GSI measures in both the public right-of-way and for private developments.

<u>Inspection Training</u>: Education and training of inspectors is yet another challenge, as some inspectors may not be familiar with LID/GSI BMPs and need to be trained for different levels of inspections (identified in Section 3.7). Untrained inspectors may not be able to identify different types of LID/GSI measures and how they function. If inspectors cannot understand the LID/GSI BMPs during construction, the LID/GSI measure may not be identified as incorrectly constructed. Additionally, some inspectors may not understand different LID/GSI maintenance triggers which results in ineffective inspections and poorly maintained LID/GSI systems.

Some specific challenges associated with maintenance of LID/GSI systems include the following (Orange County Public Works 2011):

- Vegetation management
    - Overgrowth
    - Barren areas
    - Dying or dead vegetation
    - Vegetation identification
- Erosion issues
    - Lack of energy dissipation
    - Replacement or addition of plants
    - BMP brought online before plants became established
- Sediment and trash accumulation
    - Blocking inlets
    - Capacity reduction and clogging

Maintenance Information Tracking: As the number of constructed LID/GI measures increases and the resulting maintenance requirements also increase, the time and effort needed to adequately track LID/GI maintenance can become more time-intensive and challenging. Tracking of maintenance should include 1) the maintenance action that was performed (e.g. vegetation removal); 2) quantification of maintenance action (e.g. volume of sediment removed); and 3) costs to perform the maintenance including labor costs (e.g. labor hours) and other costs (e.g. hauling and dumping fees). Maintenance tracking is also identified in the Section 5 Asset Management under subsection 5.1 Record Keeping.

4.2 Bioretention Maintenance

Bioretention systems are the most common type of LID/GSI measure as they are versatile and can be implemented with many different configurations. Bioretention systems slow, clean, and infiltrate stormwater, which reduce the volume of stormwater runoff and its associated pollutants. Bioretention systems are composed of:

1. Aggregate layer at their base to allow for storage of stormwater.
2. Engineered BSM that helps to remove pollutants and provides a growing media for the plants.
3. Specific bioretention plants that are selected based on the climate zone and the ability to be inundated with stormwater.
4. Non-floating mulch layer to protect the soil and keep it moist, which helps with plant health.

Additionally, depending upon the configuration, bioretention systems may have structural components such as overflow risers, curbs, inlets, energy dissipaters, and other appurtenant elements.

Some bioretention systems may have underdrains and so function as more of a biofiltration system. These bioretention systems with underdrains biofilter stormwater and then discharged the water to the storm drain system. Some bioretention systems are designed with side slopes and others are designed as concrete bioretention planter boxes. The following sections address the maintenance triggers and tasks associated with bioretention systems.

4.2.1 General Maintenance

General maintenance includes inspection or observation of inlet and outlet structures, side slopes and bioretention inverts, erosion, burrows, emergence of trees or woody vegetation, graffiti or vandalism, and fence damage. Inspections or observations performed by maintenance staff are critical as the operations and maintenance manual for a site should identify maintenance triggers that can be observed by maintenance staff to identify when certain types of maintenance are needed. General maintenance should consider the following:

- Proper and timely maintenance is essential to continuous and effective operation.
- All structural components must be inspected, at least once annually, for cracking, subsidence, spalling, erosion and deterioration.
- Components expected to receive and/or trap debris and sediment must be inspected for clogging annually prior to the wet season, as well as after every storm exceeding 1 inch of rainfall.
- Sediment removal should take place when all runoff has drained, and the basin is dry.
- Disposal of debris, trash, sediment and other waste material must be done at suitable disposal or recycling sites and in compliance with all applicable local, state and federal waste regulations.
- Maintenance frequency: Annually or after rain events of 3 inches or more.
- Maintenance indicators: Standing water 96 hours after a storm event; burrows, holes, or mounds; debris or trash present; sediment depth exceeds 10% of the facility design; erosion.
- Recurring conditions in a bioretention system after significant storm events such as sediment accumulation that may indicate an issue with the bioretention system or the drainage area to the bioretention system.

4.2.2 Drainage Time

Effective drainage of bioretention systems is essential to their proper function. Drainage time provides a good trigger to identify if a bioretention system is functioning properly. Specifics about drainage time include the following:

- The bioretention system must be inspected at least annually to determine if the infiltration or biofiltration capacity of the basin has decreased.
- Ponded water and drawdown failure can be caused by the following:
    - Crusting or sealing of the soil surface via accumulation of fine-grained soil, organic matter, etc.
    - Heavily compacted soil.

- Large amounts of sediment accumulation in the soil.
- Blocked or clogged overflow structures.

- If the bioretention system fails to drain the design storm within 96 hours, consider the following:
  - Remove excess sediment.
  - Remove dead and excess vegetation.
  - If bioretention system continues to fail to drain after removal of excess sediment and excess vegetation:
    - Pump water and use for non-potable use (i.e. dust control). Do not discharge pumped water downstream.
    - Flush bioretention system cleanout ports if available.
    - If the bioretention system does not drain, evaluate replacement of top 2-3 inches of BSM for the entire bioretention area and replace if necessary. Typical replacement method to avoid compaction consists of removing the top 2-3 inches of BSM by hand with shovels, properly disposing of the BSM at an approved facility, and then shoveling by hand 2-3 inches of new BSM to replace the removed BSM.

4.2.3 Trash / Debris Accumulation

Excessive trash or debris accumulation causes problems that extend beyond poor aesthetics. Trash and debris accumulation can clog or inhibit the infiltration or biofiltration capacity of the BSM, and clog overflow structures of bioretention systems. Clogged or inhibited infiltration or biofiltration capacity could lead to extended drawdown times and unwanted ponding. Additionally, clogged overflow structure grates can lead to overflowing and flooding.

- All trash and debris should be removed from bioretention systems before the start of the rainy season (October 1) or as frequently as site conditions dictate. All material should be discarded at an appropriate facility.
- Maintenance Indicator: Excessive debris or trash present, where trash could inhibit the capacity or the function of the bioretention system.

4.2.4 Sediment Management

Some sediment accumulation in bioretention systems is normal and expected; however excess sediment in bioretention systems will reduce their capacity and could clog the basin in its entirety.

- Steps must be taken to remove sediment accumulation on an annual basis (or more often, depending on site conditions) to keep the bioretention systems functioning properly. This built-up sediment must be removed to ensure water can flow freely into and through the bioretention systems, as well as to maintain the BSM filtration and infiltration capacity. Typical removal methods consist of removing sediment with shovels and properly disposing of the sediment at an approved facility.
- Replace any damaged vegetation as a result of removal of sediment in bioretention system.
- Investigate the source of excess sediment in the drainage area to the bioretention system.

- Maintenance Indicator: Sediment depth exceeds 10% of the bioretention system design or drain time exceeds 96 hours.

4.2.5 Bioretention Soil Media Repair/Erosion

Inflow and water movement through bioretention systems may cause erosion and scouring of the BSM surface over time, or immediately after construction during the plant establishment period. Erosion and subsequent sediment deposition can be detrimental to the BSM filtration capacity, cause damage to plants, and create clogging in overflow structures.

- Repair measures must include identifying and correcting the cause of the erosion by repairing the erosion damage and removing any sediment created by the erosion process.
- Identify if erosion is caused by lack of energy dissipation, or damaged energy dissipation in the bioretention system. If necessary add energy dissipation and flow dispersal measures to reduce channelized flow (rock cobble or rip-rap level spreader, etc.).
- Reseed and/or revegetate barren spots as appropriate for the area.
- Re-mulch as necessary.
- Maintenance Indicator: Erosion on the side slopes or invert of the bioretention system, rilling on the side slopes of the bioretention system, and/or erosion near inlet or outlet riser.

4.2.6 Vegetation Management

Since vegetation plays an important role in treatment processes and supports infiltration or biofiltration capacity, healthy and well-established vegetation is essential for bioretention systems. Thus, vegetation replanting and removal of weeds and dead plants are important, especially in the first one -year establishment period. Vegetation also helps to stabilize side slopes, prevent erosion, and enhance filtration into the engineered soil media by creating pathways for water to infiltrate along plant root structures. In addition to supporting evapotranspiration, plant roots help aerate the soil, minimize soil compaction, replenish organic materials in the soil, and provide a habitat for beneficial bacteria that aid in the biological breakdown and mitigation of pollutants deposited by stormwater into the facility.

Excessive vegetation can degrade bioretention systems by taking up basin capacity and blocking of overflow risers. Poorly-sited, spreading or overgrown plant material can create blockages at the inlet point of bioretention systems. Overgrown vegetation can block stormwater flows from entering the facility, potentially causing stormwater to pond upstream of the inlet or bypass the unit entirely. If only a portion of the design capture volume of stormwater can enter the bioretention system, the facility function will be significantly diminished. Maintenance practices associated with LID/GSI facility vegetation include the following:

- Cutting or removing vegetation and clippings as appropriate.
- Removal of any emergent trees, or woody vegetation.
- Any plant material that blocks the inlet of a facility must be pruned, thinned, or be removed and disposed of.

- Removal of excess vegetation that reduces the capacity of the bioretention system.
- Dead, diseased, dying, or missing plants must be replaced. If many plants have died, consult with a horticultural expert on the cause of the die-off, and remedy the cause before replanting.
- Maintenance Indicator: Emergence of trees or woody vegetation; average plant height is greater than 12 inches.

4.2.7 Rodent Damage and Burrowing

Rodent damage and animal burrows in bioretention systems can cause structural, landscape, and stormwater flow-based issues. Burrows can undermine structural components, leading to unwanted settlement. Burrows may also create preferential flow paths through the section of the berm, causing piping and erosion problems in the berms. Rodents can also damage plants and plant root systems.

- If rodent or other animal damage is observed, consult a licensed professional pest control service for eradication, or trapping and relocation, as appropriate.
- Where burrows cause seepage, erosion, or leakage, backfill firmly.
- Maintenance Indicator: Visible borrows, holes, or mounds.

4.2.8 Structural Damage

Minor damage to structural components such as bioretention system edges or overflow structures should be repaired on a yearly basis. More significant structural damage must be repaired as soon as possible.

- Minor repairs can consist of, but are not limited to, patching chips and cracks to concrete structures and resetting outlet structure frames and grates. Major repairs can consist of removal and replacement of damaged overflow risers, or structural bracing and supplemental reinforcement of failing structural components.
- Maintenance Indicator: Minor or major structural damage. Inspect after all large earthquakes (Magnitude 5.0 or higher) or other incidents that may affect the bioretention system.

4.2.9 Life Span

The life span of bioretention systems can be up to 20 years and potentially longer if properly maintained. Bioretention life span depends significantly on the maintenance of the bioretention system and the stabilization of the bioretention system drainage area. More sediment entering the basin equates to a reduction in the bioretention system life span.

4.3 Permeable Pavement

Permeable pavement includes a range of different types of systems that allow stormwater to drain through the pavement surface and into its base. Permeable paving consists of a porous surface layer and an underlying clean aggregate layer. The aggregate layer provides temporary storage until stormwater infiltrates into the soil below or in some cases flows to a perforated pipe underdrain. General types of permeable pavement include permeable pavers, pervious concrete, and porous asphalt.

4.3.1 General Maintenance

General maintenance includes inspection of the pavement surface, the surrounding areas of the pervious pavement, and the upstream drainage area of the permeable pavement. General maintenance and inspection should consider the following:

- Proper and timely maintenance is essential to continuous and effective operation of permeable pavement and to prevent clogging.
- Maintenance Indicator: Standing water visible on the pavement more than 48 hours after the most recent rainfall; structural damage to the pavement, or broken pavers; weed growth, sediment, vegetation, or other material clogging the permeable pavement surface; signs of contamination on the pavement surface.

4.3.2 Trash / Debris Accumulation

Excessive trash or debris accumulation causes problems that extend beyond poor aesthetics. Trash and debris accumulation can clog or inhibit the infiltration or filtration capacity of the permeable pavement system. Clogged or inhibited infiltration or filtration capacity could lead to unwanted ponding.

- All large trash and debris should be removed from the permeable pavement system before the start of the rainy season (October 1st) or as frequently as site conditions dictate. All material should be discarded at an appropriate facility.
- Large trash and debris should be removed before sweeping or vacuuming the permeable pavement.
- Smaller trash and debris can be removed by routine vacuuming.
- Rakes and leaf blowers can be used to remove leaves.
- Maintenance Indicator: Excessive debris or trash present, to where the function of the permeable pavement could be affected.

4.3.3 Vacuuming

- Sediment and smaller debris accumulated on the permeable pavement can clog the surface and prevent stormwater infiltration or filtration. After large trash and debris have been removed, permeable pavement should be vacuumed to clear all sediment and other debris from the pavement surface. (SFPUC 2018). The following are considerations for vacuuming: Prior to vacuuming, remove bulky debris and waste materials from pavement surfaces that are too large to be picked up by vacuum hose (e.g., litter, tree branches, wire, car parts).
- Vacuum sediment and debris from the entire surface area of the permeable pavement installation using a dry vacuum.
- Give extra attention to pavement edges and areas where sediment has accumulated.
- Sweep up sediment and debris from surrounding surface areas, especially those that slope toward the permeable pavement.

- Note and report damage in pavement, including holes, cracks, excessive scuffing, settlement, and areas of standing water.
- It is important to vacuum the sediment and debris from upstream, or highest point, to downstream, or lowest point, to prevent any sediment from being carried back onto the vacuumed surface.
- Maintenance Indicator: Surface Ponding (> 48 hours after rainfall), excessive sediment or other material logged in the voids of the permeable surface.

4.3.4 Pressure Washing and Restorative Vacuuming

Permeable pavement is intended to let water pass through its surface into the aggregate base and soil below or into underdrains. Over time, deep cleaning and unclogging of permeable pavement may become necessary and is best accomplished by simultaneous pressure washing and restorative vacuuming. (SFPUC 2018). The following are the considerations for pressure washing and restorative vacuuming:

- Do not use extremely high pressures with a pressure washer. High pressures can dislodge joint aggregate in unit pavers or damage pervious concrete and porous asphalt surfaces.
- Prior to vacuuming or pressure-washing, remove bulky debris and waste materials from pavement surfaces that may be too large to be picked up by a vacuum hose (e.g., litter, tree branches, wire, car parts).
- Vacuum and pressure wash impacted areas of the permeable pavement.
- Dispose of the sediments and debris at an appropriate facility.
- Note and report any damage in the pavement, including holes, cracks, excessive scuffing, settlement, dislodged aggregate, and areas of standing water.
- After vacuuming and pressure washing permeable pavers, re-joint the pavers with the appropriate aggregate based on the original design or the paver manufacturer's recommendation.
- Maintenance Indicator: Extended Surface Ponding (> 48 hours after rainfall), excessive sediment or other material logged in the voids of the permeable surface.

5 LID/GSI BMP Asset Management

Effective asset management and tracking LID/GSI facilities within a jurisdiction is crucial for managing maintenance and quantifying aggregate benefits. First, it is important to identify where LID/GSI measures are located within the jurisdiction and in which watershed they are located. LID/GSI facility owners must report changes in ownership and responsibility for the operation and maintenance of post-construction LID/GSI measures to the corresponding jurisdiction to ensure the changes are properly recorded in public records. LID/GSI facility ownership and operation change information must be conveyed to all appropriate parties when there is a change in project or site ownership (County of San Diego 2016). LID/GSI facility owners must at least provide the following information to the jurisdiction:

- Local project identifier and description of the project (such as application number, tentative tract number, review number, etc.).
- Type of structural treatment control BMPs.
- Location of BMPs.
- Parties responsible for construction and, operation and maintenance (SARWQCB 2011).

5.1 Recordkeeping

Maintaining records of BMP metadata is also central to providing background information to jurisdiction staff. For example, a new inspector performing operation and maintenance LID/GSI facility inspections would need to have several pieces of information before being able to properly perform a maintenance and operation BMP inspection, such as:

- BMP site and maintenance plan or as-built construction plans.
    - Location of the BMP.
    - Owner contact information.
    - Type of BMP.
    - BMP dimensions and functionality.
    - How the BMP must be maintained and how often.
- Inspection history.
    - Past inspector(s).
    - Frequency of inspection.
    - Past inspection results.
    - Historical issues.

Additionally, record keeping can help with future planning for maintenance of LID/GI BMPs. Tracking of maintenance performed is critical to being able to forecast future operation and maintenance costs of LID/GI BMPs. Tracking of maintenance performed should include:

- Maintenance activity
- Quantification of maintenance action
- Costs to perform the maintenance

Maintenance tracking can be integrated into an electronic form so that as maintenance is performed photos can be taken and quantities and labor hours spent can be entered into the electronic form in the field.

5.2 Electronic forms

Hard copy inspection forms may be used for LID/GSI facility inspections and tracking, but paper copies may be completed incorrectly, fields may be skipped, and pages may be misplaced or lost. Many jurisdictions are moving towards web-based inspection forms that can be completed in the field via tablet. Using tablets in the field reduces the extra time that would be required to scan, and hand enter hard copy data into computer databases.

Online tools such as Survey123 for ArcGIS can be used to develop electronic LID/GSI inspection forms that link directly to a jurisdiction database. Survey123 allows users to easily design forms which are accessible via a mobile app for data entry in the field. The program integrates into ArcGIS to enable spatial analysis and other data analysis (Law 2017). Figure 5-1 shows a screenshot of the County of Orange BMP inspection form through the Survey 123 app (County of Orange 2018).

Figure 5-1. County of Orange BMP Inspection Form Survey 123

Data on LID/GSI facilities is very valuable in the long-term as it allows jurisdictions to gauge the effectiveness of LID/GSI infrastructure over time. Limited data has been collected thus far on LID/GSI measure effectiveness in Southern California because the implementation of LID/GSI measures is relatively new to the region (Haan-Fawn Chau 2009). Also, data from LID/GSI measures in Southern California cannot be compared to other LID/GSI facilities in the United States since BMPs are designed based on the Mediterranean climate, which is distinctly different from other regions of the country. LID/GSI BMP monitoring data is vital to the progress of regional regulations, organizations such as Southern California Stormwater Monitoring Coalition (SMC) California Stormwater Quality Association (CLEAN), and BMP functionality in the Southern California region.

6 LID MONITORING

6.1 Monitoring Purpose

The primary goals of LID/GSI facilities are to remove pollutants from stormwater runoff and infiltrate, retain, and/or treat runoff. The purpose of a monitoring study is to establish that the implemented BMP provides the hydrologic and pollutant reduction benefits as expected based on its design and application. There is a need to establish performance metrics and ranges of acceptable performance for LID BMPs in Southern California and throughout the rest of California.

The initial step in creating a monitoring program is to create targeted research questions that guide the creation of a sampling and monitoring plan, which provides pertinent and useful data. The following process can be used to develop targeted research questions:

- Background planning:
  - Who - are the stakeholders, involved parties?
  - What - are the issues, problems, needs?
  - Where - is the focus of the study/interest? Are there single or multiple locations?
  - When - will changes be implemented, have related events or studies taken place?
  - Why - is this problem, need, issue being addressed; why is this study critical to addressing it?
  - How - will possible solutions, interventions, other aspects of the study be assessed for effectiveness; how will results be delivered and/or implemented?
- Development of specific questions:
  - Problem - what is the main problem you are addressing, what are the characteristics of the LID/GSI BMP site? Of the surrounding area? Of the watershed? Of similar sites?
  - Method – what to implement to address the problem of interest?
  - Comparison – compare methods from other studies. In your context, is it important to review studies that have addressed similar problems, methods, or measured outcomes?
  - Outcome of interest - what are the measurable outcomes (standardized measures if possible) that would demonstrate effectiveness of the study?
  - Time frame - are there are specific time frames of interest for your study? (Virginia Tech 2018).

6.2 Southern California Stormwater Monitoring Coalition (SMC) California LID Evaluation & Analysis Network (CLEAN) Monitoring Protocol

This section outlines the process of data collection for a specific LID or GSI project. It provides project management information, specific project information (meta data) to be collected, monitoring plan review recommendations, specific details on the data acquisition process including monitoring equipment, site set-up guidance, monitoring parameters for hydrology and water quality, and describes the intended use of the data collected. As much as possible, sample collection and analysis methods are standardized for comparability. However, due to different study needs, the recommended sampling frequency and schedule may vary substantially. Consequently, sampling schedules are included for three identified project types: Basic BMP Performance Verification; BMP Performance over Time, and Special BMP Studies (Table 6-1, Table 6-2, and Table 6-3 respectively).

Basic BMP Performance Verification—for new BMP installations:

- To establish that the implemented BMP provides the hydrologic and pollutant reduction benefits as expected based on its design and application.
- To fulfill effectiveness assessment requirements for grant-funded BMPs.
- To support quantitative BMP effectiveness inputs to watershed management plans and impacts on receiving water quality.
- To support regional studies of bioretention BMP performance (such as the SMC CLEAN Project).

BMP Performance over Time:

- To evaluate the lifespan of bioretention media, both hydraulic performance and water quality performance, or otherwise predict major maintenance needs (e.g., media replacement) for common bioretention installations.
- To evaluate the performance implications of plant conditions and maintenance.
- To support cost-benefit evaluations.

Special BMP Studies:

- Proof-of-concept to evaluate new bioretention soil media types, new designs, or unique BMP arrangements[2].
- To evaluate the performance impacts of specific factors such as plant palette; construction practices; rainfall characteristics, or other.
- To evaluate pollutant fate and transport.

This data collection protocol is designed to ensure that monitoring data are adequate to evaluate the effectiveness of the aggregate of LID/GSI measures and are collected in a consistent manner to ensure that data from different LID/GSI measures installations will be comparable. Improved understanding of the hydrologic and water quality benefits of LID/GSI measures will improve efforts to modify LID/GSI designs, specifications, and maintenance measures to optimize performance. Many individual LID/GSI measures should be monitored throughout regional watersheds. Collectively, such data can be used to determine how effectively each class of LID/GSI measures reduce runoff volume and maintain or restore pre-project hydrologic parameters; how effectively they reduce pollutant loads and concentrations in runoff; what maintenance is required to ensure BMP performance over time; and what is the typical lifespan of bioretention media. Monitoring data collected, depending on the protocol options selected, will support evaluations of LID performance for individual projects, for multiple projects at small and large scales, and for various LID design

[2] The focus of the SMC CLEAN has been field testing of BMPs however innovative designs could also benefit from bench scale lab testing with synthetic stormwater.

approaches and implementation conditions. For example, monitoring for Basic BMP Verification or proof-of-concept studies for new designs or new bioretention media should be designed to stand alone since conclusions must be drawn from a single (or very few) installations.

This protocol is an integral part of a comprehensive project evaluation process. The process requires a complete project description and implementation records; stated objectives and management questions; a monitoring/sampling protocol; laboratory test methods, analytical procedures, and Quality Assurance/Quality Control procedures; data evaluation methods; and reporting specifications. The LID/GSI monitoring is part of an iterative process as identified in **Error! Reference source not found.** on the following page. The effectiveness evaluation should be scaled to the scope and life expectancy of the project. Most LID/GSI facilities are expected to function effectively for 20 years or longer if adequately maintained. If possible, prior to investing in full water quality monitoring, perform visual monitoring of at least one storm to identify any functional defects that may need to be corrected. A comprehensive evaluation will include documentation and evaluation of maintenance and performance over the life of the project BMP.

6.2.1 Pre-Monitoring Check

Before monitoring is scheduled to commence the basic functionality of the BMP must be checked. This pre-monitoring check should verify:

- BMP is built and sized per design.
- Preferred construction practices were used to minimize soil compaction or contamination.
- Correct BSM materials used and installed correctly.
- Correct elevations to ensure functionality.
- Inlet and outlet in good condition.
- Hydraulic connectivity between BMP and inlet/outlet conveyance.

6.2.2 Contributing Area Condition Evaluation

The condition of the area contributing runoff to the BMP must be evaluated initially and periodically to verify the size of the area, the land use and use intensity, and the surface cover condition.

6.2.3 Plant Condition Assessment

The condition of the plants in the bioretention BMP must be periodically evaluated and documented, including consideration of the following parameters:

- Planted per Design
    - Plant type
    - Placement/spacing
- % Cover
- Irrigation system observations
- Maturity
    - Plant establishment date
- No plants by design

Table 6-1. Monitoring/Sampling Frequency Options - Basic

Table 1: Basic BMP Performance Verification		
Year 1	**Year 2**	**Year 3**
Pre-monitoring check	**3 events; early, mid, late season:** • Influent, effluent, hydrology • Contributing area observations • Plant condition observations • Maintenance condition tracking	**1 event:** • Influent, effluent, hydrology • Contributing area observations • Plant condition observations • Maintenance condition tracking
2 events; early and mid/late season: • Influent and effluent samples; • hydrology; • contributing area observations;		**2 additional events required if significant BMP changes occur:** • Influent, effluent, hydrology • Visual monitoring of contributing area • Plant condition observations
Monthly plant condition observations		

Table 6-2. Monitoring/Sampling Frequency Options – Performance over Time

<table>
<tr><th colspan="4">Table 2: BMP Performance over Time</th></tr>
<tr><th>Year 1</th><th>Year 2</th><th>Year 3 - 10[1]</th><th>Year 11 - 20[1]</th></tr>
<tr><td>Pre-monitoring check</td><td rowspan="2">3 events; early, mid, late season:
• Influent, effluent, hydrology
• Contributing area observations;
• Plant condition observations
• Maintenance condition tracking</td><td rowspan="2">2 events; early and mid/late season:
• Influent, effluent, hydrology
• Contributing area observations;
• Plant condition observations
• Maintenance condition tracking</td><td rowspan="2">2 events; early and mid/late season:
• Influent, effluent, hydrology
• Contributing area observations;
• Visual hydrologic function verification
• Plant condition observations
• Maintenance condition tracking</td></tr>
<tr><td rowspan="2">2 events; early and mid/late season:
• influent and effluent samples;
• hydrology;
• Contributing area observations;</td></tr>
<tr><td rowspan="4">3 events required after significant BMP changes occur:
• Influent, effluent, hydrology
• Contributing area observations;
• Plant condition observations
• Maintenance condition tracking</td><td>3 events required after significant BMP changes occur:
• Influent, effluent, hydrology
• Contributing area observations;
• Plant condition observations
• Maintenance condition tracking</td><td>2 events required after significant BMP changes occur:
• Influent, effluent, hydrology
• Contributing area observations;
• Plant condition observations
• Maintenance condition tracking</td></tr>
<tr><td>Monthly plant condition observations</td><td>[1]Evaluate data after year 5 and confirm or revise sampling frequency.</td><td>[1]Evaluate data after year 10 and confirm or revise sampling frequency.</td></tr>
<tr><td>First event after plant establishment:
• Influent, effluent, hydrology
• Contributing area observations
• Plant condition observations</td><td colspan="2" rowspan="2">Evaluate and revise schedule in response to any significant changes to BMP, major plant or structural failure, change, or replacement;

Evaluate and revise schedule with any significant changes in contributing area condition.</td></tr>
<tr><td rowspan="2">Maintenance condition tracking
(develop protocol with CWH)</td></tr>
<tr><td colspan="3">Older, established BMPs can begin monitoring using the Year 2 schedule.</td></tr>
</table>

Table 6-3. Monitoring/Sampling Frequency Options – Special Studies

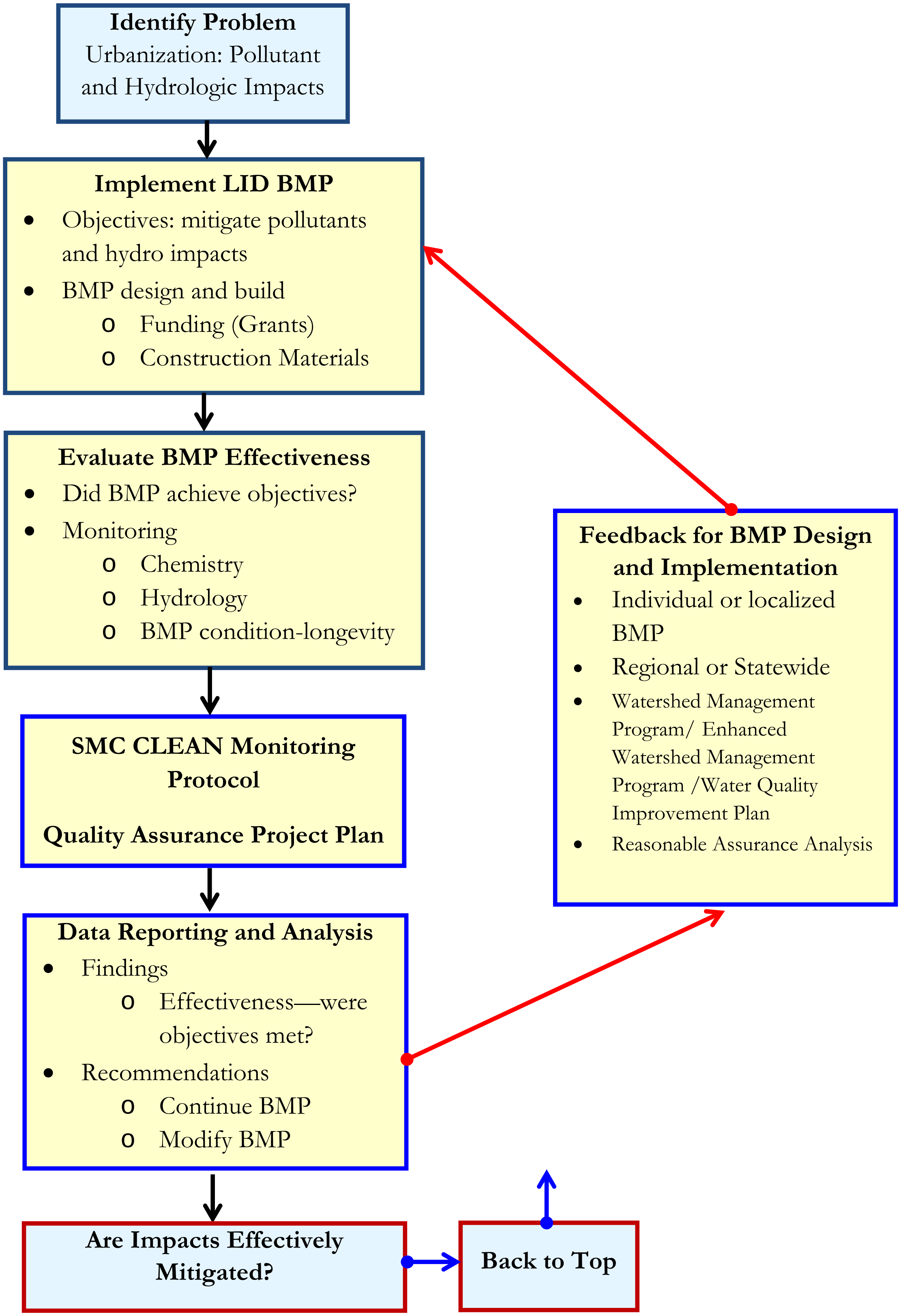
<table>
<tr><th colspan="4">Table 3: Special BMP Studies</th></tr>
<tr><th>Year 1</th><th>Year 2</th><th>Year 3</th><th>Beyond Year 3</th></tr>
<tr>
<td>Pre-monitoring check</td>
<td rowspan="4">3 events; early, mid, late season:
• Influent, effluent, hydrology
• Soil moisture
• Contributing area observations
• Maintenance condition tracking
• Monthly plant condition observations</td>
<td rowspan="2">3 events; early, mid, late season:
• Influent, effluent, hydrology
• Soil moisture
• Contributing area observations
• Maintenance condition tracking
• Monthly plant condition observations</td>
<td rowspan="4">Evaluate study objectives and existing data; confirm or revise sampling frequency.

• Evaluate and revise schedule in response to any significant changes to BMP, major plant or structural failure, change, or replacement.

• Evaluate and revise schedule with any significant changes in contributing area condition.</td>
</tr>
<tr>
<td rowspan="2">2 events; early and mid/late season:
• influent and effluent samples;
• Hydrology;
• Soil moisture;
• Contributing area observations;

In addition:
For studies requiring pollutant removal data to evaluate performance of bioretention soil media:
• Collect effluent samples;
For studies where pollutant removal is determined by volume of retention;
• Ensure flow monitoring equipment is functional prior to each event</td>
</tr>
<tr>
<td rowspan="2">2 additional events required if significant BMP changes occur:
• Influent, effluent, hydrology
• Soil moisture
• Contributing area observations
• Monthly plant condition observations</td>
</tr>
<tr>
<td>Monthly plant condition observations</td>
</tr>
</table>

Figure 6-1. Iterative Process & LID/GSI Monitoring



6.2.4 Integration of Monitoring into LID/GSI BMP Design

LID/GSI BMPs are inherently challenging to monitor due to their design as part of the landscape. LID conveyance features are subtler and distributed when compared to conventional BMPs which have defined inlet and outlet structures. Therefore, monitoring approaches should be considered and monitoring features should be integrated as part of the BMP design. LID/GSI measure designs should be modified based on the type of monitoring that will be performed. Monitoring details of specific design plans are discussed in Section 6.3 below.

6.2.5 Project Description and Implementation[3]

- Site drawings – Design plans, specifications, As-builts.
- Design storm, drainage area size, and sizing calculations.
- Drainage area land uses and percentages.
- Historic site information.
- Native soils information (including analysis of all inorganics measured in the water quality protocol), geotechnical report, infiltration tests.
- Engineered soil matrix information, soil matrix source.
- Plant information/list, plant source.
- Mulch information/source.
- Construction records, contractor information.
- Maintenance protocols.
- Maintenance records, maintenance contractor information.
- Inspection records.
- Data tracking protocols.
- Data access information.
- Data reporting protocols.
- Other information being collected for each site and why it is being collected.

6.2.6 Monitoring Plan Review and Reporting

LID project monitoring plans should be consistent with the requirements of the agency requesting/requiring project monitoring and should be reviewed before being implemented. Some projects may have a monitoring plan review requirement imposed by the jurisdiction where the project has been implemented or by a regulatory agency (i.e. State Water Resources Control Board (SWRCB))

[3] The international BMP database provides guidance for collecting data. http://www.bmpdatabase.org/data-entry.html

for a grant funded project or as part of a 401 Water Quality Certification or other regulatory requirement (SWRCB 2012). For projects in the geographic scope of the SMC, projects can submit their LID monitoring plan to the SMC CLEAN project for review.

Monitoring data should be reported as specified by the jurisdiction approving the project and per applicable regulatory reporting requirements (e.g. California Environmental Data Exchange Network/ Surface Water Ambient Monitoring Program). For LID/GSI projects in the geographic region of the SMC, LID monitoring and meta data will be submitted to the SMC CLEAN Data Submittal Tool.

6.2.7 Measurements

Monitoring will include these measurements:

- Rainfall depth
- Influent and effluent flow rate (used to calculate flow volume)[4]
- Bypass Occurrence and/or Flow Rate
- Influent and effluent pollutant concentration
- Soil moisture (optional)

6.2.8 Site Setup

Develop BMP configuration schematic including:

- Contributing drainage area(s)
- Influent sampling point(s)
- Underdrain/effluent sampling point (s)
- Overflow/bypass sampling point(s)

Flow rate of water into and/or out of the selected LID/GSI measure and pollutant concentration should ideally be measured during runoff events at relevant site-specific points which could include:

- Inflow
- Overflow
- Underdrain/Effluent
- Bypass
- Vadose zone or within the bioretention soil media or gravel reservoir (optional)

[4] See flow monitoring guidance: http://www.openchannelflow.com/blog/isco-releases-7th-edition-of-its-flow-measurement-handbook

If all inlet/outlet points cannot be monitored, representative sites should be selected that allow for scaling or modeling of the entire BMP. Monitoring of flow from the underdrain (if present) and overflow/bypass is preferred to monitoring of the overflow/bypass alone.

If possible, projects should collect hydrologic and water quality data at the proposed BMP location before the BMP is installed. These projects should characterize the pre-BMP drainage area, for stormwater volume and project specific water quality parameters to provide baseline conditions.

Each sampling point should be instrumented with a data logger, autosampler, and flow measurement devices. Site specific considerations should be taken into account for public safety and equipment security which could include placing equipment in lockable security enclosures to deter theft and vandalism and protecting tubing lines and data cables with PVC conduit. Additional sampling information can be found in the Urban Stormwater BMP Performance Monitoring report (Geosyntec and Wright Water Engineers, Inc. 2009).

6.2.9 Event Mobilization

Prior to mobilization for a sampling event, weather/storm events should be tracked using multiple weather sources such as National Oceanic Atmospheric Association National Weather Service and Accuweather to estimate the event rainfall amount and arrival time of the storm event. Rainfall estimates should equal at least the project specific threshold to ensure adequate runoff to sample (0.25 inches suggested over 24 hrs.), and for effluent sampling, the antecedent dry period should be sufficient so that the BMP has completely drained water from previous rain events.

When event conditions are met, the sampling team should conduct a pre-event site visit to ensure the site is prepared for monitoring and the equipment remains properly installed and begin sampling preparation procedures.

6.2.10 Sampler Programming

6.2.10.1 Composite samples

Minimum: collect a single volume-adjusted or time-weighted composite sample at the inlet and outlet/overflow which will represent the influent and effluent event mean concentrations for the storm event. Flow-weighted composite sampling is strongly encouraged as it provides a more representative event mean concentration.

Enhanced: collect a flow weighted composite sample representing the "first flush" or rising limb of the hydrograph, and a composite sample representing the remaining flow for the event at the inlet and outlet/overflow. This requires using an autosampler equipped with multiple bottles or switching out the composite sample over the course of the storm. These samples would be analyzed separately. Composite sampling methods are discussed in Section 6.2.10.2 through 6.2.10.4.

6.2.10.2 Time-based

Based on the duration of the forecasted storm event autosamplers should be programmed to sample for up to 24 hours, or for the full duration of the storm if shorter than 24 hours, to provide a composite sample to represent the event mean concentration for the event. For a 24-hr. storm, tiered programming is recommended; where the first 12 discrete auto samples are collected every 30 minutes and the final 12 samples are collected at 1.5 hrs. For a storm event shorter than 24 hours the program should be appropriately scaled so that at least 75% of the storm is sampled. Time-based composite sampling is a straightforward sampling method that can be used for new sites where the hydrograph is not known. However, time-based sampling will not provide an accurate or representative event mean concentration since the sample pacing will not match the flow hydrograph shape. Also, sample volume and timing set before the storm can cause too many or too few samples to be collected if the rainfall patterns differ significantly from the forecast.

If multiple bottles are used to collect samples on a time-based schedule, these samples can be composited by hand on a flow-weighted basis, otherwise known as volume-adjusted composite sampling. A volume-adjusted composite sample is typically collected as many discrete time-paced samples over the course of the storm. After the storm, a portion of each discrete sample is combined to create the volume adjusted composite sample. The amount of each discrete sample added is proportionate to the volume of the storm represented by the time interval associated with the discrete sample.

6.2.10.3 Volume-based

Preferably, autosamplers will be programmed for volume-weighted sampling by triggering samples based on a user-defined volume-to-sample quantity. This method produces the most accurate event mean concentration estimation. This method requires a good estimate of flow rate and shape/timing of the hydrograph. Adjustments are usually required based on experience from initial storm events. Underestimation of runoff will result in collection of additional samples and increased sample pacing which can backlog the autosampler tubing rinse/purge routine; backlogged samples then become time-weighted. Overestimation of runoff will result in collection of fewer samples and reduced representation of the event. Estimation of storm volumes and hydrographs can be improved by observing the monitoring site and instrumentation during the sampling event and adjusting pacing if needed. Hydrologic response of the BMP contributing area can also be better understood by monitoring and evaluating rainfall and flow only during storm event(s) prior to initiation of water quality sampling. Volume-based sampling provides a more representative event mean concentration since sample volume is directly linked to flow measurement and matched the hydrograph shape. However, volume-based sampling can be more complicated to implement in the field as the storm size and hydrograph need to be anticipated in order to set the correct flow pacing. Incorrect flow pacing could result in the collection of either too small of a sample volume or too large of a sample volume that is collected during only a portion of the storm.

6.2.10.4 General setup

The autosampler should be programmed to conduct a triple rinse of the line, take a water sample of a predefined volume, and then purge the line.

The auto sampler/bubbler should be programmed to trigger sample collection based on a minimum flow/water level when water begins to overflow the weir. This can be done by setting a zero-water level at ambient atmospheric pressures and setting the trigger to be the elevation of the top of the weir. Sample bottles should be then loaded into the auto sampler and iced for sample preservation prior to setting the sampler to standby.

Finally, all field meters should be calibrated/checked per manufacturer's instructions for in-situ instructions.

6.2.10.5 Grab Samples

Grab sampling may be required to collect samples for a specific parameter such as oil and grease or bacteria. Such grab samples should be collected during the estimated peak of a storm event in an area with representative flow. Collect water grab samples using a clean high-density polyethylene bottle (or a glass bottle for hydrocarbon analysis). If possible, avoid reusing sample bottles to minimize the risk of contamination. Once bottled, water samples are to be put on ice for rapid cooling to reduce biological activity. See United States Environmental Protection Agency *Industrial Stormwater Monitoring and Sampling Guide* (EPA-832-B-09-003; 2009) for grab sampling procedure.

6.2.11 Field Water Quality Monitoring

Use field meter to measure temperature, pH, electrical conductivity, dissolved oxygen, turbidity and other parameters at selected times during the storm event.

6.2.12 Sample Collection

Multiple trips to collect or retrieve the composite / grab samples may be required to ensure hold times are met (sampling collection times should be calculated based on the final sample of the composite). Discrete samples for the rising, peak, and declining limbs of the hydrograph should be composited together in a clean vessel and homogenized prior to subsampling into containers for sample analysis. Personnel should wear disposable gloves to prevent sample contamination. One subsample should be used to collect in-situ measurements such as temperature, conductivity, pH, and dissolved oxygen.

6.2.13 Laboratory Preparation and Submittal

Transport samples to a safe, dry, and clean area for preparation to ship to a certified contract laboratory for processing. Alternatively subsamples for dissolved species should be filtered using a 0.45-micron filter in the field where possible using a syringe filter to ensure hold times are met for these parameters. Samples requiring acid preservation should then have their pH adjusted to <2 as required.

Prepare Chain of Custody and field sheets for accurate documentation of the collection and processing of samples. Chain of Custody forms must accompany samples to the analytical laboratory as per Environmental Protection Agency (EPA) guidelines. All samples should be transported and stored on ice or with gel-based ice packs to ensure samples stay at our below the 6°C sample preservation requirement.

6.2.13.1 Recommended Constituent Sampling

Common parameters that the certified contract laboratory should test for are listed below with their typical units and reporting limits from the 2015 Surface Water Ambient Monitoring Program (**Error! Reference source not found.**Table 6-4). A prioritized list of pollutants should be developed for each project in the event this is so that in the event that adequate sample volume cannot be collected, the bottles for the highest priority pollutants will be filled.

Table 6-4. Recommended Constituent List

Parameter	Analysis Method	Volume Requirement [a]	Preservation Requirements [b]	Common Units	Target Detection Limit
Conventional					
pH	SM 4500-H+	N/A	N/A	s.u.	N/A
Conductivity	SM 2510	250 mL	Cool, ≤6°C	µS/cm	2.5
Turbidity	EPA 180.1	100 mL	Cool, ≤6°C	NTU	1
Total Suspended Solids (TSS)	SM 2540-B	250 mL	Cool, ≤6°C	mg/L	2.0
Suspended Solids Concentration (SSC)	ASTM D3977	250 mL	Cool, ≤6°C	mg/L	1.0
Total Hardness	SM 2340-B	250 mL	NHO_3 or H_2SO_4 to pH<2	mg/L	1
Bacteria					
Fecal Coliform [c]	SM 9221-E	100 mL	Cool, 10°C; 0.0008% Na_2S2O_3	MPN/100 mL	2
Enterococcus [c]	EPA 9000-1600	100 mL	Cool, 10°C; 0.0008% Na_2S2O_3	Colonies/100 mL	1
Nutrients					
Total Phosphorus	SM 4500 – P E	250 mL	Cool, ≤6°C; H_2SO_4 to pH <2	mg/L	0.5
Total Kjeldahl Nitrogen (TKN)	SM 4500-N	250 mL	Cool, ≤6°C; H_2SO_4 to pH <2	mg/L	0.5
Metals – Total					
Cadmium	EPA 200.8(m)	250 mL	Cool, ≤6°C; HNO_3 to pH <2	µg/L	0.03
Copper	EPA 200.8(m)	250 mL	Cool, ≤6°C; HNO_3 to pH <2	µg/L	0.10
Lead	EPA 200.8(m)	250 mL	Cool, ≤6°C; HNO_3 to pH <2	µg/L	2
Zinc	EPA 200.8(m)	250 mL	Cool, ≤6°C; HNO_3 to pH <2	µg/L	0.70
Metals - Dissolved					
Cadmium	EPA 200.8	250 mL	Cool, ≤6°C; filtration, 0.45µm; HNO_3 to pH <2	µg/L	0.03
Copper	EPA 200.8	250 mL	Cool, ≤6°C; filtration, 0.45µm; HNO_3 to pH <2	µg/L	0.10
Lead	EPA 200.8	250 mL	Cool, ≤6°C; filtration, 0.45µm; HNO_3 to pH <2	µg/L	2
Zinc	EPA 200.8	250 mL	Cool, ≤6°C; filtration, 0.45µm; HNO_3 to pH <2	µg/L	0.70

Parameter	Analysis Method	Volume Requirement [a]	Preservation Requirements [b]	Common Units	Target Detection Limit
			Organics		
Pesticides	EPA 625(m)	1-L (glass)	Cool, ≤6°C	μg/L	0.005 - 0.2
			Hydrocarbons		
Total Petroleum Hydrocarbons (TPH) [c]	EPA 625(m)	1-L (glass)	Cool, ≤6°C; HCL to pH <2	mg/L	0.5
a: Volume requirements may vary depending on specific laboratory used for analysis b: Source- 40 CFR Part 136.3, Table 2 c: Grab sample only					

6.3 SMC CLEAN Standard Data and Information List

The following is the list of data/information that will be requested and compiled for each of the LID projects data/information is being obtained for the SMC CLEAN project. The list comprises monitoring data as well as meta data so that analysis can be performed to answer the proposed SMC CLEAN targeted research questions. Based on coordination with the SWRCB this list may serve as a preliminary list of data-information required to be gathered associated with future LID grant projects.

- Monitoring Data
  - Monitoring protocol
  - Monitoring parameters
  - Research question parameters (common 303-d constituents)
    - Bacteria – Fecal coliform, Enterococci
    - Pesticides
    - Nutrients – TKN, Total Phosphorus
    - Metals – Cadmium, Copper, Zinc, Lead
  - Water chemistry,
    - Total suspended solids / turbidity
    - Field parameters - pH, total hardness, Conductivity
    - TPH
  - Monitoring elements integrated into LID feature.
  - Water quality data – inlet/outlet.
  - Whole-storm water flow data – inlet/outlet.
  - Draw down time/volume.
  - Precipitation data.

- Meta Data
  - Design plans and specifications.
  - As-builts.
  - Design storm, drainage area size, and sizing calculations.
  - Drainage area land uses and percentages.
  - Native soils information (including analysis of all inorganics measured in the water quality protocol), geotechnical report, infiltration tests.
  - Engineered soil matrix information, soil matrix source.
  - Plant information/list, plant source.
  - Mulch information/source.
  - Construction records, contractor information.
  - Maintenance protocols.
  - Maintenance records, maintenance contractor information.
  - Inspection records.
  - Data tracking protocols.
  - Data access information.
  - Data reporting protocols.
  - Other information being collected for each site and why it is being collected.

6.4 Alternative LID GSI Testing

6.4.1 Synthetic Stormwater Testing

LID/GSI effectiveness monitoring has historically been performed during storm events to measure in situ conditions during natural wet weather events. Wet weather monitoring is based on changing weather predictions and occurs in a non-controlled environment, which can result in unexpected field conditions (i.e. large sediment loads, higher or lower than expected flow rates, equipment malfunction, etc.). Wet weather monitoring study results can be uncertain due to poor characterization of discharge into and out of the LID/GSI or due to pollutant sampling issues (Gulliver and Anderson 2008).

Synthetic stormwater can be used in certain situations to simulate stormwater runoff by controlling flow discharge and pollutant concentrations for accurate evaluation of LID/GSI effectiveness. Synthetic runoff consists of potable or deionized water and may contain targeted pollutants at predetermined concentrations or loads. Smaller-scale, lined LID/GSI, such as small biofiltration basins and filtration tree boxes, are ideal for synthetic stormwater testing because smaller volumes are required to simulate a storm event. In larger LID/GSI measures synthetic stormwater testing is less feasible due to the large volumes needed to produce outlet runoff well in excess of LID/GSI retention volume. A higher ratio of outlet runoff to retention volume is required to ensure that biases resulting from small-scale effects such as first flush pollutant release from LID/GSI media is not introduced. needs to be sustainably larger than the retention that could be caused by wash off from the media.

For synthetic runoff testing to be feasible, the following conditions must be met:

1. There must be an available water supply to provide sufficient volume for flow measurement and sample collection at the LID/GSI outlet.
2. All synthetic stormwater effluent must be contained and properly disposed of. The nearest downstream catch basin can be temporarily blocked to prevent synthetic stormwater from reaching the downstream MS4.
3. Flow into the LID/GSI must be able to be measured from one concentrated inlet. The inlet must be accessible for water quality samples and hydraulic flow measurements. Alternatively, for lined or small-scale LID/GSI measures surface water elevations in the LID/GSI can be measured to estimate inlet flow. Infiltration can be assumed to be negligible if the stormwater LID/GSI is filled rapidly with synthetic stormwater and the infiltration rate into the soil media is relatively slow or infiltration below the LID/GSI is blocked by a liner. LID/GSI infiltration testing should be conducted prior to using this method.
4. Flow out of the LID/GSI, other than infiltration, must be able to be measured from one concentrated outlet. The outlet must be accessible for water quality samples and hydraulic flow measurements (Gulliver and Anderson 2008).

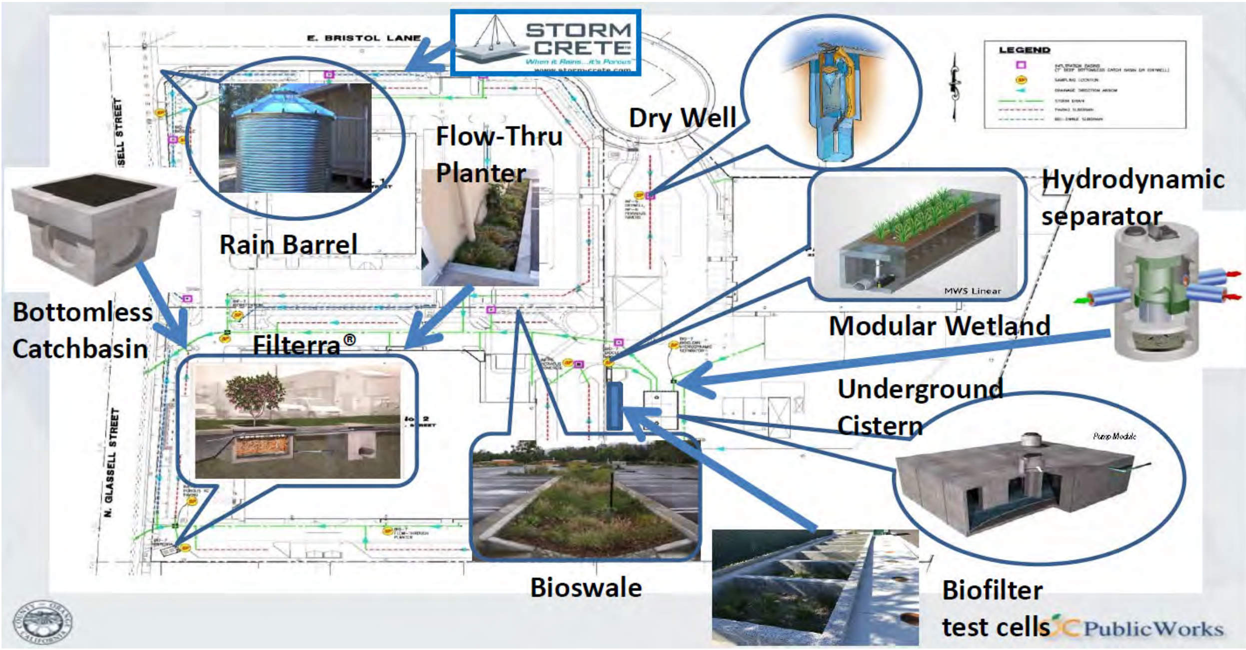
The necessary permits must be obtained and associated regulatory agencies notified prior to performing synthetic stormwater testing. Synthetic stormwater testing is only feasible for small-scale LID/GSI that are small enough to be filled with synthetic stormwater and meet the above qualifications. Gulliver and Anderson (2008) provide information on synthetic stormwater testing and assessing LID/GSI filtration retention times.

6.4.2 Multiple LID/GSI Testing

Conventional monitoring protocols may not be able to be applied to locations with multiple LID/GSI measures that are designed to work in concert. A parking lot with bio-swales and permeable pavement that overflow into a downstream biofiltration basin is an example of a multiple LID/GSI system. The LID/GSI testing facility located in Orange County is a constructed example of multiple LID/GSI measures working in tandem (

Figure 6-2) (Peng 2019). Because the LID/GSI measures now represent an entire system, it is not possible to isolate the separate parts and the LID/GSI are assumed to be working together as one unit.

Figure 6-2 Orange County Public Works Glassell Campus LID Project.



In these situations, a mass-emission cumulative effect approach can be utilized. A mass-emission approach measures pre-construction and post-construction water quality and hydraulic conditions for the entire site rather than the conventional method of monitoring individual LID GSI inflow and outflow. The mass-emission approach would require pre-site or pre-development monitoring to establish baseline conditions before the LID GSI were installed. Pre- and post-development monitoring results are compared to measure site effectiveness. The mass-emission approach measures storm water site characteristics on a larger scale and considers improvements to the entire project site, such as improvement to inflow prior to LID GSI treatment, which may not be captured using only individual LID GSI testing.

6.5 Standard Design and Monitoring Plans

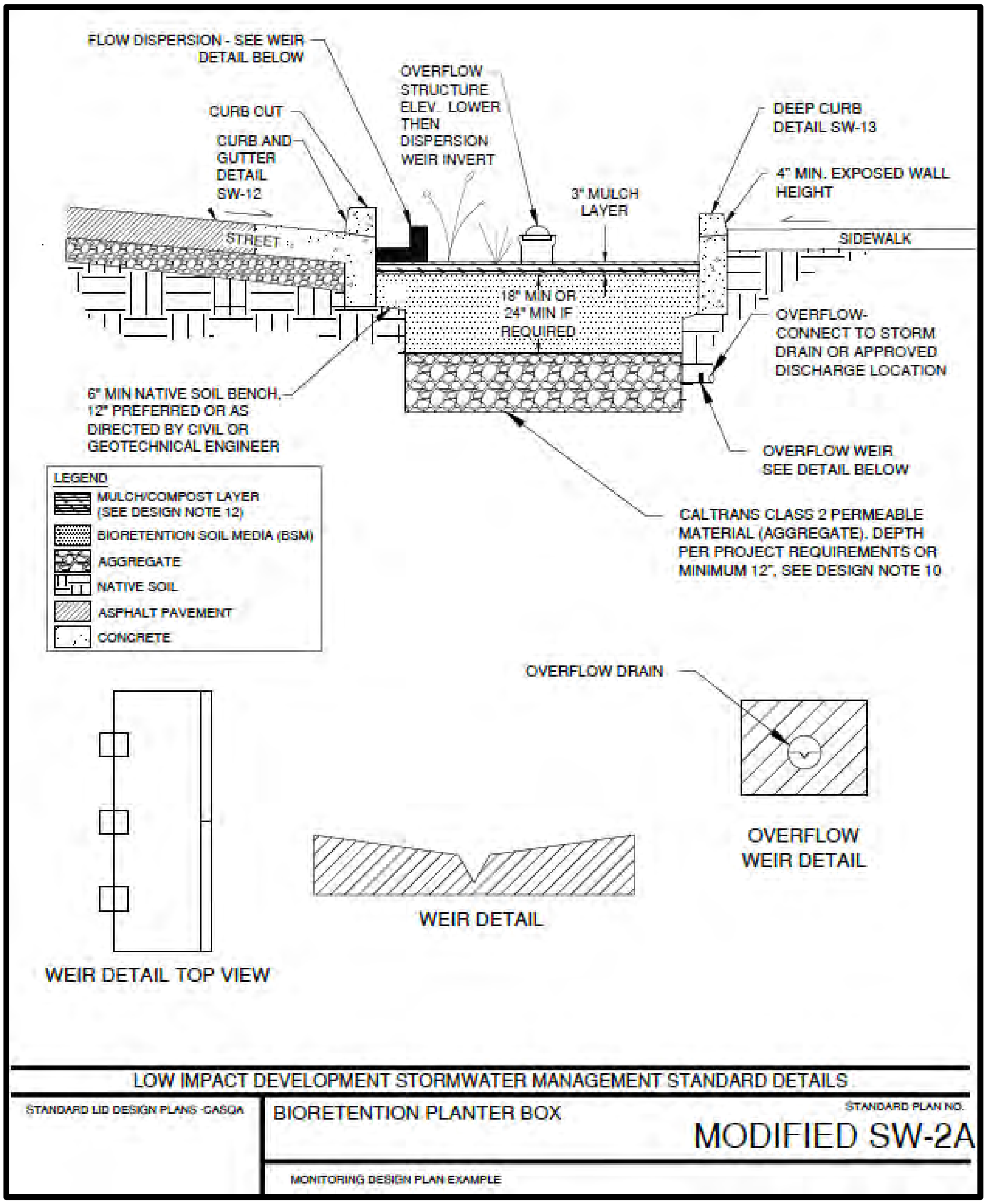
Standard monitoring design plans are outlined below to demonstrate in detail how LID/GSI facilities may be configured to accurately measure flow and to collect representative water quality samples. The design plans below are provided as examples only, LID/GSI facility monitoring plans must be designed based on individual BMP configurations. Examples of LID/GSI facility monitoring procedures are also included to provide additional information on how flow could be measured, and samples collected.

6.5.1 Standard Design Plan 1. Street Biofiltration Planter Box with Underdrain

The following standard design plan example outlines a biofiltration planter box LID/GSI facility with an underdrain in between a sidewalk and street (Figure 6-3). The below design plan was adapted from the CASQA standard design plans as an example (CASQA 2018b). The example biofiltration planter box receives sheet flow from an adjacent street or pavement through curb cut inlets. A large square flow monitoring container is set just inside the biofiltration planter such that the stormwater flow from the street collects in the container and then flows over a triangular, v-notch weir into the biofiltration area. The flow monitoring container must be wide enough to collect all sheet flow into the LID/GSI measure and is expected to span multiple curb cut inlets. The flow monitoring container must be tall and deep enough to allow flow to settle, turbulence to subside, and for flow to steadily overtop the weir. The flow monitoring box dimensions must be sized based on the characteristics of flow to the LID/GSI measure and the size and configuration of the LID/GSI measure. The flow monitoring container is installed only for monitoring purposes and is not part of the LID/GSI measure. Inside the biofiltration area stormwater either infiltrates through the soil media or flows into the overflow structure and out into the MS4 system.

It is assumed for design purposes that stormwater can only flow into the BMP through the curb cuts. It is also assumed that the BMP is contained such that all flow within the BMP either infiltrates into the soil or flows into the overflow structure.

Figure 6-3. Standard Design Plan 1 Biofiltration Planter Box

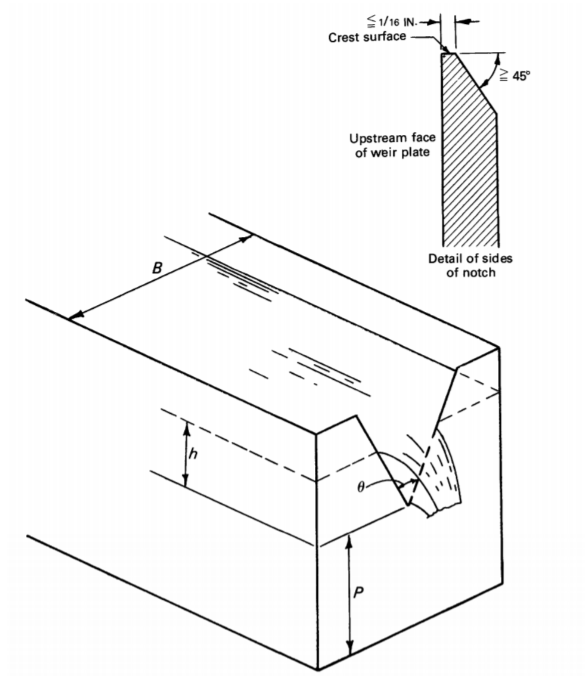


6.5.1.1 Flow measurement

The flow monitoring container would be installed against the curb cuts and sealed. The monitoring container is a temporary installation and is not part of the BMP design. A flow bubbler is installed inside the monitoring box to measure the height of the water as it flows over the weir into the BMP. Weir equations use the area of a known geometric shape to estimate the volume of water traveling over time, which results in a flow rate (

Figure 6-4) (USGS 1981).

Figure 6-4. USGS V-notch weir schematic



The Triangular Weir (V-Notch Weir) equation below can be used to calculate flow in cubic feet per second:

$$\boldsymbol{Q} = \boldsymbol{K_u}\,[\tan\left(\frac{\theta}{2}\right)]H^{2.5}$$

Where: Q = Discharge (m^3/s), θ = Angle of v-notch (degrees), H = head on apex of v-notch (m), K_u = 1.38 (USDOT, 2009).

For flow heights above the capacity of the triangular notch, a modified version of the Triangular Weir equation could be used.

$$\boldsymbol{Q} = \boldsymbol{K_u}\,[\tan\left(\frac{\theta_a}{2}\right)]\,{H_{max}}^{2.5} + \boldsymbol{K_u}\,[\tan\left(\frac{\theta_b}{2}\right)]H^{2.5}$$

Where: Q = Discharge (m^3/s), θ_a = Angle of lower v-notch (degrees), θ_b = Angle of upper v-notch (degrees), H_{max} = height of lower v-notch (m), H = head on apex of upper v-notch (m), K_u = 1.38

To measure output flow from the BMP, the nearest downstream stormwater catch basin would need to be accessed and a weir installed in the underdrain conveyance as it connects to the catch basin. Portable volumetric weirs can be purchased or made by cutting plastic sheeting (such as plastic marine board), as seen in

Figure 6-5 (Michael Baker International, 2018).

Figure 6-5. V-Notch Weir with Sampler and Bubbler Installation in Underdrain

The conveyances would need to be investigated to ensure no additional stormwater connections are contributing to flow at the downstream flow monitoring location. Water quality samples would be collected at the input and output weir locations.

6.5.1.2 Pollutant loading

Calculating pollutant load is a primary objective to determine LID/GSI facility performance. Pollutant load is defined as the mass of a substance that passes a particular point of a LID/GSI measure (for example at the inlet or outlet) in a specified amount of time (e.g., daily, annually). Pollutant load is essentially the product of water discharge and the concentration of a substance in the water (Meals et al. 2013). Pollutant loads can be calculated using the below equation:

$$Load\left(\frac{lbs}{day}\right) = Concentration\ x\ Discharge\ Volume\ x\ Unit\ Conversion\ Factor$$

The pollutant load reduction is calculated using the below equation and is expressed as a percentage. A negative pollutant load percentage indicates a reduction in the effluent sample pollutant load.

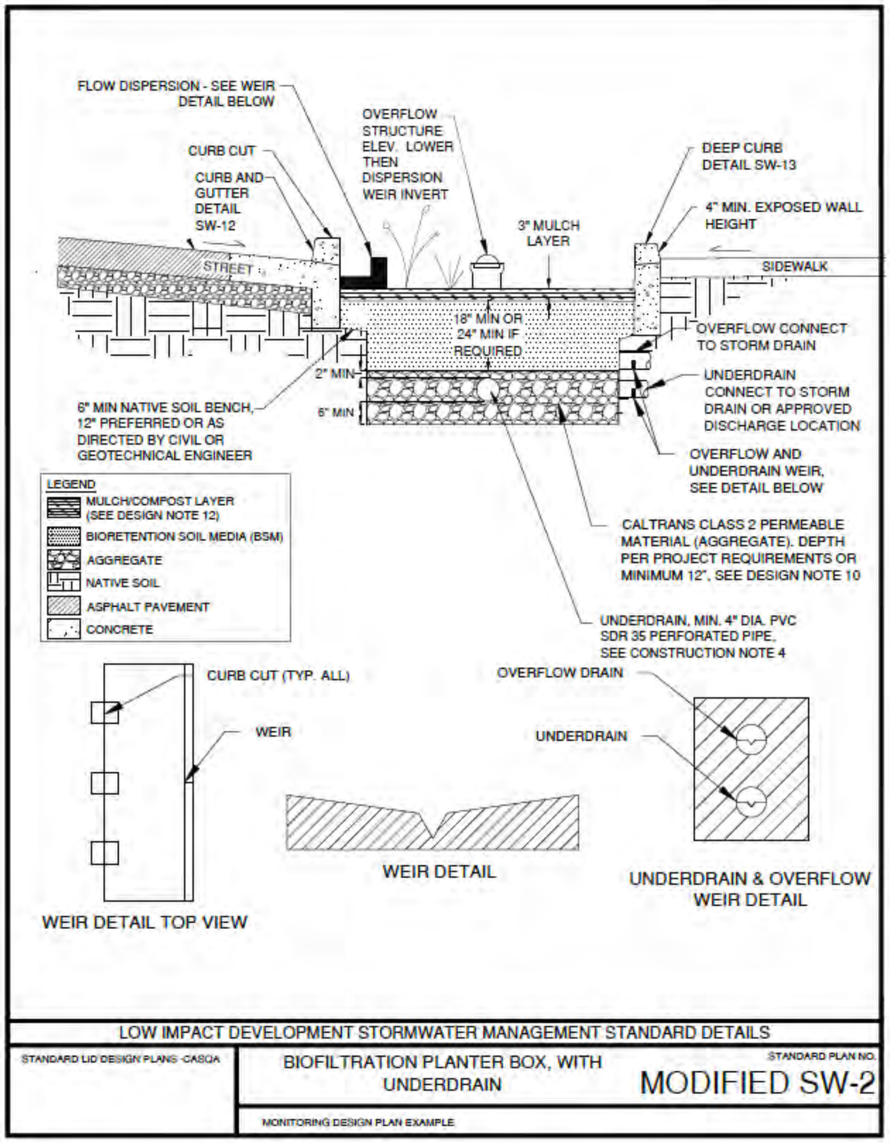
$$Percent\ Load\ Reduction = \frac{(Outlet\ Load - Inlet\ Load)}{Inlet\ Load}\,x\ 100$$

6.5.2 Standard Design Plan 2. Street Biofiltration Planter Box with Underdrain

The following standard design plan example has the same layout as Plan 1, outlined above, with the exception that Plan 2 incorporates an underdrain (

Figure 6-6) (CASQA 2018b). Stormwater infiltrates through the soil media and flows into an underdrain. As water fills the biofiltration planter box, water would overtop the overflow structure and flow into the overflow pipe. A weir and flow meter would be installed in both the underdrain and overflow pipes as described in Design Plan 1 to measure flow into the BMP. This design plan assumes that the underdrain and overflow pipes are separated, and no other pipe junctions contribute flow.

Figure 6-6. Standard Design Plan 2 Biofiltration Planter Box with Underdrain



6.5.3 Weir installation

Successful weir installation depends on several factors. Note that the below weir installation guidelines may need to be modified based on constraints of the LID/GSI measure configuration.

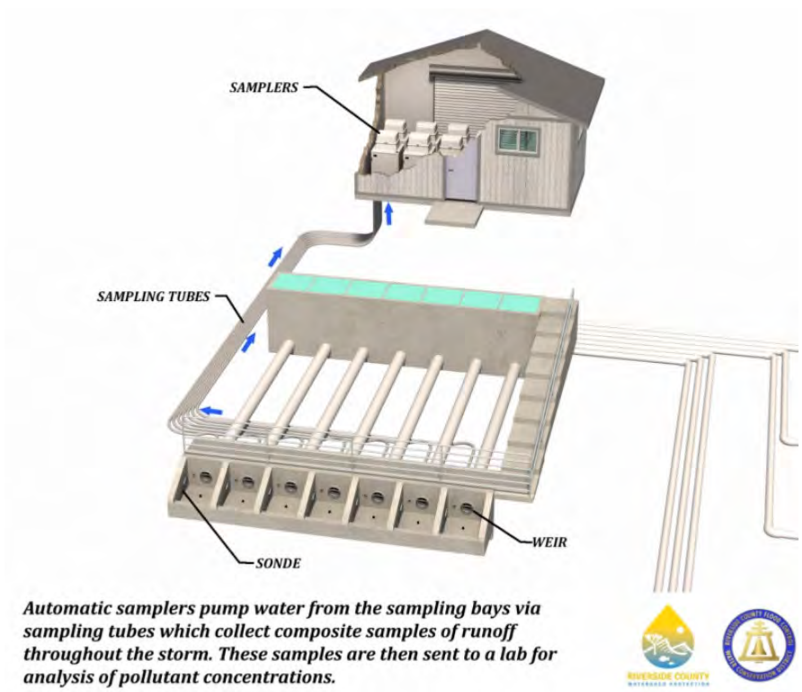
- Approach channel should be straight and of uniform cross-section for a distance of 15 to 20 times the maximum anticipated water depth (head) (h) upstream of the weir.
- The approaching flow should be sub-critical, tranquil, and be uniformly distributed across the width of the channel.
- Center the weir in the flow stream.
- Weirs must be level from front-to-back and from side-to-side. No deviation is allowed.

- Set the lowest point of the crest (the edge of the weir over which flow passes, (P) at least 2-3 times (h) above the channel floor.
- At full flow, the sidewalls on each side of the weir should extend 2- times water depth (h) on either side of the maximum width of the flow over the crest to the channel sidewalls.
- The lowest point of the crest should be at least 2 inches (5 cm) above the downstream water level.
- The point of measurement is 3-4-times water depth (h) upstream of the weir. Any closer and the head reading is affected by drawdown as the flow approaches the weir.
- The zero elevation for the point of measurement is the same elevation as the lowest point of the weir crest – this is the same as the water surface being the weir once flow over the weir has ceased (Open Channel Flow 2018).

6.5.4 Porous Pavement and Pervious Areas

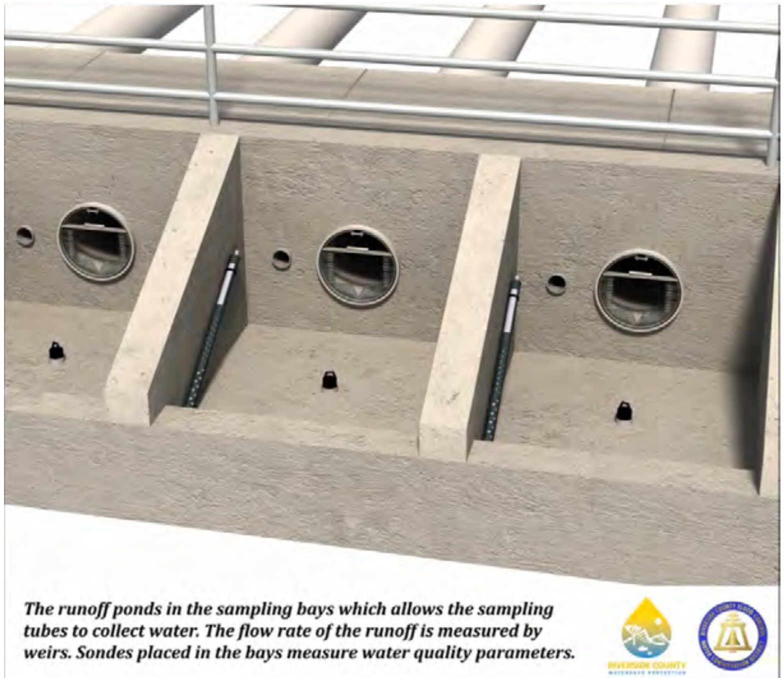
Flow monitoring and sampling for porous pavement and pervious area LID/GSI measures can be difficult to perform due to the large surface area and multiple inflow and outflow points. Riverside County and the Riverside County Flood Control and Water Conservation District (RCFC & WCD) built the Low Impact Development Testing and Demonstration Facility, that is dedicated to the long-term study of LID BMPs. LID planter boxes and multiple types of pervious pavement were installed on-site. Each BMP was built with a separate underdrain and outflow samples are collected from each BMP, as seen in Figure 6-7 below (RCFC & WCD, 2018).

Figure 6-7. Riverside County Low Impact Development Testing and Demonstration Facility Water Quality Sampling Graphic Overview



BMP flow is measured using weirs installed in the downstream conveyances, as seen below (Figure 6-8.) (RCFC & WCD 2018).

Figure 6-8. Riverside County Low Impact Development Testing and Demonstration Facility Flow Monitoring Outlet Weir Graphic



6.6 Other Monitoring Resources

In addition to the SMC CLEAN monitoring protocol there are other monitoring protocols and monitoring resources available including:

- Technology Assessment Protocol - Ecology Protocol: See: http://www.wastormwatercenter.org/tape-program
- San Diego Stormwater BMP Design Manual
  - See: https://fortress.wa.gov/ecy/publications/documents/1810038.pdf.
- Caltrans Stormwater Program: See http://www.dot.ca.gov/env/stormwater/
- Sacramento Stormwater Quality Partnership: See: http://www.beriverfriendly.net/
- International Stormwater BMP Database Monitoring Guidance
  - See: http://www.bmpdatabase.org/Docs/2009%20Stormwater%20BMP%20Monitoring%20Manual.pdf

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Appendix H

SMC LID-GI Long-Term Effectiveness Evaluation Needs - White Paper

Green Infrastructure (GI) & Low Impact Development (LID)

Long-Term Effectiveness Evaluation Needs for the SMC

White Paper

SMC LID Effectiveness Evaluation Background

In 2006 the San Bernardino County Flood Control District, with SMC Member Agencies and the California Stormwater Quality Association (CASQA) as project partners, submitted a State Proposition 40 grant proposal for the LID Guidance and Training Project. The project grant submittal was successful and $600,000 of funding was awarded to complete the following Tasks: 1) Compile and Evaluate Existing Information on LID BMP Effectiveness; 2) Coordinate with other Stakeholders; 3) Conduct Field Monitoring of LID Features; 4) Develop a LID Technical Manual with results of field monitoring. The duration of this initial phase of the project was from 2006 -2010, which culminated with posting of the Southern California LID Manual on the California LID Portal (www.californialid.org) in April of 2010.

In 2011 the SMC developed a revised approach to evaluate LID BMP effectiveness; an approach that includes water quality monitoring of LID features, and extensive coordination and data collection from other LID implementation projects in southern California. In 2011 and 2012 a draft revised Scope of Work was developed. The revised scope included updates to the monitoring and LID BMP effectiveness evaluation tasks for the Project, to coordinate completion of revised Scope tasks, and coordinate with CASQA and stakeholders to update the LID Manual as appropriate, based on effectiveness results and to manage the project progress in coordination with the SMC. From 2013 to 2014, Dr. Matt Yeager, with the assistance from Daniel Apt and Scott Taylor of Michael Baker International, worked with the SMC members to develop a Scope of Work (SOW) for this project, funded from remaining SMC funds allocated to the overall project.

In the development of the Southern California LID Manual and associated tasks and the development of the later SOW to evaluate LID BMP effectiveness the SMC recognized that LID concepts in Southern California are affected by differences associated with Southern California compared to the areas of the east coast where LID had been formulated and different from those areas such as the Pacific Northwest where LID has been successfully implemented. These differences include first and foremost the climate in Southern California as well as the fact that it is not uniform across Southern California. Overall the Mediterranean climate of Southern California is much dryer than other parts of the country where LID and GI have been successfully implemented, however there are many regional differences as the climate in the Southern California coastal plains, mountains, and deserts are very different and affect LID and GI implementation. Additionally, California is being affected by climate change that includes long periods of drought, a change in rainfall patterns with more intense storm events, and recent years of significantly higher rainfall totals well above average. The variability in rainfall with some years being less than the average of 12 inches per year and some years being more than three times the average has a significant affect on how LID and GI is implemented. With this variability in rainfall and changes in how California receives its precipitation (e.g. less snow pack) water supply is a primary concern, that also effects LID and GI. It is these differences, why the effectiveness of LID and GI needs to specifically be evaluated for Southern California and not rely upon effectiveness studies performed in other parts of the country.

SMC CLEAN Phase I (2015-2020)

In August of 2015 the SMC LID BMP Monitoring/Effectiveness project began with a consultant team that included Daniel Apt (project lead), Dr. Matt Yeager, Dr. Michael Trapp, and Scott Taylor. A Technical Advisory Committee (TAC) was formed and one of the first tasks was to brand the project. With input from the TAC the project was branded as the SMC California LID Evaluation and Analysis Network (SMC CLEAN). The tasks of the initial phase of the SMC CLEAN project included the following:

- Task 1 - Form and Coordinate a Project Technical Advisory Committee
- Task 2 - Research Existing Data
- Task 3 - Implement initial monitoring procedures in a beta test phase
- Task 4 - Summarize all monitoring data, make recommendations, and update the LID Manual
- Task 5 - Ongoing Collaboration with Project Partners

With input from the SMC CLEAN TAC the focus of the first phase of the SMC CLEAN project was to evaluate bioretention/biofiltration systems as these are the most common LID BMP being implemented in Southern California. Discussions with the SMC CLEAN Technical Advisory Committee identified two primary needs to be addressed by the project. First, a short term need for a quantification of LID performance in southern California, needed to provide empirical data to calibrate estimates for compliance measures such as the recently developed watershed programs (i.e. EWMPs, WQIPs, etc.) and their associated watershed/water quality models [i.e. Reasonable Assurance Analysis (RAA), Reasonable Assurance Studies (RAS)]. The second is a long term need for a collaboration entity and clearinghouse of LID monitoring data in order to compile enough data to understand the effectiveness of various LID BMPs over time and understand how the differences in design, construction, and maintenance affect their performance. The following mission statement was intended to guide the SMC CLEAN project to address the short- and long-term goals:

> The mission of SMC CLEAN is to develop a thorough understanding of the effectiveness of LID BMPs in California both in the short term for use in calibration of watershed programs and the long term for modification of LID design, construction, and maintenance, through coordination with project partners and others performing LID monitoring and serving as a clearing house for LID monitoring information, developing targeted LID research questions and performing targeted LID monitoring based on these questions, analysis of LID monitoring data, and recommendations for the design, construction, maintenance, and monitoring of LID in updates to the Southern California LID Manual to ensure that LID BMPs are implemented in the most effective manner.

The following are the primary work products to date of the SMC CLEAN Phase I:

1. Work Plan
2. Targeted Research Questions
3. Standard LID Project Data-Information List
4. Monitoring Protocol
5. Updated Southern California LID Manual
6. LID & GSI Construction, Inspection, Maintenance, and Monitoring Guidance Manual

As the first phase of the SMC CLEAN project proceeded it became apparent that obtaining LID monitoring data was challenging as not many LID systems had been monitored in Southern California, and for many of the LID systems that had been monitored the data was not available or accessible. Additionally, it was identified that with the variability of factors that could affect performance of LID and GI systems (e.g. proper design, construction, maintenance) that not only water quality monitoring data was needed but the meta data associated with the design, construction, maintenance, and inspection of LID and GI systems was needed. This lack of both water quality monitoring data and meta data for LID and GI systems made it clear that a comprehensive evaluation of the effectiveness of LID and GI systems in Southern California would not be possible until this data could be collected and tracked for long periods of time to understand the effects of maintenance and other factors, and made accessible so analysis can be performed.

GI & LID Effectiveness Needs for the SMC

A key finding of the SMC CLEAN Phase I and previous LID effectiveness evaluation work performed by the SMC and its partner agencies, is that long-term monitoring and data for LID and GI projects in southern California is essential to truly understand the effectiveness of LID and GI systems in southern California. The primary need is for the collection, tracking, and access to monitoring and meta data (design, construction, maintenance, and inspection information) of LID and GI systems in Southern California to understand the effectiveness of various LID and GI BMPs with different designs and configurations as well as to understand how construction practices and maintenance activities may affect performance and effectiveness. Through collection, tracking, and access to monitoring data an understanding of how best to conduct monitoring of these systems can be obtained. With the collection of LID and GI systems monitoring and meta data analysis of this data can be performed so that design, construction, maintenance, and monitoring recommendations can be made so that LID and GI BMPs are implemented and maintained in the most effective manner.

As implementation of LID and green infrastructure (GI), driven by MS4 Permit and water quality requirements, becomes ever more prevalent, a comprehensive and quantitative understanding of the effectiveness of LID and GI in Southern California becomes more critical. The original emphasis on LID was focused in the Land Development sections of the MS4 Permits where permittees must ensure that new and redevelopment projects implement LID BMPs with sizing requirements designed to comply with volume-based retention standards instead of implementing conventional stormwater quality treatment devices. Most California Phase I MS4 permits now allow or require permittees to develop watershed management plans, which must ensure that discharges will achieve Water Quality Based Effluent Limits and not cause or contribute to exceedances of receiving water limitations. As these plans have been developed, LID in the form of GI has been identified as a significant piece of the compliance schema. In Los Angeles County an analysis of the Watershed Management Plans (WMPs) and Enhanced Watershed Management Plans (EWMPs) developed identified approximately 40% of the BMPs to meet compliance are based on implementation of LID and GI systems. Due to constraints of land availability and the high cost of land acquisition, (GI) is identified in most of these watershed management plans as a primary watershed control measure. As LID and GI becomes more prevalent in the stormwater quality regulatory schema, and serves as a fundamental tool for watershed and receiving water protection, understanding these systems' actual field performance becomes a requirement to demonstrate compliance.

The SMC's work to date shows that a quantitative understanding of the effectiveness of LID and GI systems will require a significant amount of data, much more than currently available. The SMC should take a leading role in evaluating LID and GI effectiveness, especially in southern California, while continuing to coordinate, and expand this coordination, with other organizations (e.g. universities) and initiatives performing monitoring and effectiveness evaluations. Additionally, water quality monitoring data and meta data describing designs, materials, construction procedures, inspections, and maintenance information should be sought from others that are implementing, inspecting, monitoring, and maintaining LID and GI systems in Southern California to enhance the data set and support a more robust performance evaluation of different types of LID and GI systems in Southern California.   As the primary stormwater monitoring organization in southern California, the SMC should actively seek LID/GI monitoring and meta data, and serve as a clearinghouse and coordination network for LID/GI monitoring effectiveness information for Southern California and potentially all of California.   It will also be essential for the SMC to reach out and engage with other initiatives and organizations performing LID/GI monitoring and effectiveness evaluations using field and laboratory approaches, and in other regions, to gain the most comprehensive understanding of these systems.

LID/GI Monitoring Challenges & Solutions

Significant technical challenges must be overcome to collect robust quantitative water quality and hydrologic monitoring data from LID/GI systems. Robust monitoring data requires a strong experimental design and control of experimental conditions. Monitoring design also needs to ensure that data is comparable to other relevant data sets, which can partly overcome by a standard monitoring and sampling protocol. A monitoring plan should also be clear about the purpose and goals of the monitoring as there are many elements of research for LID and GI systems the monitoring plan can go beyond the intended purpose and goals. The use of standard LID and GI monitoring protocols (e.g. SMC CLEAN LID Monitoring protocol) is also acritical element to support the development of LID effectiveness data that can be properly compared.

Storm sampling is already challenging due to storm unpredictability and this is exacerbated by a lack of a consistent sampling protocol. Logistics of storm sampling can also be challenging if multiple sites are being sampled at the same time. Storm sampling can also be dangerous, and safety should always be considered first. The use of a standard protocol will help to reduce these challenges.

Most existing LID and GI BMPs are not designed for water monitoring so hydrologic instrumentation and water quality sample collection approaches typically must be improvised and are specific to each BMP. This poses challenges for the collection of both influent and effluent water quality samples and also being able to obtain flow measurements. Retrofit of existing built LID and GI BMPs to allow for accurate monitoring is in many cases not feasible due to costs. In many cases the configuration of LID and GI BMPs will not allow for monitoring as retrofits for monitoring are not feasible. In such cases complete replacement of the BMP is needed to be able to perform monitoring. These challenges can be overcome by the use of designs that integrate monitoring features and standard designs that integrate monitoring elements. The use of these types of designs should be considered even if monitoring is not considered for the immediate future as, retrofit of BMPs to integrate monitoring elements if needed in the future will always be more expensive. Development and use of standard LID/GI designs with integrated monitoring features (e.g. SMC CLEAN bioretention/biofiltration design with integrated monitoring) can facilitate monitoring by providing access points for flow instrumentation and influent/effluent sample collection.

Infiltration is a key treatment function in LID and GI BMPs however, it is very difficult to sample the water that is actually infiltrated. This presents challenges to truly understand the pollutant removal performance of these systems as well as understanding the actual volumes that are infiltrated. Solutions to this challenge include lining a portion of an infiltration based BMP and include and underdrain, which helps to understand pollutant removal performance. To better understand the volume infiltrated influent and overflow monitoring can be performed. Additionally, lined experimental BMPs with indirect measures of effluent (volume and mass balance combined with influent and overflow monitoring) underdrain sampling, lab-based column testing, and in-situ column testing, can help to address this challenge.

The frequency of storm events in Southern California is another challenge. As identified above the Southern California climate is changing as just in the past decade Southern California has recorded as little as a few inches of annual rainfall as well as annual rainfall over 40 inches. This variability makes it extremely difficult to obtain monitoring data. Part of the solution is a longer time period (e.g. 10 years) for monitoring at LID and GI sites, which reduces the impact of this variability as the variability of a year to another year of the amount of rainfall received at a site is not as impacted as if monitoring only occurred for 2-3 years, where you could have 2-3 dry years in a row.

The variability of where storm events occur with the different climate variability regions (coastal plains, mountains, deserts) in Southern California presents another challenge. For a Southern California monitoring program with this variability, part of the solution is to have redundant sites across the different types of climate regions. This redundancy will help for comparability of data for the different types of climate regions which is also needed.

The variability of different types of climate regions in Southern California also presents a monitoring challenge as the configuration/design of some LID/GI BMPs will need to take into account these factors. These modifications to the configuration/design of LID/GI BMPs need to be considered in the monitoring and analysis of the monitoring data. Part of the solution is the establishment of multiple LID/GI monitoring sites for each of the configuration/design changes to be able to have comparable data.

Monitoring in-situ also poses challenges associated with control of a site and the different unknown factors (e.g. vandalism, dumping, etc.) that could affect the monitoring results. More controlled sites with reduced potential factors that may affect results are needed to help calibrate the various in-situ field monitoring data. Existing monitoring facilities like the Orange County Public Works (OCPW) Glassell

Yard LID retrofit and the Riverside County Flood Control and Water Conservation District (RCFCWCD) campus LID retrofit or other existing facilities or to future facilities that are in a controlled environment can provide data to help calibrate other monitoring sites. Long-term (e.g. 10 years) monitoring of these controlled sites are needed to understand how maintenance affects their performance.

LID/GI Data Interpretation Challenges & Solutions

A significant challenge with interpretation of LID and GI data is an incomplete data set. This can include a lack of hydrologic data due to sampling procedures, lack of instrumentation to collect hydrologic data, or instrument failure. This challenge can helped be overcome by a more controlled BMP testing approach with the construction of LID and GI facilities in contained environments (e.g. municipal yard) and standard BMP monitoring protocols.

Another data interpretation challenge is short-term data sets as it is difficult to quantify or determine trends with typical high data variability for short-term data sets. This can be due to lack of data due to variable climatic conditions in Southern California during short-term monitoring, where not enough storm events occur or storm events that do occur have shorter durations, which are problematic for gathering data. As identified above this challenge can be overcome by a long-term and controlled BMP monitoring program.

The variability in different LID and GI system designs and sizing offers a challenge to have comparable data. Numerous design manuals have been developed in California and even within Southern California there is significant variability in LID and GI designs. Although there have been efforts to develop standard designs applicable across jurisdictions (e.g. CASQA Standard Bioretention Designs) there are still a wide variety in designs for specific LID and GI systems such as bioretention systems. This variety of design configurations for the same LID BMPs poses a significant challenge for LID monitoring, however understanding how these design configurations affect BMP performance will be important moving forward. This challenge can in part be overcome by the development and adoption of standard designs by jurisdictions in Southern California. Monitoring can then focus on systems designed with the standard designs to evaluate performance. Additionally, using standard designs will help to ensure comparability between monitoring data for different specific LID and GI designs (e.g. bioretention/biofiltration systems).

Proper construction of LID designs is also an issue that needs to be considered and use of the construction guidance is critical for proper construction of LID and GI BMPs. The materials used for construction of LID and GI systems and the construction of the LID and GI BMPs is extremely important and has a significant impact on the performance of these systems. The use of poor or substandard materials and/or the inadequate execution of the approved design during construction can dominate the performance trend for these systems. Included is the challenge that the quality of the materials used for construction may not be known or documented. These challenges can be overcome by QA/QC of the materials used for construction LID and GI systems, construction protocols and inspections at specific points of construction, post-construction hydrologic testing for each site, training on all aspects of construction and materials, outreach to materials suppliers, the development of materials testing protocols, and testing and certification of materials.

Maintenance also poses a challenge for LID and GI monitoring but understanding how maintenance of LID and GI BMPs affects performance will be a critical piece to understanding the long-term effectiveness of LID and GI BMPs. We assume that the lack of maintenance in LID and GI systems causes poor BMP performance or failure, but we should understand how does lack of maintenance or inadequate maintenance incrementally affect performance. An understanding of what happens to performance if there is inadequate maintenance, such as if plants die or mulch is not replaced, is needed. This challenge is exacerbated by both a wide range of possible BMP conditions over time, the lack of maintenance documentation, and the lack of a formal maintenance plan for sites. Additionally, some designs can affect the ability of adequate maintenance to be performed. These challenges can be overcome in part by standard designs, materials QA/QC, standard maintenance procedures and protocols, standard maintenance data documentation, inspections, and training.

Long-Term LID/GI Monitoring Study

To have a thorough understanding of the performance of LID and GI BMPs a long-term study of 10 years is needed that will allow monitoring of a substantial amount of storm events and understand how LID and GI systems perform overtime and to understand a variety of factors, such as maintenance, that affect performance. There is a significant need to quantitatively understand the performance of LID and GI systems in Southern California so that specified designs will provide predictable water quality and hydrologic benefits. LID and GI systems are complex, and performance is affected by numerous factors. Performance data for LID and GI systems are difficult to obtain and therefore a long-term and more controlled monitoring approach is required. This need to quantitatively understand the performance of LID and GI systems in Southern California requires significant work in several areas that are in line with the mission of the SMC and SMC CLEAN. Several key elements of this work are briefly described and recommended in the sections below.

Research Focus

An important element of any future work of the SMC focused on effectiveness of LID and GI is to identify what the focus of future research should be. As part of the SMC CLEAN Phase I project the focus was on bioretention and biofiltration as the most common LID and GI BMP implemented in Southern California, however any future SMC work should identify if the scope of LID and GI BMPs should go beyond bioretention/biofiltration to include other LID and GI BMPs and if so, which targeted research questions should be answered for those BMPs. As an example of targeted research questions, the bioretention/biofiltration targeted research questions developed as part of the SMC CLEAN Phase I are provided in Attachment A. The SMC CLEAN Phase I bioretention/biofiltration targeted research questions are still valid and should be part of and be the primary research focus for the future SMC LID & GI effectiveness evaluation. Research being performed by others in California and around the country related to LID and GI should be evaluated to focus the SMC research and monitoring efforts to be able to best answer the existing and any new targeted research questions based on gaps in other research being performed and to best focus the SMC resources.

One potential additional area of focus for future SMC LID & GI effectiveness evaluation is the evaluation of the materials that are used for construction of LID & GI systems. As part of Phase I of the SMC CLEAN a LID & GI BMP materials survey is being completed that is intended to provide input as to the quality and protocols being used for assessment of the quality of the materials used in the construction of bioretention systems in California. The results of this study should be used to formulate a scope for bioretention materials study that may include column testing of the components bioretention soil media (BSM) sourced from suppliers of BSM materials and testing of identified BSM specifications in the state (e.g. BASMAA BSM Specification).

Collaboration & Communication

Collaboration with those entities both within and outside of the SMC member organizations should continue to 1) obtain data and information regarding the monitoring and effectiveness of LID and GI BMPs; 2) continue to engage those that have participated on the SMC CLEAN TAC either to continue the SMC CLEAN TAC or formulate a new TAC and draw on the experience and knowledge of TAC members; 3) pursue opportunities for joint monitoring projects; and 4) pursuit of funding to be able to monitor and evaluate the effectiveness of LID and GI BMPs. Communication should at a minimum take the form of 1) providing updated information on the SMC website about the effectiveness of LID and GI systems and the SMC efforts to evaluate their effectiveness; 2) providing forums or workshops about the effectiveness of LID and GI systems and the results of monitoring projects; and 3) publication of results of SMC efforts regarding LID and GI monitoring and effectiveness evaluations.

LID & GI BMP Data Submittal Tool & Portal

Based on evaluations as part of the SMC CLEAN Phase I project there is a need for the development of a LID & GI BMP Data submittal tool so that there is a central repository for collected LID monitoring and meta data in Southern California so that adequate data analysis can be performed to understand the primary elements that affect performance of LID & GI BMPs in Southern California. The LID & GI BMP Data submittal tool has the potential to have many functional elements, however the intent of the tool is to facilitate better data collection of monitoring and meta data so that more thorough analysis can be performed. A standard set of LID and GI information will need to be evaluated for the portal and the SMC CLEAN Standard LID Project Data-Information List can be used as source to identify the scope of data that the LID & GI BMP Data submittal tool should collect.

The identified standard set of LID and GI information will define the functional elements of the LID & GI BMP Data submittal tool. The functional elements of the portal should be evaluated to include elements that will encourage entities to use the tool and provide the critical monitoring and meta data needed to evaluate the performance of LID & GI BMPs. The LID & GI BMP Data submittal tool should include at a minimum of the following:

1. User friendly web-based data submittal interface that allows for streamlined data upload.
2. Database where LID & GI monitoring and meta data is stored
3. A web-based query tool/interface so that users can query data and information in the tool.
4. A map element to identify the location of LID & GI monitoring projects.
5. A reporting element so that queries and general information about the LID & GI

6. A mobile application that can be used for inspections and monitoring of LID & GI BMPs.
7. Federated data acquisition tool for obtaining data/information from other databases

LID & GI BMP Standards and Specifications

Many of the issues associated with the implementation of LID and GI systems is the variety of different designs for the same LID or GI system that make it difficult for contractors to construct these systems effectively. The SMC should evaluate the potential development of statewide LID & GI BMP standards and specifications for California. This will need to include coordination with the State Water Resources Control Board, CASQA, and others about the need for the development of statewide LID & GI BMP standards and specifications. The CASQA-LIDI standard bioretention plans and specifications, as a comprehensively peer reviewed set of plans and specifications should be considered for statewide LID & GI BMP standards and specifications for bioretention, biofiltration, pervious pavements, and green streets. This efforts should include coordination with ASTM about potential development of LID & GI BMP standards and specifications as part of the Greenbook: Standard Specifications for Public Works Construction. If the results of the evaluation for the development of statewide LID & GI BMP standards and specifications for California are positive an advisory group should be formed for their development.

California LID & GI BMP Testing and Certification Program

Based on input from the SMC CLEAN TAC there is a desire to evaluate the development of a California LID & GI BMP Testing and Certification Program. This effort should evaluate the need among MS4s, developers, regulators, academia, and manufacturers of proprietary LID & GI BMP systems for the development of a California LID & GI BMP Testing and Certification Program. Surveys and outreach should be performed to these groups and others to understand the need to develop a LID & GI testing and certification program in California. If the results of the evaluation is to develop a LID & GI testing and certification program in California an advisory group should be developed.

Monitoring Plan & Monitoring

Based on the results of the research focus described above a monitoring plan and associated QAPP should be developed for the SMC LID & GI long-term study. The monitoring plan should ensure data collection will support effectiveness metrics, including:

1. Water quality
2. Runoff, infiltration, and evaporation volume
3. Runoff timing
4. Design standards
5. Quality of materials and effective construction and installation
6. Ranking of performance from low to high
7. Determine how to integrate the information into the management systems

The monitoring plan should identify the proposed new/continuing monitoring sites, sampling parameters, schedule and budget. Based on the monitoring plan and associated QAPP monitoring of a selected set of LID & GI BMPs should commence. This will include monitoring at the identified sites in the monitoring plan to be accomplished through tasks led by the SMC and through in-kind services and coordination with other projects. The monitoring results should also be linked to any available monitoring data of downstream receiving waters. The monitoring plan should be revaluated every two years and additional monitoring sites should be evaluated.

Data Analysis & Recommendations

The project monitoring data and meta data developed though the future SMC LID & GI monitoring should be analyzed to answer the targeted research questions identified as part of the research focus analysis. Analysis of data should be performed at identified frequencies for the duration of the long-term study but at least 3 times during the 10 year project duration. Based on the data analysis the following recommendations and updates are proposed:

1. Update SMC CLEAN monitoring protocol based on lessons learned
2. Update SMC CLEAN Standard LID Project Data-Information based on lessons learned
3. Make recommendations for update of the LID & GI BMP Data Submittal Tool & Portal
4. Prepare interim project reports at to be identified frequencies
5. Prepare Draft Final Project Report and solicit input from the project TAC
6. Update the SoCal LID Manual based on data analysis
7. Prepare Final Project Report

Schedule

The proposed duration of the SMC Long-Term LID & GI Effectiveness Study is 10 years. Optimally the SMC Long-Term LID & GI Effectiveness Study would start shortly after the conclusion of SMC CLEAN Phase 1 (June 30, 2020).

Attachment A

SMC CLEAN Phase I Targeted Research Questions

SMC CLEAN Phase I Bioretention/Biofiltration Targeted Research Questions

Bioretention/Biofiltration Short-Term Targeted Research Questions

1. What are the pollution removal benefits of bioretention systems in Southern California?
    i. Calculate/characterize the pollutant removal benefits of bioretention systems with underdrains
    ii. Calculate/characterize the pollutant removal benefits of bioretention systems without underdrains.
    iii. If possible, discern whether changes in the bioretention soil matrix (BSM) being implemented in Southern California affects performance across pollutants.
2. What are the hydrologic benefits of bioretention systems in Southern California?
    i. Calculate/characterize the volume reduction of bioretention systems with and without underdrains with various site soil types.
    ii. Calculate/characterize the flow duration effects of bioretention systems.
    iii. Compare/evaluate the measured hydrologic benefits (volume and flow attenuation) with bioretention system design parameters.

Bioretention/Biofiltration Long-Term Targeted Research Questions

1. How do specific bioretention designs/configurations affect pollutant removal and hydrologic performance?
    i. What are the most common bioretention designs/configurations (isolate soil depth, aggregate depth, and underdrain configuration as the differentiating factors) being implemented in Southern California (identify maximum 3 configurations)?
2. How do different bioretention plants affect pollutant removal and hydrologic performance?
    i. How do systems with and without plants affect pollutant removal and hydrologic performance?
    ii. What are the effects of different plants as identified in studies by others?
3. How does maintenance for bioretention systems affect pollutant removal and hydrologic performance?
    i. What is the frequency of monitoring for an individual LID BMP that would need to be performed to identify the pollutant removal and hydrologic performance effects of maintenance of an individual LID BMP?
    ii. What type of maintenance records are needed to identify the pollutant removal and hydrologic performance effects of maintenance of an individual LID BMP?
    iii. Can preliminary conclusions be drawn regarding pollutant removal and hydrologic performance effects of maintenance with information currently being collected and if so, what are they?
4. What kind of impacts are evident from improper construction of bioretention systems and how are these impacts affecting pollutant removal and hydrologic performance?
    i. What are the typical construction errors that are seen with bioretention systems?

ii. What are the qualitative impacts affecting pollutant removal and hydrologic performance of the typical construction errors that are seen with bioretention systems?

5. What Southern California specific factors (i.e. climate) effect affect pollutant removal and hydrologic performance in comparison to bioretention data from project partners outside of Southern California?
   i. What are the translators for Southern California of performance from bioretention studies performed elsewhere?
   ii. How do bioretention design parameters (soil depth, aggregate depth, and underdrain configuration) affect the translators?

Appendix I

SMC CLEAN Long-Term Study (Phase 2) Scope of Work

Long-Term SMC CLEAN Study

Scope of Work

Project Background

In 2006 the San Bernardino County Flood Control District, with SMC Member Agencies and the California Stormwater Quality Association (CASQA) as project partners, submitted a State Proposition 40 grant proposal for the LID Guidance and Training Project. The project grant submittal was successful and $600,000 of funding was awarded to complete the following Tasks: 1) Compile and Evaluate Existing Information on LID BMP Effectiveness; 2) Coordinate with other Stakeholders; 3) Conduct Field Monitoring of LID Features; 4) Develop an LID Technical Manual with results of field monitoring. A technical advisory committee (TAC) was formed to guide the LID Project, which included representatives from the six coastal southern California Counties, the Santa Ana and Los Angeles Regional Water Boards, the development community, and other stakeholders. The TAC met over half a dozen times and provided significant comment on the development of the Southern California LID Manual. The duration of this initial phase of the project was from 2006 -2010, which culminated with posting of the Southern California LID Manual on the California LID Portal (www.californialid.org) in April of 2010.

In 2011 the SMC developed a revised approach to evaluate LID BMP effectiveness; an approach that includes water quality monitoring, and extensive coordination and data collection from other LID implementation projects in southern California. In 2011 and 2012 a draft revised Scope of Work was developed. The revised scope included updates to the monitoring and LID BMP effectiveness evaluation tasks for the Project, to coordinate completion of revised Scope tasks, and coordinate with CASQA and stakeholders to update the LID Manual as appropriate, based on effectiveness results and to manage the project progress in coordination with the SMC.

From 2013 to 2014, Dr. Matt Yeager, with the assistance from Daniel Apt and Scott Taylor of Michael Baker International, worked with the SMC members to develop a Scope of Work (SOW) for this project, funded from remaining SMC funds allocated to the overall project. This project was discussed at length at SMC quarterly meetings, progressing from a project outline, to a draft SOW, to a final SOW which was reviewed and approved by the SMC in the fall of 2014. To support development of the SOW, a questionnaire was distributed to the SMC members and Municipal Separate Storm Sewer System (MS4) permittees to determine if local jurisdictions required effectiveness monitoring for LID BMP installations. Very few jurisdictions were found to require monitoring for LID BMPs and such monitoring was mostly limited to grant funded LID projects. Therefore, a key feature of this project is the development of a standard methodology for monitoring LID BMPs, so future monitoring data will be more comparable.

SMC CLEAN Phase I

In August of 2015 the SMC LID BMP Monitoring/Effectiveness project began with a consultant team that included Daniel Apt (project lead), Dr. Matt Yeager, Dr. Michael Trapp, and Scott Taylor. A Technical Advisory Committee (TAC) was formed and one of the first tasks was to brand the project. With input from the TAC the project was branded as the SMC California LID Evaluation and Analysis Network (SMC CLEAN). The tasks of the initial phase of the SMC CLEAN project included the following:

- Task 1 - Form and Coordinate a Project Technical Advisory Committee
- Task 2 - Research Existing Data
- Task 3 - Implement initial monitoring procedures in a beta test phase
- Task 4 - Summarize all monitoring data, make recommendations, and update the LID Manual
- Task 5 - Ongoing Collaboration with Project Partners

As the first phase of the SMC CLEAN project proceeded it became apparent that obtaining LID monitoring data was challenging as not many LID systems had been monitored in Southern California and for many of the LID systems that had been monitored the data was not available. With input from the SMC CLEAN TAC the focus of the first phase of the SMC CLEAN project was to evaluate bioretention/biofiltration systems as the most common LID BMP being implemented in Southern California.

SMC CLEAN Mission

Discussions with the SMC CLEAN Technical Advisory Committee identified two primary needs associated with the project. The first is a short term need for a quantification of LID performance in Southern California, needed for use in providing empirical data to calibrate estimates for compliance measures such as the recently developed watershed programs (i.e. EWMPs, WQIPs, etc.) and their associated watershed/water quality models (i.e. RAA, RAS). The second is more of a long term need to serve as collaboration entity and clearinghouse of LID monitoring data in order to obtain enough data to understand the effectiveness of various LID BMPs overtime and understand how the differences in design, construction, and maintenance affect their performance. The following mission statement was intended to guide the SMC CLEAN project to address the short and long-term goals:

> The mission of SMC CLEAN is to develop a thorough understanding of the effectiveness of LID BMPs in California both in the short term for use in calibration of watershed programs and the long term for modification of LID design, construction, and maintenance, through coordination with project partners and others performing LID monitoring and serving as a clearing house for LID monitoring information, developing targeted LID research questions and performing targeted LID monitoring based on these questions, analysis of LID monitoring data, and recommendations for the design, construction, maintenance, and monitoring of LID in updates to the Southern California LID Manual to ensure that LID BMPs are implemented in the most effective manner.

The mission statement above was integrated into an SMC CLEAN Work Plan for the first phase of the SMC CLEAN Project which included goals and objectives associated with each goal. The following are the deliverables of the SMC CLEAN Phase I project:

- Scope of Long Term SMC CLEAN Study
    - Future Data Needs, Scope, Subsequent phases of SMC CLEAN
    - LID BMP Data Submittal Tool standard info & scope
- SMC LID Manual Updates
    - Main Body Updates

    - So Cal SMC LID Construction, Monitoring, & Maintenance Manual
        - SMC CLEAN monitoring protocol
        - SMC CLEAN Standard Data and information list
        - Standard data collection methods (similar to Regional Monitoring Program)
        - Standard design plans with WQ monitoring (bioretention & porous pavement) using CASQA standard plan set
        - Inspection guidance, protocols, checklists
        - LID Maintenance guidance & protocols
        - LID Construction guidance & protocols
- SMC CLEAN Project Report
    - Data evaluation and analysis (results of performance monitoring)
    - Comparison to data outside of California
    - Lessons learned (data collection, stakeholder collaboration, monitoring)
    - Reference and summary of the So Cal SMC LID Construction, Monitoring & Maintenance Manual & Main SMC LID Manual updates
    - Long Term SMC CLEAN Scope

SMC CLEAN Long-Term Study (Phase 2) Project Overview

SMC CLEAN is designed to: understand the effectiveness of LID BMPs through the development of specific LID research questions; research existing LID monitoring data; coordinate ongoing LID monitoring; implement LID monitoring through the standard methodology and monitoring protocol developed; compile and analyze LID monitoring data; and develop recommendations and provide additional updates of the Southern California LID Manual. The primary purpose of SMC CLEAN is to understand the effectiveness of various LID BMPs with different designs and configurations so that design, construction, maintenance, and monitoring recommendations can be made in an updated LID Manual to ensure that LID BMPs are implemented in the most effective manner.

As LID and green infrastructure (GI) become ever more prevalent a comprehensive and quantitative understanding of the effectiveness of LID and GI becomes more important. The original emphasis on LID was focused in the Land Development sections of the MS4 Permits where permittees must ensure that new and redevelopment projects implement LID to comply with volume-based retention standards instead of implementing conventional stormwater quality treatment devices. MS4 permits now allow permittees to develop watershed management plans which must ensure that discharges will achieve Water Quality Based Effluent Limits and not cause or contribute to exceedances of receiving water limitations. As these plans have been developed, LID in the form of GI has been identified as a significant piece of the compliance schema. Due to constraints of land availability and the high cost of land acquisition, (GI) is identified in most of the watershed management plans as a primary watershed control measure. As LID and GI have become more prevalent in the stormwater quality regulatory schema, and serve as a fundamental tool for watershed and receiving water protection, understanding their true effectiveness becomes ever more relevant.

A main goal of SMC CLEAN is to coordinate with others evaluating the effectiveness of LID and those performing LID monitoring. The long-term SMC CLEAN study will coordinate with partners to research and evaluate LID monitoring data. The types of LID BMPs to be evaluated and monitored will be identified. SMC CLEAN will perform analysis of this data and the aim is that the project will eventually serve as a clearinghouse and coordination network for LID monitoring effectiveness information for California.

There are however many challenges with LID monitoring and understanding the true effectiveness of LID BMPs. Many LID features were not designed to be monitored and so accurately obtaining data and understanding the effectiveness of the LID BMPs can be challenging. Use of the SMC CLEAN bioretention/biofiltration design with integrated monitoring and the development of other improved standard LID BMP designs are needed that facilitate monitoring by incorporating features that provide access for flow instrumentation and influent/effluent sample collection. Use of the SMC CLEAN LID Monitoring protocol will support the development of LID effectiveness data that can be properly compared. The variety of design configurations for the same LID BMPs also poses a challenge for LID monitoring, however understanding how these design configurations affect BMP performance will be critical moving forward. Proper construction of LID designs is also an issue that needs to be considered and use of the SMC LID construction guidance is critical for proper construction of LID BMPs. Finally, maintenance and its inconsistent implementation also poses a challenge for LID monitoring but understanding how maintenance of LID BMPs affects performance will be a critical piece to understanding the effectiveness of LID BMPs. Use of the SMC LID maintenance guidance will help to see better performance of LID BMPs.

The following tasks have been developed to accomplish the primary purpose of the SMC CLEAN Long-Term Study of understanding of the effectiveness of LID BMPs. To have a thorough understanding of the performance of LID BMPs a long-term study is needed that will allow monitoring of a substantial amount of storm events and understand how LID systems perform overtime and an understanding of a variety of elements, such as maintenance, affect performance. The tasks also consider that there is a significant amount of knowledge and experience in California regarding LID, that there are many partners evaluating the effectiveness of LID, that there is a significant amount of existing LID data available, as well as the LID monitoring challenges and needs as identified above.

Task 1 – SMC CLEAN Collaboration Efforts - Technical Advisory Committee, Work Plan, Website, Collaboration with Project Partners, and Funding Pursuits

The current SMC CLEAN Technical Advisory Committee will continue to serve and there will be an evaluation of the addition of new SMC CLEAN TAC members. The consultant team will propose a list of potential additional TAC Members to the SMC CLEAN TAC for consideration. The consultant team will coordinate and facilitate all SMC CLEAN TAC meetings. The consultant will develop an SMC CLEAN Long-Term Study work plan and schedule within 60 days of contracting with the consultant team. The schedule will be based on the tentative timeframe of the SMC CLEAN Long-Term Study of 10 years, which is based on discussions with the current SMC CLEAN TAC, data evaluations identifying a long-term study of 10 years is needed to isolate factors such as maintenance to understand the performance of LID BMPs. The consultant team will use the SMC CLEAN Phase I Work Plan in development of the SMC

CLEAN Long-Term Study work plan. Revisions to the work plan will be made based on input form the SMC CLEAN TAC. The Work Plan will be updated every 2 years based on information developed and coordination with project partners as well as input form the SMC CLEAN TAC.

This task will also include ongoing updates to the SMC CLEAN website that will include both public and private accessible webpages for ease of distribution of draft products to the SMC CLEAN TAC and others. The consulting team will provide ongoing updates to the SMC at each of the SMC Steering Committee meetings for the duration of the SMC CLEAN Long-Term Study. The SMC CLEAN TAC's responsibility is to review and comment on draft consulting team products and provide input during SMC CLEAN TAC meetings.

A key component of the SMC CLEAN is coordination and collaboration with project partners about ongoing LID monitoring and evaluations of LID systems. This task also includes coordination and collaboration with project partners. This includes SMC municipalities performing LID monitoring and/or evaluations including but not limited to:

1. OCPW Glassell Yard
2. RCFCWCD Campus
3. County of San Diego
4. County of Los Angeles
5. City of Los Angeles – Green Streets
6. Others

Understanding what LID research the academic community is engaged in is critical to best use of the SMC resources for the SMC CLEAN Long-Term Study. The consultant team will coordinate with university project partners and identify opportunities for long-term collaboration with university project partners. Potential universities to partner with:

1. UC Irvine
2. UCCE – Irvine
3. UCLA
4. UCSD Scripps
5. UC MRPI Grant
6. LMU
7. Others

Additionally, there are other organizations and initiatives that are engaged in LID monitoring, research, and management that will be important for the consulting team to coordinate and collaborate with including:

1. SWRCB – LID/GI Data Standards Initiative
2. SCCWRP
3. Council for Watershed Health
4. Others

Additionally, as part of this task funding opportunities will be evaluated to leverage the funds dedicated by the SMC toward the SMC CLEAN project. This will include evaluation of grant opportunities including state and federal grants non-traditional sources of funding from the multiple benefits that LID and green infrastructure may provide, as well as funding opportunities from private environmental foundations. The SMC CLEAN project will also evaluate opportunities to jointly pursue funding with its project partners and collaborate on what funding project partners may be able to bring to the SMC CLEAN.

Task 2 – Research Focus & Research of Data and Information

An important element of the SMC CLEAN Long-Term Study is to identify what the focus of the research will be. As part of the SMC CLEAN Phase I project the focus was on bioretention and biofiltration as the most common LID BMP implemented in Southern California. The consultant team will continue this focus and will also evaluate adding other LID BMPs. The consulting team will evaluate and update and then implement the bioretention/biofiltration targeted research questions to understand bioretention/biofiltration BMP performance over time. The following are the bioretention/biofiltration targeted research questions developed as part of the SMC CLEAN Phase I project that will be evaluated by the consulting team:

<u>Bioretention/Biofiltration Short-Term Targeted Research Questions</u>

1. What are the pollution removal benefits of bioretention systems in Southern California?
   i. Calculate/characterize the pollutant removal benefits of bioretention systems with underdrains
   ii. Calculate/characterize the pollutant removal benefits of bioretention systems without underdrains.
   iii. If possible, discern whether changes in the bioretention soil matrix (BSM) being implemented in Southern California affects performance across pollutants.
2. What are the hydrologic benefits of bioretention systems in Southern California?
   i. Calculate/characterize the volume reduction of bioretention systems with underdrains.
   ii. Calculate/characterize the flow duration effects of bioretention systems.
   iii. Compare/evaluate the measured hydrologic benefits (volume and flow attenuation) with bioretention system design parameters.

<u>Bioretention/Biofiltration Long-Term Targeted Research Questions</u>

1. How do specific bioretention designs/configurations affect pollutant removal and hydrologic performance?
   i. What are the most common bioretention designs/configurations (isolate soil depth, aggregate depth, and underdrain configuration as the differentiating factors) being implemented in Southern California (identify maximum 3 configurations)?
2. How do different bioretention plants affect pollutant removal and hydrologic performance?
   i. How do systems with and without plants affect pollutant removal and hydrologic performance?
   ii. What are the effects of different plants as identified in studies by others?
3. How does maintenance for bioretention systems affect pollutant removal and hydrologic performance?
   i. What is the frequency of monitoring for an individual LID BMP that would need to be performed to identify the pollutant removal and hydrologic performance effects of maintenance of an individual LID BMP?
   ii. What type of maintenance records are needed to identify the pollutant removal and hydrologic performance effects of maintenance of an individual LID BMP?

    iii. Can preliminary conclusions be drawn regarding pollutant removal and hydrologic performance effects of maintenance with information currently being collected and if so what are they?
4. What kind of impacts are evident from improper construction of bioretention systems and how are these impacts affecting pollutant removal and hydrologic performance?
    i. What are the typical construction errors that are seen with bioretention systems?
    ii. What are the qualitative impacts affecting pollutant removal and hydrologic performance of the typical construction errors that are seen with bioretention systems?
5. What Southern California specific factors (i.e. climate) effect affect pollutant removal and hydrologic performance in comparison to bioretention data from project partners outside of Southern California?
    i. What are the translators for Southern California of performance from bioretention studies performed elsewhere?
    ii. How do bioretention design parameters (soil depth, aggregate depth, and underdrain configuration) affect the translators?

The consulting team will evaluate and expand on the targeted research questions regarding LID BMP performance over time to include other LID BMPs than bioretention/biofiltration. The consulting team will develop a list of commonly implemented LID BMPs in Southern California and develop a short list of LID BMPs for monitoring and evaluation and will present this list to the SMC CLEAN TAC for input. A final list of LID BMPs and associated targeted research questions for these BMPs will be developed. The Consulting team will also evaluate other relevant LID BMP monitoring work, including their:

1. Objectives
2. Data
3. Findings—analysis—recommendation

A significant element of this task is the compilation of existing LID BMP performance data and information. The consulting team will perform the following subtasks to compile existing LID BMP performance data and information:

1. Query SMC jurisdictions regarding their LID BMP approval process, inspection requirements, tracking requirements, and any ongoing monitoring at individual sites.
2. Evaluate the international BMP database, and coordinate with SMC members, CASQA membership, and Caltrans to identify other California LID BMP sites with monitoring data.
3. Summarize approaches and evaluate their strengths and weaknesses with respect to
    i. Management questions
    ii. Data collected
    iii. Duration of study

Analysis of the compiled data by the consultant will include the following elements:

1. Characterize and quantify water quality benefits to the extent possible
2. Evaluate LID BMP performance over time

3. Evaluate the role of maintenance in LID BMP performance and monitoring
4. Evaluate LID BMP designs for inclusion of monitoring and maintenance features
5. Evaluate the current data set based on the SMC CLEAN Standard LID Project Data-Information List
    a. Evaluate the quality of the current data set
    b. Identify data gaps

Task 3 – LID BMP Data Submittal Tool & Portal

Based on evaluations as part of the SMC CLEAN Phase I project there is a need for the development of an LID BMP Data submittal tool so that there is a central repository for collected LID monitoring and meta data so that adequate data analysis can be performed to understand the primary elements that affect performance of LID BMPs. The LID BMP Data submittal tool has the potential to have a many functional elements, however the intent of the tool is to facilitate better data collection of monitoring and meta data so that more thorough analysis can be performed. The consultant team will evaluate and update SMC CLEAN Standard LID Project Data-Information List as a first step to identify the scope of data that the LID BMP Data submittal tool will collect.

Based on the updated SMC CLEAN Standard LID Project Data-Information List the consultant team will define the functional elements of the LID BMP Data submittal tool. In consideration of the functional elements the consultant should evaluate those functional elements that will encourage entities to use the tool and provide the critical monitoring and meta data needed to evaluate the performance of LID BMPs. The LID BMP Data submittal tool will include at a minimum of the following:

1. User friendly web-based data submittal interface that allows for streamlined data upload.
2. Database where LID monitoring and meta data is stored
3. A web-based query tool/interface so that users can query data and information in the tool.
4. A map element to identify the location of LID monitoring projects.
5. A reporting element so that queries and general information about the LID monitoring projects and query results can be reported.

Optional functional elements of the tool include:

1. A mobile application that can be used for inspections and monitoring of LID BMPs.
2. Federated data acquisition tool for obtaining data/information from other databases

Task 4 – Monitoring Plan, QAPP, Project Monitoring

Based on the data analysis performed in Task 3 the consulting team will develop an SMC CLEAN Long-Term Study Monitoring Plan and associated QAPP. The monitoring plan to be developed will be developed to ensure data collection will support effectiveness metrics, including:

1. Water quality
2. Runoff, infiltration, and evaporation volume
3. Runoff timing
4. Design standards
5. Quality of materials and effective construction and installation
6. Ranking of performance from low to high
7. Determine how to integrate the information into the management systems

The monitoring plan will identify proposed new/continuing monitoring sites, sampling parameters, schedule and budget of the proposed SMC CLEAN Long-Term Study monitoring. The SMC CLEAN Long-Term Study Monitoring Plan and associated QAPP will be provided to the SMC CLEAN TAC for review, discussion, approval.

Based on the approved SMC CLEAN Long-Term Study Monitoring Plan and associated QAPP monitoring of a selected set of LID BMPs will commence. This will include monitoring at the identified sites in the monitoring plan to be accomplished through tasks led by the SMC CLEAN and through in-kind services and coordination with other projects. The monitoring results will also be linked to any available monitoring data of downstream receiving waters. The monitoring plan will be revaluated every two years and additional monitoring sites may be added. As part of the re-evaluation the schedule and budget and input and approval from TAC for any proposed changes in the monitoring plan will be sought.

Task 5 – Data Analysis & Recommendations

The project monitoring data and meta data will be analyzed to answer targeted research questions. Analysis of data will be performed at to be identified frequencies but at least 3 times during the 10 year project duration. Based on the data analysis the following recommendations and updates will be made:

1. Update SMC CLEAN monitoring protocol based on lessons learned
2. Update SMC CLEAN Standard LID Project Data-Information based on lessons learned
3. Make recommendations for update of the LID BMP Data Submittal Tool & Portal
4. Prepare interim project reports at to be identified frequencies
5. Prepare Draft Final Project Report and solicit input from the TAC
6. Update the SoCal LID Manual based on data analysis
7. Prepare Final Project Report