

Low Impact Development Manual for Southern California:

Technical Guidance and Site Planning Strategies

Prepared for

the Southern California Stormwater Monitoring Coalition

in cooperation with the State Water Resources Control Board

By

The Low Impact Development Center Inc


April 2010

Prepared for the Southern California Stormwater Monitoring Coalition, in cooperation with the State Water Resources Control Board, by the Low Impact Development Center, Inc.

Funding for this project has been provided in full or in part through an agreement with the State Water Resources Control Board. The contents of this document do not necessarily reflect the views and policies of the State Water Resources Control Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. (Gov. Code 7550, 40 CFR 31.20)

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Executive Summary

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 alluvial channels. Two-thirds of urban streams have excessive nutrient pollution, and fecal coliform bacteria in these streams commonly exceed standards for water recreation (USGS, 2008). Water pollution not only impacts the beneficial uses of our receiving waters (e.g. aquatic life, recreation), but also represents a significant cost to cities as they strive to comply with increasingly stringent state and federal water quality regulations. The Southern California region, under the jurisdiction of three California Regional Water Quality Control Boards (RWQCBs), is faced with rapid population growth and continuous budget constraints. The region will meet the challenge of improving receiving water quality by incorporating low impact development (LID) stormwater techniques.

Stormwater is increasingly being managed through the strategies and principles of Low Impact Development, which is defined as an ecosystem-based approach to designing a built environment that remains a functioning part of an ecosystem rather than existing apart from it. 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 (California Department of Water Resources, 2009). LID for new development may only reduce the rate of increase of water quality degradation. Incorporating LID in redevelopment, where feasible, can replicate and enhance a site's hydrologic function, though it should be noted that creating a built environment that is a functioning part of an ecosystem in developed areas where water quality is already degraded may take extensive redevelopment and long periods of time, perhaps 50 to 100 years, before any benefits to water quality may be observed.

The purpose of this LID Manual is to serve as a resource that can be used to guide communities 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. It is intended to complement evolving local stormwater management requirements driven by the adoption of new municipal separate storm sewer system (MS4) permits under the Clean Water Act. New MS4 permits are increasingly requiring the adoption of LID techniques to minimize increases in runoff volume and peak discharge rates resulting from land development. Local permits are discussed in Appendix B.

Hydromodification has been identified as a leading source of water quality impairment in the United States (EPA, 2004). Hydrologic modifications change a site's runoff and 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 certain 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.

How to Use This Manual

This manual provides site planning and design guidance, but given the varying site conditions and regulations throughout the region it is not practical to provide suggestions and guidance for every possible situation. The recommendations in this manual are not intended to supersede any local regulations. The manual consists of concepts and techniques presented 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 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 building.
- **Step 3: Implement LID Principles**
  Presents site planning strategies to minimize the generation of stormwater runoff.
- **Step 4: Use LID BMPs to Mitigate Impacts**
  Discusses the selection and application of LID BMPs mitigate unavoidable stormwater runoff.
- **Step 5: Evaluate Design**
  Identifies methods for assessing the successful application of LID to a given site. Discusses the use of a number of modeling methods to evaluate LID designs.

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

Appendix A: 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, LEED, and the Sustainable Sites Initiative
Details how LID can be used to achieve LEED or Sustainable Sites Initiative Certification.

Section 1: The Impacts of Development and How LID Can Help

There are many potential benefits associated with the use of Low Impact Development (LID) practices. In addition to stormwater management, LID implementation can result in environmental, economic, and community benefits.

Potential Environmental Benefits

- Improved water quality
- Maintenance of predevelopment runoff volume
- Maintenance of predevelopment runoff discharge rate
- Groundwater recharge
- Terrestrial and aquatic habitat preservation
- Reduced potable water and energy demand
- Improved air quality
- Carbon sequestration
- 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)
- Improved marketability
- Energy cost reduction and water conservation

Potential Community Benefits

- Improved aesthetic value
- Provides “green job” opportunities
- Educational opportunities
- Health benefits

The primary factor to be considered 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 results in a high degree of regional variation in total rainfall and storm size and 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 maintain or mimic the natural hydrologic function of a site.

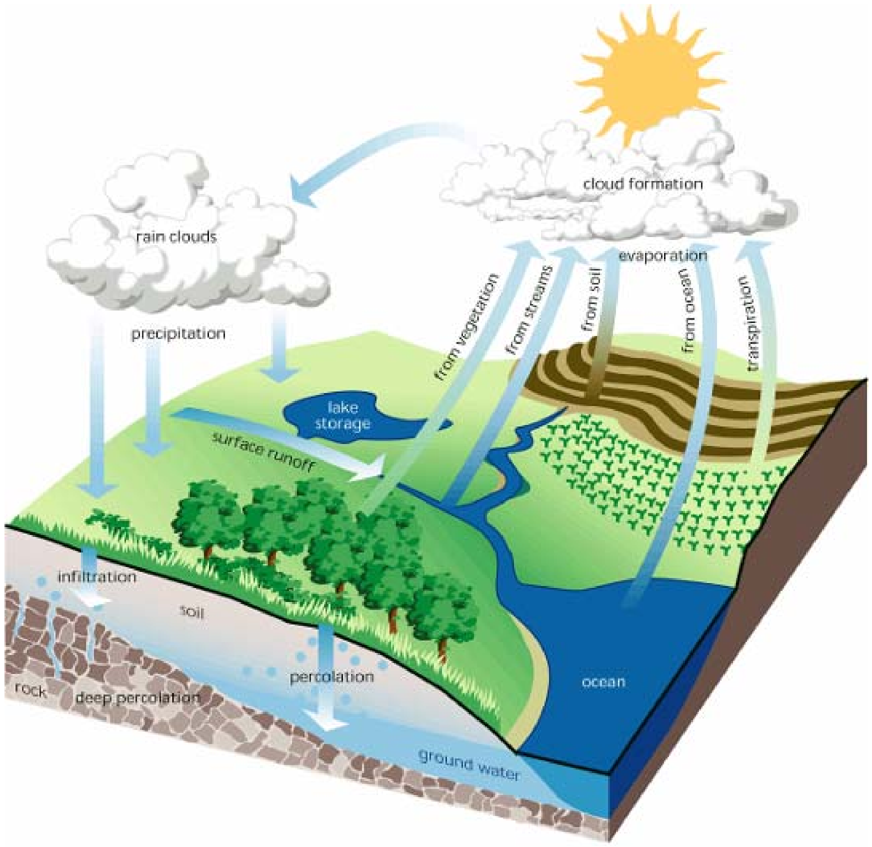

Figure 1. The Hydrologic Cycle.
Source: FISRG, 1998

Water cycles in the various regions of Southern California behave differently 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 lead to increasing concern over water importation. This, in turn, has led to efforts to manage groundwater resources and promote groundwater recharge (EMWD, 2005; OCWD, 2004).

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
- Modifications 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 primary goal of Low Impact Development is to preserve a site's predevelopment hydrology. The effects of changes to runoff patterns caused by land use modifications, or hydromodification, can be reduced by addressing targeted watershed goals and objectives through the use of structural and non-structural techniques that store, infiltrate, evaporate, and detain runoff. Achieving site design goals 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 deteriorating water quality. Land use modifications may impact every aspect of site development and affect the hydrologic response of the site.

Figure 2 illustrates effects of development on the natural hydrologic cycle. 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 bank erosion.

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. One LID design objective, for example, may be to preserve sediment load for a given site. 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.

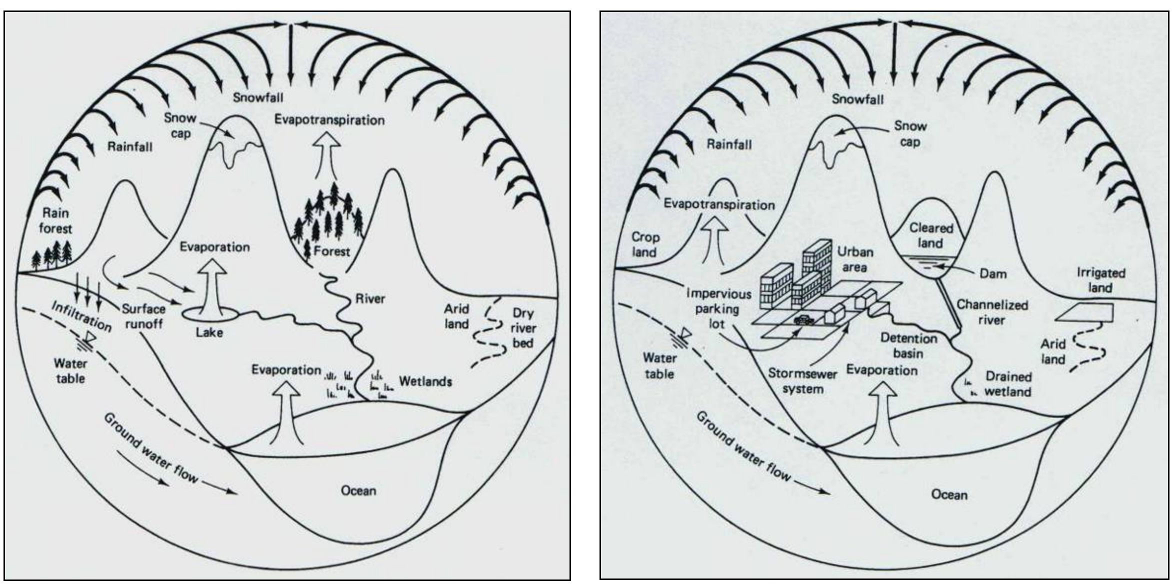

Figure 2. Natural Hydrologic Cycle (left); Hydrologic Cycle of a Developed Environment (right).
Source: McCuen, 1998

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Section 2: The LID Site Design Process

This manual establishes a framework for the LID site design process that informs all stages of planning and design. LID is not intended to be 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 Low Impact Development project, consideration of 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.

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.

The process of planning a Low Impact Development project begins with a comprehensive understanding of the unique features of the site to be developed, which will guide the development of goals for minimizing the impact of the project. Next, a set of LID principles are included in the site planning process, to guide the creation of a site plan that works with the site's natural features and minimizes the generation of runoff. Once a sound site plan has been created, selected LID BMPs are included to capture and treat runoff where they are needed. The site plan is then evaluated to ensure that the stated goals have been met.

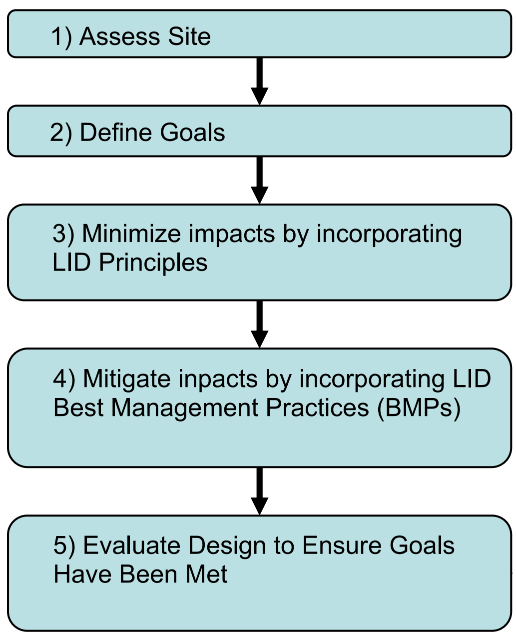

Figure 3. The LID Site Design Process.
Source: The Low Impact Development Center, Inc.

It is important to note that while the LID Site Design Process is presented in a linear fashion, in practice, steps three through five are an iterative process, where structural and non-structural design elements are added and adjusted in response to the modeling results until the project goals are met.

This design process is intended to be 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. These factors drive the site design, and guide the selection of the most appropriate practices and BMPs for the site.

The LID Site 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 Design Process, the project professional must search for a balance that meets all requirements within the project budget.

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 more costly than in new development.

The economics of LID implementation warrants evaluation on both a capital and lifecycle basis. 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 treatment 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 the 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 potential increase in marketability and desirability of LID projects.

Figure 4. Use of the LID Site Design Process to Maintain or Restore Hydrologic Function.
Source: The Low Impact Development Center, Inc.

Integration with MS4 Permit Requirements
LID principles have been incorporated into local MS4 permits. The exact structure of these requirements varies by municipality, therefore, an effort has been made to present a design method that is sufficiently general to conform to a variety of local requirements. Discussion of specific local permitting issues is included in Appendix B.

Step 1: Conduct Site Assessment

A comprehensive site assessment is a fundamental starting point in the development of an LID site design. 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 and geotechnical 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 (roads, parking lots and structures), structural, and non-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

Table 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 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	• 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 • US EPA	• 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
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 • US EPA • California EPA • California Department of Toxic Substances Control	• Phase One

Source: The Low Impact Development Center, Inc.

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.

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, taking note of where the water flows.

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.

References and Resources

Cal-Atlas: http://atlas.ca.gov

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

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

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 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.

References and Resources

USGS Topographic Maps: http://topomaps.usgs.gov/

LID Site Assessment – *Soils and Geology*

As many LID BMPs are designed to infiltrate runoff, understanding the site's soil type, characteristics, and profile 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 non-point 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, a safety factor of 10 is appropriately applied – and can usually be reduced once in situ 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 Natural Resources Conservation Service (NRCS) has compiled soils data on the U.S. Department of Agriculture (USDA) website. The online soil survey is called the Web Soil Survey (WSS) 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-SCS, 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 a 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 percent 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. 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-SCS, 1986). A vegetative cover can increase these rates 3 to 7 times (Lindsey et. al., 1992).

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.

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 basin flooding, sprinkler infiltrometers, cylinder or double-ring infiltrometers, and lysimeters. Appropriate techniques should be selected based on the method of stormwater application being considered and may be subject to local guidance. Basin flooding and cylinder infiltrometer tests are preferred for the design of stormwater retention facilities (US EPA, 1998). The standard US Public Health Service percolation test used to design septic drain fields is not recommended.

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 tine 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, 2003):

- 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 age, 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, 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.

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. Table 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. 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.

References and Resources

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

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

USGS - Geologic Information for Southern California http://scamp.wr.usgs.gov/

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/

USGS - National Landslide Overview Map of the United States
http://landslides.usgs.gov/learning/nationalmap/

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

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 5. 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 6. 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 7. 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

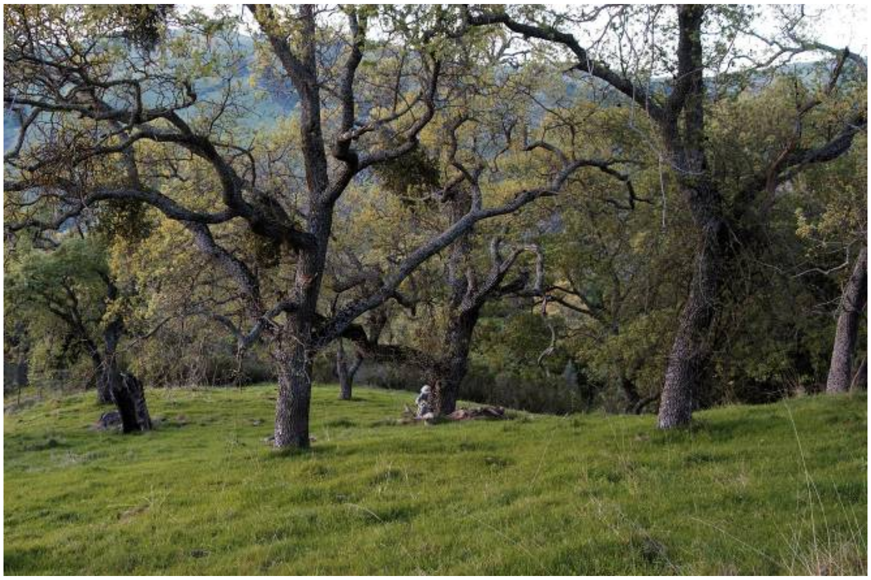

Figure 8. Oak Woodland.
Source: Daniel Griffin, University of Arkansas Tree-Ring Laboratory

- 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 9. 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 10. Pinyon-Juniper Woodland.
Source: Joel Michaelsen; 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 11. Pine Forest.
Source: Joel Michaelsen; 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 12. 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 13. Joshua Tree Woodland.
Source: Carrie Tai

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LID Site Assessment – *Ecoregion*

Ecoregions and Native Plant Communities

Landscaping within a Low Impact Development 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-FS, 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. These features are summarized in Table 3 and Table 4 for the subsections that occur in the project area. Understanding the unique elements in a specific ecoregion the BMP is located in 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.

Table 3. Climate and Vegetation of the Southern California Coast Ecoregion.

Subsection	Mean Annual Temp. & Precip.	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 4. Climate and Vegetation of the Southern CA Mountains and Valleys Ecoregion.

Subsection	Mean Annual Temp. & Precip.	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

Sources: USDA-FS, 1997, and CA-DFG, 2009

Table 4 (cont.): Climate and Vegetation of the Southern CA Mountains and Valleys Ecoregion.

Subsection	Mean Annual Temp. & Precip.	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

Sources: USDA-FS, 1997, and CA-DFG, 2009

Table 4 (cont.): Climate and Vegetation of the Southern California Mountains and Valleys Ecoregion.

Subsection	Mean Annual Temp. & Precip.	Surface Water	Predominant Vegetation	Less Common Vegetation
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
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

References and Resources

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LID Site Assessment – *Sensitive and Restricted Areas*

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

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:

- Wetlands
  - o http://www.ceres.ca.gov/wetlands/
- Streamside Management Areas / Watercourse and Lake Protection Zones
  - o http://www.swrcb.ca.gov/water_issues/programs/nps/encyclopedia/2b_sma.shtml
- Floodplains
  - o http://www.fema.gov/plan/prevent/fhm/dfm_dfhm.shtm
  - o http://www.water.ca.gov/floodmgmt/lrafmo/fmb/fes/
  - o Contact appropriate local agency for additional flood hazard areas
- Habitat for threatened or endangered species
  - o Local MSHCP
  - o 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
  - o As-built plans
  - o Utility companies

References and Resources

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

Orange County Watersheds http://www.ocwatersheds.com/

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

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

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

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

San Diego County Multiple Species Habitat Conservation Program
http://www.sandiego.gov/planning/mscp/

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

Western Riverside County Regional Conservation Authority Multiple Species Habitat Conservation Plan
http://www.wrc-rca.org/library.asp

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, 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
- Cal/EPA link: http://www.calepa.ca.gov/brownfields/

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.

References and Resources

City of Emeryville, CA. *Stormwater Guidelines for Green, Dense Redevelopment*. http://www.epa.gov/smartgrowth/pdf/Stormwater_Guidelines.pdf

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

US EPA. 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 often include minimum requirements for implementation of LID. Since these requirements vary depending on the local 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
  - Hydrograph matching
  - 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 Low Impact Development 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 Low Impact Development.

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 level can be compared to the following metrics.

Table 5. Levels of LID, Water Quality Treatment, and Hydrologic Control.

Level of Low Impact Development	Evaluation Metrics to be Achieved by Project	Notes
"Limited" Impact Development	Water Quality Treatment • 85^{th} percentile average annual runoff captured and treated before release	Caution required. New runoff may create hydrologic conditions of concern.
"Limited" Impact Development	Hydrologic Control • Post development hydrograph significantly altered from predevelopment hydrograph through retention.	Caution required. Runoff reduction may create hydrologic conditions of concern by starving downstream waters of low flows. The reduction or elimination of low flows may have restorative benefits to downstream waters where prior developments have altered predevelopment hydrology.
Low Impact Development	Water Quality Treatment • 85^{th} percentile average annual runoff captured and treated before release Hydrologic Control • Mimics predevelopment runoff volume for regionally appropriate events (e.g., 1yr, 2yr, 5yr, and 10yr, 24hr storm events)	Elevated peak flows may create hydrologic conditions of concern.
Low Impact Development	Water Quality Treatment • 85^{th} percentile average annual runoff captured and treated before release Hydrologic Control • Mimics predevelopment runoff volume <u>and peak flows</u> for regionally appropriate events (e.g., 1yr, 2yr, 5yr, and 10yr, 24hr storm events)	Maintenance or restoration of predevelopment runoff hydrograph prevents downstream degradation.

Source: The Low Impact Development Center, Inc.

Step 3: Implementing LID Principles

<u>Introduction</u>

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:

- **<u>LID Principles</u>** that **minimize** the causes (or drivers) of project impacts, and
- **<u>LID BMPs</u>** that help **mitigate** unavoidable impacts.

Incorporating LID Principles 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 BMPs. As such, a project proponent should exhaust all available and applicable measures to minimize impacts, before moving on to mitigating the remaining impacts.

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

Table 6. Examples of LID Principles and Where Within a Project Lifecycle They Can Be Implemented.

Phase	LID Principles (minimization)	LID Principles/ 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 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. An 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. 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.

These areas are typically characterized by:

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

Table 7. 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.

Promoting infiltration in close proximity to buildings, paved structures, or steep slopes has the potential to create geotechnical hazards, such as slope destabilization or premature failure of structures. A geotechnical engineer should always be consulted when designing infiltration-based BMPs to ensure that site conditions are suitable and any potential concerns have been addressed.

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.

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.

Table 8. 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.

Protect Existing Vegetation and Sensitive Areas

A thorough site assessment will identify any areas containing dense vegetation or well-established trees. 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.

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.

Table 9. 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.

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. Below is a partial list of techniques that can reduce the amount of impervious area that will be created as part of a project. 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: http://cfpub.epa.gov/npdes/greeninfrastructure/munichandbook.cfm.

Table 10. 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. Work with a geotechnical engineer to determine the minimum level of compaction necessary to provide structural stability.
Occupancy	N/A

Source: The Low Impact Development Center, Inc.

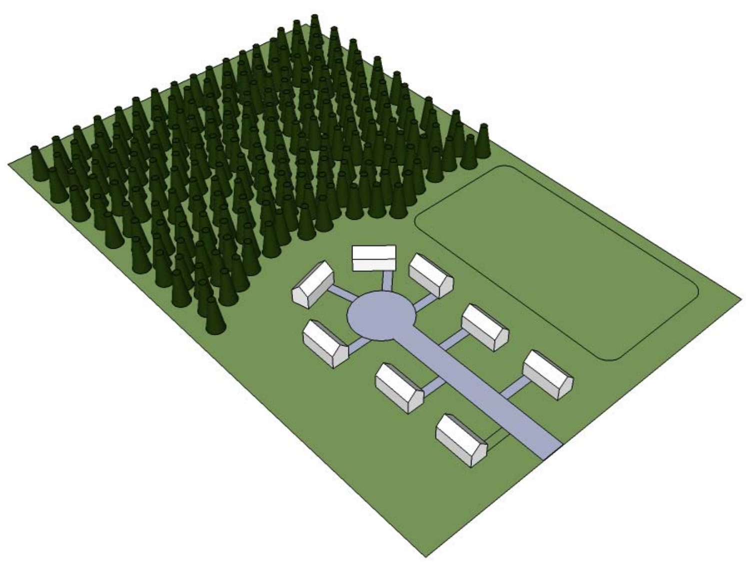

Figure 14. Residential development, showing housing clustered in one part of the site, preserving forest cover and creating space for a playing field (e.g. soccer, football, or other recreational area).
Source: The Low Impact Development Center, Inc.

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. Runoff from numerous impervious drainage areas may converge, combining their volumes, peak runoff rates, and pollutant loads. 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. This reduces the amount of directly connected impervious area (DCIA), and will reduce the peak discharge rate by increasing the time of concentration (T_c), 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, particularly for practices that are designed to concentrate and infiltrate runoff. Consult with the project geotechnical engineer to identify areas where infiltration can be accommodated.

Discharge 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.

Table 11. 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 turf, 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.

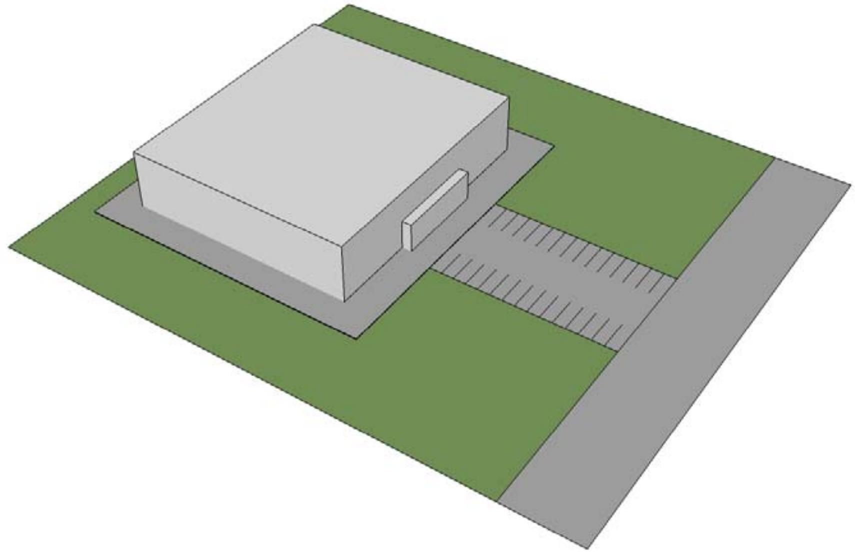

Figure 15. Commercial site showing directly connected impervious areas. The roof drains to the sidewalk, which drains to the parking lot, and then directly onto the street.
Source: The Low Impact Development Center, Inc.

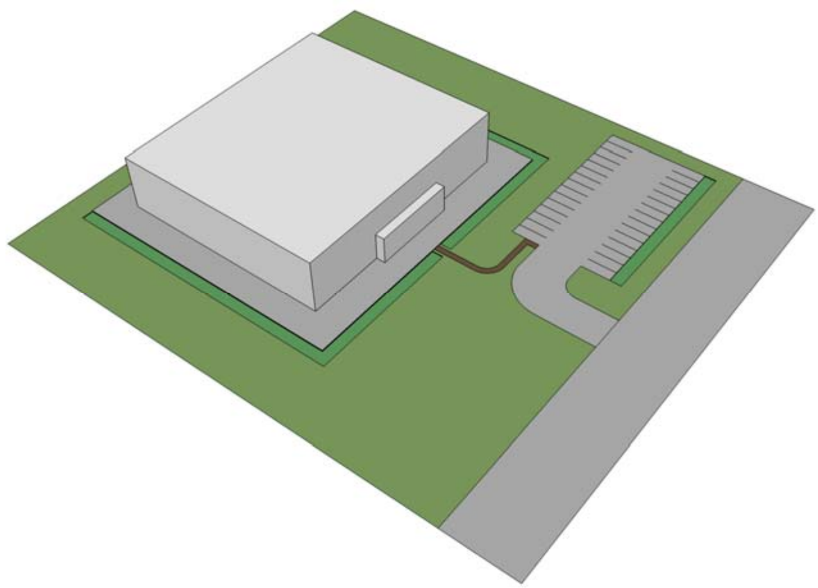

Figure 16. Commercial area in which impervious surfaces have been disconnected. Runoff from the roof and sidewalk are captured by bioretention cells. Sidewalks are separated from the parking lot by a large vegetated area. The parking lot drains to a bioretention cell rather than directly to the street.
Source: The Low Impact Development Center, Inc.

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.

Soil compaction resulting from the movement of heavy construction equipment can reduce soil infiltration rates by 70-99 percent (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.

Site designers should work with civil and geotechnical engineers to determine which areas must be graded and compacted to provide soil stability, and which areas may be left undisturbed.

Table 12. 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.

<u>Establish Vegetation and Soil Protection Areas</u>
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.

<u>Use of Mulch and Load Distributing Matting</u>
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.

<u>Pre / Post Construction Soil and Plant Treatments</u>
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

Introduction

Maximizing plant cover protects the soil and improves ability of the site to retain stormwater, minimize runoff, and help to prevent erosion. Plants have multiple impacts on 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.

When revegetating 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 A 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, 2002). 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 (CAL FIRE) - http://www.fire.ca.gov

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

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

University of California Agriculture and Natural Resources SAFE Landscapes - http://groups.ucanr.org/SAFE/

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.

The Water Conservation in Landscaping Act of 2006 requires local agencies to adopt landscape water conservation ordinances. Agencies can either adopt the Department of Water Resources' Model Water Efficient Landscape Ordinance, or create their own ordinances, which must be at least as effective. The model ordinance is available at: http://www.water.ca.gov/wateruseefficiency/landscapeordinance/.

Additional Information

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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 13 provides additional details on the sources of these pollutants/indicators.

Table 13. 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 (TSS)

The largest source of suspended solids is soil erosion. Protecting and revegetating soil is the best practice for reducing 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 (E&S) 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 the grass.

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.

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Step 4: Use LID BMPs to Mitigate Impacts

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

This chapter provides descriptions, basic design guidance, and selection criteria for the most commonly used LID BMPs. Detailed information on the five primary BMPs used in LID (Bioretention, Capture/Reuse, Permeable Pavement, Vegetated Roofs, and Soil Amendments) is provided. Other BMPs are described briefly, and links are provided to more detailed sources of information.

The LID BMPs discussed in this manual can be divided into two broad types based on how they function. LID 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 BMPs can be configured to function as either type. Below is a summary list of various common types of BMPs.

Table 14. 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			✓
Proprietary Devices			✓
* 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 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 BMPs.

Table 15. 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	○	◉	○
Proprietary Devices	○	○	○

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.

Table 16. Environmental Benefits of 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	✓					
Proprietary Devices	✓					

Source: Adapted from WERF, 2006.

Table 17. BMP Performance – Influent/Effluent Water Quality.

BMP	Sediment (mg/L)	Nitrogen (mg/L)	Phosphorus (mg/L)	Metals – Zn (µg/L)	Oil and Grease (mg/L)	Bacteria (#/100mL)	Temp	Notes
Bioretention without underdrain	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
Bioretention with underdrain	34/15.5[*]	1.68/1.14[†]	0.61/0.16[*]	107/46[*]	30.8/2.5[‡]	641.5/86.5[§]	Moderate[**]	
Permeable Pavement without underdrain	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
Permeable Pavement with underdrain	xx/17.0[††]	xx/1.23[††]	xx/0.09[††]	xx/17[††]	xx/0.018[‡‡]	No data	Moderate	
Capture and Reuse	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
Vegetated Roofs	No data	1.3/1.63***	0.012/0.057***	No data	N/A	xx/22§	Moderate	
Downspout Disconnection	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
Soil Amendments	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
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	
Infiltration Basins	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
Infiltration Trenches	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge

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

Table 17 (Cont.): BMP Performance – Influent/Effluent Water Quality.

BMP	Sediment (mg/L)	Nitrogen (mg/L)	Phosphorus (mg/L)	Metals – Zn (µg/L)	Oil and Grease (mg/L)	Bacteria (#/100mL)	Temp	Notes
Dry Wells	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
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

Key: [*]Davis, 2007 [§]Clary et al, 2008 [†]Hunt et al, 2008 [‡]Hong et al, 2006 [***]Teemusk and Mander, 2007
[**]Jones and Hunt, 2008 [§§]Caltrans, 2004 [††]Geosyntec, 2008 [‡‡]International Stormwater BMP Database, 2009

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

Table 18. 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.

Table 18 (Cont.): BMP Site Suitability Criteria.

BMP	Available space			Maintenance		
	Low	Med	High	Low	Med	High
Bioretention		✓		✓	✓	
Bioretention with underdrain		✓		✓	✓	
Permeable Pavement	✓				✓	✓
Permeable Pavement with underdrain	✓				✓	✓
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	✓				✓	
Proprietary Devices	✓					✓

Source: The Low Impact Development Center, Inc.

Table 19. Maintenance Considerations for LID 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
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

Infiltration Feasibility

In many jurisdictions, infiltration-based BMPs are given preference over capture- or filtration-based BMPs. The feasibility of using infiltration is determined primarily by the nature of the soils and topography at the site. The following checklist can be used for a preliminary assessment of the feasibility of using infiltration-based BMPs on a site; however, a geotechnical engineer should be consulted anytime infiltration is being considered. In areas where infiltration-based BMPs are planned, appropriate infiltration and percolation tests must be performed to verify soil and subsoil infiltration and percolation rates.

Table 20. Site Factors Influencing the Feasibility of Infiltration.

Site Factor	Acceptable Range
Hydrologic Soil Group	A or B
Soil infiltration rate	At least 0.5 in/hr
Slope	Less than 5% Note: terraced bioretention designs can accommodate slopes up to 15%
Depth to bedrock or impermeable layers	Varies based on site conditions
Depth to seasonal high water table	At least 10 feet
Setback from buildings with basements	At least 50 feet*
Setback from buildings without basements	At least 5 feet*
Landslide risk	Low
Soil contamination	None

* Infiltration designs can be used adjacent to structures if an impermeable membrane is used to protect the structure and if otherwise compatible with engineering specifications. All distances noted are subject to the geotechnical engineer's review and approval based on specific site conditions.

Source: The Low Impact Development Center, Inc.

Cost

In 2009, the Water Environment Research Foundation (WERF) published the second version of its BMP and LID Whole Life Cost Models. The spreadsheet tools are intended to guide the determination of capital and maintenance costs for nine selected stormwater management practices that include:

1. Extended detention basins;
2. Retention ponds;
3. Swales;
4. Permeable pavement;
5. Green roofs;
6. Large commercial cisterns;
7. Residential rain gardens;
8. Curb-contained bioretention; and
9. In-curb planter vaults.

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

Literature reviews and costing methods used by queried U.S. stormwater agencies were used to develop the 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. The model uses default assumptions, design equations, and unit costs derived from manufacturers, RS Means 100, or reported costs from stormwater agencies. Using the models in this manner 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 do note that regional cost data were not normalized to national cost data and data from multiple locations were averaged to determine the model default values.

The models can also provide site-specific cost estimates as nearly every cost component of each model 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 models and User Guide are available for free at WERF web site: http://www.werf.org/AM/Template.cfm?Section=Search_Publications&TEMPLATE=/CM/ContentDisplay.cfm&CONTENTID=10836.

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Bioretention

Bioretention cells are small-scale, vegetated, shallow depressions that address pollutants contained in stormwater runoff by filtration through an engineered soil medium. 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 17. Bioretention Cell in Parking Lot, Caltrans District 11 Headquarters, San Diego, CA.
Source: Wallace Roberts & Todd, Inc.

Cost

Bioretention cells often replace areas that would have been landscaped and maintenance-intensive, so the net cost can be less than the conventional alternatives. In addition, the use of bioretention can decrease the cost for stormwater conveyance systems on a site. Bioretention cells cost approximately $3-4 per square foot for simple residential designs, and $10-40 per square foot for commercial installations (LIDC, 2007).

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

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 – 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)

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 and CDWR, 2000).

Applications

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

Potential Applications

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

Residential

Residential settings often provide favorable conditions in which to incorporate bioretention. 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. 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 grass yard, or a vegetated channel can be used as pretreatment for bioretention cell influent.

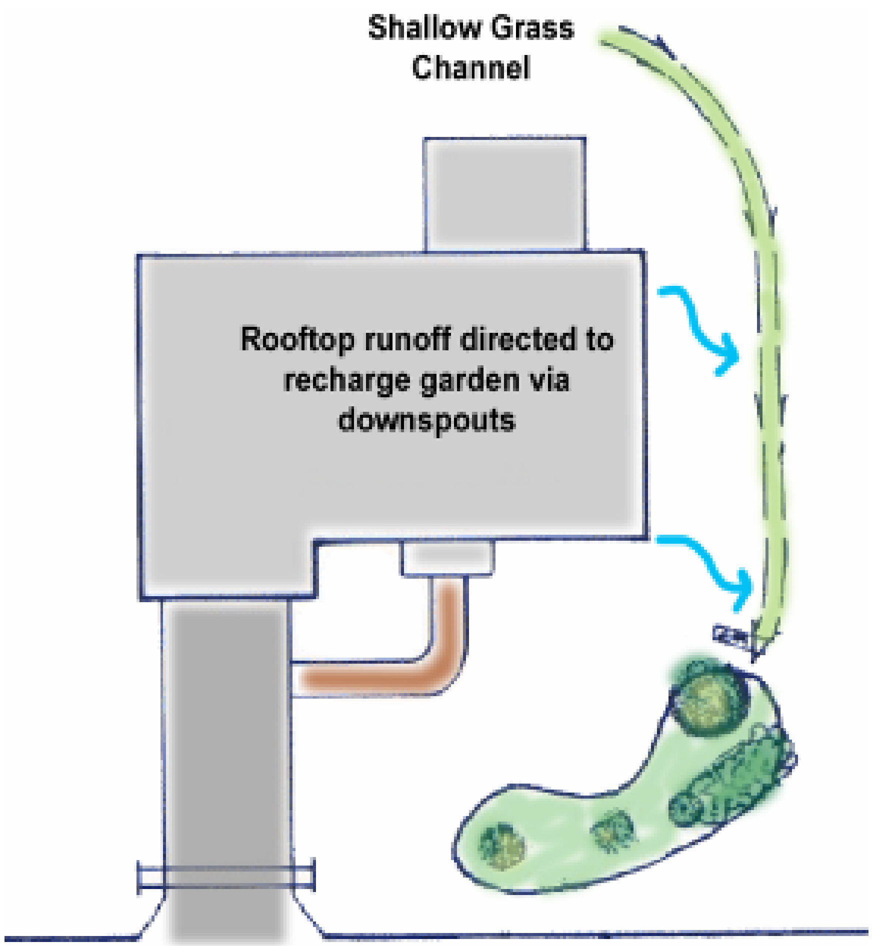

Figure 18. Single-Family Residential Lot Drainage Schematic.
Source: Claytor and Schueler, 1995, with modifications by Cahill Associates

Figure 19. Roof leader draining to bioretention cell.
Source: Wild Ones Natural Landscapers, Ltd., Applewood, MI.

<u>Planter Box</u>
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. 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 20. 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 21. Parking Lot Bioswale, Oxnard, CA.
Source: Ed Gripp

- *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.

<u>Roadway</u>
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 schematic of this type of arrangement is shown below.

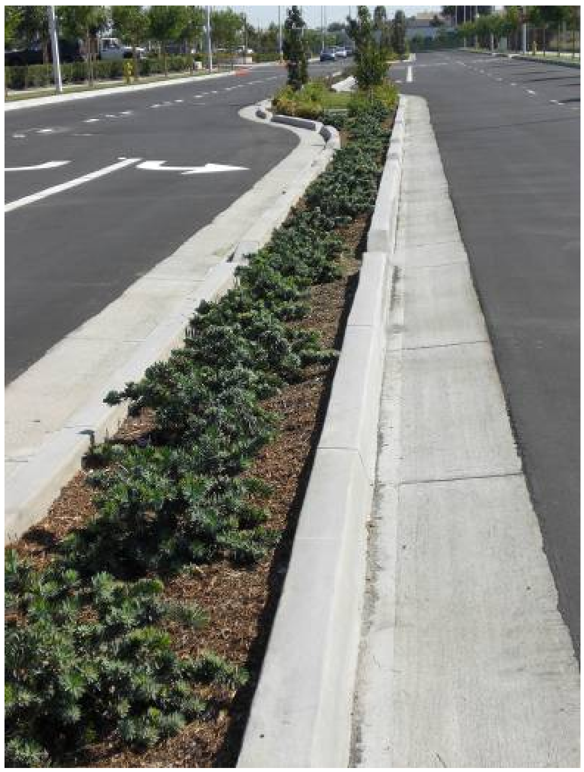

Figure 22. Linear Bioretention, Downey, CA.
Source: Bill DePoto

<u>Dry Swales</u>
In addition to the common “cell” design, bioretention can be incorporated into vegetated swales. Such structures can be used to provide infiltration and water quality treatment while conveying larger flows to supplemental storage BMPs.

Figure 23. Bioretention cell for street/yard drainage, Los Angeles, CA.
Source: Bill DePoto

Site Factors

- Depth to water table: Ten (10)- foot minimum for infiltration (Regional Boards and local agencies may have differing requirements.)
- Depth to bedrock: Varies with site conditions (Regional Boards and local agencies may have specific requirements.)
- 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 percent), 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: 50 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 grassed 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.

Figure 24. Bioretention cell for street/yard drainage, Downey, CA.
Source: Bill DePoto

Figure 25. Curb cut directing water from the street into a bioswale.
Source: Haan-Fawn Chau

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 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: 50 percent sand, 30 percent topsoil, and 20 percent organic material by volume (LIDC, 2003). 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 21 can be expected to have infiltration rates ranging from 25 – 130 in/hr (Hsieh and Davis, 2005).

Table 21. Bioretention Soil Medium (BSM) Specification.

Component	Properties
Sand	Conforms to ASTM C33 Fine Aggregate
Organic Material	Compost or shredded hardwood mulch
Topsoil	
• Sand (2.0 – 0.050 mm)	50 – 85% by weight
• Silt (0.050 – 0.002 mm)	0 – 50% by weight
• Clay (less than 0.002 mm)	10 – 20% by weight[1]
• Organic Matter	1.5 – 10% by weight
• pH	5.5 – 7.5 (NOTE: pH can be corrected with soil amendments if outside acceptable range)
• Magnesium	Minimum 32 ppm (NOTE: magnesium sulfate can be added to increase Mg)
• Phosphorus (Phosphate - P_2O_5)	Not to exceed 69 ppm P-index should be less than 25
• Potassium (K_2O)	Minimum 78 ppm (NOTE: potash can be added to increase K)
• Soluble Salts	Not to exceed 500 ppm

Source: The Low Impact Development Center, Inc., 2003

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 A 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

[1] If the proposed topsoil is known to contain expansive clays, clay content should not exceed 10% by weight.

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.

<u>Underdrain</u>
In areas with HSG group A or B soils, bioretention cells may often be constructed without underdrains in order to maximize infiltration. In areas with less-permeable (typically HSG Group C or D soils), underdrains may be required to ensure adequate drainage. Underdrains are typically constructed of a 6" diameter perforated pipe connecting to an existing stormwater conveyance structure or outlet. Underdrains should be surrounded by at least a six inch layer of ASTM No. 57 aggregate.

<u>Enhanced Nitrogen Removal</u>
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 et al, 2007).

<u>Overflow</u>
Provide for the direct discharge of excess runoff during large storm events when the subsurface and surface storage capacity is exceeded.

Examples of outlet controls include domed risers, inlet structures, weirs, and similar devices.

Figure 26. Positive Overflow Device: Domed Riser.
Source: Macomb County Michigan Public Works Office

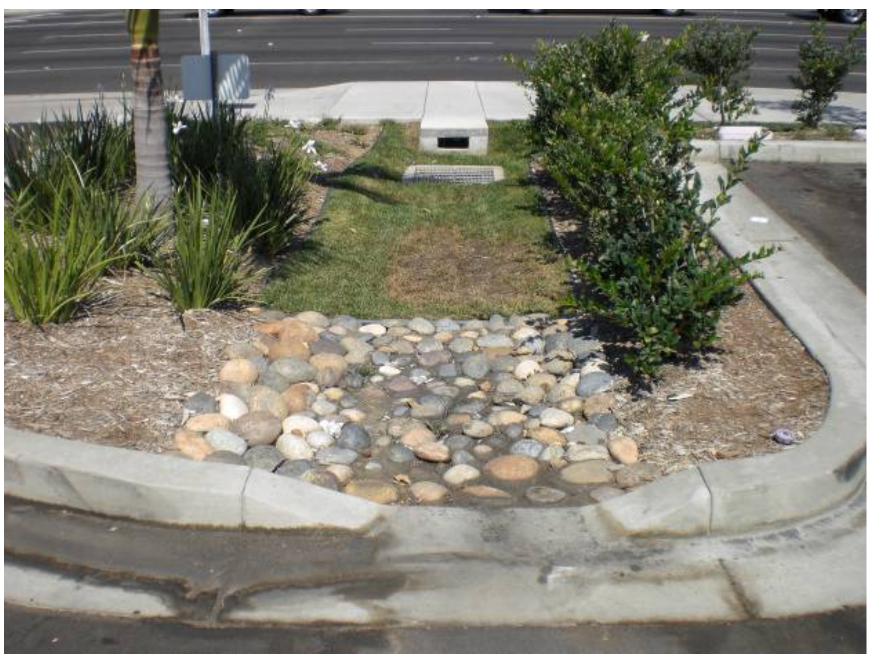

Figure 27. Inlet Structure, Downey, CA.
Source: Bill DePoto

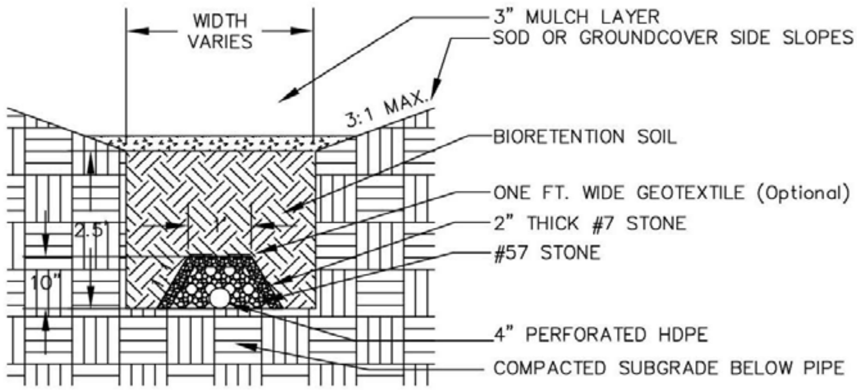

Figure 28. Detailed cross-section of a bioretention cell.
Source: LID Center

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 (85^{th} 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:

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

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

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 storage volume, V_{BMP}, accounts for both surface ponding and the available pore space within the soil medium. The total area required can then be calculated using the above equation for surface area.

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 Bioretention Soil Medium (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.

Figure 29. 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).

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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. 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

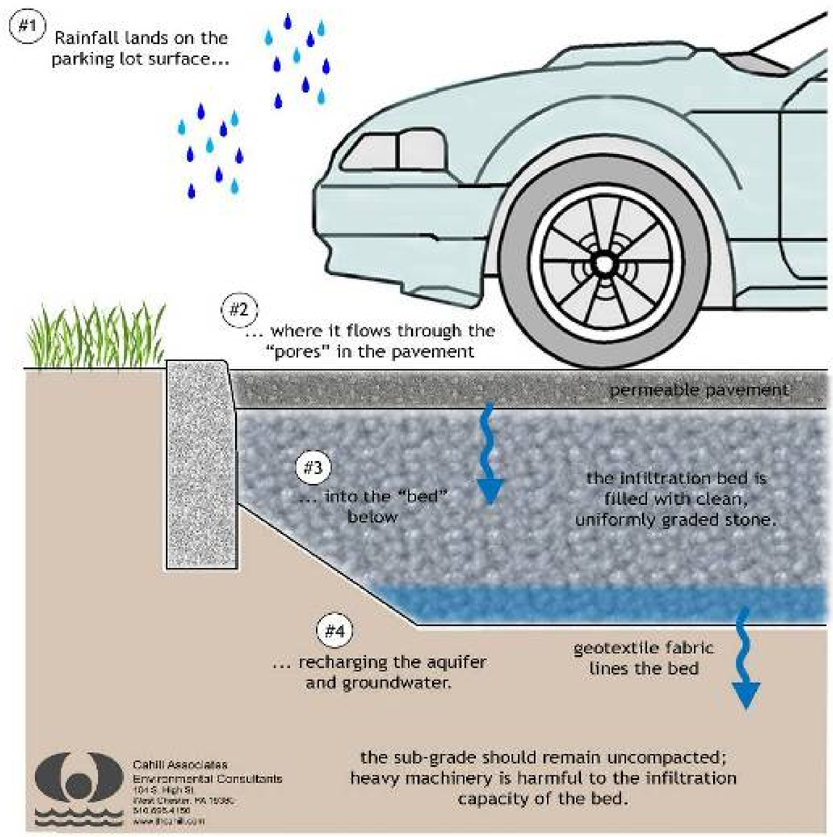

Figure 30. Cross-section showing design components of a permeable pavement with subsurface infiltration bed. Where infiltration is infeasible, underdrains can be fitted into the subsurface bed.
Source: Cahill Associates

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 without pretreatment, such as a vegetated filter strip
- 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. 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.

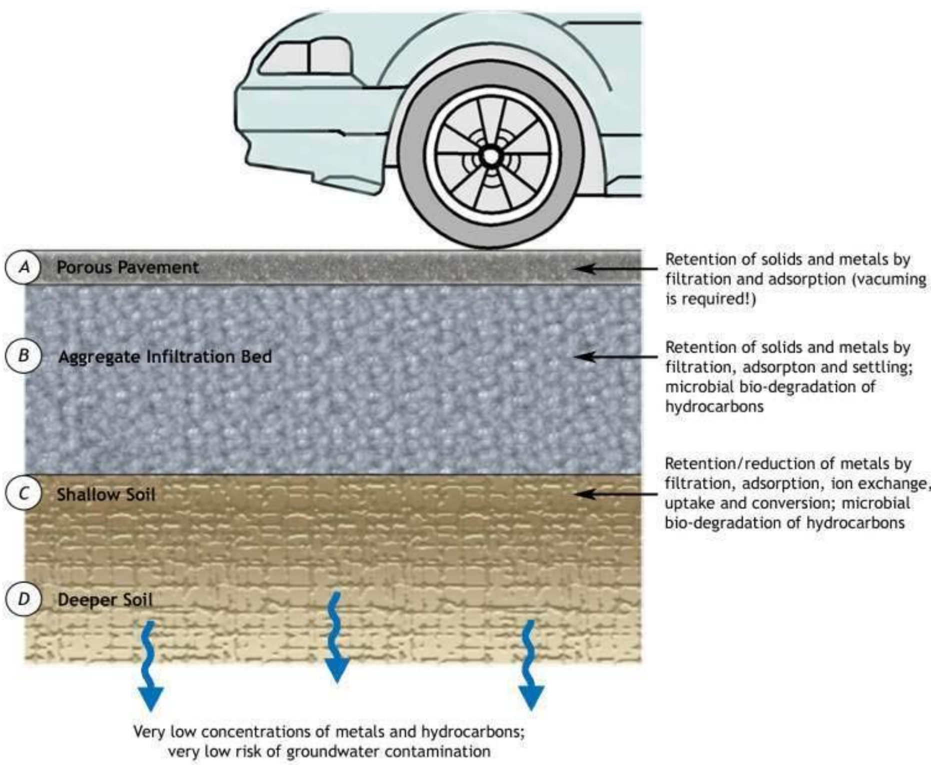

Figure 31. Water quality benefits of pervious pavement with subsurface infiltration.
Source: Cahill Associates

Table 22. 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; UNHSC, 2007
Infiltration Bed or filter layer	Filtration, Adsorption, Settling, Microbial Bio-Degradation	TSS, Metals, and Hydrocarbons, plus Total Organic Carbon, COD, Nitrogen	Balades et al, 1992 & 1995; Diniz and Espey, 1979; 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 all 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, 2006

Source: Cahill Associates

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 23 and Table 24 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 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 23. 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 are based on actual cost received by the County of San Diego						

Source: Cahill Associates

Table 24. 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 are based on actual cost received by the County of San Diego						

Source: Cahill Associates

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.

<u>Potential Applications</u>

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

Parking Areas

Figure 32. Parking Lot, City of Downey, CA.
Source: California Watershed Engineering

Figure 33. Pervious Paver Parking Stalls, Redlands, CA.
Source: Jeff Endicott

Figure 34. Pervious Paver Driveway, Chino, CA.
Source: Jeff Endicott

<u>Pervious Pavement Walkways</u>
Pervious pavement, both as asphalt and concrete, can also be used in walkways and sidewalks. 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 35. Pervious Concrete Sidewalk, Santa Monica, CA.
Source: Bill DePoto

Playgrounds / Basketball / Tennis

Figure 36. Pervious asphalt basketball court at 2nd Ward Neighborhood Park in Upper Darby, PA.
Source: Cahill Associates

Streets and Alleys


Figure 37. Pervious asphalt street in residential neighborhood in Portland Oregon.
Source: Cahill Associates

Figure 38. Pervious paver parking edge in residential neighborhood in Portland Oregon.
Source: Cahill Associates

Figure 39. Porous friction course over traditional asphalt.
Source: Caltrans

Variations

Pervious Bituminous Asphalt

Pervious bituminous asphalt pavement was first studied in the early 1970's 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. 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.

Because pervious asphalt is standard asphalt with reduced fines, it is similar in appearance to standard asphalt. 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 40. Pervious asphalt parking lot at Flinn Springs County Park in El Cajon, CA.
Source: Cahill Associates

Figure 41. Close-up showing pervious asphalt pavement atop a stone infiltration/storage bed at the San Diego County Operations Center in Kearny Mesa, 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 can not 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 and the National Ready Mix Association (see References).

Figure 42. Pervious concrete in Cerritos, CA.
Source: Bill DePoto

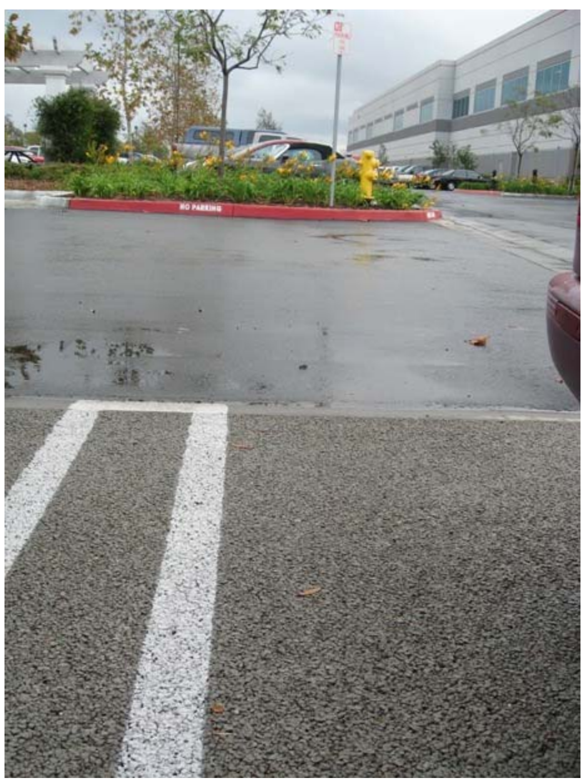

Figure 43. Pervious concrete parking areas, Haas Automation, Inc., Oxnard, CA.
Source: Lorraine Rubin

Permeable Pavers

Permeable pavers consist of interlocking units (often concrete) that provide some portion of surface area that may be filled with a pervious material such as gravel. These units are often very attractive and are especially well suited to plazas, patios, small parking areas, etc. 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 25 lists the open area percentage of several commonly used paver products. Please note that 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 25. 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 44. Turfstone™ Pavers.
Source: Interlocking Paving Systems, Inc.

Figure 45. Turfstone™ Driveway.
Source: Nicolock

Figure 46. Checker Block® Shoulder.
Source: Nicolock

Figure 47. NetPave® 50.
Source: Rehbein Solutions, Inc.

Figure 48. Permapave.
Source: Permapave USA

Figure 49. Uni Eco-stone® Pavers.
Source: Interlocking Paving Systems, Inc.

Figure 50. Acker-Stone Aqua-Via.
Source: Acker-Stone Industries

Figure 51. Aqua Bric® Type 4 (ADA Compliant).
Source: ORCO Block Co., Inc., Photography by RA Hanson

Figure 52. SF Rima™ Paving Stones at the
Persico Commercial Center in the City of Downey, 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.

<u>Reinforced Turf</u>
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.

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 53. 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 percent. 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 Figure 54. 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 even if the performance of the pervious pavement surface is compromised.

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.

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 pervious pavements do not exist, the following guidelines can be used.

Figure 54. Design subsurface infiltration beds to "step" down a slope, maintaining level bed bottoms and earthen berms between beds.
Source: Andropogon Associates

Site Factors

1. Water Table Separation: Ten (10) feet (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: Varies with site conditions (Regional Boards and local agencies may have specific 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.

Percolation tests should be performed by a qualified professional to verify soil permeability in the locations where previous pavements are planned. If soils are found to have percolation rates less than 0.5 in/hour, pervious pavements should be fitted with underdrains and treated as filtration rather than infiltration practices. If pervious pavements are planned in close proximity to buildings or other structures, a geotechnical engineer should be consulted to evaluate the risk of creating unstable soil conditions. A thorough analysis of the soil profile and potential barriers to infiltration must be performed prior to implementing pervious 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. 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 26 and Table 27). 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 should be compacted only to the extent necessary to provide structural stability at the direction of the geotechnical engineer. 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 26. 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 27. Minimum Total Pervious Asphalt Pavement Thickness (aggregate base course + pervious asphalt surface course). Required to Bear Structural Load on Various Subgrades.

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.

Figure 55. Pervious concrete parking lot with river stone edge treatment at 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.

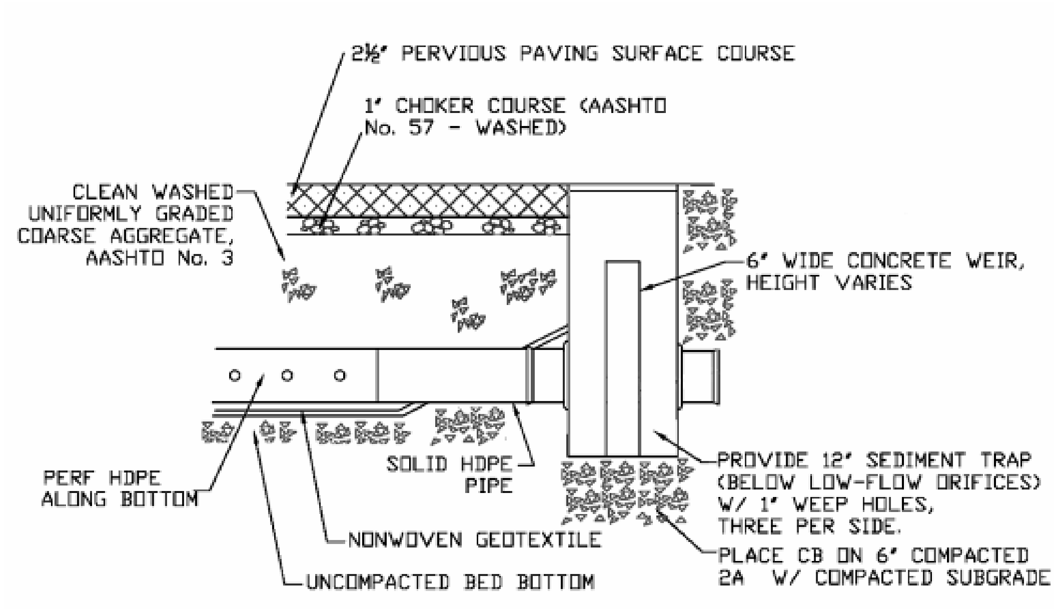

Figure 56. Example detail of an overflow device from a pervious asphalt system.
Source: Cahill Associates

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

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

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

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.

Construction Guidance

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

- Unnecessary 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 should be compacted to the minimum extent necessary, as determined by geotechnical analysis.

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. These berms do not require compaction if proven stable during construction.

Figure 57. 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. 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 58. 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 devise. Applied water shall infiltrate directly without puddle formation or surface runoff.

Figure 59. Water on Porous Asphalt.
Source: Fishbeck, Thompson, Carr & Huber, Inc.

<u>Maintenance Considerations</u>

- 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.

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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. 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.

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 several thousand 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.

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.

Figure 60. Outdoor Cistern with Overflow Directed to Pervious Area.
Source: SEMCOG

Figure 61. Cisterns used for irrigation.
Source: Sunset Publishing Corporation

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 percent of demand. Similarly, other non-potable uses comprise a large percentage of water demand. Domestic toilet flushing accounts for 11 percent of water demand. In office buildings, toilet flushing accounts for 25 percent of demand, while cooling systems account for 23 percent. 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

Residential

Rain barrels are most commonly used in residential settings. 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 62. Residential rain barrel in Los Angeles.
Source: LA Rainwater Harvesting Program

Figure 63. Large-scale residential system in Los Angeles, CA.
Source: Tree People

<u>Commercial</u>
Capture/reuse systems for commercial settings can vary in size and may consist of cisterns with several thousand gallons of storage capacity. Because non-potable uses can constitute up to 85 percent 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 64. Large cistern for vegetated roof plaza maintenance.
Source: Cahill Associates

Figure 65. 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. 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 66. Rainstore™ unit beneath brick pavers on a vegetated rooftop plaza.
Source: Cahill Associates

Figure 67. 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.

Table 28. 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 bibbs), 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. Detailed specifications and design guidance can be found through the American Rainwater Catchment Systems Association (http://www.arcsa.org).

Table 29. Minimum Water Quality Guidelines and Treatment Options for Stormwater Reuse.

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

Source: The Low Impact Development Center, Inc.

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

System Design

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

Tank, Collection, and Distribution

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

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

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

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

Cross-contamination

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

Construction

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

Maintenance

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

Maintenance Schedules:

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

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

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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.

Figure 68. 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

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 and 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

Figure 69. Vista Hermosa Park Ranger Station, Los Angeles.
Source: Greenroofs.com

Figure 70. 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.

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.

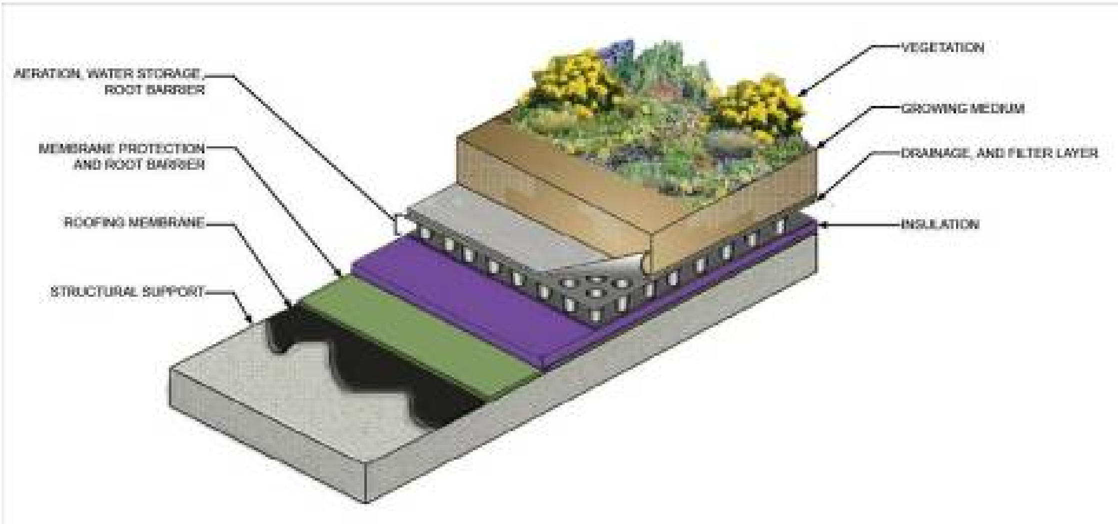

Figure 71. Green Roof Schematic.
Source: Cahill Associates

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.

References and Resources

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BMP Factsheets

The following factsheets cover several additional BMPs that are commonly used in LID designs. These 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). 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 72. 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 percent 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 percent of the roof area draining to the downspout (Portland BES, 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.

Links to Detailed Information

California Stormwater Quality Association. 2003. *Roof Runoff Controls, SD-11*. California Stormwater BMP Handbook New Development and Redevelopment.
http://www.cabmphandbooks.com/Documents/Development/SD-11.pdf

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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.

Figure 73. 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. 2007. *Low Impact Development Handbook.*
http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.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. They are also commonly used as pretreatment for other BMPs.

Figure 74. Filter strip used as pretreatment for highway runoff.
Source: RBF Consulting

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)

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-31: Vegetated Buffer Strip. http://www.cabmphandbooks.com/Documents/Development/TC-31.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. 2007. *Low Impact Development Handbook.* http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

Vegetated Swales

Vegetated swales are broad, shallow channels designed to convey and either filter or infiltrate stormwater runoff. 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 75. A vegetated swale with curb cuts in Playa Vista, California.
Source: Keith Linker

Figure 76. A vegetated swale with curb cuts in El Monte, California.
Source: Bill DePoto

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, T_c

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.
http://www.cabmphandbooks.com/Documents/Development/TC-30.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. 2007. *Low Impact Development Handbook.*
http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

Infiltration Basins

Infiltration basins are shallow impoundments designed to collect and infiltrate stormwater. 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 77. 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.
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County of San Diego. 2007. *Low Impact Development Handbook.*
http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

Infiltration Trenches

Infiltration trenches are narrow trenches that have been back-filled with stone. 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 78. Infiltration Trench.
Source: RBF Consulting

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 percent
- 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. http://www.cabmphandbooks.com/Documents/Development/TC-10.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. 2007. *Low Impact Development Handbook.* http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

Dry Wells

A dry well is an underground storage facility used to capture and infiltrate runoff from downspouts or small impervious areas. 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.

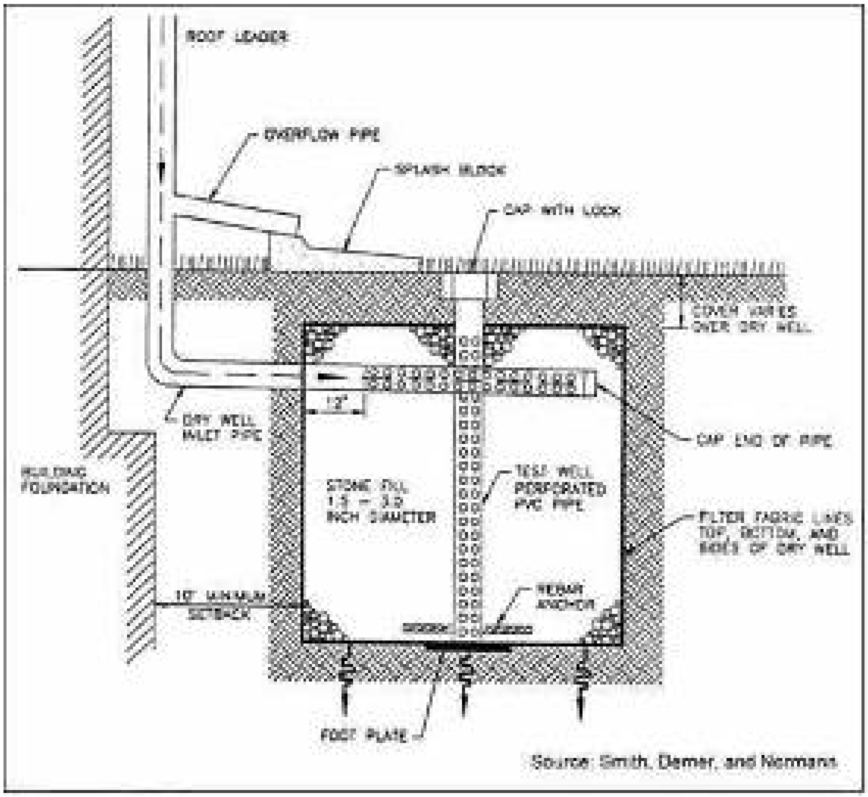

Figure 79. Schematic of a dry well.
Source: Stormwater Management for Maine, 1995. (UFC Manual).

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. 2007. *Low Impact Development Handbook.*
http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

U.S. Department of Defense. 2004. *Unified Facilities Criteria (UFC) Low Impact Development Manual*. UFC 3-210-10. http://www.lowimpactdevelopment.org/lid%20articles/ufc_3_210_10.pdf

U.S. Environmental Protection Agency. *Underground Injection Control for Region 9 Class V Wells.*
http://www.epa.gov/region09/water/groundwater/uic-classv.html

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. 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 80. Dry pond.
Source: RBF Consulting

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.
http://www.cabmphandbooks.com/Documents/Development/TC-22.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. 2007. *Low Impact Development Handbook.*
http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

Constructed Wetlands

Constructed wetlands are shallow, engineered vegetated systems designed to provide stormwater detention and pollutant removal. Natural wetlands SHOULD NOT be used to treat stormwater.

Figure 81. 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. http://www.cabmphandbooks.com/Documents/Development/TC-21.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. 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 82. 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/ft^2
- 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

Links to Detailed Information

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

City of Austin. 2009. Environmental Criteria Manual. http://www.amlegal.com/austin_nxt2/gateway.dll?f=templates&fn=default.htm&vid=amlegal:austin_environment

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. 2007. *Low Impact Development Handbook.* http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-40: Media Filter. http://www.cabmphandbooks.com/Documents/Development/TC-40.pdf

Sacramento Stormwater Management Program. 1999. *Investigation of Structural Control Measures for New Development.* http://www.sacstormwater.org/ConstructionandNewDevelopment/Manuals/SCM/SCMReport.pdf

Technology Acceptance and Reciprocity Partnership (TARP). 2001. *The Technology Acceptance Reciprocity Partnership Protocol for Stormwater Best Management Practice Demonstrations.* http://www.mass.gov/dep/water/laws/swprotoc.pdf

Washington State Department of Ecology. 2008. *Guidance for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology (TAPE).* http://www.ecy.wa.gov/biblio/0210037.html

Proprietary Devices

Proprietary devices include water quality inlets, catch basin controls or stand-alone vaults that prevent sediment, oils, floatable trash, and debris from being transmitted through the collection system. Proprietary devices may be used with other BMPs as part of a stormwater treatment train. However, these controls are generally considered pretreatment devices, as they typically provide limited treatment when compared to other BMPs, and often do not provide detention or retention of stormwater runoff.

Figure 83. Catch basin insert.
Source: REM Inc.

Benefits

- Remove trash, debris, sediment, and/or oils
- Good retrofit capability

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

Links to Detailed Information

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-50: Water Quality Inlet. http://www.cabmphandbooks.com/Documents/Development/TC-50.pdf

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet MP-50: Wet Vault. http://www.cabmphandbooks.com/Documents/Development/MP-50.pdf

Sacramento Stormwater Management Program. 1999. *Investigation of Structural Control Measures for New Development.* http://www.sacstormwater.org/ConstructionandNewDevelopment/Manuals/SCM/SCMReport.pdf

Step 5: Evaluate Design

A successful LID 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 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 BMP or set of 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 85^{th} percentile storm event.

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

- Predevelopment peak discharge rates should be maintained.

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

- Environmentally sensitive site features should be preserved.

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

LID Hydrologic Analysis

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

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

Background on Modeling LID

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

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

Commonly Used Models for LID Design

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

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

California Stormwater BMP Handbook Approach

Source: California Stormwater Quality Association

Storm Simulation Type: Continuous

Stormwater Analysis Capability: Volume, Flow

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

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

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

References:

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. Section 5, Treatment Control BMPs. http://www.cabmphandbooks.com/Documents/Development/Section_5.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.

References:
CASQA, 2003. *California Stormwater BMP Handbook for New Development and Redevelopment*. Available online: http://www.cabmphandbooks.com/

Kuichling, E., 1889. *The Relation Between Rainfall and the Discharge of Sewers in Populous Districts*¸ Transactions ASCE 20(402):1-60.

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.

References:

NRCS, 1986. *Urban Hydrology for Small Watersheds*. Washington, DC: USDA.

NRCS – WinTR-55 Computer Model
http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/WinTR55.html

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.

References:

USACE, HEC-1 Flood Hydrograph Package
http://www.hec.usace.army.mil/software/legacysoftware/hec1/hec1.htm

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.

References:
USEPA – Exposure Assessment Models: HSPF http://www.epa.gov/ceampubl/swater/hspf/

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.

References:
USEPA – Ecosystems Research Division: Stormwater Management Model (SWMM)
http://www.epa.gov/athens/wwqtsc/html/swmm.html

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 grass 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.

References:

WinSLAMM - http://www.winslamm.com/default.html

Selecting the Appropriate Model to Evaluate Your LID Design

All of the models described in the preceding section can be utilized for evaluation of LID 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 30 further describes the differences between these models.

Table 30. 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
Appropriateness 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 Conditions
Land cover: California sagebrush
Curve number: 35

Analysis
Using the California Stormwater BMP Handbook approach, the required storage volume for 85 percent 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 percent 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.

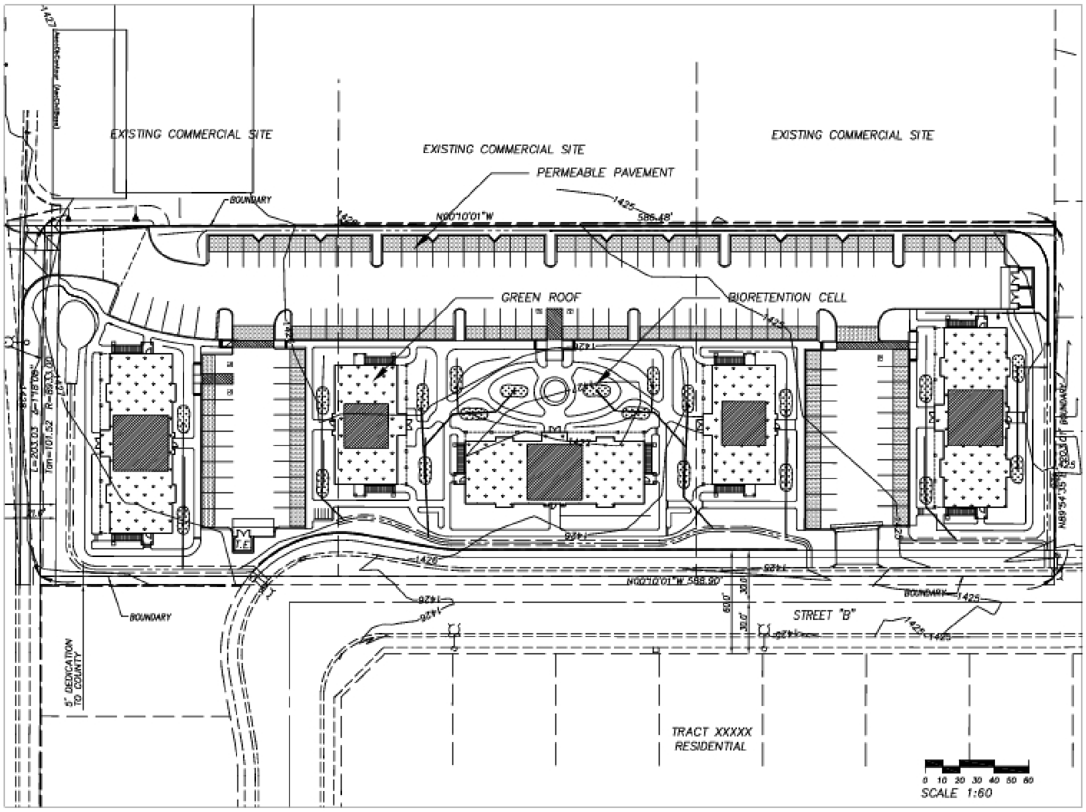

Figure 84. Retrofit of an existing commercial site.
Source: The Low Impact Development Center, Inc.

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 Conditions
Land cover: California sagebrush
Curve number: 35

Analysis
Using the California Stormwater BMP Handbook Approach, the required storage volume for 85 percent 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 of the 57 houses in the development with two 55-gallon rain barrels. This would provide a total of 834 cubic feet of storage over the entire development.
3. Build two bioretention cells on each of the 57 lots, totaling 580 square feet per lot, assuming a 6-inch ponding depth, and 30-inch media depth. This would provide a total of 45,493 cubic feet of storage over the entire development.
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.

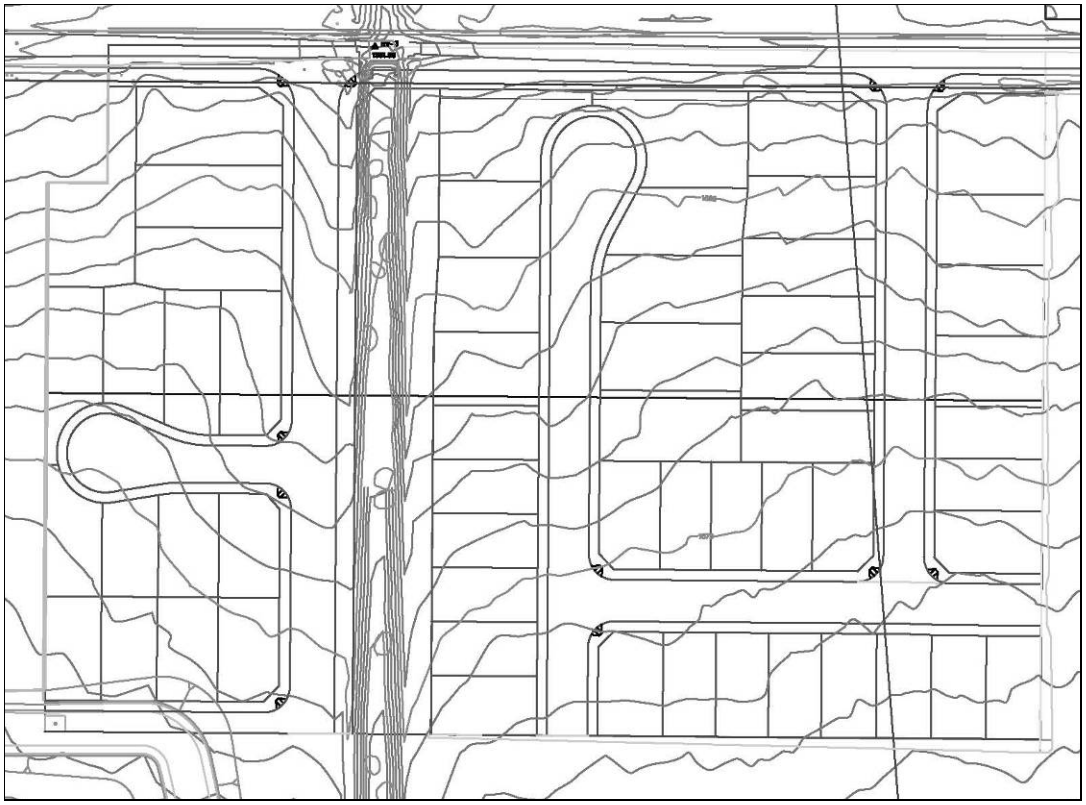

Figure 85. Existing residential subdivision.
Source: The Low Impact Development Center, Inc.

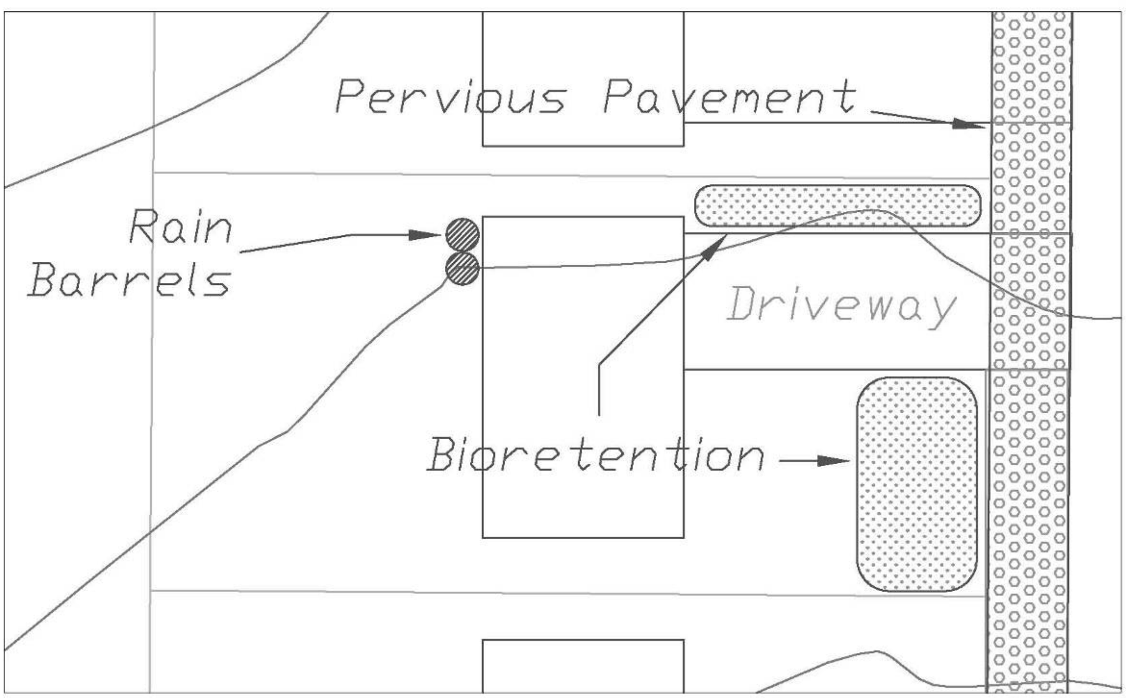

Figure 86. LID retrofits to an existing residential lot.
These retrofits are to be applied to each lot in the subdivision.
Source: The Low Impact Development Center, Inc.

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 percent 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

<u>Analysis</u>
Using the California Stormwater BMP Handbook Approach, the required storage volume for 85 percent 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 percent 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. This would provide 38,023 cubic feet of storage.
3. Install pervious pavement with 6-inch gravel storage layer in front parking lots. This would provide 21,572 cubic feet of storage.
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.

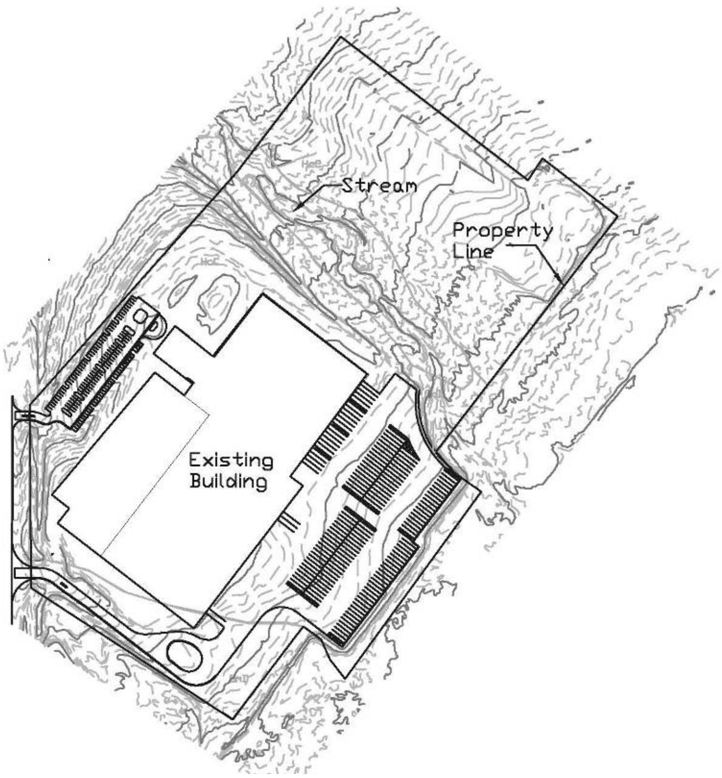

Figure 87. Existing commercial development.
Source: The Low Impact Development Center, Inc.

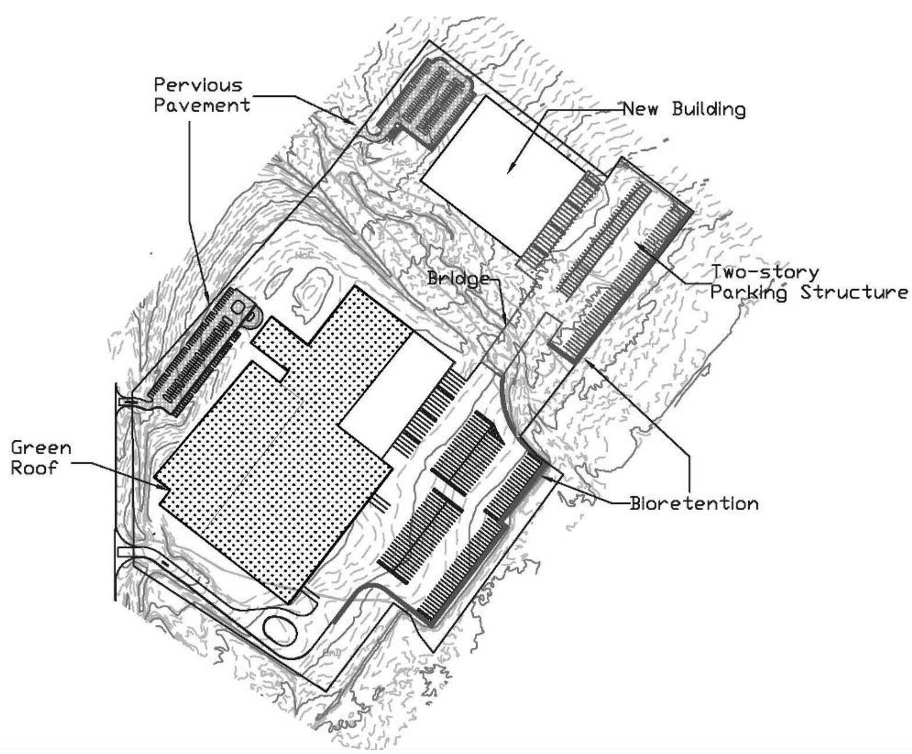

Figure 88. Proposed retrofits and addition to existing commercial development.
Source: The Low Impact Development Center, Inc.

Case Study 4: Residential Development

Design a 118-lot residential subdivision on an undeveloped parcel.

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 percent 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 percent.

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 percent capture would be 59,653 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 of the 115 houses in the development. This would provide a total of 841 cubic feet of storage.
2. Install pervious pavement with 1-foot gravel storage layer in driveways. This would provide a total of 11,500 cubic feet of storage over the entire development.
3. Install pervious pavement with 1-foot gravel storage layer on sidewalks. This would provide 11,193 cubic feet of storage.

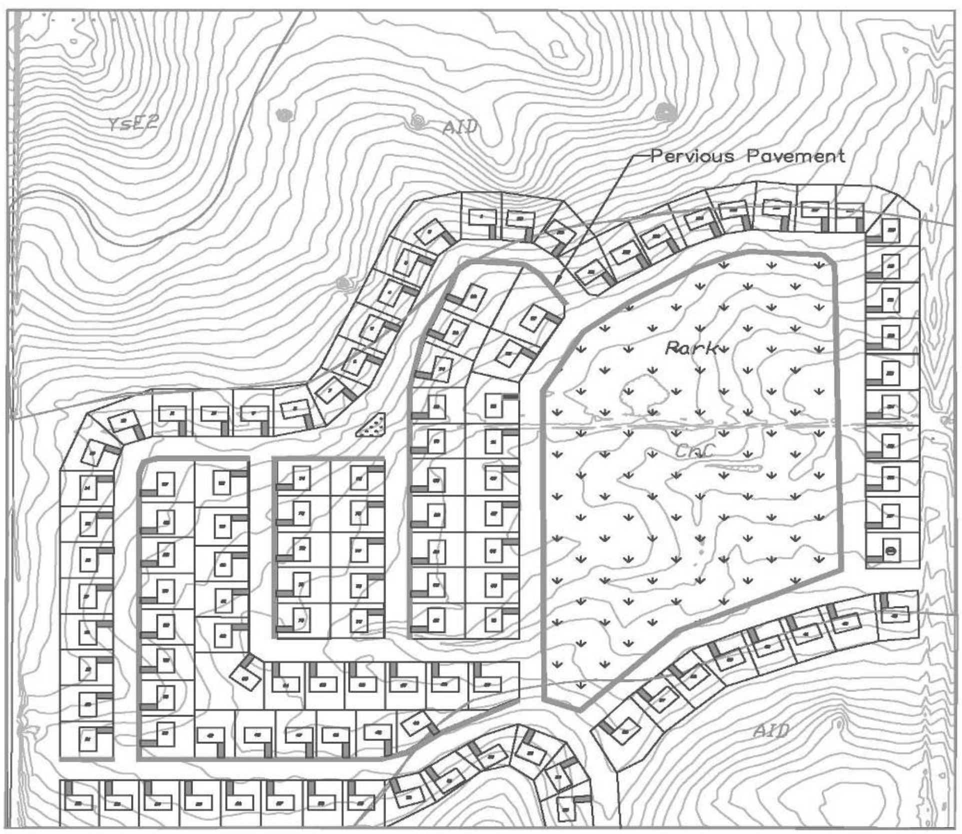

Figure 89. Residential subdivision design.
Source: The Low Impact Development Center, Inc.

Appendix A: Lists of Plants Suitable for Southern California

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 31. Master Plant List.

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	✓	✓	✓	✓✓			✓	✓		✓

Master Plant List (Cont.)				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 'Lester Rowntree'	Lester Rowntree Manzanita	broadleaf evergreen tree/shrub		✓	✓		chaparral	✓	✓		✓	✓			✓		
Arctostaphylos 'Pacific Mist'	Pacific Mist Manzanita	groundcover	7-9, 14-24	✓	✓		chaparral	✓	✓		✓	✓			✓		
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	✓	✓			✓			✓		

Master Plant List (Cont.)				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
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 praegracilis	California Field Sedge	creeping perennial		✓	✓	✓	riparian	✓	✓	✓			✓	✓		✓	
Ceanothus arboreus	Island Ceanothus	broadleaf evergreen tree/shrub		✓	✓		css, chaparral	✓			✓	✓			✓		
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	✓	✓			✓			✓		

Master Plant List (Cont.)				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 '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	✓	✓		✓✓				✓		
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	✓			✓✓				✓		

Master Plant List (Cont.)				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
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	✓	✓		✓✓				✓		
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	✓	✓		✓✓				✓		

Master Plant List (Cont.)				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**
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	✓	✓		✓✓				✓		✓
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	✓	✓	✓	✓	✓			✓	✓	

Master Plant List (Cont.)				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
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	✓			✓✓				✓		
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	✓	✓		✓✓				✓	✓	

Master Plant List (Cont.)				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
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	✓			✓	✓			✓		
Quercus lobata	Valley Oak	deciduous tree	4-9, 12-24	✓	✓	✓	grassland, woodland	✓			✓	✓			✓		
Rhamnus californica	Coffeeberry	evergreen shrub	4-9, 14-24	✓	✓		chap, woodland	✓	✓		✓	✓			✓		

Master Plant List (Cont.)				**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**
Rhamnus californica 'Eve Case'	Coffeeberry	evergreen shrub	4-24	✓	✓		chap, woodland	✓	✓		✓	✓			✓		
Rhamnus crocea	Redberry	evergreen shrub	14-21	✓	✓		css, chaparral	✓	✓		✓✓				✓		
Rhamnus ilicifolia	Hollyleaf Redberry	evergreen shrub	7-16, 18-21	✓	✓	✓	chaparral, woodland, forest	✓	✓		✓✓				✓		
Rhus integrifolia	Lemonadeberry	evergreen shrub	8, 9, 14-17, 19-24	✓	✓		css, chaparral	✓	✓		✓✓				✓		
Rhus ovata	Sugar Bush	evergreen shrub	9-12, 14-24	✓	✓	✓	css, chaparral	✓	✓		✓✓				✓		
Ribes aureum var. gracillimum	Golden Currant	semi-deciduous shrub	1-24		✓	✓	chap., woodland	✓	✓		✓✓	✓			✓		
Ribes malvaceum 'Dancing Tassels'	Dancing Tassels Currant	deciduous shrub	6-9, 14-21	✓	✓	✓	chap., woodland	✓	✓	✓	✓	✓			✓		
Ribes speciosum	Fuchsia Flowering Gooseberry	deciduous shrub	8, 9, 14-24	✓	✓	✓	chap., woodland		✓	✓		✓	✓		✓	✓	
Ribes viburnifolium	Catalina Perfume	evergreen shrub	8, 9, 14-24	✓	✓	✓	css	✓	✓	✓	✓✓	✓			✓	✓	
Romneya coulteri	Matilija Poppy	clumping semi-evergreen perennial	4-12, 14-24	✓	✓		css, chaparral	✓	✓		✓				✓		
Romneya trichocalyx	Hairy Matilija Poppy	clumping semi-evergreen perennial		✓	✓	✓	css, chaparral	✓			✓✓				✓		
Rosa californica	California Wild Rose	semi-deciduous shrub		✓	✓	✓	riparian, woodland	✓	✓	✓		✓	✓		✓	✓	
Salix lucida ssp. Lasiandra	Lance-leaf Willow	deciduous tree		✓	✓	✓	many	✓	✓				✓	✓		✓	
Salvia apiana	White Sage	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Salvia cedrosensis	Cedros Island Sage	perennial		✓			scrub	✓	✓		✓✓				✓		✓
Salvia clevelandii	Cleveland Sage	evergreen shrub	8, 9, 12-24	✓	✓		css, chaparral	✓	✓		✓✓				✓		
Salvia greggii	Autumn Sage	woody perennial	8-24		✓	✓	grassland, woodland	✓	✓		✓✓	✓			✓		✓

Master Plant List (Cont.)				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 32. 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 (Cont.)				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	✓	✓			✓	✓		✓		

General Plant List (Cont.)				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 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 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	✓			✓✓				✓		

General Plant List (Cont.)				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
Fremontodendron californicum	California Flannelbush	evergreen shrub	7-24	✓	✓	✓	chap, forest	✓			✓✓				✓		
Galvezia speciosa	Island Bush Snapdragon	evergreen shrub	14-24	✓	✓		css	✓	✓			✓			✓		
Heteromeles arbutifolia	Toyon	broadleaf evergreen tree/shrub	5-9, 14-24	✓	✓	✓	chaparral	✓	✓		✓✓				✓		
Hyptis emoryi	Desert Lavender	semi-evergreen shrub		✓	✓	✓	scrub	✓	✓		✓✓				✓		
Isocoma menziesii var. menziesii	Menzies' Goldenbush	evergreen subshrub		✓			css, beach/dune	✓	✓		✓✓				✓		
Iva hayesiana	Hayes Iva	evergreen shrub	10-13	✓	✓	✓	css, marsh	✓	✓		✓✓				✓		
Justicia californica	Chuparosa	semi-deciduous shrub		✓	✓	✓	scrub	✓	✓		✓	✓	✓		✓		
Keckiella antirrhinoides	Yellow Bush Penstemon	semi-evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓✓				✓		
Lepechinia fragrans	Fragrant Pitcher Sage	semi-evergreen shrub		✓	✓		chaparral	✓	✓		✓	✓			✓		
Mahonia nevinii	Nevin's Barberry	evergreen shrub	8-24	✓	✓	✓	css, chaparral	✓			✓✓	✓			✓		
Malacothamnus fasciculatus	Chaparral Mallow	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Malosma laurina (Rhus laurina)	Laurel Sumac	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Ornithostaphylos oppositifolia	Baja Bird Bush	evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓✓				✓		
Prunus ilicifolia ssp. Ilicifolia	Hollyleaf Cherry	broadleaf evergreen tree/shrub	7-9, 12-24	✓	✓	✓	chap., woodland	✓	✓		✓✓				✓		
Rhamnus californica	Coffeeberry	evergreen shrub	4-9, 14-24	✓	✓		chap., woodland	✓	✓		✓	✓			✓		
Rhamnus californica 'Eve Case'	Coffeeberry	evergreen shrub	4-24	✓	✓		chap., woodland	✓	✓		✓	✓			✓		
Rhamnus crocea	Redberry	evergreen shrub	14-21	✓	✓		css, chaparral	✓	✓		✓✓				✓		
Rhamnus ilicifolia	Hollyleaf Redberry	evergreen shrub	7-16, 18-21	✓	✓	✓	chaparral, woodland, forest	✓	✓		✓✓				✓		
Rhus integrifolia	Lemonadeberry	evergreen shrub	8, 9, 14-17, 19-24	✓	✓		css, chaparral	✓	✓		✓✓				✓		

General Plant List (Cont.)				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
Rhus ovata	Sugar Bush	evergreen shrub	9-12, 14-24	✓	✓	✓	css, chaparral	✓	✓		✓✓				✓		
Ribes aureum var. gracillimum	Golden Currant	semi-deciduous shrub	1-24		✓	✓	chap., woodland	✓	✓		✓✓	✓			✓		
Ribes malvaceum 'Dancing Tassels'	Dancing Tassels Currant	deciduous shrub	6-9, 14-21	✓	✓	✓	chap., woodland	✓	✓	✓	✓	✓			✓		
Ribes speciosum	Fuchsia Flowering Gooseberry	deciduous shrub	8,9, 14-24	✓	✓	✓	chap., woodland		✓	✓		✓	✓		✓		
Ribes viburnifolium	Catalina Perfume	evergreen shrub	8,9, 14-24	✓	✓	✓	css	✓	✓	✓	✓✓	✓			✓		
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		✓		✓	✓			✓		

General Plant List (Cont.)				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	✓	✓	✓	✓				✓		
Arctostaphylos 'Pacific Mist'	Pacific Mist Manzanita	groundcover	7-9, 14-24	✓	✓		chaparral	✓	✓		✓	✓			✓		
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	✓	✓		✓✓				✓		

General Plant List (Cont.)				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
Eriogonum crocatum	Saffron Buckwheat	evergreen subshrub/ herbaceous perennial	12-24	✓	✓		css	✓			✓✓				✓		
Eriogonum fasciculatum 'Dana Point'	Dana Point Buckwheat	groundcover	8, 9, 12-24	✓	✓		css	✓	✓		✓✓				✓		
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	✓	✓		✓✓				✓		

General Plant List (Cont.)				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 greggii	Autumn Sage	woody perennial	8-24		✓	✓	grassland, woodland	✓	✓		✓✓	✓			✓		
Salvia sonomensis *	Creeping Sage	perennial	7-9, 14-24	✓	✓	✓	chap., woodland	✓	✓		✓				✓		
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 (Cont.)	

[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 33. 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	✓	✓				✓	✓		✓	

Bioretention Plant List (Cont.)				**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**
Groundcovers, Vines, Succulents, Perennials, Annuals																	
Achillea millefoilum	Yarrow	herbaceous perennial	1-24	✓	✓	✓	riparian	✓	✓	✓			✓			✓	
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	✓	✓	✓				✓		✓	

Bioretention Plant List (Cont.)				**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**
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	✓	✓		✓✓					✓	
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 34. 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	✓	✓		✓✓						

Vegetated Roof Plant List (Cont.)				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**
Epilobium canum	Hoary California Fuchsia	herbaceous perennial		✓	✓	✓	css, chaparral	✓	✓		✓✓						
Eriogonum crocatum	Saffron Buckwheat	evergreen subshrub/ herbaceous perennial	12-24	✓	✓		css	✓			✓✓						
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	✓			✓	✓					

Vegetated Roof Plant List (Cont.)				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
Nasella pulchra	Purple Needlegrass	bunchgrass		✓	✓	✓	css, chap, woodland	✓	✓		✓✓						

[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 B: California Planning and Regulatory Framework for LID

Introduction

Low Impact Development is a relatively new practice in California. As such, LID is still being integrated into the California planning process. Very few general plans have water or water resources elements, and even fewer specifically address LID and hydromodification. Since the general plan is the foundation of the California planning process, and LID is not well addressed in general plans, LID is also inconsistently addressed in subsequent steps in the planning process.

When LID is addressed in the planning process, it is frequently incorporated at the site planning stage, which is too late in the process to make the kinds of impacts that are possible.

Currently, the State Water Resources Control Boards and California Regional Water Quality Control Boards are driving the use of LID measures in new development. The US Environmental Protection Agency, which has published several documents on both low impact development and smart growth as stormwater best management practices, also encourages LID.

NOTE: The following information is current as of the publishing of this document. Please contact the appropriate regulatory agency for the most up-to-date information.

LID in NPDES Stormwater Permits

Municipal Permits

Since the adoption of the San Diego County Municipal Separate Storm Sewer Systems (MS4) Permit in 2007, municipal permits within the region have contained specific LID and hydromodification requirements. The LID terminology is new, but the underpinnings of LID in MS4 permits in Southern California have existed for some time. The major emphasis of the LID requirements in municipal permits is on reduction of impervious area in order to facilitate infiltration and reduce urban runoff. New MS4 permits include LID requirements that apply to specified categories of new development and redevelopment projects. The Permittees are tasked with the responsibility of developing design and maintenance criteria and establishing minimum standards for the use of LID practices. They are also required to develop manuals or technical guidance for municipal employees and private sector practitioners involved with the implementation of LID practices.

San Diego County MS4 Permit

San Diego County's current MS4 Permit was adopted in 2007 (RWQCB Order No. R9-2007-01, NPDES Permit No. CAS0108758). The permit was the first in the region to contain specific LID requirements. Priority Development Projects are required, where feasible, to:

a) Conserve natural areas, including existing trees, other vegetation, and soils.
b) Construct streets, sidewalks, or parking lot aisles to the minimum widths necessary, provided that public safety and a walkable environment for pedestrians are not compromised.
c) Minimize the impervious footprint of the project.
d) Minimize soil compaction.
e) Minimize disturbances to natural drainages (e.g., natural swales, topographic depressions, etc.)
f) Minimize directly connected impervious areas and promote infiltration.

g) Drain a portion of impervious areas (rooftops, parking lots, sidewalks, walkways, patios, etc) into pervious areas prior to discharge, where feasible.
h) Properly design and construct the pervious areas to effectively receive and infiltrate or treat runoff from impervious areas, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors.
i) Construct a portion of walkways, trails, overflow parking lots, alleys, or other low-traffic areas with permeable surfaces, such as pervious concrete, porous asphalt, unit pavers, and granular materials, where site and soil conditions permit.

In addition, Priority Development Projects are required to maintain predevelopment flow rates and durations for a range of storms designated by the County.

Orange County MS4 Permits

Orange County has two separate NPDES Permits, which are administered by the Santa Ana and San Diego Regional Water Quality Control Boards. The current Santa Ana Region Permit was renewed in 2009 (RWQCB Order No. R8-2009-0030, NPDES Permit No. CAS618030). The San Diego Region Permit was also renewed in 2009 (RWQCB Order No. R9-2009-002, NPDES Permit No. CAS0108740).

Santa Ana Region: The permit requires priority development projects to ascertain the impact of the development on the site's hydrologic regime, and attempt to maintain or replicate the pre-development hydrologic regime through the use of design techniques that create a functionally equivalent post-development hydrologic regime. This is accomplished 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. LID site design principles must be followed to reduce runoff to a level consistent with the maximum extent practicable (MEP) standard. Priority development projects are required to infiltrate, harvest and re-use, evapotranspire, or bio-treat the 85th percentile storm event. Biotreatment systems may only be used if infiltration, evapotranspiration, and reuse are infeasible.

The Permittees are required to minimize the short and long-term impacts on receiving water quality from new developments and significant re-developments, including submittal of a Water Quality Management Plan (WQMP), emphasizing implementation of LID principles and addressing hydrologic conditions of concern, prior to issuance of any grading or building permits or recordation of any subdivision maps. The WQMPs are required to include BMPs for source control, pollution prevention, site design, LID implementation and structural treatment control BMPs.

San Diego Region: The permit requires the following LID BMPs to be implemented at all Development Projects where applicable and feasible:

a) Conserve natural areas, including existing trees, other vegetation, and soils.
b) Construct streets, sidewalks, or parking lot aisles to the minimum widths necessary, provided that public safety is not compromised.
c) Minimize the impervious footprint of the project.
d) Minimize soil compaction to landscaped areas.
e) Minimize disturbances to natural drainages (e.g., natural swales, topographic depressions, etc.)
f) Disconnect impervious surfaces through distributed pervious areas.

Priority Development Projects are required to implement LID BMPs which will collectively minimize directly connected impervious areas, limit loss of existing infiltration capacity, and protect areas that provide important water quality benefits necessary to maintain riparian and aquatic biota, and/or are particularly susceptible to erosion and sediment loss.

The following LID BMPs must be implemented at all Priority Development Projects where technically feasible as required below:

(i) Maintain or restore natural storage reservoirs and drainage corridors (including depressions, areas of permeable soils, swales, and ephemeral and intermittent streams.
(ii) Projects with landscaped or other pervious areas must, where feasible, drain runoff from impervious areas (rooftops, parking lots, sidewalks, walkways, patios, etc) into pervious areas prior to discharge to the MS4. The amount of runoff from impervious areas that is to drain to pervious areas shall not exceed the total capacity of the project's pervious areas to infiltrate or treat runoff, taking into consideration the pervious areas' geologic and soil conditions, slope, and other pertinent factors.
(iii) Projects with landscaped or other pervious areas must, where feasible, properly design and construct the pervious areas to effectively receive and infiltrate or treat runoff from impervious areas, prior to discharge to the MS4. Soil compaction for these areas shall be minimized. The amount of the impervious areas that are to drain to pervious areas must be based upon the total size, soil conditions, slope, and other pertinent factors.
(iv) Projects with low traffic areas and appropriate soil conditions must construct walkways, trails, overflow parking lots, alleys, or other low-traffic areas with permeable surfaces, such as pervious concrete, porous asphalt, unit pavers, and granular materials.

LID BMPs are required to capture and retain the volume of runoff produced from a 24-hour 85th percentile storm event, if technically feasible. LID biofiltration BMPs may be used to treat any volume that cannot be retained onsite. Conventional BMPs may only be used if LID BMPs are infeasible.

The Hydromodification Management Plan (HMP) shall be incorporated into the local Sewer System Management Plan (SSMP) and implemented by each Co-permittee so that estimated post-project runoff discharge rates and durations shall not exceed pre-development discharge rates and durations. Where the proposed project is located on an already developed site, the pre-project discharge rate and duration shall be that of the pre-developed, naturally occurring condition.

Riverside County MS4 Permit

The current Riverside County MS4 Permit was adopted in 2010 (RWQCB Order No. R8-2010-0033, NPDES Permit No. CAS618033). Priority development projects are required to infiltrate, harvest and use, evapotranspire, or bio-treat the 85th percentile storm event. Preference is given to retention through infiltration, harvest and use, and/or evapotranspiration. If these techniques cannot feasibly treat the entire design storm volume, then bio-treatment BMPs can be used. The permit requires new development and redevelopment projects disturbing more than one acre to maintain pre-development site hydrology (including runoff volume, velocity, duration, time of concentration) to the maximum extent practicable for the 2-year return frequency storm.

San Bernardino County MS4 Permit

The current San Bernardino County MS4 Permit was adopted in 2010 (RWQCB Order No. R8-2010-0036, NPDES Permit No. CAS618036). Priority development projects are required to infiltrate, harvest and use, evapotranspire, or bio-treat the 85th percentile storm event. Preference is given to retention through infiltration, harvest and use, and/or evapotranspiration. If these techniques cannot feasibly treat the entire design storm volume, then bio-treatment BMPs can be used. The permit requires new development and redevelopment projects disturbing more than one acre to maintain pre-development site hydrology (including runoff volume, velocity, duration, time of concentration) to the maximum extent practicable for the 2-year return frequency storm.

Ventura County MS4 Permit

Ventura County's current MS4 Permit was adopted in 2000, and is currently under revision (RWQCB Order No. R4-2009-0057, NPDES Permit No. CAS004002). The proposed permit establishes a 5 percent limit on effective impervious area (EIA) for new development and redevelopment, and requires that the design storm runoff volume from 95 percent of the impervious area be retained by infiltration, evapotranspiration, or reuse. EIA is the portion of surface area that is hydrologically connected via sheet flow over a hardened conveyance or impervious surface without intervening medium to mitigate stormwater from the design storm. On infill projects where 5 percent is not technically feasible, the project must reduce percent EIA to as close to 5 percent as feasible and no more than 30 percent of the total project area. The EIA difference may be made up through off-site mitigation. Off-site mitigation is required for the volume of stormwater from the design storm that that cannot be retained on-site within the 5 percent EIA limitations. Any design storm volume runoff from the impervious area of the site needs to be treated for stormwater quality.

Treatment BMPs must be selected in the following order of preference: Infiltration BMPs, BMPs that store and reuse stormwater, BMPs that incorporate vegetation and integrate multiple uses, BMPs that percolate runoff through engineered soils and allow it to slowly discharge downstream, and proprietary treatment control BMPs that are based on LID. Bioretention with an underdrain (biotreatment) is considered a treatment BMP and can be used only after the design storm volume has been retained and the water used on site.

A Technical Guidance Manual (TGM) was developed in 2002 for the previous permit to explain how to design and implement a variety of specific LID and Best Management Practices (BMPs) for the treatment of storm water utilizing source control, site design and structural treatment control. The 2002 TGM will be updated for the new permit requirements to provide cost effective strategies to successfully meet the latest storm water quality improvement goals. The new TGM will also provide alternative compliance measures where LID is infeasible or limited.

Los Angeles County MS4 Permit

Los Angeles County's current MS4 Permit was issued in 2001 and amended in 2006, 2007, and 2009 (RWQCB Order No. R4-2001-182, NPDES Permit No. CAS004001). A new permit is currently under development. There are no specific LID requirements in the current permit. The current LA County MS4 Permit requires that post-construction treatment control BMPs incorporate, at a minimum, one of the following design standards:

1. Volumetric Treatment Control BMP (Any of the four methods would be acceptable)
    a. 85th percentile 24-hour runoff event, or
    b. Volume of runoff produced from a 0.75 inch storm event, or
    c. Volume of annual runoff based on unit basin storage to achieve 80 percent volume treatment, or
    d. Volume of runoff from a historical-record based reference 24-hour rainfall for treatment that achieves the same reduction in pollutant loads achieved by the 85th percentile 24-hour runoff event.
2. Flow Based Treatment Control BMP (Any of the three methods would be acceptable)
    a. Flow of runoff produced from a rain event equal to at least 0.2 inches per hour intensity, or
    b. The flow of runoff produced from a rain event equal to at least two times the 85th percentile hourly rainfall intensity for Los Angeles County, or
    c. The flow from runoff produced from a rain event that will result in treatment of the same portion of runoff as treated using volumetric standards above.

The current Los Angeles County MS4 Permit does not require any LID measures. However, the Los Angeles County Department of Public Works proactively developed an LID manual for both private and public projects. As of January 2009, such projects within unincorporated LA County are required to implement LID measures (County of Los Angeles, 2009). The LID manual requires infiltration of ΔV, the increase of the runoff volume at parcel level (if possible). If parcel level LID is not possible, then the developer can apply for a regional LID solution. Currently, Los Angeles County is developing another LID Manual for infrastructure projects such as highways and drainage projects.

Phase II Municipal Permits

The SWRCB adopted a statewide General Phase II MS4 Permit in April 2003 (SWRCB Order No. 2003-0005-DWQ). The general permit covers small MS4s that are not directly regulated by the Phase I permits. Phase II communities are required to develop stormwater management programs that reduce the discharge of pollutants to the maximum extent practicable (MEP) and protect water quality. The Permittees are required to address stormwater runoff from new development and redevelopment projects that disturb more than one acre by developing and implementing control strategies, which can include a combination of structural and non-structural BMPs.

General Construction Permits

As of July 2010, all discharges related to construction activity will be required to obtain coverage under the statewide Construction General Permit (SWRCB Order No. 2009-0009-DWQ). The new permit establishes statewide post-construction runoff standards and requires the maintenance of a site's predevelopment hydrology in order to control hydromodification.

The regulatory approach of the permit is one of effluent limitation and hydrograph control. The pre-development site hydrology must be evaluated and approximated using structural and non-structural controls so that there is no increase in the volume of runoff that leaves the site and no decrease in the time of concentration.

Incorporating LID into the Planning Process

Incorporating LID into 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.

Possible Approaches to Incorporate 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. Not many 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 Local Government Commission 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 Local Government Commission (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

A specific plan is a 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 Local Government Commission.

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 Low Impact Development (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.

Changes to Los Angeles Municipal Code

The City of Los Angeles amended Chapter VI Article 4.4 Section 64.72 of the Los Angeles Municipal Code in January 2010 to incorporate LID. The code was amended to “expand the applicability of the existing Standard Urban Stormwater Mitigation Plan (SUSMP) requirements by providing stormwater and rainwater LID strategies for planning, and construction of development and redevelopment projects that require building permits” (LA DPW, 2010).

The City’s LID ordinance requires that stormwater runoff from development and redevelopment projects be managed to the maximum extent feasible through onsite infiltration, evapotranspiration, capture and reuse, and biofiltration or bioretention BMPs.

Including LID in Stormwater Ordinances

County of Contra Costa

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 (CCCCWP) 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.

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Appendix C: 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. There are currently nine LEED Green Building Rating Systems, all of which are voluntary, consensus-based, and market-driven (U.S. Green Building Council, 2009). 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. A minimum of 40 points are needed for LEED certification. Two rating systems most relevant to LID are for new construction and neighborhood development.

The LEED for New Construction Rating System is designed to guide high-performance commercial and institutional projects, including office buildings, high-rise residential buildings, government buildings, recreational facilities, manufacturing plants, and laboratories of all sizes (U.S. Green Building, 2009). The intent is to promote healthful, durable, affordable, and environmentally sound practices in building design and construction (U.S. Green Building Council, 2009). Credit categories relating to LID include: Sustainable Sites, Water Efficiency, and Materials and Resources. Table C-1 provides examples of LEED credits that LID can be used to address.

Table 35. 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 36. 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

Source: The Low Impact Development Center, Inc.

Table C-2 (Cont.): LEED for Neighborhood Development Credit Options.

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP/Strategy
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
	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 37. 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
	Credit 3.8	Maintain water features to conserve water and other resources	1-4	Multiple LID BMPs

Source: The Low Impact Development Center, Inc.

Table C-3 (Cont.): Sustainable Sites Initiative Prerequisite and Credit Options.

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP/Strategy
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

Source: The Low Impact Development Center, Inc.

Table C-3 (Cont.): Sustainable Sites Initiative Prerequisite and Credit Options.

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP/Strategy
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
Monitoring and Innovation	Credit 9.2	Innovation in site design	8	LID Site Design Process
		Total Possible Points:	**127**	

Source: The Low Impact Development Center, Inc.

References and Resources

Congress of New Urbanism, Natural Resources Defense Council, and U.S. Green Building Council. 2009. *LEED 2009 for Neighborhood Development Rating System*. http://www.usgbc.org/DisplayPage.aspx?CMSPageID=148

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