FINAL

County of San Diego

Low Impact Development Handbook

Stormwater Management Strategies

Wdzfè 2014

Department of Public Works

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San Diego, California 92123

County of San Diego

DEPARTMENT OF PUBLIC WORKS

COUNTY ENGINEER
COUNTY ROAD COMMISSIONER
COUNTY SURVEYOR
COUNTY AIRPORTS
FLOOD CONTROL
WASTEWATER MANAGEMENT

INTRA - MEMO

Date: June 24, 2014

TO: Richard Crompton, Director REC 7/2/14
Department of Public Works

VIA: Troy Bankston, Deputy Director TB 06/27/14
Department of Public Works

FROM: CT Cid Tesoro, LUEG Program Manager
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SUBJECT: APPROVAL FOR THE LOW IMPACT DEVELOPMENT HANDBOOK

The County's Low Impact Development (LID) Handbook, approved in 2007, has been updated for consistency with the County's updated Standard Urban Stormwater Mitigation Plan (SUSMP), and the recently adopted Hydromodification Management Plan (HMP). The SUSMP was redesigned in 2008 using a unified LID approach that integrates site planning and design measures with engineered, small-scale Integrated Management Practices (IMPs). On January 5, 2011, the County's SUSMP was updated with HMP standards pursuant to requirements in the San Diego Regional Water Quality Control Board, Order No. R9-2007-0001 (Permit). At that time, six LID practices were utilized to meet HMP requirements: self-treating/retaining, pervious pavements, bio retention, flow-through planter, infiltration, cisterns/vaults with bio retention. As a result, the LID Handbook has been updated to effectively relate requirements in the SUSMP, HMP and seamlessly integrate as an Appendix to the SUSMP. The LID Handbook update accomplishes several key objectives:

- All LID design guidelines are consistent with the current SUSMP, HMP and new MS4 Permit
- Provides guidance consistent with the current research on LID implementation
- Creates an IMP selection matrix to guide decision making on the appropriate IMPs for the project
- Provides technical design guidance for up to 10 different IMP types

The Watershed Protection Program Development and Construction section solicited the Land Development community for local experts for the revision to the County's LID Handbook. The stakeholder group that participated in the update process consisted of: San Diego State University, Building Industry Association, Coastkeeper, local engineering consultants, local landscape architects, and appropriate County departments. The participation of the stakeholder group consisted of attending meetings, reviewing LID handbook chapters and providing technical expertise. Once the updated LID Handbook is adopted by the County, it will be posted to the DPW SUSMP web page and the appropriate educational outreach will follow.

If you have further questions or need additional information, please contact René Vidales, Program Coordinator, at (858) 694-3246 or Rene.Vidales@sdcounty.ca.gov.

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CONTENTS

FIGURES

TABLES

ABBREVIATIONS AND ACRONYMS

AC	asphalt concrete
ADA	Americans with Disabilities Act
ADVs	acoustic Doppler velocity meters
ASTM	American Society for Testing and Materials
BMO	Biological Mitigation Ordinance
BMP	best management practice
BOD	biochemical oxygen demand
Caltrans	California Department of Transportation
CASQA	California Stormwater Quality Association
CEQA	California Environmental Quality Act
CIMIS	California Irrigation Management Information System
County	County of San Diego
DCIA	directly connected impervious area
E. coli	*Escherichia coli*
ESA	environmentally sensitive areas
ET	evapotranspiration
FAR	floor area ratio
HMP	Hydromodification Management Plan
HOA	homeowners association
HSG	hydrologic soil group
IMP	integrated management practice
in	inches
IWS	internal water storage
LID	low impact development
MEP	maximum extent practicable
meq	milliequivalents
mg/L	milligrams per liter
mL	milliliters
MPN	most probable number
MSCP	Multiple Species Conservation Program

NCDC	National Climatic Data Center
n.d.	no date
$NO_{2,3}$-N	nitrite+nitrate nitrogen
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
O&M	operation and maintenance
PICP	permeable interlocking concrete pavers
ppm	parts per million
RPO	Resource Protection Ordinance
RWQCB	Regional Water Quality Control Board
SANDAG	San Diego Association of Governments
SDCWA	San Diego County Water Authority
SUSMP	Standard Urban Stormwater Mitigation Plan
SWMP	Stormwater Management Plan
SWPPP	Stormwater Pollution Prevention Plan
TAs	total arsenic
TCd	total cadmium
TCr	total chromium
TCu	total copper
TKN	total Kjeldhal nitrogen
TMDL	total maximum daily load
TN	total nitrogen
TNi	total nickel
TPb	total lead
TZn	total zinc
UD	underdrain
USEPA	U.S. Environmental Protection Agency
WPO	Watershed Protection, Stormwater Management, and Discharge Control Ordinance
$	dollar
%	percent
°F	degrees Fahrenheit
µg/L	micrograms per liter

1 Introduction

1.1 Purpose and Organization of the LID Handbook

The goal of the County of San Diego (the County) Low Impact Development (LID) Program is to protect water quality by preserving and mimicking natural hydrologic functions through the use of stormwater planning and management techniques on a project site. The purpose of the *Low Impact Development Handbook* (LID Handbook) is to provide a comprehensive list of LID planning and stormwater management techniques for developers, builders, contractors, planners, landscape architects, engineers, and government employees as guidance to reference before developing a project site. The LID Handbook has been developed for the County under the guidance of the LID Technical Advisory Committee. Local municipal guidelines should be followed, if available, and the LID Handbook should be referenced after municipal compliance.

Examples of LID engineering solutions include infiltration and filtration of runoff in landscaped bioretention areas, permeable surfaces and soils, evapotranspiration by vegetation, biodegradation of pollutants by soil bacteria, and infiltration for groundwater recharge. Conventional development and storm drain system design typically inhibit natural hydrologic functions by creating large impermeable surfaces that prevent infiltration and groundwater recharge, increase runoff, and discharge polluted runoff off-site and eventually into streams, rivers, lakes, lagoons, bays, and ultimately the Pacific Ocean (Mount 1995). In addition to providing water quality benefits, LID practices reduce a fraction of runoff from developed areas and can assist with water conservation.

The LID Handbook is intended to complement the current *County of San Diego Standard Urban Stormwater Mitigation Plan Requirements for Development Applications* (Standard Urban Stormwater Mitigation Plan, or SUSMP) (County of San Diego 2012); *San Diego County's Hydrology Manual* (Hydrology Manual) (County of San Diego Department of Public Works 2003); and the *Water Efficient Landscape Design Manual* (Landscape Design Manual) (County of San Diego Department of Planning and Land Use 2010). Local design engineers, architects, landscape professionals, and contractors should use the current versions of the SUSMP and Landscape Design Manual for specific information related to the performance, design, operation, inspection, and maintenance of structural treatment controls and LID practices such as vegetated swales, bioretention basins, and permeable pavement. The LID Handbook provides guidance for new development and redevelopment to incorporate these practices and other techniques that reduce runoff, increase groundwater recharge, and improve water quality.

The County of San Diego SUSMP should be the first guidance document referenced during the development planning process. Once the SUSMP has been referenced, the LID Handbook is then intended to serve as a guide for LID implementation. This includes new development or redevelopment (net addition of more than 5,000 square feet of impervious surface, more than 1 acre of land disturbance, or both) of residential, commercial, industrial, civic (e.g., parks and churches), or public works projects. The LID Handbook should be used to reference LID planning policies and procedures, as well as general site designs for reducing stormwater quality impacts from new development and redevelopment projects. Once a conceptual LID site plan is developed, stormwater treatment, storm drainage, and flood control facilities should be designed on the basis of the design criteria presented in the current version of the

SUSMP (County of San Diego 2012). During the construction phase, best management practices (BMPs) should be employed to comply with the current San Diego County *Watershed Protection, Stormwater Management, and Discharge Control Ordinance* (WPO) (County of San Diego 2010a).

The LID Handbook is organized as follows, and is intended to be used by practitioners with varying levels of experience (Figure 1-1).

LID Handbook Organization

Section 1	**Introduction** provides LID background, benefits and goals, and an overview of stormwater regulations and management.
Section 2	**Site Planning Practices** contains LID planning practices, including land use planning, site assessment, retrofit considerations, and site design examples.
Section 3	**Integrated Management Practices** provides a brief discussion of LID integrated management practices (IMPs or on-site LID techniques).
Section 4	**Implementation Considerations** includes construction sequencing and critical steps for ensuring proper construction; guidance for conducting inspections during and after construction; guidance for maintenance and monitoring; and guidance for implementing demonstration projects.
Appendix A	**Integrated Management Practice Design Guidance** presents detailed design guidance, including cost estimates for implementation and operation and maintenance (O&M) over the life of the IMP.
Appendix B	**Integrated Management Practice Design Templates** includes standard design templates and design spreadsheets.
Appendix C	**Fact Sheets** contain educational materials detailing the basic design components and multiple benefits of LID practices.
Appendix D	**Inspection and Maintenance Checklist** consists of adaptable templates for IMP maintenance personnel.
Appendix E	**Plant Palette** describes locally appropriate plants to use when implementing IMPs.
Appendix F	**Geotechnical Considerations** describes details regarding geotechnical investigations and reporting for LID IMPs.
Appendix G	**Example Bioretention Soil Media Specifications** provides details on bioretention soil mixture and testing to achieve regulatory compliance and provide water quality treatment.

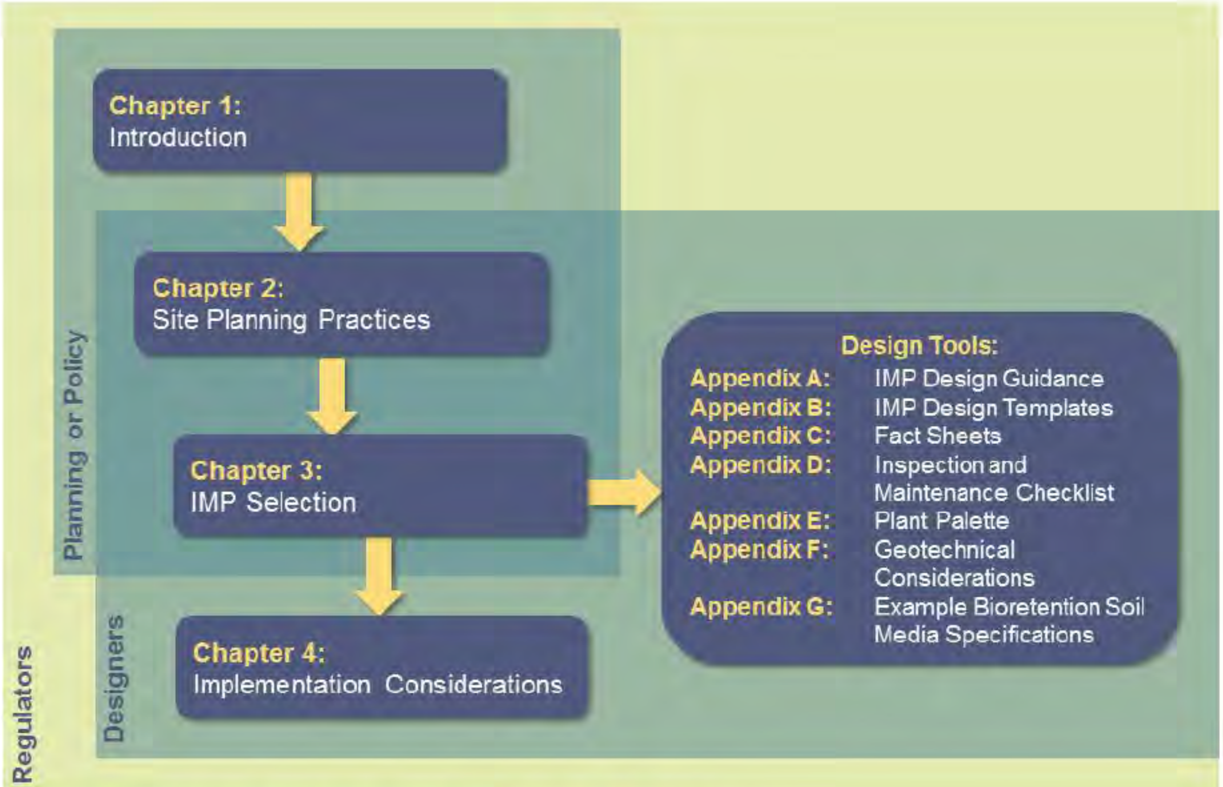


Figure 1-1. Document organization and intended audience.

1.2 Overview of Low Impact Development

LID is an innovative stormwater management approach with the basic principle that is modeled after nature: manage rainfall runoff at the source using uniformly distributed decentralized micro-scale controls. LID is "a stormwater management and land development strategy that emphasizes conservation and the use of on-site natural features integrated with engineered, small-scale hydrologic controls to more closely reflect pre-development hydrologic functions" (San Diego RWQCB 2013). This can be accomplished by creating site design features that direct runoff to vegetated areas containing permeable or amended soils, protect native vegetation and open space, and reduce the amount of hard surfaces and compaction of soil. LID practices are based on the premise that stormwater management should not be seen as merely stormwater disposal. Rather than conveying the runoff from small frequent storm events directly into underground pipes and drainage systems for discharge off-site, LID integrated management practices (IMPs) dissipate and infiltrate stormwater runoff with landscape features and, where practical, permeable surfaces located on-site, thereby reducing runoff volumes and filtering runoff before it leaves the site. Most forms of development can incorporate LID design techniques and practices.

Goals of LID

- Protect water quality
- Reduce runoff
- Reduce impervious surfaces
- Encourage open space
- Protect significant vegetation
- Reduce land disturbance

1.2.1 Challenges and Limitations of LID Practices

Not all sites can effectively use all LID techniques. Soil permeability, existing soil contamination, slope, and water table characteristics might limit the potential for local infiltration. Urban areas planned for multi-family and mixed-use development or high-rise construction and locations with existing high contaminant levels in the soil might be severely limited or precluded from using LID infiltration techniques on-site. A more community-level approach to LID, rather than a site-by-site approach, might be warranted. Other noninfiltration LID techniques such as street trees, permeable pavements with an underdrain, raised sidewalks, rainwater harvesting with appropriately designed barrels or cisterns, and vegetated roofs/modules/walls are still an option for projects in the urban setting; however, these techniques must be carefully integrated into projects with thorough consideration of engineering and geotechnical limitations.

Benefits of LID

- Protects surface and groundwater resources
- Reduces nonpoint source pollution
- Reduces habitat degradation
- Applicable to greenfields, brownfields, and urban developments
- Groundwater recharge
- Meets total maximum daily load (TMDL) and other stormwater requirements
- Ancillary benefits, including aesthetics, quality-of-life, air quality, water conservation, and property values

Source: Coffman 2002

1.2.2 LID and Stormwater Management Planning

Consideration of the strategies outlined in Figure 1-2 during the planning phase of a stormwater management scheme helps guide the decision-making process when selecting and designing BMPs to manage stormwater. The construction activities involved in translating a design concept for a stormwater management scheme into on-the-ground solutions will vary depending on what BMPs are included.

Strategies fall under the two broad categories of: Planning Practices; and IMPs. Common LID planning practices include site design planning based on natural land contours and decreasing the impervious surface. These methods include the following:

- Reducing impervious surfaces
- Disconnecting impervious areas
- Conserving natural resources
- Using cluster/consolidated development
- Using xeriscaping and water conservation practices

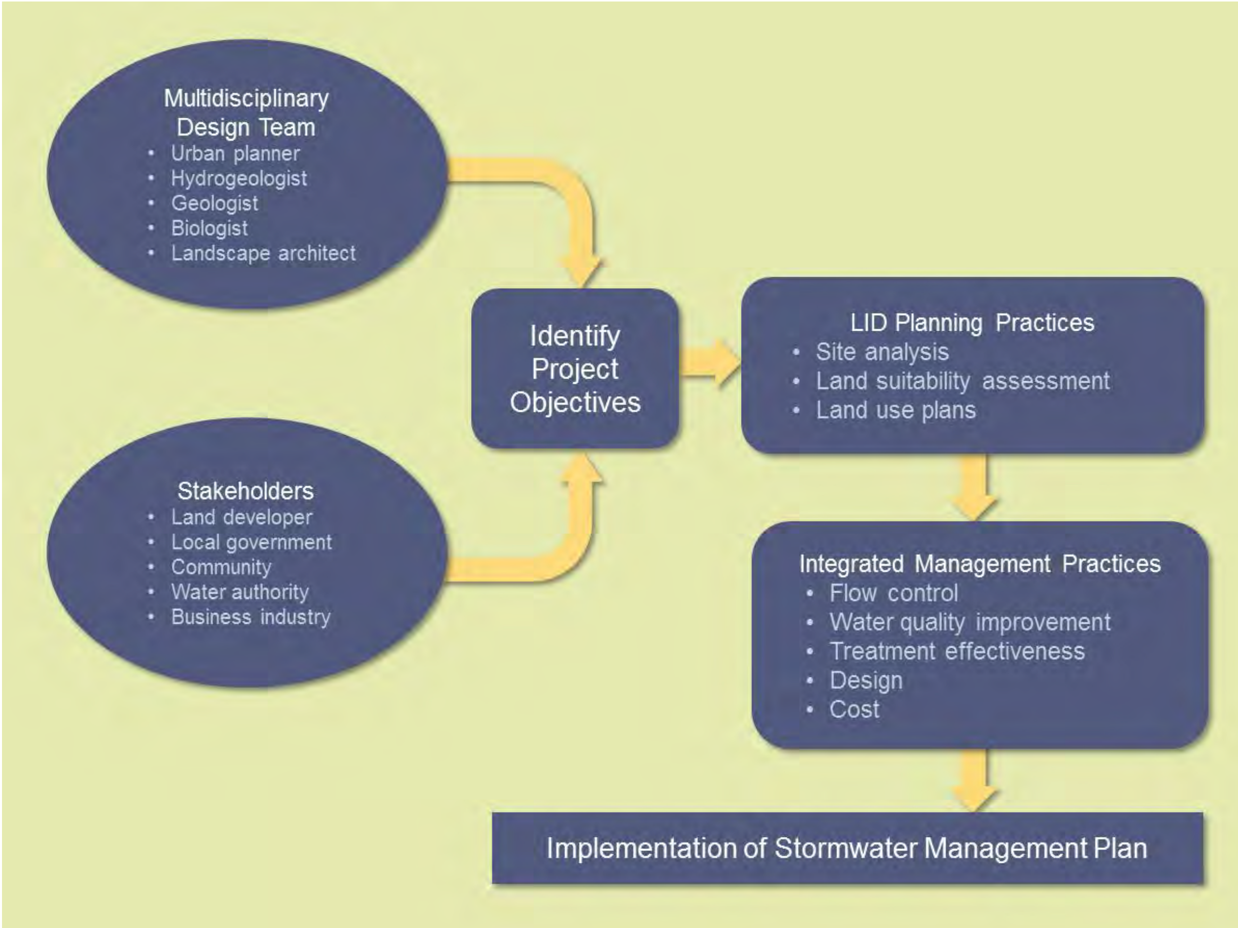


Figure 1-2. LID planning and implementation.

The basic LID strategy for handling runoff is to reduce the volume and decentralize flows. This is usually best accomplished by creating a series of smaller retention or detention areas that allow localized filtration instead of carrying runoff to a remote collection area for treatment (Lloyd et al. 2002). These are known as structural LID IMPs and may qualify as a treatment control BMP if it is properly sized.

Table 1-1 presents the common structural IMPs, along with their ability to improve water quality, address hydromodification, or both.

Table 1-1. Runoff management functions provided by the structural LID IMPs

Structural IMP	Model SUSMP water quality control	Model SUSMP hydromodification control
Bioretention and bioretention swales	●	●
Permeable pavement	●[1]	●
Rock infiltration swales	●	●
Flow-through planter	●	●
Vegetated (green) roof systems	●[2]	●
Sand filters	●	
Rainwater harvesting and reuse systems	-- [3]	●
Vegetated swales	Recommended for pretreatment, conveyance	
Vegetated filter strips/buffers	Recommended for pretreatment, conveyance	

[1] Considered a self-treating or self-retaining area by model Standard Urban Stormwater Mitigation Plan (SUSMP)

[2] Runoff from vegetated roofs requires no further water quality treatment

[3] Can be used for water quality control when combined with infiltration or filtration IMP

1.2.3 LID and the Water Conservation in Landscaping Act

The County updated landscaping ordinance complies with the 2006 State of California Water Conservation in Landscaping Act, Government Code 65991 and 65595 (County of San Diego 2010b). This ordinance replaces the previous County Zoning Ordinance to instate more comprehensive, effective water conservation methods for landscaping by requiring water budgets, promoting installation and maintenance of efficient irrigation systems and plant selection, and reducing excess water from over-irrigation (County of San Diego 2010b).These design requirements will support landscapes that are essential to the quality of life in San Diego County as well as reduce the use of limited water supplies for irrigation and landscaping. The requirements will also be compatible with a variety of other landscaping objectives, including erosion control, brush management, and invasive plant species control, as well as filtering, treating, and using stormwater runoff in landscaped areas. Landscape design, installation, maintenance, and management can and should be water efficient (County of San Diego 2010c). The right to use water is limited to the amount reasonably required for the beneficial use to be served and the right does not and must not extend to waste or unreasonable methods of use.

1.3 Stormwater Management

1.3.1 State and Federal Stormwater Regulations

The California Regional Water Quality Control Board (RWQCB), a division of the State of California Environmental Protection Agency, requires all local jurisdictions to implement a stormwater program to address stormwater concerns. The RWQCB issued the region's first Municipal Stormwater Permit, or National Pollutant Discharge Elimination System (NPDES) permit, in 1990 (Order No. 90-42) and renewed the permit in 2001 (Order No. 2001-01), 2007 (Order No. 2007-0001), and 2013 (Order No. 2013-0001). The Municipal Stormwater Permits allow San Diego County jurisdictions to discharge stormwater runoff via storm drains into natural water bodies, contingent on meeting programmatic, monitoring, and regulatory criteria. Permit requirements mandate that the jurisdictions regulate development and existing establishments to comply with stormwater requirements.

The permit is a product of the federal Clean Water Act. Congress passed the Clean Water Act in 1972, and it was extended to include stormwater concerns in 1990; thus making it illegal to release pollutants above certain concentrations and loads into waterways. The RWQCB is responsible for ensuring that federal and state water regulations are implemented at the local level.

The RWQCB adopted a revised Municipal Stormwater Permit (Order No. R9-2013-0001) on May 8, 2013. The revised permit intends to further reduce the pollution conveyed by storm drains into local waterways by requiring additional stormwater improvements. The permit requires that San Diego jurisdictions require all developments, regardless of project type or size, to incorporate BMPs including LID techniques. The LID Handbook will serve as the guidance structure for these LID techniques. Additional detailed information about stormwater requirements can be found on the RWQCB Region 9 website at http://www.waterboards.ca.gov/rwqcb9/water_issues/programs/stormwater/.

1.3.2 Stormwater Management Plans and IMPs

To meet the goals of the NPDES permit renewed in 2001, the County established the *Watershed Protection, Stormwater Management, and Discharge Control Ordinance* (WPO) (County of San Diego 2010a). The WPO defines the requirements that are legally enforceable by the County. The County also established *Standard Urban Stormwater Mitigation Plan (SUSMP) Requirements for Development Applications* (County of San Diego 2012). The County SUSMP will be replaced with the BMP Design Manual in 2015. The SUSMP addresses land development and capital improvement projects. It focuses on project design requirements and related post-construction requirements, but not on the construction process itself. The SUSMP also addresses the WPO requirements.

To comply with the Clean Water Act, the state Water Code, and the above-mentioned WPO, San Diego County requires that property owners complete a Stormwater Management Plan (SWMP) before issuing any permit. The purpose of a SWMP is to document BMPs that will be implemented, upon final completion of the project, to prevent pollutants from entering stormwater conveyances and receiving waters. Priority development projects shall complete a Major SWMP. Priority development projects are required to have treatment control BMPs. When properly sized, IMPs can fulfill the treatment control BMP requirement.

Projects that do not meet the priority development project criteria are considered nonpriority projects. As such, these projects need only to complete a Minor SWMP. All projects east of the Pacific/Salton Divide should complete a Minor SWMP. Projects east of the Pacific/Salton Divide should comply with post-construction requirements in the state’s construction general permit.

1.4 LID Considerations in San Diego

San Diego County is between Orange and Riverside counties on the north, the U.S./Mexico International Border on the south, Imperial County on the east, and the Pacific Ocean on the west. San Diego County is incredibly diverse. With approximately 4,260 square miles of land (SANDAG 2004), the County includes a large variety of geologic and topographic conditions, land uses, and climate types, all of which influence stormwater runoff planning strategies. Key physical factors in San Diego County that affect the function, design, and performance of LID measures include climate (precipitation, temperature, evapotranspiration); geology (slopes and soils); hydrology (rain distribution and runoff); groundwater; surface water quality objectives; and land use planning and constraints.

1.4.1 Climate

One of the key physical factors in San Diego that can affect the function, design, and performance of LID measures is climate (precipitation, temperature, evapotranspiration). San Diego County has a mild, equable climate characterized by warm, dry summers and mild winters. The climate can vary considerably, however, between the coastal, mountain, and desert areas (Figure 1-3). Figure 1-4 shows major rivers and other water bodies, as well as the divide that separates the western (South Coast Basin) and eastern (Colorado River Basin) watersheds. This divide follows the mountain ridgeline with elevations that vary from 3,000 to 5,000 feet above sea level. Precipitation that falls east of the divide flows to the Salton Sea Basin, while runoff from precipitation west of the divide flows down the western slope to the Pacific Ocean. RWQCB has designated the western side of the divide as Region 9, and it is regulated by the Municipal Stormwater Permit (Order No. R9-2013-0001).

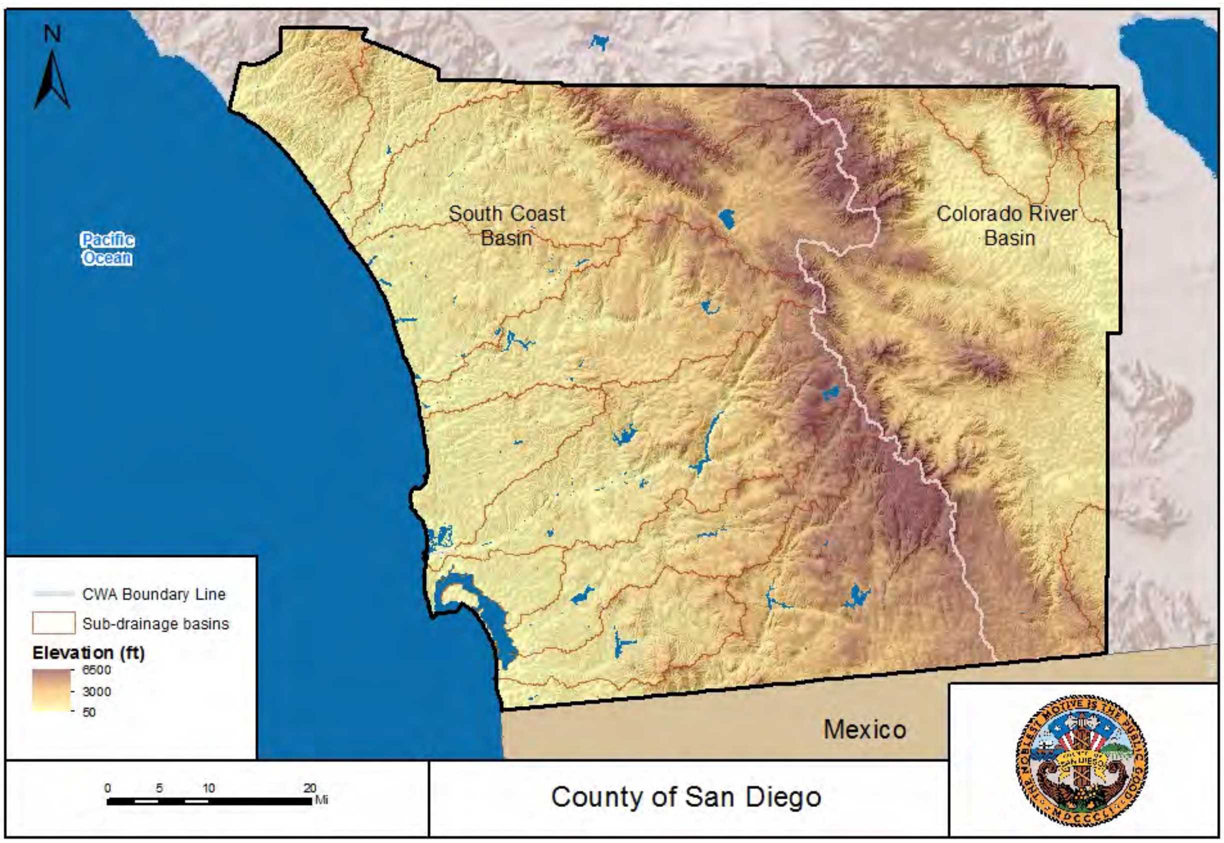


Figure 1-3. San Diego County topographic features affecting climate.

Figure 1-4. Major rivers and creeks in San Diego.

1.4.1.1 Precipitation

Rainfall across San Diego County is variable, with most rain falling from November to April. The average rainfall is highest in the mountains and lowest along the coast and in the desert. Most of the County experiences light rainfall, although some of the central mountain areas receive more than 30 inches per year. Annual precipitation along the coast averages 10 inches. The amount increases with elevation as moist air is lifted over the mountains. Some reporting points in the Cuyamaca and Vulcan Mountains measure more than 35 inches per year, with areas on Mt. Palomar receiving up to 45 inches. Totals diminish rapidly with decreasing elevation on the eastern slopes of the mountains, with some desert stations reporting as low as 2.5 inches per season. The map below (Figure 1-5) presents the average annual precipitation across San Diego County. Table 1-2 summarizes the average monthly distribution of rainfall across the year within San Diego County.

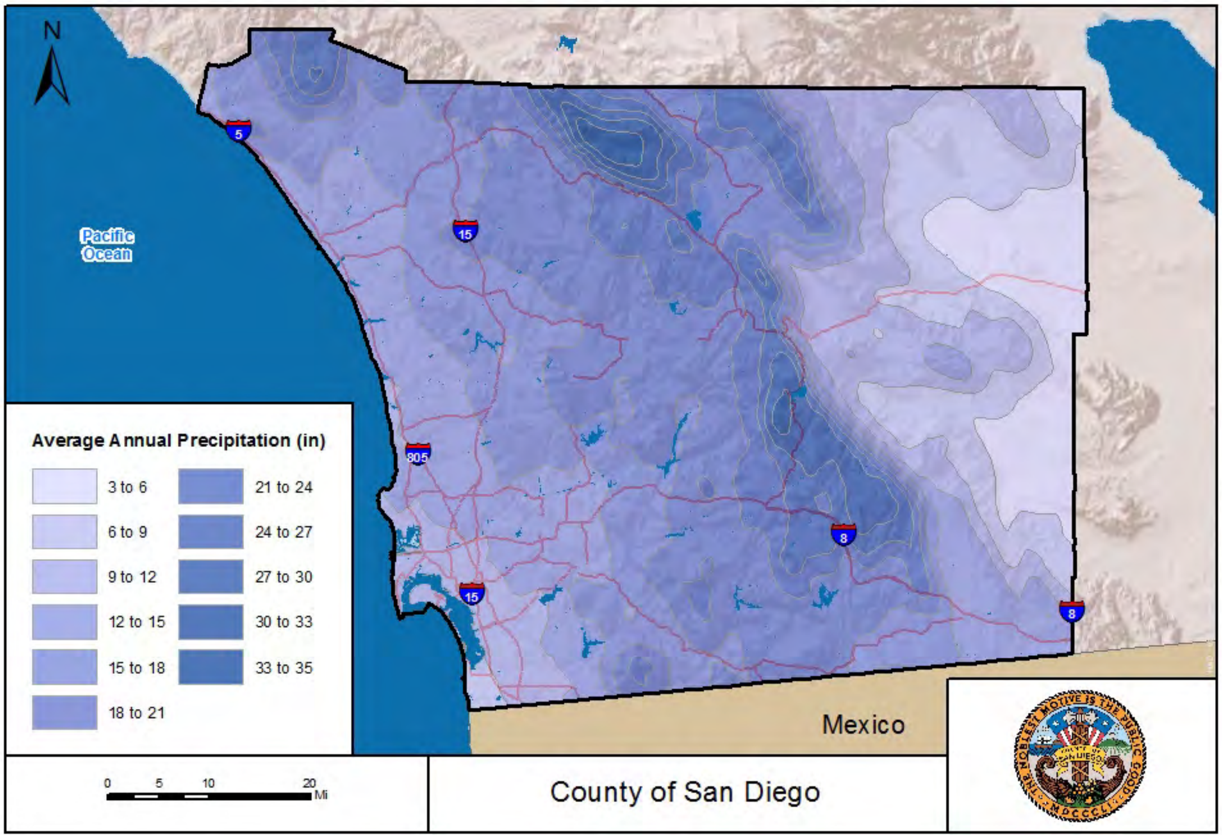


Figure 1-5. Average annual precipitation.

Table 1-2. Average monthly rainfall in San Diego County (inches)

Location	Monthly												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Alpine	3.03	3.60	3.14	1.24	0.36	0.15	0.23	0.15	0.27	0.74	1.75	2.11	16.77
Borrego Desert Park	1.14	1.32	0.84	0.17	0.05	0.02	0.30	0.44	0.31	0.24	0.39	0.91	6.13
Boulevard	2.93	3.37	3.22	1.01	0.29	0.10	0.41	0.60	0.21	0.95	1.26	2.67	17.02
Camp Pendleton	2.86	2.94	2.46	1.03	0.28	0.10	0.10	0.10	0.23	0.66	1.24	2.11	14.11
Campo	2.98	3.23	2.69	0.96	0.18	0.11	0.32	0.70	0.34	0.82	1.13	2.27	15.73
Carlsbad Airport	2.51	2.44	1.68	1.02	0.18	0.11	0.10	0.09	0.25	0.63	1.12	1.71	11.84
Chula Vista	1.94	2.30	1.69	0.69	0.09	0.07	0.03	0.01	0.14	0.53	0.91	1.43	9.83
Cuyamaca	5.54	6.52	5.77	2.67	0.71	0.20	0.41	0.82	0.74	1.88	3.26	4.89	33.41
Descanso Ranger Station	4.50	4.94	4.00	1.98	0.57	0.16	0.32	0.59	0.48	1.16	2.00	3.03	23.73
El Cajon	2.25	2.58	2.35	0.84	0.13	0.07	0.14	0.02	0.15	0.61	1.36	1.81	12.31
El Capitan Dam	2.90	3.54	3.26	1.27	0.30	0.08	0.07	0.05	0.19	0.86	1.44	2.42	16.38
Escondido	3.03	3.41	2.65	1.15	0.25	0.12	0.08	0.08	0.21	0.71	1.17	2.14	15.00
Henshaw Dam	5.42	5.64	4.63	1.86	0.45	0.14	0.28	0.48	0.55	1.09	2.21	3.94	26.69

Location	Monthly												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Imperial Beach	1.79	2.04	1.86	0.80	0.21	0.08	0.07	0.04	0.20	0.65	1.14	1.63	10.51
Julian	3.90	4.78	4.28	1.82	0.29	0.12	0.27	0.37	0.46	1.02	2.32	3.29	22.92
La Mesa	2.40	2.41	2.41	0.92	0.15	0.08	0.04	0.03	0.21	0.69	1.45	1.89	12.68
Lakeside	2.73	3.39	2.93	1.18	0.25	0.10	0.09	0.05	0.22	0.81	1.52	2.28	15.55
Oceanside	2.65	3.07	2.21	0.97	0.26	0.11	0.12	0.15	0.24	0.70	1.03	2.15	13.66
Ocotillo Wells	0.61	0.93	0.67	0.18	0.12	0.06	0.24	1.14	0.34	0.25	0.25	0.52	5.31
Palomar Mountain	5.88	6.61	4.75	1.91	0.55	0.17	0.37	0.77	0.51	1.23	2.48	4.97	30.20
Poway	2.69	3.02	2.41	0.97	0.26	0.10	0.03	0.09	0.20	0.57	1.28	1.93	13.55
Ramona Airport	3.32	3.11	3.08	1.40	0.30	0.12	0.13	0.15	0.29	0.72	1.19	2.23	16.04
San Diego Airport	1.98	2.27	1.81	0.78	0.12	0.07	0.03	0.02	0.15	0.57	1.01	1.53	10.34
San Pasqual	2.65	3.13	2.44	1.05	0.25	0.09	0.08	0.05	0.20	0.65	1.34	2.09	14.02
Vista	2.67	2.98	2.20	0.99	0.19	0.10	0.06	0.05	0.22	0.63	1.25	1.80	13.14

Note: 30-year normal precipitation for the period 1981–2010.
Source: NCDC 2013.

1.4.1.2 Temperature

Moderate temperatures are found year-round near the coast, while the interior part of the County has generally warm summers and cool winters. The average annual temperature is in the low 60s (Fahrenheit) on the coastal plain and in the coastal valleys it drops into the mid-50s at higher elevations in the mountains, and increases to values over 70 degrees in the desert areas at the eastern edge of the County. During the winter the mean minimum temperature drops to the mid-40s along the immediate coast, below 30 degrees in the mountains, and is in the mid-30s over the desert. July maximum temperatures average in the 70s along the coast, increasing to around 90 degrees in the foothills, and can exceed 100 degrees in the desert area. Table 1-3 summarizes the average monthly distribution of temperature in San Diego County.

Table 1-3. Average monthly temperature in San Diego County (°F)

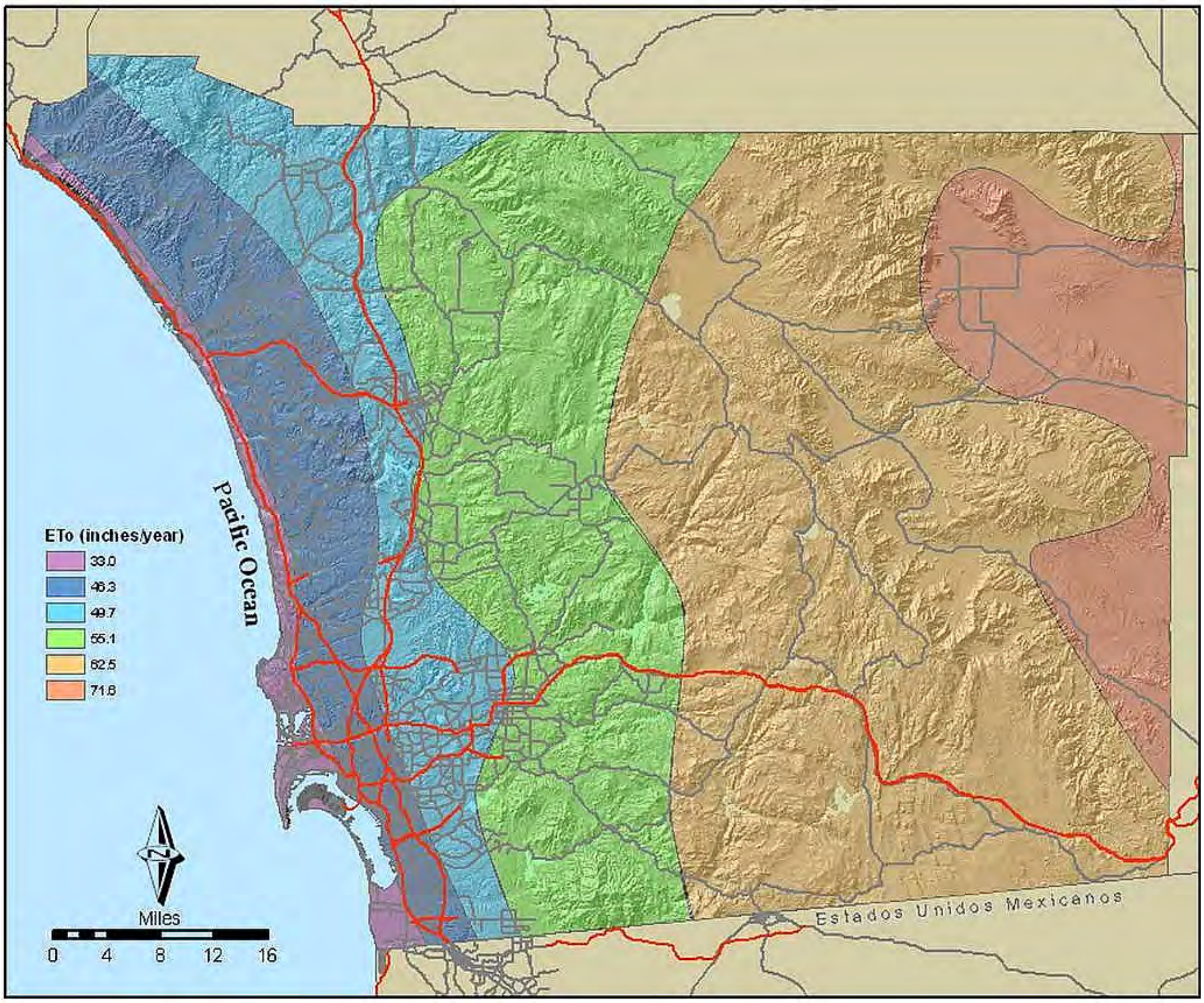
Location	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alpine	54.1	54.2	55.9	59.2	63.2	68.4	74.3	75.7	73.3	66.5	59.2	53.5
Borrego Desert Park	56.2	58.5	63.5	68.9	76.7	84.8	90.8	90.3	84.8	74.4	63.2	55.3
Camp Pendleton	54.3	54.9	56.7	59.2	62.9	66.2	70.6	71.1	69.9	64.9	58.8	53.5
Campo	48.5	49.5	51.6	55.1	60.7	66.2	72.8	73.7	69.1	60.7	53.0	47.7
Carlsbad Airport	55.4	55.8	56.9	59.1	62.0	64.8	68.2	69.9	68.6	65.2	59.7	55.2
Chula Vista	57.2	57.8	59.2	61.2	63.8	66.3	70.2	71.7	70.6	66.8	61.0	56.4
Cuyamaca	40.2	41.0	44.1	48.0	54.5	62.0	69.5	69.2	63.6	53.9	45.6	39.8
El Cajon	55.8	57.0	59.7	62.9	66.7	70.5	75.2	76.6	74.6	68.3	60.7	55.0
El Capitan Dam	55.3	56.3	57.9	61.7	65.7	70.7	75.7	76.0	74.6	68.7	60.7	55.7
Escondido	56.0	56.8	59.1	62.7	66.3	70.3	74.9	76.2	74.0	68.0	60.9	55.1
Henshaw Dam	44.6	45.8	48.7	52.2	58.3	64.5	71.5	72.3	67.0	58.0	49.5	43.6
Imperial Beach	56.4	57.6	59.0	60.7	63.2	65.8	68.4	70.0	68.9	64.4	59.4	56.7
Julian	44.9	45.7	47.4	52.2	58.1	65.6	73.1	72.6	67.9	59.8	51.1	44.1
La Mesa	57.9	58.4	60.1	63.2	65.9	69.4	73.7	75.3	74.1	68.4	62.2	57.4
Mount Laguna	41.2	41.2	45.6	51.1	58.2	65.0	71.1	70.2	65.2	55.4	47.6	41.2
Oceanside	53.0	54.2	55.7	58.6	61.8	65.3	68.6	69.4	67.8	62.9	56.9	52.6
Ocotillo Wells	58.8	61.5	67.5	73.6	81.3	88.6	95.3	93.8	89.0	78.7	65.5	57.3
Palomar Mountain	42.9	42.6	46.4	50.8	58.5	67.1	73.5	73.2	68.1	58.4	49.0	42.7
Ramona Airport	50.2	51.0	52.9	55.9	61.5	67.0	72.1	74.0	70.5	63.4	55.5	49.6
San Diego Airport	57.1	57.9	59.4	61.7	64	66.4	70.0	71.6	70.6	66.7	61.3	56.5
San Pasqual	55.5	56.8	58.8	61.9	66.1	70.1	74.8	75.9	73.7	67.6	60.1	54.7
Vista	56.0	56.2	57.6	60.4	63.6	66.8	71.0	72.3	71.1	66.3	60.4	55.4

Note: 30-year normal air temperature for the period 1981–2010.
Source: NCDC 2013

1.4.1.3 EVAPOTRANSPIRATION

The term *evapotranspiration* refers to the total transfer of moisture to the atmosphere from the soil, water bodies, vegetation canopy (evaporation), and plants (transpiration). Evapotranspiration can represent a significant water loss from a watershed. Types of vegetation and land use significantly affect evapotranspiration and, therefore, the amount of water leaving a watershed. Factors that affect evapotranspiration include the plant type (root structure and depth), the plant's growth stage or level of maturity, percentage of soil cover, solar radiation, humidity, temperature, and wind.

Monthly reference evapotranspiration, which is a measure of potential evapotranspiration from a known surface, such as grass or alfalfa, has been estimated for San Diego County by the California Irrigation Management Information System (CIMIS) and is represented in Figure 1-6.



Source: CIMIS 1999

Figure 1-6. Reference evapotranspiration (ET) for San Diego County (inches/year).

1.4.2 Geology and Soils

San Diego County can be divided into three distinct geomorphic provinces: (1) the Coastal Plain, (2) the Peninsular Range, and (3) the Salton Trough. The Coastal Plain is largely covered in sedimentary formational units. The Peninsular Range generally consists of granitic and other hard rock. The Salton Trough represents a relatively small, remote portion of the County, and has a limited extent of pervious sandy deposits. Unlike many other areas of California, San Diego County has relatively little in the way of pervious soils, such as alluvium-filled valleys and dune deposits. Thus, stormwater infiltration devices (lacking underdrains) might not be appropriate for many portions of the County.

A qualified engineer practicing geotechnical services shall review the proposed stormwater infiltration IMPs, including permeable pavements, to provide a professional opinion regarding the potential adverse geotechnical conditions that the implementation of these practices created. Geotechnical conditions such as slope stability, expansive soils, compressible soils, seepage, groundwater, and loss of foundation or pavement subgrade strength should be addressed. Where appropriate, mitigation recommendations should be provided. The review should include the impact on existing and proposed improvements. Appendix F provides further details for proper geotechnical investigations. The U.S. Department of Agriculture Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service, conducted a soil survey of the San Diego area in the early 1970s. The NRCS has classified San Diego area soils with respect to: (1) their ability to accept and absorb water, (2) their tendency to produce runoff, and (3) their erodibility (Bowman 1973). See the Caltrans Infiltration Study (Caltrans 2003) for more information on infiltration site selection.

While the majority of the County has soils that present significant limitations to infiltration potential, a few exceptions are noted. For example, the soils along the major streams of the Coastal Plain and the foothills have slight limitations to potential infiltration. The Lake Henshaw drainage corridor and the tributary drainage basin to the east, extending northwest and east along valley floors, comprise a large area where infiltration limitations are moderate. The valleys of the southern part of the mountain zone include scattered areas of soils that have slight limitations to infiltration. The desert zone includes extensive areas of soils that formed in alluvium and have slight limitations to infiltration.

The soil survey classified soil runoff potential into four hydrologic soil groups labeled A through D (Figure 1-7). Group A and B soils exhibit the greatest infiltration rates (unless soils are compacted during construction) and are generally best suited to stormwater percolation. The San Diego area, however, has a relatively high concentration of group C and D soils, which exhibit lower percolation rates that generally limit the use of infiltration-based stormwater management systems. Instead, bioretention type LID facilities are often equipped with underdrains. Such a design provides for filtration of the water quality design event through an engineered soil media as well as incidental infiltration of low flows.

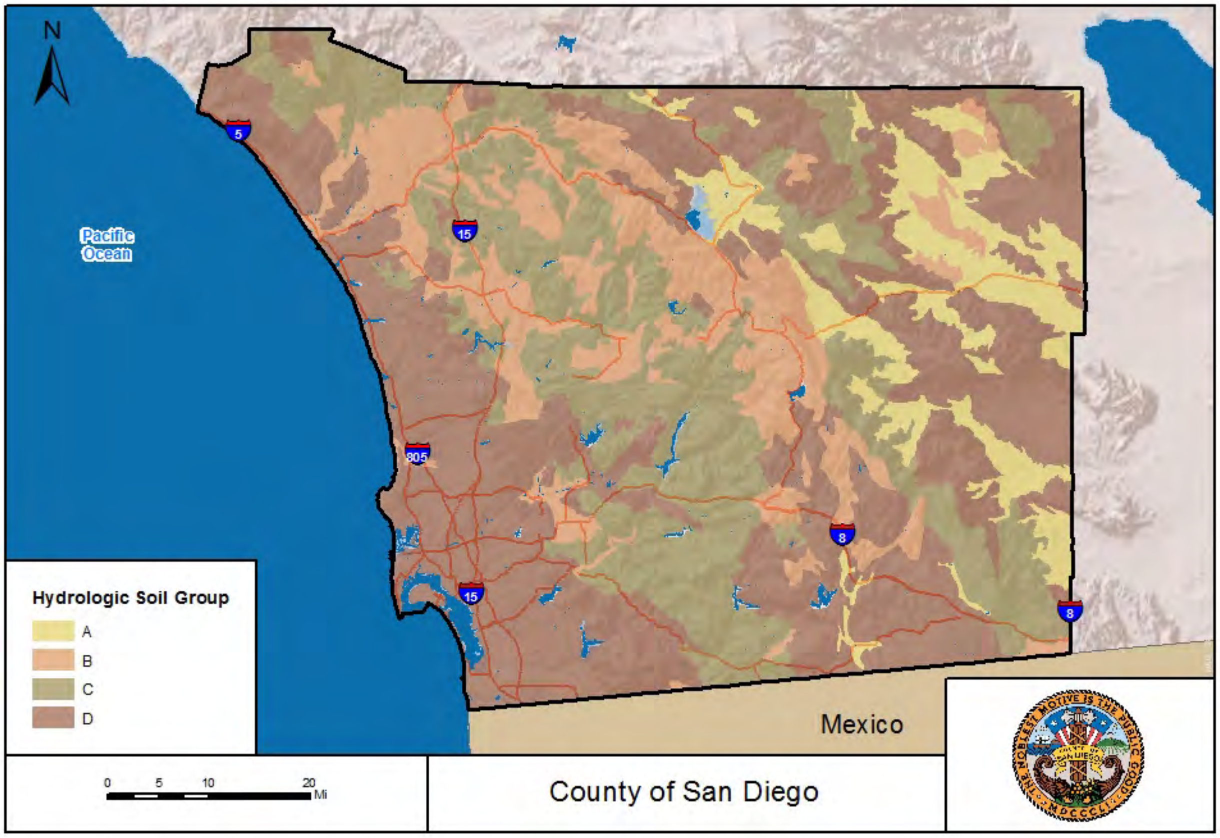


Figure 1-7. Hydrologic soil groups.

The hydrologic soil groups are defined as:

- **Group A** soils have a high rate of percolation and a low runoff potential. The rate of water transmission is high; thus, runoff potential is low. Group A soils are generally referred to as sandy soils.
- **Group B** soils have moderate percolation rates when thoroughly wet. These are chiefly soils that are moderately deep to deep, moderately well-drained to well-drained, and moderately coarse textured. Rate of water transmission is moderate.
- **Group C** soils have a slow percolation rate when thoroughly wet. They are chiefly soils that have a layer impeding the downward movement of water, or they are moderately fine to fine-textured soils that have a slow infiltration rate. The rate of water transmission is slow.
- **Group D** soils have very slow percolation rates when thoroughly wet. They are clays that have a high shrink-swell potential, soils that have a high permanent water table, soils that have a claypan or clay layer at or near the surface, or soils that are shallow over nearly impervious material. The rate of water transmission for group D soils is very slow.

The soil survey also evaluated erodibility. The majority of soils in the San Diego area exhibit moderate or severe erosion potential.

Data for a specific site, preliminary infiltration, runoff, and erodibility can be obtained by referring to the soil survey and consulting the complete national listing provided by the NRCS, or by performing an on-site investigation. For further detailed mapping, the California Geological Survey can be referenced. Retaining a qualified engineer practicing geotechnical services and conducting exploratory excavations at the site are highly recommended. Consideration should be given to the effects of urbanization on the natural hydrologic soil group. If heavy equipment can be expected to compact the soil during construction, or if grading will mix the surface and subsurface soils, appropriate changes should be made in the soil group selected (County of San Diego 2003).

1.4.3 Hydrology

Hydrology is the scientific study of the waters of the Earth and its atmosphere; their occurrence, circulation, distribution, chemical and physical properties; and their reaction with their environment, including the relation to living things. While the science of hydrology includes many aspects such as groundwater movement, oceanography, meteorology, and other aspects, the purpose of this section is to examine surface runoff.

This section describes the type of storm runoff events occurring in San Diego County as a result of the region's climate (discussed in section 1.4.1) combined with geology (discussed in section 1.4.2), topography, predominant soils, land use, and other factors. It also describes how these factors impact engineering design of stormwater conveyance features, including design of LID features. The practices described in this LID Handbook are designed to address surface runoff resulting from direct precipitation, with a goal of mimicking native field conditions as closely as possible to reduce surface runoff from developed areas. The LID Handbook describes LID features that can be incorporated on project sites to achieve this goal. Including native vegetation in landscaping is a complementary, beneficial practice to LID. It reduces the need for and amount of irrigation, which minimizes excess surface runoff and subsurface flow of irrigation water that is not representative of native field conditions.

1.4.3.1 Storm Intensity

Due to the convective winter weather pattern and relative proximity to the jet stream, San Diego County typically has high-intensity, short-duration storm events. Regardless of the amount of total rainfall delivered (measured in inches), the intensity with which it is delivered (measured in inches per hour) often results in flashy, high peak-flow rates of storm runoff. The design of LID features used in San Diego County must account for the high-intensity storms to provide for conveyance or bypass and appropriate erosion prevention. The engineer must assess how the design storm event that governs the design of stormwater conveyance systems for flood control (e.g., the 100-year storm event) will affect the LID features, which are typically designed for more frequent (85^{th} percentile) storm events. The engineer must determine whether the 100-year storm event should bypass the LID feature, or be conveyed through the LID feature, accounting for proper energy dissipation, scour prevention, and capacity. It is necessary to provide for overflow from the LID feature and to provide bypass if safe overflow (that would not result in erosion, flooding, or safety concerns) is not practical or achievable.

1.4.3.2 LAND COVER, SLOPE, AND SOIL TYPE

Land cover, slope, and soil type influence the ability of the watershed to capture or attenuate runoff. Within a development project, land cover is almost entirely determined by engineering design (site design). The intent of LID features is to enhance the land cover to mimic the project site's natural ability to intercept, store, and route runoff in the pre-development condition. This can be achieved by a combination of reducing the development features that act to reduce infiltration, preserving infiltration areas, and preserving natural drainage routes where possible. Section 3 of the LID Handbook discusses seven site design and LID concepts to meet these goals.

The design of LID features must respect hydrologic constraints presented by slopes (natural and engineered), soil types (natural and engineered/compacted), and the historical development of the area to provide a safe development. The naturally steep slopes and clayey soils that are predominant in San Diego County present unique challenges to achieving the goals stated above, and their hydrologic effects must be considered in the design of LID features. Steep slopes and clayey soils are not conducive to infiltration; forcing infiltration into such systems could cause slope or infrastructure failure. LID features that replace infiltration lost to impermeable surfaces should not exceed pre-development conditions or concentrate infiltration volumes that were previously dispersed throughout the site in the pre-development condition without considering subsurface geology and flow paths. Furthermore, knowledge of how tributary and downstream areas were developed in the past (e.g., whether underdrains were used in existing fill areas) is vital to help determine how increased infiltration could affect the project site as well as downgradient properties.

The existing soil types in the majority of developable area in San Diego County typically have low infiltration rates (less than 0.5 inch per hour (in/hr)) due to clays. Furthermore, steep slopes in San Diego County present a challenge to minimizing fill, as fill is often added to maximize buildable area. To protect fill slopes from erosion or failure, they are designed to drain runoff safely from the land surface to an engineered system, which minimizes intrusion of water into the fill. Based on these factors, neither the natural nor the engineered/compacted soils are conducive to infiltrating excess runoff on or above steep slopes. Increased seepage conditions could develop from increased infiltration of surface water to the subsurface, potentially creating problems on properties adjacent and downgradient from infiltration projects. Therefore, developers must work closely with a qualified engineer practicing geotechnical services on the design of infiltration IMPs to evaluate the site constraints as well as the potential impacts to downstream property owners.

Because of the difficulty of conveying runoff safely from fill areas and slopes, site design LID techniques can be used to reduce impervious areas. To maximize buildable area, developers can use techniques such as constructing streets, bicycle lanes, sidewalks, and parking lot aisles to the minimum width necessary; increasing building density (number of stories above or below ground); and minimizing the use of impervious surfaces, such as decorative concrete, in the landscape design. The function of natural absorption areas can be mimicked by maximizing canopy interception in the site landscaping, minimizing soil compaction, and replacing soil absorption in controlled locations where underdrain systems can be included to protect against increased seepage conditions. Underdrains can be used with planters, tree wells, biofiltration areas, and other landscaped areas with controlled drainage.

1.4.4 Groundwater Infiltration

1.4.4.1 Aquifer Characteristics in San Diego County

San Diego County has a variety of aquifer types and geologic environments that have different associated groundwater issues. The coastal zone is mostly supplied with imported potable water from the member agencies of the San Diego County Water Authority (SDCWA), partly because of the limited groundwater aquifer storage available in the coastal region. The remaining portion of the County (approximately 65 percent by area) depends solely on groundwater resources. For land to the east of the SDCWA boundary (shown in Figure 1-3), water resources are limited to naturally occurring surface and groundwater resources. In this area, no imported water is, or will likely become, available in the foreseeable future because of a lack of infrastructure, a limited availability of water within the desert southwest, the cost of providing these services, and the political approval needed to extend the SDCWA boundaries.

Groundwater resources in the County that lie east of the SDCWAs service area are limited due to the amount of rainfall and resulting infiltration, or groundwater recharge, as well as limited groundwater storage. The majority of this area is underlain by fractured rock aquifers that restrict development because of very limited groundwater storage. The area is underlain by relatively shallow alluvial aquifers typically found in river and stream valleys and intermountain valleys adjacent to and, in many cases, overlying fractured rock aquifers. Some of these aquifers have a relatively thin saturated thickness and, therefore, have limited storage. Desert basins in the extreme eastern portion of the County have relatively large storage capacity, but have extremely limited groundwater recharge. Because of the limited groundwater recharge, desert basins are particularly prone to groundwater overdraft, where groundwater extraction exceeds long-term groundwater recharge. High groundwater demand in Borrego Springs has resulted in an overdraft condition.

1.4.4.2 High Groundwater Conditions

High groundwater levels can occur in areas served by municipal water systems (i.e., where the groundwater is not withdrawn for use as a water supply) because septic system and irrigation return flows contribute water imported from another hydrologic system. Parts of Valley Center, Rainbow, Ramona, and a few areas east of Escondido have historic records of high groundwater. These areas have recorded septic tank failures which have led to bacteria and nitrate contamination of groundwater. A technical septic system failure occurs when the water table rises to within 5 feet of the bottom of a septic system disposal field. A minimum 10-foot separation is required to prevent the underlying groundwater and nearby surface waters from being contaminated by bacteria, nitrates, and possible virus strains in the wastewater. Stormwater infiltration devices may not be feasible in areas with septic systems.

In general, perennially high groundwater conditions are uncommon in the groundwater-dependent areas of the County east of the SDCWA line. A few exceptions include parts of Jacumba and a few other sporadic instances largely in alluvial aquifer environments.

1.4.4.3 Groundwater Contamination Concerns

Some pollutants, such as nitrates, bacteria, total dissolved solids, petroleum products, and solvents, can migrate to depths that can ultimately threaten water supply wells. Illegal dumping of waste oil, pesticides, herbicides, paint, paint thinner, and other chemical products into any type of infiltration device presents additional risk for groundwater contamination. Local water districts and other agencies generally have policies and strategies to protect groundwater supplies from these threats. These policies seek to balance the environmental benefits of infiltration with the compelling need to protect the quality of soil and groundwater supplies.

1.4.4.4 Groundwater infiltration concerns

A U.S. Geological Survey study of a groundwater recharge basin in Fresno showed that a wide variety of urban runoff pollutants were removed by absorption within the top 1.5 inches of sediment in the basin, and that no pollutants were found in the sediment at a depth greater than 6 inches. The results showed that the pollutants did not travel more than 6 inches deep—typically well above the level of groundwater wells. In the County, a 10-foot separation is recommended between infiltration practices and the top of the groundwater table to allow sufficient biological activity and filtration to occur.

With proper maintenance of stormwater management systems, pollutants infiltrating into the soil do not usually pose a risk of contaminated soil or groundwater. Risk is greater when pollutant sources are concentrated, such as in a heavy industrial site, at retail gas outlets, or in the case of illegal disposal.

Additional information on groundwater can be found in the groundwater section of the San Diego County *Low Impact Development Literature Index* (County of San Diego 2007).

1.4.4.5 Fire Safety Considerations

Although many practices are available to help reduce the impact of stormwater runoff in developed areas, the selected approach must account for public safety above all other factors. Fire safety demands accessibility to structures by fire apparatuses (trucks and other emergency vehicles) and allows residents to relocate in a safe manner in advance of an oncoming fire, flood, or other catastrophe. State and County fire codes specify how fire access roads are to be designed to provide emergency vehicle access within recognized operational parameters. Dead end roads must meet the California Code of Regulations Title 14 and County fire code requirements for secondary access and emergency vehicle turnarounds.

Vegetation management (fuel modification) must be maintained in compliance with fire codes, particularly adjacent to buildings and to grass-surfaced fire lanes. Landscaping restrictions limit the amount and type of native and ornamental vegetation within 100 feet or more of structures. Landscaping near specially designed roadways with grass covering must not interfere with fire apparatus access or with firefighter perception of vehicle accessibility.

Any design that allows water to travel through surfaces intended for travel by emergency vehicles must meet accepted County of San Diego design criteria to allow all-weather safe passage by heavy fire equipment. Areas designed for fire engine access that appear to be lawns or meadows (e.g., turf block) must be clearly marked as fire lanes and have an irrevocable easement which prohibits the installation of anything that could obstruct or appear to obstruct its use by fire engines. Fire officials want responding apparatus operators to be able to recognize designated fire lanes (fire access roadways) that appear to be lawns, and have confidence in the area's capability of safely supporting 50,000–75,000 pound engines and ladder trucks. Fire apparatuses can only use such surfaces in wet situations if the surface is virtually flat. Any grade makes traction and control very difficult.

Developments must be designed to permit testing of fire protection systems. Discharge of potable water from fire hydrants and sprinkler system test valves must be directed to permeable areas.

1.4.5 Standard Mitigation and Project Design Considerations for Vector Control

Minimizing mosquito production potential requires that water not be standing for sufficient time to permit eggs to develop to adult mosquitoes. For stormwater IMPs, this can be achieved by one of three ways: (1) discharging all captured water within 96 hours, (2) denying mosquitoes access to standing water, or (3) making the habitat less suitable for mosquito breeding. The most effective design strategy to exclude vectors from IMPs is to design the system to ensure that water is discharged within 96 hours, thereby eliminating the potential vector breeding source. Bioretention facilities typically dewater the surface ponding layer in less than 12 hours following a rainfall event, which is much less than the 96-hour threshold. Rapid dewatering is one of the main advantages of bioretention compared to traditional water quality basins.

The following recommendations are adapted from the document, *Managing Mosquitoes in Stormwater Treatment Devices*, prepared by the University of California (UC), Agriculture and Natural Resources, UC Mosquito Research Program. Managing standing water to eliminate the potential for vector breeding sources associated with stormwater treatment facilities must be addressed in a project's SWMP.

Measures to promote rapid discharge of captured water in IMPs include:

- Selecting or designing an alternative stormwater device that provides adequate constituent removal and drains completely within 96 hours. Special attention to groundwater depth is essential to determining water residence times.
- Incorporating features that prevent or reduce the possibility of clogged discharge orifices (e.g., debris screens). Using weep holes is not recommended because of the potential for rapid clogging.
- Using the hydraulic grade line of the site to select a treatment IMP that allows water to flow by gravity through the structure. Pumps are not recommended because they are subject to failure and often require sumps that hold water.
- Designing distribution piping and containment basins with adequate slopes that drain fully and prevent standing water. The design slope should consider the buildup of sediment between maintenance periods.
- Avoiding the use of loose riprap or concrete depressions that might hold standing water.
- Avoiding barriers, diversions, or flow spreaders that might retain standing water.

Additional information on mosquitoes and other vectors in San Diego can be found in the vector section of the San Diego County *Low Impact Development Literature Index*.

1.4.6 LID Treatment BMP Design Considerations

The design criteria for sizing site design IMPs have been developed as part of the SUSMP (County of San Diego 2012). IMPs can also be designed as treatment or pollution control IMPs. When IMPs are designed to have a treatment or pollution-reduction function, the sizing of the LID storage and treatment components need to account for additional regulatory drivers. For example, the San Diego Region Municipal Stormwater Permit (Order No. R9-2007-0001 and Order No. R9-2013-0001) requires that all Priority development projects have treatment control BMPs (see D.d.(1) of the Permit) and all treatment control BMPs meet the following design criteria:

- Volume-based BMPs – 24-hour, 85th percentile storm event.
- Flow-based BMPs – Maximum flow rate generated by a rainfall intensity of 0.2 inch per hour rainfall or maximum flow rate from 85th percentile hourly rainfall intensity.

The Permit allows for IMPs that are correctly designed to effectively infiltrate, filter, or treat runoff to be considered as treatment control IMPs. LID treatment/pollution control IMPs implemented in jurisdictions that need to consider additional pollution reduction goals as part of a TMDL program might also include design approaches that consider design storms based on *pollutograph* data and specific pollutant reduction goals of the watershed. These design approaches will depend on the specific watershed and jurisdictional regulatory drivers.

Applying these regulatory-driven approaches to the BMP design also needs to consider the specific site conditions as listed below. Sites with a greater number of constraints to increased infiltration and storage requirements will require additional engineered system components. For example, sites with low permeability soils will require additional storage above the sub-soils (where appropriate). Applying LID treatment control BMPs to sites that are characterized as least favorable for infiltration BMPs might not be suitable from a cost-benefit perspective when compared to other BMPs. Table 1-4 presents a possible range of site types from most (Site A) to least favorable (Site C) based on site conditions. Possible engineering solutions are listed in Table 1-4 to address site constraints. The design approach to LID treatment IMPs needs to consider possible engineering solutions; however, a cost-benefit analysis should be performed to compare with other possible IMPs that could help address water quality goals.

Table 1-4. Possible engineering solutions to address constraints at three hypothetical sites from the most favorable conditions (Site A) to the least favorable (Site C)

Site constraints	Site A	Site B	Site C	Possible engineering solutions
Low permeability soils	●	●	●	Increase storage by increasing depth and porosity of sub-base layers and amending sub-soils (or line and drain)
Shallow groundwater			●	Evaluate potential mounding and migration of constituents to verify IMP will not impact groundwater
Adjacent to existing structures		●	●	Provide underdrains and/or liners to prevent seepage from damaging existing structures
Space is limited		●	●	Evaluate the potential to provide greater storage below ground or provide storage through green roofs, rain barrels or other rain collection techniques
Adjacent to existing infrastructure/utilities	●	●	●	Provide underdrains and/or liners to prevent seepage from damaging existing structures

Site constraints	Site A	Site B	Site C	Possible engineering solutions
Proximity to foundations			●	Provide underdrains and/or liners to prevent seepage from damaging existing structures
Potential slope stability issues		●		Evaluate the potential for increased pore water pressure from increased infiltration
Presence of expansive soils			●	Provide underdrains and/or liners to prevent seepage from damaging existing structures. Rely on evapotranspiration as primary function rather than infiltration.

The approach to evaluating a site for the application of IMPs should first include identifying the desired level of treatment based on the regulatory drivers. The regulatory drivers can then be used to assign a design volume or flow. Site conditions should be assessed to identify the site constraints that might prevent achievement of the treatment goal. On the basis of the site constraints, a cost-benefit analysis should be conducted to evaluate site design alternatives that meet water quality goals. This cost-benefit analysis should evaluate the increased costs incurred to achieve higher infiltration or overall treatment volume based on site constraints. At higher treatment volumes and flows, costs are likely to increase sharply at a point where significant additional engineering components are required to address existing site constraints. Figure 1-8 shows that this point of sharp cost increase should then be compared to other water quality treatment options as required by the specific regulatory drivers. Sites with less favorable conditions (Site C) will have sharply increased costs at lower infiltration/treatment volume as compared to more favorable sites (Site A). Therefore, applying LID treatment BMPs to these less favorable sites might not be cost-effective.

The design considerations for applying IMPs should be compared to the applicable watershed and jurisdictional urban runoff management program goals and design guidelines.

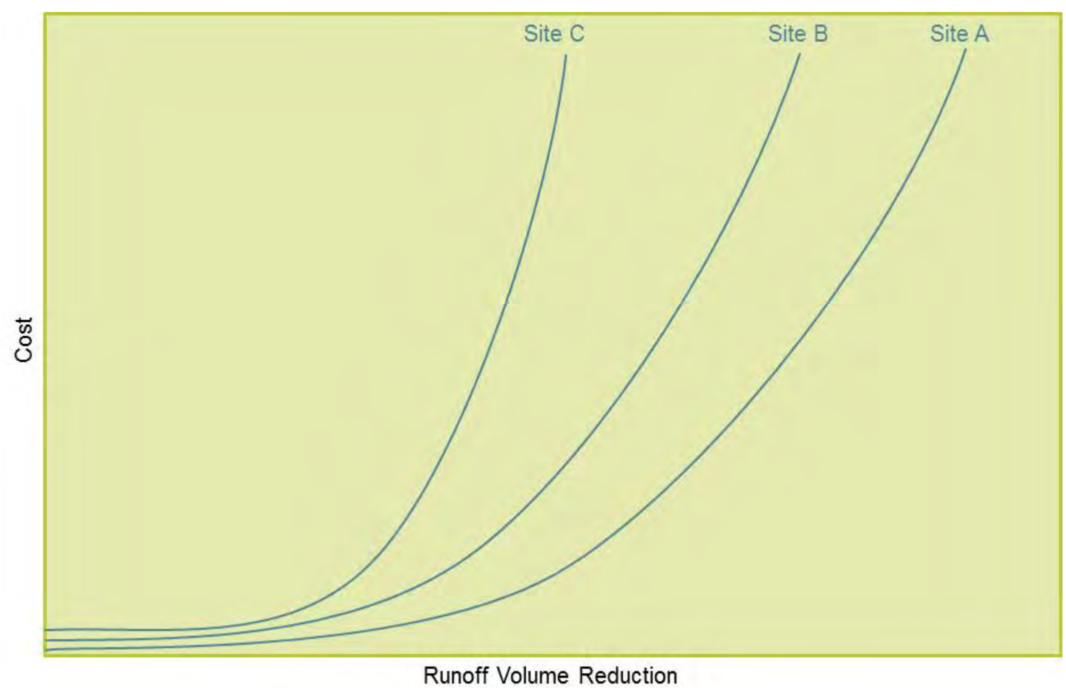


Figure 1-8. Comparison of costs at different levels of runoff volume reduction for three hypothetical sites with varying constraints (Site A is the least constrained, Site C is the most constrained).

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2 SITE PLANNING PRACTICES

2.1 SITE ASSESSMENT

Conducting a comprehensive inventory and assessment of site conditions is the crucial initial step for implementing low impact development (LID). To identify how stormwater moves through the site before development, the site assessment process should evaluate existing conditions such as existing hydrologic features and natural resources, existing site topography, soil types and depth to groundwater, existing vegetative cover and impervious areas, and drainage features (Figure 2-1).

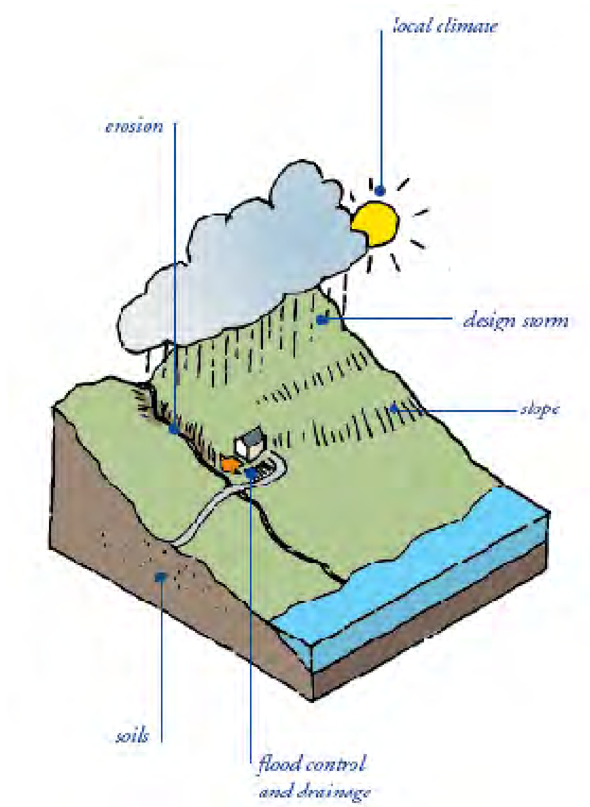

Figure 2-1. Climatic and site factors that affect LID design.

Next, the assessment must consider the land use requirements outlined in the San Diego County General Plan, which is a set of guiding principles designed to protect the County's unique and diverse natural resources and maintain the character of its rural and semi-rural communities. The assessment must also consider Multiple Species Conservation Program (MSCP) requirements (if applicable), open space and setback requirements, road design standards, sidewalks and parking requirements, driveways, and regulations regarding the use of cluster developments. Using this information, site planners and designers should consider how road design, lot configuration and construction practices can incorporate existing natural features on the site to retain beneficial natural hydrologic functions. In instances where these features do not exist or cannot be retained, LID site design integrated management practices (IMPs) should be used to mimic the site's pre-existing hydrologic function.

Site designers and municipal planners must understand site conditions and constraints and consider these as the basis for selecting appropriate stormwater quality controls. Site analyses should indicate how each of the constraints and opportunities (where applicable) affect the site (Coombes and Paskin 2002).

Use the following inventory check list to assist with identifying and evaluating a potential site for LID:

Site Assessment Checklist

Landform

- ❑ Existing site contours/topography
- ❑ Top and toe of slopes
- ❑ Steep slopes (>4%)
- ❑ Orientation of the site (north arrow)
- ❑ Natural features (contiguous natural areas)
- ❑ Existing site impervious area

Water Features

- ❑ Creeks and rivers
- ❑ Water flow direction
- ❑ Water quality issues
- ❑ Drainage patterns
- ❑ Ponds and reservoirs
- ❑ Wetlands areas
- ❑ Riparian zones
- ❑ Environmentally sensitive areas (ESA)
- ❑ Flood hazard zones
- ❑ Depth to groundwater
- ❑ Seeps and springs

Soils

- ❑ Soil type
- ❑ Permeability of soils
- ❑ Expansive soils
- ❑ Collapsible soils
- ❑ Landslides
- ❑ Depth to topsoil and subsoil
- ❑ Potential erosion areas
- ❑ Contaminated soils

Plants and habitat

- ❑ Vegetation type
- ❑ Evapotranspiration
- ❑ Existing trees and shrubs
- ❑ Weed species
- ❑ Sensitive species
- ❑ Vegetation to be removed
- ❑ MSCP area
- ❑ Dedicated Biological open space
- ❑ Park lands and preserves

Climate

- ❑ Average temperature
- ❑ Average precipitation
- ❑ Areas of full or partial shade
- ❑ Wildfire hazard

Site features

- ❑ Existing structures noted to be removed or retained
- ❑ Location and height of walls/fences
- ❑ Archaeological sites
- ❑ Easements
- ❑ Location of existing overhead and underground utilities
- ❑ Connections to existing municipal storm drainage conveyance system
- ❑ Aesthetic qualities on site
- ❑ Aesthetics qualities around the site

Land use planning

- ❑ General Plan and zoning requirements
- ❑ Setbacks and buffer requirements
- ❑ Parking lot requirements
- ❑ Landscaping requirements
- ❑ Building restrictions
- ❑ Street requirements
- ❑ Fire safety requirements
- ❑ Clustered development requirements
- ❑ Sidewalk and driveway requirements
- ❑ Lot configuration requirements
- ❑ High intensity land use areas
- ❑ Heavy vehicular or pedestrian traffic areas

Adjacent lands

- ❑ Quantification of off-site drainage to site
- ❑ Location of adjacent structures
- ❑ Rooftop and floor levels of adjacent buildings
- ❑ Form and character of adjacent buildings

2.2 SITE PLANNING

Assessment of the existing site, as outlined in the previous section, can be used to produce a series of constraint and opportunities maps to assist in the IMP planning process. Permeable soils or soils offering the best available infiltration potential should also be noted and used. Map layers showing different aspects of a site (soils map, slopes map, hydrology map, zoning, etc.) can be combined to delineate the places best suited for development. Building sites, road layout, and stormwater infrastructure should be configured within these optimal development areas to reduce disturbance to soil, significant vegetation, and drainage paths, and to take advantage of a site's natural stormwater processing capabilities.

To reduce directly connected impervious areas and promote filtration and infiltration, the site planning principles below must be considered to guide the layout and orientation of development projects. As required by the San Diego Region Municipal Stormwater Permit (San Diego RWQCB 2013), the following site design strategies must be implemented where applicable and feasible:

- Preserve or restore natural drainage corridors, storage reservoirs, topographic depressions, areas of permeable soils, existing trees, natural vegetation areas within the project footprint, natural swales, buffers around natural water bodies and riparian habitats, and ephemeral and intermittent streams.

- Minimize the impervious footprint of the site by constructing streets, sidewalks, and parking lot aisles to the minimum widths necessary, providing that public safety is not compromised.

- Minimize soil compaction in landscaped areas. Landscape with native or drought-tolerant species.

- Disconnect impervious surfaces by dispersing runoff from impervious surfaces to distributed pervious areas (such as directed roof downspouts that disperse runoff to a lawn).

- Design and construct landscaped or other pervious areas, such as turf, gravel, pervious pavement, or green roofs, to effectively receive and infiltrate or retain runoff from impervious areas before it discharges from the site. Such areas are referred to as self-retaining areas and no further treatment is required. Permeable materials should be used for site areas with low traffic and appropriate soil conditions.

- Drain impervious surfaces to engineered IMPs, such as bioretention facilities, located at, or as close as possible to, the source (i.e., the point where stormwater initially meets the ground) to minimize the transport of runoff and pollutants to the municipal separate storm sewer system (MS4) and receiving waters. IMPs infiltrate or percolate runoff through engineered soil and allow it to drain away slowly.

- Depending on the site conditions and local regulations, consider the feasibility of harvesting and using rainwater in conjunction with IMPs.

- Landscaping with native or drought tolerant species.

Combining two or more strategies might work best for the project. The strategies outlined above can provide multiple and complementary project benefits, such as reducing heat island effects, improving air quality, increasing the potential for water conservation, and decreasing the need for stormwater infrastructure.

The following sections define these LID site planning principles and how to apply them while designing an LID project site plan.

2.2.1 Conserve Natural Areas, Soils, and Vegetation

Consistent with San Diego County's Conservation and Open Space Element of the General Plan, the first site planning strategy is to conserve natural resources on site (County of San Diego 2011a). Assess the site for *significant trees*[1], shrubs, sensitive vegetation, and permeable soils and refer to applicable local codes, standards, easements, setbacks, etc., to define the protected areas (areas that should be left undisturbed, see Figure 2-2), define the development envelope (areas that are most suitable for development, see Figure 2-3), and create the draft site plan (County of San Diego 2011a).

Use the following guidelines to determine the sensitivity of the site's vegetated areas and rank them in order of increasing sensitivity. Within each of the categories detailed below, hillside areas should be considered more sensitive than flatter areas.

1. Areas devoid of vegetation, including previously graded areas and agricultural fields.
2. Areas of non-native vegetation, disturbed habitats, and eucalyptus woodlands, where receiving waters are not present.
3. Areas of chamise or mixed chaparral, and non-native grassland.
4. Areas containing coastal scrub communities.
5. All other upland communities.
6. Occupied habitat of sensitive species and all wetlands (as both are defined by the San Diego County Biological Mitigation Ordinance).

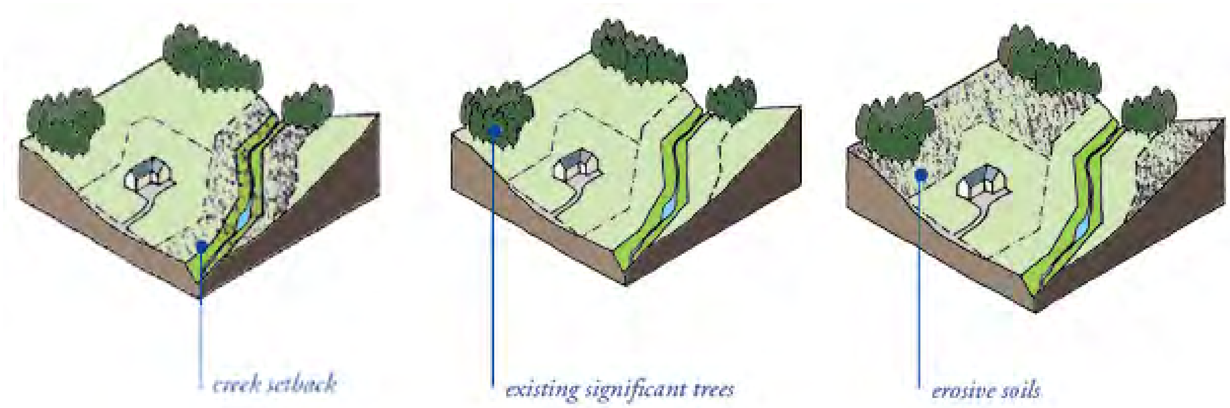

Figure 2-2. Examples of protected areas.

[1] Any tree which is more than 12 inches in diameter as measured 4.5 feet above the root crown; or any tree with a diameter of any two trunks of at least 16 inches as measured 4.5 feet above the root crown. Any oak tree of the *Quercus* genus more than 6 inches in diameter as measured 4.5 feet above the root crown; or any such tree with a total diameter of any two trunks of at least 8 inches as measured 4.5 feet above the root crown.

Where possible, conform the site layout along natural landforms, avoid excessive grading and disturbance of vegetation and soils, and replicate the site's natural drainage patterns. Set the development envelope back from creeks, wetlands, and riparian habitats. Preserve significant trees, especially native trees and shrubs, and identify locations for planting additional native or drought tolerant trees and large shrubs. Concentrate development on portions of the site with less permeable soils and preserve areas that can promote infiltration.

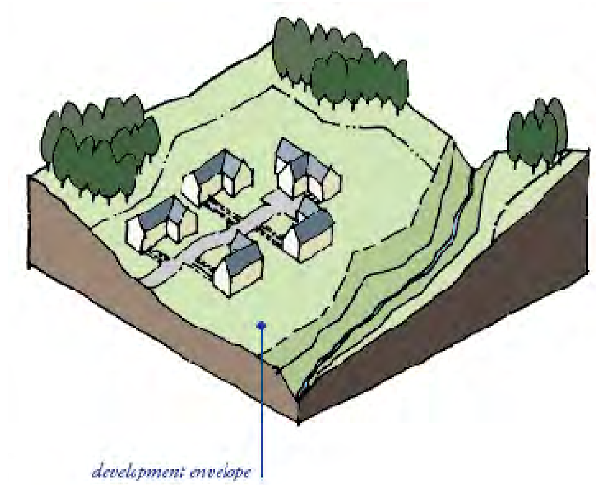

Figure 2-3. Development envelope.

The upper soil layers of a natural area contain organic material, soil biota, vegetation, and a configuration favorable for storing and slowly conveying stormwater. The canopy of existing native trees and shrubs also provide a water conservation benefit by intercepting rainwater before it hits the ground. By minimizing disturbances in these areas, natural processes intercept stormwater, providing a water quality benefit. By keeping the development envelope to the least environmentally sensitive areas of the site and set back from natural areas, stormwater runoff is reduced, water quality can be improved, environmental impacts can be decreased, and many of the site's most attractive native landscape features can be retained. Retaining these natural landscape features might also count toward landscaping credit for a development's required landscape plans. In some situations, site constraints, regulations, economics, or other factors might not allow avoidance of all sensitive areas on a project site. The standard California Environmental Quality Act (CEQA) review process will ensure that projects impacting biological resources on-site will offset those impacts with mitigation either elsewhere on-site or through off-site nature preserve creation to comply with CEQA, the Biological Mitigation Ordinance (BMO), MSCP objectives (if applicable), and other County requirements.

2.2.2 MINIMIZE DISTURBANCES TO NATURAL DRAINAGES

The next site planning strategy focuses on minimizing impacts to natural drainages (natural swales, topographic depressions, etc.). During the site assessment, natural drainage paths must be identified along with their connection to creeks and rivers, if any. Natural drainage pathways offer a benefit to the stormwater management strategy, since the soils and habitat already function as a natural filter or infiltration area. When determining the development footprint of the site, natural drainage paths should be avoided. By keeping the development envelope set back from natural drainage corridors (Figure 2-4), the water quality benefit to the watershed can be maintained.

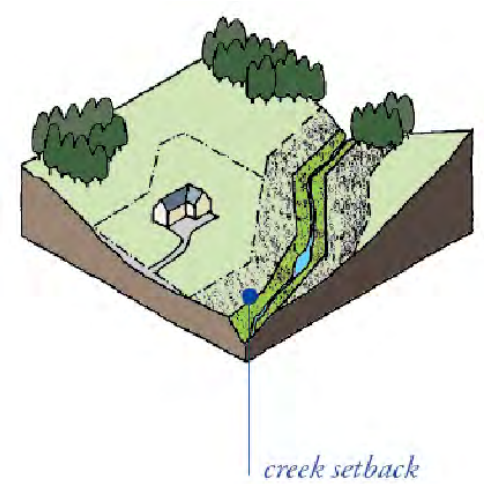

Figure 2-4. Setback from natural drainage corridor.

Implementing *treatment train* IMPs, such as filter strips and bioretention areas, further protects the natural drainage corridor from the adverse effects of urban runoff. In some situations, site constraints, regulations, economics, or other factors might not allow for the complete avoidance of drainage. The standard CEQA review process will ensure that projects impacting on-site drainage corridors will offset those impacts with mitigation to comply with CEQA, the BMO, the Resource Protection Ordinance (RPO), MSCP objectives (if applicable), and other County requirements.

2.2.3 Minimize and Disconnect Impervious Surfaces

Development typically increases impervious surfaces on formerly undeveloped land and reduces the capacity of remaining pervious surfaces to capture and infiltrate rainfall (Bay and Brown 2005). In traditional development, the runoff from these impervious surfaces is captured by pipes and is directly connected to the municipal storm drainage system. Impervious areas directly connected to the storm drainage system have been identified as contributing to degraded receiving water quality.

2.2.3.1 Minimize Impervious Surfaces

For all types of development, limit the overall coverage of paved areas and roofs. Where allowed by local zoning and design standards—and provided that public safety and walkable environment are not compromised—this can be accomplished by designing more compact, taller structures; narrower streets and sidewalks; smaller parking lots (e.g., fewer parking stalls, smaller stalls, and more efficient lanes); and indoor and underground parking. Examine the site layout and identify areas where landscaping can be substituted for pavement.

Minimizing impervious surfaces helps retain the permeability of the project site, allowing natural processes to filter and reduce nonpoint sources of pollution. Transportation-related surfaces such as streets, sidewalks, and parking lot aisles, should be constructed to the minimum width necessary, provided that public safety, circulation, and pedestrian access are not compromised (San Diego RWQCB 2013). In addition, low traffic areas are required to be constructed with permeable materials where underlying site conditions allow (San Diego RWQCB 2013).

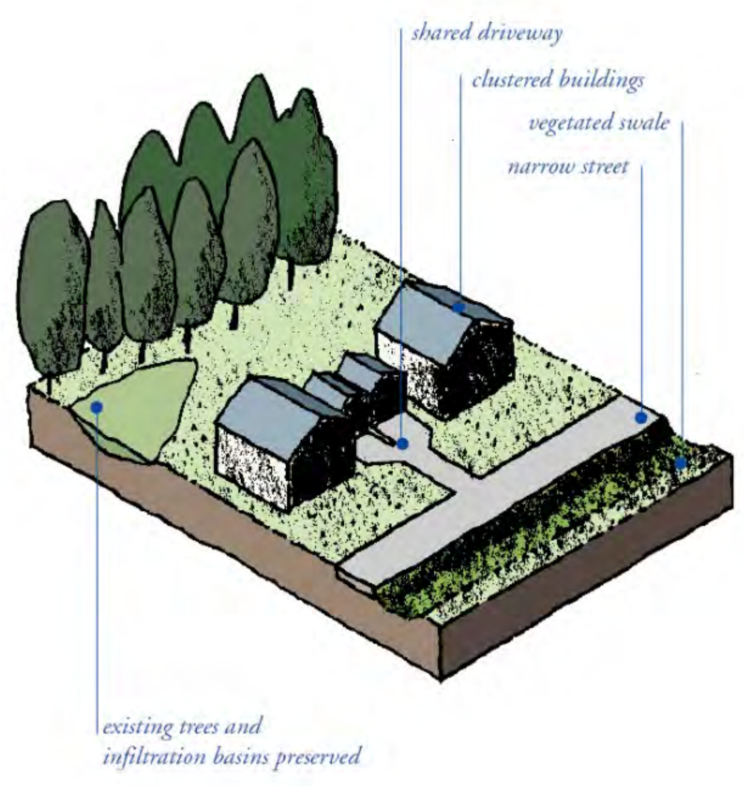

Figure 2-5. Example site layout that minimizes directly connected impervious surfaces.

2.2.3.2 Disconnect Impervious Surfaces

Creating pervious surfaces between impervious surfaces is an effective way to intercept urban runoff and reduce runoff volumes. This technique can be achieved by disconnecting continuously paved areas with landscaping or permeable materials and by directing roof runoff into vegetation, soils, or other permeable materials. The results include reduced stormwater peak flows and runoff volumes and filtration of the runoff before discharge to the municipal stormwater system or natural watercourses. Any impervious surface that drains into a catch basin, storm drain, or other impermeable conveyance structure is considered a *directly connected impervious area*. These impervious surfaces are principally comprised of rooftops and conventional pavements. Impervious surfaces that flow into a pervious area are not considered to be directly connected impervious area. However, the pervious area receiving the impervious surface runoff must be of appropriate width, area, location, slope, and design to effectively treat the contributing impervious area's runoff (Urbonas and Stahre 1993).

2.2.4 Minimize Soil Compaction

The fourth site planning strategy is to minimize soil compaction in planned pervious areas (infiltration areas, landscaping, lawns, green space, etc.) and reduce the overall area of soil disturbance. The upper soil layers contain organic material, soil biota, and a configuration favorable for storing and slowly conveying stormwater downgradient. By protecting native soils and vegetation in appropriate areas during the clearing and grading phase of development, the site can retain some of its existing beneficial hydrologic function. It is important to recognize that areas adjacent to and under building foundations, roads, and manufactured slopes must be compacted with minimum soil density requirements to comply with the Grading Ordinance (County of San Diego 2011b).

Clearing and grading exposes and compacts the underlying subsoil, producing a site with significantly different hydrologic characteristics as compared to the pre-development conditions. For this reason, avoid disturbing planned green space and proposed landscaped areas where possible. Areas planned for preserving beneficial hydrologic function should be protected during the grading and construction phase so that vehicles and construction equipment do not intrude and inadvertently compact the area. In urban sites, it might not be possible to completely avoid soil disturbance in the proposed pervious areas. In proposed landscaping areas where compaction cannot be avoided, re-tilling of the soil surface should be performed to allow for better infiltration capacity of underlying soil. Soil amendments are recommended and might be necessary to increase permeability and organic content. Soil stability, density requirements, and other geotechnical considerations associated with soil compaction must be reviewed by a qualified, licensed engineer (see Appendix F for further geotechnical information).

2.2.5 Drain Runoff from Impervious Surfaces to Pervious Areas

Identify opportunities to direct runoff from impervious areas to adjacent landscaping areas. The design, including slopes and soils, must reflect a reasonable expectation that an inch of rainfall will soak into the soil and produce no runoff. For example, a lawn or garden depressed 3 or 4 inches below the surrounding walkways or driveways provides a simple but functional landscape design element. Figure 2-6 shows examples of functional landscape design elements.

All priority development project sites are required, by Region 9 permits, to have at least one treatment control BMP. For sites subject to stormwater treatment requirements only, a 2:1 maximum ratio of impervious area to pervious areas (self-retaining area criteria) is acceptable, provided that the soils will drain adequately. For sites also subject to hydromodifcation flow-control, a maximum 1:1 ratio of impervious to pervious areas for self-retaining areas is mandatory. In some cases, runoff may be directed from impervious areas to pervious pavement. The pore volume of pavement and base course must be sufficient to retain an inch of rainfall, including runoff from the tributary area. The slopes and soils must be compatible with infiltrating the volume without producing runoff.

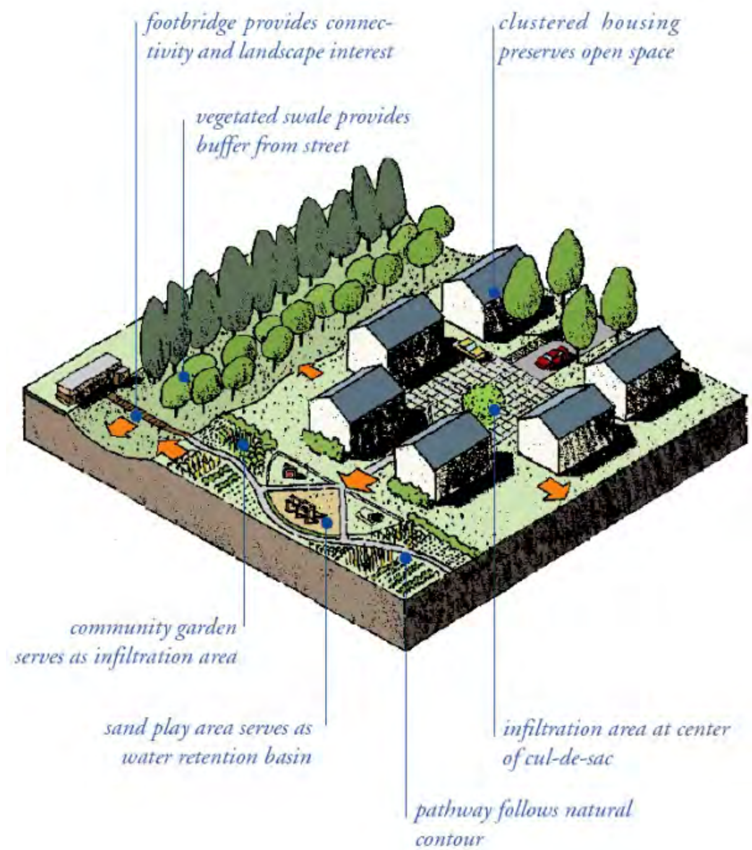

Figure 2-6. Functional landscape design elements that infiltrate stormwater.

Landscaped areas or other pervious areas (such as lawns) are required to be designed and constructed to receive stormwater runoff from rooftops, parking lots, sidewalks, walkways, patios, etc. (San Diego RWQCB 2013). An example is shown in Figure 2-7. These pervious areas help to slow, retain, filter, and treat runoff in the first few inches of the soil before discharging into the municipal stormwater system. When directly infiltrating into the ground using pure *infiltration IMPs* (e.g., infiltration trench, infiltration basin, dry wells), the soil conditions, slope and other pertinent factors must be addressed by a qualified licensed engineer.

Important Note: Proposed stormwater infiltration IMPs, including permeable pavements, must be reviewed by a qualified engineer practicing geotechnical services to provide a professional opinion regarding the potential adverse geotechnical conditions created by implementing the practices. Geotechnical conditions such as slope stability, expansive soils, compressible soils, seepage, groundwater, and loss of foundation or pavement subgrade strength should be addressed. Where appropriate, mitigation recommendations should be provided. The impact and associated liability on existing, proposed, and future improvements should be included in the review.

Location: Mission Valley Library. Source: C. Sloan.

Figure 2-7. Landscaped area infiltrates runoff from adjacent impervious areas.

Site Planning Resources

San Diego County General Plan	http://www.sdcounty.ca.gov/pds/gpupdate/docs/BOS_Aug2011/C.1-4_Conservation_and_Open_Space.pdf
California Environmental Quality Act (CEQA)	http://www.sdcounty.ca.gov/pds/zoning/formfields/PDS-202.pdf
Biological Mitigation Ordinance (BMO)	http://www.sdcounty.ca.gov/pds/mscp/bmo.html
Resource Protection Ordinance (RPO)	http://www.sdcounty.ca.gov/pds/docs/res_prot_ord.pdf
Multiple Species Conservation Program (MSCP)	http://www.sdcounty.ca.gov/pds/mscp/index.html

2.3 LID Site Design Examples

LID site design strategies reduce the quantity of runoff and improve the quality of stormwater runoff from new development and redevelopment. LID site design attempts to mimic the site's pre-developed (natural) hydrologic function. Site techniques involve the following:

- Reducing impervious surfaces.
- Disconnecting impervious surfaces from storm drains and other impervious surfaces to allow natural infiltration and treatment of stormwater runoff (e.g., Figure 2-8).
- Increasing opportunities for infiltration and conveyance through vegetated and landscaped features.
- Reducing soil compaction in the areas of the proposed LID treatment facility.
- Reducing road and driveway widths in exchange for additional landscaping and green space.
- Protecting sensitive natural areas, habitats, and important drainage corridors.
- Linking greenways, parks, wilderness, and conservation land.

Location: Palomar Airport in San Diego County, California.

Figure 2-8. Parking lot that drains to a vegetated swale.

This section provides guidance on how LID concepts can be addressed for three basic types of land use development: residential, commercial, and industrial.

The site planning principles and design concepts described in the following pages are integrated in a series of design examples. The examples are illustrative only and are not intended to represent comprehensive requirements for all development projects. Actual sites and projects will require various combinations and engineering ingenuity to suit unique site conditions.

To provide multiple opportunities for stormwater treatment and to maximize the effectiveness of the LID design, a treatment train approach should be used. For example, a site can be designed by combining LID methods such as installing a landscaped bioretention cell, adding a grass swale, and installing permeable pavers as overflow areas. The following LID design examples show that by recognizing stormwater as a resource, and making it a primary consideration in site design, communities can be built to reward the investment, enhance the natural environment, and create an ideal place for people to live and work.

2.3.1 Residential

2.3.1.1 Clustered Low-Density Residential Design

Clustered development, a site planning technique in use for several decades, considers not only individual lots, but larger site boundaries. It concentrates development on one portion of a site and maintains more of the site as open space. Clustered designs include strategies such as using smaller lot sizes, reducing setbacks and frontages, creating alternative street layouts to reduce road networks (section 3.1.3), and developing alternative driveway, sidewalk, and bike path designs (see section 3.1.5). When choosing the development envelope for a site, features such as drainage corridors and creeks, sensitive habitat areas, steep slopes, and highly erosive or permeable soils should be protected.

A focal point of clustered development is reducing the actual footprint of the development project and the footprint of the roadway network internal to the project (Figure 2-9). Clustered development can provide increased area for passive recreation, when usable open space is concentrated in a public or semi-public place instead of being divided in many large, private yards. However, clustered developments can face resistance in the marketplace because home buyers sometimes prefer the larger lot sizes and wider streets of conventional urban and rural development patterns. Clustered development should include appropriate landscaping (e.g., native plants, xeriscaping) to blend with the surrounding environment. These landscaping areas can also be used in conjunction with LID treatment solutions.

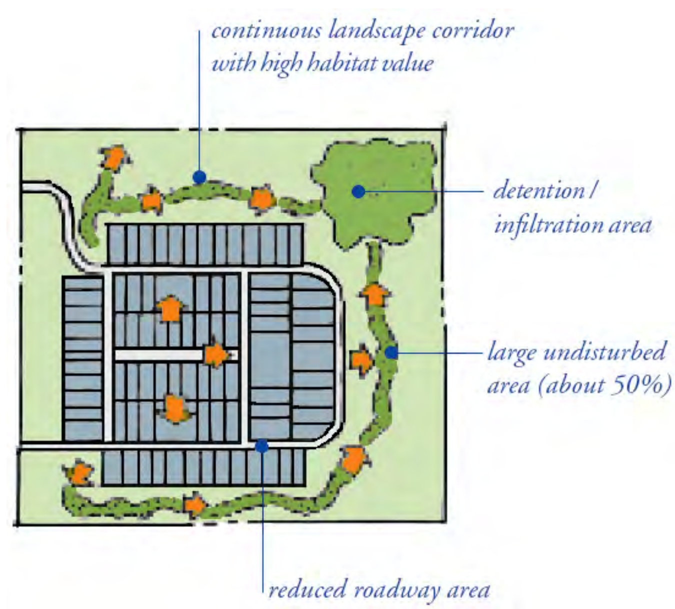

Figure 2-9. LID strategies for clustered low-density residential design.

In a watershed plan that employs clustered, dense development to preserve open space, on-site treatment in the more densely developed portion of the watershed might not be necessary. Dense or clustered development allows for significant areas to be preserved and remain undeveloped, reducing the need to mitigate throughout the entire watershed.

2.3.1.2 Single Residential Lot

A single-family residential lot can provide significant opportunities for stormwater management (Figure 2-10). LID solutions can add aesthetic richness that will directly benefit the project and the surrounding community. When the ratio of impervious cover relative to land area is low, landscape areas can accommodate a variety of subtle filtration strategies. Stormwater management techniques can also provide habitat for wildlife, create shade, improve character, provide supplemental irrigation water, and promote growth of landscape planting. When planning a subdivision of small single-family lots, carefully assess whether lot-by-lot LID infiltration solutions are appropriate. Consider all physical, engineering, geotechnical, and public health and safety constraints, as well as the long-term maintenance and practicality of approaching infiltration at this level. An alternate approach would create a larger LID facility on a dedicated maintenance lot, in which runoff from multiple individual lots would drain to the facility and maintenance would be provided by the homeowners association. LID techniques that should be considered as part of the subdivision planning include conserving natural resources, disconnecting impervious surfaces by pitching driveways toward yards, and allowing roof runoff to drain to lawns before entering the storm conveyance system.

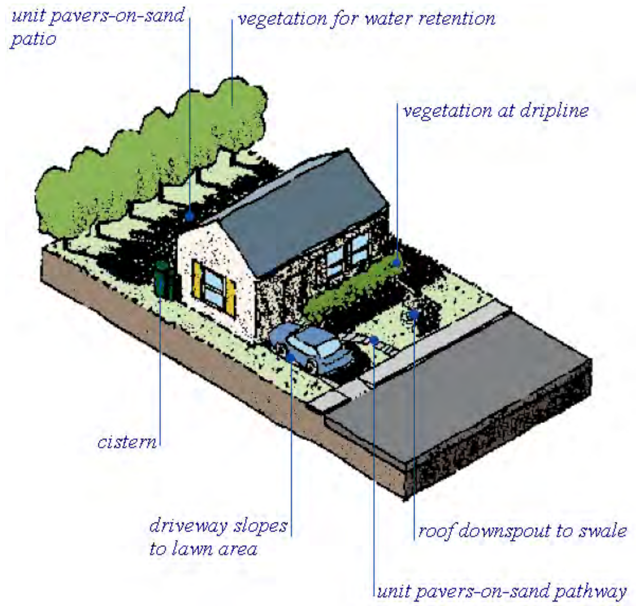

Figure 2-10. LID strategies for single residential lot design.

2.3.1.3 Multi-Family Residential Site

In urban areas, many of the sites available for new construction are infill or redevelopment sites. These sites usually have higher densities (typically from 12 to 100 units per acre) that demand a greater proportion of pavement and roof coverage.

Opportunities for on-site stormwater management exist even in the most densely developed infill sites, though these opportunities require greater creativity or multiple uses of space. For instance, an underground storage reservoir can be created to promote filtration and stormwater storage before releasing water into the municipal stormwater system. Figure 2-11 shows a pervious, grassed fire lane in a multi-family residential development.

Source: EOA, Inc.

Figure 2-11. Pervious emergency fire lane in a multi-family residential setting.

In urban high-rise development projects, the vast majority of the site is often covered by buildings with only a minimal amount of landscaping. Although these high-density sites present limited opportunities to incorporate LID stormwater treatment solutions, this sort of development represents a highly efficient way to develop land and reduce pressure on the development of rural and undeveloped land. By allowing high density in urban cores (often referred to as smart growth), rural lands can be preserved more effectively, thus providing a watershed benefit by reducing impacts to water quality and encouraging groundwater recharge and habitat conservation.

2.3.1.4 Residential Hillside Site

Hillside sites present particular challenges for stormwater management (Figure 2-12). LID strategies focusing on infiltration are typically best suited to more level sites. Infiltration strategies are impractical for hillside sites because they could potentially cause landslides and severe slope damage. Carefully stabilizing disturbed slopes is required. The licensed engineer must prove that stormwater management facilities are located so that infiltrated water does not compromise the integrity of building foundations, slopes, or other structures.

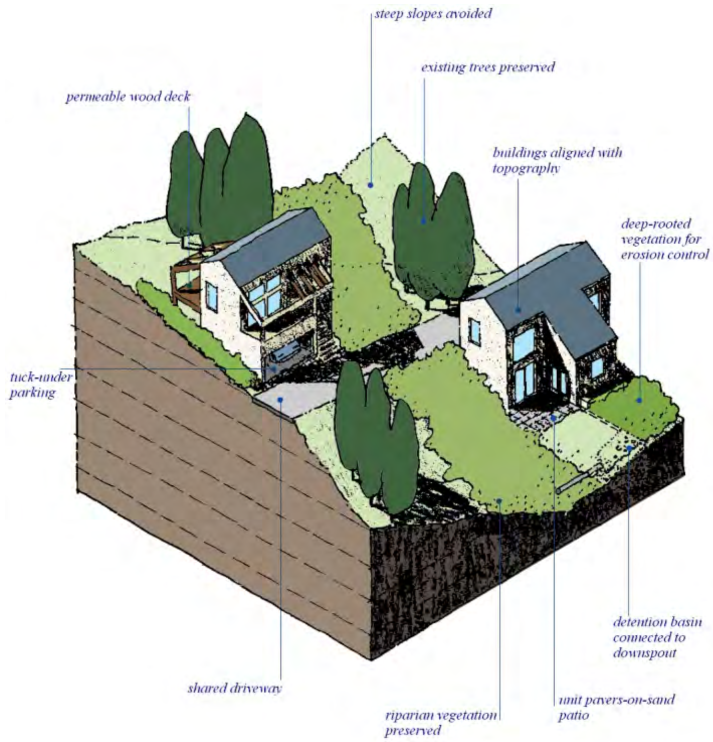

Figure 2-12. LID strategies for hillside sites.

2.3.1.5 Large Residential Flat Site

Larger flat sites present some of the greatest opportunities for stormwater management (Figure 2-13). If soils have adequate percolation rates, infiltration facilities are easily incorporated into the design. In more poorly drained soils, flat sites allow for detention and filtration systems that can slow the speed of runoff from the site. These systems allow sediments to settle and minimize the discharge of high velocity flows, thus helping to meet hydromodification objectives.

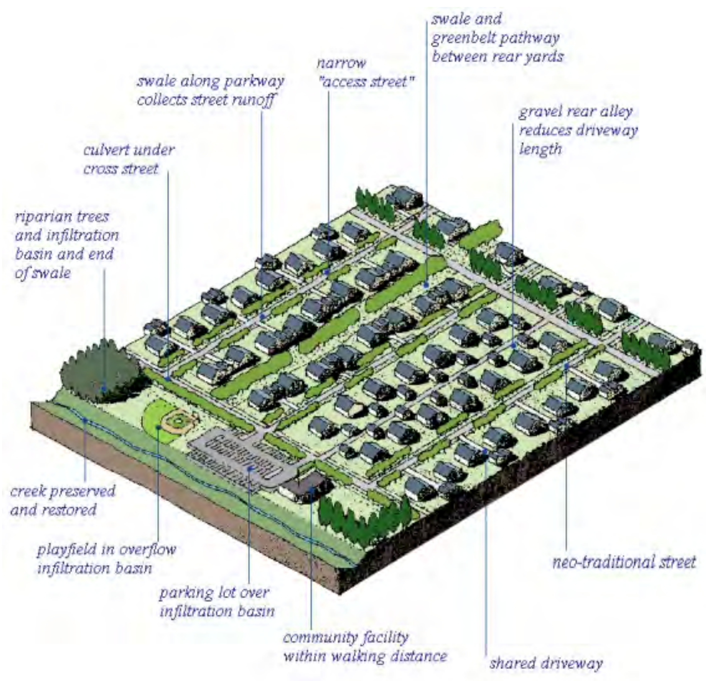

Figure 2-13. LID strategies for large residential flat sites.

Figure 2-13 shows how the site planning and design principles discussed earlier can be applied at the neighborhood scale. For the purposes of illustration, two different street access systems are shown: driveways from the street or rear alley access. Each has different planning implications, but both can be integrated with appropriate stormwater management.

Each cluster of buildings could also contain small-scale LID design elements.

2.3.2 COMMERCIAL

2.3.2.1 COMMERCIAL SHOPPING CENTER

Shopping centers present many opportunities for stormwater management, especially in the parking areas (Figure 2-14). Bioretention facilities can be incorporated into spaces between parking aisles. Recognizing that much of the parking is only necessary during peak times, such as the holiday season, a proportion of outlying stalls may be paved with permeable materials.

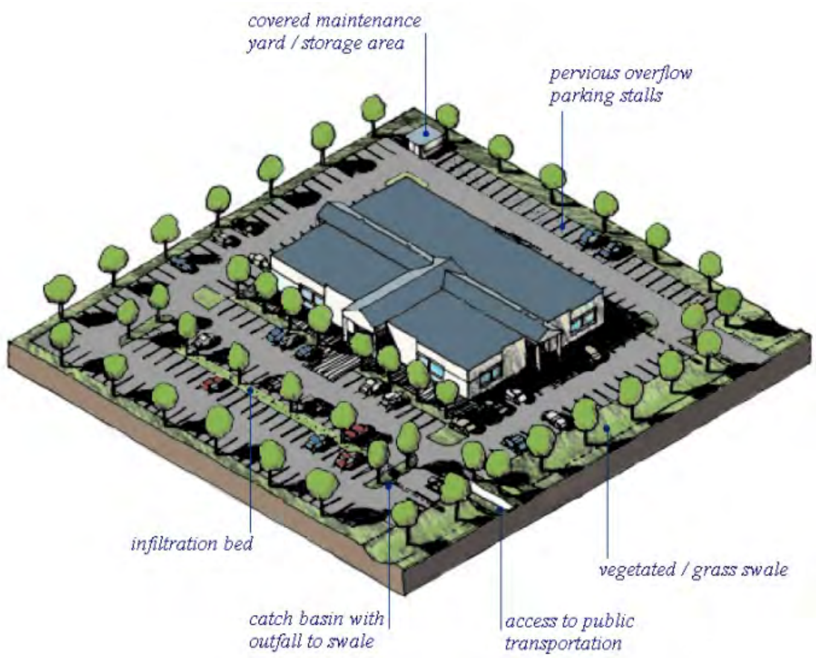

Figure 2-14. LID strategies for commercial shopping centers.

The utility functions inherent in any shopping center also need attention, such as restaurant wash-down areas, trash collection areas, and service yards. These outdoor work areas require specific techniques to prevent polluted runoff from entering the storm drain system or local water bodies. Similarly, potentially hazardous materials used within the shopping center require special attention and treatment. Finally, trash and other storage areas can be properly designed and constructed to prevent pollutants from running off these areas into the storm conveyance system.

If well-designed, correctly installed, and properly maintained, stormwater management techniques can enhance the aesthetic character of a shopping center and improve its marketability.

2.3.2.2 Commercial Office Building

Office buildings can integrate stormwater management techniques in many ways (Figure 2-15). Landscape areas for employee use and perimeter screening can be designed as bioretention areas to infiltrate or filter runoff. These facilities de-water quickly after storm events and do not pose a vector issue. They can also be designed as fountains or other decorative features to enhance aesthetics.

Parking lot areas can be treated with the use of permeable materials. Impervious parking stalls can be designed to drain to landscaped infiltration areas.

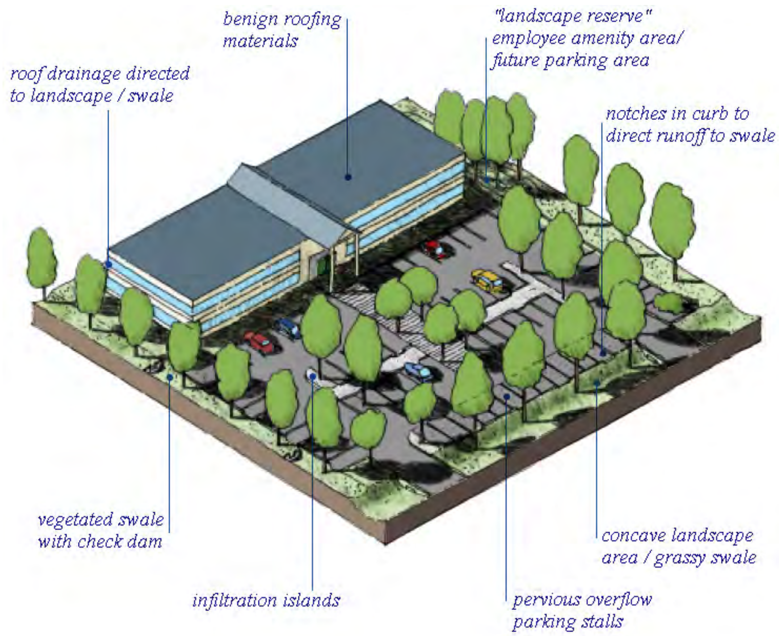

Figure 2-15. LID strategies for commercial office buildings.

A portion of the required parking may be allowed to be held in *landscape reserve*, until a need for the full parking supply is established. As a result, the original construction can be built with enough parking to meet currently anticipated staff needs. If the parking demand increases, the area held in landscape reserve can be modified to accommodate parking. In this way, parking is held to a minimum on the basis of actual use, rather than by a zoning formula that might not apply to the office building's actual personnel parking needs.

2.3.2.3 Commercial Restaurant

Restaurants offer a strong contrast between infiltration opportunities and special activity areas (Figure 2-17). Carefully selecting materials, such as brick or stone paving for outdoor patios, can enhance the restaurant's aesthetic appeal, while allowing for stormwater management. Landscape plantings can also be selected for stormwater treatment.

Parking can be provided in a variety of ways, with hybrid parking lots for staff that stay for long shifts, or with landscaped infiltration islands in lots with conventional paving for patrons who stay for shorter periods.

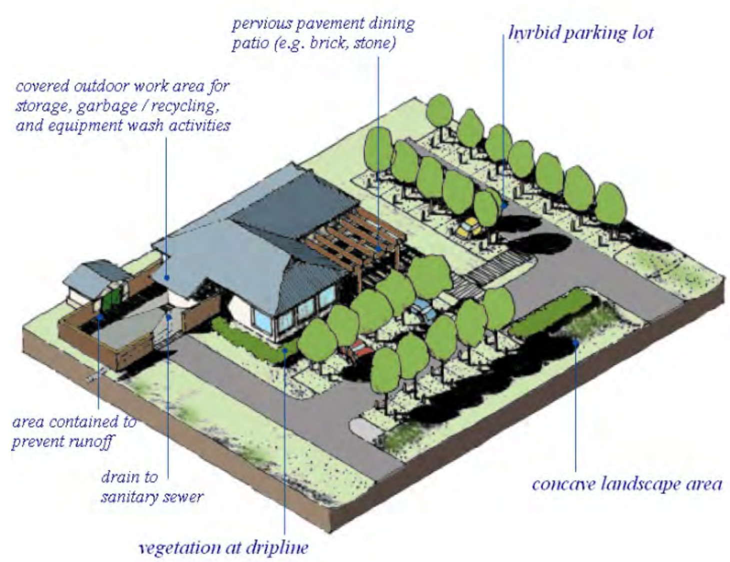

Figure 2-16. LID strategies for commercial restaurants.

In contrast to these stormwater treatment opportunities, restaurants have special activity areas that need to be isolated from the storm conveyance system. Grease, stored items, trash, and other food waste must be kept in properly designed and maintained special activity areas. Local ordinances might have design guidelines for allowable square footage of covered and uncovered areas.

2.3.3 INDUSTRIAL

2.3.3.1 INDUSTRIAL PARK

Industrial parks present special challenges when designing for stormwater management (Figure 2-17). They usually require large paved areas for truck access and employee parking, and space is usually limited. Industrial parks often have chemical storage and other special activity areas that require that infiltration techniques be avoided.

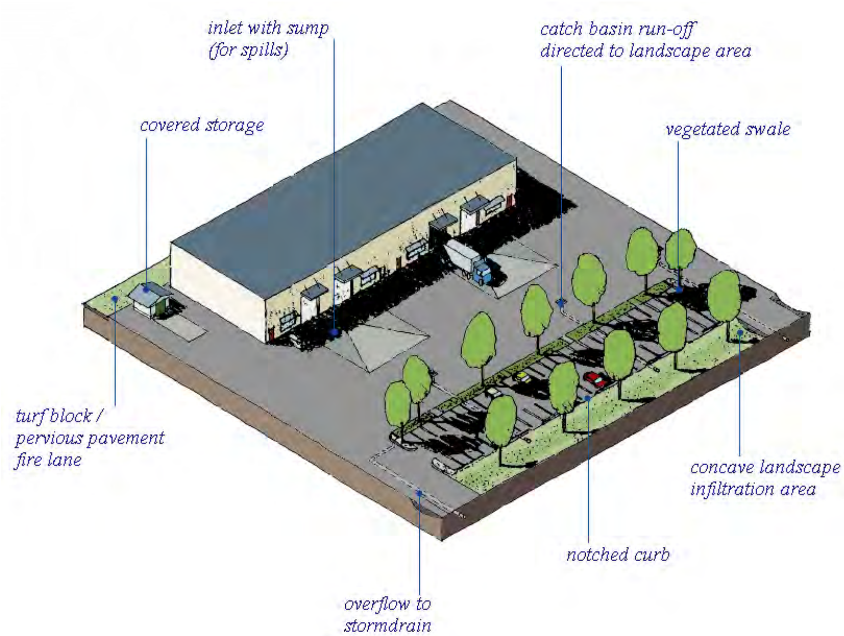

Figure 2-17. LID strategies for industrial parks.

Still, opportunities exist to incorporate design details to protect stormwater quality, including collecting and treating runoff in landscaped areas and properly managing special activity areas.

2.4 Retrofit Considerations

Retrofits are IMPs that are installed in already-developed areas where development occurred prior to stormwater requirements or where existing practices are not effective. Retrofitting can include replacing traditional roofs with green roofs, disconnecting or redirecting downspouts to pervious areas or newly installed IMPs, removing or replacing impervious surfaces with pervious surfaces, and implementing rainwater harvesting practices like rain barrels and cisterns.

Retrofitting in urban environments is sometimes challenging compared to implementing IMPs in new development settings. Retrofit opportunities are constrained by a number of site factors, including the presence of structures such as buildings, retaining walls, and paved areas; aboveground and underground utilities; previously contaminated soils (known or suspected); and highly compacted urban soils that function as impervious surface due to low permeability. Designers might also need to preserve pedestrian and vehicle access.

Directly connected impervious surfaces might constitute the majority of the site area, and pervious areas might be limited. When planning a retrofit project, designers can evaluate existing impervious areas to determine if some can be converted to pervious surface. Also, some impervious surface might be able to be reconfigured to drain to pervious areas, disconnecting them from the storm drain system and reducing the volume of runoff leaving the site. It is important to ensure that the pervious area is large enough and can infiltrate fast enough to avoid flooding or standing water; emergency overflow should be provided to safely convey large flows.

If the site layout allows, IMPs can be set back from existing infrastructure to prevent damage to foundations, retaining walls, and utilities. Alternatively, facilities can be designed with hydraulic restriction layers (see Appendix A.11.6) and/or underdrains (see Appendix A.11.4) to prevent migration of stormwater to unwanted areas. The same techniques can be used to prevent mobilization of known or suspected pollutants in soils.

If native soils have been compacted as a result of urban development or heavy equipment, they can be physically reconditioned (e.g., raking, tilling, amending) to adjust drainage characteristics, improve soil structure, and add organic matter (USEPA 2011). IMPs can also be installed with engineered media to ensure performance if in-situ conditions are poorly suited to stormwater management.

Retrofits to incorporate IMPs in existing developments require creative site design and, in some cases, modifications to the design of IMPs to protect existing site features. Retrofits can provide water quality benefits in high-priority urban areas where water resources might already be impacted and few other options exist to achieve such improvements.

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3 Integrated Management Practices

A variety of low impact development (LID) design concepts and specific engineering solutions are introduced in this chapter and are further detailed in design guidance provided in Appendix A and Appendix C. The techniques presented are neither all-inclusive nor appropriate for every site or condition; however, as planners and designers become more familiar with the design concepts, they will likely use their ingenuity to develop a *treatment train* of LID strategies that achieves water quality goals.

Before specific LID solutions can be developed for a particular project, the project designer must first determine the appropriate development category for the project (e.g., multi-family residential). Next, the designer must determine the project's runoff and hydrology conditions, taking into consideration factors such as soil conditions; grading and creating slopes; selecting paving materials; collecting and channeling runoff from roof, driveway, parking, and road surfaces; and others.

The individual design aspects of a project might make little difference to the overall hydrologic characteristics of the project, but, taken together, they significantly change the natural hydrology of the project site and can present stormwater management challenges. Fortunately, a project that combines a series of individual LID solutions on-site can effectively control stormwater and mitigate any water quality impacts.

3.1 LID Design Concepts

Minimizing impervious surface coverage and using natural elements to reduce stormwater runoff are key principles of LID. Selecting the appropriate LID concepts will depend on the elements included in the site development or redevelopment. Major design elements that can be adapted for LID include:

- Roads
- Parking lots
- Driveways
- Sidewalks
- Bike paths
- Buildings
- Landscaping

The following subsections describe LID design concepts relevant to each site element. These LID concepts should be considered early in the design process to control runoff quantity and quality and to minimize the need for structural integrated management practices (IMPs).

3.1.1 Self-Treating Areas

Self-treating areas (also called *zero-discharge* areas) are landscaped or turf areas that drain directly off-site or to a storm drain system without discharging runoff to on-site impervious areas. Self-treating landscaped areas are assumed to produce runoff less than or equal to the pre-project site condition. Examples include upslope undeveloped areas which are conveyed around a proposed development and grassed slopes which drain off-site and do not mix with other developed site runoff. In general, self-treating areas do not include impervious areas (must be at least 95% lawn, landscaping, or natural area and less than 5% impervious) and have slopes that are gentle enough to ensure that runoff will be filtered through the vegetation and soil. Runoff from self-treating areas does not require additional treatment or flow control. Refer to chapter 4 of the SUSMP (County of San Diego 2012) for full details.

3.1.2 Self-Retaining Areas

Self-retaining areas are designed to retain the first one inch of rainfall without producing any runoff. The technique works best on flat, heavily landscaped sites; however, it can also be used on mild slopes if a one-inch rainfall would be expected to generate no runoff. To create self-retaining turf and landscape areas in flat areas, a concave cross-section should be graded so that the self-retaining areas will hold the first inch of rainfall. Grading should be directed toward the center of the pervious area at slopes of 4 percent or flatter per SUSMP (County of San Diego 2012) recommendations. Any overflow inlets should be set 3 inches above the low point to allow ponding. Runoff from impervious or partially pervious areas can be managed by routing to self-retaining pervious areas. For example, roof downspouts can be directed to lawns, and driveways can be sloped toward landscaped areas. The maximum ratio is 2 parts impervious area for every 1 part pervious area for water quality treatment. For hydromodification flow control, the maximum ratio is 1 part impervious areas for every 1 part pervious area. Runoff from the impervious area must be directed to and dispersed within the pervious area, and the entire area must be designed to retain an inch of rainfall without overflowing from the self-retaining area. Under some circumstances, pervious pavement (e.g., crushed stone, permeable asphalt, or pervious concrete) can be considered a self-retaining area. Adjacent roofs or impervious pavement may drain to the pervious pavement in the same maximum ratios as described above. Properly designed self-retaining areas that accept flow from impervious areas or partially impervious areas can be classified as treatment control IMPs, as required by the Permit for Priority Development Projects. Runoff from self-retaining areas does not require additional treatment or flow control. Refer to chapter 4 of the SUSMP (County of San Diego 2012) for full details.

3.1.3 LID Road Design

General Description

Roads comprise a significant portion of a community’s impervious coverage and are one of the largest contributors of stormwater flows and pollutant loads. LID road design is a strategy to reduce this impact by minimizing impervious coverage and maximizing stormwater infiltration and pollutant uptake.

Road Design Standards

Roads are at the nexus of a wide variety of land-use and environmental issues. With a number of possible configurations, roads constitute a large design element in any development. In a typical neighborhood, the public right-of-way (i.e., the road or street) comprises approximately 20 to 25 percent of total land area, making it the single most important determinant of neighborhood character. Roads also can comprise up to 70 percent of a residential community's total impervious land cover, with the remainder of impervious land coverage in the form of rooftops and other structures. As a result, road design is one of the greatest factors in a development's impact on stormwater quality. Roads are subject to municipal ordinances, standards, and management, allowing local jurisdictions to have a great deal of control over their design. For these reasons, the road is one of the most important design elements in site planning and an element that can be most directly affected by local ordinances and policies.

Elements of LID Road Design

The overall objectives for LID road designs are:

- Reduce directly connected impervious area by reducing the overall road network coverage.
- Minimize or eliminate effective impervious area and concentrated surface flows on impervious surfaces by reducing or eliminating hardened conveyance structures (pipes or curbs and gutters).
- Infiltrate and slowly convey storm flows in roadside bioretention cells and swales, and through permeable paving and aggregate storage systems under the pavement.
- Design the road network to reduce site disturbance, avoid sensitive areas, and reduce landscape fragmentation.
- Create connected street patterns and open space areas to promote walking, biking, and access to transit and services.
- Maintain efficient fire, safety, and emergency vehicle access.

Based on the above objectives, the following general concepts should be considered when planning roadways:

- Road layout – Consider alternatives that reduce impervious coverage such as reducing the length of the road network by exploring alternative road layouts. Clustering homes and narrowing lot frontages can reduce road length by reducing the overall development area. Another approach is to lengthen street blocks and reduce cross roads by providing pedestrian and bicycle paths mid-block to increase access.
- Road width – Road width is a function of land use, density, road type, average daily traffic, traffic speeds, street layout, lot characteristics and parking, drainage, emergency access, and underground utilities.
- Cul-de-sac design – Cul-de-sacs create large areas of impervious coverage in neighborhoods. Alternatives to the traditional cul-de-sac can reduce impervious coverage. Examples of alternatives which reduce impervious surfaces are a T-shaped hammerhead turnaround, standard radius cul-de-sac with landscaped center-island for bioretention (see section 3.2.1.1), grid street systems, and a loop road network (Schueler 1995).
- Rights-of-way – Reflect the minimum required to accommodate the travel lane, parking, sidewalk, and, if present, vegetation in rights of way.
- Permeable materials – Use permeable materials in alleys and on-street parking where feasible (less than 4 percent slope).

- Increased access – Create paths to open space and other opportunities for pedestrians and bicyclists in subdivisions where alternative street layouts such as loop networks and cul-de-sacs are used.

- Traffic calming features – Traffic circles, chicanes, chokers, and center islands can provide for pedestrian safety while also managing stormwater using bioretention or other infiltration practices (Victoria Transport Policy Institute 2007).

- Accessibility – All County accessibility requirements for roadway designs must be followed for LID design

- Drainage options:
  - Maintain drainage – Preserve natural drainage patterns to the extent feasible and avoid locating streets in low areas or highly permeable soils.
  - Uncurbed roads – Build uncurbed roads using vegetated swales where feasible.
  - Urban curb/swale system – Runoff drains along a curb and enters a surface swale via a curb cut, instead of entering a catch basin to the storm drain system.
  - Concave medians – Depress median below the adjacent pavement and design it to receive runoff through curb inlets or sheet flow. This can be designed as a landscaped swale or a biofilter.

Driveway, private road, and public (nonmobility element) road design is influenced at the individual parcel and subdivision scale and is the focus of this section. Road design is site specific; accordingly, this section does not recommend specific road designs. Instead, the strengths and weaknesses of different road layouts are examined in the context of LID to help designers provide adequate transportation systems while reducing impervious surface coverage.

Road Width Considerations

Although reduced pavement width is a goal of LID, project designers should consider the following:

- Complete streets policies require accommodation of all users (motor-vehicle operators, bicyclists, pedestrians) on all roads and may require adequate surface and space to accommodate all users

- Turnouts and/or parking bays may be added to narrow roads at intervals to accommodate broken down vehicles, provide refuge areas for vehicles to pull over when emergency vehicles are rushing by to a scene, and help keep maintenance vehicles from blocking a through lane.

- Typical fire department standards require greater paved width for emergency vehicle access. A principal concern is that emergency access might be blocked if a vehicle becomes stalled in the lane. Grid street systems and loop road systems provide multiple alternate emergency access routes to address this concern, though there might be a marginal increase in response times.

- Hillside sites have special access concerns and fire risks. Because of the potential for lanes to be blocked by a single vehicle with no comparable alternate route, reduced street widths might not be advisable on long cul-de-sac streets or narrow hillside sites.

Road Drainage

Concrete curb and gutters are commonly required along both sides of a residential road, regardless of the number of houses served. The curb and gutter system serves several purposes, including collecting stormwater and directing it to underground conveyance drainage systems, protecting the pavement edge, preventing vehicle trespass onto the pedestrian space, providing an edge against which street sweepers can operate, and helping to organize on-street parking. Curb and gutter systems also provide a directly connected conduit to natural water bodies and can collect and concentrate pollutants. Several alternatives to typical curb and gutter systems are available that meet functional requirements while lessening the street's impact on stormwater quality. Note that these alternatives are discussed and recommended in the SUSMP (County of San Diego 2012).

3.1.3.1 Public Road Standards

Current public and private road standards typically result in 60-80 percent impervious land coverage in the public right-of-way or the private road easement. The runoff from these impervious surfaces can negatively affect water quality. Road standards that allow a hierarchy of road sizes according to average daily traffic volumes yields a wide variety of benefits, including improved aesthetics from street trees and green parkways, reduced impervious land coverage, and reduced heat island effect. If the reduction in road width is accompanied by a drainage system that allows runoff to infiltrate, the impact of roads on stormwater quality can be effectively mitigated.

The design of public (nonmobility element) roads shall use at least one of the following LID features (County of San Diego 2003):

1. Reduce sidewalk widths as long as the Americans with Disabilities Act (ADA) requirements are met.
2. Incorporate landscape buffer areas between sidewalks and streets.
3. Design nonmobility element streets for the minimum required pavement widths.
4. Minimize the number of residential street cul-de-sacs and incorporate landscaped areas to reduce impervious cover.
5. Urban curb/swale system: street slopes to curb, periodic swale inlets drain to a vegetated swale. For more information on curb cut design please see Appendix A.11.2.

Guidelines for the design and construction of public improvement projects within the unincorporated areas of San Diego County reference the San Diego County Public Road Standards.

For guidelines that incorporate alternative road designs into a project reference the San Diego County Flexibility in County Road Design.

In no way shall these LID features be designed to block sight distance for motorists from adjacent streets and driveways, create obstacles for pedestrians, impede the visibility and maintenance of traffic control devices and signs, and reduce or eliminate clear recovery area and minimum horizontal clearances from fixed objects. The landscaping maintenance mechanism through a landscaping district or County department shall be obtained prior to installation of the landscaping.

3.1.3.2 Private Road Standards

A private road is used where required by subdivision and zoning ordinance requirements. Curbs and gutters are replaced by gravel shoulders that are graded to form a drainage way, with opportunities for biofiltration and landscaping. Road sheet flow drains to a vegetated swale or gravel shoulder. Other characteristics of a private road standard include curbs at street corners and the placement of culverts under driveways and road crossings.

Typically, a narrow two-lane paved roadway is constructed to a width of 24 feet. Most of the time, single vehicles use the center of the paved roadway. Protecting the roadway edge and organizing parking are two significant issues in rural street design. Roadway edge protection can be achieved by flush concrete bands, steel edge, or wood headers. Upon recommendation of the local fire authority, parking can be restricted by use of signage or striping.

Private roads should incorporate one of the following elements for enhanced stormwater quantity and quality control (BASMAA 1999; County of San Diego 2003):

1. Rural swale system – Road sheet flows to vegetated swale or gravel shoulder, curbs at street corners, culverts under driveways and road crossings.

2. Urban curb/swale system – Road slopes to curb, periodic swale inlets drain to a vegetated swale.

Guidelines for the minimum design and construction requirements for private road improvements in the unincorporated areas of the County can be found in the San Diego County Standards for Private Roads.

Road LID Design Options

As described above, several options are available to reduce and treat roadway runoff. The following design options should be incorporated where practicable during roadway design.

3.1.3.3 Urban curb/swale system

On streets where a more urban character is desired or where a rigid pavement edge is required, curb and gutter systems can be designed to empty into drainage swales *(Figure 3-1)*.

These swales can run parallel to the street, in the parkway between the curb and the sidewalk, or can intersect the street at cross angles, and run between residences, depending on topography. Runoff travels along the gutter, but instead of emptying into a catch basin and underground pipe, multiple openings in the curb direct runoff into surface swales or infiltration/detention basins. If lined with vegetation or gravel/rock and gently sloped, these swales function as biofilters. Because the concentration of flow will be highest at the curb opening, erosion control must be provided, which might include a forebay for ease of debris removal.

Locations: Seaside Ridge Development, Encinitas, California.

Figure 3-1. Urban curb/swale system.

For more information on curb-cuts please see Appendix A.11.2.

3.1.3.4 Rural Swale Systems

On streets where a more rural character is desired, concrete curbs and gutters are not required *(Figure 3-2)*.

Since the street does not have a hard edge, the pavement margins can be protected by a rigid header of steel, a strip of wood, or a concrete band poured flush with the street surface. Parking can be permitted on a gravel shoulder. If the street is crowned in the middle, this gravel shoulder can also serve as a linear swale (with appropriate slopes), permitting infiltration of stormwater along its entire length. Because runoff from the street is not concentrated, but dispersed along its entire length, the buildup of pollutants in the soil is reduced. If parking is not desired on the shoulder, signage or striping can be installed along the shoulder to prevent vehicle trespass. Swales should be designed so that errant vehicles may recover without losing control. In these ways, edge treatments—other than continuous concrete curb and gutters with underground drainage systems—can be integrated into street design, creating a headwaters street system that reduces impacts on stormwater quality but captures the most attractive elements of traditional neighborhood design (County of San Diego 2003).

Location: San Diego, California.

Figure 3-2. Rural swale system.

For more information on swales please see Appendix A.9.

3.1.3.5 Concave Median

Conventional median design includes a convex surface rising above the pavement section, with drainage directed towards a curb and gutter system. Runoff is conveyed rapidly off the median and the street directly into a catch basin/underground pipe system, concentrating pollutants and carrying them to water bodies.

If the soil level in the median is designed as a concave surface slightly depressed below the pavement section, water is directed from the street into the median *(Figure 3-3)*.

Concave medians are especially valuable at treating the first flush runoff, which carries a high concentration of oils and other pollutants from the street, especially if the median is designed as a landscaped swale or turf/rock lined biofilter. Because of the relatively small area provided by the median for stormwater infiltration and retention, a catch basin and underground storm drain system might be required. By

Location: County Operations Center, San Diego, California.

Figure 3-3. Swale.

setting catch basin rim elevations just below the pavement elevation, but above the flow line of the infiltration swale, a few inches of water will collect in the swale before overflowing into the underground system.

3.1.3.6 Cul-de-sac Design

Cul-de-sac streets present special opportunities and challenges. Because cul-de-sac streets terminate, they require a turn-around area large enough to accommodate large trucks. County fire code requires a minimum paved radius width of 36 feet in residential areas. If an entire 36-foot radius turnaround is paved, it creates a 4,071-square-foot impervious circle. Aside from the implications for stormwater quality, this is especially unfortunate as a design element, because it creates a heat island at the front of several homes. A turnaround with a central concave landscaped area can reduce impervious coverage and provide stormwater infiltration or detention opportunities. Design of a landscaped cul-de-sac must be coordinated with fire department personnel to accommodate turning radii and other operational needs (County of San Diego 2001).

Road Drainage Maintenance Considerations

The perception that surface swale systems require a great deal of maintenance is a barrier to their acceptance. In practice, maintenance is required for all drainage systems, and surface systems can require comparable or less maintenance than underground systems. Design factors for low maintenance include:

- Erosion control at curb openings.
- Shallow side slopes and flat bottoms (as opposed to ditches that can erode).
- A cobble or rip-rap bottom combined with plantings.
- Proper plant selection to facilitate weed control.
- Sufficient access points to facilitate maintenance activities.

Maintenance practices for surface systems are different than most urban public works department practices; as a result, some employee retraining might be required for maintaining road systems that use surface swales instead of concrete curbs and underground pipes. One advantage of surface drainage systems is that problems, when they occur, are easy to fix because they are visible and on the surface.

3.1.4 LID Parking Lot Design

General Description

Parking lots comprise a sizeable portion of a community’s impervious coverage. They are significant sources of stormwater runoff, which carry pollutants to the storm drain system and local surface waters. Several strategies can be implemented to mitigate this impact, including reducing impervious surfaces, adding perimeter landscaping, and using permeable materials in overflow parking areas and bioretention basins in parking lot islands. Considerations for integrating LID concepts in parking lot design are also provided in the *County of San Diego Parking Design Manual* (County of San Diego 2013).

Parking is the greatest single land use in most industrial, office, and commercial development. A standard parking stall occupies only 160 square feet, but when combined with aisles, driveways, curbs, overhang space, and median islands, a parking lot can require up to 400 square feet per vehicle, or nearly one acre per 100 cars. Since parking is usually accommodated on an asphalt or concrete surface with conventional underground storm drain systems, parking lots typically generate a great deal of directly-connected impervious area which make them a significant contributor to environmental degradation. Parking lots can be designed to both reduce the impervious land coverage of parking areas and to filter runoff before it reaches the storm drain system.

Stormwater management in parking lots can mimic natural hydrologic functions by incorporating design features that capture, treat, and infiltrate or detain stormwater runoff rather than conveying it directly into the storm drain system. Management options include:

- Landscaped retention, also known as bioretention, areas (Appendix A.1) can be installed within and at the perimeter of parking lots to capture and infiltrate or detain runoff.

- Parking groves, which include permeable landscaped areas designed with grades several inches below the impervious parking surface can delineated by flat concrete curbs, shrubs, trees, and bollards (small vertical posts).

- Permeable surfaces can be installed in downgradient parking stalls and in overflow parking areas (Figure 3-4). Permeable materials that can be used include permeable pavers, permeable asphalt concrete (AC), and pervious concrete. In some circumstances, gravel or wood chips can also be used.

- Stormwater runoff from the top floor of parking garages can be drained to planter boxes placed at the perimeter of the parking lot or at street level.

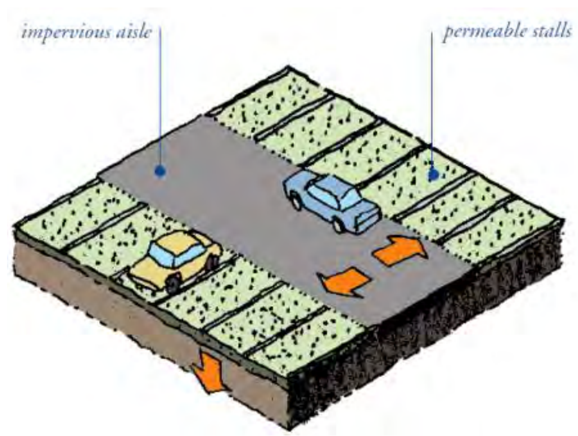


Figure 3-4. LID parking lot design.

Reducing Impervious Surfaces

Research has shown that zoning regulations typically require more parking spaces than are needed. Parking lot size is usually based on peak demand rather than average usage.

Parking codes should be reviewed and revised to either reduce parking minimums or require reduction in directly connected impervious areas. Parking codes should also be revised to allow shared parking for businesses with different hours of peak demand. Commercial centers that experience peak demand only during holidays can use bus and shuttle services to transport people from parking areas at government facilities and schools, which are typically vacant during holidays.

Other strategies to reduce the total parking area include installing compact parking spaces and determining the most space-efficient design for parking spaces (i.e., angled or perpendicular). Consideration should be given to design options such as underground parking, multi-storied garages, or planting vegetation on and around parking surfaces (Figure 3-5). As noted above, vegetation and landscaping can be designed to intercept rainfall and capture stormwater. Planting trees as a component of parking lot landscaping can reduce impervious coverage and reduce the urban heat island effect of parking lots by shading heat-adsorbing surfaces.

Location: Encinitas, California.

Figure 3-5. Vegetated open cell unit pavers.

3.1.5 LID Driveway, Sidewalk, and Bike Path Design

Driveways, sidewalks, and bike paths add a significant amount of impervious coverage to a community and are an element of a site's design that can be altered to minimize directly connected impervious areas. Driveways often slope directly to the street and storm drain system and contribute significantly to stormwater pollution. Three primary strategies can be implemented to reduce these impacts, including:

- Reduce pavement widths.
- Direct surface flow from pavements to a permeable landscaped area
- Utilize permeable paving materials.

Driveways

Driveways offer a relatively simple opportunity to improve both the aesthetics and permeability of residential developments. By allowing tandem parking, shared driveways, or rear alley access, municipalities can reduce mandated driveway requirements. For designers and developers, the driveway's intimate relationship with the residence, and its relative freedom from government regulation, make it an element that can be designed to increase permeability as well as market appeal. Some treatments, such as vegetated permeable pavers or gravel, require greater maintenance than poured-in-place asphalt or concrete designs. Other materials, such as brick or unit pavers, require a greater initial expense.

Disconnected Impervious Driveway

A conventional driveway that drains to the storm drain system is a directly connected impervious area which collects and concentrates pollutants. The easiest way to reduce the impact of a conventional impervious driveway on water quality is to slope it to drain onto an adjacent turf or groundcover area (Figure 3-6). By passing driveway runoff through a permeable landscaped area, pollutants can be dispersed and removed in the soil.

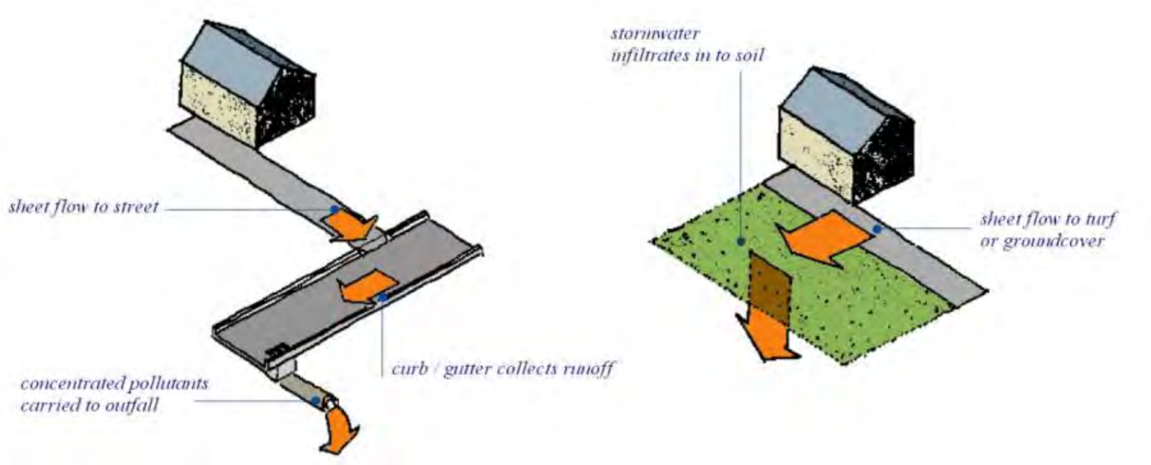


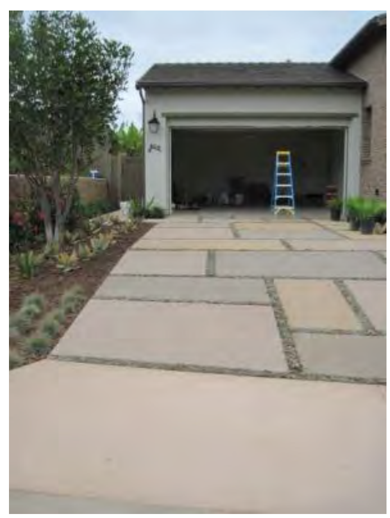
Figure 3-6. Pathways of stormwater flow over (a) directly connected and (b) disconnected impervious surfaces.

Crushed Aggregate Driveway

Gravel and other granular materials can make a suitable permeable pavement for rural and other low-traffic driveways. Because it is lightly used by very slow moving vehicles, a well-constructed driveway of granular material can serve as a relatively smooth pavement, although maintenance can be challenging because fine sediment will migrate through the profile and eventually clog the subsoil interface. In choosing a granular material for a gravel driveway, use crushed stone aggregate. Crushed aggregate driveways shall be designed so that aggregate is not spread into pedestrian walkways and the intersecting roadway through vehicular travel and erosion. For proper infiltration and stormwater storage, the aggregate must be washed and open-graded (see Appendix A.3).

Permeable Pavements

Permeable pavement can be installed to create an attractive and self-treating driveway (Figure 3-7). A pavement of permeable interlocking concrete pavers, brick, stone, or open cell unit pavers can make the driveway more integrated with the garden rather than an extension of the street penetrating deep into the garden space. For parking, a permeable, engineered base structural section might be required in addition to a sand setting bed. Some pavements can also be installed on very fine gravel. The voids or joints between pavers should be routinely maintained to prevent clogging by fine sediment and vegetative debris.



Location: Seaside Ridge Development, Encinitas, California.

Figure 3-7. Permeable pavement driveway.

Two-Track Driveways

Concrete paving only under the wheel tracks is a viable, inexpensive design if the driveway is straight between the garage and the street. By leaving the center strip open to be planted with groundcover or filled with a permeable material such as gravel, a driveway of two concrete wheel tracks can significantly reduce impervious surface coverage compared with a single-lane concrete driveway. Drainage, climate, and maintenance must be considered with the design of this technique so that the landscape can be planned appropriately.

Flared Driveways

Long driveways or driveways that serve multi-car garages do not require the full multi-lane width along their entire length. The approach to the garage can be a single lane, adequate to accommodate the relatively infrequent vehicle trips, while the front of the garage can be flared to provide access to all garage doors (Figure 3-8). This strategy can reduce overall pavement cost and land coverage while maintaining adequate access for all parking spaces.

Source: RBF Consulting.

Figure 3-8. Flared driveway.

3.1.6 LID Building Design

By definition, buildings create impervious land coverage. An important planning consideration is the site coverage and floor area ratio (FAR). Buildings of equal floor area ratio can have widely different impervious coverage. For example, a two-story building with 1,000 square feet of floor area will create 500 square feet of impervious area, while a one-story building of the same floor area will create twice the impervious land coverage. Therefore, multi-story buildings have less impact on stormwater quality than a single-story building with the same square footage. Once the building size and coverage is determined, a number of techniques are available that will collect rooftop runoff from individual buildings and allow it to infiltrate into the soil.

3.1.6.1 Rain Water Harvesting

A key LID technique in a setting with soils relatively restrictive to infiltration is water harvesting. Rain barrels can be used at smaller residential scales, while cisterns are more suitable at larger-scale commercial and light industrial developments. Water harvesting has successfully reduced runoff discharged to the storm drain system and conserved water in applications at all scales (Figure 3-9). Local municipal regulations should be followed for proper use of the water harvested, e.g., toilet flushing.

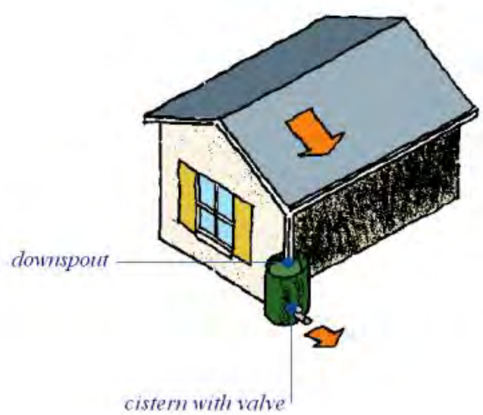


Figure 3-9. Cistern for residential rooftop rainwater management and harvesting.

Cisterns and Rain Barrels

Cisterns and rain barrels capture roof runoff from the roof downspout and provide an effective way to store and slowly release runoff into the soil. These harvesting systems mitigate the peak flow increases caused by rooftop impervious land coverage, especially for small storms. Cisterns and rain barrels can be incorporated into the aesthetics of the building and garden. Details regarding the functions and performance of cisterns and rain barrels are provided in section 3.2.3.1.

Large-Scale Harvesting

Successful water harvesting project examples show that large buildings, including vertically elevated as well as horizontally spread buildings, can successfully harvest water for nonpotable uses. For example, in downtown Seattle, the King County Government Center collects enough roof runoff to supply more than 60 percent of the government center's toilet flushing and plant irrigation water requirements, saving approximately 1.4 million gallons of potable water per year. A smaller public building in Seattle, the Carkeek Environmental Learning Center, drains roof runoff into a 3500-gallon cistern to supply toilets. The Natural Resources Defense Council office in Santa Monica is another example of a medium-scale rain harvesting application.

For more information on rainwater harvesting please see Appendix A.8.

3.1.6.2 Foundation Planting

For buildings that do not use a gutter system, landscape planting and planter boxes around the base of the eaves can infiltrate stormwater and protect the soil from erosion caused by concentrated sheet flow coming off the roof (Figure 3-10). Foundation plantings can reduce the physical impact of water on the soil and provide a subsurface matrix of roots that encourage infiltration. These plantings must be sturdy enough to tolerate the heavy runoff sheet flows and periodic soil saturation but should not have large woody roots that can grow under and disturb building foundations. Unvegetated foundation swales formed with cobbles and gravel can also be used to protect foundations from potential water damage. See section 3.2.1 for details on flow-through planters and section 3.2.4.1 for swales.

Figure 3-10. Foundation planting.

3.1.6.3 Downspout to Swale

Discharging the roof downspout to landscaped areas via swales allows for pollutant removal and infiltration of the runoff. The downspout can be directly connected to a pipe that carries the roof runoff away from the building foundation and releases it into a swale, landscaped area, or self-retaining area. An energy dissipater, such as rock or cobble, is recommended at the outlet. The roof runoff is slowed by the rocks, absorbed by the soils and vegetation, and the remaining runoff can then flow away from the building foundation towards the storm drain.

3.1.6.4 Vegetated (Green) Roofs

Vegetated roofs (also known as green roofs and eco-roofs) offer a number of benefits in the urban landscape including increased energy efficiency, improved air quality, reduced temperatures in urban areas, noise reduction, improved aesthetics, extended life of the roof, and, most importantly, improved stormwater management. Stormwater benefits include reduced volume of stormwater runoff, reduced quantity of industrial effluent, extended lifetime of infrastructure, reduced flooding potential, and reduced need for downstream structural IMPs (Peck and Johnston 2006).

Vegetated roofs fall into two categories: intensive and extensive. Intensive roofs are designed with a relatively deep soil profile and are often planted with ground covers, shrubs, and trees. Intensive green roofs might be accessible to the public for walking, or can serve as a major landscaping element of the urban setting. Extensive vegetated roofs are designed with shallow, light-weight soil profiles and ground cover plants adapted to the harsh conditions of the rooftop environment (Hinman 2005).

For more details, see section 3.2.2.2 and Appendix A.6.

3.1.7 LID Landscaping Design

In the natural landscape, most soils infiltrate a high percentage of rainwater through a complex web of macropores and other spaces formed by biological activities in the soil column. Natural processes that affect soil include roots growing into and separating particles of clay, insects excavating voids in the soil mass, roots decaying and leaving networks of macropores, leaves falling and forming mulch over the soil surface, and earthworms burrowing and ingesting organic detritus to create richer, more porous and permeable soil (Harris 1992). In the developed environment, a certain amount of soil must be covered with impervious surface, but the remaining landscape can be designed and maintained to maximize its natural permeability and infiltration capacity.

One simple strategy to improve infiltration is to grade landscape surfaces. If a landscape surface is graded to have a slightly concave slope, it will hold water (Figure 3-11). The infiltration value of concave vegetated surfaces is greater in permeable soils. Soils of heavy clay or underlain with hardpan provide less infiltration value. In these cases, concave vegetated surfaces must be designed as retention/detention basins, with proper outlets or underdrains to an interconnected system.

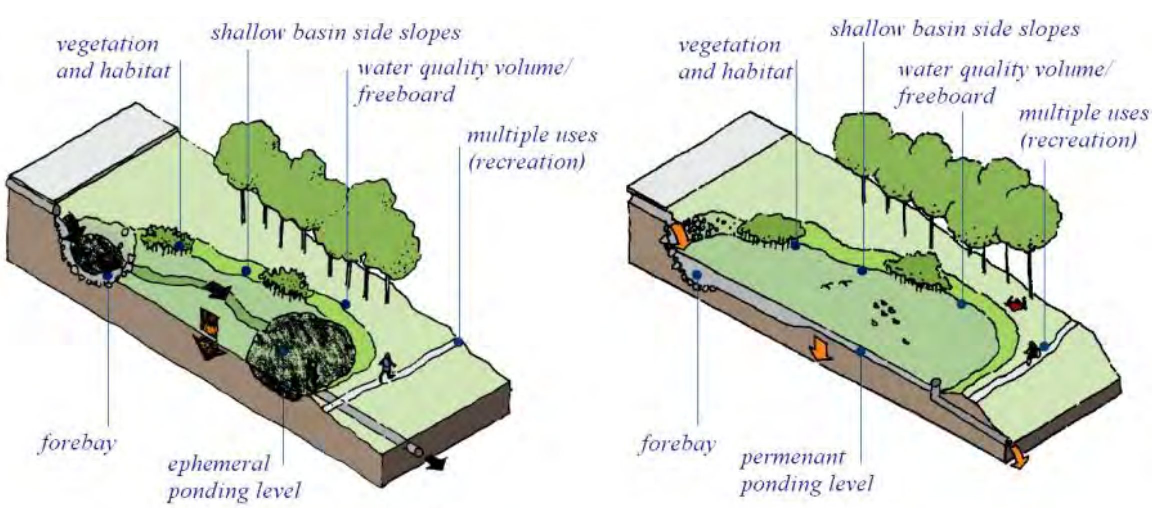


Figure 3-11. Options for LID landscape design.

Aeration techniques such as drilling, scarifying, and roto-tilling can break up soil and enhance percolation. In addition, properly amending the soil and increasing soil organic matter can significantly increase water holding capacity.

Water-Efficient Landscaping

All landscape improvements shall conform to the County of San Diego's Landscape Water Conservation Design Manual and the State of California's Water Conservation Landscape Ordinance (County 2010). When a local water agency serving a proposed project has adopted more stringent water conservation landscape requirements, the landscaping and irrigation design must comply with the water agency's requirements.

Where appropriate for the site and the intended stormwater management technique, the landscaping may include natural features such as rock and stone.

Where service is available to the project site and appropriate for the intended use, recycled or reclaimed water must be used for irrigation.

3.1.7.1 Plant Species Selection

The proper selection of plant materials can improve the infiltration potential of landscape areas. Deep rooted plants help to build soil porosity. Plant leaf-surface area helps to collect rainwater before it lands on the soil, especially in light rains, increasing the overall water-holding potential of the landscape. A single street tree can have a total leaf surface area of several hundred square feet, depending on species and size. This above ground surface area created by trees and other plants greatly contributes to the water-holding capacity of the land.

A large number of plant species will survive periodic inundation. These plants provide a wide range of choices for planted infiltration/detention basins and drainage swales. Most inundated plants have a higher survival potential on well drained alluvial soils than on fine-textured shallow soils or clays (Hinman 2005). When designing landscapes for stormwater management, appropriate groundcover and plant species must be selected. Xeriscape plants, salt grass lawns, woody perennials, and cobbles can all be used, depending on the desired aesthetic effect.

Selection of appropriate plant material for LID projects is dependent on several factors, these include:

- Micro-climatic conditions of planting area (i.e., sun exposure, salinity, temperature highs and lows, prevailing winds).
- Soil type (i.e., clay, sand, silt).
- Drought or temporary inundation tolerance.
- Plants ability to aid in the removal of contaminants.
- Visual characteristics of plants (texture, color, form).
- Maintenance requirements.
- Noninvasive.
- Disease resistance.

Final selection of plant material needs to be made by a landscape architect experienced with LID improvement projects. Water retention areas and bio-swales need to have access for periodic maintenance activities.

For more information on plant species please see Appendix E.

3.1.7.2 Soil Amendments

Development activities often remove, disturb, and compact topsoil on construction sites. Consequently, infiltration and water storage capacity of post-development soils decreases and stormwater runoff potential increases. In addition, soils in the arid climate of San Diego tend to lack organic matter and nutrients, and often have a high silt and clay content. Soils high in clay content have slow infiltration rates, resulting in a high runoff potential. Properly amending soils can increase their porosity and permeability, leading to increased infiltration and water storage capacity. Benefits accrued by enhanced infiltration include decreased stormwater runoff, decreased polluted runoff from landscaping practices, and improved water conservation.

Organic soil amendments improve soils by increasing the water-holding capacity in sandy soils, improving the physical characteristics of clay soils by altering the soil structure and percolation rates, and by providing a steady supply of nutrients and organics to help remediate groundwater pollution. Properly prepared organic material can increase the microbial diversity in the soil and enhance plant health and immunity to disease. Composted products from licensed facilities are recommended, as these products have undergone a process to reduce pathogens and have a carbon: nitrogen ratio of less than 25:1. They can be tilled into the soil or can be applied as a top dressing to existing landscaped areas.

Landscaped areas that include decorative turf grass are a major contributor to stormwater runoff contaminated by fertilizers and pesticides. In landscaped areas where soils have been compacted and not amended, soils can behave like impervious areas, generating considerable amounts of runoff. By properly amending soils, the runoff potential can be reduced. Amending soils also reduces irrigation needs, as water is more easily infiltrated into the ground and retained in the soil matrix where it can be used by plants. Fertilizer needs can also be reduced by incorporating appropriate soil amendments, thereby reducing stormwater pollution.

3.1.7.3 Street Trees

Trees can be used as a stormwater management tool in addition to providing more commonly recognized benefits such as energy conservation, air quality improvement, and aesthetic enhancement. Tree surfaces (roots, foliage, bark, and branches) intercept, evaporate, transpire, store, or convey precipitation before it reaches surrounding impervious surfaces. In bioretention cells or swales, tree roots build soil structure that enhances infiltration capacity and reduces erosion (Street Tree Seminar, Inc. 1999).

Local community planning areas often have specific guidelines for the type and location of trees planted along public streets or rights-of-way. The extent and growth pattern of the root structure must be considered when trees are planted in bioretention areas or other stormwater facilities with underdrain structures or near paved areas such as driveways, sidewalks, utilities, or streets.

3.2 Structural IMP Design

LID site design concepts should be considered the first line of defense for stormwater management before structural IMPs are considered. By evaluating LID design options first, structural IMP sizing could potentially be reduced. Once a site configuration is optimized to reduce stormwater and pollutant sources, runoff from the remaining impervious surfaces should be intercepted and treated by structural IMPs installed throughout the watershed. Structural IMPs can be used in conjunction with LID design concepts to treat runoff near its source using one of three basic elements: infiltration, retention/detention, and biofiltration. The following section introduces structural IMPs that can be implemented either alone or in combination, depending on site and other conditions, to meet SUSMP (County of San Diego 2012) water quality and hydromodification criteria. All Priority Development projects are required to have at least one structural IMP that satisfies the requirements under the Permit for a treatment control IMP.

The various categories or types of development listed in section 2 present unique challenges that make certain LID solutions appropriate for some types of development but not for others. For example, permeable pavement might be an effective and appropriate solution for a low-rise office building; however, in a high-rise residential or office building with underground parking and virtually no undeveloped areas, permeable pavement would not be an effective or appropriate solution. Additionally, downstream conditions on neighboring properties, manufactured slopes, the location of structures and utilities, and other design aspects of a project can present unique challenges for designers and engineers, making what are otherwise effective LID solutions inappropriate for the specific site.

3.2.1 Infiltration IMPs

Infiltration systems have been used by Caltrans and local jurisdictions in California for about three decades (CASQA 2003); however, heavy clay soils, formational materials, and rock sometime limit their local application. The basic design goal of infiltration systems is to provide opportunities for the majority of runoff from small storms to enter the soil rather than discharging directly into a surface water body. This is generally accomplished by retarding the flow of runoff and by bringing it into contact with the soil by holding it in basins or subsurface reservoirs. Infiltration can be ideal and economical for managing and conserving runoff near its source because it filters pollutants through the soil and restores natural flows to groundwater and downstream water bodies.

Attenuating flow through infiltration, while allowing evaporation and evapotranspiration, is an effective stormwater management practice that helps to block the transport of pollutants to receiving waters. Infiltration systems are typically volume-based facilities designed to match pre-development condition infiltration rates and to infiltrate the design storm runoff volume into the soil. Infiltration practices can range from a single shallow depression in a lawn, to a treatment train comprised of a swale and bioretention area. Depending on configuration and type, treatment mechanisms include filtration, settling, straining, sorption, and biological transformations.

Infiltration IMPs can be either open or closed. Open infiltration practices are usually vegetated – the vegetation maintains the porous soil structure, reduces erosion, and uses water through evapotranspiration. Xeriscaped rock-lined basins are also common but do not provide as many pollutant removal unit processes. Closed infiltration practices (such as infiltration trenches and permeable pavement) can be constructed under the land surface with washed, open graded crushed stone, leaving the surface to be used for parking or other uses (see section 3.2.1.4 and Appendix A.3). Subsurface infiltration IMPs do not require planting, but are generally more difficult to maintain and more expensive than surface systems. For further discussion on infiltration and soil testing to ensure infiltration IMPs are suitable for proposed sites, refer to Appendix F for geotechnical considerations.

3.2.1.1 BIORETENTION

Bioretention systems are essentially surface and sub-surface water filtration systems. They function like sand filters; however, whereas sand filters provide water quality treatment via passage of stormwater through a sand medium, bioretention systems use both plants and underlying filter soils to remove contaminants and reduce stormwater runoff volumes. Due to the variety of treatment mechanisms at work within the system, bioretention areas consistently provide relatively high load reductions for most pollutants. Appendix G outlines bioretention soil media specifications designed to provide pollutant removal.

Bioretention areas are typically planted with grasses, shrubs, and trees that can withstand short periods of saturation (i.e., 12–96 hours) followed by longer periods of drought (Figure 3-12). In addition to transpiring significant stormwater volumes, vegetation can enhance pollutant removal, reduce soil compaction, and provide ecological and aesthetic value (Barrett et al. 2013; Hatt et al. 2009; Li et al. 2009). Vegetation adapted to the San Diego region is preferable for use in bioretention areas because native ecotypes can typically tolerate periods of extreme drought and can promote infiltration and evapotranspiration with their root systems. Bioretention vegetation can be chosen to mimic predevelopment communities while being aesthetically pleasing. Appendix E provides a plant list to guide vegetation selection.

Location: 43rd Street and Logan Avenue San Diego, California.

Figure 3-12. Bioretention area.

Hydrology

Runoff from the contributing area is captured and temporarily stored in a shallow surface basin before infiltration. The captured runoff then infiltrates into the approximately 2- to 4-foot-deep bioretention soil media bed, which has an infiltration rate capable of draining the bioretention area within a specified design drawdown time (usually surface water should draw down in 12–24 hours, and subsurface water should drain in 48–96 hours).

After the stormwater percolates through the soil media, it infiltrates into the underlying subsoil if site conditions allow for adequate infiltration rates (typically greater than 0.5 inches per hour). The volume-reduction capability of bioretention areas can be enhanced by providing a gravel drainage layer beneath the bioretention area. When subsoil infiltration rates are slower than 0.5 inches per hour, filtered water is directed toward a stormwater conveyance system or other IMP via underdrain pipes. Volume reduction via partial infiltration and storage in the soil (approximately 20 to 70 percent, depending on soil conditions) can still occur when underdrains are present as long as an impermeable liner is not installed (Davis et al. 2012); partial infiltration occurs in those cases because some of the stormwater bypasses the underdrain and percolates into the subsoil (Davis et al. 2012; Hunt et al. 2006; Strecker et al. 2004).

Underdrains should be modified when practicable to create a sump or internal water storage (IWS) zone by upturning or elevating the underdrain outlet—this enhances infiltration and pollutant load reductions while maintaining an aerated root zone for plant health (Brown and Hunt 2011). Bioretention areas should be lined with an impermeable barrier when conditions prevent infiltration (such as in clay soils or near building foundations and steep slopes). Moderate volume reduction can still be achieved by lined systems because significant stormwater volumes can be stored in the available pore space of the media to be used by vegetation between storm events (Davis et al. 2012; Li et al. 2009).

Bioretention areas are designed to capture a specified design volume and can be configured as online or offline systems. Online bioretention areas require an overflow system for managing extra volume created by larger storms. Offline bioretention areas do not require an overflow system but do require some freeboard (the distance from the overflow device and the point where stormwater would overflow the system). Bioretention can also be designed for hydromodification control per SUSMP (County of San Diego 2012) requirements. Controlled experiments demonstrated reductions in peak discharge from fully lined (noninfiltrating) bioretention cells with as little as 2 feet of filter media (Li et al. 2010). Peak attenuation is most effectively achieved by infiltrating practices with high surface storage and media pore volume, and by pairing bioretention in a treatment train with a detention-type IMP (Brown et al. 2012; Davis et al. 2012; Hunt et al. 2012).

Water Quality

Bioretention areas provide comprehensive pollutant load reduction at various depths through physical, chemical, and biological mechanisms. Table 3-1 describes the effectiveness of bioretention for targeted management of specific water quality constituents. Infiltration provides the most effective mechanism for pollutant load reduction and should be encouraged where practicable. Treatment performance can also be enhanced (particularly for nitrogen, pathogens, and other pollutants that are removed by sorption) by installing deep media with slow infiltration rates (1 to 2 inches per hour) (Bright et al. 2010; Hathaway et al. 2011; Hunt et al. 2012; Hunt and Lord 2006; Rusciano and Obropta 2007).

Applications

Bioretention can be adapted and incorporated into almost any landscape. Common applications of bioretention include parking lot islands, areas along the perimeter of pavement, throughout landscaped areas, near roof downspouts, and along roadways. Examples of bioretention are provided in Figure 3-13 to Figure 3-16.

Table 3-1. Pollutant removal characteristics of bioretention

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]	Removal processes	Minimum recommended media depth for treatment	References
Sediment	High	8.3	Settling in pretreatment and mulch layer, filtration and sedimentation in top 2 to 8 inches of media.	1.5 feet	Hatt et al. 2008; Hunt et al. 2012; Li and Davis 2008; Geosyntec Consultants and Wright Water Engineering 2012; Stander and Borst 2010;
Metals	High	TCd: 0.94 µg/L, TCu: 7.67 µg/L, TPb: 2.53 µg/L, TZn: 18.3 µg/L	Removal with sediment and sorption to organic matter and clay in media.	2 feet	Hsieh and Davis 2005; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012
Hydro-carbons	High	N/A	Removal and degradation in mulch layer.	N/A	Hong et al. 2006; Hunt et al. 2012
Total phosphorus	Medium (-240% to 99%)	0.09	Settling with sediment, sorption to organic matter and clay in media, and plant uptake. Poor removal efficiency can result from media containing high organic matter or with high background concentrations of phosphorus.	2 feet	Clark and Pitt 2009; Davis 2007; Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2006; Hunt and Lord 2006; ; Li et al. 2010
Total nitrogen	Medium (TKN: -5% to 64%, Nitrate: 1% to 80%)	TN: 0.90, TKN: 0.60, $NO_{2,3}$-N: 0.22	Sorption and setting (TKN), denitrification in IWS (nitrate), and plant uptake. Poor removal efficiency can result from media containing high organic matter.	3 feet	Barrett et al. 2013; Clark and Pitt 2009; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2006; Hunt et al. 2012; Kim et al. 2003; Li et al. 2010; Passeport et al. 2009;
Bacteria	High	Enterococcus: 234 MPN/ 100 mL, *E.coli*: 44 MPN/100 mL	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in mulch layer and media.	2 feet	Hathaway et al. 2009; Hathaway et al. 2011; Hunt and Lord 2006; Hunt et al. 2008; Hunt et al. 2012; Jones and Hunt 2010;
Thermal load	High	68–75 °F	Heat transfer at depth and thermal load reduction by volume reduction (ET and infiltration). IWS enhances thermal load reduction.	4 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012; Jones and Hunt 2009; Jones et al. 2012; Winston et al. 2011; Wardynski et al. 2013

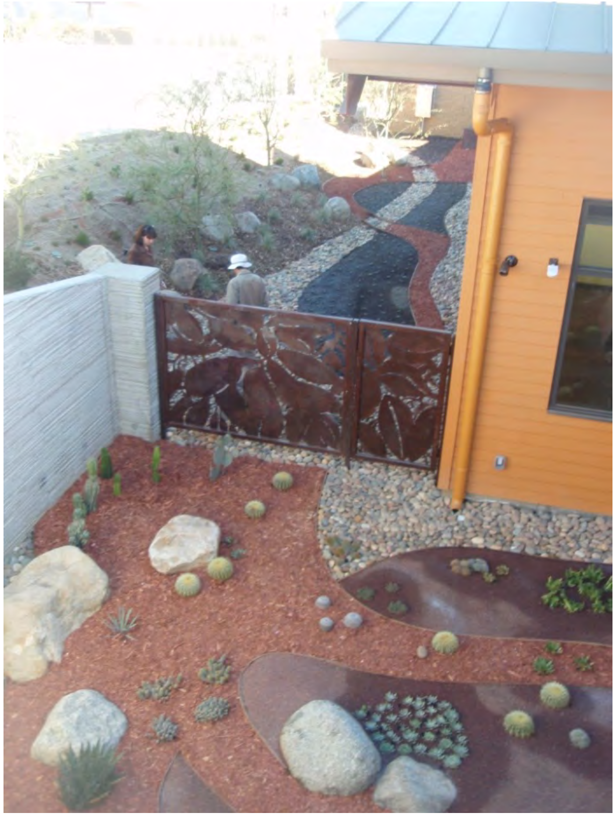
[1] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data.

Location: 805 and Bonita Road, Chula Vista, CA.

Figure 3-13. Bioretention area treating highway and commercial roadway runoff.

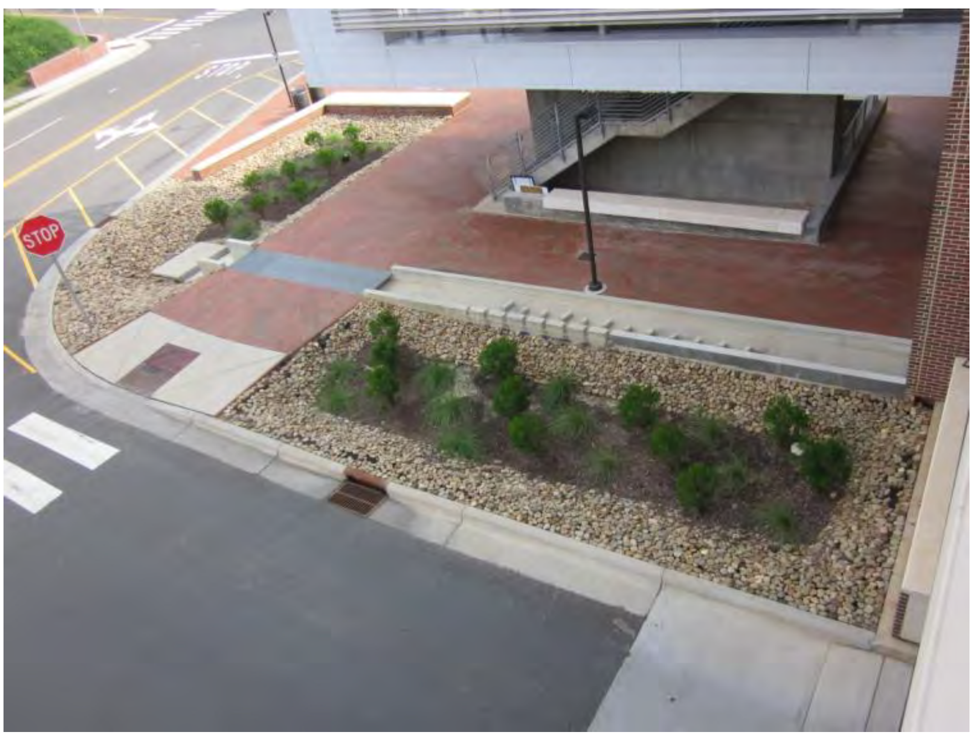
Location: County of San Diego Family Resource Center - Southeast, San Diego, California. Source: RBF Consulting.

Figure 3-14. Bioretention parking lot island.



Location: Fallbrook, CA.

Figure 3-15. Bioretention on the grounds of the Fallbrook Library.



Location: North Carolina State University campus, Raleigh, NC.

Figure 3-16. Parallel bioretention areas treat parking structure runoff conveyed by a concrete flume.

Appendix A outlines major design components and site considerations and describes the process for designing bioretention areas. For more information on bioretention please see Appendix A.1.

3.2.1.2 Bioretention Swales

Bioretention swales are shallow, open, vegetated channels, often referred to as linear bioretention, that are designed to treat runoff primarily by filtration through soil media and infiltration. Bioretention swales can convey stormwater and can be used in place of traditional curbs and gutters; however, when compared with traditional conveyance systems, the primary objective of bioretention swales is to infiltrate and improve the quality of water rather than convey it (although bioretention swales can be designed to manage excessive flow). Bioretention swales can have ranges of design variations with or without check dams, subsurface storage media, and underdrains. Soil media, such as that used in bioretention areas, can be added to a bioretention swale to improve water quality, reduce the runoff volume, and modulate the peak runoff rate, while also conveying excess runoff . For further details on bioretention swale soil media, please refer to Appendix G for bioretention soil media specifications. Bioretention swales are typically planted with grasses, shrubs, and trees that can withstand short periods of saturation (12 to 96 hours) followed by longer periods of drought (Figure 3-17).

Location: Harbor Drive, San Diego, California.

Figure 3-17. Bioretention swale in median (rendering).

Hydrology

Bioretention swales share the same functions as bioretention areas in that they are vegetated and mulched or grassed (i.e., landscaped) shallow depressions that capture and temporarily store stormwater runoff but are designed to be narrow and linear to fit within certain site constraints. The captured runoff infiltrates through the bottom of the depression and an approximately 2- to 4-foot-deep layer of soil media that has an infiltration rate capable of draining the bioretention area (to the bottom of the media) within a specified design drawdown time (usually within 48 hours). The soil media treats the stormwater using filtration, adsorption, and biological uptake.

After the stormwater infiltrates through the soil media, it percolates into the underlying subsoil if site conditions allow for adequate infiltration and slope protection. If site conditions do not allow for adequate infiltration or slope protection, filtered water is directed toward a stormwater conveyance system or other IMP via underdrain pipes.

Bioretention swales are designed to capture a specified design volume and can be configured as online or offline systems. Online bioretention swales require an overflow system for managing extra volume created by larger storms. Offline bioretention swales do not require an overflow system because higher flows bypass once the bioretention swale fills to capacity. Offline bioretention swales require some freeboard (the distance from the overflow device and the point where stormwater would overflow the system).

If an underdrain is not needed because infiltration rates are adequate and slope is not a concern, the remaining stormwater passes through the soil media and percolates into the subsoil. Partial infiltration (approximately 20 to 25 percent, depending on soil conditions) can still occur when underdrains are present as long as no impermeable barrier is between the soil media and subsoil. Partial infiltration occurs in such cases because some of the stormwater bypasses the underdrain and percolates into the subsoil (Hunt et al. 2006; Strecker et al. 2004).

Water Quality

Bioretention swales are volume-based IMPs intended primarily for water quality treatment and, depending on site slope and soil conditions, can provide high volume reduction. Where site conditions allow, the volume-reduction capability can be enhanced for additional volume reduction by omitting underdrains and providing a gravel drainage layer beneath the bioretention swale.

Bioretention swales function like bioretention areas and remove pollutants through physical, chemical, and biological mechanisms. Although horizontal flow on the bioretention swale surface can strain some larger pollutants, SUSMP (County of San Diego 2012) criteria dictate that stormwater must percolate vertically through the soil media for treatment. Table 3-2 reports water quality performance for bioretention swales.

Table 3-2. Pollutant removal characteristics of bioretention swales

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]	Removal processes	Minimum recommended media depth for treatment	References
Sediment	High	8.3	Settling in pretreatment and mulch layer, filtration and sedimentation in top 2 to 8 inches of media.	1.5 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hatt et al. 2008; Hunt et al. 2012; Li and Davis 2008; Stander and Borst 2010;
Metals	High	TCd: 0.94µg/L, TCu: 7.67µg/L, TPb: 2.53µg/L, TZn: 18.3 µg/L	Removal with sediment and sorption to organic matter and clay in media.	2 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2012
Hydro-carbons	High	N/A	Removal and degradation in mulch layer.	N/A	Hong et al. 2006; Hunt et al. 2012

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]	Removal processes	Minimum recommended media depth for treatment	References
Total phosphorus	Medium (-240% to 99%)	0.09	Settling with sediment, sorption to organic matter and clay in media, and plant uptake. Poor removal efficiency can result from media containing high organic matter or with high background concentrations of phosphorus.	2 feet	Clark and Pitt 2009; Davis 2007; Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2006; Hunt and Lord 2006; Li et al. 2010
Total nitrogen	Medium (TKN: -5% to 64%, Nitrate: 1% to 80%)	TN: 0.90, TKN: 0.60, $NO_{2,3}$-N: 0.22	Sorption and setting (TKN), denitrification in IWS (nitrate), and plant uptake. Poor removal efficiency can result from media containing high organic matter.	3 feet	Barrett et al. 2013; Clark and Pitt 2009; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2006; Hunt et al. 2012; Kim et al. 2003; Li et al. 2010; Passeport et al. 2009;
Bacteria	High	*Enterococcus*: 234 MPN/100 mL, *E.coli*: 44 MPN/100 mL	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in mulch layer and media.	2 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hathaway et al. 2009; Hathaway et al. 2011; Hunt et al. 2008; Hunt et al. 2012; Hunt and Lord 2006; Jones and Hunt 2010;
Thermal load	High	68–75 °F	Heat transfer at depth and thermal load reduction by volume reduction (ET and infiltration). IWS enhances thermal load reduction.	4 feet	Hunt et al. 2012; Jones et al. 2012; Jones and Hunt 2009; Wardynski et al. 2013; Winston et al. 2011

[1] Concentrations are based on bioretention performance data. Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data.

Applications

Bioretention swales can be applied in situations similar to bioretention, including parking lot islands, along the perimeter of paved areas, throughout landscaped areas, near roof downspouts, and along roadways. Bioretention swales are well-suited to green street retrofit projects because of their narrow, in linear design. Examples of bioretention swales are provided in Figure 3-18 and Figure 3-19.

Location: Logan Avenue, San Diego, CA.

Figure 3-18. Bioretention swale in median (rendering).

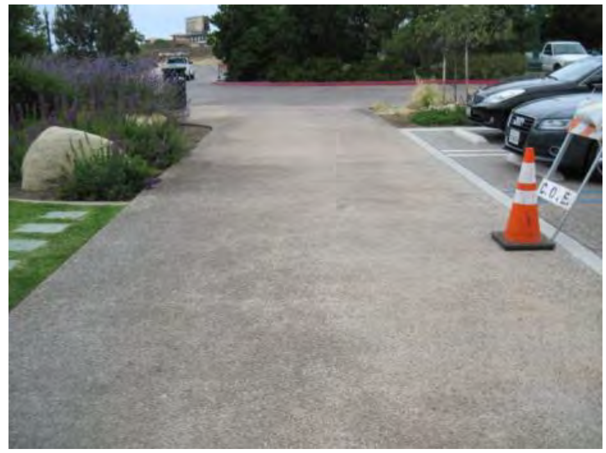
Location: Fresh and Easy Neighborhood Market, Oceanside, California.

Figure 3-19. Parking lot bioretention swales.

Appendix A outlines major design components and site considerations and describes the process for designing bioretention swales. For more information on bioretention swales please see Appendix A.2.

3.2.1.3 Permeable Pavement

Permeable pavements can infiltrate stormwater while simultaneously providing a stable load-bearing surface *(Figure 3-20)*.



Location: Cottonwood Creek Park, Encinitas, CA.

Figure 3-20. Example of pervious concrete.

While forming a surface suitable for walking and driving, permeable pavements also contain sufficient void space to infiltrate runoff into the underlying reservoir base course and soil. Permeable pavement can dramatically reduce impervious surface coverage without sacrificing intensity of use.

The four main categories of permeable pavements include poured-in-place pervious concrete, permeable asphalt concrete, permeable pavers, and granular materials. All of these permeable pavements (except some low-traffic unit pavers) have the same type of reservoir *base course* (a layer of material directly under the surface layer). This base course provides a stable load-bearing surface as well as an underground reservoir for water storage, which eliminates the possibilities of mud, mosquitoes, and safety hazards that are sometimes perceived to be associated with ephemeral surface drainage. The base course can store large volumes of runoff, and can be linked to roof runoff collection systems when aboveground cisterns are not feasible. In Europe and Australia, subsurface reservoir layers have been used to store and reuse stormwater to offset nonpotable water demand and for geothermal heating and cooling. As with cisterns, proper precautions must be taken to prevent accidental ingestion of reused stormwater from a reservoir layer.

The base course and reservoir layer must meet two critical requirements:

- It must be open-graded, meaning that the particles are of a limited size range, so that small particles do not choke the voids between large particles. Open-graded crushed stone of all sizes has a 38 to 40 percent void space, allowing for substantial subsurface water storage (Ferguson 1998).

- It must be washed, angular crushed stone, not rounded river gravel. Rounded river gravel will rotate under pressure, causing the surface structure to deform. The angular sides of a crushed stone base will form an interlocking matrix, allowing the surface to remain stable.

Depending on the use of the surface, additional base course aggregate might need to be added to support the intended load. This pertains to applications subject to heavy vehicle loads, but also applies for large areas where settling could result in unwanted puddles on surfaces, such as pedestrian walkways.

When used properly, permeable pavement can facilitate biodegradation of oils from cars and trucks, help rainwater infiltrate soil, decrease urban heating, replenish groundwater, allow tree roots to breathe, and reduce total runoff (Hansen 2005). Permeable pavement can be designed as a self-treating area or self-retaining area per SUSMP (County of San Diego 2012) criteria.

Hydrology

Permeable pavement systems are designed to reduce surface runoff by allowing stormwater to infiltrate the pavement surface. While the specific design can vary, all permeable pavements have a similar structure consisting of a surface course layer and an underlying stone aggregate reservoir layer. Where soils permit, permeable pavement allows captured runoff to fully or partially infiltrate into underlying soils; where infiltration is restricted (such as in clay soils or near sensitive infrastructure), permeable pavement can be lined with an impermeable membrane and used as subsurface detention system to allow settling of fine solids and hydromodification control.

Volume reduction primarily depends on the drainage configuration and subsoil infiltration capacities. Systems installed without underdrains in highly permeable soils can achieve practically 100 percent volume reduction efficiency (Bean et al. 2007). Systems installed in restrictive clay soils can still significantly reduce volume (Fassman and Blackbourn 2010; Tyner et al. 2009). The volume reduction can be further enhanced by treating the subgrade with scarification, ripping, or trenching (as discussed in section 4.1; Brown and Hunt 2010; Tyner et al. 2009), by omitting underdrains (where practicable), or by incorporating an IWS layer by upturning underdrain inverts to create a sump (Wardynski et al. 2013). Permeable pavement systems can also effectively attenuate peak flow by reducing overall runoff volumes, promoting infiltration, and increasing the lag time to peak discharge (Collins et al. 2008).

Water Quality

Permeable pavement systems, when designed and installed properly, consistently reduce concentrations and loads of several stormwater pollutants, including heavy metals, oil and grease, sediment, and some nutrients. The aggregate sub-base improves water quality through filtering and chemical and biological processes, but the primary pollutant removal mechanism is typically load reduction by infiltration into subsoils. Table 3-3 reports water quality performance of permeable pavement.

Table 3-3. Pollutant removal characteristics of permeable pavement

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]	Removal processes	References
Sediment	High[1] (32% to 96%)	13.2	Settling on surface and in reservoir layer.	Bean et al. 2007; CWP 2007; Fassman and Blackbourn 2011Gilbert and Clausen 2006; MWCOG 1983; Pagotto et al. 2000; Roseen et al. 2009, 2011; Rushton 2001; Schueler 1987; Toronto and Region Conservation Authority 2007;

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]	Removal processes	References
Metals	High (65% to 84%)	TAs: 2.50µg/L, TCd: 0.25µg/L, TCr: 3.73 µg/L, TCu: 7.83µg/L, TPb: 1.86µg/L, TNi: 1.71 µg/L, TZn: 15.0 µg/L	Removal with sediment and possible sorption to aggregate base course.	Bean et al. 2007; Brattebo and Booth 2003; CWP 2007; Dierkes et al. 2002; Fassman and Blackbourn 2011; Gilbert and Clausen 2006;MWCOG 1983; Pagotto et al. 2000; Roseen et al. 2009, 2011; Rushton 2001; Schueler 1987; Toronto and Region Conservation Authority 2007;
Hydro-carbons	Medium (92% to 99%)	N/A	Removal in surface course and aggregate layer.	Roseen et al. 2009, 2011
Total phosphorus	Low (20% to 78%)	0.09	Settling with sediment, possible sorption to aggregate, and sorption to underlying soils.	Bean et al. 2007; CWP 2007; Gilbert and Clausen 2006; MWCOG 1983; Roseen et al. 2009, 2011; Rushton 2001; Schueler 1987; Toronto and Region Conservation Authority 2007; Yong et al. 2011
Total nitrogen	Low (-40% to 88%)	TKN: 0.80, *$NO_{2,3}$-N: 0.71*	Setting, possible denitrification in IWS, sorption in underlying soils (TKN).	Collins et al. 2010; CWP 2007; MWCOG 1983; Schueler 1987;
Bacteria	Medium	N/A	Sedimentation, filtration, sorption, desiccation, and predation in surface course and reservoir layer.	Myers et al. 2009; Tota-Maharaj and Scholz 2010
Thermal load	Medium	58–73 °F	Heat transfer at depth, thermal buffering through profile, and thermal load reduction by volume reduction (infiltration). IWS enhances thermal load reduction.	Wardynski et al. 2013

[1] Run-on from adjacent surfaces with high sediment yield can cause premature clogging of the surface course or subsurface interface. Permeable pavement should not be used to treat runoff from pervious surfaces or other areas with high sediment yield.

[2] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations in *italics* were (statistically) significantly higher than influent concentrations.

Types

3.2.1.3.1 Pervious Concrete

Pervious concrete, also known as Portland cement pervious pavement, was developed in Florida in the 1970s. Pervious concrete is a discontinuous mixture of coarse aggregate, hydraulic cement and other cementitious materials, admixtures, and water, which has a surface-void content of 15–25 percent, allowing water and air to pass through the pavement.

Pervious concrete, like other concretes, acts as a rigid slab. It has an open, rough appearance and provides a walking or riding surface similar to aggregate concrete (Figure 3-21).

Location: Cottonwood Creek Park, Encinitas, California.

Figure 3-21. Pervious concrete.

An aggregate base course can be added to increase total pavement thickness or hydraulic storage. Pervious concrete is an extremely permeable material: in tests by the Florida Concrete and Products Association, permeability of new surfaces has been measured as high as 56 inches per hour. With improper installation or mix, permeability can be reduced to 12 inches per hour. Even after attempts to clog the surface with soil by pressure washing, the material retained some permeability (Florida Concrete and Products Association, n.d.). Because of its porosity, pervious concrete pavements usually do not require curbs and gutters for primary drainage control.

Pervious concrete might be suitable for light- to medium-duty applications such as residential access roads, residential street parking lanes, parking lots, overflow parking areas, utility access, sidewalks, bike paths, maintenance walkways/trails, residential driveways, stopping lanes on divided highways, and patios.

3.2.1.3.2 Permeable Asphalt Concrete (AC)

Permeable AC consists of an open-graded asphalt concrete over an open-graded aggregate base, over a draining soil. Unlike traditional asphalt concretes, permeable AC contains very little fine aggregate (dust or sand), and is comprised almost entirely of stone aggregate and asphalt binder. Without fine sediment filling the voids between larger particles, permeable AC has a void content of 12–20 percent, which makes it very permeable (Figure 3-22).

Location: Flinn Springs County Park, El Cajon, California.

Figure 3-22. Permeable asphalt concrete.

In installations where permeable AC has been used over a permeable base, the pavement becomes an infiltration system which allows water to pass through the surface and collect in the open-graded aggregate base. This will achieve stormwater management without curb or gutter systems. In these sites, which mostly consist of parking lots and light duty roads, permeability has been maintained over long periods without special maintenance. On light duty streets built of permeable AC, some loss of porosity occurs in localized areas because of sedimentation or scuffing at intersections caused by repeated wheel turning, but the overall performance of the pavement is not significantly compromised (Ramsey et al. 1988).

Permeable AC might be suitable for light- to medium-duty applications such as residential access roads, residential street parking lanes, parking lots, overflow parking areas, utility access, sidewalks, bike paths, maintenance walkways/trails, residential driveways, stopping lanes on divided highways, and patios. Permeable AC is widely used by Caltrans and transportation departments in Georgia, Texas, North Carolina, and Oregon as a wearing course (also known as a permeable friction course overlay) on freeways because its porosity creates a superior driving surface in rainy weather by allowing better drainage, traction, and visibility (Hansen 2005). These installations are always over an impermeable asphalt layer and are not permeable pavements, but have demonstrated effective pollutant removal capability (Caltrans 1995; Eck et al. 2012). Permeable AC overlays have also been used in heavy-use applications such as airport runways and highways because its porosity creates a favorable driving surface in rainy weather (Caltrans 1995).

3.2.1.3.3 Permeable Pavers

Permeable pavers are an alternative to conventional pavement and can create an opportunity for infiltration of stormwater runoff and groundwater recharge. For areas without heavy traffic, permeable pavers are an alternative to conventional asphalt and concrete. Permeable pavers are modular systems with pervious openings that allow water to infiltrate the surface. Runoff that percolates through the pavement profile is either detained in an underlying gravel bed, infiltrated into the underlying soil, or both. Types of permeable pavers include permeable interlocking concrete pavers, open cell unit pavers, and brick/natural stone pavers. These types are introduced in the following subsections.

3.2.1.3.3.1 Permeable Interlocking Concrete Pavers (PICP)

Solid, pre-cast permeable interlocking concrete pavers (PICP) are available in a wide variety of colors, shapes, sizes, and textures (Figure 3-23). They are designed to be set on a bedding course of aggregate and form an interlocking pavement surface that can bear heavy traffic loads. Stormwater infiltrates the pavement profile through gravel-filled void spaces between the pavers. PICP is generally considered the industry-standard for permeable pavers because the structural design prevents shifting and rocking that can occur when using open cell unit pavers or brick/natural stone pavers. A monitored demonstration site of PICP at the San Diego County Operations Center detected no runoff from the pavers during the 2005–2006 and 2006–2007 wet seasons. PICP tend to have high abrasion resistance, and can be suitable in situations where vehicle turning may cause other permeable pavements to ravel.

Location: Kellogg Park, La Jolla, California.

Figure 3-23. Permeable interlocking concrete pavers.

3.2.1.3.3.2 Open Cell Unit Paver

Open celled unit pavers are available in either precast concrete or plastic and are filled with soil and typically planted with turf (Figure 3-24). They were developed in Germany in the 1960s to reduce the *heat island effect* of large parking areas and are now used throughout the world. The products vary in size, weight, surface characteristics, strength, durability, interlocking capabilities, proportion of open area per grid, runoff characteristics, and cost. Laboratory tests have shown that open-celled units have runoff coefficients of from 0.05 to 0.35, depending on slope and surface configuration (Ramsey et al. 1988).

When planted with turf, they are generally most successful in overflow parking areas, driveways, or emergency access roads. If installed in heavily used parking areas, the turf often does not get adequate sunlight and on heavily traveled roadways it can be worn away from tire abrasion. Open-celled unit pavers can also be filled with alternatives to turf which includes either inert gravel or a lower maintenance groundcover such as chamomile. These alternatives can absorb some traffic and might be more appropriate to meet the State Water Conservation goals in San Diego. Because of their irregular surface, open-celled unit pavers generally do not provide comfortable walking surfaces, though the degree of comfort varies depending on design. Furthermore, open cell unit pavers that do not interlock can shift and rock under traffic loading.

Location: Shelter Island, San Diego, California.

Figure 3-24. Open cell unit pavers.

Applications

Permeable pavements can be used in a wide array of applications, including parking lots, parking lanes on light duty roads, pedestrian plazas, and alleys. Examples of permeable pavement in San Diego County are provided in Figure 3-25, Figure 3-26, and Figure 3-27.

For more information on permeable pavement please see Appendix A.3.

Location: Kellogg Park, La Jolla, California.

Figure 3-25. Permeable interlocking concrete pavers.

Location: Flinn Springs County Park, El Cajon, California.

Figure 3-26. Permeable asphalt concrete.

Location: Filippis Pizza Grotto, San Diego, California.

Figure 3-27. Pervious concrete.

3.2.1.4 Rock Infiltration Swale

A rock infiltration swale functions like a bioretention swale except that the surface is covered by cobble instead of mulch (Figure 3-28). Rock infiltration swales are flexible practices that can be incorporated throughout new or existing development and can also function as stormwater conveyance devices. Low-maintenance trees and shrubs can be planted in the soil media to improve function and aesthetics, but rock infiltration swales are typically implemented where conditions are too dry to support vegetation or where maintenance of vegetation is undesired.

Location: Cottonwood Creek Park, Encinitas, California.

Figure 3-28. Rock infiltration swale.

Hydrology

Rock infiltration swales are shallow, often narrow, depressions that capture and temporarily store stormwater runoff. The captured runoff percolates through the bottom of the depression and an approximately 2- to 4-foot deep layer of soil media, which has an infiltration rate capable of draining the rock infiltration swale (to the bottom of the media) within a specified design drawdown time (usually 10 to 48 hours). After the stormwater infiltrates through the media, it percolates into the subsoil, if site conditions allow for adequate infiltration and slope protection. If site conditions do not allow for adequate infiltration or slope protection, filtered water is directed toward a stormwater conveyance system or other stormwater runoff IMP via underdrain pipes. Rock infiltration swales can be designed to help meet hydromodification criteria and also for conveyance of higher flows.

Rock infiltration swales are designed to capture a specified design volume and can be configured as online or offline systems. Online IMPs require an overflow system for managing extra volume created by larger storms. Offline IMPs do not require an overflow system but do require some freeboard (the distance from the overflow device and the point where stormwater would overflow the system) and a diversion structure.

If an underdrain is not needed because infiltration rates are adequate and slope is not a concern, the remaining stormwater passes through the soil media and infiltrates into the subsoil. Partial infiltration (approximately 20 to 50 percent, depending on soil conditions) can still occur when underdrains are present as long as an impermeable barrier is not between the soil media and subsoil. Partial infiltration occurs in such cases because some of the stormwater bypasses the underdrain and percolates into the subsoil (Hunt et al. 2006; Strecker et al. 2004).

Water Quality

Rock infiltration swales are volume-based IMPs intended primarily for capture and infiltration of the design water quality treatment volume. These practices perform water quality functions similar to bioretention swales, with the exception that they do not typically allow for plant uptake because rock infiltration swales tend to be unplanted. Water quality improvement is accomplished through sedimentation, filtration, and adsorption associated with percolation of runoff through aggregate and underlying soil. Where site conditions allow, the volume-reduction and pollutant-removal capability of a rock infiltration swale can be enhanced to achieve additional credit toward meeting the volume-reduction requirement by omitting underdrains and providing a gravel drainage layer beneath the soil media. Table 3-4 reports water quality performance of rock infiltration swales.

Table 3-4. Pollutant removal characteristics of rock infiltration swales

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]	Removal processes	Minimum recommended media depth for treatment	References
Sediment	High	8.3	Settling in pretreatment and mulch layer, filtration and sedimentation in top 2 to 8 inches of media.	1.5 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hatt et al. 2008; Hunt et al. 2012; Li and Davis 2008; Stander and Borst 2010;
Metals	High	TCd: 0.94µg/L, TCu: 7.67µg/L, TPb: 2.53µg/L, TZn: 18.3 µg/L	Removal with sediment and sorption to organic matter and clay in media.	2 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2012
Hydro-carbons	High	N/A	Removal and degradation in mulch layer.	N/A	Hong et al. 2006; Hunt et al. 2012
Total phosphorus	Medium (-240% to 99%)	0.09	Settling with sediment, sorption to organic matter and clay in media, and plant uptake. Poor removal efficiency can result from media containing high organic matter or with high background concentrations of phosphorus.	2 feet	Clark and Pitt 2009; Davis 2007; Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2006; Hunt and Lord 2006; Li et al. 2010
Total nitrogen	Medium (TKN: -5% to 64%, Nitrate: 1% to 80%)	TN: 0.90, TKN: 0.60, $NO_{2,3}$-N: 0.22	Sorption and setting (TKN), denitrification in IWS (nitrate), and plant uptake. Poor removal efficiency can result from media containing high organic matter.	3 feet	Barrett et al. 2013; Clark and Pitt 2009; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2006; Hunt et al. 2012; Kim et al. 2003; Li et al. 2010; Passeport et al. 2009;

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]	Removal processes	Minimum recommended media depth for treatment	References
Bacteria	High	*Enterococcus*: 234 MPN/100 mL, *E.coli*: 44 MPN/100 mL	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in mulch layer and media.	2 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hathaway et al. 2009; Hathaway et al. 2011; Hunt and Lord 2006; Hunt et al. 2008; Hunt et al. 2012; Jones and Hunt 2010;
Thermal load	High	68–75 °F	Heat transfer at depth and thermal load reduction by volume reduction (ET and infiltration). IWS enhances thermal load reduction.	4 feet	Hunt et al. 2012; Jones and Hunt 2009; Jones et al. 2012; Wardynski et al. 2013; Winston et al. 2011;

[1] Concentrations are based on bioretention performance data. Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data.

Applications

Rock infiltration swales can be incorporated along roadways, along the perimeter of parking lots, and in areas of concentrated flow throughout the landscape. An example of a rock infiltration swale in San Diego County is provided in Figure 3-29.

Appendix A outlines major design components and site considerations and describes the process for designing rock infiltration swales. For more information on rock infiltration swales please see Appendix A.4.

Location: Seaside Ridge Development, Encinitas, California.

Figure 3-29. Rock infiltration swale.

3.2.2 Filtration IMPs

IMPs that do not incorporate infiltration as a primary design feature are known as *filtration IMPs*. These include planter boxes, vegetated roofs, and sand filters. Most infiltration IMPs (including bioretention, bioretention swales, and permeable pavement) can also be modified using an impermeable liner to perform as filtration IMPs. These practices should only be considered if on-site infiltration or retention practices are not feasible.

3.2.2.1 FLOW-THROUGH PLANTERS

A flow-through planter is a concrete box containing soil media and vegetation that functions like a small bioretention area but is completely lined and must have an underdrain (Figure 3-30). Flow-through planters have been implemented around paved streets, parking lots, and buildings to provide initial stormwater detention and treatment of runoff. Such applications offer an ideal opportunity to minimize directly connected impervious areas in highly urbanized areas. In addition to stormwater management benefits, flow-through planters provide green space and improve natural aesthetics in tightly confined urban environments. The vegetation and soil media in the planter box provide functions similar to bioretention area. Refer to Appendix E for vegetation specifications and Appendix G for soil media details.

Location: Downtown San Diego, California.

Figure 3-30. Flow-through planter.

Hydrology

Flow-through planters are vegetated and mulched or grassed (i.e., landscaped), shallow depressions that capture, temporarily store, and filter stormwater runoff before directing the filtered stormwater toward a stormwater conveyance system or other IMP via underdrain pipes. The captured runoff infiltrates through the bottom of the depression and an approximately 2-to 4-foot deep soil media layer that has an infiltration rate capable of draining the planter box (to the bottom of the soil media) within a specified design drawdown time (usually 48 hours). The soil media provides treatment through filtration, adsorption, and biological uptake. Some volume reduction (15 to 20 percent) is possible through evapotranspiration and storage in the soil media (Hunt et al. 2006). Flow-through planters are typically planted with grasses, shrubs, and trees that can withstand short periods of saturation (10 to 24 hours) followed by longer periods of drought. Flow-through planters are ideal for treating cistern discharge where infiltration is restricted.

Water Quality

Flow-through planters are typically volume-based IMPs intended primarily for water quality treatment that can also provide some peak-flow reduction and volume reduction. Flow-through planters should be used only in place of bioretention areas where geotechnical conditions do not allow for infiltration. Although flow-through planters do not allow for infiltration into the sub-soils, they still provide functions considered fundamental for LID practices and meet SUSMP (County of San Diego 2012) requirements for water quality treatment. Flow-through planters remove pollutants through physical, chemical, and biological mechanisms. Specifically, they use sorption, microbial activity, plant uptake, sedimentation, and filtration, similar to bioretention areas. Flow-through planters are capable of consistent and high pollutant removal for sediment, metals, and organic pollutants (e.g., hydrocarbons). Current research shows that pollutant removal is possible with underdrains through the function provided at the surface and by the soil media. Table 3-5 reports the water quality performance of flow-through planters.

Table 3-5. Pollutant removal characteristics of flow-through planters

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]	Removal processes	Minimum recommended media depth for treatment	References
Sediment	High	8.3	Settling in pretreatment and mulch layer, filtration and sedimentation in top 2 to 8 inches of media.	1.5 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hatt et al. 2008; Hunt et al. 2012Li and Davis 2008; Stander and Borst 2010
Metals	High	TCd: 0.94µg/L, TCu: 7.67µg/L, TPb: 2.53µg/L, TZn: 18.3 µg/L	Removal with sediment and sorption to organic matter and clay in media.	2 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2012
Hydro-carbons	High	N/A	Removal and degradation in mulch layer.	N/A	Hong et al. 2006; Hunt et al. 2012
Total phosphorus	Medium (-240% to 99%)	0.09	Settling with sediment, sorption to organic matter and clay in media, and plant uptake. Poor removal efficiency can result from media containing high organic matter or with high background concentrations of phosphorus.	2 feet	Clark and Pitt 2009; Davis 2007; Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2006; Hunt and Lord 2006; Li et al. 2010
Total nitrogen	Medium (TKN: -5% to 64%, Nitrate: 1% to 80%)	TN: 0.90, TKN: 0.60, $NO_{2,3}$-N: 0.22	Sorption and setting (TKN), denitrification in IWS (nitrate), and plant uptake. Poor removal efficiency can result from media containing high organic matter.	3 feet	Barrett et al. 2013; Clark and Pitt 2009; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2006; Hunt et al. 2012; Kim et al. 2003; Li et al. 2010; Passeport et al. 2009;
Bacteria	High	*Enterococcus*: 234 MPN/100 mL, *E.coli*: 44 MPN/100 mL	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in mulch layer and media.	2 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hathaway et al. 2009; Hathaway et al. 2011; Hunt and Lord 2006; Hunt et al. 2008; Hunt et al. 2012; Jones and Hunt 2010;

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]	Removal processes	Minimum recommended media depth for treatment	References
Thermal load	High	68–75 °F	Heat transfer at depth and thermal load reduction by volume reduction (ET and infiltration). IWS enhances thermal load reduction.	4 feet	Hunt et al. 2012; Jones and Hunt 2009; Jones et al. 2012; Wardynski et al. 2013; Winston et al. 2011;

[1] Concentrations are based on bioretention performance data. Effluent concentrations displayed in **bold** were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data.

Applications

Flow-through planter boxes can be applied in situations where infiltrating bioretention is not feasible, including areas near buildings or in rights-of-way when utility conflicts restrict infiltration (Figure 3-31).

Figure 3-31. Roadside flow-through planter.

Appendix A outlines major design components and site considerations and describes the process for designing flow-through planter boxes. For more information on flow-through planter boxes please see Appendix A.5.

3.2.2.2 Vegetated (Green) Roofs

Vegetated roofs reduce runoff volume and rates by intercepting rainfall in a layer of rooftop growing media (Figure 3-32). Captured rainwater then evaporates or is transpired by plants back into the atmosphere. Rainwater in excess of the media capacity is detained in a drainage layer before flowing to roof drains and downspouts. Vegetated roofs are highly effective at reducing or eliminating rooftop runoff from small to medium storm events, which can reduce downstream pollutant loads; however, vegetated roofs do not typically improve the quality of captured rainwater.

Location: County of San Diego Operations Center, San Diego, California.

Figure 3-32. Extensive vegetated roof.

In addition to stormwater volume reduction, vegetated roofs offer an array of benefits, including extended roof lifespan, improved building insulation and energy use, reduction of urban heat island effects, opportunities for recreation and rooftop gardening, noise attenuation, air quality improvement, wildlife habitat, and aesthetics. Vegetated roofs can be designed as extensive, shallow-media systems or intensive, deep-media systems depending on the design goals, roof structural capacity, and available funding. Extensive vegetated roofs in the San Diego region will likely require drip irrigation in the summer, but air conditioner condensate or harvested rainwater can be used for this purpose. Although commonly called green roofs, vegetated roofs need not be green year-round and are often planted with drought-tolerant desert plants.

Hydrology

The main benefits that vegetated roofs provide are significant rainfall volume retention and evapotranspiration, and reduced peak discharge from rooftops. While hydrologic performance of vegetated roofs varies with media and material type, roof pitch, vegetation, climate, and season, vegetated roofs tend to retain (on average) between 45 and 75 percent of annual rainfall (Berndtsson 2010). Vegetation has been shown to significantly enhance rooftop rainwater retention when compared with unplanted soil media, especially in the summer and in arid environments, although the majority of water retention and evaporation occurs in the soil media (Berndtsson 2010; Schroll et al. 2011; Wolf and Lundholm 2008). High runoff retention mimics evapotranspiration and canopy interception of natural systems, which shifts the urban water balance more toward predevelopment hydrologic conditions.

Water Quality

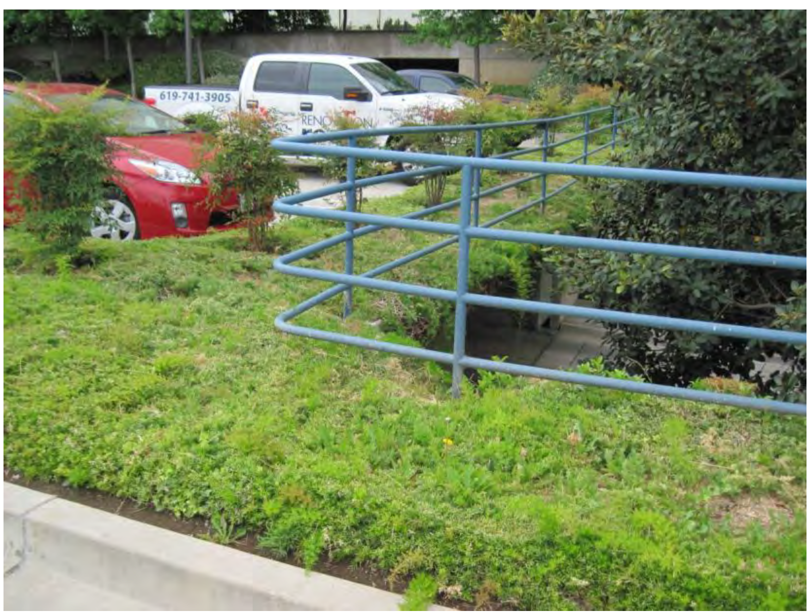
The body of knowledge surrounding vegetated roof effluent quality is limited. In general, vegetated roofs are expected to export higher phosphorus and nitrogen concentrations than measured in rainfall (Berndtsson 2010). This is mainly from release of nutrients from organic matter and fertilizers in the vegetated roof soil media. Nevertheless, overall nutrient loads can be reduced when water volume reduction is considered (Kohler et al. 2002). Vegetated roofs also tend to reduce heavy metal loads relative to incoming loads from precipitation (Berndtsson 2010). Vegetated roofs are considered self-treating areas by the SUSMP (County of San Diego 2012); effluent does not require further treatment.

Applications

Vegetated roofs are applicable for structures with sufficient structural capacity. Examples of vegetated roofs in San Diego County are provided in Figure 3-33 and Figure 3-34.

Location: Fallbrook Library in Fallbrook, California.

Figure 3-33. Extensive vegetated roof.



Location: La Mesa, California.

Figure 3-34. Intensive plantings on the top level of a parking structure.

Appendix A outlines major design components and site considerations and describes the process for designing vegetated roofs. For more information on vegetated roofs please see Appendix A.6. Additional information can also be found in the *Design Guideline and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West* (Tolderlund 2010).

3.2.2.3 Sand Filters

Sand filters have proven effective in removing several common pollutants from stormwater runoff. Sand filters generally control stormwater quality, providing very limited flow rate control (USEPA 1999). The purpose of sand filters is to manage the first flush, which typically contains the highest concentration of pollutants.

Two strategies are available for incorporating sand filters into the site design. *Surface sand filters* (sometimes known as Austin sand filters) are open basins that allow sunlight penetration to enhance pathogen removal. Surface sand filters can be integrated into the site plan as recreational facilities such as volleyball courts or open space. The second option is a *subsurface sand filter* (sometimes known as a Delaware sand filter) which is a closed basin that can be easily incorporated belowground into the edge of parking lots and roadways (Figure 3-35). Subsurface sand filters require very little space in a site but generally have smaller drainage areas and can be more challenging to maintain. Both types of sand filter require some form of pretreatment (such as a filter strip, swale, forebay, or sedimentation chamber) to remove gross solids and larger particles.

Location: San Antonio, Texas.

Figure 3-35. Surface sand filter.

Hydrology

Sand filters are filtering IMPs that remove trash and pollutants by passing stormwater vertically through a sand media. Sand filters are generally applied to land uses with a large fraction of impervious surfaces and ultra-urban locations. Although an individual sand filter can handle only a small contributing drainage area, multiple units can be dispersed throughout a large site.

Sand filters are designed primarily for water quality enhancement; however, surface sand filters can store a substantial volume of water and be used for peak flow attenuation. Sand filters typically employ underdrain systems to collect and discharge treated stormwater but can also be designed as infiltration-type systems when the soils have sufficient permeability or infiltration rates. Infiltration further enhances a sand filter’s ability to mitigate flood flows and reduces the erosive potential of urban runoff.

Water Quality

Sand filters are capable of removing a wide variety of pollutant concentrations in stormwater via settling, filtering, and adsorption processes. Sand filters have been a proven technology for drinking water treatment for many years and now have been demonstrated to be effective in removing urban stormwater pollutants including total suspended solids, particulate-bound nutrients, biochemical oxygen demand

(BOD), fecal coliform, and metals (USEPA 1999). Sand filters are volume-based IMPs intended primarily for treating the water quality design volume. In most cases, sand filters are enclosed concrete or block structures with underdrains; therefore, only minimal volume reduction occurs via evaporation as stormwater percolates through the filter to the underdrain. Table 3-6 reports the water quality performance of sand filters.

Table 3-6. Pollutant removal characteristics of sand filters

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]	Removal processes	References
Sediment	High (74% to 95%)	<u>8.7</u>	Settling in pretreatment and surface, filtration and sedimentation in media.	Barrett 2003, 2008, 2010; Bell et al. 1995; Geosyntec Consultants and Wright Water Engineering 2012; Horner and Horner 1995;
Metals	High (14% to 87%	<u>TAs: 0.87µg/L,</u> <u>TCd: 0.16µg/L,</u> <u>TCr: 1.02µg/L,</u> <u>TCu: 6.01µg/L,</u> <u>TPb: 1.69µg/L,</u> <u>TNi: 2.20µg/L,</u> <u>TZi: 19.9µg/L</u>	Removal with sediment (optional: sorption to organic matter and clay amendments in media).	Barrett 2010; Geosyntec Consultants and Wright Water Engineering 2012
Total phosphorus	Low (-14% to 69%)	<u>0.09</u>	Settling with sediment (optional: sorption to organic matter and clay amendments in media). Poor removal efficiency can result from media containing high organic matter or with high background concentrations of phosphorus.	Barrett 2010; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012;
Total nitrogen	Low (20%)	TN: 0.82, TKN: 0.57, *$NO_{2,3}$-N: 0.51*	Sorption and setting (TKN) and denitrification in IWS (nitrate). Poor removal efficiency can result from media containing high organic matter.	Barrett 2008; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012;
BOD	High (-27% to 55%)	N/A	Sedimentation, filtration, and biodegradation.	Barrett 2010
Bacteria	High (fecal coliform: -70% to 54%, fecal streptococcus: 11% to 68%)	<u>Fecal coliform: 542 MPN/100mL</u>	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in surface layer.	Barrett 2010; Geosyntec Consultants and Wright Water Engineering 2012

[1] <u>Underlined</u> effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

Applications

Sand filters can be incorporated in many situations throughout the landscape, particularly in and around parking lots (Figure 3-36 and Figure 3-37).

Location: San Carlos Recreation Area, San Diego, California.

Figure 3-36. Surface sand filter with concrete energy dissipater (rendering).

Location: North Carolina State University, Raleigh, North Carolina.

Figure 3-37. Subsurface sand filter in parking lot.

Appendix A outlines major design components and site considerations and describes the process for designing sand filter. For more information on sand filters please see Appendix A.7.

3.2.3 Volume-Storage and Reuse IMPs

Techniques used to capture and store runoff from rooftops and other surfaces can be used at many scales to meet hydromodification and water quality goals. On a smaller scale, properly sized rain barrels can be used to mitigate rooftop runoff from small residential dwellings and outbuildings. Cisterns (either surface or subsurface containers) and subsurface reservoir beds can be used for capturing and storing larger volumes of runoff from both rooftop and overland flow. Rainwater harvesting is most effective for hydrologic and water quality control if adequate capacity is available to capture the desired water quality volume—this is accomplished by slowly dewatering the temporary storage reservoir (preferably to irrigate a vegetated area or to offset other potable water uses) between storm events.

3.2.3.1 Cisterns and Rain Barrels

A cistern is an above-ground storage vessel with either a manually operated valve or a permanently open outlet (Figure 3-38). If the cistern has an operable valve, the valve can be closed to store stormwater for irrigation or infiltration between storms. This system requires continual monitoring by the resident or grounds crews, but provides greater flexibility in water storage and metering. If a cistern is provided with an operable valve and water is stored inside for long periods, the cistern must be covered to prevent mosquitoes from breeding. A cistern system with a permanently open outlet can also provide for metering stormwater runoff. If the cistern outlet is significantly smaller than the size of the downspout inlet (e.g., ¼- to ½-inch diameter), runoff will build up inside the cistern during storms, and will empty out slowly after peak intensities subside. The cistern must be designed and maintained to minimize clogging by leaves and other debris. In the drier regions of the County, cisterns and rain barrels might only fill up a couple times a year and might be more practical when the system is supplemented with graywater from a County-permitted *graywater system*.

Location: San Pasqual Academy, Escondido, California.

Figure 3-38. Rain barrels.

Hydrology

Cisterns are typically placed near roof downspouts so that flows from existing downspouts can be easily diverted into the cistern. Runoff enters the cistern near the top and is filtered to remove large sediment and debris. Collected water exits the cistern from the bottom or can be pumped to areas more conducive for infiltration. Cisterns can be used as a reservoir for temporary storage or as a flow-through system for peak flow control. Cisterns are fitted with a valve that can hold the stormwater for reuse, or they release the stormwater from the cistern at a rate below the design storm rate. Regardless of the intent of the storage, an overflow must be provided if the capacity of the cistern is exceeded. The overflow system should route the runoff to an IMP for treatment or safely pass the flow into the stormwater drainage system. The overflow should be conveyed away from structures. The volume of the cistern should be allowed to slowly release, preferably into an IMP for treatment or into a landscaped area where infiltration has been enhanced.

Cisterns have been used for millennia to capture and store water. Droughts in recent years have prompted a resurgence of rainwater harvesting technology as a means of offsetting potable water use. Studies have shown that adequately designed and used systems reduce the demand for potable water and can provide important hydrologic benefits (Vialle et al. 2012; DeBusk et al. 2012). Hydrologic performance of rainwater harvesting practices varies with design and use; systems must be drained between rain events to reduce the frequency of overflow (Jones and Hunt 2010). When a passive drawdown system is included (e.g., an orifice that slowly bleeds water from the tank into an adjacent vegetation bed or infiltrating practice), significant runoff reduction can be achieved (DeBusk et al. 2012).

Water Quality

Because most rainwater harvesting systems collect rooftop runoff, the water quality of runoff harvested in cisterns is largely determined by surrounding environmental conditions (e.g., overhanging vegetation, bird and wildlife activity, atmospheric deposition,), roof material, and cistern material (Despins et al. 2009; Lee et al. 2012; Thomas and Greene 1993). Rooftop runoff tends to have relatively low levels of physical and chemical pollutants, but elevated microbial counts are typical (Gikas and Tsihrintzis 2012; Lee et al. 2012; Lye 2009; Thomas and Greene 1993). Physicochemical contaminants can be further reduced by implementing a first-flush diverter (discussed later); however, first-flush diverters can have little impact on reducing microbial counts (Lee et al. 2012; Gikas and Tsihrintzis 2012).

The pollutant reduction mechanisms of rain tanks are not yet well understood, but sedimentation and chemical transformations area thought to help improve water quality. Despite limited data describing reduction in stormwater contaminant concentrations in cisterns, rainwater harvesting can greatly reduce pollutant loads to waterways if stored rainwater is infiltrated into surrounding soils using a low-flow drawdown configuration or when it is used for alternative purposes such as toilet flushing or vehicle washing. Rainwater harvesting systems can also be equipped with filters to further improve water quality.

Applications

A cistern typically holds several hundred to several thousand gallons of rainwater and come in a variety of sizes and configurations. Figure 3-39 shows a typical aboveground plastic cistern and Figure 3-40 shows the same cistern with a wooden wrap. Cistern can also be decorative such as the one shown in Figure 3-41 at the Children's Museum in Santa Fe, NM or be placed below ground as shown in Figure 3-42.

Smaller cisterns (fewer than 100 gallons), or rain barrels, can be used on a residential scale (Figure 3-43). Collected water can be used to supplement municipal water for nonpotable uses, primarily irrigation. Although useful for raising public awareness and for meeting basic irrigation needs, rain barrels do not typically provide substantial hydrologic benefits because they tend to be undersized relative to their contributing drainage area. Figure 3-44 shows rain barrels adequately sized for the contributing roof area.

Appendix A outlines major design components and site considerations and describes the process for designing rainwater harvesting systems. For more information on cisterns please see Appendix A.8.

Figure 3-39. Typical plastic cistern.

Figure 3-40. Wood wrapped cistern.

Source: Santa Fe, New Mexico, Children's Museum.

Figure 3-41. Decorative cistern.

Figure 3-42. Below-ground cistern.

Figure 3-43. Residential rain barrel.

Figure 3-44. Rain barrels adequately sized for contributing roof area.

3.2.4 CONNECTIVITY IMPS

IMPs that maintain slow, shallow, overland flow through vegetation or rocks can be used to remove sediment-associated pollutants by settling and straining. Examples include vegetated swales and vegetated filter strips. These practices are typically used for conveying runoff to other structural IMPs and for pretreatment.

Shallow and low-velocity flows are generally achieved by grading the site and sloping pavement in a way that promotes sheet flow of runoff. The key concept is to move water slowly through vegetation at a shallow depth that optimizes residence time. The slow movement of runoff provides an opportunity for sediments and particulates to settle or be strained and subsequently degraded through biological activity (CASQA 2003). Connectivity IMPs should be vegetated (and/or rock-lined) with appropriate plant material such as xeriscape plants or salt grass to match the climate, soil conditions, and relevant landscaping requirements. In the dry arid regions of the County, rock swales and xeriscaping are appropriate to meet state water conservation goals. Furthermore, connectivity IMPs can be designed with soil amendments to allow for limited volume reduction and flow attenuation.

3.2.4.1 VEGETATED SWALES

Vegetated swales can be a particularly effective design strategy in large conventionally paved parking lots. Parking lot drainage can be integrated with landscaping to provide filtration, evaporation, infiltration and detention of stormwater (Figure 3-45). Swales provide low maintenance solutions and act as linear IMPs along the perimeter of the lot or along internal islands. Stormwater is directed to these linear landscaped spaces and travels slowly over rocks and vegetated surfaces, reducing runoff velocities and allowing pollutants to settle out. Check dams or gravel weirs can also be added to swales to further slow and spread concentrated flows.

Location: Harbor Drive, San Diego, California.

Figure 3-45. Vegetated swale in median (rendering).

Hydrology

Vegetated swales are flow-based IMPs intended primarily for surface conveyance. Vegetated swales can help reduce the peak flow rate by increasing the site's time of concentration (the minimum time before runoff is contributed from the entire drainage area) and providing marginal volume reduction through infiltration. Installation costs can be lower than conventional subsurface storm drain conduit.

Water Quality

Vegetated swales remove sediment and particulate-bound pollutants through physical processes of sedimentation and filtration through vegetation. Load reductions are primarily accomplished by reducing concentrations as runoff flows through the practice (as compared to load reductions accomplished by practices that reduce stormwater volume), particularly at sites with compacted clay soils. Although high sediment load reductions have been observed in well-constructed swales, performance is highly variable and generally depends on flow rate, particle settling velocity (as determined by particle size distribution), and flow length (Bäckström 2003; Bäckström 2006; Deletic and Fletcher 2006; Yu et al. 2001). The sediment load reductions tend to be primarily associated with coarser sediment particles (sand) that do not pose as great a threat to downstream aquatic life as finer sediment particles (Deletic 1999; Luell 2011; Knight et al. 2013). Because swales offer minimal contact between runoff and sorptive surfaces, dissolved constituents and metals that tend to be associated with finer sediment particles (such as dissolved copper and zinc) can be harder to remove (Zanders 2005). In some cases, swales have been shown to export heavy metals (Bäckström 2003). USEPA (2012) reports that swales typically export pathogens. To achieve optimal removal of fine sediment particles, minimum swale lengths of 246 feet and 361 feet have been recommended, along with residence times of 5 to10 minutes (Bäckström 2003; Yu et al. 2001; Claytor and Schueler 1996). Additionally, flow depth should not exceed the height of the vegetation. These design parameters can make swales difficult to implement for water quality improvement in areas with limited available footprint. Table 3-7 reports the water quality performance of swales.

Table 3-7. Pollutant removal characteristics of vegetated swales

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]	Removal processes	References
Sediment	High (20% to 98%)	13.6	Sedimentation and filtration.	Deletic and Fletcher 2006, Yu et al. 2001, Bäckström 2003, Bäckström 2006, Geosyntec Consultants and Wright Water Engineering 2012
Metals	Medium	TAs: 1.17µg/L, TCd: 0.31µg/L, TCr: 2.32µg/L, TCu: 6.54µg/L, TPb: 2.02µg/L, TNi: 3.16µg/L, TZi: 22.9µg/L	Removal with sediment.	Fassman 2012; Geosyntec Consultants and Wright Water Engineering 2012
Total phosphorus	Low	*0.19*	Settling with sediment and plant uptake.	Deletic and Fletcher 2006; Geosyntec Consultants and Wright Water Engineering 2012
Total nitrogen	Low	TN: 0.71, TKN: 0.62, $NO_{2,3}$-N: 0.25	Sedimentation (TKN) and plant uptake.	Deletic and Fletcher 2006; Geosyntec Consultants and Wright Water Engineering 2012
Bacteria	Low (typically exports pathogens)	E. coli: 4190 MPN/100 mL, Fecal coliform: 5000 MPN/100 mL	Limited sedimentation, desiccation, predation, and photolysis at surface.	EPA 2012, Geosyntec Consultants and Wright Water Engineering 2012

[1] Concentrations are based on vegetated swale performance data. Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

Applications

Swales can be used in many different settings for conveyance and limited treatment of runoff. Examples of vegetated swales in San Diego County are provided in Figure 3-46 and Figure 3-47.

Location: Torrey Del Mar Park, San Diego, California.

Figure 3-46. Vegetated swale.

Location: Balboa Mesa Shopping Center, San Diego, California.

Figure 3-47. Vegetated Swale.

For more information on swales please see Appendix A.9.

3.2.4.2 VEGETATED FILTER STRIPS

Filter strips are areas of either planted or native vegetation, situated between a potential, pollutant-source area and a structural IMP that receives runoff (Figure 3-48). The term *buffer strip* is sometimes used interchangeably with filter strip. Vegetated filter strips are broad-sloped, open vegetated areas that accept shallow runoff from surrounding areas as distributed or sheet flow. Vegetated filter strips can also be used to stabilize the banks of structural IMPs that receive overland sheet flow.

Figure 3-48. Vegetated filter strip.

Hydrology

Filter strips are often used as pretreatment devices for other, larger-capacity IMPs such as bioretention areas. They assist by filtering sediment and associated pollutants before they enter the larger-capacity IMP, preventing clogging and reducing the maintenance requirements for the larger-capacity IMP. Filter strips provide an attractive and inexpensive vegetative IMP that can be easily incorporated into the landscape design of a site. Filter strips are commonly used in the landscape designs of residential, commercial, industrial, institutional, and roadway applications. They should be installed adjacent to the impervious areas that they are intended to treat. If installed for pretreatment of concentrated flows, concrete level spreaders or reverse slot drains should be used to redistribute flows and prevent preferential flow paths caused by erosion. Vegetated filter strips are flow-based IMPs that can, depending on site slope and soil conditions, provide limited volume reduction, peak flow mitigation, and can increase a site's time of concentration.

Water Quality

Vegetated filter strips are well-suited for treating runoff from roads, highways, driveways, roof downspouts, small parking lots, and other impervious surfaces. They can also be used along streams or open vegetated waterways to treat runoff from adjacent riparian areas. In such applications, they are commonly referred to as buffer strips. Because of their limited ability to provide peak attenuation and their ability to decrease sediment loads, vegetated filter strips are often used as a pretreatment for other IMPs. They have not been widely accepted as primary IMPs because of the wide range of pollutant removal efficiencies (Schueler et al. 1992; Young et al. 1996).

Although some assimilation of dissolved constituents can occur, filter strips are generally more effective in trapping sediment and particulate-bound metals, nutrients, and pesticides. Nutrients that bind to sediment include phosphorus and ammonium; soluble nutrients include nitrate. Biological and chemical processes could help break down pesticides, uptake metals, and use nutrients that are trapped in the filter. Vegetated filter strips also exhibit good removal of litter and other debris when the water depth flowing across the strip is below the vegetation height. Maintenance of vegetative cover is important to ensure that filters trips do not export sediment due to erosion of exposed ground (Winston et al. 2012). Table 3-8 reports the water quality performance of vegetated filter strips.

Table 3-8. Pollutant removal characteristics of vegetated filter strips

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]	Removal processes	References
Sediment	High (-195% to 91%)	19.1	Sedimentation and filtration.	Geosyntec Consultants and Wright Water Engineering 2012; Knight et al. 2013; Winston et al. 2011;
Metals	Medium	TAs: 0.94 µg/L, TCd: 0.18 µg/L, TCr: 2.73 µg/L, TCu: 7.30 µg/L, TPb: 1.96 µg/L, TNi: 2.92 µg/L, TZi: 24.3 µg/L	Removal with sediment.	Knight et al. 2013; Geosyntec Consultants and Wright Water Engineering 2012
Total phosphorus	Low (-126% to 40%)	*0.18*	Settling with sediment and plant uptake.	Geosyntec Consultants and Wright Water Engineering 2012; Knight et al. 2013; Winston et al. 2011;
Total nitrogen	Low (TN: -17% to 40%, TKN: -18% to 39%, $NO_{2,3}$-N:-18% to 43%)	TN: 1.13, TKN: 1.09, $NO_{2,3}$-N: 0.27	Sedimentation (TKN) and plant uptake.	Geosyntec Consultants and Wright Water Engineering 2012; Knight et al. 2013; Winston et al. 2011;
Bacteria	Low (likely exports pathogens)	N/A	Limited sedimentation, desiccation, predation, and photolysis at surface.	USEPA 2012

[1] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

Applications

Vegetated filter strips can be used to pretreat runoff before it enters other IMPs, including along roadways, edges of parking lots, and downgradient of downspouts. An example of a vegetated filter strip is shown in Figure 3-49.

For more information on vegetated filter strips please see Appendix A.10.

Location: Apex, North Carolina.

Figure 3-49. Vegetated filter strip treats roadway runoff draining to a bioretention area.

3.3 Selecting Structural IMPs

Selecting the proper structural IMP type and location depends on site-specific precipitation patterns, soil characteristics, slopes, existing utilities, and any appropriate setbacks from buildings or other infrastructures. Furthermore, selecting applicable and feasible IMPs will depend on the type of project, its characteristics, pollutants of concern, and the planning elements associated with the project's location.

A general checklist for characterizing drainage areas is below:

- Total area
- Percent imperviousness (total and directly connected)
- Soil characteristics, potential geotechnical hazards
- Depth to water table
- Topography, slope
- Land cover and land use (existing and future)
- Self-treating and self-retaining areas
- Utilities, water supply wells
- Development history and existing buildings

- Storm drainage systems, location of outfalls
- Projected roadway alignment modifications, roadway expansion
- Rainfall records and statistical analysis of storm characteristics and frequency

An IMP selection matrix is presented at the end of this section and is based on the site characteristics and potential functions of each IMP. The function and configuration that dictate IMP selection include tributary area, available site area for IMP implementation, slope, depth to seasonal high water table, soil characteristics and infiltration rates, setbacks, and pollutant reduction potential.

The objectives of stormwater IMPs are to slow and filter runoff using natural features and to remove or significantly reduce pollutants in stormwater runoff. Infiltration and evapotranspiration, along with retention for reuse, offer additional benefits of the IMPs. Pollutants of concern include sand, silt, and other suspended solids; trash; metals such as copper, lead, and zinc; nutrients such as nitrogen and phosphorus; certain bacteria and viruses; and organics such as petroleum hydrocarbons and pesticides. The major unit processes for pollutant removal include sedimentation (settling), filtration and straining, biotransformation through plant uptake, ion exchange, adsorption/absorption, and bacterial decomposition. Floatable pollutants such as oil and debris can be removed by most practices that allow filtration/straining, but separator structures designed to skim pollutants from the top of the water or draw cleaner water from below the surface can also be used. Table 3-9 indicates the major or dominant unit processes used for pollutant removal and secondary and optional processes based on designs of IMPs that incorporate those unit processes.

Table 3-9. Water quality unit processes for pollutant removal

Pollutants	Removal processes					
	Settling	Filtration/ straining	Sorption	Bioaccumulation	Biotransformation/ phytoremediation	Other (e.g., photolysis; volatilization)
Sediment	●	●	○	○	○	○
Nutrients	●	◖	●	●	●	○
Trash	●	●	○	○	○	◖
Metals	●	○	●	●	●	○
Bacteria	●	(●)	○	●	● &	● *
Oil and grease	○	●	●	◖	●	●
Organics	●	◖	◖	●	●	●
Pesticides	●	◖	●	◖	●	○
Oxygen demanding substances	●	●	○	○	●	○

Symbols: ● major function; ◖ secondary function; ○ insignificant function; ( ) optional function; & consumed by other organisms; * photolysis

Structural IMPs often provide multiple unit processes, depending on design. Table 3-10 shows the removal processes for each structural IMP type to be discussed in the following subsection, including the major functions, followed by secondary and possible optional unit operations, depending on design. IMPs can be used singularly or in series with multiple IMP types integrated as management practices to achieve the desired level of pollutant removal. Many IMPs can be used as standalone controls to meet both the hydromodification plan and water quality criteria in the SUSMP (County of San Diego 2012). Alternatively, meeting targeted treatment objectives can be achieved using a series of stormwater treatment systems in a treatment train. That approach can apply to new designs and in retrofitting existing IMPs. Such systems can often be designed along rights-of-way, in parking lots, or incorporated into landscaped areas to fit in relatively small or long, linear areas.

IMPs can be online or offline from the storm drainage systems, used singularly or in combination, or shared by multiple drainage areas, pursuant to local regulatory criteria (depending on project location and its jurisdiction), as outlined in Appendix A.

Table 3-10. Hydrologic and water quality unit processes for structural IMPs

Structural IMPs	Hydrologic/ hydromodification processes			Removal processes					
	Storage/detention or flow attenuation	Infiltration	Evapotranspiration	Settling	Filtration	Sorption	Bioaccumulation	Biotransformation/ phytoremediation	Other (e.g., photolysis; volatilization)
Infiltration IMPs									
Bioretention	●	(●)	◖	◖	●	◖	●	●	(◖)
Bioretention swale	(●)	(●)	◖	◖	◖	◖	◖	◖	(◖)
Permeable pavement	●	(●)	○	◖	●	(◖)	○	○	○
Infiltration trench	●	●	(◖)	◖	●	◖	○	○	○
Filtration IMPs									
Planter boxes	●	(●)	◖	◖	●	◖	(●)	(●)	(◖)
Vegetated (green) roof	(●)	○	●	◖	○	○	(◖)	(◖)	○
Sand filter	◖	(◖)	○	○	●	(◖)	○	○	(◖)
Volume-Storage and Reuse IMPs									
Cisterns/rain barrels	●	○	○	○	○	○	○	○	○
Connectivity IMPs									
Vegetated swale	(◖)	(◖)	◖	●	●	○	○	○	○
Vegetated filter strip	○	●	●	◖	◖	◖	○	○	○

Symbols: ● major function; ◖ secondary function; ○ insignificant function; ( ) optional function

IMPs can be implemented in combination to provide the maximum potential treatment for a site configuration. For example, a treatment train can be designed so stormwater first flows across vegetated filter strips, then drains into a vegetated swale, and is then conveyed to a bioretention area that infiltrates and filters it through a soil media. Such a treatment train can be integrated into the site to maximize hydrologic and water quality treatment using the unit processes of each IMP type. Effectiveness of individual or multiple integrated practices can be assessed in terms of removing substances or groups of pollutants.

Identifying and selecting IMPs on the basis of the pollutant(s) of concern is a function of site constraints, properties of the pollutant(s) of concern, IMP performance, stringency of permit requirements, contributing land use, and watershed-specific requirements such as total maximum daily loads. Pollutants of concern are especially important in water quality-limited stream segments and must be carefully reviewed in relationship to unit processes and potential IMP performance. Potential pollutants from various land uses are provided in chapter 2 of the SUSMP (County of San Diego 2012); IMPs should be selected based on their capacity to remove these anticipated pollutants.

3.3.1 IMP Selection Matrix

Table 3-11 is a tool to help project designers consider and select LID stormwater management practices according to site characteristics and constraints. Existing or expected site characteristics can be used to determine individual practices or a suite of practices that might be appropriate in site design. In addition, relative cost considerations can help project designers select specific IMPs, particularly between two or more IMPs that achieve the project's goal and meet permit compliance requirements. Therefore, the table lists dollar signs as qualitative costs for a relative comparison between types of IMPs rather than actual values.

Estimated costs in this table and in Appendix A.12 cover all components of construction and operation and maintenance for various-sized projects, but do not cover other conveyance needs that might be applicable. Cost estimates are based on the design standards recommended in Appendix A and can vary widely by the necessary configuration of the IMP and site constraints. These cost numbers are estimates and intended for planning purposes only. The project manager must refine these numbers throughout the phases of design to prepare a more accurate project construction estimate for bidding purposes. Cost estimates, particularly the maintenance costs, do not account for cost savings that result from using integrated practices (e.g., integrating bioretention areas into landscaping where the routine maintenance could be included in the budget for typical landscape maintenance). Including various sizes of projects in the maintenance costs attempts to include those costs in which an economy of scale has been observed. The sizes selected for this analysis were as follows:

- Large IMP system = 4,000 square feet.
- Medium IMP system = 2,000 square feet.
- Small IMP system = 500 square feet.

These categories are based on typically sized IMPs. The IMP system can include the application of multiple IMPs implemented in a treatment train. Appendix A.12 also provides more detailed information on costs that are based on the frequency and type of maintenance required, such as routine maintenance (costs associated with maintenance required monthly, up to every 2 years), intermediate maintenance (costs associated with maintenance required every 6 to 10 years) and replacement maintenance (costs associated with replacing the system; estimated as a service life of 20 years). Table 3-11 does not include the more detailed frequency costs.

Once individual or groups of IMPs have been selected using this matrix, consult Appendix A to develop detailed designs.

Table 3-11. Structural IMP selection matrix according to site characteristics

Attribute		LID practice type													
		Bioretoention[a]		Bioretention swale		Permeable pavement[b]		Rock infiltration swales	Planter boxes	Vegetated (green) roof	Sand filter		Vegetated filter strip	Vegetated swale	Cisterns/rain barrels
		(no UD)	**(UD)**	**(no UD)**	**(UD)**	**(no UD)**	**(UD)**				**(no UD)**	**(UD)**			
2012 County SUSMP treatment control		Yes		Yes		No Run-on: Self-Treating Area (No) Run-on: Self-Retaining Area (Yes)		Yes	Yes	Self-Treating Area (No)	Yes		Pretreatment only (No)	Yes (recommended for pretreatment only)	Yes if combined w/ bioretention
2012 County SUSMP hydromodification control		Yes		Yes		Yes		Yes	Yes	No	No		No	No	No, unless cistern is specially designed for HMP flow control
Maximum allowable contributing drainage area (acres)		< 5		< 2		Self-Treating: No Run-on Self-Retaining: Contributing run-on drainage area to permeable pavement area ratio must be less 2:1		< 2	< 5	Rooftop (Self Treating Area)	< 5		< 1	< 2	Rooftop
Soil infiltration rate (inches/hour)		> 0.5	< 0.5	> 0.5	< 0.5	> 0.5	< 0.5	> 0.5	N/A	N/A	> 0.5	< 0.5	N/A	N/A	N/A
Water table separation[c] (feet)		> 10	≥ 2	> 10	≥ 2	> 10	≥ 2	> 10	N/A	N/A	> 10	≥ 2	> 2	> 2	Below-grade tanks must be above the water table and bedrock[d]
Depth to bedrock (feet)		> 10	≥ 2	> 10	≥ 2	> 10	≥ 2	> 10	N/A	N/A	> 10	N/A	> 2	> 2	
IMP slope		< 0.5%		< 4%		< 4%		<4%	< 0.5%	< 45°	< 6%		< 6%	< 4%	N/A
Pollutant removal[e]	Sediments	High		High		High		High	High	Pollutant removal of green roofs generally occur through stormwater volume reduction.	High		High	Medium	Pollutant removal provided by downstream IMP, refer to specific IMP for removal efficiency (although stormwater volume reduction can reduce total pollutant loads if rainwater is harvested and reused)
	Nutrients	Medium		Medium		Low		Medium	Medium		Low		Low	Low	
	Trash	High		High		High		High	High		High		High	High	
	Metals	High		High		High		High	High		High		Medium	Medium	
	Bacteria	High		High		Medium		High	High		High		Low	Low	
	Oil & grease	High		High		Medium		High	High		High		Medium	Medium	
	Organics	High		High		Low		High	High		High		Medium	Medium	
	Pesticides	High		High		Medium		High	High		High		Medium	Medium	
	Oxygen demanding substances	High		High		Medium		High	High		High		Medium	Medium	
Runoff volume reduction		High	Medium	High	Medium	High	Medium	High	Low	High	Medium	Low	Low	Low	Medium
Peak flow control		Medium		Medium		Medium		Medium	Low	Medium	Medium		Low	Low	Medium
Groundwater recharge		High	Low	High	Low	Medium	Low	High	N/A	N/A	Medium	Low	Low	Low	Low
Setbacks (feet)	Structures	> 10		> 10		> 10		> 10		N/A				> 10	> 5
	Steep slopes	> 50		> 50		> 50		> 50		N/A				> 50	> 50
Costs[f]	Construction	$ - $$		$ - $$		$$ - $$$		$ - $$	$$	$$$	$ - $$		$	$	$ - $$
	O & M (small)	$$ - $$$		$$ - $$$		$$ - $$$		$$	$$	$$	$$ - $$$		$$	$$	$$
	O & M (medium)	$ - $$[g]		$ - $$[f]		$$		$ - $$	$ - $$	$$	$$		$	$ - $$	$ - $$
	O & M (large)	$ - $$[g]		$ - $$[f]		$ - $$		$ - $$	$ - $$	$$	$$		$	$ - $$	$ - $$

Notes: UD = Underdrain; [a] If lined, see planter box column; [b] If lined, see sand filter with underdrain column; [c] Separation depth from bottom of IMP to water table; [d] For tank outlet and overflow; [e] Based on SUSMP pollutant grouping scheme; [f] Costs are relative, can be variable project to project, and are generalized. Please see Appendix A.12 for more specific cost information; [g] Based on necessary regular landscape maintenance already required.

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3.3.2 MAXIMIZING MULTIPLE BENEFITS OF IMPS

IMPs can provide excellent ecosystem services and aesthetic value to stakeholders. Bioretention areas can enhance biodiversity and beautify the urban environment with native vegetation. Permeable pavements inherently provide multi-use benefits because the facilities double as parking lots and transportation corridors. Harvesting rainwater provides an alternative nonpotable water source. The following components can be incorporated into IMPs to promote multi-use benefits:

- Simple signage or information kiosks to raise public awareness of stormwater issues and educate the public about the benefits of watershed protection measures; provide a guide for native plant and wildlife identification.
- Volunteer groups can be organized to perform basic maintenance as an opportunity to raise public awareness.
- Larger IMPs can be equipped with pedestrian cross-paths or benches for wildlife viewing.
- Sculptures and other art can be installed within the IMP and outlet structures or cisterns can incorporate aesthetically-pleasing colors, murals, or facades.
- Vegetation with canopy cover can provide shade, localized cooling, and noise dissipation.
- Enhanced pavement textures, colors, and patterns can calm traffic, increase aesthetic appeal, enhance pedestrian safety, and draw attention to multi-use stormwater practices.
- Bird and butterfly feeders can be used to attract wildlife to the IMPs.
- Ornamental plants can be cultivated along the perimeter and in the bed of vegetated IMPs (invasive plants should be avoided).
- IMPs can function as irrigation beds for stormwater captured by other IMPs, such as rainwater harvesting or the reservoir layer of permeable pavement.
- Using captured runoff as a nonpotable -water supply for flushing toilets, washing cars, filling swimming pools, sweeping streets, and other uses.
- Permeable pavers can be selected to maintain the character of historic districts while providing stormwater management solutions.
- Incorporating creative downspout designs for small practices (rain chains).

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4 Implementation Considerations

Once integrated management practices (IMPs) have been selected, sited and designed, it is critical for IMP effectiveness that proper implementation be tracked, inspected and monitored. Construction errors that result in deviation from intended IMP designs can lead to failure or undermining of intended IMP functions. If IMPs are not adequately maintained, these functions can be similarly undermined, leading to shortened IMP life and reduced function, thus it is also important that IMPs are maintained and inspected on a regular basis. Additionally, monitoring of IMP hydrology and water quality is critical to evaluating IMP performance and compliance with pollutant load reduction and hydrologic attenuation requirements.

This section outlines key considerations for implementation, maintenance and monitoring of successful and effective IMPs. This section also covers the importance of demonstration projects in ensuring the continual improvement of IMP planning, design and construction.

4.1 IMP Construction

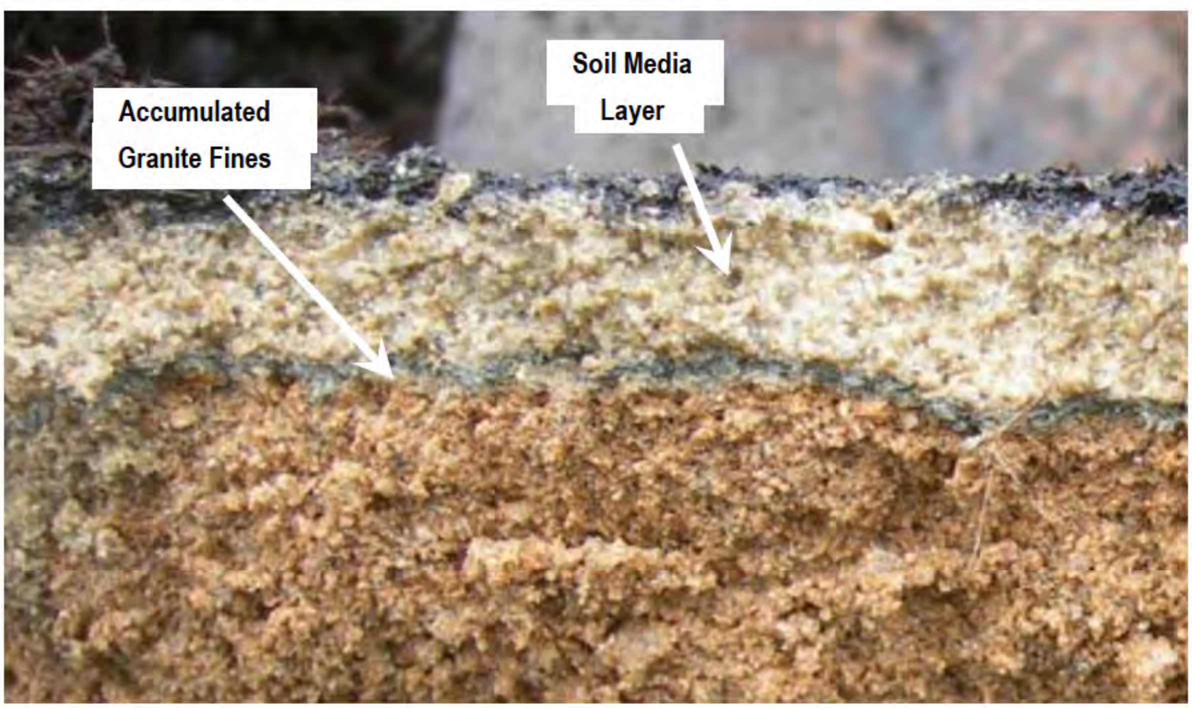
Essential functions of structural IMPs can be compromised by common construction practices if soil is compacted by heavy equipment, if the area experiences erosion and sediment accumulation, or if work is performed in saturated conditions. Construction oversight and inspections by a qualified inspector familiar with the functions of structural IMPs are recommended for quality control and assurance. As part of construction oversight, inspectors should ensure that the proper erosion control practices are implemented in accordance with the Construction General Permit (Order 2012-0006-DWQ) as well as any other pertinent federal, state, and local regulations.

Sensitive areas designated for protection should be delineated before grading and clearing starts; ideally, these restrictions should be indicated on the site plan. Areas of existing vegetation that are planned for preservation should be clearly marked with a temporary fence. If trees have been identified for preservation, equipment should be prohibited within the drip line to prevent root and trunk damage. Trenching and excavating should not occur within the drip line, and trenches outside, but adjacent to, the drip line should be filled in quickly to avoid root drying.

Soil-disturbing activities at the construction site can increase erosion and sediment accumulation risks. Apply an effective combination of temporary soil erosion and sediment controls to minimize the discharge of sediments from the site or into a stormwater drainage system or natural receiving water. The California Stormwater Quality Association’s (CASQA’s) *Construction BMP Handbook* and Caltrans’ *Construction Site Best Management Practices (BMPs) Manual* provide detailed guidance and specifications for erosion and sediment control practices that apply to all construction sites. Properly applying the temporary controls (both on-site and for off-site parcels with the potential to contribute sediment) is essential and can help preserve the long-term capacity and functions of the permanent stormwater IMPs. Inspecting and maintaining these temporary controls are required, and will ensure that they remain effective.

Proper construction sequencing can reduce the risk of clogging by excessive accumulation of fine particles in the soil media layers. During construction, the extent of disturbed, exposed soils should be limited to reduce the risk of erosion. Imported soil media should not be incorporated into IMPs until all areas of the construction site are stabilized. Soil media should not be installed until at least the first course of asphalt (minimum 1 inch) has been set for roads and parking lots, which minimizes the amount of fines washed from the bedding layers into the IMP. A geotextile liner might not be sufficient to prevent fines from migrating into and clogging the soil media layer; for that reason, proper construction sequencing is crucial. Figure 4-1 and Figure 4-2 are examples of the fines that can accumulate and clog the soil media if proper construction sequencing is not followed.

Figure 4-1. Example of a bioretention area installed before permanent site stabilization, with the inset photo showing the clay layer clogging the mulch surface.



Source: NCSU-BAE.

Figure 4-2. Accumulated fines layer as a result of improper construction sequencing.

Construction specifications might include the following measures intended to protect the IMP while construction operations are underway:

- Establish a protective zone around valued natural areas and trees that will be preserved.
- Minimize the use of heavy equipment, especially in areas where infiltration IMPs will be.
- Minimize soil disturbance and unprotected exposure of disturbed soils.
- Expose only as much area as needed for immediate construction.
- As areas are cleared and graded, apply appropriate erosion controls to minimize soil erosion.
- Protect stormwater infiltration IMPs from unwanted sedimentation during the construction phase.
- Provide a temporary outlet to convey runoff down slope with sediment traps at outlets and inlets.
- Minimize the movement of soil into the drainage system.
- Use sediment and erosion protection practices early in the site clearing and grading process to reduce the sediment-laden runoff reaching soils intended for future infiltration.
- Protect future infiltration facilities from sediment from adjacent properties.

Inspections of all construction phases are essential to ensure that IMPs are properly installed, especially when critical elements of a structural IMP are being installed, such as inverts, inlets, outlets, overflow, and underdrains. In the design notes, designers should stipulate whether the type of materials specified cannot be substituted because they might not perform as well (e.g., engineered media). If an element of a structural IMP system was not properly constructed or the wrong materials were used, the entire system could fail.

Accurate grading of stormwater infrastructures, including structural IMPs and hardscape areas, is critical for ensuring that the water flows unimpeded and the IMP functions as intended. Research has shown that structural practices with insufficient storage capacity (whether because of carelessness when specifying outlet structure elevations or inaccurate grading) might not perform the functions for which they were installed (Brown and Hunt 2011; Luell et al. 2011). The designer and contractor should work together to ensure that the project is correctly built as planned. If necessary, arrange for appropriate training to occur before starting an IMP construction project and provide additional training on-demand during construction. Conduct a survey to verify that the intended average ponding depth has been provided (Figure 4-3); simply measuring the height of the outlet structure relative to the ground surface is inadequate (Wardynski and Hunt 2012).

Construction activities inherently compact a site’s soils and can dramatically decrease infiltration rates. Contractors should be clearly instructed to minimize compaction by using tracked equipment, excavating the last 12 inches using a toothed excavator bucket, and by minimizing the number of passes over the proposed subgrade—and by operating the equipment outside of the IMP area where possible (Figure 4-4). Earth moving activities should take place during dry conditions, to the extent practicable, to reduce the occurrence of smearing the underlying soil surface, which can reduce soil permeability. To mitigate compaction and partly restore infiltration capacity to the underlying soil (for practices that are intended to infiltrate), the subgrade should be treated by scarification or ripping to a depth of 9 to 12 inches (Figure 4-5; Tyner et al. 2009). If the design infiltration rate is not restored after scarifying or ripping, trenches can be installed along the subgrade to enhance infiltration. Trenches should be constructed 1-foot-wide by 1-foot-deep on 6-foot centers and filled with a 0.5-inch layer of washed sand, then topped off with pea gravel (Tyner et al. 2009).

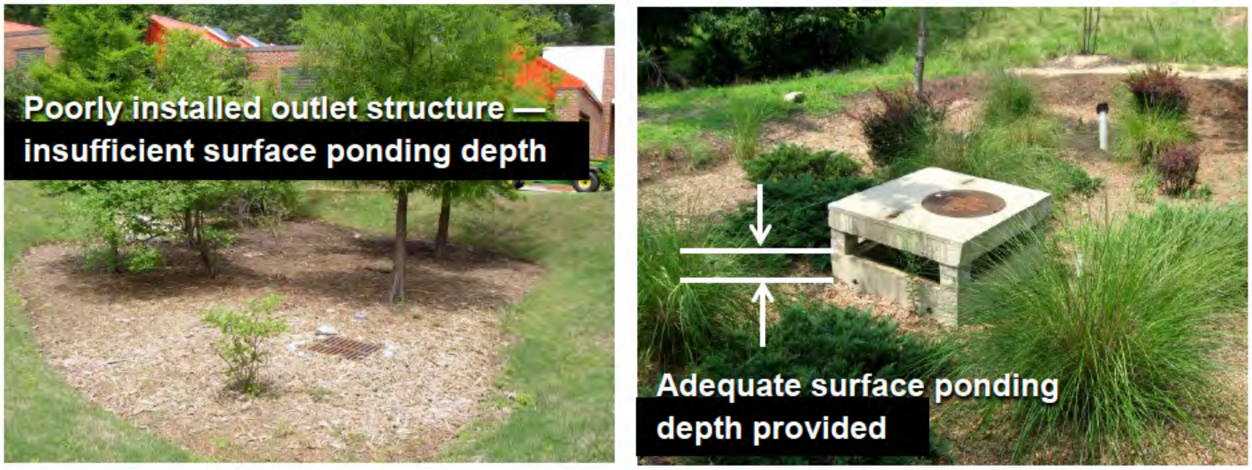


Figure 4-3. Accurate grading and outlet elevations must be provided to achieve intended hydrologic and water quality functions.

Figure 4-4. Heavy equipment (especially wheeled equipment) should be operated outside the excavated area to prevent compaction.

Source: NCSU-BAE.

Figure 4-5. For infiltrating practices, mitigate subsoil compaction by ripping grade to a depth of 12 inches.

Many urban sites, especially retrofit conditions, have little or no organic material in the soil structure because they have been paved over for many years. Excavation also tends to unearth relatively infertile subsoils. A soil test can determine the suitability of site soils for plant growth, especially for practices where vegetation will be planted in excavated soils (such as stormwater wetlands). Amendment with 2 to 4 inches of topsoil could be required to improve plant establishment. Information on specific soil media requirements for each respective IMP is included in Appendix A.

In summary, some key items to be aware of when inspecting for proper IMP installation are:

- Instruct contractors to minimize compaction by using tracked equipment, excavating the last 12 inches using a toothed excavator bucket, minimizing the number of passes over the subgrade, and operating the equipment outside of the IMP area where possible.
- Check as-built conditions of inverts, inlets, outlets, overflow, and underdrains with IMP plans and details.
- Ensure that design notes stipulate whether the type of materials specified cannot be substituted.
- Survey as-built conditions and compare with IMP plans to ensure accurate grading of stormwater infrastructures, including structural IMPs and hardscape areas as well as to ensure that the intended ponding depth has been provided.

- As necessary, arrange for appropriate training on proper methods to ensure intended IMP function and effectiveness is achieved, to occur before starting an IMP construction project and provide additional training on-demand during construction.

4.2 IMP Operation, Maintenance and Inspection

To sustain the effectiveness and function of structural IMPs and comply with a project's Maintenance Plan (to be prepared in accordance with chapter 5 of the SUSMP (County of San Diego 2012) regular maintenance and inspections are essential.

Operation and Maintenance

The major goal of IMP operation and maintenance is to ensure that the IMP is meeting the specified design criteria for stormwater flow rate, volume, and water quality control functions. If structural LID systems are not properly maintained, IMP effectiveness can be reduced, resulting in water quality impacts. Routine maintenance and any need-based repairs for a structural IMP must be completed according to schedule or as soon as practical after a problem is discovered. Deferred IMP maintenance could result in detrimental effects on the landscape and increased potential for water pollution and local flooding.

Training should be included in program development to ensure that maintenance staff has the proper knowledge and skills. Most structural IMP maintenance work—such as mowing, removing trash and debris, and removing sediment—is nontechnical and is already performed by property maintenance personnel. More specialized maintenance training might be needed for more sophisticated systems.

Typical IMP maintenance activities include periodic inspection of surface drainage systems to ensure clear flow lines, repair of eroded surfaces, adjustment or repair of drainage structures, soil cultivation or aeration, care of plant materials, replacement of dead plants, replenishment of mulch cover, irrigation, fertilizing, pruning and mowing. Landscape maintenance can have a significant impact on soil permeability and its ability to support plant growth. Most plants concentrate the majority of their small absorbing roots in the upper 6 inches of the soil surface if the surface is protected by a mulch or forest litter. If the soil is exposed or bare, it can become so hot that surface roots will not grow in the upper 8 to 10 inches. The common practice of removing all leaf litter and detritus with leaf blowers creates a hard crusted soil surface of low permeability and high heat conduction. Proper mulching of the soil surface improves water retention and infiltration, while protecting the surface root zone from temperature extremes (Hinman 2005).

In addition to impacting permeability, landscape maintenance practices can adversely affect water quality. Because commonly used fertilizers and herbicides are a source of toxic compounds, use of these substances should be kept to a minimum. Overwatering, which can be a significant contributor to runoff and dry weather flows, should be prevented. Watering should only occur to accommodate plant health and should be adjusted at least four times a year. Whenever practical, use weather-based irrigation controllers and follow real-time evapotranspiration (plant water use) data from the California Irrigation Management Information System (CIMIS) from the Department of Water Resources. Organic methods for fertilizers and pest control (including Integrated Pest Management) should be used.

General maintenance activities for the two major categories of structural facilities (infiltration and biofiltration/filtration) are as follows:

Infiltration IMPs

- Mowing and maintaining upland vegetated areas if applicable.
- Cleaning and removing debris after major storm events.
- Cleaning out accumulated sediment.
- Repairing or replacing stone aggregate.
- Maintaining inlets and outlets.
- Removing accumulated sediment from forebays or sediment storage areas when 50 percent of the original volume has been lost.

Biofiltration and Filtration IMPs

- Removing trash and debris from control openings.
- Watering and mowing vegetated areas.
- Removing and replacing all dead and diseased vegetation.
- Stabilizing eroded side slopes and bottom.
- Repairing erosion areas.
- Mulching void areas if needed.
- Maintaining inlets and outlets.
- Repairing leaks from the sedimentation chamber or from deteriorating structural components.
- Removing the top few inches of media and cultivating the surface when the filter bed is clogged.
- Cleaning out accumulated sediment from the filter bed once depth exceeds approximately one-half inch or when the filter layer no longer draws down within 24 hours.

In regions where dry and wet seasons are clearly distinguished, as is the case in San Diego County, conducting special maintenance activities before spring and fall storms can help to prevent increased erosion. If an IMP does not meet the specified design criteria, it must be repaired, improved, or replaced before a wet season starts. Any accumulated sediment and trash should be removed to maximize the performance of the facility throughout the following wet season. Any disturbed area that is not actively being graded must be fully protected from erosion.

Detailed descriptions of operation and maintenance for specific types of LID IMPs are in Appendix A and general maintenance issues are presented in the following sections.

4.2.1 Bioretention

Maintenance activities for bioretention units should focus on the major system components, especially landscaped areas. Bioretention landscape components should blend over time through plant and root growth, organic decomposition, and natural soil horizon development. Those biological and physical processes over time will lengthen the facility’s life span and reduce the need for extensive maintenance.

Irrigation of vegetated areas might be needed during the plant establishment period. During extended drought, temporary supplemental irrigation could be used to maintain plant vitality. Irrigation frequency will depend on the season and type of vegetation. Native plants generally require less irrigation than nonnative plants and should be incorporated into site designs where feasible. Controlled drainage can also be used to manage soil moisture by selectively elevating the underdrain outlet in dry periods; this will result in greater soil moisture retention between rainfall events. The underdrain outlet should always be no less than 18 inches below the soil surface to prevent saturation of the plant rooting zone.

Routine maintenance should include a twice-yearly evaluation of the trees and shrubs and subsequent removal of any dead or diseased vegetation (USEPA 1999). Corrective actions should be taken to remove areas of standing water in the IMP to restore proper infiltration rates and prevent mosquito and other vector habitat formation. To maintain the treatment area's appearance, pruning and weeding might be necessary. Replace mulch for aesthetics or when erosion is evident. Depending on pollutant loads, soil media might need to be replaced within 5 to 10 years of construction (USEPA 2000).

Source: NCSU-BAE.

Figure 4-6. Bioretention area clogged with sediment.

Stabilizing the area around the bioretention area can reduce maintenance by reducing the sediment flowing into the IMP. Figure 4-6 shows an example of how a bioretention area can become clogged with sediment if the surrounding area is not properly stabilized. Proper design of inlet systems can also reduce maintenance requirements by preventing trash and other gross solids from entering the bioretention area. In some cases, the inlet design will allow trash and gross solids to collect by the street for easy removal by a street sweeper or maintenance crew (Figure 4-7).

Source: Portland BES.

Figure 4-7. Inlet sump to remove gross solids.

4.2.2 Bioretention Swales

The maintenance objectives for bioretention swale systems consist of optimizing stormwater conveyance capacity, runoff volume control, and pollutant removal efficiency. To meet those objectives, a consistent ground cover must be maintained in the channel. Maintenance activities involve replacing or redistributing mulch, mowing (where appropriate), controlling weeds, irrigating during drought conditions, reseeding or sodding bare areas, and clearing debris and blockages. Vegetation should be managed on a regular schedule during the growth season to maintain adequate coverage. Accumulated sediment should also be removed manually to avoid concentrated flow. Fertilizer and pesticides should be applied only when plants are becoming established. Irrigation might be needed to maintain plant vitality, especially during plant establishment or in periods of extended drought. Irrigation frequency will depend on the season and type of vegetation. Native plants require less irrigation than nonnative plants and should be incorporated into site designs where feasible. Bioretention swales should be designed to minimize flow and prevent the type of erosion shown in Figure 4-8. Excessive flows should be diverted to prevent erosion and minimize maintenance

Figure 4-8. Erosion caused by excessive flows in a bioretention swale.

4.2.3 Permeable Pavement

Figure 4-9. Plant growth, debris buildup, and puddles indicate that permeable pavement is clogging. Prompt maintenance should be performed to prevent joints from fully sealing.

The main goal of the maintenance program for permeable pavement is to prevent clogging by fine sediment particles tasks (Figure 4-9). The primary maintenance requirements include regular inspections as well as a combination of preventative tasks, including timely removal of debris (e.g., leaf litter, acorns, grass clippings, mulch) and stabilizing surrounding areas. To maintain the infiltrative capacity of permeable pavements, vacuum sweeping should be performed at least twice per year. Frequency of vacuum sweeping should be adjusted according to the intensity of use and deposition rate on the permeable pavement surface. Settled paver block systems might require resetting. When modular pavements incorporate turf into their void area, normal turf maintenance practices, including watering, fertilization, and mowing, might be required (FHWA 2002).

For proper performance, maintenance staff must ensure that stormwater is infiltrating properly and is not standing or pooling on the surface of the permeable pavement. Standing water can indicate clogging of the void space. In such cases, vacuuming is necessary. If ponding still occurs, it might be necessary to inspect the media sub layer and possibly the underdrain.

4.2.4 Infiltration Trenches

The primary maintenance requirement for infiltration trenches involves inspecting and removing sediment and debris accumulation to prevent clogging. In addition to reduced water quality performance, standing water caused by clogged infiltration trenches can become a nuisance and harbor mosquito breeding. The pretreatment device must also be inspected, repaired, and maintained as needed. If a vegetated pretreatment is used, periodically mow the areas to maintain the grass height at an equal or greater height of the design flow depth. Accumulated debris must be removed monthly from the infiltration trench surface and the pretreatment areas.

4.2.5 Planter Boxes

General maintenance requirements for planter boxes are the same as the routine periodic maintenance of any landscaped areas or bioretention IMPs. The primary maintenance requirement for planter boxes is inspection of the vegetation and soil media. Regularly remove any accumulated trash and sediment in the device, especially after large storms, and inspect soils to evaluate root growth and channel formation in the soil media.

4.2.6 Green Roofs

Operating and maintaining green roofs primarily involves maintaining drainage structures and vegetation. Roof drains, gutters, and downspouts should be routinely inspected for clogging. If excess material tends to build up around drainage structures, the source of the problem should be remediated. To prevent vegetation from growing too close to roof drains and to identify roof drains for maintenance personnel, a circle of white gravel can be placed around the drain to designate a *no plant zone* as shown in Figure 4-10. Vegetation should be inspected periodically, especially during prolonged dry weather, to determine irrigation needs and general health. Periodically inspecting growing media and underlying drainage layers might also be necessary for extensive green roofs to ensure that reservoir layers are not filling with sediment deposits or extensive root networks. Intensive green roofs could require pruning and mowing, depending on vegetation type. As with all IMPs, appropriate health and safety protocols should always be followed when inspecting and maintaining green roofs. Foot traffic should be limited, to the extent practicable, to reduce plant damage.

Figure 4-10. No plant zone for a green roof.

4.2.7 Sand Filter

The primary maintenance requirement for sand filters is to remove trash, accumulated sediment, and media contaminated with hydrocarbons. If the filter does not drain within 48 hours, or if sediment has accumulated to a depth of 6 inches, the top layer (1 to 3 inches) of sand (media) must be replaced.

4.2.8 Cisterns and Rain Barrels

General maintenance activities for cisterns and rain barrels are similar to the routine periodic maintenance for on-site drinking water wells. The primary maintenance requirement is to inspect the tank and distribution system and test any backflow-prevention devices. Rain barrels require minimal maintenance several times a year and after major storms to prevent any clogging. Cisterns also require inspections for clogging and structural soundness twice a year, including inspection of all debris and vector control screens. If a first-flush diverter is used, it should be dewatered and cleaned between each significant storm event. Self-cleaning filters and screens, such as the ones shown in Figure 4-11, can help prevent debris from entering the cistern and reduce maintenance. Accumulated sediment in the tank must be removed at least once a year.

Figure 4-11. Self-cleaning inlet filters.

4.2.9 Vegetated Swales

The maintenance objectives for vegetated systems include optimizing filtration and stormwater conveyance capacity. To meet those objectives, a dense, healthy vegetative cover must be maintained in the channel. Maintenance activities involve mowing, controlling weeds, irrigating during drought conditions, reseeding bare areas, and clearing debris and blockages. Manage vegetation on a regular schedule during the growth season to maintain adequate coverage. Accumulated sediment should also be removed manually to avoid concentrated flow. Minimize fertilizer and pesticide application, possibly to periods of plant establishment only. Irrigation might be needed to maintain plant vitality, especially during plant establishment or in periods of extended drought. Irrigation frequency will depend on the season and type of vegetation. Native plants require less irrigation than nonnative plants and should be incorporated into site designs where feasible.

4.2.10 Vegetated Filter Strips

Vegetated filter strips require minimal maintenance, with the majority of maintenance satisfied through mowing. Mowing, for safety and aesthetics or to suppress weeds and woody vegetation, might be necessary once or twice a year. Primary maintenance activities are similar to other vegetated areas. However, gravel diaphragms or verges could require the removal of encroaching grass and sediment.

Irrigation might be needed to maintain plant vitality, especially during plant establishment and extended periods of drought. Irrigation frequency can be determined—as with other turf management—on the basis of the season and type of vegetation. Native plants often require less irrigation than nonnative plants and are recommended when feasible.

Trash tends to accumulate in strip areas, especially along roadways. The need for litter removal should be determined through periodic inspections, but litter should always be removed before mowing.

Inspections

Inspections should be conducted both routinely and as needed to ensure the ongoing success of the above maintenance activities. As-needed inspection and corresponding maintenance should be conducted after major storms. Routine activities, performed regularly (e.g., monthly), ensure that the IMP is in good working order and continues to be aesthetically pleasing. Routine inspection is an efficient way to prevent potential nuisance situations from developing and reduce the need for repair or maintenance. Routine inspection reduces the chance that polluted stormwater runoff will leave the site because problems can be quickly identified and corrected. Property maintenance personnel should be instructed to inspect IMPs during their normal routines. The project Maintenance Plan, required by the SUSMP (County of San Diego 2012), specifies the schedule and task required for IMP inspection.

In addition to regularly scheduled inspections, all IMPs should be inspected after any event or activity that could damage the IMP, particularly after every large storm event. Post-storm inspections should occur after the expected drawdown period for the IMP, when the inspector can determine if the IMP is draining correctly.

Routine and as-needed IMP inspections consist of the following technical and nontechnical activities:

- Inspect the general conditions of the IMP and areas directly adjacent to the IMP.
- Maintain access to the site, including the inlets, side slopes (if applicable), forebay (if one exists), IMP area, outlets, emergency spillway, etc.
- Examine the overall condition of vegetation.
- Eliminate any possibility of public hazards.
- Check the conditions of inflow points, pretreatment areas (if they exist), and outlet structures.
- Inspect and maintain the inlet and outlet regularly and after large storms.
- Ensure that the pretreatment areas meet the original design criteria.

- Check the encroachment of invasive plants in vegetated areas. This could require more frequent inspections in the growing season.
- Inspect water quality improvement components. Specifically, check the stormwater inflow, conveyance, and outlet conditions.
- Inspect hydrologic functions such as maintaining sheet flow where designed, ensuring functional pretreatment, maintaining adequate design storage capacity, and verifying proper operation of outlet structures.
- Check conditions downstream of the IMP to ensure that the flow is not causing hydromodification issues below the facility (e.g., excessive erosion, sedimentation).

Chapter 5 of the SUSMP (County of San Diego 2012) provides guidance on preparation of inspection checklists for inclusion in the project's Maintenance Plan. Appendix F of the SUSMP (County of San Diego 2012) includes private treatment control operation and maintenance verification forms for bioretention facilities, vegetated swales and higher rate biofilters; media filters and higher rate media filters; infiltration devices, constructed wetlands, and nonstandard treatment control practices. As an additional resource, checklists with maintenance specifications and requirements are provided in Appendix F. In general, individual IMPs can be described with minimum performance expectations, design criteria, structural specifications, date of implementation, and expected life span as provided in chapter 3 and detailed in Appendix A. Recording such information will help the inspector determine whether an IMP's maintenance schedule is adequate or requires revision and will allow comparison between the intended design and the as-built conditions. Checklists also provide a useful way for recording and reporting whether major or minor renovation or routine repair is needed. The effectiveness of an IMP might be a function of the IMP's location, design specifications, maintenance procedures, and performance expectations. Inspectors should be familiar with the characteristics and intended function of the IMP so they can recognize problems and know how they should be resolved.

In every inspection, whether routine or as needed, the inspector should document whether the IMP is performing correctly and whether any damage has occurred to the IMP since the last inspection. Ideally, the inspector will also identify what should be done to repair the IMP if damage has occurred. Documentation is very important in sustaining an efficient inspection and maintenance schedule, providing evidence of ongoing inspection and maintenance, and detecting and reporting any necessary changes in overall management strategies.

4.3 IMP Monitoring

Performance monitoring of stormwater IMPs is an important component of LID implementation programs. Monitoring provides the IMP designer and regulator with a mechanism to validate certain design assumptions and to quantify compliance with pollutant-removal performance objectives. Specific monitoring objectives should be considered early in the design process to ensure that LID practices are adequately configured for monitoring. Detailed monitoring guidance provided by EPA is listed in this chapter's references section (USEPA 2012). The instrumentation and monitoring configuration will vary from site to site, but the following general principles should be considered.

4.3.1 Monitoring Hydrology

An inlet/outlet sampling setup is suggested as the most effective monitoring approach to quantify flow and volume in stormwater IMPs. The runoff source and type of IMP will dictate the configuration of inflow monitoring. A weir or flume is typically installed at the inlet of IMPs that receive concentrated, open channel flow (e.g., from a pipe, curb cut, or a swale as shown in Figure 4-12, Figure 4-13, and Figure 4-14). Often a baffle box is used in conjunction with weirs to slow flows for more precise readings, as shown in Figure 4-15. The height of water flowing over the structure is automatically recorded (typically with a pressure transducer, such as a bubbler), which is used to calculate the rate of inflow. By integrating the flow rate over each monitored time step, total runoff volume for each storm event can be calculated. When runoff enters a practice via conduit, weirs or weir boxes can still be used for monitoring, but acoustic doppler velocity meters (ADVs) might be preferred. ADVs measure flow by recording the velocity and depth of water and will provide more accurate results if inflow pipes are expected to flow full (pressure flow), although some models require heavy turbidity to attain accurate readings. Outflow can be monitored using similar techniques as inflow by installing a weir or ADV at the point of overflow/outfall.

Figure 4-12. Inflow pipe to a bioretention area equipped with compound weir and bubbler for flow measurement. Water quality sampling tube and strainer are visible inside pipe.

Figure 4-13. Inlet curb cut with a v-notch weir.

Figure 4-14. Outlet of a roadside bioretention bumpout equipped with a V-notch weir for flow monitoring.

Figure 4-15. Underdrains from permeable pavement equipped with 30° V-notch weir boxes and samplers for flow and water quality monitoring.

It is critical during hydrologic monitoring that no downstream tailwater interfere with the monitoring device or false readings will be generated. To prevent tailwater effects at the inlet, the invert of the inflow pipe should be well above the expected temporary ponding depth of the IMP (Figure 4-16)—this is typically not possible with offline IMPs because the point of inlet is also the elevation that water bypasses. Additional freeboard between the inlet and the maximum expected water depth should be provided to prevent the inlet monitoring device from being inundated by tailwater from the IMP (Figure 4-17). The same considerations should be addressed when monitoring outflow by ensuring that the receiving storm drain network has sufficient capacity to convey high flows and prevent tailwater from inundating the outflow monitoring device. Figure 4-18 shows an example of potential monitoring points.

Figure 4-16. Example of a bioretention underdrain outlet with sufficient drop to install a flow monitoring weir without encountering tailwater.

Figure 4-17. Poorly installed H-flume at the inlet to a bioretention area in which the invert of the weir is too low and tailwater from the bioretention will interfere with measurement.

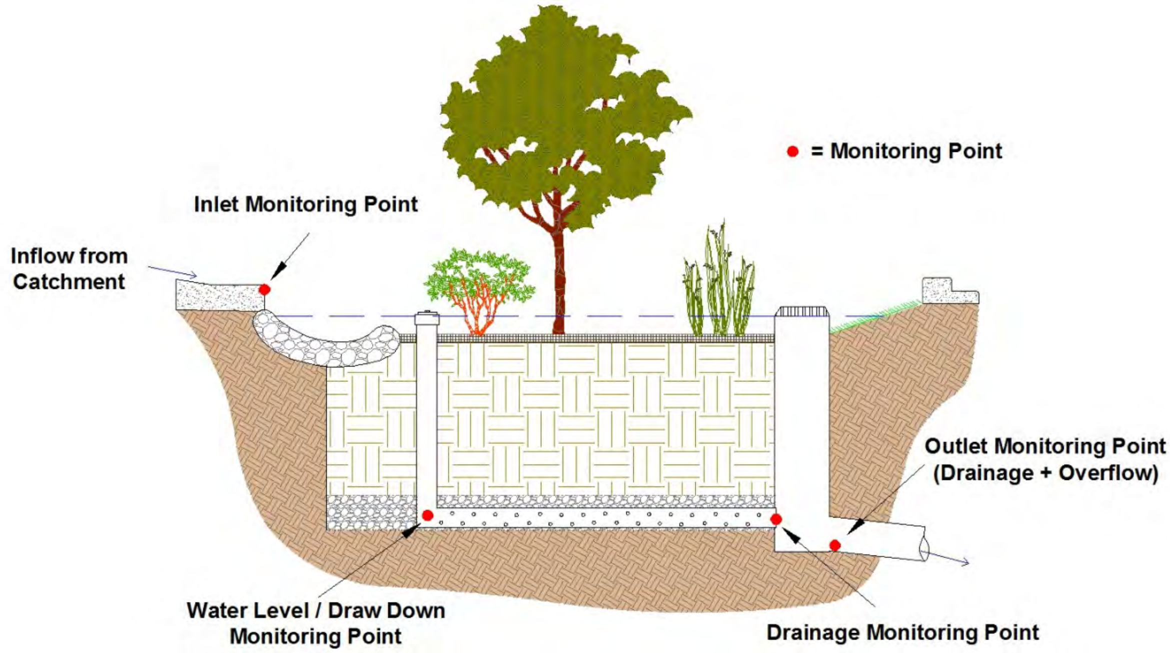


Figure 4-18. Monitoring points.

In addition to monitoring inflow and outflow, rainfall should be recorded on-site. Rainfall data can also be used to estimate inflow to IMPs that receive runoff only by sheet flow or direct rainfall (e.g., permeable pavement or green roofs). The type of rain gauge depends on monitoring goals and frequency of site visits. An automatic recording rain gauge (e.g., tipping bucket rain gauge), used to measure rainfall intensity and depth, is often paired with a manual rain gauge for data validation (Figure 4-19). For more advanced monitoring, weather stations can be installed to simultaneously monitor relative humidity, air temperature, solar radiation, and wind speed; these parameters can be used to estimate evapotranspiration.

Figure 4-19. Example of manual (left) and tipping bucket (right) rain gauges.

Water level (and drawdown rate) is another useful hydrologic parameter. Depending on project goals, perforated wells or piezometers can be installed to measure infiltration rate and drainage. Care should be taken when installing wells to ensure that runoff cannot enter the well at the surface and *short circuit* directly to subsurface layers; short circuiting can result in the discharge of untreated runoff that has bypassed the intended treatment mechanisms. It might be useful to pair soil moisture sensors with water level loggers in instances where highly detailed monitoring performance data are required (such as for calibration and validation of models).

4.3.2 Monitoring Water Quality

Although hydrologic monitoring can occur as a standalone practice, water quality data must be paired with flow data to calculate meaningful results. Flow-weighted automatic sampling is the recommended method for collecting samples that are representative of the runoff event and can be used to calculate pollutant loads (total mass of pollutants entering and leaving the system). Simply measuring the reduction in pollutant concentrations (mass per unit volume of water) from inlet to outlet can provide misleading results because it does not account for load reductions associated with infiltration, evapotranspiration, and storage.

Influent water quality samples are typically collected just upstream of the inlet monitoring device (e.g., weir box, flume) just before the runoff enters the IMP. The downstream sampler should be at the outlet control device just before the overflow enters the existing storm drain infrastructure. A strainer is usually installed at collecting end of the sampler tubing to prevent large debris and solids from entering and clogging the sampler. Automatic samplers should be programmed to collect single-event, composite samples according to the expected range of storm flows. Depending on the power requirements, a solar panel or backup power supply might be needed.

In addition to collecting composite samples, some water quality constituents can be monitored in real-time. Some examples include dissolved oxygen, turbidity, conductivity, and temperature.

4.3.3 Sample Collection and Handling

Quality assurance and quality control protocols for sample collection are necessary to ensure that samples are representative and reliable. The entire sample collection and delivery procedure should be well documented, including chain of custody (list of personnel handling water quality samples) and notes regarding site condition, time of sampling, and rainfall depth in the manual rain gauge. Holding times for water quality samples vary by constituent, but all samples should be collected, placed on ice, and delivered to the laboratory as soon as possible (typically 6 to 24 hours) after a rainfall event. Some water quality constituents require special treatment upon collection, such as acidification, to preserve the sample for delivery. Appropriate health and safety protocols should always be followed when on-site, including using personal protective equipment such as safety vests, nitrile gloves, and goggles.

4.4 Demonstration Projects

Demonstration or pilot projects provide value to the planning, design, and maintenance communities providing valuable information. These projects can serve as learning opportunities and provide essential information about successful components and components that must be improved through all phases of design construction and post-construction. Information gathered can also provide further understanding and acceptance for nonmunicipal entities through the application of LID IMPs. That understanding can reduce concerns about risk, as experience and technical knowledge is gained from implementing demonstration projects.

Demonstration projects provide concrete examples of how LID IMPs can be implemented in an environment. These projects can reduce people's uncertainty about whether the LID IMPs will actually work in a particular setting. Demonstration projects can offer overall guidelines and examples for the designs, materials, and implementation of structural IMPs and inform site planning, design, and development strategies associated with integrating LID management practices. Those projects can be used as guidelines for performance evaluations, long-term operation and maintenance needs, and cost estimations for individual or integrated LID treatment trains. The projects also allow engineers and designers to verify proper function and maintenance of the systems.

Demonstration projects can illustrate how stormwater LID IMP strategies might be incorporated into other areas of site development strategies. Alternative transportation options to enhance safer street environments, such as traffic safety and control, can improve stormwater quantity and quality problems. Demonstration projects can also be useful in forensic engineering for systems that fail or do not meet quality or flow-control expectations. Improvements can then be made to future designs on the basis of the iterative, adaptive management approach. Monitoring demonstration projects is essential. Monitoring is a fundamental component of implementing SWMP; it helps to evaluate the success of the plan or facility and identifies whether changes are needed to the operation, maintenance (procedures or frequency), or design to meet regulatory goals. The monitoring program is often unique to each IMP or demonstration site and must be designed in the context of the program objectives. For example, a monitoring program for a municipality seeking to comply with monitoring requirements under its National Pollutant Discharge Elimination System (NPDES) permit might have relatively straightforward goals for certain pollutants of concern. However, more in-depth monitoring information gathered to determine the factors affecting LID facility performance are also important.

By monitoring demonstration projects for performance, results can be used to predict the water quality and flow benefits of implementation as compared to costs. This will help decision makers determine the most cost-efficient facility for various conditions that will have the most benefit to water quality and will help meet regulatory requirements. In addition, the information gathered on technical performance of IMPs is expected to provide important input for simulation modeling of pollutant impacts associated with specific management scenarios in other locations or at a larger scale. Key principles of monitoring pilot projects include:

- Dedicate the time and resources to develop a sound monitoring plan. Complexities of plans will vary depending on monitoring objectives.
- Be sure to plan and budget for an adequate number of samples to enable proper data interpretation.
- Be aware of the many variables that need to be documented as part of a monitoring program.
- Be sure that the monitoring design properly identifies the relationship between storm characteristics and the design basis of the IMP and answers selected management questions.
- Properly implement and follow the monitoring plan, clearly documenting any adjustments to the program. Particularly important are proper equipment installation and calibration, proper sample collection techniques and analysis, and maintenance of equipment for longer-term programs.
- Maintain data in an organized and well-documented manner, including monitoring data, IMP design and maintenance practices, and site characteristics.
- Clearly report study limitations and other caveats on using the data.

4.4.1 Demonstration Project Case Studies

The following demonstration projects are provided to supplement the content of the Handbook by illustrating various considerations of LID and IMP design for meeting County SUSMP requirements. These case studies are for demonstration purposes only, thus the design material was abridged for simplicity. The following format should not be considered a comprehensive report that will satisfy local SUSMP submittal requirements. Some project components were modified from the original design to demonstrate specific concepts from the Handbook.

4.4.1.1 Demonstration Project: San Diego International Airport – Terminal 2 Parking Lot

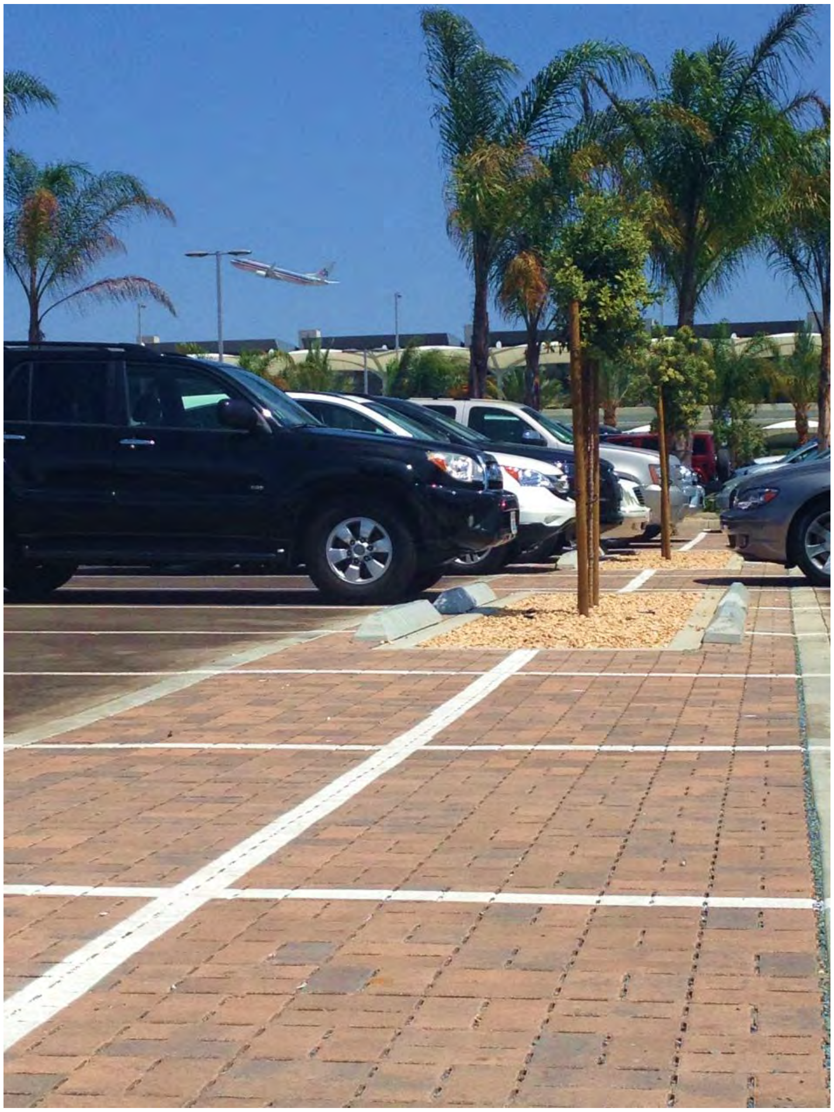


Figure 4-20. Permeable pavement in the Terminal 2 parking lot.

PRIORITY DEVELOPMENT PROJECT

Location
San Diego International Airport, North Harbor Drive, San Diego

Highlighted IMPs
Rock Infiltration Swales
Permeable Pavement

Impervious Area Treated by Highlighted IMPs
9.7 acres

IMP Footprint
3.7 acres

Other IMPs On-site
Swales

Media Filters

Construction Date
2012

Design Engineer
URS Corporation

4.4.1.1.1 Site Background and Proposed Development

The San Diego International Airport recently expanded and improved its facilities. Improvements included a dual-level roadway for passenger departures and arrivals, increased capacity for overnight aircraft parking, 10 new gates, and enhanced indoor facilities. As a component of the expansion, the Terminal 2 short-term parking lot was retrofit with IMPs for stormwater management.

The parking lot is located between Terminal 2 and North Harbor Drive, as shown in Figure 4-21

Figure 4-21. Terminal 2 short-term parking site location.

4.4.1.1.2 Design Criteria

Runoff from the Airport outfalls to San Diego Bay near Harbor Island, which is impaired for metals (copper) and organics (PCBs) according to USEPA's 303(d) list. Due to elevated levels of copper in the vicinity of the Airport outfall, heavy metals were considered the primary pollutant of concern for the priority development project. Secondary pollutants of concern were sediment, nutrients, organic compounds, trash and debris, oxygen demanding substances, oil and grease, bacteria and viruses, and pesticides.

A detailed drainage report was prepared for the site and the 0.55-inch, 24-hour rain event was identified as the 85th-percentile water quality design storm. Because runoff from the site ultimately discharges directly to San Diego Bay, no hydromodification criteria were warranted.

4.4.1.1.3 LID Site Planning Practices

The following site planning practices should be considered during all projects:

- Conserve natural areas, soils, and vegetation
- Minimize disturbances to natural drainages
- Minimize and disconnect impervious surfaces
- Minimize soil compaction
- Drain runoff from impervious surface to pervious surfaces

The Terminal 2 parking lot was a retrofit and was built on fill material, so conservation of natural areas, soils, vegetation, and natural drainages were challenging LID design goals for this project. Nevertheless, designers made efforts where practicable to protect existing vegetation, provide vegetated swales to disconnect impervious surfaces, minimize impervious surfaces, drain rooftops to landscaped areas, and provide native, drought-tolerant vegetation. Had this project been new development, additional self-treating or self-retaining landscaped areas could be incorporated into islands, medians, and the perimeter of the site to reduce stormwater runoff. Soil compaction was minimized during construction to the maximum extent practicable to limit any impacts to the infiltration rate of the subsoils.

4.4.1.1.4 IMP Selection

Primary treatment control for the Terminal 2 parking lot was provided by manufactured high-flow filters, but the designer chose to incorporate LID as a method to reduce the required treatment volume (and, subsequently, the required high-flow filter size). To reduce runoff volume from the parking lot, permeable pavement was incorporated throughout the site as self-retaining areas. Each permeable pavement was sized to capture and infiltrate the volume of runoff from its respective drainage area associated with the 85th percentile storm event. Similarly, rock infiltration swales were incorporated into parkway along the transit center with the goal of reducing runoff to the high-flow filters by capturing and infiltrating runoff.

4.4.1.1.5 IMP Design

Once IMPs were selected to meet the SUSMP criteria, the design steps presented in Table 4-1 and Table 4-2 could be employed to incorporate rock infiltration swales and permeable pavement into the site design. Photos are shown in Figure 4-22, Figure 4-23, Figure 4-24, Figure 4-25, and Figure 4-26.

Table 4-1. Rock infiltration swale design steps

Design step		Design component/ consideration	General specification
1	**IMP Siting**	Layout and site incorporation	Based on available space, maintenance access, and existing storm drains, rock infiltration swales were incorporated into the landscaped areas along the transit center roadways adjacent to the Terminal 2 short-term lot.
2	**Determine IMP Function and Configuration**	No underdrain	Subsoil infiltration rates allowed full infiltration. Underdrains and impermeable liners were not necessary. Subgrade compaction was minimized.
		Lateral hydraulic restriction barriers	Geotextile was used along the perimeter of the excavation to minimize migration of native soils into amended soils.
3	**Determine IMP Sizing Approach**	Flow-based (common SUSMP methodology)	Used volume-based method below.
		Volume-based (water quality methodology)	Each rock infiltration swale was sized to capture in the soil media void space the runoff volume associated with the 85th percentile storm.
4	**Size the System**	Temporary ponding depth	2 inches of surface ponding was provided to encourage infiltration into the amended soil media
		Soil media depth	1.5 feet of soil media was provided
		Surface Area (Volume-based water quality)	The surface area required to store treatment volume within the soil media depth was determined by dividing the required treatment volume by the effective media depth (product of the media depth and porosity)
5	**Specify Soil Media**	Composition and texture	Sandy loam
		Permeability	5 in/hr per SUSMP, although site-specific volume-based sizing method indicated that a minimum design infiltration rate of 3.6 in/hr would be appropriate to minimize the risk of infiltration failure
6	**Design Inlet and Pretreatment**	Inlet	Provided curb cuts to intercept gutter flow
		Pretreatment	Cobble-lined inlet provides pretreatment and energy dissipation
7	**Select and Design Overflow/Bypass Method**	Outlet configuration	Online: All runoff is routed through system—an elevated overflow structure was installed at the elevation of maximum ponding.
		Hydromodification control	Not necessary – drains to San Diego Bay. (If required, provide additional storage in subsurface aggregate layer and size an appropriate nonclogging orifice or weir to dewater detention volume.)
8	**Select Surface Material**	Cobble or gravel	Surface was stabilized with gravel or decorative cobble.
9	**Design for Multi-Use Benefits**	Additional benefits	Drought-tolerant vegetation was included along the banks of the IMP to improve aesthetics.

Figure 4-22. Curb cut and cobble energy dissipation at inlet to rock infiltration swale.

Figure 4-23. Cobble and gravel stabilize the surface of the rock infiltration swale and prevent scour of underlying soil media. The outlet structure in the foreground is elevated 2" above the bed of the rock infiltration swale to ensure that the design storm flow is retained and filtered through the media.

Table 4-2. Permeable pavement design steps

Design step		Design component/ consideration	General specification
1	**Determine IMP Treatment Volume**	Runoff calculations	Per SUSMP (County of San Diego 2012), the volume of the 24-hour 85th percentile storm is required for the water quality treatment method (County of San Diego 2012 SUSMP, Chapter 2)
2	**IMP Siting**	Layout and site incorporation	Based on available space, permeable pavement was incorporated into parking stalls and along the perimeter of the parking lot.
3	**Select Permeable Pavement Surface Course**	Surface course type	Permeable interlocking concrete pavers (PICP) were selected for practicality and aesthetics.
4	**Determine IMP Function and Configuration**	No underdrain	Subsoil infiltration rates allowed full infiltration. Underdrains and impermeable liners were not necessary. Subgrade compaction was minimized.
		Lateral hydraulic restriction barriers	Geomembranes were used to restrict lateral flows to adjacent subgrades, foundations, or utilities.
		Subgrade slope and geotextile	Subgrade slope should be 0.5% or flatter. Baffles should be used to ensure water quality volume is retained. Geotextile should be used along perimeter of cut to prevent soil from entering the aggregate voids.
5	**Design the Profile**	Surface area and reservoir depth	Water quality volume should be fully stored within the aggregate base layers below the surface course. Base layer should be washed ASTM No. 57 stone (washed ASTM No. 2 may be used as a subbase layer for additional storage).
		Structural Design	A pavement structural analysis should be completed by a qualified and licensed professional.
6	**Design for Overlow/Bypass**	Large storm routing	Modular/Paver-type systems (PICP): internal overflow is generally recommended to prevent upflow and transport of bedding course-this site allowed surface overflow because slopes were gradual and flow was dispersed over a large area.
7	**Edge Restraints and Transitions**	Transition strip	A concrete transition strip was provided around the perimeter of PICP to contain pavers and delineate permeable surfaces.
8	**Design Signage**	Signage regulations	Signage should indicate prohibited activities that cause premature clogging and alert pedestrians and maintenance staff that the surface is intended to be permeable.
9	**Design for Multi-Use Benefits**	Additional benefits	Attractive patterns and colors were installed.

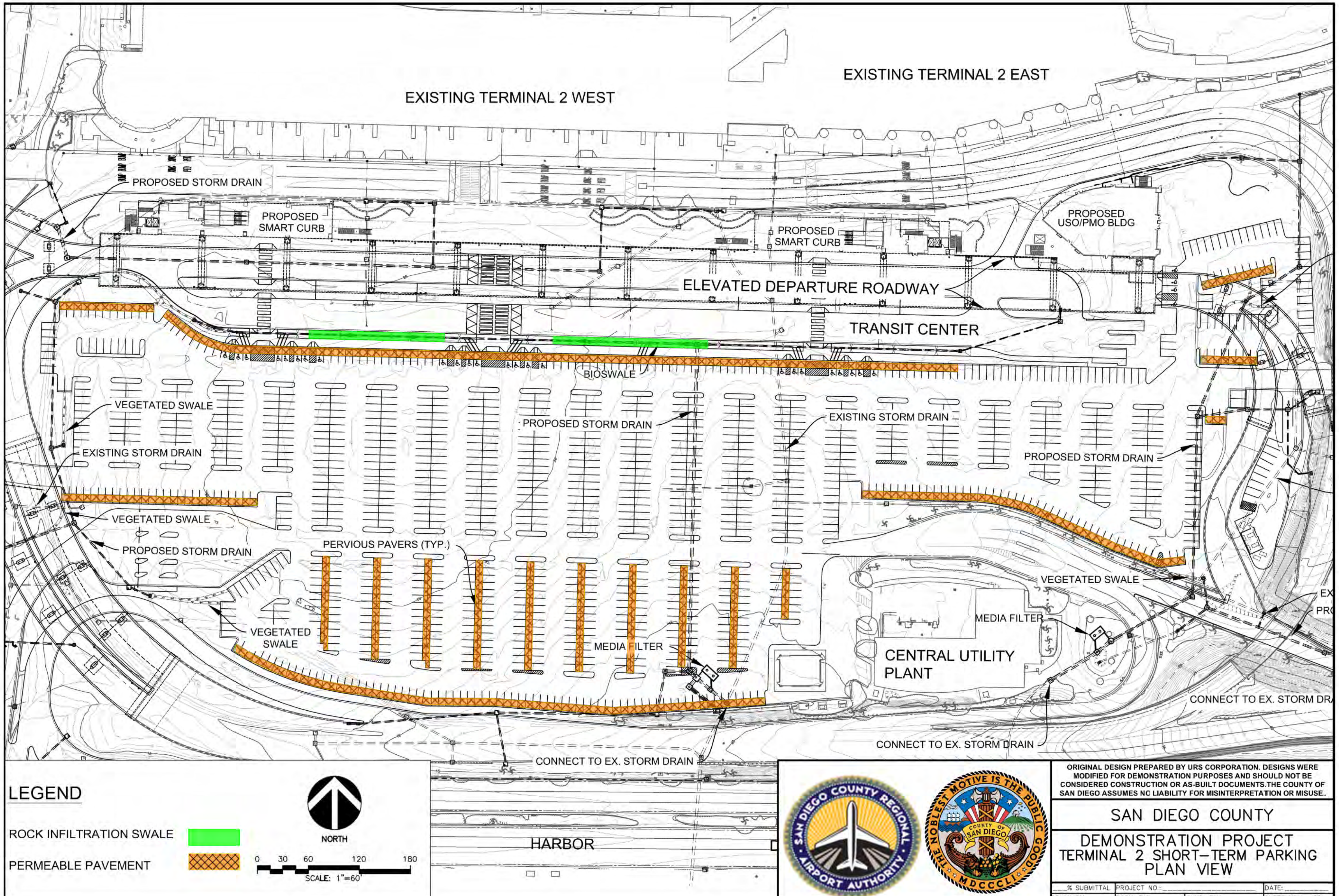
Figure 4-24. A concrete transition strip was used to delineate the permeable surface and provide edge restraints for the pavers.

Figure 4-25. PICP was chosen as the surface course for this application. Bedding and joint fill material consists of washed ASTM No. 8.

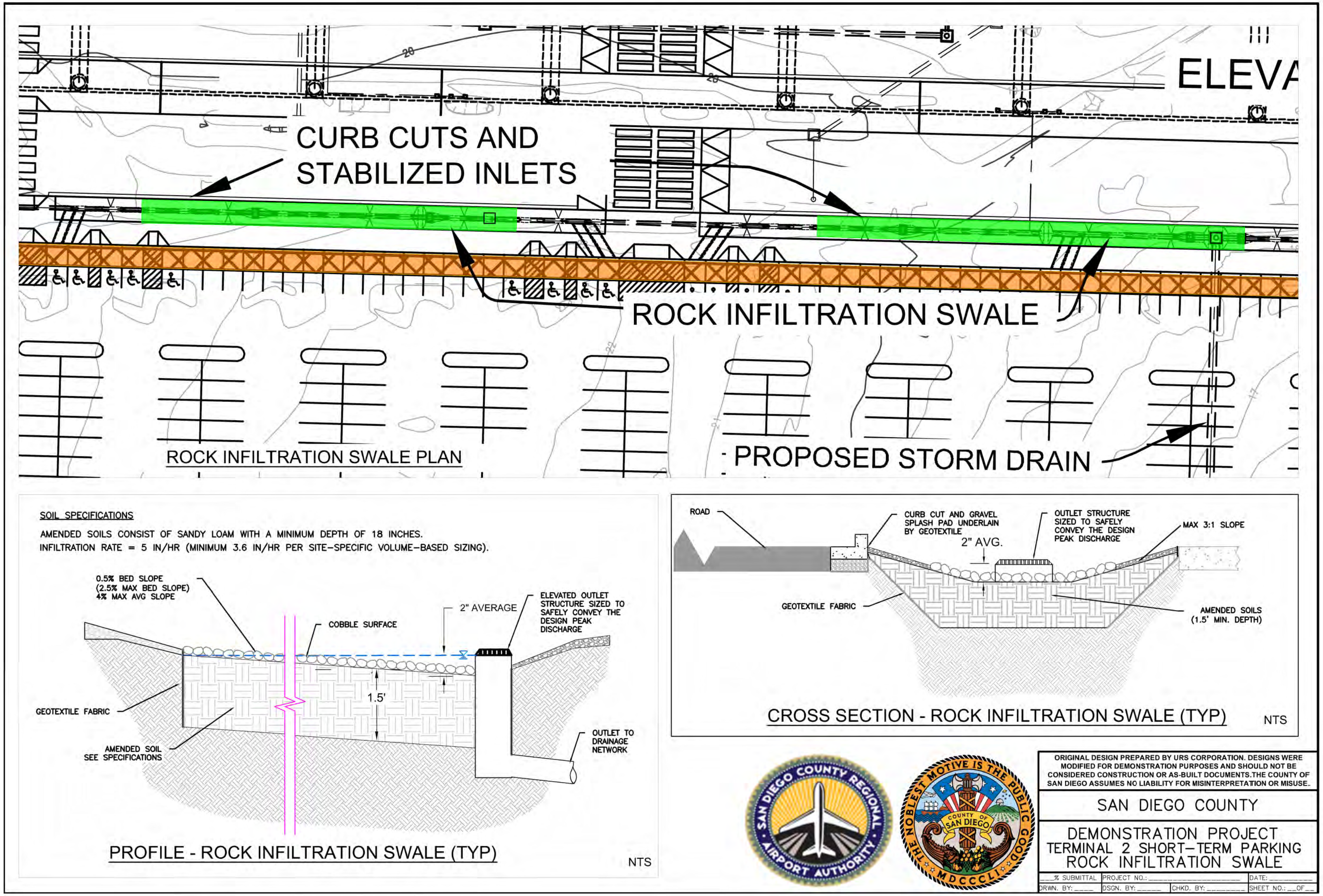
Figure 4-26. Surface overflow was provided for larger storm routing. Generally, internal bypass is effective for PICP applications to prevent upwelling and transport of the bedding course materials, but gradual slopes and diffuse flows deemed internal bypass unnecessary for this site.

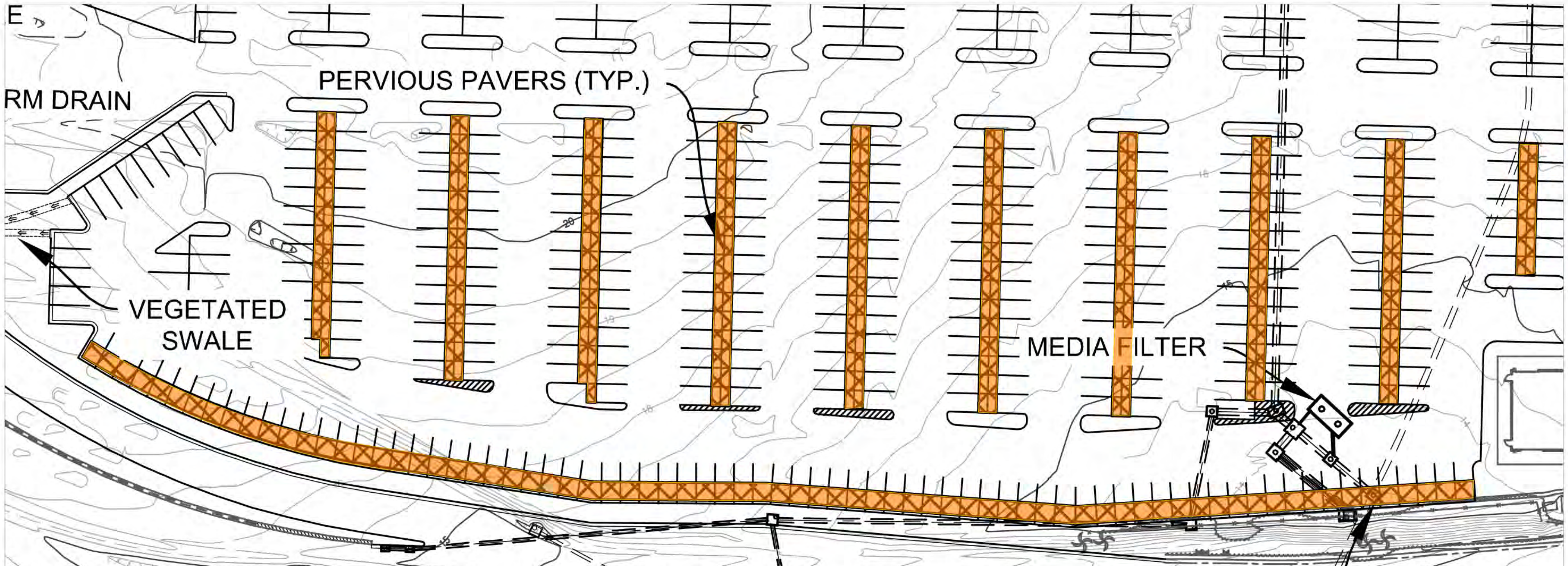
4.4.1.1.6 Design Details

The following sheets provide example plans, profiles, and cross sections of the IMPs installed at the Terminal 2 short-term parking lot.

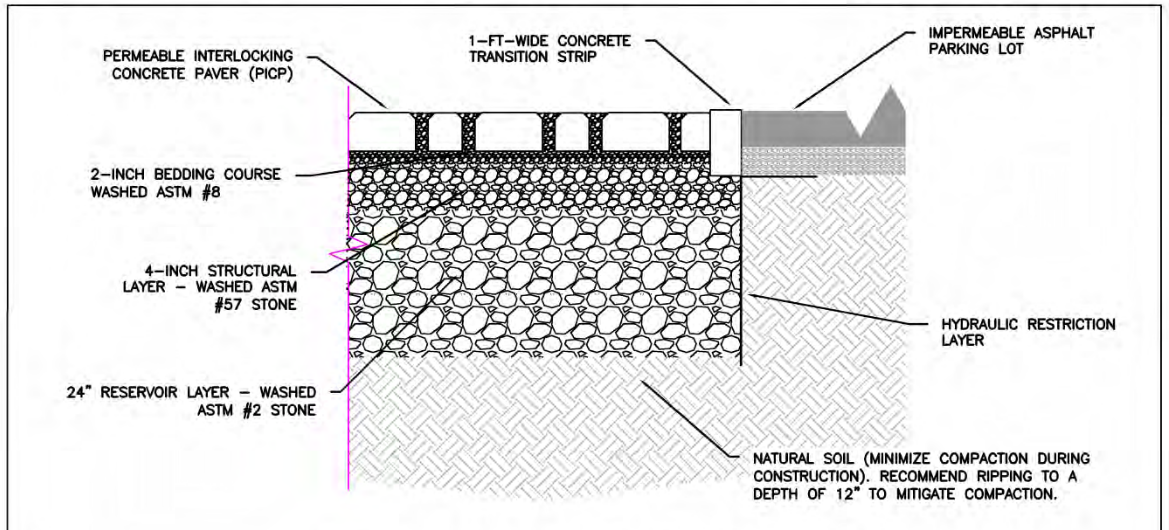


EXISTING TERMINAL 2 WEST
EXISTING TERMINAL 2 EAST
PROPOSED STORM DRAIN
PROPOSED SMART CURB
PROPOSED SMART CURB
PROPOSED USO/PMO BLDG
ELEVATED DEPARTURE ROADWAY
TRANSIT CENTER
BIOSWALE
VEGETATED SWALE
PROPOSED STORM DRAIN
EXISTING STORM DRAIN
EXISTING STORM DRAIN
PROPOSED STORM DRAIN
VEGETATED SWALE
PROPOSED STORM DRAIN
PERVIOUS PAVERS (TYP.)
VEGETATED SWALE
VEGETATED SWALE
MEDIA FILTER
MEDIA FILTER
CENTRAL UTILITY PLANT
CONNECT TO EX. STORM DRAIN
CONNECT TO EX. STORM DRAIN
CONNECT TO EX. STORM DRAIN
HARBOR
LEGEND
ROCK INFILTRATION SWALE
PERMEABLE PAVEMENT
NORTH
0 30 60 120 180
SCALE: 1"=60'
ORIGINAL DESIGN PREPARED BY URS CORPORATION. DESIGNS WERE MODIFIED FOR DEMONSTRATION PURPOSES AND SHOULD NOT BE CONSIDERED CONSTRUCTION OR AS-BUILT DOCUMENTS.THE COUNTY OF SAN DIEGO ASSUMES NO LIABILITY FOR MISINTERPRETATION OR MISUSE.
SAN DIEGO COUNTY
DEMONSTRATION PROJECT
TERMINAL 2 SHORT-TERM PARKING
PLAN VIEW


ELEVA
CURB CUTS AND
STABILIZED INLETS
ROCK INFILTRATION SWALE
ROCK INFILTRATION SWALE PLAN
PROPOSED STORM DRAIN
SOIL SPECIFICATIONS
AMENDED SOILS CONSIST OF SANDY LOAM WITH A MINIMUM DEPTH OF 18 INCHES.
INFILTRATION RATE = 5 IN/HR (MINIMUM 3.6 IN/HR PER SITE-SPECIFIC VOLUME-BASED SIZING).
0.5% BED SLOPE
(2.5% MAX BED SLOPE)
4% MAX AVG SLOPE
COBBLE SURFACE
2" AVERAGE
ELEVATED OUTLET STRUCTURE SIZED TO SAFELY CONVEY THE DESIGN PEAK DISCHARGE
1.5'
GEOTEXTILE FABRIC
AMENDED SOIL SEE SPECIFICATIONS
OUTLET TO DRAINAGE NETWORK
PROFILE - ROCK INFILTRATION SWALE (TYP)
NTS
ROAD
CURB CUT AND GRAVEL SPLASH PAD UNDERLAIN BY GEOTEXTILE
2" AVG.
OUTLET STRUCTURE SIZED TO SAFELY CONVEY THE DESIGN PEAK DISCHARGE
MAX 3:1 SLOPE
GEOTEXTILE FABRIC
AMENDED SOILS (1.5' MIN. DEPTH)
CROSS SECTION - ROCK INFILTRATION SWALE (TYP)
NTS
SAN DIEGO COUNTY REGIONAL AIRPORT AUTHORITY
THE NOBLEST MOTIVE IS THE PUBLIC GOOD
COUNTY OF SAN DIEGO
MDCCCL
ORIGINAL DESIGN PREPARED BY URS CORPORATION. DESIGNS WERE MODIFIED FOR DEMONSTRATION PURPOSES AND SHOULD NOT BE CONSIDERED CONSTRUCTION OR AS-BUILT DOCUMENTS.THE COUNTY OF SAN DIEGO ASSUMES NO LIABILITY FOR MISINTERPRETATION OR MISUSE.
SAN DIEGO COUNTY
DEMONSTRATION PROJECT
TERMINAL 2 SHORT-TERM PARKING
ROCK INFILTRATION SWALE



PERMEABLE PAVEMENTPLAN (TYP.)



PERMEABLE PAVEMENT PROFILE (TYP.)

NTS

PERMEABLE INTERLOCKING CONCRETE PAVERS

TYPE: ASTM C936, HYDRAULICALLY PRESSED CONCRETE OF 8,000 PSI MINIMUM, 28 DAY COMPRESSIVE STENGTH.

SIZE: 5X10X3 INCH

STYLE: INTERLOCKING

CRUSHED STONE FILLER, BEDDING, BASE, AND SUBBASE:

CRUSHED STONE WITH 90% FRACTURED FACES, LA ABRASION < 40 PER ASTM C131, MINIMUM CBR OF 80% PER ASTM d1883

DO NOT USE ROUNDED RIVER GRAVEL

ALL STONE MATERIAL SHALL BE WASHED WITH LESS THAN 1% PASSING THE NO. 200 SIEVE

JOINT/OPENING FILLER, BEDDING, BASE, AND SUBBASE SHALL CONFORM TO ASTM D448 GRADATION.

ORIGINAL DESIGN PREPARED BY URS CORPORATION. DESIGNS WERE MODIFIED FOR DEMONSTRATION PURPOSES AND SHOULD NOT BE CONSIDERED CONSTRUCTION OR AS-BUILT DOCUMENTS.THE COUNTY OF SAN DIEGO ASSUMES NO LIABILITY FOR MISINTERPRETATION OR MISUSE.

SAN DIEGO COUNTY

DEMONSTRATION PROJECT
TERMINAL 2 SHORT-TERM PARKING
PERMEABLE PAVEMENT DETAILS

___% SUBMITTAL	PROJECT NO.: ______		DATE: ______
DRWN. BY: ____	DSGN. BY: ____	CHKD. BY: ____	SHEET NO.: __OF__

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4.4.1.1.7 Implementation Considerations

Construction technique and sequencing are critical to IMP performance. Failure of improperly constructed systems can be easily avoided by effectively communicating with the contractor and by inspecting the system during key steps. In addition to the general construction considerations provided in chapter 4, emphasizing the following points will help ensure successful installation of rock infiltration swales and permeable pavement:

- Inspect soil media before placement
- Inspect aggregate upon delivery to ensure thorough washing was performed
- Verify that average ponding depth is provided in rock infiltration swale
- Inspect subgrade elevations and grading
- Test subgrade infiltration rate
- Minimize and mitigate subsoil compaction by scarifying subsoil surface
- Inspect surface course placement and curing

Following construction, maintenance is necessary to prolong the performance of rock infiltration swales and permeable pavements. Table 4-3 and Table 4-4 provide detailed lists of maintenance activities for the IMPs.

Table 4-3. Rock infiltration swale inspection and maintenance tasks

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Catchment inspection	Weekly or biweekly with routine property maintenance	Excessive sediment, trash, or debris accumulation on the surface of bioretention.	Permanently stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas might need to be re-graded.
Inlet inspection	Weekly or biweekly with routine property maintenance	Internal erosion or excessive sediment, trash, and debris accumulation	Check for sediment accumulation to ensure that flow into the bioretention is as designed. Remove any accumulated sediment.
Trash and leaf litter removal	Weekly or biweekly with routine property maintenance	Accumulation of litter and leafy debris within bioretention area	Litter and leaves should be removed to reduce the risk of outlet clogging, reduce nutrient inputs to the bioretention area, and to improve facility aesthetics.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Erosion at outlet	Remove any accumulated mulch or sediment. Ensure IMP maintains a drain down time of less than 96 hours.
Miscellaneous upkeep	12 times per year	Tasks include trash collection, spot weeding, removing invasive species, and removing debris from the overflow device.	

Table 4-4. Operation and maintenance tasks for permeable pavement

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Catchment inspection	Weekly or biweekly during routine property maintenance	Sediment accumulation on adjacent impervious surfaces or in voids/joints of permeable pavement	Stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas might need to be graded to drain away from the pavement.
Miscellaneous upkeep	Weekly or biweekly during routine property maintenance	Trash, leaves, weeds, or other debris accumulated on permeable pavement surface	Immediately remove debris to prevent migration into permeable pavement voids. Identify source of debris and remedy problem to avoid future deposition.
Preventative vacuum/regenerative air street sweeping	Twice a year in higher sediment areas	N/A	Pavement should be swept with a vacuum power or regenerative air street sweeper at least twice per year to maintain infiltration rates.
Replace fill materials	As needed	For paver systems, whenever void space between joints becomes apparent or after vacuum sweeping	Replace bedding fill material to keep fill level with the paver surface.
Restorative vacuum/regenerative air street sweeping	As needed	Surface infiltration test indicates poor performance or water is ponding on pavement surface during rainfall	Pavement should be swept with a vacuum power or regenerative air street sweeper to restore infiltration rates.

4.4.1.1.8 Lessons Learned

Design and construction of LID features can often present new and unexpected challenges. During design of the Terminal 2 short-term parking lot IMPs it became evident that, due to topographical constraints and drainage patterns, locations of available land for LID do not always coincide with areas to which runoff flows. This challenge often arises during LID design and must be overcome with creative solutions that do not always conform to engineering paradigms. The airport IMPs demonstrate such innovative design by intercepting diffuse flow along the entire parking lot perimeter using a narrow band of permeable pavement (instead of converting the entire parking stall to permeable pavement per typical designs).

Sourcing and furnishing the specified materials was another challenge encountered during construction. It was difficult to find a quarry or supplier that provided washed ASTM No. 2 and No. 8 aggregates matching the design specifications. Material substitutions can occasionally be made but it is critical that any substituted material conforms to the original design intent, does not negatively impact the water quality performance of the IMP, and protects the public safety, health, and welfare. The proper washed crushed aggregate was eventually sourced and the permeable pavers were successfully installed.

Construction oversight and open communication with the contractor was also deemed an important component to the success of the project. Explaining the intent and purpose of specific water quality features to the contractor was critical to ensure compaction was minimized and to ensure that IMPs were constructed to retain and infiltrate water instead of freely draining to the storm drains. This was particularly important in retrofit scenarios, such as where existing concrete channels were converted to swales. Deliberate and thorough communication will improve the quality of installed LID features and will also raise contractor awareness during future projects.

4.4.1.2 Demonstration Project: Scripps Proton Therapy Center

RIORITY DEVELOPMENT PROJECT

Location
Scripps Proton Therapy Center, Summers Ridge Road, San Diego

Highlighted IMPs
Bioretention
Bioretention Swales

Impervious Area Treated
4.5 acres

IMP Footprint[1]
0.85 acres
(water quality + HMP)

Other LID Features
Permeable Pavement (Plastic Grid Pavers)

Construction Date
October 2012

Design Engineer
Rick Engineering

[1]*See Design Criteria*

4.4.1.2.1 Site Background and Proposed Development

Scripps health, Scripps Clinic Medical Group, and Advanced Particle Therapy are constructing a 102,000-square-foot facility for advanced radiation therapy treatment. The Scripps Proton Therapy Center (SPTC) will have capacity to treat 2,400 patients annually and will house a cyclotron particle accelerator for proton beam generation. To meet SUSMP requirements in a cost-effective manner, LID IMPs were incorporated throughout the site.

The facility is located off of Summers Ridge Road in the Fenton Carroll Canyon Technology Center of San Diego's Mira Mesa community, as shown in Figure 4-27.

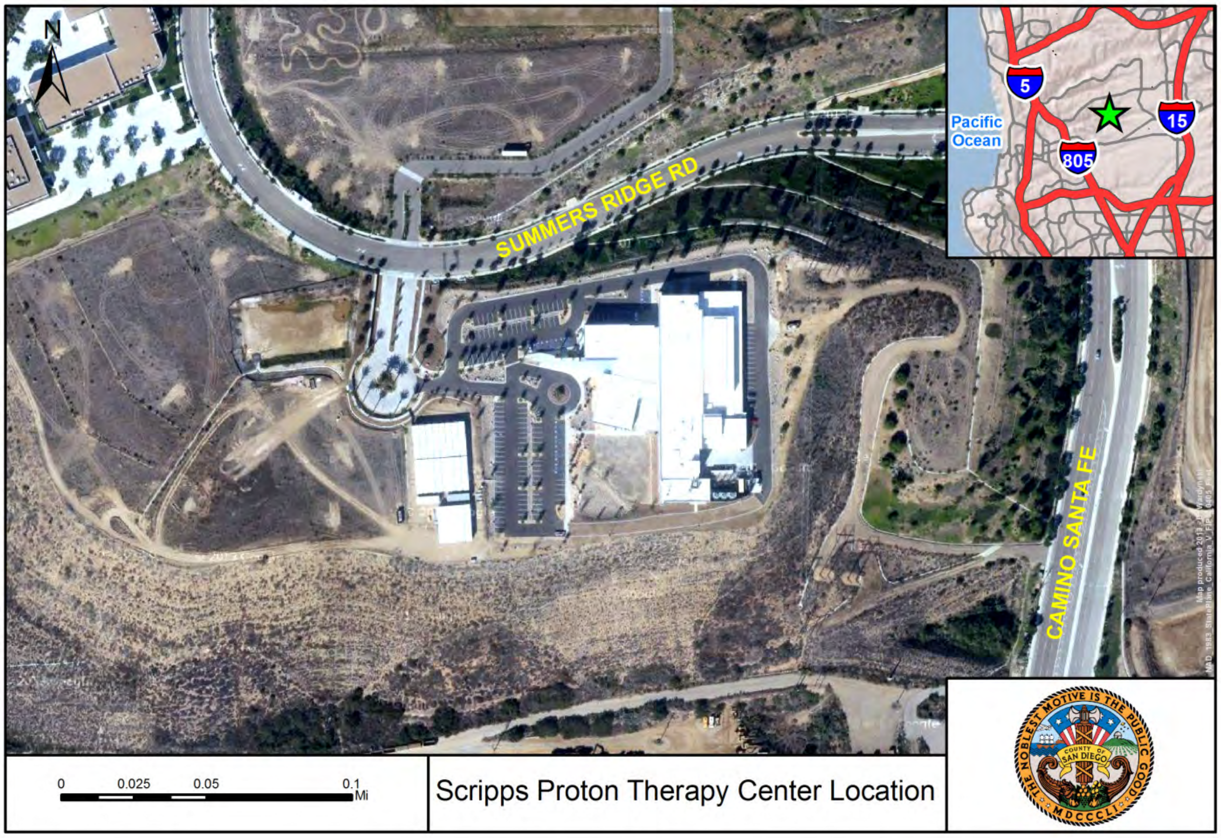

Figure 4-27. Aerial view of Scripps Proton Therapy Center (photo credit Google 2013).

4.4.1.2.2 Design Criteria

The WQTR identified the following anticipated or potential pollutants from the project site:

Anticipated	**Potential**
• Heavy metals	• Sediment
• Trash and Debris	• Organic compounds
• Oil and Grease	• Oxygen demanding substances
	• Pesticides

Because runoff from the project site ultimately drains to the Los Penasquitos Lagoon, sediment was considered the primary pollutant of concern.

Hydromodification criteria did not apply to this project because the project extent was less than the 50-acre threshold in the 2008 Storm Water Standards Manual. For demonstration purposes, the IMPs in this example project have been enhanced to demonstrate the sizing requirements to meet both the water quality and hydromodification control of the $0.1Q_2$ flow threshold as required by the SUSMP.

4.4.1.2.3 LID Site Planning Practices

The following site planning practices should be considered during all projects:

- Conserve natural areas, soils, and vegetation
- Minimize disturbances to natural drainages
- Minimize and disconnect impervious surfaces
- Minimize soil compaction
- Drain runoff from impervious surface to pervious surfaces

The SPTC was constructed in a technology park complex that was mass graded prior to the onset of site design, so conservation of natural areas, soils, vegetation, and natural drainages were not feasible LID design goals for this project. Had this project been new development, the site could be designed to minimize impacts to native hydrologic conditions by clustering development, retaining natural features throughout the site, and minimizing roadway widths. The site was designed to minimize directly-connected impervious surfaces, and, wherever practicable, runoff flows to pervious surfaces incorporated in parking lot medians, perimeters, and in landscaped areas. Soil compaction was minimized during construction to the extent practicable to allow infiltration in self-treating areas, although underlying soils precluded infiltrating practices.

4.4.1.2.4 IMP Selection

The primary pollutant of concern for the project site was sediment, so bioretention with underdrains was selected as the IMP to meet SUSMP criteria. Bioretention was selected due to high sediment removal performance and the flexibility to incorporate throughout the site to treat runoff near its source (per LID principles). Underlying soils were classified as Hydrologic Soil Group D so underdrains were included to ensure adequate drainage. Some facilities would require impermeable liners due to proximity to steep slopes—these IMPs should be sized as flow-through planters because they would not allow incidental infiltration.

4.4.1.2.5 IMP Design

Once IMPs were selected to meet the SUSMP criteria, the design steps shown in Table 4-5 could be employed to incorporate bioretention and bioretention swales into the site design. Photos of the site are shown in Figure 4-28 through Figure 4-31.

Table 4-5. Bioretention and bioretention swales design step process

Design step		Design component/ consideration	General specification
1	**IMP Siting**	Layout and site incorporation	Based on available space and maintenance access, bioretention was incorporated into landscaped areas, along the parking lot perimeter, and parking medians throughout the site.
2	**Determine IMP Function and Configuration**	Impermeable liner	Where required per geotechnical specifications, a geomembrane liner was installed for slope and infrastructure protection (facilities with impermeable liners should be designed as flow-through planters).

Design step		Design component/ consideration	General specification
		Underdrain (required if subsoil infiltration rate is less than 0.5 in/hr [HSG C & D])	Schedule 40 PVC pipe with perforations (slots or holes) every 6 inches. The 4-inch diameter lateral pipes should join a 6-inch collector pipe, which conveys drainage to the downstream storm network. Provide cleanout ports/observation wells for each underdrain pipe. The underdrain should be elevated 12" above the subgrade, consistent with hydromodification design assumptions.
		Lateral hydraulic restriction barriers	Impermeable geomembrane was used to restrict lateral flows to adjacent subgrades, foundations, or utilities.
3	**Determine IMP Sizing Approach**	Flow-based (common SUSMP methodology)	Refer to SUSMP (County of San Diego 2012) chapters 2 and 4 for appropriate sizing factors to determine surface area, ponding depth, and media depth. For the purpose of this example, IMPs on this site were sized to meet water quality and hydromodification requirements using a sizing factor of 0.16. Flow from the contributing drainage area would require detention such that discharge does not exceed the $0.1Q_2$ flow threshold.
4	**Size the System**	Temporary ponding depth	10 inches per hydromodification design assumptions
		Soil media depth	1.5 feet per SUSMP
		Slope and grade control	Check dams were used to maintain maximum 2.5% bed slope. Install a 4-inch deep layer of ASTM No. 57 stone (underlain by filter fabric) extending 2 feet downslope from the check dam to prevent erosion.
		Surface area(volume-based water quality)	Sized using the flow-based method per SUSMP requirements.
5	**Specify Soil Media**	Composition and texture	Per SUSMP, specified loamy sand with minimum long-term percolation rate of 5 in/hr.
		Permeability	
		Chemical composition	
		Drainage layer	
6	**Design Inlet and Pretreatment**	Inlet	Runoff enters by diffuse flow from parking lot or through curb cuts along driving lanes
		Pretreatment	Gravel pads provided at inlets for energy dissipation and pretreatment
7	**Select and Design Overflow/Bypass Method**	Outlet configuration	Online: All runoff is routed through system—install an elevated overflow structure or weir at the elevation of maximum ponding.
		Hydromodification control	If necessary, additional aggregate storage could be specified to provide hydromodification control where the surface area is not available for design of IMPs using the sizing factors. Alternative designs would require verification by modeling.
8	**Select Mulch and Vegetation**	Mulch	Hardwood mulch, gravel, and cobble were used
		Vegetation	Drought tolerant, native plants
9	**Design for Multi-Use Benefits**	Additional benefits	Attractive xeriscaped landscaping design, irrigated with reclaimed water

Figure 4-28. Bioretention swales with raised outlet structures capture, convey, and filter parking lot runoff through a soil media layer.

Figure 4-29. Roads and parking lots are graded towards bioretention areas that treat runoff near its source.

Figure 4-30. Curb cuts accept gutter flow from driving lanes into bioretention swales.

Figure 4-31. Bioretention areas with raised outlet structures are distributed throughout the site to transform traditional landscaped areas into stormwater IMPs.

4.4.1.2.6 Design Details

The following sheets provide example plans, profiles, and cross sections of the IMPs installed at the SPTC.

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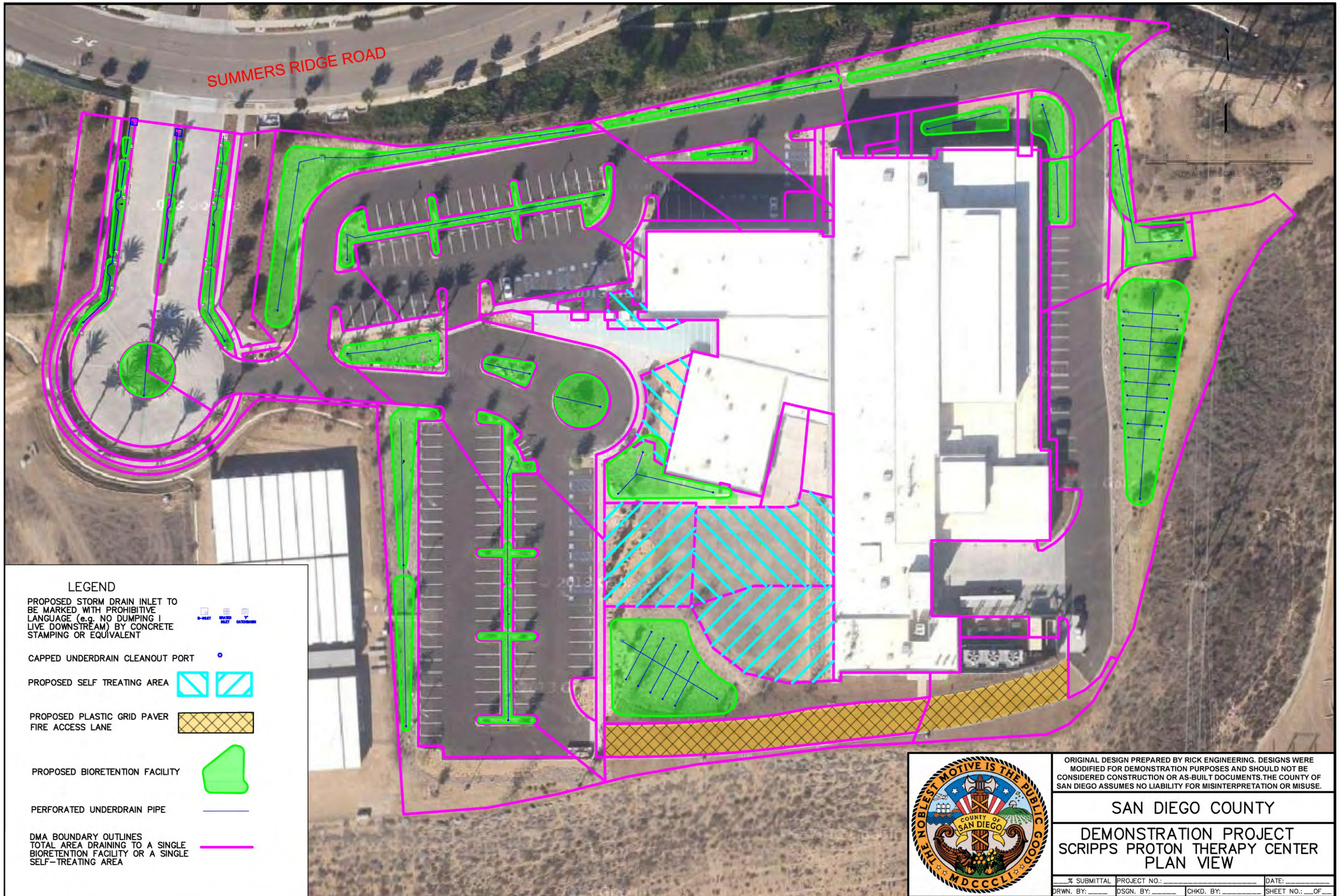

SUMMERS RIDGE ROAD
LEGEND
PROPOSED STORM DRAIN INLET TO BE MARKED WITH PROHIBITIVE LANGUAGE (e.g. NO DUMPING I LIVE DOWNSTREAM) BY CONCRETE STAMPING OR EQUIVALENT
CAPPED UNDERDRAIN CLEANOUT PORT
PROPOSED SELF TREATING AREA
PROPOSED PLASTIC GRID PAVER FIRE ACCESS LANE
PROPOSED BIORETENTION FACILITY
PERFORATED UNDERDRAIN PIPE
DMA BOUNDARY OUTLINES TOTAL AREA DRAINING TO A SINGLE BIORETENTION FACILITY OR A SINGLE SELF-TREATING AREA
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SCRIPPS PROTON THERAPY CENTER
PLAN VIEW
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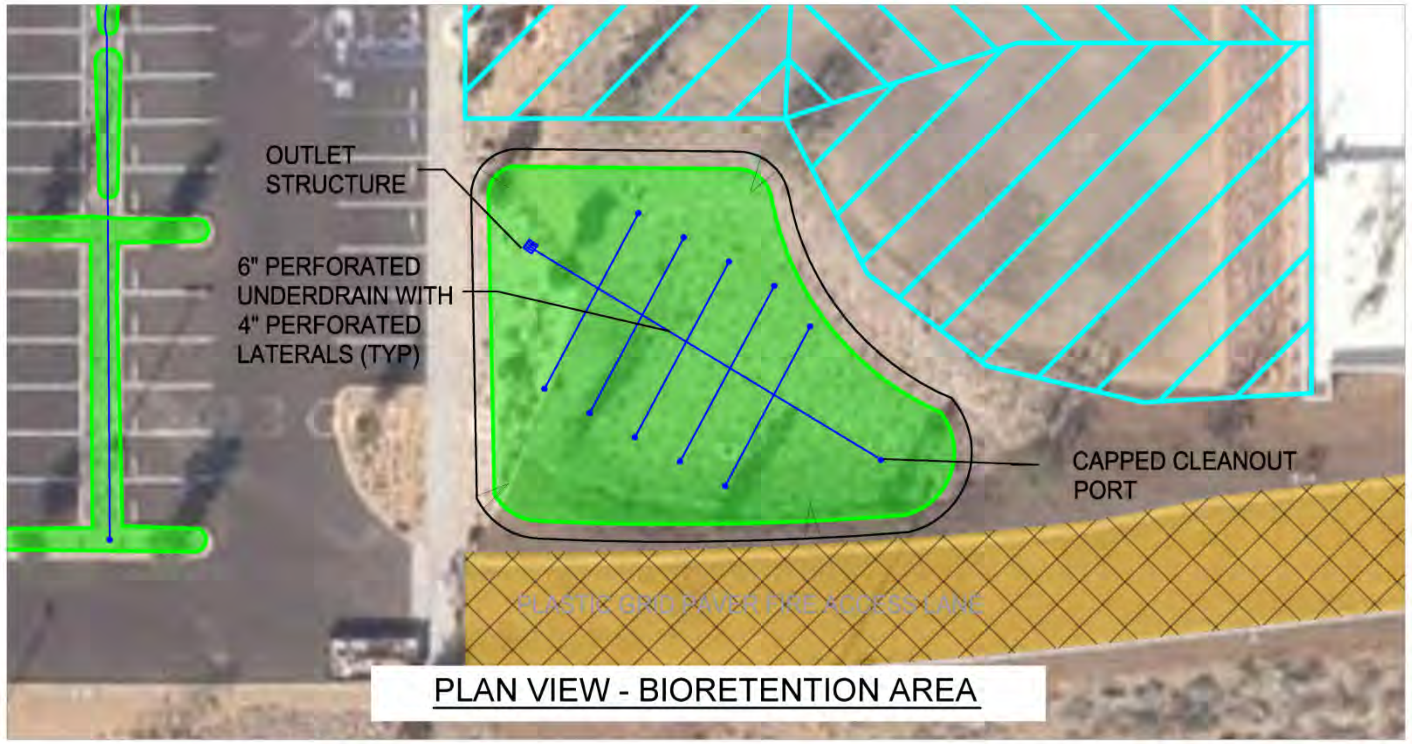


PLAN VIEW - BIORETENTION AREA

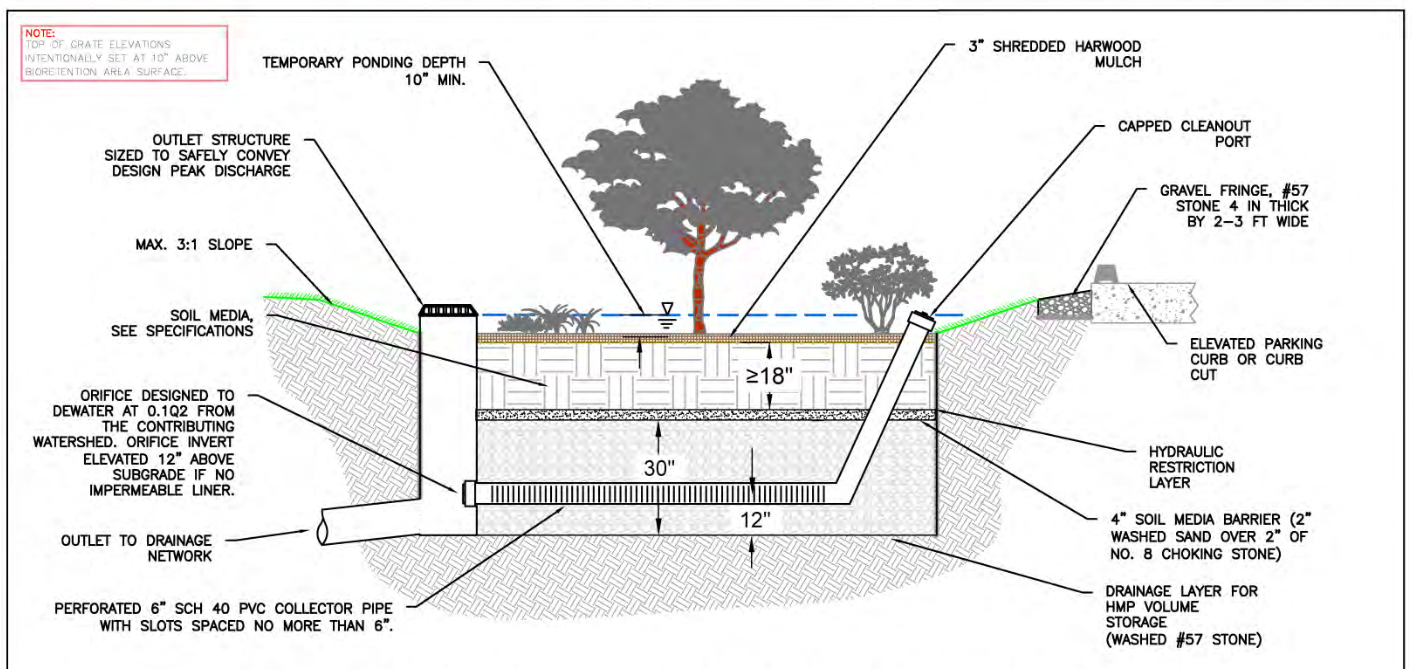
SOIL MEDIA SPECIFICATIONS

18" DEPTH OF LOAMY SAND WITH MINIMUM LONG–TERM PERCOLATION RATES OF 5 IN./HR.

VEGETATION SPECIFICATIONS

FOR BIORETENTION TO FUNCTION PROPERLY AS STORMWATER TREATMENT AND BLEND INTO THE LANDSCAPING, VEGETATION SELECTION IS CRUCIAL. APPROPRIATE VEGETATION WILL HAVE THE FOLLOWING CHARACTERISTICS:

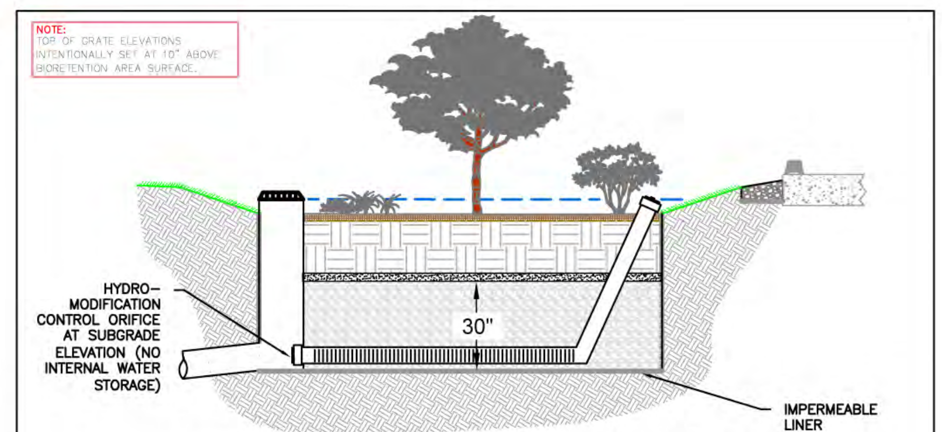
1. PLANT MATERIALS MUST BE TOLERANT OF SUMMER DROUGHT, PONDING FLUCTUATIONS, AND SATURATED SOIL CONDITIONS FOR 10 TO 48 HOURS.
2. IT IS RECOMMENDED THAT A MINIMUM OF THREE TREE, THREE SHRUBS, AND THREE HERBACEOUS GROUNDCOVER SPECIES BE INCORPORATED TO PROTECT AGAINST FACILITY FAILURE FROM DISEASE AND INSECT INFESTATIONS OF A SINGLE SPECIES. PLANT ROOTING DEPTHS MUST NOT DAMAGE THE UNDERDRAIN, IF PRESENT. SLOTTED OR PERFORATED UNDERDRAIN PIPE MUST BE MORE THAN 5 FEET FROM TREE LOCATIONS (IF SPACE ALLOWS).
3. NATIVE PLANT SPECIES OR HARDY CULTIVARS THAT ARE NOT INVASIVE AND DO NOT REQUIRE CHEMICAL INPUTS ARE RECOMMENDED TO BE USED TO THE MAXIMUM EXTENT PRACTICABLE.
4. SHADE TREES SHOULD BE FREE OF BRANCHES BELOW 1/3 THEIR TOTAL HEIGHT.



UNLINED BIORETENTION AREA PROFILE (TYP.)

THIS DETAIL SHOULD BE APPLIED WHEN GEOTECHNICAL SPECIFICATIONS ALLOW INCIDENTAL INFILTRATION. IF INFILTRATION IS PROHIBITED, DESIGN AS FULLY–LINED SYSTEM (FLOW–THROUGH PLANTER). ALL NOTES APPLY TO FULLY–LINED SYSTEMS UNLESS OTHERWISE NOTED.

NTS



FULLY LINED BIORETENION PROFILE

THIS DETAIL SHOULD BE APPLIED WHEN GEOTECHNICAL SPECIFICATIONS PROHIBIT INFILTRATION (SUCH AS NEAR STEEP SLOPES AND SENSITIVE INFRASTRUCTURE). THE FACILITY SHOULD BE SIZED AS A FLOW–THROUGH PLANTER AND SHOULD CONTAIN NO INTERNAL WATER STORAGE.

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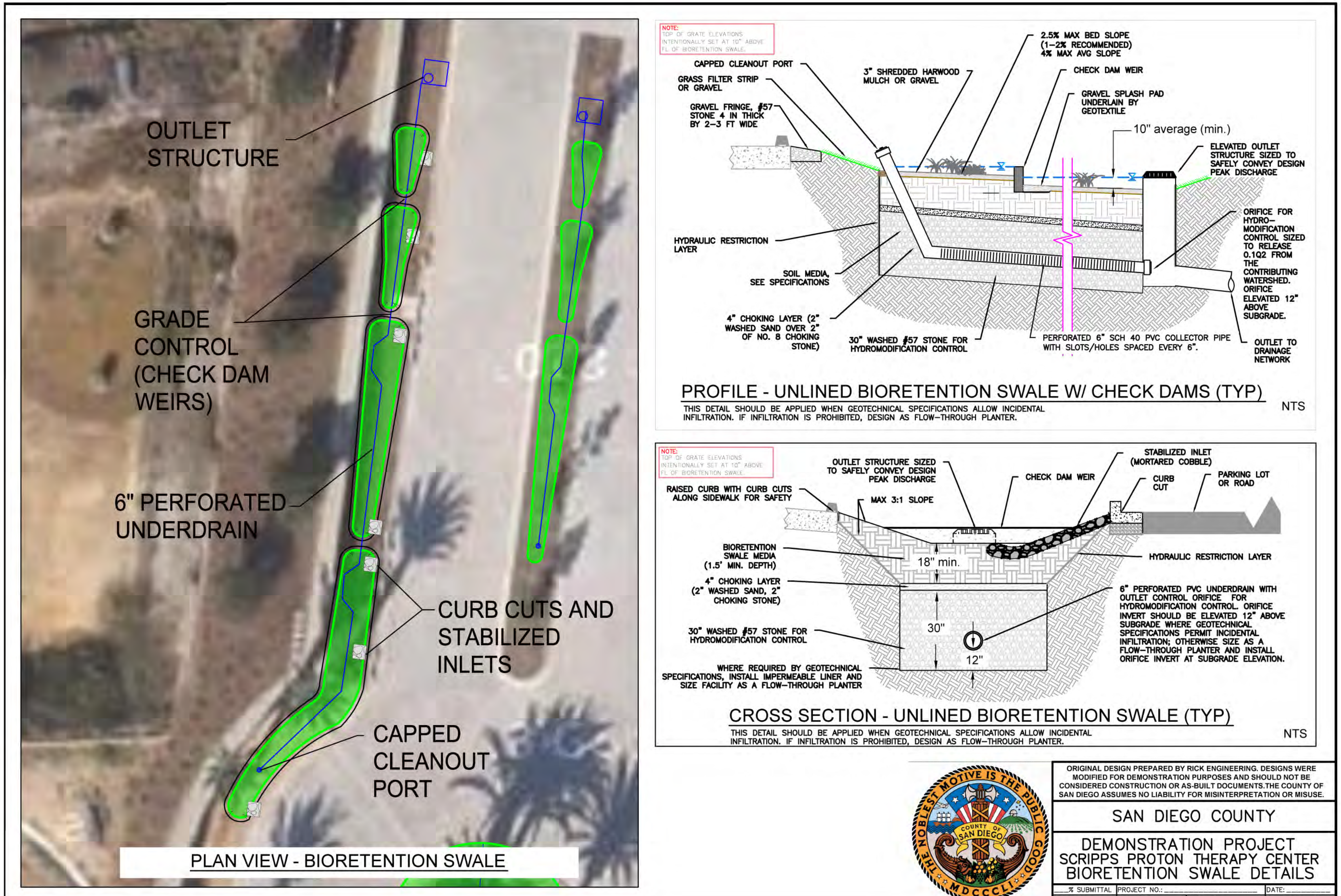
OUTLET STRUCTURE
GRADE CONTROL (CHECK DAM WEIRS)
6" PERFORATED UNDERDRAIN
CURB CUTS AND STABILIZED INLETS
CAPPED CLEANOUT PORT
PLAN VIEW - BIORETENTION SWALE
NOTE: TOP OF GRATE ELEVATIONS INTENTIONALLY SET AT 10" ABOVE FL OF BIORETENTION SWALE.
CAPPED CLEANOUT PORT
GRASS FILTER STRIP OR GRAVEL
GRAVEL FRINGE, #57 STONE 4 IN THICK BY 2-3 FT WIDE
3" SHREDDED HARWOOD MULCH OR GRAVEL
2.5% MAX BED SLOPE (1-2% RECOMMENDED) 4% MAX AVG SLOPE
CHECK DAM WEIR
GRAVEL SPLASH PAD UNDERLAIN BY GEOTEXTILE
10" average (min.)
ELEVATED OUTLET STRUCTURE SIZED TO SAFELY CONVEY DESIGN PEAK DISCHARGE
HYDRAULIC RESTRICTION LAYER
SOIL MEDIA, SEE SPECIFICATIONS
ORIFICE FOR HYDRO-MODIFICATION CONTROL SIZED TO RELEASE 0.1Q2 FROM THE CONTRIBUTING WATERSHED. ORIFICE ELEVATED 12" ABOVE SUBGRADE.
4" CHOKING LAYER (2" WASHED SAND OVER 2" OF NO. 8 CHOKING STONE)
30" WASHED #57 STONE FOR HYDROMODIFICATION CONTROL
PERFORATED 6" SCH 40 PVC COLLECTOR PIPE WITH SLOTS/HOLES SPACED EVERY 6".
OUTLET TO DRAINAGE NETWORK
PROFILE - UNLINED BIORETENTION SWALE W/ CHECK DAMS (TYP)
THIS DETAIL SHOULD BE APPLIED WHEN GEOTECHNICAL SPECIFICATIONS ALLOW INCIDENTAL INFILTRATION. IF INFILTRATION IS PROHIBITED, DESIGN AS FLOW-THROUGH PLANTER.
NTS
NOTE: TOP OF GRATE ELEVATIONS INTENTIONALLY SET AT 10" ABOVE FL OF BIORETENTION SWALE.
OUTLET STRUCTURE SIZED TO SAFELY CONVEY DESIGN PEAK DISCHARGE
CHECK DAM WEIR
STABILIZED INLET (MORTARED COBBLE)
CURB CUT
PARKING LOT OR ROAD
RAISED CURB WITH CURB CUTS ALONG SIDEWALK FOR SAFETY
MAX 3:1 SLOPE
BIORETENTION SWALE MEDIA (1.5' MIN. DEPTH)
18" min.
HYDRAULIC RESTRICTION LAYER
4" CHOKING LAYER (2" WASHED SAND, 2" CHOKING STONE)
6" PERFORATED PVC UNDERDRAIN WITH OUTLET CONTROL ORIFICE FOR HYDROMODIFICATION CONTROL. ORIFICE INVERT SHOULD BE ELEVATED 12" ABOVE SUBGRADE WHERE GEOTECHNICAL SPECIFICATIONS PERMIT INCIDENTAL INFILTRATION; OTHERWISE SIZE AS A FLOW-THROUGH PLANTER AND INSTALL ORIFICE INVERT AT SUBGRADE ELEVATION.
30" WASHED #57 STONE FOR HYDROMODIFICATION CONTROL
30"
12"
WHERE REQUIRED BY GEOTECHNICAL SPECIFICATIONS, INSTALL IMPERMEABLE LINER AND SIZE FACILITY AS A FLOW-THROUGH PLANTER
CROSS SECTION - UNLINED BIORETENTION SWALE (TYP)
THIS DETAIL SHOULD BE APPLIED WHEN GEOTECHNICAL SPECIFICATIONS ALLOW INCIDENTAL INFILTRATION. IF INFILTRATION IS PROHIBITED, DESIGN AS FLOW-THROUGH PLANTER.
NTS
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4.4.1.2.7 IMPLEMENTATION CONSIDERATIONS

Construction technique and sequencing are critical to bioretention and bioretention swale performance. Failure of improperly constructed systems can be easily avoided by effectively communicating with the contractor and by inspecting the system during key steps. In addition to the general construction considerations provided in chapter 4, emphasizing the following points will help ensure successful installation of bioretention and bioretention swales.

- Minimize and mitigate compaction by scarifying subsoil surface
- Inspect soil media before placement
- Verify that average ponding depth is provided (a note was provided in the construction plans indicating that outlet structures are intended to be elevated above the bed of the bioretention area or bioretention swale).

Bioretention areas and bioretention swales require regular plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant removal capabilities. Table 4-6. provides a detailed list of maintenance activities.

Table 4-6. Inspection and maintenance tasks

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Catchment inspection	Weekly or biweekly with routine property maintenance	Excessive sediment, trash, or debris accumulation on the surface of bioretention.	Permanently stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas might need to be re-graded.
Inlet inspection	Weekly or biweekly with routine property maintenance	Internal erosion or excessive sediment, trash, and debris accumulation	Check for sediment accumulation to ensure that flow into the bioretention is as designed. Remove any accumulated sediment.
Trash and leaf litter removal	Weekly or biweekly with routine property maintenance	Accumulation of litter and leafy debris within bioretention area	Litter and leaves should be removed to reduce the risk of outlet clogging, reduce nutrient inputs to the bioretention area, and to improve facility aesthetics.
Pruning	1 to 2 times per year	Overgrown vegetation that interferes with access, lines of sight, or safety	Nutrients in runoff often cause bioretention vegetation to flourish.
Mowing	2 to 12 times per year	Overgrown vegetation that interferes with access, lines of sight, or safety	Frequency depends on location and desired aesthetic appeal.
Mulch removal and replacement	1 time every 2 to 3 years	2/3 of mulch has decomposed	Mulch accumulation reduces available surface water storage volume. Removal of decomposed mulch also increases surface infiltration rate of fill soil. Remove decomposed fraction and top off with fresh mulch to a total depth of 3 inches

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Temporary watering	1 time every 2 to 3 days for first 1 to 2 months, sporadically after established	Until established and during severe droughts	Watering after the initial year might be required.
Fertilization	1 time initially	Upon planting	One-time spot fertilization for first year vegetation.
Remove and replace dead plants	1 time per year	Dead plants	Within the first year, 10% of plants can die. Survival rates increase with time.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Erosion at outlet	Remove any accumulated mulch or sediment. Ensure IMP maintains a drain down time of less than 96 hours.
Miscellaneous upkeep	12 times per year	Tasks include trash collection, plant health, spot weeding, removing invasive species, and removing mulch from the overflow device.	

4.4.1.2.8 Lessons Learned

The cobble lining applied to the bed of the bioretention areas at this site was primarily installed for an aesthetic surface condition. While cobbling in some areas, particularly around inlets, may be beneficial, extensive cobbling should be avoided because it must be removed by hand for maintenance. A gravel or mulch surface cover may provide a more easily maintained bioretention bed that can be mechanically maintained by backhoe or shovel.

Providing the required soil media infiltration rates was challenging at this site due to over-compaction of bioretention areas. To avoid laborious removal and replacement of soil media, it is important that material is minimally compacted upon installation.

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5 DEFINITIONS

Aquifer The underground layer of rock or soil in which groundwater resides. Aquifers are replenished or recharged by surface water percolating through soil. Wells are drilled into aquifers to extract water for human use.

Average daily traffic The average total number of vehicles that traverse a road or highway on a typical day. Often used to classify and design roadway systems.

Base course A layer of material directly under the surface layer.

Biofilter Any of a number of devices used to control pollution using living materials to filter or chemically process pollutants.

Bioretention A technique that uses parking lot islands and planting strips to collect and filter urban stormwater, that includes grass and sand filters, loamy soils, mulch, shallow ponding and native trees and shrubs.

Bioretention Swale A technique that uses swales to collect and filter urban stormwater, that includes grass and sand filters, loamy soils, mulch, shallow ponding and native trees and shrubs.

Buffer A zone created or sustained adjacent to a shoreline, wetland or stream where development is restricted or prohibited to minimize the negative effects of land development on animals and plants and their habitats.

Catchment The smallest watershed management unit, defined as the area of a development site to its first intersection with a stream, usually as a pipe or open channel outfall.

Check dam (a) A log or gabion structure placed perpendicular to a stream to enhance aquatic habitat. (b) An earthen or log structure, used in grass swales to reduce water velocities, promote sediment deposition, and enhance infiltration.

Cluster development A development pattern for residential, commercial, industrial, institutional, or combination of uses, in which the uses are grouped or clustered, rather than spread evenly throughout the parcel as in conventional lot-by-lot development. A local jurisdiction may authorize such development by permitting smaller lot sizes if a specified portion of the land is kept in permanent open space to provide natural habitat or open space uses through public or private dedication.

Constructed wetland An artificial wetland system designed to mitigate the impacts of urban runoff.

Contamination The impairment of water quality by waste to a degree that creates a hazard to public health through poisoning or through the spread of disease.

Cul-de-sac A circular section located at the end of an access street that permits vehicles to turn around.

Curbs A concrete barrier on the margin of a road or street that is used to direct stormwater runoff to an inlet, protect pavement edges, and protect lawns and sidewalks from encroachment by vehicles.

Density The average number of families, persons, or housing units per unit of land, usually density is expressed per acre.

Design storm A rainfall event of specified duration, intensity, and return frequency (e.g., a 2 year 6 hour event) that is used to calculate runoff volume and peak discharge rate.

Detention The temporary storage of storm runoff which is used to control discharge rates sufficiently to provide gravity settling of pollutants.

Detention time The amount of time water actually is present in a basin. Theoretical detention time for a runoff event is determined from the period of release from the basin.

Directly connected impervious area (DCIA) The square footage of all impervious surfaces (see *impervious surface area*) that flow directly into a conveyance stormwater system.

Disturbance The act of moving, grading, tilling, clearing, taking or repositioning the natural environment's soil surfaces and/or vegetation that was previously undisturbed by man.

Drainage basin A land area bounded by high points, which drains all surface water into a single stream, other body of water, or storm drain infrastructure. See also *watershed*.

Ephemeral stream A stream or waterway that holds water only for a few hours or days, and dries up shortly after rain storms.

Erosion The wearing away of land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices related to farming, residential or industrial development, road, building, or timber cutting.

Evaporation practices Practices that temporarily store runoff and evaporate it (retention, detention, reservoirs, etc.).

Evapotranspiration The combined loss of water from a given area, and during a specified period of time, by evaporation from the soil surface and transpiration from plants into the atmosphere.

Excess parking Parking spaces that are constructed over and above the number required or predicted based on the parking demand ratio for a particular land use or activity

Feasible Capable of being accomplished in a successful manner within a reasonable period of time, taking into account economic, environmental, and technological factors. Infeasibility must be supported by substantial evidence developed through a good faith effort to investigate alternatives that would result in less adverse impacts. A substantial modification to the configuration of a development, or reduction in density or intensity, would not be considered infeasible unless supported by the above factors.

Filter fabric Textile of relatively small mesh or pore size that is used to (a) allow water to pass through while keeping sediment out (permeable), or (b) prevent both runoff and sediment from passing through (impermeable).

Filter strips A vegetated area that treats sheetflow and/or interflow to remove sediment and other pollutants. Used to treat shallow concentrated stormflows over very short contributing distances in urban areas. Sometimes referred to as buffer strips.

Filtration practices Stormwater management practices that do not incorporate infiltration as a primary design feature, including planter boxes, vegetated roofs, and sand filters. Most *infiltration practices* (including bioretention, bioretention swales, and permeable pavement) can also be modified using an impermeable liner to perform as filtration IMPs.

First flush The delivery of a disproportionately large load of pollutants during the early part of storms due to the rapid runoff of accumulated pollutants. The first flush of runoff has been defined several ways (e.g., one-half inch per impervious acre).

Flow-based practices IMPs for which the pollutant removal rate depends on the rate of flow through the facility. Examples include filter strips, swales, sand filters, and screening devices.

Forebay An extra storage space provided near an inlet of a wet pond or constructed wetland to trap incoming sediments before they accumulate in the pond.

Fuel modification Managing vegetation, particularly adjacent to buildings and to grass-surfaced fire lanes, to prevent escalation of fires, which is important to maintain compliance with fire codes.

Graywater system On-site systems that use wastewater from sinks, showers, tubs, and washing machines for subsurface landscape irrigation through the use of mulch basins, disposal trenches or subsurface drip irrigation fields. See http://www.sdcounty.ca.gov/deh/water/lu_graywater_systems.html.

Green building Environmentally responsible, resource efficient construction throughout the life-cycle of a structure (design, construction, operation, maintenance, renovation and deconstruction). Also known as a sustainable or high-performance building.

Green space The proportion of open space in a cluster development that is retained in an undisturbed vegetative condition.

Groundwater Subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated

Habitat The specific area or environment in which a particular type of plant or animal lives. An organism's habitat must provide the basic requirements for life and should be free of harmful contaminants.

Hammerhead A "T" shaped turnaround option for lightly traveled residential streets. Creates less impervious cover compared to a circular cul-de-sac.

Heat island effect The increase in ambient temperatures generated by heat radiating from paved surfaces exposed to sunlight.

Hybrid parking lots Use multiple paving techniques to better utilize the space by combining impervious aisles with permeable stalls.

Hydrology The science of the behavior of water in the atmosphere (air), on the surface of the earth, and underground.

Impermeable Not able to be infiltrated by water.

Impervious surface Any surface which cannot be effectively (easily) penetrated by water. Examples include conventional pavements, buildings, highly compacted soils, and rock outcrops.

Impervious surface area The ground area covered or sheltered by an impervious surface, measured in plan view (i.e., as if from directly above). For example, the impervious surface area for a pitched roof is equal to the ground area it shelters, rather than the surface area of the roof itself.

Imperviousness The percentage of impervious surface within a development site or watershed.

Infill Developing vacant parcels or redeveloping existing property in urban or sub-urban areas.

Infiltration The downward entry of water into the surface of the soil, as contrasted with percolation which is movement of water through soil layers.

Infiltration basin A concave vegetated surface (e.g., pond) designed to hold water so that it can gradually infiltrate into the soil.

Infiltration practices Any treatment IMP designed primarily to percolate water into the subsurface. These include infiltration trench, infiltration basin, dry wells, permeable pavements without an underdrain, and sub-surface reservoir beds without an under-drain. IMPs that have some incidental infiltration but are designed primarily to retain water or to treat water, such as bioretention, filter strips, permeable pavements with an underdrain, or vegetated swales, are not infiltration IMPs.

Intermittent stream A stream that flows mostly during the rainy or wet season and may not flow at all during other times of the year.

Integrated Management System (IMP) An LID BMP that provides small-scale treatment, retention and or detention and is integrated into the site layout, landscaping and drainage design. When properly sized, it may qualify as a treatment control BMP/IMP as required for priority development projects.

Low impact development A stormwater management and land development strategy that emphasizes conservation and the use of on-site natural features integrated with engineered, small-scale hydrologic controls to more closely reflect pre-development hydrologic functions.

Management Practice A method, activity, maintenance procedure, or other management practice for reducing the amount of pollution entering a water body. The term originated from the rules & regulations developed pursuant to the federal Clean Water Act (40 CFR 1 30).

National Pollutant Discharge Elimination System A provision of the Clean Water Act that prohibits discharge of pollutants into waters of the United States unless a special permit is issued by EPA, a state, or another delegated agency.

Natural Drainage A drainage consisting of native soils such as a natural swale or topographic depression which gathers and/or conveys runoff to a permanent or intermittent watercourse or water body.

No plant zone Area of green roof where plants are excluded to prevent vegetation from growing too close to roof drains and to identify roof drains for maintenance personnel.

Nonpoint source pollution Runoff that enters water from dispersed and uncontrolled sources, such as rainfall or snowmelt moving over and through the ground rather than single, identifiable sources. A nonpoint source is any source of water pollution that does not meet the legal definition of point source in section 502(14) of the Clean Water Act (e.g., agricultural practices, on-site sewage disposal, automobiles, and recreational boats). While individual sources may seem insignificant, they may contribute pathogens, suspended solids, and toxicants which result in significant cumulative effects.

Open space A portion of a cluster development that is set aside for public or private use and is not developed with homes. The space may be used for active or passive recreation, or may be reserved to protect or buffer natural areas (see also green space).

Parking groves A variation on the hybrid parking lot design, parking groves use a grid of trees and bollards to delineate parking stalls and create a shady environment. The permeable stalls reduce impervious land coverage while the trees reduce heat island effect and improve soil permeability.

Percolation The downward movement of water through soil layers, as contrasted with infiltration which is the entry of water into the surface of the soil.

Perennial stream A stream channel that has running water throughout the year.

Permeable A type of soil or other material that allows passage of water or other liquid.

Permeable pavement Asphalt or concrete paving material consisting of a coarse mixture cemented together with sufficient interconnected voids to provide a high rate of permeability.

Permeable surfaces Areas characterized by materials that allow stormwater to infiltrate the underlying soils (e.g., soil covered or vegetated areas)

Pervious A soil or material that allows the passage of water or other liquid.

Point Source Pollution A source of pollutants from a single point of conveyance, such as a pipe. For example, the discharge from a sewage treatment plant or a factory is a point source.

Pollutants A chemical or other additive that adversely alters the physical, chemical, or biological properties of the environment.

Pollutograph A chart of stormwater quality data throughout the duration of a storm that is used to evaluate pollutant concentrations and identify the presence or absence of a *first flush*.

Private roads The lowest order street in the hierarchy of streets, it conducts traffic between individual dwelling units to Public streets (such as collector and Residential collector streets). Private roads convey the lowest traffic volume, and are prime candidates for reduced street widths.

Public roads consist of two main types:

> **Mobility element roads.** Mobility element roads are considered the regional backbone or skeleton road system. These roads provide for the vehicular movement of goods and services between various parts of the County. Traffic on mobility element roads are given preference at intersections, and some access control may be considered to maintain capacity to carry high volumes of traffic.
>
> **Nonmobility element roads.** These roads feed vehicular traffic onto the mobility element system of roads. They provide access to residential neighborhoods and commercial/industrial areas. Of the two types of Public roads, nonmobility element roads are afforded the most flexibility with regards to implementing LID concepts.

Ravel Loosening or separation of the pavement surface course, typically caused by excessive abrasion.

Receiving waters Lakes, rivers, wetlands, bays, and coastal waters that receive runoff.

Recharge Infiltration of surface water to groundwater.

Recharge area A land area in which surface water infiltrates soil and reaches to the zone of saturation, such as where rainwater soaks through the earth to reach an aquifer.

Retrofit To provide or add new equipment, parts, structures, or techniques unavailable at the time of original construction.

Riparian area Habitat found along the bank of a natural and freshwater waterway, such as a river, stream, or creek, that provides for a high density, diversity, and productivity of plant and animal species.

Runoff Water from rain, melted snow, or agricultural or landscape irrigation that flows over the land surface.

Runoff coefficient The runoff coefficient is based on permeability and determines the portion of rainfall that will run off the watershed. The runoff coefficient value, expressed as C, can vary from close to zero to up to 1.0. A low C value indicates that most of the water is retained for a time on the site, as by soaking into the ground or forming puddles, whereas a high C value means that most of the rain runs off.

Sand filter Small scale sand filter units are usually located in below ground concrete pits (as residential/lot level) comprising of a preliminary sediment trap chamber with a secondary filtration chamber. Larger scale sand filters may be comprised of a preliminary sedimentation basin with a downstream sand filter basin-type arrangement.

Self-retaining areas Areas designed to retain the first one inch of rainfall without producing any runoff.

Self-treating areas Landscaped or turf areas that drain directly off-site or to a storm drain system without discharging runoff to on-site impervious areas. Also called *zero discharge areas*.

Setback A zone designated to protect sensitive areas from negative impacts associated with development.

Shared parking A parking strategy designed to reduce the total number of parking spaces needed within an area, by allowing adjacent users to share parking areas during noncompeting hours of operation (e.g., a shared lot for a theater and an office building).

Sheetflow A flow condition during a storm where the depth of stormwater runoff is very shallow in depth and spread uniformly over the land surface. This sheet flow quickly changes into concentrated channel flow within several hundred feet.

Short circuit A situation in which polluted runoff bypasses a stormwater treatment facility.

Significant tree Any tree which is more than 12 inches in diameter as measured 4.5 feet above the root crown; or any tree with a diameter of any two trunks of at least 16 inches as measured 4.5 feet above the root crown. Any oak tree of the *Quercus* genus more than 6 inches in diameter as measured 4.5 feet above the root crown; or any such tree with a total diameter of any two trunks of at least 8 inches as measured 4.5 feet above the root crown.

Smart growth A set of development principles to improve community livability, including mixing land uses, creating a range of housing types, preserving green space, creating compact and walkable development with a variety of transportation options, and focusing new development in or near areas of existing development.

Steep slope An area of land that has a slope angle of 25% or greater.

Stormwater conveyance A system of gutters, pipes, or ditches used to carry stormwater from surrounding land areas to constructed or natural drainage systems.

Stormwater runoff Rain that flows off the surface of the land without entering the soil.

Structural control A practice that involves design and construction of a facility to mitigate the adverse impact of urban runoff and often requires maintenance.

Subdivision The process (and the result) of dividing a parcel of raw land into smaller buildable sites, streets, open spaces, and public areas, and the designation of utilities and other improvements. Regulations govern the density and design of new subdivisions.

Surface water Water on the surface of the land that has not infiltrated the soil including streams, lakes, rivers, and ponds.

SUSMP Standard Urban Stormwater Mitigation Plan for land development projects and public improvement projects.

Swale An open drainage channel that has been explicitly designed to detain, evaporate, and/or infiltrate the runoff associated with a storm event.

Thermal load Heat energy stored and transported by stormwater runoff. Thermal load is a function of both the temperature and quantity (mass or volume) of runoff.

Treatment control IMP (treatment control BMP) Any engineered system designed and constructed to remove pollutants by simple gravity settling of particulate pollutants, filtration, biological uptake, media absorption or any other physical, biological, or chemical process.

Treatment train A stormwater technique in which several treatment types (filtration, infiltration, retention, evaporation) are used in conjunction with one another and are integrated into a comprehensive runoff management system.

Unit pavers Concrete grid and modular pavement whose spaces are filled with pervious materials such as sod, sand, or gravel.

Vector A vector is any insect (mosquitoes), arthropod, rodent or other animal that is capable of harboring or transmitting a causative agent of human disease.

Volume-based practices IMPs for which pollutant removal depends on the volume of stormwater treated, such as detention, retention, and infiltration basins.

Water table The upper surface of groundwater or the level below which the soil is saturated with water. The water table indicates the uppermost extent of groundwater.

Watercourse A permanent or intermittent stream or other body of water, either natural or improved, which gathers or carries surface water.

Watershed The geographic region within which water drains into a particular river, stream or body of water. A watershed includes hill, lowlands, and the body of water into which the land drains. Watershed boundaries are defined by the ridges of separating watersheds. See also *drainage basin.*

Xeriscape Landscaping commonly used in arid regions that requires little or no irrigation through the selection of drought-tolerant plants.

Zero discharge areas Landscaped or turf areas that drain directly off-site or to a storm drain system without discharging runoff to on-site impervious areas. Also called *self-treating areas*.

Zoning A set of regulations and requirements which govern the use, placement, spacing, and size of land and buildings within a specific area (zone).