Chapter 4
Reducing Stormwater Impacts

4.1 Introduction and Purpose

Policy Statement

The mission of Sonoma County Water Agency (SCWA) is to effectively manage the resources in its care for the benefit of people and the environment in its service area. It is the policy of SCWA to encourage the use of Low Impact Development (LID) techniques to the greatest extent practical to reduce the adverse impacts of stormwater runoff on water quality, stream and riparian conditions, and flooding. This guidebook describes LID planning approaches and techniques.

Purpose

The purpose of this chapter is to (1) provide guidance on how to incorporate LID stormwater approaches into the site planning and design process and (2) provide an introduction to LID BMPs and treatments that can be applied to development sites. The combination of using LID planning approaches and BMP treatments helps reduce and avoid deleterious effects of stormwater resulting from urban development. This chapter is intended for several audiences, including land-use planners, engineers, landscape architects, and developers in Sonoma County who may be working with staff at Sonoma County and cities in the County for project approvals.

Regulatory Background: Sonoma County NPDES Permitting and LID

The Federal Clean Water Act of 1972 regulates discharges to surface waters (other than dredge or fill material) through the National Pollutant Discharge Elimination System (NPDES). Under the NPDES, municipalities are required to maintain compliance with the conditions of NPDES permits for their stormwater discharges. The municipalities, in turn, require that individual projects within their jurisdiction comply with the requirements of these permits.

SCWA, Sonoma County, and the City of Santa Rosa are co-permittees under a former 2003 municipal NPDES permit and waste discharge requirements for Municipal Separate Storm Sewer System (MS4) discharges from Sonoma County within the North Coast Regional Water Quality Control Board's (RWQCB's) jurisdiction (Order No. R1-2003-0062, NPDES No. CA0025054). The co-permittees developed a Storm Water Management Plan (SWMP 2007) and a Standard Urban

Storm Water Mitigation Plan (SUSMP 2005) to guide construction, post-construction, industrial, commercial, and storm system operation and management operations within the permit area.

As of October, 2009, a new NPDES permit was adopted (Order No. R1-2009-0050, NPDES No. CA0025054, WDID No. 1B96074SSON). The 2009 NPDES Permit (Special Provisions Part 5) describes the development of an Integrated Water Quality and Water Resource Plan for new development and redevelopment. This plan is to include an LID manual, post-construction treatment BMP criteria, and a hydromodification control and mitigation plan. It is envisioned that these three components of the overall water quality plan will be developed in phases and that, once complete, these components will be included in an updated SUSMP manual. This process is shown in the upper portion of **Figure 4-1**.

This guidebook represents a first step in fulfilling the "LID manual" requirement of the Integrated Water Quality and Water Resource Plan of the NPDES permit. As specified in the permit, the LID manual should include guidance on the following LID objectives and strategies:

A. Site assessment;

B. Site planning and layout;

C. Vegetative protection, revegetation, and maintenance;

D. On-site soil protection with the goals of reducing soil compaction, retaining topsoil and facilitating runoff capture;

E. Retention of natural runoff infiltration, storage and evapotranspiration rates;

F. Techniques to minimize land disturbance;

G. Techniques to implement LID measures;

H. LID BMP design guidance;

I. LID BMP maintenance guidance;

J. Integrated water resources management practices;

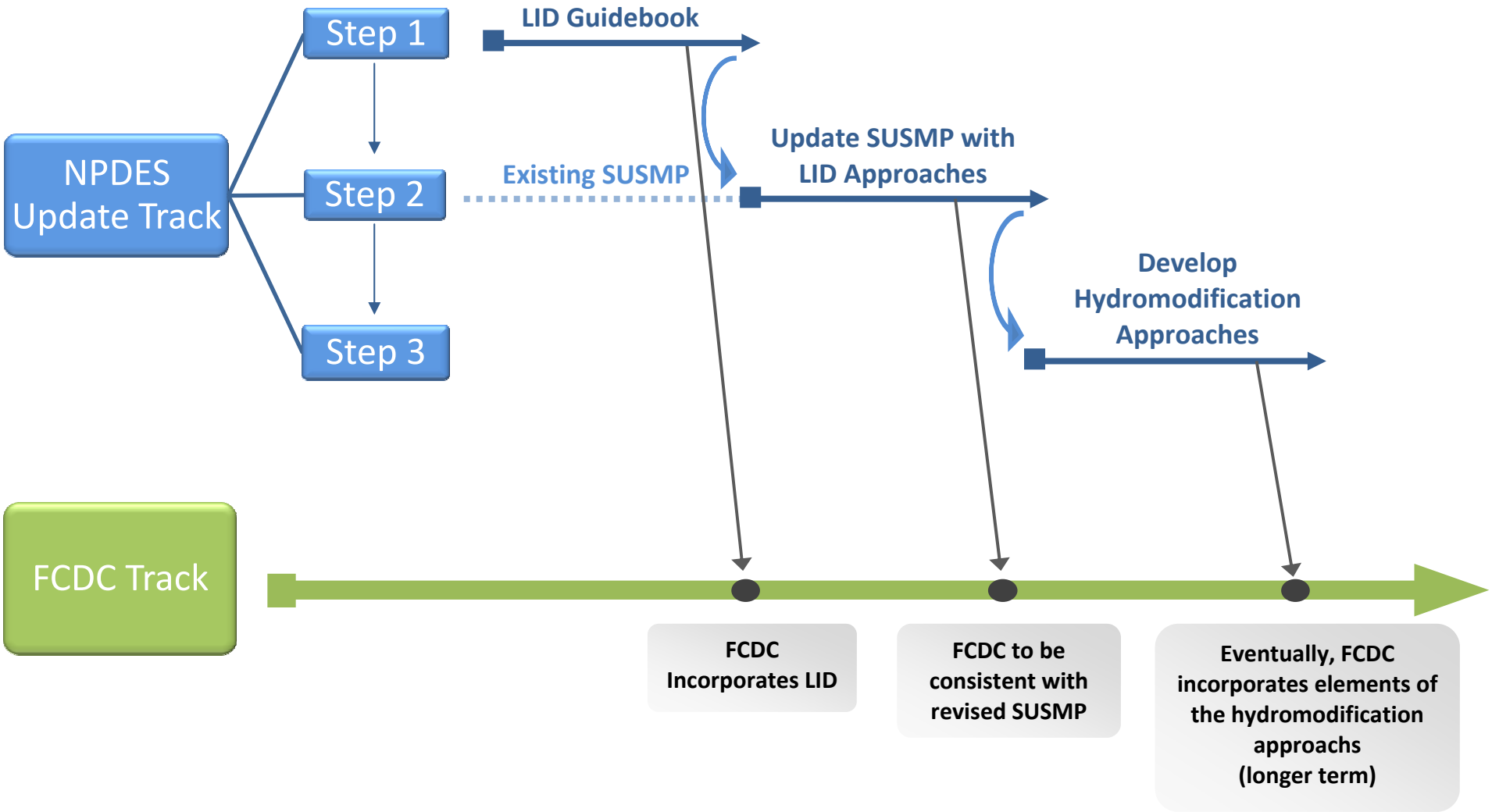
K. LID design and flow modeling guidance;

L. Hydrologic analysis; and

M. LID offset credits.

The 2009 NPDES Permit also describes the need for hydromodification control criteria. These criteria would limit the extent to which new development and redevelopment projects may alter post-development stormwater runoff discharge rates, velocities, and durations to receiving creeks. Hydromodification approaches are implemented to prevent post-project downstream erosion and associated impacts to stream habitat in receiving waters. The NPDES Permit requires that LID strategies be the preferred method to meet these requirements. However,

Figure 4-1: Relationship between NPDES Permitting, Development of the LID Guidebook, and the FCDC Process



other methods are likely needed when LID approaches alone cannot reduce post-development related discharges. The NPDES Permit requires that more specific hydromodification control criteria be developed in a Hydromodification Control Plan as the third component of the overall integrated water quality plan (Figure 4-1). The Hydromodification Control Plan will include approaches to analyze and evaluate potential hydromodification effects, as well as, design criteria to use to mitigate for potential hydromodification effects on receiving streams.

Hydromodification refers to changes in runoff volume, frequency, and duration due to urban development. Increased runoff and streamflow from urban areas discharged to natural watercourses can adversely impact aquatic ecosystems and stream habitats and cause stream bank erosion and physical modifications.

Hydromodification management is a process that preserves natural hydrograph attributes for a development site and its watershed. Hydromodification Management Plans (HMPs) have been developed by cities and counties in California to comply with NPDES permitting requirements. In Sonoma County, these criteria and requirements are specified in the 2009 NPDES permit.

SCWA's Flood Control Design Criteria

SCWA's Flood Control Design Criteria Manual (FCDC) is the standard reference in the County for hydrology and hydraulics, providing criteria for the design of waterways, channels, and closed conduits. With the exception of the city of Healdsburg (which does not use the FCDC), all plans in the County submitted for hydrology/hydraulic review are subject to FCDC standards.

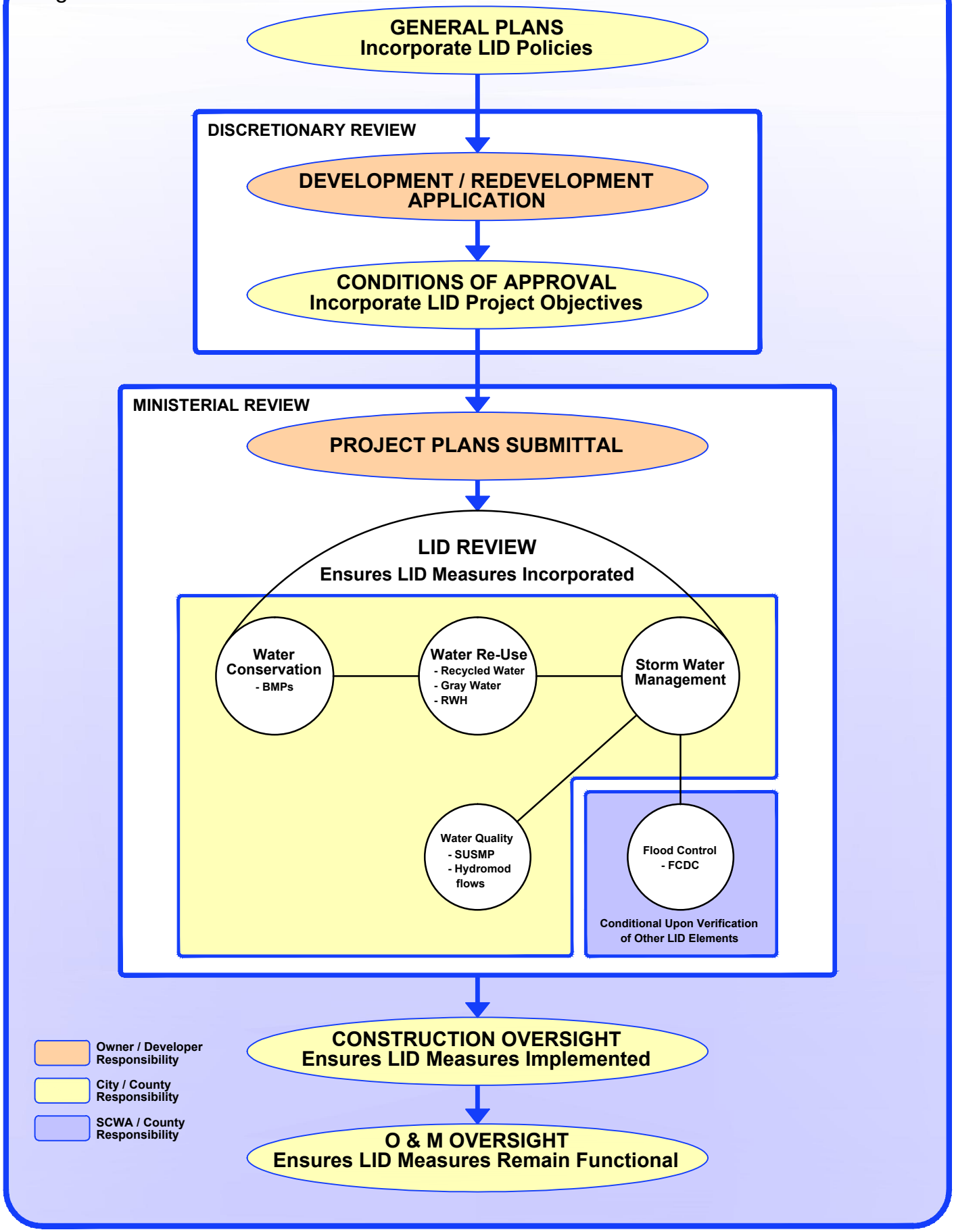
SCWA is currently updating the FCDC to reflect more modern approaches to hydrology analysis and runoff management, including LID principles and practices. The revised FCDC will be consistent with the LID approaches outlined in this guidebook, as well as with the other components of the Integrated Water Quality and Water Resources Plan as described above. The lower portion of Figure 4-1 illustrates how the FCDC's runoff management aspects will be consistent with the component plans developed for NPDES compliance.

Development Plan Review Process

Figure 4-2 graphically depicts how LID strategies are incorporated into the plan review process. At the municipal and regional scale, city and county general plans incorporate LID policies to guide land uses and measures to reduce impacts. Specific practices are then integrated into new development or redevelopment project plans during the discretionary review process. Similarly, ministerial review for issuance of building permits, grading permits, etc. will be subject to review for compliance with LID requirements as stated in the NPDES Permit. Figure 4-2 is color-coded to indicate which entities may have primary responsibility for overseeing the different steps of the review process.

This guidebook does not provide specific design parameters for the purposes of NPDES permit compliance, nor does it recommend or exclude specific LID features. Agencies with ministerial review responsibilities should be contacted directly to obtain guidance for specific LID features that may require additional permitting coordination. For example, for projects that require a

Figure 4-2 LID Review Process



building permit, project plans should be submitted to the local city or county development or permit review department for guidance on application of LID features into the site design. **Appendix 3** includes a sample LID checklist based on the site planning process of this guidebook. This checklist is provided as an example to help potential project applicants and city/county staff identify key LID considerations during the planning, design, and review of projects.

It is important to note that LID planning in Sonoma County is broader than just stormwater management. As shown in Figure 4-2, the review process seeks to ensure that LID approaches to water conservation and reuse are also applied. These water resource topics are discussed in other chapters of this guidebook. Water conservation and reuse approaches are not regulated under the NPDES Permit, but are guided or regulated by other local, state, and federal standards or requirements. Regulations and standards for water conservation and reuse approaches are presented in the preceding chapters of this guidebook.

After plan review is complete, LID measures must be adequately installed and maintained following construction.

Chapter 4 Organization

The remainder of this chapter is organized into the following sections:

- Section 4.2 – *LID Approach to Stormwater Management*. This section describes LID principles and general approaches to on-site stormwater management.
- Section 4.3 – *The LID Stormwater Planning Process*. This section presents a step-by-step process to incorporate LID into the project design and implementation process. Planning steps include site assessment, site planning, design and selection of LID measures, and project construction, operations and maintenance.
- Section 4.4 – *LID Fact Sheets*. This section presents informative fact sheets for several LID on-site stormwater management techniques.
- Section 4.5 – *Off-site, Retrofit, and Regional Approaches*. This section describes off-site mitigation, retrofit, and other regional approaches that can be used to manage stormwater in addition to the on-site LID approaches.
- Appendix 3 – Project Review Checklist
- Appendix 4 – Reference Maps

4.2 LID Approach to Stormwater Management

4.1 Introduction and Purpose
4.2 LID Approach to Stormwater Management
4.3 The LID Stormwater Planning Process
4.4 LID Fact Sheets
4.5 Off-site, Retrofit, and Regional Approaches

LID stormwater management is a site design strategy with the goal of avoiding and minimizing hydrologic and water quality impacts associated with development. The LID strategy emphasizes design practices and techniques that effectively capture, filter, store, evaporate, detain, and infiltrate runoff close to its source. LID also seeks to conserve natural resources and preserve ecological functions. The LID concept is based on the premise that stormwater management involves more than just preventing flooding, and that runoff is a valuable resource if used wisely. LID recognizes the value of pre-existing hydrologic functions and their influence on the surrounding environment.

The LID stormwater management approach recognizes that urban design, landscape architecture, and engineered infrastructure are intrinsically linked.

While LID is recognized as a valuable approach to stormwater management at the site scale, it is not the only approach to stormwater reduction and mitigation. As depicted in **Figure 4-3**, effective stormwater management occurs at several scales. Regional planning and watershed management approaches (including "smart growth" techniques) can minimize stormwater impacts through careful siting considerations. Regional stormwater management facilities (such as detention basins) also provide an effective means to capture or manage stormwater. Regional approaches to stormwater management are discussed later in this chapter (Section 4.5). In addition to LID, regional planning, and regional facilities; stream restoration and channel stabilization measures may be needed to address downstream erosion caused by hydromodification.

"Smart growth" refers to community development that is designed to preserve natural resources, protect air and water quality, and reuse developed land. Principles include mixing land uses, providing opportunities for alternative transportation, and utilizing compact building designs (EPA 2009).

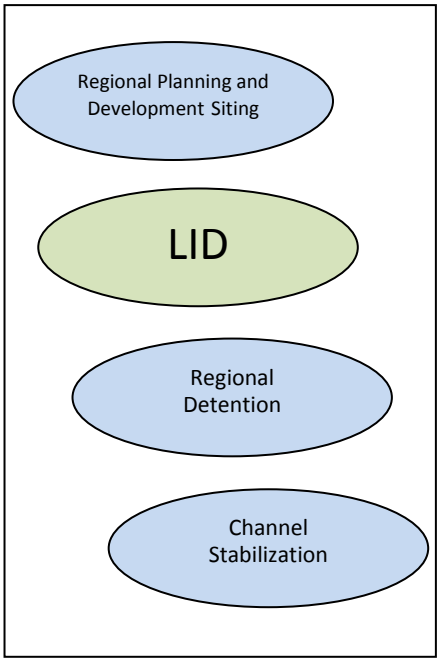


Figure 4-3: Stormwater Planning Approaches

Additionally, it should be stated that LID is generally used in conjunction with conventional stormwater infrastructure, such as municipal storm drains and drainage channels. LID techniques are best suited for minimizing the impacts of small-to-moderate-sized storms on water quality and hydromodification. For most sites, conventional stormwater infrastructure is also needed to prevent flooding during large rainfall events.

Section 4.2 continues with a summary of how the hydrologic cycle is affected by development and stormwater, a review of four guiding principles of LID stormwater management, a discussion of challenges to LID use, and an overview of LID design features.

Stormwater LID and the Hydrologic Cycle

As described above in Chapter 1, the hydrologic cycle describes the movement and storage of water across the atmosphere, the land surface, the subsurface, and the ocean basins. Runoff and streamflow are a relatively small, but very important, component of the overall cycle. Stormwater LID approaches focus on preventing runoff generation.

Preserving and utilizing infiltration, the process by which rainfall enters the soil, is perhaps the most important aspect of LID stormwater management. Healthy soils (with moderate to high infiltration capacities) provide a critical role in receiving, storing, and infiltrating rainfall. Soils are not solely mineral composites. Healthy soils maintain biota and organic matter that chemically and physically bind mineral particles into stable aggregates; these build soil structure and provide pore spaces.

__Infiltration__ is the process by which rainfall enters the soil. Infiltration is determined by the available soil pore space (porosity) and the interconnectivity of these cavities (permeability). After a storm, water that has infiltrated into surface soils may evaporate, be used by plants, or flow by gravity deeper into the soil.

Once water has infiltrated beneath the root zone, there is no longer any opportunity for evaporation or transpiration. The water then __percolates__ downward through the soil to the groundwater table.

Although the terms infiltration and percolation are often used interchangeably, infiltration generally refers to the process by which water enters and moves through soil, whereas percolation is infiltration that occurs beneath the root zone.

Porosity and permeability are the keys to good infiltration. Soil porosity is the available pore space (or voids) that a soil has for water or air. Permeability is the way in which such pore spaces are arranged or structured such that water is able to move down through the linked pores or cavities by gravity. The ability for water to move down through the soil is called hydraulic connectivity. Clays and microbes in soils also play an important role in potential pollutant filtering and degradation, and enable moisture retention for use by vegetation. As soil conditions vary across the landscape (or within a development site) the influence of these soil functions on the hydrologic system also varies.

Evaporation releases water back to the atmosphere. This can happen directly from water vaporizing from the land, vegetation, or soil surface or being released from open water bodies. Evaporation also occurs from near surface soil pores when the vaporizing force is greater than the capillary or suction forces acting to keep moisture in the soil. Transpiration is the process where plants release water back to the atmosphere through their stomata and lenticels. Evapotranspiration (ET) refers to the collective processes of evaporation and transpiration. ET is a fundamental consideration for the effective operation of LID stormwater features. As described later in this chapter, many LID features rely on detaining and holding collected runoff. If such collected runoff can be effectively evaporated or transpired following a rainfall event, then the LID feature will have more available volume to store runoff during the next rainfall event.

In California's two-season Mediterranean climate, the rainy season is also our winter season, when evaporation and transpiration rates are at their lowest. That said, breaks between winter storms with sunshine and/or strong winds do provide opportunities for evaporation and

transpiration. During the later winter and early spring weeks, particularly after March when annual vegetation growth is strong and daylight hours are longer, the role of evapotranspiration improves greatly.

Surface water that is not infiltrated, evaporated, or transpired is available as runoff to streams and downstream waters. The amount and timing of runoff and streamflow over a given time period (storm event, season, or year) reflect the region and watershed's climate, topography, geology, and soils. As described in Chapter 1 and illustrated in **Figure 1-6**, development alters the quantity, quality, and timing of stormwater runoff in ways that can be detrimental to the land surface and to streams. Land development generally increases impervious surfaces, reduces tree and vegetation cover, and compacts or removes healthy soils. These changes typically reduce and disrupt infiltration and water storage processes provided by shallow surface depressions, upper soil layers, shallow subsurface flows, and vegetation uptake and evapo-transpiration. These changes result in increased surface runoff and increased pollutant loadings to receiving waters.

LID Principles

LID stormwater management relies on four fundamental principles:

1. **Avoid** hydrologic impacts by integrating site topography, soil, and hydrology assets into the site plan and design features
2. **Conserve** existing soils, vegetation, and hydrologic features
3. **Minimize** impervious areas and maximize permeability
4. **Manage** stormwater on-site through LID features

The first two principles emphasize protecting and using existing resources, while the last two principles shift focus to impact management and controls.

Principle 1: Avoid impacts by integrating existing topography, soil, and hydrology assets into the site plan and design features

Historically, site drainage approaches often sought to direct runoff as rapidly and efficiently as possible away from the site. In contrast, LID seeks to mimic pre-development hydrologic functions, most notably by favoring on-site retention and infiltration. LID uses existing topography and open space opportunities to slow, capture, and infiltrate stormwater. Implementing this principle first requires a thorough assessment of pre-development site conditions to understand how to incorporate the existing drainage features and hydrologic functions into the post-project site design. The site assessment process is discussed further in Step 1 of Section 4.3.

Principle 2: Conserve existing soils, vegetation, and natural features

Conserving soils, vegetation, and natural hydrologic features such as creeks, ponds, and wetlands helps reduce runoff and maintain hydrologic functioning of the site. Such natural features provide opportunities to capture, filter, store, evaporate, detain, and infiltrate runoff

while providing habitat for wildlife species and aesthetic benefits. As discussed above, evaporation and transpiration processes often supplement LID treatments. Plants that are part of LID features allow for some stormwater volume control via transpiration while also providing some stormwater treatment by taking in pollutants (phytoremediation). The conservation of wetlands and other natural features also helps avoid project impacts to habitats and species[1]. The identification of site areas to be conserved and protected occurs through the LID site assessment and planning processes described in Section 4.3.

Principle 3: Minimize impervious areas and maximize permeability

During the planning phase of the LID process, impervious areas are minimized in order to eliminate impervious surfaces that cause off-site runoff. Methods to reduce impervious area include clustering development, limiting the building footprint, maximizing permeable surfaces, directing drainage from impervious areas toward more pervious areas, and creating a site design with less pavement and roof area. Using these measures can reduce stormwater runoff volumes, flow rates, and the need for additional stormwater management facilities. Smart growth approaches that cluster development may also protect open spaces and thereby maintain the hydrologic functions and benefits of those open spaces. Methods to minimize impervious areas and maximize permeability are further discussed in Section 4.3 (Step 2) below as part of the LID planning processes.

Impervious surfaces that drain to pervious ground generate less runoff than impervious surfaces that are directly connected to downstream drainage systems.

Principle 4: Manage stormwater on-site using LID features

This principle builds on the previous three principles by incorporating LID features into the actual project site design. When natural features have been avoided and conserved and impervious surfaces have been minimized, stormwater runoff generated by the development is then managed on-site using LID features (or treatments). The LID site design approach integrates natural features with engineered small-scale hydrologic controls to maintain or closely mimic the pre-development hydrologic conditions. LID features can be designed for **detention** or **retention**. Detention is the temporary storage or slowing of stormwater, while retention refers to permanent capture of stormwater. Depending on the design of the LID feature, detention can provide stormwater treatment via settling, filtration, or biologic uptake of pollutants. In many LID features involving retention, retained water is designed to be lost via infiltration and evaporation/transpiration.

Detention involves the short-term storage of stormwater to slow and detain runoff. Retention involves the long-term capture of runoff on-site.

[1] Compliance with Clean Water Act (CWA) and Endangered Species Act (ESA) regulations focused on wetlands and threatened and endangered species often requires significant project planning and mitigation efforts to meet applicable federal, state, and local regulations. Use of LID to avoid and minimize potential CWA and ESA related impacts is an added benefit beyond the stormwater management advantages.

Retained water may also be reused on-site for landscape irrigation. LID features are summarized below in *Overview of LID Features,* and described more fully in the fact sheets of Section 4.4.

Overview of LID Features

LID features are constructed structures or landscapes that provide a variety of stormwater management functions. Classic examples of LID features are vegetated swales, green roofs, rain barrels, permeable paving and infiltration trenches. Within this document, LID features have been grouped into the following five categories:

In other documents, "LID Features" may be called:

- Integrated Management Practices (IMPs)
- LID Best Management Practices (BMPs)
- LID Treatments

- **Biofilters:** A biofilter is any vegetated area to which stormwater is intentionally directed. Biofilters come in many shapes and sizes, and often use multiple hydrologic processes (infiltration, evaporation/transpiration and detention/retention) to manage stormwater flows and quality. Common biofilter treatments include vegetated swales, rain gardens, and flow-through planters. Constructed wetlands are another type of biofilter. These are discussed in Section 4.5.

- **Permeable Paving:** Permeable paving provides important infiltration opportunities for stormwater management. Permeable surfaces include permeable concrete, permeable asphalt, and permeable paver blocks. These can be installed on non-vehicle traffic areas such as footpaths and courtyards, and roads and parking lots where vehicles are present. Due to the infiltrating properties of permeable paving, pollutant removal in vehicle traffic areas is an added functional benefit, if the pavers are properly maintained. Permeable paving systems are generally used to maximize infiltration, but they also provide some detention capacity and may be used in areas where infiltration capacities are limited.

- **Green Roofs:** A green roof is a vegetation and soil roof system used in place of a conventional roof. Green roofs are designed to infiltrate rain falling on the roof within an engineered rooftop soil matrix. Infiltrated rain is used by the rooftop vegetation and eventually discharged to the atmosphere via evaporation and transpiration.

- **Rainwater Harvesting Systems:** A rainwater harvesting system typically collects the run-off from a building's roof and stores the water in a tank for later reuse. Harvested rainwater is often used for landscape irrigation but may also be used for other purposes such as toilet flushing.

- **Subsurface Detention/Infiltration Strategies:** For smaller sites with space constraints, subsurface structures can be used to manage stormwater on-site. Subsurface detention and infiltration structures range from simple gravel infiltration trenches to highly engineered underground storage structures. A variety of pre-fabricated products are available to facilitate subsurface detention and infiltration. Additionally, stormwater

management benefits can be realized by amended site soils so as to promote detention and infiltration. However, in land uses that may generate higher pollutant loading, some type of pre-treatment may be necessary prior to infiltrating stormwater.

- **Soil Amendments:** Amending site soils can improve a soils ability to retain rain water, promote detention and infiltration, and thereby reduce runoff. Soil amending might involve soil additives to improve physical structure or chemical balance. Beside these properties, a very important element of a soil that supports its overall health is the soils biologic content, including its surface organic content, as well as microbial organisms deeper below. A healthy soil with rich biologic activity will generally provide good soil structure and thereby favor good infiltration conditions.

Table 4-1 compares how LID features use infiltration, evaporation/transpiration, detention, or retention processes to manage stormwater.

Table 4-1: LID Feature Comparison

LID Feature Categories	Infiltration	Evaporation/ Transpiration	Detention	Retention
Biofilters	✓	✓	✓	✓
Permeable Surfaces	✓		✓	
Green Roofs		✓	✓	
Rainwater Harvesting Systems		✓		✓
Subsurface Detention/Infiltration Strategies	✓	✓	✓	
Soil Amendments	✓	✓	✓	✓

Challenges to LID Implementation

There are many potential limits and challenges to implementing stormwater LID measures. Some challenges are merely problems of perception, whereas other issues represent substantive constraints. LID is not a panacea for all stormwater issues, but it does provide a flexible design approach that can improve stormwater quality and prevent deleterious hydromodification impacts. Below is a discussion of some of the commonly noted challenges to LID implementation.

Cost: Despite common misperceptions, LID is often the most economical way to manage a site's stormwater. Studies and surveys conducted by the U.S. Environmental Protection Agency (EPA) have found LID practices save money for developers, property owners, and communities. LID can provide savings compared to conventional stormwater management techniques even if benefits such as enhanced property values and aesthetic amenities are not considered to have a monetary value.

As part of the **Brooklyn Creek Basin Program**, the City of Portland is implementing hundreds of LID features including bioretention areas and rain barrels throughout a 2.3 square mile neighborhood. In combination with sewer improvements, these LID features will alleviate basement flooding problems. The alternative solution – upgrading an undersized combined sewer trunk line – would have been more expensive.

Maintenance: All stormwater management strategies (including LID features and conventional techniques) require maintenance. LID features such as bioretention areas have an advantage over conventional stormwater management structures because, being above ground, they are not "out of sight, out of mind." Because LID features like bioretention areas and green roofs provide aesthetic benefits, property owners have additional incentives to keep them looking good and functioning properly.

Vector Control: LID features may create standing water sources and can therefore be a potential breeding ground for mosquitoes. Mosquitoes are vectors of disease and have the potential to seriously affect public health. LID features can create standing water and conditions that are excellent mosquito breeding habitat. With proper design and maintenance, however, mosquito breeding in LID features can be prevented. LID features like bioretention areas should be designed to drain fully within 72 hours. For larger stormwater control features that require longer detention times (such as detention ponds or constructed wetlands), using mosquito-eating fish may be warranted. Vegetation growing in and around the feature should be properly managed to reduce mosquito breeding habitat. LID features that maintain standing water can also attract rodents such as rats, raccoons, opossums, and skunks. LID features should be monitored frequently to reduce and control mosquito populations, particularly for rainwater harvesting, subsurface detention systems, and stormwater filters. In addition to ensuring that standing water drains in a timely fashion, rodents may be discouraged through other means such as fencing and trapping. Potential LID designers should consult the Marin/Sonoma Mosquito & Vector Control District for further information on requirements for mosquito and rodent issues. The Marin/Sonoma Mosquito & Vector Control District should be notified of the locations where conventional and LID stormwater systems are to be constructed and used in

Sonoma County. These sites are entered into a database and periodically surveyed for presence of mosquito and other vectors.

Groundwater Protection: As discussed throughout this guidebook, one of the most prominent LID strategies is to infiltrate as much stormwater as possible. Because stormwater is potentially contaminated, there may be some concern that infiltrated stormwater might negatively affect groundwater quality. Studies have shown, however, that infiltration through soil is generally effective at removing common stormwater pollutants and that infiltrating LID features rarely pose any significant threat to groundwater quality. Infiltrating LID features may not, however, be appropriate for certain industrial sites that have the potential to generate elevated levels of pollutants in stormwater.

Results from the long-term **Los Angeles Basin Water Augmentation Study** by the Los Angeles & San Gabriel Rivers Watershed Council indicate that storm water infiltration has not negatively impacted groundwater quality at six monitoring sites.

California Climate: California's seasonal rainfall pattern poses particular challenges for LID implementation. In California, rainfall primarily occurs during the wet winter months and is followed by a long dry-season that extends from mid-Spring to mid-Fall. During the winter rain season, frontal storms arriving from the Pacific may come in successive waves with little break between storm events. During the winter season, LID features that rely on lengthy dry periods between storm events may be overwhelmed by successive storms. During the dry summer season, vegetated LID features (such as biorentention areas), may struggle to maintain plants without some supplemental irrigation (most often from a potable water source). Careful plant selection can, however, provide vegetated LID features that remain effective and attractive throughout the year with minimal supplemental irrigation. The most common use for water collected by rainwater harvesting systems is landscape irrigation. With rainfall occurring in the winter and irrigation needs occurring in the summer, significant storage capacity is required if the collected rainwater is to be used when it is most needed.

Regulatory, Institutional and Legal Barriers: LID is still a new strategy for managing stormwater. In some instances the regulatory, institutional and legal framework has not kept pace with recently-developed techniques and applications for LID approaches. One example of this is the reuse of rainwater. Currently, rainwater use in California lies in a legal/regulatory "gray area." Use of untreated rainwater is generally considered acceptable only for landscape irrigation. This regulatory context is, however, slowly changing to support other uses of rainwater such as toilet flushing. The City of San Francisco recently adopted codes and policies that make rainwater use for toilet flushing legal with a permit. In Sonoma County, LID is supported and advocated by many local agencies. It is anticipated that the regulatory, institutional, and legal context in Sonoma County will increasingly facilitate the use of LID.

4-3 The LID Stormwater Planning Process

4.1 Introduction and Purpose
4.2 LID Approach to Stormwater Management
4.3 The LID Stormwater Planning Process
4.4 LID Fact Sheets
4.5 Off-site, Retrofit, and Regional Approaches

The LID Planning Process:
Step 1 - Site Assessment
Step 2 - Site Planning Process
Step 3 - LID Design Objectives and Feature Selection
Step 4 - LID During Construction Phase
Step 5 - LID Operations and Maintenance

Developing and implementing LID for stormwater management follows a process of site planning, construction, and post-construction activities for development and redevelopment projects. The LID planning process is summarized in **Figure 4-4**. In this guidebook, LID principles and approaches are applied at each stage of the planning process. The LID planning process may be applied to residential, commercial, industrial, and municipal projects, regardless of size. This section describes each step in the planning process of **Figure 4-4**. Where possible, the discussion is tailored to conditions encountered in Sonoma County. **Figure 4-5** depicts an area of Sonoma County on the Santa Rosa Plain that is currently on the fringe of urban development. This area and the site shown in the highlighted box of **Figure 4-5** will be used throughout this section as a hypothetical development site to illustrate the LID planning process.

Successful LID planning requires early collaboration and close communications amongst property owners, planners, architects, engineers, builders, and the project developers. It is important that the LID concept for stormwater management plan does not conflict with (and is integrated with) the site, grading, and landscaping plans for the project.

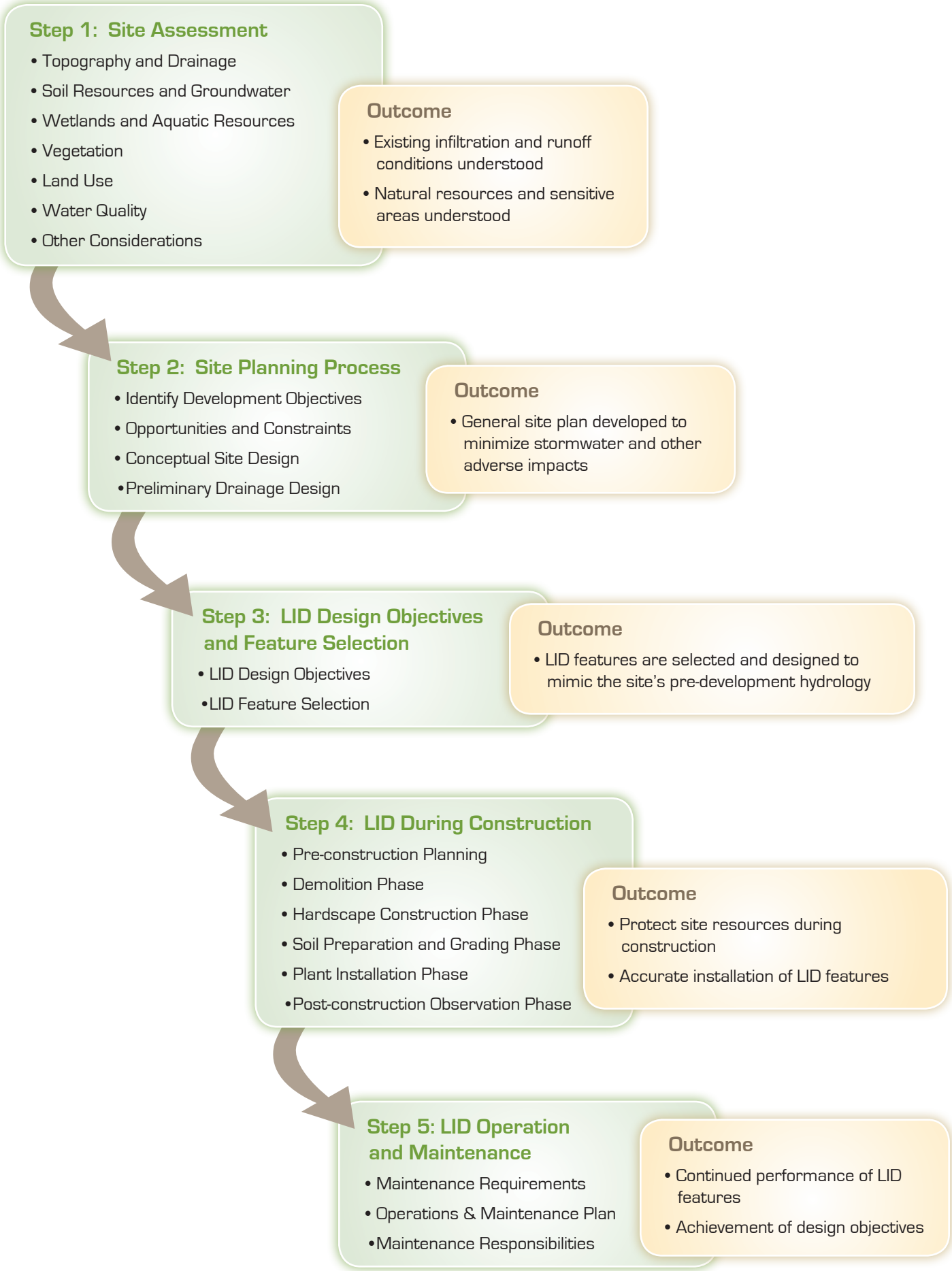
Typical LID Stakeholders include:
- Land developers
- Land use planning agencies
- Stormwater managers
- Water quality regulators
- Local community
- Consulting engineers

Step 1: Site Assessment

The Site Assessment represents the first step of the LID planning process and is fundamental to all subsequent steps. The objective of the Site Assessment is to understand the site well enough to inform and guide the site planning and LID feature design steps. The Site Assessment should be conducted with overall project goals in mind while identifying and evaluating specific pre-project site conditions. This LID Guidebook discusses the Site Assessment process in depth. This is intentional and follows guidance from the RWQCB regarding the importance of understanding and recognizing on-site resources to improve LID planning and effectiveness.

Site Assessment:
a) Topography and Drainage
b) Surface Hydrology
c) Soil and Infiltration
d) Groundwater
e) Wetlands, Ponds, and Floodplains
f) Vegetation, Riparian Resources, and Upland Habitats
g) Land Use
h) Water Quality
i) Other Site Considerations

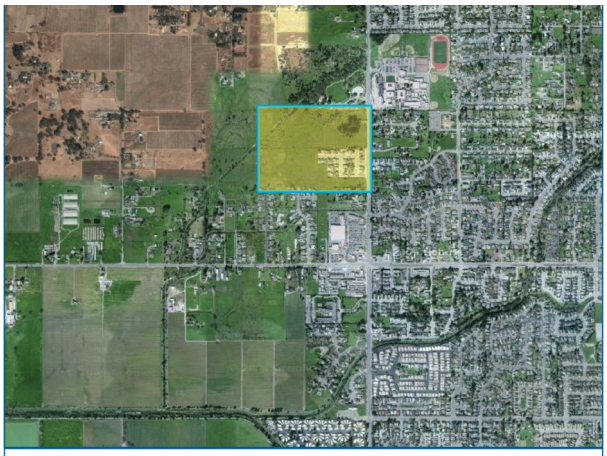
Figure 4-4 LID Planning Process



(a) Topography and Drainage

Existing site topography determines general flow patterns on-site prior to any grading activities. For LID planning, key topographic considerations include recognizing steeper areas that have potential to generate more runoff and identifying depressions or low lying areas that may provide opportunities for retention and infiltration. Hillslope gradients and lengths should be assessed, as several LID approaches are limited above certain slope thresholds. Conversely, exceedingly flat sites should be mapped carefully so that natural drainage directions may be understood. Understanding the site's base elevation in relation to any existing adjacent stormwater delivery system (to which the site may eventually route runoff) is also important.

Figure 4-5: Site Assessment



hypothetical site located on the fringe of developed area

Surface topography should also be studied to identify locations of sediment erosion, transport, and deposition. Because surface topography reflects underlying geology and soils, understanding site topography within the larger watershed will help with the later planning steps of identifying potential opportunities or constraints to LID treatments. Some useful framing questions to assess the site's setting within its watershed include:

- Upper Watershed and Headwaters Areas: Is the site located in steeper upper watershed or headwater areas? Under existing conditions are surface erosion rates high? Are there any signs of mass movement or slope failure? Are there any channels on site and are they incised? Are there springs or seeps on site, and if so where is the water coming from and where is it flowing to? Is on-site vegetation playing an important role in providing surface cover, reducing erosion, or stabilizing slopes?

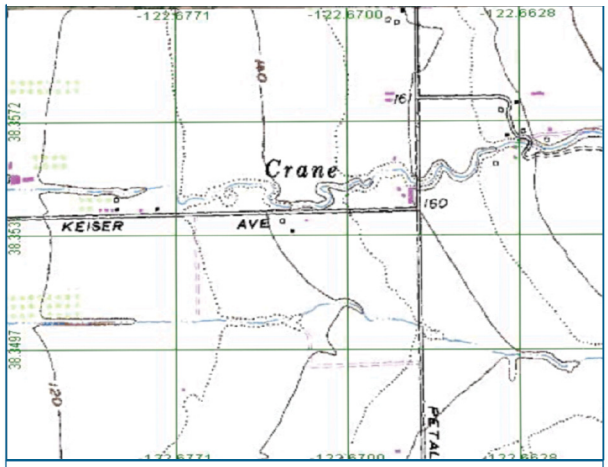
- Mid Watershed Areas: Is the site located in the transition zone between upper headwaters and lower watershed areas? Is the site located on an alluvial fan? Are there any significant breaks in slope on the site which would encourage sediment deposition? If the site has historically been a depositional area, do the deposits appear to have high infiltration capacities (to be assessed below in soil section)? Geologic faults are also often found in transitional slope areas in Sonoma County. Are faults present and do they influence surface water or groundwater movement (also addressed below)? These transitional slope zones are commonly important areas that support wildlife habitat and vegetation while recharging groundwater and streamflow.

- Lower Watershed Areas: Is the site located in the gentler sloping lower watershed? Are there indications of less permeable soils or a high water table on-site that may

encourage ponding or reduced infiltration rates? In Sonoma County most historic development has occurred within these lower watershed zones, thus the site may be influenced by surrounding existing land uses or storm drainage systems.

Figure A-1 in **Appendix 4** provides a topographic map of Sonoma County. **Figure A-2** shows the topography of southern Sonoma County, including the Laguna de Santa Rosa watershed (SCWA Zone 1A) and portions of the Petaluma River watershed (SCWA Zone 2A) and Sonoma Creek watershed (SCWA Zone 3A). **Figure 4-6** shows a portion of a USGS topographic quadrangle from southern Sonoma County. The area shown in Figure 4-6 is an alluvial fan setting, where historically abundant sediment delivered from the upper watershed was deposited and stored along the fan. The map includes 10-ft elevation contours and depicts a few creeks and swales. Development in such areas should consider infiltration possibilities and sediment delivery patterns, as these issues directly affect stormwater runoff. The topographic assessment should also consider potential wetlands and vernal pools, as they provide sensitive upland or aquatic habitats and may be relevant to stormwater management.

Figure 4-6: Site Topography



example of existing topography and hydrology

(b) Surface Hydrology

The assessment of site surface hydrology begins with understanding rainfall conditions, including average annual precipitation and more specific storm event rainfalls observed at local gages. Specific LID treatments will have different design capacities based on rainfall rates, so understanding an expected range for daily 24-hr rainfall amounts, as well as shorter duration intensities (1-hr, 30-min) is also useful. **Figure A-3** in **Appendix 4** shows average annual rainfall as isoheyets (lines or contours of equal rainfall) for Sonoma County.

LID features can function for a range of storm events, but are typically designed for events smaller than the flood control "design storm"

Understanding existing hydrologic conditions is essential to assess potential post-project runoff conditions. As shown in Figure 4-1, hydromodification criteria will be developed as part of the Integrated Water Quality and Water Resources Plan.

Existing runoff patterns on site should be identified based on the topography assessment described above. Additional details should be included to precisely map out the existing drainage pattern from where channelized flows are first observed (smaller rills or gullies) to any larger primary drainage courses or streams. Existing drainage features should be studied for evidence of maximum water elevations and whether the features are perennial, intermittent, or

ephemeral. Is the site affected by any surrounding runoff delivered from other urbanized areas? Understanding the site's existing drainage pattern is important in planning for post-project runoff management. Subsequent planning steps will integrate these hydrology considerations into the site design, aiming to preserve areas and features that provide infiltration functions.

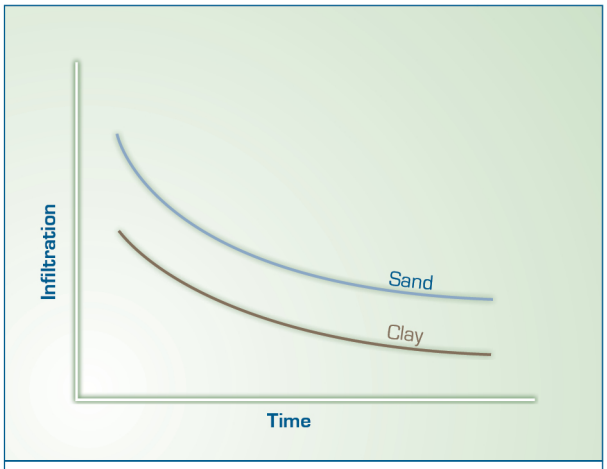
(c) Soil and Infiltration

As described above in the introductory sections, infiltration is one of the fundamental LID strategies. LID site planning favors preserving areas with higher infiltrating soils, locating development over less permeable areas, and routing runoff toward higher infiltration areas where possible. Because soil and infiltration are so critical to the entire LID approach, the site assessment for soils and infiltration is very important.

Infiltration rates are affected by soil texture and structure, vegetation types and cover, antecedent water content in the soil, soil temperature, and rainfall intensity. For example, coarse-grained sandy soils with large pore spaces between grains typically drain quickly and sustain relatively high infiltration rates. In contrast, soils with a higher proportion of smaller grained clay minerals will have reduced porosity and permeability. **Figures 4-7 (a) and (b)** compare infiltration and runoff outcomes for generally sandy or clay soil conditions. Infiltration capacity is greatest at the beginning of a rain event and decreases over time as soil pore spaces fill with water during the event.

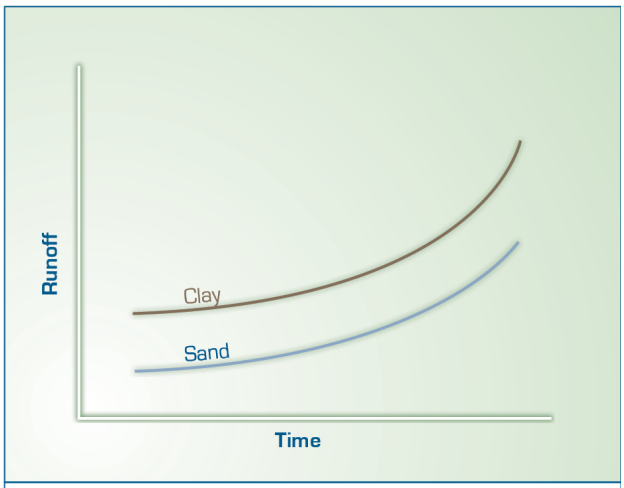
Figure 4-8 illustrates how the difference in runoff generated from sandy and clay terrains lessens when moving from moderate sized events to large or extreme rainfall events. At higher magnitude events, infiltration capacities may be exceeded by rainfall intensities. Following a series of storm events, higher antecedent soil moisture conditions may saturate available pore spaces. The difference between sandy and clay soils lessens as soils reach and maintain saturation during the extreme event. **Figure 4-8** also compares developed and non-developed conditions for generally sandy or clay soils. Under moderate rainfall events, the developed site on sandy soils may have runoff that approaches or surpasses the non-developed clay soil. However, under the larger magnitude, or extreme runoff conditions, these relative differences diminish.

Figure 4-7(a): Soil Infiltration



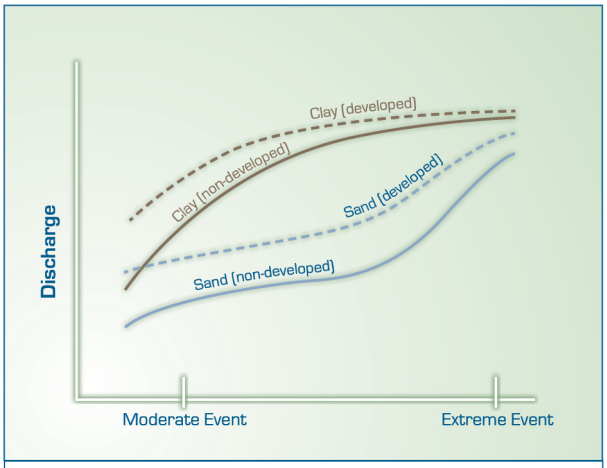
soil infiltration over time
during and following a wetting event

Figure 4-7(b): Soil Runoff



soil runoff during and following a wetting event

Figure 4-8: Change in Runoff

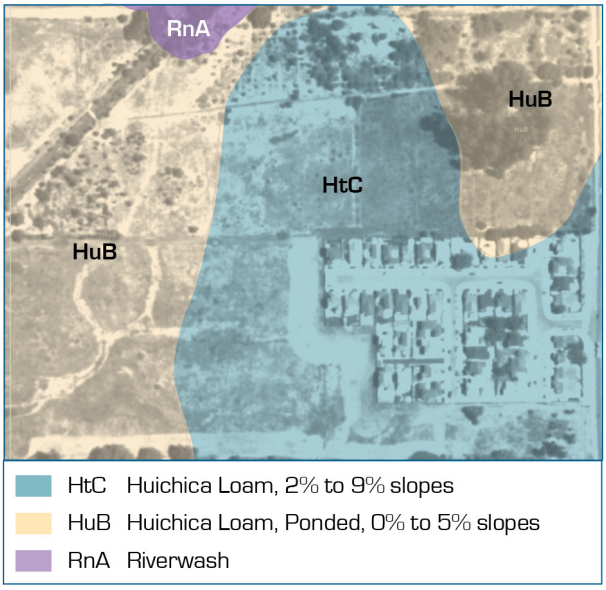


change in runoff in developed and
non-developed conditions

Vegetation has several important interactions with soil that influence infiltration. Root action, organic material, and biota from vegetation improve soil structure through increased particle aggregation and enlarged root pore spaces. Forests with complete canopy coverage protect soil surfaces from erosion and surface sealing which can reduce infiltration. The thick litter and duff on the surface beneath forests also supports infiltration. As a result, coniferous forests typically have the highest infiltration rates of any vegetative types (not accounting for site specific soils or geology). The removal of tree cover through development can thus have an adverse affect on infiltration. Similarly, the removal of top soil associated with mass grading typically results in a heavily compacted soil with lower infiltration rates. As described below in Step 4 of the LID planning process, LID approaches during construction aim to preserve and protect valuable top soil.

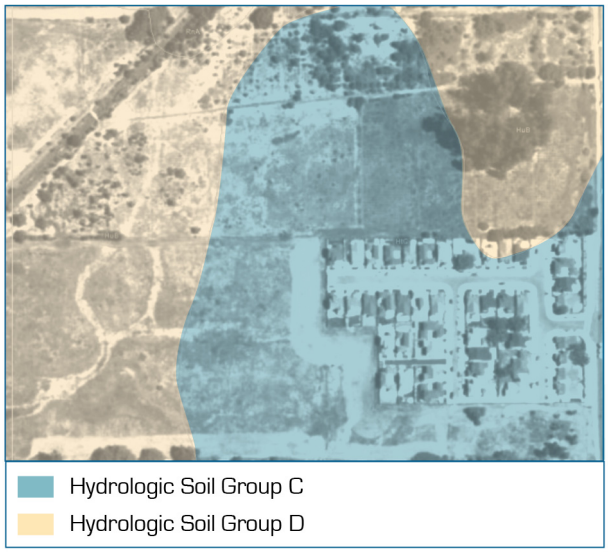
The soil assessment involves understanding the properties and conditions of surface soils and underlying horizons. The USDA Natural Resource Conservation District (NRCS) collects soil data and information for nearly the entire United States, including Sonoma County. In addition to delineating soil types and names, soil surveys include valuable information about soil hydrologic and engineering properties, as well as suitability for various land uses. **Figure 4-9** illustrates soil types for the hypothetical development site referenced earlier in this section. NRCS soil surveys provide data regarding infiltration conditions, including presence of low permeability layers, highly permeable sand/gravel layers, depth to groundwater, and other soil properties useful to assess the site's ability to infiltrate and percolate. This information can be found at their interactive Web Soil Survey website: http://websoilsurvey.nrcs.usda.gov.

Figure 4-9: Site Soil Types



Soils are varied in Sonoma County, being derived from diverse landform, geologic, climatic, and biologic conditions. The Soil Survey for Sonoma County includes 15 soil associations (USDA NRCS 2009). At the association level, soils are generally distinguished according to their geomorphic and topographic setting; whether they are located in basins, tidal flats, floodplains, terraces, alluvial fans, high terraces, foothills, uplands, or mountains. In general, the soils in the lowland basins, floodplains, and alluvial fans range from gravelly sandy loams to clays - most often composed of clays and clay loams that formed in alluvium from sedimentary and volcanic material. These soils vary in drainage capacity from poor to excessive, with the more clay-textured soils draining more poorly. Soils on the high terraces, foothills, uplands, and mountains consist of gravelly to stony sandy loams to clay loams and range in drainage capacity from moderate to excessive, with the coarser textured soils draining better.

Figure 4-10: Site Hydrologic Groups



Soils in the USDA soils classification system are divided into four Hydrologic Soil Groups, all of which are very relevant to LID planning. Soils in Hydrologic Soil Group A have high infiltration rates and low runoff potential, B soils have moderate infiltration, C soils have slow infiltration, and D soils have very slow infiltration rates and high runoff potential. Soils in the C and D category tend to have higher clay content and encourage ponding. Soils in the A and B groups tend to have a higher sand proportion and are typically preferable for LID treatments that use infiltration. **Figure 4-10** shows the hypothetical development site on the Santa Rosa Plain with a mix of Hydrologic Soil Group C soils and D soils. Relatively better C-class infiltration conditions occur in the central portion of the site and poorer infiltrating D-class soils occur in the western and northeastern portions of the site. **Figure 4-11** shows Hydrologic Soil Groups for Sonoma County. **Figure 4-12** shows Hydrologic Soils in the southern Sonoma County area, including the Laguna de Santa Rosa watershed and portions of the Petaluma River and Sonoma Creek watersheds.

Hydrologic Soil Group maps provide only a general indication of the infiltration capacity at a site. In some cases, field testing of infiltration rates may be warranted. Simple field infiltration test methods include excavating "test pits," filling the pits with water, and recording the time required for water levels in the pit to drop. This type of field evaluation of infiltration is similar to tests conducted for septic system design. More sophisticated field infiltration tests, such as single-ring or double-ring infiltrometer tests provide more precise estimates of a soil's longer-term infiltration capacity. Field infiltration tests should be supervised by a qualified hydrogeologist or geotechnical engineer.

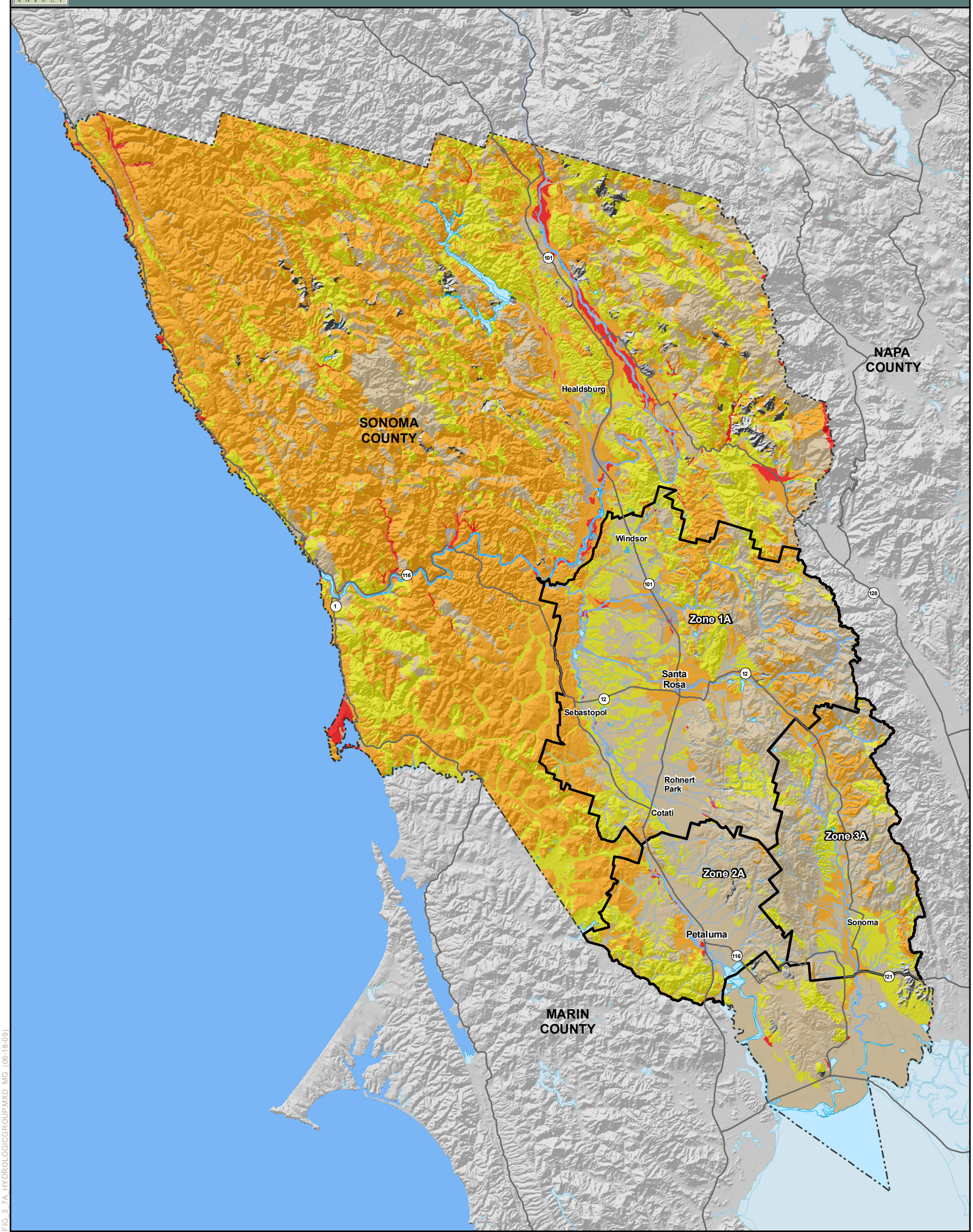
(d) Groundwater

As described above in reference to the hydrologic cycle, groundwater collects from infiltrated rainfall and streamflow that percolates by gravity through surficial soils and shallow subsurface zones to saturated strata (aquifers) below that act as groundwater reservoirs. As simplified in **Figure 1-6**, groundwater aquifers may occur at several levels, including near surface zones known as shallow-subsurface flow, where the process of interflow (or throughflow) moves subsurface water down slope toward streams or seeps. At deeper levels larger and more regional aquifers (or groundwater basins) are found. Aquifers tend to be associated with porous and permeable sedimentary rocks or alluvium that has higher water-bearing capacities, but groundwater can also be held in less porous igneous or metamorphic rocks that have permeability through large joints or fractures. Faults, such as the Rogers Creek Fault Zone (**Figure A-5** in **Appendix 4**), can provide another avenue for groundwater to collect and migrate.

In terms of stormwater management, preservation of naturally functioning interactions between the processes of surface infiltration, soil pore filling, shallow subsurface throughflow, and groundwater is a key aspect of the LID approach. As part of the site assessment, it is important to understand how the site contributes to groundwater; and conversely, to recognize if and how site features are supported by subsurface water. For example, a site may have a swale which provides a good conduit for infiltration and deeper percolation to groundwater, or it might have a vernal pool or wetland that is supported by shallow subsurface flows.

Sonoma County Water Agency

Low Impact Development Guidebook



Hydrologic Soil Group

A B C D

SCWA Flood Control Zone Boundary

Highway

Streams and Channels

Water Bodies

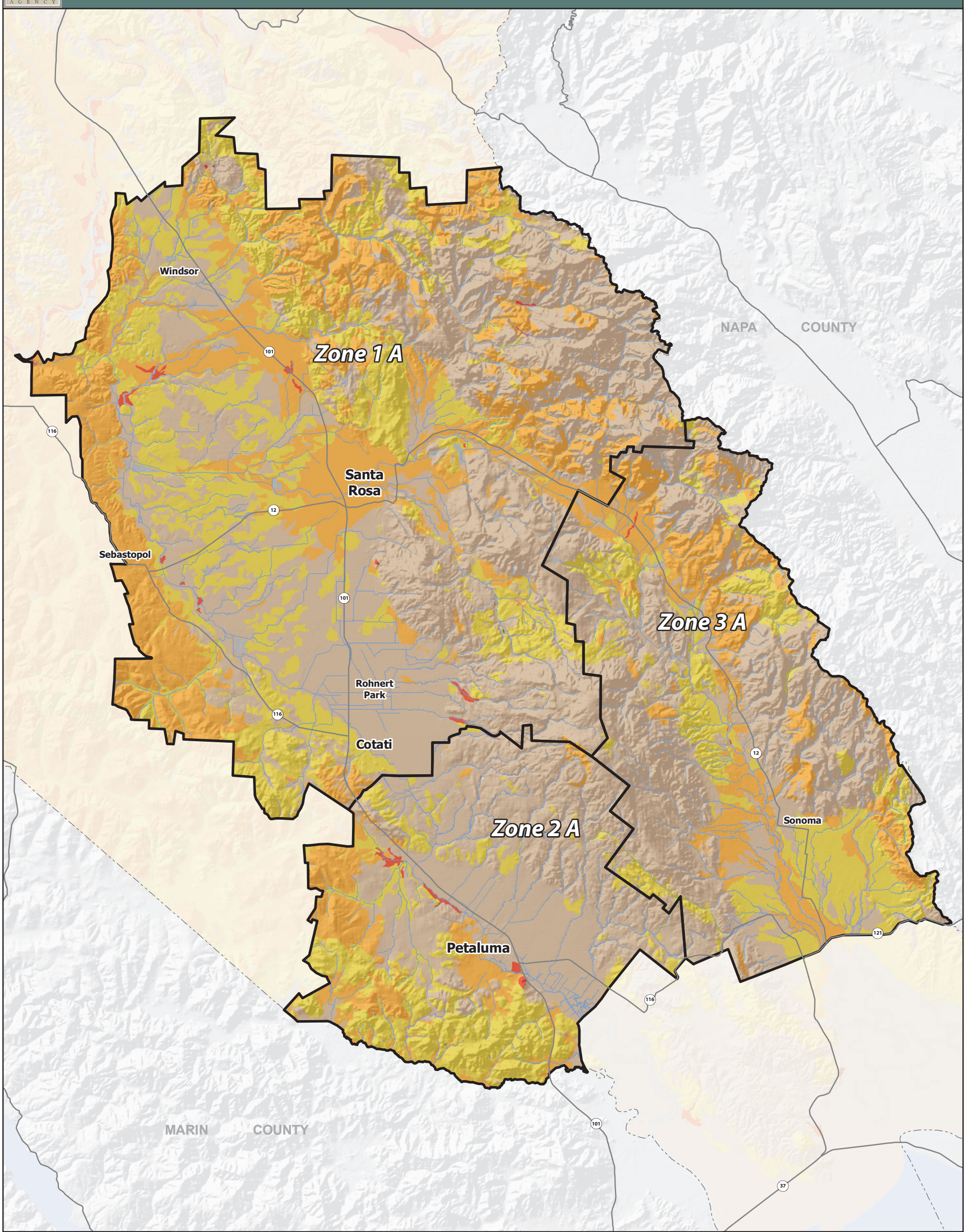
0 1 2 3 4
Miles

Figure 4-11

Hydrologic Soils of Sonoma County

Horizon WATER and ENVIRONMENT

e:\Projects2008\Horizon\SCWA\GIS\Arcmap\Layouts\Ch3\FIG_3_7A_HYDROLOGICGROUP.MXD MG (06-18-09)



Hydrologic Soils Group

A B C D

SCWA Flood Control Zone Boundary
Streams and Channels
Highway
Water Bodies

Erosion factor Kf indicates the erodibility of the fine-earth fraction, or the material less than 2 millimeters in size. (NRCS, SSURGO 2004)

Figure 4-12

Hydrologic Soils Group

0 1 2 3 4
Miles

Horizon WATER and ENVIRONMENT

Figure A-7 in **Appendix 4** shows the groundwater basins of southern Sonoma County. Groundwater basins in Sonoma County are generally associated with surface topography and watershed patterns. However, surface watersheds and groundwater basins are not always aligned or coterminous. For example, a portion of the northern Laguna de Santa Rosa watershed that surficially drains Mark West Creek overlies the Alexander Valley groundwater basin that continues north outside of the Mark West and Laguna de Santa Rosa watersheds.

In terms of site planning, impervious surfaces can sever pathways for groundwater recharge. Additionally, subsurface elements of development including foundations, subsurface pipes or cable vaults, or other infrastructure can disrupt or block the horizontal movement of shallow subsurface flows. In subsequent site planning steps, identifying buildable areas over portions of the site that provide the least contributions to groundwater recharge may reduce such impacts.

It should be noted that for a particular site or area, the LID strategy to maximize on-site infiltration should also be weighed against any potential contamination issues. If increased infiltration of runoff with impaired, contaminated, or poor water quality would potentially pollute groundwater resources, then other approaches should be sought.

In Sonoma County, stream channels are often important recharge corridors that provide water directly to aquifers below. Earthen stream channel beds prevalent throughout the county are often comprised of coarse-grained sands, gravels, and cobble which provide excellent recharge capacity. Lower Mark West Creek, lower Santa Rosa Creek, the Laguna, and Petaluma River alluvial plains are identified as key recharge streams (Sonoma County 2006), but many additional earthen bed creeks across the alluvial plains and fans in the county provide similar functions. LID features that are designed to reduce site erosion (particularly in areas of fine sediments and clay soils) provide an indirect benefit of maintaining groundwater recharge capacities in downstream creeks by preventing pore reduction (clogging) in the channels. Note that concrete engineered channel beds and banks effectively eliminate groundwater recharge.

(e) Wetlands, Ponds, and Floodplains

Wetlands

Wetlands are valuable aquatic features that provide and support habitat, water quality treatment, groundwater recharge, and flood control benefits. Wetlands typically occur in low lying areas along the margins of creeks and drainages or in depressions away from drainages that are fed by springs, seeps, or other seasonal water sources. In northern California, water levels in typical wetlands gradually rise in the beginning of the wet season and subside slowly as the wet season ends.

Due to presence of abundant vegetation, wetland soils are rich in organic nutrients and provide excellent water quality filtration functions. For these reasons, mimicking wetland functions has become a popular and effective method for stormwater treatment. In the LID stormwater management approach, these features are referred to as biofilters or bioretention areas and are described and illustrated in Section 4.4.

Wetlands are extremely sensitive and highly valuable hydrologic and biological features. The majority of vegetation and wildlife species that inhabit these aquatic features (especially amphibians) are specifically adapted to a seasonally moist environment.

In terms of LID planning, wetlands should be identified and emphasized for protection during site design, as their native vegetation, soils, and hydrologic functioning can provide many stormwater and water quality benefits. During the site assessment wetlands should be mapped, water sources identified, and if possible hydroperiod conditions (including the seasonal range, depth, and duration of inundation) that support the wetland should be measured. Reduced infiltration and shallow subsurface flows associated with post-development conditions can drastically affect wetland functioning (Azous and Horner 2001). Development projects with impacts to wetlands often require a time-consuming permitting and environmental compliance process as well as costly mitigation. The use of LID approaches that protect and maintain wetland features through the site planning process is strongly encouraged.

Hydroperiod is the seasonal occurrence of flooding and/or soil saturation that represents the depth, frequency, duration, and seasonal pattern of innundation.

Ponds

Natural ponds are similar features to wetlands in their functioning, though they are typically larger, deeper, and retain more water. Ponds can be seasonal or perennial, depending upon precipitation, infiltration rates, and underlying soils and geology. Ponds provide breeding and juvenile rearing habitat for amphibian species, such as turtles, frogs, and salamanders, and support wetland plant species, birds, and other wildlife. Ponds function to capture, retain, and cleanse storm runoff as well. Sediment and contaminants transported within storm runoff are allowed to settle out of the water column within a pond. If the bottom of the pond is permeable, infiltration below the pond can recharge groundwater. Because natural ponds provide many hydrologic and biologic benefits, stormwater management approaches often include construction of engineered retention and detention basins that mimic these aspects of natural ponds (see Section 4.5). Similar to wetlands, if ponds are present on a project site, their location should be mapped, their volume and hydroperiod measured, and they should be prioritized for protection and preservation through the LID site design.

Floodplains

Floodplains are low-lying areas adjacent to rivers and creeks that (without constructed flood protection features such as levees) are occasionally inundated by high stream flows that move overbank and spread on the adjacent lands. Floodplains provide natural hydrologic storage during high magnitude flow events. As seasonal or periodic aquatic environments, floodplains support a wide variety of plant and wildlife species and are sensitive to hydrologic changes. Regional planning and project siting steps should avoid locating development in floodplains, even prior to LID considerations for a project. Section 4.5 describes use of floodplains as regional approaches to stormwater management.

A development project located within the natural floodplain or channel migration zone is not considered a low impact development project.

(f) Vegetation, Riparian Resources, and Other Habitats

Site vegetation and hydrology are intrinsically connected through the many components of the hydrologic cycle described above. For stormwater management, site vegetation provides water and nutrient uptake, evapo-transpiration, interception of precipitation (which reduces soil erosion), soil pore spaces, and root tunnels promoting infiltration, shading, as well as other habitat and aesthetic benefits. Common vegetation communities in Sonoma County include Douglas fir and redwood forest, oak and bay woodlands, grassland, and chaparral.

For the LID site assessment, primary vegetation types should be mapped and their condition described. Any special-status vegetation should be identified, as well as the presence of undesirable invasive and/or exotic species. On-site trees should be evaluated for their use into the site plan. Vegetation characteristics to consider include:

Special-status species are defined as plants and animals that are legally protected under the Endangered Species Act (ESA), California Endangered Species Act (CESA), or other regulations, and species that are considered sufficiently rare by the scientific community to qualify for such listing. These species are typically the focus of avoidance, minimization, and mitigation requirements under the California Environmental Quality Act (CEQA).

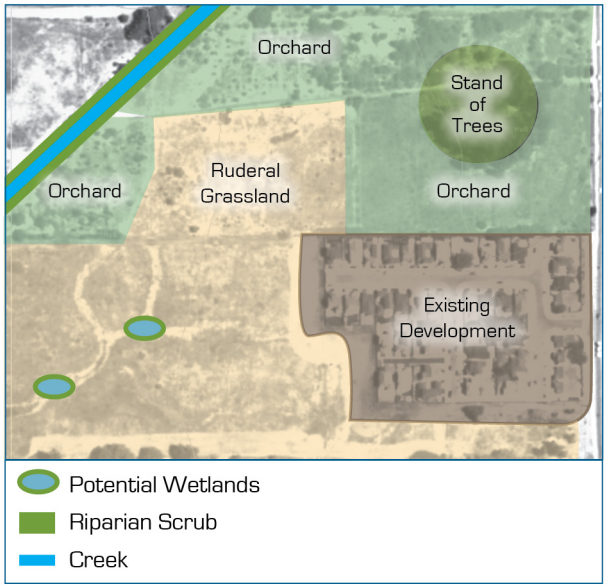
- species;
- plant age/development (seral) stage;
- extent of canopy;
- major pest or pathological problems;
- extensive crown damage;
- weakly attached co-dominant trunks that could cause damage or safety hazards if dislodged;
- stability of the trunk and any extensive decay or damage; and
- ability to withstand influences of post development conditions.

Riparian vegetation is found along stream courses and is dependent upon streamflow hydrology and moisture. In Sonoma County the riparian tree community typically includes willows, alders, box elders, laurel, ash, and oaks, with riparian scrub and understory shrubs beneath. Riparian vegetation provides several important functions including stabilizing streambanks, providing soil structure, filtering sediment and nutrients, shading streams and moderating temperatures, and providing woody debris to adjacent streams. Riparian corridors provide several important migration, breeding, refugia, and foraging habitats for special-status wildlife species including amphibians and birds.

Site assessments of riparian areas should carefully consider the hydrologic connectivity between the site and adjacent streams and how existing riparian plants, particularly mature trees, are dependent upon moisture sources. Post-development changes to surface or ground hydrology could result in decline of riparian trees.

Figure 4-13 illustrates the mapping of vegetation types for the hypothetical development site. In addition to the stand of existing mature trees, potential wetlands and the on-site creek are also mapped in relation to the vegetation cover.

Figure 4-13: Site Vegetation & Habitat



Other Habitats

Protecting and enhancing wildlife habitat contributes to the hydrologic functioning by increasing transpiration, promoting soil infiltration, supporting nutrient cycling, and reducing sediment erosion and transport. Fish and amphibians are highly sensitive to changes in aquatic environments, especially those resulting from stormwater runoff. The presence and quality of the site's aquatic habitats are assessed in the above step for wetlands and riparian areas. In addition to these aquatic habitats, there are many other wildlife species and habitats which can occur on-site that should be evaluated during the site assessment. For example, habitats for burrowing mammals, migrating and nesting birds, roosting areas for bats, and insects, including species listed as threatened or endangered under the state or federal Endangered Species Acts or otherwise protected by law, should be assessed (as reasonable) to understand the diversity and health of the site. In many locations for proposed development, surrounding urban settings may heavily influence the quality and diversity of habitat at a site. Often there is a high potential to improve or restore habitat as part of the project plan.

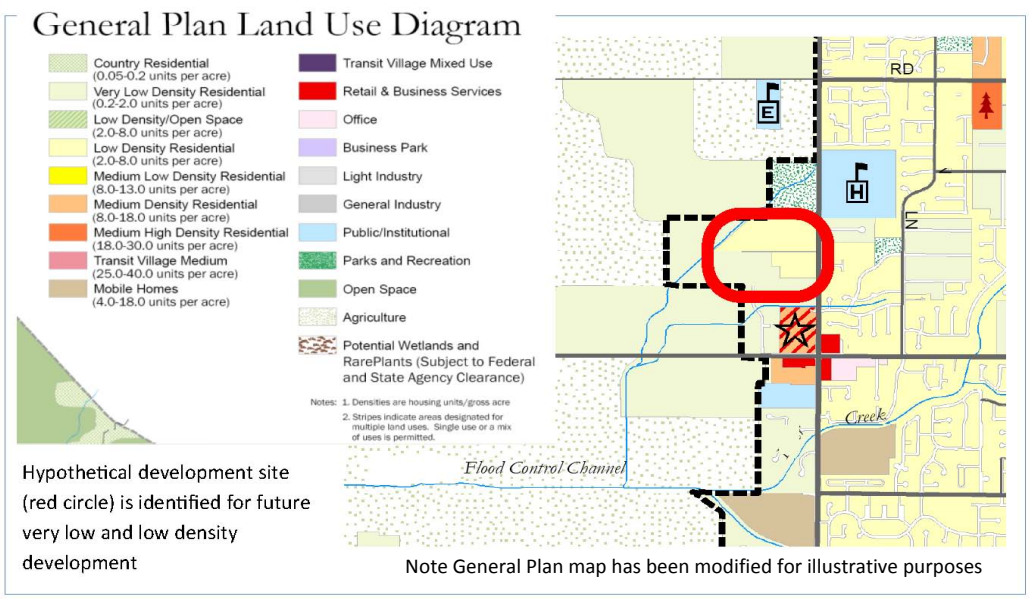
(g) Land Use

The past land use of the site and adjacent sites can strongly influence current site conditions and potential future development in relation to stormwater management. The LID site assessment process considers the current, past, and proposed land uses of the site. Adjacent sites are also considered for how their topography, surface drainage, and subsurface flows may drain onto, or away from, the project development site. The location and characteristics of adjacent structures and buildings are assessed to ensure that proper drainage pathways are designed to prevent conflicts with adjacent land uses and aesthetics. Similarly, adjacent open spaces including federal, state, or local preserves should be identified.

A county's general plan describes land use categories, permitted uses, and allowable densities. New development projects are reviewed and approved for consistency with the terms of the general plan. For example, **Figure 4-14** shows the designated land use for the hypothetical development site according to the applicable General Plan for the area. In this case the site is planned for very low density (0.2-2.0 units/acre) and low density (2.0 – 8.0 units/acre) residential development. Land use designations establish maximum densities and can be

developed for lower densities. If the application of LID features requires a significant portion of the site's developable area, then the buildable portions of the site may require higher density development to achieve the development project objectives.

Figure 4-14: Planned Land Use



The land use assessment also evaluates zoning plans, conservation plans such as Habitat Conservation Plans (HCPs) or Natural Community Conservation Plans (NCCPs), building restrictions, public access requirements, availability of utilities, and setbacks, such as easement, parking lot, and landscaping requirements. In southern Sonoma County, the 2005 Santa Rosa Plain Conservation Strategy (SRPCS) provides conservation and protection strategies for four federally listed wildlife and plant species that may be impacted by development on the Santa Rosa Plain. For sites within the SRPCS boundary, the site assessment should review findings of the SRPCS for the individual project site.

As part of the land use assessment, potential occurrences of legacy contamination both at the site and at all adjacent sites should be investigated. Legacy contamination can result from past land use activities, such as gas stations or dry cleaners, where chemicals may have leached into soil or groundwater. Legacy contamination can also occur from naturally-occurring mineral deposits like arsenic, which are toxic to humans and wildlife. In the case of chemicals, the contaminant plume can migrate to adjacent soils or groundwater aquifers. Disturbance and improper handling of contaminated areas during construction or post-development can increase the potential for harm to the public and wildlife. It is likely that this portion of the site assessment was previously investigated by the developer as part of the purchase of the property. However, this information should be reviewed and considered as part of the overall LID site assessment. Additionally, future planned land uses which could influence the quality of

stormwater runoff should be considered in the site assessment. For example, additional treatment measures may be needed in the LID stormwater management design for future gas stations, commercial parking lots, or industrial operations.

Land use information is available at the city or county office applicable to the project site. Locations of documented sites with contaminated soil or groundwater are available online through the GeoTracker database maintained by the State Water Resources Control Board.

(h) Water Quality

Urban development generates pollution sources through vehicle emissions and maintenance waste, municipal sewage, pesticides, household hazardous waste, pet waste, trash, and other sources. Under conventional stormwater management systems, these pollutants are either washed (or directly deposited) into storm drains and transported to local streams, rivers, lakes, estuaries like the San Francisco Bay, and eventually to the ocean.

The effect of pollutant contributions from a single residential home or small business may be small, but, when considered collectively at the watershed scale, significant environmental impacts to local water resources can be observed (USEPA 2005). LID site planning and implementation of LID features can provide water quality treatment control for both small and large storm events and reduce pollutant loading and transport. As described above, LID achieves water quality protection by using native soils and vegetation, or bioengineered solutions, to naturally filter stormwater. The LID approach also reduces the introduction of urban pollutants, such as trash and gasoline byproducts, into the environment by encouraging pollution prevention practices by residents and business owners (Prince George's County 1999).

Existing conditions at the proposed development site may be particularly influential to the quality of surface or ground waters at or surrounding the site, especially if a watercourse is located within the property. For instance, stormwater infiltration areas can convey contaminants to underlying groundwater, and improperly installed drainage outlets can encourage erosion and sedimentation. To better understand potential post-development impacts, the site assessment evaluates on-site conditions that influence surface water and groundwater quality.

Water quality data gathered from the site or from locations upstream or downstream to the site can inform the site plan and design. Water quality data may be available from federal, state, or local monitoring efforts, including the U.S. Geological Survey, Regional Water Quality Control Boards, Sonoma County Water Agency, and local residents and volunteer creek monitors. Combined with information about the soil and vegetation characteristics of the site, water quality characteristics can be used to adjust the effectiveness of on-site LID features.

Water quality is protected and managed by the State Water Resources Control Board and its Regional Water Quality Control Boards (North Coast and San Francisco Bay Regions for Sonoma County), as described in Section 4.1. The Regional Water Quality Control Boards establish "beneficial uses" of water bodies within their region. If any beneficial uses become impaired,

the water body can be added to the Clean Water Act Section 303(d) list of Impaired Water Bodies. The pollutant responsible for the impairment is listed, and all additional contributions of that pollutant to the listed water body are subject to restriction. For example, if the proposed development would potentially contribute additional sediment to a water body whose quality is already impaired by sediment, the development must be designed to ensure that no additional sediment is discharged to that water body. Therefore, the site assessment should include review of the current 303(d) List and any water quality restrictions, such as Total Maximum Daily Load (TMDL) conditions, applicable to the property. This information may influence the site plan and selection of LID features.

Beneficial Uses define the resources, services, and qualities of aquatic ecosystems and underground aquifers for which the RWQCBs are responsible to protect with the goal of achieving the highest water quality consistent with maximum benefit to the people of the state.

(i) Other Site Specific Considerations

The following site consideration topics are briefly discussed as they are important within the overall LID planning process. Though these topics may only be indirectly related to stormwater issues, they are important in assessing the suitability for LID use on-site.

Easements

The site assessment includes mapping of existing or potentially required easements on or adjacent to the project site. Easements are unbuildable areas set by local utility or city agencies to provide access to underground utility lines, such as sewer pipelines and communication lines, or to overhead power lines. Easements can also consist of natural areas that are prohibited from development (e.g., conservation easements), subject to the conditions in the easement. Easement information is available at the city or county planning department or at local municipal authorities. The presence of easements on-site may influence the selecting and locating of LID treatments.

Stream Setbacks

As part of the project approval process, developments must also comply with city and county stream setback ordinances. The following communities currently have ordinances for stream or creek setbacks: Cotati, Cloverdale, Healdsburg, Rohnert Park, Santa Rosa, Sebastopol, and Windsor, and the County of Sonoma. Stream setback restrictions are contained in city or county development codes. The specific restrictions on development adjacent to streams are defined differently in each ordinance. In general, the ordinances direct that no structure, road, parking access, parking spaces, paved areas, or swimming pools be constructed within a creek or creekside setback area. Setback distances vary from 30 to 50 feet from the top of a stream bank throughout Sonoma County. Some setback ordinances also restrict vegetation removal or planting and development adjacent to a wetland.

Existing utilities, streets, fire safety requirements

The locations of existing municipal structures such as utilities and streets may constrain the project plan and opportunities for LID use. Streets or underground utility lines may be located closest to one side of the parcel; thus layout designs may be restricted by existing structures or

standards. Existing or proposed on-site septic systems could require additional planning to ensure proper functioning and coordinated use with LID features, especially for septic leach fields. Additionally, city or county standards may require setbacks from fire fighting facilities or for public safety. For example, city standards may require setbacks around fire hydrants and tree clearance under overhead lines. This information is available from the city or county planning department or from local municipal authorities.

Aesthetics

Aesthetic values of the current site and its relationship with the surrounding landscape are evaluated in the site assessment. The county, city, or neighborhood may have specific requirements for the visual character of the area, such as placement of trees or other landscaping features, restricted use of certain materials or paint colors, or road and sidewalk designs. Aesthetic resources are commonly documented by photos and observational accounts recorded during site surveys.

Step 2: Site Planning

The LID Planning Process:
Step 1 - Site Assessment
Step 2 - Site Planning Process
Step 3 - LID Design Objectives and Feature Selection
Step 4 - LID During Construction Phase
Step 5 - LID Operation and Maintenance

This section describes the process of integrating the baseline resource information from the Site Assessment of Step 1 into the development's site plan. The Site Planning processes is essentially an iterative mapping exercise conducted by stakeholders and the designer team to achieve development objectives while avoiding and minimizing stormwater and other impacts. Stakeholders include the land developer, local planning agencies, stormwater managers, water quality regulators, and the local residential and business community. The design team may include agency or consultant urban planners, landscape architects, hydrologists, geologists, and biologists. In Step 2, the Site Planning process proceeds according to the 4 sub-steps, labeled (a) through (d) as shown in the highlight box. Each of these stages builds on the previous tasks while incorporating LID principles.

Step 2 – The Site Planning Process:
- *a) Identify Development Objectives*
- *b) Opportunities and Constraints*
  - *Conservation Areas*
  - *Buildable Areas*
- *c) Conceptual Site Design*
- *d) Preliminary Drainage Design*

(a) Identification of Development Objectives

It is important to establish the specific objectives of the development project to guide the rest of the planning process. The development objectives should include a broad and flexible planning approach on which the LID principles can apply. The development objectives can include a general description of the targeted on-site land uses, such as residential housing or parking for an adjacent office building, etc. Yet the development objectives should also frame more specific goals for on-site land use, such as residential housing for 20 families or parking for a minimum of 50 cars. These framing objectives should include the minimum utility or density requirements for the building footprint for which the developer can feasibly pursue the project. Other thematic objectives such as aesthetic or recreational aspects can be incorporated into the development objective as well: "residential housing for 20 families that includes an open space

recreational area" or "parking for a minimum of 50 cars that blends into the surrounding vegetated landscape."

(b) Opportunities and Constraints Based on Site Assessment

Building on the resource information gathered during the site assessment, and following the LID principles described above, an opportunities and constraints analysis carefully reviews the site's existing resources, assets, and limiting factors or constraints, and attempts to balance these pros and cons in light of the development objectives.

In terms of stormwater management, the opportunities analysis seeks to preserve existing natural resources and minimize impacts from potential development runoff. The following opportunities (framed as questions) can potentially be integrated into the site plan:

- How does site topography influence drainage and where does water naturally flow to or collect?
- Where are the site's higher infiltrating areas and how well do they drain?
- How do the site's poorer draining areas relate to site topography and a potential building area?
- How do existing vegetation and soil resources support any existing hydrologic features?
- Are there site drainage opportunities or unique site features?

The question relating to the site's poorer infiltrating soils is framed as an "opportunity" because areas of poorer infiltration may provide suitable building areas, whereby the relative impact (in terms of stormwater generation) of developing impervious surfaces above the poorer infiltrating soils will be less than developing impervious soils above well draining soils.

In terms of the constraints analysis, each specific development site will have its own particular constraints, but the following questions help identify initial limiting factors to incorporating LID principles into the site plan:

- Does the site's physical location and setting in the watershed present constraints due to being on an active floodplain, in an area of slope instability, or in a seismic or liquefaction hazard zone?
- Does the site's topography contain steep or excessive slopes (>25%) that may challenge or prevent certain LID treatment approaches?
- Is the site dominated by, or have significant portions underlain by bedrock or a very thin soil mantle that prevents infiltration?
- If the site has a soil cover, what are the infiltration properties? Is the site dominated by poorly infiltrating soils?
- Is depth to groundwater very shallow such that ponding and poor percolation characterize the site?

- In terms of land use planning – is the site constrained by particular zoning uses or required set-backs that would limit how an LID site plan could be developed?
- Do existing or planned utilities, easements, or roadways constrain how stormwater could be routed, infiltrated, or managed through LID approaches on-site?
- Do existing or planned utilities, roadways, or other infrastructure interfere with shallow subsurface flows (interflow) that help drain the site laterally off-site?
- Are there known or potential soil contamination or water quality conditions on-site or adjacent the site that would prevent the use of infiltration as a stormwater strategy?
- Are there local aesthetic or community requirements which constrain the site plan and possible stormwater solutions?

Figure 4-15: Site Planning

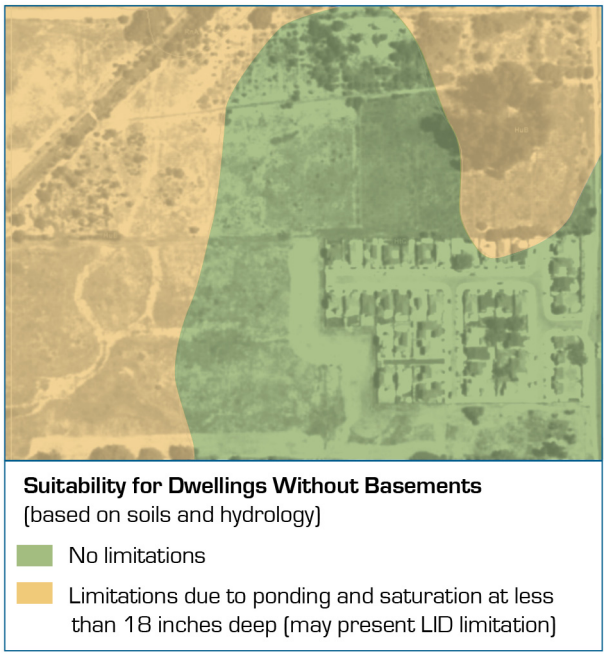


Figure 4-15 illustrates the constraints analysis approach for one parameter of infiltration and shows soil ponding and saturation properties at the hypothetical development site. The western and northeastern portions of the site are constrained by ponding and potential soil saturation at depths less than 18 inches from the surface. The central portion of the site is not constrained by ponding and saturation.

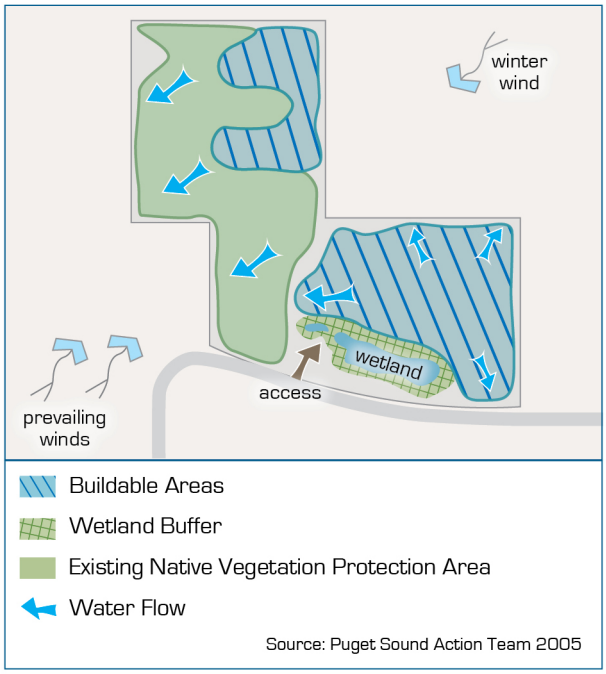
(c) Conceptual Site Design

With information from the Site Assessment, Development Objectives, and Opportunities and Constraints planning steps in hand, the site design process moves ahead. The first step to develop the site plan is to generally delineate conservation areas to be preserved and/or enhanced, and buildable areas to be developed. **Figure 4-16** demonstrates this delineation of conservation versus buildable areas for a site. Figure 4-16 also illustrates several other elements that can be included in the initial concept site plan, including references to flow directions, the presence of wetlands, buffers, and even prevailing wind directions.

Conservation Areas

Reducing the development footprint and increasing vegetation and soil conservation areas can provide the single largest reduction of storm flows (AHBL 2002). In addition to reducing potential runoff, conservation areas can provide erosion and sediment control, water quality treatment, and other stormwater functions. Beyond stormwater, conservation areas provide habitat protection, open space corridors, visual buffers, and other benefits.

Figure 4-16: Site Opportunities and Constraints



According to the Puget Sound Action Plan (2005), a LID guidance manual for the Puget Sound region of the Pacific Northwest, conservation areas supporting native vegetation and soil should be prioritized as follows:

1. Riparian areas that connect and create contiguous riparian conservation areas.
2. Critical and wildlife habitat areas that connect and create contiguous conservation areas.
3. Areas that create common open space among and/or within developed sites.
4. Conservation areas on individual lots that connect to areas on adjacent lots or common conservation areas.
5. Conservation areas on individual lots.

Buildable Areas

Buildable areas are identified as the locations within the site plan that would have the least effect on existing hydrology or habitat while taking advantage of a site's natural stormwater processing capabilities. Construction of structures, roads, and stormwater infrastructure should be configured within the buildable areas. Keeping consistent with the LID principles, the area of disturbance is limited to the minimum area required for roads, utilities, building pads, landscape areas, and other developed areas.

Figure 4-17: Site Planning – Conservation and Buildable Areas

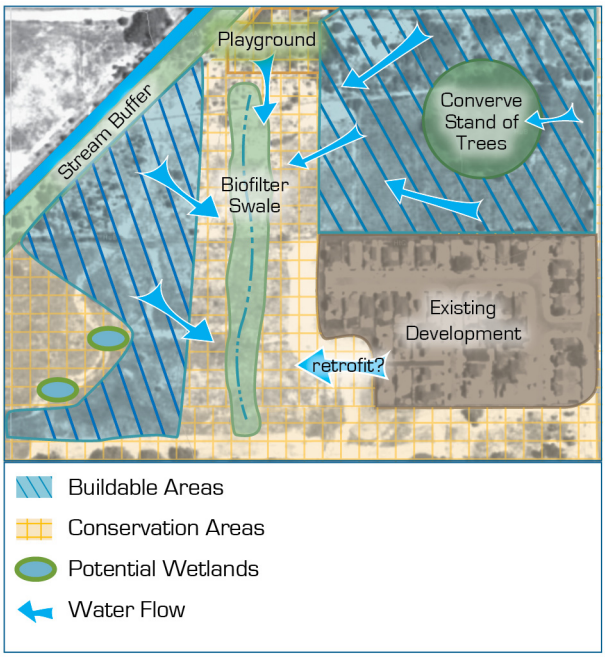


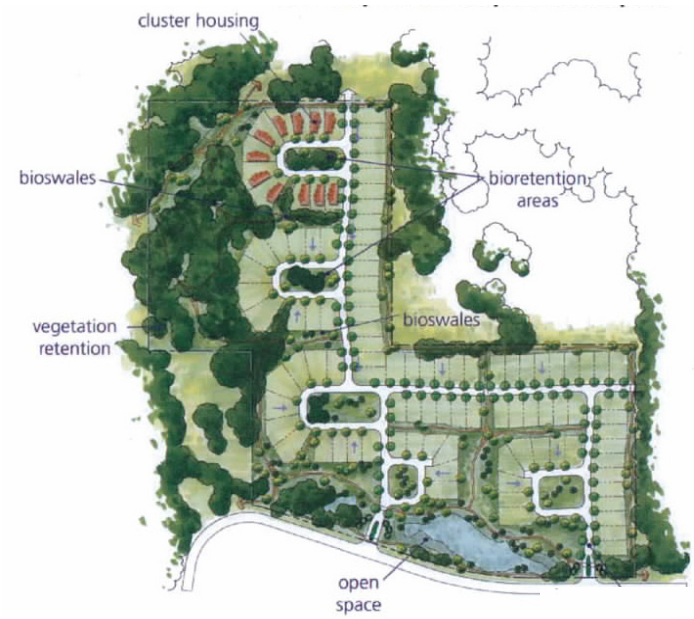
Figure 4-17 illustrates the delineation of conservation and buildable areas for the hypothetical development site. The hypothetical LID site plan includes two primary buildable areas based on understanding of the site's existing topography, soils, flow paths, wetlands, creeks, vegetation, as well as practical considerations of existing development and roadway access. The buildable areas are located on the poorer infiltrating soils, making use of the central portion of the site as a conservation area with a biofilter swale that will collect and infiltrate runoff from the adjacent development. There may be an opportunity to "retrofit" the existing development in the southeast quadrant of the site by routing its runoff to the central biofilter swale. Retrofitting existing sites with LID measures is further described in Section 4.5 below. Areas around the existing stream course in the northwest site and the wetlands of the southwest site are protected in conservation areas and have buffers. The open space around the biofilter provides a good communal area for a recreational path with a tot play yard at its north end.

LID methods to reduce total impervious areas, concentrate surface flows, and increase infiltration include increasing residential density by clustering houses together, minimizing road widths, and maximizing open space throughout the parcels. The following bullets include design guidance for the site planning and layout of building lots, roads, parking lots, subdivision lots, building drainage design, stream crossings, and planted trees. These LID design approaches are illustrated in the 3 concept site plans in **Figure 4-18** taken from the Low Impact Development Technical Guidance Manual for Puget Sound (Puget Sound Action Team 2005) and other stormwater management publications (Center for Watershed Protection 2008).

Roads, Driveways, and Parking Areas

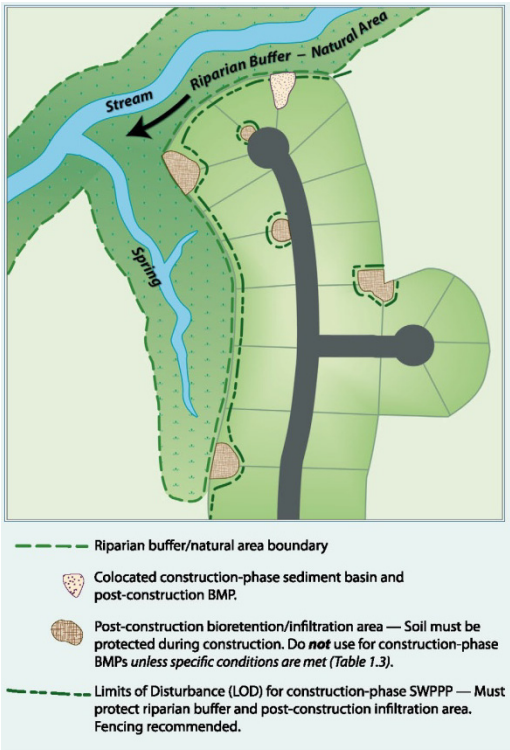
- Design the road network to minimize site disturbance, avoid sensitive areas, and reduce fragmentation of landscape.
- Reduce total impervious area by reducing the overall road network coverage, road widths, driveway lengths, and sidewalk widths.
- Minimize or eliminate impervious area and concentrated surface flows on impervious surfaces by reducing or eliminating hardened conveyance structures, such as pipes or curbs and gutters.

Figure 4-18: Conceptual Site Designs



Source: Puget Sound Action Team 2005

Source: Puget Sound Action Team 2005



Source: Hirschman, D. and Kosco, J. 2008

- Infiltrate and slowly convey storm flows in roadside bioretention cells and swales, and through permeable paving and aggregate storage systems under the pavement.
- Create connected street patterns and utilize open space areas to promote walking, biking, and access to public transit and services.
- Provide efficient fire and safety vehicle access.

Subdivision and Lot Layout

This primarily applies to lots for residential housing, but the concepts are similar for other land uses where impervious structures would be constructed.

- Minimize site disturbance.
- Strategically locate lots to disperse stormwater to open space areas.
- Orient lots and buildings to maximize opportunities for on-lot infiltration or open conveyance through bioretention swales to downstream LID features.
- Cluster homes to reduce development area and road lengths
- Design subdivision with shared driveways
- Lengthen street blocks to reduce the number of cross streets and overall road network per home
- Provide mid-block pedestrian and bike paths to reduce distances to transit, and open space pathways or common areas between homes

Building Drainage Design

The objective for building design is to disconnect roof stormwater from stormwater conveyance and pond systems, and reduce site disturbance from the building footprint. Strategies to achieve this objective include:

- Reduce the building footprint. Designing multiple-story structures is one method to reduce the building footprint.
- Orient the long axis of the building along topographic contours to reduce the need to level the land.
- Control roof runoff water on-site.
- Use low impact foundations (with reduced footprint and reduced excavation needs) to minimize soil compaction.
- Limit clearing and grading activities to the minimum amount necessary to maneuver machinery.

Stream Crossings

- Eliminate, or reduce to an absolute minimum, all stream crossings.

- Where stream crossings are unavoidable, bridges are preferable to culverts.
- Locate bridge piers or abutments outside of the active channel or channel migration zone.
- If culverts are utilized, install slab, arch, or box type culverts, preferably using bottomless designs that more closely mimic stream bottom habitat.
- Utilize the widest possible culvert design to reduce channel confinement.
- Minimize stream bank armoring and establish native riparian vegetation and large woody debris to enhance bank stability and diffuse increased forces created by road crossings structures.
- Do not discharge storm flows directly from impervious surfaces associated with roads directly to the stream—disperse and infiltrate stormwater or detain and treat flows.

Tree Planting

Appropriate selection and placement of tree species will increase energy conservation, air quality improvement, and aesthetic enhancement for the site, as well as reduce potential problems with pavement damage from roots and poor growth performance. When selecting trees for the site design, consider:

- The available growing space.
- Type of soil and availability of water.
- Longevity or life-span (a 100 year life span is ideal).
- Evapotranspiration productivity
- Tolerance for urban pollutants.
- Growth rate.
- Tolerance to drought, seasonally saturated soils, and poor soils.
- Canopy spread and density.
- Foliage texture and persistence.
- Overhead wires.
- Vehicle and pedestrian lines of sight.
- Proximity to paved areas and underground structures.
- Proximity to neighbors, buildings, and other vegetation.
- Prevailing wind direction and sun exposure.

Additional desired functions, such as shade, aesthetics, windbreak, privacy screening, etc.

(d) Preliminary Drainage Design

Following the development of the conceptual site plan, a preliminary drainage design is prepared to generally identify runoff source areas and routing directions. This step is preliminary because the final drainage design will be developed iteratively with the design of specific LID treatments (Section 4.4) selected for the site.

One example of a preliminary drainage design process is presented in the Contra Costa Clean Water Program (CCCWP) Stormwater C.3 Guidebook (*Stormwater Quality Requirements for Development Application*) from 2008 (4th Edition) which includes a nine-step drainage design, as shown in the highlight box.

The Drainage Design Process

- *Step 1 - Delineate drainage management areas (DMAs)*
- *Step 2 – Classify DMAs and determine runoff factors*
- *Step 3 – Tabulate DMAs*
- *Step 4 – Select and lay out Integrated Management Practices (IMPs)*
- *Step 5 – Make size and rain adjustment factors for IMPs*
- *Step 6 – Calculate areas and volumes for IMPs*
- *Step 7 – Determine if IMP areas and volumes are adequate*
- *Step 8 – Compute maximum orifice flow rates*
- *Step 9 – Write summary report*

From the Contra Costa Clean Water Program Stormwater Guidebook 2008

The drainage design process begins with delineating drainage management areas (DMAs). DMAs are essentially subwatersheds of the project site. DMAs follow grade breaks and roof ridge lines as well as boundaries between pervious and impervious surfaces. In Step 2, DMAs are categorized in terms of how their runoff is handled or routed, and in Step 3 runoff conditions are tabulated for the individual DMAs. Since specific LID features and treatments are not yet determined in the process, Steps 1-3 involving calculating runoff from the DMAs will need to occur iteratively following the selection and design of specific LID treatments.

In terms of runoff generation and routing, there are four general types of DMAs:

1. Self-treating areas: non-developed areas that do not route runoff to LID treatments.
2. Self-retaining areas: designed to retain the first one inch[2] of rainfall without generating runoff.
3. Areas draining to self-retaining areas: drain impervious areas (or partially impervious areas) to more permeable areas.
4. Areas that drain to LID treatments.

[2] Note that the revised Phase 1 2009 MS4 NPDES Order for Sonoma County requires that volume based BMPs shall infiltrate or treat runoff from the 85th percentile 24-hour storm, which in the Santa Rosa area is 0.92 inches.

Experience in Contra Costa County suggests that, in general, two-parts impervious area can be routed to one-part of pervious area (by square footage) when only water quality treatment (and not flow-control) requirements apply. If flow-control requirements apply then the maximum ratio is more likely one-part impervious area for every one-part of pervious area. Sizing factors have been developed to relate how much treatment area is needed for impervious DMA areas. Water quality treatment and flow-control treatment approaches are discussed more in Step 3 below.

Figure 4-19: Site Planning – Drainage Management Areas

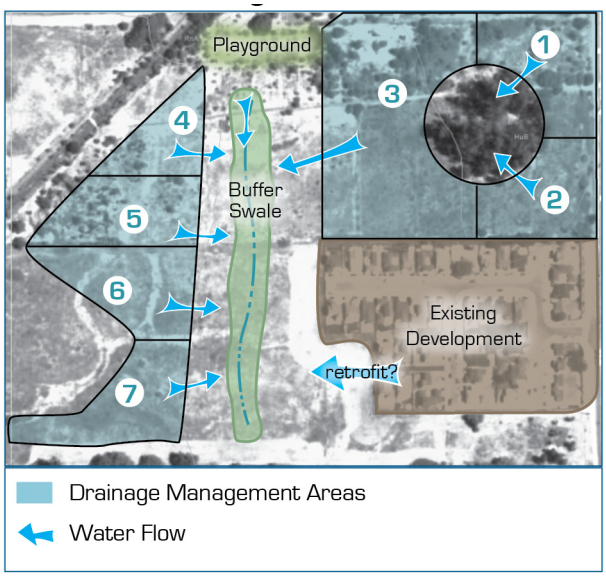


Figure 4-19 illustrates a preliminary drainage design for the hypothetical development site. Drainage management areas (DMAs) are delineated according to their topography and flow routing. In Figure 4-19, runoff from the DMAs in the buildable areas is routed to pervious areas. This is the case of *areas draining to self-retaining areas*, as described above. Additionally, the central portion of the hypothetical site plan in Figure 4-19 involves a biofilter swale that receives runoff. This is the case of *areas draining to LID treatments.* Figure 4-19 is general in nature and is used to illustrate the concepts introduced in this section while showing the site at a similar scale to the previous site development figures in this guidebook. Also to consider, the routing of stormwater to riparian areas should consider inclusion of a buffer area surrounding the riparian area to dissipate, infiltrate, and remove pollutants from overland flow. In this way, such a riparian area can provide a self-treating approach for the parcel.

Step 3: LID Design Objectives and Feature Selection

The LID Planning Process:
- *Step 1 - Site Assessment*
- *Step 2 - Site Planning Process*
- ***Step 3 - LID Design Objectives and Feature Selection***
- *Step 4 - LID During Construction Phase*
- *Step 5 - LID Operation and Maintenance*

After the site planning process has been initiated and a conceptual site design and preliminary drainage design is developed (with general drainage management areas delineated), specific LID features can be selected and designed so as to effectively manage stormwater on-site. In most cases, LID features are combined with pollution source controls and conventional stormwater controls to form an overall site stormwater management strategy.

LID Design Objectives

In addition to protecting on-site amenities from damage from ponded and flowing water, the overall site stormwater management strategy should provide protection to the off-site environment by:

1. Minimizing the volume and rate of stormwater leaving the site (hydromodification control), and
2. Minimizing the concentrations of pollutants in stormwater leaving the site (water quality treatment objectives).

In general, the site stormwater strategy should aim to fulfill these two objectives to the greatest degree practical. Further discussion of these two design objectives and how LID techniques can help achieve them is provided below.

Hydromodification Control Objectives

As discussed earlier in this document, high volumes and high velocities of storm water discharged from developed areas into natural watercourses can adversely impact aquatic ecosystems and stream habitat and cause stream bank erosion and physical modifications. These changes, collectively termed hydromodification, can also result in increased flooding to downstream areas.

As described above, and shown in Figure 4-1, a regional hydromodification control plan (HCP) will be developed as part of the Integrated Water Quality and Water Resource Plan. Following the regional HCP, it is expected that HCPs for individual watersheds will be developed with input from local stakeholders. The regional and watershed HCPs will provide guidance for post-project runoff requirements. Typically, hydromodification control plans will specify post-project criteria, such that runoff conditions following the project are similar to pre-project conditions.

Figure 4-20: Hydrograph Comparisons: Pre- and Post-Development

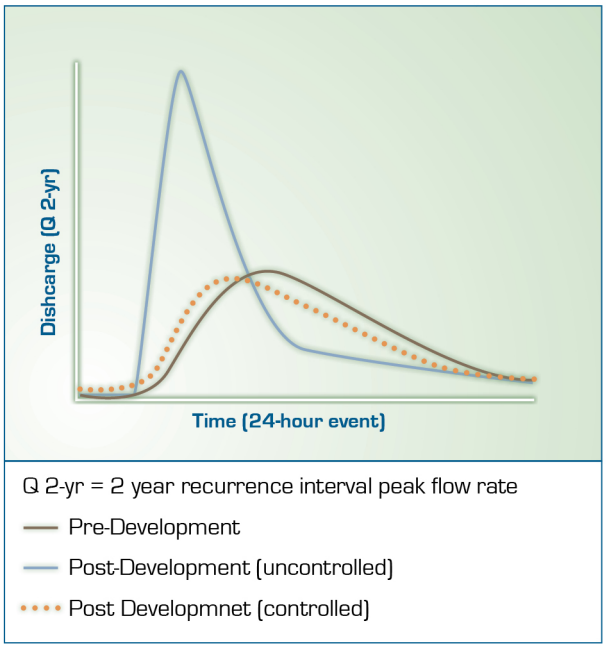


Figure 4-20 compares hydrograph results for a 2-yr recurrence 24-hr discharge event under pre-development, post-development (without hydromodification controls), and post-development (with hydromodification controls) scenarios.

In attempting to maintain a site's general pre-development runoff conditions, there are four aspects to the hydrograph that

should be considered:

1. **Time of concentration:** what is the time needed for rainfall runoff to flow from the drainage area's most distant location to be discharged off-site, and how is this time affected by the development?
2. **Peak flow rate**: can the maximum rate at which runoff leaves the site during a storm be kept similar to the pre-developed condition?
3. **Duration:** how does the total time (when runoff is leaving the site during and after a storm event) change following development?
4. **Volume:** can the total amount of runoff that leaves the site be kept similar to the pre-developed condition?

At most sites, the hydromodification control requirements can be achieved by taking a LID approach to site planning and by using LID features to control runoff. Similar to designing conventional stormwater management systems, designing LID features begins with understanding the size of inflows to the feature during the design storm (i.e. the 2-year 24-hour storm or larger). Knowing the rate and volume of inflows, the feature can then be sized appropriately to manage stormwater via detention, retention, and/or infiltration.

Demonstrating that a site's planned stormwater management strategy (including LID features) will effectively mimic pre-development runoff conditions is best accomplished using computerized numerical models. Some communities have developed a set of standardized LID features and corresponding sizing criteria that have been designed so as to provide hydromodification control appropriate to that region. If the standardized LID features are employed in the designated manner, modeling is then not required. At present, Sonoma County has not developed a specific list of approved LID features with corresponding design/sizing criteria. Such a strategy may be adopted in the future as part of the regional hydromodification control plan (HCP).

Water Quality Treatment Objectives

Land development often increases concentrations of pollutants in stormwater runoff. Types and sources of pollutants vary but can include heavy metals (such as copper from vehicle brake pads or mercury from atmospheric deposition), petroleum hydrocarbons (such as gasoline and motor oil), trash (from on-site users or blowing debris), nutrients and pesticides (from landscaping features), or increased sediment (from disturbed areas). Concentration of pollutants can be reduced by implementing both pollution source controls and stormwater treatment measures.

Existing stormwater regulations require that pollution source controls and stormwater treatment be implemented to the "Maximum Extent Practicable" (MEP). MEP refers to the technology-based performance standard established by Congress in the Clean Water Act. To achieve the MEP standard, all practices that prevent stormwater pollution must be employed to the extent that these practices are technically feasible and are not cost prohibitive.

MEP generally emphasizes pollution prevention and source control best management practices (BMPs) as the first line of defense to be used in combination with treatment methods as a backup (or additional line of defense). The MEP is a moving target and will continue to evolve based on national, statewide and local experience. The NPDES Permit requires a "*New and Redevelopment Integrated Water Quality/Water Resource Plan*" where volumetric and/or flow-based criteria for water quality protection be established. Numerical limits for specific storm water pollutants are not currently prescribed or implemented in Sonoma County.

Source controls can include site operational procedures (such as restricting the use of herbicides, pesticides and fertilizers) and infrastructure controls (such as storing dumpsters under rain awnings). This document does not provide detailed discussions of source control measures. The Sonoma County and City of Santa Rosa SUSMP (2005) outlines what source controls are appropriate to specific types of projects.

> *"Source Control BMPs are relatively low-technology and in many cases low-cost practices that help keep pollutants out of storm water. Source controls are not intended to remove pollutants after they have entered storm water. Source control BMPs must be selected to address specific activities or features that will be included in the project." (EOA 2005, page 2-5)*

Treatment methods are employed to address pollutants that cannot be avoided via source controls. A variety of treatment methods exist, including conventional stormwater treatment devices (such as oil/water separators, vortex separators, or filtration units) and LID features (such as biofiltration areas). LID features are generally preferred over conventional stormwater treatment devices because of the additional benefits afforded by LID (such as groundwater recharge and site greening). Conventional stormwater treatment devices may sometimes be an effective supplement to LID features, especially when a site is likely to generate particular pollutants of concern that can effectively be targeted by particular conventional stormwater treatment devices.

The same LID site planning techniques and LID features that are implemented to achieve a hydromodification control objective are also generally useful in achieving the MEP water quality protection. LID site planning techniques, such as minimizing impervious area, act as source controls and many LID features provide water quality treatment via various mechanisms such as filtration, settling, and phytoremediation.

LID Feature Selection

As described throughout this document, the general LID approach is to reduce hydromodification and water quality impacts from development through site design and source control measures that avoid and minimize runoff. While these LID site planning techniques may reduce the amount of runoff requiring treatment, it is generally also necessary to retain, manage, or treat stormwater runoff actively through LID design features in order to ensure that post-development hydrograph matches the pre-development hydrograph, and that stormwater pollution is controlled to the MEP.

General LID Feature Types:
- Biofilters
- Permeable Surfaces
- Green Roofs
- Rainwater Harvesting Systems
- Subsurface Detention/Infiltration

The actual selection of specific LID features will depend upon site specific conditions, including the site concept plan, the general development objectives, as well as the anticipated runoff conditions associated with the post-project scenario.

In Section 4.2 above, in the sub-section *Overview of LID Features*, general families of LID treatment features were introduced, as shown in the highlight box (left). Once the conceptual site design and preliminary drainage design are developed and provide an estimate of on-site runoff quantities, the most appropriate LID feature types can be considered for selection.

The information described above relating to design objectives for hydromodification and water quality effects will also be considered in evaluating LID feature types. In addition to hydrologic requirements, additional factors to be considered in the selection of the most suitable LID features include surrounding land use activity, potential pollutants of concern, LID feature effectiveness, site constraints (area, slope, soils, topography, etc.), cost, and maintenance requirements (Santa Clara Valley Urban Runoff Pollution Prevention Program 2004).

Section 4.4 of this guidebook provides more detailed snapshots of various LID treatments and features through a series of fact sheets. In the fact sheets the following topics are addressed:

- LID feature description
- Function and benefits
- Selection criteria and limitations/site constraints
- Applications
- Example schematics and photographs
- Key design and installation considerations
- Estimated costs
- Maintenance information
- References and additional resources

Step 4: Construction Phase

The LID Planning Process:
- *Step 1 - Site Assessment*
- *Step 2 - Site Planning Process*
- *Step 3 - LID Design Objectives and Feature Selection*
- ***Step 4 - LID During Construction Phase***
- *Step 5 - LID Operation and Maintenance*

For LID features to operate effectively post-development they must be properly constructed and installed. Because so many LID features rely on gravity fed drainage, the grades and elevations of soil and hardscape elements (i.e., curb cuts, trench drains, curb heights, etc.) are critical and must be carefully constructed and checked throughout the installation process. Even minor discrepancies in elevation can prevent an LID treatment, such as a curb cut, from functioning as designed.

Construction Management for LID:
- *a) Pre-construction Planning*
- *b) Demolition Phase*
- *c) Hardscape Construction Phase*
- *d) Soil Preparation and Grading Phase*
- *e) Plant Installation Phase*
- *f) Post-construction Observation*

The San Mateo Countywide Water Pollution Prevention Program (SMCWPPP) developed a *Sustainable Green Streets and Parking Lots Design Guidebook* (2009) to provide designers, builders, and municipal staff a state-of-the-art reference manual for LID street and parking lot design. The following measures were identified to protect conservation areas and ensure proper installation of LID features during construction (SMCWPPP 2009).

(a) Pre-Construction Planning

- In the construction bid, separate the work to be conducted by the general contractors and landscape contractors.
- Establish specific qualifications for each discipline's tasks, to ensure quality assurance in the contractor selection process.
- Add sufficient time and funding for the design team to regularly inspect the site to ensure accuracy of installation of LID features during construction.
- Phase the project to complete operations in one section of the site before clearing and grading the next. This will reduce equipment activity and potential damage to conservation areas.
- Begin clearing, grading, and heavy construction activity during the driest months and conclude by late fall.
- Establish and maintain erosion and sediment controls before or immediately after clearing and grading activity begins.
- Map native soil and vegetation protection areas on all plans and delineate these areas on-site with appropriate fencing from clearing, grading, and construction damage.

(b) Demolition Phase

- For retrofit projects, inspect native soil conditions under existing concrete or asphalt areas to determine if soil mix adjustments are necessary.
- Check for undetected utility lines or vaults.

(c) Hardscape Construction Phase

- Inspect forms prior to pouring concrete or asphalt elements to ensure accurate grades and elevations for conveying runoff into stormwater facilities.

(d) Soil Preparation and Grading Phase

- Soil preparation and grading activities should be conducted in dry conditions without standing water on the soil surface.
- Excavate native soil to design depth, rototill any compacted soil surrounding the excavated area.
- Till in imported topsoil mix with native soil conditions in 6-inch lifts. Finish topsoil grade below the final grade of the stormwater facility to account for a mulch layer.
- Check final grades to assure that elevations and side slopes are built accurately. Make adjustments in the field as necessary.
- Within the Conservation Areas and where LID features are being installed, do not compact soil with heavy equipment during construction. Use only foot-compaction or a landscape-roller to finish the grade of the LID feature.
- Temporarily block off stormwater entrances, if possible, to protect the newly graded soil conditions from receiving stormwater flow.

(e) Planting Phase

- Make sure that plant installation activities are done in dry conditions without standing water on the soil surface.
- If plants are installed in dry summer months, provide irrigation during the predetermined establishment period for the plants.
- Prior to the plants being delivered to the project site, verify with the contractor that the correct plant species and quantities were ordered.
- Apply specified mulch material to establish final grade of the stormwater facility.

(f) Post-Construction Observation Phase

- Visit the project site often (particularly during or soon after rainfall events) to determine if it is performing successfully. Look for any signs of erosion, poor plant health, lack of maintenance, prolonged periods of ponding of water, and inlet, overflow, checkdam or other stormwater facility malfunctions.
- Survey the general public to determine if the project is successful from a community perspective.

Step 5: Operations and Maintenance

The LID Planning Process:
Step 1 - Site Assessment
Step 2 - Site Planning Process
Step 3 - LID Design Objectives and Feature Selection
Step 4 - LID During Construction Phase
Step 5 - LID Operations and Maintenance

This section describes the responsibilities for long-term care of LID features, the contents of an Operations and Maintenance (O&M) Plan, and long-term guidance on what items to address in order to prevent deterioration and failure of LID features.

(a) Identifying Maintenance Responsibilities

During the project development process, the party responsible for maintenance of the LID features will be identified and designated. Maintenance responsibilities may belong to a city, the County, a homeowners' association (HOA), or the site owner/developer, depending on the project site, its location, its scale, adjacent land ownership, and existing maintenance responsibilities. For example, most LID features installed within a single parcel residence (see Figure 4-18b) or a small group of homes (Figure 4-18c) can be maintained by the landowners through educational training and a modest commitment to maintenance activities. In this way, most single family residence and small scale LID treatments are maintained similar to landscaping or other home-ownership commitments. Landowners are more likely to value the benefits of LID features and thus maintain them properly. LID features installed for a larger grouping of homes (as shown in Figure 4-18a) or a complex of townhomes or apartments is best maintained by the developer, the city, or a homeowners' association to ensure effective upkeep of the LID features. This is especially important for rental properties, as residential turnover is high. For LID treatments to consistently perform according to design, it is important that O&M responsibilities at all scales are supported in perpetuity.

(b) Operations & Maintenance Plan

The parties responsible for maintaining a site's LID treatments should prepare an operations and maintenance (O&M) plan for the site that will identify the procedures, schedule, and persons responsible for implementing and documenting O&M activities. Additionally, to minimize mosquito habitat and allow access for mosquito surveillance and control, vegetation maintenance, such as cattail removal, should be included in the O&M plan. As part of the NPDES Permit, Part 9, Section 9 *Storm Drain Operation and Management and Trash Management*, permittees are required to develop an Operations and Management plan that addresses:

- Catch basin cleaning
- Trash management at public events
- Trash receptacles
- Catch basin labels

- Trash excluders
- Storm drain maintenance
- Spill response plan
- Co-permittee owned treatment control BMPs

The following is an example outline for an O&M plan specific for LID treatments based on a successful stormwater program for the City of Portland, Oregon (2008).

Example Outline for LID Operations & Maintenance Manual

1. Introduction
    a. Summary of overall Stormwater Management Plan
    b. Table identifying each stormwater facility, including stormwater source, square footage treated, and discharge point
    c. Map of specific location of stormwater facilities
    d. Identification of who will assume responsibility for ongoing operations
2. Maintenance Schedule
    a. When and how often facilities will be inspected
    b. Specific intervals between maintenance duties
    c. Definition of what size storms require additional inspections
    d. Irrigation schedule (if applicable)
3. Operations and Maintenance Procedures
    a. Specific procedures for each facility type
    b. Likely deficiencies and corrective actions
    c. Course of action for unexpected deficiencies
4. Financial Responsibility
    a. The party(s) fiscally responsible for operating and maintaining the stormwater facility must be designated.
5. Inspection and Maintenance Logs
    a. Examples and instructions for maintaining inspection and maintenance logs are required as part of NPDES permit conditions.

The date, description, and contractor (if applicable) for all repairs, landscape maintenance, and facility cleanout activities will be recorded with records made available upon request to City, County, and/or Regional Water Quality Control Board as appropriate.

Additionally, maintenance of LID features for public health and safety is required. Vegetation must be maintained in compliance with fire codes, particularly adjacent to buildings and fire lanes. Any source of standing water, including natural and constructed wetlands, detention

basins, and other stormwater conveyance systems (even those below ground) can be breeding grounds for mosquitoes and other vectors which could result in adverse public health effects. The most effective methods to minimize the mosquito production potential within LID features are: (1) ensure that standing water does not remain within the LID feature for more 72 hours, (2) deny mosquitos' access to standing water, or (3) make the habitat less suitable for mosquito breeding. LID features with standing water can also attract rodents, such as rats, raccoons, opossums, and skunks, which can be vectors of human diseases. In addition to ensuring that standing water is eliminated in a timely fashion, rodents may be discouraged through other means such as fencing and trapping. The O&M Manual should include a method to monitor and eliminate rodents from LID features.

4.4 LID Fact Sheets

4.1 Introduction and Purpose
4.2 LID Approach to Stormwater Management
4.3 The LID Stormwater Planning Process
4.4 LID Fact Sheets
4.5 Off-site, Retrofit, and Regional Approaches

The following pages contain fact sheets for these classes of LID features:

- Biofilters
- Permeable Pavement
- Green Roofs
- Rainwater Harvesting Systems
- Subsurface Detention/Infiltration Strategies

Each fact sheet includes a description of the basic functions and benefits of the LID feature, selection criteria, applications, design and installation considerations, costs, and maintenance activities. Examples of each LID feature are included in each fact sheet.

Page intentionally left blank

Introduction: A biofiltration area is any vegetated area to which stormwater is intentionally directed. Common biofiltration treatments include:

- rain gardens/biorentention areas,
- flow-through planters,
- vegetated swales,
- vegetated filter strips.

Curb cuts allow any runoff from the permeable pavement to flow into a biofilter (Chicago, IL)
Photo: Abby Hall, US EPA

Function & Benefits: Biofilters come in many shapes and sizes, and often use multiple hydrologic processes (infiltration, evaporation/transpiration, and detention/retention) to manage stormwater flows and quality. Biofilters treat stormwater via filtration (through soil and through plant material), settling, and phytoremediation (uptake of pollutants by plants).

In addition to their stormwater management benefits, biofilters are visually interesting landscape features and provide habitat for wildlife.

Biofilter in a Portland, Oregon sidewalk. Street runoff is directed into the biofilter via small check dams in the gutter.
Photo: RMC Water & Environment

Selection Criteria: Biofilters can be used in a wide variety of applications and can be designed to suit particular site needs. Selection considerations for using biofilters include:

- Biofilters work best in infiltrating soils but can be designed with underdrain systems in areas with low infiltration rates.
- Biofilters are generally installed on flat ground (rain gardens) or gentle slopes (vegetated swales). For steep sites, terraced rain garden or vegetated swales with check dams may be an option.
- Care should be taken when installing biofilters on sites with shallow depths to groundwater. There should be at least two feet of separation between the bottom of the biofilter and the water table to prevent the swale bottom from being saturated, which impacts plant growth and can foster mosquito breeding.

Sonoma County Example: Lowes Home Improvement Store, Cotati, CA

The Lowe's Home Improvement store in Cotati features a large vegetated swale that treats runoff from the store's parking area. The parking lot also features areas of permeable asphalt.

Vegetated swale/biorentention area at the Lowe's Home Improvement Store in Cotati, CA
Photo: David Woltering

Applications: Biofilters have wide applicability and can be used in residential, commercial, and industrial settings.

RESIDENTIAL

Rain gardens at the Jordan Cove Urban Watershed Project in Connecticut collect and treat runoff from the adjacent houses.

Photo: University of Connecticut

Vegetated swales along Seattle's residential "Street Edge Alternatives" project.

Photo: Seattle Public Utilities

COMMERCIAL

Flow-through planters receive roof run-off at the Emery Station East office building in Emeryville, CA

Photo: Abby Hall, US EPA

Runoff from the parking lot of Portland's New Seasons Market is directed to a vegetated swale.

Photo: RMC Water & Environment

MUNICIPAL/INSTITUTIONAL

Rain garden at the Glencoe Elementary School in Portland, OR captures water from nearby paved areas.

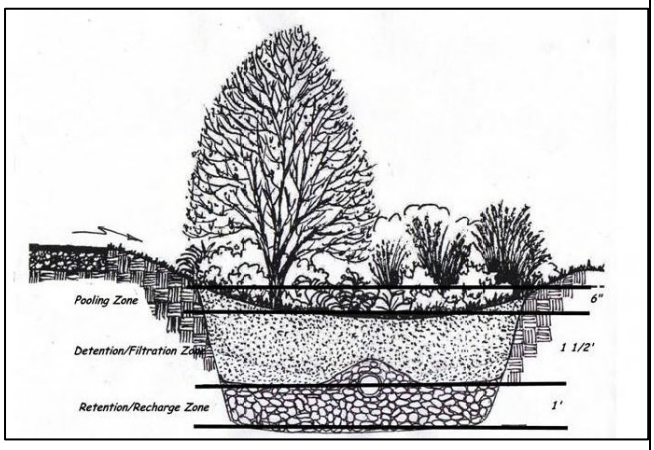
Photo: RMC Water & Environment

Biofiltration curb extension in Portland, OR. Stormwater flows into the curb extension from the gutter.

Photo: RMC Water and Environment

Design: As biofilters vary widely in their applications, so does the complexity of the biofilter design process. In general, when designing a biofilter the following design aspects are considered:

- **Sizing:** Biofilters are generally sized based on hydromodification control objectives for runoff volume. Flow rate, and duration control are also sometimes considered in sizing biofilters. With proper design, water quality treatment objectives can be met along with hydromodification control objectives.
- **Ponding/Drainage Time:** Design ponding depths of biofilters vary. Some vegetated swales are designed to have no ponding, whereas biorentention areas in well-infiltrating soils are sometimes designed with ponding depths up to 2 feet. Biofilters should be designed to drain within 72 hours. Longer ponding times may provide breeding opportunities for mosquitoes. Biofilters lacking underdrains may require soils with high infiltration characteristics. On-site percolation/infiltration studies may be necessary.
- **Soil amendments:** Depending on local soil conditions, imported soils are commonly used for the first two feet of a biofilter in order to achieve appropriate detention capacity (in soil interstitial spaces) and treatment (via filtration through the soil).



Schematic of a biorentetion area showing ponding, amended soils, and an underdrain.
Graphic: Prince George's County, 2007

- **Conveyance:** If the biofilter is designed to convey water from one point to another (vegetated swales), appropriate slopes should be designed (generally between 1% and 2%). Biofilters may be constructed on steeper slopes by using check dams or terracing.
- **Plant Selection:** Plants for biofilters must be carefully selected in order to tolerate brief periods of inundation (up to 3 days) while also being drought-tolerant. Plants within biofilters should require minimal irrigation during the dry season. Native plants are recommended because they are adapted to the local climate. Low to medium height native vegetation is preferred to minimize mosquito habitat. Cattails and bull rushes are not recommended due to their fast growing capacity and attraction for mosquito populations.

Installation: Because biofilters rely on gravity fed drainage, the grades and elevations of soil and hardscape elements (i.e., curb cuts, trench drains, curb heights, etc.) are critical and must be carefully constructed and checked throughout the installation process. A minor discrepancy in elevation can prevent drainage from occurring as designed. Care should also be taken to avoid compacting native and imported soils to the greatest extent possible.

Cost: The costs for constructing biofiltration areas varies widely depending on site conditions, design objectives and plant selection. Biofilter areas are, however, often the least expensive means of achieving stormwater management objectives for runoff control and water quality (i.e. less expensive than conventional stormwater conveyance/treatment and less expensive than other LID features). Studies indicate that integrating bioretention across a site can achieve a net reduction of between 15 and 50 percent of the site development costs compared with conventional BMPs (Prince George's County 2007). Biofilters that are constructed with underdrains will be more expensive than biofilters that rely only on infiltration to remove ponded water.

Maintenance: Maintenance activities for biofilters include:

- Irrigate as needed. Irrigation may be necessary in the first 1-3 dry seasons following construction to establish newly-planted vegetation.
- Manually remove weeds and debris and prune plant overgrowth.
- Cut back grass and prune overgrowth 1-2 times a year.
- Do not apply fertilizers, herbicides, or pesticides.
- Remove litter and debris.
- Rake, till, or amend to restore infiltration rate.
- Inspect occasionally after storm events to ensure that the biofilter is draining appropriately and water is not ponding for more than 72 hours.

Forebay structure allows for easy trash removal. Drought-tolerant sedges are low-maintenance plants (Portland, OR)

Photo: RMC Water & Environment

References and Resources:

Contra Costa County Clean Water Program. 2008 "Contra Costa Clean Water Program Stormwater C.3 Guidance Manual" http://www.cccleanwater.org/new-developmentc3/

Fairfax County, Virginia. 2005. "LID BMP Fact Sheet: Planter Boxes." http://www.lowimpactdevelopment.org/fairfax.htm

Prince George's County. 2007. "Biorentention Manual" http://www.co.pg.md.us/Government/AgencyIndex/DER/ESG/Bioretention/pdf/Bioretention%20Manual_2009%20Version.pdf

San Mateo Countywide Water Pollution Prevention Program. 2009. "San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook" http://www.flowstobay.org/ms_sustainable_streets.php

US Environmental Protection Agency. "Bioretention (Rain Gardens) Fact Sheet." http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse

US Environmental Protection Agency. 2004. "Stormwater BMP Design Guide – Volume 2: Vegetative Biofilters (EPA/600/R-04/121A)."

Wisconsin Department of Natural Resources. "Rain Gardens: A How-To Manual for Homeowners." http://www.dnr.state.wi.us/runoff/rg/rgmanual.pdf

Introduction: A variety of permeable surfaces can be used as alternatives to conventional impermeable paving surfaces such as asphalt and concrete. In general, permeable pavement systems are intended to manage only the rainwater that falls on them but with proper design they can also manage limited amounts of runoff from other site areas.

Permeable paving surfaces include:

- Permeable (porous) concrete
- Permeable (porous) asphalt
- Permeable pavers
- Grass and gravel "pavers"

Permeable Concrete
Photo: HydroSTON®

Concrete pavers in a pedestrian area at a Philadelphia school allow for stormwater infiltration and plant growth.
Photo: Abby Hall, US EPA

Function & Benefits: Permeable paving systems consist of a durable, load bearing, pervious surface that overlies a crushed stone base. The base rock detains rainwater that percolates through the pervious surface above. If soil conditions allow, the detained rainwater held in base rock then infiltrates through the underlying soil to the deeper aquifer below and provides recharge benefits. In soils with low infiltration capacity, permeable pavement systems are installed with an underdrain system.

In addition to providing stormwater management benefits, permeable pavement systems can also add a visual interest to the site. Permeable pavers can be arranged in interesting patterns and grass pavers allow for green spaces in unexpected areas.

Selection Criteria: As a general rule, permeable pavement is suitable for low speed/low traffic areas such as parking lots and pedestrian walkways. Selection considerations for using permeable pavement include:

- Permeable pavement has a lower load-bearing capacity than conventional pavement and should not be used in areas that receive regular traffic from large vehicles (such as loading docks).
- Permeable paving should only be used in flat areas and on gentle slopes (<5%).
- Soil pores in permeable pavement can become clogged with fine sediment, which reduces infiltration capacity. As such, permeable paving should not be used in areas that may receive significant quantities of dust or sand via wind transport or stormwater flows.

Permeable paving in courtyard of Sebastopol's Florence Lofts
Photo: David Abbott; Sonoma West Times

Sonoma County Example: Florence Lofts, Sebastopol, CA

Florence Lofts is a 12-unit townhouse development site on 1.1 acres at the north end of downtown Sebastopol. In addition to many other impact avoidance measures, the property makes extensive use of permeable paving. The parking areas and the courtyard utilize a 6-inch layer of permeable concrete over a 10 inch layer of drain rock.

Applications: Permeable paving is often a viable alternative to conventional asphalt and concrete.

RESIDENTIAL

Simple gravel parking area at a house in Alameda County, CA.

Photo: www.bluegreenbldg.org

Ecostone® paver driveway at the Jordan Cove Urban Watershed Project in Connecticut (www.jordancove.uconn.edu)

Photo: University of Connecticut

COMMERCIAL

Grass pavers form the parking stalls at the Little House Café in Alameda, CA.

Photo: RMC Water & Environment

Permeable paver parking lot at a West Berkeley office building.

Photo: www.bluegreenbldg.org

MUNICIPAL/INSTITUTIONAL

A parking lot on the University of California, Merced campus uses gravel pavers in the parking stalls and conventional asphalt in the driving lanes.

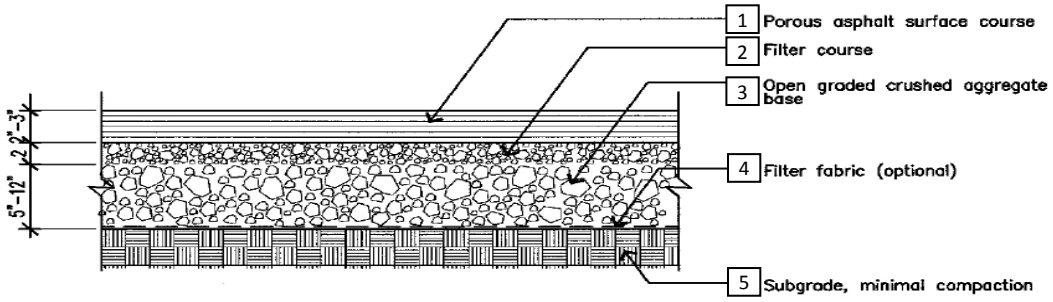
Photo: Horizon Water and Environment

Sand-set pavers (permeable sand fills the spaces between tiles) are used in the parking lanes on Naito Parkway, Portland, Oregon.

Photo: RMC Water & Environment

Design: Permeable paving systems consists of several layers:

1. Permeable surface: The decision of what type of surface to use is based on cost/maintenance considerations as well as aesthetic preferences.
2. Filter course: A narrow layer (~2") of small (~0.5") crushed rock should underlie the pervious surface.
3. Aggregate base: To allow for subsurface water storage, the aggregate base must be open graded (limited size range), crushed stone (angular stones, not rounded stones such as pea gravel). The depth of the base rock layer can vary based on loading requirements and desired stormwater detention capacity.
4. Geotextile liner: A geotextile liner is sometimes placed between the aggregate base and the soil to prevent fines from migrating upward into the aggregate base and filling the void spaces. Geotextile liners can, however, clog with fines that have infiltrated though the pavement and aggregate, thereby inhibiting infiltration. The decision whether or not to use a liner at a particular site should be made by a qualified engineer.



Graphic: BASMAA, 1999

Unless a site's underlying soils are known to be capable of rapid infiltration rates, it is generally recommended that permeable paving systems be designed with an underdrain system. Depending on the stormwater management needs at the site, the underdrain may discharge into the municipal storm sewer or to another on-site stormwater management feature (such as a biofiltration area).

Installation: Handling and installation procedures for permeable paving systems are different from conventional pavement. As such, contractors experienced with permeable paving systems should be used whenever possible. Consistent with other LID techniques, the soils underlying the aggregate base should be compacted as minimally as possible during the site grading and construction phase. During installation, care should be taken not to introduce fine sediments into the permeable surface or aggregate base.

Costs: In general, permeable paving initially costs more than conventional asphalt or cement paving techniques. Construction costs for permeable asphalt and concrete may be 50% more than conventional asphalt and concrete. Construction costs for permeable pavers and grass/gravel pavers vary considerably. Some sources estimate that permeable pavement can be up to 25 percent cheaper than traditional pavement when all construction and drainage costs are included. Permeable paving reduces the need for stormwater conveyances and treatment structures, resulting in cost savings elsewhere. Permeable paving also reduces the amount of land needed for stormwater management, possibly allowing more development on a site.

Maintenance: Maintenance activities for permeable pavements include:

- Keep adjacent landscaped areas well-maintained and prevent soil from being transported onto the pavement.
- Permeable concrete and asphalt surfaces should be cleaned once or twice a year using vacuum sweeping machines. Vacuuming is most effective during dry conditions.
- For paving stones, periodically add joint material (sand) to replace material that has been transported.
- Grass pavers may require periodic reseeding to fill in bare spots.
- Prevent large root systems from damaging subsurface components.
- Monitor regularly to ensure that the paving surface drains properly after storms. The infiltration rates can also be tested.
- Do not reseal or repave with impermeable materials.
- Inspect the surface annually for deterioration and repair as needed.

Demonstrating infiltration rates at a Villanova University. Permeable concrete (upper) permeable asphalt (lower)

Photo: Abby Hall, US EPA

References and Resources:

Abbott, David, Sonoma West Times "Lofty ideals - Green design, partnerships at heart of downtown lofts", http://www.sonomawest.com/articles/2008/03/27/sonomawest/news/doc47eaa7e6756eb710930701.txt

Boston Metropolitan Area Planning Council. "Massachusetts Low Impact Development Toolkit" www.mapc.org/LID.html

Center for Stormwater Protection. Stormwater Management Fact Sheet: Porous Pavement. http://www.stormwatercenter.net.

North Carolina State University and A&T State University Cooperative Extension. 2006. "Urban Waterways: Pemeable Pavements, Green Roofs, and Cisterns." http://www.bae.ncsu.edu/stormwater/PublicationFiles/BMPs4LID.pdf

Port of San Francisco/San Francisco Public Utilities Commission. 2009. "Draft San Francisco Stormwater Design Guidelines" http://sfwater.org/mto_main.cfm/MC_ID/14/MSC_ID/361/MTO_ID/543

Puget Sound Action Team. 2005. "Low Impact Development: Technical Guidance Manual for Puget Sound." Publication No. PSAT 05-03. Olympia: Puget Sound Action Team and Washington State University Pierce County Extension. www.psat.wa.gov/Publications/LID_tech_manual05/LID_manual2005.pdf

Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP). 2003. "BMP Fact Sheets: Porous Pavement." http://www.scvurppp-w2k.com/pdfs/2003workshop/three/porous_pavement.pdf

Sierra Club Green Home – Permeable Paving www.sierraclubgreenhome.com/go-green/landscaping-and-outdoors/permeable-paving/

Introduction: A green roof is a vegetated roof system used in place of a conventional roof. Green roofs are relatively common in Europe and are becoming increasingly popular in the United States. American cities such as Chicago and Portland have well-established programs that support the use of green roofs.

There are generally two green roof categories: intensive or extensive. Intensive roofs (sometimes called rooftop gardens) have a thicker layer of soil and are thus able to support larger vegetation and foot traffic. Extensive vegetated roofs use a thin layer of soil and smaller plants and cannot be walked upon.

Green Roof atop Chicago City Hall
Photo: Wikimedia Commons

Function & Benefits: Green roofs manage stormwater by capturing some or all of the rain that falls on the roof and then slowly release the water to the atmosphere by allowing for evaporation and transpiration through the rooftop plants. Typical green roofs have been found to reduce annual roof runoff volumes by 50 to 65 percent and to reduce peak flows for large rain events (those exceeding 1.5 inches) by approximately 50 percent.

In addition to providing stormwater management benefits, green roofs also:

- Provide insulation (possibly lowering cooling and heating costs for the building)
- Reduce the urban heat island effect
- Create habitat for wildlife including birds and beneficial insects
- Provide aesthetic and recreational amenities

Selection Criteria: Green roofs may be especially appropriate for projects where:

- ground-level space is constrained and opportunities for stormwater management using other LID features are limited;
- the green roof can be seen from the ground or other adjacent structures;
- building occupants can access (but not necessarily walk upon) the green roof;
- the urban or building setting is lacking in vegetation.

American Society of Landscape Architects (ALSA) building in Washington DC
Photo: ALSA

Sonoma County Example: Salmon Creek Falls Environmental Center, Occidental, CA

The construction of the Salmon Creek Falls Environmental Center was completed in the Spring 2009. A portion of the Center's 10,500 square foot roof will be planted with cuttings started by the Center's students. The Center has many other green features and has applied for LEED Certification.

Salmon Creek Falls Environmental Center
Photo: Kevin Falkerson, Symbios Holistic Development (May 2009)

Applications: Green roofs can be used on a wide variety of structures.

RESIDENTIAL

Small structures like this backyard shed in Portland, Oregon are a good place to experiment with green roofs (see www.sustainablestormwater.com/blog).

Photo: Dave Elkin, Portland Sustainable Stormwater

Green roofs have been in use for centuries. Sod roofs provide insulation in the cold climate of Norðragøta on Eysturoy, Faroe Islands.

Photo: Erik Christensen

COMMERCIAL

The West Elm store in Emeryville, CA boasts a green roof (left) and solar array (right) that are highly visible from the adjacent freeways.

Photo: TBD

Ford's River Rouge truck plant in Dearborn, Mich., has a 10-acre "living" roof — the largest in the world.

Photo: William McDonough + Partners

MUNICIPAL

A 1,200 square foot green roof was constructed atop the Summit Pump Station in central San Francisco

Photo: San Francisco Public Utilities Commission

The green roof at Portland's Metro Regional Center building was retrofitted onto an existing roof terrace. Hardy succulents are used on this extensive green roof.

Photo: RMC Water & Environment

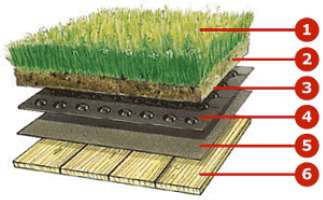
Design: Green roofs vary in design, but most modern green roofs are composed of several layers which (from top to bottom) generally include:

1. Vegetation - Drought-tolerant plants should be selected so as to minimize irrigation requirements.
2. Growing medium - Specialized lightweight soils are often used.
3. Root barrier - A layer of filter fabric is often used to prevent roots and soil particles from entering the drainage/storage layer below.
4. Drainage/storage layer - Gravel or specialized plastic products may be used to facilitate drainage and create water storage capacity.
5. Waterproofing layer - A variety of products may be used.
6. Structural support - The roof structure must be designed so as to accommodate the weight of the green roof layers plus the weight of the rainwater that will be retained.

Green roofs are generally installed on roof slopes less than 20 degrees (40 percent or a 5 in 12 pitch) but specialized designs allow for green roofs in almost unlimited shapes and sizes.

Green roofs may be designed for a particular application or modular green roof systems may be used. Modular systems are essentially trays of vegetation in a growing medium that are grown off-site and placed on the roof to achieve complete coverage. Typically, the manufacturers of modular green roof systems work with the building architect and structural engineer to ensure that the building can accommodate the modular green roof.

Because a poorly designed green roof may lead to leakage and/or structural damage, it is generally recommended that the services of experienced professionals be employed when considering the use of a green roof.



Green Roof Layers
Graphic : Triton Chemicals

The steep "hills" of the Academy of Sciences green roof (San Francisco, CA)
Photo: Tim Griffith

Modular green roof being assembled
Photo: GreenGrid Systems

Cost: Installation costs for green roofs are often more than double the installation costs for a conventional roof. Green roofs, however, typically last twice as long (about 40 years) as conventional roofs. Additionally, green roofs have lower heating/cooling costs and lower maintenance costs that conventional roofs. Current estimates place the overall life cycle cost of a green roof at approximately 10% more than that of a conventional roof. Costs for green roofs are likely to decrease in the future as green roofs become more common and green roof technologies are further developed.

Maintenance: Maintenance activities for a green roof include:

- Inspecting the roof regularly to check drainage and vegetation. Inadequate drainage can result in water ponding which can damage the structure and encourage mosquito breeding.
- Occasionally removing dry vegetation to ensure that combustible material does not accumulate. Some plant types, such as grasses, may need more frequent trimming while others, such as succulents, will rarely need maintenance. Do not use pesticides.
- Irrigating as necessary. Most green roofs are designed to need minimal watering but irrigation may be necessary to maintain plants during extended dry periods and to establish plants after they are initially installed.

Low maintenance succulents (*Sedum*) Portland's Metro Regional Center
Photo: RMC Water & Environment

References and Resources:

City of Chicago. 2007. "Chicago Green Roofs." Chicago: Office of the Environment. http://www.artic.edu/webspaces/greeninitiatives/greenroofs/main.htm

City of Portland. 2007. "Ecoroofs." Portland: Office of Sustainable Development. http://www.portlandonline.com/osd/index.cfm?a=bbehci&c=ecbbd .

City of Portland. 2006. "Ecoroof Questions and Answers." Portland: Bureau of Environmental Services." http://www.portlandonline.com/shared/cfm/image.cfm?id=153098

City of Toronto. 2007. "Greenroofs". www.toronto.ca/greenroofs/

Low Impact Development Center, Inc. 2007. "Maintenance of Greenroofs." www.lid-stormwater.net/greenroofs/greenroofs_maintain.htm .

Paladino Green Buidling Strategies. 2005. "Green Roof Feasibility Review" http://your.kingcounty.gov/solidwaste/greenbuilding/documents/KCGreenRoofStudy_Final.pdf

Puget Sound Action Team. 2005. "Low Impact Development: Technical Guidance Manual for Puget Sound." Publication No. PSAT 05-03. Olympia: Puget Sound Action Team and Washington State University Pierce County Extension. www.psat.wa.gov/Publications/LID_tech_manual05/LID_manual2005.pdf

US Environmental Protection Agency. 2009. Heat Island Effect Website. http://www.epa.gov/heatisland/mitigation/greenroofs.htm

Introduction: A rainwater harvesting system typically collects the run-off from a building's roof and stores the water for later reuse. Storage tanks (or cisterns) are an important component of rainwater harvesting systems and can range from small wooden barrels (such as wine barrels) to large custom-designed cisterns. Harvested rainwater is often used for landscape irrigation but may also be used for other purposes such as toilet flushing.

Although roofs are the most common "watershed" in rainwater harvesting, other collection surfaces are possible. At the Cambria Elementary School in Cambria, CA (photo at right) the entire campus, including the fields, was designed to collect all available stormwater and hardscape runoff. Under the soccer field, large pipes store up to 2,000,000 gallons of water. Harvested water is used for irrigating the athletic fields.

Cambria Elementary School, Cambria CA
Photo: Rehbein Environmental Solutions

Wine barrel cistern
Photo: Adrienne Aiona

Function & Benefits: Rainwater harvesting systems can collect up to 100% of the runoff from their catchment areas as long as there is capacity in their storage tanks. When the storage tank is full, additional stormwater can be directed to a biofiltration area or directed to a storm drain system. Reductions in peak flows and runoff volumes using rainwater harvesting systems depend on storage tank (cistern) sizes and water use between storms. Rainwater harvesting provides additional benefits when it is reused onsite to reduce potable water demands. Even when collected water is not reused, improved capture and storage provides several stormwater benefits.

Selection Criteria: Rainwater harvesting can be applied on a wide range of scales from a single home's rain barrel to a commercial or municipal site with a large underground storage tank. Rainwater harvesting requires a few key elements:

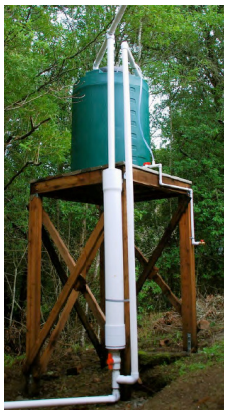
- A drainage area from which to collect water
- An approved application for captured water
- An appropriate overflow point for excess water

Rainwater harvesting is most beneficial at:

- Sites with irrigation needs
- Sites with limited space for landscaped facilities
- Sites that can install underground storage

Stormwater benefits are maximized when rainwater is used for non-potable indoor uses such as toilet flushing. However, these systems require additional infrastructure including pipes, pumps and signage. Contrary to common misconceptions, rainwater harvesting is not illegal in California. Permits from local jurisdictions may however be required, particularly if harvested rainwater is to be used for purposes other than landscape irrigation.

Two 500 gallon pillow tanks installed under the deck of a San Leandro home store enough water to supply toilet and laundry water through the rainy season
Photo: www.watersprout.com



Rainwater tank at the Occidental Arts and Ecology Center
Photo: Jim Coleman/Brock Dolman

Sonoma County Example: Occidental Arts and Ecology Center, Occidental, CA

The Occidental Arts and Ecology Center harvests rainwater for various uses at the Center. OAEC's education programs include information about rooftop rainwater harvesting and techniques to encourage "harvesting water in the soil" such as creating rain gardens, berm and swale configurations, and other landscape features that allow draining rainwater to safely infiltrate through the soil.

Applications: Rainwater harvesting can be applied at many different scales.

RESIDENTIAL

Two 1,800 gallon cisterns capture rainwater for irrigation use at TreePeople's Hall House demonstration project in Los Angeles, CA.

Photo: David O'Donnell

Plastic rain barrel at a home in Santa Monica, CA. Plastic rain barrels are available commercially.

Photo: Abby Hall, US EPA

COMMERCIAL

A 5,300 gallon tank made of Atlantis D-Raintank units stores roof runoff from a Sydney, Australia big-box hardware store. Harvested water is used in the store's nursery department.

Photo: Atlantis - www.atlantis-america.com

Cisterns at the Chesapeake Bay Foundation's headquarters in Annapolis, MD collect rainwater for use in bathroom and mop sinks, gear washing, irrigation, fire suppression, and laundry.

Photo: Chesapeake Bay Foundation

MUNICIPAL/INSTITUTIONAL

A 200,000 gallon cistern at the Santa Monica Public Library under construction and completed. The water is collected from the library roof and used for landscape irrigation.

Photo: www.smpl.org

Cisterns at the Chicago Center for Green Technology are screened with trellised vines. The 12,000 gallon cisterns store water for irrigation.

Photo: Abby Hall, US EPA

Design: There are several aspects to the design of rainwater harvesting systems:

- **Collection surface:** Rainwater harvesting is easiest when the collection surface is relatively clean (requiring little treatment before storage and reuse) and is elevated (such that gravity flow may be used to drain and reuse the water). Roofs fill these two criteria very well.
- **Pre-treatment:** Prior to storing the rainwater, it is often advisable to implement simple treatment measures to prevent the storage recepticle from collecting excessive sediment and debris. Pre-treatment mechanisms can be as basic as a metal mesh covering to prevent leaves from entering the roof downspout. "First flush diverters" or "roof washers" can also be purchased to divert or treat the initial (more polluted) volume of any storm.
- **Conveyance (from surface to tank):** If rainwater is being harvested from a roof, conveyance from the collection surface to the storage tank is generally already available in the form of the roof gutters and downspouts.
- **Storage tank:** Storage tanks should be completely sealed, and if any vents exist they should be covered with fine mesh screening (less than 1/16") to prevent mosquitos and other pests from entering. Tank sizing, tank type and tank location are important aspects of designing rainwater harvesting systems:
  - Tank sizing: The storage tank should be sized in accordance with the design objectives. For example, if the rainwater harvesting system is intended mostly as a stormwater management tool, the tank will be sized relative to the amount of runoff from the roof during the design storm and the ability to drain the tank after the storm has passed. If water conservation is the priority, a larger tank may be desired so as to capture the runoff from multiple storms.
  - Tank type: For small residential rainwater harvesting systems, simple off-the-shelf containers are often used. Larger rainwater harvesting system may wish to use custom designed tanks (such as poured-in-place concrete tanks). Transparent or translucent tanks are not recommended as sunlight contributes to the growth of algae within the tank.
  - Tank location: Rainwater storage tanks are most often placed on level ground adjacent to the building directly beneath a downspout. Tanks can be placed more or less anywhere on a site with the use of conveyance systems and pumps. Tanks can be located below ground (saving space but requiring pumping for water reuse), on elevated platforms below roof level (allows gravity flow into and out of the tank but requires that a platform be constructed), or even on top of the roof (requires pumping into the tank and possibly structural reinforcing of the building). If possible, tanks should be placed in a cool or shaded area to limit algal growth.

Roof runoff from portable classrooms is stored in two 2,500 gallon cisterns to water the Da Vinci Middle School in Portland, OR. Overflow runs through the raingarden into a stormwater wetland.
Photo: Adrienne Aiona

- **Treatment:** For use in landscape irrigation, no treatment of collected rainwater is required. Treatment may be required if the collected rainwater is to be reused for other purposes.
- **Overflow:** When the storage tank is full, additional stormwater can be directed to a biofiltration area or directed to a storm drain system.

Cost: Costs for rainwater harvesting systems vary widely, depending mostly on the volume and type of the storage tank and the pumping requirements. Rainwater harvesting systems provide cost savings by off-setting needs for potable water and by collecting rainwater that would otherwise require management through conventional or LID techniques.

Maintenance: Maintenance activities for rainwater harvesting systems include:

- As-needed cleaning of the collection surface. Cleaning of roofs may be warranted at the end of the dry season to remove excess dust. Leaves should be removed from gutters to prevent clogging.
- Storage tank should be inspected periodically to ensure that they are not leaking, do not contain excessive algal growth, do not have openings greater than 1/16", and are not hosting mosquito larvae or other insects.
- Drain/clean first flush diverters/roof washers as needed.
- Vents or inlets to or from the system should be screened and checked regularly.

References and Resources:

American Rainwater Catchment Systems Association (ARCSA) www.arcsa-usa.org

Bennett, Kirk "The California Rainwater Harvester" www.buildurbandams.com

Cold Climate Housing Research Center 2003. Best Management Practices for Rainwater Catchment Systems in Alaska www.uas.alaska.edu/attac/dlfiles/BMP.pdf

Dolman, Brock and Lundquist, Kate 2008 "Roof Water Harvesting for a Low Impact Water Supply" http://oaecwater.org/education/roofwater-harvesting-booklet

International Rainwater Catchment Systems Association (IRCSA) www.ircsa.org

Port of San Francisco/San Francisco Public Utilities Commission. 2009. "Draft San Francisco Stormwater Design Guidelines" http://sfwater.org/mto_main.cfm/MC_ID/14/MSC_ID/361/MTO_ID/543

Texas Water Development Board 2005 "Texas Manual on Rainwater Harvesting, Third Edition www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rdedition.pdf

Tank Town (Texas-based builder/supplier of rainwater harvesting system) https://rainwatercollection.com/

TreePeople 2007 "Rainwater as a Resource: A Report on Three Sites Demonstrating Sustainable Stormwater Management" www.treepeople.org/files/Rainwater_as_a_Resource.pdf

Rich, Deborah 2008. "Get Out of the Drain Age, Into the Retain Age", San Francisco Chronicle, December 6 2008. www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2008/12/06/HOTB1496GP.DTL&type=homeandgarden

Occidental Arts and Ecology Center www.oaec.org and www.oaecwater.org

WaterSprout www.watersprout.com

Introduction: For smaller sites with space constraints, subsurface infiltration and detention strategies can be used to manage stormwater on-site. Types of subsurface detention/infiltration strategies include:

- Infiltration trenches
- Underground infiltration galleries
- Soil amendments

A perforated pipe delivers rooftop runoff to the full length of this infiltration trench. After completion the area will be covered with sod and the trench will be invisible.
Photo: Cahill Associates, Inc.

Function & Benefits: Subsurface detention/infiltration structures allow on-site stormwater management with minimal surface space requirements.

- Infiltration trenches store water in the void space between crushed stone or gravel; the water slowly percolates downward into the subsoil.
- Underground infiltration galleries create void spaces for stormwater detention and provide a broad underground surface though which infiltration can occur.
- Amending site soils is a strategy that improves the soils ability to retain rain water and thereby prevents some degree of runoff from occurring. The intent of soil amendments is to mimic the infiltration functions of healthy naturally occurring topsoils that may have been removed or compacted by development.

Parking lot runoff directed to this infiltration basin is pretreated by a vegetated filter strip.
Photo: California Stormwater Quality Association, 2004

Selection Criteria: Infiltration trenches and underground infiltration galleries are best used on sites that, due to space constraints, cannot use other LID stormwater management techniques such as biofiltration areas. Infiltration capacity testing is advisable prior to the consideration of these types of LID features to ensure that proper drainage can be achieved.

Soil amendments are useful particularly on sites where the natural topsoil has already been degraded or where significant regrading/surface disturbance is a necessary part of the site development plan.

Sonoma County Example: Simple steps like adding mulch cover to exposed soils can significantly improve the ability of the ground surface to detain stormwater and reduce stormwater runoff. At the Sonoma County Administration Center, the use of mulch cover in the landscaping has been designed so as to need little irrigation water while also reducing stormwater runoff.

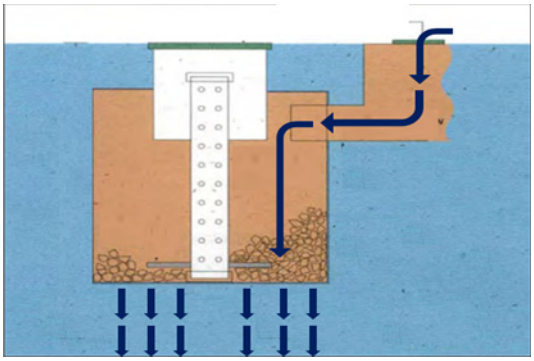
Mulch under drought tolerant plants at the Sonoma County Administration Center
Photo: Sonoma County Permit and Resource Management Department

Applications: Subsurface strategies can be applied at many different scales and locations.

RESIDENTIAL

A grate in the driveway at TreePeople's Hall House demonstration project in Los Angeles, CA directs stormwater into a "infiltration well." Infiltration wells function like small infiltration trenches.

Photo: David O'Donnell



Cross-section schematic of the driveway infiltration well at the TreePeople Hall House (see left). Water flows through the grate and into the gravel filled infiltration well. A perforated pipe topped by a valve box allows for checking to see if proper drainage is occurring.

Graphic: modified from TreePeople graphic

COMMERCIAL

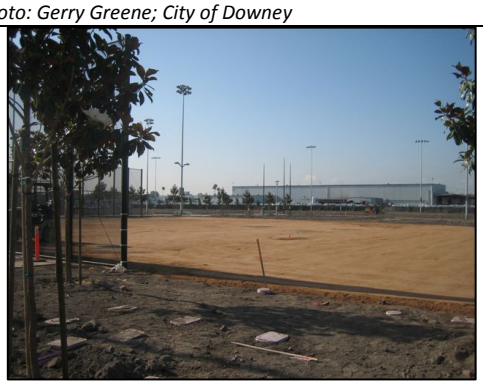
Subsurface structure beneath parking lot: runoff passes through depressed landscape medians (pictured) and a vegetated swale before entering the subsurface detention/infiltration structure.

Photo: Gerry Greene; City of Downey

Underground infiltration gallery using StormTech arched plastic chambers being constructed beneath a commercial parking lot in Downey, CA (near Los Angeles).

Photo: Gerry Greene; City of Downey

MUNICIPAL/INSTITUTIONAL



An 8 acre-foot stormwater vault lies beneath sports fields at the Discovery Sports Complex in Downey, CA. Runoff from over 60 acres is treated by various LID and conventional stormwater devices before entering the facility vault.

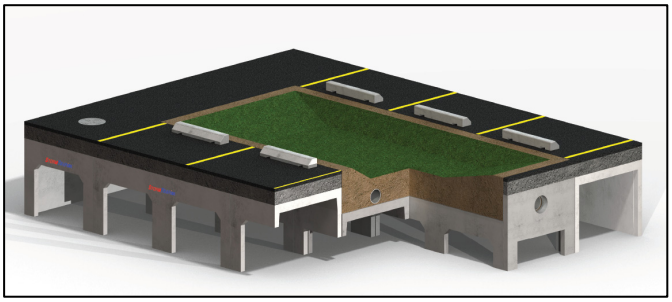
Photo: City of Downey, May 2008

The stormwater vault at the Discovery Sports Center allows for infiltration through large holes in the concrete structure. 20 ft. deep rock-filled wick drains enhance infiltration

Photo: RMC Water and Environment

Design:

- Infiltration trenches and underground infiltration galleries: Infiltration trenches, and underground infiltration galleries should be sized to accommodate the full volume of the runoff from the design storm and to drain after the conclusion of the storm. As these structures are vulnerable to clogging, pre-treatment mechanisms should be included in the design to prevent debris and sediment from flowing into the structure with the runoff. Pre-treatment also helps protect groundwater from pollutants such as petroleum hydrocarbons. Filter fabric (non-woven geotextiles) is sometimes used to line the sides and bottoms of these structures in order to prevent in-situ soils from migrating into the void spaces. Infiltration trenches and underground infiltration galleries should be designed with some mechanism for overflow drainage. An observation well (a perforated PVC leading to the bottom of the structure) should be included in the design to allow monitoring of the drawdown rate. Infiltration trenches and underground infiltration galleries should not be located near septic systems/leach fields as each will interfere with the proper operation of the other. Any vents or holes in access lid should be screened with fine mesh (less than 1/16") to prevent adult mosquito access into the system.



Biofilters can be used to treat runoff before it enters a detention/infiltration structure.
Graphic: StormTrap

- Soil Amendments: Soil amendments consist of compost, mulch, and top soil. Supplements such as lime (for pH adjustment) , gypsum (in order to increase calcium and sulfur) and nutrients (particularly insoluable nitrogen) can also be useful in the soil amendment mix. These additional components help offset nutritional deficiencies and control acidity. In order to determine the appropriate mix for soil ammendments, a thorough soil analysis of the native soil is advisable. Developing a healthy soil with good structure and infiltration capacity also involves ensuring that the soil contains micro biota, bacteria, and other organisms which are essential at recycling nutrients, creating pore space, oxygenating the soil, and improving stability and infiltration.

Cost: Costs for detention/infiltration structures vary widely depending on the depth, materials used, and individual site conditions. Costs for soil amendments can be obtained from local nurseries/soil suppliers.

Maintenance:

- Infiltration trenches: The most important aspect of maintaining infiltration trenches is ensuring that pre-treatment mechanisms are functioning properly and excess sediment is not accumulating.
- Underground infiltration galleries: Maintenance of pre-treatment mechanisms is also very important for underground infiltration galleries. Underground infiltration galleries can also be designed to facilitate access for maintenance activities such as pressure washing of gravel base and for mosquito surveillance and control.
- Soil amendments: Care should be taken to not compact amended soils (for example, amended soils should not be driven upon). Maintaining vegetation cover and periodic mulching protects amended soils from erosion.

References and Resources:

California Stormwater Quality Association. 2004. "Stormwater Best Management Practice Handbook: New and Redevelopment." http://www.cabmphandbooks.com/

Hansen, Stefanie. "Play On". Storm Water Solutions February 2008 Volume: 5 Number: 1 http://www.estormwater.com/Play-On-article9488

Low Impact Development Center – LID Urban Design Tools http://www.lid-stormwater.net/soilamend_home.htm

Massachusetts Low Impact Development Toolkit, "Fact Sheet #5 – Infiltration Trenches and Dry Wells" http://www.mapc.org/regional_planning/LID/PDFs/trenchesdrywells.pdf

McDonald, David "Soil Restoration with Organics Enters Mainstream of Storm Water Practices" BioCycle April 2005, Vol. 46, No. 4, p. 20 http://www.jgpress.com/archives/_free/000412.html

Port of San Francisco/San Francisco Public Utilities Commission. 2009. "Draft San Francisco Stormwater Design Guidelines" http://sfwater.org/mto_main.cfm/MC_ID/14/MSC_ID/361/MTO_ID/543

Puget Sound Action Team. 2005. "Low Impact Development: Technical Guidance Manual for Puget Sound." Publication No. PSAT 05-03. Olympia: Puget Sound Action Team and Washington State University Pierce County Extension. www.psat.wa.gov/Publications/LID_tech_manual05/LID_manual2005.pdf

Personal communication with Kraig Erickson, construction manager for the installation of the StormTrap structure at Downey Discovery Sports Complex

Presentation by Gerry Greene, "MS4 Permits: What's LID got to do with it?".Delivered at the APWA Southern California Chapter April Luncheon April 26, 2007, Centre at Sycamore Plaza, Lakewood

Presentation by Nathan Quarles, "Municipal Storm Water Program – County of Sonoma" Delivered at the North Coast Regional Water Quality Control Board meeting, June 12, 2008.

TreePeople 2007 "Rainwater as a Resource: A Report on Three Sites Demonstrating Sustainable Stormwater Management" http://www.treepeople.org/files/Rainwater_as_a_Resource.pdf

4.5 Off-site, Retrofit, and Regional Approaches

4.1 Introduction and Purpose
4.2 LID Approach to Stormwater Management
4.3 The LID Stormwater Planning Process
4.4 LID Fact Sheets
4.5 Off-site, Retrofit, and Regional Approaches

This section discusses off-site, retrofit, and regional runoff management approaches to use beyond the immediate project site approaches presented earlier in this chapter. The approaches discussed in this chapter span a range of options and scales.

At the simplest level, local off-site solutions may be pursued to mitigate individual projects that do not meet stormwater or flood control requirements. This might involve implementing the LID techniques described previously in this chapter at another local project site. Off-site mitigation can also occur through applying in-lieu fees that support more regional stormwater and flood control solutions. Retrofit options are also discussed in this chapter for situations where it is feasible and effective to modify an existing land use or site design to reduce stormwater discharges.

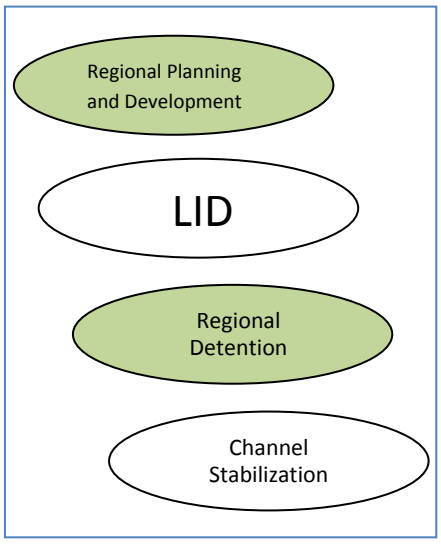


Figure 4-21: Stormwater planning and management approaches occur on-site and off-site and occur at different scales

As shown in **Figure 4-21** (and Figure 4-3), stormwater planning and management approaches can occur through different types and scales of activities. Regional land use planning and watershed management approaches are used at the broadest scale to locate developments in appropriate settings that would avoid or minimize stormwater and other impacts. At the site scale, LID measures are selected and designed to address the specific needs of the individual project. Regional detention facilities provide another avenue to manage stormwater at individual creek or watershed scales, and may be located either upstream or downstream of developed areas. Lastly, channel stabilization may be necessary if stormwater effects aren't adequately managed through the other approaches and protective measures are needed to prevent stream erosion downstream of development. Effective stormwater management may use and integrate all of these approaches.

The previous sections of Chapter 4 focused on site-specific planning and design for LID features at the site scale. In contrast to these earlier on-site topics, this section also reviews regional scale approaches that are typically implemented by city, County, and agency partnerships. Regional approaches can be pursued for large-scale development projects where regional runoff management opportunities are available. Regional approaches can be developed through cooperative planning initiatives that integrate stormwater from multiple developments or existing land uses. In other cases, regional approaches are more focused toward land use planning, seeking "smart growth" or regional LID approaches to avoid and minimize stormwater and other development impacts.

4.5.1 Purpose and Need for Off-site Stormwater Management

4.5.1 Purpose and Need for Off-site Stormwater Management
4.5.2 Off-site Retrofit Opportunities
4.5.3 Regional Approaches

When to Pursue Off-Site Approaches

Off-site approaches to stormwater management may be appropriate in the following cases:

- Where on-site LID cannot meet stormwater design objectives because of site constraints such as small size, extreme slopes, impermeable soils, etc. Or, where the development plans cannot be designed or modified to effectively integrate LID techniques while still meeting development objectives.
- Where off-site approaches are more cost-effective and efficient. This may be the case where on-site LID is possible, but due to the site constraints identified above, it would only provide limited benefits. Alternatively, off-site approaches may be more advantageous than on-site plans where multiple developments could more effectively pool resources to develop regional solutions.
- Where a combination of on-site and off-site stormwater management can yield the greatest benefits.

Municipal NPDES Waiver Program

The municipal NPDES Permit (2009) provides a means for off-site or regional approaches to stormwater management. A waiver from SUSMP requirements is allowed where it is impractical for a specific project to implement appropriate stormwater reducing BMPs. A project developer can pay an in-lieu fee, toward a mitigation fund that supports regional or sub-regional stormwater mitigation projects. Such projects would:

- Result in equivalent or improved storm water quality,
- Protect stream habitat,
- Be fiscally sustainable and have secure funding,
- Promote cooperative problem solving by diverse interests, and
- Be completed in four years or less including the construction and start-up of treatment facilities.

The NPDES Permit also requires creating a management framework to fund regional mitigation solutions. If an approved watershed management plan, integrated water resources management plan, regional stormwater mitigation plan, or wetlands recovery plan exists that can provide stormwater management and treatment benefits, then mitigation credit can be applied to an individual project. It is anticipated that developers will be able to mitigate and retrofit for potential stormwater impacts on their own properties. A successful off-site mitigation program will require some flexibility in determining appropriate and allowable sites. Off-site stormwater mitigation locations should not be limited to specific sites directed by regulatory agencies or cities. As such, regional stormwater solutions are an important

consideration in addition to the on-site treatments emphasized by LID. The off-site, retrofit, and regional approaches presented in this section are consistent with the NPDES waiver program.

Strategies and Considerations for Off-Site Solutions

For an off-site solution to be effective, the solution must align with, and mitigate for, the project impacts. In other words, off-site approaches should address the extent and scale of the on-site project impacts. Ideally, the off-site treatment should also be located within the same general geographic region (or primary watershed) as the impacted site.

In designing off-site solutions, the scale of the impact must be considered. Are project impacts occurring at the parcel, neighborhood, specific plan, or sub-watershed scale? Smaller-scale impacts will be matched with smaller-scale solutions (or may be most practically addressed by an in-lieu fee which is used to fund a larger project). Where multiple parcels or an entire area share impacts, they may be better served by larger sub-regional or regional solutions.

As an example of a parcel-specific solution, consider a site where post-project discharge peaks (for a certain recurrence interval and duration) exceed pre-project conditions and cannot be reduced on-site due to steep slopes surrounding the site's buildable area which make infiltration, detention, or retention infeasible within the site's conservation areas. Such a project may seek to find an area lower in the watershed with a gentler gradient that could be used to effectively infiltrate, store, or detain runoff and therefore mitigate for the on-site increases in peak discharge.

At regional scales, larger stormwater management facilities become more practical, such as detention basins, larger floodplain conservation areas, or flood control reservoirs that are capable of effectively addressing runoff from larger watershed source areas or multiple developments. Examples of regional stormwater approaches are described below in Section 4.5.3.

Multi-Benefit Projects

Off-site solutions also provide opportunities to address multiple objectives beyond stormwater. The trend in stormwater management in California has moved towards projects which support the concept of integrated regional water management (IRWM). In this framework, projects are designed to not only solve immediate issues related to stormwater quantity or quality, but also effectively address other concerns such as water supply, water reuse and recycling, flood control, watershed management, and habitat protection and restoration.

These multiple benefits can be enjoyed regardless of the scale of the solution. For instance, a small-scale vegetated swale that is located off-site may not only slow water velocities and provide water treatment functions, but also provide wildlife habitat and habitat connectivity, and serve as a recreational or aesthetic amenity for the community. Larger-scale solutions often increase the scale of such benefits. For example, the preservation and management of open space in a highly erosive area not only reduces sediment loads to downstream areas, but also provides for habitat amenities, groundwater recharge, and a wide variety of other benefits.

Developers are encouraged to think about the ways in which a project can provide multiple benefits when approaching off-site solutions, and design such solutions accordingly.

4.5.2 Off-Site Retrofit Opportunities

4.5.1 Purpose and Need for Off-site Stormwater Management
4.5.2 Off-site Retrofit Opportunities
4.5.3 Regional Approaches

Retrofitting refers to implementing LID techniques and treatments at previously developed sites to reduce stormwater impacts. If conditions are right, retrofitting can be a cost-effective means to mitigate impacts that cannot be adequately addressed at the project site. Examples of the LID practices described in this guidebook that can be implemented at already developed sites include roof gardens and vegetated roofs, rain barrels, and replacement of impervious surfaces with pervious surfaces such as permeable pavement. Retrofit opportunities may offer fruitful ways to mitigate stormwater impacts and provide benefits to both the on-site developer and the off-site receiver for such retrofits. Retrofitting also effectively integrates a longer-term view of stormwater management in which all development—past, present and future—is designed to meet stormwater management goals.

Parking Lots

One promising opportunity in Sonoma County, considering their size and effect on stormwater, is the retrofitting of parking lots. Traditional parking lots contain large areas of impervious surface which greatly reduces the time of concentration, reduces runoff duration, increases net runoff volume, and reduces subsurface infiltration and recharge. Additionally, parking lots typically introduce contaminants from automobiles and other sources, such as oil, grease, heavy metals, nutrients, and particulates. Currently in Sonoma County there are a few parking lot retrofit demonstration projects, including at the County Fairgrounds, at the County Administrative Center parking lot, and a few other projects sponsored by Caltrans.

Retrofitting a parking lot can include installation of vegetated drainage swales which can slow and filter stormwater, rain gardens, and use of infiltration galleries and basins to reduce the volume of stormwater and increase subsurface recharge. For parking lots that drain internally to a drainage point within the parking lot itself, the retrofit opportunities may be more limited, depending upon the parking lot size and graded elevations. Extensive regrading to achieve suitable elevations that enable infiltration would likely make such a project cost prohibitive. In these cases, pervious paving may represent the best and most practical option to reduce runoff, if even limited to a portion of the parking area. Pervious paving can be targeted to particular areas of the parking lot, such as at selected parking stalls, around buildings, at lot boundary areas or margins, or near landscaped areas to achieve targeted results.

Depending on the configuration, gradient, and elevations of the existing parking lot, LID improvements may be relatively easy. For instance, angled parking creates a triangle of unused area at the head of each parking space that can be used for installation of vegetated swales or planters (**Figure 4-22**). Existing islands in parking lots or medians between rows of parking can provide similar opportunities. In some cases, parking spaces can be shortened by several feet to

allow for installation of swales or other biofilter-type features. Other opportunities include routing of stormwater to an off-site treatment feature such as a constructed wetland, or reconstructing a portion of the parking lot to provide such a feature. Key constraints to LID retrofitting for parking lots include having a suitable gradient and having elevations of potential runoff receiving areas (such as swales) that will enable capture and detention.

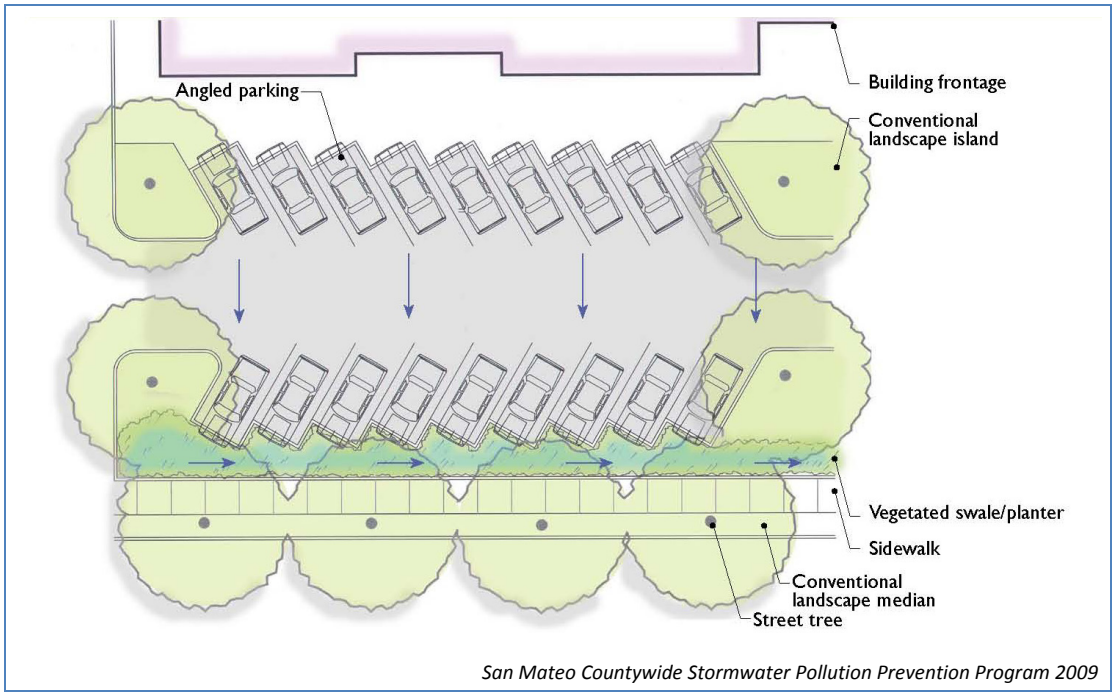


Figure 4-22: Vegetated Swale or Planter within Angled Parking Lot

In considering LID retrofit options for parking lots, the lots need to be carefully evaluated for their existing space requirements, entrance and egress requirements, drainage flow lines and patterns, and lot overall design to determine what LID opportunities exist. The retrofit evaluation will consider not only stormwater treatment but also the usability of the parking area. At many locations, parking lot capacity exceeds expected daily and even peak use, in which case there is available space for retrofit options. In other instances, the parking lot can simply be reconfigured (e.g., resizing of parking spaces) to allow space for LID features without compromising parking lot capacity. LID features in parking lots need to be carefully designed and sized to accommodate a particular storm event flow, and allow for overflow when an event exceeds the design capacity. Ongoing inspection and maintenance of the retrofits are also required.

Streets and Other Paved Areas

Other regional opportunities to reduce impervious areas and improve stormwater quality include retrofitting paved areas throughout a city or large developed areas with permeable paving materials and applying biofilter features (similar to those discussed above) along streets and sidewalks. The site planning and design practices described above in Chapter 4 can be

applied at the street-scale, as well as for large business parks or residential complexes. LID retrofit opportunities can be applied to more efficiently utilize street and public rights-of-way for stormwater management. For example, underutilized portions of streets and sidewalk areas can be retrofitted with stormwater curb extensions and various types of vegetated swales that capture, treat, and even prevent runoff from pervious areas from entering the existing underground storm drainage system. Public spaces such as courtyards between office or residential buildings and walkways can be retrofitted with permeable paving materials, as discussed in the above Fact Sheet on permeable paving. The San Mateo Countywide Stormwater Pollution Program's *Sustainable Green Streets and Parking Lots Design Guidebook* (2009) includes many examples of these retrofit techniques.

4.5.3 Regional Approaches

4.5.1 Purpose and Need for Off-site Stormwater Management
4.5.2 Off-site Retrofit Opportunities
4.5.3 Regional Approaches

This section provides a general description of the following regional stormwater management approaches: dry ponds, multi-objective detention basins, floodplain and channel restoration, constructed wetlands, stormwater injection, and watershed source control protection. Taken together, these regional approaches not only provide stormwater benefits, but also provide flow management benefits for larger magnitude "flood flows," especially when these approaches are integrated throughout a drainage system or watershed.

Dry Ponds

Dry ponds are a type of detention basin that are also commonly referred to as dry extended detention ponds, detention ponds, or extended detention ponds. Dry ponds are basins that detain stormwater runoff for a minimum duration to moderate discharge peaks and allow sediment particles and associated pollutants to settle out. Dry ponds, in contrast to wet ponds, do not hold a permanent pool of water. Dry ponds can be sized and designed to address higher frequency (lower magnitude) stormwater type events, lower frequency (higher magnitude) flood control events, or a range of events. Because of this flexibility, dry ponds are a very widely applied stormwater treatment practice.

In general, dry ponds are best used on sites with a minimum drainage area of 10 acres (Center for Watershed Protection 2000). The basin or pond site needs enough elevation change (slope) between pond inlets and outlets to maintain flow through the system. Dry ponds can be constructed in almost all soil and geology types, but the base of the pond should not intersect the groundwater table. Dry ponds or basins that are specifically intended to detain and retain flows and encourage infiltration and groundwater recharge will need to be developed in higher infiltrating/percolating soil and subsurface conditions (**Figure 4-23**).

Figure 4-23: Dry pond detention basin in Riverside, CA receives runoff from steep bedrock watershed areas upstream. This dry pond site provides excellent infiltration capabilities into deep alluvium

Depending upon land uses in the runoff source areas, the water quality of incoming flows, and/or any known pollutant or contamination issues, interaction between percolation from the pond and the groundwater table below may or may not be desired. In areas with high sediment loads, a sediment forebay is often used above (upstream) of the pond or basin to capture coarse sediments before they enter the main basin. If water quality from the runoff source area is of particular concern, design of the dry pond should seek to maximize retention and detention times as possible. In general, dry ponds and detention basins are effective at physical detention, but in some cases may not provide as effective water quality treatment as smaller scale LID treatments.

Depending on the pond size, local climate, past storm events, sediment trapping efficiency of the pond, etc., the pond may have variable effectiveness at pollutant removal. Such basins typically require annual maintenance to remove accumulated sediments and clear inlets and outlets of debris or vegetation. Stagnant water can lead to mosquito breeding, especially in ponds with overgrown vegetation and general lack of maintenance. In general, however, dry ponds should be designed to drain within 72 hours of a rainfall event in order to prevent mosquito breeding, and the potential for mosquito-borne disease transmission and/or public health issues.

Multi-Objective Detention Basins

Multi-objective detention basins are similar to dry ponds in that they provide potential stormwater, water quality, and flood control benefits. However, they also provide additional water resources, natural resources, recreational, and other land use and educational benefits. Multi-objective basins are specifically designed to address an array of topics and issues. Such basins may be on-line (within the direct flow course of the drainage system, with a more direct

hydraulic connection to inflows and outflows), or located off-line (not directly within the flow course of the drainage system, whereby the connection to inflows and outflows is more moderated and managed).

Figure 4-24 shows the completed construction of an award winning multi-objective detention basin design in Placer County by the Placer County Flood Control and Water Conservation District (PCFCWCD). The Miner's Ravine Off-Channel Detention Basin was designed to mitigate increased stormflows in the Dry Creek watershed resulting from upstream development and increased watershed imperviousness over the last few decades. The gravity-draining basin was designed to detain a portion of peak flows for up to six hours without affecting surrounding surface water elevations on the floodplain. Beyond stormwater and flood control management, the basin provides several other benefits, including wetlands restoration, floodplain and channel restoration through a levee setback, no fish-trapping effects, native vegetation restoration throughout, a multi-use recreational trail, and interpretive signage. Though the residence detention time is fairly short, the basin promotes and enhances groundwater infiltration and recharge.

Maintenance issues for multi-objective detention basins are similar to those described above for dry pond type basins. However, if the multi-objective basin provides habitat (through enhancement or restoration activities) then the maintenance approach to the basin will need to be sensitive to those habitat requirements.

Figure 4-24: Miner's Ravine Off-Channel Detention Basin, Placer County, CA

Hegedus 2008

In southern Sonoma County, there are a number of existing stormwater and/or flood control basins or reservoirs. These include:

- Brush Creek Reservoir,
- Piner Reservoir,
- Matanzas Reservoir,
- Spring Lake Reservoir, and
- Cook Creek Sediment Basin.

The reservoirs listed above provide the benefits of flood control, stormwater management, natural resource conservation, and recreation. **Figure 4-25** shows a portion of the Brush Creek Reservoir at its inlet facility and dam. The Cook Creek Sediment Basin is a smaller and more targeted facility, specifically designed to capture sediment delivered from a very erosive headwater source area (**Figure 4-26**). The Cook Creek Sediment Basin has been very effective at trapping sediment, which has reduced the need for sediment removal in downstream flood control channels. By providing a focused location to concentrate sediment removal activities, the Cook Creek Sediment Basin provides a cost-effective strategy to sediment management and reduces high impact maintenance activities in downstream channels. As it is located within the generally coarser sediment and soil conditions of the Rohnert Park area alluvial fan, the Cook Creek Basin is thought to also provide good groundwater recharge benefits.

Figure 4-25: Brush Creek Reservoir provides detention to foothill tributary streams in the Santa Rosa Creek watershed

Figure 4-26: Cook Creek Sediment Basin captures and traps sediment from high yielding headwaters areas

As shown in the topographic map and profiles of **Figures A-1 and A-5** in **Appendix 4**, the rapid break in gradient along the western slopes of Sonoma Mountain, Taylor Mountain, and the southern Mayacamas Range in southern Sonoma County creates a strong need for sediment and runoff management. Flows and sediment are transported from the steeper headwater areas and delivered (or deposited) on the alluvial fans and plains below. Similar to the Cook Creek Sediment Basin, other opportunities for multi-objective basins occur in southern Sonoma County. However, any new basin concepts would likely integrate additional natural resource and groundwater management into the design objectives along with sediment and runoff capture.

Floodplain and Channel Restoration

Channel and floodplain restoration projects can be very effective means to provide regional stormwater and flood control management. For floodplains, the general approach is quite simple in theory: let "floodplains act as floodplains" and enable overbank flows to spread from stream channels onto their adjacent floodplains and thereby use the natural detention and storage capacity of the low lying floodplain areas to moderate downstream discharge and water surface elevations. But floodplain restoration is far more involved and difficult in practice due to the myriad of existing flood control facilities that may require alteration, the potential flood threat to other lands, structures, and infrastructure that also may require modification, land ownership issues, zoning, etc.

Typically, agricultural lands have been the target areas for successful floodplain restoration projects. In agricultural lands, to maximize the arable growing land, levees or engineered banks were commonly developed to prevent streams from going overbank. The removal or phased setting-back of levees or engineered stream banks can allow localized or widespread floodplain

inundation, depending upon local conditions. Floodplain restoration in rural lands also poses fewer flood risks to structures, people, and infrastructure compared to more urban areas. The process of floodplain inundation (if not destructive) is also generally restorative to soil resources, with both agricultural and ecological benefits. Ecologists and environmental regulators are enthusiastic supporters of floodplain restoration because it not only restores a natural area, but also restores the physical processes that can sustain the habitats in those areas and help to stabilize morphology of adjacent stream channels or rivers. A key limit to floodplain restoration in agricultural areas is the willingness of current landowners to sell their properties (to land conservancies) or to enter into easement agreements with a local partnering land use agency that would typically take management responsibility for the restored floodplain.

As described above, floodplain restoration in more urban environments is more difficult due to the presence of existing infrastructure. However, floodplain restoration in urban environments can be achieved. An example of a very successful floodplain restoration project in a semi-urban and agricultural environment is taken from the Napa River Flood Management Plan, a cooperative effort between multiple agencies and led by the Napa County Flood Control and Water Conservation District (NCFCWCD) and the US Army Corps of Engineers (USACE). This far reaching plan (**Figure 4-27**) was based on the "living river concept" to provide the Napa River with as much room as feasible and to re-occupy historic floodplains in the lower watershed. The project involved several engineering works, including the rebuilding of several bridges, roads, and a flood bypass channel. This successful project has won awards and acclaim for improving flood management, lowering the flood risk in the City of Napa, and providing several miles of restored floodplains.

Figure 4-27: Aerial Views of Lower Napa River and Floodplain and the Napa River Flood Project

Channel restoration activities can also provide regional stormwater and flood management benefits. This typically occurs on a smaller scale than the larger floodplain restoration projects, and involves expanding stream and channel areas that were previously constricted or narrowed through engineered facilities or other channel incision processes. Expanded channel areas that allow flows to expand and spread onto adjacent channel bars and bench features can provide additional runoff storage detention within the channel easement (without involving overbanking onto adjacent floodplains).

In Sonoma County there may be several opportunities for additional stream channel and floodplain restoration projects that would provide the regional benefits of runoff detention and storage, groundwater recharge, and natural resource enhancement and restoration. In addition to floodplain restoration projects, land use planning policies that discourage or prohibit urban development in active floodplains are another means to protect the hydrologic functions of floodplains.

Constructed Wetlands

Constructed wetlands are also known as stormwater wetlands or treatment wetlands. They are engineered and designed shallow pools and depressions that incorporate wetland vegetation and attributes to store and detain runoff and also provide water quality treatment (Center for Watershed Protection 2000). Constructed wetlands are especially effective at removing stormwater pollutants, including nutrients (nitrogen and phosphorus) and bacteria. Constructed wetlands are fundamentally different from natural wetland systems in that they typically provide less plant and animal biodiversity, and do not typically have underlying soils that contain high levels of organic material. Constructed wetlands have wide application and can be used effectively as a retrofit approach to an existing development or land use.

As illustrated in **Figure 4-28**, a sediment forebay, similar to dry ponds, is an important design consideration to reduce sedimentation and the need for sediment removal maintenance activities. For best results, constructed wetlands need a sufficient drainage area to maintain a shallow permanent pool, and therefore may not work in particular climates or watersheds. For effective water quality filtration, it is recommended that the surface area of the constructed wetland be at least 1% of the source area draining to it (e.g. 100 acre drainage area would require a 1 acre wetland), and the wetland should be 3 times longer than it is wide, with different elevation zones within the wetland to provide different settling areas (Bay Area Stormwater Management Agencies Association 1999).

Constraints for the use of constructed wetlands include the requirement for adequate space, vector control (e.g., the creation of mosquito breeding areas), the potential release of nutrients back into the drainage system during the non-growing season, and very limited groundwater recharge capacity due to the sealing effect of sediment and organic matter (which can accumulate on the wetland substrate over time). Some of these concerns are illustrated in **Figure 4-29**, which shows a constructed wetland in Sonoma County.

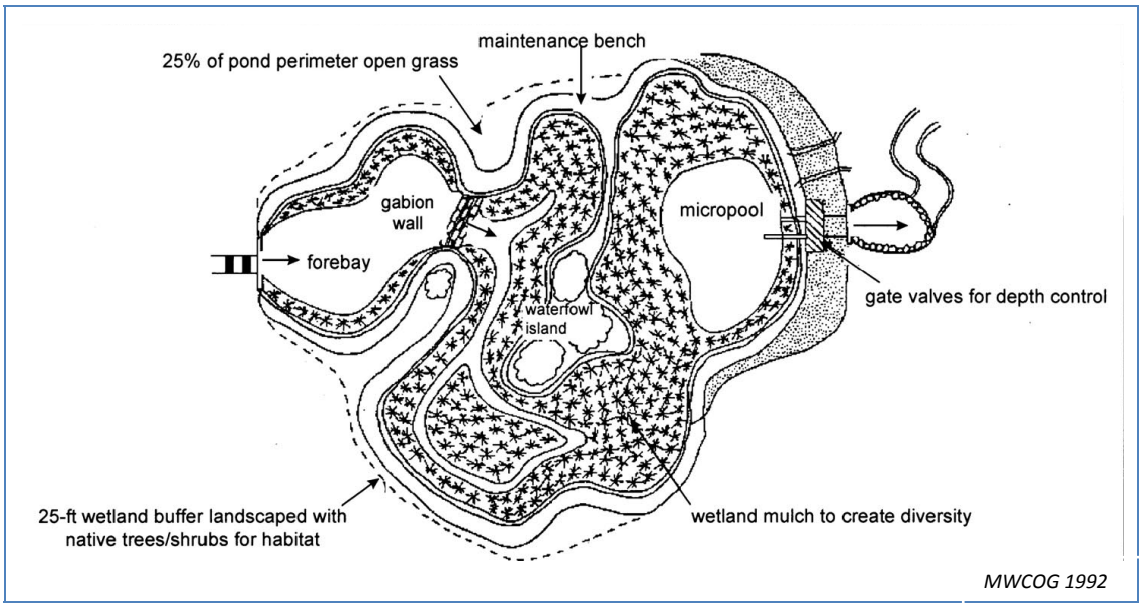


Figure 4-28: Example Design Approach for Constructed Wetlands

Figure 4-29: Constructed Wetland in Southern Sonoma County

Stormwater Percolation Systems

Stormwater percolation systems are designed to allow stormwater to penetrate the subsurface zone and thereby recharge groundwater. Prior to the percolation process, collected stormwater is typically treated through a settling process (using a swale or sediment basin) to remove finer sediments. Pre-treatment can also include oil separators or other specific water quality treatments, either conventional or bioengineered. The collected stormwater is then routed to an infiltration area, usually developed in clean gravel or stone, where the water can infiltrate. Percolation systems can use a vertical infiltration process (including pipes, infiltration wells (or dry wells), and sumps) or a horizontal process (such as French drains and trenches) to accomplish the infiltration.

Use of stormwater percolation systems must consider local groundwater use for drinking water supplies, and therefore must be located at a safe distance away from any water supply wells and areas susceptible to a high groundwater table. The effectiveness of stormwater percolation systems will greatly depend upon soil, geologic, and topographic conditions. Percolation systems are generally best applied to small sites less than 5 acres that have relatively high impervious cover with excellent infiltration capacity beneath. The system should be constructed so that soil infiltration rates range between 0.5 and 3 inches per hour. In addition, the soils should have no greater than 20% clay content, and less than 40% silt/clay content (Center for Watershed Protection 2000). Stormwater percolation systems are relatively expensive to maintain to prevent sedimentation and clogging of the infiltration well. Stormwater percolation and injection is also highly regulated by federal and state agencies and requires higher levels of regulatory oversight and coordination than some of the other regional management approaches described in this section.

Figure 4-30 depicts a stormwater infiltration well (dry well) installed on a property in Sonoma County. These types of features can provide valuable groundwater recharge benefits and are actively being pursued in Sonoma County, particularly in conjunction with agricultural operations, such as vineyards.

Watershed Source Control Protection

Another approach to regional stormwater management involves land use and watershed management planning efforts to avoid, reduce, and mitigate stormwater or flooding effects. Sonoma County and cities within the county have various policies that relate to 100-year flood zones as defined by the Federal Emergency Management Agency (FEMA). Several cities in the County have policies that restrict development in areas along FEMA 100-yr flood zones unless adequate protection for flood hazards is incorporated. This includes the cities of Petaluma, Rohnert Park, and Santa Rosa which require flood protection for new or remodeled habitable structures within areas along local rivers and creeks (i.e. Petaluma River, Spring Creek, Matanzas Creek, Copeland Creeks, etc). In unincorporated areas of Sonoma County located in FEMA-mapped 100-year flood zones, a “zero net fill” requirement is enforced. Additionally, Policy PS-2f of the Sonoma County General Plan (2020) seeks to reduce fill placement that would impact flood storage or retaining flood water.

The conservation of watershed lands through protective easements or restrictions on development can minimize runoff impacts or mitigate other watershed sources of stormwater runoff. Additionally, restoration activities in watershed lands that reduce existing runoff or sediment yields also provide stormwater benefits. This approach can be used for watershed

Figure 4-30: Infiltration Well Installed in Sonoma County

lands in which the soil has historically been compacted, the vegetation removed or thinned, or for local creeks that have been incised and eroded. Restoration projects that return vegetation cover, stabilize incised or eroded creeks, and provide soil benefits that can increase infiltration conditions all help to provide the regional benefits of reducing runoff and stormflows.