City and County of San Francisco
2030 Sewer System Master Plan

TASK 800
TECHNICAL MEMORANDUM NO. 809
LOW IMPACT DESIGN MODELING

FINAL DRAFT
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LOW IMPACT DESIGN MODELING

1.0 INTRODUCTION

As part of the SSMP, the SFPUC requested an analysis of low impact design (LID) to reduce wet weather flows into the combined sewer system. LID is an innovative approach to stormwater management that relies on decentralized, small-scale stormwater facilities and site-design techniques to reduce stormwater volume and peak flow rate, as well as to remove stormwater pollutants. Unlike traditional stormwater management, LID relies on natural hydrologic systems to slow down, capture, infiltrate and treat rainwater where it falls.

The purpose of this technical memorandum (TM) is to summarize findings of the LID analysis and recommendations for development of policies, programs and projects.

1.1 Background

This memo builds on four previous reports that addressed stormwater management for San Francisco:

- CH2M HILL (1997) *Overview of Wastewater Management Alternatives for Reducing Pollutant Mass Discharge to the Bay- DRAFT*
- Brown and Caldwell (2004) *Screening of Feasible Technologies (SOFT*)
- Jencks (2005) *Finding Room for Stormwater: A Review of Site & Design Opportunities in San Francisco*
- Hydroconsult Engineers, Inc. (2007) *Technical Memorandum 2: Leland Avenue Street Drainage Improvements*

The CH2M HILL report included a brief review of rooftop catchment as a flow reduction strategy. According to the report, sandy soil conditions in portions of the Richmond, Sunset, Vicente, and Lake Merced districts of the City would allow aquifer recharge with captured roof runoff. The report asserted that if half the roofs were disconnected from the combined sewer system in those areas, the volume of untreated CSOs could be reduced by over 40 percent. Potential disadvantages included mosquito breeding and structural foundation problems if systems were improperly designed.

The Brown and Caldwell report described and evaluated several upstream source-control and stormwater reduction measures for their effectiveness, costs, site constraints, and appropriateness for Bayside subwatersheds. Brown and Caldwell's key recommendations for upstream controls were as follows:

- Reduce the impervious surface acreage by re-vegetating formerly paved areas.

- Install vegetated swales and filter strips in redevelopment areas and along boulevards and larger streets.
- Install infiltration facilities where possible, such as to the north and east of Golden Gate Park.
- Install new and retrofitted eco-roofs and storm water storage.

Jencks (2005) analyzed the potential to implement landscape-based stormwater BMPs in San Francisco, and quantified the potential volume-reduction impacts of those practices in the Islais Valley Watershed. Jencks found that converting 100 percent of streets and right-of-ways to permeable pavement would reduce runoff by an average of 15 percent for seven design storms ranging from 1- to 100-year return intervals. Retrofitting 100 percent of the flat roofs to vegetated roofs would reduce runoff by 29 percent. Street trees were found to have negligible effect on stormwater runoff volumes; however, that finding may be conservative due to the low interception rate assumed (1.5 percent). If a combination of those BMPs were implemented (twice as many trees per block, 100 percent of flat roofs converted to vegetated roofs, 100 percent of pavement converted to permeable pavement, and schools and parks retaining all runoff on-site), stormwater runoff would be reduced on average by 58 percent.

Hydroconsult Engineers, Inc. recently completed a hydraulic modeling study on the drainage benefits of LID in the Leland Avenue vicinity of San Francisco's Sunnydale Sewershed. The hydrologic model, constructed using Infoworks Collection System software, demonstrated drainage benefits for four design storms: 2-yr and 5-yr recurrence intervals with 1-hr and 3-hr durations. The drainage improvements modeled included streetscape improvements (permeable pavement with infiltration and curb cut-out garden beds) and improvements at a proposed new library site (new pervious areas and an vegetated roof). The analysis found that implementing the streetscape and library improvements resulted in a 30 percent decrease in peak runoff flow rates and a 12 percent decrease in runoff volume.

Hydroconsult also developed a simplified spreadsheet-based calculation tool, the Modified Rational Method Tool (MRMT), which estimates peak flow rates and runoff volumes, and can be used to ascertain drainage improvements that may result from implementing LID. The MRMT provides a means to broadly assess drainage improvements at sites around the City and County of San Francisco where there is no existing hydraulic model.

1.2 Scope

To better understand the potential benefits of LID in San Francisco, the project team analyzed several LID strategies for urban areas. The analysis included the following steps:

- Literature review and case studies,

- Review of existing programs within SFPUC and other San Francisco departments that could complement or support LID,
- GIS spatial analysis of potential LID implementation in San Francisco,
- Modeling of LID scenarios within the collection system model.

2.0 OVERVIEW OF LOW IMPACT DESIGN

LID is an innovative approach to stormwater management that relies on decentralized, small-scale stormwater facilities and site-design techniques to reduce stormwater volume and peak flow rate, as well as to remove stormwater pollutants. Unlike traditional stormwater management, LID aims to slow down, capture, infiltrate and treat rainwater where it falls. Decentralized stormwater controls “have the potential to reduce the frequency and volume of CSO events by using natural hydrologic cycle elements to dampen the stormwater surges that overwhelm the conveyance capacities of combined systems” (Weinstein et al, 2006). Typical LID practices for urban areas include vegetated roofs, vegetated swales, rain gardens, permeable pavement, urban forestry, roof-drain disconnection, rainwater harvesting, and stream daylighting.

LID has several advantages over large transport systems and centralized storage or detention facilities. LID: 1) requires less space, 2) causes less disturbance to communities during construction, 3) allows flexibility to respond to evolving economic and environmental conditions, 4) provides ancillary benefits such as energy conservation, natural habitat, and aesthetic quality.

LID comprises both a core set of principles and a toolbox of stormwater control strategies. The core principles, adapted from *NRDC (2002)*, .are:

- To integrate stormwater management early in site planning activities
- To use natural hydrologic functions as the integrating framework for site development
- To focus on preventing problems associated with runoff before they happen rather than mitigating problems after they occur
- To emphasize simple, nonstructural, low-tech, and low-cost methods of on-site stormwater management
- To manage runoff as close to the source as possible
- To distribute small-scale stormwater management practices throughout the landscape
- To rely on natural landscape features and processes to slow and filter runoff and encourage groundwater recharge

- To create a multifunctional landscape

The following sections describe several LID practices that are applicable to urban areas such as San Francisco. A more comprehensive literature review is included in Task 800 Technical Memorandum No. 808.

2.1 Vegetated roofs

Vegetated roofs, also known as ecoroofs, green roofs, or living roofs, are categorized as intensive or extensive depending on the substrate depth and vegetation type. An intensive vegetated roof, or rooftop garden, has a deep growing medium planted with shrubs and small trees, often arranged with walking paths and seating areas. By contrast, an extensive vegetated roof covers a rooftop with shallow layers (< 6 inches) of lightweight growing medium, low-growing vegetation, subsurface drainage, and a waterproof membrane. This section focuses on extensive vegetated roofs, which offer greater benefits for stormwater management.

Vegetated roofs can be installed on most types of commercial, multifamily, and industrial structures, as well as single-family homes, garages, and sheds. Roofs with slopes up to 40 degrees are appropriate, though vegetated roofs are most suitable on roof slopes between 5 to 20 degrees (1:12 and 5:12). Vegetated roofs can be used for new construction or to re-roof an existing building. Candidate roofs for a “green” retrofit must have sufficient structural support to hold the additional weight of the vegetated roof, generally 10 to 25 lb/ft^2 saturated.

Vegetated roofs absorb rainfall and release it slowly, thereby reducing the runoff volume, reducing peak flow, and delaying the time to peak. Rainfall retention and detention are influenced by the storage capacity of the growing medium, antecedent moisture conditions, rainfall intensity and duration, and perhaps (though inconclusively) by roof slope. On average, vegetated roofs retain 50 to 65 percent of rainfall annually, and reduce peak flows for large rain events (>1.5 in) by approximately 50 percent.

Vegetated roofs also filter out contaminants as the runoff flows across the roof and degrade those contaminants by binding them to the growing medium or via direct plant uptake. Studies have shown reduced concentrations of suspended solids, copper, zinc, and PAHs from vegetated roof runoff, and increased concentrations of phosphorus and nitrogen.

2.2 Bioretention

The term bioretention refers to dispersed, small-scale landscape features designed to attenuate and treat stormwater runoff. Examples of bioretention include rain gardens, curb bulb-outs, vegetated swales, and tree-box filters. Though bioretention designs vary widely, all bioretention areas have the same basic features: a soil mixture, drainage mechanism, and vegetation.

Bioretention systems can be installed in parking lots, roadway median strips and right-of-ways, parks, residential yards, and other landscaped areas. System designs can be adapted for a variety of physical conditions. In areas where infiltration is appropriate, bioretention can be designed to temporarily store runoff while it slowly infiltrates into the underlying soils. Where infiltration is not appropriate, or if rainwater reuse is desired, bioretention areas can be contained (within an impervious liner) and equipped with an underdrain that discharges runoff to a conveyance, dispersal, or storage facility. The primary considerations in siting a bioretention system are space availability, suitability of the soils for infiltration, infiltration rate, seasonal high water table, depth to bedrock, and slope.

Bioretention systems improve stormwater runoff quality, reduce runoff volumes to varying degrees (depending on sizing and infiltration or flow-through design), and delay and reduce runoff peaks. Bioretention systems that are designed as small-scale infiltration systems are most effective for reducing runoff volumes. Those designed as flow-though systems (discharging to the municipal sewer) show lower retention rates, but are effective at delaying and reducing peak runoff.

2.3 Urban Forests

Urban forests, made up of publicly and privately maintained street and park trees, offer myriad benefits to the urban environment, including stormwater mitigation. Trees intercept rainfall before it reaches the ground, retaining a portion in the tree crown and thereby reducing runoff volume and peak flow.

In 2003, the City of San Francisco Street Tree Resource Analysis (Maco et al, 2003) reported that approximately 56 percent of all street-tree planting sites in the city are unplanted, ranging from 28 percent in affluent districts to 74 percent in underserved districts (e.g., Bayview-Hunters Point). These unplanted areas present an opportunity not only for significant stormwater reductions, but also for addressing environmental justice issues.

The analysis found that San Francisco's street trees reduce stormwater runoff by an estimated 13,270,050 ft^3 (99 million gallons) annually, for a total value to the city of $467,000 per year. On average, street trees in San Francisco intercept 1,006 gallons per tree annually. Certain tree species were better at reducing stormwater runoff than others; those demonstrating the highest stormwater reduction benefits were Blackwood acacia (large broadleaf evergreen), Monterey pine (large conifer), Monterey cypress (large conifer), and Chinese elm (medium deciduous).

2.4 Permeable Paving

Permeable paving surfaces, also known as pervious or porous pavement, are comprised of a porous, load-bearing surface and an underlying aggregate layer that allows for temporary rainwater storage prior to infiltration or drainage to a controlled outlet. Several types of

paving surface are available to match site conditions, intended use, and aesthetic preferences. Common permeable paving systems include the following:

- Permeable hot-mix asphalt: Similar to standard hot-mix asphalt, but with reduced aggregate fines;
- Open-graded concrete: Similar to standard pavement, but without the fine aggregate (sand and finer) and with special admixtures incorporated (optional);
- Concrete or plastic block pavers: Either cast-in-place or pre-cast blocks have small joints or openings that can be filled with soil and grass or gravel;
- Plastic grid systems: Grids of plastic rings that interlock and are covered with soil and grass or gravel.

Permeable pavement systems are most appropriate in areas with low-speed travel and light- to medium-duty loads, such as parking lots, low-traffic streets, street-side parking areas, driveways, bike paths, patios, and sidewalks. Site conditions (including soil type, depth to bedrock and water table, slope, adjacent land uses) should be assessed to determine whether infiltration is appropriate, and to ensure that excessive sediments and pollutants are not directed onto the permeable surfaces. Permeable paving surfaces must be cleaned periodically, usually by street sweeping or pressure washing, to keep pore spaces from becoming clogged.

Research and monitoring projects have shown that permeable pavements are effective at reducing runoff, delaying the onset of runoff, and improving water quality. Infiltration rates of permeable surfaces decline over time to varying degrees depending on design and installation, sediment loads, and maintenance.

2.5 Roof Rainwater Harvesting

Downspout disconnection, also called roof drain redirection, involves diverting rooftop drainage away from the sewer and into infiltration, detention, or storage facilities. In areas where site conditions allow infiltration, roof drainage can be conveyed to bioretention cells, dry wells, or simply dispersed onto a lawn or landscaped area. On sites that are not amenable to infiltration, roof drains can instead be routed into storage tanks or lined bioretention facilities that discharge to the sewer.

The term *rainwater harvesting* refers to the practice of collecting rainwater from rooftops or other surfaces and storing it for later use. After pretreatment (e.g. leaf screens and first-flush diverters), collected rainwater is stored in rain barrels or cisterns, which are available in a range of materials, sizes, and aesthetics. Captured rainwater can be used for on-site landscape irrigation, non-potable household uses, and industrial or commercial uses. Depending on the desired use, a rainwater treatment system may be required.

Rainwater can be harvested from residential, commercial, and industrial rooftops. The main siting constraints for downspout disconnection and rainwater harvesting are: 1) roof drainage configuration, 2) site conditions for storage tank and construction of new laterals, and 3) rainwater uses.

Roof rainwater harvesting can retain up to 100 percent of roof runoff on site, with only that water in excess of storage capacity contributing to stormwater flows. Rainwater pretreatment devices also improve the quality of runoff entering the sewer.

2.6 Stream Daylighting and Diversion

Stream daylighting refers to projects that uncover and restore streams that were previously buried in underground pipes and culverts, covered by decks, or otherwise removed from view (Pinkham, 2000). Stream diversion, more akin to sewer separation than to stream restoration, involves installing a new pipeline to divert the stream flow directly into another water body rather than into the combined sewer.

The volume of inflow that can be diverted from the sewer system will be specific to local hydrology and therefore cannot be generalized. Nevertheless, several past and planned projects demonstrate the potential for CSO and treatment capacity benefits:

- Since 1988, the City of Zurich, Switzerland, has daylighted over 11 miles (18 km) of streams and brooks to reduce flows into their CSS and wastewater treatment facilities. As a result, nearly 4.5 million gallons per day has been diverted from the city's two wastewater treatment plants (Pinkham, 2000; City of Zurich, 2006).

- The City of Portland, Oregon, included stream diversion as one of four "Cornerstone Projects" of their CSO abatement program. Tanner Creek and several smaller creeks had previously been piped into the CSS, which frequently overflowed into the Willamette River. The City is currently installing new pipelines to allow Tanner Creek to flow directly into the Willamette River. The finished project is expected to remove approximately 165 million gallons of stormwater annually from the CSS (City of Portland, 2005).

- The City of Seattle and King County recently installed new pipelines to divert Ravenna Creek from the CSS, and are daylighting two segments of the creek that flow through City parks. The County expects to divert wet-weather flows of 1.3 mgd and storm flows of 3.2 mgd. In addition, Ravenna Creek will augment Lake Washington during dry weather with 1 cfs of streamflow (Goon, 2006).

2.7 Summary

Table 1 summarizes the LID strategies reviewed in this technical memorandum.

Table 1 Summary of Low Impact Design Strategies
San Francisco Sewer System Master Plan
City and County of San Francisco

LID Strategy	Applications	Siting Constraints	Potential Benefits	Potential Drawbacks	Performance	
					Retention and Detention	Water Quality
Vegetated roofs	Residential, commercial and industrial rooftops	• Roof slope • Structural support • Maintenance access	• Stormwater mitigation • Building energy conservation • Extended roof life • Reduced heat island effect • Improved air quality • Wildlife habitat • Urban amenities • Market for recycled materials • Job creation	• Plants require irrigation while becoming established and during dry periods • Must be properly drained to prevent mosquito breeding	• Retain 50% to 65% of rainfall annually • Reduce peak flows for large rain events (>1.5 in) by approx. 50%.	• Reduce suspended solids, copper, zinc, and PAHs • Increase phosphorus and nitrogen
Bioretention	Parking lots, street right-of-ways and islands, planter boxes, other landscaped areas	• Slope • Soils • Depth to bedrock • Depth to water table	• Stormwater mitigation • Aesthetics • Improved function of street right-of-way • Wildlife habitat • Reduced heat island effect	• Plants require irrigation while becoming established and during dry periods • Must be properly drained to prevent mosquito breeding	• Widely ranging - dependent on infiltration rates, sizing, design • Up to 100% retention for infiltration systems • Lower retention for flow-through systems (~0.4%) • Delay onset of runoff and reduce peak flows	• Reduce runoff temperature • Reduce concentrations of: copper, lead, zinc, cadmium, chromium, phosphorus, nitrogen, ammonia, oil & grease, TSS, TOC
Urban Forest	• Streets, yards and parks • 56% of all street-tree planting sites in SF remain unplanted		• Stormwater mitigation • Reduced heat island effect • Air quality improvement • Building energy conservation • Quality of life • Atmospheric CO2 reduction • Wildlife habitat • Longer life of street pavement	• Root intrusion into sewer lines • Utility line interference • Sidewalk heave • Visibility of street signs and traffic at intersections	• On average, street trees in San Francisco intercept 1,006 gallons per tree annually • Highest stormwater reduction benefits demonstrated by Blackwood acacia, Monterey pine, Monterey cypress, and Chinese elm	

Table 1 Summary of Low Impact Design Strategies
San Francisco Sewer System Master Plan
City and County of San Francisco

LID Strategy	Applications	Siting Constraints	Potential Benefits	Potential Drawbacks	Performance	
					Retention and Detention	Water Quality
Permeable Paving	Low-traffic streets, parking areas, driveways, sidewalks, bike paths	• Soils • Slope • Depth to bedrock • Depth to water table • Vehicle weight/ traffic • Access for disabled persons • Sediment and pollutant load	• Stormwater mitigation • Noise reduction • Increased safety for vehicular traffic	• Requires strict sediment control and periodic sweeping to prevent pervious surface from becoming clogged • Requires specialized training for construction	• Can eliminate surface runoff for most storms • Retention highly variable • Delays onset of subsurface runoff and reduces peak	• Reduce concentrations of zinc, copper, lead, calcium, TSS, nitrogen, phosphorus, silica • Increase nitrogen, conductivity, and hardness in some cases
Stream Daylighting and Diversion	Streams previously culverted and routed into the combined sewer system	• Original stream channel may be developed	• Stormwater mitigation • Easier to maintain than buried culverts • Habitat restoration • Aesthetics • Public amenity • Outdoor laboratory for schools • Quality of life	• Original stream channel often developed upon • Social and psychological challenges due to fear, construction disruptions, etc. • Institutional challenges due to land ownership, liability, permitting	• Specific to local hydrology • Case studies show positive results	
Roof Rainwater Harvesting	Residential, commercial and industrial buildings	• Space requirements for storage tank • Depth to bedrock (for buried cistern or installation of new laterals • Configuration of roof drain (internal or external)	• Stormwater mitigation • Water conservation	• Roof runoff quality may be inadequate for desired use	• Up to 100 percent retention for onsite storage and reuse	• Roofing materials may contribute contaminants to runoff (e.g. copper) • Depending on desired use, rainwater may require pretreatment, filtration, and/or disinfection

3.0 MODELING APPROACH

The objective of the LID analysis was to reach a planning-level view of how extensively LID could be implemented in San Francisco, and the drainage benefits that could be achieved. The aim was also to establish a foundation of theory and data on which to build further studies. Model findings will be used to guide policies, programs and projects for reducing combined sewer discharges (CSDs), improving level-of-service for the existing sewer system, and promoting best practices for new and redevelopment in the combined sewer area.

The overall approach to the LID analysis is summarized in Table 1. Following the LID literature review, the project team selected several LID practices that would be most broadly applicable to San Francisco and for which modeling could be supported by available data and resources. Next, the potential spatial distribution of these practices throughout the city was analyzed using geographic information system (GIS) software, spreadsheets, and supporting data. Model parameters were then generated for a range of LID implementation scenarios. Lastly, several LID scenarios were simulated in the InfoWorks collection system model. Each of these steps is detailed in the following sections.

- Select LID practices to evaluate
- Establish siting constraints for each LID practice
- Utilize GIS to determine potential LID coverage
- Develop scenario assumptions
- Simulate LID scenarios in the collection system model
- Select LID practices to evaluate

3.1 Selection of LID Toolbox

For this analysis, the project team selected only those LID practices that would be widely applicable across San Francisco and for which modeling could be supported by adequate data and resources. The LID practices that were selected included: vegetated roofs, street trees, roof disconnection, lined bioretention systems, and lined permeable pavement systems. Infiltration practices and stream daylighting were evaluated but were excluded from the modeling. The following sections describe the LID practices that were evaluated, and detail the assumptions and constraints applied to each LID practice that was selected for modeling.

3.1.1 Infiltration Practices

The potential for infiltration practices, such as un-lined bioretention and permeable pavement systems, was evaluated by creating an infiltration zone map of San Francisco. The infiltration zone map, developed using GIS software, represented areas that would generally be appropriate or inappropriate for infiltration practices. Delineation of the infiltration zones was based on the following five variables:

- slope (0-5 percent, 5-10 percent, >10 percent)
- depth to bedrock (0-10 feet, >10 feet)
- soil contamination
- soil group classification (US SCS groups A, B, C, D)
- liquefaction risk (very low, low, medium, high, very high).

The first infiltration zone map, produced early in the LID analysis process (May of 2006), showed that only 15 percent of the city would be amenable to infiltration. The other 85 percent of the city would be unsuitable for infiltration due to one or more of the following factors: steep slope, shallow depth to bedrock, soil contamination, landfill, low-permeability soils, liquefaction hazard, landslide hazard. Subsequent iterations of the infiltration zone map further refined the infiltration zone categories, with a much smaller area categorized as "not recommended" for infiltration. Still, only a small percentage of the city would be considered ideal for infiltration. Based on those findings, the project team decided that infiltration practices would not be widely applicable throughout the city, and therefore should not be included in the LID modeling. These practices could, however, be considered on a site-specific basis, and should be included in future modeling studies. Figure 1 presents version 4 of the infiltration zone map, developed in June 2006.

3.1.2 Stream Daylighting

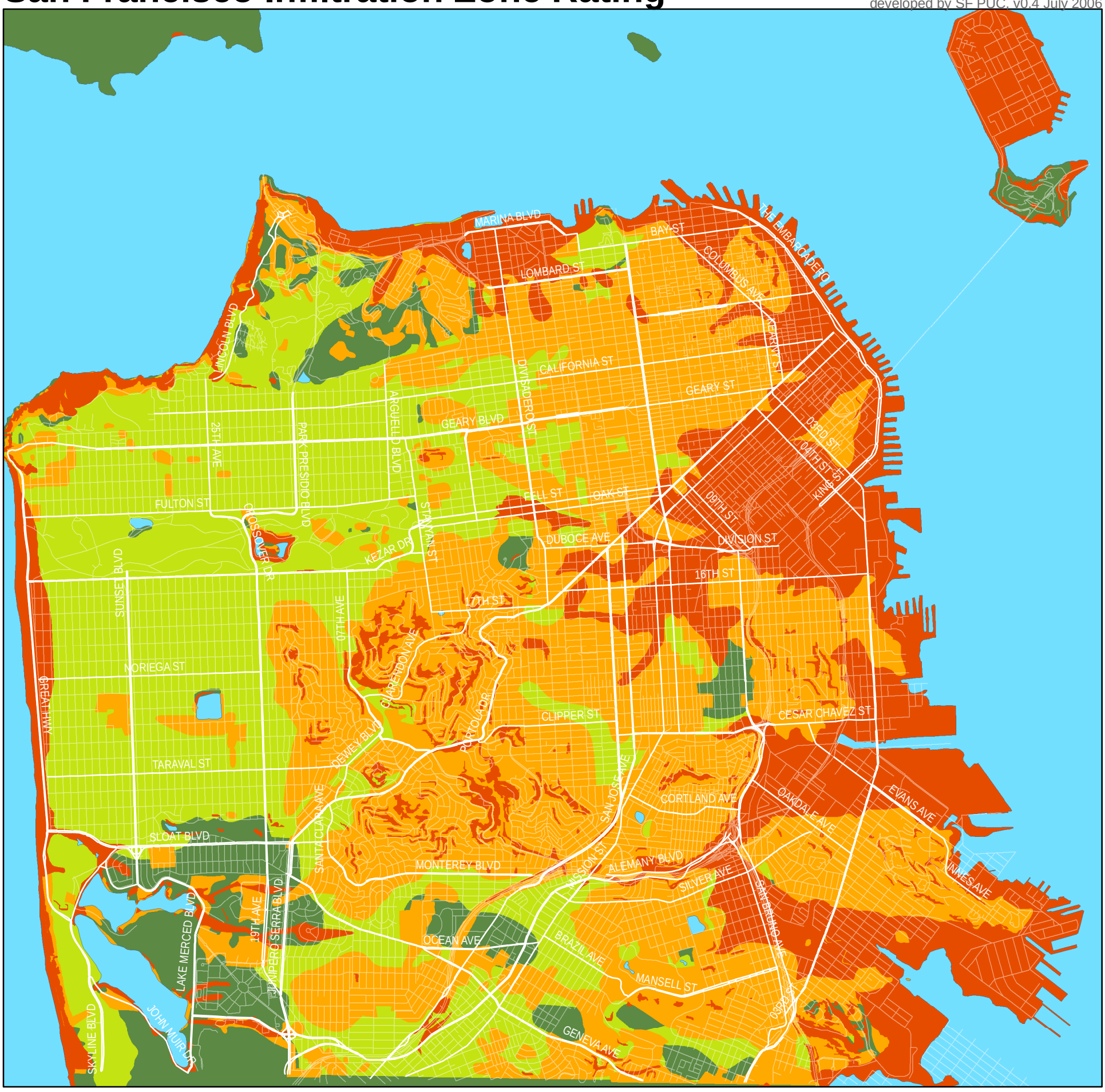
Stream daylighting was excluded from the modeling analysis because it represented a concentrated rather than distributed stormwater control, and would require site-specific investigations that are outside the scope of this analysis.

3.1.3 Vegetated roofs

Extensive vegetated roofs were selected to be included in the LID modeling analysis. For this analysis, it was assumed that vegetated roofs would consist of a waterproof membrane, a drainage layer, 3 to 6 inches of growing medium, and low-growing plants. Vegetated roofs of this type typically retain 50 to 60 percent of annual rainfall, reduce peak flow, and have a rainfall storage capacity of between 0.4 and 0.8 inches. It was assumed that all buildings would have (or could be retrofitted to have) adequate structural support for a vegetated roof, and that vegetated roofs would only be installed on roofs with slopes less than 20

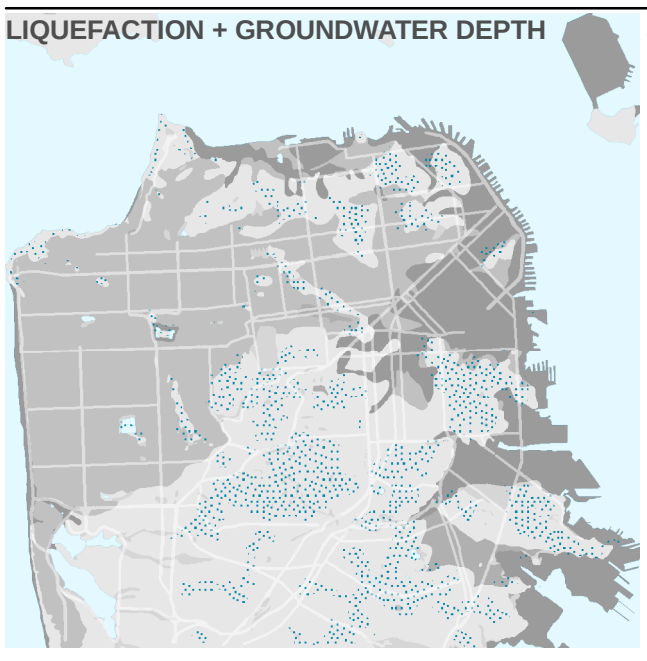
San Francisco Infiltration Zone Rating

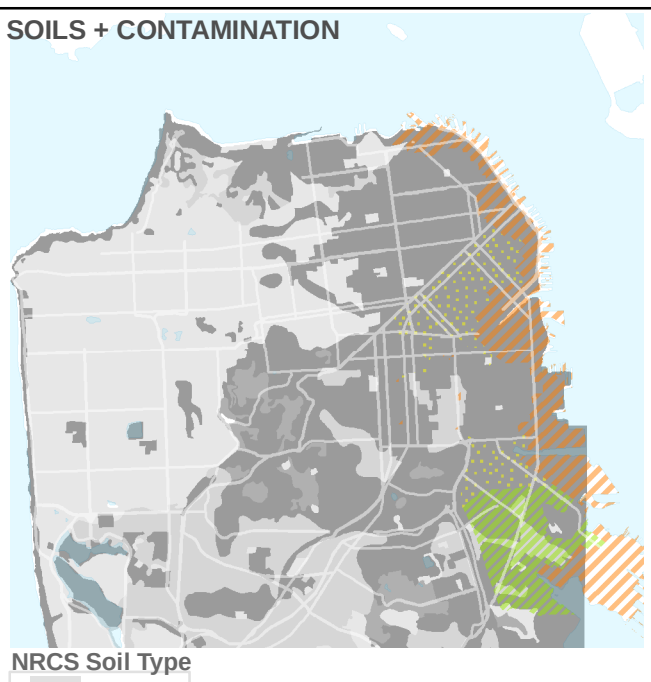
developed by SF PUC, v0.4 July 2006

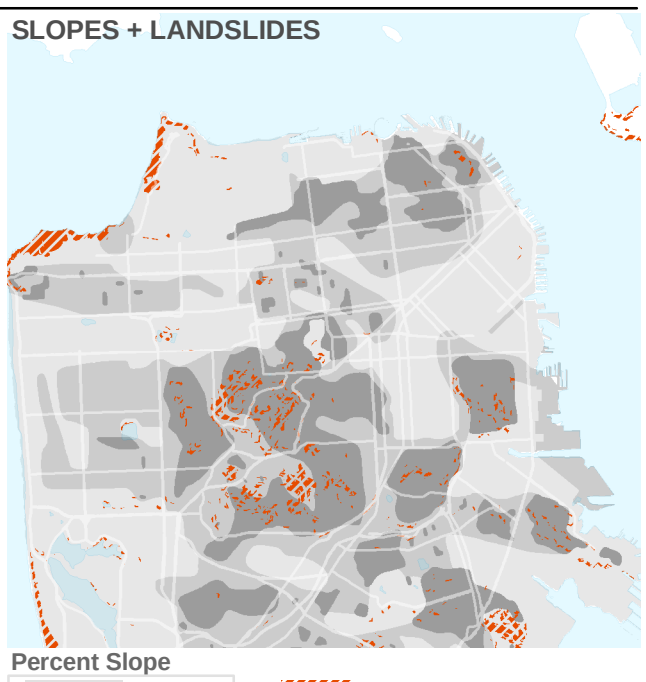


INFILTRATION ZONES

Not Recommended		Very High to High Liquefaction Hazard, Landslide Hazard
Challenging		D Soils, Slope > 10%, Groundwater Depth < 10', Maher (Contaminated) Site
Further Study		C Soils, Slope 5-10%, Medium Liquefaction Hazard
OK		A or B Soils, Slope < 5%, Low to Very Low Liquefaction Hazard







Liquefaction Hazard

VH H M L VL

Groundwater Depth < 10 '

NRCS Soil Type

A
B
C
D

Maher Area

Known fill

Serpentine rock, requires asbestos testing

Percent Slope

0-5%
5-10%
> 10%

Landslide Hazard

degrees (approx. 40 percent, or 5:12 pitch). It was assumed that 75 percent of the roof footprint would be covered with a vegetated roof, to allow for the area of HVAC and other mechanical systems often located on flat roofs.

3.1.4 Rainwater Harvesting from Rooftops

The majority of roof drains within San Francisco are directly connected to the combined sewer. For the LID modeling analysis, the project team chose to evaluate roof drain disconnection combined with rainwater harvesting - i.e., collecting runoff from roof surfaces and reusing it on-site, thereby eliminating that flow from the combined sewer. The volume withheld from the sewer depends on the sizing of the rainwater storage system (e.g. cisterns), which can range from as little as 50-gallon rain barrels to several-thousand-gallon storage tanks.

For this analysis, it was assumed that all types of roofs, regardless of zoning or roof slope, could be disconnected from the sewer. In reality, different building types in San Francisco may be more or less amenable to roof drain disconnection. The majority of large commercial and institutional buildings in San Francisco have roof drains that connect to the sanitary sewer at the street. Residences, in contrast, have roof drains that connect with sanitary drain pipes within the building (often in the basement). Large buildings may therefore be easier and less costly to disconnect. Buildings with external roof drains would be the easiest to disconnect, but such buildings are uncommon in San Francisco.

3.1.5 Street Trees

Of the entire urban forest, the project team chose to focus on street trees and thus to build on work already completed in the San Francisco Street Tree Resource Analysis (Maco et al, 2003). That study reported findings on the number of unplanted street tree sites, by tree size, in each supervisor district. Most of the sites identified were void spaces that would require cutting out concrete; a small percentage of the sites were empty basin planting sites where sidewalk cutouts existed but were not planted. Table 2 summarizes the available tree-planting sites in San Francisco.

Data on street tree sizes, interception rates, and ages were provided by the U.S. Forest Service Urban Forestry Research Center[1]. Three street trees that are typical to San Francisco were selected to represent small, medium and large broadleaf evergreens for the modeling analysis. Broadleaf evergreens (as opposed to deciduous trees) were selected because they because they are in full-leaf during the rainy winter season, and therefore intercept the most rainfall. Table 3 summarizes the diameter at breast height (dbh), crown diameter, and maximum interception rates for the selected trees.

1 Personal communication with Greg McPherson at the Center for Urban Forestry, University of California, Davis.

Table 2 Available Tree Planting Sites in San Francisco
San Francisco Sewer System Master Plan
City and County of San Francisco

Supervisor District	# of Void Spaces (Requiring Cutting out of Concrete)	# of Empty Basins (Existing Sidewalk Cutouts)	Total # of Unplanted Spaces	% of Zone Unplanted	Planting Spaces Available per Tree Size		
					Small (#)	Medium (#)	Large (#)
1	7319	368	7687	52	3459	4074	153
2	5148	141	5289	33	1956	2380	899
3	5448	112	5560	61	667	2279	2613
4	19199	835	20034	74	8013	11419	801
5	3257	194	3451	28	690	2588	172
6	12599	448	13047	58	260	5349	7436
7	23815	263	24078	68	2407	19021	2889
8	4896	540	5436	29	1413	3207	815
9	5896	673	6569	38	1707	3481	1379
10	17988	454	18442	66	6600	9925	1915
11	16715	1285	18000	71	5040	12060	900

Notes:
(1) Adapted from Maco et al, 2003: Table 13, page 22

Table 3 Maximum Rainfall Interception During a Single Storm Event in San Francisco, and Crown Diameters
San Francisco Sewer System Master Plan
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Botanical Name (Common Name)	Tree Type(2)	DBH(3) classes (inches)	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	42+
Eucalyptus sideroxylon (Red Ironbark)	Broadleaf evergreen, large	Interception (gal)	0.9	6.9	18.6	39.1	65.4	97.3	134.9	178.2	227.2
		Crown diameter (ft)	9.2	12.8	18.0	25.3	31.8	38.4	44.6	50.9	55.1
Ficus nitida (Indian Laurel Fig)	Broadleaf evergreen, medium	Interception (gal)	0.7	3.0	12.5	36.3	72.8	122.1	122.1	122.1	122.1
		Crown diameter (ft)	2.3	7.9	16.1	26.2	35.8	44.9	44.9	44.9	44.9
Tristania laurina (Small-Leaf Tristania)	Broadleaf evergreen, small	Interception (gal)	0.9	6.1	21.1	54.3	54.3	54.3	54.3	54.3	54.3
		Crown diameter (ft)	4.9	10.5	18.7	29.2	29.2	29.2	29.2	29.2	29.2

Notes:
(1) These data are based on measurements of tree dimensions for a sample of about 35 street trees per species in San Francisco and Dr. Qingfu Xiao's (Urban Forestry Center) interception model that runs hourly with San Francisco Airport weather data.
(2) Note that broadleaf evergreens are more effective intercepting winter rainfall than deciduous species because they are in-leaf then.
(3) DBH = Diameter at breast height

It was assumed for this analysis that tree planting practices would remain essentially the same as current practices; specifically, that tree well soils would be highly compacted, thereby remaining functionally impervious.

3.1.6 Bioretention

As explained above, the project team decided to exclude infiltration practices from the modeling analysis. Chosen instead were lined bioretention cells, which discharge to the sewer rather than allowing infiltration into underlying soils. Lined bioretention systems function as small-scale detention facilities that temporarily store runoff from adjacent drainage areas and discharge that runoff through an underdrain to the combined sewer. Lined bioretention systems typically retain only a small percentage of the total inflow volume, but can significantly reduce peak runoff rates.

For this analysis, it was assumed that bioretention systems would only be located in parking lots, streets, and sidewalks with adequate clearance to bedrock and gentle slopes. Bioretention cells should be located in areas with greater than 4-foot depth to bedrock; however, the GIS data available for this analysis only characterized depth to bedrock as greater than or less than 10 feet. Bioretention siting was therefore limited to areas with greater than 10-foot depth to bedrock. Applying this constraint produces a more conservative estimate of potential bioretention applications. Bioretention siting was also limited to areas with less than 5 percent slope. Bioretention facilities can be designed for areas with steeper slope (e.g. the weep garden design), but a 5 percent slope limit is typical for street and parking lot applications.

To size these bioretention systems, the project team utilized the volume-based sizing methodology recommended in the California Stormwater BMP Handbook (CASQA, 2003). Using this methodology, a unit basin storage volume of 0.5 inches was determined - i.e., the bioretention facility would be sized to capture the first 0.5 inches of runoff from the adjacent drainage areas. Runoff beyond the storage capacity will flow directly to the sewer. It was also assumed that the bioretention facilities would be designed to drain completely within 72 hours, as per CASQA recommendations for prevention of mosquito breeding.

3.1.7 Permeable Pavement

As with bioretention, permeable paving systems can be designed with or without infiltration. Based on the decision to exclude infiltration practices, the project team chose to model lined permeable paving systems. These systems function as small-scale detention facilities, in which rainwater that falls directly on the paved surface infiltrates into an aggregate layer and discharges via an underdrain to the sewer. Rainfall beyond the storage capacity will flow directly to the sewer. These systems are designed to drain completely within 72 hours.

The aggregate layer typically ranges between 18 and 36 inches deep, depending on storage needs and constraints, and the void space is typically 20 to 40 percent (PSAT,

2005). For this analysis, the project team chose a middle-of-the-road design: 27-inch aggregate layer with 30 percent void space, which provides approximately 8 inches of storage depth.

Permeable paving systems can be installed in areas with low-weight vehicles and low-speed traffic, with appropriate slope for the given surface type and adequate clearance to bedrock. For this analysis, the project team limited permeable pavement to parking lots and sidewalks. Streets were excluded because of the difficulty, given available GIS data, to identify streets with low-weight and low-speed traffic. Siting was further constrained to areas with slope less than 5 percent and depth to bedrock greater than 10 feet.

3.2 GIS Spatial Analysis

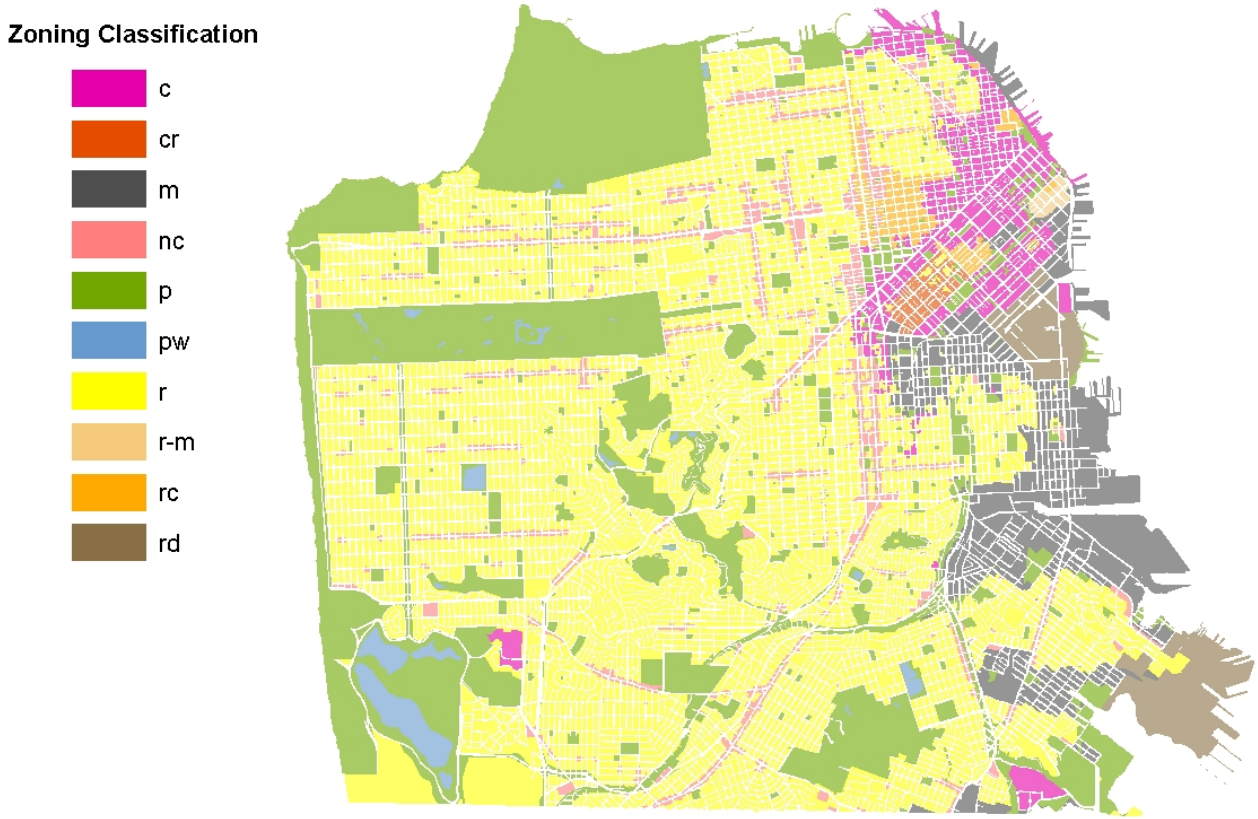
The purpose of the spatial analysis was to determine the extent to which LID practices could be implemented throughout San Francisco, given a set of physical constraints. The project team utilized aerial photos and geographic information systems (GIS) software to evaluate potential implementation areas for green roofs, roof disconnection, street trees, and lined bioretention and permeable pavement facilities. As discussed above, infiltration systems (i.e. unlined bioretention and permeable pavement) were not evaluated. The following sections summarize the methods used to determine potential implementation areas for each LID practice.

3.2.1 Roof and parking lot coverage

GIS data were not available for parking lots or buildings. Consequently, the project team devised an alternative method for estimating parking lot and roof areas. This method consisted of three main steps: 1) delineate general zoning classifications for San Francisco, 2) analyze satellite imagery to estimate the percentage of land covered by building roofs and parking lots for each zoning class, and 3) apply those percentages within GIS to estimate the parking lot and roof areas in each subcatchment.

Zoning districts, as defined by the San Francisco Planning Department, were simplified into 10 generalized classifications, illustrated in Figure 2 and listed in Table 4. Two classifications, RD (Redevelopment) and PW (Public Water), were excluded from the analysis. RD covers two redevelopment areas, Hunter's Point Shipyard and Mission Bay, which lack building cover and public infrastructure. In addition, these areas are changing rapidly and aerial images may therefore be inaccurate. PW included only water bodies; no buildings or parking lots were present.

For the remaining eight zoning classifications, it was assumed that: 1) these zoning districts reflected complete yet distinct land uses of the city, and 2) the roof coverage and parking lot coverage would be similar throughout each defined district. The P general classification covers public lands, some of which are not included in SFPUC service area, such as the Golden Gate National Recreation Area, Therefore, this classification was roughly split into



Abbreviations	
c - Commercial	cr - SOMA Service, Light Industrial, Residential
m - Industrial	nc - Neighborhood commercial
p - Public	pw - Public water body
r - Residential	r-m - Downtown residential
rc - Residential commercial mix	rd - Redevelopment area

Figure 2. Simplified Zoning Classifications

San Francisco Sewer System Master Plan

City and County of San Francisco

Table 4	Simplified Zoning Classifications for Roof and Parking Lot Analysis San Francisco Sewer System Master Plan City and County of San Francisco	
GenClass	**Description**	**Area (acres)**
C	Commercial	912
CR	SOMA Service, Light Industrial, Residential	94
M	Industrial	1,817
NC	Neighborhood Commercial	944
P	Public	7,088
PW	Public Water Body	349
R	Residential	10,540
R-M	Downtown Residential	33
RC	Residential Commercial Mix	227
RD	Redevelopment Area	736

city-owned public lands and federal lands. Only the city-owned lands were analyzed for roof and parking lot coverage.

The percent of rooftop coverage was estimated by analyzing aerial satellite photos of two typical blocks within each zoning class. Blocks were selected that: 1) fit the description of the zoning district code, 2) did not contain a mix of zoning districts or include special land uses, 3) were representative of typical building types (i.e. roof cover and roof slope) for the zoning district, and 4) did not otherwise differ from the norm. One block with slightly higher density and one with slightly lower density were selected, and the average of the two was taken. Two categories of roof slope were then identified: over 20-degree slope and under 20-degree slope. Roof slope was estimated by viewing oblique-angled “Bird’s Eye View” aerial imagery from different angles.

Large parking lots (over 1/2 acre) were identified by viewing black and white one-foot aerial satellite images (scale of 1:5,000 feet) for each of the eight generalized zoning districts. Unlike the roof analysis, the parking lot analysis did not rely on representative blocks; rather, parking lot areas were identified for the entire zoning district. Since only parking lots over 1/2 acre were identified, the parking lot coverage estimates are likely conservative.

Roof Coverage Analysis. The percent of rooftop coverage was estimated by analyzing aerial satellite photos of two typical blocks within each zoning class. Blocks were selected that: 1) fit the description of the zoning district code, 2) did not contain a mix of zoning districts or include special land uses, 3) were representative of typical building types (i.e. roof cover and roof slope) for the zoning district, and 4) did not otherwise differ from the norm. One block with slightly higher density and one with slightly lower density were selected, and the average of the two was taken.

The percentage of block area covered by building roofs was estimated by analyzing color aerial satellite images (250-mm, care of Microsoft Terraserver) to identify the areas covered by building roofs. Two categories of roof slope were then identified: over 20-degree slope and under 20-degree slope. Roof slope was estimated by viewing oblique-angled “Bird’s Eye View” aerial imagery from different angles. A sample image used for the rooftop analysis is shown in Figure 3.

Parking Lot Analysis. Large parking lots (over one half acre) were identified by viewing black and white one-foot aerial satellite images (scale of 1:5,000 feet) for each of the eight generalized zoning districts. Unlike the roof analysis, the parking lot analysis did not rely on representative blocks; rather, parking lot areas were identified for the entire zoning district. Since only parking lots over 1/2 acre were identified, the parking lot coverage estimates are likely conservative. A sample image used for the parking lot analysis is shown in Figure.4.

3.2.2 GIS Mapping

ArcView GIS software was used to compile relevant GIS layers and to analyze land uses within each subcatchment. Existing GIS data was available for sidewalks, zoning classifications, supervisor districts, subcatchments, depth to bedrock, and slope. A pavement layer, representing paved streets, was generated from the sidewalk and zoning layers. The newly derived parking lot and rooftop data was combined with existing GIS layers (zoning, sidewalks, pavement). These layers were overlaid with the existing subcatchment delineations to break down the land cover information for each subcatchment.

3.2.2.1 Pavement Coverage

Existing GIS data were available for private land (blocks within the zoning layer) and sidewalks, but not for street coverage. To generate a pavement layer, representing paved streets, it was assumed that all area beyond private land consisted of paved streets. This may have slightly overestimated the total street area, as many streets have landscaped medians and a few streets are unpaved.

3.2.2.2 Land Cover and Subcatchment Layers

New land cover coverage was derived using the zoning layer, curb area layer (sidewalks), and the newly derived pavement layer. An existing subcatchment layer, developed by Metcalf & Eddy for the Infoworks collection system model, was used for subcatchment delineation. The entire City and County of San Francisco watershed consists of 931 subcatchments.

Figure 3. Sample Rooftop Analysis for Typical Block in Residential/Commercial District

San Francisco Sewer System Master Plan

City and County of San Francisco

M Classification:
Large Parking Lots

parking

Block

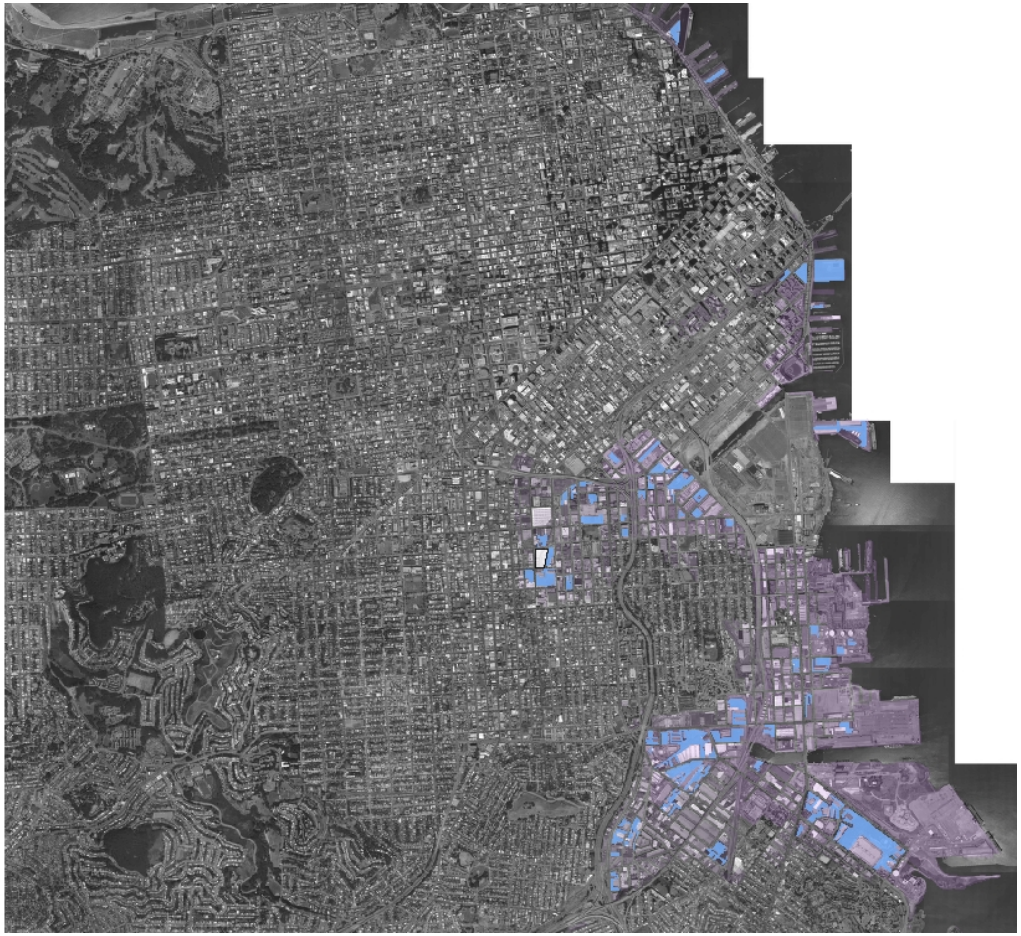


Figure 4. Sample Parking Lot Analysis for Industrial Zoning District

San Francisco Sewer System Master Plan

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The newly developed land cover layer was overlaid with the existing subcatchment coverage to break down the land cover information for each subcatchment. The entire overlay is presented in Figure 5, and a close-up example is illustrated in Figure 6.

3.2.3 Application of LID Siting Constraints

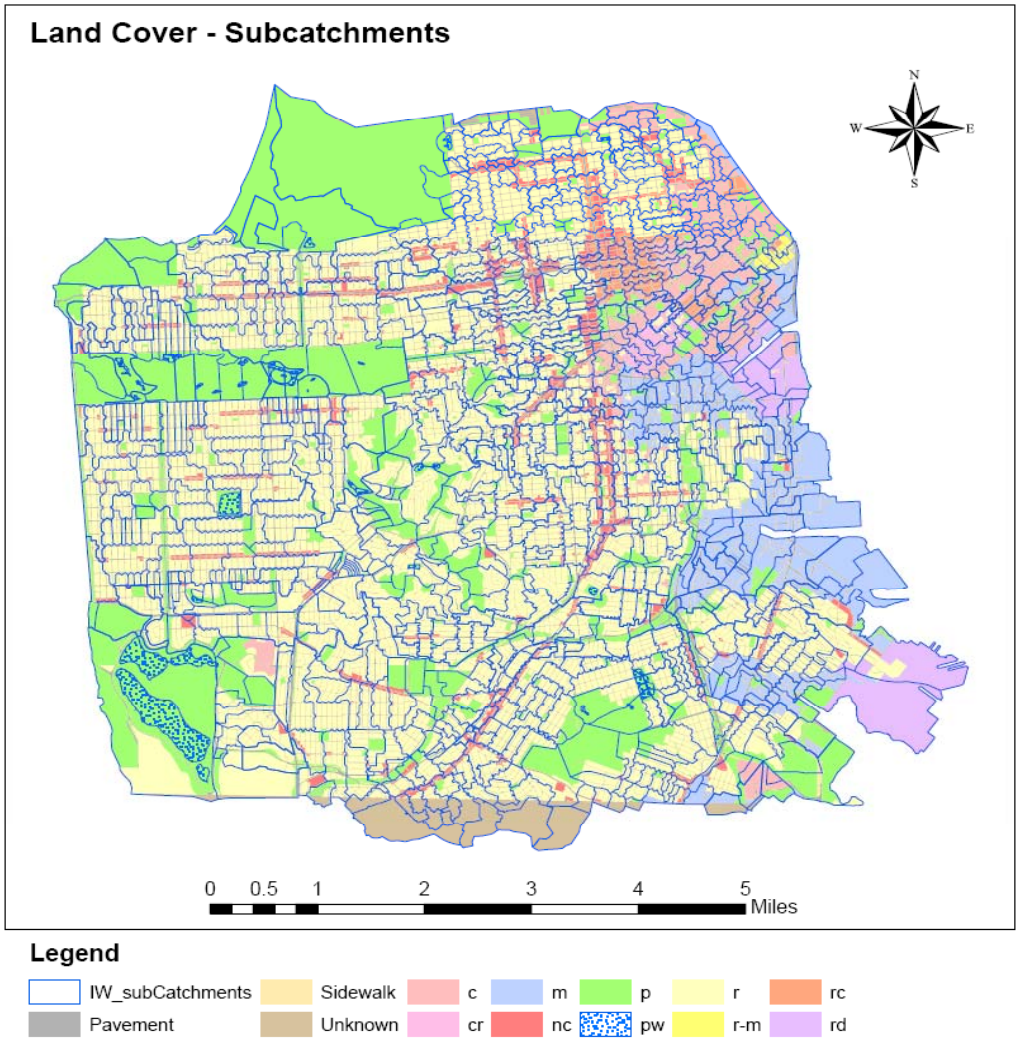
For each LID practice, a set of constraints was applied within GIS to limit LID implementation to the most appropriate areas. These siting constraints are summarized in Table 5. The following sections briefly describe how the siting constraints were applied in the GIS analysis to determine the areas for LID practices in each subcatchment.

Table 5 Siting Constraints Applied for GIS Spatial Analysis of LID Practices
San Francisco Sewer System Master Plan
City and County of San Francisco

LID Practice	Siting Constraints/Assumptions
Vegetated roofs (roof area)	• Roof slope < 20 degrees (~40%, or 5 in 12 pitch) • Assumed 75% of the eligible area can be greened
Roof Disconnection (roof area)	• All rooftops
Street Trees (crown area)	• Available planting sites identified in San Francisco Street Tree Resource Analysis (2003) • Option 1 (young trees): Crown area based on tree size at 10-20 years old • Option 2 (mature trees): Crown area based on tree size at full maturity
Bioretention (sidewalk, parking lot, streets)	• Slope < 5% • Depth to bedrock > 10 ft • Parking lots over 1/2 acre only • Sidewalk % impervious assumed based on existing street trees • Assumed all parking lots have < 5% slope
Permeable Pavement (sidewalk, parking lot)	• Slope < 5% • Depth to bedrock > 10 ft • Parking lots over 1/2 acre only • Sidewalk % impervious assumed based on existing street trees • Assumed all parking lots have < 5% slope

3.2.3.1 Vegetated roofs

The area of rooftops with slopes less than 20 degrees was estimated using the land cover-subcatchment layer (Figure 5) and the rooftop analysis results for each zone, as described in section 3.2.1.



Abbreviations	
c - Commercial	cr - SOMA Service, Light Industrial, Residential
m - Industrial	nc - Neighborhood commercial
p - Public	pw - Public water body
r - Residential	r-m - Downtown residential
rc - Residential commercial mix	rd - Redevelopment area

Figure 5. Overlaying Land Cover and Subcatchments Coverage

San Francisco Sewer System Master Plan

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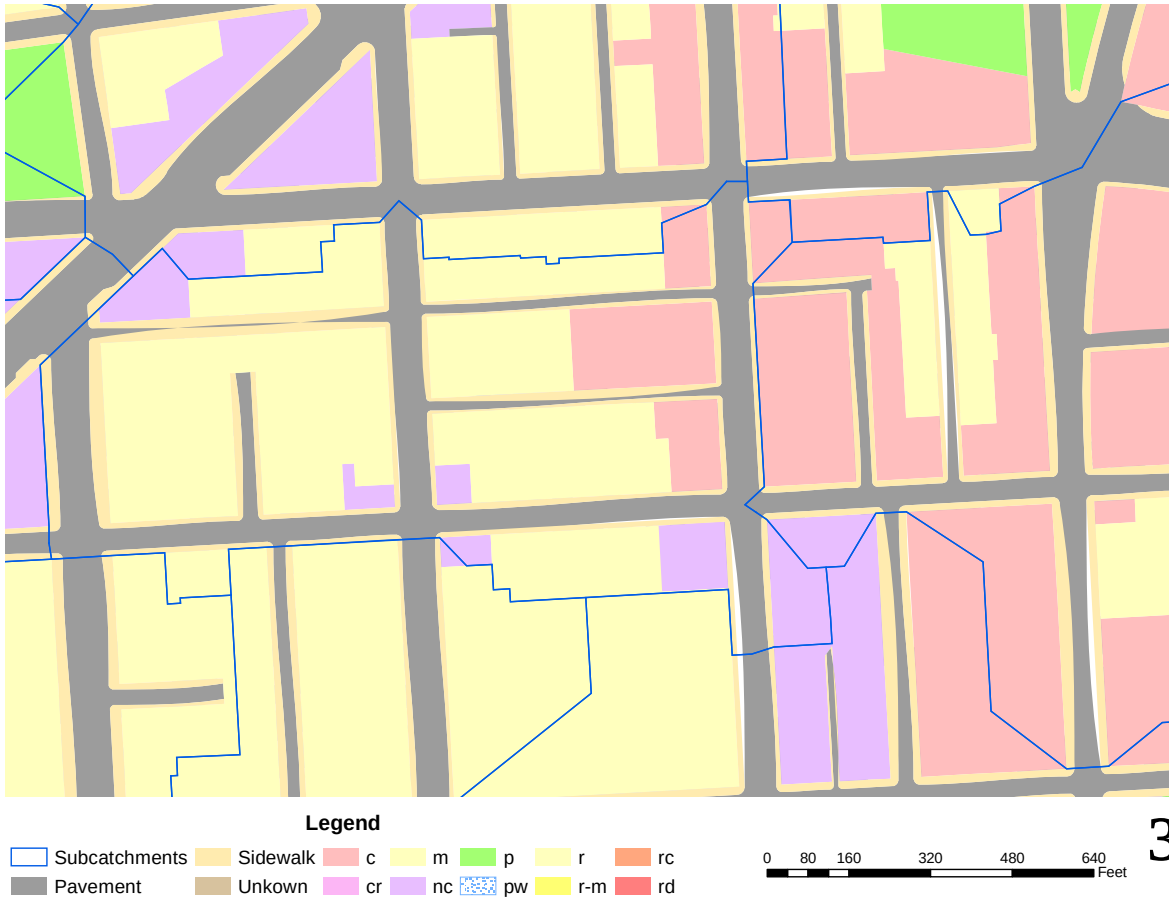

Abbreviations	
c - Commercial	cr - SOMA Service, Light Industrial, Residential
m - Industrial	nc - Neighborhood commercial
p - Public	pw - Public water body
r - Residential	r-m - Downtown residential
rc - Residential commercial mix	rd - Redevelopment area

Figure 6. Close-Up Example of Overlaying Land Cover and Subcatchments Coverage

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3.2.3.2 Street Trees

As described in section 3.1.5, data were available from the SF Street Tree Resource Analysis on the number of unplanted street tree sites in each supervisor district. The GIS layer for supervisor districts, shown in Figure 7, was overlaid with the subcatchment layer to determine the predominant supervisor district for each subcatchment. Using an overlay of land use and supervisor districts, the total sidewalk area for each supervisor district was determined and the density of available tree sites per sidewalk area for each supervisor district was calculated. The number of tree-planting sites available in each subcatchment was then calculated by multiplying the sidewalk area for each subcatchment by the tree-site density for the appropriate supervisor district.

3.2.3.3 Roof Disconnection

Rooftop area for each subcatchment was estimated using the land cover-subcatchment layer (Figure 5) and the results of rooftop analysis for each zone, as described in section 3.2.1.

3.2.3.4 Bioretention Cells

The potential areas for bioretention cells were estimated based on the status of bedrock and slope for each subcatchment. Slope and depth to bedrock are presented in Figure 8.

Parking lots: The parking lot coverage for each subcatchment was estimated using the land cover-subcatchment layer and the results of parking lots analysis for each zone. All parking lots were assumed less than 5 percent slope. For each subcatchment, the proportion of area with greater than 10 feet depth to bedrock was estimated using the subcatchment and bedrock data layers. This proportional area for each subcatchment was then used to estimate the potential parking lots for bioretention. For example, if 80 percent of a subcatchment area had a depth to bedrock greater than 10 ft, the total parking lot area was multiplied by 80 percent to get the potential parking lot area for bioretention.

Pavement (streets) and Curb Area (sidewalks): Pavement and sidewalk areas meeting slope and bedrock criteria were estimated for each subcatchment, using the land cover-subcatchment coverage and the slope-bedrock coverage.

Calculation of Curb Area Percent Impervious

Since sidewalk areas defined in GIS are made up partially of pervious landscaped areas (e.g. tree wells), the percent imperviousness of the curb area needed to be defined. Impervious curb area was estimated by subtracting tree well area from the total curb area. Tree well area was estimated for each supervisor district using estimates of existing street trees presented in the Street Tree Resource Analysis (Maco et al, 2003). The area per street tree was assumed to be 16 square foot per tree, reflecting the typical 4-foot by 4-foot tree well in San Francisco.

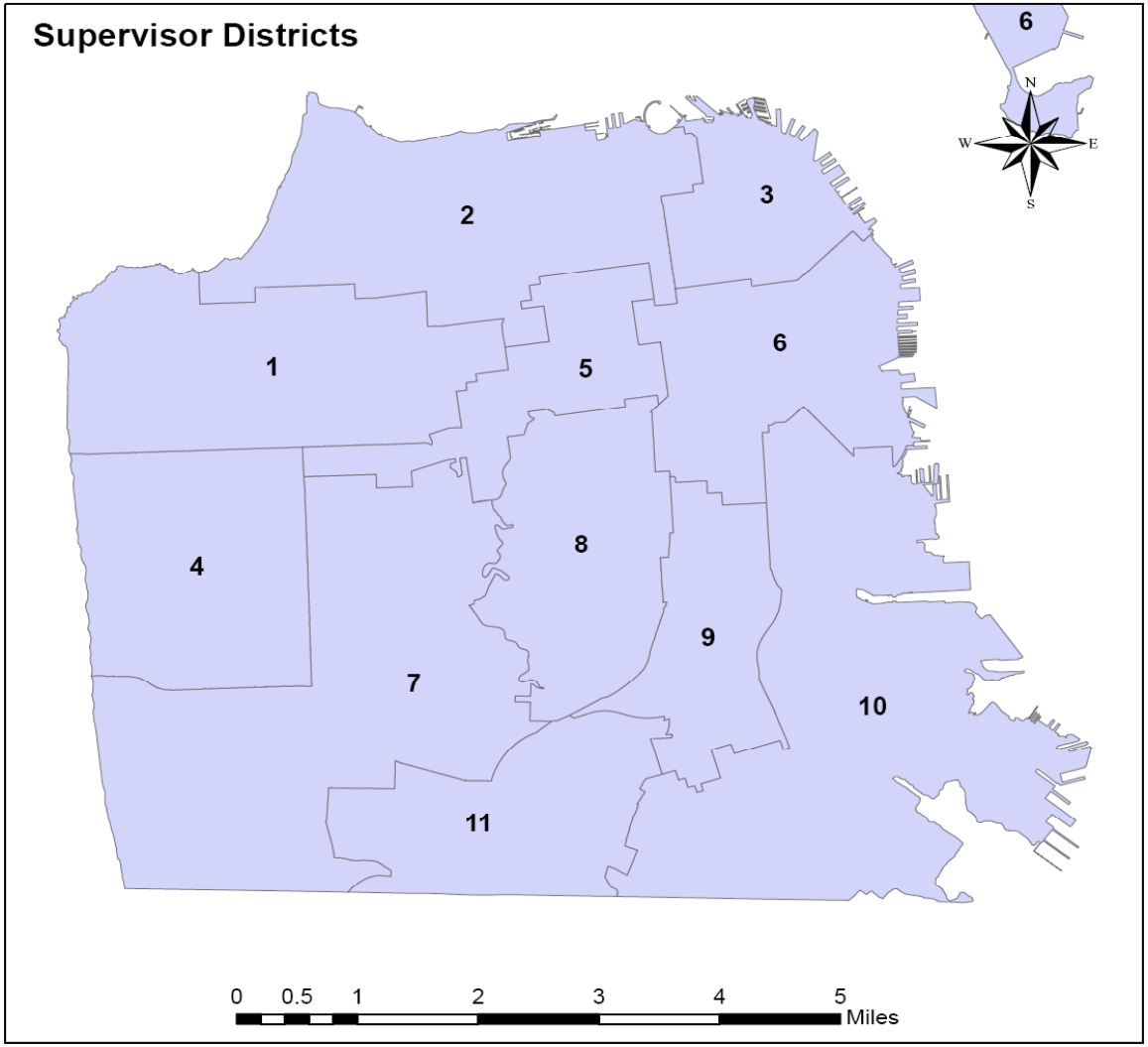
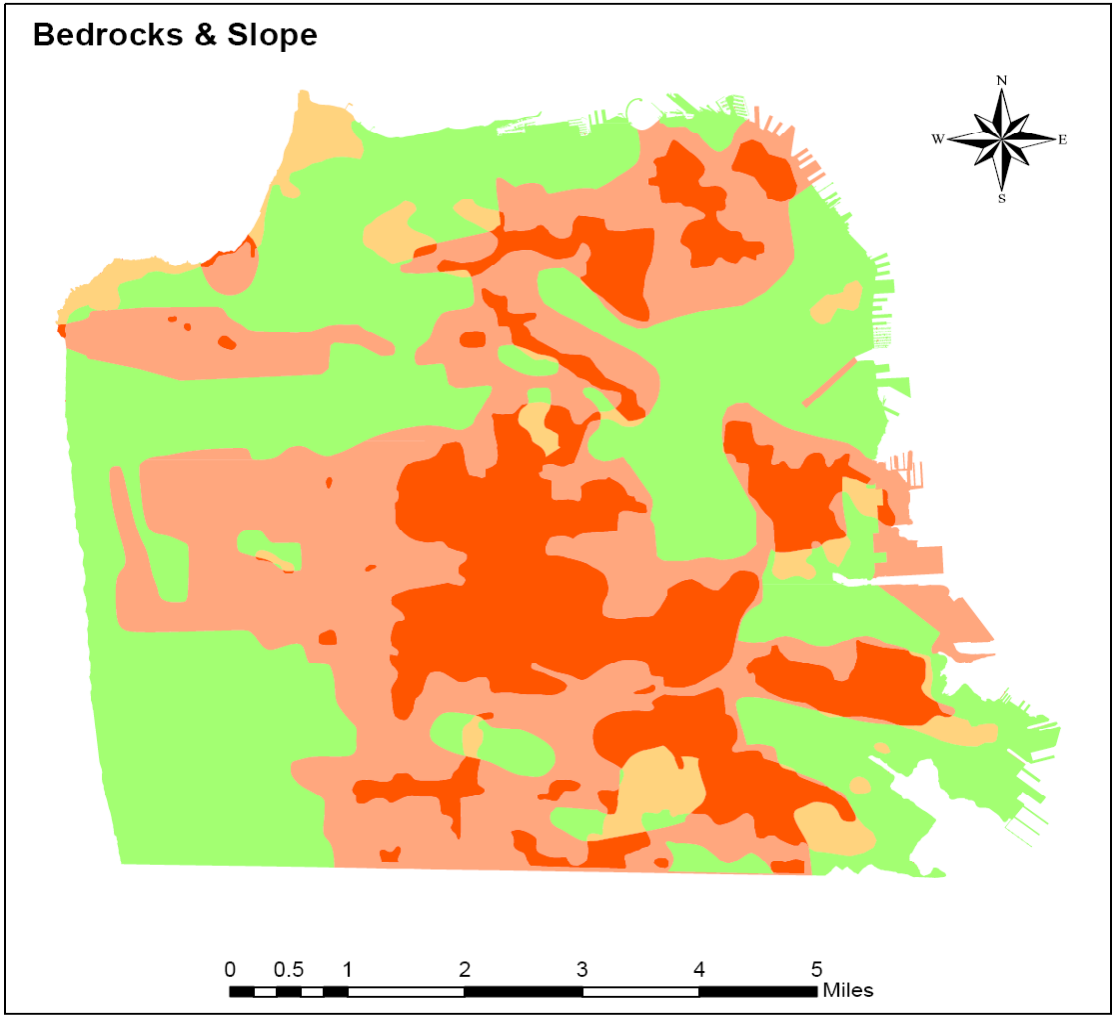


Figure 7. San Francisco Supervisor Districts

San Francisco Sewer System Master Plan

City and County of San Francisco



Legend

- Sloper:0-5 / Bedrock:10 over
- Slope:5 over / Bedrock:10 over
- Slope:0-5 / Bedrock:0-10
- Sloper:5 over / Bedrock:0-10

Figure 8. Slope and Depth to Bedrock

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3.2.3.5 Permeable Pavement

Areas for permeable pavement were estimated using the methods described above for bioretention, except for parking lots and sidewalks only.

3.2.4 Spatial Analysis Findings

The total land area of San Francisco, as calculated in GIS, is 28,729 acres (excluding public water bodies and subcatchment areas lying outside city limits). Impervious land surfaces making up the majority of that area are as follows:

- Roofs: 8,323 acres (29 percent of land area)
- Roofs with less than 20-degree slope: 6,387 acres (22 percent of land area)
- Sidewalks: 2,460 acres (9 percent of land area)
- Streets: 4,749 acres (17 percent of land area)
- Parking lots greater than 1/2 acre in size: 577 acres (2 percent of land area)
- Streets, sidewalks and parking lots combined = 7,786 acres (27 percent of land area).

Table 6 presents the maximum surface areas that could be converted to each LID practice. These maximum areas were determined in GIS, using the siting constraints described above.

3.3 Model Construction

The overall approach to modeling was to:

- Build LID practices onto the baseline collection system model,
- Define the scenarios for modeling
- Run model simulations for select rainfall conditions, and
- Compare runoff volume, peak flows and combined sewer overflows to baseline.

The following sections describe the baseline model and the modifications to that model for the LID analysis.

3.3.1 Baseline Model

LID implementation scenarios were modeled within the baseline collection system model, which was developed and calibrated to mimic the sewer system's hydraulic performance under a variety of hydrologic (rainfall) conditions. The model was constructed using Infoworks Collection System (CS) modeling program by Wallingford Software.

Table 6 Maximum Surface Areas eligible for LID in San Francisco San Francisco Sewer System Master Plan City and County of San Francisco			
LID Practice	**Max. Potential Area Converted**	**Percent of Surface Type**	**Percent of Total City Area**
Vegetated roof (roof area)	4,800 acres	58% of total roof area	16%
Roof Disconnection (roof area)	8,300 acres	100% of total roof area	28%
Street Trees (crown area for mature trees)	4,300 acres (127,000 trees)	60% of total street and sidewalk area	15%
Bioretention (sidewalk, parking lot, streets)	2,900 acres	37% of total street, sidewalk and parking lot area	10%
Permeable Pavement (sidewalk, parking lot)	1,200 acres	41% of total sidewalk and parking lot area	4%
Total (1)	14,100 acres		38%

Notes:
(1) Total area of streets, parking lots, sidewalk, and roofs that qualify for one or more LID practice. Individual conversion areas overlap - e.g. roofs eligible for “greening” also qualify for roof disconnection.

The baseline model, representing the existing combined sewer system, included only the main interceptors and sewers with pipe diameters over 30 inches. It also included 29 combined sewer overflow locations and 3 wastewater treatment facilities. Eight major drainage basins were divided into 931 subcatchments.

Runoff was calculated within the baseline model using the SWMM (stormwater management model) runoff model. In this model, the catchment is divided into impervious and pervious fractions. In the impervious fraction, runoff is calculated using a non-linear reservoir model based on Manning’s equation applied to overland flow. The flow depth is determined from a mass balance over the basin with input from rainfall and output from runoff. In Manning’s equation, the flow depth is reduced by the depression storage. The same approach is used in the pervious fraction, with the addition of infiltration as an outflow in the mass balance. Several equations are available to simulate infiltration, and among those the Horton equation was selected for this project. Overall, the parameters needed to simulate runoff are the catchment area, percent impervious, Manning’s n, width, slope and depression storage (DS), as well as the Horton infiltration parameters. Infoworks CS assigns these runoff parameter values to each *surface type*, such as “impervious”, “pervious”, or any other user-defined surface.

3.3.2 Model Modifications

For each LID practice, runoff parameters and network design were modified from the baseline model to best represent the expected drainage performance. Two performance levels were modeled for each LID practice, ranging from low to high expectations for drainage performance. The following sections describe how the model was modified to represent each LID practice.

3.3.2.1 Vegetated roofs

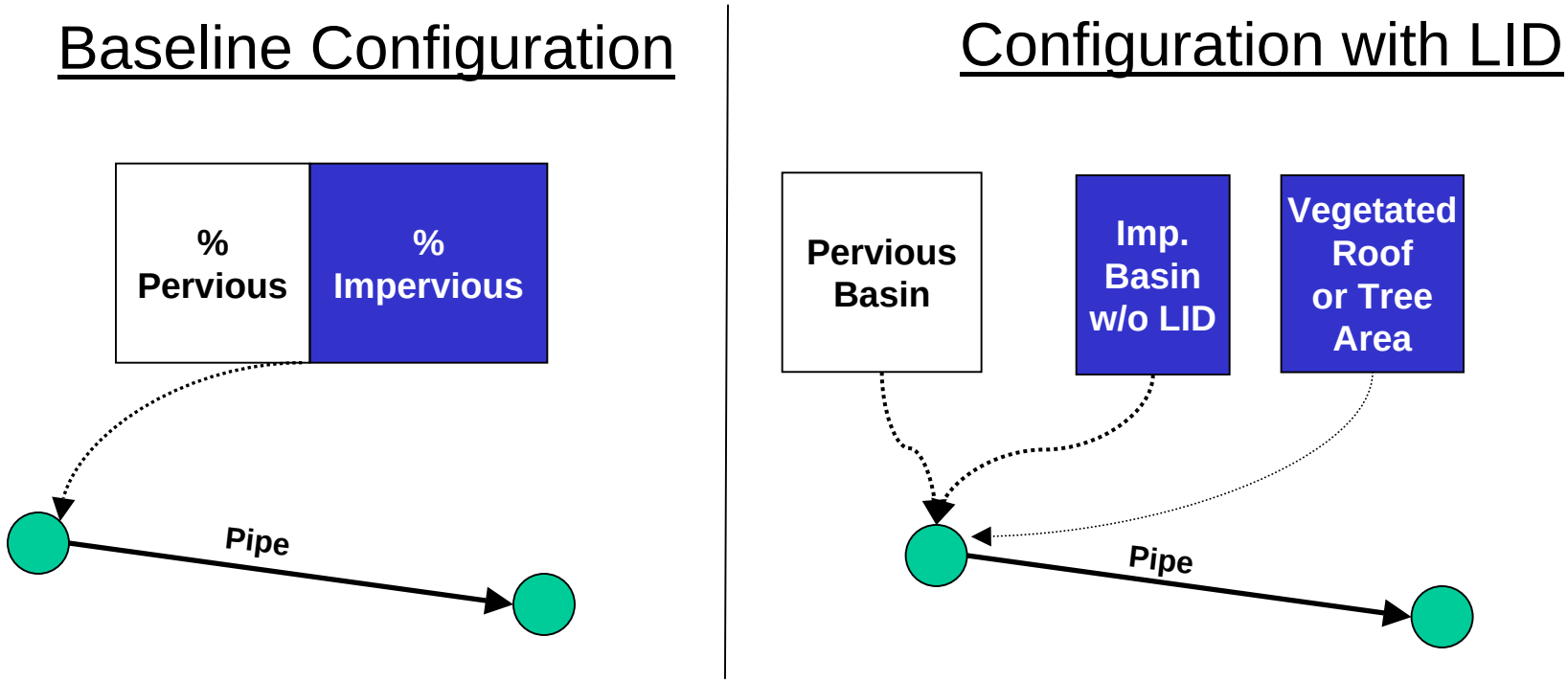
Vegetated roofs absorb rainfall into the growing media and eventually lose that rainfall via evaporation. The roughness of the vegetated roof also slows the flow of runoff over the roof surface. To represent these hydrologic characteristics, vegetated roofs were represented in the model as a new surface type with depression storage (DS) and Manning's-n (roughness) values higher than those for impervious surfaces. The area to be converted to vegetated roofs was removed from the baseline impervious surface area and placed in the new vegetated roofs surface type. These model changes are illustrated in Figure 9.

DS and Mannings-n were adjusted to match vegetated roofs' expected drainage performance. A DS range of 0.4 to 0.8 for vegetated roofs corresponded with published research data on the storage capacity of vegetated roofs. Mannings-n values of 0.15 and 0.6 were selected to reflect the range of vegetation and drainage layer characteristics for vegetated roofs.

3.3.2.2 Street Trees

Street trees intercept rain in the tree crowns and subsequently evaporate or absorb that rain, thus reducing the volume of rainfall that reaches the ground and delaying the onset of runoff. Rainfall interception depends on a number of dynamic factors, including rainfall intensity and duration, temperature, wind, and sunlight. For this model, rainfall interception was simplified to a maximum interception for a given tree and size. That maximum interception is defined as the crown storage capacity, i.e. the maximum amount of water that the tree crown can hold. It was assumed that the maximum interception was functionally equivalent to depression storage in the model, since the tree crown will absorb all the rain that falls on it up to the storage capacity, and the rest will run off. The rain that is stored in the crown will be lost only through evaporation.

Street trees were represented in the model as a new surface type, with a DS value based on the maximum interception volume for a single storm event (i.e. crown storage capacity). The area converted from impervious surface to street trees was equal to the weighted average of crown area for small, medium, and large trees, as determined in the spatial analysis. Three species of broadleaf evergreens were selected to represent typical small, medium and large street trees in San Francisco. These trees were modeled at two levels of maturity: "young" trees around 10 to 20 years of age, and "mature" trees at or close to their



NOTES:

- Vegetated roof and tree crown areas moved from baseline impervious into new surface types
- Sum of LID, Pervious, and Impervious areas equals original area.
- Depression storage (DS) and Manning's coefficient of roughness (n) adjusted for LID area

Figure 9. Model Representation of Vegetated Roofs and Street Trees

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maximum size. The trees were also modeled at two performance levels: the low performance level assumed smaller crown sizes and interception rates for each tree than the high performance level. Table 7 summarizes the parameters used for low and high performance expectations for the three selected species of street trees. The model representation of street trees is illustrated in Figure 9.

3.3.2.3 Roof Disconnection

Roof disconnection was represented in the model as area removed completely from the subcatchment impervious area. Thus, the area removed from the subcatchment would not produce any runoff. To represent low performance for roof disconnection, only 50 percent of the roof disconnection area was removed from the subcatchment area. This was done to represent undersized rainwater harvesting systems that would only capture half the rainfall volume on average. The high performance level was represented by removing 100 percent of the roof disconnection area, with the assumption that all runoff from the disconnected roofs would be kept from entering the sewer. The model representation of roof disconnection is illustrated in Figure 10.

3.3.2.4 Bioretention and Permeable Pavement

Lined bioretention and permeable pavement systems were represented as small-scale detention facilities by creating storage nodes within the sewer network. Bioretention storage volume was calculated based on a unit basin storage of 0.5 inches (i.e. the first 0.5 inches of runoff from contributing drainage area would be captured in the bioretention facility). Permeable pavement storage volume was calculated based on a storage depth of 8 inches. The storage nodes were designed to overflow directly to the sewer network, and to drain completely within 72 hours. Figure 11 illustrates how bioretention and permeable pavement were represented in the model.

Table 8 summarizes how each LID practice was represented within the model.

3.4 Model Runs

The following sections describe the LID implementation scenarios and rain events that were modeled.

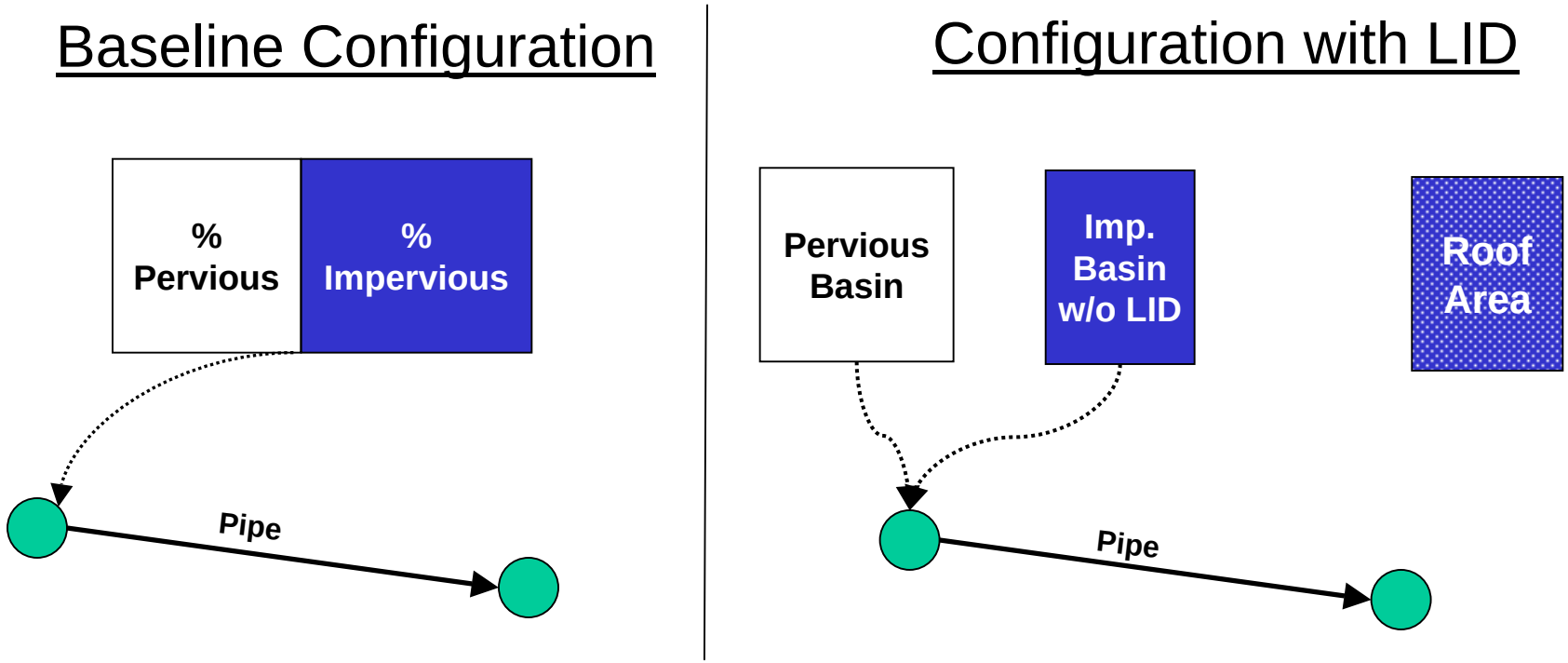
3.4.1 <u>LID Scenarios</u>

Several scenarios for LID implementation were developed for the model. These implementation scenarios range from Baseline (no improvements) to Ultimate (the maximum feasible LID improvements), and encompass individual LID practices as well as combinations. A 30-year program target was developed to represent a reasonable level of LID implementation that could be achieved with an active LID program. The LID implementation targets are summarized in Table 9.

Table 7 Street Tree Interception Rates and Crown Area
San Francisco Sewer System Master Plan
City and County of San Francisco

Botanical Name (Common Name)	Low Performance[1]			High Performance[1]		
	DBH class[2]	Interception depth (in)	Crown area (ft2)	DBH class[2]	Interception depth (in)	Crown area (ft2)
Interception likely to result after 10-20 years (Young trees)						
Eucalyptus sideroxylon (Red Ironbark)	large 12-18	0.125	501	large 12-18	0.125	501
Ficus nitida (Indian Laurel Fig)	med 6-12	0.099	203	med 12-18	0.107	541
Tristania laurina (Small-Leaf Tristania)	small 6-12	0.123	275	small 6-12	0.123	275
Maximum Potential Interception (Mature trees)						
Eucalyptus sideroxylon (Red Ironbark)	large 36-42	0.141	2031	large 42+	0.153	2386
Ficus nitida (Indian Laurel Fig)	med 18-24	0.116	1004	med 24-30	0.123	1587
Tristania laurina (Small-Leaf Tristania)	small 6-12	0.123	275	small 12-18	0.130	670

Notes:
(1) Interception depth and crown area calculated from data on San Francisco street trees provided by USDA Urban Forestry Center.
(2) DBH = Diameter at breast height.



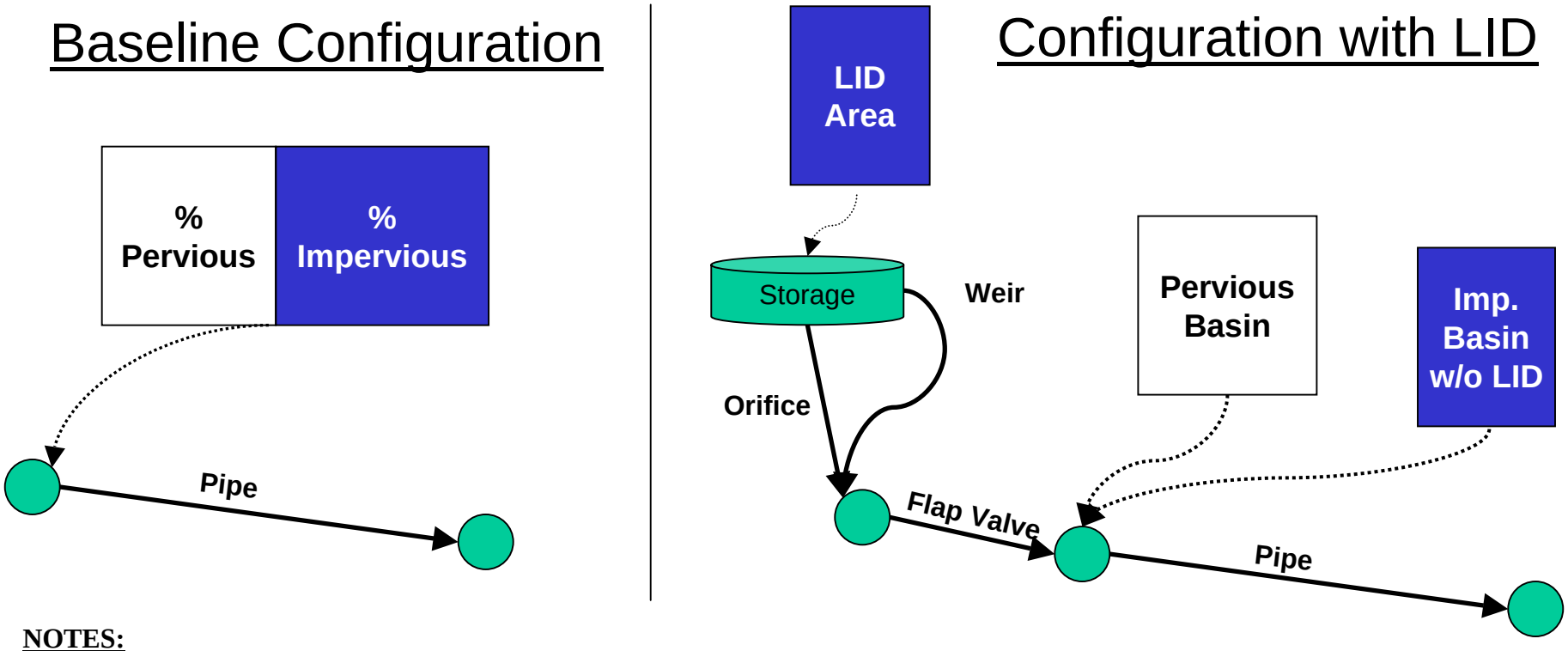
NOTES:

- Roof disconnection area removed from subcatchment altogether, thereby eliminating all runoff from that area into the combined sewer.
- Sum of LID, Pervious, and Impervious areas equals original area.

Figure 10. Model Representation of Roof Disconnection

San Francisco Sewer System Master Plan

City and County of San Francisco



NOTES:

- Drainage areas for permeable pavement and bioretention moved from impervious surface into new surface types. New LID surface type has same runoff parameters as impervious surface.
- One detention storage unit was located at the outlet of each subcatchment.
- Sum of LID, Pervious, and Impervious area equals original area.
- Orifice has limiting discharge so that the full storage basin will empty in 72 hours.
- Weir is set at an elevation such that when the storage basin is full the excess will overflow to the system.
- A flap valve was installed to prevent backflow into the storage unit.

Figure 11. Model Representation of Permeable Pavement and Bioretention

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Table 8 Summary of Model Representations for each LID practice
San Francisco Sewer System Master Plan
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BMP	Description	Model Representation	Low Performance Parameters	High Performance Parameters
Vegetated roofs	• Extensive vegetated roof, 3- to 6-inch media depth, planted with low-growing plants • Assume 75% of roof footprint can be converted to vegetated roof	• Impervious surface type with increased depression storage and roughness • A portion of impervious surface is converted to vegetated roof surface	• DS = 0.4 • n = 0.15 • No infiltration	• DS = 0.8 • n = 0.6 • No infiltration
Street trees(1)	• Two maturity levels modeled: (1) Tree sizes expected within 10 to 20 years after planting, and (2) Tree sizes at full maturity. • Small, medium, and large broadleaf evergreens typical to San Francisco • Assume tree wells will remain highly compacted	• Impervious surface type with increased depression storage and roughness • Total crown area converted from impervious area to street tree area • Depression storage equal to max. interception rate for a single storm • Total interception volume = DS * crown area	Young: • DS = 0.07 • n = 0.2 • No infiltration Mature: • DS = 0.09 • n = 0.2 • No infiltration	Young: • DS = 0.12 • n = 0.6 • No infiltration Mature: • DS = 0.14 • n = 0.6 • No infiltration
Roof disconnection	• Disconnect roof downspouts from combined sewer • Assume runoff is contained and reused on-site	• Roof area removed from the subcatchment impervious area	• 50% of roof area removed from subcatchment area	• 100% of roof area removed from subcatchment area
Bioretention(2)	• Lined rain gardens and swales providing temporary rainwater storage • Underdrained to sewer • Sized in accordance with CASQA methodology for volume-based design(3)	• One detention storage unit within each subcatchment, sized to detain the runoff from the bioretention drainage area within that subcatchment • Drainage orifice sized to draw down storage volume within 72 hours • Overflow directly into sewer network	• Storage volume = drainage area * design storm depth • Design storm depth = 0.5 inches	

Table 8	**Summary of Model Representations for each LID practice San Francisco Sewer System Master Plan City and County of San Francisco**			
BMP	**Description**	**Model Representation**	**Low Performance Parameters**	**High Performance Parameters**
Permeable Pavement(2)	• Porous concrete or asphalt, paver blocks, and grids • Gravel layer under porous surface provides temporary rainwater storage • Underdrained to sewer • Storage depth based on typical 27" depth with 30% void space	• One detention storage unit within each subcatchment, sized to detain the runoff from the permeable pavement area within that subcatchment • Drainage orifice sized to draw down storage volume within 72 hours • Overflow directly into sewer network	• Storage volume = drainage area * storage depth • Storage depth = 8 inches	

Notes:
(1) Low-end performance parameters for street trees were determined by selecting smaller tree sizes. Depression storage was re-calculated to allow the same crown-area input into the model for high and low performance. Therefore, DS does not represent actual interception rates.
(2) A single performance level was assumed for bioretention and permeable pavement.
(3) California Stormwater Quality Association (CASQA), 2003. *California Stormwater BMP Handbook: New Development and Redevelopment.*

Table 9	Program Targets for LID Implementation San Francisco Sewer System Master Plan City and County of San Francisco			
	LID Practice	**Percent of Max. Potential (1)**	**Target Area Converted**	**Target**
30-Yr Target	Vegetated roofs	5%	240 acres	1000 Vegetated roofs (2)
	Roof Disconnection	10%	830 acres	9000 residential roofs and 1800 buildings disconnected (3)
	Street Trees	80% at young tree size	1,020 acres	100,000 new trees planted
	Bioretention	10%	300 acres	100 city blocks retrofitted with bioretention (4)
	Permeable Pavement	10%	120 acres	60 parking lots paved with permeable pavement (5)
Ultimate Target	Vegetated roofs	50%	2,400 acres	10,000 vegetated roofs (2)
	Roof Disconnection	50%	4,160 acres	45,000 residential roofs and 9000 buildings disconnected (3)
	Street Trees	100% at full maturity size	1,280 acres	127,000 new trees planted
	Bioretention	50%	1450 acres	480 city blocks retrofitted with bioretention (4)
	Permeable Pavement	50%	600 acres	300 parking lots paved with permeable pavement (5)

Notes:
(1) Represents the percent of the maximum eligible conversion area, as determined in the GIS analysis.
(2) Assumes average vegetated roof size of 10,000 ft^2
(3) Assumes 2000 ft^2 for typical residential roof and 10,000 ft^2 for typical commercial/institutional building.
(4) Assumes the impervious area on one city block = 3 acres.
(5) Assumes an average 2 acres per parking lot.

3.4.2 Modeled Rainfall Events

LID scenarios were modeled with a range of design storms and with continuous simulation of a typical rainfall year. The design storms selected were 3-month, 1-year and 5-year recurrence intervals, each with a duration of 24 hours. These design storms were selected to demonstrate LID effectiveness under a range of rainfall intensities. The 5-yr event is used by the San Francisco Department of Public Works (SFDPW) as the drainage system design standard.

Table 10 summarizes the characteristics of the design storm events. These design storms vary slightly at different gage locations around San Francisco, to account for regional variability in rainfall patterns.

Table 10	Summary of Design Storms used for LID Analysis San Francisco Sewer System Master Plan City and County of San Francisco		
Return Period	**Duration (hours)**	**Peak Intensity (in/hr)**	**Rainfall Depth (in)**
3 month	24	1.29	1.39
1 year	24	2.18	2.27
5 year	24	3.48	3.77
Note: Peak intensity and rainfall depth are averaged from 27 gages around San Francisco.			

4.0 MODELING RESULTS

A range of LID implementation scenarios were simulated with discrete-event design storms and continuous simulation of a typical year's rainfall. The overall results demonstrate that the LID practices analyzed can reduce runoff volume and peak flow rate, as well as CSD volume. However, the effect of LID on any particular subcatchment depends on the extent to which LID can be implemented in that subcatchment (e.g. the number of available street tree sites) and on hydrologic characteristics of the subcatchment.

The following sections describe citywide results for single design storms and for the typical rainfall year. These results should serve mainly as a guide to more detailed procedures that need to be undertaken to truly assess the benefits of LID. For example, since LID practices are very site-specific to an individual subcatchment, it is advisable to study an upstream subcatchment that is directly tributary to a CSD or a local flooding area. Modeling this subcatchment with and without LID and comparing the results of decreased (or eliminated) CSDs or flooding (both on peak flow, volume, and frequency) would provide the full picture of LID effectiveness.

4.1.1 Runoff Volume

Modeling results show that implementing vegetated roofs, street trees and roof disconnection will reduce the volume of runoff entering the combined sewer. Runoff volume reductions for the typical rainfall year are summarized in Table 11. Overall, implementing the 30-year LID target would reduce annual runoff volume by 400 to 700 million gallons (MG), or 4 to 7 percent annually. The ultimate target, which represents a hypothetical maximum implementation level, would reduce annual runoff volume by 2200 to 3500 MG, or 23 to 27 percent. As shown in Figures 12 and 13, roof disconnection makes up the majority of the potential runoff volume reduction, followed by street trees and then vegetated roofs.

Table 11 Citywide Runoff Volume during Typical Rainfall Year San Francisco Sewer System Master Plan City and County of San Francisco			
LID Practice	**% of Max Potential Implemented**	**Annual Runoff Volume Reduction (MG)**	**Percent Annual Runoff Volume Reduction (%)**
Vegetated roofs	5%	48 - 63	0.5 - 0.7%
	50%	479 - 631	5.0 - 6.6%
Street Trees	80% Young Trees	108 - 155	1.1 - 1.6%
	100% Mature Trees	465 - 638	4.9 - 6.7%
Roof Disconnection	10%	243 - 485	2.5 - 5.1%
	50%	1237 - 2411	13.0 - 25.3%
30-Year Target	5%GR+ 80%ST+ 10%RD	398 - 703	4.2 - 7.4%
Ultimate Target	50%GR+ 100%ST+ 50%RD	2174 - 3535	22.8 - 37.1%

Further analysis of these results is shown in Table 12. Model results show that vegetated roofs reduce runoff volume by approximately 5 to 6 gallons annually per square foot converted, and retain on average 30 to 40 percent of the annual rainfall. Compared to monitoring data from vegetated roofs in other U.S. cities, the annual retention rate of 30 to 40 percent is conservative.

Model results show that street trees intercept approximately 1100 to 1500 gallons annually per tree when the trees are 10 to 20 years old. At full maturity, street trees intercept approximately 3700 to 5100 gallons annually per tree. This volume reduction is higher than the annual average reported in the San Francisco Street Tree Resource Analysis (1006 gallons per tree). However, the Street Tree Resource Analysis results represented all tree types in San Francisco, while the LID model represented broadleaf evergreens only. Broadleaf evergreens intercept more rainfall than deciduous species where winter rainfall patterns prevail; therefore, higher interception rates are expected. The highest annual interception rate for a tree species reported in the Street Tree Resource Analysis was for Monterey Pine (a large conifer) at 4,200 gallons/tree.

Disconnecting rooftops from the combined sewer can reduce runoff volume by approximately 7 to 14 gallons per square foot disconnected, and can keep approximately 43 to 86 percent of the annual rainfall from entering the sewer. This large range represents the assumption that between 50 and 100 percent of the rain falling on the disconnected roofs would be captured and reused on site (with the remainder flowing to the sewer).

4.1.2 Runoff Peak Flow Rate

Reductions in runoff peak flow rate are important because they indicate how LID might improve level-of-service of an existing sewer, e.g. reducing street flooding, and how LID

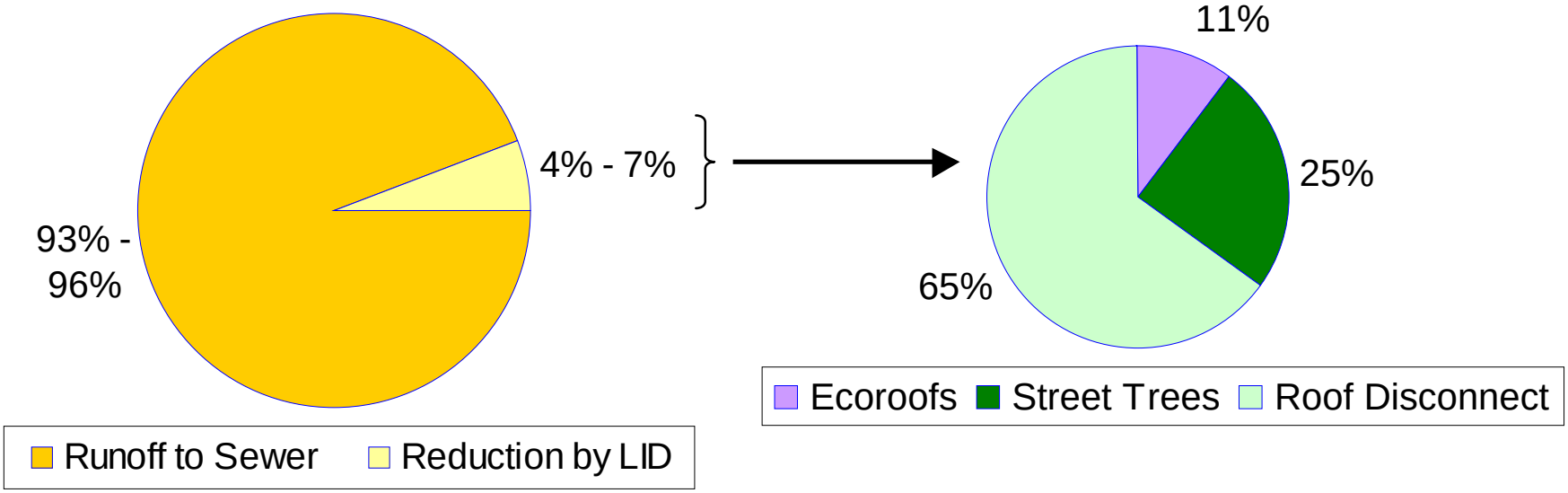

Figure 12. Annual Runoff Volume Reduction: 30-Year Program Target

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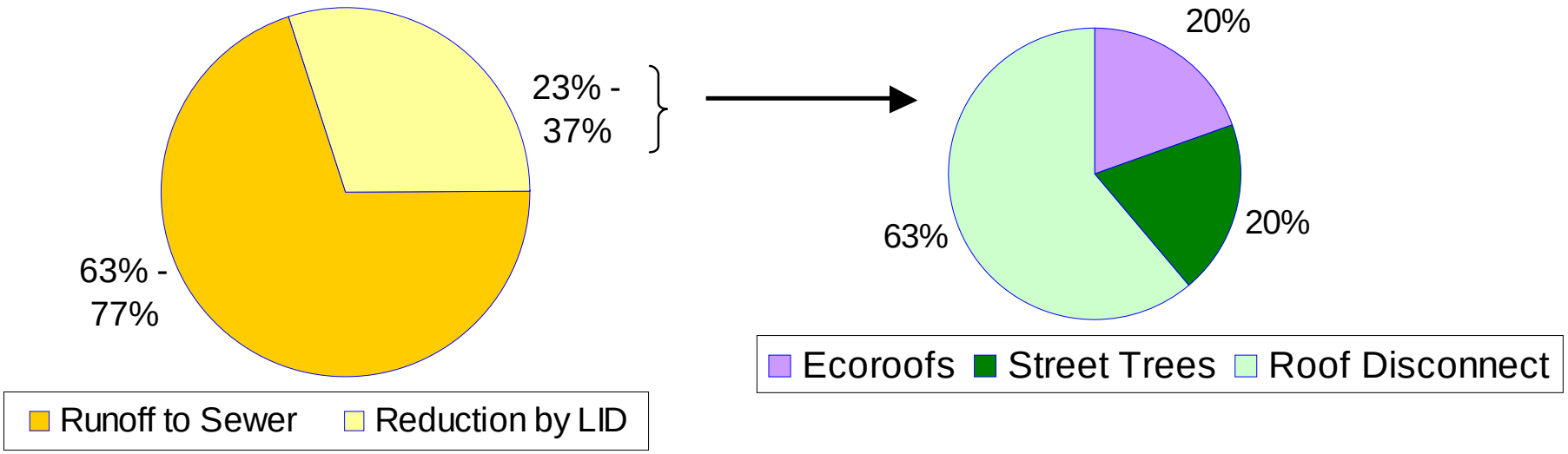

Figure 13. Annual Runoff Volume Reduction: Ultimate Target

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Table 12	Volume Reduction per Unit Converted San Francisco Sewer System Master Plan City and County of San Francisco						
LID Practice	**% of Max Potential Implemented**	**Annual Runoff Volume Reduction (MG)**	**Unit Converted**	**Volume Reduction per Unit Converted**		**Inches Captured**	**Percent of typical year rainfall (1)**
Vegetated roofs	5%	48 - 63	234 acres	5 - 6	gal/sf	8 - 10	29 - 39%
	50%	479 - 631	2,339 acres	5 - 6	gal/sf	8 - 10	29 - 39%
Street Trees	80% Young	108 - 155	100,785 trees	1100 - 1500	gal/tree		
	100% Mature	465 - 638	125,315 trees	3700 - 5100	gal/tree		
Roof Disconnection	10%	243 - 485	808 acres	7 - 14	gal/sf	11 - 22	43 - 86%
	50%	1,237 - 2,411	4,019 acres	7 - 14	gal/sf	11 - 22	44 - 88%

Notes:
(1) Rainfall amounts for modeled typical rainfall year vary throughout city. Average is 25.7 inches.

might reduce combined sewer discharges. The LID model demonstrated peak flow reductions for all of the LID practices modeled. Peak flow reductions were determined for design storms only, not for the typical rainfall year.

Peak flow reductions are summarized in Table 13 and illustrated in Figure 14.

4.1.3 Combined Sewer Discharge

The baseline CSD overflow volume for the typical rainfall year is 1470 MG. LID modeling demonstrated that implementing the 30-year LID target would reduce this annual volume by approximately 200 to 400 MG, or 14 to 27 percent of baseline. Implementing the ultimate target would reduce annual CSD volume by 900 to 1300 MG, or 60 to 90 percent.

5.0 CONCLUSIONS AND RECOMMENDATIONS

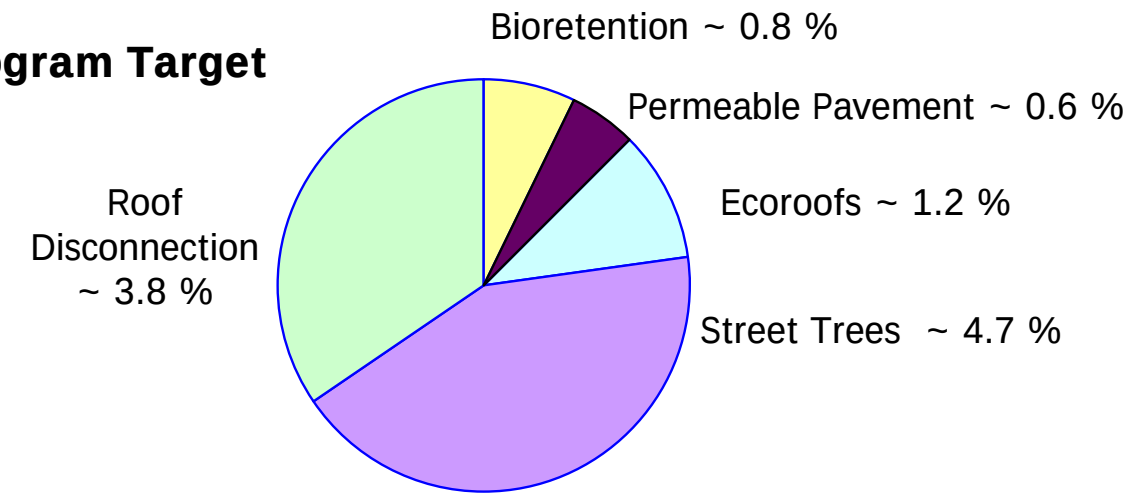
While more studies are necessary, LID analysis results thus far indicate that LID can provide economic, environmental, and other benefits to San Francisco ratepayers. LID modeling demonstrated that implementing the hypothetical 30-year target (equal to 18 percent of the maximum LID conversion) would to reduce citywide runoff volume by up to 7 percent, peak flows by up to 15 percent, and CSD volume by up to 27 percent. A review of other LID studies and installations showed that LID provides the additional benefits of pollutant reduction, energy conservation, water conservation, natural habitat, and beautification.

Table 13	Summary of Peak Flow Reduction Results San Francisco Sewer System Master Plan City and County of San Francisco			
		Percent Peak Reduction (%)		
LID Practice	% of Max Potential Implemented	3-mo, 24-hr Design Storm	1-yr, 24-hr Design Storm	5-yr, 24-hr Design Storm
Vegetated roofs	5%	1.1 - 1.5 %	0.9 - 1.4 %	0.8 - 1.2 %
	50%	11.2 - 14.5 %	9.4 - 13.5 %	8.4 - 12.0 %
Street Trees	80% Young Trees	4.5 - 5.4 %	4.3 - 5.3 %	4.0 - 5.0 %
	100% Mature Trees	17.7 - 21.5 %	16.8 - 20.7 %	15.7 - 19.7 %
Roof Disconnection	10%	2.5 - 5.1 %	2.5 - 5.1 %	2.5 - 5.1 %
	50%	12.9 - 25.2 %	12.9 - 25.2 %	12.9 - 25.1 %
Bioretention	10%	1.5%	0.6%	0.3%
	50%	6.2%	1.5%	2.0%
Permeable Pavement	10%	0.5%	0.6%	0.6%
	50%	2.6%	2.9%	3.1%
30-Year Target: Total	5%GR+ 80%ST+ 10%RD+ 10%BR + 10% PP	11.3 - 15.1 %	10.7 - 14.6 %	10.1 - 14.0 %
Ultimate Target: Total	50%GR+ 100%ST+ 50%RD+50%BR+50% PP	46.1 - 61.2 %	42.4 - 58.6 %	39.9 - 56.4 %

The current regulatory framework for San Francisco's stormwater and combined sewer systems provides a favorable environment for LID. SFPUC currently holds an NPDES stormwater permit that regulates stormwater flows in separate sewer areas. The San Francisco Bay Regional Water Quality Control Board Storm Water Permit Division has included a provision within stormwater NPDES permits that LID best practices must be incorporated into stormwater management to address the impacts of stormwater pollutants on San Francisco Bay water quality. In November 2008, the City of San Francisco passed one of the most progressive green building ordinances in the Country. The Green Building Ordinance will work in tandem with the San Francisco Stormwater Guidelines, which require the use of LEED SS Credit 6.1 within the combined sewer areas for all projects that trigger the Green Building Ordinance.

Given the potential benefits of LID for San Francisco, the project team recommends that SFPUC pursue further studies and develop policies and programs to implement LID. The key recommendations, described in detail below, are as follows:

30-Year Program Target



Ultimate Target

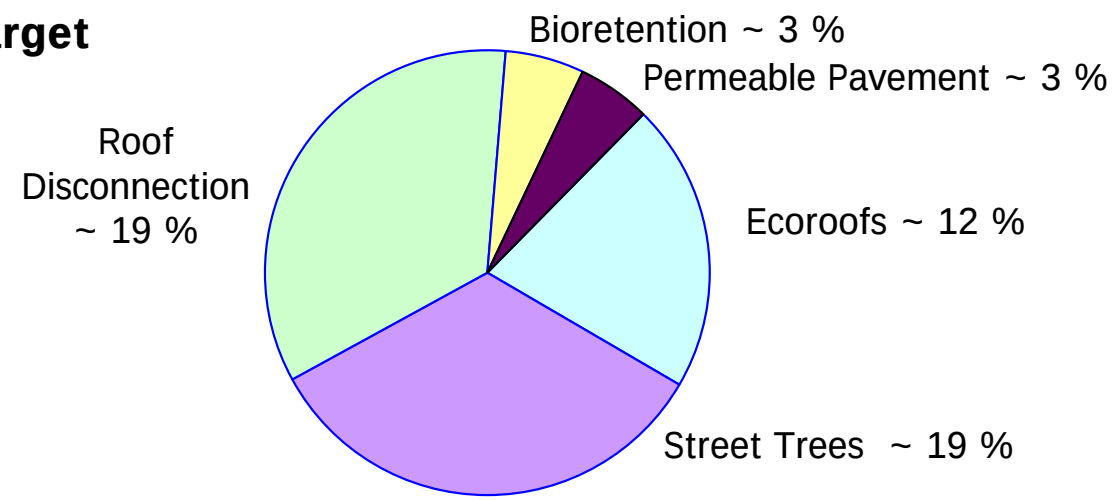


Figure 14. Citywide Peak Flow Reductions for LID Practices Modeled Individually

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- Continue to conduct system analyses to determine where and how best to implement LID as a part of planned and ongoing Capital Improvement Projects both in the right of way and at the basin scale.
- Establish an Urban Watershed Management Program to develop policies, programs and requirements for the implementation of LID.
- Construct, monitor, and maintain LID demonstration projects.

5.1 System Analyses

The aim of the modeling described in this memo was to determine the potential citywide benefits of LID, thus addressing the question of *whether* to implement LID in San Francisco. The next phase of modeling must focus on *where* and *how* to implement LID. Further studies will enable SFPUC to determine which sub-catchments will most benefit from LID (such as flood-prone areas) and which technologies will be most effective in those areas. It is recommended that SFPUC improve on the available spatial and hydrologic data, and model LID applications with more precise land cover data and modeling techniques. Specific recommendations are described below.

5.1.1 Recommendations:

- Develop and/or improve GIS data for land cover/land use, building attributes, soils, bedrock, and groundwater.
- Perform a sensitivity analysis to determine which subcatchments would be most affected by a reduction in impervious area.
- With improved GIS data sets, update the infiltration data and maps to identify target areas for infiltration practices.
- Develop block-scale models of LID implementation in flood-prone or CSD-prone areas, in conjunction with the surface drainage model update.
- Model infiltration practices such as unlined bioretention and permeable pavement systems.
- Compile data on the flow contribution of buried creeks to the combined sewer system.
- Analyze buried streams, along with land use and sewer system data, to identify specific diversion/daylighting opportunities.
- Utilize pilot programs to directly measure reductions in peak flow, volume, and pollutant levels for different combinations of LID practices within a subcatchment.

5.2 Policies

Recommendations:

1) Establish ratepayer incentives for LID implementation.

SFPUC should establish rate incentives and/or subsidies to encourage private property owners to implement LID practices on their properties. For example, SFPUC could provide a rate discount for property owners who reduce the impervious surfaces on their property or replace their existing roof with a vegetated roof.

SFPUC has completed a preliminary analysis of the cost for collection, transport, treatment and disposal of wet weather flows. Findings from the incentives analysis should be used to identify opportunities for incentives and subsidies to promote LID implementation.

2) Revise existing codes and design standards to remove restrictions on innovative stormwater design and to encourage multi-functional design.

SFPUC is working with several City agencies to implement the Better Streets Master Plan, an effort to revisit the standard designs for the city's right-of-ways. The goal is to update these standards to increase pedestrian safety, enhance urban forestry and other plantings, and reduce the stormwater runoff from streets and sidewalks. Once these standards are adopted, they will become the templates for rebuilding streets and sidewalks. As part of this effort, SFPUC is analyzing street maintenance needs, and is implementing codes and policies to integrate capital planning and maintenance of streets in San Francisco.

It is recommended that the SFPUC develop policies requiring implementation of stormwater management facilities within the right of way. The SFPUC should also study the allocation of costs and benefits associated with streetscape stormwater facilities, and should recommend policies regarding ultimate ownership and operations responsibilities for stormwater facilities within the right of way.

4) Establish a project review protocol to ensure that new and redevelopment projects mitigate impacts on the combined sewer system.

SFPUC has been developing procedures for project review of new and redevelopment projects, with regard to stormwater and sanitary flows. The review process applies to all the emerging communities like Hunters Point Shipyard, Treasure Island, the Bayview Redevelopment Area, as well as rapidly developing areas such as Visitacion Valley and Executive Park.

5) Establish an internal project review protocol for identifying greening opportunities in SFPUC capital projects.

As the SFPUC implements a number of capital projects as a part of its 5-year Wastewater Capital Improvement Program and Sewer System Master Plan, each project should be

evaluated for greening opportunities that either enhance the neighborhood and or increase the drainage performance of the affected area. Additionally, the SFPUC should develop a resource guidance document that can be applied to all SFPUC department projects (whether Wastewater, Water or Power) that promotes sustainability and resource conservation.

5.3 Programs

SFPUC should establish and staff several programs designed to support LID implementation, to ensure sound design and construction practices, and to provide ongoing maintenance for publicly owned LID systems.

Recommendations:

1) Establish an urban watershed planning program

The objective of the watershed program will be to develop a watershed management plan for each of San Francisco's nine major drainage areas. The watershed management plans will, among other things, identify drainage goals for each basin, along with opportunities and best practices for implementing LID. As part of the system analyses recommended above, information will be gathered about the unique physical, hydrologic, social, and historical character of each of these basins. Program staff will collaborate with the various government agencies and community groups to identify opportunities for LID, establish goals for LID implementation, and support neighborhood groups in fulfilling those goals. The watershed planning and management program, in whatever form it takes, may serve as an umbrella program for the programs recommended below.

Within the watershed planning program will be two sub-programs: flood management and aquatic resources management. The flood management program will apply multi-purpose stormwater management and LID techniques to benefit flood-prone areas. Flood management strategies might include creek daylighting in areas where culverted creeks flood under heavy rain events, acquisition of chronically flooded properties, and the application of LID technologies in areas with spot flooding. The aquatic resources management program will target several water bodies served by separate sewer areas, including Lake Merced, Pine Lake, and Lobos Creek. These water bodies could benefit from the use of LID and runoff management and infiltration projects. In addition, LID projects that result in increased habitat values for birds and aquatic species would need staff expertise in habitat enhancement and management.

3) Establish a neighborhood stewardship grants program

The aim of this program will be to assist homeowners and community groups that are interested in developing small-scale LID projects in their neighborhoods. Projects would have to address stormwater, but ideally would provide multiple functions such traffic calming, beautification, shading, and runoff reduction. Residents and community groups

could submit project proposals and receive small grants to assist in those parts of the project that reduce stormwater runoff to combined sewers in their neighborhood.

4) Establish a technical assistance program

The objective of the technical assistance program will be primarily to ensure that LID techniques are properly and safely designed and implemented. For example, SFPUC has an interest in preventing infiltration-based facilities from being installed in areas where infiltration may increase liquefaction risks or disturb contaminated sites. To provide guidance, SFPUC is developing a map showing problem areas or where further analysis and design may be needed. SFPUC has also begun to develop design guidelines for its separate sewer areas for sizing and locating stormwater BMPs that will assist developers in managing their stormwater onsite.

5) Establish a Green "Works" Program for maintaining permanent stormwater control facilities

The City of San Francisco has historically had trouble funding maintenance of green spaces, streets and right-of-ways (ROWs). Since stormwater BMPs become part of the sewerage system infrastructure, it is imperative that SFPUC assume responsibility and allocate funding for sustained maintenance of stormwater BMPs. SFPUC has an on-going program to hire at risk individuals for job training, community outreach and environmental justice issues. This program could be expanded to train individuals in the specialized needs of installing, maintaining and monitoring stormwater BMPs. To add value to the community, as well as those who participate in this "green infrastructure" training team, this team could be trained to conduct community outreach on pollution prevention, stormwater management, wastewater treatment, and watershed health.

5.4 Demonstration Projects

Demonstration projects can provide many important benefits to a nascent LID program. They can increase knowledge about the costs, implementation challenges, performance, maintenance requirements, and public acceptance of innovative technologies. Monitoring is particularly important for understanding, and developing confidence in, the performance potential of these technologies. Demonstration projects also provide valuable educational opportunities for regulatory agencies, developers, program staff, students, and the public at large.

It is recommended that SFPUC fund the planning, design, construction, maintenance, and monitoring of several LID facilities. Some of the demonstration projects described below are already underway - in conceptual planning, design, or construction phases. However, funding has not yet been allocated for ongoing public outreach, maintenance, and monitoring of these LID facilities. Other projects described below are only concepts at this point, and will require feasibility studies before proceeding.

Recommendations:

1) Vegetated roof Demonstration Project

SFPUC partnered with the San Francisco Library to implement a vegetated roof and other stormwater management facilities at the Ortega Library. Funds for capital components have already been secured, but it is recommended that SFPUC allocate funding for ongoing monitoring and maintenance of the vegetated roof, as well as for public outreach.

2) Sunset Parking Lot Retrofit

SFPUC has retrofit a 3.5-acre parking lot located in the separate sewer area adjacent to Lake Merced, one of San Francisco's few natural areas. The project combines swales planted with native vegetation, tree planting, and an infiltration basin that will prevent most rain events from discharging to the lake. The SFPUC plans to conduct performance monitoring of the swale and provide public outreach consisting of interpretative signage. It is recommended that SFPUC allocate funding for ongoing monitoring and maintenance of the swales, as well as for public outreach.

3) 25th Avenue North - Innovative Drainage Improvement Plan

Recently the 25th Avenue North neighborhood has experienced significantly more combined sewer overflow (CSO) events than predicted in the system design. These additional CSO events are caused by a stormwater connection made to the Seacliff #2 collection system in September 2002. The pump station is unable to handle the additional load.

The proposed solution to the current problem is to develop low impact development stormwater management interventions that will intercept the storm flows from a 100-year, 2-hour design storm. The proposed controls under consideration include an infiltration basin in the 25th Avenue North eastern cul-de-sac, rebuilding the curb areas of the project area with modular porous pavement, and re-contouring streets to discourage stormwater from entering the area. The project is in a conceptual design phase, with plans to present the design solution to the community for feedback and approval. It is recommended that SFPUC allocate funding for the completion of this project, along with funds for public outreach and ongoing monitoring and maintenance.

4) SFRA Model Block Demonstration Project

The San Francisco Redevelopment Agency (SFRA) approached SFPUC to partner in developing a streetscape redesign for the 1700 Block of Newcomb. SFPUC is working with SFRA, Department of Public Works (DPW), a non-profit group called Architecture for Humanity, and the neighbors to develop a conceptual plan and construction drawings of a neighborhood block that will detain stormwater and beautify the streetscape. Currently, Architecture for Humanity is working with the community to develop the conceptual design

and the plan is to have DPW develop the construction documents. This project is fully funded, including funds for monitoring.

5) Basin Scale LID Projects

The SFPUC conducted a Bayside Basin Charrette to identify basin-scale LID projects such as creek daylighting, green streets, and large-scale stormwater harvesting. The charrette participants identified candidate capital improvement projects for the east side of the City. These projects have been conceptually designed, and analyzed for their costs and benefits. A charrette for the Western Basins is planned for Fall of 2009.

Once the candidate projects have been selected, the next step is to identify a long-term Capital Improvement Plan to coincide and intersect both with larger scale flood relief projects implemented by the SFPUC as well as complementary projects spearheaded by other agencies. It is recommended that these projects be implemented as a part of the SFPUC's Capital Improvement Plan over the next 15 years.

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REFERENCES

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