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THE GREEN VISIONS PLAN

for 21st century southern california

11. Best Management Practices (BMPs) for the Treatment of Stormwater Runoff

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THE GREEN VISIONS PLAN

for 21st century southern california

The mission of the Green Visions Plan for 21st Century Southern California is to offer a guide to habitat conservation, watershed health and recreational open space for the Los Angeles metropolitan region. The Plan will also provide decision support tools to nurture a living green matrix for southern California. Our goals are to protect and restore natural areas, restore natural hydrological function, promote equitable access to open space, and maximize support via multiple-use facilities. The Plan is a joint venture between the University of Southern California and the San Gabriel and lower Los Angeles Rivers and Mountains Conservancy, Santa Monica Mountains Conservancy, Coastal Conservancy, and Baldwin Hills Conservancy.

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INTRODUCTION

Over the past three decades, urban runoff has been identified as a critical source of pollution in the United States. This runoff is now regulated under the Clean Water Act through National Pollutant Discharge Elimination System permitting, with pollution limits defined as total maximum daily loads. Urban and stormwater runoff are critical sources of contamination, particularly for waters near cities, which include the majority of the population. The United States Environmental Protection Agency (USEPA) ranks urban runoff and storm drain discharges as the second most significant source of water quality impairment to US estuaries, and the fourth most significant source of impairment to US lakes (NRDC 1999).

Stormwater pollution prevention and treatment is an important regulatory issue in southern California and the United States. The poor quality of stormwater runoff in southern California and elsewhere arises from two human alterations of the environment: the conversion of soils and other pervious surfaces to concrete, asphalt, buildings, and other impervious surfaces, and the release of pollutants from residential neighborhoods and industrial areas.

Since 1992, cities with populations over 100,000, certain industries, and construction sites over five acres have developed and implemented stormwater plans under Phase I of the National Pollutant Discharge Elimination System (NPDES) stormwater regulations. Since 1992, cities with populations over 100,000, certain industries, and construction sites over five acres have developed and implemented stormwater plans under Phase I of the National Pollutant Discharge Elimination System (NPDES) stormwater regulations. Since 1999, municipalities with more than 50,000 people and densities greater than 1,000 persons per square mile have been required to develop stormwater plans. Municipalities with more than 10,000 residents and a density greater than 1,000 persons per square mile must develop stormwater plans if designated by the state (NRDC 1999).

Most everyday human activities, including driving vehicles, maintaining lawns and parks, disposing of waste and walking pets, can contribute to stormwater pollution, because these activities leave pollutants on impervious surfaces. Common pollutants in stormwater and urban runoff include sediments, toxic metal particles, pesticides and fertilizers, oil and grease, pathogens, excess nutrients, and trash. These pollutants are washed from streets and roads, rooftops, and parking lots during rain events and are carried by the runoff to streams, rivers, and oceans (NRDC 1999).

The presence of pollutants and increased velocity and volume of runoff affects the hydrology and water quality in the watershed, increasing flooding, degrading stream channels, damaging wildlife habitat, changing water temperature, increasing erosion and sedimentation, and reducing water quality. This damages ecosystem function, biological diversity, public health, recreation, economic activity, and general community well-being. The environmental, aesthetic, and public health impacts of diffuse pollution will not be eliminated until stormwater pollution is controlled (NRDC 1999).

The Santa Monica Mountains Conservancy (SMMC) and Los Angeles and San Gabriel Rivers and Mountains Conservancy (RMC) have two major interests in the use of best management practices (BMPs). The first is with source area projects, i.e. matrix and conversion projects, which utilize small, local devices, such as bioswales and filter strips, to facilitate comprehensive neighborhood, street, alleyway, and industry greening efforts. The second is with stormwater parks that capture and treat stormwater from the surrounding watershed. The stormwater is detained, treated, and infiltrated in the park, allowing for groundwater recharge, recreational and open space usage, and habitat restoration.

This white paper descibes the uses and impacts of common stormwater BMPs, pollutant removal efficiencies and climate constraints, local stormwater parks, and an analysis of applicable BMPs for stormwater park design at a candidate SMMC management site to illustrate how the Conservancies might conduct their own BMP analyses for new or proposed stormwater parks.

STORMWATER BEST MANAGEMENT PRACTICES

The USEPA defines stormwater BMPs as techniques, measures, or structural controls that are used for a given set of conditions to manage the quantity and/or improve the quality of stormwater runoff in the most cost-effective manner. Two classes of BMPs are often distinguished. Structural BMPs are systems that are engineered and constructed, whereas nonstructural BMPs consist of pollution prevention techniques designed to stop pollutants from entering urban runoff (USEPA 1999).

BMPs have become a common means for controlling runoff quality since the early 1990s and their effectiveness has been evaluated through studies conducted in the United States, Europe, and other parts of the world (Roesner et al. 2001). The following subsections distinguish four groups of BMPs, which are classified based on the type of intervention or location in the hydrologic cycle where modifications are made.

Runoff Capture at Source

At source technologies (Table 1) are located near or on the impervious surface and are used for reducing the rate and volume of runoff generated during rainfall events. The water retention and detention properties of these technologies can be enhanced through selection of the engineered media (BF Environmental Consultants 2004).

Detention and Retention of Peak Flow

Detention and retention practices (Table 2) temporarily store runoff, and then discharge it through a pipe or other outlet structure into streams and other water bodies. A variety of forms of detention and retention practices exist; most commonly, detention ponds, extended detention ponds, and retention or wet ponds (NRDC 1999, FHWA 2003).

Treatment of Captured Flow

Capture and treat technologies (Table 3) are among the more difficult to define. These range from “natural” filtration technologies such as constructed wetlands, basins, and grassed strips, to engineered flotation technologies such as water quality inlets, continuous deflection separation, and Stormceptors at the curb.

Table 1: At Source Technologies[1]

BMP	Description	Intended Impacts
Porous Pavements	Utilize porous asphalt and concrete and several types of lattice-type pavers (hollow concrete blocks and paving stones) Used in parking lots for office buildings, recreational facilities and shopping centers, emergency stopping areas, traffic islands, sidewalks, road shoulders, and low-traffic roads	Allows stormwater to percolate through pavement and infiltrate into soil while streets, parking lots, sidewalks, and other surfaces retain their function for automobiles and pedestrians
Green Roofs	Rooftop areas that support living vegetation Vary from small gardens and planters to roofs that are completely covered by sod and plants Include waterproofing and root barrier layer, a drainage and filter layer, soil and plants, and an optional insulation layer	Direct cost savings and benefits include reduction in size and cost of HVAC equipment on new and retrofitted buildings and reduction in energy costs due to the insulating properties of most green roof systems
Rain Barrels	Collect roof runoff in water-tight barrels set next to buildings with gutter downspout funneling rainwater into them	Rainwater is collected and stored so it can be used later to water lawns and gardens Used with rain gardens, rain gutter retrofits, small swales and pervious paving to reduce runoff from clusters of houses
Cisterns	Collect roof runoff in large, underground or surface containers designed to hold large volumes of water (500 gallons or more) Made of fiberglass, concrete, plastic, brick or other materials	Rainwater is collected and stored so it can be used later to water lawns and gardens Used with rain gardens, rain gutter retrofits, small swales and pervious paving to reduce runoff from clusters of houses
Dry Wells	Temporarily store and infiltrate stormwater runoff from roofs of structures in a subsurface storage facility Consist of excavated pit filled with aggregate wrapped in geotextile or a pre-fabricated storage chamber	Reduce stormwater volume generated by roofs Improve water quality through infiltration Enhance and promote groundwater recharge

[1] Compiled from Schueler (2000), FHWA (2003), Minnesota Metropolitan Council (2003), Menomenon Valley Partners (2005), Belan and Otto (2004), BF Environmental Consultants (2004), and USEPA (2004).

Table 2: Detention Technologies[1]

BMP	Description	Intended Impacts
Detention Ponds	One or more dry ponds that temporarily store runoff and then discharge it through a pipe or other outlet structure into streams and other water bodies	Control runoff from impervious area by storing and releasing it at a slowed rate through an outfall Remove pollutants through settling, infiltration, nutrient uptake, adsorption, and physical filtration
Extended Detention Ponds	Longer, often coupled systems that facilitate longer detention times for optimal pollutant removal	Detention time is a function of flow rate and pond volume Provides water quality treatment of first flush runoff and some reduction of peak flows for small storm events
Retention Ponds	One or more permanent pools of water that enhance particulate settling by increasing residence time and provide conditions for growth of aquatic vegetation, thereby enhancing filtration, metal and nutrient uptake	Pollutant removal efficiency is a function of pond depth, residence time, drainage area-to-pool volume ratio, and existence of aquatic vegetation May also enhance aesthetics and/or provide recreational benefits such as parks, soccer fields, and baseball fields

[1] Compiled from Schueler (1987), Schueler et al. (1992), Yu and Kaighn (1992), NRDC (1999), Schueler (2000), FHWA (2003), Devinny et al. (2004), and USEPA (2004).

Table 3: Capture Technologies[1]

BMP	Description	Intended Impacts
Constructed Wetlands	Upstream pond with deep water and downstream wetland Imitate natural function of wetlands Utilize aerobic or anaerobic vegetation to remove pollutants from water	Remove pollutants through sedimentation, filtration, plant uptake, degradation, biological uptake and conversion Remove metal pollutants through plant uptake, precipatation by carbonates, absorption to substrate soils, adsorption and exchange onto algae layers, iron hydroxide formation and precipatation by sulfides
Filtration	Utilizes porous media, which could be soil, sand, gravel, peat, compost, and various combinations such as peat and sand, soil and sand, and sand and gravel to remove particulates from water System performance is dependent on particle shape and size, size of voids in filter media, and velocity at which fluid moves through media	Remove solids and attached pollutants such as metals and nutrients through straining, adsorption, chemical transformation, and microbial decomposition Organic filtration media such as peat or leaf compost can also be effective at removing soluble nutrients from urban runoff
Filtration Basins	Permanent pool with sediment chamber through which stormwater flows	Remove solids and attached pollutants such as metals and nutrients
Underground Filters	Multi-chamber underground vault accessible by access holes or grate openings	Water stored in underground chambers is pretreated through settling Stored water flows through a filter chamber and then a sand filter. Filtered runoff is collected in underdrains and discharged into adjacent storm drains or natural channels. Flow exceeding a filter's capacity during large rainfall events is diverted around sand filter by means of an overflow weir
Sand Filters	Consist of a settling area and filter, usually with a sand medium An off-line facility can be used to provide additional capture and treatment of any water volume	Removes particulates from urban stormwater Often used to manage first flush
Grassed Swales	Land surface is shaped to direct stormwater through a broad, relatively flat grassed area Soil may require preparation to maximize infiltration prior to planting of grass	Remove sediment and increase infiltration Frequently located in medians or along shoulders of roads

Vegetated Strips	Gently sloped vegetated areas similar to grassed swales	Remove sediments and increase infiltration Often utilized on roadway shoulders and/or safety zones, but typically require soils with high percolation rates that can efficiently infiltrate water over short lengths Commonly used as a pre-treatment BMP located upstream of other BMPs capable of greater pollutant removal rates Settle out fine and coarse sediment, trapping debris and trash, and separating oil and grease from runoff
Water Quality Flotation Inlets	Utilize settling and surface oil separation mechanisms, and/or filtration, flotation, or vortex motion settling and separating mechanisms	Designed to allow floatable materials such as styrofoam "peanuts" used for packaging, and other low-density materials to accumulate and be manually removed Oil and grease or hydrocarbon trap with a submerged outlet pipe allows contaminants to accumulate and to be removed
Stormceptors	Remove oil and sediment from storm runoff through an engineered stormwater treatment structure Made of a round precast concrete tank and fiberglass partition and often placed in storm sewer maintenance holes Commonly referred to by one of the following terms: an oil-grit separator, oil and grit separator (OGS), oil-sediment separator, or an oil and sediment separator (OSS)	Prevent non-point source pollution from entering downstream lakes and rivers Utilize gravity separation to treat stormwater Capture oil spills and suspended solids Allow part of the peak flow during infrequent storm events to bypass treatment chamber
CDS – Continuous Deflection Separation	Introduces stormwater tangentially to a screen so that water flows against screen, is pushed through screen and the raised lips of screen mesh apertures cause the solid particles to be deflected away	Separates contaminants through indirect screening at both high and low flow rates Can be designed and sized to suit local flow rates Can treat a 3- to 20-year storm event

[1] Compiled from Wieder (1988), Henrot and Wieder (1990), Wildeman et al. (1993), Faulkner and Skousen (1994), USEPA (1999), NRDC (1999), Schueler (2000), FHWA (2003), Devinny et al. (2004), USEPA (2004), CDS Technologies, Inc. (2005), and Stormceptor (2005).

Runoff Infiltration and Groundwater Recharge

The Federal Highway Administration (FHWA 2003) defines infiltration technologies (Table 4) as all "infiltration basins, trenches, and bioretention" areas which "use the interaction of the chemical, physical, and biological processes between soils and water to filter out sediments and other soluble constituents from urban runoff." Stormwater is percolated into the ground using this group of BMPs and as a consequence, fine suspended material is removed by soil filtration, dissolved materials are adsorbed and organic compounds are biodegraded, and the remaining treated runoff passes into the groundwater.

Infiltration is the most effective means of controlling stormwater runoff because it prevents both the water and its contaminants from reaching the runoff flow. In Los Angeles, it is likely that the percolated water will enter an aquifer and become a valuable resource. Runoff is cooled as it flows though the ground, thereby reducing the detrimental thermal effects that runoff may have on aquatic ecosystems (NRDC 1999). However, infiltration is not appropriate in all areas (USEPA 1999). It is mostly suited to areas with at least modestly permeable soils and even then, infiltration may not be possible for highly polluted waters that will threaten groundwater quality.

Table 4 Infiltration Technologies[1]

BMP	Description	Intended Impacts
Infiltration Basins	Shallow depression created by excavation or berming that captures stormwater and promotes infiltration into soil Utilize chemical, physical, and biological processes in soils to remove sediments and other soluble constituents from urban runoff	Remove fine suspended material by soil filtration, dissolved materials by adsorption, and organic compounds by biodegradation Remaining treated runoff passes into groundwater Prevents both water and its contaminants from reaching stream network Usually limited to roadway interchanges and large residual parcels of land and may not be suitable for dense urban areas
Infiltration Trenches/ Ditches	Excavated trench lined and backfilled with stone to form subsurface basin	Diverts and stores runoff until it can infiltrate into soil, usually over a period of several days Most effective with pretreatment included in design, such as vegetated filter strips or grassed swales Ideal for small urban drainage areas Soil layer and presence of microbes enhance filtration and vegetation aids constituent removal
Bioretention Areas	Conditioned soil layers containing a mixture of detritus, humus, and mineral and biological complexes in shallow depressed areas	Small areas can be located in medians, parking lot islands, or grassy areas along streets, making these ideal for constricted urban areas

[1] Compiled from USEPA (1999), NRDC (1999), Schueler (2000), FHWA (2003), and USEPA (2004).

BMP PERFORMANCE

No one BMP can solve all stormwater problems. Each has limitations based on the local goals (i.e. problems to be addressed), drainage area served, available land, cost, desired pollutant removal efficiency, and site-specific factors such as soil type, slope and depth of groundwater table. The advantages and disadvantages of common BMPs should be carefully considered to select the appropriate BMP or group of BMPs for a particular location (USEPA 1999). An example of this is the infiltration basin, which is popular because it facilitates groundwater recharge, can serve large developments, removes particulate and soluble pollutants, replicates pre-development hydrology more than other BMPs, and provides more habitat support than other infiltration systems. These basins require permeable soil with a sufficient depth of rock and water table level. Even when working as intended, infiltration basins may still cause problems because they sometimes will contaminate groundwater or expand mosquito breeding grounds. They also require regular maintenance to prevent clogging and may still have a high rate of failure.

Notwithstanding these limitations and occasional problems, BMPs are attractive because they can effectively remove a wide range of pollutants from urban runoff when properly designed (Table 5). The pollutant removal efficiency of a BMP depends on numerous site-specific variables, including the size, type and design of the BMP; the soil types and characteristics; the geology and topography of the site; the intensity and duration of the rainfall; the length of antecedent dry periods; climatological factors such as temperature, solar radiation, and wind; the size and characteristics of the contributing watershed; and the properties and characteristics of the various pollutants (USEPA 1999). Table 5 summarizes the percent pollutant removal efficiencies for a range of pollutants and common BMPs reported in the literature.

Role of BMPs in Semi-Arid and Arid Watersheds

Little consideration was given to the effect of climate and weather variations on stormwater BMPs until recently. Not surprisingly, most BMPs require modifications while others are considered unacceptable in arid and semi-arid regions (Table 6). The watersheds in the Los Angeles basin can be considered semi-arid, yet they have distinctive wet and dry seasons. Previous studies, primarily those conducted in humid eastern watersheds, did not consider such water constraints (Schueler 2000).

The Los Angeles area commonly receives 15 to 35 inches of rain during a short period in the winter. There are typically only 20 to 25 days of rain per year, although the storms are sometimes intense. Overall, the area has a very limited local water supply, and relies on an extensive system for water importation, which is costly in financial, environmental, and political terms. These conditions enhance the value of multiple use facilities, because the alternate uses will be possible for a large part of the year and infiltration will help to sustain or possibly increase groundwater resources. Enhancement of local water resources is particularly valuable. The challenges of designing and operating BMPs in semi-arid environments have discouraged their adoption in the Los Angeles area. Government regulation of stormwater runoff quality and a commitment to reducing flood problems have forced more consideration of BMPs in recent years.

A substantial effort was made in the Sun Valley project, which was funded by Los Angeles County to develop alternative approaches for flood control and runoff quality management (Figure 1). This is an urbanized area with considerable industrial development that currently lacks storm drains and experiences frequent flooding. Four alternative plans were developed to: (1) maximize infiltration; (2) maximize water conservation and wildlife habitat; (3) maximize stormwater reuse by industry; and (4) emphasize conveyance to traditional storm drains (Los Angeles County Department of Public Works 2003, Devinny et al. 2004). Notably, the alternative that maximized the use of onsite BMPs was rejected as too expensive; however, the other plans included a variety of BMPs such as industrial reuse, infiltration basins in parks, tree planting and mulching, infiltration in parking lots, and infiltration in vaults beneath the streets. The project was undertaken to determine whether there was an approach to flood control other than simply

Table 5: Percent Pollutant Removal Efficiencies for Common BMPs[1]

BMP	TSS[2]	NO_3^- N[2]	TKN[2]	P[2]	Total Copper	Total Lead	Total Zinc	Dissolved Copper	Dissolved Lead	Dissolved Zinc	Fecal Coliform
Porous Pavements	91	27	81	61	42	74	81	N/A	N/A	N/A	N/A
Detention Basin	74	49	42	48	67	79	72	66	75	62	N/A
EDBs	72	8	17	39	58	72	73	76	74	84	N/A
Retention Pond	74	49	42	48	67	79	72	66	75	62	N/A
Wetlands	76	46	24	56	25	54	49	N/A	N/A	N/A	97
Water Quality Inlet	0	15	N/A	15	8	11	17	16	6	14	N/A
Filtration Basin	74	49	42	48	67	79	72	66	75	62	N/A
Underground Sand Filter	80	N/A	40	56	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sand Filter	82	N/A	47	50	58	86	86	24	36	78	76
Grassed Swales	52	N/A	10	37	N/A	13	38	N/A	N/A	N/A	N/A
Vegetated Strips	69	39	48	37	90	53	62	85	78	78	N/A
Infiltration Basin	84	65	38	69	65	58	60	N/A	N/A	N/A	100
Infiltration Trench	84	N/A	55	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Bioretention Areas	49	27	31	N/A	N/A	63	68	77	49	57	74

[1] Compiled from Yousef et al. (1985), Martin and Smoot (1986), Hogland et al. (1987), Schueler (1987), Yu and Benelmouffok (1988), City of Austin (1990, 1995), Kahn et al. (1992), Schueler et al. (1992), Yu and Kaighn (1992), Harper and Herr (1993), USEPA (1993), Yu et al. (1993, 1994), Bell et al. (1995), Horner and Horner (1995), Gain (1996), Young et al. (1996), USEPA (1999), FHWA (2003), and California Department of Transportation (2004)

[2] TSS is Total Suspended Solids, NO_3-N is Nitrogen as Nitrate, TKN is Total Kjeldahl Nitrogen, and P is Phosphorus

Table 6: List of BMPs and Modifications Required in Arid and Semi-Arid Watersheds (from Schueler 2000)

BMP	**Semi-Arid Watersheds**	**Arid Watersheds**
Green Roofs	Preferred Recharge rooftop runoff onsite	Preferred Dry well design for recharge of residential rooftops
Extended Detention Ponds	Acceptable Require a dry or wet forebay	Preferred Require multiple storm extended detention ponds, stable pilot channels, and a dry forebay
Constructed Wetlands	Limited Use Require supplemental water Use of submerged gravel wetlands can help reduce water loss	Not Recommended Evaporation rates too great to maintain wetland plants
Sand Filters	Preferred Require a mix of coarse and fine media to prevent premature clogging and to ensure sufficient treatment	Preferred Require greater pretreatment Exclude pervious areas
Grassed Swales	Limited use unless site is irrigated Rock berms and grade control essential to prevent erosion in open channels	Not recommended for pollutant removal Rock berms and grade control needed for open channels to prevent channel erosion
Infiltration Basins	Major Modification Multiple pretreatment required Treat impervious areas	Major Modification Multiple pretreatments required Treat impervious areas Soil limitations
Bioretention Areas	Major Modification Require runoff to supplement irrigation Require xeriscaping plants Need to avoid trees Replace mulch with gravel	Major Modification No irrigation required Better pretreatment Treat impervious areas Requires xeriscape plants or no plants Replace mulch with gravel

building storm drains. In Figure 1, the park areas for the Sun Valley Watershed Management Plan are outlined in green. The MRCA has several parcels of land designated as potential “Upper Los Angeles River Proposition 50” projects. There are two such sites within the Sun Valley Watershed and these are delineated in blue. The watershed boundary as noted in the Sun Valley Watershed Management Plan is shown in red. The work already completed or now underway illustrates some of the roles that BMPs might play in the Los Angeles Region as documented below.

The Sun Valley Park and Recreation Center was the first project implemented (Figure 1). It was designed to provide relief of street flooding, reduce stormwater pollution, and increase groundwater supply, recreational opportunities, and community beautification. Upstream stormwater flows through a system of catch basins and storm drains into the park. The water is then carried through underground treatment units, where larger particles of sediment and oil and grease are extracted. A heavy metals treatment device was installed to treat low flows, which are the most polluted. Stormwater is then conveyed through

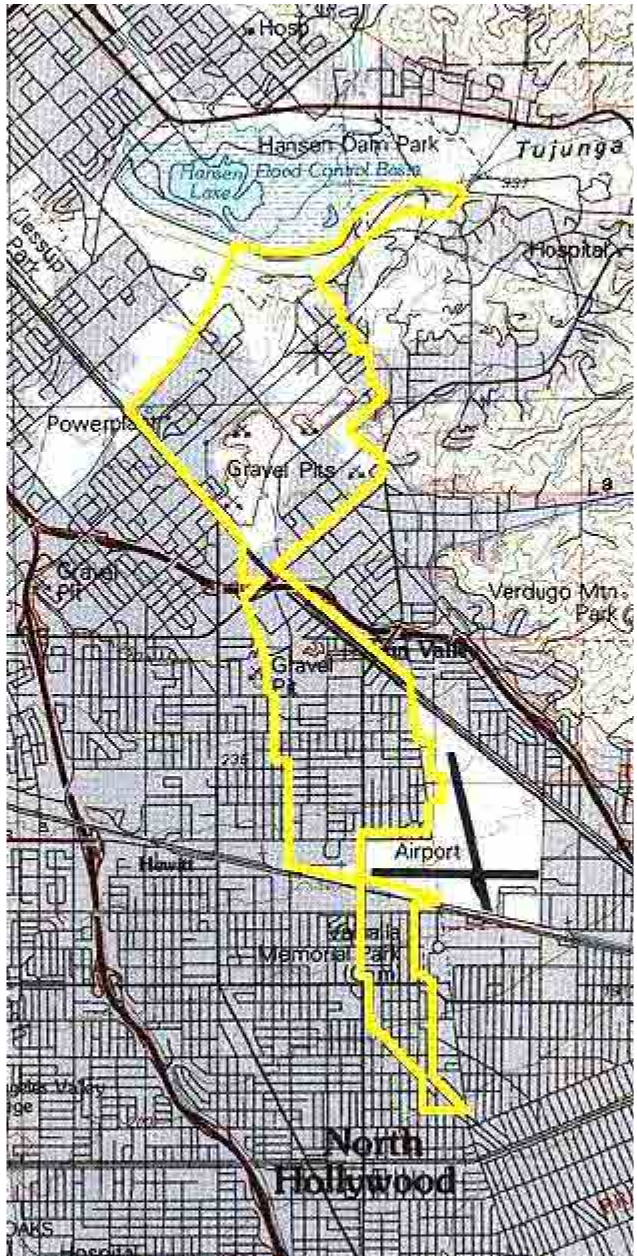

Figure 1: Sun Valley Watershed (LADPW 2003)

two underground infiltration basins, where it percolates into the soil. The underground construction allows the surface of the park to remain undisturbed. Concurrent with the construction of the treatment facility, the park was improved by adding a soccer/football field, restoring the walkway, repairing the baseball field, and planting native species (Los Angeles County Department of Public Works 2003).

Stonehurst Park, located to the south of Allegheny Street and Dronfield Avenue and north of the Cal Mat Pit, will be modified to capture and infiltrate stormwater flows (Figure 1). This 13-acre park will have a storage capacity of about 4.3 acre-ft when the modifications are completed. Approximately 20% of its total area will be depressed by two feet to capture runoff from a contributing area of 49 acres. The park will act as an infiltration basin for up to 50-year storm events and will be dry within two days of an average storm event. The stormwater will be initially captured by catch basins and a pipeline will lead water to a stormwater separation device to remove trash and suspended material (Los Angeles County Department of Public Works 2003).

Another proposed infiltration site is the Sun Valley Middle School. The design for this location, which would infiltrate runoff from the school grounds and nearby upstream neighborhoods, includes strategic tree planting, water storage and reuse for landscaping, depressed playing fields for collection of rainwater, and underground storage tanks to hold water for infiltration (Los Angeles County Department of Public Works 2003).

The proposed Wentworth Street stormwater park (Figure 1) is currently a vacant lot. Approximately 80 percent of the park will be depressed by an average of two feet to obtain a storage capacity of 4.6 acre-ft. The park will capture runoff from a contributing area of 14 acres for a 50-year storm event and will be dry within two days of the average storm event. The stormwater will be initially captured by catch basins and a pipeline that will lead water to a stormwater separation device to remove trash and suspended material similar to Stonehurst Park (Los Angeles County Department of Public Works 2003).

Outside of Sun Valley, there are few proposed or planned stormwater parks. One proposed park will be constructed at the 40-acre Taylor Yards site and will utilize many of the BMPs described in this white paper. The Taylor Yard Park design includes one regulation soccer field and three junior soccer fields that will double as infiltration basins during storm events. The current plan calls for the park to be graded to decrease stormwater runoff velocity and maximize stormwater infiltration, while maintaining a recreational and aesthetic park area. Taylor Yard Park will have a multi-purpose competition sports field, natural parkland area, transitional parkland with turf, trees, and picnicking areas, and an ox-bow river for riparian natural habitat. All features such as spectator seating, amphitheater, and walkways will be natural and the landscaping will seek to minimize stormwater runoff (City of Los Angeles Department of Recreation and Parks and California State Parks 2003).

ANALYSIS OF CANDIDATE MRCA PROJECT SITE

The MRCA has identified numerous potential "Upper Los Angeles River Proposition 50" projects. These multiple use sites would serve as recreation and open space areas, stormwater parks, and habitat conservation areas. To determine whether a site is suitable for a BMP park, the surrounding land use, expected stormwater runoff pollutant concentrations from these areas, desired water quality effluent concentration, and estimated removal efficiencies of the BMPs should be considered. The effects of urban runoff on water quality are site-specific and certain characteristics should be considered when selecting BMPs (Barrett et al. 1995). The selection of in situ treatment methods is primarily determined by the site-specific particulate characteristics and loading rates. The selection of appropriate water quality and drainage measures requires identification of solid gradation, mass loading, surface area, and specific gravity of the soil at each site. The surrounding land use may be the most important general factor influencing pollutant loads from impervious surfaces. Unusual local factors can also influence the quality of runoff (Driscoll et al. 1990). The Los Angeles County Department of Public Works has published the concentrations for common stormwater runoff pollutants for eight major land classes based on water quality sampling conducted from 1994 to 2000 (Table 7).

The SMMC has identified several potential Proposition 50 project sites which might serve multiple purposes and one such site, Pacoima Wash, was selected for illustrative purposes in this white paper. This particular site is characterized by a series of long, narrow stretches connecting several larger parcels and is located between a freeway and arterial streets and the concreted Pacoima Wash (Figure 2). The long stretches could be converted into infiltration trenches or vegetation swales. The City of San Fernando (2004) has proposed transforming the Pacoima Wash area into a community amenity by constructing a bike path and open space system that may serve as a larger part of the regional open space/recreational system. Infiltration trenches and vegetated swales could still be employed should the City of Fernando decide to design a bike path along the wash. The bicycle path should be constructed of porous pavements, which could facilitate further treatment of stormwater runoff from the drainage area. The following subsections will evaluate the application of three BMP alternatives: porous pavements, infiltration basins, and a combination of the two. The bicycle path will be constructed of porous pavements and the larger parcels will be converted to infiltration basins.

Alternative 1: Porous Pavement Bicycle Path

As previously noted, the City of San Fernando has proposed creating a stretch of bicycle paths along the Pacoima Wash as one component of a comprehensive recreational plan for the Pacoima Wash. The City's vision includes fostering a connection with nature by integrating the bicycle path and open space into a greenway that would encompass the Wash. This would allow the City to explore restorative efforts such as increasing permeability, establishing wildlife habitat, controlling and treating polluted stormwater runoff. The bike path would connect residents to the Angeles National Forest, to an existing bike path on First Street, to a future high school and middle school, and three proposed MRCA open space sites (City of San Fernando 2004).

Porous pavements should be considered for the construction of the bike path. As noted earlier, porous pavements utilize a type of porous asphalt or concrete or a series of lattice-type pavers, which are hollow concrete blocks and paving stones. They are best employed in situations where heavy traffic and travel will not occur, such as freeway shoulders, parking lots, sidewalks, and bike paths. Porous pavement design considerations include:

- Areas with a minimum soil infiltration capacity of 7 mm/h (0.27 in/h)
- Installations should be 30 m (100 ft) upgradient and 3 m (10 ft) downgradient of building foundations

Table 7: Average Pollutant Concentrations from Eight Major Land Use Classes (LADPW 2005)

Constituent	High Density Single Family Residential	Light Industrial	Vacant	Retail/ Commercial	Multi-family Residential	Transport-ation	Education	Mixed Residential
Total Suspended Solids (mg/L)	104.7	229.4	164.7	67.4	46.4	75.4	103.0	69.1
Nitrate-N (mg/L)	1.0	0.9	1.1	0.6	1.7	0.8	0.6	0.7
Kjeldahl-N (mg/L)	2.8	3.1	0.8	3.4	1.9	1.8	1.6	2.7
Total Phosphorus (mg/L)	0.4	0.4	0.1	0.4	0.2	0.4	0.3	0.3
Dissolved Copper (ug/L)	8.4	20.2	n/m	14.6	6.8	32.7	12.8	11.5
Dissolved Lead (ug/L)	n/m	n/m	n/m	n/m	n/m	n/m	n/m	n/m
Dissolved Zinc (ug/L)	39.1	460.2	n/m	164.1	75.4	203.9	66.0	125.8
Total Copper (ug/L)	15.3	31.0	9.1	34.8	12.2	51.9	21.5	17.3
Total Lead (ug/L)	9.6	14.9	n/m	11.5	5.1	9.1	4.5	8.7
Total Zinc (ug/L)	80.4	565.6	38.8	238.5	134.9	279.5	123.7	184.9
Fecal Coliform (MPN/100 mL)	1085353.7	653070.4	2174.8	1071656.5	n/m	1340166.7	n/m	n/m

Figure 2. MRCA land parcels along the Pacoima Wash

Table 8: Pacoima Wash Land Use Areas

LADPW Land Use	Area (Acres)	Percent Total Area
High Density Single Family Residential	4145.8	17.6%
Mixed Residential	452.3	1.9%
Multi-Family Residential	121.3	0.5%
Retail/Commercial	369.9	1.6%
Education	141.7	0.6%
Light Industry	413.3	1.8%
Transportation	1295.3	5.5%
Vacant	16225.3	68.8%
Open Space	435.5	1.9%

- Sufficient pavement thickness should be employed to protect the subgrade from being overstressed
- Materials should be compacted to provide strength and to resist densification under traffic (FHWA 2003).

We here envisage two scenarios for a porous pavement bike path running down one side of the Pacoima Wash to illustrate the opportunities for controlling and treating stormwater runoff. These scenarios summarize what would happen to predicted effluent concentrations of 10% (i.e. 20% of the runoff from one side of Pacoima Wash) and 25% (i.e. 50% of the runoff from one side of Pacoima Wash) were captured and infiltrated (treated) by the porous pavement bicycle path.

The various land uses and their total areas in Pacoima Wash and its drainage basin area summarized in Table 8 were multiplied by the pollutant concentrations (Table 7) and the average removal efficiencies for the porous pavement BMP (Table 5) to determine the effluent concentrations under each scenario.

This approach would produce a 9.1% improvement (12.9 mg/L) for total suspended solids under the 10% scenario and a 22.7% (32.5 mg/L) improvement for total suspended solids under the 25% scenario assuming that the land uses from which storm runoff was captured and treated matched the Pacoima Wash land uses percentages (Table 8). The largest reductions would accompany light industrial land uses and the smallest reductions would be those associated with multi-family residential land uses given the mean pollutant concentrations summarized in Table 7. Dividing the largest mean pollutant concentration by the smallest mean pollutant concentration for the different pollutants recorded in Table 7 indicates the magnitude of the differences that could be expected when the porous pavement bicycle path BMP captures runoff from smaller areas with different distributions of specific land uses. The switch from a drainage basin with multi-family residential to light industrial land uses would produce a five-fold increase in total suspended solid concentration but a three-fold increase in total lead and copper concentrations, for example.

Alternative 2: Infiltration Basin Stormwater Parks

The City of San Fernando, in conjunction with MRCA, is also considering several parcels of land for parks and open space. With proper grading, these spaces can double as infiltration basins during the wet season. An infiltration basin is a shallow depression created by excavation or berming that captures stormwater and promotes infiltration into soil. In the Sun Valley Park, infiltration basins are constructed as underground storage tanks, which capture excess stormwater runoff and slowly allow infiltration into the ground. The Conservancies might consider this form of infiltration basin at one or more of the open space sites. Design considerations for above ground infiltration basins include:

- Sufficient surface area and soil infiltration capacity
- A minimum buffer of 3 m (10 ft) between the basin invert and the seasonal high groundwater level is used in some western states
- Most infiltration basins require pretreatment to cut down on maintenance (e.g. detention ponds, riprap, or porous pavements)
- Performance can be improved by keeping the infiltration area large, ensuring the bottom is flat, and vegetating with a dense turf of water-tolerant grass
- Actual size is dependent on long-term meteorological trends, the site's demonstrated minimum infiltration rate, and the dewatering time (FHWA 2003).

Given the general lack of open surface area in the urban settings like those in the northeast San Fernando Valley, infiltration trenches are generally more applicable than infiltration basins; however, the parks and open spaces proposed along Pacoima Wash would provide sufficient land for a series of infiltration basins (FHWA 2003).

We can envisage two sets of infiltration basins – the first set might capture and infiltrate (i.e. treat) 10% of the drainage on the north side of the wash (i.e. 5% of the drainage basin as a whole) and the second might capture and infiltrate 50% of the drainage on the south side of the wash (i.e. 25% of the drainage basin). These scenarios would produce 4.6 and 22.7% reductions in total suspended solid pollutant concentrations, respectively given the approach outlined for the first alternative and the caveat that different land use allocations might cause a four- to six-fold increase in effluent concentrations for several pollutants.

Alternative 3: Combination of Porous Pavement and Infiltration Basins

Given that space is adequate along the Pacoima Wash, it seems most suitable to create a series of infiltration basin/stormwater parks connected by a porous pavement bicycle path. With the combination of the two BMPs, the reductions in effluent concentrations can be increased beyond that accomplished with only one BMP with little extra effort.

Combining a porous pavement bicycle path that captures and treats 50% of the runoff from one side of Pacoima Wash (25% overall) with a series of stormwater infiltration basins that capture and treat 50% of the runoff from one or other or both sides of Pacoima Wash could be expected to produce a 68% (98 mg/L) improvement (reduction) in total suspended solid effluent concentrations for example. Different pollutants would generate different predictions given the mix of land uses in Pacoima Wash (Table 8) and the pollutant concentrations predicted for different land use classes (Table 7).

As should be expected, this third alternative, a combination of porous pavements and infiltration basins, is best. The Conservancies should keep in mind that these are rough estimates and none of the calculations were created based on the shaded areas in Figure 2 and the land uses for the areas from which storm runoff might be captured and infiltrated (trenched).

DISCUSSION AND CONCLUSIONS

This white paper described those stormwater best management practices that may be suitable for Los Angeles parks. In order to meet this requirement, the BMPs must be suitable for semi-arid watersheds, such as those in the Los Angeles basin, and applicable to parks and other urban open spaces. A stormwater management system that utilizes a system of native landscaping and vegetation to treat and convey stormwater allows natural infiltration to occur near the area of rainfall. Engineering terrain, vegetation, and soil features to perform this function, replaces construction of costly conventional conveyance systems and allows the site's hydrologic assets to function in a more natural way (Menomenon Valley Partners 2005).

No one best management practice is capable of removing all the pollutants associated with urban runoff from stormwater. As seen in the stormwater park examples it is often best to apply several BMPs in series, even if they are the same devices, i.e. the Central Park Wets Ponds of Austin, Texas. This was supported in the three alternatives compared for the purpose of this report. Two BMPs are better than one when treating and infiltrating stormwater. Regardless of the constraints associated with urbanization and climate in Los Angeles, the appropriate BMPs for the location can be determined through field reconnaisance, computer analysis, and planning.

REFERENCES

Barrett M E, Malina J F, Jr, Charbeneau R J, and G H Ward 1995 Water quality impacts of highway construction and operation. *Journal of Environmental Engineering* 124: 1121-1128

Belan G and B Otto 2004 *Catching the Rain: A Great Lakes Resource Guide for Natural Stormwater Management.* Washington, DC, American Rivers

Bell W, Stokes L, Gavan L J, and T N Nguyen 1995 *Assessment of the Pollutant Removal Efficiencies of Delaware Sand Filter BMPs*. Alexandria, VA, City of Alexandria, Department of Transportation and Environmental Services

BF Environmental Consultants 2004 Stormwater BMP, Capture Reuse BMP. WWW document, http://www.webdesignpros.net/consult/infiltrationbmp.htm

Bina A and J S Devinny 2006 *Stormwater Control through Retrofit of Industrial Surfaces.* Los Angeles, CA, University of Southern California GIS Research Laboratory and Center for Sustainable Cities Technical Report

California Department of Transportation 2004 *BMP Retrofit Pilot Program, Final Report.* Sacramento, CA, California Department of Transportation, Division of Environmental Analysis, Report ID CTSW-RT-01-050.

CDS Technologies, Inc. 2005 Engineering Healthy Waterways. WWW document, http://www.cdstech.com/

City of Austin 1990 *Stormwater Pollutant Loading Characteristics for Various Land Uses in the Austin Area*. Austin, TX, Environmental Resources Management Division, Environmental and Conservation Services Department, City of Austin

City of Austin 1995 *Characterization of Stormwater Pollution for the Austin, Texas Area*. Austin, TX, Environmental Resources Management Division, Environmental and Conservation Services Department, City of Austin

City of Austin 2005 Watershed Protection Development Review, Central Park Wet Ponds. WWW document, http://www.ci.austin.tx.us/watershed/centralpark/htm

City of Los Angeles Department of Recreation and Parks and California State Parks 2003 *Public Consensus Conceptual Plan for Taylor Yard, Los Angeles, California.* Sacramento, CA, California State Parks

City of San Fernando 2004 Pacoima Wash Project. WWW document, http://www.ci.san-fernando.ca.us/sfold/extra/pacoima_wash/overview.shtml

Claytor R A and T R Schueler 1996 *Design of Stormwater Filtering Systems.* Silver Spring, MD, The Center for Watershed Protection

Devinny J S, Kamieniecki S, and M Stenstrom 2004 Alternative Approaches to Stormwater Quality Control. Unpublished Report Prepared for Los Angeles Regional Water Quality Control Board

Driscoll E D, Shelley P E, and E W Strecker 1990 *Pollutant Loading and Impacts from Highway Stormwater Runoff: Volume III, Analytical Investigation and Research Report.* Washington, DC, Federal Highway Administration, Office of Research and Development Report, No. FHWA-RD-88-008

Faulkner B B and J G Skousen 1994 Treatment of acid mine drainage by passive treatment systems. In *Proceedings of the nternational Land Reclamation and Mine Drainage Conference,* Pittsburgh, Pennsylvania: 250

FHWA (Federal Highway Administration) 2003 Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring. WWW document, http://www.fhwa.dot.gov/environment/ultraurb/5mcs9.htm

Gain S W 1996 *The Effects of Flow-Path Modifications on Urban Water-Quality Constituent Retention in Urban Stormwater Detention Pond and Wetland System, Orlando, Florida*. Orlando, FL, Florida Department of Transportation

Harper H H, and J L Herr 1993 *Treatment Efficiencies of Detention with Filtration Systems*. Orlando, FL, Environmental Research and Design, Inc.

Henrot J and R K Wieder 1990 Processes of iron and manganese retention in laboratory peat microcosms subjected to acid mine drainage. *Journal of Environmental Quality* 19: 312-320

Hogland W, Niemczynowice J, and T Wahlan 1987 The unit superstructure during the construction period. *The Science of the Total Environment* 59: 411-424

Horner R R and C R Horner 1995 Design, Construction, and Evaluation of a Sand Filter Stormwater Treatment System, Part II, Performance Monitoring. Unpublished Report to Alaska Marine Lines, Seattle, Washington

Kahn Z, Thrush C, Cohen P, Kulzer L, Franklin R, Field D, Koon J, and R Horner 1992 *Biofiltration Swale Performance, Recommendations, and Design Considerations.* Seattle, WA, Municipality of Metropolitan Seattle, Water Pollution Control Department

Los Angeles County Department of Public Works 2003 *Draft Sun Valley Watershed Management Plan, Los Angeles, California.* Los Angeles, CA, Los Angeles County Department of Public Works

Martin E H and J L Smoot 1986 *Constituent-Load Changes in Urban Stormwater Runoff Routed Through a Detention Pond - Wetlands Systems in Central Florida. Tallahassee, FL,* US Geological Survey Water Resources Investigations Report No. 85-4310

Menomenon Valley Partners 2005 Menomenon Valley Sustainable Design Guidelines. WWW document, http://design.renewthevalley.org.

Minnesota Metropolitan Council and Barr Engineering 2003 *Chapter 3: Impervious Surface Reduction: Green Rooftops.* St. Paul, MN, Minnesota Metropolitan Council (available at http://www.metrocouncil.org/environment/watershed/BMP/manual)

NRDC (Natural Resources Defense Council) 1999 Stormwater Strategies: Community Responses to Stormwater Pollution. WWW document, http://www.nrdc.org/water/pollution/storm/stoinx.asp

Roesner L A, Fellow P E, Bledsoe B P, and Brashear R W 2001 Are best management practice criteria really environmentally friendly? *Journal of Water Resources Planning and Management* 127(3): 150-154

Schueler T R 1987 *Controlling Urban Runoff: A Practical Manual For Planning and Designing Urban BMPs*. Washington, DC, Metropolitan Washington Council of Governments

Schueler T R 2000 *Stormwater Strategies for Arid and Semi-Arid Watersheds.* Ellicott City, MD, Center for Watershed Protection Article No. 66

Schueler T R, Kumble P A, and M A Heraty 1992 *A Current Assessment of Urban Best Management Practices - Techniques for Reducing Non-Point Source Pollution in the Coastal Zone*. Washington, DC, Metropolitan Washington Council of Governments, Department of Environmental Programs, Anacostia Restoration Team

Stormceptor (2005). StormceptorR. WWW document, http://www.stormceptor.com/index.php

USEPA (United States Environmental Protection Agency) 1999 *Preliminary Data Summary of Urban Storm Water Best Management Practices.* , Washington, DC, US Enviornmental Protection Agency, Report No. EPA-821-R-99-012

USEPA (United States Environmental Protection Agency) 2004 *National Management Measures Guidance to Control Nonpoint Source Pollution from Urban Areas.* Washington, DC, US Environmental Protection Agency

Wieder R K 1988 Determining the capacity for metal retention in man-made wetlands constructed for treatment of coal drainage. *Mine Drainage and Surface Mine Reclamation* 1: 375-381

Wildeman T R, Updegraff D M, Reynolds J S, and J L Bolis 1993 Passive bioremediation of metals from water using reactors or constructed wetlands. In Means J L and R E Hinchee (eds) *Emerging Technologies for Bioremediation of Metals.* Boca Raton, FL, Lewis Publishers: 13-25

Young G K, Stein S, Cole P, Kammer T, Graziano F, and F Bank 1996 *Evaluation and Management of Highway Runoff Water Quality.* Washington, DC, Federal Highway Administration, Office of Environment and Planning, Report No. FHWA-PD-96-032

Yousef Y A, Wanielista M P, and H H Harper 1985 Removal of highway contaminants by roadside swales. *Transportation Research Record* 1017: 62-68

Yu S L and D E Benelmouffok 1988 Field Testing of Selected Urban BMPs. In Strech M (ed) *Critical Water Issues and Computer Applications.* New York, American Society of Civil Engineers: 309-312

Yu S L and R J Kaighn 1992 *VDOT Manual of Practice for Planning Stormwater Management*. Charlottesville, VA, Virginia Department of Transportation, Virginia Transportation Research Council, Report No. FHWA/VA-92-R13

Yu S L, Barnes S L, and V W Gerde 1993 *Testing of Best Management Practices for Controlling Highway Runoff*. Richmond, VA, Virginia Department of Transportation, Report No. FHWA/VA-93-R16

Yu S L, Kaighn R J, and S L Liao 1994 *Testing of Best Management Practices for Controlling Highway Runoff, Phase II*. Richmond, VA, Virginia Department of Transportation, Report No. FHWA/VA-94-R21