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Publication Date
2018

Peer reviewed

Optimization of Green Stormwater Infrastructure Projects in the City of Los Angeles

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ABSTRACT

Stormwater poses flooding and pollution in metropolitan areas, and impacts of unclean urban stormwater have given rise to green stormwater infrastructure (GSI). The City of Los Angeles' (City) Los Angeles Sanitation (LASAN) has spent over $600 M for the past 15 years applying GSI for stormwater treatment/capture/infiltration/reuse. These GSI project types comprise natural treatment systems, mechanical process systems, and passive systems in public sites (e.g., right-of-ways, alleys, lakes, parks, parking lots). After construction of GSI projects, the optimization of these projects was initiated to ensure that the individual project elements are functioning as a system in an optimal manner to assist in meeting water quality requirements and maintaining long-term project sustainability. The optimization of GSI will cover all the aspects of using GSI and the lessons learned from the design, construction, optimization phases, and from water quality and quantity characteristics achieved. After the optimization period, the GSI projects will proceed to operations and maintenance (O&M) phase of the project. Uses of GSI are to capture, slow, infiltrate, and retain stormwater on site, employing systems that include catch basin intercepts, dry well chambers, wetlands, cisterns, replacing asphalt with permeable surfaces, percolating stormwater through infiltration, rain gardens, bioswales, providing underground storage for reuse, treating stormwater runoff before it enters water bodies. GSI projects' performances during storm events rendering water quality and water-supply benefits and achieving total maximum daily loads (TMDLs) that must be met. Optimization of GSI have other benefits for the community, including fewer beach closures, cleaner communities, healthier environments, lowered health risks, enhanced recreational opportunities, and lower demand for potable water.

INTRODUCTION & GREEN STORMWATER INFRASTRUCTURE (GSI) PROJECTS

Stormwater (urban runoff) is a major source of water-quality degradation in rivers, lakes, seas, swamplands, and aquifers, all of which serve natural and socioeconomic functions. The decreasing of water quality in water bodies receiving urban storm runoff is persistent in metropolitan areas across the United States and elsewhere (Hagekhalil et al., 2015; Loáiciga et al., 2015). Stormwater exhibits harmful physical-chemical-biological characteristics, large biochemical-oxygen demand, oil and grease, water-borne pathogens, suspended and total dissolved solids, trash, heavy metals, pesticide and nutrient content that damage the quality of receiving waters. In addition, the threat posed by stormwater is that of urban flooding and a protection planning commonly recommends the deployment of Low Impact Developments (LIDs) Stormwater Control Measures (SCMs) that capture some of the stormwater at development sites to the extent that soil permeability and other physical constraints permit it. Due to the harmful impact that polluted stormwater has on receiving waters, State and Federal guidelines in the United States have been enacted to protect stormwater quality. One such tool is the allowed Total Maximum Daily Loads (TMDLs) of pollutants to natural waters from urban storm runoff. The body of technical publications in the arena of stormwater quantity, stormwater quality management, impaired water quality, LIDs, SCMs [SCM is herein used synonymously to the term Best Management Practice (BMP)], TMDLs, and is voluminous (Zhen and Yu, 2004; Davis 2005; City of Los Angeles 2009A, 2009B, and 2009C; Hagekhalil et al., 2015; Sebti et al., 2016; Sadeghi et al., 2016 and 2017; City of Los Angeles 2016). One regulatory mechanism is through the setting of TMDLs, which, in turn, has given rise to a multi-billion-dollar industry of LIDs (Currier et al., 2005; Houle et al., 2013; Kalman et al., 2000; Kurkalova 2015).

Figure 1 shows a map of the City of Los Angeles (City) boundaries and the GSI projects, which has an area of 473 squared miles (1,225 km2), and 17,400 miles of streets (28,000 km), with a population of about 4 million people. Los Angeles' storm drain system consists of 1,500 miles of pipes (2,414 km), 100 miles of open channel (161 km). The LIDs/SCMs in Los Angeles includes about 38,000 screened catch basins and thousands of others. Its average daily dry weather and wet weather runoffs are about 50 million gallons (189,250 m^3) and 10 billion gallons (38 million m^3), respectively [LA Sanitation (LASAN) City of Los Angeles data from 2017]. A peculiar phenomenon observed in the GSI study area, that adversely impacts stormwater quality, is the "first flush" stormwater contamination (Stenstrom and Kayhanian, 2005). This is the generation of large amounts of stormwater pollutants during the first few storms over urban areas following a dry period during the summer season (Larsen et al., 1998). One way to treat first flush stormwater contamination is by deploying LIDs/SCMs that retain stormwater and its pollutants at the point of origin or through their paths through urban areas (Strecker et al., 2001; Davis, 2005; City of Los Angeles 2016).

City of Los Angeles Proposition O (Prop O), a $500 million General Obligation Bond, has funded numerous water quality improvement projects in the City since voters enacted it in 2004. Since 2006, the City, implemented several Prop O stormwater management and water quality projects using Prop O funds, including natural treatment systems, mechanical stormwater capture and use systems, and passive systems. These projects improve water quality by reducing pollutant loads to the impaired waters and increase the water supply, improving flood management and creating or enhancing open space, habitat, and recreation benefits. In 2014, the optimization phase for the several of these GSI projects was initiated. The focus was to ensure that project elements are working optimally to help meet water quality requirements and maintain long-term project sustainability. Table 1 identifies these projects according to their categories, and Figure 1 identifies the GSI project locations within the City.

MONITORING RESULTS AND OPTIMIZATION

The GSI project types comprise Natural Treatment Systems, Mechanical Process Systems, and Passive Systems in public sites. The optimization efforts included detailed functional analysis and preliminary recommendations for each system, and follow up detail maintenance requirements with Standard Operating Procedures (SOPs). The GSI developed projects are from preliminary monitoring results from 2016–2017. The focus of this paper is summarizing the results of monitoring, and providing revised assessments of functionality and revised recommendations for these GSI projects.

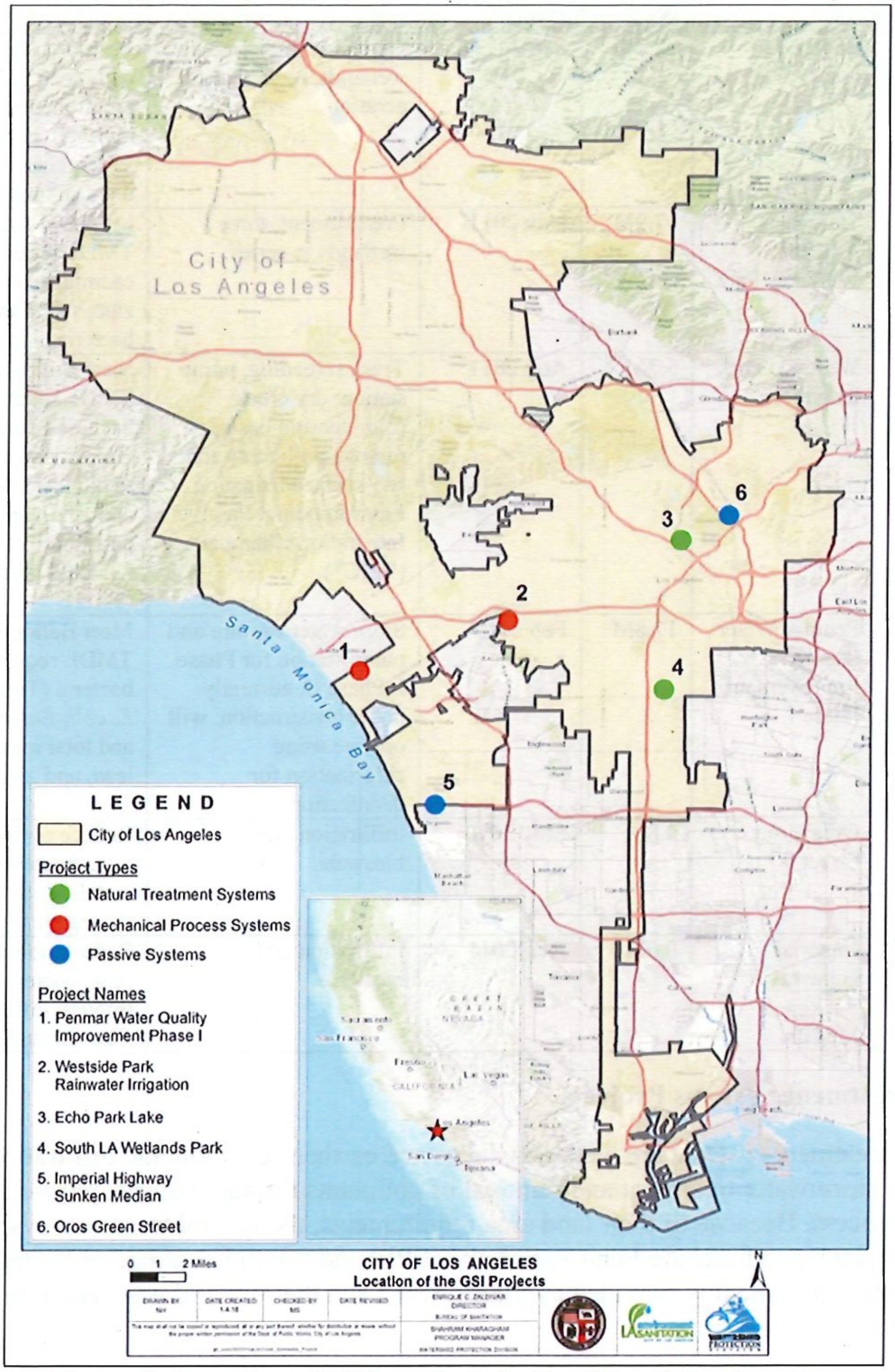


Figure 1. Location of GSI projects in the City of Los Angeles.

Table 1. GSI Projects with Process Description

Category	GSI Project	Project Cost ($)	Project Completion Date	Process Description	Water Quality Benefits
Natural Treatment Systems	Echo Park Lake	37.2M	Sep 2013	Diversion, pretreatment, wetlands, recirculation, aeration.	Meet lake total maximum daily load (TMDL) requirements for nitrogen, phosphorus, PCBs, chlordane, dieldrin, and trash.
	South Los Angeles Wetlands Park	17.9M	Nov 2011	Pretreatment, three wetlands in series.	Meet Los Angeles River TMDL requirements for cadmium, copper, lead, zinc, selenium, nitrogen, bacteria, and trash.
Mechanical Process Systems	Westside Park Irrigation	5.7M	Aug 2011	Trash screening, pump station, dry creek (bioretention basin) to remove pollutants and, sub-surface irrigation, Environmental Passive Integration Chamber (EPIC®).	Meet Ballona Creek TMDL requirement for bacteria (Total Coliform, *E. coli*, *Enterococcus*), total metals (copper, lead and zinc), and total phosphorus and Total Kjeldahl Nitrogen (TKN).
	Penmar Water Quality Improvement Phase I	17.8M	Feb 2015	Stormwater capture and pump station for Phase I. Phase II, currently under construction, will operate using chlorination for disinfection.	Meet Ballona Creek TMDL requirement for bacteria (Total Coliform, *E. coli*, *Enterococcus*) and total metals (copper, lead, and zinc).
Passive Systems	Oros Green Street	0.8M	May 2010	Infiltration and bioswale.	Reduce pollutant levels (e.g., bacteria, sediment, metals, and nutrients) through infiltration.
	Imperial Highway Sunken Median	0.6M	Aug 2011	Infiltration and bioswale.	Reduce pollutant levels (e.g., bacteria, sediment) through infiltration and flow-through treatment.

Natural Treatment Systems Projects

Natural treatment systems are wetlands, lakes and earthen retention and infiltration basins that provide stormwater treatment and removal of pollutants through natural, physical, and biological process. Because of their land area requirements, the natural treatment system projects are relatively large, and include Echo Park Lake (EPL) and South Los Angeles Wetland (SLAW), where treatment is provided by plants, soils, and their natural associated microbial ecosystems.

Echo Park Lake (EPL)

Echo Park (drainage area is about 732 acres) is a 29-acre open space recreational facility located at 751 Echo Park Avenue, in the Echo Park/Silver Lake community of Los Angeles. As part of the EPL rehabilitation project, the lake was drained and relined to reduce water loss by seepage, sediments were dredged and trash removed, constructed wetlands were added for water quality improvement, trash capture devices were installed, and a historic lotus bed was reconstructed and replanted. EPL provides pretreatment of diverted runoff by two hydrodynamic separators and subsequent treatment directly in one constructed wetland and through recirculation of lake water through three constructed wetlands. The wetlands are located around the perimeter of the lake and serve to remove excess nutrients, algae, sediments, and other pollutants. EPL occupies 13 acres, and the remaining 16 acres consist of recreational open space. Amenities at the park include a footbridge, boathouse, historic lotus bed, paddle boating, catch-and-release fishing, model boating, jogging, and walking around the perimeter pathways.

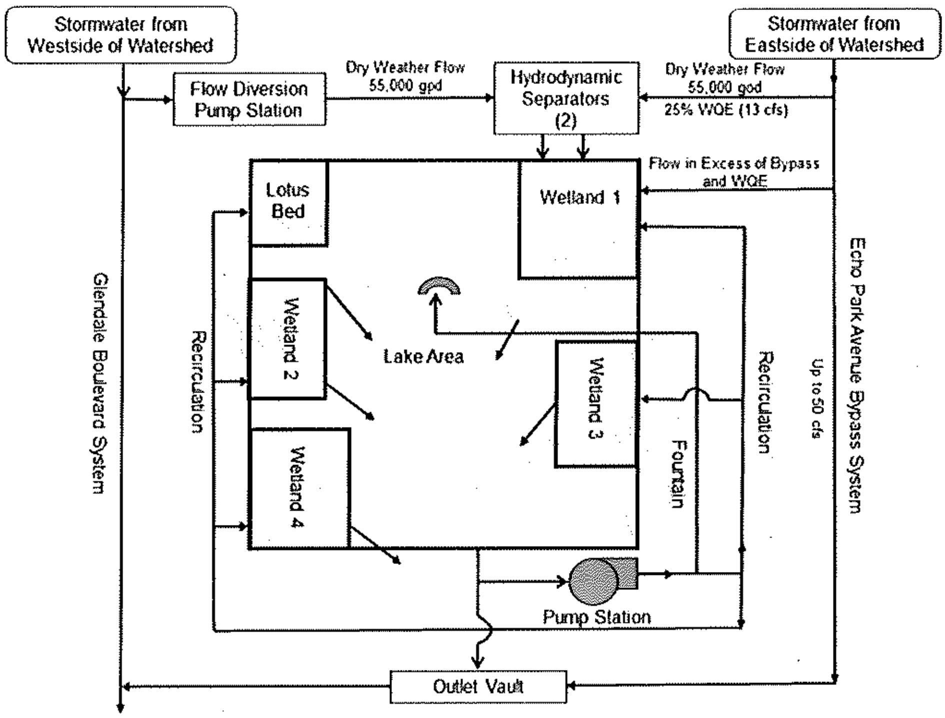


Figure 2. Echo Park Lake Process Flow Diagram

A process flow diagram of Echo Park Lake is shown in Figure 2 identifying the project operations components as follows:

- Diversion structure on the eastern side of the lake routes all dry weather flow (55,000 gallons per day [gpd]) and flow up to 25 percent of the water quality event (WQE) (13 cubic feet per second).
- Diversion structure on the western side of the lake controls dry weather flow (55,000 gpd) through a flow diversion pump station.
- Hydrodynamic separators provide pre-treatment of diverted runoff by using the hydraulic energy of the stormwater flow to create a vortex. The vortex and screen separates much of the sediments and suspended solids, which settle into a sump where they remain until removed during periodic maintenance.
- Four areas of constructed wetlands provide treatment of recirculated lake water and urban runoff through removal of nutrients, both by the uptake through plants and the additional

physical and biochemical reactions that take place in the constructed wetlands.

- The lotus bed at the northwestern portion of the lake provides additional benefits to water quality. The lotus is a flowering plant known for its beauty, and is of historic and cultural significance to Echo Park and lake user community. The plant provides water quality benefits through reduction of nitrogen within the root zone, shading of the water surface, and uptake of plant nutrients from soil and water.
- Recirculation system draws water from the south end of the lake and distributes to constructed wetlands at various locations throughout the lake, as well as the lotus bed.

The 2017 data show significant reductions of cadmium, copper, lead, and zinc in wet weather samples at EPL. Similarly, microbiological indicators of coliform bacteria showed a consistent pattern of reduction through the system by over two orders of magnitude. The revegetating the lake wetland zones in multiple phases starting in spring of 2017. While the initial replanting helps to increase the extent of vegetative coverage, additional phases are anticipated to fully optimize the wetland system. Figure 3 shows the initial phase of wetland replanting.

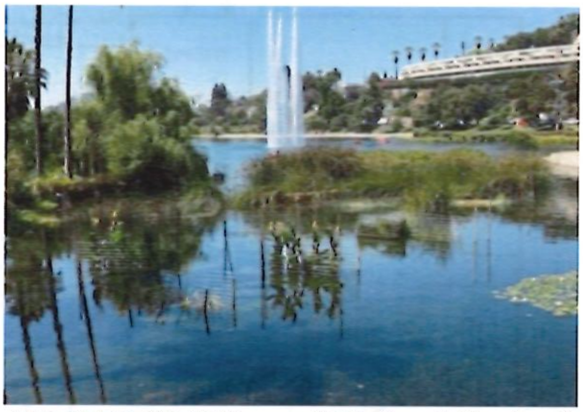
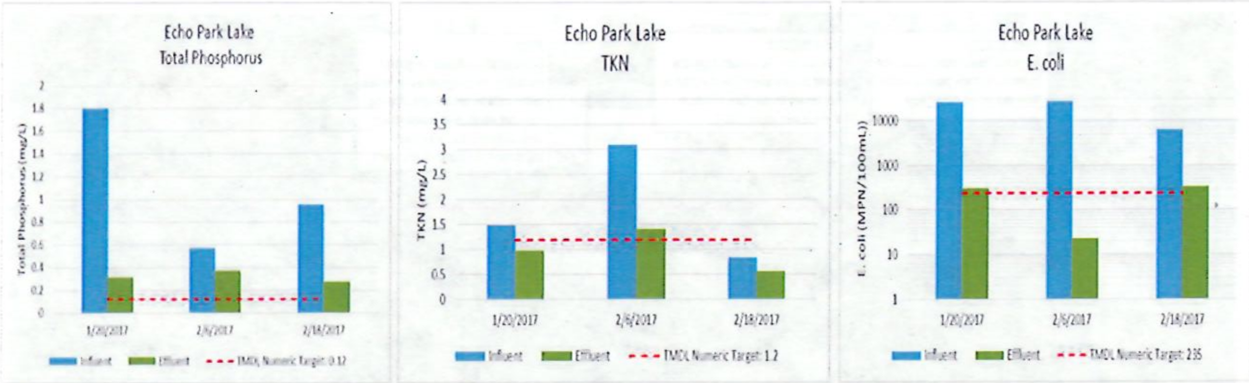


Figure 3. Wetland Cell 1 Initial Phase of Wetland Replanting, June 26, 2017

For the constituents listed below, wet weather monitoring was performed for three storm events on January 20, 2017, February 6, 2017, and February 18, 2017, with the following results (some of the results shown in Figure 4):

- Total phosphorus was reduced to an outflow average of 0.32 mg/L (0.27 to 0.37 mg/L). Although this value represents a 71 percent reduction from the inflow concentration, it is above the EPL TMDL numeric target of 0.12 mg/L (Figure 4a). Optimization plans being implemented to re-vegetate the littoral wetlands are expected to provide greater opportunity for phosphorus uptake and removal.
- TKN (Total Kjeldahl Nitrogen) concentrations at the outflow averaged 0.98 mg/L (0.56 to 1.4 mg/L) at the outflow, representing a 46 percent reduction when compared to the inflow (Figure 4b). Based on previous sampling data, nitrate-nitrite nitrogen was below detection limits. As a result, TKN was compared to the TMDL numeric target for total nitrogen. One event was above the TMDL numeric target of 1.2 mg/L.
- For *E. coli,* outflow showed an average reduction of 98 percent. The values ranged from 23 to 326 MPN/100 mL, with two events above the Los Angeles River TMDL numeric limit of 235 MPN/100 mL (Figure 4c).
- When properly maintained, the hydrodynamic separators and bar screens effectively remove trash from the stormwater inflow. Any trash within the lake is generally from on-site sources.



(a) (b) (c)

Figure 4. Echo Park Lake. (a) Total Phosphorus, (b) TKN, (c) *E. coli.*

South Los Angeles Wetland Park Project (SLAW)

The SLAW Park Project (drainage area is about 525 acres) was constructed to replace the parking lot of a decommissioned bus yard and designed to treat urban runoff from a 520-acre watershed. The SLAW provides pretreatment of diverted runoff by a hydrodynamic separator unit and subsequent treatment through a three-cell treatment wetland prior to release back into the stormwater conveyance system. The SLAW provides valuable green space and an opportunity for public recreation and education while creating a 4.5-acre wetlands habitat and cleaner water in urban Los Angeles. Monitoring data confirmed that the wetlands perform mostly as designed, although some issues with water quality, water levels, and vegetation were observed (Shown in Figure 5).

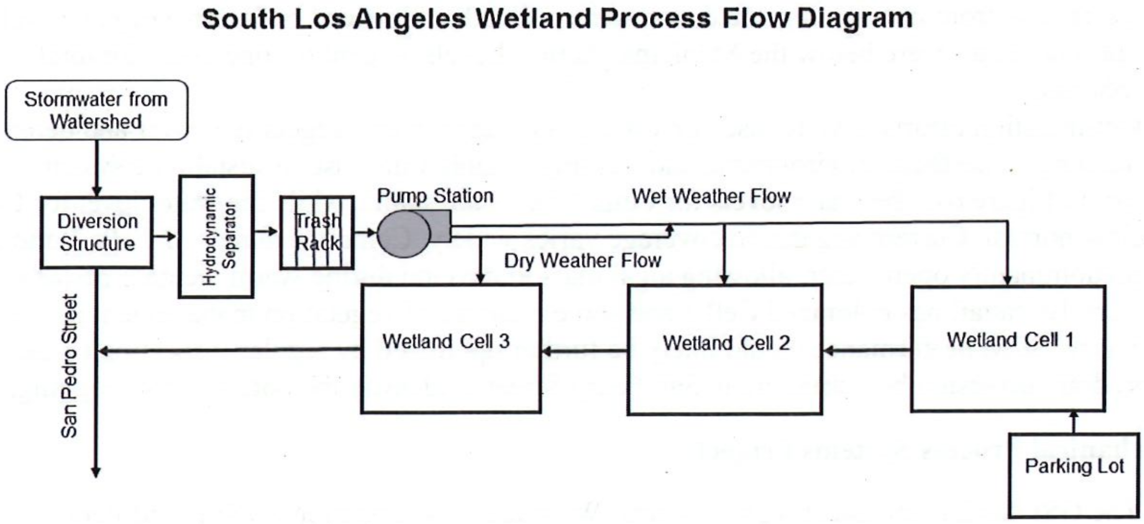


Figure 5. South Los Angeles Wetlands Park Process Flow Diagram

Figure 6. South Los Angeles Wetlands Park Recommendations

The 2017 wet weather monitoring data show significant reductions in metals and bacteria. All total metals are below the Total Maximum Daily Load (TMDL) numeric limit, except for one event for total zinc. Total phosphorus and Total Kjeldahl Nitrogen (TKN) increased in average concentrations from the influent to the effluent, consistent with the expectations of concentrations from heavily vegetated treatment wetlands influenced by internal organic cycling. All nutrient values were below the Municipal Action Levels, except for one event for total phosphorus.

Optimization efforts have focused on establishing appropriate vegetative cover and density, maintaining an aesthetic environment, and limiting potable water use to sustain the system (shown in Figure 6). The water levels for Cells 1 and 2 are stable, while the water level for Cell 3 is below normal. Current vegetation coverage varies widely. Central channels of Cells 1 and 2 are predominantly open water, allowing algal mats to develop during warm weather periods. Conversely, cattail has colonized Cell 3 and some measure of vegetation management is necessary. SCM performance would likely be further optimized by regular inspection of the storm drain diversion box structure in San Pedro Street to identify the potential for clogging.

Mechanical Process Systems Projects

The GSI has 2 mechanical SCM projects: Westside Park Irrigation (WSPI) and Penmar Water Quality Improvement (PWQI). Chlorination is the primary disinfection mechanism for Penmar (Phase II, currently under construction), and Westside Park uses soil filtration for bacterial control between Environmental Passive Integration Chamber (EPIC®) distribution and return system elements.

Westside Park Irrigation (WSP)

The WSP Irrigation (drainage area is about 298 acres) covers approximately 4.5 acres and lies within the existing power line property by City of Los Angeles, Department of Water and Power (Shown in Figure 7). The stormwater is collected through a series of inlets and is conveyed through various storm drain pipes to the existing reinforced concrete box storm drain at the northwestern portion of Westside Park. Runoff is diverted from the storm drain, passes through a trash rack, and stored until needed in the pump wet-well.

Comparisons of influent and effluent from three wet weather sampling events showed significant reduction in bacteria concentration (shown in Figure 8). Effluent concentrations for total and dissolved metals, including cadmium, copper, lead, and zinc, showed the desired treatment and removal. These results indicate that the EPIC® system performed in reducing bacteria and metals via sand filtration. Effluent concentrations of nutrients, including total phosphorus, TKN, and total nitrogen were reduced, which suggests nutrient uptake by the EPIC® system, possibly by the plants.

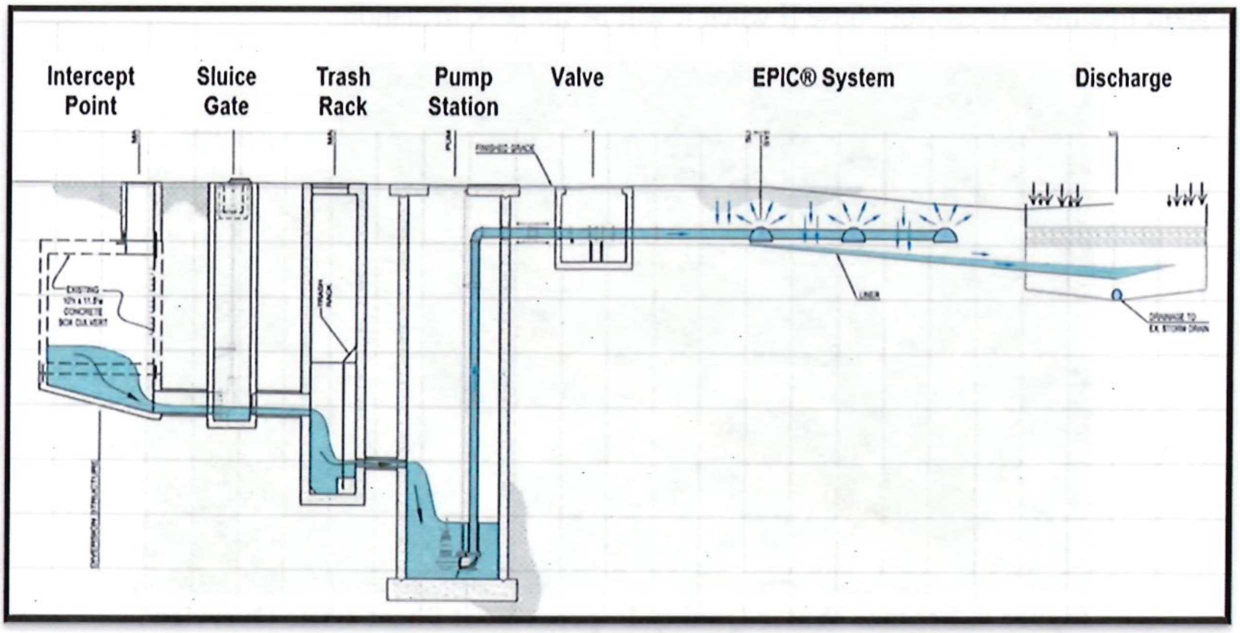


Figure 7. Westside Park Irrigation BMP Profile View

(a) (b) (c)

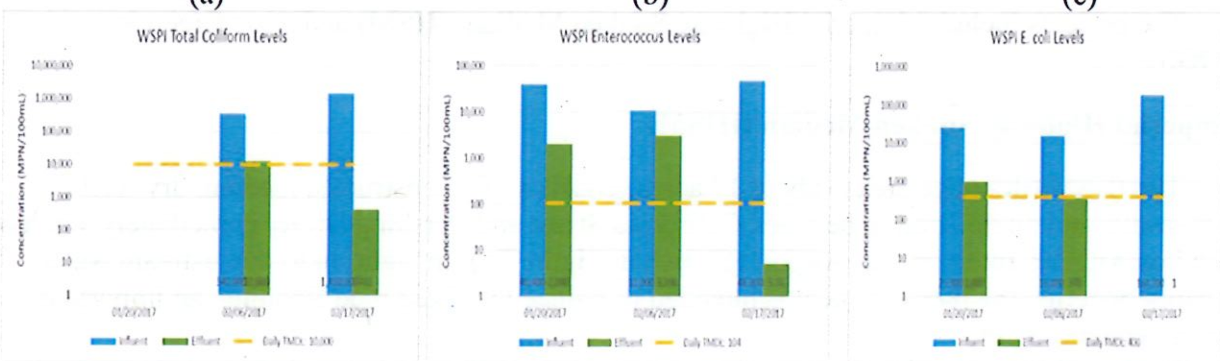


Figure 8. WSPI Bacteria Levels (a) Total Coliform; (b) Enterococcus; c) E. coli.

However, sediment, trash, and debris buildup in the storm drain diversion box may have limited influent flows to the trash rack vault. Incorporating pretreatment at the influent would improve the SCM's overall performance, extend its life, and reduce maintenance costs.

Penmar Water Quality Improvement (PWQI)

The PWQI Project (drainage area is about 1,468 acres) consists of two phases. Phase I diverts run-off to a reservoir beneath the softball field of the Penmar Recreation Center, and is discharged to the adjacent sanitary sewer. Phase II of the project is currently under construction and will treat and re-use the diverted water for park irrigation (shown in Figure 9).

Water discharged from the reservoir is collected from the wet well vault, where samples were collected for characterization. Results from three wet weather sampling events indicated influent bacteria concentrations exceeded the water quality standard. In general, influent concentrations for total and dissolved metals, including copper, lead, and zinc, exceeded the water quality standard. Since the captured runoff is being diverted to the sanitary sewer, the runoff is not contributing to the impact of water quality to the watershed. The influent samples will be used to support treatment needs for Phase II when it will be for park irrigation.

Figure 9. Penmar Water Quality Improvement Phase I Site Overview.

Passive SCM Projects

The projects include: Imperial Highway Sunken Median (IHSM) and Oros Green Street (OGS).

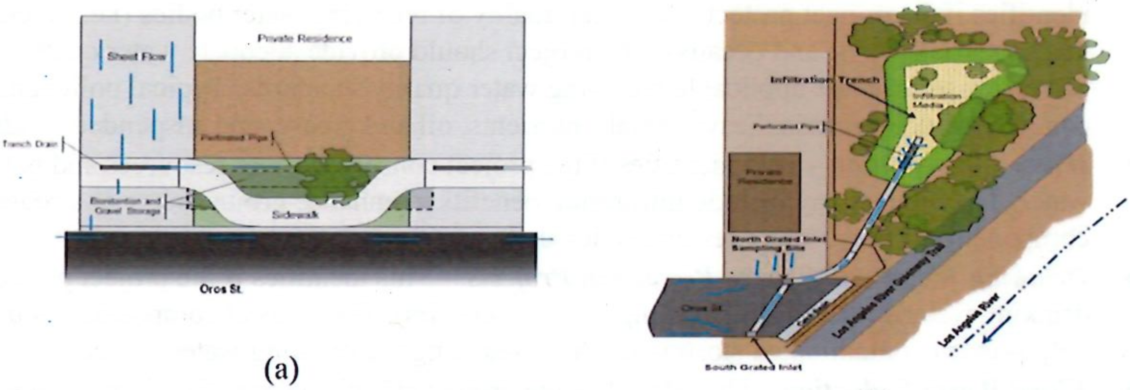
Imperial Highway Sunken Median (IHSM)

The IHSM (drainage area is about 17 acres) consists of a constructed median, dry wells, a bio-swale, and an infiltration between California Street and Pershing Drive, immediately south of the Los Angeles International Airport (Shown in Figure 10). In addition to downstream water quality benefits, the IHSM project is intended to reduce localized road flooding, an important safety enhancement.

During all three wet weather sampling events, no runoff was observed to leave the system at the downstream end of IHSM. Therefore, it is assumed that 100 percent of the runoff that enters

IHSM SCM is being infiltrated, resulting in 100 percent pollutant reduction for the associated load. However, sediment, debris, and vegetation were observed to clog more than half of the culvert capacity under Main Street. Flooding was also observed in the median and over the westbound lanes, affecting high-speed oncoming traffic on the west side of the intersection of Main Street and Imperial Highway. This suggests that either the stormwater volume conveyed to IHSM SCM is greater than the volume assumed for the original design basis (insufficient project capacity and/or underestimated drainage area) or that the IHSM SCM is not functioning as designed (i.e., dry wells are clogged). In either case, improvements are needed for public safety.

Figure 10. Imperial Highway Sunken Median Stormwater SCM Tributary Area. The project area is the long and narrow rectangular area in the middle of the Figure (green colored).



(a)

(b)

Figure 11. Oros Green Street Overview (a) sidewalk and (b) infiltration trench design.

Oros Green Street (OSD)

The OGS (drainage area is about 8 acres) stormwater SCM is a distributed consisting of four curbside bioretention facilities/an infiltration trench. Infiltration trench located in Steelhead Park, captures/infiltrates runoff from 2.3 acres between Oros Street and adjacent residential properties. Over the 2016–2017 monitoring season, influent concentrations of total suspended solids, copper, and zinc were measured at somewhat high levels while concentrations of *E. coli* varied considerably. Since this is an infiltration SCM, there is no effluent to be sampled and therefore, it is assumed that the associated pollutant load was reduced by 100 percent for infiltrated water. During monitoring, the infiltration trench and, to a lesser extent, the driveway trench drains were partially clogged with accumulated debris. However, the small amount of bypass from rainfall greater than or equal to the design storm demonstrates effective system performance. Figure 11 shows the Oros Green Street Overview (a) sidewalk design and (b) infiltration trench design. In addition, photos of site conditions at OSD are shown in Figure 12.

Figure 12. Oros Green Street Vegetation/Infiltration Trench Drain Inlet/Driveway Trench Drains.

CONCLUSION

The multiple benefits of the GSI projects optimization are as follows for project performance and whether the project's multi-benefit objective was attained:

- ***Water Quality Protection for Rivers, Lakes, Beaches, Bays, and the Ocean*** - This identifies if the project protects the water quality of receiving water bodies (i.e., rivers, lakes, beaches, bays, and oceans). The project should provide adequate water quality protection to meet the applicable receiving water quality standards. Typical pollutants of concern include bacteria, heavy metals, nutrients, oil and grease, and suspended solids.
- ***Water Conservation*** - This identifies if the project conserves water resources and potable water. The project may include infiltration benefits to enhance groundwater or a reuse component to reduce water resources demand.
- ***Drinking Water and Source Protection Projects*** – This identities if the project protects drinking water sources (i.e., drinking water reservoirs). This project component should help prevent contaminated stormwater from reaching the drinking water source.
- ***Flood Water Reduction*** - This identifies the project effectiveness in flood management and flood reduction. Flood water reduction includes diverting water to a storage tank or infiltration/detention of stormwater.
- ***River and Neighborhood Parks that Prevent Polluted Runoff*** - This performance identifies if the project effectively diverts polluted water from reaching tributary rivers, lakes, beaches, bays and oceans.
- ***Improve Water Quality Projects*** - This identifies if the project effectively improves water quality and reduces pollutants of concern. The project should provide treatment or management of runoff to improve water quality before discharge.
- ***Stormwater Capture and Cleanup*** - This identifies if the project captures and treats

stormwater. The project should capture portions of the wet weather flow and most of the dry weather flow.

- ***Reuse Projects*** - This identifies if the project augments local water demand (i.e., irrigation, maintains lake water level) using captured stormwater.

ACKNOWLEDGMENT

The authors thank many employees of the City of Los Angeles, especially those from the WPD of the LASAN and others from governmental/private agencies who contributed to this paper.

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