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SHORT COMMUNICATION

Green Stormwater Infrastructure (GSI) for Stormwater Management in the City of Los Angeles: Avalon Green Alleys Network

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Abstract
Stormwater runoff creates flooding/pollution hazards in urban areas and Green Stormwater Infrastructure (GSI) provides modern technologies for prevention and mitigation. The Avalon Green Alley Network North and South GSI Demonstration Project (The GSIs) described in this article is a joint partnership between Los Angeles Sanitation (LASAN) and The Trust for Public Land (TPL). The GSIs is located in public alley right-of-way in a high-density neighborhood (residential, schools, parks, commercial building). The GSIs slows and infiltrates stormwater on site, capturing runoff from intersecting street catch basins, employing dry-well chambers, replacing impervious/conventional asphalt with permeable surfaces, percolating stormwater, and providing underground storage. The GSIs north section is closed to vehicular traffic after construction of a grassy swale to capture stormwater. Stormwater drains toward interlocking pavers and into underground infiltration trenches, with extra flows conveyed to a dry-well system. Monitoring includes groundwater monitoring wells, flow meters, and water-level loggers (measure water quality/quantity). Further benefits for the community includes of growing of vines/espalier trees, artistic paving, and mural artwork evoking artistic expression. The GSIs approach is setting a new trend for stormwater management in the City of Los Angeles in the untapped 1440 km of alleys, and serves as a model of community development through stormwater management to other cities.

Keywords Green Stormwater infrastructure (GSI) · Stormwater control measures (SCM) · Infiltration trench · Permeable pavers · Dry Wells · Green alleys

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Electronic supplementary material The online version of this article (https://doi.org/10.1007/s40710-019-00364-z) contains supplementary material, which is available to authorized users.

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1 Introduction

Urban stormwater runoff is a foremost cause of water-quality degradation in rivers, lakes, seas, wetlands, and aquifers. The degradation of water quality in water bodies receiving urban storm runoff is pervasive in metropolitan areas across the United States and elsewhere (Zhen and Yu 2004; Davis 2005; City of Los Angeles 2009a, b, c; Hagekhalil et al. 2014; Loáiciga et al. 2015a, b; Sadeghi et al. 2017a, b). Stormwater exhibits deleterious physical-chemical-biological features. Additionally, stormwater carries Biochemical-Oxygen Demand (BOD), debris, heavy metals, pesticides, oil and grease (petroleum), water-borne pathogens, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and nutrient content, all which impair the receiving waters (Novotny 2002; Gülbaz and Kazezyılmaz-Alhan 2018). Another threat posed by stormwater is that of urban flooding. Regulatory agencies have enacted Total Maximum Daily Loads (TMDLs) of pollutants in stormwater discharging to natural waters. There is, however, chronic non-compliance of stormwater with TMDLs across the United States and elsewhere. Substantial urbanization and extensive flood control network throughout the more than 1181 km^2 area of the City have resulted in significant water quality problems locally. Los Angeles Sanitation (LASAN) existing stormwater permit (National Pollutant Discharge Elimination System (NPDES)) includes TMDL restrictions that impose the City to address such contaminants as bacteria, metals, pesticides, polychlorinated biphenyls, trash, and other pollutants. As of 2018, LASAN has 22 TMDL that carry stringent numerical limits/tight compliance schedules, and meeting these requirements is expected to cost approximately $8 billion over the next decade.

Green Stormwater Infrastructure (GSI), Low Impact Developments (LID), Best Management Practices (BMP), or Stormwater Control Measures (SCM) have emerged as a new alternative to cope with urban stormwater. LIDs are required to capture some of the stormwater at development and post-development sites to the extent that soil permeability and other physical constraints permit it (City of Los Angeles 2009a, b, c, 2016). GSI, LID, BMP, and SCM are now important components of a multi-billion-dollar stormwater management industry nationwide and worldwide (Davis 2005; Houle et al. 2013; Kurkalova 2015; Sebti et al. 2016; Guo 2017; Clary and Piza 2017).

The City of Los Angeles (the City henceforth) has approximately 10,461 km of paved streets, 16,093 km of sidewalks, 1448 liner kilometers of alleys, and 34,000 catch basins. Los Angeles' alleys alone have a combined total area of about 8 km^2, which is twice the size of New York's Central Park. Although individually alleys are relatively small spaces, collectively when combined with streets and sidewalks they provide abundant capacity to integrate GSI to improve environmental and community health in neighborhoods which do not have undeveloped land. Green alleys are a unique form of GSI as they have the environmental benefits of green streets (through the absorption of water), the social benefits of parks (as they serve as social, recreation spaces), and the health benefits of trails (since they provide connections to destinations and safe travel alternatives) (City of Los Angeles 2012; National Association of City Transportation Officials 2017; Clary and Piza 2017). Through the implementation of the Avalon Green Alley Network: GSI Demonstration (The GSIs), streets and alleys within the project area will be gradually developed into greener, safer, and smarter networks that include usable open space, safe connections to community destinations, and low-impact infrastructure. Simple interventions can add vegetation, cool the microclimate, increase visibility, and make alleys more livable and efficient.

Communities throughout the United States are investing in green infrastructure projects such as green alleys and streets in order to realize benefits that include stormwater management, improved community gathering opportunities, and increased public safety. The programs vary based on topographical, demographic and community needs. Chicago, with nearly 3219 km of alleyways, was one of the first communities to develop a green alley program on a large scale, and since 2006, has installed more than 100 green alleys in a variety of neighborhoods with quantifiable success (City of Chicago 2010). Cities in at least ten states followed suit with their own unique green alley and street programs. Communities at the forefront of this movement towards greener infrastructure can provide helpful data and best practices for communities interested in taking a more active approach to managing stormwater or improving community quality-of-life through the development of green alleys.

In 2018, LASAN published The Wilmington Urban Greening Plan (WGP) - Toward a Greener Los Angeles (City of Los Angeles 2018), to provide a set of recommended improvements to the neighborhood of Wilmington. These improvements from the WGP will connect spaces, reduce stormwater pollution, improve air quality, make the neighborhoods more livable/walkable, and will further function as a template for future retrofits in the neighborhoods throughout the City. The WGP provides solutions that address needed improvements to infrastructure, water quality and quantity, air pollution, non-motorized transportation, open space amenities (City of Los Angeles 2018). Wilmington is considered a disadvantaged community and is particularity burdened with air pollution as a result of its close proximity to the Port of Los Angeles. In addition, the receiving waters for Wilmington area all have elevated levels of pollutants that include metals, nutrients, toxic organic compound and bacterial indicators. By implementing the WGP with Green Street and Alleys, it will be a way to make Wilmington become a greener and more sustainable neighborhood, benefitting its burdened population in the City.

This paper showcases a green alleys project located in the City's 9th Council District. The GSIs described here is relevant to GSIs that rely on the subsurface as a retention reservoir for storm runoff (Loáiciga 2005; Yorko et al. 2010; Campana 2017). Past research has studied a major effect in stormwater quality called "first flush" stormwater contamination (Larsen et al. 1998; Stenstrom and Kayhanian 2005), whereby large amounts of polluted stormwater is generated during the first rains following long periods of dry weather. The effort to reduce the pollution of receiving water bodies by contaminated stormwater in semi-arid climatic regions must address first-flush impacts, and this paper demonstrates how the stormwater is captured and treated on site using GSIs/LIDs. The Avalon Green Alley Network system is designed to mimic a natural system by slowing stormwater velocities, treating the water before it flows off-site, and infiltrating it to the subsurface. The GSI system herein presented is a state-of-the-art application in the field of stormwater control. Green alleys are becoming an important part of the areas in major cities that have maximum development (build-out) to capture and treat stormwater, and this paper shows these methods.

2 Project Characteristics and Methods

The Avalon Alley Networks was selected because of its: disproportionately high population density; poor air quality; high rates of obesity, diabetes, and heart disease; economic disadvantage; highly impervious groundcover; low percentage of tree canopy; and high density of alleys in relation to the rest of the City (City of Los Angeles 2012). Over the years, these alleys have seen consistent dumping of garbage, poor lighting and overgrown vegetation, limited access due to a citywide gate and lock policy (later deemed illegal), as well as other public safety issues. Areas of policy and outreach important to the Avalon Alley Networks include watershed health and management, sustainable communities and green initiatives, community and neighborhood planning.

2.1 Avalon Green Alley Design and Cost

These two sites (Avalon Alley South and North) for the project are part of the overall Avalon Green Alley Network, one of six high priority networks identified in the South Los Angeles Green Alley Master Plan (City of Los Angeles 2012). Fig. 1 depicts the location of the Avalon Green Alley Networks (Avalon Alley South and North) in the City and the 1440 km of alleys. The total cost for Avalon Alley North and South was $3.88 million. The majority of the funding for the GSIs was from State of California Water Resources Control Board Prop 84 (South $0.89 M and North $1.15 M, for a total of $ 2.04 M). The remainder of cost was funded by LASAN (Los Angeles Sanitation), City of Los Angeles Proposition O (Prop O), California Natural Resources Agency and other funding sources. Fig. 2 depicts the Avalon Green Alley South and North Projects and the drainage area (more detailed maps are presented in the Supplemental Material).

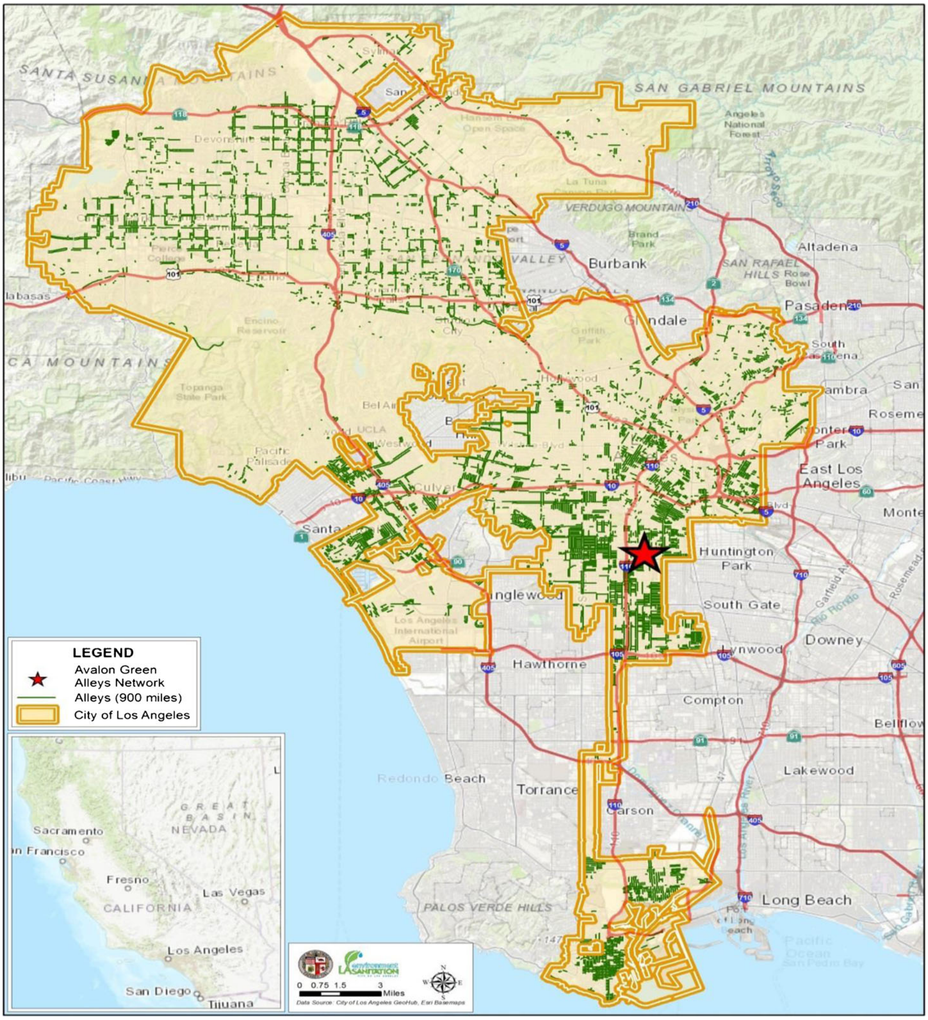

Fig. 1 Location of the Avalon Green Alley Networks and 1440 km of alleys in the City of Los Angeles

Fig. 2 The Avalon Green Alley Network in the City and two green (South and North) alleys retrofits are encircled by dashed red line

The average stormwater capture rate is about 6.4 million liters/yr which will be treated and infiltrated into the ground of the Avalon Green Alley Network (South and North sections). Water quality elements (they remove pollutants such as trash, bacteria, metals, sediments, oil and grease) in alley section of the project include: interlocking pavers; underground infiltration trench; filter media in catch basins; dry well (primary and secondary chamber systems); rain gardens. Water quality monitoring equipment includes: groundwater monitoring wells, flow meters, water-level loggers.

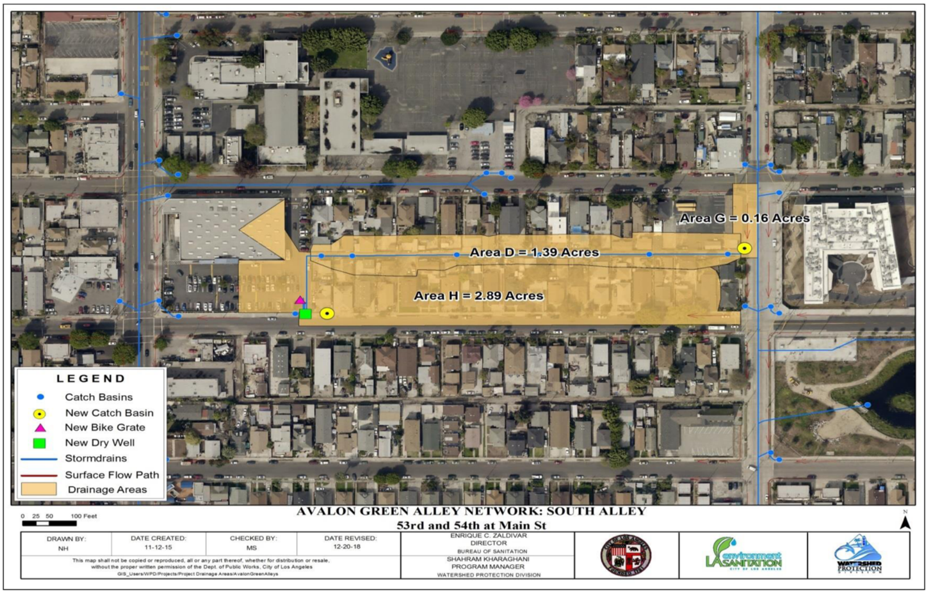

Fig. 3 The drainage area (4.44 acres) of the Avalon Green Alley South Project showing the GSI locations in the City of Los Angeles

Figure 3 shows the Avalon Green Alley infiltration trench and dry wells design system/layout (LASAN), respectively. The Avalon Green Alley North grassy swale section (the southern section of the North alley) was closed to vehicular traffic after construction. The cost of the GSI at the Avalon Alley South and North are listed in Table 1. Tables 2, 3 and 4 present all the water quality data for the Avalon Green Alley Network. Cost saving for The GSIs was gained by using the same design and construction team at the Avalon South and North alleys.

The total cost of the Avalon Alley South project was $1,602,642 and the scope of work completed is descried below:

- Project took place in a 1403-square-meter public alley right-of-way
- Installation of two (2) dry wells
- Installation of two (2) catch basins on the streets to capture runoff
- Installation of six (6) bike grate catch basins on the alley to capture runoff
- Infiltration trench in the alley 93 square-meter of permeable surfaces (permeable pavers)
- Providing 57 cubic meters of underground storage (infiltration trench)
- Percolating 189,271 liters of stormwater per 1.9 cm rain event
- Capture, clean and infiltrate more than 3.8 million liters of stormwater per year

The total cost of the Avalon Alley North project was $1,935,870 and the scope of work completed is described below:

- Project took place in a 1133-square-meter public alley right-of-way
- Installation of two (2) dry wells (two primary and two secondary chambers)

Table 1 GSI costs at the Avalon Alley South and North

Design and planning Item	Avalon green alley South	Avalon green alley North
Project administration	$220,642	$407,000
Community outreach		$275,000
Planning included with Avalon Alley South (Design and Construction Documents)		$40,000
Planning	$174,000	
Design and construction documents	$76,000	
Design and planning total	**$470,642**	**$722,000**
Construction		
Item		
Mobilization	$280,700	$295,000
Demolition	$130,200	$140,000
Grading	$67,500	$62,070
Concrete Flatwork	$233,800	$230,000
Permeable pavers and Infiltration Trench	$112,700	$96,000
Alley Grating Basins with Inserts	$14,000	$16,100
Street Catch Basins	$25,900	$21,000
Torrent Maxwell Dry Wells	$80,700	$126,000
Stormwater Infiltration Planter (incl. plants)		$26,000
Other Subdrainage	$41,500	$36,700
Planting	$28,000	$48,000
Construction Total	**$1,015,000**	**$1,096,870**
Monitoring		
Item		
Equipment (from Avalon South)	$32,000	$32,000
Data Gathering and Reports	$85,000	$85,000
Monitoring Total	**$117,000**	**$117,000**
Grand Total	**$1,602,642**	**$1,935,870**

Table 2 Wet weather monitoring results at Avalon Alley South, showing concentrations for all constituents analyzed from water samples from each monitoring location

Sample location	Source	Sample date	Event	Sample time	Total coliforms (MPN/100 mL)	*E. coli* (MPN/100 mL)	Enterococcus (MPN/100 mL)
San Pedro St Catch Basin	Influent from San Pedro St.	1/5/2016	Wet 1	10:30 AM	8.1×10^4	7.4×10^2	1.0×10^4
54th St catch basin	Influent from San Pedro St.	1/5/2016	Wet 1	10:30 AM	4.1×10^5	4.9×10^4	8.7×10^4
55th St catch basin (dup)	Influent from 54th St.	1/5/2016	Wet 1	9:40 AM	9.9×10^4	<100	3.1×10^3
Secondary dry well	Effluent from primary dry well	1/5/2016	Wet 1	11:30 AM	2.9×10^5	1.4×10^3	7.6×10^3
Secondary dry well	Effluent from primary dry well	3/6/2016	Wet 2	3:30 AM	3.1×10^5	8.0×10^3	5.5×10^4
Secondary dry well (dup)	Effluent from primary dry well	3/6/2016	Wet 2	4:00 AM	2.7×10^4	<100	7.8×10^3
Secondary dry well	Effluent from primary dry well	3/11/2016	Wet 3	14:50 PM	2.2×10^5	1.2×10^3	8.7×10^3
Groundwater well	Groundwater	3/10/2016	Dry 1	11:40 AM	<100	<100	<10
In alley (close to Food-4-Less)	Surface grab from within alley	3/11/2016	Wet 3	14:20 PM	1.5×10^5	4.1×10^2	6.4×10^2
In alley (dup)	Surface grab from within alley	3/11/2016	Wet 3	14:16 PM	7.3×10^4	8.2×10^2	1.5×10^3
Groundwater well	Groundwater	3/18/2016	Dry 2	13:17 PM	<100	<100	<10

- Installation of three (3) catch basins on the streets to capture runoff
- Installation of three (3) bike grate catch basins on the alley to capture runoff
- Infiltration trench in the alley 139 square-meter of permeable surfaces (permeable pavers)
- A pedestrian only section in the south portion of the alley with two (2) rain gardens
- Providing 124 cubic meter of underground storage (infiltration trench)
- Percolating 113,562 L of stormwater per 1.9 cm rain event
- Capture, clean and infiltrate more than 3.8 million liters of stormwater per year

3 Stormwater Monitoring

The stormwater monitoring procedures evaluate the effectiveness of the Avalon Green Alley Network in enhancing water quality, conserving water through the infiltration of captured water, and providing flood management. The installed GSIs are constructed to divert and treat stormwater drain flow from the alley's contributing watershed area (see Supplemental Material).

Table 3 Wet weather monitoring results at Avalon Alley North, showing concentrations for all constituents analyzed from water samples from each monitoring location

Sample location	Source	Sample date	Event	Sample time	Total coliforms (MPN/ 100 mL)	*E. coli* (MPN/ 100 mL)	Enterococcus (MPN/ 100 mL)
52nd St. Catch Basin	Influent from 52nd St.	11/20/2016 (PM)	Storm Event #1	9:50 PM	4.1×10^5	5800	1.0×10^4
Towne Ave Primary Drywell*	Effluent from catch basin near Towne Ave.			10:35 PM	$>2.4 \times 10^6$	8800	1.7×10^4
Towne Ave Catch Basin	Influent from Towne Ave.			9:18 PM	4.4×10^5	2900	1.7×10^4
Towne Ave Catch Basin Duplicate	Influent from Towne Ave.			9:30 PM	3.0×10^5	7300	1.1×10^4
Towne Ave Secondary Drywell	Effluent from primary drywell	12/16/2016 (AM)	Storm Event #2	3:43 AM	1.3×10^6	6.0×10^4	2.3×10^4
Towne Ave Catch Basin	Influent from Towne Ave.			2:50 AM	2.2×10^5	3.8×10^4	3.3×10^4
Towne Ave Secondary Drywell Duplicate	Effluent from primary drywell			4:02 AM	1.6×10^6	3.8×10^4	1.4×10^4
Towne Ave Secondary Drywell	Effluent from primary drywell	12/21/2016 (PM)	Storm Event #3	10:36 PM	3.7×10^5	1.7×10^4	3.7×10^4
Towne Ave Catch Basin	Influent from Towne Ave.			10:44 PM	1.7×10^5	1.7×10^4	2.8×10^4

The installation of a water quality monitoring system is another GSI component. Field monitoring consists of two approaches: (1) discharge and volume measurements to examine

Table 4 Wet weather monitoring results at Avalon Alley South, for load reduction (4.44 acres [1.78 hectares] Drainage Area)

Wet Weather Load Reduction at Avalon South Alley with Theoretical Volume for 4.44 acres[1.78 hectares] Drainage Area (January 5, 2016–1.4 in. [3.5 cm] of rain-72,000 gal [266,400 L])

Parameter	San Pedro Street Catch Basin Influent Load (kg)	54th Street Catch Basin Influent Load (kg)	Average of Catch Basins Load Removal from System (kg)
Ammonia-N	0.14	0.14	0.23
Hardness	3.78	0.14	4.15
Nitrate	0.06	0.14	0.13
Nitrite	0.01	0.14	0.02
Cadmium (Dissolved)	0.00	0.00	0.00
Cadmium (Total)	0.00	0.00	0.00
Copper (Dissolved)	0.005	0.005	0.005
Copper (Total)	0.05	0.005	0.03
Lead (Dissolved)	0.00	0.00	0.00
Lead (Total)	0.08	0.005	0.04
Zinc (Dissolved)	0.01	0.01	0.01
Zinc (Total)	0.081	0.03	0.42
Organic Nitrogen	0.023	0.14	0.14
Suspended Solids	33.30	16.20	24.75
Total Kjeldahl Nitrogen	0.38	0.80	0.60
E. coli (presented as MPN)	2.02×10^{11}	1.33×10^{13}	6.78×10^{12}

the overall water balance and flows (hydraulic performance) of the Avalon Alley project elements; and (2) water quality sampling to document the pollutant loads through the system. The monitoring results have been compared to water quality results with other projects in the City (Sadeghi et al. 2017a).

3.1 Avalon Green Alley South

Stormwater enters the system primarily via curbside catch basins located on E 54th Street (catch basin-1) and San Pedro Street (catch basin-9) (Supplemental Material).

3.1.1 Wet Weather for Avalon Green Alley South

Three storm events were sampled during the post-construction phase of monitoring – on January 5 (storm event # 1), March 6 (storm event # 2), and March 11 (storm event # 3), 2016 respectively. The January 5th storm event was the largest in magnitude and produced 3.5 cm of accumulated rainfall for its duration. The March 6 and March 10 events were similar in magnitude and produced approximately1.35 cm and 1.25 cm of accumulated rainfall, respectively (data from the Water Resources Division of the Los Angeles Department of Water and Power precipitation map). Flow velocities recorded at the junction between the primary and secondary dry wells ranged from almost 0.08 cm/s (at peak rain event) to 0.01 cm/s (near the end of a rain event). Influent pollutant concentrations for wet weather conditions (storm event #1) from the San Pedro Street and E 54th Street catch basins sampled on January 5th are shown in the Supplemental Material. For storm event #1, resulting in approximately 42,752 L of runoff over the course of the storm. Similarly, for storm event #2, generating 11,023 L of stormwater runoff, and for storm event #3 generating 6965 L of stormwater runoff.

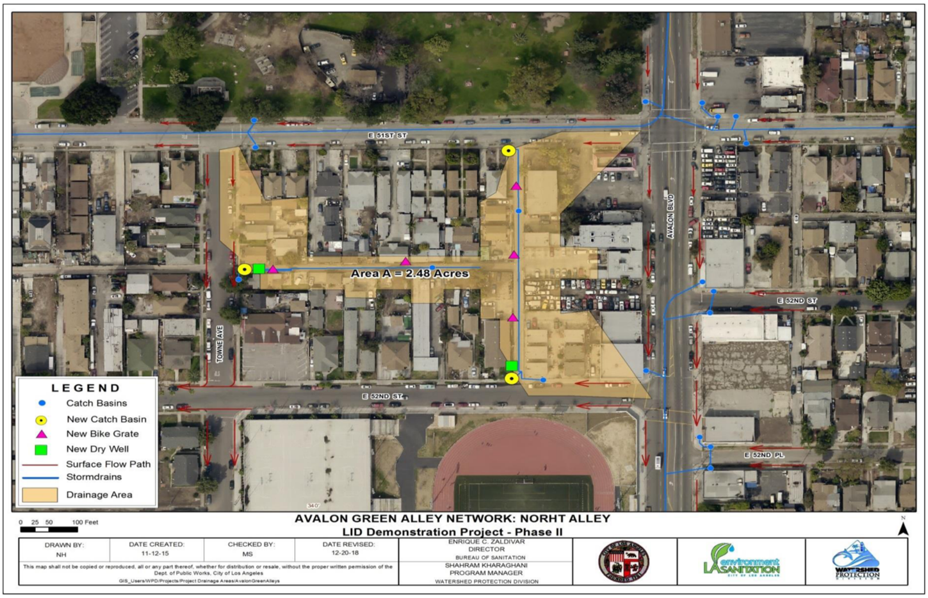

Fig. 4 The drainage area (2.48 acres) of the Avalon Green Alley North Project showing the GSI locations in the City of Los Angeles

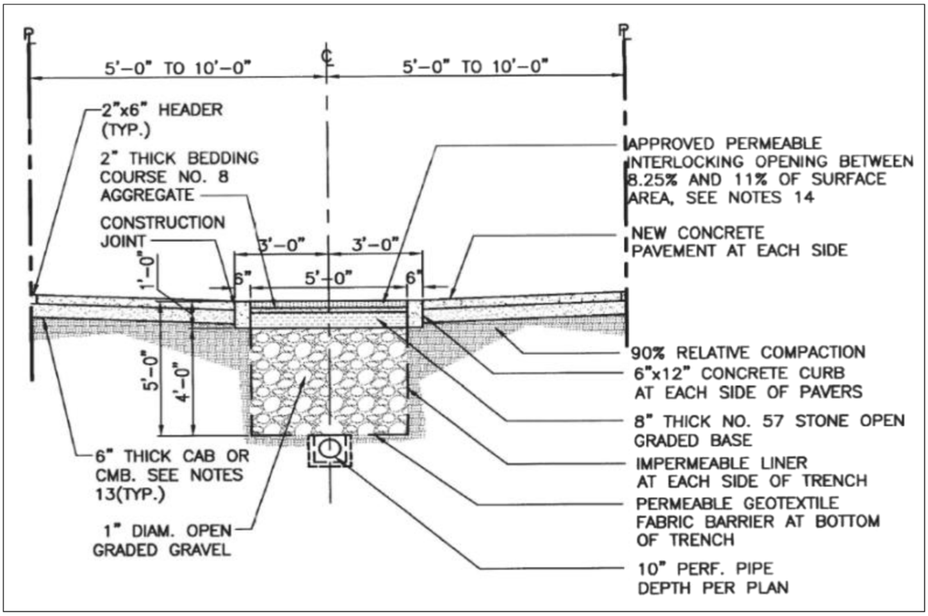

Fig. 5 View of the Avalon Green Alley infiltration trench system

3.1.2 Infiltration of Stormwater for Avalon Green Alley South

The infiltration galleries appear to be very effective at infiltrating stormwater at the site based on the data from the level loggers and visual observation during storm events. This coincides with the heaviest rainfall amounts recorded for this storm event (the largest of the three events observed

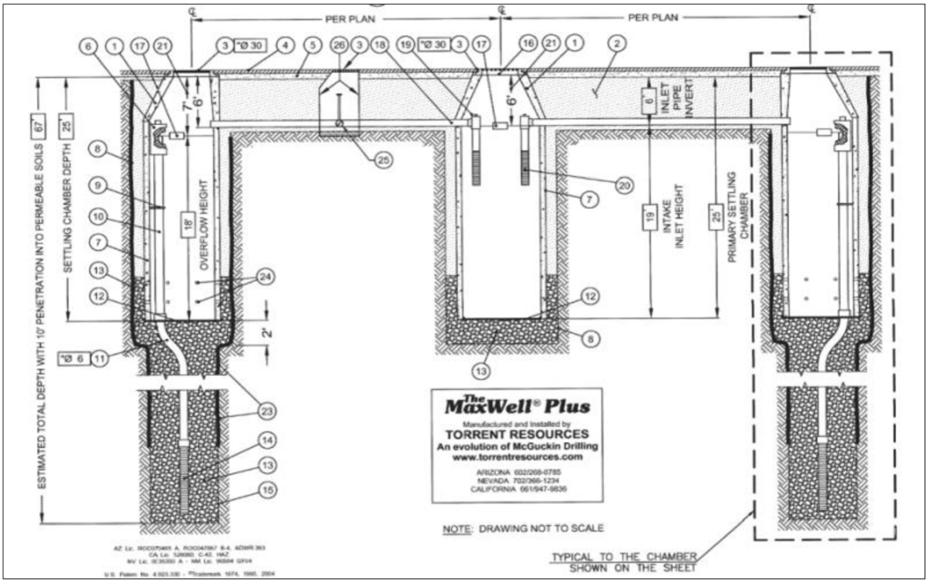

Fig. 6 View of the Avalon Green Alley Dry Wells System by Torrent Resources with one primary and two secondary chamber systems. Well dimensions are variable according to site conditions

for this study) which occurred at approximately 1:13 pm. Water levels approached almost 1.25 cm in the well, and within 15 min (next reading) were one half of this amount 0.65 cm. Within the next 15 min, water levels were below 1.25 cm. This indicates very rapid infiltration of stormwater (very low centimeters (less than 1.25 cm) show high stormwater infiltration rates in the soil textures) through the porous pavement and the infiltration trenches (through the permeable Geotextile filter fabric at the bottom of the trench). In addition, excess stormwater in the trenches is slowly directed to a 25 cm diameter perforated pipe which is then connected to the dry wells placed at the end of the alley. Rapid infiltration of stormwater is corroborated by photographic documentation of the alley during heavy rain, where water pooled for a very short time in areas that contained the porous pavement and underlying infiltration trenches (photographs presented in the Supplemental Material).

3.1.3 Pollutant Reductions for Avalon Green Alley South

This case study illustrates the "first-flush" phenomenon as it relates to stormwater contamination in highly urbanized areas. The first large storm of the season that occurred for storm event #1 was preceded by several weeks of no or very light antecedent rainfall and subsequently delivered large amounts of stormwater pollutants in the runoff, mostly due to the first flush phenomenon (Stenstrom and Kayhanian 2005). Most concentrations of metals were generally higher in surface water samples than in groundwater samples (water quality samples collected at 37 m below ground level in the groundwater monitoring well). This was especially true for copper, lead, nickel and zinc, heavy metals of particular concern for human and aquatic life health. Boron was detected in greater concentrations in groundwater than in surface and secondary well water samples. Concentrations of some metals (e.g., chromium) and chloride showed increased concentrations in groundwater samples compared to the surface and secondary well water samples. Nutrients generally had lower concentrations in groundwater than surface water samples (data presented in Supplemental Material).

3.1.4 Trash Capture for Avalon Green Alley South

The trash guards installed at the San Pedro Street and E 54th Street catch basins appear effective at preventing some large debris and trash from entering the GSI system, as indicated by the large amounts of intercepted items observed at these monitoring locations over the course of the study. Trash is also intercepted by the drain screen that is present in the Food-4-Less driveway catch basin. However, plastic bags, plastic cups, styrofoam, and other debris were observed to be present in the primary dry well during routine sampling, indicating that periodic maintenance and cleaning of the debris screen and more effective street catch basin guards could reduce or eliminate the volume of trash entering the primary well (presented in the Supplemental Material). The maintenance and cleaning of dry wells primary and secondary chambers require heavy cleaning service from LASAN vacuum trucks, whereas the cleaning of the simple catch basin screens or Floguards (by KriStar) is carried out with light equipment.

3.2 Avalon Green Alley North

Stormwater enters the drainage system primarily via curbside catch basins located at 51st Street, 52nd Street, and Towne Ave. Three storm events were sampled during the post-construction phase of monitoring on November 20, December 16, and December 21, 2016. Influent pollutant concentrations for wet weather conditions (storm event #1) from the 52nd St. and Towne Ave. catch basins were sampled on November 20th, 2016. Influent concentrations of non-bacterial pollutants were consistently higher at the Towne Ave. catch basin than those at the 52nd St. catch basin. The December 16th storm event was the largest in magnitude and produced 3.38 cm of accumulated rainfall over its duration. The November 20th and December 21st rain events produced 1.6 cm and 1.8 cm of accumulated rainfall, respectively (Supplemental Material). Figure 4 shows the drainage area of the Avalon Green Alley North project (LASAN map). Figure 5 shows the infiltration trench system for the alley project (City of Los Angeles standard plans). Figure 6 shows the dry wells for the Avalon Alley project with one primary and two secondary chamber system (Torrent Resources, Inc.).

4 Results and Discussion

The Avalon Alley Networks project area is highly impervious, but has stormwater capture opportunities in its alleys, which have several benefits over park systems in terms of stormwater capture. Unlike open space purchases, alley redevelopment has no acquisition costs. In addition, green alleys are more effective—and cost-effective—for water infiltration because their widespread distribution allows them to capture and treat stormwater and its associated pollution throughout the City (total 1440 km), rather than only in areas near parks. Green alley networks treat water pollution more effectively than other infiltration control measures placed elsewhere by virtue of their location near the source of the pollution, and have the potential to revitalize some of the most polluted and neglected parts of the City. Resulting groundwater recharge will allow municipalities to reduce the purchase of expensive, imported water. In addition, indirect benefits include: remediating the urban heat island effect; increasing rain capture, air quality, and biodiversity; reducing wind speeds and ozone concentrations; and improving soil quality (City of Los Angeles 2012).

Influent pollutant concentrations for wet weather conditions at Avalon Alley South (storm event #1) from the San Pedro Street and E 54th Street catch basins sampled on January 5th are shown in Table 4. Influent concentrations for most pollutants were consistently higher from the E 54th Street catch basin compared to the San Pedro Street catch basin. The E 54th Street catch basin was the first location sampled as the heaviest rain commenced, therefore, this represents a "first flush" event and concentrations would be expected to be highest in this sample. Overall, pollutant concentrations were less in the San Pedro Street catch basin samples that occurred later during the storm event, confirming the first-flush effect. Pollutant concentrations in the secondary well were consistently higher compared to influent sampled at the catch basins, but this is probably related to the fact that very little rainfall had occurred prior to storm event #1, allowing pollutants to accumulate in the watershed and the GSIs. Patterns in concentrations of bateria (*E. coli*, Enterococcus, and total coliforms) exhibited similar patterns, with the highest concentrations recorded in surface runoff samples (see Tables 2 and 4). The sample collected from San Pedro Street had the highest concentrations recorded. Concentrations were orders of magnitude lower in the secondary well samples, and tended to decrease over the course of the study with each successive storm event. Groundwater samples had extremely low bacterial loads compared to the other samples collected. It is also noted, that for the purposes of calculating pollutant loads, "non-detects" were assigned a value equal to the method detection limit (MDL). For values that were above the MDL, yet below reporting limits, the estimated values were used. The raw data for Avalon Alley South are presented in Tables 2 and 4 (list the MDL and reporting limits for each sample result). Avalon Alley South data shown in Table 4 indicates that pollutant concentrations for storm event #1 were consistently higher than those detected in storm event #2 and #3. This is probably related to the fact that very little rainfall had occurred prior to storm event #1, allowing pollutants to accumulate in the watershed. The three sample events provide a good characterization of the overall pollutant load for wet weather conditions - the first storm event is representative of an early season "first flush" storm, whereas the second storm event is representative of storms that occur later in the season. An examination of the concentration data for both storms indicates that stormwater runoff in this subwatershed is impacted by metals (i.e., copper, zinc, and to a lesser extent lead), total suspended solids, nitrogen, and fecal contamination.

Avalon Alley North data are shown in Table 3 for the 2.48 acres (1.00 ha) of drainage area. A 100% load reduction was calculated as all the stormwater was infiltrated through the infiltration gallery (25 cm (10-in.) underdrain pipes in the gallery has the overflows into the two dry wells at the end of the alley), infiltration gallery, and permeable pavers. The Towne Ave. catch basin was the first location sampled as the heaviest rain commenced. During storm event #1 the highest concentrations of bacteria (*E. coli*, Enterococcus, and total coliforms) were recorded in samples from the Towne Avenue primary drywell, which corroborates the trend in non-bacterial pollutant concentrations. During storm event #2 results were more mixed. Specifically, the duplicate sample from the Towne Avenue drywell showed the highest total coliforms concentration and the highest *E. coli* concentration, and the Towne Avenue catch basin showed the highest Enterococcus concentration. Lastly, during storm event #3, total coliforms and Enterococcus concentrations were higher at Towne Avenue drywell than at Towne Avenue catch basin, while *E. coli* concentrations at the two locations did not differ.

Table 4 shows the load reduction for 4.44 acres (1.78 ha) of drainage area in the Avalon Alley South for the Wet Weather January 5, 2016 rain event of 3.5 cm (theoretical stormwater runoff is about 266,400 L) and this was calculated for the two catch basins. The Wet Weather January 5, 2016 rain event for Avalon South is exemplary of the stormwater-capture system performance. A 100% load reduction was calculated as all the stormwater was infiltrated through the infiltration gallery (25 cm (10-in.) underdrain pipes in the gallery flows to dry wells), permeable pavers, and dry wells for the total area in Avalon Alley South site. Throughout wet weather, pollutant load reduction during wet-weather events are reported on a per-event basis for the pollutants of concern by assuming that each sampled concentration applied to the entire duration of the storm event. These concentrations were used to estimate total infiltrated loads as listed in Table 4, where it is seen that 100% of the pollutant loads at the sub-regional GSI were reduced. The wet-weather event removed pollutants from the Avalon North and South sites and kept contaminants from entering the Los

Angeles River. No dry-weather flows were observed during monitoring at the Avalon North and South sites. It was inferred 100% of dry-weather flows and associated pollutants were captured at the Avalon North and South sites.

As many cities and counties across USA and around the world have been developing green alleys, ultimately it will be the available funding that will determine the implementation of these projects (City of Chicago 2010; City of Richmond 2011; City of Los Angeles 2012; The Laneway Project 2016; National Association of City Transportation Officials 2017; City of Los Angeles 2018). As funding is tenable, the green alley projects should be carried out in the order in which they are ranked as analysis has shown that these green projects will be most beneficial. Metrics should be replaced as needed to ensure significance of the GSI of the ranking system. In addition, as initial green alleys projects/improvements begin to deteriorate with age or simply no longer meet given GSI standard, the green alleys that were once considered complete should be reintroduced to the list of projects with new priorities. It is recommended that community outreach be conducted at all stages of the project procurement. As these green alleys are added, it should be fully evaluated to assess progress in terms of stormwater quality, local air quality, quality of life of the community involved, and making neighborhoods more livable and walkable.

5 Conclusions

LASAN plans to implement additional green alley retrofits in the City. It will install similar green stormwater management measures a few blocks from the Avalon South and North GSIs in the near future. Both The GSIs are part of the overall Avalon Green Alley Network, one of six high priority networks identified in the City's South Los Angeles Green Alley Master Plan, written in partnership with The Trust for Public Land (City of Los Angeles 2012). The six networks were identified through a process that analyzed South Los Angeles neighborhoods for the greatest potential for capturing and cleaning stormwater runoff, while also creating more open space and improving community connections. LA Sanitation will also assess opportunities to develop green alley master plans for other underserved areas of the City. These planning efforts and construction projects will be pursued as funding is secured. Ultimately, the repurposed alleys will form interconnected open space networks that improve stormwater management, and enhance the quality of life of neighborhoods across Los Angeles.

A three-pronged approach was followed to improve water quality and meet regulatory requirements: education and outreach to the public on stormwater issues; enforcement of laws, codes, and ordinances to prevent/penalize polluting activities; and the implementation of GSI (structural measures) such as the Avalon Alley Project to remove pollutants from urban runoff. Thus, this GSIs is one of several measures that through the capture of multiple pollutants, will contribute towards enhancing the beneficial uses of receiving waters, preserving the aquatic marine habitat, and reducing the potential risks to human health and safety. This note's case study described GSI for green alleys and deployment within the City. The main objective was to provide the best GSI selection and sizing for urban stormwater quality and quantity management for green alleys. A second objective of this study was to provide examples of urban stormwater control in a cost-effective manner through GSI deployment. GSI examples presented in this work are envisioned to: deliver improved GSI designs for green elements; promote the implementation of GSI to manage stormwater; improve the quality of receiving water bodies and meet TMDL requirements; reduce hazards for human safety and health; preserve aquatic habitats; improve water conservation and water management; recharge groundwater.

Other key benefits of implementing GSI in the case study are safe walking and biking routes for the community, alley lighting, community activities near the new rain gardens in the closed alley section with no vehicular traffic. The GSI study presented can be used economically and practically through 1440 km of public alleys' right-of-way within the City.

Regarding future research work on green alleys, several areas of inquiry are identified: watershed-scale hydrologic; climatic changes; water-quality/quantity; socio-economic integrative analyses for GSI; controlled field testing of GSI with the objective of furthering the sustainability of large urban areas and their impacted environments. The following are other areas for forthcoming research to expand the current work on GSI:

- Compare the hydrologic watershed models and identify their limitations and factors;
- Methods to specify budget constraints when working with many different GSI;
- Consider possible impacts of climate change on rainfall intensity and stormwater generation in urban areas, and how these changes might have on GSI performance;
- Continue the study and application of GSI, LID, SCMs, such as vegetated swales, green roofs, porous asphalt/concrete, green streets/alleys, percolation wells, rainwater harvesting, mulching, tree planting, and others;
- Further characterization of rainfall events and their patterns and their specification in the GSI and research statistical methodology for refining rainfall patterns and assessing the potential effect of climate change on storm runoff generation and its pollutants load;
- Refine the Operations, Maintenance, Replacement costs and their effects on the GSI design models and field testing of their performance;
- Further research applying GIS for more detailed and electronic processing of spatial variables mapped digitally within urban regions (rainfall, soils, groundwater, topography, land use, roads, pollutant sources, storm runoff infrastructure, and others);
- Study changing and expanding population and land use within urban areas and their effects on stormwater runoff and pollutant loads. In addition, research contamination of water bodies with degraded storm runoff that hinders their hydrologic, ecologic, and socioeconomic functions;
- Study the performance of SCMs in different conditions of variable storm events and possible impacts of climate change;
- Outreach and community involvement for improving GSI effectiveness and social and economic effects for GSI sizing and selection;
- Study the cost of SCMs development and treatment based on State and Federal regulations on total maximum daily loads (TMDLs) of pollutants to natural waters from urban storm runoff.

All these areas of further research deserve attention and resources to advance the state-of-the-art on the design, implementation, and management of GSI treatment technologies.

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