Sunset Boulevard Greenway Annual Monitoring Report 2016-2017

Project Overview

The San Francisco Public Utilities Commission (SFPUC) is currently implementing the first phase of the 20-year $6.9 billion citywide Sewer System Improvement Program (SSIP). As part of the first phase of the SSIP, the SFPUC is constructing eight green infrastructure (GI) Early Implementation Projects (EIPs), one in each of San Francisco's urban watersheds. The Sunset Boulevard Greenway project is the EIP in the Sunset watershed. It features large end-of-block and smaller mid-block bioretention planters to manage stormwater runoff from 14 blocks of Sunset Boulevard and 37th Avenue within the landscaped parcels along the west side between 37th Avenue and Sunset Boulevard. All 14 project blocks will contain soft-edged, infiltrative bioretention planters (i.e. rain gardens) designed to allow runoff to infiltrate through 18 inches of bioretention soil until saturation at which point it overflows through a trench drain and back out to the street. The project is being constructed in phases with the final completion scheduled for 2020. This report focuses on the initial Model Block completed in the spring of 2016 between Ulloa Street and Vicente Street (Figure 1).

Sunset Boulevard is a large arterial roadway with three lanes of traffic traveling north and three traveling south, a 15-foot wide central landscaped median, and large 100-foot wide City-owned landscaped parcels fronting the eastern and western sides. The area generally slopes westward toward the Pacific Ocean, and the roadways in each direction are crowned. The longitudinal slope of the roadway ranges from 1% to 6%.

The Model Block rain gardens are sized to manage stormwater runoff from the street, sidewalks, and the adjacent landscaped areas, collectively referred to as the drainage management area (DMA). Location and design of each facility responds to the unique site characteristics of each block, particularly the topography and existing mature Monterey Cypress trees. All rain gardens were initially sized by designers in accordance with the EIP Minimum Performance Metric, which calls for an aggregate 0.75 inches of unit storage[1]. For typical rain gardens, this translates into a sizing ratio[2] of around 5%. Facility sizing was refined during design development using a site-specific hydrologic model[3] to more accurately reflect site conditions. Highly permeable sandy soils[4] resulted in a final rain garden sizing ratio of 4.0% for the Model Block.

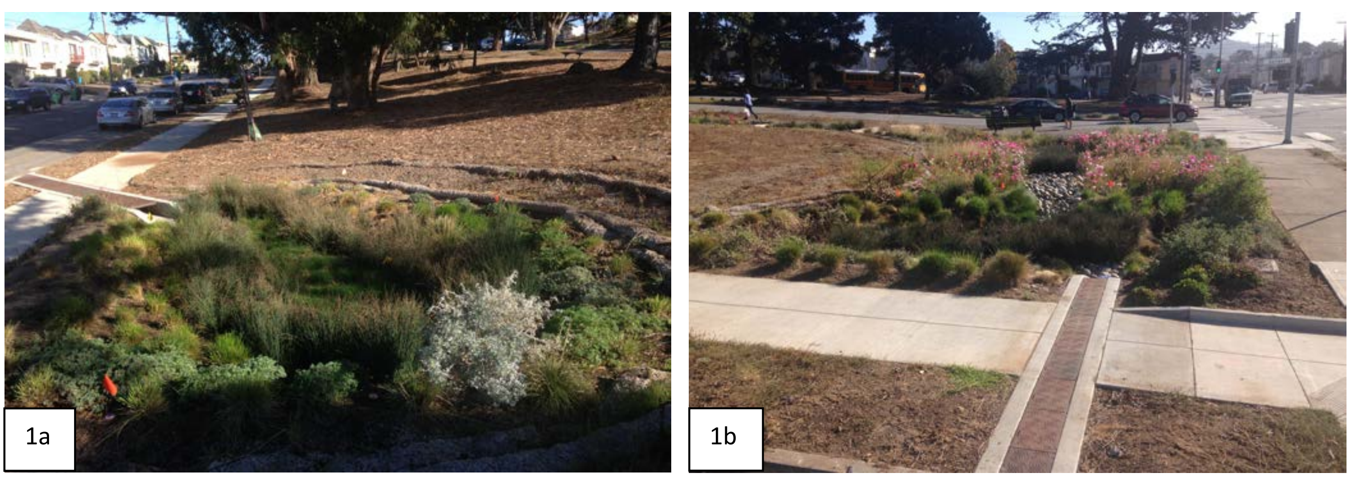

Figure 1a and 1b: The mid-block and end-of-block rain gardens, respectively, on the Model Block

[1] Unit Storage Depth is a measure of the storage capacity provided by GI relative to its DMA. It is equal to the depth of water that, if multiplied by the DMA, is equal to the storage provided by the GI facilities.
[2] Sizing Ratio is a measure of GI facility footprint relative to its DMA. It is equal to the facility size divided by the DMA.
[3] EPA Stormwater Management Model (SWMM), Version 5.1.
[4] Double-Ring Infiltrometer test performed near the model block indicated a design infiltration rate of 10 in/hr

Performance of the Model Block rain gardens for the 2016-17 water year was measured through post-construction flow monitoring in catch basins at the end of two separate blocks. The end-of-block flows from the Model Block are compared to an unimproved block that represents baseline “pre-construction” flow conditions, and the difference between the two flows is credited to facility performance. No monitoring was conducted prior to construction. The two monitoring locations for 2016-2017 rainy season (Figure 2) are located at:

- 37th Avenue @ Rivera (baseline block)
- 37th Avenue @ Vicente (Model Block)

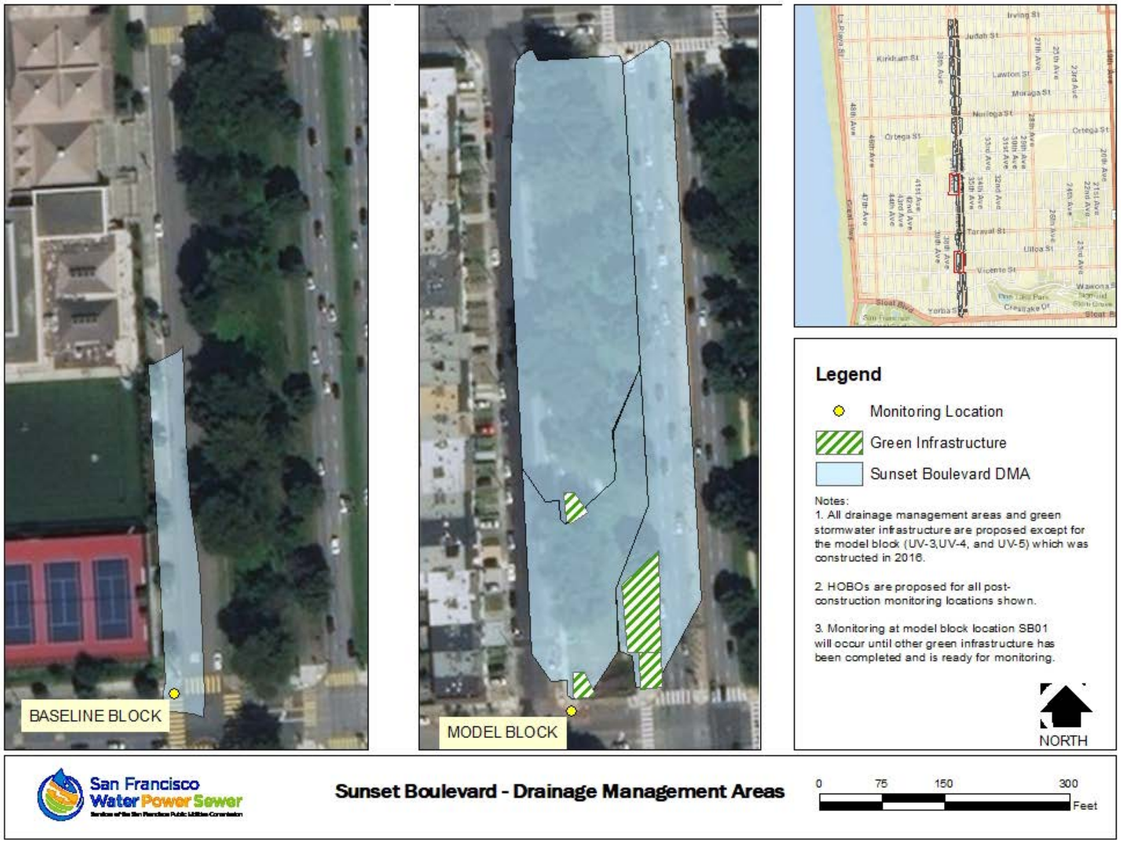

Figure 2: Project overview map

Table 1 provides the DMAs for both the baseline block and the Model Block, as well as the sizing ratio for the Model Block rain gardens. The DMAs were delineated using the subcatchment layer from the City and County of San Francisco (CCSF) Hydrologic and Hydraulic model and were then adjusted according to field observations of drainage patterns during wet conditions. Pervious surfaces produce much less stormwater runoff than impervious surfaces, but they do still produce runoff once saturated and, therefore, should not be ignored when calculating the DMA. Effective Impervious Area is a standardized measure of drainage area equal to the total impervious surfaces plus 5 percent of the pervious surfaces, which assumes that on average the pervious surfaces produce 1/20 of the runoff that impervious surfaces do.

Table 1: Characteristics of the Sunset Boulevard GI facilities and Drainage Management Areas (DMAs)

Metric		Baseline Block	Model Block
Total Effective Impervious Area (ft2)		15,420	34,185
Rain Gardens	Impervious Area (ft2)	15,394	31,869
	Pervious Area (ft2)	510	46,316
	Facility Area (ft2)	N/A	1,375
	Sizing Ratio (%)	N/A	4.0%

Over the 2016-2017 monitoring period, data was captured for 43 separate storms producing measurable runoff occurring from 10/14/2016 through 4/19/2017. The measured rainfall for those 43 storms totaled 30.35 inches. Due to an equipment error at the baseline block during the last service period, four storms have peak flow and volume calculated using data from the other storms. More detailed information on the methods used to obtain the monitoring results is included in the Technical Appendix.

The Model block is estimated to have reduced the total volume of stormwater entering the sewer system from the project area by 95% (850,000 gallons) during the 2016-17 rainy season.

During the monitoring period, an unmapped mid-block catch basin was discovered on the baseline block, which reduced the baseline block drainage area by half as shown in Figure 2. Another unexpected discovery during the monitoring period was that the catch basin downstream of the Model Block receives direct runoff from the eastern half of Sunset Boulevard (see Figure 3). Field reconnaissance during wet conditions revealed that the intended catch basin on Sunset Boulevard is bypassed and runoff instead flows to the same catch basin on 37th Avenue that receives overflow from the Model Block. This results in direct runoff to the catch basin from 22,950 ft^2 of impervious area and 50,860 ft^2 of pervious area. The overflow from the rain garden is isolated within the total measured flow at the Model Block catch basin by subtracting the calculated direct runoff to the catch basin.

In response to potential error sources introduced by the unexpected run-on to the model Block, a quality assurance check was added by building a hydrologic model to simulate runoff within the project area. The EPA Stormwater Management Model, Version 5.1 (SWMM) was used to simulate stormwater runoff in the project area using 2016-17 rainfall data collected at the nearby Oceanside Water Pollution Control Plant. The infiltration rate of the native soils is an important parameter in determining project performance. A double-ring infiltrometer test performed at the rain garden location prior to construction indicated an infiltration rate of 30.24 inches per hour. Applying the SFPUC-recommended factor of safety of three, a maximum infiltration rate of 10 inches per hour was input into the SWMM model. The results of the SWMM simulation are compared against the monitored results below in the Results section.

Figure 3: Direct Runoff to Model Block Catch Basin

Learning Goal

The Sunset Boulevard Greenway involves a large-scale application of rain gardens across a site with varying topography. The goal of this EIP is to directly analyze the impact of slope on the performance of bioretention planters in the ROW. This project is located on highly infiltrative soils and will also provide an interesting performance comparison to other EIPs with poor soils.

Results of Monitoring Period 2016-2017

The model block reduced total volume and peak discharge rates to the CSS and the results of the monitoring data are discussed below in relation to the two metrics. More detailed information on the methods used to obtain these results is included in the Technical Appendix.

Was Flow Volume Reduced?

Stormwater flow was monitored at the catch basin downstream of the rain gardens at the Model Block and at the catch basin for the baseline block. The measured baseline block volume and flow rates were extrapolated on a per storm basis to represent inflows to the rain gardens from the model block. A SWMM model was also built and parameterized based on site conditions. According to both the monitoring results and the supporting modeling results, the overflow from the Model Block was significantly less than the baseline flow during the 2016-17 monitoring period. (Figure 3). The monitored volume reduction across the whole rainy season was 95%. The SWMM model predicted that the rain gardens would reduce runoff volume by 99%.

Table 2: Volume reduction during the 2016-2017 rainy season

Site	Performance Basis	Bioretention			
		Inflow (gals)	Outlfow gals)	Volume Reduction (%)	(gallons)
Model Block	Monitored	599,725	29,727	**95%**	569,998
	Modeled	594,411	6,065	**99%**	588,346

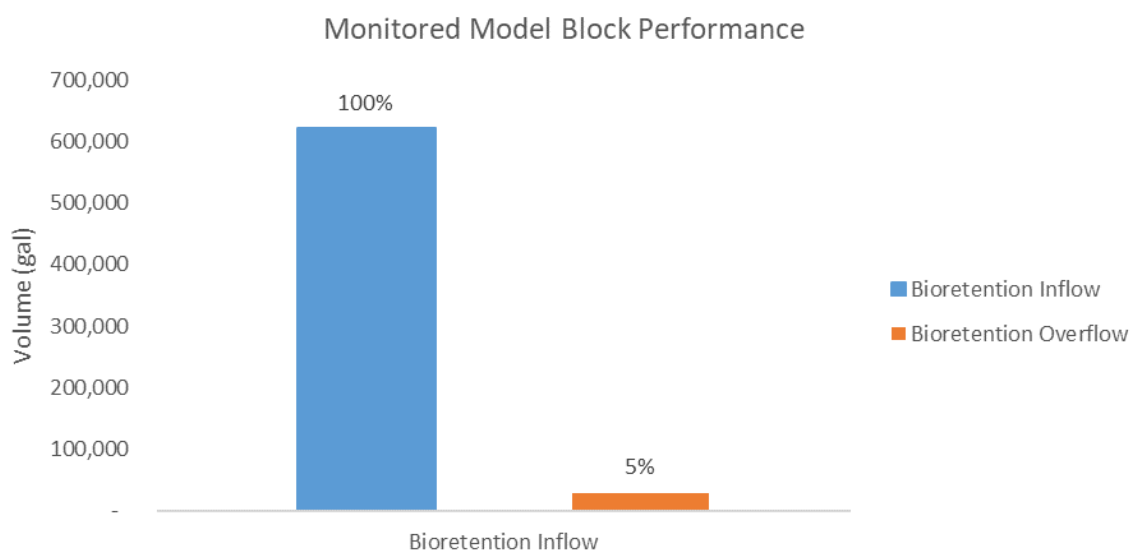

Figure 3: Model Block performance for the 2016-2017 monitoring period.

Figure 4 provides an overview of the inflow to, and overflow from, the Model Block rain gardens during the full monitoring period. Many low-intensity storms produced little to no overflow from the bioretention, meaning that all runoff entering the facility was fully infiltrated by the rain garden.

A 1.66-inch storm occurring over 37 hours on December 7th was the storm with the largest depth fully managed by the Model Block. A total of 33 out of 43 storms were fully managed by the planters at the Model Block. The overflow volume from the most intense storm was reduced by 49%. The remainder of this section will further report on the performance of the rain gardens during back-to-back storms and individual storms selected to represent various types of storms the site experienced during the 2016-2017 monitoring period.

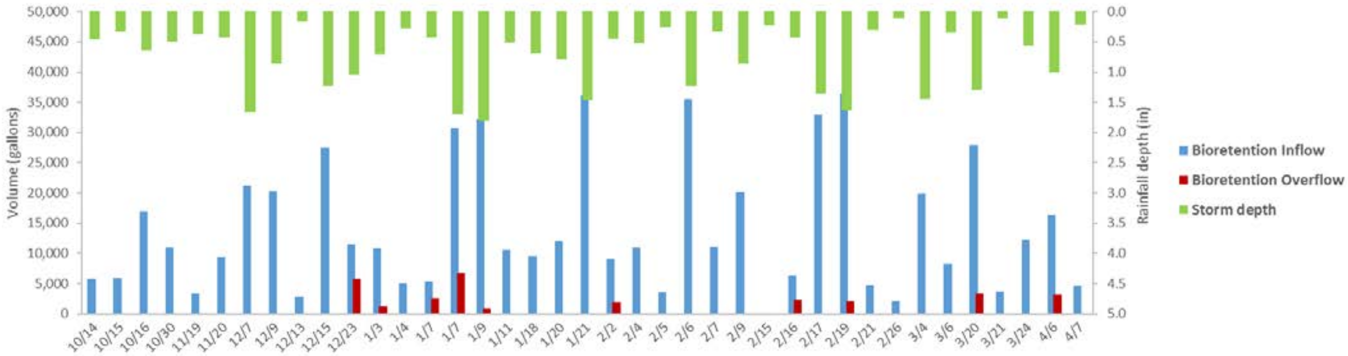

Figure 4: Hydrograph showing inflow and bioretention outflow of the 2016-2017 Monitoring Period

Were Peak Flow Rates Reduced?

The rain gardens reduced peak flow rates by an average of 94% for the whole rainy season. Storms without any overflow had a 100% peak flow rate reduction. In general, the more intense the storm, the higher probability of an overflow. The storm must also last long enough and produce enough runoff volume to exceed the storage capacity of the planter, meaning that duration is also a factor in determining which storms produce overflow.

Of the 43 storm events producing measurable runoff during the 2016-2017 rainy season, no overflow occurred for 33 of those storms, while 10 storms produced overflow from the rain gardens to the CSS. The largest storm that did not produce overflow had a total depth of 1.66 inches over 37 hours with a maximum intensity of 0.36 inches per hour. For the 8 storms that did produce overflow, the average peak flow reduction was 55% and ranged from 37% to 76% (Table 3). The overall average peak flow reduction for all 43 storms was 94%.

Table 3: Peak flow reduction characteristics for the events in each bioretention unit

	Storms with Overflow				Storms with no overflow (fully managed)	
Site	# of Storm Events	Min Peak Reduction	Max Peak Reduction	Average Peak Reduction	# of Storm Events	Largest Storm Event with No Overflow (in)
Model Block	10	37%	76%	55%	33	1.66

How Did GI Hold Up During Back-to-Back Storms?

Back-to-back storms were defined as successive storm events with the second storm starting within 6 to 24 hours of the end of the first. Twenty-six (26) of the 43 storms during the monitoring period were categorized as back-to-back storms. Volume reduction by the rain gardens averaged 96% for the second of back-to-back storms and 93% for isolated storms. The average rainfall depth was 0.75 inches for the second storm in back-to-back events and 0.63 inches for all other storms. The higher rainfall depth for the second of back-to-back would generally be expected to result in a lower reduction percentage, which was not the case. However, the average duration of the second of back-to-back storms was 15 hours, while the average duration for the first of back-to-back or isolated storms was 10.5 hours (Table 4). The longer duration provided more time for infiltration, thus offsetting the impact of higher rainfall depth. The result of this analysis is that back-to-back storms had no discernible impact on rain garden performance, demonstrating that the sandy soils at this site drain quickly.

Table 4: Back-to-back storm performance

	2nd of Back-to-Back Storms			All Other Storms		
Site	Average Storm Depth (in)	Average Volume Reduction (%)	Average storm duration (hh:mm)	Average Storm Depth (in)	Average Volume Reduction (%)	Average storm duration (hh:mm)
Model Block	0.75	96	15:05	0.63	93	10:30

Example of Individual Storm Analyses

Figure 5 shows the hydrograph for a large storm event, Storm 27, which produced 1.69 inches of rainfall over the course of 27 hours from the evening of January 7th to the evening of January 8th, 2017. The difference between inflow and outflow is the flow reduction provided by the rain gardens. There was a separate 0.43-inch storm earlier in the day on January 7th so the antecedent soil moisture conditions were close to saturated. The data show that the total inflow to the Model Block was 30,700 gallons and reduction for this storm was approximately 24,000 gallons (78%), and peak flow reduction was 60%. A majority of the overflow occurred during the first half of the storm when the rainfall intensity was highest and the soil was already saturated from the previous storm. Minor overflow occurred in the middle section of the storm when the rainfall intensity died down. More overflow occurred at the end of the storm when a large burst of intense rainfall occurred.

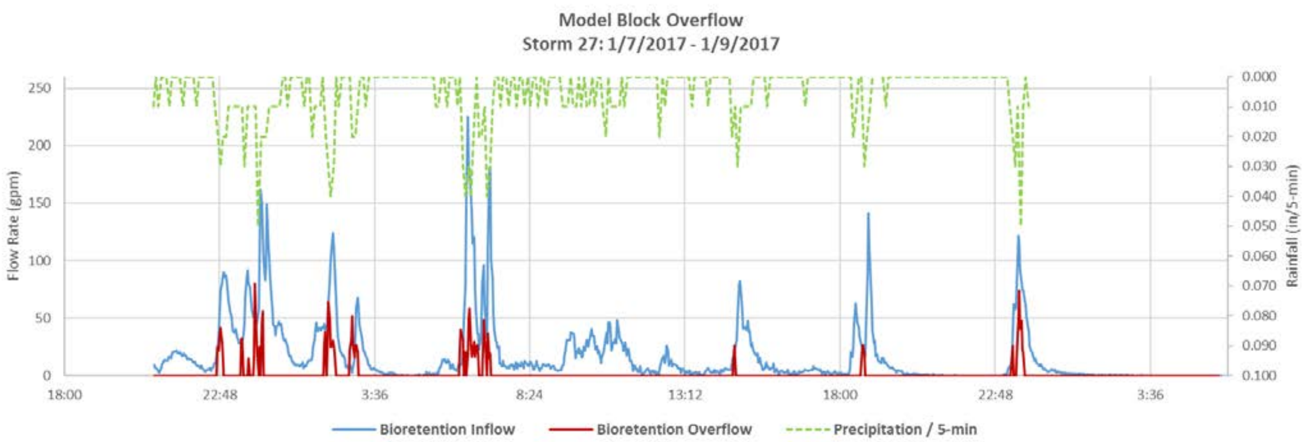

Figure 5: Hydrographs for Storm 27

Storm 17 was characterized by low-intensity rainfall lasting 37 hours, which yielded a total rainfall depth of 1.66" with a maximum 5-minute intensity of 0.36 in/hr. The total inflow to the Model Block rain gardens was 21,200 gallons and all runoff was completely absorbed by the planters for a 100% reduction in volume and peak flow (Figure 13). The low-intensity rainfall was fairly constant over the course of the storm, which provided enough time for the ponded water to infiltrate before reaching the overflow level. This was the largest storm fully managed by the rain gardens during the 2016-17 water year.

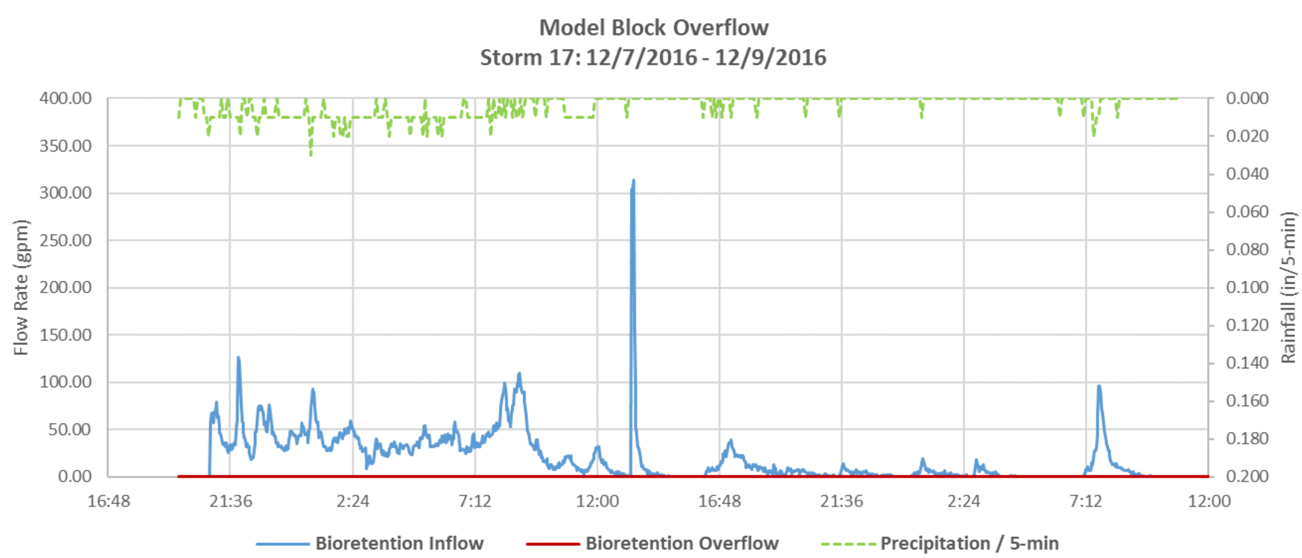

Figure 6: Hydrograph for Storm 17

Summary

GI reduced the volume of stormwater entering the CSS considerably. The volume reduction from the Sunset Boulvard Greenway Model Block was approximately **570,000 gallons (95%)** for the 2016-2017 rainy season. On an individual storm basis, overflow from the Model Block rain gardens was mainly related to storm intensity; less intense storms were fully managed while a few intense storms produced the majority of overflow. Out of the 43 storms producing measurable runoff during the monitoring period, 33 storms were fully managed, while 10 produced overflow. The average peak flow reduction for all measurable storms was 94%, and the reduction rate for storms that produced overflow from the rain gardens to the CSS had a range of 37%-76%.

SWMM model simulation of the project for the 2016-17 water year, which used measured rainfall from the nearby Oceanside Water Pollution Control Plant and an infiltration rate of 10 inches per hour based on a double-ring infiltrometer test, forecast a total volume reduction of 99%. The monitoring results were slightly less than the model prediction with an estimated 95% volume reduction. The Sunset Boulevard Model Block is located on highly infiltrative soils and, despite the wet winter, the rain gardens performed very well in their first year.

Lesson Learned

Sunset Boulevard Greenway is the first EIP to utilize an end-of-block monitoring approach with a single water level sensor in the downstream catch basin. The approach proved successful and cost-effective. Flow monitoring at this site was not, however, without complications. There were two primary lessons learned that should be carried forward to future GI monitoring projects.

1) There was additional, unexpected tributary area draining directly to the monitored catch basin on the Model Block. The subcatchment layer from the CCSF Hydrologic and Hydraulic model showed the northbound lanes of Sunset Boulevard draining to a separate catch basin, but field reconnaissance during wet conditions showed that that intended catch basin was being bypassed and runoff was instead flowing to the same catch basin as overflow from the Model Block. This direct runoff had to be subtracted from the measured flows in order to isolate the overflow from the planters, which required additional data processing and introduced an additional source of potential error into the analysis.

   The first EIP to be monitored was the Oak & Fell green street project. That project also experienced issues with unexpected run-on, but in that instance the run-on actually drained into the GI facilities and thus became part of the DMA, affecting project performance. The lessons learned from that project also included field verifying drainage areas during wet conditions prior to design. Performance of the rain gardens on the Sunset Green Boulevard Model Block was not affected by unexpected runoff, but measurement of overflow from the rain gardens was. The lesson learned on this project is that the same principle of field verifying drainage patterns during wet conditions should also be applied to selection of monitoring locations with the goal of avoiding catch basins that receive significant runoff from outside of the project area.

2) The method of concurrently monitoring an unimproved baseline block and an improved block allows for direct comparison of their hydrologic responses during the same storms as a means to calculate performance. While this method is preferable to comparing against either a pre-construction monitoring period with different storms or against modeled runoff, there were drawbacks on this project due to: A) differences in size and character between the baseline block and Model Block, and B) unexpected run-on to the Model Block catch basin. The baseline block for this project was one third of the size and four blocks away from the Model Block, and it was also flatter and more impervious. These physical differences translated into differences in the scale and timing of peak flows, which required additional data processing when extrapolating measured flow from baseline block to represent inflow to the Model Block rain gardens, introducing more room for error. It may be hard to find a representative baseline block closer than four blocks away from the project area, but future projects using a baseline block to represent pre-construction conditions should choose a block as similar in size, location, and character to the improved block as is possible.

   Inlet and outlet monitoring is recommended on future GI projects if technically and economically feasible.