Mission Valencia Green Gateway Annual Monitoring Report 2017-2018

Project Overview

The San Francisco Public Utilities Commission (SFPUC) is currently implementing the 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 Mission Valencia Green Gateway (MVGG) project is the EIP in the Islais Creek watershed and was completed at the end of 2016.

Prior to the MVGG EIP the project area was a highly impervious streetscape with little to no stormwater storage or infiltration. Before construction most of the rain falling onto the street and sidewalk during storm events ran off into the combined sewer system (CSS). The GI elements were designed and installed to slow and infiltrate stormwater runoff, thereby reducing flows to the sewer, increasing groundwater recharge, and returning some of the natural hydrologic function to the watershed. The SFPUC monitored the performance of MVGG for two wet seasons after construction 2017-18 (Year 1) and 2018-19 (Year 2); this report presents the detailed results for the first year of monitoring.

The MVGG EIP features eleven bioretention planters and one infiltration gallery located within the street right-of-way that manage stormwater runoff from Mission Street, Valencia Street, Duncan Street, and Tiffany Avenue. The bioretention planters (i.e. rain gardens) are designed to infiltrate runoff through an 18-inch layer of engineered bioretention soil until saturation at which point runoff overflows to a sewer connection in Valencia Street. The infiltration gallery located within the Tiffany Avenue right-of-way provides infiltration through 36-inches of gravel and is connected to the sewer to convey excess runoff when the facility is saturated.

The MVGG green infrastructure is designed to manage stormwater runoff from the street, sidewalks, the adjacent landscaped areas, and the facility itself, collectively referred to as the drainage management area (DMA). 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 and resulted in a rain garden sizing ratio of 4.8% and an infiltration gallery sizing ratio of 5.4%. Additional run-on from private parcels discovered during post-construction inspections reduced the effective sizing ratios to 2.8-3.5% (Table 1).

Figure 1: Rain Gardens at Valencia Street and Duncan Street

Figure 2: Rain Garden at Mission Street and Valencia Street

[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.

Figure 3: Rain Garden on Valencia Street

Figure 4: Rain Garden on Duncan Street

Performance of MVGG rain gardens and infiltration gallery for the 2017-18 water year was measured through pre-and post-construction flow monitoring. Pre-construction flow monitoring was conducted in four catch basins within the project area and post-construction flow monitoring was conducted in catch basins located at the overflow sewer connections on Valencia Street and Tiffany Avenue. The facility overflows from MVGG are compared to a modeled baseline flow condition that was calibrated to pre-construction flow monitoring. The difference between modeled baseline flows and monitored flows is credited to facility performance. The three monitoring locations for the 2017-2018 rainy season (Figure 5) are located at:

- West side of Valencia Street @ Duncan St
- East side of Valencia Street @ Duncan St
- Tiffany Ave

The DMAs draining to the GI facilities were delineated using the subcatchment layer from the City and County of San Francisco (CCSF) Hydrologic and Hydraulic model, then they were adjusted according to field observations of drainage patterns during wet weather conditions. These site inspections during wet weather revealed more DMA than was assumed during design; i.e., more surface area drains to the GI facilities than is shown by the City's subcatchment spatial data layer. The DMA was estimated to be 2.2 acres, which would have provided a sizing ratio of 5% with the final configuration of the rain gardens and infiltration gallery. However, the observed DMA totals 3.4 acres. The biggest increase was found in the Tiffany Ave Infiltration Gallery DMA, which increased from 22,000 square feet to 42,000 square feet due contributions from private parcels. Table 1 provides the final DMAs and sizing ratios for the GI facilities. The project area is essentially 100% impervious.

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

Metric	MVGG Rain Gardens	Tiffany St Infiltration Gallery
Total DMA[1] (ft^2)	105,700	43,315
Impervious Area (ft^2)	102,000	42,100
Pervious Area (ft^2)	0	0
Facility Area (ft^2)	3,700	1,215
Sizing Ratio (%)	3.5%	2.8%

[1] Total DMA is the sum of all tributary drainage area plus the facility itself.

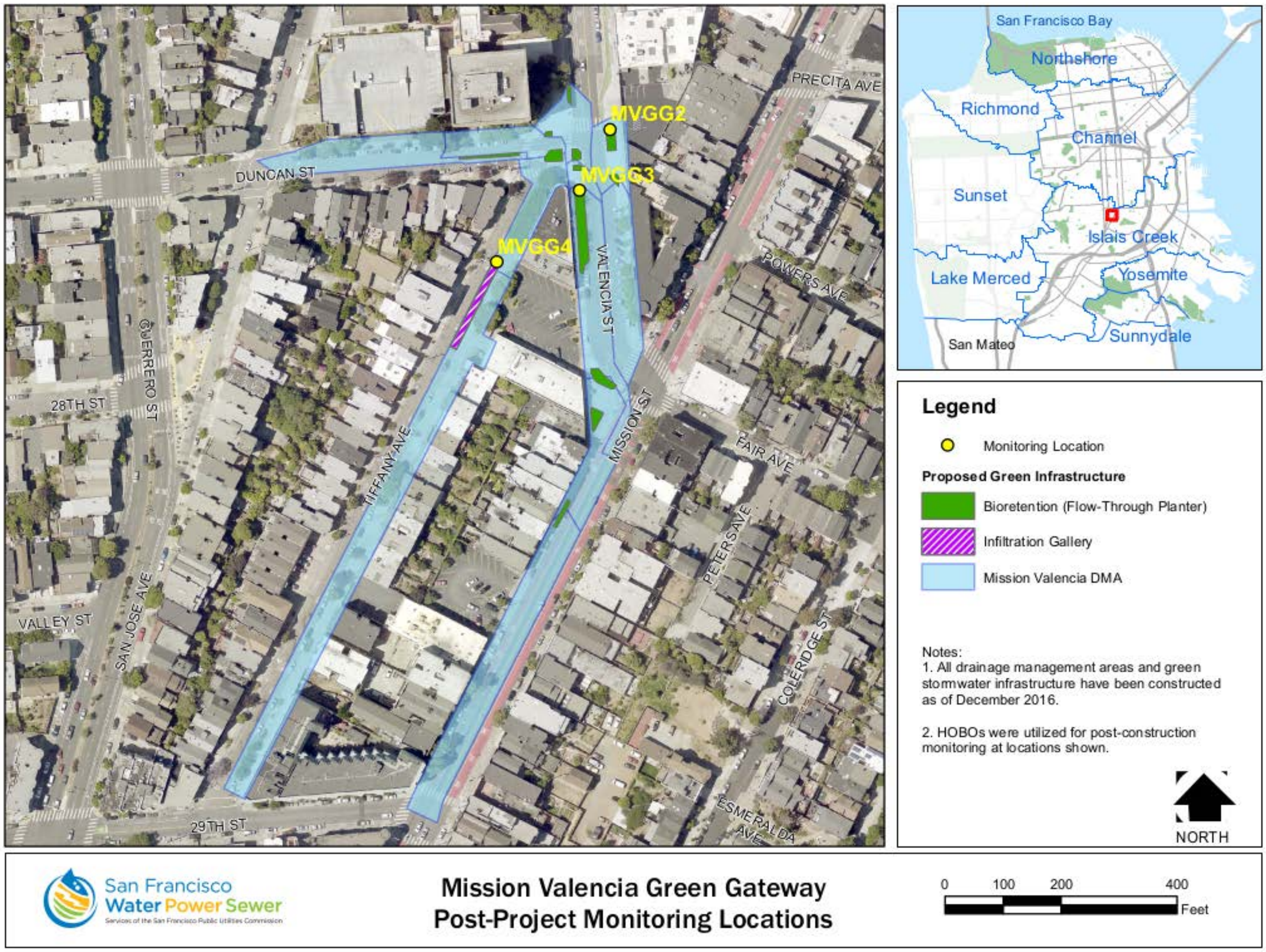


Figure 5: Project overview map

The Mission Valencia Green Gateway project is estimated to have reduced the total volume of stormwater entering the sewer system from the project area by 86% (1,500,000 gallons) during the 2017-18 rainy season.

Learning Goal

The MVGG rain gardens are hydraulically connected and act in aggregate. The goal of this EIP is to understand the performance of multiple bioretention facilities that are hydraulically connected and function as one large facility. In addition, this EIP contains the only infiltration gallery with directly measurable performance.

Results of Monitoring Period 2017-2018

MVGG reduced total volume and peak discharge rates to the CSS. The results of the monitoring data are discussed below in relation to these two primary performance metrics. Because the MVGG rain gardens are hydraulically connected, they act in aggregate. Therefore, project performance is reported in aggregate for the rain gardens and separately for the infiltration gallery.

Was Flow Volume Reduced?

Stormwater overflow from the system was monitored at the catch basins downstream from the connected rain gardens and from the infiltration gallery. The measured pre-construction runoff representing inflow to the facilities was based on the calibrated SWMM model discussed previously. Overflow from the monitored blocks was significantly less than the inflow during the various storm events. Monitored volume reduction during each storm event ranged from 72%-100%. Measured across the entire rainy season, GI reduced runoff volume by an estimated 86%. Figure 11 provides an overview of the inflow to, and overflow from, the rain gardens and infiltration gallery during the full monitoring period.

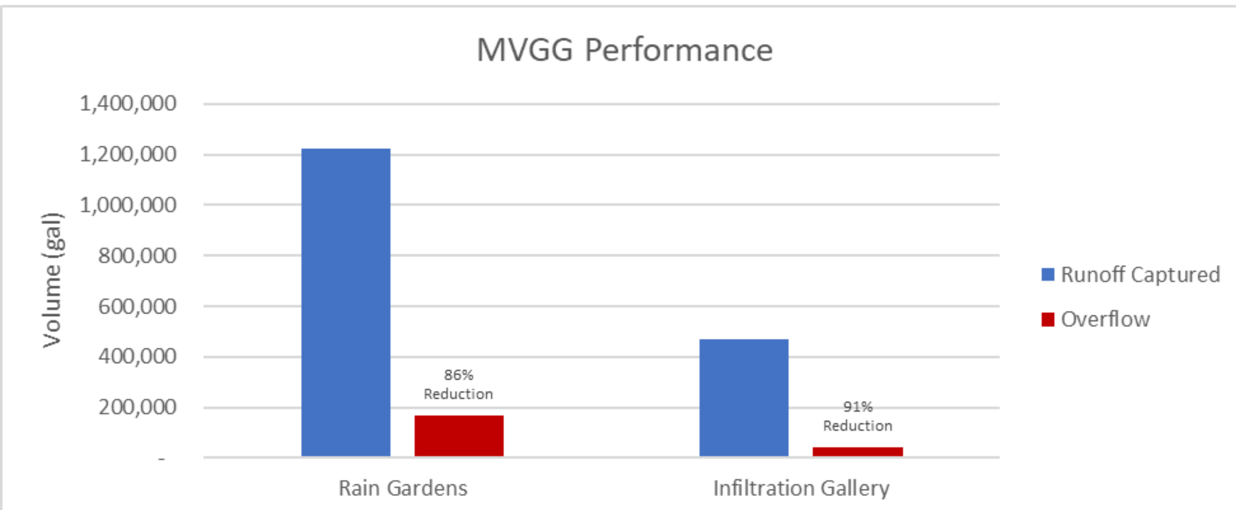


Figure 6: MVGG performance for the 2017-2018 monitoring period.

Comparing modeled versus measured performance (Table 5), the monitored blocks significantly exceeded SWMM model predictions. This is likely the result of several factors that resulted in an overly conservative estimate of the in-situ infiltration rate. As noted previously, the infiltration rate of the native soil is a major determinant of GI performance. The geotechnical investigation found up to three feet of silty, clayey fill on top of native soils. The infiltration tests were performed at an excavated depth of 2-2.5 feet, possible still in fill material, while the bottom of the GI facilities are around four feet below grade, well into native soils. Another contributing factor is that the SWMM model simulates one-dimensional infiltration in the vertical direction only, while in reality infiltration also occurs laterally. Lastly, the SFPUC policy of applying a 0.33 adjustment factor to the infiltration rate as determined by double-ring infiltrometer testing, which is consistent with standard practice nationally, is intended to be a conservative measure that accounts for soil compaction, siltation, or other potential impacts over the lifetime of the facility that may diminish infiltration capacity. Based on monitoring results, the infiltration rates input to the SWMM model likely underestimate the actual infiltration capacity of the underlying native soil during the monitoring period.

Table 2: Modeled versus measured performance for the 2017-2018 rainy season

Site	DMA	Facility Size	BMP Sizing Ratio	Modeled Flow Reduction			Measured Flow Reduction		
				Volume		Peak Flow[1]	Volume		Peak Flow[1]
	(sf)	(sf)	(%)	(gallons)	(%)	(%)	(gallons)	(%)	(%)
Rain Gardens	105,683	3,700	3.5%	810,000	66%	78%	1,030,000	84%	97%
Infiltration Gallery	42,115	1,215	2.8%	366,000	78%	80%	428,000	91%	82%

[1] Values are an average from storms with greater than 0.1 inches of rainfall.

A 4.32-inch storm over 34 hours on April 5th, 2018 was the largest storm during the monitoring period. Volume reduction for this storm was 81% across the monitored blocks. The largest storm fully managed by the rain gardens was 1.01 inches on March 20, and the largest at the infiltration gallery was 0.35 inches on October 19. For the full monitoring period, the rain gardens fully managed 33 of the 37 monitored storms, and the infiltration gallery fully managed 25 of 37. Figure 12 provides an overview for the monitored rain gardens and infiltration gallery showing the rainfall, inflow to the GI facilities, and overflow from the facilities to the CSS during the full monitoring period. Rainfall is shown in green on the top axis with its values on the left axis. Inflow is shown in blue and outflow in red on the bottom axis with their values on right axis. Periods of intense rainfall exhausted facility storage and produced overflow to the sewer system, although the overflow was significantly dampened from corresponding inflow to the facility. Many low-intensity storms produced little to no overflow from the green infrastructure, meaning that all runoff entering the GI facilities was fully infiltrated.

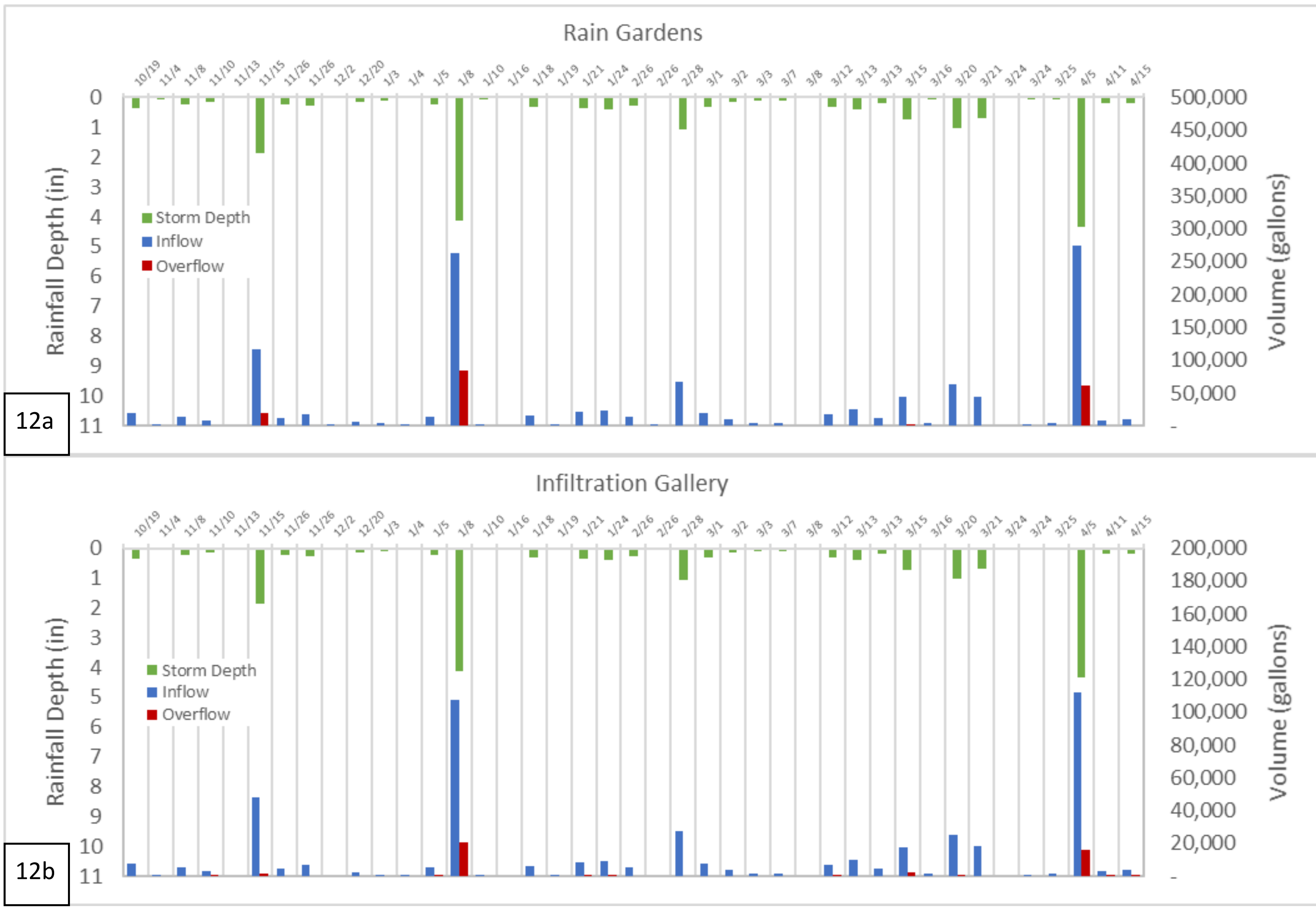


Figure 7a and 12b: Hydrographs showing inflow and outflow at the MVGG rain gardens and infiltration gallery

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

Back-to-back storms are defined as successive storm events with the second storm starting within 6 to 24 hours of the end of the first. Of the 23 storms greater than 0.1 inch, there were 7 storms that qualify as back-to-back. The average rainfall depth was 0.39 inches for the second storm in back-to-back events and 0.84 inches for all other storms greater than 0.1 inch. For the rain gardens, only one of the seven back-to-back storms overflowed a mere 70 gallons. As a result there was almost a 100% volume reduction for the 2nd of back-to-back storms at the rain gardens, as compared to 83% for all other storms. For the infiltration gallery, two of the back-to-back storms overflowed resulting in a 96% reduction, as compared to 90% for all other storms. Because isolated storms and the first of back-to-back storms produced over twice as much rainfall as the second of back-to-back storms, performance was actually better for the latter. Performance generally decreases in the second of back-to-back storms for facilities in poorly drained soils, providing another indication that the bottom of the GI facilities at MVGG are below the silty, clayey layer of imported fill on the surface. The three other EIP sites analyzed thus far (Phase I of the Permeable Wiggle, Sunset Green Boulevard, and Holloway Green Street) also found no discernible impacts on performance for back-to-back storms.

Table 3: Back-to-back storm performance

Site	2nd of Back-to-Back Storms			All Other Individual Storms		
	Average Storm Depth[1]	Average Volume Reduction	Average storm duration	Average Storm Depth[1]	Average Volume Reduction	Average storm duration
	(in)	(%)	(hh:mm)	(in)	(%)	(hh:mm)
Rain Gardens	0.39	99.96%	7:48	0.84	83%	11:08
Infiltration Gallery		96%			90%	

[1] Only includes storms with greater than 0.1 inches of rainfall.

Were Peak Flow Rates Reduced?

The MVGG rain gardens reduced peak flow rates by an average of 96% for the whole rainy season among storms producing greater than 0.1 inch of rainfall. 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 GI facility, meaning that duration is also a factor in determining which storms produce overflow.

Of the 37 storm events monitored during the 2017-2018 rainy season, no overflow occurred for 33 of those events at the rain gardens and four events produced overflow. At the Tiffany Ave infiltration gallery, 25 events had no measured overflow and 12 events produced overflow. The largest storm that did not produce overflow at the rain gardens had a total depth of 1.01 inches over 25.5 hours with a maximum intensity of 0.6 inches per hour. The largest storm that did not produce overflow at the infiltration gallery had a total depth of 0.35 inches over 2 hours with a maximum intensity of 0.48 inches per hour.

Table 4: Peak flow reduction characteristics

Site	Storms with Overflow				Storms with no overflow (fully managed)	
	# of Storm Events	Min Peak Reduction	Max Peak Reduction	Average Peak Reduction	# of Storm Events	Largest Storm Event with No Overflow (in)
Rain Gardens	4	64%	99.5%	78%	33	1.01
Infiltration Gallery	12	17%	99.7%	75%	25	0.35

Across all storm events producing overflow, the average peak flow reduction at the rain gardens was 78% and ranged from 64% to 99% (Table 7). The average peak flow reduction at the infiltration gallery as 75% and ranged from 17% to 99.7% across all events producing overflow. For all storms producing greater than 0.1 inch of rainfall, the average peak flow reduction across the whole project was 93%.

At Mission Valencia Green Gateway 25 out of 37 storms were fully managed, and the peak flow rate was reduced by an average of 93%.

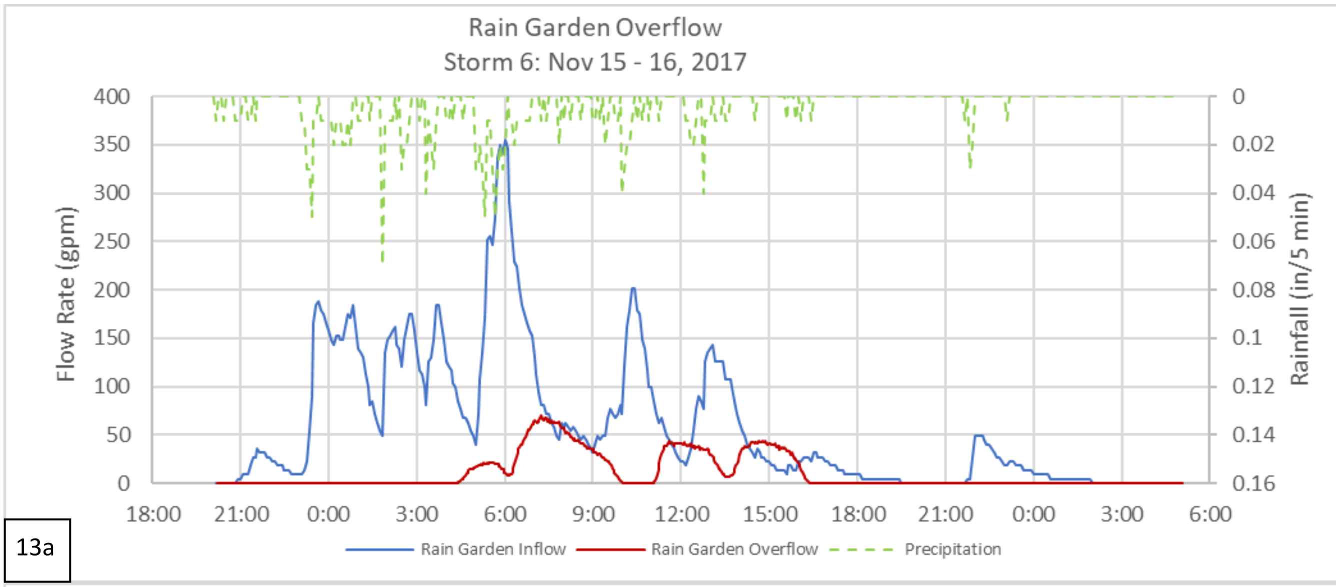
Examples of Individual Storm Analyses

Three storms were selected to represent various types of storms experienced during the 2017-2018 monitoring period. Storm 6 was a large storm with a duration of around one day. Storm 32 was a medium sized storm also lasting about one day. Storm 35 was a medium sized storm with a shorter duration of 14 hours.

Table 5: Discharge characteristics for highlighted storms

		Storm 6	Storm 32	Storm 35
Storm Characteristics	Storm Date(s)	Nov 15 – 16, 2017	Mar 15-16, 2018	Mar 21-22, 2018
	Storm Total Rainfall (in)	1.87	0.72	0.71
	Storm Duration (hh:mm)	26:55:00	22:40	14:10
	Peak 5-minute Intensity (in/hr)	0.84	1.2	0.48
Rain Gardens	Volume Reduction (%)	83%	99.9%	100%
	Peak Flow Reduction (%)	81%	99%	100%
Infiltration Gallery	Volume Reduction (%)	96%	89%	99.70%
	Peak Flow Reduction (%)	81%	17%	94%

Figure 13 shows the hydrograph for a large storm event, Storm 6, which produced 1.87 inches of rainfall over the course of 26 hours from the evening of November 15th to the evening of November 16th, 2017. The difference between inflow and outflow is the flow reduction provided by the rain gardens. The data show that the total inflow to the rain gardens was 117,000 gallons and reduction for this storm was approximately 97,000 gallons (83%), and peak flow reduction was 81%. As can be seen in Figure 13, a majority of the overflow occurred during the middle of the storm when the rainfall intensity was highest approximately 8 hours after the beginning of the storm. More overflow occurred at the second half of the storm when rainfall intensity increased. Inflow to the infiltration gallery was 48,000 gallons and reduction for this storm was approximately 46,000 gallons (96%). The overflow from the infiltration trench only occurred after the rainfall intensity exceeds approximately 0.02 inches in 5 minutes.



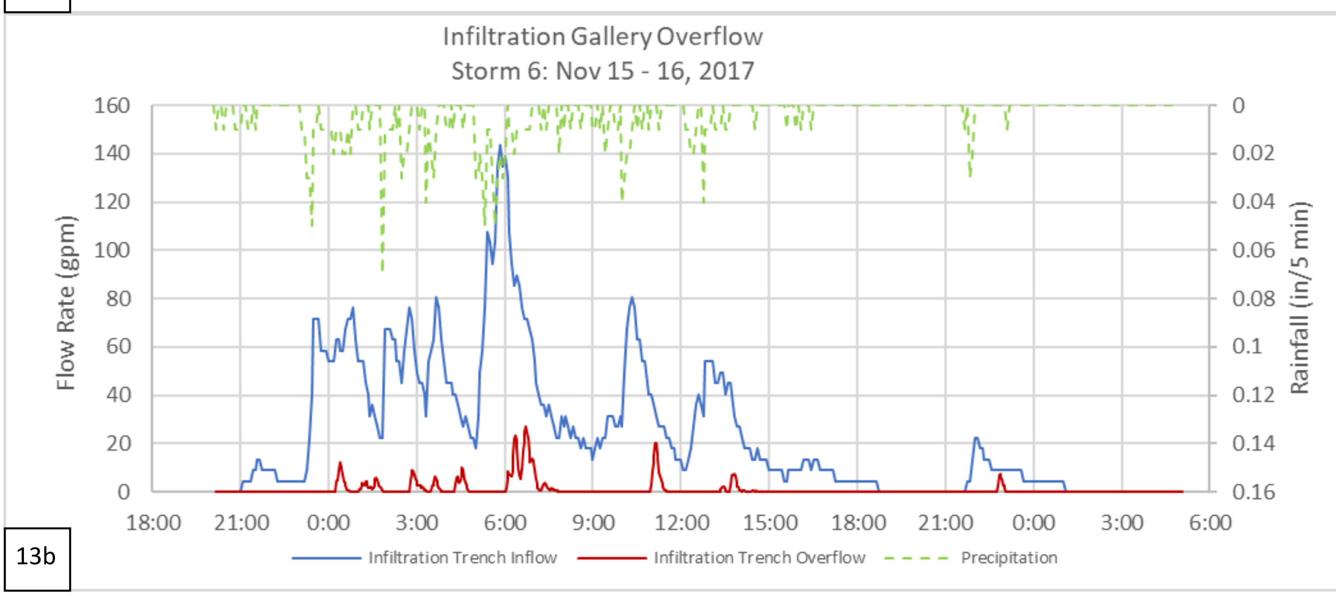


Figure 8a and 13b: Hydrographs for Storm 6 at the MVGG rain gardens and infiltration gallery

Storm 32 was a high intensity storm with total rainfall depth of 0.72 inches over 22 hours with a peak intensity of 1.2 inches per hour. The total inflow to the rain gardens was 45,000 gallons and with approximately 66 gallons of measured overflow, a reduction of 99.9%. The inflow to the infiltration gallery was 18,000 gallons and reduction for this storm was 16,000 gallons (89%). As can be seen in Figure 14 the overflow from the infiltration gallery occurs when rainfall intensity was highest. The nature of the storm with two intense bursts of rainfall that exceeded 0.07 inches in 5 minutes created enough runoff to cause the infiltration gallery to overflow to the CSS. After the peak of the rainfall passes the infiltration gallery managed the rest of the runoff over the next several hours (Figure 14).

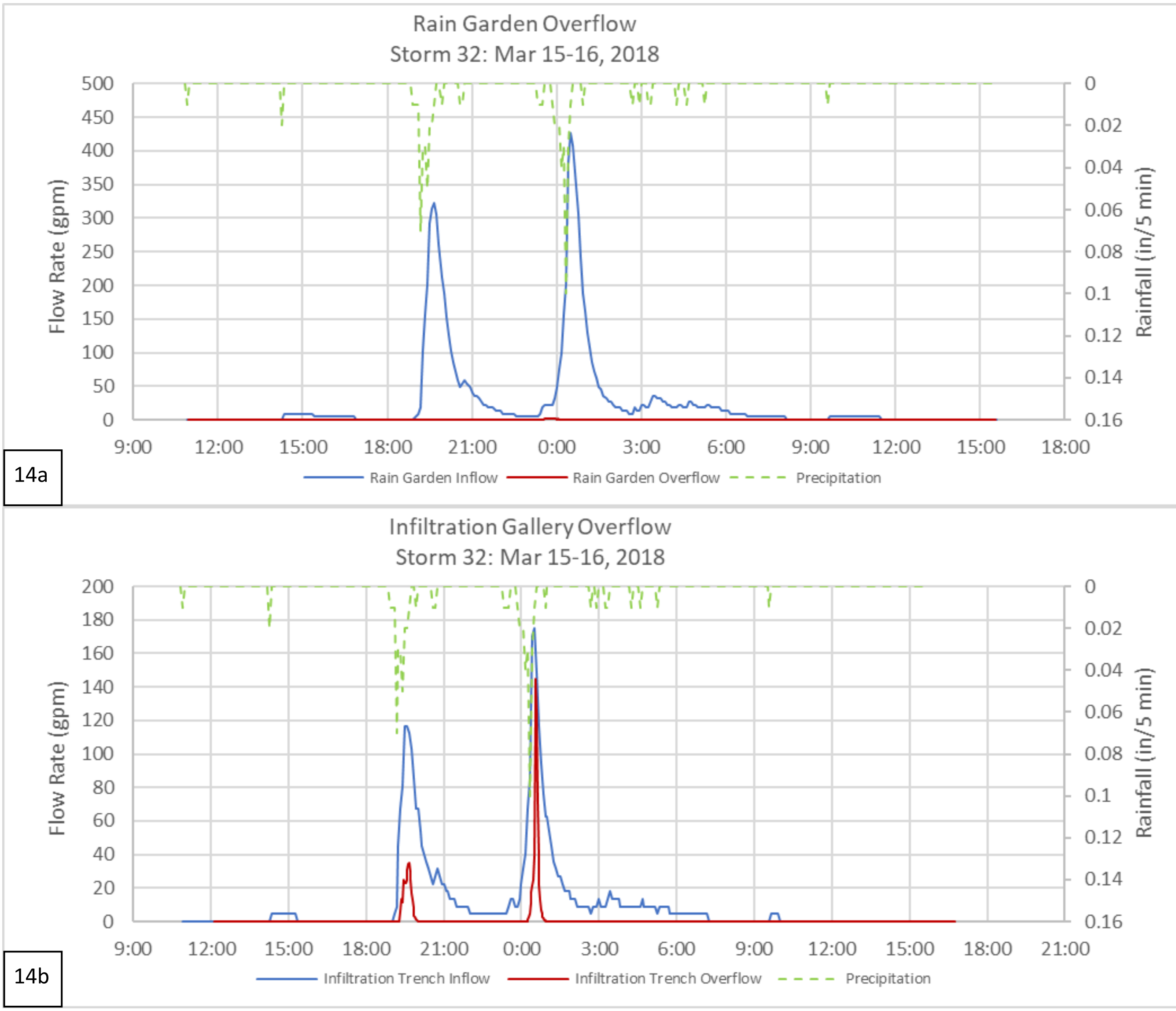


Figure 9a and 14b: Hydrographs for Storm 32 at the MVGG rain gardens and infiltration gallery

Storm 35 was characterized by low-intensity rainfall lasting 14 hours, which yielded a total rainfall depth of 0.71 inches with a maximum 5-minute intensity of 0.48 inches per hour. The total inflow to the rain gardens was 45,000 gallons and all runoff was completely absorbed by the planters for a 100% reduction in volume and peak flow (Figure 15). 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. The total inflow to the infiltration gallery was 18,000 and 99.7% of the volume was managed by the facility resulting in approximately 50 gallons of overflow to the CSS.

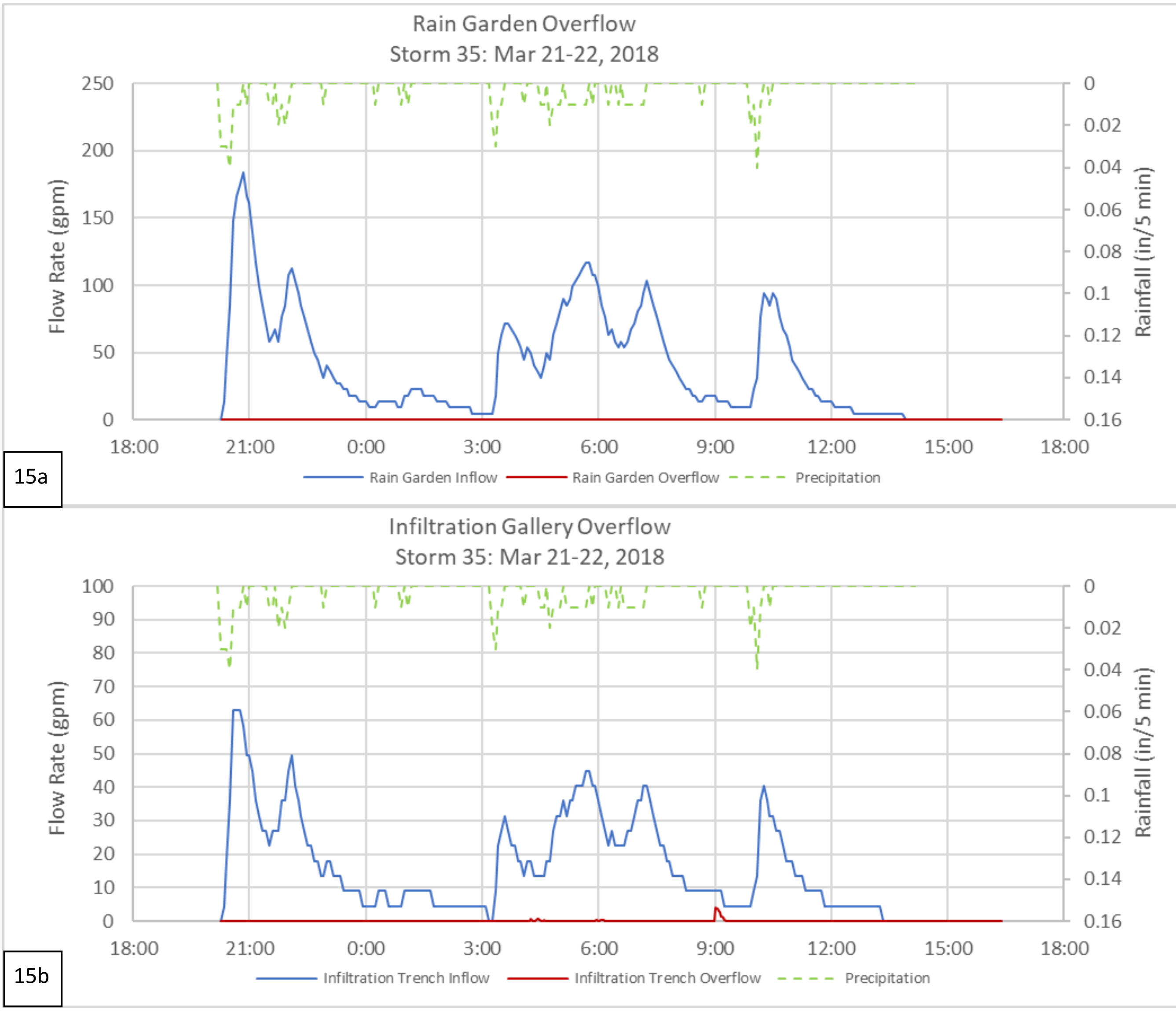


Figure 10a and 15b: Hydrograph for Storm 35 at the MVGG rain gardens and infiltration gallery

Summary

GI reduced the volume of stormwater entering the CSS considerably. The volume reduction from the Mission Valencia Green Gateway was approximately **1,500,000 gallons (86%)** for the 2017-2018 rainy season. Storms that produced overflow to the CSS had a volume reduction rate in the range of 65%-99.9%.

Out of the 41 storms producing measurable runoff during the monitoring period, 25 storms were fully managed, while 12 produced overflow and 4 were not monitored. The average peak flow reduction for all measurable storms was 90%. Storms that produced overflow to the CSS had a peak flow reduction rate in the range of 58%-99%.

Modeling results were strongly correlated to the monitoring results, although the monitored performance was higher (86% monitored volume reduction versus 69% modeled reduction) due to conservative infiltration assumptions input to the model.

Overflow from the green infrastructure was related to two main characteristics: 1) storm intensity – less intense storms produced little to no overflow while more intense storms produced overflow on most blocks; 2) storm volume – bigger storms overwhelm the infiltration capacity of the native soil and bioretention facility resulting in overflow. The majority of storms were fully managed, but longer storms with intense bursts resulted in overflow to the CSS.

Lesson Learned

There were three primary lessons learned from the Mission Valencia Green Gateway project that should be carried forward to future GI monitoring projects.

1) The infiltration tests were conducted before construction at a depth that did not correspond to the base of the built GI facilities. The tests were conducted in a layer of imported fill while the base of the GI facilities were excavated deeper into native soils. It would be preferable if future infiltration tests were conducted at the same elevation as the base of the GI facilities, which might necessitate waiting to perform the tests until 35% design is complete.

2) There was additional, unexpected tributary area draining directly to the Tiffany Ave and Valencia Street. Field reconnaissance during wet conditions showed that that private property runoff was flowing to the street draining to the rain gardens and to the Tiffany Ave infiltration gallery. This additional DMA was estimated and added to the modeled flows which required additional data processing.

   The Oak & Fell and Sunset Boulevard projects both experienced issues with unexpected run-on. For Oak & Fell, the run-on drained into the GI facilities, thus becoming part of the DMA and affecting project performance. For Sunset Boulevard, the additional drainage area flowed directly into the downstream catch basin, so those flows were subtracted out of the monitored flow to account for only the performance associated with the target DMA. The lessons learned from those projects included field verifying the project DMA during wet conditions prior to design. The same principle should be applied to selection of monitoring locations with the goal of avoiding catch basins that receive significant runoff from outside of the project area.

3) Pre-construction monitoring allows for the direct measurement of hydrologic response of the drainage management area, which is useful in calculating post-construction performance. However, pre-construction monitoring is expensive. Pre-construction monitoring data at MVGG were used to develop a rainfall-runoff relationship of the drainage management area using a calibrated SWMM model. Because construction reconfigured the drainage pattern in the project area, the area monitored in pre-construction was not the same DMA monitored in post-construction, so the rainfall runoff relationship had to be extrapolated to the actual DMA. When possible, it is preferable for pre-construction monitoring to target the exact post-construction DMA. If that is not possible, alternative methods of establishing pre-construction flows may be more cost effective.

Summary Table for Mission Valencia Green Gateway

					MVGG Rain Gardens							Tiffany Ave Infiltration Gallery							MVGG Total						
					Volume				Flow			Volume				Flow			Volume				Flow		
Storm Number	Storm Start	Storm Duration (hh:mm)	Rainfall Depth (in)	Peak 5-minute Rainfall Intensity (in/hr)	Inflow to GI (gal)	Overflow (gal)	Retention Volume (gal)	Block Scale Volume Reduction (%)	Peak Flow Entering GI (gpm)	Peak Overflow (gpm)	Peak Discharge Reduction (%)	Inflow to GI (gal)	Overflow (gal)	Retention Volume (gal)	Block Scale Volume Reduction (%)	Peak Flow Entering GI (gpm)	Peak Overflow (gpm)	Peak Discharge Reduction (%)	Inflow to GI (gal)	Overflow (gal)	Retention Volume (gal)	Volume Reduction (%)	Peak Flow Entering GI (gpm)	Peak Overflow (gpm)	Peak Discharge Reduction (%)
1	10/19/2017 23:20	2:00	0.35	0.48	20,579	0	20,579	100%	260	0	100%	7,855	0	7,855	100%	90	0	100%	28,433	0	28,433	100%	350	0	100%
2	11/4/2017 3:35	0:55	0.07	0.24	1,728	0	1,728	100%	22	0	100%	516	0	516	100%	9	0	64%	2,244	0	2,244	100%	31	0	100%
3	11/8/2017 21:05	3:35	0.25	0.24	14,071	0	14,071	100%	108	0	100%	5,274	0	5,274	100%	40	0	99.7%	19,345	0	19,345	100%	148	0	100%
4	11/10/2017 7:45	4:00	0.13	0.72	7,742	0	7,742	100%	112	0	100%	2,805	117	2,688	96%	36	15	59%	10,548	117	10,430	99%	148	15	90%
5	11/13/2017 16:55	0:05	0.01	0.12	0	0	0	100%	0	0	100%	0	0	0	100%	0	0	100%	0	0	0	100%	0	0	100%
6	11/15/2017 20:10	26:55	1.87	0.84	122,531	19,927	102,603	84%	390	68	83%	47,733	1,943	45,790	96%	144	27	81%	170,264	21,871	148,393	87%	534	95	82%
7	11/26/2017 9:25	5:20	0.22	0.24	11,580	0	11,580	100%	67	0	100%	4,443	0	4,443	100%	22	0	100%	16,023	0	16,023	100%	90	0	100%
8	11/26/2017 20:45	6:45	0.28	0.72	18,402	0	18,402	100%	153	0	100%	6,867	0	6,867	100%	54	0	94%	25,269	0	25,269	100%	206	0	100%
9	12/2/2017 23:30	0:15	0.03	0.12	67	0	67	100%	4	0	100%	0	0	0	100%	0	0	100%	67	0	67	100%	4	0	100%
10	12/20/2017 1:15	1:25	0.13	0.36	5,745	0	5,745	100%	72	0	100%	2,087	0	2,087	100%	22	0	100%	7,832	0	7,832	100%	94	0	100%
11	1/3/2018 18:40	2:45	0.1	0.36	3,591	0	3,591	100%	40	0	100%	1,234	0	1,234	100%	13	0	73%	4,825	0	4,825	100%	54	0	100%
12	1/4/2018 16:30	4:50	0.03	0.12	1,077	0	1,077	100%	4	0	100%	112	0	112	100%	4	0	100%	1,189	0	1,189	100%	9	0	100%
13	1/5/2018 8:35	13:25	0.24	0.24	15,126	0	15,126	100%	81	0	100%	5,633	480	5,153	91%	27	8	69%	20,758	480	20,278	98%	108	8	92%
14	1/8/2018 1:00	30:35	4.13	0.60	275,986	84,562	191,424	69%	395	121	69%	107,518	21,064	86,453	80%	148	51	66%	383,504	105,627	277,877	72%	543	172	68%
15	1/10/2018 13:25	1:35	0.06	0.12	3,030	0	3,030	100%	31	0	100%	1,055	0	1,055	100%	9	0	82%	4,084	0	4,084	100%	40	0	100%
16	1/16/2018 1:30	0:05	0.01	0.12	0	0	0	100%	0	0	100%	0	0	0	100%	0	0	100%	0	0	0	100%	0	0	100%
17	1/18/2018 10:05	9:50	0.3	0.24	16,674	0	16,674	100%	76	0	100%	6,373	0	6,373	100%	27	0	91%	23,047	0	23,047	100%	103	0	100%
18	1/19/2018 5:45	2:15	0.02	0.12	830	0	830	100%	4	0	100%	67	0	67	100%	4	0	100%	898	0	898	100%	9	0	100%
19	1/21/2018 23:10	8:20	0.35	0.36	21,634	0	21,634	100%	117	0	100%	8,303	293	8,011	96%	45	10	78%	29,937	293	29,644	99%	162	10	94%
20	1/24/2018 14:45	10:05	0.38	0.60	23,631	0	23,631	100%	121	0	100%	9,201	665	8,536	93%	40	13	67%	32,832	665	32,167	98%	162	13	92%
21	2/26/2018 3:40	4:15	0.26	0.36	14,497	0	14,497	100%	148	0	100%	5,431	0	5,431	100%	54	0	100%	19,928	0	19,928	100%	202	0	100%
22	2/26/2018 20:45	0:05	0.01	0.12	157	0	157	100%	4	0	100%	0	0	0	100%	0	0	100%	157	0	157	100%	4	0	100%
23	2/28/2018 22:30	12:30	1.07	1.20	70,466	17,976	52,491	74%	323	0	100%	27,266	0	27,266	100%	126	0	100%	97,733	17,976	79,757	82%	449	0	100%
24	3/1/2018 21:00	1:35	0.32	1.20	21,252	10,211	11,041	52%	305	0	100%	8,124	0	8,124	100%	103	0	100%	29,376	10,211	19,165	65%	408	0	100%
25	3/2/2018 13:20	4:20	0.16	0.36	10,031	0	10,031	100%	72	0	100%	3,815	0	3,815	100%	27	0	94%	13,846	0	13,846	100%	99	0	100%
26	3/3/2018 21:05	2:30	0.09	0.24	5,117	0	5,117	100%	45	0	100%	1,840	0	1,840	100%	13	0	87%	6,957	0	6,957	100%	58	0	100%
27	3/7/2018 23:05	3:50	0.11	0.12	4,825	0	4,825	100%	49	0	100%	1,773	0	1,773	100%	13	0	100%	6,598	0	6,598	100%	63	0	100%
28	3/8/2018 17:35	0:05	0.01	0.12	0	0	0	100%	0	0	100%	0	0	0	100%	0	0	100%	0	0	0	100%	0	0	100%
29	3/12/2018 16:15	5:45	0.31	0.60	18,425	0	18,425	100%	233	0	100%	6,957	211	6,746	97%	81	18	78%	25,381	211	25,171	99%	314	18	94%
30	3/13/2018 5:00	6:55	0.41	0.36	26,997	0	26,997	100%	166	0	100%	10,346	0	10,346	100%	58	0	95%	37,343	0	37,343	100%	224	0	100%
31	3/13/2018 20:55	14:05	0.2	0.36	12,276	0	12,276	100%	90	0	100%	4,668	0	4,668	100%	27	0	100%	16,943	0	16,943	100%	117	0	100%
32	3/15/2018 10:55	22:40	0.72	1.20	46,634	70	46,564	100%	476	2	99%	17,998	2,047	15,951	89%	175	145	17%	64,632	2,117	62,515	97%	651	147	77%
33	3/16/2018 23:00	9:25	0.08	0.48	4,488	0	4,488	100%	49	0	100%	1,324	0	1,324	100%	18	0	100%	5,812	0	5,812	100%	67	0	100%
34	3/20/2018 8:35	25:35	1.01	0.60	65,193	0	65,193	100%	399	0	100%	25,157	357	24,800	99%	139	16	88%	90,350	357	89,993	100%	539	16	97%
35	3/21/2018 20:15	14:10	0.71	0.48	46,656	0	46,656	100%	202	0	100%	18,245	0	18,245	100%	63	0	94%	64,901	0	64,901	100%	265	0	100%
36	3/24/2018 1:05	0:05	0.01	0.12	0	0	0	100%	0	0	100%	0	0	0	100%	0	0	100%	0	0	0	100%	0	0	100%
37	3/24/2018 21:25	0:10	0.05	0.36	2,469	0	2,469	100%	36	0	100%	785	0	785	100%	13	0	100%	3,254	0	3,254	100%	49	0	100%
38	3/25/2018 5:20	2:25	0.08	0.24	4,937	0	4,937	100%	63	0	100%	1,795	0	1,795	100%	22	0	100%	6,732	0	6,732	100%	85	0	100%
39	4/5/2018 19:55	34:05	4.32	0.96	286,781	61,281	225,500	79%	570	194	66%	111,781	15,910	95,871	86%	206	128	38%	398,562	77,191	321,371	81%	776	322	58%
40	4/11/2018 18:40	1:20	0.17	0.48	8,999	0	8,999	100%	126	0	100%	3,321	90	3,231	97%	45	10	78%	12,320	90	12,230	99%	171	10	94%
41	4/15/2018 16:35	16:10	0.2	0.24	10,503	0	10,503	100%	67	0	100%	3,591	117	3,474	97%	22	12	48%	14,093	117	13,977	99%	90	12	87%
	Total	317:00	19.26		1,224,726	194,027	1,030,699	84.2%	5,485	386		471,295	43,293	428,002	90.8%	1,943	453		1,696,021	237,320	1,458,701	86.0%			
	Average	7:43	0.47	0.42	29,871	4,732	25,139	96.5%	134	9	96.8%	11,495	1,056	10,439	98.0%	47	11	82.1%	41,366	5,788	35,578	96.9%	181	20.48	93.3%
	Maximum	34:05	4.32	1.20	286,781	84,562	225,500		570	194		111,781	21,064	95,871		206	145		398,562	105,627	321,371		776	322.3	

NOTES: 1. Monitoring data missing for storms 21-24, extrapolated from calibrated SWMM model (shown in red)

2. Average Peak Discharge Reduction includes only storms producing >0.1 inch of rainfall depth.