San Francisco State University Site 1 Vegetated Infiltration Basin Monitoring Report: Rainy Seasons 2011-12 and 2012-13

Project Overview

San Francisco State University (SFSU) has implemented several green infrastructure (GI) installations across the main campus. The campus has many impervious areas including expansive rooftops, sidewalk areas, and parking lots that result in high stormwater flow rates into the combined sewer system (CSS) without abatement. Stormwater runoff in some locations is now being directed into bioretention planters, vegetated swales, cisterns and other GI controls. These efforts take advantage of the plentiful pervious areas on SFSU's campus that can be used for stormwater retention, treatment, and infiltration or evapotranspiration. SFSU Site 1 (Figure 1) is a small, vegetated infiltration basin adjacent to the University Mail Room building that receives stormwater flows directly from the roof as well as a small portion of the adjacent parking lot. Using campus resources, campus Facilities Operations staff, and student volunteers, the area was re-graded and drainage rerouted for the facility to receive and infiltrate stormwater runoff in an effort to improve the small catchment's hydrologic function.

Multiple groups were involved in the monitoring and analysis of the site, including SFPUC, Sustainable Watershed Designs, and SFEI (referred to hereafter as "the Team"). Following GI implementation, the Team monitored inflow to the infiltration basin (Figure 2) as well as outflow from the basin to the sewer drain in order to assess changes in stormwater volume, peak flow rates, and delays between rainfall and flow to the sewer.

Figure 1. A) Map showing location of SFSU vegetated infiltration basin, B) View of vegetated infiltration basin post installation, and C) View of infiltration basin and mail room roof.

Site Summary	Project Features	SFSU Site 1
A 1,000 ft^2 undeveloped area adjacent to the University Mail Room was re-graded and transformed into a small, vegetated infiltration basin consisting of plants and an overflow drain. The basin was designed to slow down and retain stormwater runoff from the catchment. Stormwater flow entering and exiting the basin was monitored to assess the basin's effectiveness at reducing flow volumes and rates to the CSS. The vegetated infiltration basin is performing well and retains the vast majority of stormwater inflows.	**Year Constructed**	2010
	GI Elements	Vegetated Infiltration Basin
	Drainage Management Area (ft^2)	5,900[1]
	% of Impervious Area Converted to GI	0%
	% of Drainage Area that is GI	17%
	Monitoring Period	2012-13 post-construction

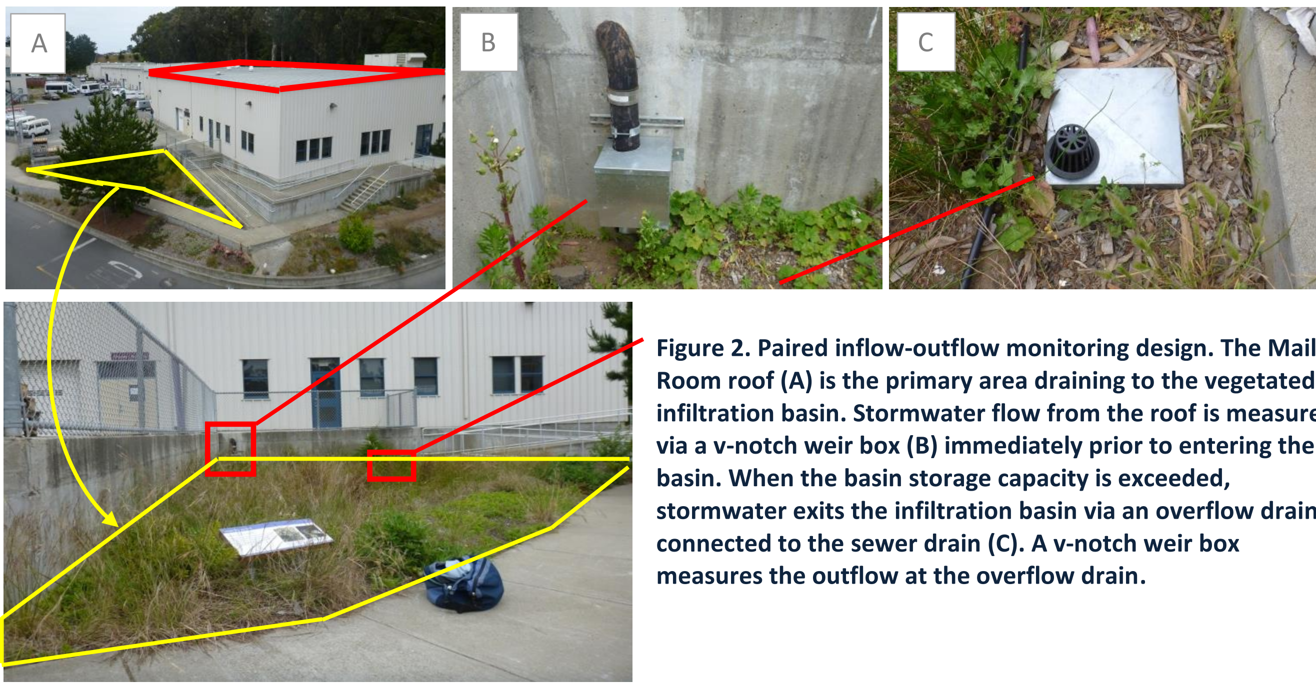


Figure 2. Paired inflow-outflow monitoring design. The Mail Room roof (A) is the primary area draining to the vegetated infiltration basin. Stormwater flow from the roof is measured via a v-notch weir box (B) immediately prior to entering the basin. When the basin storage capacity is exceeded, stormwater exits the infiltration basin via an overflow drain connected to the sewer drain (C). A v-notch weir box measures the outflow at the overflow drain.

Hydrologic Improvement Highlights

	SFSU Site 1
Flow Volume Reduction[2]:	93%
Peak Flow Rate Reduction[3]:	90%
Delay in Flow[4]:	160 minutes
Largest Storm with no Flow[5]:	0.91 inches

[1] The drainage area to the outlet includes the roof draining to the inlet (4900 ft^2), the infiltration basin itself (1000 ft^2, although approx. 800 ft^2 flows to the outlet) plus approx. 200 ft^2 of the adjacent parking lot. Runoff from the parking lot flowed into the infiltration basin as sheetflow and could not be measured. Performance reported in this study is likely greater than actual due to assumptions that runoff from the parking lot is negligible.
[2] Flow Volume Reduction Percentage = $(Volume_{inlet} – Volume_{outlet}) / Volume_{inlet}$ X 100
[3] Average peak flow rate reduction measured for all storm events with measureable outflow.
[4] Change in the median lag time between the start of rainfall and the start of detectable inflow versus the start of rainfall and the start of detectable outflow.
[5] Largest storm measured during the monitoring period with complete capture of all runoff volume.

Project Findings: Rainy Seasons 2011-2012 and 2012-2013

Was Flow Volume Reduced?

Throughout much of SFSU's campus, the impervious surfaces including rooftops, streets, sidewalks and parking lots have little or no storage or infiltrative function, and as a result most rainfall runs off into the CSS. GI elements are designed to detain and retain rainfall, thereby reducing outflow to the CSS. A reduction in flow volume is one straightforward and important measure of GI effectiveness at managing stormwater on site. If outflow volume decreases from pre- to post-GI implementation, the volume reduction represents infiltration or evapotranspiration within the catchment, and thus a reduction in stormwater entering the CSS.

At SFSU Site 1, the vegetated infiltration basin substantially reduced flow volumes to the CSS (Figure 3 and Table 1). Prior to vegetated infiltration basin installation, runoff from the rooftop and parking lot areas to the CSS would have equaled the flow measured at the inlet to the infiltration basin, which amounted to 67% of total rainfall[6] during the monitoring period. Post infiltration basin installation, runoff volume to the CSS was approximately 15-fold lower (only 4% of rainfall onto the catchment area flowed to the CSS). Assuming similar relative performance[7] during an average rainfall year when approximately 21 inches of rain falls in this part of San Francisco, the vegetated basin would retain approximately 5,700 cubic feet (or 43,000 gallons). On an individual storm basis, the basin retained 72-100% of the stormwater flow volume. During the study period, 45 of 58 storms monitored at the site produced no measureable stormwater outflow. Storm size with no resulting outflow ranged from 0.01 to as much as 0.91 inches. Overall, flow volume to the sewer was reduced by 93%.

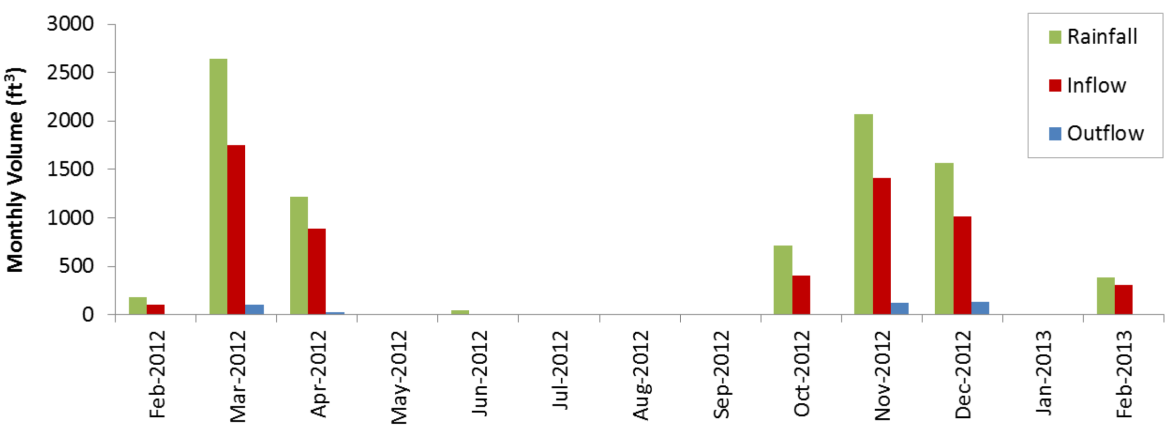


Figure 3. Monthly rainfall and flow volume measured at the vegetated infiltration basin inlet and outlet.

Table 1. Total rainfall and flow volumes at the SFSU Site 1 inlet and outlet during Rainy Season 2011-12 and 2012-13 monitoring period and flow estimates based on an average rainfall year.

	Monitored Storms			Average Yearly Estimates[8]		
Catchment	Total Rainfall[6] (ft^3)	Flow (ft^3)	% of Rainfall Measured as Flow	Total Rainfall (ft^3)	Flow (ft^3)	Total Volume Diverted from CSS (ft^3)
SFSU 1 inlet	8,800	5,900	67%	9,100	6,100	5,700[9]
SFSU 1 outlet		400	4%		400	

[6] Total rainfall reported in Table 1 includes only rainfall volume falling onto drainage area into the infiltration basin and not the basin itself.
[7] The monitored rainy seasons were drier than average; it is unknown how the infiltration basin performance would be affected during a wetter year.
[8] Data are normalized to an average rainfall year (21 inches for this part of San Francisco). The estimated results are a simple scaling based on the monitoring data shown in the left-hand side of Table 1. Variations in rainfall intensity and duration might impact the estimate by a few percent.
[9] 5,700 ft^3 is equivalent to 43,000 gallons.

Were Peak Flow Rates Reduced?

When a catchment's land cover consists of a high proportion of impervious surfaces such as asphalt or concrete (sidewalks, roads, parking lots) and roofs, a large fraction of rainfall quickly becomes runoff and produces higher peak flow rates relative to natural or landscaped areas that retain or infiltrate water. At the local scale, this can result in street surface ponding. Further downstream, when flows from multiple catchment areas combine, large peak flow rates can trigger combined sewer discharges. A reduction in peak flow rates is therefore an important measure of success, consistent with the goal of GI implementation to slow and infiltrate stormwater runoff.

The vegetated infiltration basin at SFSU Site 1 substantially reduced peak flow rates to the CSS relative to peak flows measured at the inlet. Peak outflow rates were, on average, 90% lower than peak inflows during storms producing flow from the outlet (n=13, range of reduction 59% to 99%; Table 2). Reductions in peak flow rates are especially important during storms with higher rainfall intensities when hydraulic challenges in the CSS can flare up. The feature performed comparably well across the range of small and larger storms (Figure 4 and Table 2). However, the greatest storm return interval was less than a 1-yr return; therefore, only relatively common, small storms were observed during the monitoring period and used to form the conclusions described here. Data from additional monitoring or modeling efforts could be used to assess the effectiveness of SFSU Site 1 during larger storm events.

Table 2. Reduction in peak flow rates for the subset of storm events that had 5-minute peak rainfall intensity greater than 0.5 inches per hour.

SFSU Site 1 Vegetated Infiltration Basin						
Storm Date	**Peak 5-minute Rainfall (converted to in/hr)**	**Storm Return Interval (year; based on 3 hour duration)[10]**	**Inlet Peak Flow Rate (cfs)**	**Outlet Peak Flow Rate (cfs)**	**Peak Flow Rate Reduction**	**Average Peak Flow Rate Reduction**
4/12/2012	2.04	< 0.25	0.34	0.002	99%	90%[11]
4/12/2012	1.56	< 0.25	0.25	0.005	98%	
12/2/2012	1.32	0.5	0.12	0.05	59%	
10/24/2012	0.96	< 0.25	0.22	0	100%	
2/28/2012	0.84	< 0.25	0.21	0	100%	
4/10/2012	0.84	< 0.25	0.11	0	100%	
3/31/2012	0.72	0.25	0.27	0	100%	
11/20/2012	0.72	< 0.25	0.09	0.002	98%	
12/11/2012	0.72	< 0.25	0.05	0	100%	
11/17/2012	0.60	< 0.25	0.10	0	100%	
11/28/2012	0.60	< 0.25	0.18	0	100%	
3/16/2012	0.60	< 0.25	0.07	0.01	85%	
12/5/2012	0.60	0.5	0.07	0.007	89%	

[10] A 0.5-yr return interval occurs on average two times in one year; a 0.25-yr return interval occurs on average four times in one year; and a <0.25-yr return interval occurs on average *more* than four times in one year.
[11] This metric is the average peak flow rate reduction for *all* observed storms that produced outflow (n=13). For the 13 storms presented in the table, seven of which did not result in any flow to the CSS, the average peak flow rate reduction was 94%.

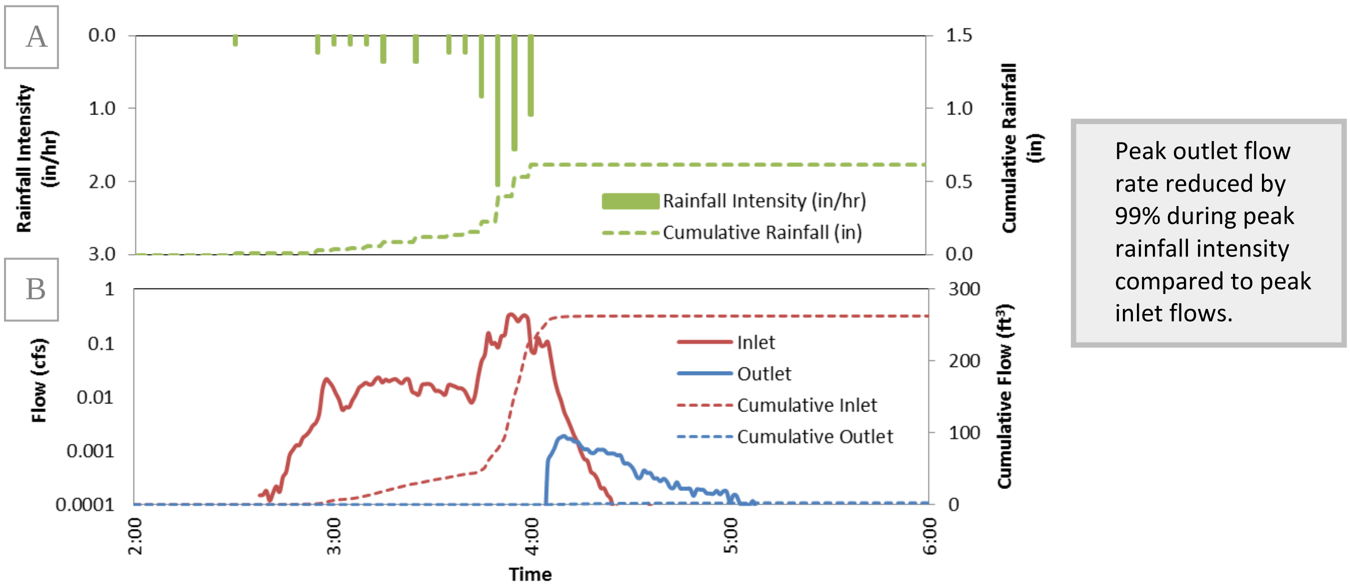


Figure 4. A) Rainfall intensity and cumulative rainfall during the highest intensity rainfall event on April 12, 2012. B) Storm hydrograph with inlet and outlet flow rates and cumulative flow volume during this short duration storm event. Note log scale on primary y-axis.

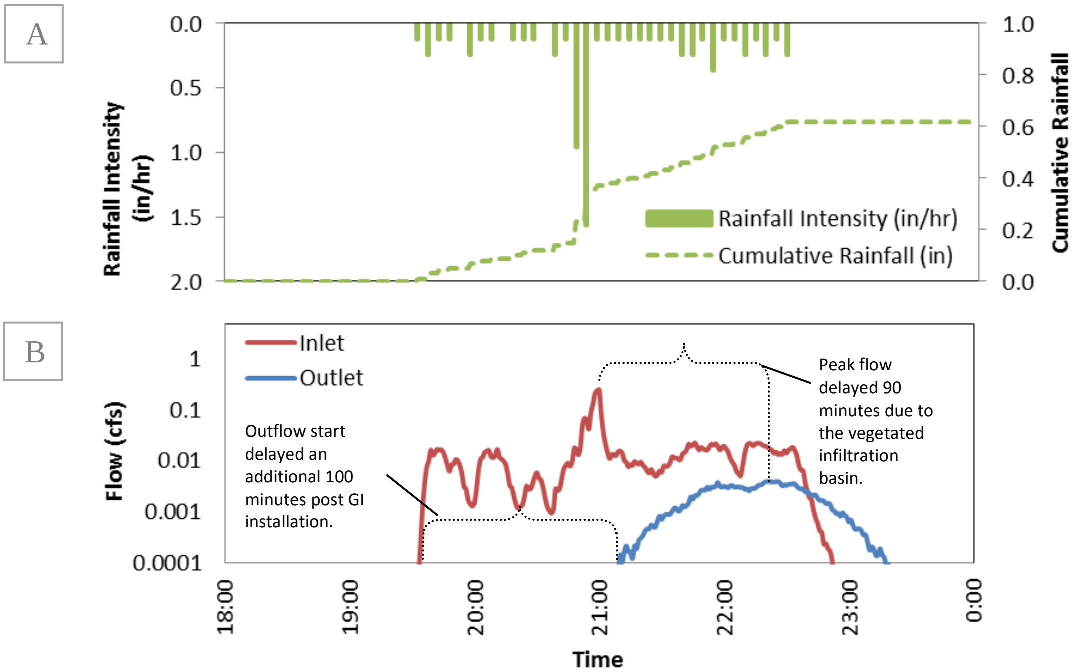
Were Lag Times Between Rainfall and Flow Increased?

The time delay (or "lag time") between rainfall and outflow is a measure of catchment responsiveness (flashy versus lagged) to rainfall. Large proportions of impervious area in a catchment rapidly convey runoff to the CSS and result in shorter lag times. GI elements help to increase the lag time between rainfall and outflow. At the local scale, implementing GI and delaying flows to the CSS in strategic locations can result in reduced likelihood that the CSS becomes locally overwhelmed. Two measures of lag time are reported here: the difference between rainfall and flow start times and the difference between peak rainfall and peak flow times. An increase in either of these measures indicates success; a larger increase in time indicates a higher level of temporary or permanent storage within the catchment area.

Lag times were assessed during the 13 (out of 58) storms where measurable outflow occurred. Lag times between the start of rainfall and the start of flow increased by a median of 160 minutes at SFSU Site 1(Table 3 and Figure 5). Similarly, the lag from the peak in rainfall to the peak flow rate was also considerably delayed (median lag time was 117 minutes).

Table 3. Median lag time between start of rainfall to start of flow ($Start_I$ to $Start_F$) and peak of rainfall to the peak of flow ($Peak_I$ to $Peak_F$).

	SFSU Site 1	
	Median Lag Time (minutes)	
	$Start_I$ to $Start_F$	$Peak_I$ to $Peak_F$
Inlet	<1	<1
Outlet	160	117
Increased lag due to GI elements	160	117



Outflow start was delayed up to several hours post installation of the small, vegetated infiltration basin.

Median peak rainfall to peak flow lag time increased by two hours.

Figure 5. A) Rainfall intensity and cumulative rainfall during a storm event on April 12, 2012. B) Storm hydrograph showing inflow and outflow at the small, vegetated infiltration basin during this storm event.

Summary

The demonstration project at SFSU Site 1 illustrates that GI had a substantial positive impact on the catchment's hydrology. In summary,

- GI installation at SFSU Site 1 resulted in a 15-fold reduction in total flow volume to the CSS (total based on all storms monitored).
- Three quarters of monitored storms had no measureable outflow to the CSS.
- There was an average 90% peak stormwater flow rate reduction for storms with measurable outflow.
- On an average annual basis, SFSU Site 1 diverts approximately 5,700 cubic feet (43,000 gallons) of stormwater from the CSS either via infiltration and/or evapotranspiration.
- Outflow to the CSS was delayed up to several hours and median peak outflows were delayed by two hours.

The combination of reduced flow volume, reduced peak flow rates, and increased lag time effectively reduces the total instantaneous demand on the CSS. The results indicate that GI has the potential to be an effective mechanism for stormwater management if implemented broadly and strategically on campus and throughout the City of San Francisco.