San Francisco State University Site 3 Basin and Swale System Monitoring Report: Rainy Seasons 2011-12 and 2012-13

Project Overview

Since 2010, San Francisco State University (SFSU) professors, facilities and grounds crews, and the SFSU Planning Department have successfully collaborated on several green infrastructure (GI) installations across the campus. The traditional lawn areas surrounding the SFSU Science Building were selected for GI construction with the intention to serve as an educational opportunity for the SFSU community. Features were installed on both the north and south sides of the building to receive stormwater runoff from the building roof. This analysis focuses on the 3,900 ft^2 area on the north side of the building (SFSU Site 3).

The SFSU Site 3 basin and swale includes a two-stage system for infiltrating and detaining storm flows: the upper portion includes a flat, small infiltration basin surrounded by berms with a raised spillway that ponds and infiltrates stormwater runoff (Figure 1). After reaching the top of the spillway, runoff flows into a swale which slopes westward toward an outlet drain.

The conversion of this area to a stormwater management system was implemented by student volunteers overseen by SFSU staff and faculty, who completed the installation cooperatively over several weeks. Multiple groups were involved in the project monitoring and analysis, including SFPUC, Sustainable Watershed Designs, and SFEI (referred to hereafter as "the Team"). Following GI implementation, the Team monitored inflow into the basin and swale system (Figure 2) and outflow to the combined sewer system (CSS) to assess changes in stormwater volume, peak flow rates, and delays between rainfall and flow to the sewer.

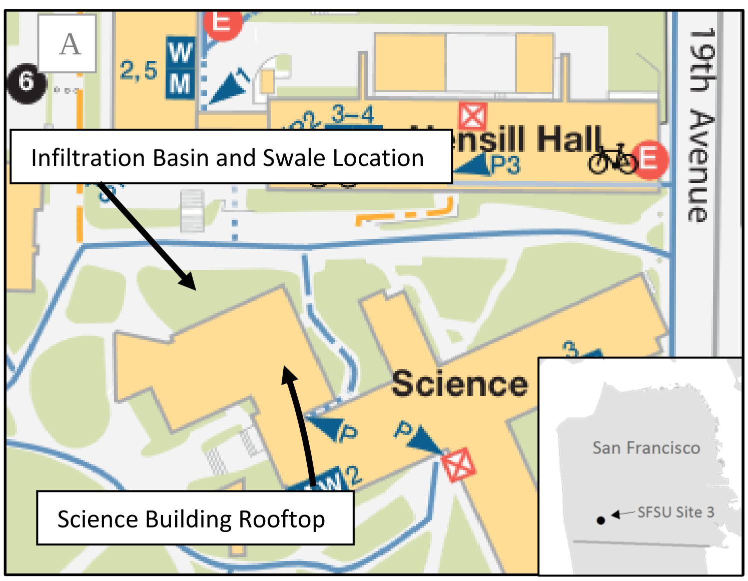


Figure 1. A) Map showing location of SFSU basin and swale, B) SFSU Science Building with system in front, and C) View of basin and swale.

Site Summary	Project Features	SFSU Site 3
Stormwater runoff from the SFSU Science Building rooftop previously flowed unabated to the combined sewer system (CSS) and is now managed by GI controls on the north and south sides of the building (south side GI not included in this analysis). The location provides good access for public education as it is located near high traffic pedestrian paths and has been studied frequently by University classes. Stormwater flows entering and exiting the basin and swale system were monitored to assess effectiveness at reducing stormwater volumes and flow rates to the CSS. The system is performing well and retains the vast majority of stormwater runoff.	**Year Constructed**	2010
	GI Elements	Basin and Swale System
	Drainage Management Area (ft^2)	6,550[1]
	% of Impervious Area Converted to GI	0%
	% of Drainage Area that is GI	8.4 %
	Monitoring Period	2012-13 post-construction

Figure 2. Paired inflow-outflow monitoring design. A portion of the Science Building roof (red highlight) drains to the basin and swale (A). Roof runoff enters the basin and swale system via piping from the downspout (B) as well as holes in the roof gutters. Stormwater runoff ponds and infiltrates the upper basin in the system during storm events. Excess runoff spills over to a sloped, vegetated swale and finally into an overflow drain (C) connected to the CSS. A v-notch weir box under the overflow drain grate measures outflow.

Hydrologic Improvement Highlights

	SFSU 3
Flow Volume Reduction[2]:	95%
Peak Flow Rate Reduction[3]:	94%
Delay in Flow[4]:	220 minutes
Largest Storm with no Flow[5]:	0.91 inches

[1] The drainage area to outlet includes partial Science Building roof (3,100 ft^2), two-stage basin and swale system itself (550 ft^2; outlined in orange in Figure 2), plus landscaped area which receives drip from the rooftop and drains towards the basin and swale system and outlet drain (outlined in yellow in Figure 2 (2900 ft^2)).

[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 rainfall start and the start of detectable inflow versus rainfall start and the start of detectable outflow.

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 to 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.

The two-stage basin and swale system at SFSU Site 3 substantially reduced flow volumes to the CSS (Figure 3 and Table 1). Prior to installation of the system, an estimated 82% of total rainfall drained to the CSS (based on modeled flows[6] at the inlet during the monitoring period). Post installation, the proportion of rain entering the CSS has been reduced twenty-fold (4% of rainfall draining to the CSS). Assuming similar relative performance[7] during an average rainfall year when approximately 21 inches of rain falls on this part of San Francisco, the basin and swale system could divert approximately 4,350 cubic feet (or 33,000 gallons) of stormwater from the CSS.

On an individual storm basis, the basin and swale system retained 52-100% of the stormwater inflows. During the monitoring period, 32 of 53 storms monitored produced no measureable outflow. Storm size with no resulting outflow, ranged from 0.01 to 0.91 inches. Overall, flow volume to the CSS was reduced by 95%.

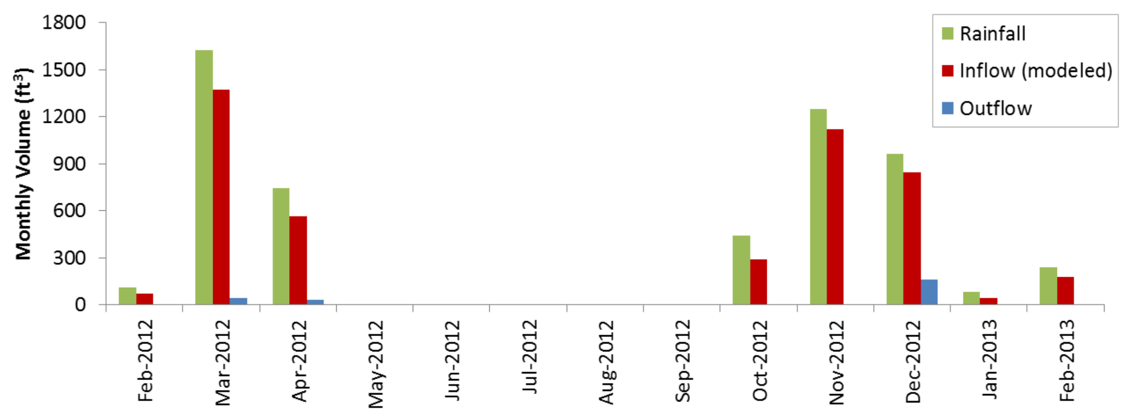


Figure 3. Monthly rainfall and flow volume modeled at the SFSU Site 3 INLET and measured at the outlet.

Table 1. Total rainfall and estimated inflow and outflow volumes during the Rainy Season 2011-12 and 2012-13 monitoring period and flow estimates based on an average rainfall year.

Catchment	Monitored Storms			Average Yearly Estimates[8]		
	Total Rainfall (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 3 inlet (modeled)	5,500	4,500	82%	5,600	4,600	4,350[9]
SFSU 3 outlet		240	4%		250	

[5] Largest storm measured during the monitoring period with complete capture of all rainfall volume.
[6] Inlet flows were modeled due to runoff from leaky roof gutters not being captured as part of monitored inlet flows into the basin and swale system.
[7] The monitored rainy seasons were drier than average; it is unknown how the system's 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 Table 1. Variations in rainfall intensity and duration might impact the estimate by a few percent.
[9] 4,350 ft^3 is equivalent to 33,000 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 basin and swale system at SFSU Site 3 substantially reduced peak flow rates to the CSS relative to the modeled peak flows. Peak outflow rates were on average 94% lower than peak inflows during storm events producing measurable flow at the outlet (n=21; range of reduction 44% 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 basin and swale system performed comparably well across the range of storms observed (Table 2) excepting one storm event (Figure 4) where peak flow was reduced by only 44%. This event had very high antecedent rainfall. Most storm events measured during the monitoring period were classified as a 0.5-year return interval or smaller (Table 2). Additional monitoring or modeling efforts would be needed to assess the effectiveness of this system 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 3 Basin and Swale System						
Storm Date	Peak 5-minute Rainfall (converted to in/hr)	Storm Return Interval (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	0.14	0.02	90%	94%[11]
4/12/2012	1.56	0.25	0.11	0.003	97%	
12/2/2012	1.32	0.5	0.09	0.05	44%	
10/24/2012	0.96	<0.25	0.07	<0.0002	100%	
2/28/2012	0.84	<0.25	0.06	0	100%	
4/10/2012	0.84	0.25	0.06	<0.0002	100%	
3/31/2012	0.72	<0.25	0.05	<0.0002	100%	
11/20/2012	0.72	0.25	0.05	<0.0002	100%	
12/11/2012	0.72	<0.25	0.05	0	100%	
3/16/2012	0.60	<0.25	0.04	0.005	88%	
11/17/2012	0.60	<0.25	0.04	<0.0002	100%	
11/28/2012	0.60	<0.25	0.04	0.0001	100%	
12/5/2012	0.60	0.5	0.04	0.008	81%	

[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* storms that produced outflow (n=21). For the 13 storms presented in the table, eight of which did not result in any outflow to the CSS, the average peak flow rate reduction was 92%.

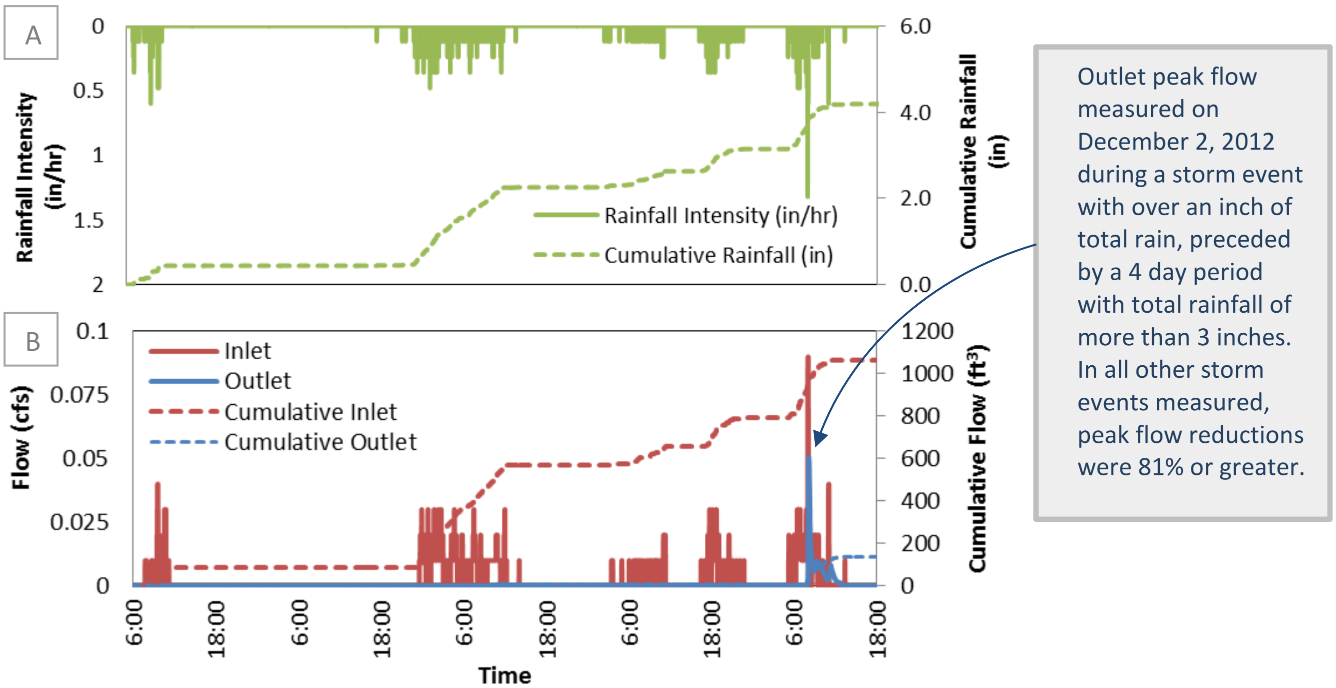


Figure 4. A) Rainfall intensity and cumulative rainfall during a storm series in late November - early December 2012. B) Storm hydrograph for inlet and outlet flow rates and cumulative flow volume during this period.

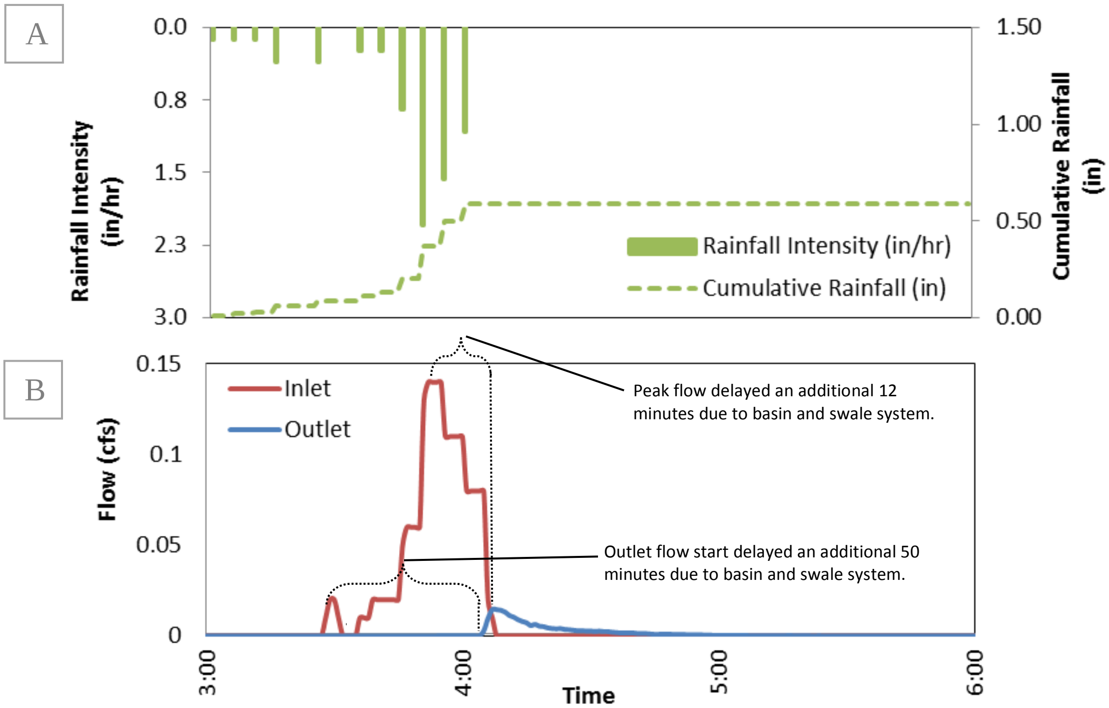
Were Lag Times Between Rainfall and Flow Increased?

The time delay 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. GI elements help to increase the lag time between rainfall and outflow. At the local scale, implementing GI in strategic locations can result in delayed flow to the CSS and reduces the likelihood of street surface ponding. 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 21 (out of 53) storms where measurable outflow occurred. The median lag time between the start of rainfall and the start of flow was 220 minutes (Table 3 and Figure 5). Similarly, the time from peak rainfall to the peak flow rate was also considerably delayed with a median lag time of 90 minutes.

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

	SFSU Site 3	
	Median Lag Time (minutes)	
	$Start_I$ to $Start_F$	$Peak_I$ to $Peak_F$
Inlet[12]	<10	<10
Outlet	230	100
Increased lag due to GI elements	220	90

[12] Inlet lag time metrics presented above were based on best professional judgment. The modeled inlet flows simulated very short delays to peak flow but longer delays to the start of flow at the inlet, presumably due to conservative input model parameters. See Technical Appendix for further discussion.



Outflow to the CSS was delayed up to several hours.

Median lag time from peak rainfall to peak flow increased 90 minutes.

Figure 5. A) Rainfall intensity and cumulative rainfall during a storm event on April 12, 2012. B) Storm hydrograph showing inlet and outlet flow rates and annotated lag times during this storm event.

Summary

The demonstration project at SFSU Site 3 is a two-stage basin and swale system that promotes substantial reductions in stormwater flows to the CSS. In summary,

- GI installation at SFSU Site 3 resulted in a twenty-fold reduction in total flow volume to the CSS.
- Peak stormwater outflow rates were reduced by 94% in storms with measurable outflow.
- Sixty percent of storms monitored had no outflow to the CSS.
- On an average annual basis, SFSU Site 3 diverts approximately 4,350 cubic feet (33,000 gallons) of stormwater from the CSS via either infiltration and/or evapotranspiration.
- Outflow to the CSS was delayed up to several hours and median peak outflows were delayed by 90 minutes.

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.