Newcomb Avenue Green Street
Monitoring Report Rainy Seasons 2011-2012 and 2012-2013

Project Overview

The Newcomb Avenue Green Street (Figure 1) was a City of San Francisco (City) pilot project to assess the benefits of green infrastructure (GI) implementation to the City's combined sewer system (CSS). The model block seeks to provide multiple benefits including urban beautification, traffic calming, increased community gathering spaces, and some return to historical watershed function. Elements implemented on the model block include curb extensions, stormwater planters, permeable pavers, and trees which provide canopy cover. The analysis provided in this report focuses on stormwater runoff reduction draining to the CSS along this block of Newcomb Avenue.

Multiple groups were involved in the project monitoring and analysis, including SFDPW, SFPUC, Sustainable Watershed Designs, and SFEI (referred to hereafter as "the Team"). The Team monitored outflow in the northern and southern storm drains (Figure 2) to assess changes in stormwater volume, peak flow rates, and delays between rainfall and outflow (performance indicators) following GI implementation. Newcomb Avenue GI implementation pre-dated performance based site design. The City has subsequently developed performance-based standards which will be implemented in future projects.

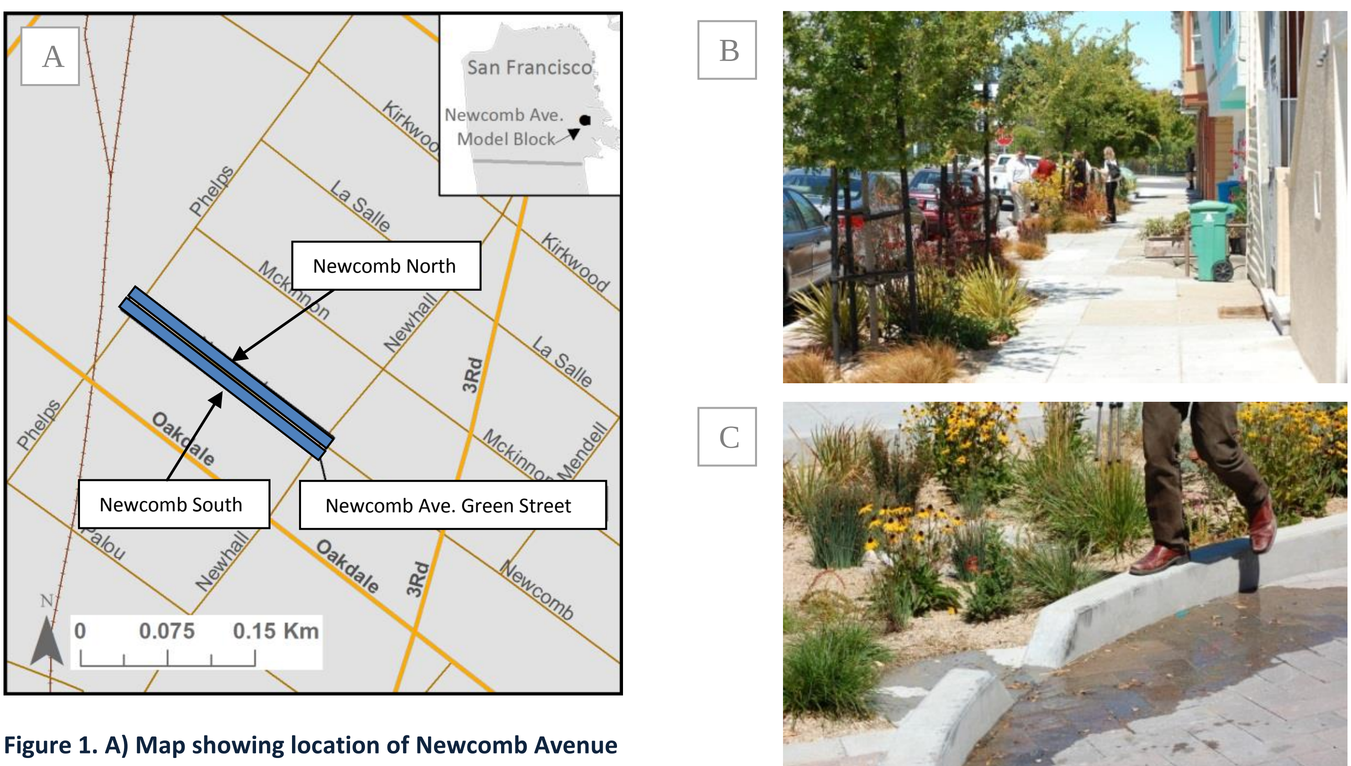


Figure 1. A) Map showing location of Newcomb Avenue Green Street, B) Sidewalk planters along the north side of the Newcomb Avenue Green Street, and C) Water entering the bioretention planter.

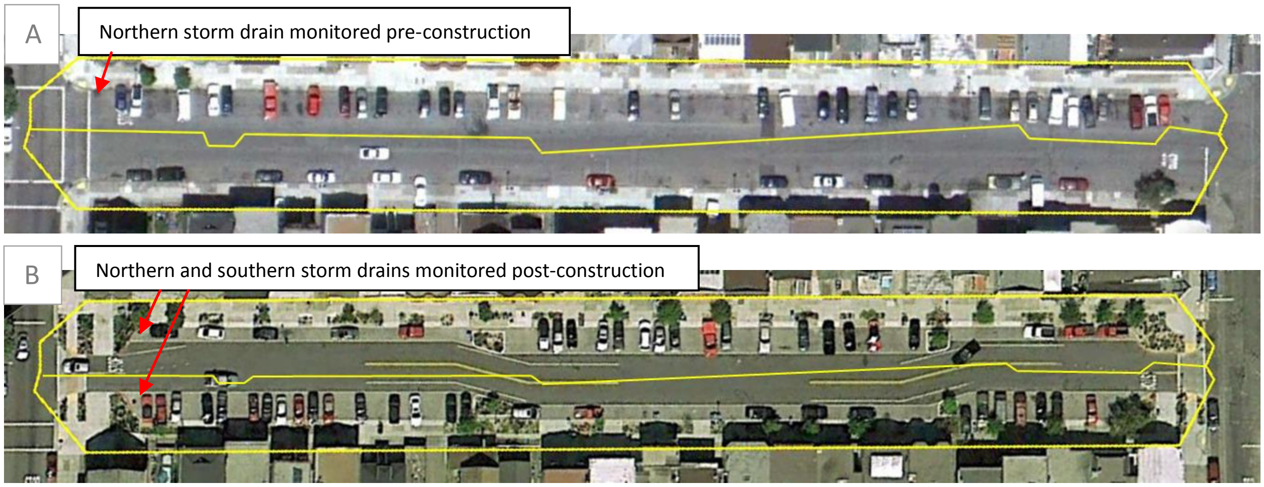


Figure 2. Aerial photos of Newcomb Avenue catchment A) pre-construction and B) post-construction. Subcatchments are outlined in yellow. Monitored storm drains are marked with red arrows.

Site Summary	Project Features	Newcomb North	Newcomb South
The 1700 block of Newcomb Avenue in the Bayview District of San Francisco was redeveloped as a model "Green Street". Stormwater runoff from this residential city block is now retained within or passes through green infrastructure elements prior to entering the combined sewer system. The north and south sides of this city block were monitored before and after implementation to assess green infrastructure effectiveness at reducing stormwater runoff to the combined sewer system.	Year Constructed	2012	
	GI Elements	Permeable Pavers, Bioretention Planters	
	Drainage Management Area (ft^2)	23,750	25,050
	% of Impervious Area Converted to GI[1]	29%	27%
	% of Impervious Area Converted to Traditional Landscaping[2]	14%	14%
	Monitoring Period	2009-10 pre-construction; 2012-13 post-construction	2012-13 post-construction

Hydrologic Improvement Highlights[3]

	Newcomb North	Newcomb South
Flow Volume Reduction[4]:	78%	85%
Peak Flow Rate Reduction[5]:	73%	82%
Delay in Flow[6]:	24 minutes	14 minutes
Largest Storm with no Flow[7]:	0.25 inches	0.07 inches

[1] Only includes GI elements. Does not include pervious elements (e.g., traditional landscaping) installed in the catchment.
[2] Only includes traditional landscaping (not GI) elements that were installed in the catchment (i.e. chicane islands and traditional landscape planters).
[3] Metrics in this report are based on all available data for each subcatchment. During the monitoring period there were 37 storm events at Newcomb North and 24 storm events at Newcomb South.
[4] Flow Volume Reduction Percentage = $(Volume_{pre\text{-}construction} - Volume_{post\text{-}construction}) / Volume_{pre\text{-}construction} \times 100)$
[5] Average peak flow rate reduction measured for all storm events with measureable outflow.
[6] Change in the median lag time between the start of rainfall and the start of detectable outflow from pre- to post-construction.
[7] Largest storm measured during the post-construction monitoring period at each site with complete capture of all rainfall volume.

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

Was Flow Volume Reduced?

In typical urban areas, 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 serves as one straightforward and important performance 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.

In both the North and South catch basins, GI elements substantially reduced flow volumes to the CSS (Figure 3 and Table 1). Prior to GI implementation, the vast majority of rain that fell onto the Newcomb North and Newcomb South catchments flowed into the CSS (91% and 92%, respectively). Post-implementation, the proportion of rain that entered the CSS was four to seven times less (only 20% and 13%, respectively). During an average rainfall year when approximately 21 inches of rain falls on this part of San Francisco, GI elements at Newcomb Avenue could divert 64,000 cubic feet (or 479,000 gallons) of stormwater from discharging into the CSS.

On an individual storm basis, Newcomb North retained 61-100% of the estimated pre-construction flow volume while Newcomb South retained 57-100% of the estimated pre-construction flow volume. During the monitoring period, 12 of 37 storms monitored at Newcomb North produced no measureable stormwater outflow (storm size with no resulting outflows ranged from 0.01 to 0.25 inches), while 5 of 24 monitored storms at Newcomb South produced no measureable outflows (storm size with no resulting outflow ranged from 0.01 to 0.07 inches; common small storms with a return interval of well less than a 0.25 year).[8]

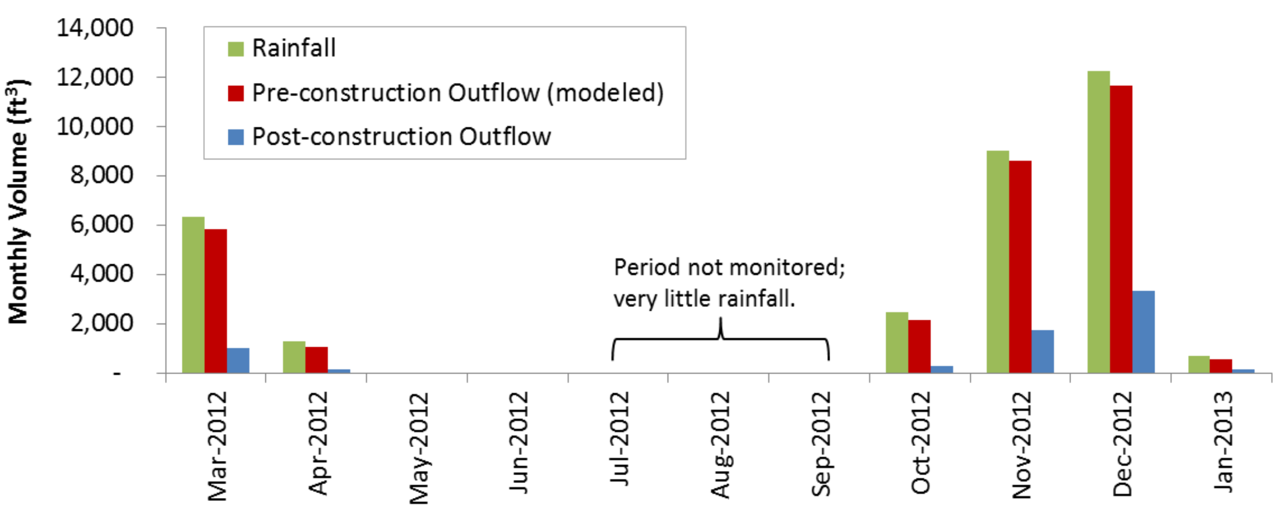


Figure 3. Monthly rainfall and outflow volume measured post-construction at Newcomb North as compared with modeled outflow volumes under pre-construction conditions.

[8] The number of monitored storms varies between the northern and southern sides of the street because equipment malfunction resulted in missing storm data.

Table 1. Total rainfall and outflow volumes pre- and post-construction at the north and south subcatchments of the Newcomb Avenue Green Street during the monitored storms, and flow estimates based on an average year of rainfall.

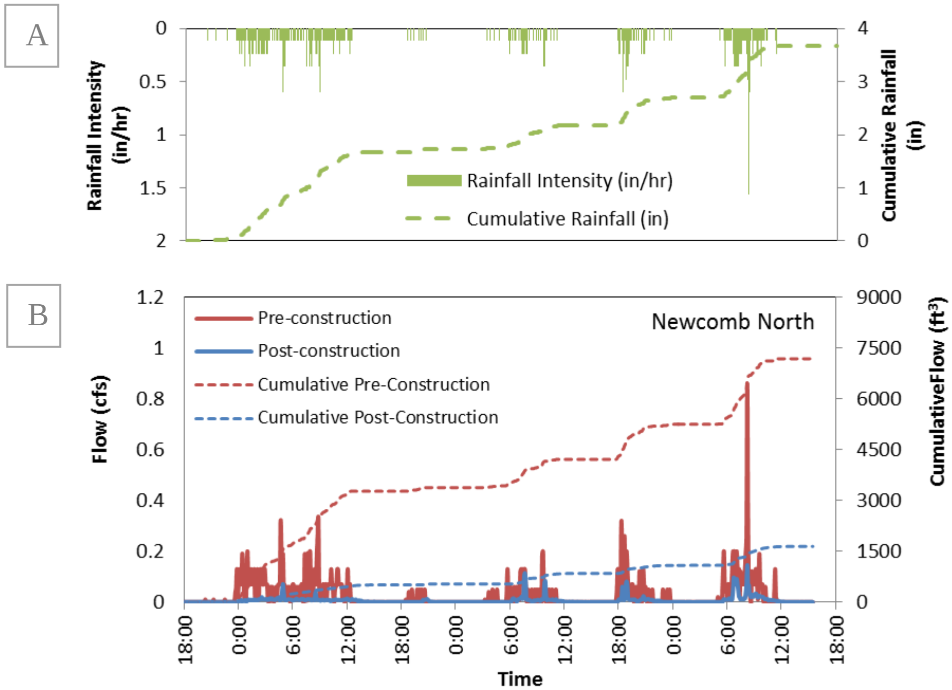
	Monitored Storms[9]			Average Yearly Estimates[10]		
Catchment	Total Rainfall (ft^3)	Outflow (ft^3)	% of Rainfall Measured as Outflow	Total Rainfall (ft^3)	Outflow (ft^3)	Total Volume Diverted from CSS (ft^3)
Newcomb North pre-construction (modeled)	31,900	29,100	91%	41,600	37,900	64,000[11]
Newcomb North post-construction		6,500	20%		8,300	
Newcomb South pre-construction (modeled)	26,300	24,100	92%	43,800	40,300	
Newcomb South post-construction		3,500	13%		5,700	

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, if peak flow rates exceed the sewer network's capacity, street surface ponding can occur. Further downstream, when flows from multiple catchment areas combine, large peak flow rates can exceed CSS capacity and trigger combined sewer discharges. A reduction in peak flow rate is therefore an important indicator of success, consistent with the goal of GI implementation to reduce the frequency of these combined sewer discharges through infiltration and slowing of stormwater runoff.

GI elements at Newcomb North and Newcomb South substantially reduced peak flow rates relative to estimated pre-construction flows. At Newcomb North, post-construction peak flow rates were on average 73% lower than pre-construction rates (range 43% to 98%; see Table 2 for subset). At Newcomb South, the peak flow rates decreased by an average of 82% (range 50% to 99%; see Table 2 for subset). Reductions in peak flow rates are especially important during storms with higher rainfall intensities when the CSS capacity can be exceeded. The GI elements performed comparably well across the range of storms observed (Figure 4 and Table 2). However, the maximum 5-minute rainfall intensity measured during the monitoring period was 1.56 inches/hour, which corresponds to a storm of only moderate intensity (i.e., 0.5 year return interval). Additional monitoring or modeling efforts are needed to assess the effectiveness of the Newcomb GI elements during larger storm events.

[9] The number of monitored storms varies between the northern and southern sides of the street because equipment malfunction resulted in missing storm data.
[10] 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.
[11] 64,000 ft^3 is equivalent to 479,000 gallons.



During the largest rainfall period monitored, peak flow rates were reduced by 84% compared to pre-construction conditions.

Figure 4. A) Rainfall intensity and cumulative rainfall during a series of storm events from November 29 to December 2, 2012 at Newcomb Avenue North. B) Storm hydrograph for Newcomb North with modeled pre-construction and monitored post-construction flow rates and cumulative flow volume during the 72-hour storm period.

Table 2. Reduction in peak flow rates for the subset of storms with 5-minute peak rainfall intensity > 0.5 inches per hour.

NEWCOMB NORTH						
Storm Date	**Peak 5-minute Rainfall (converted to in/hr)**	**Storm Return Interval (year; based on 3 hour duration)[12]**	**Pre-construction Peak Flow Rate (cfs; modeled)**	**Post-construction Peak Flow Rate (cfs)**	**Peak Flow Rate Reduction**	**Average Peak Flow Rate Reduction**
3/27/2012	0.60	< 0.25	0.33	0.09	73%	73%[13]
11/8/2012	0.60	< 0.25	0.09	0.02	77%	
11/17/2012	0.60	< 0.25	0.32	0.17	47%	
11/20/2012	0.60	0.25	0.33	0.17	48%	
11/29/2012	0.60	< 0.25	0.33	0.07	78%	
12/25/2012	0.60	< 0.25	0.33	0.13	61%	
3/31/2012	0.72	< 0.25	0.38	0.09	75%	
10/22/2012	0.84	< 0.25	0.46	0.08	83%	
11/9/2012	1.08	< 0.25	0.58	0.01	98%	
12/21/2012	1.08	< 0.25	0.59	0.15	74%	
12/1/2012	1.56	0.25	0.86	0.15	83%	

[12] 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.
[13] This metric is the average peak flow rate reduction for *all* storms that produced measurable outflow and had reliable data (n=25). For the 11 storms presented in the table, the average peak flow rate reduction was 72%.

Table 2 (cont). Reduction in peak flow rates for the storms that had 5-minute peak rainfall intensity > 0.5 inches per hour.

NEWCOMB SOUTH						
Storm Date	Peak 5-minute Rainfall (converted to in/hr)	Storm Return Interval (year; based on 3 hour duration)	Pre-construction Peak Flow Rate (cfs; modeled)	Post-construction Peak Flow Rate (cfs)	Peak Flow Rate Reduction	Average Peak Flow Rate Reduction
3/27/2012	0.60	< 0.25	0.34	0.10	70%	82%[14]
11/8/2012	0.60	< 0.25	0.09	0.04	50%	
11/17/2012	0.60	< 0.25	0.34	0.06	83%	
11/20/2012	0.60	0.25	0.35	0.08	76%	
11/29/2012	0.60	< 0.25	0.35	0.03	91%	
3/31/2012	0.72	< 0.25	0.4	0.09	77%	
4/12/2012	0.84	< 0.25	0.49	0.08	83%	
11/9/2012	1.08	< 0.25	0.61	0.03	94%	
4/12/2012	1.20	0.75 – 1.0	0.7	0.07	90%	
12/1/2012	1.56	0.25	0.9	0.07	92%	

Were Lag Times Between Rainfall and Flow Increased?

The time delay (or "lag time") between rainfall and outflow is a measure of catchment responsiveness to rainfall – flashy versus lagged response. Large proportions of impervious area in a subcatchment, in addition to reducing retention or infiltration and increasing flow rate, 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. Newcomb Avenue GI elements increased lag times between the start of rainfall and the start of measurable outflow by an estimated 24 and 14 minutes at the north and south catchments, respectively (Table 3 and Figure 5)[15]. Although peak flow rates were considerably reduced in both catchments (Table 2), the lag time between the peak rainfall rate and the peak flow rate did not significantly change between pre- and post-GI implementation (Table 3 and Figure 5).

Table 3. Median lag time (in minutes) between start of rainfall to start of flow ($Start_I$ to $Start_F$) and peak of rainfall to peak of flow ($Peak_I$ to $Peak_F$) at Newcomb Avenue.

	Newcomb North		Newcomb South	
	Median Lag Time (in minutes)			
	$Start_I$ to $Start_F$	$Peak_I$ to $Peak_F$	$Start_I$ to $Start_F$	$Peak_I$ to $Peak_F$
Pre-construction[16]	<1	8	<1	2
Post-construction	25	10	15	5
Increased lag due to GI	24	2	14	3

[14] This metric is the average peak flow rate reduction for *all* storms that produced measurable outflow and had reliable data (n=19). For the 10 storms presented in Table 2, the average peak flow rate reduction was 81%.

[15] The increase in start-to-start lag time may be exaggerated by the inability of equipment to measure very low flows during post-construction conditions.

[16] Pre-construction lag times were measured for Newcomb North during monitoring in 2009-10, whereas pre-construction lag times for Newcomb South were modeled.

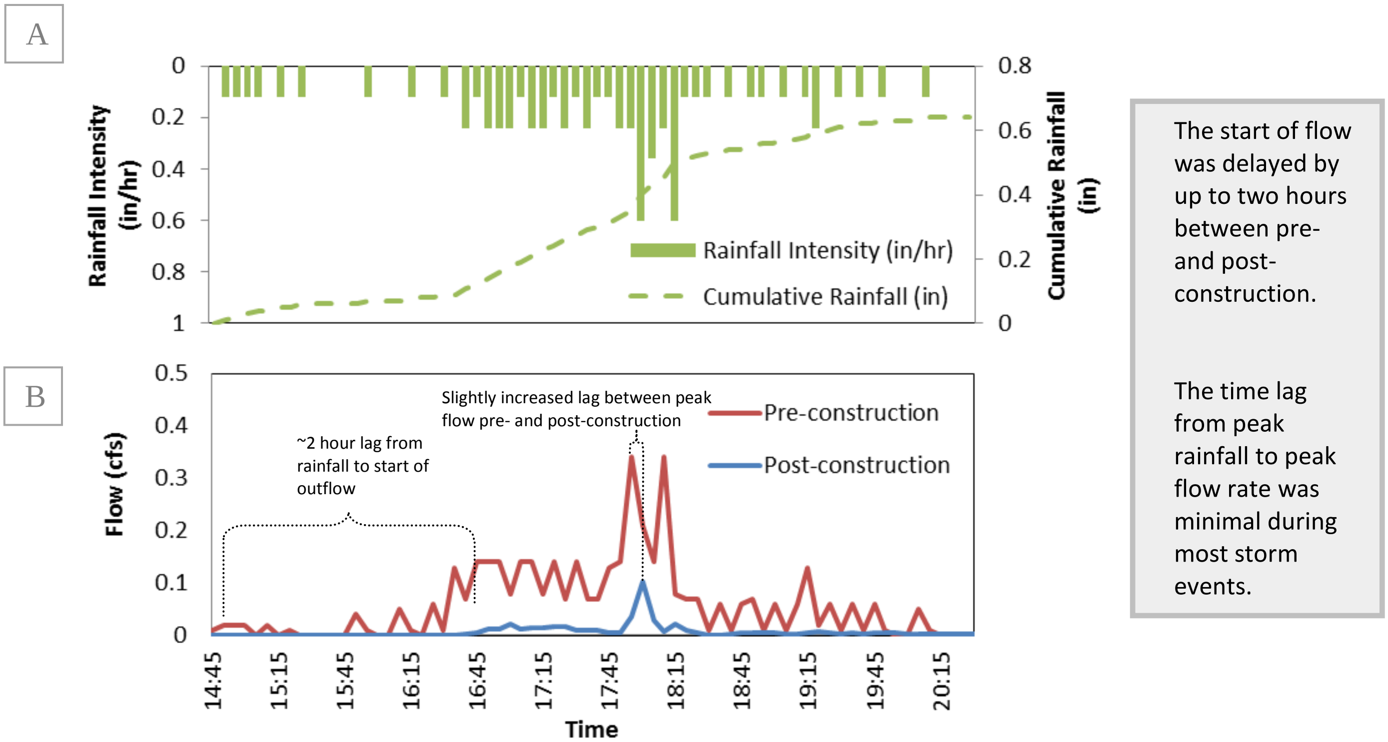


Figure 5. A) Rainfall intensity and cumulative rainfall at Newcomb South during a storm event on March 27-28, 2012. B) Storm hydrograph for Newcomb South with modeled pre-construction and monitored post-construction outflows during this storm event.

Summary

The demonstration project at Newcomb Avenue illustrates that GI has the potential to substantially reduce stormwater flow volume and rates. In summary,

- GI implementation at Newcomb Avenue resulted in a four to seven-fold reduction in total flow volume to the CSS during observed storms.
- Peak stormwater flow rates were reduced by an average of 73% and 82% in the north and south catchments, respectively.
- On an average annual basis, an estimated 64,000 cubic feet (479,000 gallons) of stormwater was diverted from the CSS, via either infiltration or evaporation.

The combination of reduced flow volume and reduced peak flow rates effectively reduces the total instantaneous demand on the CSS. The results of this monitoring effort provide evidence that GI may be an effective mechanism for stormwater management if implemented broadly and strategically throughout the City.