RESEARCH REPORT:

Stormwater Monitoring in the Edith J. Carrier Arboretum: Impacts of Stream Restoration

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1 INTRODUCTION

The Edith J. Carrier Arboretum is a 125-acre urban botanical preserve located within the city of Harrisonburg, VA on the campus of James Madison University. The Arboretum is named for Edith J. Carrier, the wife of JMU President Emeritus, Ronald E. Carrier, for her years of service to the university. The Arboretum is a combination of naturalized botanical gardens and natural eastern upland deciduous forest. The Arboretum also contains an unnamed branch of Siebert Creek, a tributary to Blacks Run. This creek is a part of the larger North River watershed, which flows to the South Fork Shenandoah, Potomac River, and ultimately to the Chesapeake Bay. Upstream development has increased the water flow through the Arboretum over the past several decades, which has led to increased erosion of the stream channel and degraded stream quality.

In an effort to restore the physical and ecological conditions of the tributary, JMU collaborated with Ecosystem Services and the National Fish and Wildlife Foundation to conduct a stream restoration project on the Arboretum tributary. The goal of the project was to restore an approximately 1080 ft section of the tributary and integrate the stream into the existing botanical garden and natural area. Activities included reshaping the stream channel to incorporate a more natural meandering pattern, reconnecting the stream to its floodplain, incorporating wetland areas, and using native plantings to stabilize the stream banks.

Additional goals of the restoration project were to provide water quality benefits and improvements to downstream waterbodies such as Blacks Run and the Chesapeake Bay, both of which are included on the federal list of impaired waterbodies. A more stable stream channel and reduced erosion throughout the Arboretum should translate into reduced sediment, nitrogen, and phosphorus loads to downstream waterbodies. These pollutants are the primary constituents responsible for impairment of Blacks Run and the Chesapeake Bay. Within the Bay, sediment clouds the water and reduces light penetration to underwater grasses, which are important habitat areas for young fish and shellfish. Excess nutrient loads, such as nitrogen and phosphorus, encourage nuisance algal growth in the Bay. When these algae die and decompose, microorganisms consume oxygen, causing low oxygen "dead zones" in the Bay. To improve the health of the Chesapeake Bay, activities that reduce sediment and nutrient loads are encouraged throughout the Bay watershed.

JMU's Department of Integrated Science and Technology embarked on a project to evaluate the success of the stream restoration project through hydrologic and water quality monitoring before, during, and after the Arboretum stream restoration project. Stormwater sampling was conducted at locations entering and exiting the Arboretum, and total suspended solids, total nitrogen, and total phosphorus were analyzed in flow weighted composite samples. In total, JMU sampled 4 storm events prior to restoration construction, 1 storm event during construction, and 4 storm events after completion of the restoration project.

2 MATERIALS AND METHODS

2.1 Hydrologic Monitoring

To measure stream flow during storm events, HOBO Water Level Sensors were installed at the Arboretum Inlet, the Arboretum Outlet, and in a reference location (Figure 1). Sensors were mounted at the bottom of storm sewer pipes with concrete drop-in anchors and security bolts. One reference sensor was installed in a tree to obtain ambient atmospheric pressure for comparison. Sensors were deployed continually during spring, summer, and fall, but were retrieved during the winter to avoid damage of the sensor's internal components due to freezing. During deployment, sensors were programed to record at 15-minute intervals.

Pressure measurements recorded by the HOBO sensors were corrected for atmospheric pressure and translated to water level data using HOBOware software. Water level data were downloaded and stored in Microsoft Excel. Within Microsoft Excel software, water level data were converted to a discharge (or flow) at each location using Manning Equation and pipe parameters (Table 1):

$$Q = A \times \frac{1.486}{n} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

Where,

Q = discharge (cfs)

A = cross sectional area of flow (ft^3)

n = Manning roughness coefficient

R = hydraulic radius (ft)

S = slope of pipe (ft/ft)

Table 1. Description of Water Depth Sensor Locations Within the Arboretum.

Location	Pipe Description	Pipe Diameter (ft)	Pipe Slope (ft/ft)	Mannings Roughness Coefficient
Inlet	Rectangular, concrete	12	0.00147	0.022
Outlet	Circular, concrete	2.5	0.0181	0.012

Figure 1. Installation of Hydrologic Monitoring Equipment in the Arboretum.

2.2 Stormwater Sampling

Nine separate storm events were sampled from 6/8/15 to 7/26/16 (Table 2). Four of these events were prior to restoration construction, one was during construction, and four were after restoration was complete. Samples were collected using automated ISCO samplers programed to collect 24 bottles at time intervals of 30 minutes or 1 hour depending upon the length of the storm. Each sample consisted of 400ml to 1000ml of stormwater. After collection, samples were transported to the JMU ISAT Environment Lab for compositing and analysis. Time interval samples were hand composited to represent flow-weighted baseline, rising limb, peak of the storm, receding limb and event mean concentrations. Flow weighting was conducted by downloading flow sensors and comparing sample times to measured flow values. Based on flow-weighting calculations, proper volumes of each time interval sample were mixed to constitute the composite. Composite samples were then analyzed for turbidity, total suspended solids, total nitrogen, and total phosphorus.

Table 2. Storm Events Sampled in the Arboretum.

Pre-Construction	Construction	Post-Construction
6/8/2015	9/10/2015	5/20/2016
6/18/2015		6/21/2016
7/14/2015		6/23/2016
7/21//2015		7/26/2016

2.3 Water Quality Analysis

2.3.1 Turbidity

Turbidity was measured using a McVan Turbidity probe. The probe uses 90° optics and infrared light to deliver clear low-noise turbidity readings. Measurements were taken by holding the probe with the infrared light and optic end in the water and slowly stirring the probe in the sample. Turbidity was measured in all time interval samples and in each composite sample. All measurements for the storm composites were recorded in the lab notebook and then entered into a Microsoft Excel spreadsheet.

2.3.2 Total Suspended Solids

Total Suspended Solids (TSS) were measured using standard method 2540 D. A 100-200ml aliquot of the sample was filtered through pre-weighed 0.45 um membrane filters and then dried for one hour at 103-105°C. Samples were allowed to cool in a desiccator for at least 24 hours and then weighed to the nearest 0.0001 g. The entire process of drying, cooling and weighing was repeated until final weights did not change by more than 4%.

Due to the tedious and time consuming nature of TSS analysis, measurements from the first two storm events were used to develop a linear regression between TSS and measured turbidity (Figure 2). Following the second storm event sampling, all TSS values were estimated from the TSS to turbidity regression.

2.3.3 Nitrogen

Total nitrogen was measured using HACH Method 10071 (Total Nitrogen Persulfate Digestion Method). This method uses an alkaline persulfate digestion under heat to convert all forms of nitrogen to nitrate. Chromotropic acid is then added to react with nitrate and form a yellow complex with an absorption of 420 nm. Nitrate concentrations were determined using a spectrometer. Nitrate standards were prepared, and a five point calibration curve was used to determine nitrogen concentrations based on the absorbance of samples at 420 nm.

2.3.4 Phosphorus

Total Phosphorus was measured using HACH TNT Method 843 (Phosphorus Reactive Low Range Method). In this method, phosphate ions react with molybdate and antimony ions in an acidic solution to form antimonyl phosphomolybdate complex, which is reduced by ascorbic acid to phosphomolybdenum blue, which has a maximum absorbance at 650 nm. A set of six phosphate standards were prepared and a calibration curve was used to determine phosphorus concentrations based on absorbance at 650 nm.

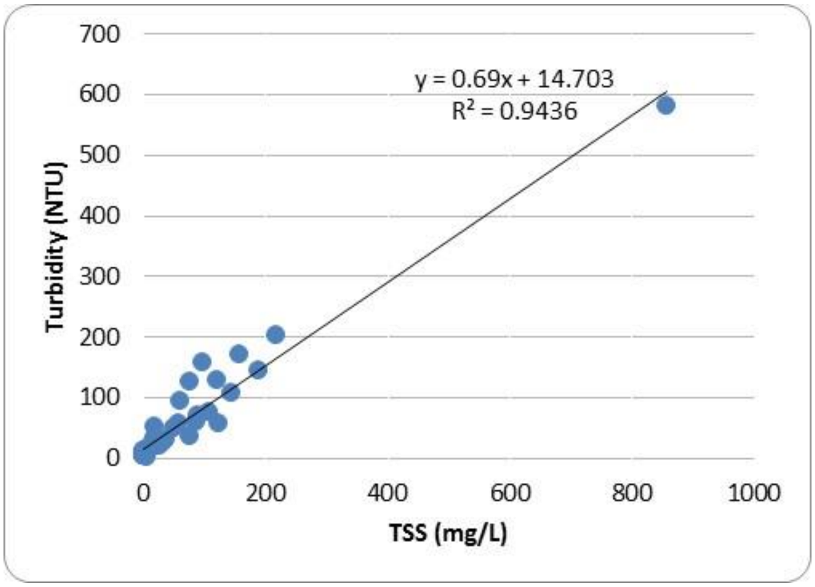

Figure 2. Regression of Turbidity and Total Suspended Solids for Stormwater Samples.

3.1 Storm Events

Figure 3 shows the discharge of the Arboretum tributary at the inlet and outlet during the project. Vertical dotted lines show the storms that were sampled. The sampled storms represent typical events for this tributary during the project period. The largest storm, on 9/29/2015, which reached a peak discharge of over 400 cfs was not sampled. It was noted that for most small to moderate-sized storms, the peak discharge in the Arboretum inlet exceeded the peak discharge in the Arboretum outlet. This is to be expected, as the low-lying Arboretum, was designed as a stormwater detention area. For larger storms, however, peak discharge in the outflow from the Arboretum exceeded discharge in the inlet. This is due to the design of the stormwater inlet and outlet structures and accumulated runoff to the Arboretum from other inlet locations besides the main tributary inlet.

Four storm events were sampled prior to commencement of the restoration project, one event was sampled during construction, and four events were sampled after construction was completed. Storm events ranged from 2.5 to 9 hours in duration (Table 3). The peak discharge ranged from 11 to 42 cfs in the inlet and <0.1 to 48 cfs in the outlet. The volume of water discharged during these events ranged from 0.4 to 1.9 million gallons in the inlet and <0.1 to 1.9 million gallons in the outlet.

Figure 4 displays a typical storm hydrograph for the Arboretum inlet and outlet locations. Most storms that produced significant runoff and flow in the Arboretum exhibited sharp rises in discharge over a relatively short time period after onset of intense rainfall. Discharge typically peaked in 30 minutes to an hour (or longer for larger rainfall events) and then decreased much more slowly over the next 4 to 10 hours. Peak discharge in the outlet was also delayed from peak discharge in the inlet. It typically took 30 minutes to an hour for peak discharge at the inlet to travel to the outlet location.

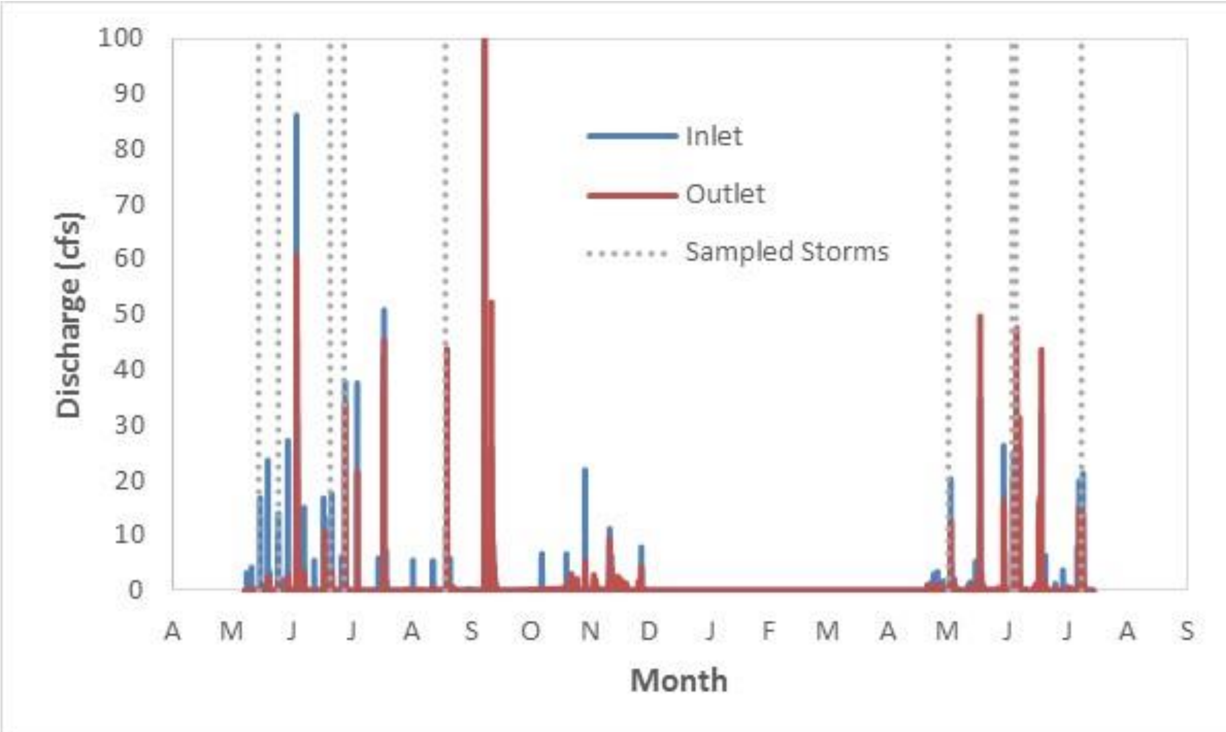

Figure 3. Stream Discharge and Sampled Storm Events During the Project.

Table 3. Characteristics of Sampled Storm Events.

Condition	Event	Duration (hr)	Peak Discharge (cfs)		Storm Volume (million gallons)	
			Inlet	Outlet	Inlet	Outlet
Pre-Construction	6/8/15	4	16	<0.1	0.4	<0.1
	6/18/15	7	14	2	1.0	0.1
	7/14/15	6.5	11	3	0.6	0.2
	7/21/15	7	38	34	1.6	1.0
Construction	9/10/15	4	42	44	1.9	1.9
Post-Construction	5/20/16	9	20	12	1.9	1.1
	6/21/16	2.5	25	20	0.7	0.5
	6/23/16	4.5	33	48	1.7	1.6
	7/26/16	5	21	13	0.9	0.7

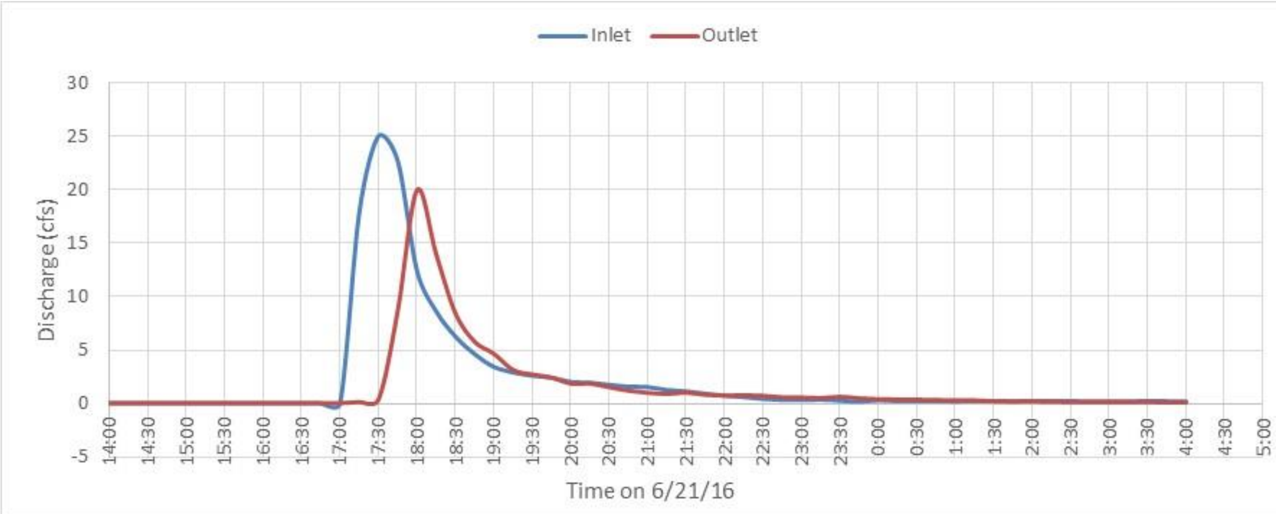

Figure 4. Typical Storm Hydrograph in the Arboretum.

3.2 Total Suspended Solids

Turbidity and TSS concentrations typically followed hydrograph curves, with the highest solids concentrations coming near the peak of discharge (Figure 5). Sometimes the solids peak could be offset from the peak discharge and be present during the rising limb or the receding limb, but typically the solids peak was observed near the peak in discharge. Rain events that varied in intensity could also produce other patterns of solids concentrations. Varying intensity events could produce multiple peaks in solids concentrations depending upon the timing of intense rainfall.

Table 4 summarizes the TSS concentrations in composited storm hydrograph samples. For each storm, flow-weighted baseline, rising limb, peak, receding limb, and event mean concentration (EMC) composites were analyzed. In general, baseline samples were low in solids, with the exception of the 7/26/16 storm, which occurred directly following a previous storm. During storm events, TSS concentrations were highly variable (4 mg/L to 1633 mg/L) depending upon storm conditions and hydrograph timing. The highest TSS concentrations were observed in the storm event collected during construction. This storm produced an event mean concentration of 895 mg/L TSS.

To better evaluate the impact of the stream restoration on water quality, concentrations in the outlet were presented as a percentage difference from inlet concentrations. Using this metric, positive values mean that concentrations increased through the Arboretum, and negative values mean that concentrations decreased through the Arboretum. Table 5 summarizes the average percent differences across storms prior to, during, and following restoration. In pre-construction storms, outlet concentrations were higher than inlet concentrations for all hydrograph sections (1 to 306% difference from inlet concentrations). During construction, concentrations were much higher in the outlet (886 to 2532% difference from inlet concentrations). After restoration construction, outlet concentrations still exceeded inlet concentrations during baseline, rising limb, and peak hydrograph sections, but receding limb and event mean concentrations decreased from inlet to outlet. Event mean concentrations in particular (the best measure of overall storm conditions) decreased 29% through the Arboretum after the restoration was complete. This is compared to an increase of 36% through the Arboretum prior to the restoration.

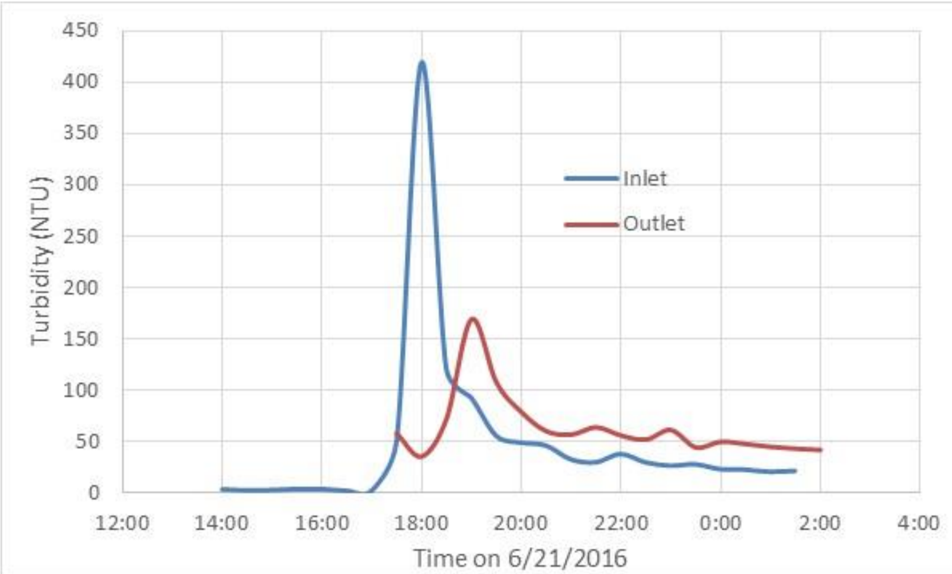

Figure 5. Turbidity Levels During a Typical Storm Event in the Arboretum.

Table 4. Total Suspended Solids in Storm Hydrograph Samples.

Conditions	Storm Event	Hydrograph Section	TSS Concentration (mg/L)		Percent Difference (%)
			Inlet	Outlet	
Pre-Construction	6/18/15	Baseline	26	4	-85%
		Rising Limb	33	143	333%
		Peak	70	120	71%
		Receding Limb	29	32	10%
		EMC	38	61	61%
	7/14/15	Baseline	<5	16	220%
		Rising Limb	108	89	-18%
		Peak	218	-	-
		Receding Limb	57	-	-
		EMC	178	-	-
	7/21/15	Baseline	7	-	-
		Rising Limb	122	856	602%
		Peak	189	157	-17%
		Receding Limb	36	33	-8%
		EMC	77	86	12%
Construction	9/10/15	Baseline	-	59	-
		Rising Limb	-	1633	-
		Peak	93	917	886%
		Receding Limb	27	570	2011%
		EMC	34	895	2532%
Post-	5/20/16	Baseline	27	6	-78%

Construction		Rising Limb	59	67	14%
		Peak	442	139	-69%
		Receding Limb	40	39	-3%
		EMC	124	58	-53%
	6/21/16	Baseline	8	-	-
		Rising Limb	-	344	-
		Peak	338	177	-48%
		Receding Limb	434	228	-47%
		EMC	276	252	-9%
	6/23/16	Baseline	4	19	375%
		Rising Limb	4	22	450%
		Peak	611	666	9%
		Receding Limb	848	442	-48%
		EMC	606	477	-21%
	7/26/16	Baseline	122	137	12%
		Rising Limb	91	144	58%
		Peak	58	241	316%
		Receding Limb	156	222	42%
		EMC	378	254	-33%

Table 5. Comparison of Inlet and Outlet Total Suspended Solids Concentrations.

	Average Percent Difference of Outlet Compared to Inlet (%)				
	Baseline	Rising Limb	Peak	Receding Limb	EMC
Pre-Construction	68%	306%	27%	1%	36%
Construction	-	-	886%	2011%	2532%
Post-Construction	103%	174%	52%	-14%	-29%

Total suspended sediment loads traveling through the Arboretum during each storm event were calculated from event mean concentrations and calculated flow volumes for each storm. Table 6 shows these loads in metric tons. TSS loads in the inlet ranged from 0.15 to 3.9 tons, while outlet loads ranged from <0.01 to 6.5 tons. The largest sediment load occurred during construction in the Arboretum outlet (6.5 tons). This storm produced an increase of 2531% in sediment load from the inlet to the outlet of the Arboretum. This represents an enormous loss of sediment (6.25 tons) from the Arboretum during this one storm event. For all other storms, both pre-construction and post-construction, the Arboretum acted as a sink for sediment. Sediment loads were reduced by 27 to 99% through the Arboretum in pre-construction storms and 27 to 73% during post-construction storms.

Table 6. Total Suspended Sediment Loads in the Arboretum Tributary During Storm Events.

Conditions	Storm Event	TSS Load (Tons)		Percent Difference (%)
		Inlet	Outlet	
Pre-Construction	6/8/2015	0.19	<0.01	-99%
	6/18/2015	0.15	0.03	-83%
	7/14/2015	0.40	-	-
	7/21/2015	0.45	0.33	-27%
Construction	9/10/2015	0.25	6.5	2531%
Post-Construction	5/20/2016	0.87	0.24	-73%
	6/21/2016	0.75	0.43	-42%
	6/23/2016	3.9	2.9	-27%
	7/26/2016	1.3	0.71	-44%

3.3 Nitrogen

Table 7 summarizes the total nitrogen concentrations in composited storm hydrograph samples. For each storm, flow-weighted baseline, rising limb, peak, receding limb, and event mean concentration (EMC) composites were analyzed. In general, nitrogen concentrations were relatively low in baseline samples and increased in rising limb, peak, and receding limb samples. For the 7/26/16 storm, however, baseline concentrations of nitrogen were higher than storm samples. The event captured on this day occurred directly following a previous storm.

During storm events, total nitrogen concentrations were variable depending upon storm conditions and hydrograph timing. Inlet flows ranged from <0.07 mg/L nitrogen to 5.74 mg/L nitrogen, and outlet flows ranged from 0.07 mg/L nitrogen to 5.18 mg/L nitrogen. Across different hydrograph sections, inlet nitrogen concentrations averaged 2.39 mg/L and outlet nitrogen concentrations averaged 1.85 mg/L.

To better evaluate the impact of the stream restoration on water quality, concentrations in the outlet were presented as a percentage difference from inlet concentrations. Using this metric, positive values mean that concentrations increased through the Arboretum, and negative values mean that concentrations decreased through the Arboretum. Table 8 summarizes the average percent differences across storms prior to, during, and following restoration. In pre-construction storms, outlet concentrations were higher than inlet concentrations for all hydrograph sections (1 to 651% difference from inlet concentrations) except for the peak, which decreased 13%. During construction, concentrations were much higher in the outlet (289 to 1199% difference from inlet concentrations). After restoration construction, outlet concentrations exceeded inlet concentrations during peak flow, but baseline, rising limb, receding limb and event mean concentrations decreased from inlet to outlet. Event mean concentrations in particular (the best measure of overall storm conditions) decreased 3% through the Arboretum after the restoration was complete. This is compared to an increase of 60% through the Arboretum prior to the restoration.

Table 7. Total Nitrogen in Storm Hydrograph Samples.

Conditions	Storm Event	Hydrograph Section	Total Nitrogen Concentration (mg/L)		Percent Difference (%)
			Inlet	Outlet	
Pre-Construction	6/18/15	Baseline	0.75	1.14	52%
		Rising Limb	0.65	1.15	78%
		Peak	1.57	1.73	10%
		Receding Limb	0.40	2.28	471%
		EMC	0.68	2.06	204%
	7/14/15	Baseline	1.29	-	-
		Rising Limb	4.00	2.19	-45%
		Peak	5.74	2.90	-49%
		Receding Limb	1.55	-	-
		EMC	4.86	-	-
	7/21/15	Baseline	<0.07	-	-
		Rising Limb	3.99	2.75	-31%
		Peak	1.67	1.67	0%
		Receding Limb	<0.07	0.65	832%
		EMC	0.43	0.07	-83%
Construction	9/10/15	Baseline	-	0.70	-
		Rising Limb	-	2.31	-
		Peak	<0.07	0.91	1199%
		Receding Limb	<0.07	0.35	400%
		EMC	0.63	2.45	289%
Post-Construction	5/20/16	Baseline	2.11	1.79	-15%
		Rising Limb	1.63	2.28	40%
		Peak	3.90	1.79	-54%
		Receding Limb	2.28	1.71	-25%
		EMC	2.68	1.63	-39%
	6/21/16	Baseline	1.28		-
		Rising Limb		3.97	-
		Peak	5.67	1.28	-78%
		Receding Limb	1.77	1.28	-28%
		EMC	1.77	1.84	4%
	6/23/16	Baseline	1.49	1.84	24%
		Rising Limb	1.70	1.56	-8%
		Peak	4.33	3.26	-25%
		Receding Limb	4.96	2.27	-54%
		EMC	4.33	5.18	20%
	7/26/16	Baseline	4.85	2.38	-51%
		Rising Limb	1.62	0.62	-62%
		Peak	0.31	2.31	650%
		Receding Limb	2.54	0.85	-67%
		EMC	1.38	1.46	6%

Table 8. Comparison of Inlet and Outlet Total Nitrogen Concentrations.

	Average Percent Difference of Outlet Compared to Inlet (%)				
	Baseline	Rising Limb	Peak	Receding Limb	EMC
Pre-Construction	52%	1%	-13%	651%	60%
Construction	-	-	1199%	400%	289%
Post-Construction	-14%	-10%	123%	-43%	-3%

Total nitrogen loads traveling through the Arboretum during each storm event were calculated from event mean concentrations and calculated flow volumes for each storm. Table 9 shows these loads in kilograms. Nitrogen loads in the inlet ranged from 2.55 to 28.0 kg, while outlet loads ranged from 0.01 to 31.0 kg. The largest nitrogen load occurred in the Arboretum outlet during the 6/23/2016 post-construction storm (31.0 kg). This storm produced an increase of 11% in nitrogen load from the inlet to the outlet of the Arboretum. The only other storm to produce an increase in nitrogen load through the Arboretum was the construction storm on 9/10/2015. Nitrogen loads increased 290% from inlet to outlet during this storm. For all other storms, both pre-construction and post-construction, the Arboretum acted as a sink for nitrogen. Nitrogen loads were reduced by 68 to 100% through the Arboretum in pre-construction storms and 12 to 65% during post-construction storms.

Table 9. Total Nitrogen Loads in the Arboretum Tributary During Storm Events.

Conditions	Storm Event	Nitrogen Load (kg)		Percent Difference (%)
		Inlet	Outlet	
Pre-Construction	6/8/2015	4.10	0.01	-100%
	6/18/2015	2.68	0.87	-68%
	7/14/2015	10.9	-	-
	7/21/2015	2.55	0.28	-89%
Construction	9/10/2015	4.55	17.8	290%
Post-Construction	5/20/2016	18.8	6.65	-65%
	6/21/2016	4.81	3.18	-34%
	6/23/2016	28.0	31.0	11%
	7/26/2016	4.68	4.11	-12%

3.4 Phosphorus

Table 10 summarizes the total phosphorus concentrations in composited storm hydrograph samples. For each storm, flow-weighted baseline, rising limb, peak, receding limb, and event mean concentration (EMC) composites were analyzed. In general, phosphorus concentrations were relatively low in baseline samples and increased in rising limb, peak, and receding limb samples.

During storm events, total phosphorus concentrations were variable depending upon storm conditions and hydrograph timing. Inlet flows ranged from 0.01 mg/L phosphorus to 0.70 mg/L phosphorus, and outlet flows ranged from 0.01 mg/L phosphorus to 1.43 mg/L phosphorus. Across different hydrograph sections, inlet phosphorus concentrations averaged 0.21 mg/L and outlet phosphorus concentrations averaged 0.24 mg/L.

To better evaluate the impact of the stream restoration on water quality, concentrations in the outlet were presented as a percentage difference from inlet concentrations. Using this metric, positive values mean that concentrations increased through the Arboretum, and negative values mean that concentrations decreased through the Arboretum. Table 11 summarizes the average percent differences across storms prior to, during, and following restoration. In pre-construction storms, outlet concentrations were higher than inlet concentrations for all hydrograph sections (1 to 651% difference from inlet concentrations) except for the peak, which decreased by 43%, and the EMC, which decreased by 6%. After restoration construction, this pattern was unchanged. Outlet concentrations increased for baseline, rising limb and receding limb portions of the hydrograph, but decreased for peak (-13%) and EMC (-35%) portions of the hydrograph. Event mean concentrations decreased 35% through the Arboretum after the restoration was complete, compared to only 6% reductions prior to construction. During construction, concentrations were much higher in the outlet than the inlet, increasing from 37% up to 1199%.

Table 10. Total Phosphorus in Storm Hydrograph Samples.

Conditions	Storm Event	Hydrograph Section	Total Phosphorus Concentration (mg/L)		Percent Difference (%)
			Inlet	Outlet	
Pre-Construction	6/18/15	Baseline	0.05	0.04	-21%
		Rising Limb	0.02	0.13	660%
		Peak	0.27	0.12	-56%
		Receding Limb	0.06	0.06	5%
		EMC	0.09	0.08	-9%
	7/14/15	Baseline	0.01	0.01	29%
		Rising Limb	0.19	0.18	-2%
		Peak	0.51	-	-
		Receding Limb	0.25	-	-
		EMC	0.45	-	-
	7/21/15	Baseline	0.04	-	-
		Rising Limb	0.29	0.13	-55%
		Peak	0.34	0.24	-29%
		Receding Limb	0.12	0.13	832%
		EMC	0.19	0.19	-4%

Construction	9/10/15	Baseline	-	0.25	-
		Rising Limb	-	1.43	-
		Peak	0.15	0.86	1199%
		Receding Limb	0.10	0.64	400%
		EMC	0.09	0.12	37%
Post-Construction	5/20/16	Baseline	0.11	0.01	-88%
		Rising Limb	0.13	0.13	2%
		Peak	0.60	0.18	-69%
		Receding Limb	0.19	0.09	-54%
		EMC	0.25	0.12	-51%
	6/21/16	Baseline	0.03	-	-
		Rising Limb	-	0.43	-
		Peak	0.32	0.14	-56%
		Receding Limb	0.26	0.16	-40%
		EMC	0.28	0.15	-46%
	6/23/16	Baseline	0.01	0.03	257%
		Rising Limb	0.01	0.08	729%
		Peak	0.50	0.48	-3%
		Receding Limb	0.70	0.39	-44%
		EMC	0.55	0.42	-24%
	7/26/16	Baseline	0.19	0.14	-28%
		Rising Limb	0.12	0.16	28%
		Peak	0.10	0.18	78%
		Receding Limb	0.04	0.15	258%
		EMC	0.21	0.17	-18%

Table 11. Comparison of Inlet and Outlet Total Phosphorus Concentrations.

	Average Percent Difference of Outlet Compared to Inlet (%)				
	Baseline	Rising Limb	Peak	Receding Limb	EMC
Pre-Construction	4%	201%	-43%	418%	-6%
Construction	-	-	1199%	400%	37%
Post-Construction	47%	253%	-13%	30%	-35%

Total phosphorus loads traveling through the Arboretum during each storm event were calculated from event mean concentrations and calculated flow volumes for each storm. Table 12 shows these loads in kilograms. Phosphorus loads in the inlet ranged from 0.23 to 3.55 kg, while outlet loads ranged from <0.01 to 2.50 kg. The largest phosphorus loads occurred in the Arboretum inlet and outlet during the 6/23/2016 post-construction storm (3.55 kg in the inlet and 2.50 kg in the outlet). For all storms except the 9/10/2015 construction storm, phosphorus loads entering the Arboretum were greater than loads leaving the Arboretum. In pre-construction storms, total phosphorus loads decreased by 37 to 96% through the Arboretum. In post-construction storms, phosphorus loads decreased by 30 to 71% through the Arboretum. During the construction storm on 9/10/2015, however, total phosphorus loads increased through the Arboretum by 37%.

Table 12. Total Phosphorus Loads in Arboretum Tributary During Storm Events.

Conditions	Storm Event	Phosphorus Load (kg)		Percent Difference (%)
		Inlet	Outlet	
Pre-Construction	6/8/2015	0.23	<0.01	-96%
	6/18/2015	0.34	0.03	-90%
	7/14/2015	1.00	-	-
	7/21/2015	1.13	0.71	-37%
Construction	9/10/2015	0.62	0.86	37%
Post-Construction	5/20/2016	1.74	0.50	-71%
	6/21/2016	0.57	0.26	-54%
	6/23/2016	3.55	2.50	-30%
	7/26/2016	0.69	0.47	-32%

4 CONCLUSIONS

4.1 Total Suspended Solids

Figure 6 shows the average event mean TSS concentrations in storm events captured prior to, during, and after restoration construction. TSS concentrations increased greatly (2532% increase) during the construction. This is likely due to the runoff of disturbed soil in the Arboretum during the construction process. In pre-construction storms, TSS concentrations increased by 36% on average from inlet to outlet. Following the restoration project, overall inlet TSS concentrations were higher (just based on the individual storm characteristics), but TSS concentrations decreased by 29% on average from inlet to outlet. These differences were not statistically significant (at alpha = 0.05) due to the limited number of storms sampled and the inherent variability in TSS concentrations among storms. The observed trend, however, is promising. TSS concentrations appear to decrease in stormwater as it flows through the Arboretum since the restoration project has been completed.

Figure 7 shows the average TSS load in storm events captured prior to, during, and after restoration construction. Like TSS concentrations, the load of TSS during construction was greatly increased (2531% increase) as stormwater flowed through the Arboretum. In pre-construction and post-construction storm events, however, TSS loads were reduced through the Arboretum. Prior to construction, TSS loads were reduced by 70% on average as stormwater flowed through the Arboretum. Following the restoration project, TSS loads were reduced by 46% on average. These results indicate that in general, the Arboretum is a sink for sediment. This applies both before and after the restoration project. The reduction in load after restoration was lower than before, but again these differences are not statistically significant.

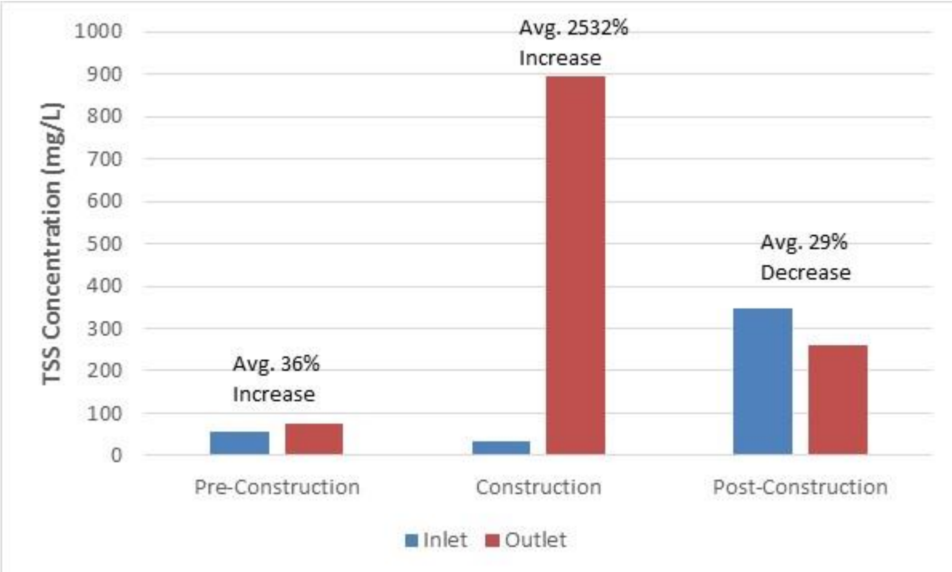

Figure 6. Average Event Mean Total Suspended Solids Concentration in Arboretum Storm Events.

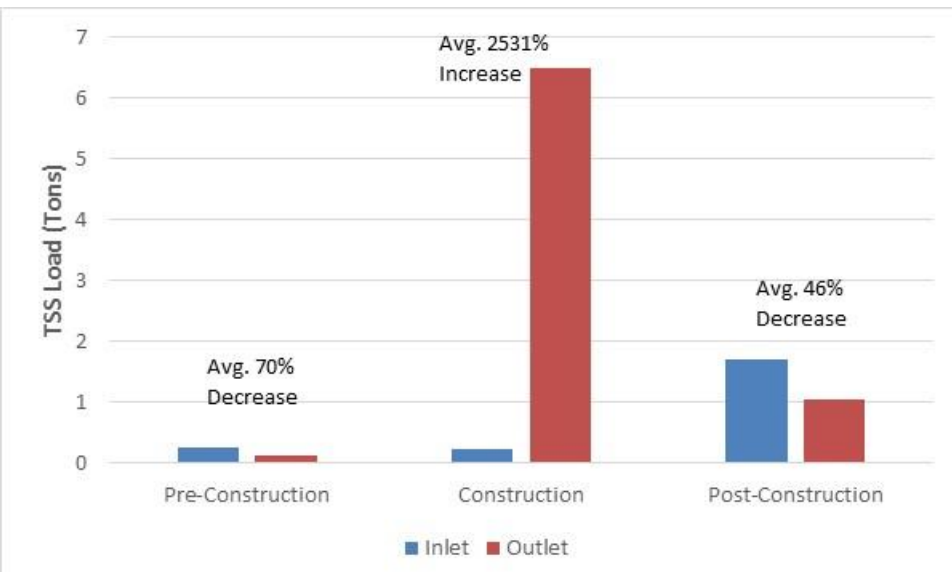

Figure 7. Average Total Suspended Solids Load in Arboretum Storm Events.

4.2 Nitrogen

Figure 8 shows the average event mean total nitrogen concentrations in storm events captured prior to, during, and after restoration construction. Like TSS concentrations, total nitrogen concentrations increased greatly (289% increase) during the construction. This is likely due to the runoff of disturbed soil in the Arboretum during the construction and the transport of nitrogen adsorbed to eroded soil. In pre-construction storms, total nitrogen concentrations increased by 60% on average from inlet to outlet.

Following the restoration project, overall inlet nitrogen concentrations were higher (just based on the individual storm characteristics), but nitrogen concentrations decreased by 3% on average from inlet to outlet. These differences were not statistically significant (at alpha = 0.05) due to the limited number of storms sampled and the inherent variability in storm sampling. The observed trend, however, is promising. Like TSS concentrations, total nitrogen concentrations appear to decrease slightly in stormwater as it flows through the Arboretum since the restoration project has been completed.

Figure 9 shows the average total nitrogen load in storm events captured prior to, during, and after restoration construction. Like TSS loads, the load of total nitrogen during construction was greatly increased (290% increase) as stormwater flowed through the Arboretum. In pre-construction and post-construction storm events, however, total nitrogen loads were reduced through the Arboretum. Prior to construction, total nitrogen loads were reduced by 89% on average as stormwater flowed through the Arboretum. Following the restoration project, total nitrogen loads were reduced by 25% on average. These results indicate that in general, the Arboretum is a sink for nitrogen as well as sediment. This applies both before and after the restoration project. The reduction in load after restoration was lower than before, but again these differences are not statistically significant.

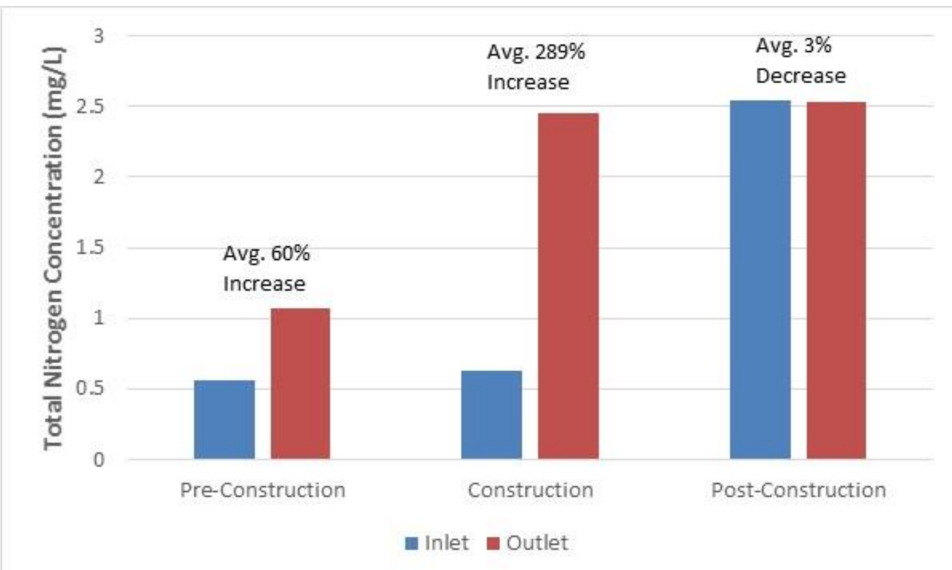

Figure 8. Average Event Mean Total Nitrogen Concentration in Arboretum Storm Events.

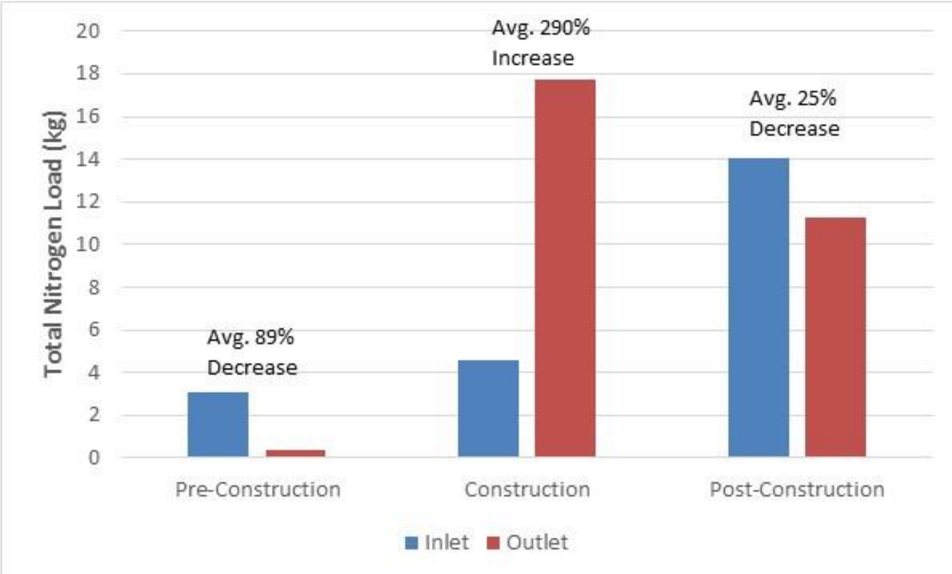

Figure 9. Average Total Nitrogen Load in Arboretum Storm Events.

4.3 Phosphorus

Figure 10 shows the average event mean total phosphorus concentrations in storm events captured prior to, during, and after restoration construction. Total phosphorus concentrations increased during construction (37% increase), but not to the extent that TSS and nitrogen concentrations increased. In pre-construction storms, total phosphorus concentrations decreased by 6% on average from inlet to outlet. Following the restoration project, overall inlet phosphorus concentrations were higher (just based on the individual storm characteristics), but phosphorus concentrations decreased by 35% on average from inlet to outlet. This difference in phosphorus concentration reductions through the Arboretum before and after restoration was statistically significant (at alpha = 0.05). Since the restoration, reductions in phosphorus concentration from inlet to outlet have been greater than prior to the restoration.

Figure 11 shows the average total phosphorus load in storm events captured prior to, during, and after restoration construction. Like phosphorus concentrations, the load of total phosphorus during construction was increased (37% increase), but not to the extent that TSS and nitrogen loads were increased. In pre-construction and post-construction storm events, total phosphorus loads were reduced through the Arboretum. Prior to construction, total phosphorus loads were reduced by 81% on average as stormwater flowed through the Arboretum. Following the restoration project, total phosphorus loads were reduced by 47% on average. These results indicate that in general, the Arboretum is a sink for phosphorus as well as sediment and nitrogen. This applies both before and after the restoration project. The reduction in load after restoration was lower than before, but again these differences are not statistically significant.

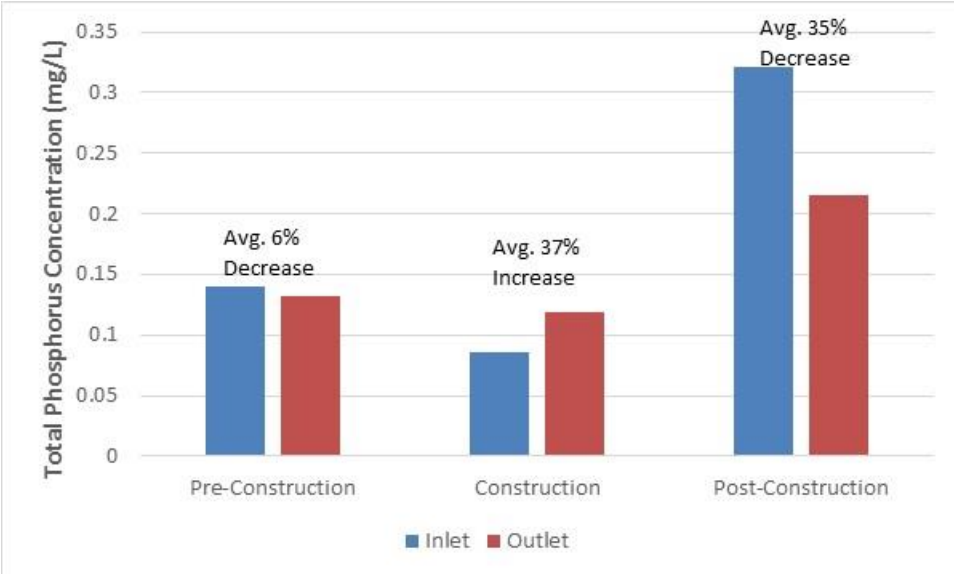

Figure 10. Average Event Mean Total Phosphorus Concentration in Arboretum Storm Events.

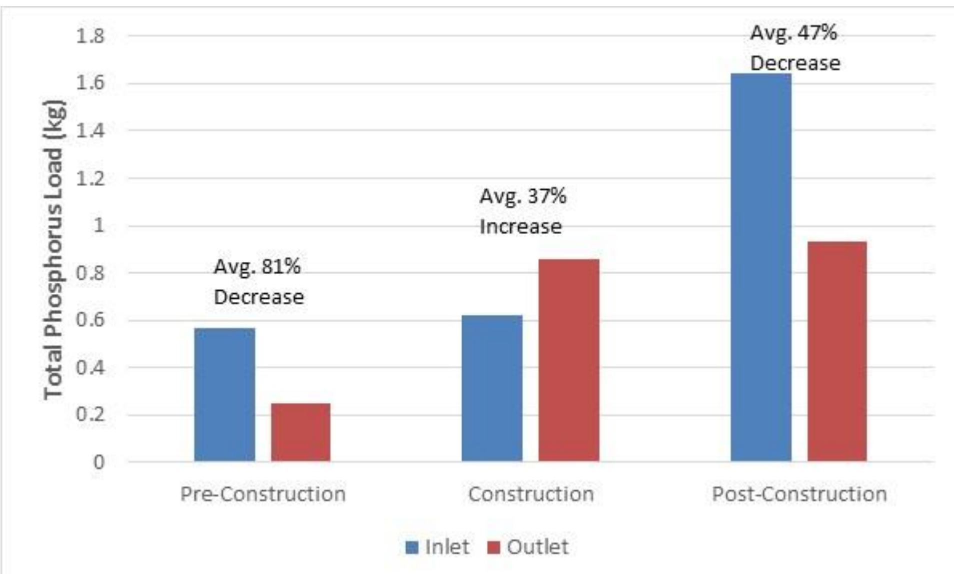

Figure 11. Average Total Phosphorus Load in Arboretum Storm Events.

4.4 Summary

During construction of the restoration project, concentrations and loads of TSS, nitrogen, and phosphorus were increased as stormwater flowed through the Arboretum. This is not unexpected due to the exposure of bare soil during construction activities and the opportunity for exposed soil to erode and runoff during storm events. After the restoration project was completed, however, data indicate that reductions in TSS, nitrogen, and phosphorus concentrations as stormwater flows through the Arboretum were enhanced. The reduction in TSS, nitrogen, and phosphorus concentrations from inlet to outlet were greater after the restoration than before the restoration. This difference was statistically significant for phosphorus, but not for TSS and nitrogen. Overall, the Arboretum remains a sink for sediment and nutrients. These data indicate that the restoration project appears to have enhanced the capacity for sediment and nutrient retention as concentrations are reduced in flows leaving the Arboretum.