700 Wood Street Bioretention Cell Performance Monitoring Report
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Background

Urban stormwater runoff can have many detrimental impacts to lakes, rivers and streams such as flooding, stream erosion and pollution. Over the past 30+ years, the City of Fort Collins Stormwater Utility (Utility) has implemented policies and design criteria to alleviate the effects of stormwater runoff on receiving waters. One such policy is to require water quality best management practices (BMPs) on all new developments. There are many different types of BMPs available which all provide different levels of performance in terms of pollutant removal and runoff reduction.

The Utility generally uses a "progressive" approach to stormwater management, where policies and design criteria are updated as needed to assure they remain consistent with current and future trends in stormwater management. As an example, the Utility recently implemented a new policy that requires the use of "low impact development" technologies (LIDs) on new and re-development projects. The bioretention cell is one type of LID BMP that is expected to be used extensively to meet this new policy. Although bioretention cells have been used for over 20+ years in other parts of the United States, there has been little research conducted to quantify the performance of bioretention cells in Colorado.

There are multiple potential benefits associated with monitoring the performance of BMPs. First, BMP performance can be compared among different types of BMPs; with potential policies being implemented to require or incentivize the use of BMPs that achieve stormwater management objectives better. Second, BMP performance monitoring can reveal opportunities for revising BMP design criteria to improve BMP performance and/or decrease costs. Considering these potential benefits, the Utility constructed a bioretention cell at its headquarters at 700 Wood Street in 2012 to serve as a demonstration and research facility. Herewithin, we will refer to this bioretention cell as BRC.

The Utility contracted with the Urban Water Center at Colorado State University (CSU) to plan and implement monitoring of the BRC for 2013, 2014, and 2015. This report documents CSU's activities, findings and recommendations based on BRC monitoring results from 2013, 2014, and 2015.

Objectives

The overall objective of this study was to determine the performance of the BRC at removing pollutants from stormwater runoff and reducing the overall volume of stormwater runoff discharged to receiving waters. With respect to stormwater pollutant reduction, the objectives were to estimate the average annual pollutant load reduction for total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP). TN and TP are nutrients that can cause eutrophication of receiving waters and are subject to potential regulation under the recent Regulation 85 promulgated by the Colorado Department of Public Health and Environment (CDPHE). TSS is not a "pollutant" per se, but has long been used as a surrogate measure of

BMP performance because of other pollutant's (e.g. heavy metals) tendency to attach to particulates in urban stormwater. It is often assumed that the removal of TSS has a direct correlation with the removal of other pollutants.

With respect to reducing stormwater runoff volume, the objectives of this study were to estimate the average annual runoff volume reduction provided by the BRC and estimate the contribution of infiltration and evapotranspiration (ET) processes that provide runoff volume reduction. Many of the problems associated with urban stormwater can be alleviated by reducing stormwater runoff volume through infiltration into the groundwater and/or ET, and better understanding the contribution infiltration and ET can help to predict BMP performance at locations with different geologic and climatological conditions.

Site Description

The BRC is located at 700 Wood Street, Fort Collins, Colorado and receives runoff from a 99,000 ft^2 parking lot. The BRC has a surface area of approximately 1,900 ft^2 and a water quality capture volume (WQCV) of approximately 1,400 ft^3, which is about 33% smaller than the WQCV required by the Utility's current design criteria.

The basin is divided into two cells, defined as East and West in this report. During a runoff event, the East and West cells receive approximately 85% and 15% of the total parking lot runoff, respectively. Runoff from each cell first enters a forebay comprised of pea gravel where trash and large particulates are removed. After flowing through the forebay, runoff enters the "ponding area" where runoff infiltrates through the filter media and into the gravel storage reservoir below. Runoff that accumulates in the gravel storage reservoir can either infiltrate in the groundwater or discharge through the underdrain which is connected to the stormwater drainage system.

As shown in Figure 1, the BRC includes approximately 18 inches (in.) of filter media, 6 in. of pea gravel and 16 in. of CDOT #4 aggregate. The pea gravel and CDOT #4 aggregate comprise the gravel storage reservoir previously mentioned. From the gravel storage reservoir, water either infiltrates into the native soil below or is discharged through an underdrain system. The underdrain is 6 inch perforated PVC pipe and acts to discharge water from the gravel storage reservoir once water reaches a certain depth within the gravel storage reservoir. (Note: The underdrain depth was different in 2013 and 2014; this is discussed in more detail below). One underdrain serves both the east and west cells and water passing through the underdrain is discharged into the storm sewer nearby.

Underdrain Design and 2014 Modification

The BRC was originally designed with the underdrain being approximately 6 inches above the bottom of the gravel storage reservoir. This meant that water discharged through the underdrain and into the storm sewer once the depth of water exceeded 6 inches in the gravel storage reservoir. All 2013 and 3 2015 monitoring results presented in this report were collected with this underdrain design.

In the spring of 2014 a vertical riser was installed on the underdrain system by CSU. The riser (Figure 2) essentially raised the depth of the underdrain to approximately 12 inches above the bottom of the gravel storage reservoir. The intention of raising the underdrain was to allow more water to infiltrate into groundwater table below; instead of being discharged through the underdrain and into the storm sewer. All 2014 and 4 2015 monitoring results presented in this report were collected with this modified underdrain design.

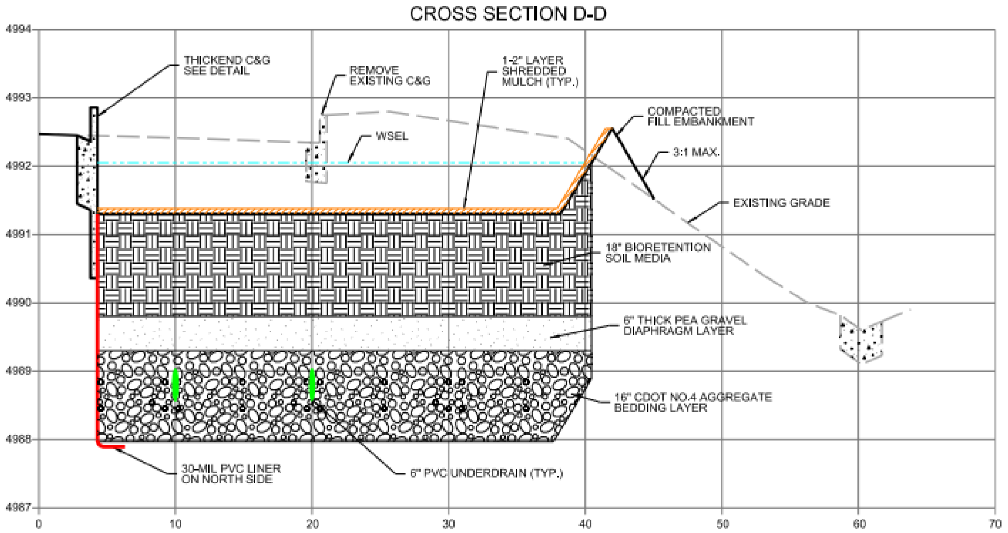

Figure 1: Cross section of the bioretention cell

Figure 2: The underdrain riser installed in 2014 to encourage infiltration.

Methods

A variety of monitoring instruments and methods were used to estimate the performance of the BRC. Flow monitoring instruments were used to estimate the rates and volumes of runoff entering the BRC and existing the BRC via underdrain discharge for each storm event. Soil moisture instruments were used to estimate the volume of runoff that evapotranspirated from the filter media for each rain event and a mass balance equation was used to estimate infiltration. ISCO auto-samplers were used to collect water quality samples from both the inlet and underdrain during runoff events to estimate the concentration of pollutants entering and leaving the BRC. Monitoring instruments were in place from approximately May-September in 2013, 2014, and 2015. Additional details on the monitoring instruments and methods are provided below.

Inflow Runoff

Runoff entered the BRC through one of two inlets. Both inlets consisted of 6 inch v-notch weirs with a pressure transducer to determine depth of flow. The East cell used a nitrogen bubbling transducer to determine flow depth every minute. The West cell utilized a HOBO pressure transducer to record absolute pressure in millibars every 10 minutes. Absolute pressure was converted into flow depth by subtracting out atmospheric pressure and converting millibars to inches of water (Equation 1). The atmospheric pressure was taken at the Fort Collins Weather Station at Colorado State University, 1.5 miles south of the site.

$$D = (P_{abs} - P_{atm}) * 0.402 \qquad \text{Equation 1}$$

Where:

D = flow depth (inches)

P_{abs} = absolute pressure (millibars)

P_{atm} = atmospheric pressure (millibars)

Flow depth can now be converted into a flow rate for each weir by utilizing Equation 2.

$$Q = 1.71 * \left(\frac{D}{12}\right)^{2.31} * 60 \qquad \text{Equation 2}$$

Where:

Q = flow rate (cubic feet per minute)

D = flow depth (inches)

Finally flow rates were converted into runoff volumes by averaging time steps between flow measurements (Equation 3).

$$V = \sum_{i=0}^{n} \left(\frac{Q_i + Q_{i-1}}{2}\right) \Delta t \qquad \text{Equation 3}$$

Where:

V = volume of runoff (cubic feet)

Q = flow rate (cubic feet per minute)

t = length of time step between measurements (minutes)

n = total number of measurements

Effluent

Effluent was classified as any water exiting the basin through the underdrain. A nitrogen bubbling transducer, identical to the one used on the east weir, was used to measure water depth present in the underdrain. A depth-flow relationship, shown in Figure 3, was created using Manning's equation to determine flow rate. A fifth power polynomial was then fitted to the graph to relate flow depth and flow rate.

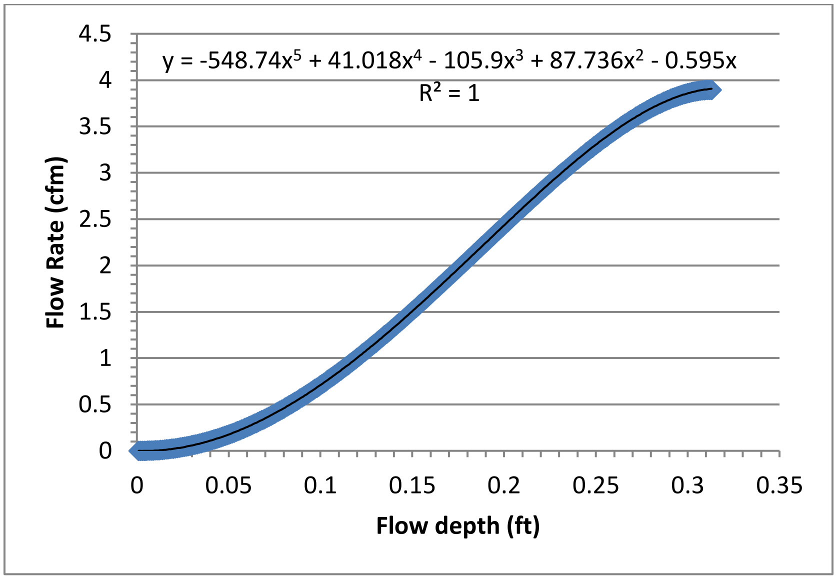

Figure 3: Relating flow depth to flow rate through the Manning's equation.

When under pipe-full conditions, the underdrain flow rate was estimated with a pressurized pipe flow equation. This was done by Equation 4 to better estimate effluent flow rates.

$$Q = A\sqrt{2gh} \qquad \text{Equation 4}$$

Where:

Q = flow rate (cubic feet per minute)

h = water height over top of pipe (ft)

A = cross sectional area of pipe (ft^2)

Flow rates were used to estimate total effluent flow volume using Equation 3.

Soil Storage and ET

In order to quantify soil storage (i.e. water retained within the filter media) and ET, volumetric water content was taken before and after each storm event. Differences in water content before and after a storm gave soil retention rates while readings between storms determined total ET. Six readings from a 4 inch Field Scout probe were averaged over each cell when determining volumetric water content. Averages were applied to the 18 inches of engineered filter media found on each cell when finding water content. It was assumed that the gravel storage reservoir below had negligible water retention capabilities after draining. Equation 5 was used to estimate ET for each storm event.

$$\Delta S = \Delta VWC * A * d \qquad \text{Equation 5}$$

Where:

ΔS = soil storage or evapotranspiration (ft^3)

ΔVWC = change in volumetric water content

A = surface area of bioretention cell (ft^2)

d = depth of engineered media (ft)

Infiltration

Infiltration volumes for each rain event were found through the use of a mass balance (Equation 6). Runoff not stored within the soil or exiting the cell by underdrain was expected to have infiltrated into the groundwater below the BRC.

$$I = R - \Delta S - O \qquad \text{Equation 6}$$

Where:

I = infiltration (ft^3)

R = total runoff (influent) from parking lot (ft^3)

ΔS = soil storage (ft^3)

O = discharge from underdrain (ft^3)

Water sampling

Water quality samples were taken at the East cell weir and the underdrain. It was assumed that the West cell's influent quality was equivalent to that of the East cell. An ISCO sampler was programed to take a sample 500 mL sample every 95 ft^3 at the East weir and the underdrain. After the storm samples were combined and a composite was taken to Stewart Environmental for analysis. Stewart Environmental tested for TSS, nitrogen and phosphorus.

Results and Discussion

Water quality samples and water quantity data were collected and analyzed for seven rain events during the 2013 monitoring season. During 2014, water quantity data were collected and analyzed for 17 events and water quality data were collected and analyzed for six rain events. In 2015, water quantity data was analyzed for 19 events and water quality was analyzed for 7 events. The first 12 storms monitored in 2015 were analyzed with the underdrain modification and the last 7 storms of 2015 were analyzed without the modification. Due to issues with equipment malfunctions and timing of storm events, not every storm event that occurred from May-September was analyzed.

Water Quantity Results

Figure 4 shows the volumes of water that entered the BRC (inflow) and exited the BRC via underdrain discharge, ET and infiltration for each monitored storm event without the underdrain modification. Note that the blue bar indicates the total volume of runoff that entered the BRC and the red bar indicates the total volume of effluent that discharged through the underdrain and into the storm sewer. This graphic shows that for all monitored events, most of the total volume of runoff was discharged back into the storm sewer after passing through the BRC. Here, we remind the reader that these results were obtained when the underdrain was only 6 inches above the bottom of the gravel storage reservoir.

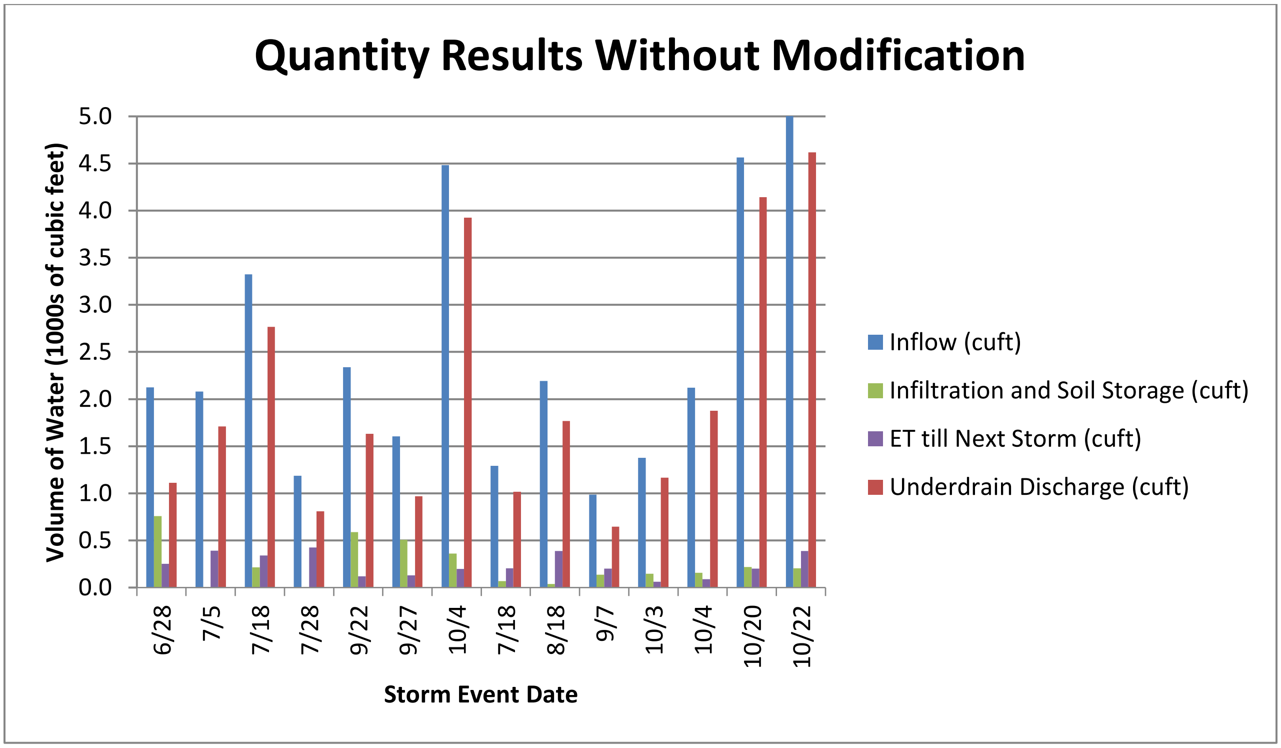

Figure 4: Storm dates and water budgets used for analysis without underdrain modificaiton.

Figure 5 shows the volumes of water that entered the BRC (inflow) and exited the BRC via underdrain discharge, ET and infiltration for each monitored storm event with the underdrain modification. Note that, again, the blue bar indicates the total volume of runoff that entered the BRC and the red bar indicates the total volume of effluent that discharged through the underdrain and into the storm sewer. The green bar indicates the volume of water that infiltrated back into the groundwater. Figure 5 shows that for all monitored events, most of the total volume of runoff was infiltrated back into the groundwater and very little water was discharged through the underdrain and into the storm sewer system. These results were obtained by increasing the depth of the underdrain to approximately 12 inches above the gravel storage reservoir bottom.

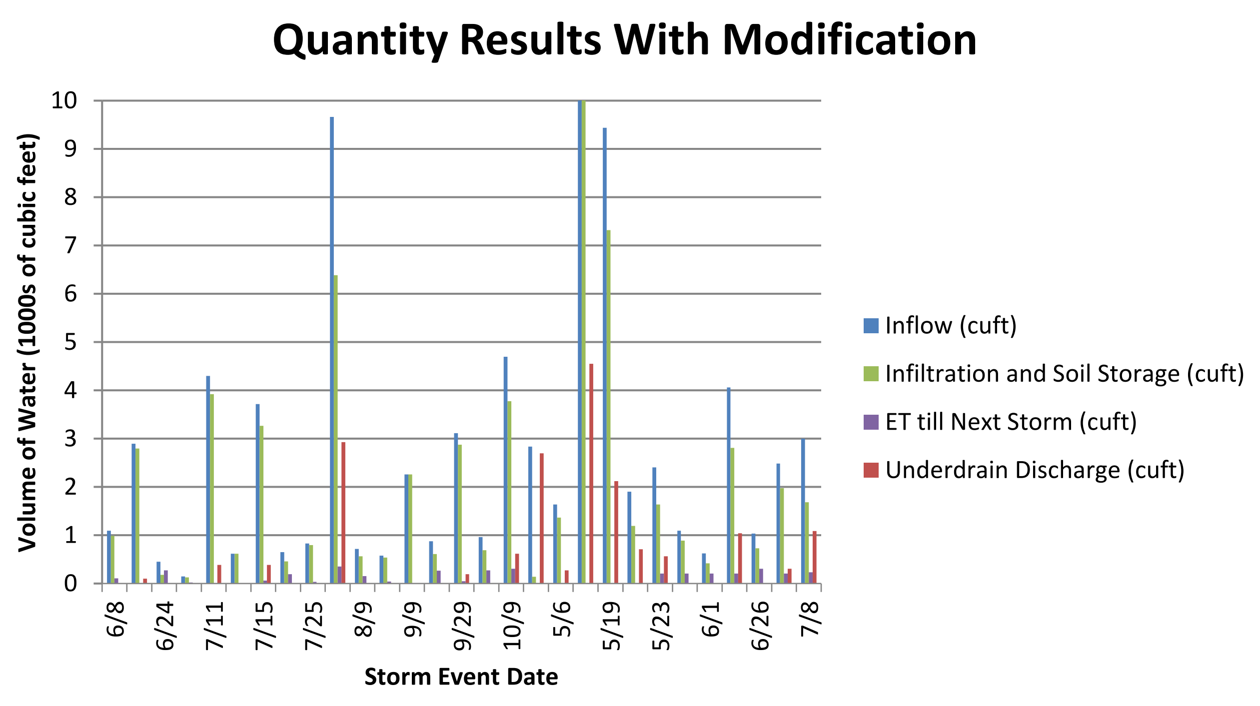

Figure 5: Storm dates and water budgets used for analysis with underdrain modificaiton.

Figure 6 shows the total volumes of water measured over the entire monitoring seasons in 2013, 2014, and 2015. 2014 and 2015 were unusually wet summers resulting in over twice as much runoff compared to 2013. However, the total volume of water discharged through the underdrain and into the storm sewer in 2014 and the first 4 storms of 2015 were less than half of that measured in 2013 and the last 3 storms of 2015 due to the underdrain modification. The amount of runoff that was infiltrated back into the groundwater during 2014 and the first 4 storms of 2015 were greater than the total amount of runoff that occurred in 2013 and the last 3 storms of 2015 also due to the underdrain modification. There was very little difference in the total volume of water evapotranspirated. This is because the filter media has a limited capacity to capture and store water during runoff events.

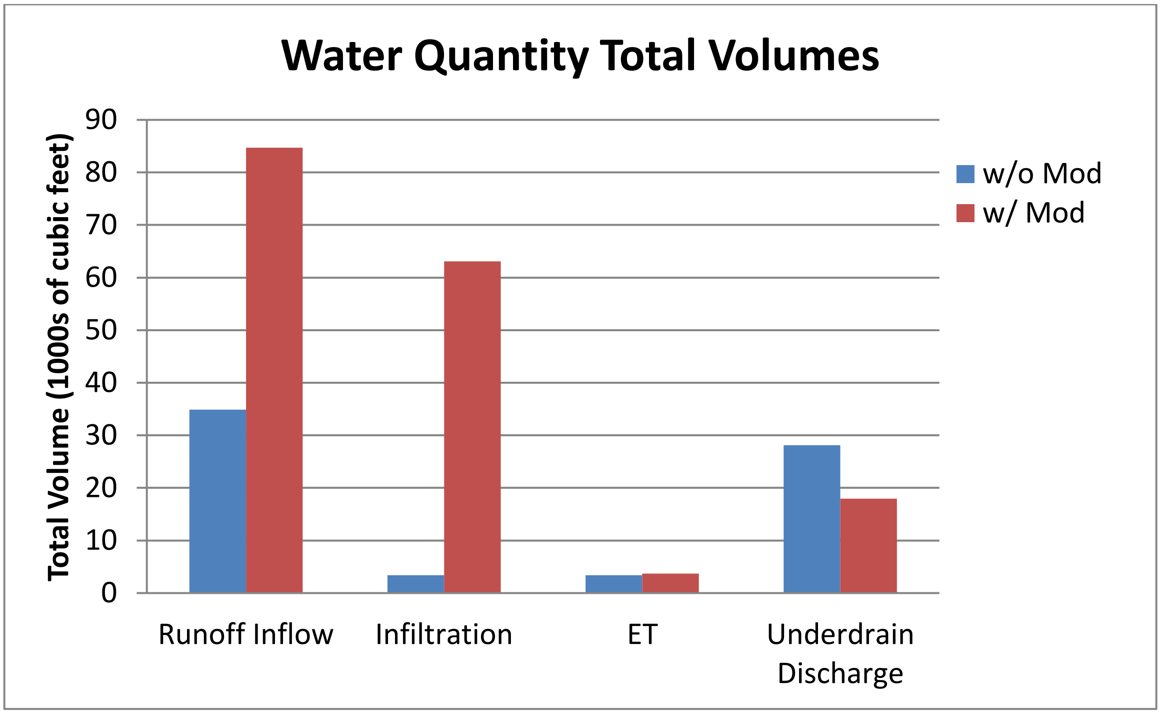

Figure 6: Total water volumes for water entering and leaving the system.

Figures 7 and 8 show the percent of total runoff volume (inflow) that exited the BRC via underdrain discharge, ET and infiltration for all monitored events with and without the underdrain modification. With the underdrain modification, 75% of all runoff that entered the BRC was discharged back into the storm sewer via the underdrain; while with the modification, that percentage was significantly reduced down to 12%.

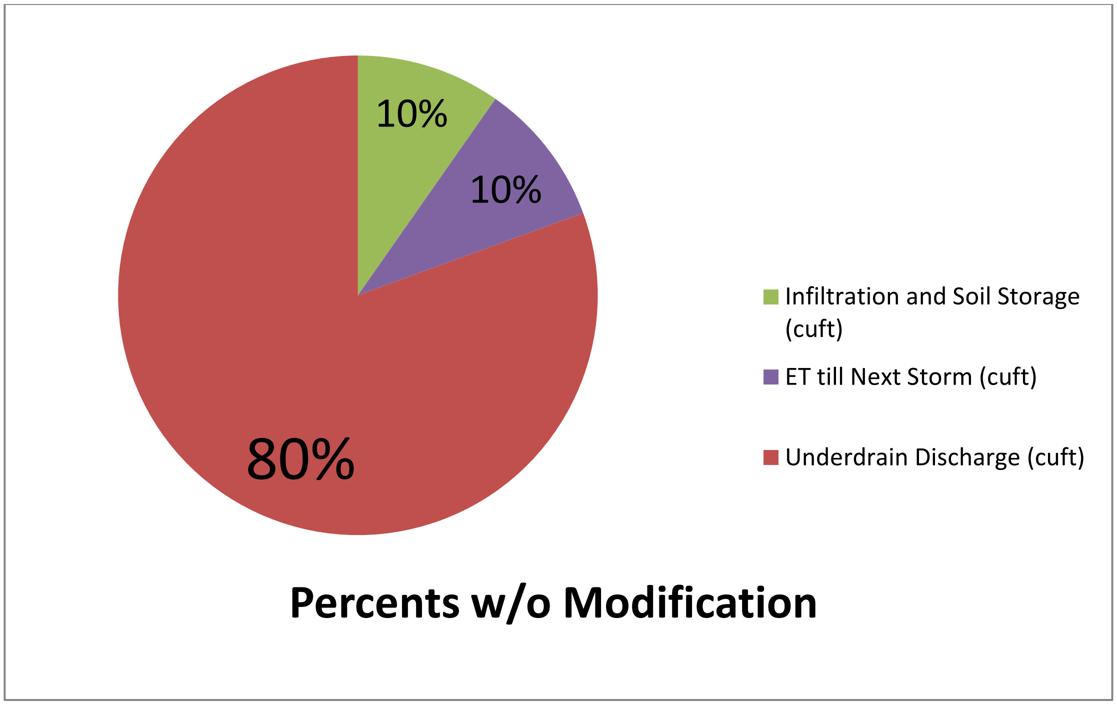

Figure 7: Percent of all runoff volume that exited the BRC via infiltration, ET and underdrain discharge without the underdrain modification.

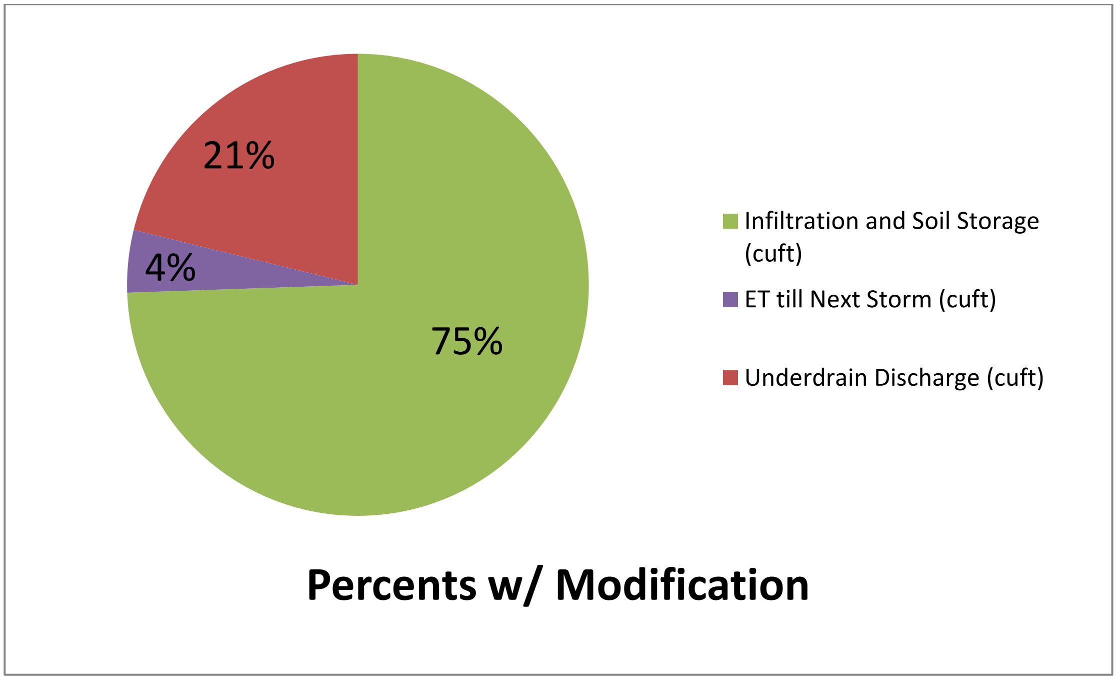

Figure 8: Percent of all runoff volume that exited the BRC via infiltration, ET and underdrain discharge with the underdrain modification

Water Quality Results

Water quality samples were collected and analyzed for seven rain events in 2013, six rain events in 2014, and 7 events in 2015. The first 4 events in 2015 were analyzed with the underdrain modification and the last 3 were analyzed without the modification. Individual sample results are presented in Appendix B of this report.

Figures 9, 10 and 1a show the average influent and effluent concentrations of TSS, total nitrogen and total and dissolved phosphorus from 2013 and 2014. Comparing influent and effluent concentrations allows one to understand the pollutant removal processes that occur within the BRC. Generally, pollutant removal is achieved by filtering as the runoff moves through the BRC filter media.

Figure 9 shows that the TSS concentrations in runoff entering the BRC is generally between 80-120 mg/L and the average TSS concentrations being discharged through the underdrain and back to the storm sewer is about 10-20 mg/L. This demonstrates that the BRC provides excellent TSS removal, which is important because it indicates excellent removal of many other pollutants such as heavy metals that tend to bind to sediment particles. The average effluent TSS concentration was lower with the modification, however so was in the average influent TSS concentration; so it is not possible to determine if the underdrain modification resulted in any improved performance in terms of TSS removal.

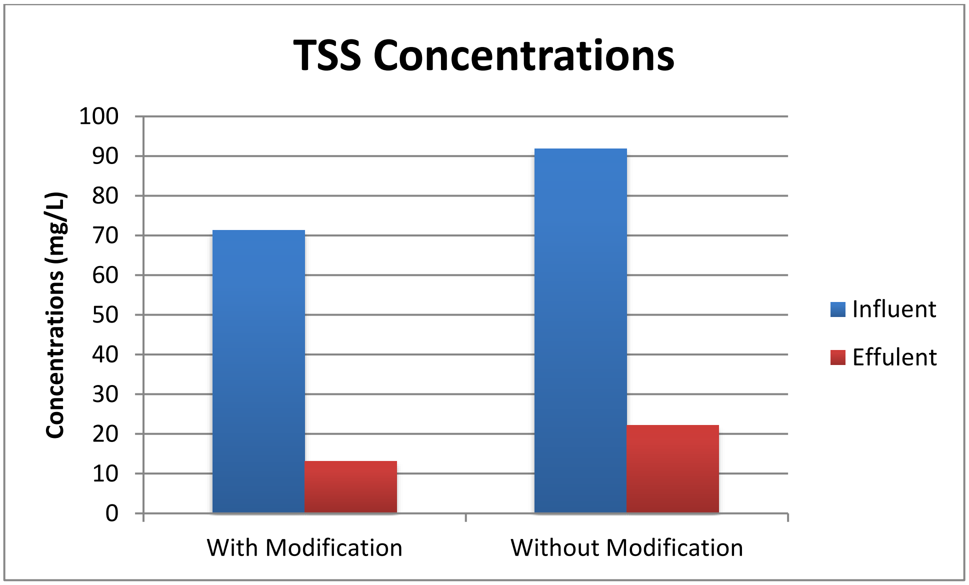

Figure 9: Average total suspended solids concentrations measured at the inlet (influent) and in the underdrain (effluent)

Figure 10 shows that the total nitrogen concentrations in runoff entering the BRC is generally about 4 mg/L and the average total nitrogen concentrations being discharged through the underdrain and back to the storm sewer is about 3 mg/L. This is about a 25% removal rate based on concentrations. Removing nitrogen from stormwater is difficult because most of the nitrogen is in the dissolved form and denitrification requires very complex treatment processes that are difficult to achieve with passive stormwater BMPs. Comparing the average effluent concentrations from 2013 and 2014, it does appear that the underdrain modification made any significant different in nitrogen removal within the BRC.

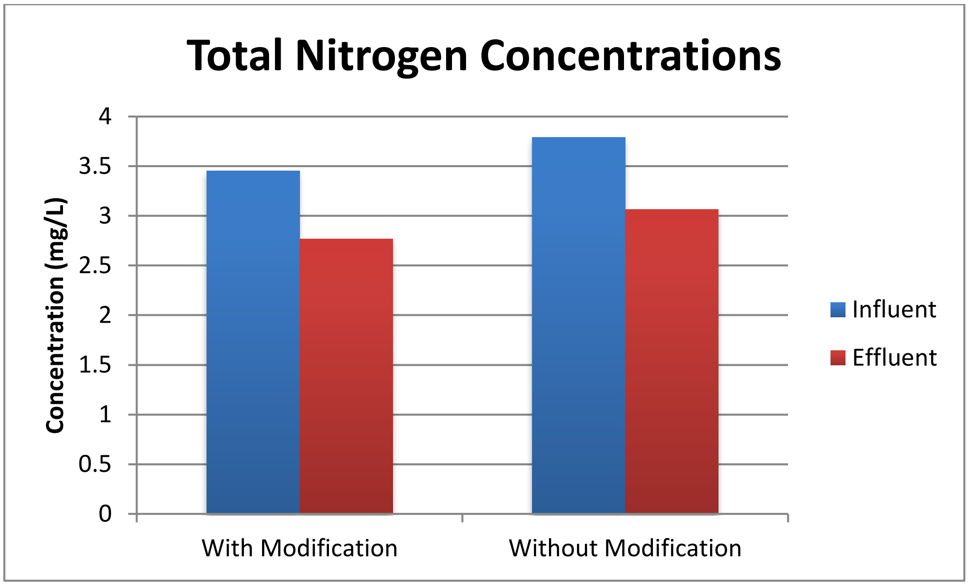

Figure 10: Average total nitrogen concentrations measured at the inlet (influent) and in the underdrain (effluent)

Figure 11 shows the influent and effluent concentrations of total phosphorus (TP) and dissolved phosphorus (DP). The average influent concentration of TP and DP are about 0.4 mg/L and 0.2 mg/L, respectively. The average effluent concentration of TP ranges from about 0.6-1.1 mg/L and for DP the average effluent concentration ranges from 0.5-0.8 mg/L. These results indicate that phosphorus is being *exported* from the BRC. In other words, there is a relatively significant source of phosphorus within the BRC that is leaching phosphorus into the runoff at is moves through the BRC. Other researchers studying bioretention have found similar results and have suggested that the source of phosphorus may be the compost that is generally included within the filter media mix. The City requires that bioretention filter media include 10-20% leaf compost and 5-10% topsoil; both of which might be sources of phosphorus. Average effluent concentrations for both TP and DP were higher with the modification. This is an unexpected result because the potential sources of phosphorus within the bioretention filter media should slowly be depleted, resulting in lower effluent concentrations over time. Potential explanations for this include the presence of an additional and unknown source of phosphorus being added to the BRC (e.g. fertilizer) or perhaps the modified underdrain has increases the leaching rate of the phosphorus within the BRC. Identifying the reason for this would require further investigation.

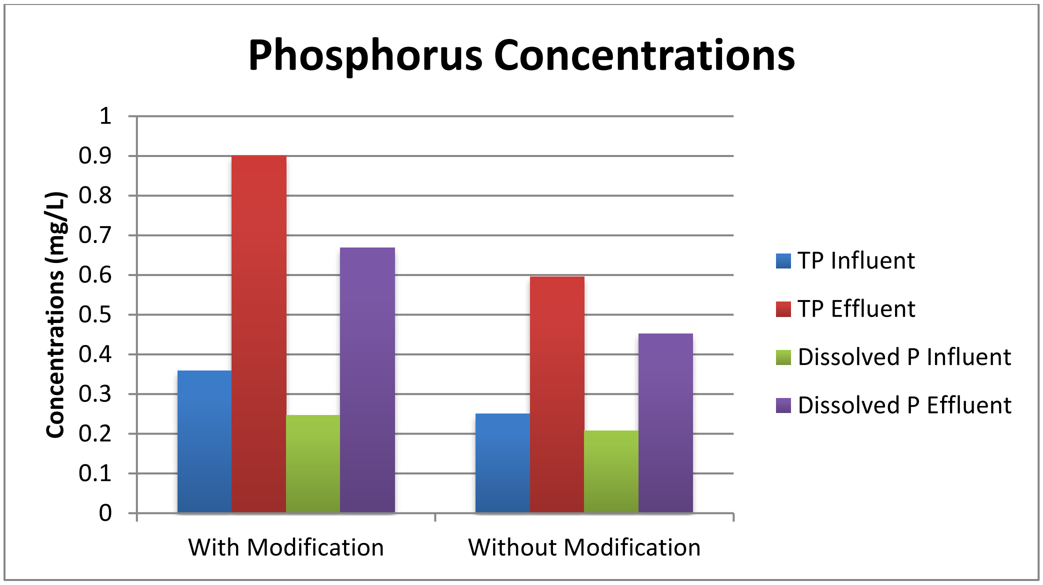

Figure 11: Average total (TP) and dissolved (DP) phosphorus concentrations measured at the inlet (influent) and in the underdrain (effluent).

Figures 12, 13 and 14 show the average annual influent and effluent loads (lbs) of TSS, total nitrogen and total and dissolved phosphorus from 2013, 2014, and 2015. Another method for evaluating pollutant removal performance of BMPs is to compare the average annual load (in lbs) of pollutants discharged into the BMP and discharged back to the storm sewer system. Ultimately, the objective of implementing BMPs is to reduce the load of pollutants discharged back to the storm sewer (which then drains to nearby lakes, rivers and streams); so this type of analysis considers BMP's ability to remove pollutants and runoff together.

Figure 12 shows the BRC reduced the load of TSS that would otherwise be discharged to the storm sewer by about 300 lbs per year with the modification and without the modification. The data suggest that approximately 200-400 lbs of TSS runs off the City parking lot each year, but with the BRC installed, the load of TSS that eventually reaches receiving waters is less than 100 lbs.

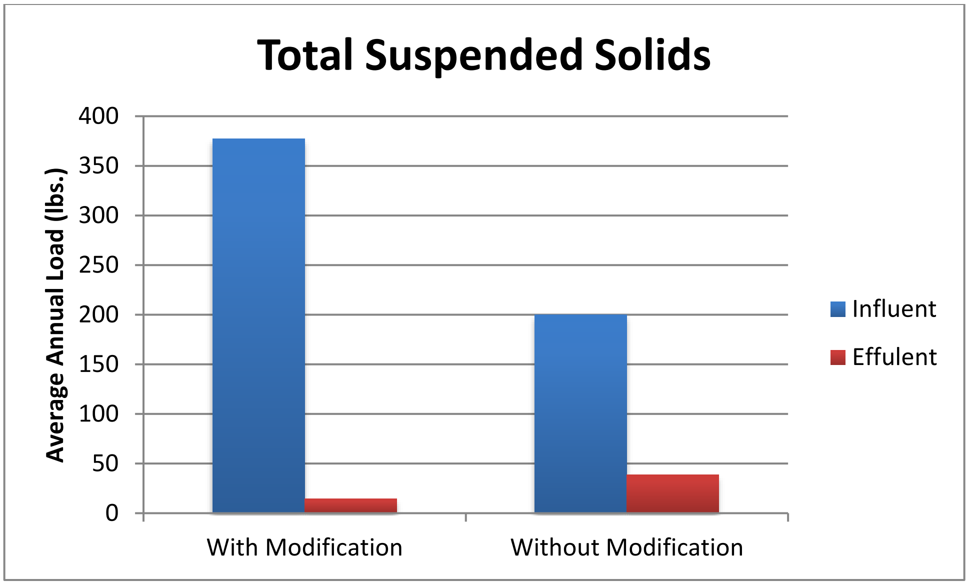

Figure 12: Average annual total suspended solids load entering the BRC (influent) and discharging back to the storm sewer system (effluent).

Figure 13 shows that the BRC prevented approximately 10 lbs and 20 lbs of total nitrogen from being discharged to receiving waters in 2013, 2014, and 2015. It can be noticed that the underdrain modification increased the amount of nitrogen removed from the water. Although runoff infiltrated in the groundwater will eventually reach nearby lakes and rivers, additional nitrogen removal is likely to occur as that water moves through the soils prior to reaching lakes and rivers.

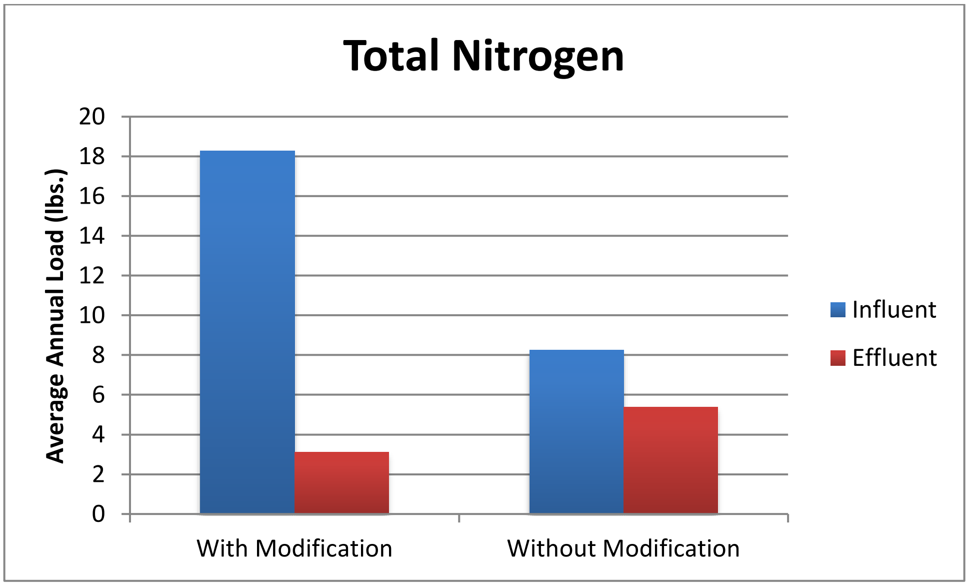

Figure 13: Average annual total nitrogen load entering the BRC (influent) and discharging back to the storm sewer system (effluent).

Without the underdrain modification, the BRC resulted in *net increase* in phosphorus loads discharged to the storm sewer (Figure 14). For TP, the increase was approximately 1 lb and for DP the increase was approximately .5 lbs. As discussed above, this is believed to be due to leaching of phosphorus from the bioretention filter media. Although phosphorus was still leaching from the filter media with the underdrain modification (Figure 11), most of the leached phosphorus was infiltrated into the groundwater. This resulted in the BRC achieving an overall phosphorus load reduction of approximately 1 lbs and .6 lbs for TP and DP, respectively.

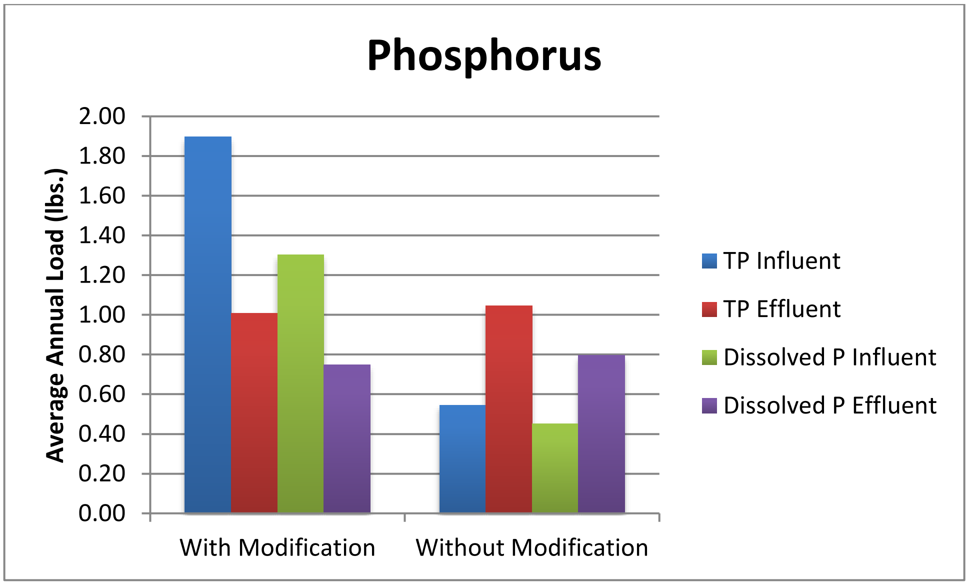

Figure 14: Average annual total (TP) and dissolved (DP) phosphorus loads entering the BRC (influent) and discharging back to the storm sewer system (effluent).

Summary, Conclusions and Recommendations

The primary objective of this study was to evaluate the performance of the BRC at the City utility parking lot in terms of stormwater pollutant and runoff reduction. The BRC was monitored during the summers of 2013, 2014, and 2015 by CSU and data were analyzed to achieve this objective. Prior to the 2014 monitoring season, the BRC underdrain system was modified to determine if a different underdrain design could increase the overall performance of the BRC. Midway through the 2015 season the underdrain modification was removed in order to gain more data without the modification.

Overall, the BRC is working very well to reduce the amount of stormwater pollutants and runoff that is discharged from the City utility parking lot to local waterways. Without the modificaiton, the BRC prevented about 161 lbs of TSS and 2.86 lbs of total nitrogen was being discharged directly to the storm sewer system; however the BRC actually increased the discharge of total phosphorus by about .5 lbs. Of all the runoff generated from the parking lot without the underdrain modificaiton, approximately 20% was prevented from entering the storm sewer system by infiltration and ET provided by the BRC.

Performance of the BRC significantly increased with the modified underdrain design. Total nitrogen removal increased from about 2.86 lbs/year to about 15 lbs/year and total phosphorus removal increased by a net total of approximately .89 lbs/year. (Note: Without the modification, the BRC exported about 1.05 lbs of phosphorus and with the modificaiton it reduced about 1.01 lbs of phosphorus). The underdrain modification increased the amount of runoff that infiltrated back into the groundwater instead of being discharged through the underdrain into the storm sewer. *Due to this demonstrated increase in performance, is highly recommended that the City consider modifying its bioretention design criteria to include this modified underdrain design.*

One issue that the result of this monitoring project also revealed was that the materials used in the bioretention filter media mix (i.e. compost and topsoil) may act as a source of phosphorus and result in a net increase in phosphorus discharges from bioretention cells. If the filter media mix is in fact the source of phosphorus, it may be that the excess phosphorus will slowly leach out and eventually be depleted. If this is the case, this identified problem may only temporary. Since nutrient removal is a critical issue that the City is facing with the upcoming promulgation of Regulation 85, it is recommended that the City continue to study this problem and potentially seek alternative bioretention filter media mixes that will not leach phosphorus.

Appendix A: Water Quantity Raw Data

Date	Rainfall (in)	Inflow (cuft)	Infiltration and Soil Storage (cuft)	ET till Next Storm (cuft)	Underdrain Discharge (cuft)
6/28/2013	0.31	2,123	758	253	1,113
7/5/2013	0.51	2,078	0	393	1,708
7/18/2013	0.59	3,323	215	341	2,767
7/28/2013	0.16	1,186	0	427	808
9/22/2013	0.28	2,339	589	118	1,632
9/27/2013	0.24	1,604	508	128	969
10/4/2013	0.59	4,482	361	198	3,924
6/8/2014	0.16	1,092	988	104	0
6/22/2014	0.34	2,896	2,796	0	100
6/24/2014	0.04	453	177	276	0
7/6/2014	0.04	147	129	18	0
7/11/2014	0.87	4,302	3,920	0	382
7/14/2014	0.12	620	620	0	0
7/15/2014	0.55	3,713	3,265	61	387
7/20/2014	0.04	651	455	196	0
7/25/2014	0.08	831	798	33	0
7/29/2014	1.5	9,663	6,382	354	2,927
8/9/2014	0.12	719	565	154	0
9/5/2014	0.08	580	537	43	0
9/9/2014	0.35	2,262	2,262	0	0
9/11/2014	0.12	873	610	263	0
9/29/2014	0.39	3,111	2,873	45	193
10/1/2014	0.16	961	688	273	0
10/9/2014	0.75	4,697	3,773	307	617
4/26/2015	0.34	2,836	141	0	2,695
5/6/2015	0.20	1,638	1,267	0	271
5/8/2105	2.01	16,621	12,072	0	4,549
5/19/2015	1.14	9,435	7,317	0	2,118
5/22/2015	0.23	2,898	1,191	0	707
5/23/2015	0.29	2,403	1,637	205	561
5/29/2015	0.13	1,095	890	205	0

6/2/2015	0.08	622	416	205	0
6/11/2015	0.49	4,095	2,808	208	1,043
6/26/2015	0.13	1,037	730	307	0
7/5/2015	0.30	2,484	1,976	205	303
7/7/2015	0.36	3,004	1,682	232	1,090
7/18.2015	0.16	1,291	69	205	1,017
8/18/2015	0.27	2,191	36	387	1,768
9/7/2015	0.12	987	138	202	647
10/3/1015	0.17	1,376	147	62	1,167
10/4/2015	0.26	2,121	158	88	1,875
10/20/2015	0.55	4,565	218	202	4,144
10/22/2015	0.63	5,209	203	387	4,619
Total 2013	2.68	17,136	2,429	1,858	12,921
Total 2014	5.71	37,571	30,839	2,125	4,606
Total 2015 w/ Mod	5.71	47,131	32,227	1,567	13,336
Total 2015 w/o Mod	2.15	17,739	968	1,533	15,263

Appendix B: Water Quality Raw Data

Table 1: Nitrogen values for 2013, 2014, and 2015.

	Total Kjeldahl N		Nitrate as N		Nitrite as N		Total Nitrogen	
Date	Total Kjeldahl N in (ppm)	Total Kjeldahl N out (ppm)	Nitrate in (ppm)	Nitrate out (ppm)	Nitrite in (ppm)	Nitrite out (ppm)	Nitrogen in (ppm)	Nitrogen out (ppm)
6/28/2013**	43.2	43.8	0.05*	1.02	0.05*	0.414	43.3	45.234
7/5/2013	2.84	3.15	0.452	1.6	0.05*	0.05*	3.342	4.8
7/18/2013	2.75	3.18	0.499	0.642	0.05*	0.05*	3.299	3.872
7/28/2013	4.65	2.49	0.956	0.05*	1.05	0.05*	6.656	2.59
9/22/2013	2.54	1.63	0.414	0.464	0.05*	0.05*	3.004	2.144
9/27/2013	3.02	2.35	0.362	0.441	0.05*	0.05*	3.004	2.144
10/4/2013	2.24	1.29	0.457	0.858	0.05*	0.05*	3.432	2.841
6/22/2014	2.41	1.73	0.343	1.29	0.05*	0.05*	2.803	3.07
7/11/2014	6.24	3.44	1.1	1.04	0.05*	0.05*	7.39	4.53
7/15/2014	3.52	2.1	0.267	0.567	0.05*	0.05*	3.837	2.717
7/29/2014	3.99	2.75	0.393	1	0.05*	0.05*	4.433	3.8
9/29/2014	1.97	1.63	2.02	0.662	0.05*	0.05*	4.04	2.342
10/9/2014	2.06	0.99	0.287	0.643	0.05*	0.05*	2.397	1.683
4/26/2015	2.36	1.84	0.354	0.412	0.05*	0.05*	2.764	2.302
5/19.2015	1.92	1.44	0.544	0.328	0.05*	0.05*	2.514	1.818
6/11/2015	1.52	0.84	0.192	1.11	0.05*	0.05*	1.762	2.00
7/8/2015	2.32	2.04	0.241	1.35	0.05*	0.05*	2.611	3.44
8/18/2015	1.64	1.40	0.439	1.46	0.05*	0.05*	2.129	2.91
9/7/2015	2.32	1.88	0.767	1.79	0.05*	0.05*	3.137	3.72
10/4/2015	1.24	1.04	0.432	0.935	0.05*	0.05*	1.722	2.025

* - Values were non-detects, half of the minimum detection limit was used for calculations.

** - Sample was determined to be an outlier and was not used in calculations.

Table 2: Phosphorus values for 2013, 2014, and 2015.

Date	Total Phosphorous		Dissolved Phosphorous	
	Total Phosphorous in (ppm)	Total Phosphorous out (ppm)	Dissolved Phosphorous in (ppm)	Dissolved Phosphorous out (ppm)
6/28/2013	0.84	1.17	0.318	0.709
7/5/2013	0.37	1.6	0.25*	1.12
7/18/2013	0.28	0.84	0.25*	0.649
7/28/2013	0.16	0.21	0.303	0.24
9/22/2013	0.069	0.087	0.069*	0.336
9/27/2013	0.06	0.263	0.06*	0.358
10/4/2013	0.078	0.381	0.078*	0.363
6/22/2014	0.228	1.35	0.228*	1.32
7/11/2014	0.396	1.05	0.25*	0.25*
7/15/2014	0.93	1.64	0.25*	1.32
7/29/2014	0.25*	1.64	0.25*	0.8
9/29/2014	0.25*	1.04	0.25*	0.596
10/9/2014	0.819	0.025*	0.25*	0.888
4/26/2015	0.025*	0.309	0.25*	0.25*
5/19/2015	0.025*	0.409	0.25*	0.25*
6/11/2015	0.581	0.781	0.25*	0.507
7/8/2015	0.198	0.700	0.25*	0.25*
8/18/2015	0.153	0.542	0.25*	0.25*
9/7/2015	0.025*	0.125	0.25*	0.25*
10/4/2015	0.47	0.735	0.25*	0.25*

* - Values were non-detects. Half of the minimum detection limit was used for calculations unless total phosphorus was less than half of dissolved phosphorus' detection limit than the total phosphorus value was used.

Table 3: Total Suspended Solids values for 2013, 2014, and 2015.

Date	Total Suspended Solids	
	TSS in (ppm)	TSS out (ppm)
6/28/2013	316	72
7/5/2013	158	50
7/18/2013	118	37
7/28/2013	40	2.5
9/22/2013	104	8
9/27/2013	33	6
10/4/2013	42	6
6/22/2014	53	14
7/11/2014	48	12
7/15/2014	340	8
7/29/2014	40	23
9/29/2014	31.5	9.5
10/9/2014	32	19
4/26/2015	12.5	7
5/19/2015	5.5	8
6/11/2015	134	13.5
7/8/2015	26	9
8/18/2015	32	11
9/7/2015	51	18
10/4/2015	25	11