Stormwater Quality Monitoring Report

Permeable Interlocking Concrete Pavement (PICP) at Denver Wastewater Management Building Denver, Colorado 2008-2010

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Table of Contents

I. Introduction

UDFCD and Stormwater Quality

The Urban Drainage and Flood Control District (UDFCD) was established by the Colorado legislature in 1969 for the purpose of assisting local governments in the Denver metropolitan area with multi-jurisdictional drainage and flood control problems. UDFCD monitors a number of stormwater Best Management Practice (BMP) sites in the Denver metropolitan area and plays a large role in stormwater quality improvement by way of research and promulgation of criteria. UDFCD samples inflow and outflow and collects data on rainfall and runoff at several BMP sites.

UCFCD's primary objectives are to:

- Determine the Event Mean Concentration (EMC) of different constituents that affect stormwater runoff.
- Assess the longer term performance of each BMP with regard to stormwater quality and runoff volume reduction.

PICP at Denver Wastewater

At the City and County Denver Wastewater Management Building, UDFCD is monitoring Permeable Interlocking Concrete Pavement (PICP). PICP is one of several different types of permeable pavement systems that are designed to infiltrate stormwater through the pavement surface. Permeable pavements are a common and important practice of Low Impact Development (LID). The PICP wearing course consists of concrete blocks that are spaced so that runoff can enter the pavement. The blocks contain ridges along the sides to create the spacing and ensure that the blocks are installed correctly. The UDFCD section, which contains a filter layer, is designed to improve water quality.

A street view of the PICP at Denver Waste Water is shown in Photograph 1.

Photograph 1. PICP with sampler box and rain gauge shown in background.

II. Site Description

Photograph 2. Denver Public Works Building (Left of island: porous asphalt, right of island: PICP).

Study Area

The PICP and a reference (control) site are located at the Denver Wastewater Management building at 2000 West 3rd Avenue in Denver. The PICP was placed in May 2008 by Rocky Mountain Hardscapes, and is located in the turn-around area of the main entrance on the south side of the island (see Photograph 2). The PICP is in the drive adjacent to a short-term parking area. The reference site is located in the employee parking area a few hundred feet northeast of the BMP. The reference site is used to compare water quality and flow of treated effluent to untreated, direct runoff. The general vicinity and location of the site are shown in Figures 1 and 2, respectively, with the PICP circled in red and the reference site indicted by a red arrow in Figure 2.

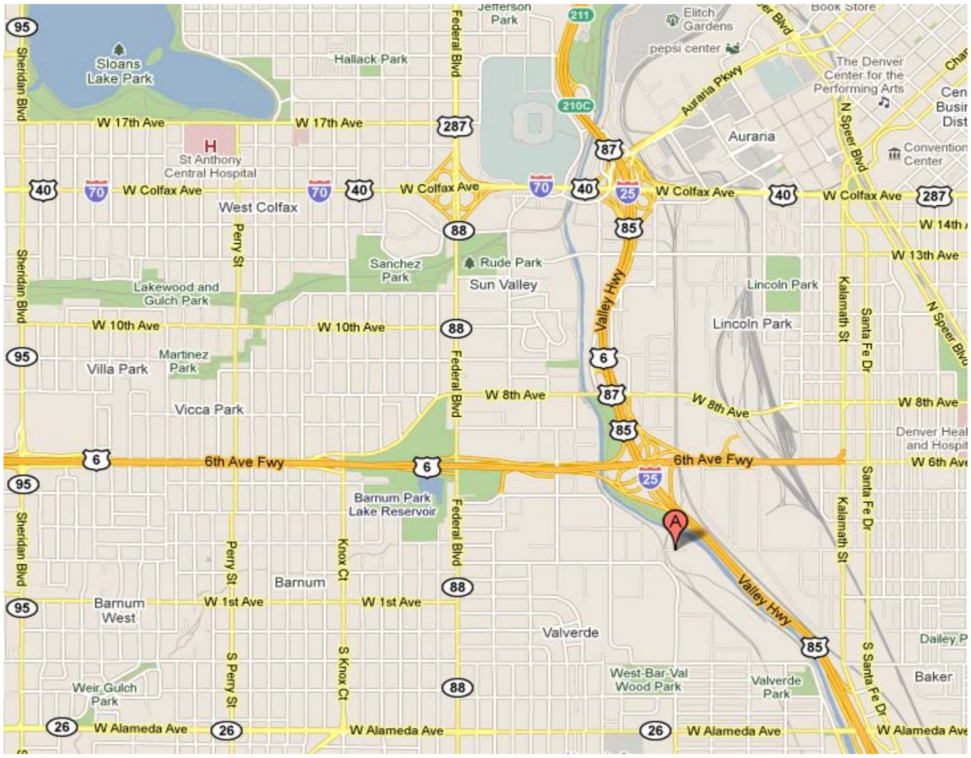


Figure 1. Vicinity Map

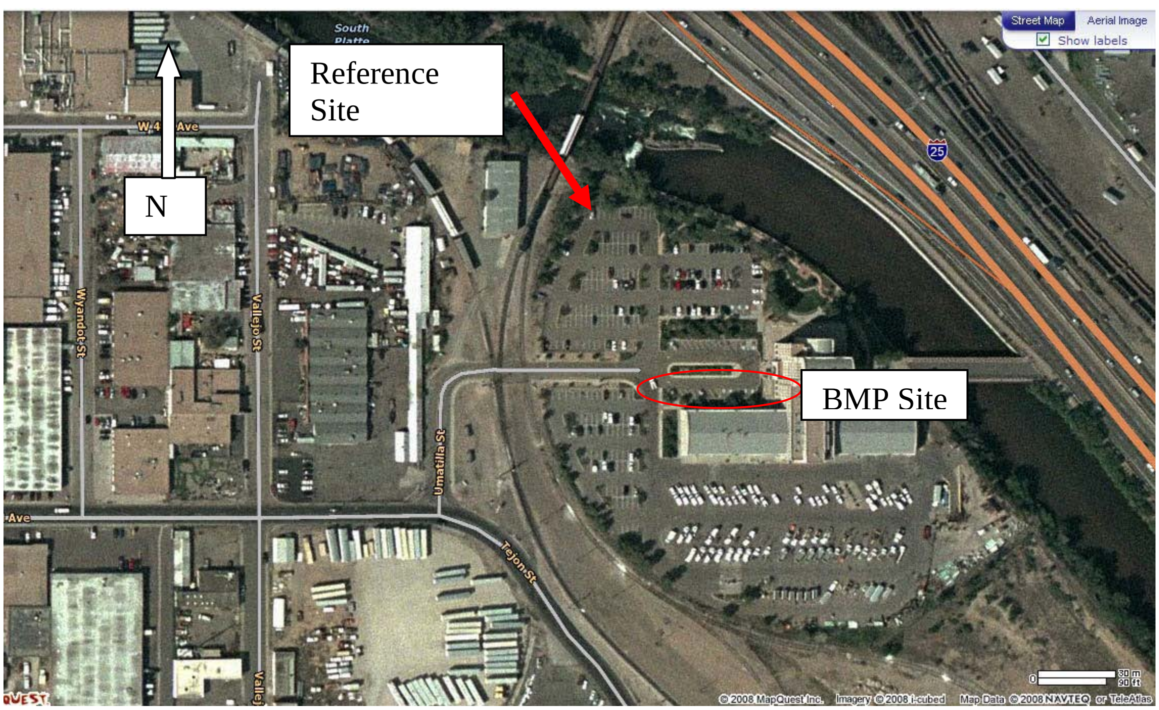


Figure 2. Location Map

Watershed

Permeable pavement is an appropriate BMP for this watershed because the tributary area is impervious and stable. The watershed consists of pavement and concrete walkways. It is 5,300 square feet, of which 3,590 square feet is impervious tributary to the PICP. A plan view of the watershed for the PICP is shown in Figure 3. Because it is located in the turn-around in front of the building, the watershed receives heavy traffic during business hours. The run-on ratio of the tributary impervious area to the permeable pavement is 2.1:1 (3,590/1,710), which is in general conformance with the Urban Storm Drainage Criteria Manual (USDCM), Volume 3 criteria. The watershed for the reference site is 8,400 square feet. It is located in a portion of the employee lot. Traffic patterns in this area differ from those of the BMP site. Traffic counts are assumed to be much lower.

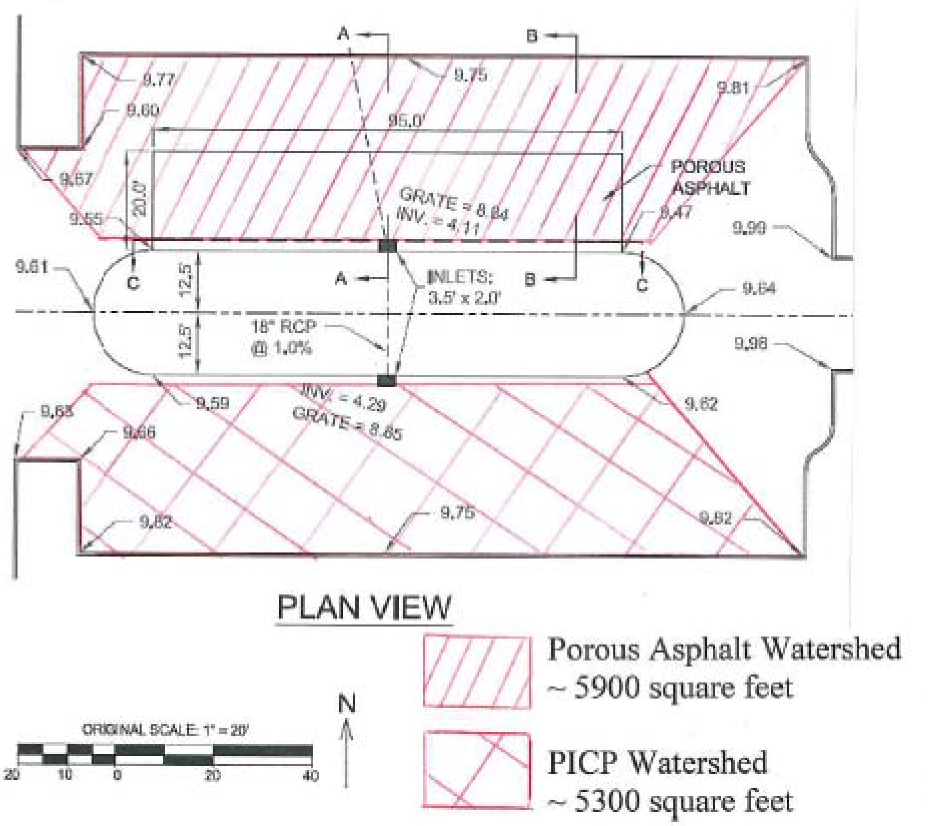


Figure 3. Plan View of the Area of the PICP Watershed

III. Methods and Materials

PICP Components

The PICP section is shown in Figure 4. The primary components include the wearing course, a reservoir layer and a filter layer. The wearing course consists of 3 1/8-inch concrete pavers on an aggregate leveling course with small aggregate (less than ½-inch) placed between the pavers.

The reservoir layer consists of larger aggregate providing structural support as well as storage volume. The filter layer, not typically included in the sections provided by the manufacturer, consists of sand and provides improved water quality. Filtered stormwater is collected in the underdrain layer and conveyed to the catch basin for sample collection and flow measurement. An impermeable plastic liner separates the underdrain layer from the subgrade. This no-infiltration section is used to ensure that outflow samples can be collected and will not be lost through infiltration into the subgrade.

Photograph 3. Concrete block pavers prior to placement.

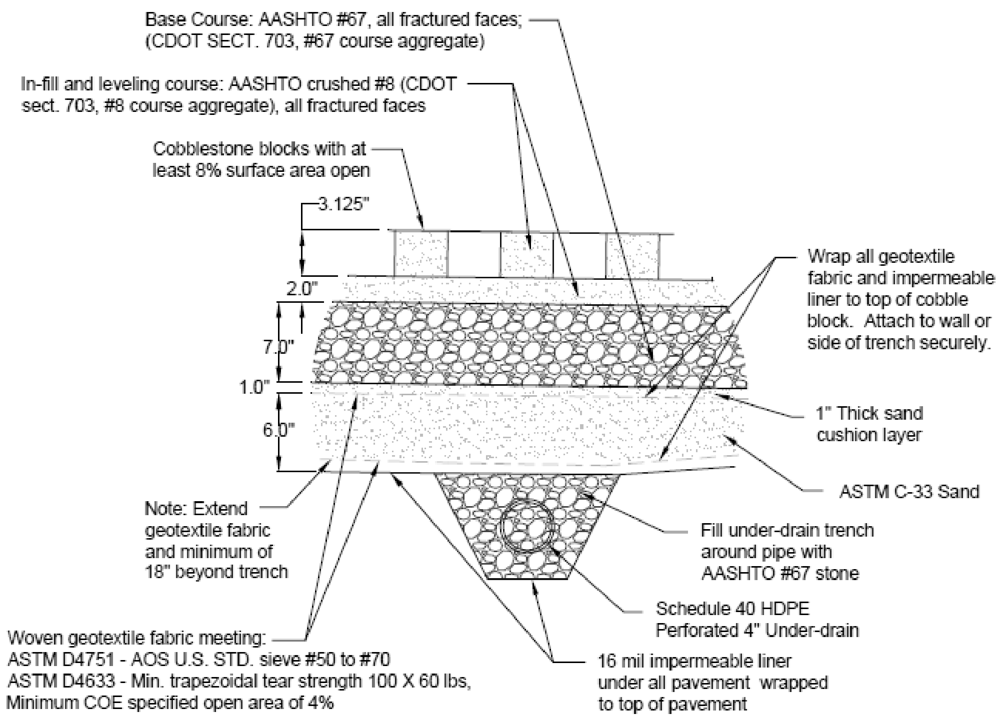


Figure 4. Cross Section of the PICP at the Monitoring Site

The PICP at this site was installed based on previous criteria that were updated in 2010 in Volume 3 of the USDCM (see Figure 4). The newer criteria, shown in Figure 5, serves to simplify the section by making use of materials that are compatible with each other eliminating the need for separation fabric.

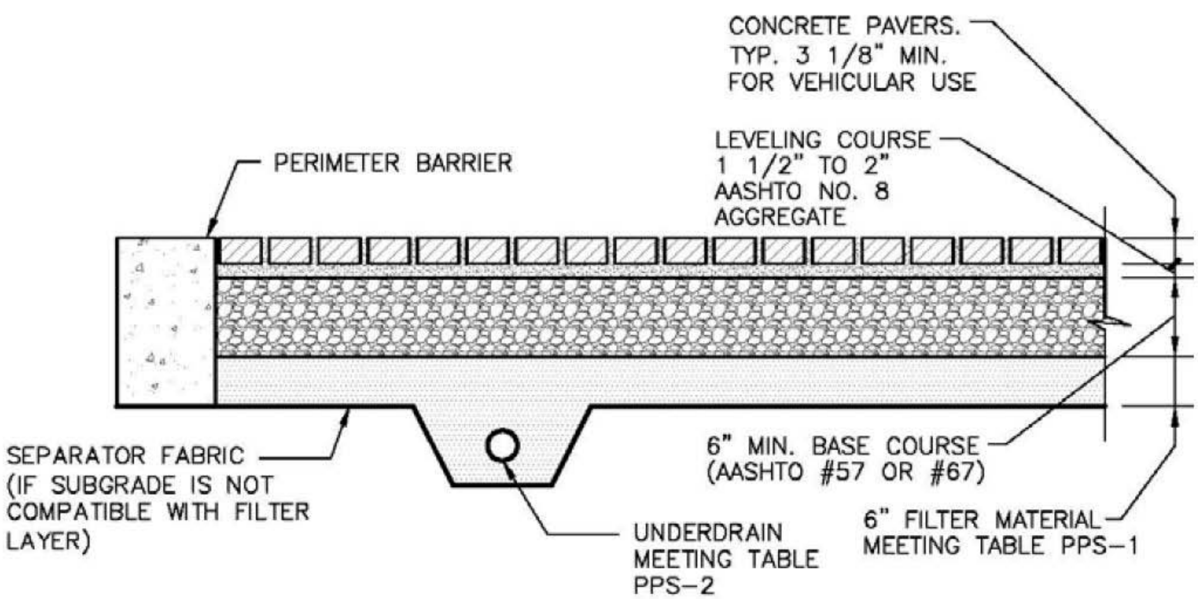


Figure 5. Current UDFCD Criteria for PICP Section

Data Collection

All samples are tested for the following:

Category	Constituent	Units	Detection Limit
Metal:	Dissolved Calcium	mg/L	1
	Dissolved Iron	mg/L	0.05
	Dissolved Magnesium	mg/L	0.1
	Dissolved Sodium	mg/L	1
	Dissolved Chromium	µg/L	1
	Dissolved Manganese	µg/L	1
	Dissolved Nickel	µg/L	1
	Dissolved Copper	µg/L	2
	Dissolved Zinc	µg/L	5
	Dissolved Selenium	µg/L	1
	Dissolved Silver	µg/L	0.2
	Dissolved Cadmium	µg/L	0.1
	Dissolved Lead	µg/L	1
	Total Beryllium	µg/L	1
	Total Chromium	µg/L	5
	Total Manganese	µg/L	1
	Total Nickel	µg/L	1
	Total Copper	µg/L	2
	Total Zinc	µg/L	20
	Total Arsenic	µg/L	5
	Total Selenium	µg/L	1
	Total Molybdenum	µg/L	5
	Total Silver	µg/L	0.2
	Total Cadmium	µg/L	0.5
	Total Antimony	µg/L	5
	Total Lead	µg/L	5
Chemical:	Chloride	mg/L	5
	Chemical Oxygen Demand	mg/L	20
Nutrients:	Nitrite+Nitrate	mg/L	0.02
	Dissolved Phosphorus	mg/L	0.01
	Dissolved Potassium	mg/L	1
	Total Phosphorus	mg/L	0.01
	Total Kjeldahl Nitrogen	mg/L	0.3
Physical:	Total Suspended Solids	mg/L	1

UDFCD has been collecting water quality and flow data from this site since 2008. Automatic samplers (ISCO Model 6712) are used to collect flow data from the PICP and the reference site throughout the runoff event. The sampling equipment is stored in a metal job box located in the landscaped island of the turn-around. Rainfall is measured to 0.01 inches by an ISCO 674 tipping bucket rain gauge (see Photograph 4) on a post near the storage box. When the rain gauge detects over 0.08 inches in two hours and the pressure transducer measures a difference in head, the ISCO sampler begins to take samples. As of the 2011 sampling season, the sampler draws a sample (500 mL) after a designated volume of five cubic feet has passed, and continues to draw samples at intervals of five cubic feet thereafter. For the time period of the data provided in this report, the rain gauge took samples after 0.01 inches of rain had fallen in 6 hours. It was modified in 2011 to avoid sampling runoff from very small events.

Photograph 4. The tipping bucket of the rain gauge assembly (cover and funnel assembly removed)

PICP Monitoring and Sampling

The monitoring station at the PICP consists of an ISCO 6712 sampler which is connected to a rain gauge and a bubbler module. The bubbler module is connected to the end of the underdrain through ¼-inch tubing, and measures flow entering the catch basin through a ¾-inch orifice. The orifice at the reference site is also ¾ inches. The tubing is attached to the sampler and passes through a conduit into the catch basin, where it is connected to a copper pipe that goes into the underdrain. The difference in head across the orifice is used to calculate flow. Water quality samples of 500 mL are collected into a single 10 L bottle from an aluminum box in the catch basin. An orifice in the bottom of the box serves to drain any residual stormwater. A plan of the site with sampling equipment and inlets is provided below in Figure 7.

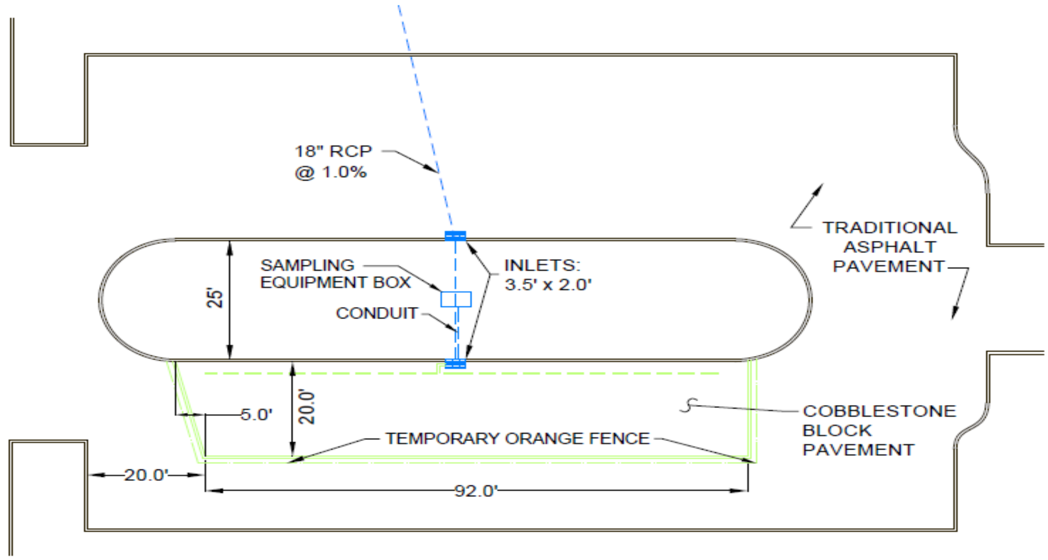
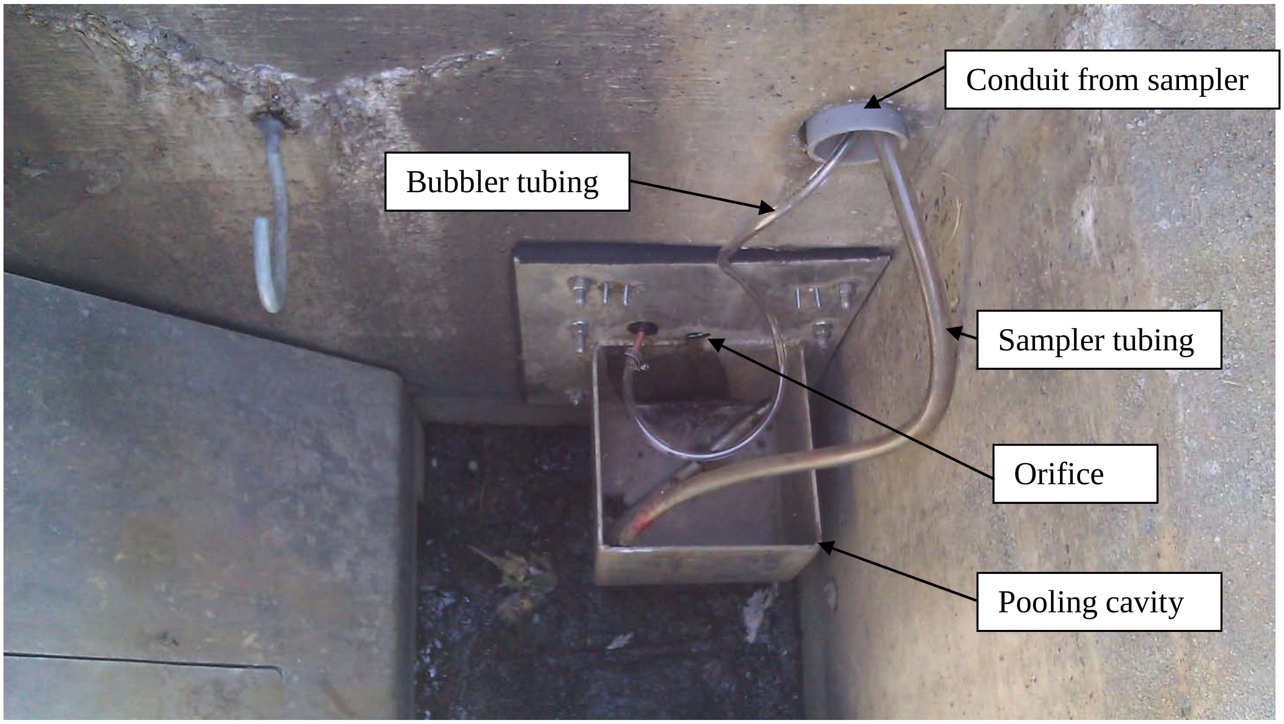


Figure 6. Plan View of the Test Site

The bubbler module and tubing were installed upstream of the orifice plate on June 23, 2011. Prior to this date and for the data provided in this report, a pressure transducer was used to measure flow through the orifice. The pressure transducer was replaced because water was repeatedly wetting the extension cable, causing errors in recorded head. The quick disconnect box, installed to keep the connection dry, repeatedly failed. The need for an extension cable could have been avoided had the original conduit between the sampler and the catch basin been larger. For this location, a bubbler will be more reliable because the bubbler tubing is not impacted by water intrusion. To measure flow with a bubbler module, the sampler pumps air through the tubing into the water and measures the force necessary to produce a bubble, and then uses that value to calculate water level. Installation of the bubbler module should improve flow readings. The catch basin is shown in Photograph 5. The orifice is designed to drain the WQCV in 12 hours.

When the PICP was first constructed, a levelogger behind a weir plate was also installed at the outlet of the catch basin to measure the total volume leaving the catch basin. This would allow the volume bypassing the pavement section to be calculated by subtracting the volume through the orifice from the total volume entering the catch basin. However, it was determined that not all flow entering the catch basin is bypass flow. For this reason, the weir may soon be removed.



Photograph 5. Catch Basin showing sampling and flow measuring components

Reference Site Monitoring and Sampling

The reference site monitoring station includes an ISCO 6712 automated sampler. Stormwater runoff from the control watershed flows into a catch basin located in the northeast corner of the parking lot. Sampler tubing pulls samples from the bottom of the catch basin while a pressure transducer measures head behind a Cipoletti weir (shown in Photograph 6). Outlet flow is calculated based on the head upstream of the weir. The sampling equipment is stored in a metal box adjacent to the parking lot in a manner similar to the PICP sampling configuration.

Photograph 6. The inlet of the reference site, shown with Cipoletti weir

Maintaining Infiltration

This pavement has been allowed to partially clog over the course of three years. Tests show good results in 2008 and 2010. In May of 2011, based on visual observation, the pavement appeared to be somewhat clogged particularly at locations where runoff from the impervious areas first enters the PICP. Early in the 2011 sampling season the PICP was swept with a vacuum sweeper. Conditions during sweeping were wet and therefore not ideal. The sweeper removed much of the small aggregate between pavers but failed to do so in areas where the PICP appeared to be especially clogged. Aggregate was added where needed early the following morning. Subsequent infiltration tests were conducted on July 22, 2011 and are provided in Figure 7.

Beginning in 2010, UDFCD started using a modified version of ASTM method C 1701 for determining the infiltration rate (see photo 7). For each test, water is poured into a 12-inch PVC pipe section held firm to the pavement by the weight of 4 buckets of concrete placed on the framework shown in the photo. A ½-inch neoprene gasket is between the pipe section and the pavement. This weight compresses the neoprene gasket to form a tight seal so that water is not lost at the surface. This is a constant head test. A finite volume of water (3600 mL) is poured into the pipe at a rate to maintain a level of 10-15mm over the area of the pipe.

Figure 7 shows rates of filtration in inches per hour for each testing date, plotted on a logarithmic scale. Note that for the first test, only one section of pavement was tested, therefore there are no minimum or maximum values.

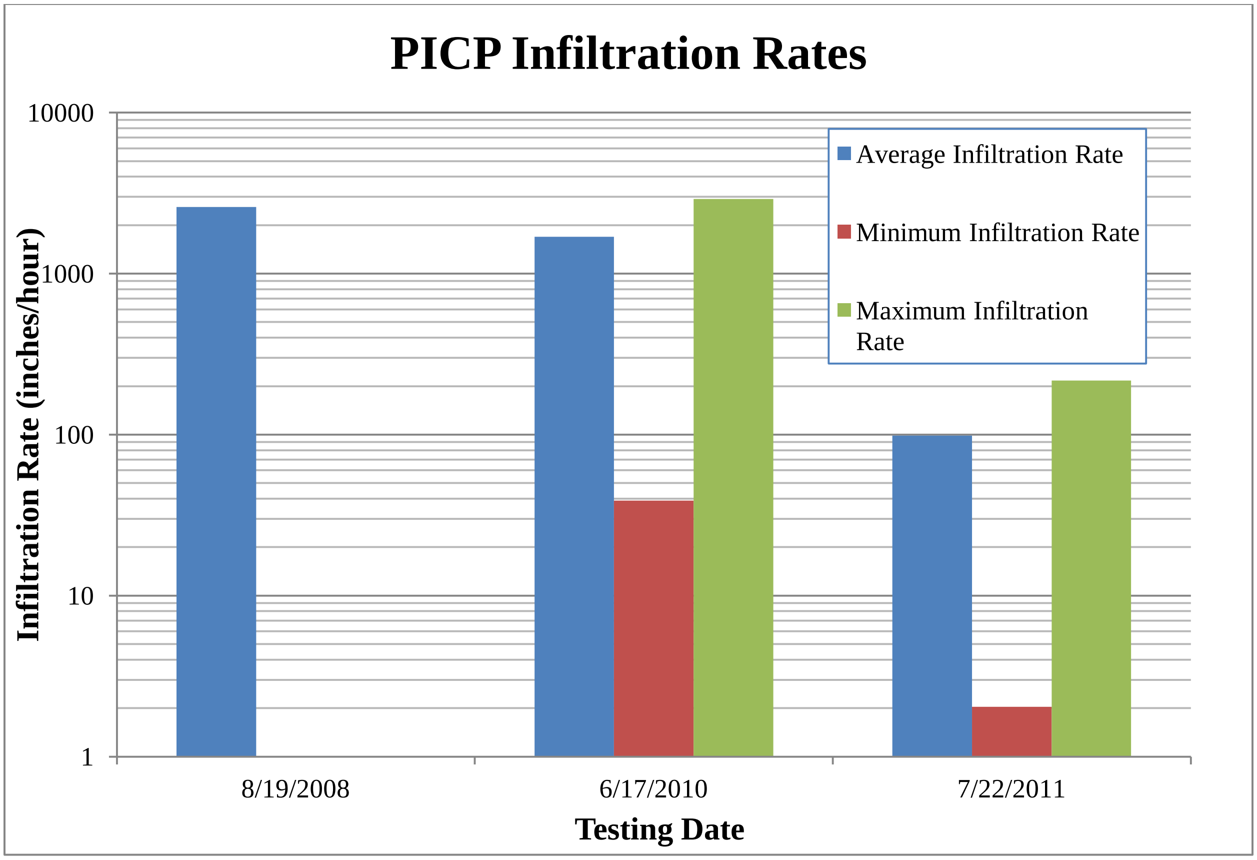


Figure 7. Infiltration Rates for Each Test Date

IV. Results and Discussion

Outflow Volume Reduction

Due to complications with the pressure transducer previously mentioned in the *PICP Monitoring and Sampling* section, calculated volumes provided in this report should not be used to calculate volume reduction through this BMP. The accuracy of volume calculations should improve with the installation of the bubbler at the BMP site. Figure 8 depicts the outflow volumes for the BMP and the reference site, which are plotted on a logarithmic scale due to the wide range of values. Only paired data was plotted. Tables 1 through 3 contain all the data for each year. The Corrected Reference Site Volume in the flow tables refers to a correction for the difference in watershed area between the reference site and that of the PICP watershed. The PICP watershed area is 0.67 that of the reference site watershed. Note that the values for storms 3a-3c in 2008, and storms 7 and 8 for 2010, are the same because they represent overlapping events with continuous flow throughout the different storm events.

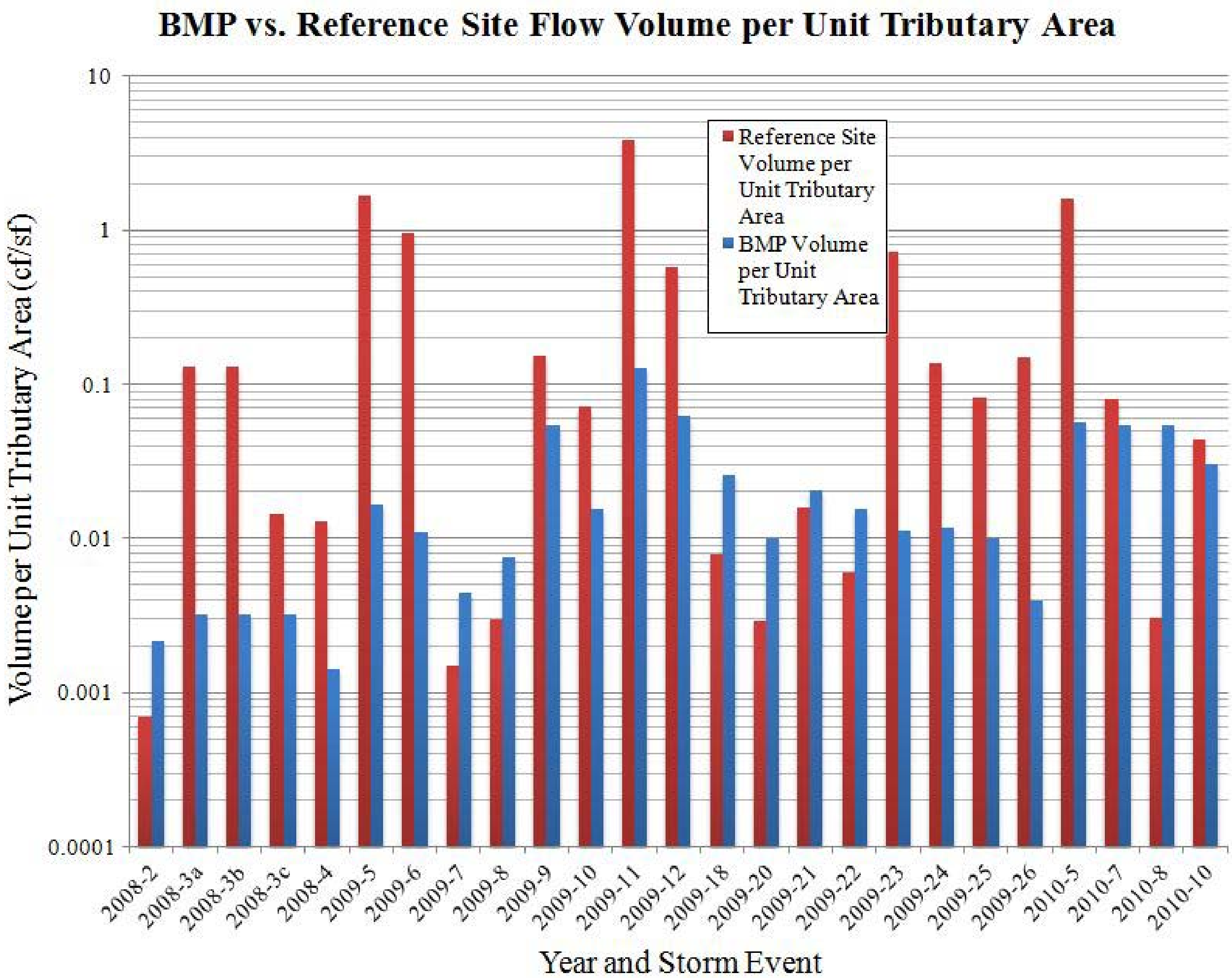


Figure 8. Comparison of Reference and PICP Flow Volumes

Table 1. Flow Data for 2008

2008 Storm Event	Reference Flow Start Date	Reference Flow Start Time	Reference Flow End Date	Reference Flow End Time	Reference Flow Duration (hours)	BMP Outlet Flow Start Date	BMP Outlet Flow Start Time	BMP Outlet Flow End Date	BMP Outlet Flow End Time	BMP Outlet Flow Duration (hours)	Rainfall (in)	Total Reference Flow Volume (cf)	Total BMP Outlet Flow Volume (cf)	Peak Reference Flow Rate (cfs)	Peak BMP Outlet Flow Rate (cfs)	Reference Site Volume per Unit Tributary Area (cf/sf)	BMP Volume per Unit Tributary Area (cf/sf)
2	8-Aug	19:37	8-Aug	19:51	0:14	8-Aug	19:36	9-Aug	5:37	10:01	1.15	5.88	11.44	0.747	0.030	0.0007	0.0022
3a	15-Aug	3:17	16-Aug	21:34	42:17	15-Aug	2:59	17-Aug	12:00	9:01	0.69	1109.39	16.98	1.533	0.020	0.1321	0.0032
3b	15-Aug	3:17	16-Aug	21:34	42:17	15-Aug	2:59	17-Aug	12:00	9:01	1.37	1109.39	16.98	1.533	0.020	0.1321	0.0032
3c	17-Aug	1:33	17-Aug	8:40	7:07	15-Aug	2:59	17-Aug	12:00	9:01	0.10	122.03	16.98	0.725	0.020	0.0145	0.0032
4	11-Sep	19:44	12-Sep	12:34	16:50	11-Sep	19:47	12-Sep	18:44	22:57	1.19	109.14	7.466	0.380	0.015	0.0130	0.0014

Table 2. Flow Data for 2009

2009 Storm Event	Reference Flow Start Date	Reference Flow Start Time	Reference Flow End Date	Reference Flow End Time	Reference Flow Duration (hours)	BMP Outlet Flow Start Date	BMP Outlet Flow Start Time	BMP Outlet Flow End Date	BMP Outlet Flow End Time	BMP Outlet Flow Duration (hours)	Rainfall (in)	Total Reference Flow Volume (cf)	Total BMP Outlet Flow Volume (cf)	Peak Reference Flow Rate (cfs)	Peak BMP Outlet Flow Rate (cfs)	Reference Site Volume per Unit Tributary Area	BMP Volume per Unit Tributary Area (cf/sf)
4	**	**	**	**	**	26-Apr	17:41	27-Apr	16:10	22.48	0.54	**	389.44	**	0.013	**	0.0735
5	9-May	22:36	11-May	8:34	33.97	9-May	21:45	10-May	15:10	17.42	0.06	13917.46	87.51	0.566	0.003	1.6568	0.0165
6	15-May	21:22	16-May	10:23	13.02	15-May	21:46	16-May	10:23	12.62	0.11	8072.26	58.15	0.754	0.002	0.9610	0.0110
7	22-May	19:45	22-May	23:44	3.98	22-May	19:18	22-May	23:44	4.43	0.17	12.59	23.47	0.023	0.003	0.0015	0.0044
8	24-May	1:01	24-May	2:13	1.20	23-May	22:46	24-May	9:00	10.23	0.05	25.19	40.15	0.013	0.001	0.0030	0.0076
9	24-May	15:51	24-May	18:44	2.88	24-May	14:07	24-May	22:00	7.88	0.69	1278.63	286.66	1.822	0.023	0.1522	0.0541
10	25-May	10:20	25-May	13:18	2.97	25-May	9:58	25-May	17:36	7.63	0.15	601.28	82.41	0.119	0.004	0.0716	0.0155
11	25-May	18:59	26-May	10:45	15.77	25-May	18:34	26-May	7:56	13.37	1.28	32645.86	681.43	1.511	0.023	3.8864	0.1286
12	2-Jun	4:40	2-Jun	14:05	9.42	1-Jun	16:13	2-Jun	14:14	22.02	0.89	4864.68	333.62	0.252	0.015	0.5791	0.0629
13	**	**	**	**	**	11-Jun	12:48	11-Jun	16:01	3.22	0.19	**	24.14	**	0.007	**	0.0046
14	**	**	**	**	**	12-Jun	17:00	12-Jun	19:19	2.32	0.07	**	12.09	**	0.002	**	0.0023
15	**	**	**	**	**	13-Jun	18:03	13-Jun	19:02	0.98	0.17	**	16.03	**	0.011	**	0.0030
16	**	**	**	**	**	25-Jun	14:28	26-Jun	0:09	9.68	0.39	**	58.18	**	0.004	**	0.0110
17	**	**	**	**	**	26-Jun	14:45	26-Jun	21:04	6.32	0.19	**	66.55	**	0.012	**	0.0126
18	1-Jul	23:30	1-Jul	23:52	0.37	1-Jul	23:36	2-Jul	3:49	4.22	0.45	66.95	135.43	0.128	0.021	0.0080	0.0256
19	**	**	**	**	**	3-Jul	17:09	3-Jul	22:51	5.70	0.40	**	128.04	**	0.021	**	0.0242
20	4-Jul	0:38	4-Jul	3:49	3.18	4-Jul	0:38	4-Jul	3:23	2.75	0.18	24.71	52.56	0.077	0.013	0.0029	0.0099
21	20-Jul	22:41	20-Jul	22:46	0:05	20-Jul	22:42	21-Jul	3:18	4.60	0.45	133.05	108.16	0.653	0.021	0.0158	0.0204
22	25-Jul	21:25	25-Jul	21:32	0.12	25-Jul	21:29	26-Jul	1:41	4.20	0.48	50.74	81.23	0.216	0.017	0.0060	0.0153
23	27-Jul	19:55	28-Jul	8:08	12.22	27-Jul	20:05	28-Jul	1:11	5.10	0.27	6172.50	58.82	0.324	0.013	0.7348	0.0111
24	29-Jul	18:46	30-Jul	1:34	6.80	29-Jul	19:06	30-Jul	6:00	10.90	0.24	1152.45	62.67	0.334	0.003	0.1372	0.0118
25	6-Aug	16:05	6-Aug	16:24	0.32	6-Aug	16:11	6-Aug	20:28	4.28	0.39	693.80	52.95	1.688	0.015	0.0826	0.0100
26	9-Aug	20:26	9-Aug	21:03	0.62	9-Aug	20:47	10-Aug	0:05	3.30	0.18	1268.16	20.89	1.337	0.010	0.1510	0.0039
28	**	**	**	**	**	12-Sep	16:12	13-Sep	10:31	18.32	0.14	**	98.21	**	0.002	**	0.0185
29	**	**	**	**	**	21-Sep	8:45	21-Sep	15:41	6.93	0.22	**	47.31	**	0.002	**	0.0089
30	**	**	**	**	**	22-Sep	19:42	23-Sep	4:16	8.57	0.03	**	56.26	**	0.002	**	0.0106
31	**	**	**	**	**	23-Sep	13:17	23-Sep	17:22	4.08	0.15	**	34.72	**	0.003	**	0.0066
33	**	**	**	**	**	25-Sep	2:45	25-Sep	12:44	9.98	0.18	**	97.97	**	0.004	0.0185	**

Table 3. Flow Data for 2010

2010 Storm Event	Reference Flow Start Date	Reference Flow Start Time	Reference Flow End Date	Reference Flow End Time	Reference Flow Duration (hours)	BMP Outlet Flow Start Date	BMP Outlet Flow Start Time	BMP Outlet Flow End Date	BMP Outlet Flow End Time	BMP Outlet Flow Duration (hours)	Rainfall (in)	Total Reference Flow Volume (cf)	Total BMP Outlet Flow Volume (cf)	Peak Reference Flow Rate (cfs)	Peak BMP Outlet Flow Rate (cfs)	Reference Site Volume per Unit Tributary Area	BMP Volume per Unit Tributary Area (cf/sf)
1	22-Apr	18:25	23-Apr	13:00	18:35	**	**	**	**	**	**	5008.07	**	0.700	**	0.5962	**
3	11-May	18:01	12-May	0:46	6:45	**	**	**	**	**	**	3301.97	**	0.443	**	0.3931	**
4	13-May	21:02	14-May	1:43	4:41	**	**	**	**	**	0.14	252.35	**	0.028	**	0.0300	**
5	14-May	15:35	15-May	5:56	14:21	14-May	15:27	15-May	15:29	12:02	0.45	13420.38	303.51	0.497	0.004	1.5977	0.0573
6	**	**	**	**	**	26-May	12:07	26-May	22:38	10:31	3.24	**	110.06	**	0.079	**	0.0208
7	11-Jun	19:37	13-Jun	13:18	20:42	11-Jun	13:29	15-Jun	7:31	66:02	1.28	675.15	284.99	0.633	0.002	0.0804	0.0538
8	13-Jun	20:31	13-Jun	22:17	1:46	11-Jun	13:29	15-Jun	7:31	66:02	0.05	25.41	284.99	0.009	0.002	0.0030	0.0538
9	4-Jul	20:56	5-Jul	2:29	5:33	**	**	**	**	**	0.63	800.41	**	0.299	**	0.0953	**
10	7-Jul	0:18	7-Jul	2:37	2:19	7-Jul	0:07	8-Jul	10:48	34:41	0.29	371.67	159.24	0.397	0.002	0.0442	0.0300
11	20-Jul	17:55	20-Jul	21:53	3:58	**	**	**	**	**	0.21	153.63	**	0.042	**	0.0183	**
12	2-Aug	20:40	3-Aug	0:35	3:55	**	**	**	**	**	0.08	201.02	**	0.041	**	0.0239	**
13	9-Aug	17:13	9-Aug	19:08	1:55	**	**	**	**	**	0.13	134.78	**	0.244	**	0.0160	**
14	24-Aug	3:54	24-Aug	8:35	4:39	**	**	**	**	**	0.07	170.52	**	0.050	**	0.0203	**

**No data

Impact on Water Quality

To conduct the water quality analysis, t-tests were performed to compare the arithmetic means for the reference site and the BMP for each constituent. Since the sample sizes for 2008 and 2010 were too small to analyze the data by year, the reference site and PICP data for all years was combined and then analyzed. In some cases, the data did not seem to fit a normal distribution, which is not unusual for a sample size under 30, so a non-parametric Wilcoxon signed-rank test was performed in addition to parametric paired t-tests and two sample t-tests. The p-values generated for each of the constituents (alpha=0.05) is shown in Table 4. The values that were significant, below the alpha level of 0.05, are highlighted in bold. It is also important to note that in cases where certain constituents were not detected in a sample, we used 0 as a number for our analysis.

Unexpectedly, some of the constituents at the BMP were in significantly higher concentrations than at the reference site. One possible explanation for some of the higher constituent concentrations at the BMP may be the differences in traffic load between the BMP and the reference site. While the current reference site is as close as possible to the PICP, it is an employee parking lot that receives much less traffic. The PICP, on the other hand, experiences heavy traffic during business hours.

Only 11 of the 29 constituents showed statistically significant differences between reference site and the PICP. Out of the 11, five showed a significant decrease from the reference site to the PICP. These included Dissolved Manganese, Toal Zinc, Chemical Oxygen Demand, Total Kjeldahl Nitrogen, and Total Suspended Solids.

All water quality data is provided in Tables 5-7. Note that in these tables, Reference was abbreviated to Ref. Box-and-whisker plots comparing inflows and outflows for each constituent are shown in Figures 10 through 43. A legend for the box-and-whisker plots is provided in Figure 9. The constituents that were significantly lower in the reference site outflows were Dissolved Magnesium (according to one test), Dissolved Sodium, Dissolved Chromium, Dissolved Selenium, Total Chromium, Total Selenium, Total Molybdenum, Chloride (according to two tests), and Nitrite+Nitrate. The constituents that were significantly lower in the PICP outflows were Dissolved Manganese, Total Zinc (according to one test), Chemical Oxygen Demand, Total Kjeldahl Nitrogen, and Total Suspended Solids.

Table 4. Significance of Differences in Constituent Concentrations at Reference and BMP

Constituent	Two Sample T-Test	Wilcoxon Signed Rank Test	Paired T-Test
Dissolved Calcium	0.2917	0.394	0.3259
Dissolved Iron	0.2749	0.9176	0.2721
Dissolved Magnesium	0.08637	**0.003845**	0.09106
Dissolved Sodium	**8.409 E-5**	**0.000324**	**6.422 E-5**
Dissolved Chromium	**1.077 E-9**	**1.526 E-5**	**1.077 E-9**
Dissolved Manganese	**0.03508**	**0.01286**	**0.02873**
Dissolved Nickel	0.428	0.3061	0.481
Dissolved Copper	0.3394	0.6416	0.3974
Dissolved Zinc	0.1713	0.05569	0.1785
Dissolved Selenium	**4.739 E-6**	**0.001581**	**4.739 E-6**
Dissolved Silver	1	N/A	1
Dissolved Cadmium	0.799	0.7973	0.7891
Dissolved Lead	0.2404	0.4227	0.2483
Total Beryllium	0.1636	0.3711	0.1636
Total Chromium	**0.0005406**	**0.0002136**	**0.0006053**
Total Manganese	0.6005	0.6603	0.5886
Total Nickel	0.6932	0.5349	0.6841
Total Copper	0.93	0.4038	0.9084
Total Zinc	0.07801	**0.001068**	0.08544
Total Arsenic	0.07867	0.1003	0.07867
Total Selenium	**1.484 E-7**	**0.0006998**	**1.484 E-7**
Total Molybdenum	**2.547 E-10**	**1.526 E-5**	**2.434 E-9**
Total Silver	0.3009	0.1975	0.302
Total Cadmium	0.15	0.2932	0.1656
Total Antimony	0.3322	1	0.3322
Total Lead	0.6214	0.3342	0.6086
Chloride	0.05588	**6.104 E-5**	**0.04542**
Chemical Oxygen Demand	**9.523 E-5**	**1.526 E-5**	**4.157 E-5**
Nitrite+Nitrate	**5.74 E-13**	**0.0003204**	**5.531 E-9**
Dissolved Phosphorus	0.1344	0.1032	0.09854
Total Phosphorus	0.9071	0.4346	0.898
Dissolved Potassium	**9.957 E-5**	**0.0006446**	**2.31 E-5**
Total Kjeldahl Nitrogen	**1.061 E-5**	**0.0003198**	**7.726 E-6**
Total Suspended Solids	**0.009343**	**3.052 E-5**	**0.005091**

Table 5. Water Quality Data for 2008

Water Quality Constituent	Storm Event 1		Storm Event 2		Storm Event 3		Storm Event 4		Storm Event 5	
	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP
Dissolved Calcium (mg/L)	**	12	11	18	6	22	13	25	9	**
Dissolved Iron (mg/L)	**	0	0.15	0	0.1	0	0.08	0	0.08	**
Dissolved Magnesium (mg/L)	**	2	1.7	2.8	1	4.3	2	4.6	1.6	**
Dissolved Sodium (mg/L)	**	12	6	21	5	34	13	38	7	**
Dissolved Chromium (µg/L)	**	1.6	0	1.5	0	4.9	0	4	0	**
Dissolved Manganese (µg/L)	**	26.2	94.1	5.4	5.7	1.8	34.2	1.1	30.2	**
Dissolved Nickel (µg/L)	**	0	1.3	0	0	0	1.5	0	0	**
Dissolved Copper (µg/L)	**	5.4	5.5	8.2	7.8	8.3	7.8	8.7	17.3	**
Dissolved Zinc (µg/L)	**	83	13	12	12.4	7.9	33.3	18	25.8	**
Dissolved Selenium (µg/L)	**	0	0	0	0	1.3	0	1.2	0	**
Dissolved Silver (µg/L)	**	0	0	0	0	0	0	0	0	**
Dissolved Cadmium (µg/L)	**	0	0.1	0.1	0	0	0.1	0	0.3	**
Dissolved Lead (µg/L)	**	0	0	0	0	0	0	0	0	**
Total Beryllium (µg/L)	**	0	0	0	0	0	0	0	0	**
Total Chromium (µg/L)	**	0	8.2	8.3	0	7.3	9.4	6.2	0	**
Total Manganese (µg/L)	**	32.1	254	72.8	74.5	31	232	42.9	124	**
Total Nickel (µg/L)	**	1.1	7.4	5.2	2.8	1.7	8.7	1.6	4.4	**
Total Copper (µg/L)	**	5.8	31.7	21	15.3	8	43.6	77.6	36.4	**
Total Zinc (µg/L)	**	97.6	188	67.4	67.1	22.6	245	36.6	147	**
Total Arsenic (µg/L)	**	0	0	0	0	0	0	0	0	**
Total Selenium (µg/L)	**	0	0	0	0	1.3	0	1.3	0	**
Total Molybdenum (µg/L)	**	0	0	13.6	0	16.6	0	16.4	0	**
Total Silver (µg/L)	**	0	0	0	0	0	0.4	0.2	0	**
Total Cadmium (µg/L)	**	0	1	0	0	0	1	0	0.9	**
Total Antimony (µg/L)	**	0	0	0	0	0	0	0	0	**
Total Lead (µg/L)	**	0	28.3	12.7	9	0	27.7	0	15.2	**
Chloride (mg/L)	**	9	6	23	**	**	**	**	**	**
Chemical Oxygen Demand (mg/L)	**	82	418	65	48	25	252	58	174	**
Nitrite+Nitrate (mg/L)	**	1	0.19	1.76	0.27	1.74	0.69	1.27	0.28	**
Dissolved Phosphorus (mg/L)	**	0.13	0.04	0.06	0.04	0.08	0.02	0.05	0.1	**
Dissolved Potassium (mg/L)	**	3	2	3	1	4	2	5	3	**
Total Phosphorus (mg/L)	**	0.21	0.9	0.3	0.13	0.12	0.46	0.18	0.33	**
Total Kjeldahl Nitrogen	**	2.8	4.5	2.2	1.2	0	4.2	1.1	2	**
Total Suspended Solids	**	11	1360	188	131	35	508	45	154	**

**No Data

Note: 0 values indicate a level below the detection limit.

Table 6. Water Quality Data for 2009

Water Quality Constituent	Storm Event 1		Storm Event 3		Storm Event 4		Storm Event 7		Storm Event 11		Storm Event 12		Storm Event 14		Storm Event 16		Storm Event 17		Storm Event 18		Storm Event 20		Storm Event 21	
	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP
Dissolved Calcium (mg/L)	5	81	**	70	**	14	16	**	6	14	3	12	19	21	7	21	41	17	8	9	23	9	21	10
Dissolved Iron (mg/L)	0.2	0	**	0	**	0.1	0.1	**	0.1	0.2	0.1	0.1	0.1	0	0.1	0	0.5	0	0	0.1	0.1	0.2	0.3	0.1
Dissolved Magnesium (mg/L)	1.4	39	**	28	**	6.2	3.6	**	1.1	4.4	0.6	4.3	3.8	7.2	1	7.2	7.6	7	1.4	3.5	4.6	3.3	3.4	3.6
Dissolved Sodium (mg/L)	29	154	**	176	**	49	20	**	7	61	5	44	21	60	8	55	32	54	7	42	20	40	15	36
Dissolved Chromium (µg/L)	0	5	**	7.1	**	3.4	0	**	0	4.3	0	4.1	0	5.2	0	4.8	0	6	0	3.7	0	2.6	0	3
Dissolved Manganese (µg/L)	33	8.4	**	5.3	**	5.1	12	**	34	3.4	17	6.1	12	8.5	14	5.4	14	2.6	28	9	4	2.5	134	8.9
Dissolved Nickel (µg/L)	1.5	0	**	0	**	0	1.9	**	0	0	0	0	2.1	1.9	2.4	0	2.6	0	0	0	1.3	0	2.3	0
Dissolved Copper (µg/L)	17	6.4	**	6.6	**	4.2	11	**	5.6	6.4	3	4.7	15	4.6	16	5.6	8.6	4.1	6.1	6.1	8.1	4.2	7.5	5.8
Dissolved Zinc (µg/L)	21	6.4	**	0	**	6	23	**	35	0	11	0	13	0	354	0	13	6.5	9.2	0	9	0	20	8.4
Dissolved Selenium (µg/L)	0	1.4	**	2.2	**	0	0	**	0	1.6	0	1.1	0	0	0	1.2	0	1.4	0	2	0	1.2	0	1.4
Dissolved Silver (µg/L)	0	0	**	0	**	0	0	**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dissolved Cadmium (µg/L)	0.2	0.9	**	0.3	**	0	0.1	**	0.3	0.2	0	0	0	0	0.7	0	0	0	0.1	0	0.2	0.2	0.3	0.1
Dissolved Lead (µg/L)	0	0	**	0	**	0	0	**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.1	0
Total Beryllium (µg/L)	0	0	**	0	**	0	0	**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Chromium (µg/L)	0	8.9	**	11	**	5.8	5.3	**	6.3	7.4	0	6.8	0	10	5.8	11	0	8.4	0	9.1	0	6.4	5.8	5.6
Total Manganese (µg/L)	110	54	**	68	**	79	164	**	176	103	62	72	63	67	92	39	239	39	48	109	61	145	257	121
Total Nickel (µg/L)	5	3	**	2.3	**	2.3	5.9	**	5.8	2.4	2.1	2.2	3	4	6.4	2.5	4.3	1.7	1.5	3.5	2.1	3.3	5.7	2.6
Total Copper (µg/L)	33	14	**	14	**	12	31	**	23	15	13	8.7	19	8.2	31	7.9	19	7.4	8.7	13	11	13	24	12
Total Zinc (µg/L)	129	37	**	30	**	24	163	**	149	25	59	0	41	21	###	0	66	0	30	26	30	32	138	25
Total Arsenic (µg/L)	0	0	**	0	**	0	0	**	0	5.4	0	0	0	0	0	0	0	0	0	0	0	0	0	3.8
Total Selenium (µg/L)	0	1.5	**	2.1	**	1	0	**	0	1.7	0	1.1	0	1	0	1.7	0	1.6	0	1.7	0	1.2	0	1.4
Total Molybdenum (µg/L)	0	6.4	**	12	**	10	0	**	0	11	0	8.9	0	9.5	0	11	6.2	13	0	8.4	0	6.5	0	8
Total Silver (µg/L)	0	6.3	**	0	**	0	0	**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Cadmium (µg/L)	0	1.2	**	0	**	0	0.8	**	0.6	0	0	0	0	0	3.6	0	0	0	0	0	0	0	0.9	0
Total Antimony (µg/L)	0	0	**	0	**	0	0	**	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0
Total Lead (µg/L)	17	5.9	**	5.7	**	0	18	**	21	6.1	5.9	0	0	0	9.4	0	6.6	0	0	5.9	0	7.8	14	5.9
Chloride (mg/L)	34	464	**	461	**	79	**	**	4	55	3	41	23	64	6	60	35	60	6	29	21	24	16	23
Chemical Oxygen Demand (mg/L)	194	54	**	46	**	54	184	**	172	40	39	26	151	31	129	24	146	0	106	35	122	29	230	53
Nitrite + Nitrate (mg/L)	1	1.5	**	1.1	**	1.1	0.7	**	0.2	1.8	0.1	1.4	0.6	2	0.3	2.4	0.1	2.4	0.5	1.4	0.3	1.1	0.2	2
Dissolved Phosphorus (mg/L)	0.1	0.1	**	0.1	**	0.1	0.1	**	0.1	0.2	0	0.1	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1
Dissolved Potassium (mg/L)	2	8	**	6	**	4	4	**	2	4	0	5	4	8	6	8	7	7	2	5	3	5	6	5
Total Phosphorus (mg/L)	0.3	0.2	**	0.2	**	0.2	0.5	**	0.4	0.3	0.2	0.2	0.1	0.1	0.3	0.1	0.4	0.1	0.2	0.3	0.1	0.3	0.7	0.2
Total Kjeldahl Nitrogen (mg/L)	3	1	**	1.1	**	1.6	4.7	**	2.5	0.8	1.1	0.8	2.2	0.6	4.5	0.6	4.1	0.5	1.8	1	2	1.2	4.2	1
Total Suspended Solids (mg/L)	129	75	**	99	**	41	198	**	436	53	116	38	104	39	235	33	230	19	91	64	55	75	481	49

**No Data

Note: 0 values indicate a level below the detection limit.

Table 7. Water Quality Data for 2009 (Cont.)

Water Quality Constituent	Storm Event 22		Storm Event 23		Storm Event 24		Storm Event 25		Storm Event 26		Storm Event 28		Storm Event 29		Storm 30		Storm Event 31		Storm Event 32		Storm Event 33	
	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP
Dissolved Calcium (mg/L)	7	10	24	11	6	14	**	13	6	**	**	27	**	22	**	23	**	23	**	19	**	16
Dissolved Iron (mg/L)	0	0.2	0.3	0.2	0	0.8	**	0.1	0	**	**	0	**	0.1	**	0	**	0.1	**	0.1	**	0.1
Dissolved Magnesium (mg/L)	1.4	3.7	4.2	3.6	1.2	4.1	**	4.6	1	**	**	7.8	**	5.4	**	5.9	**	7.1	**	5.4	**	5.5
Dissolved Sodium (mg/L)	6	32	18	34	6	42	**	35	5	**	**	41	**	46	**	50	**	55	**	42	**	30
Dissolved Chromium (µg/L)	0	2.4	0	2.5	0	3.1	**	3.8	0	**	**	2.1	**	2.5	**	3.3	**	3.7	**	2.8	**	2.8
Dissolved Manganese (µg/L)	22	8.2	75	8.6	13	15	**	6	26	**	**	15	**	7.2	**	0	**	1.5	**	3.3	**	2.3
Dissolved Nickel (µg/L)	0	0	1.4	0	0	0	**	0	0	**	**	1.5	**	0	**	0	**	0	**	0	**	0
Dissolved Copper (µg/L)	5.1	6.5	5	4.4	5.9	5.7	**	3.3	7.4	**	**	7.9	**	6.8	**	6.6	**	4	**	5.3	**	3.6
Dissolved Zinc (µg/L)	8.1	0	15	0	5.7	0	**	0	11	**	**	13	**	7.6	**	0	**	0	**	5.1	**	0
Dissolved Selenium (µg/L)	0	1.1	0	0	0	0	**	1.6	0	**	**	1	**	0	**	1.1	**	1.1	**	0	**	1.1
Dissolved Silver (µg/L)	0	0	0	0	0	0	**	0	0	**	**	0	**	0.2	**	0	**	0	**	0	**	0
Dissolved Cadmium (µg/L)	0	0.2	0.1	0	0	0	**	0.1	0.1	**	**	0.2	**	0	**	0.1	**	0	**	0	**	0
Dissolved Lead (µg/L)	0	0	0	0	0	0	**	0	0	**	**	0	**	0	**	0	**	0	**	0	**	0
Total Beryllium (µg/L)	0	0	0	0	0	0	**	0	0	**	**	0	**	0	**	0	**	0	**	0	**	0
Total Chromium (µg/L)	0	5.1	0	6	0	5.2	**	6	0	**	**	10	**	0	**	0	**	0	**	0	**	0
Total Manganese (µg/L)	106	106	121	125	33	68	**	72	82	**	**	31	**	86	**	30	**	9.5	**	23	**	34
Total Nickel (µg/L)	2.7	2.7	2.4	3.1	1.2	2.4	**	2.2	2.6	**	**	2	**	2.5	**	2.2	**	1.5	**	1.5	**	1.2
Total Copper (µg/L)	13	9.8	11	9.9	6.9	7.4	**	8.5	12	**	**	9	**	17	**	9.9	**	4.9	**	7.9	**	5.9
Total Zinc (µg/L)	75	22	49	25	25	0	**	0	49	**	**	20	**	57	**	24	**	0	**	0	**	0
Total Arsenic (µg/L)	0	0	0	0	0	0	**	0	0	**	**	0	**	0	**	0	**	0	**	0	**	0
Total Selenium (µg/L)	0	1.3	0	1	0	0	**	1.2	0	**	**	1.1	**	0	**	1.1	**	1	**	0	**	0
Total Molybdenum (µg/L)	0	7.6	0	7.5	0	8.5	**	7.5	0	**	**	8.4	**	6.8	**	8.3	**	14	**	8.9	**	7.3
Total Silver (µg/L)	0	0	0	0	0	0	**	0	0	**	**	0	**	0	**	0	**	0	**	0	**	0
Total Cadmium (µg/L)	0	0	0	0	0	0	**	0	0	**	**	0	**	0	**	0	**	0	**	0	**	0
Total Antimony (µg/L)	0	0	0	0	0	0	**	0	0	**	**	0	**	0	**	0	**	0	**	0	**	0
Total Lead (µg/L)	8.5	5.6	0	6.7	0	0	**	0	6.3	**	**	0	**	0	**	0	**	0	**	0	**	0
Chloride (mg/L)	6	19	18	24	4	35	**	23	3	**	**	47	**	87	**	99	**	53	**	41	**	30
Chemical Oxygen Demand (mg/L)	136	40	113	26	71	36	**	90	127	**	**	88	**	63	**	53	**	20	**	24	**	32
Nitrite + Nitrate (mg/L)	0.2	1.8	0.2	1.8	0.6	1.9	**	2.2	0.4	**	**	4.3	**	2.2	**	2.1	**	2.8	**	1.9	**	1.9
Dissolved Phosphorus (mg/L)	0	0.1	0.2	0.1	0	0.1	**	**	0.1	**	**	0	**	0	**	0	**	0.1	**	0	**	0
Dissolved Potassium (mg/L)	2	5	5	6	1	7	**	6	2	**	**	8	**	8	**	9	**	8	**	7	**	5
Total Phosphorus (mg/L)	0.3	0.3	0.3	0.3	0.1	0.2	**	0.2	0.2	**	**	0.1	**	0.1	**	0.1	**	0.1	**	0.1	**	0.1
Total Kjeldahl Nitrogen (mg/L)	1.8	0.7	2.3	0.6	1.8	0.6	**	0.9	2.4	**	**	1.6	**	1.2	**	1.1	**	0.4	**	0.6	**	0.6
Total Suspended Solids (mg/L)	427	33	80	39	78	26	**	40	141	**	**	26	**	41	**	20	**	13	**	10	**	25

Table 8. Water Quality Data for 2010

Water Quality Constituent	Storm Event1		Storm Event 2		Storm Event 3		Storm Event 5		Storm Event 7		Storm Event 9		Storm Event 6		Storm Event 7		Storm Event 8		Storm Event 9	
	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP
Dissolved Calcium (µg/L)	4	**	2	**	4	**	4	**	10	6	5	**	4	3	25	**	21	**	22	**
Dissolved Iron (mg/L)	0.11	**	0	**	0.1	**	0	**	0.22	2.65	0.12	**	0.07	0.96	0.58	**	0.16	**	0.2	**
Dissolved Magnesium (mg/L)	1.3	**	0.6	**	1	**	1.1	**	2.1	2	0.9	**	0.8	0.9	5.6	**	5.2	**	5.6	**
Dissolved Sodium (mg/L)	14	**	2	**	5	**	4	**	6	118	3	**	3	107	24	**	20	**	24	**
Dissolved Chromium (µg/L)	0	**	0	**	0	**	0	**	0	5.9	0	**	0	5.1	0	**	0	**	0	**
Dissolved Manganese (µg/L)	24.7	**	10.7	**	24.9	**	20.5	**	64.1	88.8	46	**	25.6	54.2	159	**	58.3	**	42.5	**
Dissolved Nickel (µg/L)	1.3	**	0	**	0	**	0	**	0	4.7	0	**	0	3.9	4.5	**	2.2	**	2.9	**
Dissolved Copper (µg/L)	5.6	**	0	**	4.6	**	3.7	**	3.6	12.1	0	**	5.2	11.3	14	**	9.6	**	18.2	**
Dissolved Zinc (µg/L)	9.8	**	9	**	10.5	**	15.9	**	10.4	17.6	0	**	8.7	24.6	33.9	**	16	**	30.5	**
Dissolved Selenium (µg/L)	0	**	0	**	0	**	0	**	0	1.2	0	**	0	1.7	0	**	0	**	1.1	**
Dissolved Silver (µg/L)	0	**	0	**	0	**	0	**	0	0	0	**	0	0	0	**	0	**	0	**
Dissolved Cadmium	0	**	0	**	0	**	0	**	0.2	0.1	0	**	0	0.2	0	**	0	**	0	**
Dissolved Lead (µg/L)	0	**	0	**	0	**	0	**	0	5.4	0	**	0	3.3	1	**	0	**	0	**
Total Beryllium (µg/L)	0	**	0	**	0	**	0	**	0	1.9	0	**	0	2	0	**	0	**	0	**
Total Chromium (µg/L)	14.9	**	6.9	**	0	**	0	**	0	26.4	11.4	**	8.2	25.7	7.2	**	8.4	**	0	**
Total Manganese (µg/L)	273	**	150	**	71.9	**	91	**	111	750	249	**	201	855	277	**	222	**	111	**
Total Nickel (µg/L)	11.2	**	5.2	**	2.2	**	3	**	2.4	18.9	8.6	**	7	19.6	9.5	**	7.4	**	5.2	**
Total Copper (µg/L)	48.1	**	20.2	**	10.4	**	12.4	**	9.9	47.6	34.4	**	28.4	52.9	45.2	**	33.5	**	28.4	**
Total Zinc (µg/L)	288	**	135	**	50.5	**	72	**	56.9	144	213	**	162	156	169	**	142	**	82.1	**
Total Arsenic (µg/L)	0	**	0	**	0	**	0	**	0	13.9	0	**	0	16.7	0	**	0	**	0	**
Total Selenium (µg/L)	0	**	0	**	0	**	0	**	0	1.7	0	**	0	2.5	1	**	0	**	0	**
Total Molybdenum (µg/L)	0	**	0	**	0	**	0	**	0	7	0	**	0	6.9	0	**	5.9	**	5	**
Total Silver (µg/L)	0	**	0	**	0	**	0	**	0	0.3	34.8	**	0	0.3	0	**	0	**	0	**
Total Cadmium (µg/L)	1.6	**	0	**	0	**	0	**	0	0	0.6	**	0.6	0.6	0.8	**	0.6	**	0	**
Total Antimony (µg/L)	0	**	0	**	0	**	0	**	0	0	0	**	0	0	0	**	0	**	0	**
Total Lead (µg/L)	34.8	**	16.4	**	0	**	7.7	**	0	38	28.8	**	19.5	39.3	14.3	**	14.3	**	7.2	**
Chloride (mg/L)	13	**	2	**	4	**	2	**	4	101	3	**	2	63	27.8	**	18.1	**	25.1	**
Chemical Oxygen Demand (mg/L)	320	**	109	**	85	**	79	**	91	88	184	**	187	68	417	**	181	**	247	**
Nitrite+Nitrate (mg/L)	0.29	**	0.05	**	0.33	**	0.55	**	0.11	1.63	0.09	**	0.31	1.26	0.08	**	0.68	**	0.81	**
Dissolved Phosphorus (mg/L)	0.09	**	0.03	**	0.2	**	0.01	**	0.06	0.52	0.04	**	0.17	0.62	0.47	**	0.17	**	0.18	**
Dissolved Potassium (mg/L)	2	**	0	**	2	**	1	**	3	6	2	**	2	5	13	**	5	**	5	**
Total Phosphorus (mg/L)	0.72	**	0.28	**	0.34	**	0.17	**	0.28	1.11	0.48	**	0.49	1.23	1.32	**	0.59	**	0.37	**
Total Kjeldahl Nitrogen (mg/L)	3.7	**	1.4	**	2.1	**	1.6	**	2	1.7	2.8	**	2.8	1.8	6.7	**	3.3	**	3.1	**
Total Suspended Solids (mg/L)	886	**	301	**	91	**	202	**	147	122	427	**	384	179	414	**	**	**	102	**

**No Data

Note: 0 values indicate a level below the detection limit.

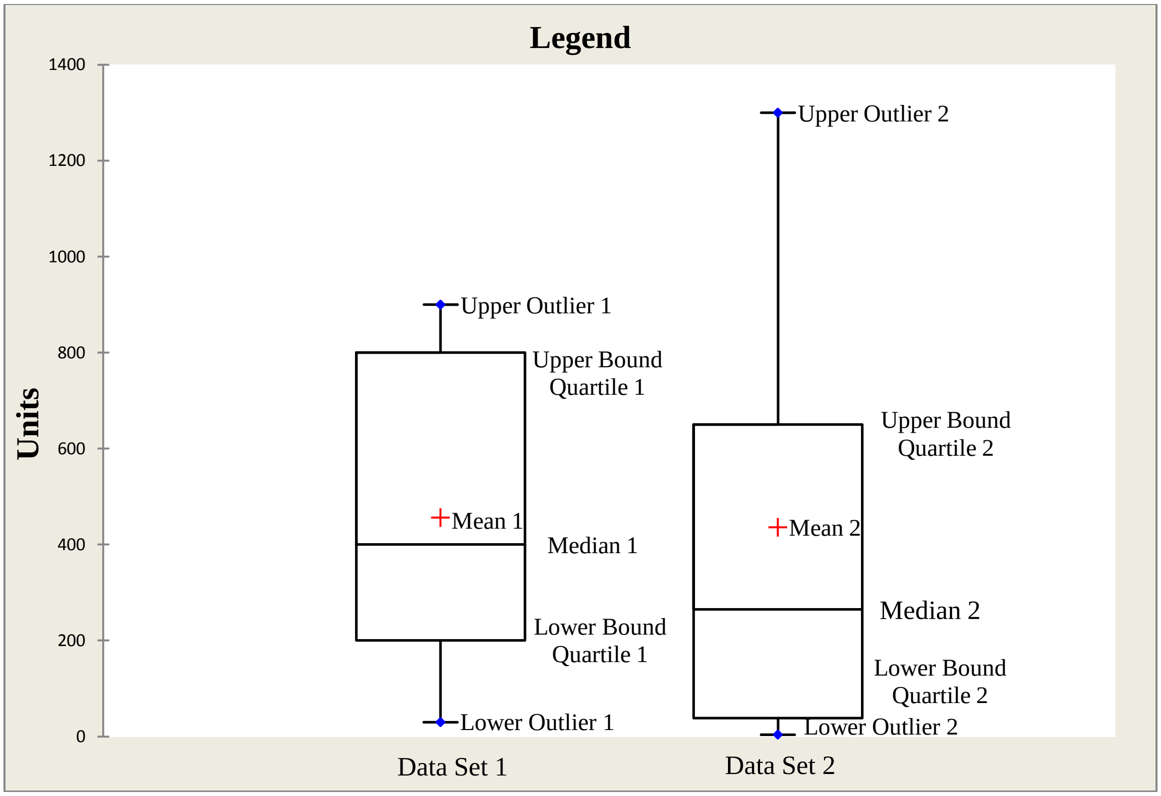


Figure 9. Legend for Box-and-Whisker Plots

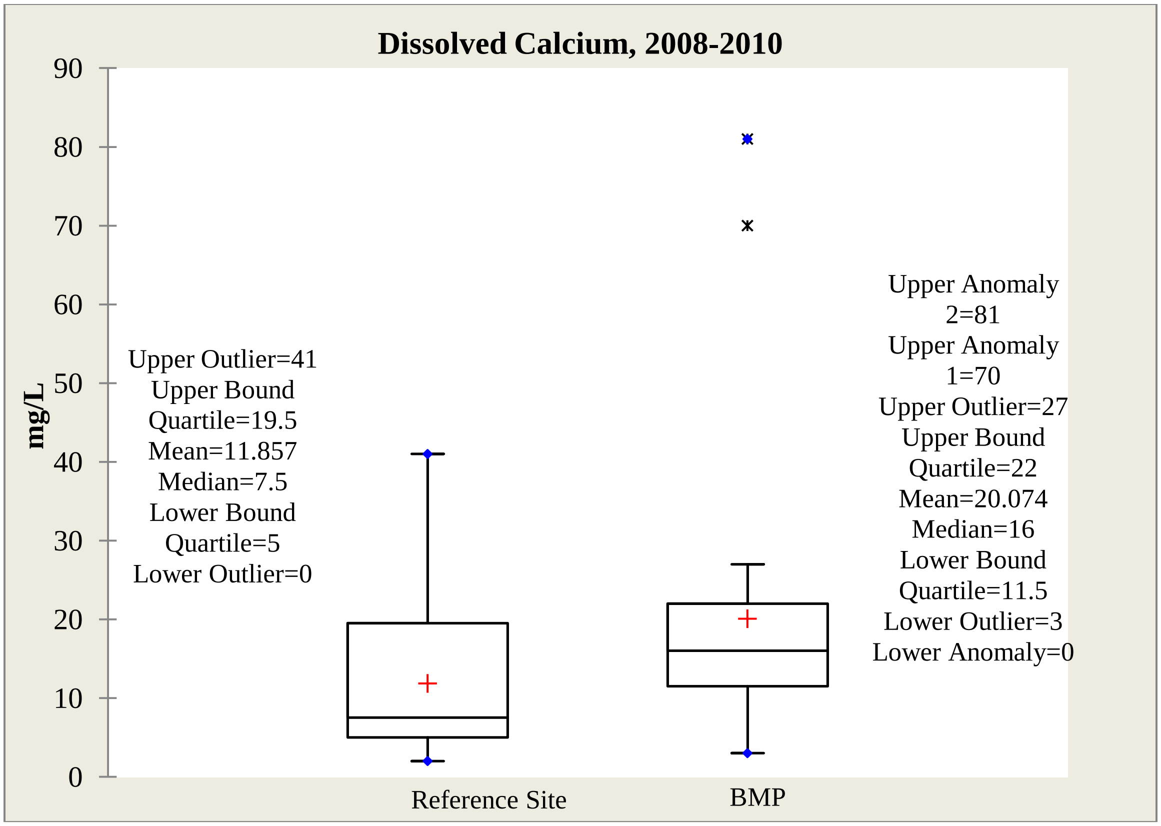


Figure 10. Dissolved Calcium Concentrations at the Reference Site and BMP

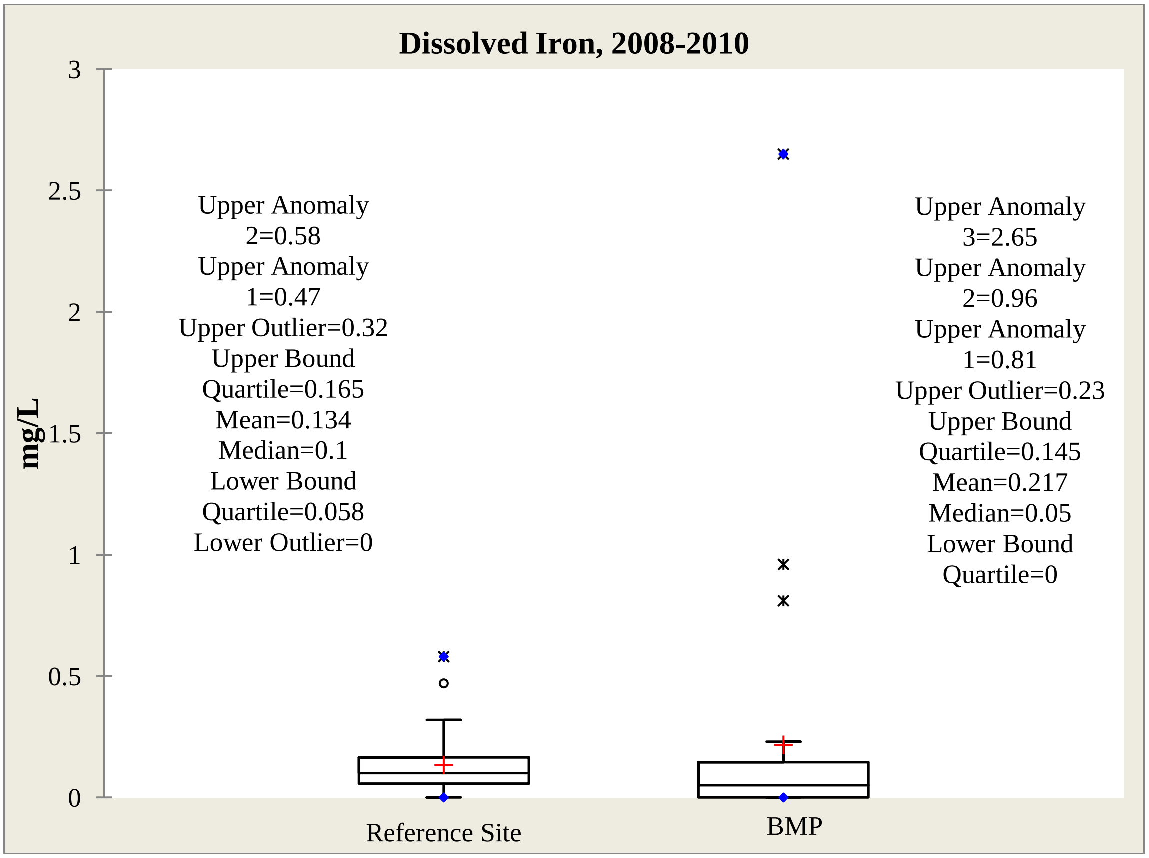


Figure 11. Dissolved Iron Concentrations at the Reference Site and BMP

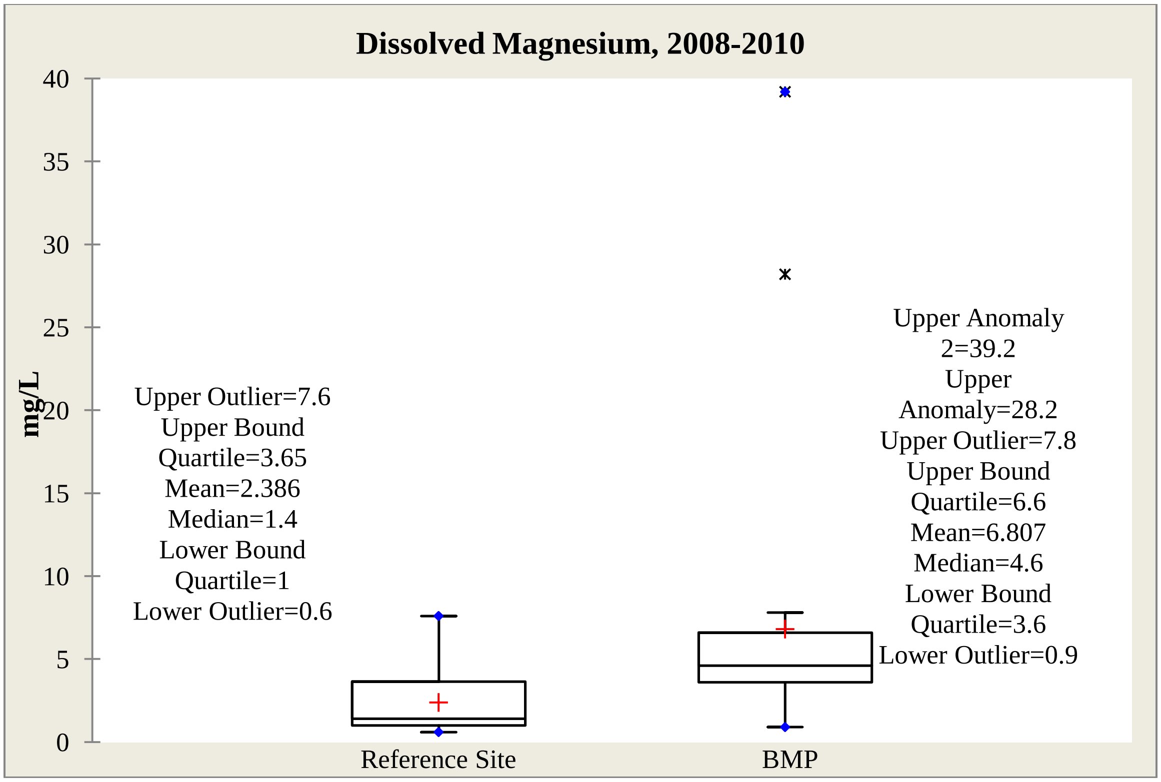


Figure 12. Dissolved Magnesium Concentrations at the Reference Site and BMP

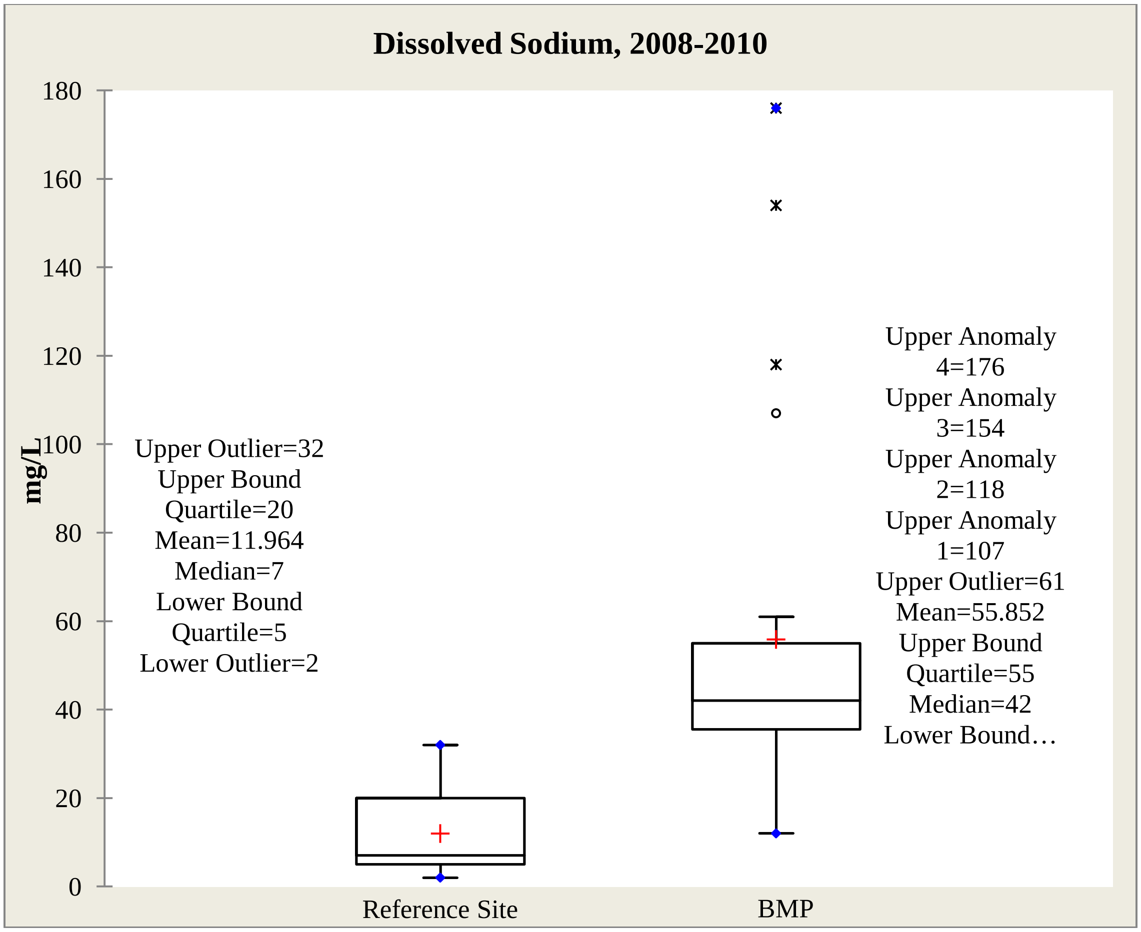


Figure 13. Dissolved Sodium Concentrations at the Reference Site and BMP

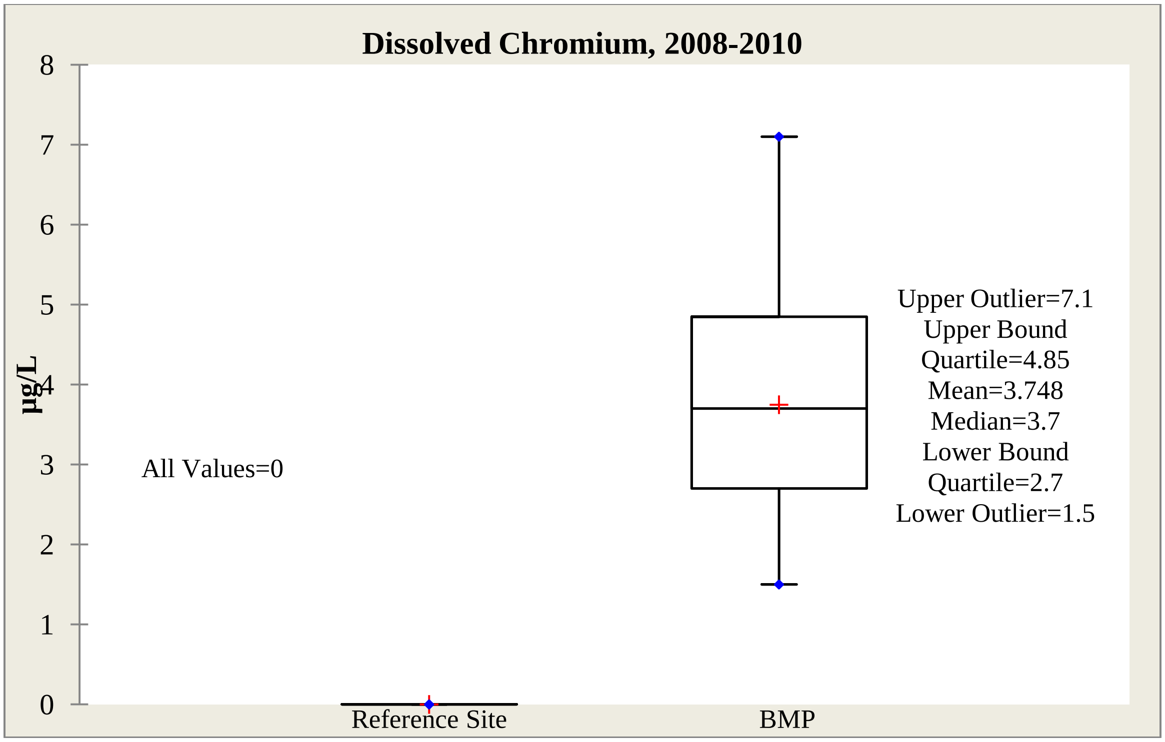


Figure 14. Dissolved Chromium Concentrations at the Reference Site and BMP

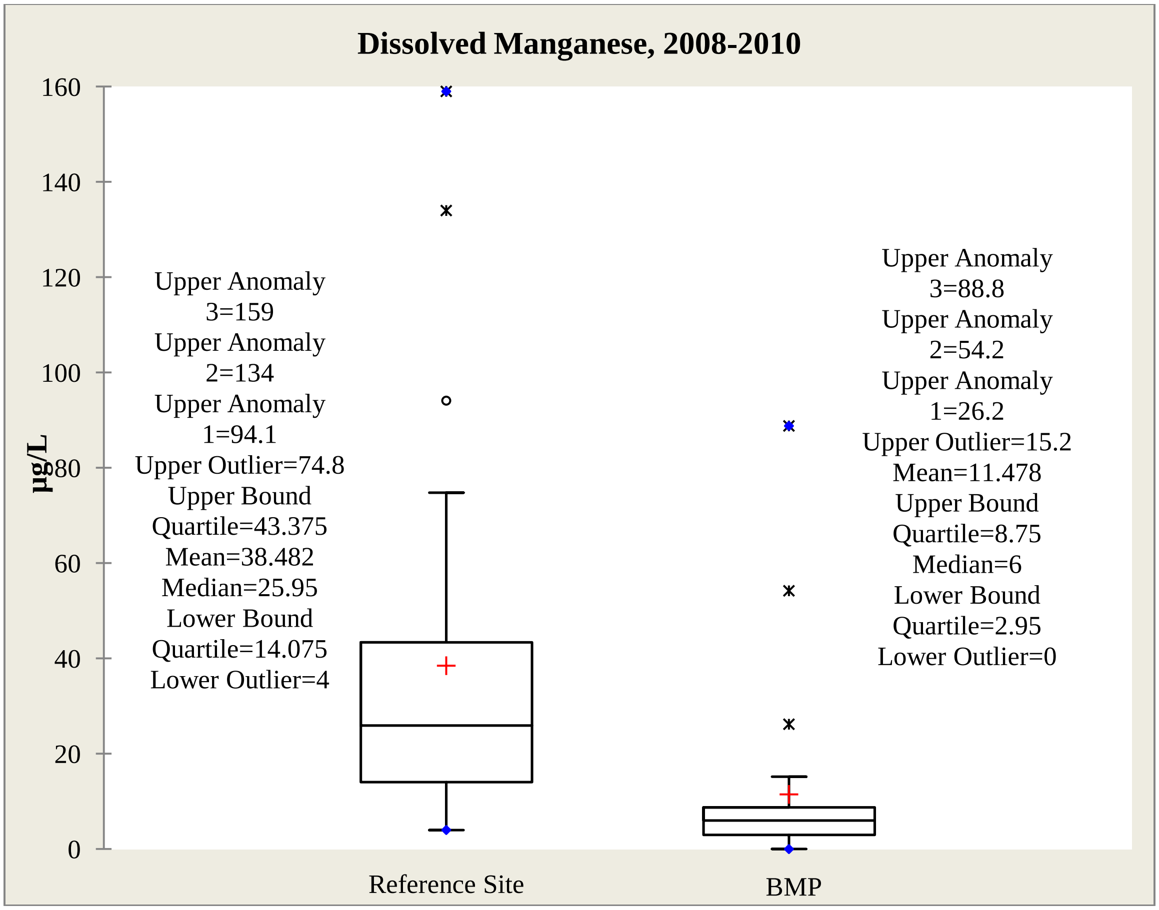


Figure 15. Dissolved Manganese Concentrations at the Reference Site and BMP

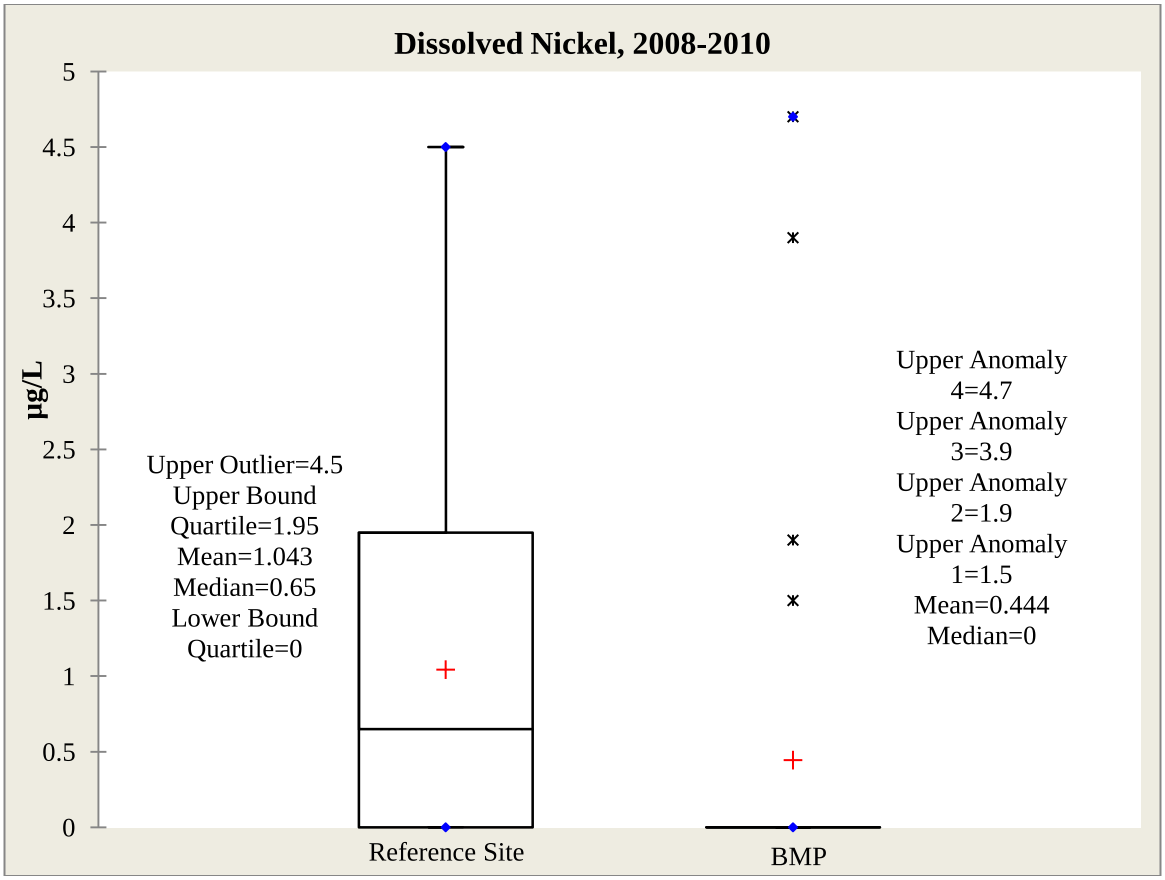


Figure 16. Dissolved Nickel Concentrations at the Reference Site and BMP

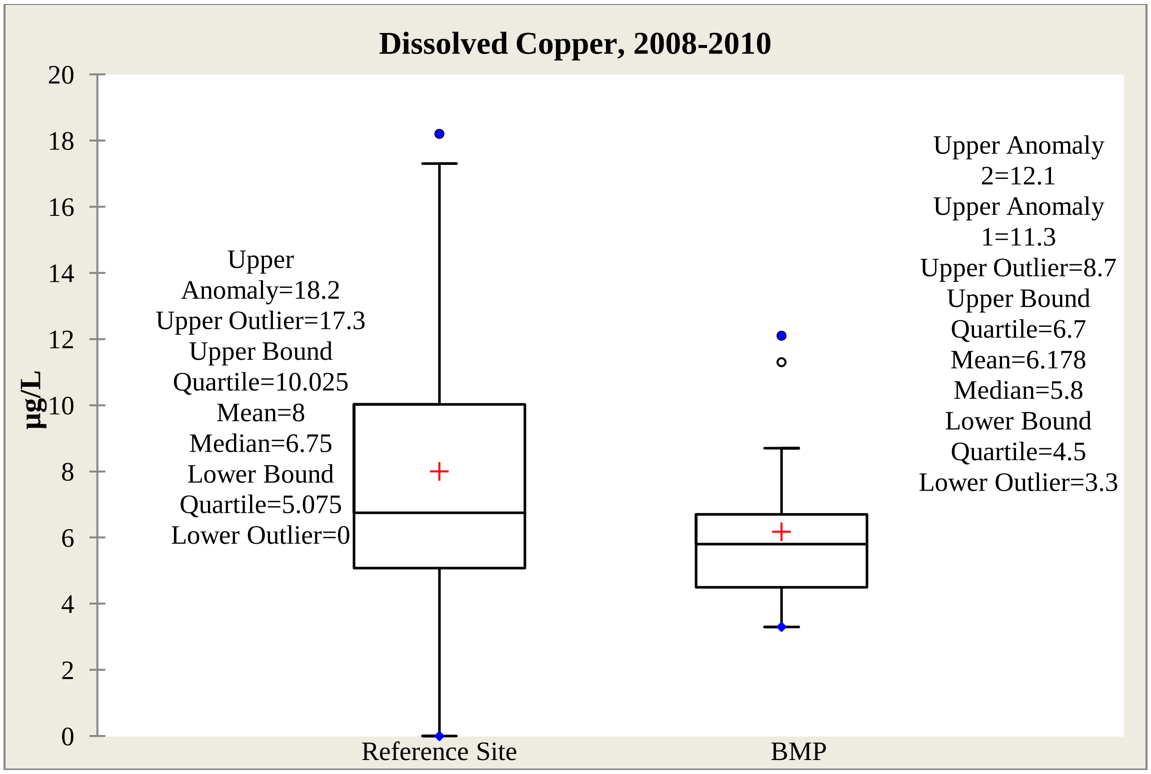


Figure 17. Dissolved Copper Concentrations at the Reference Site and BMP

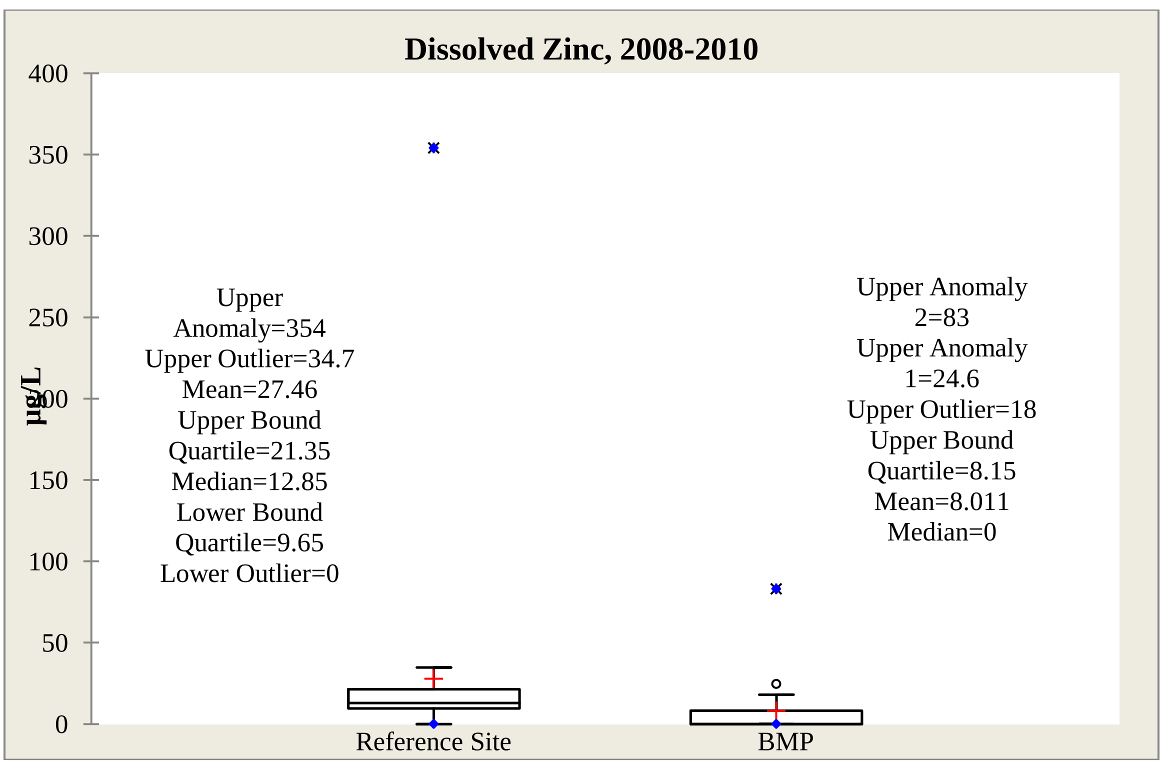


Figure 18. Dissolved Zinc Concentrations at the Reference Site and BMP

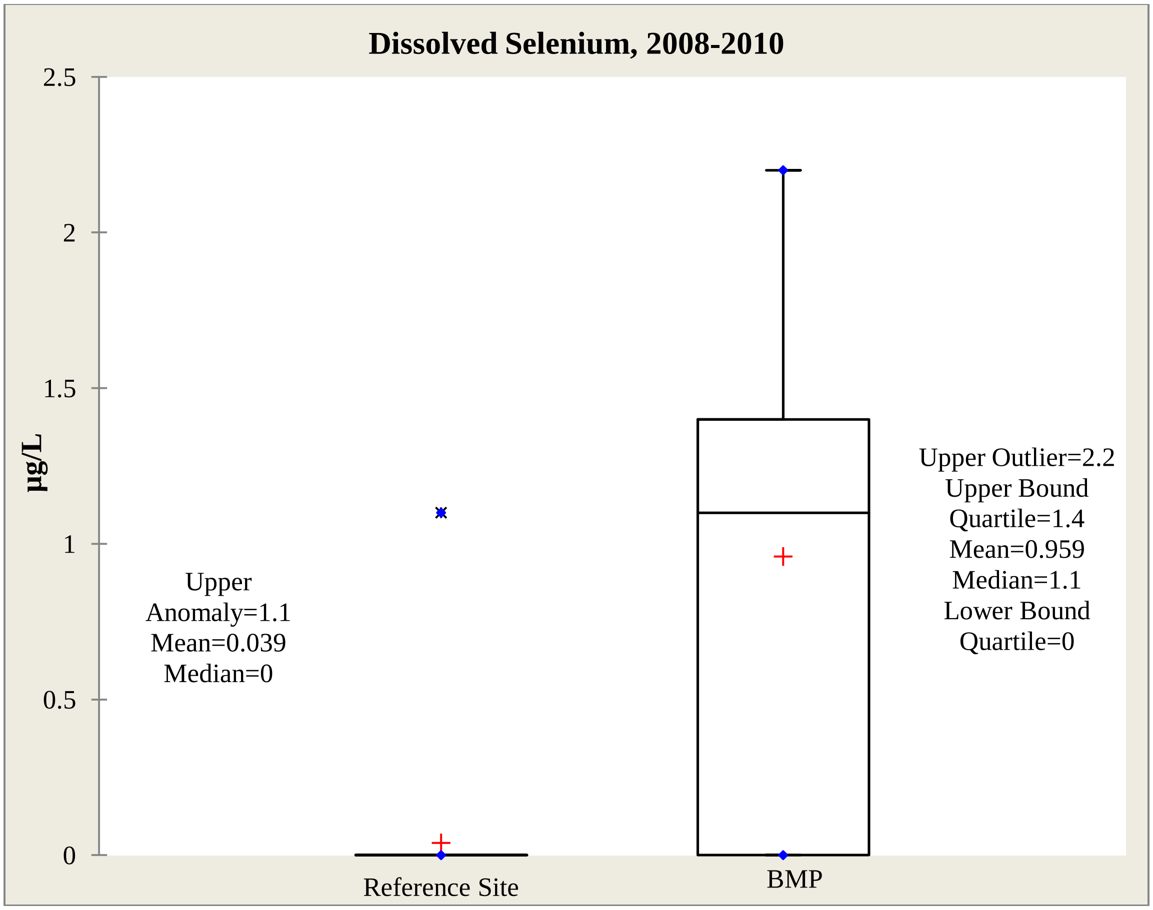


Figure 19. Dissolved Selenium Concentrations at the Reference Site and BMP

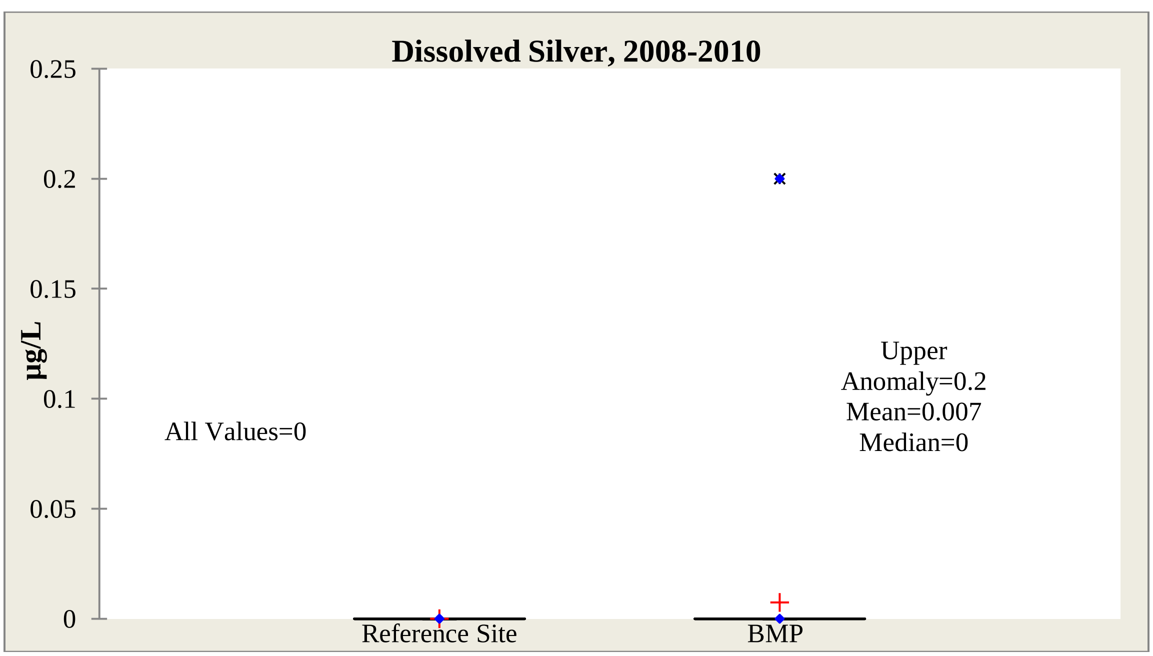


Figure 20. Dissolved Silver Concentrations at the Reference Site and BMP

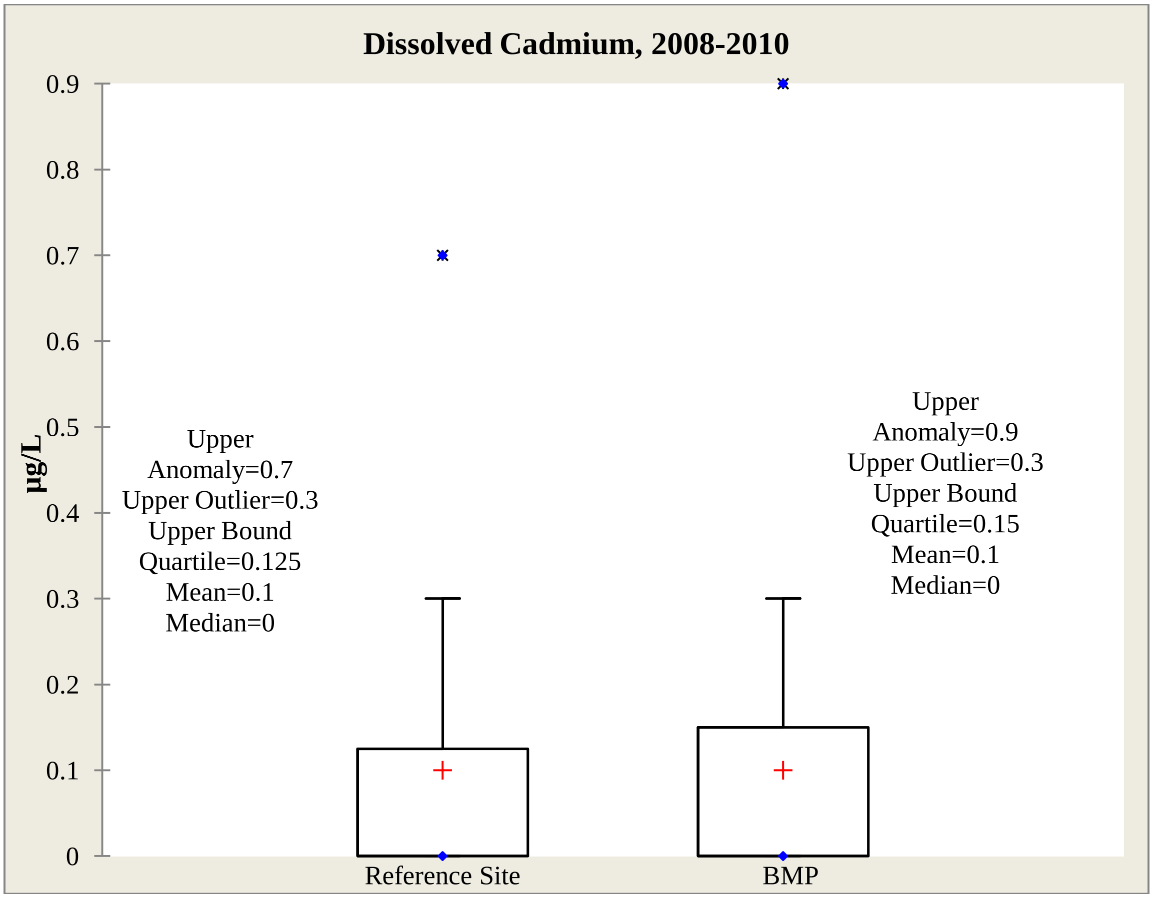


Figure 21. Dissolved Cadmium Concentrations at the Reference Site and BMP

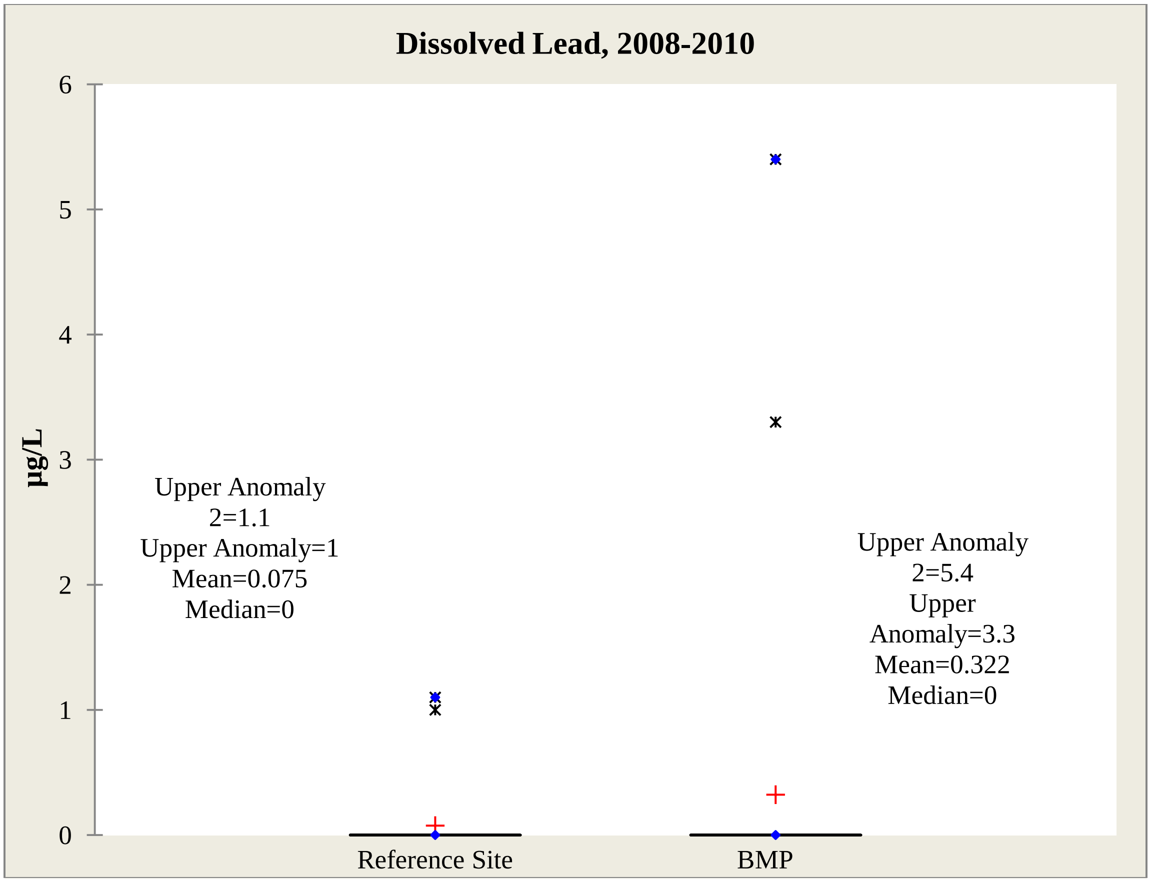


Figure 22. Dissolved Lead Concentrations at the Reference Site and BMP

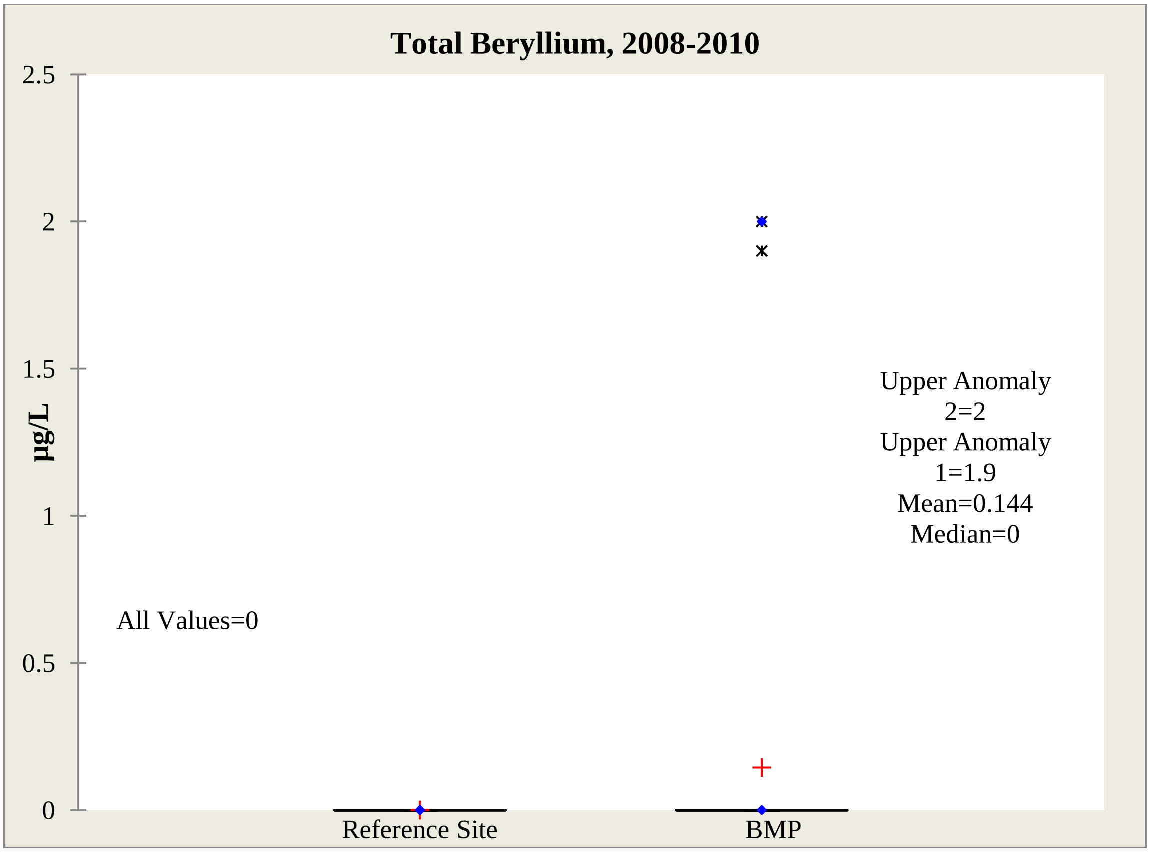


Figure 23. Total Beryllium Concentrations at the Reference Site and BMP

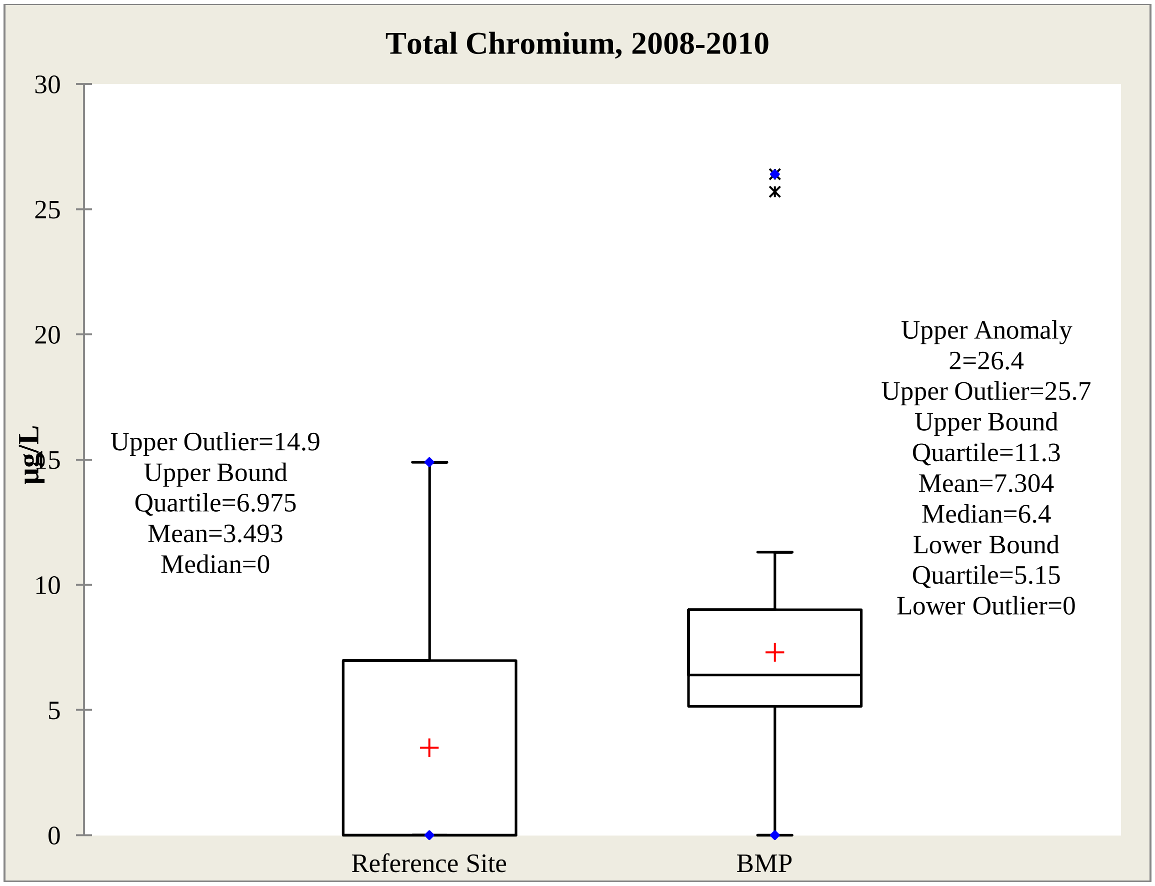


Figure 24. Total Chromium Concentrations at the Reference Site and BMP

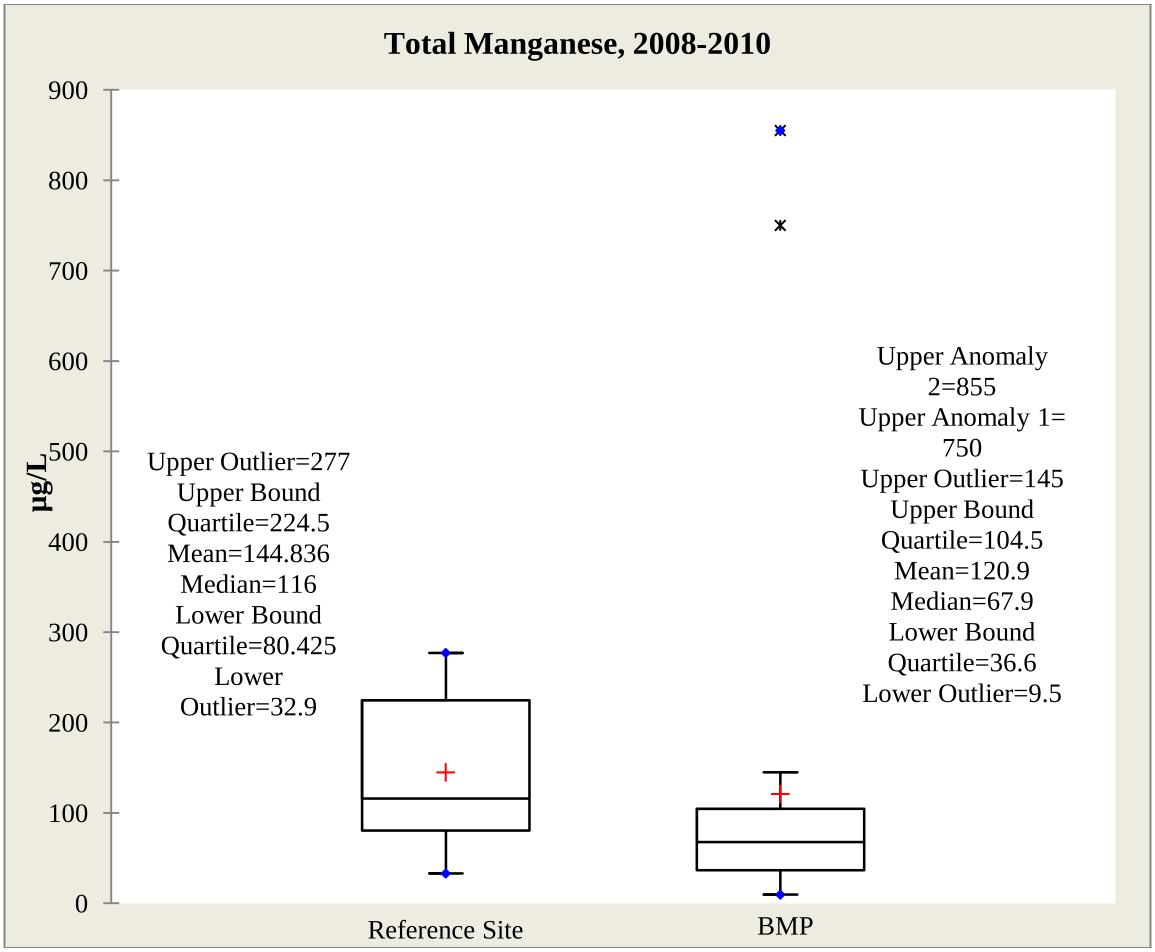


Figure 25. Total Manganese Concentrations at the Reference Site and BMP

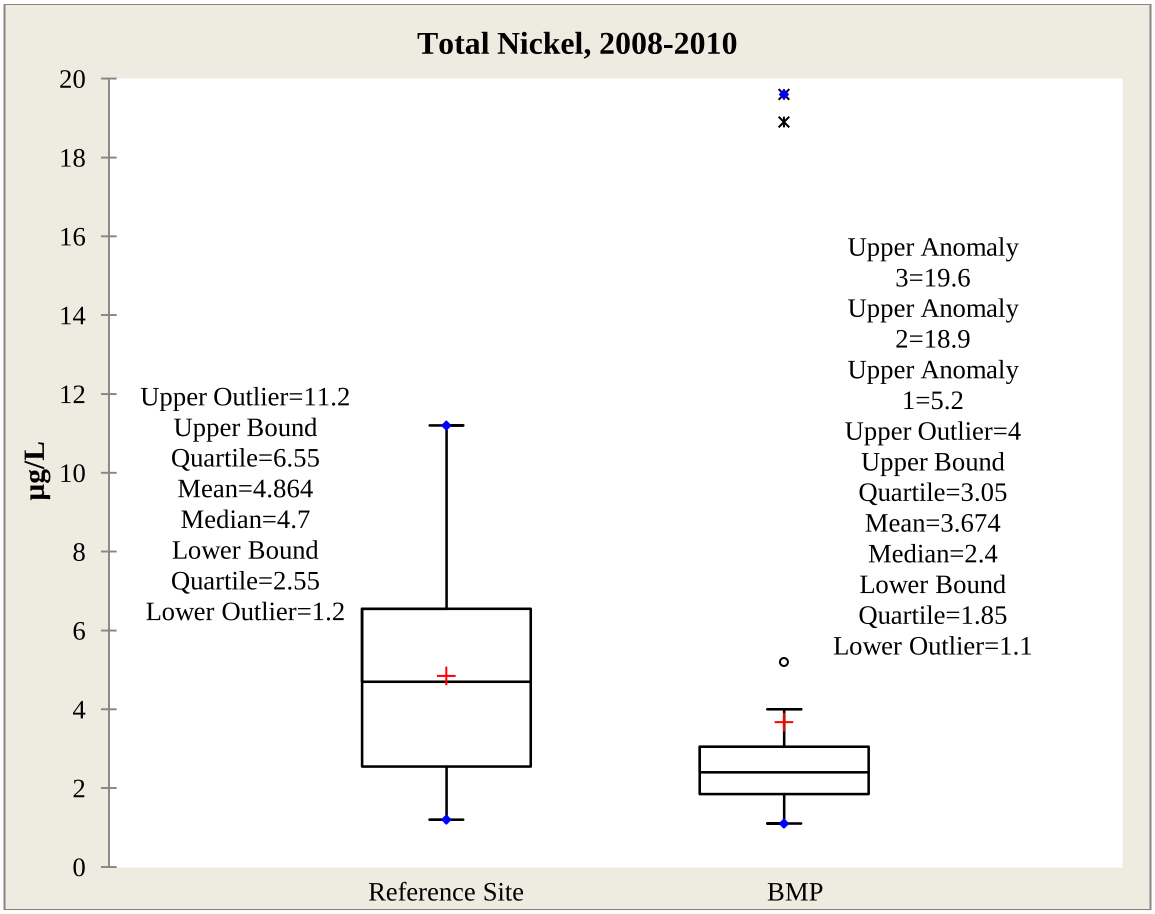


Figure 26. Total Nickel Concentrations at the Reference Site and BMP

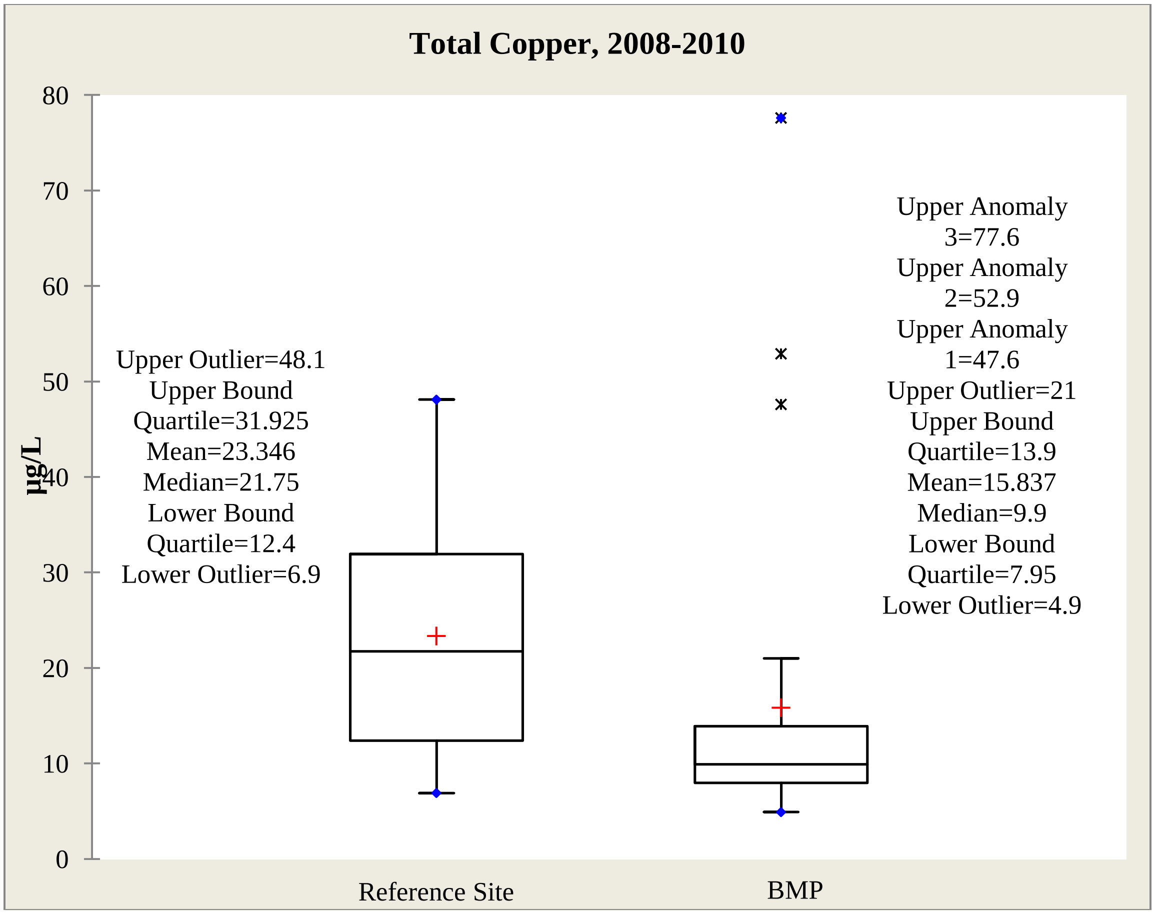


Figure 27. Total Copper Concentrations at the Reference Site and BMP

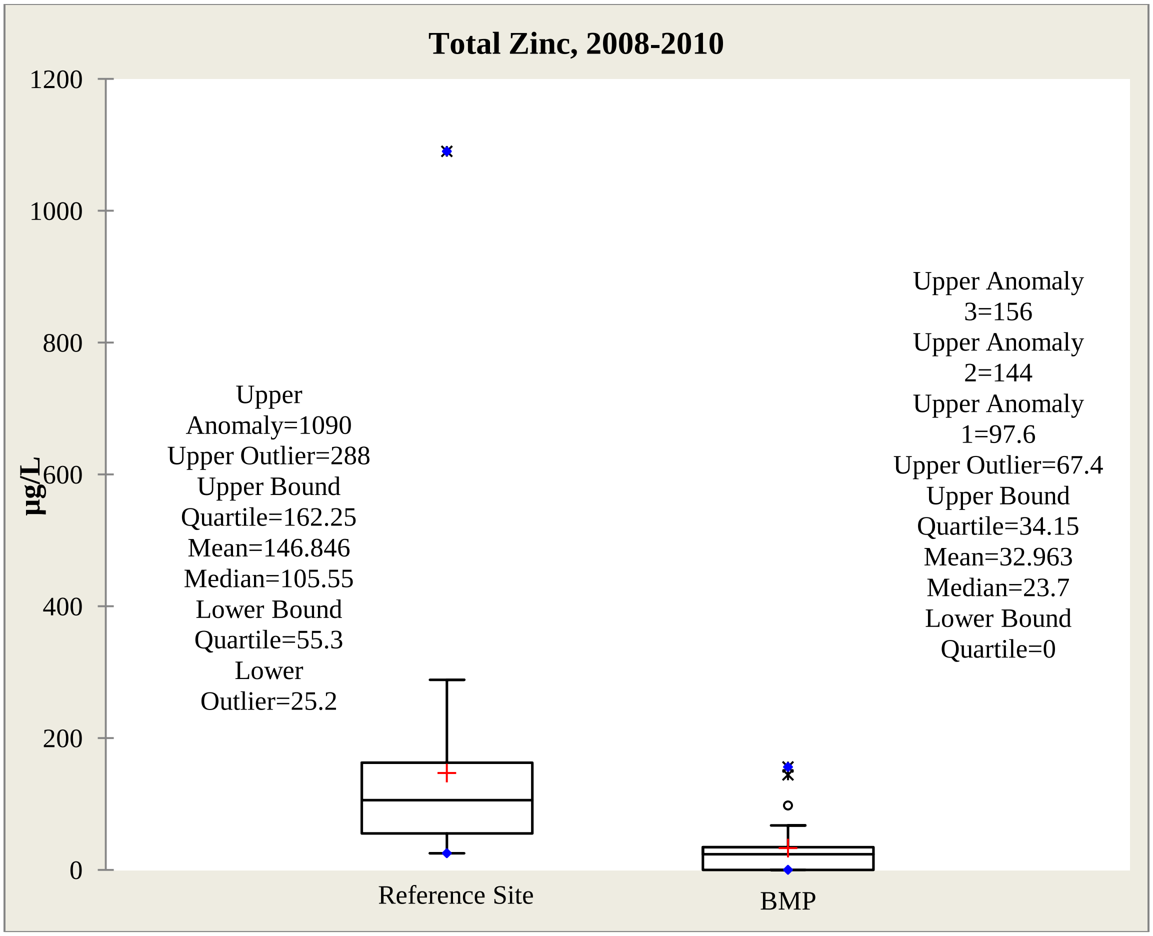


Figure 28. Total Zinc Concentrations at the Reference Site and BMP

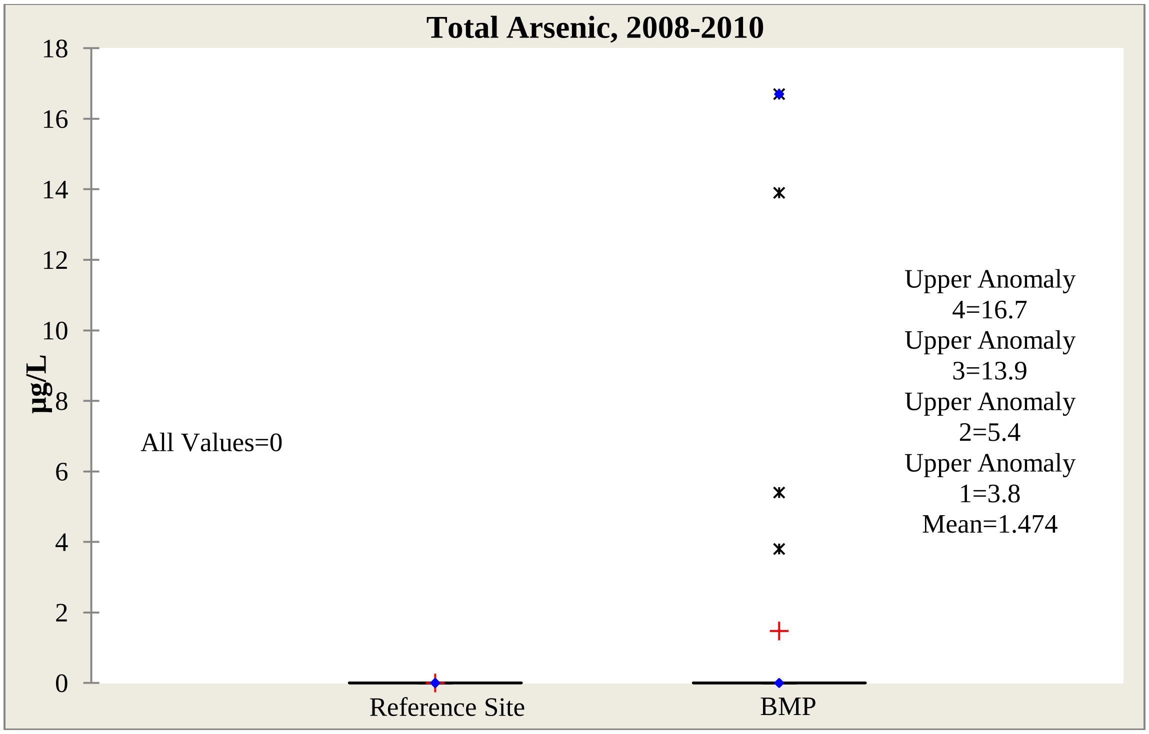


Figure 29. Total Arsenic Concentrations at the Reference Site and BMP

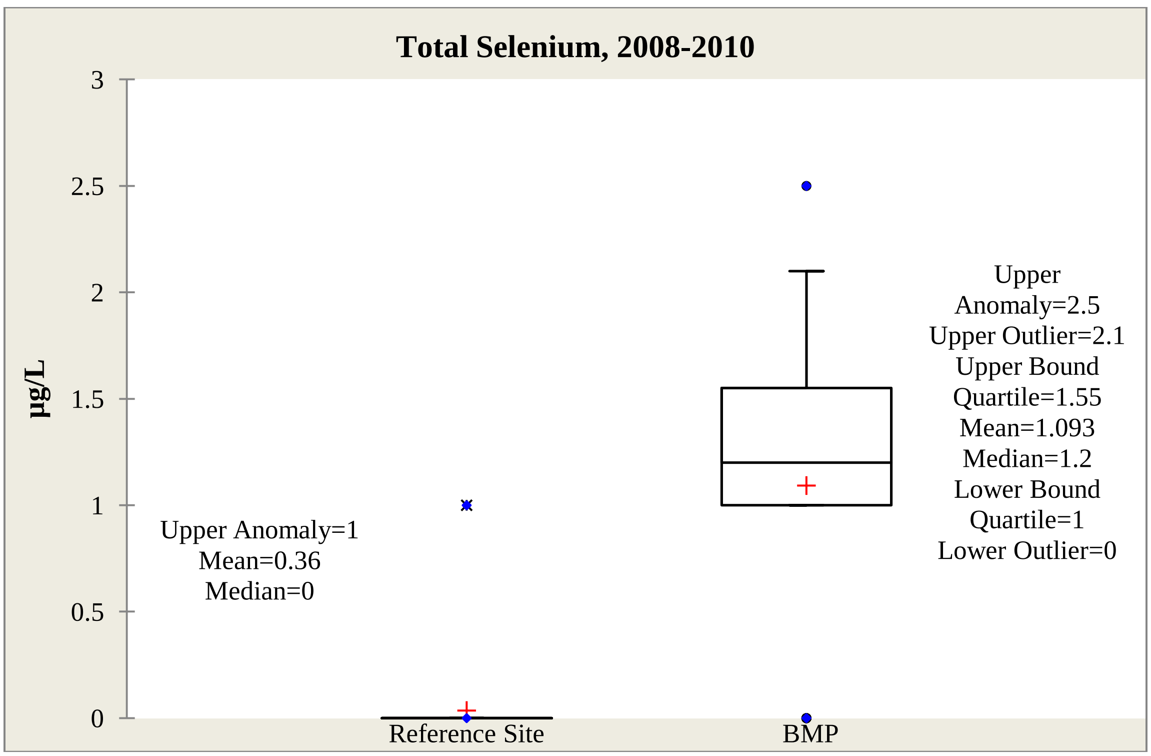


Figure 30. Total Selenium Concentrations at the Reference Site and BMP

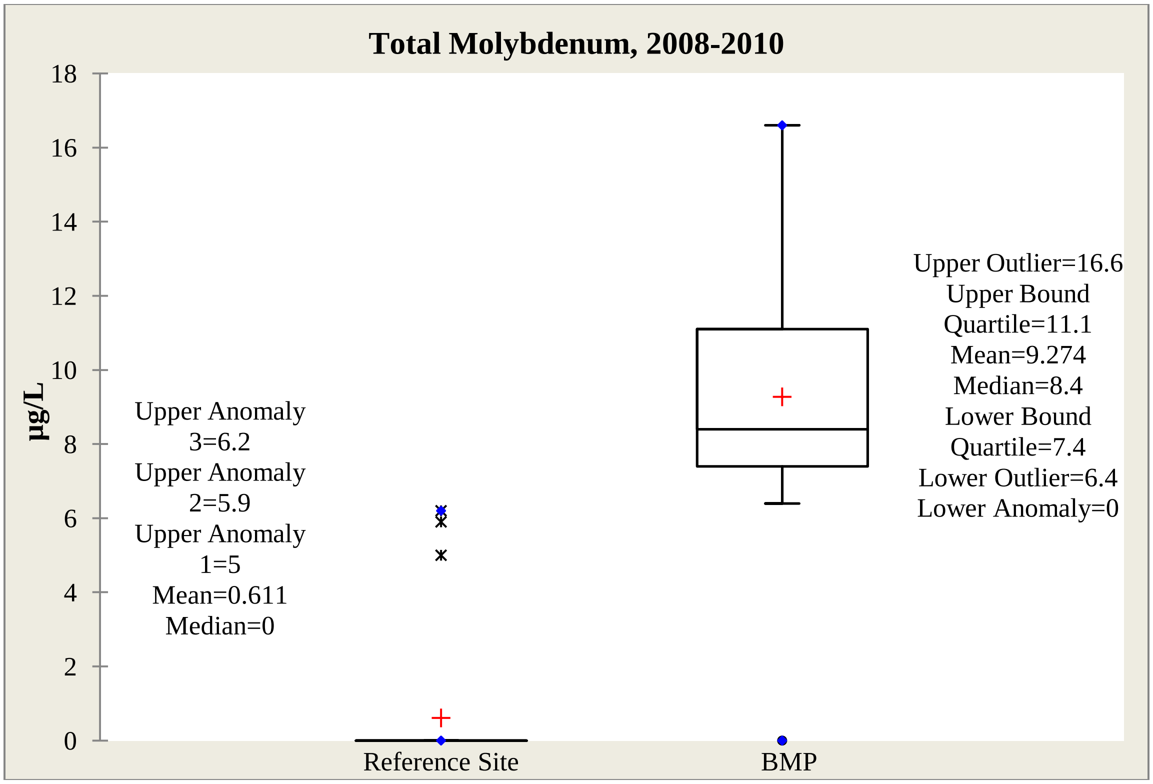


Figure 31. Total Molybdenum Concentrations at the Reference Site and BMP

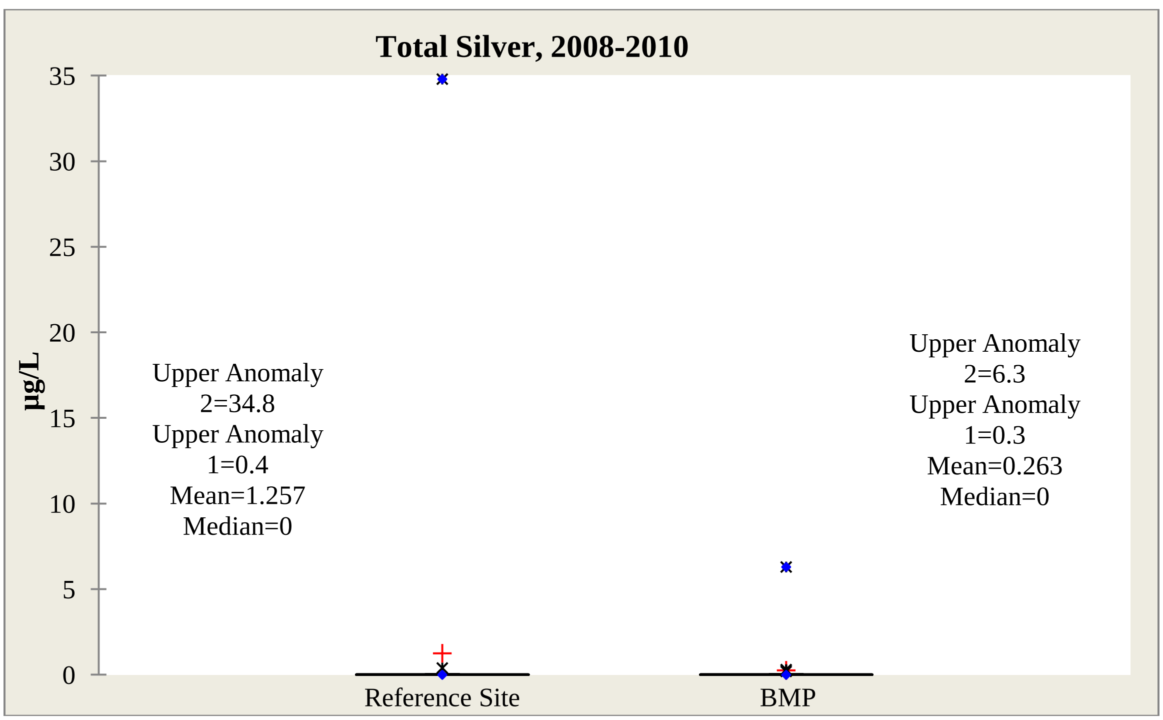


Figure 32. Total Silver Concentrations at the Reference Site and BMP

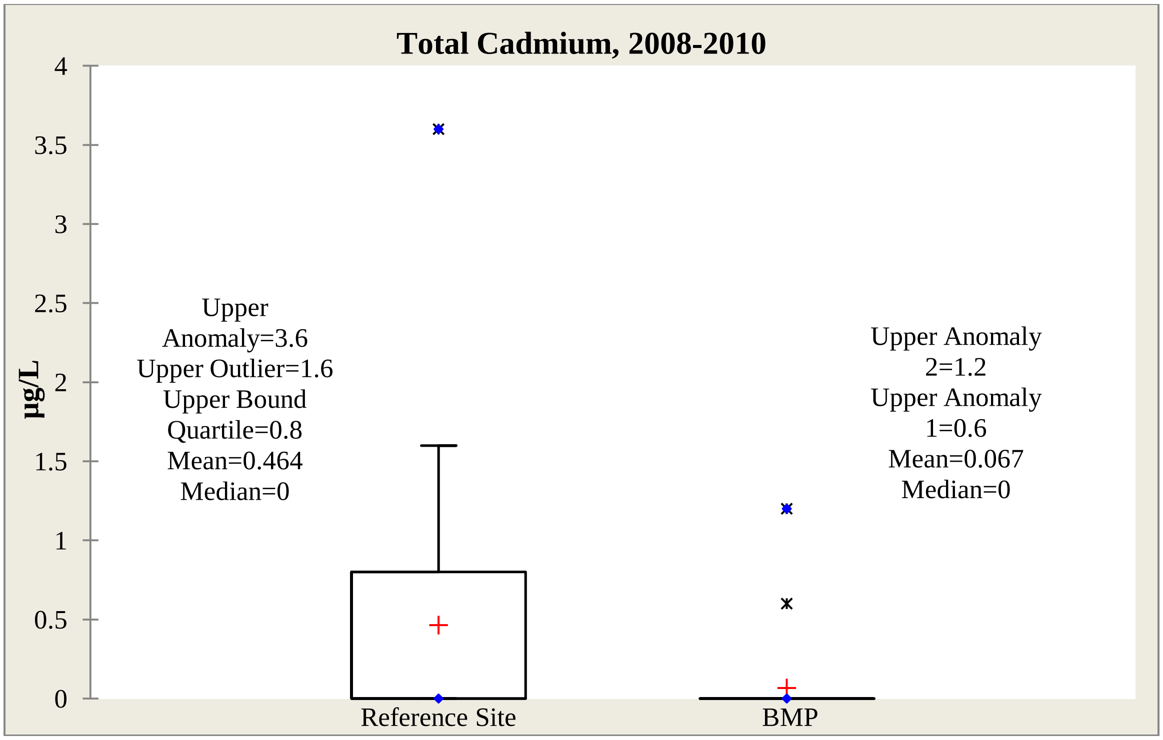


Figure 33. Total Cadmium Concentrations at the Reference Site and BMP

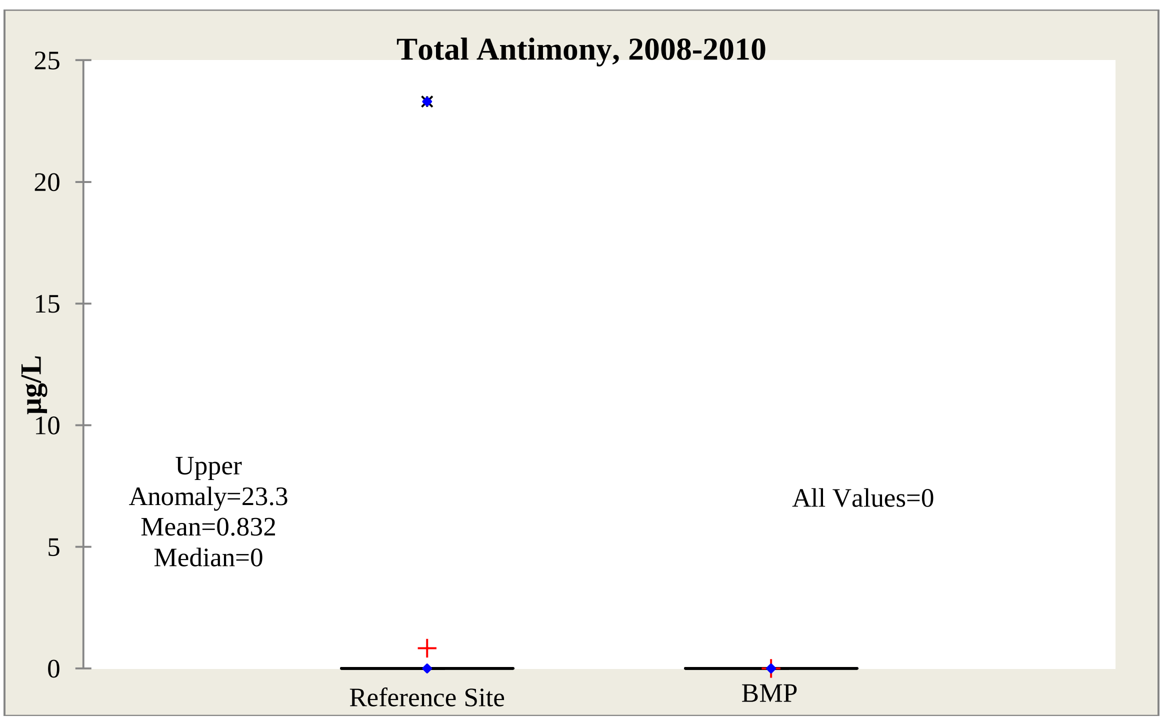


Figure 34. Total Antimony Concentrations at the Reference Site and BMP

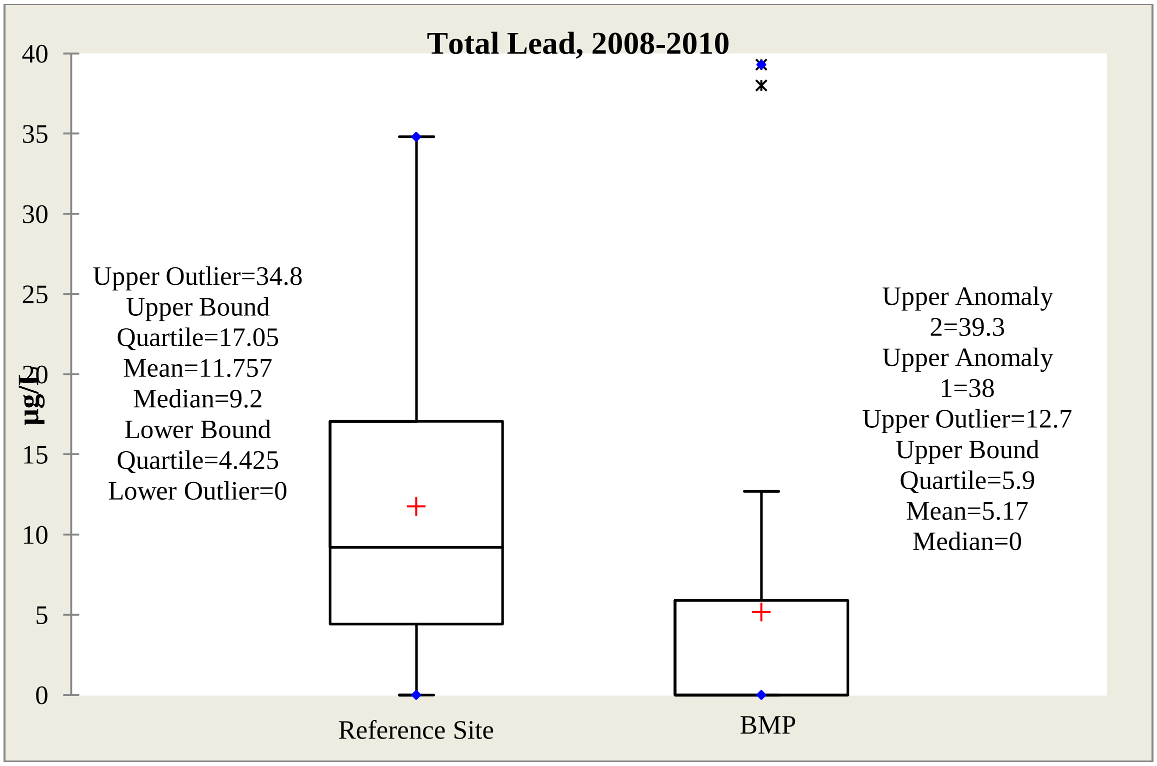


Figure 35. Total Lead Concentrations at the Reference Site and BMP

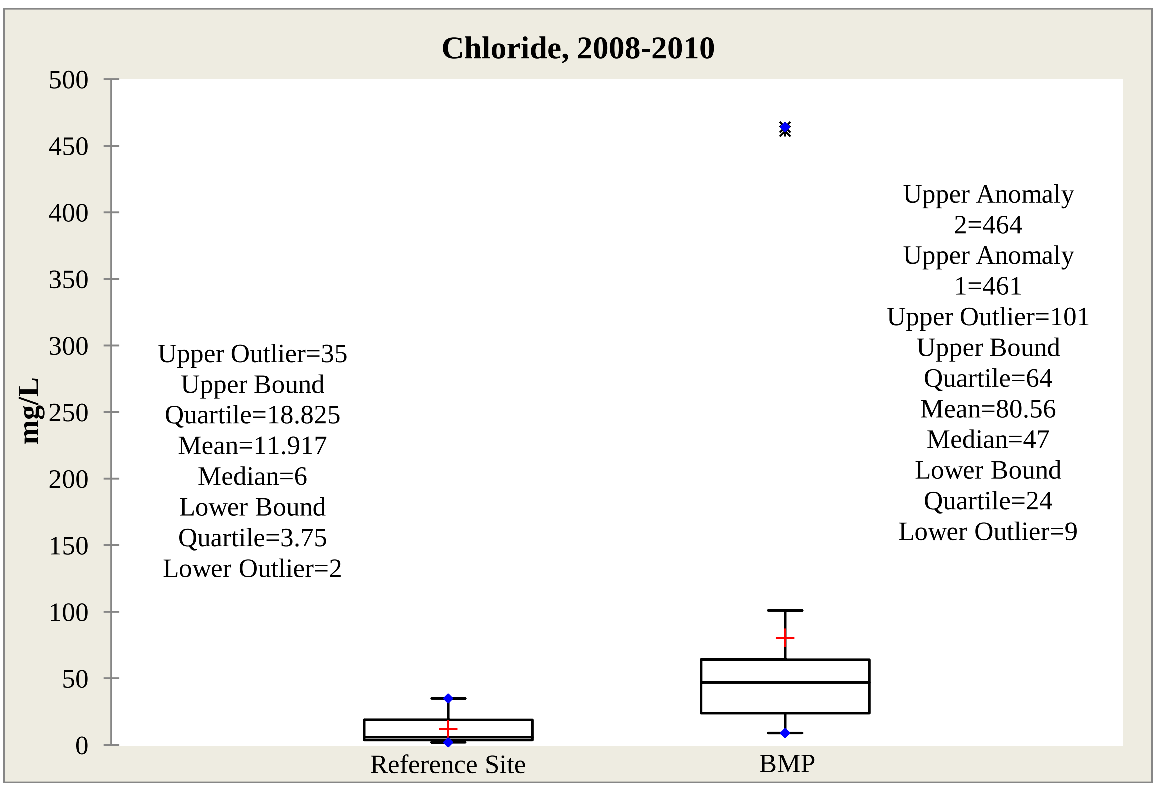


Figure 36. Chloride Concentrations at the Reference Site and BMP

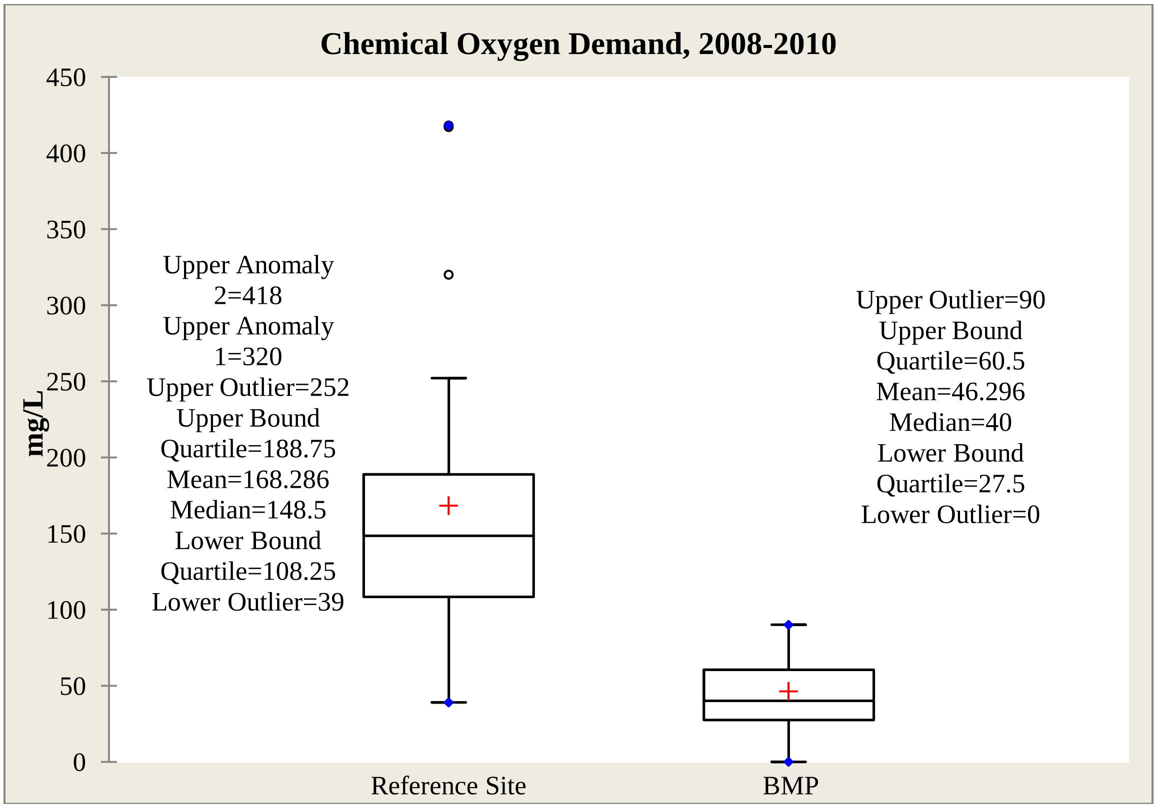


Figure 37. Chemical Oxygen Demand at the Reference Site and BMP

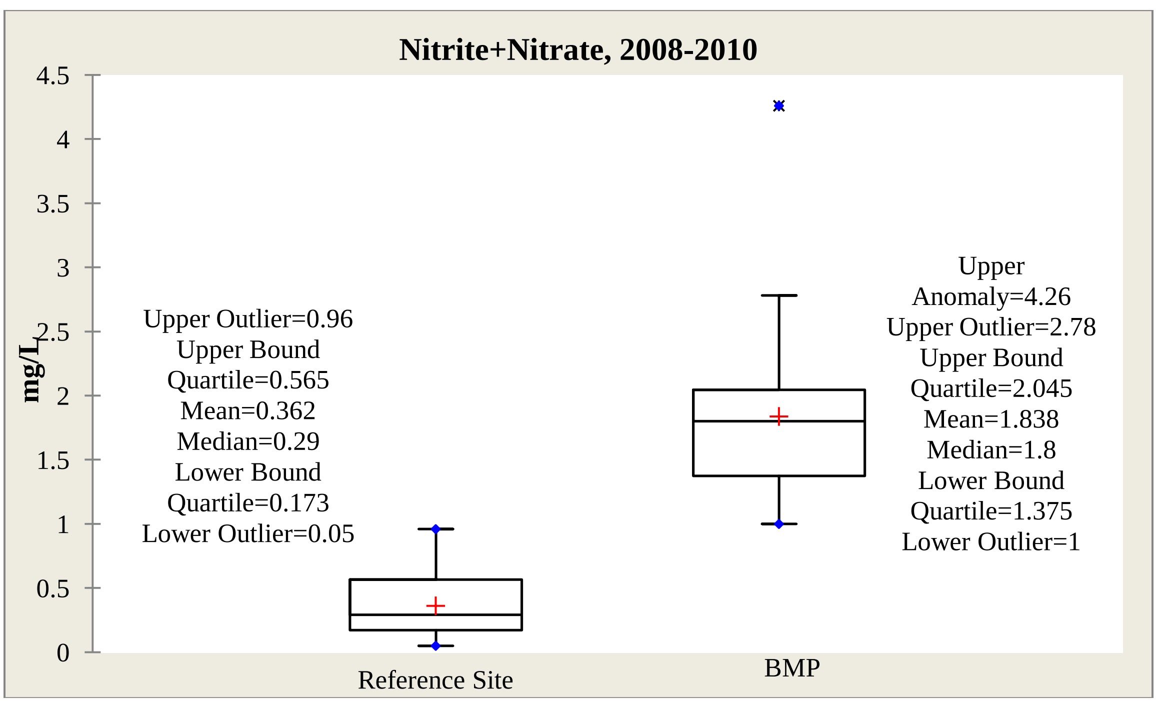


Figure 38. Nitrite + Nitrate Concentrations at the Reference Site and BMP

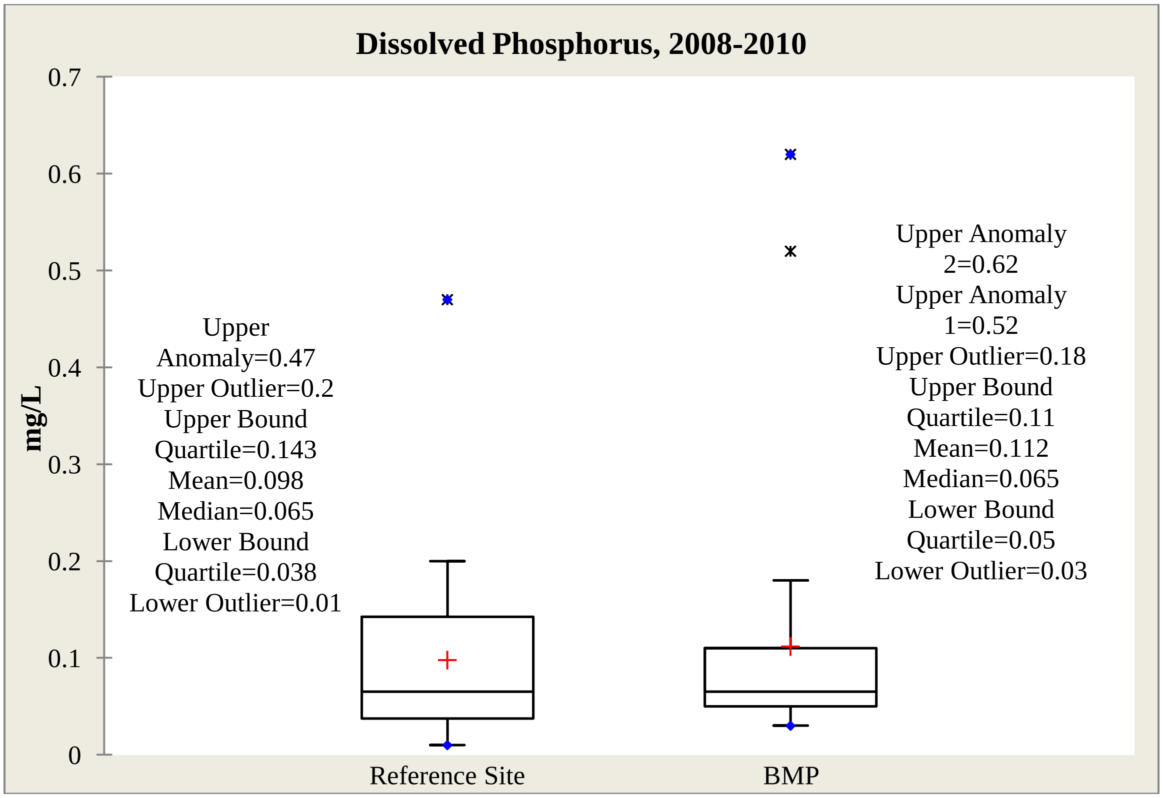


Figure 39. Dissolved Phosphorus at the Reference Site and BMP

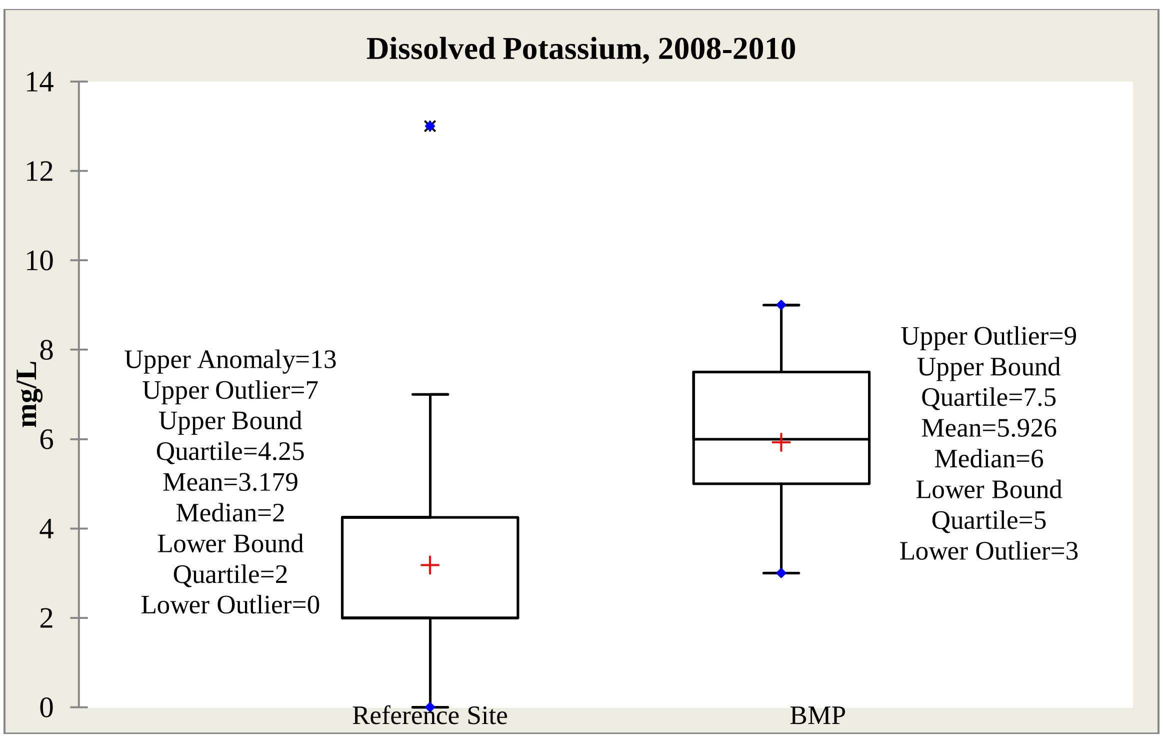


Figure 40. Dissolved Potassium Concentrations at the Reference Site and BMP

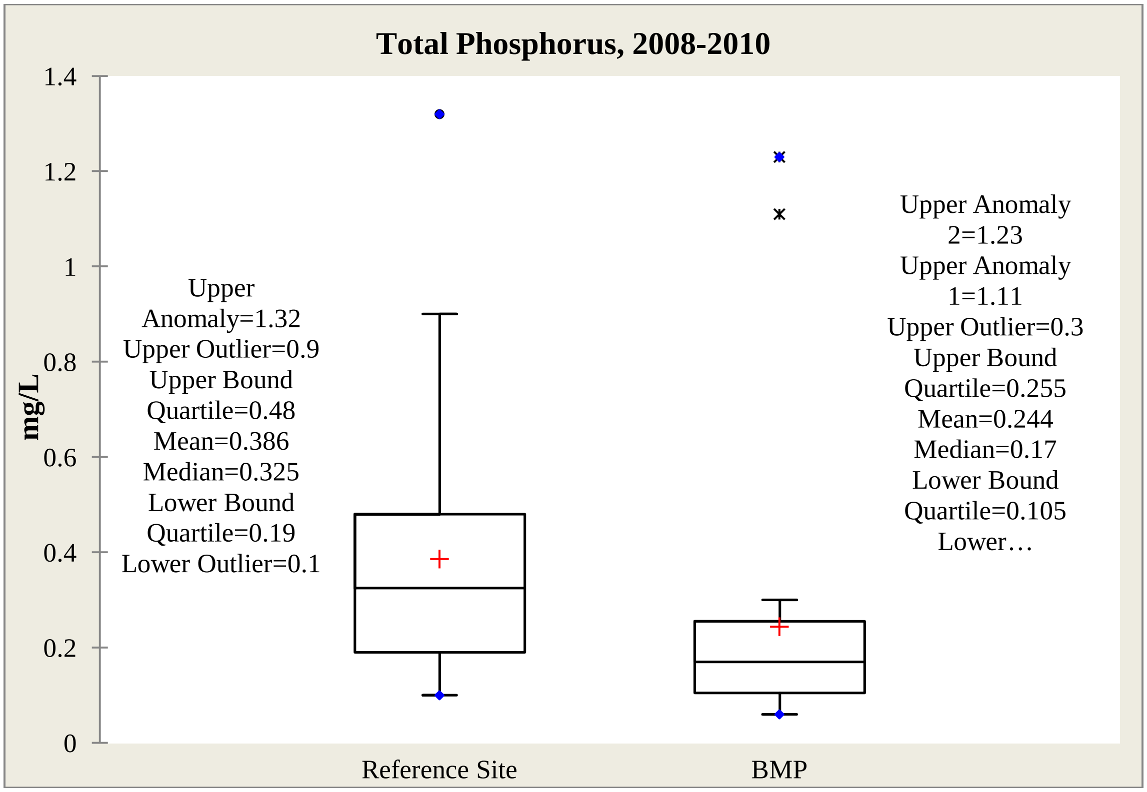


Figure 41. Total Phosphorus at the Reference Site and BMP

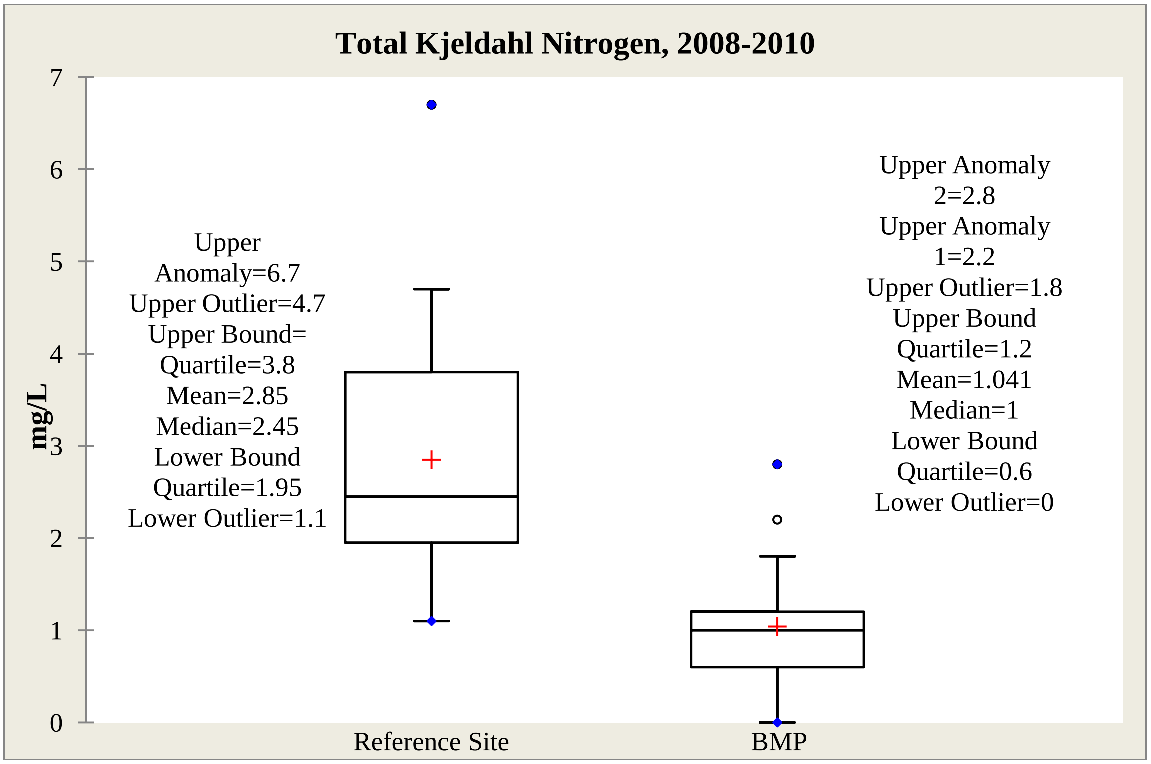


Figure 42. Total Kjeldahl Nitrogen at the Reference Site and BMP

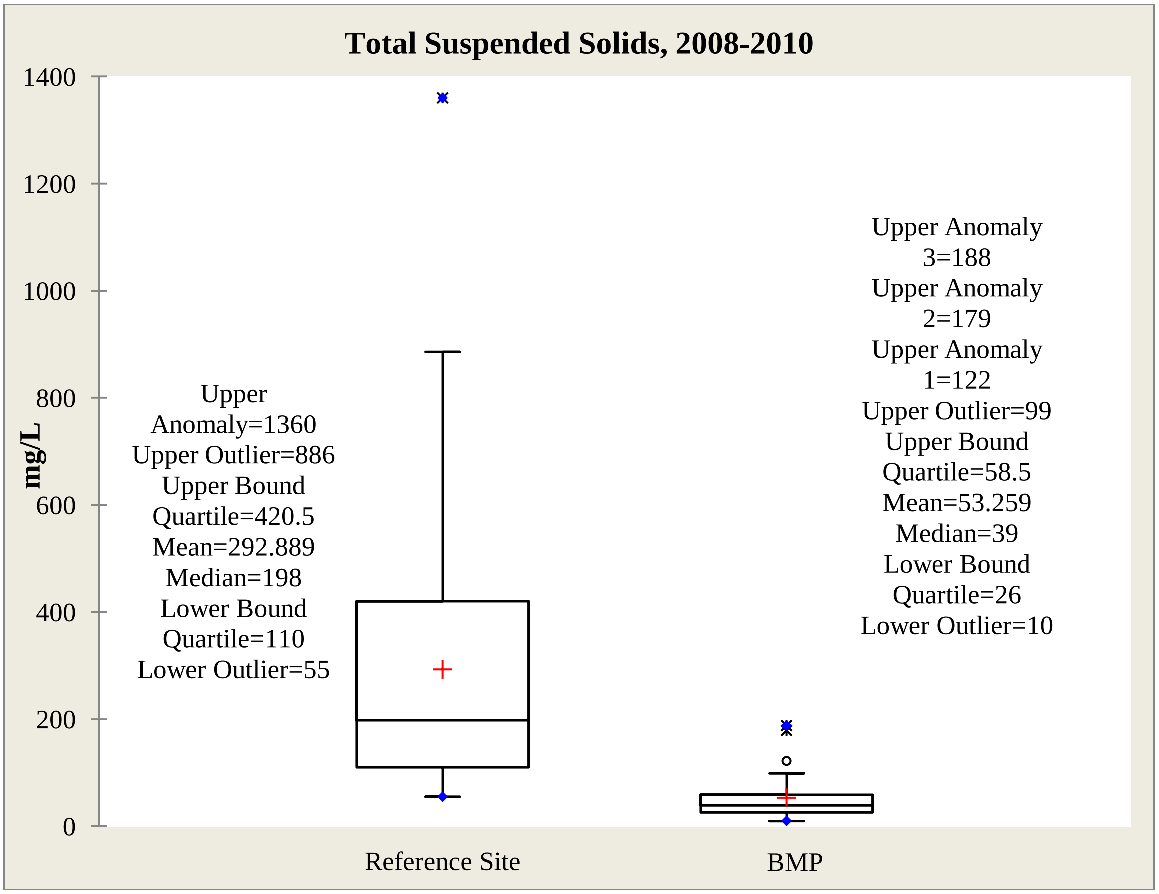


Figure 43. Total Suspended Solids at the Reference Site and BMP

V. Conclusion

Assessment of flow reduction and water quality has been difficult at the PICP site. Water intrusion to the pressure transducer extension cable at the quick disconnect box has complicated flow measurement at the PICP site. The installation of the bubbler module should improve future flow measurements. While methods for sample collection have been successful, it is hard to discern how the PICP has impacted water quality since the runoff it receives may not be comparable to the reference site. Only 11 of the 29 constituents showed statistically significant differences between reference site and the PICP. Out of the 11, five showed a significant decrease from the reference site to the PICP. These included:

- Dissolved Manganese,
- Total Zinc,
- Chemical Oxygen Demand,
- Total Kjeldahl Nitrogen, and
- Total Suspended Solids.

Water quality constituent concentrations can be compared with other permeable pavement studies found in the International Stormwater BMP database, as summarized in Table 8, which is adapted from Table 2-2 in Volume 3 of the USDCM. The database outlet values are relatively consistent with BMP data produced by this study.

Table 9. Comparison of Median Constituents for the PICP at Denver Waste Water and International Stormwater BMP Database

	Data from PICP		Data from International BMP Database	
Water Quality Constituent	Reference Median Value	BMP Median Value	Inlet Median Value	Outlet Median Value
Total Phosphorus (mg/L)	0.325	0.17	0.12	0.13
Total Suspended Solids (mg/L)	198	39	23.5	29.1
Total Kjeldahl Nitrogen (mg/L)	2.45	1	2.4	1.05
Total Cadmium (µg/L)	0	0	NA	0.3
Dissolved Copper (µg/L)	6.75	5.8	5.0	6.2
Total Copper (µg/L)	21.75	9.9	7.0	9.0
Dissolved Lead (µg/L)	0	0	0.1	0.3
Total Lead (µg/L)	9.2	0	2.5	2.5
Dissolved Zinc (µg/L)	12.85	0	25	14.6
Total Zinc (µg/L)	105.55	23.7	50	22

NA=Not Analyzed

The runoff data for the reference site and BMP can also be compared to runoff data from the Denver Regional Urban Runoff Program (DRURP), as summarized in Table 9. This provides another way to compare the data from this study to an outside source.

Table 10. Event Mean Concentration of Constituent Runoff Values: Commercial DRURP, the Reference Site and the BMP Site

Constituent	EMC Denver Commercial Concentration	EMC Reference Site Concentration	EMC BMP Concentration
Total Phosphorus (mg/L)	0.42	0.39	0.244
Total Kjeldahl Nitrogen (mg/L)	2.30	2.85	1.041
Nitrate+Nitrite (mg/L)	0.96	0.36	1.838
Total Lead (µg/L)	0.06	11.76	5.17
Total Zinc (µg/L)	0.24	146.85	32.963
Total Copper (µg/L)	0.04	23.35	15.837
Total Cadmium (µg/L)	0.00	0.46	0.067
Chemical Oxygen Demand (mg/L)	173.00	168.29	46.296
Total Suspended Solids (mg/L)	225.00	292.89	53.259

VI. References

Geosyntec Consultants, Inc., and Wright Water Engineers, Inc. 2010. *International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Nutrients*. http://bmpdatabase.org/Docs/BMP%20Database%20Nutrients%20Paper%20December%202010%20Final.pdf. (June 14, 2011).

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Urban Drainage and Flood Control District (UDFCD). 2001. *Urban Storm Drainage Criteria Manual – Volume 1 and 2.* Updated and maintained by UDFCD. Denver, Colorado

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