Stormwater Quality Monitoring Report

Porous Asphalt at Denver Wastewater Management Building
Denver, Colorado
2008-2010

October 2011

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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 all 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.

Porous Asphalt at Denver Wastewater

At the City and County Denver Wastewater Management Building, UDFCD is monitoring porous asphalt. Porous asphalt is one of several different types of permeable pavement systems designed to infiltrate stormwater through the pavement. Permeable pavements are a common and important practice of Low Impact Development (LID). Porous asphalt consists of open graded hot mix asphalt that contains less than 3% of fines passing a #200 U.S. Standard Sieve. The absence of fines creates a permeable surface that allows stormwater to infiltrate the pavement. By capturing and slowly releasing effluent, permeable pavements help to reduce outflow volume, improve water quality, and decrease effective imperviousness.

A street view of the porous asphalt at Denver Wastewater is shown in Photograph 1.

Photograph 1. The porous asphalt site with sampling inlet shown in the background

II. Site Description

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

Study Area

The porous asphalt and a reference (control) site are located at the Denver Wastewater Management building at 2000 W. 3rd Avenue in Denver. The porous asphalt was placed in May 2008 under the guidance of the Colorado Asphalt Pavement Association, and is located in the turn-around of the main entrance on the north side of the island (see Photograph 2). The porous asphalt has an area of 1840 square feet. The reference site is located in a parking lot a few hundred feet northeast of the BMP and is used to compare water quality and flow of treated effluent to untreated, direct runoff. The general vicinity and location of the porous asphalt are shown in Figures 1 and 2, respectively, with the porous asphalt circled in red and the reference site indicated by a red arrow in Figure 2.

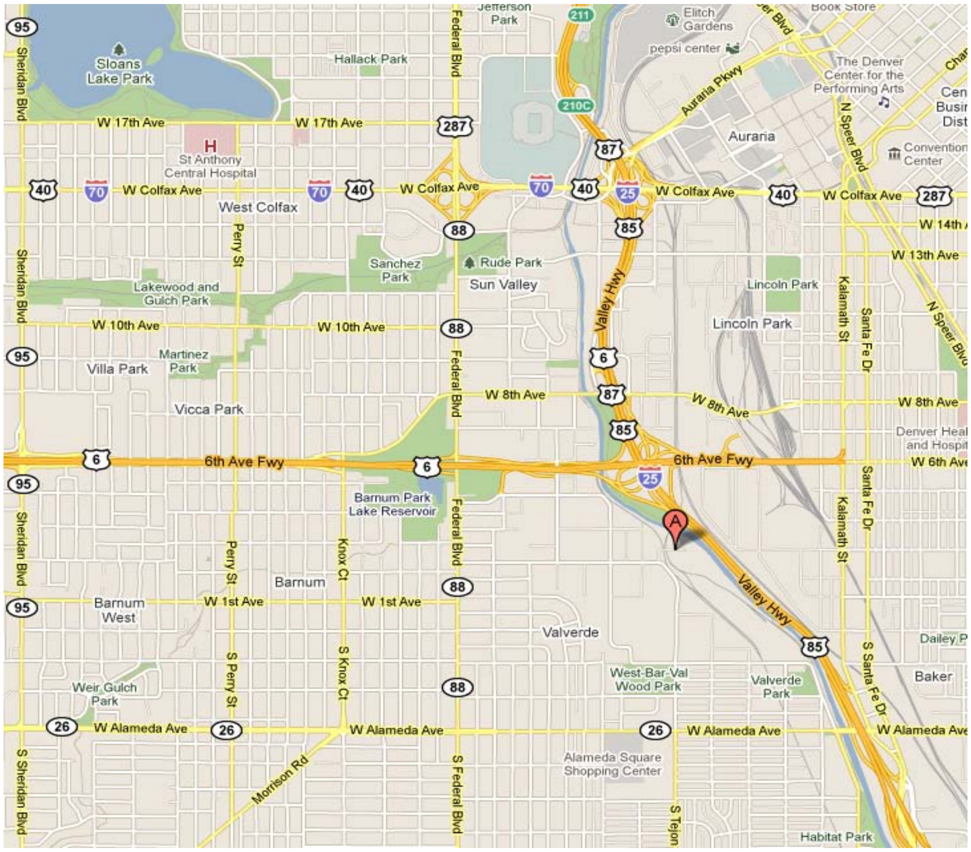


Figure 1. Vicinity Map

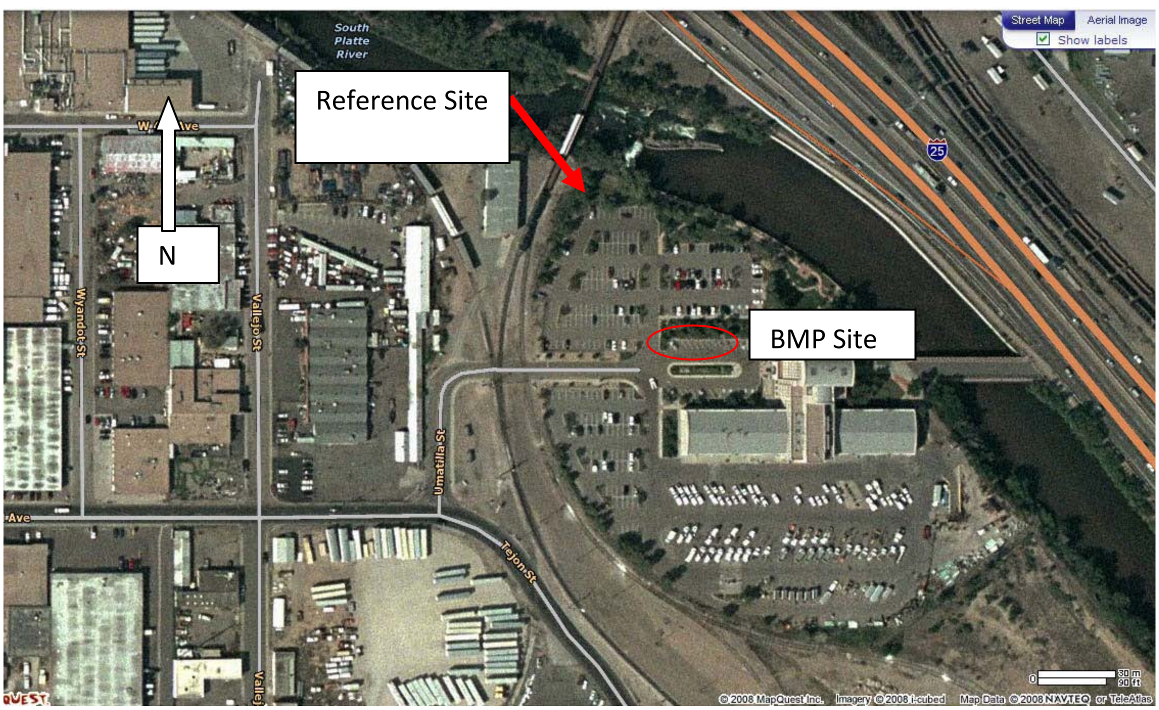


Figure 2. Location Map

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 5,900 square feet, of which 4,060 square feet is impervious tributary to the porous asphalt. A plan view of the watershed for the porous asphalt 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 porous pavement is 2.2 (4,060/1,840), which slightly exceeds the maximum recommended in the Urban Storm Drainage Criteria Manual, Volume 3. 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.

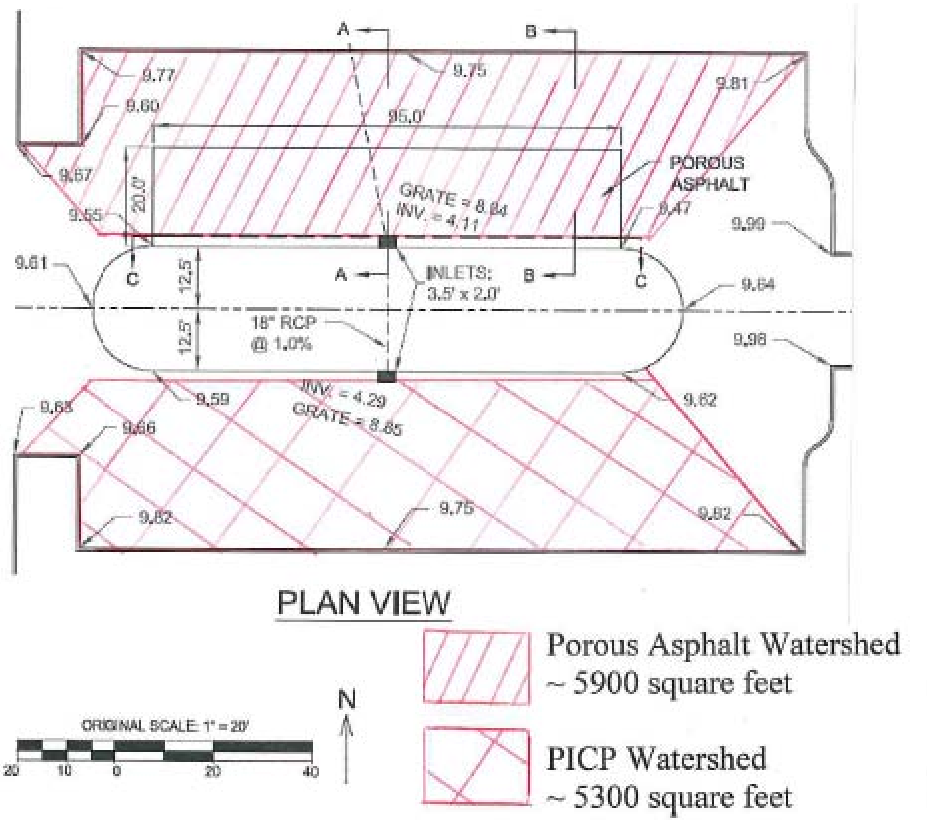


Figure 3. Plan view of the porous asphalt watershed

III. Methods and Materials

Pavement Section

The porous asphalt 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-inch open graded hot mix asphalt (see Photograph 3). All aggregate material in the asphalt should pass the ½-inch sieve. The reservoir layer consists of larger aggregate providing structural support as well as storage volume. The filter layer consists of sand and was included for improved water quality.

When the filtered water reaches the trench at the bottom, it is collected by the underdrain 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.

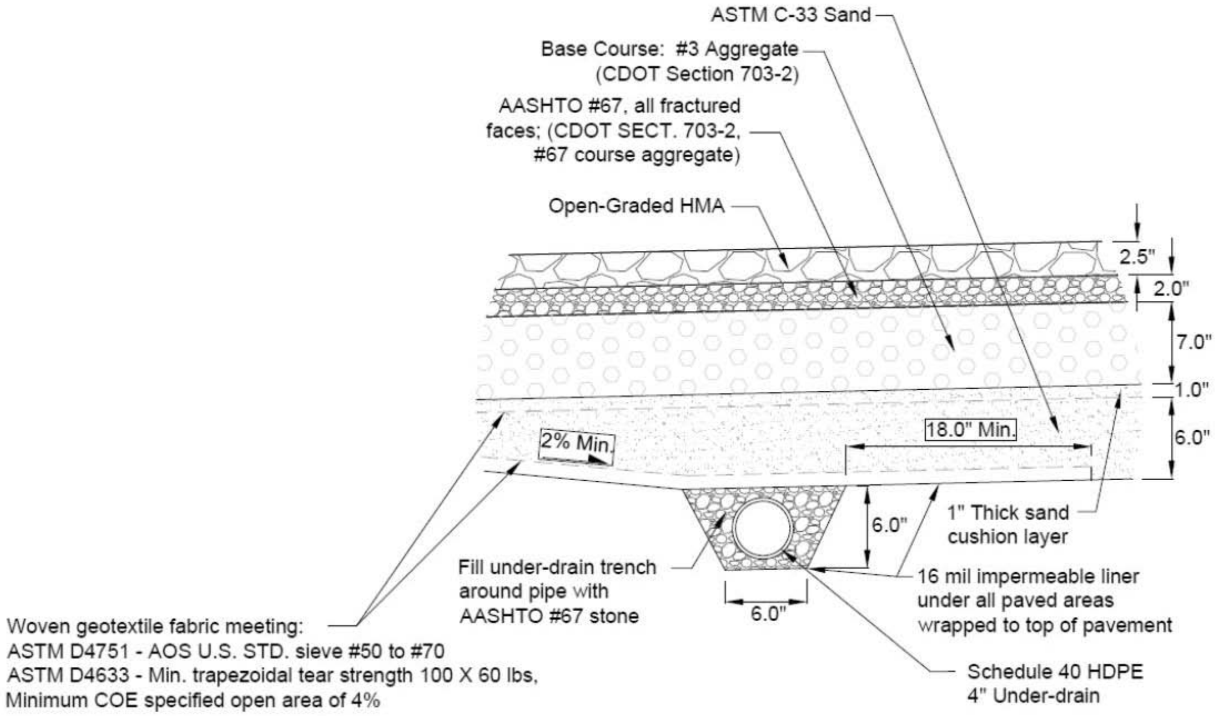


Figure 4. Cross-section of the pavement

Photograph 3. Porous asphalt wearing course. Core taken in 2011.

Data Collection

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. Rain gauge and sampler

All samples are tested for the following:

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

Porous Asphalt Monitoring and Sampling

The monitoring station for the porous asphalt 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 over the orifice is used to calculate flow. Water quality samples of 500 mL are collected into a single 10 L bottle from 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 including sampling equipment and inlets is provided in Figure 5.

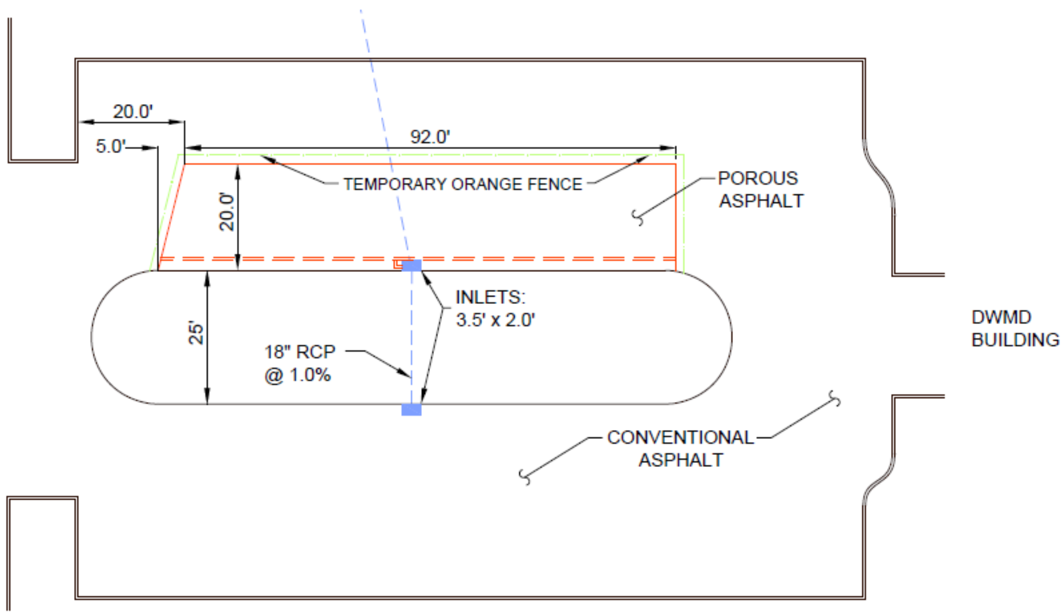
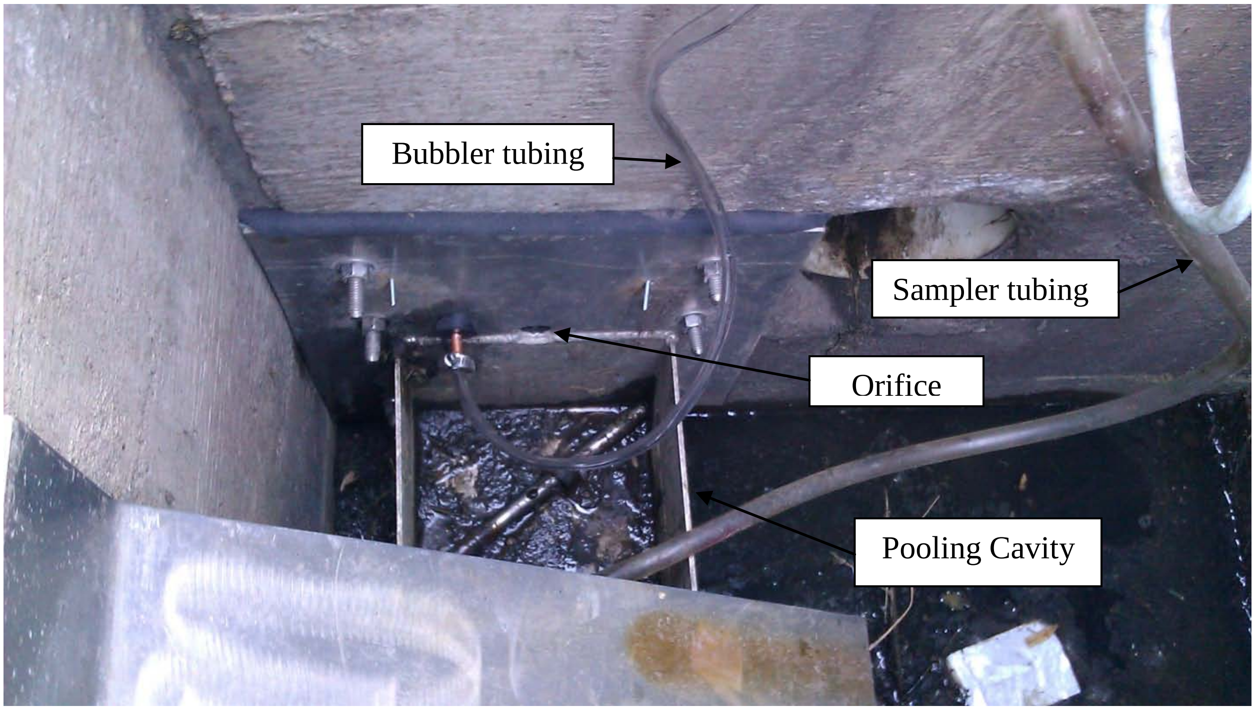


Figure 5. Plan View of Test Site

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 porous asphalt was first constructed, a levelogger behind a weir plate was also installed at the outlet to the catch basin to measure the total flow 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 leaving the catch basin is bypass flow. For this reason, the weir may soon be removed.



Photograph 5. Inlet to the porous asphalt catch basin

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 difference in 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 porous asphalt sampling configuration.

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

Maintenance Practices

This pavement has clogged over the course of three years. Tests show good results in 2008 and 2009. In June of 2010, however, infiltration rates were much lower. Clogging of the wearing course has resulted in fewer samples collected compared to that of the adjacent PICP site. In November of 2010 the pavement was cored to determine if the mix conformed to the current specification. Based on a measurement of in-place voids following cleaning of the core, it was determined that the original porous asphalt was in conformance with the specification. The pavement was power washed shortly after this determination and infiltration test where performed following the cleaning. Power washing was somewhat effective. The porous asphalt was also vacuumed with a vacuum truck in May of 2011. Conditions during vacuuming were wet which is not ideal. The porous asphalt was vacuumed again in June of 2011, and infiltration rates were somewhat improved, but much of the pavement remains clogged.

Beginning in 2010, UDFCD started using a modified version of ASTM method C 1701 for determining the infiltration rate (see photo 7). Previous to the ASTM method a falling head test was conducted. 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 6 shows rates of infiltration in inches per hour for each testing date, plotted on a logarithmic scale.

Photograph 7. The apparatus used for the infiltration test on December 9, 2010.

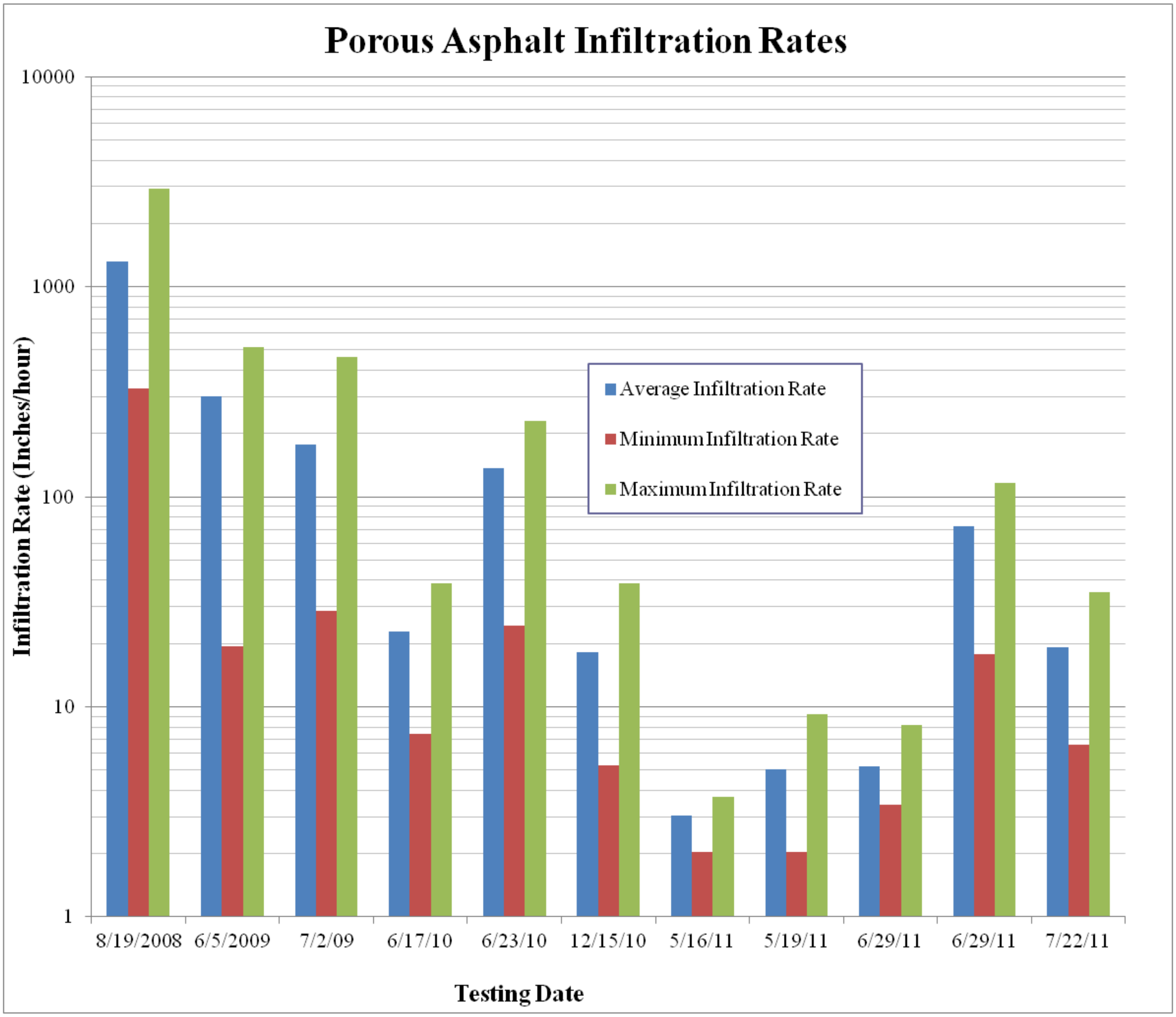


Figure 6. Infiltration Rates on Each Test Date

Note: Site maintenance included:

- Broom type street sweeper (before infiltration test) on July 2, 2009;
- Combination of street sweeping and pressure washing on June 22, 2010;
- Pressure wash with fire hose (by CAPA) on November 19, 2010;
- Vacuum truck during wet conditions (after rain) on May 18, 2011;
- Hand vacuumed after initial infiltration tests were conducted on June 29, 2011 (note two sets of tests performed on this date);
- Pressure washing in combination with vactor truck suction on July 21, 2011.

IV. Results and Discussion

Outflow Volume Reduction

Due to problems with the pressure transducer that were mentioned in the porous asphalt Monitoring and Sampling section, flow 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 7, below, depicts the outflow volumes for the BMP and reference site, which are plotted on a logarithmic scale due to the wide range of values. Only the paired data was plotted here. Tables 1-3 contain all the data for each year. The figure compares the unit flow rate (volume per area of tributary) as the reference site and BMP site have different tributary areas. The porous asphalt watershed area is 70% of the watershed area of the reference site. Note that the values for storms 3a-3c in 2008 are the same because they represent overlapping events with continuous flow throughout the different storm events.

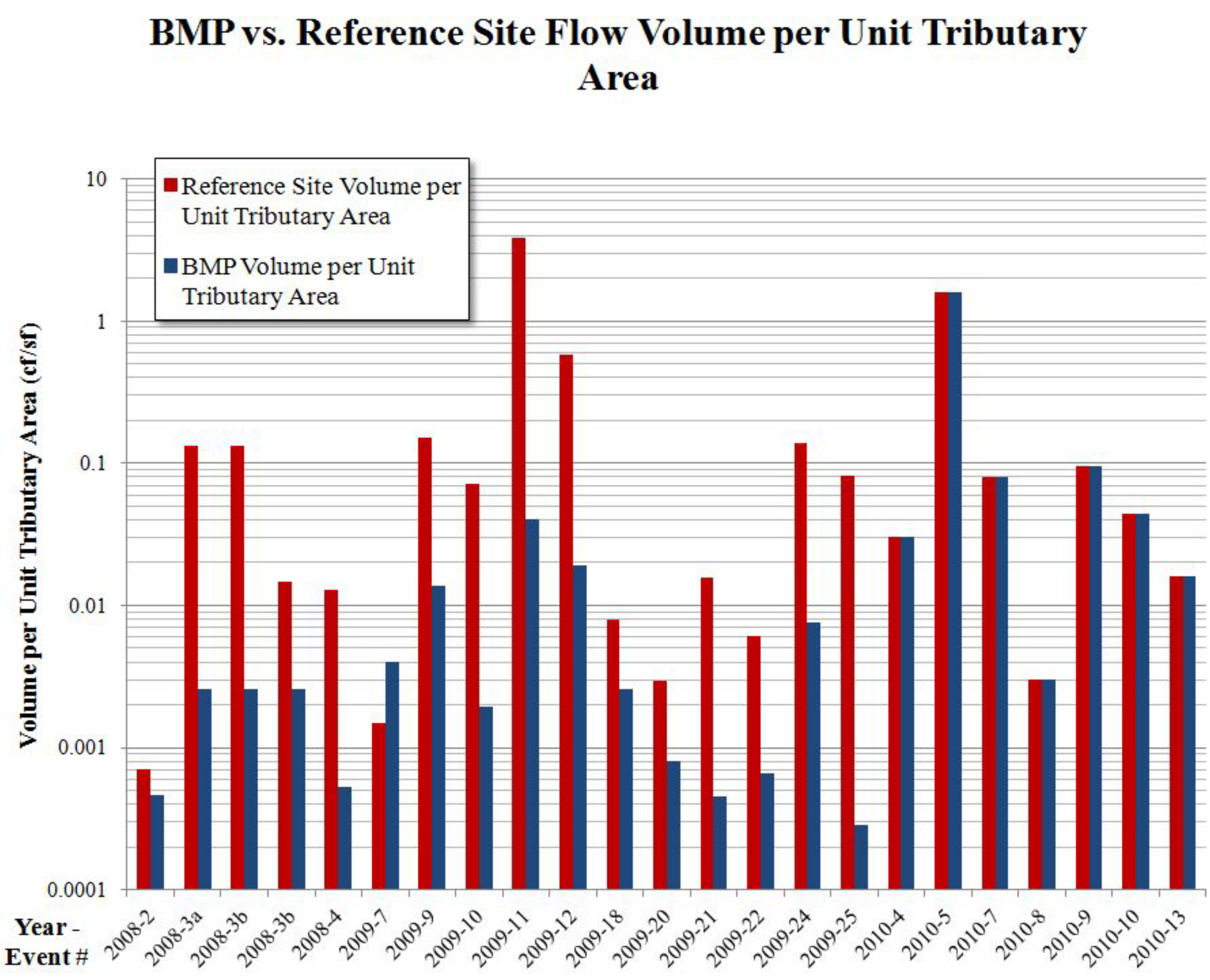


Figure 7. Comparison of Inflow and Outflow Volumes for Each Storm Event

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	19:19	8-Aug	23:57	4:38	1.15	5.88	2.74	0.75	0.02	0.0007	0.0005
3a	15-Aug	3:17	16-Aug	21:34	42:17	15-Aug	2:59	17-Aug	12:00	57:01	0.69	1109.39	15.16	1.53	0.02	0.1321	0.0026
3b	15-Aug	3:17	16-Aug	21:34	42:17	15-Aug	2:59	17-Aug	12:00	57:01	1.37	1109.39	15.16	1.53	0.02	0.1321	0.0026
3c	17-Aug	1:33	17-Aug	8:40	7:07	15-Aug	2:59	17-Aug	12:00	57:01	0.1	122.03	15.16	0.72	0.02	0.0145	0.0026
4	11-Sep	19:44	12-Sep	12:34	16:50	11-Sep	19:44	12-Sep	14:13	18:29	1.19	109.14	3.10	0.38	0.01	0.0130	0.0005

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)
1	**	**	**	**	**	16-Apr	20:04	17-Apr	17:56	21:52	1.06	**	120.19	**	0.007	**	0.02037
2	**	**	**	**	**	18-Apr	6:39	18-Apr	19:28	12:49	1.44	**	254.59	**	0.009	**	0.04315
4	**	**	**	**	**	26-Apr	22:37	27-Apr	12:08	13:31	0.54	**	149.47	**	0.005	**	0.02533
7	22-May	19:45	22-May	21:27	1:42	22-May	19:04	23-May	9:36	14:32	0.17	12.59	23.54	0.023	0.003	0.0015	0.00399
9	24-May	15:51	24-May	18:44	2:53	24-May	15:48	24-May	19:24	3:36	0.69	1278.63	81.47	1.822	0.018	0.1522	0.01381
10	25-May	10:20	25-May	13:18	2:58	25-May	10:15	25-May	12:38	2:23	0.15	601.28	11.34	0.119	0.003	0.0716	0.00192
11	25-May	18:59	26-May	10:45	15:46	25-May	18:38	26-May	3:17	8:39	1.26	32645.86	237.01	1.511	0.019	3.8864	0.04017
12	1-Jun	4:40	2-Jun	14:05	9:25	1-Jun	20:48	2-Jun	13:09	16:21	0.89	4864.68	113.86	0.252	0.006	0.5791	0.01930
13	**	**	**	**	**	11-Jun	12:53	11-Jun	13:21	0:28	0.19	**	5.85	**	0.005	**	0.00099
15	**	**	**	**	**	13-Jun	17:58	13-Jun	18:27	0:29	0.17	**	5.59	**	0.004	**	0.00095
16	**	**	**	**	**	25-Jun	18:03	25-Jun	20:34	2:31	0.39	**	19.28	**	0.004	**	0.00327
17	**	**	**	**	**	26-Jun	14:59	26-Jun	15:57	0:58	0.19	**	9.84	**	0.004	**	0.00167
18	1-Jul	23:30	1-Jul	23:52	0:22	1-Jul	23:37	2-Jul	0:37	1:00	0.45	66.95	15.38	0.128	0.008	0.0080	0.00261
19	**	**	**	**	**	3-Jul	17:11	3-Jul	18:19	1:08	0.40	**	15.26	**	0.007	**	0.00259
20	4-Jul	0:38	4-Jul	3:49	3:11	4-Jul	0:56	4-Jul	1:56	1:00	0.18	24.71	4.76	0.077	0.003	0.0029	0.00081
21	20-Jul	22:41	20-Jul	22:46	0:05	20-Jul	22:42	20-Jul	23:06	0:24	0.45	133.05	2.65	0.653	0.005	0.0158	0.00045
22	25-Jul	21:25	25-Jul	21:32	0:07	25-Jul	21:42	25-Jul	22:19	0:37	0.48	50.74	3.92	0.216	0.002	0.0060	0.00066
24	29-Jul	18:46	30-Jul	1:34	6:48	29-Jul	18:42	30-Jul	12:02	17:20	0.22	1152.45	44.53	0.334	0.001	0.1372	0.00755
25	6-Aug	16:05	6-Aug	16:24	0:19	6-Aug	16:03	6-Aug	16:24	0:21	0.39	693.80	1.68	1.688	0.005	0.0826	0.00028
27	**	**	**	**	**	18-Aug	13:09	18-Aug	14:13	1:04	0.07	**	2.66	**	0.001	**	0.00045
28	**	**	**	**	**	12-Sep	16:28	13-Sep	10:45	18:17	0.14	**	52.84	**	0.001	**	0.00896
33	**	**	**	**	**	25-Sep	1:53	25-Sep	6:07	4:14	0.18	**	17.30	**	0.001	**	0.00293

**=No Data

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 (cf/sf)	BMP Volume per Unit Tributary Area (cf/sf)
1	22-Apr	18:25	23-Apr	13:00	18:35	**	**	**	**	**	**	5008.07	**	0.70	**	0.5962	**
3	11-May	18:01	12-May	0:46	6:45	**	**	**	**	**	**	3301.97	**	0.44	**	0.3931	**
4	13-May	21:02	14-May	1:43	4:41	13-May	20:05	14-May	13:15	17:10	0.14	252.35	52.84	0.03	0.00	0.0300	0.0090
5	14-May	15:35	15-May	5:56	14:21	14-May	15:32	15-May	10:45	19:13	0.45	13420.38	50.76	0.50	0.00	1.5977	0.0086
7	11-Jun	19:37	13-Jun	13:18	41:41	11-Jun	15:39	13-Jun	11:37	43:58	1.28	675.15	23.59	0.63	0.00	0.0804	0.0040
8	13-Jun	20:31	13-Jun	22:17	1:46	13-Jun	19:49	13-Jun	21:22	1:33	0.05	25.41	1.59	0.01	0.00	0.0030	0.0003
9	4-Jul	20:56	5-Jul	2:29	5:33	4-Jul	20:18	6-Jul	16:01	43:43	0.63	800.41	133.37	0.30	0.00	0.0953	0.0226
10	7-Jul	0:18	7-Jul	2:37	2:19	7-Jul	1:37	8-Jul	7:09	29:18	0.29	371.67	62.25	0.40	0.00	0.0442	0.0106
11	20-Jul	17:55	20-Jul	21:53	3:58	**	**	**	**	**	0.21	153.63	**	0.04	**	0.0183	**
12	2-Aug	20:40	3-Aug	0:35	3:55	**	**	**	**	**	0.08	201.02	**	0.04	**	0.0239	**
13	9-Aug	17:13	9-Aug	19:08	1:55	9-Aug	16:55	10-Aug	11:24	18:29	0.13	134.78	45.03	0.24	0.00	0.0160	0.0076
14	24-Aug	3:54	24-Aug	8:35	4:41	**	**	**	**	**	0.07	170.52	**	0.05	**	0.0203	**

**=No Data

Water Quality Impacts

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 BMP data for all years was combined and then analyzed. Since the number of samples was quite small, under 30, it was unclear whether or not the data fit a normal distribution (a bell-shaped curve). Therefore, both parametric tests and non-parametric tests were performed on the data, parametric tests being used when data is normally distributed, and non-parametric tests being used when it is not normally distributed. In cases where the data did not seem to fit a normal distribution a non-parametric Wilcoxon signed-rank test was performed in addition to parametric paired t-tests and two sample t-tests. The two sample t-test is unpaired and is used to compare the means of two independent samples, and a paired t-test is used to compare two related samples over time. The p-values generated for each of the constituents (alpha=0.05) are shown in Table 4. The values that were significant, below the alpha level of 0.05, are shown in bold text. 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.

For most constituents there were few significant differences between the outflows at the reference site and the porous asphalt. Dissolved Potassium, Chloride, and Dissolved Phosphorus (according to one test) were significantly lower in the porous asphalt outflows; however, Nitrite+Nitrate, Total Selenium, and Dissolved Sodium were all in significantly higher concentrations in the porous asphalt outflows. 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 porous asphalt, on the other hand, experiences heavy traffic during business hours.

All water quality data is provided in Tables 5-7. Note that in these tables, Reference was abbreviated to Ref to save space. 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.

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

Constituent	Two sample t-test	Wilcoxon signed rank test	Paired t-test
Dissolved Calcium	0.5648	0.4053	0.5115
Dissolved Iron	0.3325	0.2785	0.2974
Dissolved Potassium	**0.03272**	**0.01198**	**0.03279**
Dissolved Magnesium	0.1177	0.09766	0.1376
Dissolved Sodium	**0.004055**	**0.01427**	**0.0088238**
Dissolved Chromium	0.1202	0.1814	0.1202
Dissolved Manganese	0.4745	0.3008	0.427
Dissolved Nickel	0.7984	1	0.8113
Dissolved Copper	0.3399	0.9102	0.4442
Dissolved Zinc	0.7379	0.7344	0.7556
Dissolved Selenium	0.08091	0.1736	0.08091
Dissolved Silver	NA (all values 0)	NA	NA
Dissolved Cadmium	0.2911	0.05791	0.2868
Dissolved Lead	0.3466	1	0.3466
Total Beryllium	0.3466	1	0.3466
Total Chromium	0.8514	1	0.8002
Total Manganese	0.5904	0.8203	0.5409
Total Nickel	0.6293	0.7344	0.5342
Total Copper	0.7032	0.7344	0.5858
Total Zinc	0.6529	0.4961	0.6691
Total Arsenic	0.3466	1	0.3466
Total Selenium	**0.04181**	**0.1003**	**0.04181**
Total Molybdenum	0.08634	0.1814	0.08634
Total Silver	0.3473	0.4227	0.3437
Total Cadmium	0.3511	0.6845	0.3581
Total Antimony	NA	NA	NA
Total Lead	0.4809	0.4469	0.3766
Chloride	**0.02107**	**0.03125**	**0.03972**
COD	0.9783	0.3594	0.9791
Nitrite+Nitrate	**0.0009447**	**0.007812**	**0.007334**
Dissolved Phosphorus	0.2752	**0.02225**	0.2677
Total Phosphorus	0.928	0.3436	0.9176
TKN	0.4265	0.25	0.4314
TSS	0.2807	0.3627	0.268

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)	**	33	11	10	6	11	13	14	9	**
Dissolved Iron (mg/L)	**	0	0.15	0.14	0.1	0.1	0.08	0.08	0.08	**
Dissolved Magnesium (mg/L)	**	6.8	1.7	2.2	1	2.3	2	2.9	1.6	**
Dissolved Sodium (mg/L)	**	64	6	28	5	18	13	19	7	**
Dissolved Chromium (µg/L)	**	5.6	0	1.2	0	0	0	0	0	**
Dissolved Manganese (µg/L)	**	13.9	94.1	21.1	5.7	2.9	34.2	1.3	30.2	**
Dissolved Nickel (µg/L)	**	2.1	1.3	1.3	0	0	1.5	0	0	**
Dissolved Copper (µg/L)	**	14.9	5.5	12.5	7.8	5.1	7.8	6.4	17.3	**
Dissolved Zinc (µg/L)	**	921	13	10.4	12.4	15.7	33.3	14.6	25.8	**
Dissolved Selenium (µg/L)	**	0	0	1	0	0	0	0	0	**
Dissolved Silver (µg/L)	**	0	0	0	0	0	0	0	0	**
Dissolved Cadmium (µg/L)	**	0.6	0.1	0.4	0	0	0.1	0.1	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)	**	6.3	8.2	0	0	0	9.4	0	0	**
Total Manganese (µg/L)	**	20.8	254	99.5	74.5	47.6	232	43.6	124	**
Total Nickel (µg/L)	**	2.5	7.4	3.1	2.8	1.7	8.7	7.3	4.4	**
Total Copper (µg/L)	**	15.3	31.7	14.7	15.3	7.5	43.6	47.7	36.4	**
Total Zinc (µg/L)	**	1010	188	26.5	67.1	33.3	245	38.2	147	**
Total Arsenic (µg/L)	**	0	0	0	0	0	0	0	0	**
Total Selenium (µg/L)	**	1	0	1.3	0	0	0	0	0	**
Total Molybdenum	**	28.8	0	8.4	0	5.8	0	0	0	**
Total Silver (µg/L)	**	0	0	0	0	0	0.4	0	0	**
Total Cadmium (µg/L)	**	0.7	1	0.7	0	0	1	0	0.9	**
Total Antimony (µg/L)	**	14	0	0	0	0	0	0	0	**
Total Lead (µg/L)	**	0	28.3	0	9	0	27.7	0	15.2	**
Chloride (mg/L)	**	75	6	12	**	**	**	**	**	**
Chemical Oxygen Demand (mg/L)	**	111	418	57	48	19	252	39	174	**
Nitrite+Nitrate (mg/L)	**	1.57	0.19	1.79	0.27	1.24	0.69	0.98	0.28	**
Dissolved Phosphorus	**	0.03	0.04	0.11	0.04	0.1	0.02	0.1	0.1	**
Dissolved Potassium (mg/L)	**	14	2	3	1	3	2	3	3	**
Total Phosphorus (mg/L)	**	0.18	0.9	0.32	0.13	0.16	0.46	0.19	0.33	**
Total Kjeldahl Nitrogen (mg/L)	**	3.7	4.5	1.5	1.2	0.9	4.2	0	2	**
Total Suspended Solids (mg/L)	**	16	1360	52	131	25	34	508	154	**

**No Data

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

Table 6. Water Quality Data for 2009

Water Quality Constituent	Event 1		Event 3		Event 7		Event 11		Event 12		Event 14		Event 16		Event 17		Event 18		Event 20	
	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref
Dissolved Calcium (mg/L)	**	5	31	**	**	16	**	6	12	3	**	19	**	7	**	41	16	8	11	23
Dissolved Iron (mg/L)	**	0.18	0	**	**	0.11	**	0.14	0.06	0.06	**	0.09	**	0.05	**	0.47	0.06	0	0.05	0.06
Dissolved Magnesium (mg/L)	**	1.4	8.5	**	**	3.6	**	1.1	4.3	0.6	**	3.8	**	1	**	7.6	3.3	1.4	2.5	4.6
Dissolved Sodium (mg/L)	**	29	46	**	**	20	**	7	44	5	**	21	**	8	**	32	31	7	25	20
Dissolved Chromium (µg/L)	**	0	0	**	**	0	**	0	4.1	0	**	0	**	0	**	0	0	0	0	0
Dissolved Manganese (µg/L)	**	32.6	16	**	**	11.8	**	33.7	6.1	16.7	**	12	**	14.2	**	13.7	73.2	28.3	6.3	4
Dissolved Nickel (µg/L)	**	1.5	1.5	**	**	1.9	**	0	0	0	**	2.1	**	2.4	**	2.6	1.1	0	0	1.3
Dissolved Copper (µg/L)	**	16.9	9	**	**	11.3	**	5.6	4.7	3	**	14.5	**	16.1	**	8.6	4.2	6.1	5.7	8.1
Dissolved Zinc (µg/L)	**	20.8	151	**	**	23	**	34.7	0	10.7	**	12.7	**	354	**	13.1	25.5	9.2	5.8	9
Dissolved Selenium (µg/L)	**	0	0	**	**	0	**	0	1.1	0	**	0	**	0	**	0	1	0	0	0
Dissolved Silver (µg/L)	**	0	0	**	**	0	**	0	0	0	**	0	**	0	**	0	0	0	0	0
Dissolved Cadmium (µg/L)	**	0.2	1.2	**	**	0.1	**	0.3	0	0	**	0	**	0.7	**	0	6.5	0.1	0.4	0.2
Dissolved Lead (µg/L)	**	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
Total Chromium (µg/L)	**	0	0	**	**	5.3	**	6.3	6.8	0	**	0	**	5.8	**	0	0	0	0	0
Total Manganese (µg/L)	**	110	40.6	**	**	164	**	176	72	61.8	**	63	**	92.2	**	239	159	47.6	70.1	61.1
Total Nickel (µg/L)	**	5	2.6	**	**	5.9	**	5.8	2.2	2.1	**	3	**	6.4	**	4.3	4.6	1.5	2.3	2.1
Total Copper (µg/L)	**	32.6	14.4	**	**	31.4	**	23.3	8.7	12.9	**	18.7	**	31	**	19	22.4	8.7	9.5	11.4
Total Zinc (µg/L)	**	129	213	**	**	163	**	149	0	59.4	**	40.7	**	1090	**	66.1	906	30	29	30.1
Total Arsenic (µg/L)	**	0	0	**	**	0	**	0	0	0	**	0	**	0	**	0	0	0	0	0
Total Selenium (µg/L)	**	0	0	**	**	0	**	0	1.1	0	**	0	**	0	**	0	1.9	0	0	0
Total Molybdenum (µg/L)	**	0	0	**	**	0	**	0	8.9	0	**	0	**	0	**	6.2	0	0	0	0
Total Silver (µg/L)	**	0	0	**	**	0	**	0	0	0	**	0	**	0	**	0	0.2	0	0	0
Total Cadmium (µg/L)	**	0	1.5	**	**	0.8	**	0.6	0	0	**	0	**	3.6	**	0	19.7	0	0.6	0
Total Antimony (µg/L)	**	0	37.8	**	**	0	**	0	0	0	**	0	**	23.3	**	0	0	0	0	0
Total Lead (ug/L)	**	16.7	0	**	**	18.1	**	20.9	0	5.9	**	0	**	9.4	**	6.6	11.4	0	0	0
Chloride (mg/L)	**	34	137	**	**	**	**	4	41	3	**	23	**	6	**	35	25	6	18	21
Chemical Oxygen Demand (mg/L)	**	194	46	**	**	184	**	172	26	39	**	151	**	129	**	146	860	106	32	122
Nitrite+Nitrate (mg/L)	**	0.96	1.22	**	**	0.72	**	0.19	1.35	0.14	**	0.64	**	0.29	**	0.05	0.59	0.48	1.44	0.34
Dissolved Phosphorus (mg/L)	**	0.12	0.07	**	**	0.14	**	0.05	0.11	0.03	**	0.03	**	0.03	**	0.09	4.25	0.1	**	0.06
Dissolved Potassium (mg/L)	**	2	4	**	**	4	**	2	5	0	**	4	**	6	**	7	10	2	4	3
Total Phosphorus (mg/L)	**	0.32	0.17	**	**	0.48	**	0.38	0.19	0.15	**	0.14	**	0.27	**	0.36	6.63	0.19	**	0.14
Total Kjeldahl Nitrogen (mg/L)	**	3	1.6	**	**	4.7	**	2.5	0.8	1.1	**	2.2	**	4.5	**	4.1	58	1.8	1.5	2
Total Suspended Solids (mg/L)	**	129	59	**	**	198	**	436	38	116	**	104	**	235	**	230	385	91	55	55

**No Data

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

Table 6. Water Quality Data for 2009 (Cont.)

Water Quality Constituent	Event 21		Event 22		Event 23		Event 24		Event 26		Event 28		Event 31		Event 32		Event 33	
	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP	Ref	BMP
Dissolved Calcium (mg/L)	21	**	7	**	24	**	6	7	6	**	**	32	**	14	**	8	**	5
Dissolved Iron (mg/L)	0.32	**	0	**	0.3	**	0	0	0	**	**	0.27	**	0.14	**	0.1	**	0
Dissolved Magnesium (mg/L)	3.4	**	1.4	**	4.2	**	1.2	1.5	1	**	**	7.2	**	2.8	**	1.6	**	1
Dissolved Sodium (mg/L)	15	**	6	**	18	**	6	6	5	**	**	19	**	11	**	6	**	4
Dissolved Chromium (µg/L)	0	**	0	**	0	**	0	0	0	**	**	0	**	0	**	0	**	0
Dissolved Manganese (µg/L)	134	**	22	**	74.8	**	12.9	17.7	26.3	**	**	87.1	**	34.4	**	18.4	**	18.1
Dissolved Nickel (µg/L)	2.3	**	0	**	1.4	**	0	0	0	**	**	2.3	**	1.4	**	0	**	0
Dissolved Copper (µg/L)	7.5	**	5.1	**	5	**	5.9	3.4	7.4	**	**	15.6	**	6.9	**	4.5	**	2.9
Dissolved Zinc (µg/L)	20.3	**	8.1	**	15.3	**	5.7	17.6	11.1	**	**	49.3	**	39.4	**	21.1	**	13.4
Dissolved Selenium (µg/L)	0	**	0	**	0	**	0	0	0	**	**	0	**	0	**	0	**	0
Dissolved Silver (µg/L)	0	**	0	**	0	**	0	0	0	**	**	0	**	0	**	0	**	0
Dissolved Cadmium (µg/L)	0.3	**	0	**	0.1	**	0	0.1	0.1	**	**	0.2	**	0	**	0	**	0.1
Dissolved Lead (µg/L)	1.1	**	0	**	0	**	0	0	0	**	**	0	**	0	**	0	**	0
Total Beryllium (µg/L)	0	**	0	**	0	**	0	0	0	**	**	0	**	0	**	0	**	0
Total Chromium (µg/L)	5.8	**	0	**	0	**	0	0	0	**	**	0	**	0	**	0	**	0
Total Manganese (µg/L)	257	**	106	**	121	**	32.9	27.7	82.4	**	**	89.9	**	44	**	38.5	**	26.3
Total Nickel (µg/L)	5.7	**	2.7	**	2.4	**	1.2	0	2.6	**	**	2.4	**	1.6	**	1.3	**	0
Total Copper (µg/L)	24	**	12.8	**	10.7	**	6.9	4.2	12.4	**	**	17	**	9.5	**	8.7	**	4.6
Total Zinc (µg/L)	138	**	75	**	49.4	**	25.2	31.6	49.2	**	**	55.4	**	62.8	**	55.4	**	29.6
Total Arsenic (µg/L)	0	**	0	**	0	**	0	0	0	**	**	0	**	0	**	0	**	0
Total Selenium (µg/L)	0	**	0	**	0	**	0	0	0	**	**	0	**	0	**	0	**	0
Total Molybdenum (µg/L)	0	**	0	**	0	**	0	0	0	**	**	6.4	**	0	**	0	**	0
Total Silver (µg/L)	0	**	0	**	0	**	0	0	0	**	**	0	**	0	**	0	**	0
Total Cadmium (µg/L)	0.9	**	0	**	0	**	0	0	0	**	**	0	**	0	**	0	**	0
Total Antimony (µg/L)	0	**	0	**	0	**	0	0	0	**	**	0	**	0	**	0	**	0
Total Lead (ug/L)	13.6	**	8.5	**	0	**	0	0	6.3	**	**	0	**	5.4	**	6.3	**	0
Chloride (mg/L)	16	**	6	**	18	**	4	8	3	**	**	27	**	15	**	8	**	5
Chemical Oxygen Demand (mg/L)	230	**	136	**	113	**	71	41	127	**	**	120	**	80	**	41	**	36
Nitrite+Nitrate (mg/L)	0.15	**	0.18	**	0.22	**	0.61	0.57	0.43	**	**	1.32	**	0.53	**	0.64	**	0.5
Dissolved Phosphorus (mg/L)	0.18	**	0.03	**	0.15	**	0.04	0.04	0.07	**	**	0.07	**	0.04	**	0.05	**	0.05
Dissolved Potassium (mg/L)	6	**	2	**	5	**	1	2	2	**	**	5	**	3	**	2	**	1
Total Phosphorus (mg/L)	0.65	**	0.26	**	0.32	**	0.1	0.1	0.19	**	**	0.13	**	0.1	**	0.11	**	0.08
Total Kjeldahl Nitrogen (mg/L)	4.2	**	1.8	**	2.3	**	1.8	1.1	2.4	**	**	2.1	**	1	**	1.1	**	0.7
Total Suspended Solids (mg/L)	481	**	427	**	80	**	78	17	141	**	**	20	**	21	**	24	**	15

Table 7. Water Quality Data for 2010

Water Quality Constituent	Event 1		Event 2		Event 3		Event 4		Event 5		Event 7		Event 9		Event 10		Event 11		Event 12		Event 14	
	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)	4	**	2	**	4	**	**	5	4	8	10	**	5	3	4	**	25	**	21	**	22	**
Dissolved Iron (mg/L)	0.11	**	0	**	0.1	**	**	0.09	0	0.06	0.22	**	0.12	1.08	0.07	**	0.58	**	0.16	**	0.2	**
Dissolved Magnesium (mg/L)	1.3	**	0.6	**	1	**	**	1.3	1.1	1.9	2.1	**	0.9	1.2	0.8	**	5.6	**	5.2	**	5.6	**
Dissolved Sodium (mg/L)	14	**	2	**	5	**	**	14	4	11	6	**	3	44	3	**	24	**	20	**	24	**
Dissolved Chromium (µg/L)	0	**	0	**	0	**	**	0	0	0	0	**	0	2.4	0	**	0	**	0	**	0	**
Dissolved Manganese (µg/L)	24.7	**	10.7	**	24.9	**	**	21.4	20.5	17.2	64.1	**	46	37.4	25.6	**	159	**	58.3	**	42.5	**
Dissolved Nickel (µg/L)	1.3	**	0	**	0	**	**	0	0	0	0	**	0	2.6	0	**	4.5	**	2.2	**	2.9	**
Dissolved Copper (µg/L)	5.6	**	0	**	4.6	**	**	4.1	3.7	5	3.6	**	0	15.7	5.2	**	14	**	9.6	**	18.2	**
Dissolved Zinc (µg/L)	9.8	**	9	**	10.5	**	**	10.2	15.9	12.7	10.4	**	0	19	8.7	**	33.9	**	16	**	30.5	**
Dissolved Selenium (µg/L)	0	**	0	**	0	**	**	0	0	0	0	**	0	0	0	**	0	**	0	**	1.1	**
Dissolved Silver (µg/L)	0	**	0	**	0	**	**	0	0	0	0	**	0	0	0	**	0	**	0	**	0	**
Dissolved Cadmium (µg/L)	0	**	0	**	0	**	**	0.2	0	0.2	0.2	**	0	0	0	**	0	**	0	**	0	**
Dissolved Lead (µg/L)	0	**	0	**	0	**	**	0	0	0	0	**	0	2	0	**	1	**	0	**	0	**
Total Beryllium (µg/L)	0	**	0	**	0	**	**	0	0	0	0	**	0	1.8	0	**	0	**	0	**	0	**
Total Chromium (µg/L)	14.9	**	6.9	**	0	**	**	0	0	0	0	**	11.4	28.3	8.2	**	7.2	**	8.4	**	0	**
Total Manganese (µg/L)	273	**	150	**	71.9	**	**	39.3	91	42	111	**	249	1190	201	**	277	**	222	**	111	**
Total Nickel (µg/L)	11.2	**	5.2	**	2.2	**	**	1.7	3	1.6	2.4	**	8.6	28.6	7	**	9.5	**	7.4	**	5.2	**
Total Copper (µg/L)	48.1	**	20.2	**	10.4	**	**	6.7	12.4	7.1	9.9	**	34.4	93.1	28.4	**	45.2	**	33.5	**	28.4	**
Total Zinc (µg/L)	288	**	135	**	50.5	**	**	30.1	72	26.7	56.9	**	213	266	162	**	169	**	142	**	82.1	**
Total Arsenic (µg/L)	0	**	0	**	0	**	**	0	0	0	0	**	0	14.9	0	**	0	**	0	**	0	**
Total Selenium (µg/L)	0	**	0	**	0	**	**	0	0	0	0	**	0	1.2	0	**	1	**	0	**	0	**
Total Molybdenum (µg/L)	0	**	0	**	0	**	**	0	0	0	0	**	0	0	0	**	0	**	5.9	**	5	**
Total Silver (µg/L)	0	**	0	**	0	**	**	0	0	0	0	**	34.8	0.3	0	**	0	**	0	**	0	**
Total Cadmium (µg/L)	1.6	**	0	**	0	**	**	0	0	0	0	**	0.6	0.9	0.6	**	0.8	**	0.6	**	0	**
Total Antimony (µg/L)	0	**	0	**	0	**	**	0	0	0	0	**	0	0	0	**	0	**	0	**	0	**
Total Lead (µg/L)	34.8	**	16.4	**	0	**	**	0	7.7	0	0	**	28.8	50.4	19.5	**	14.3	**	14.3	**	7.2	**
Chloride (mg/L)	13	**	2	**	4	**	**	18	2	11	4	**	3	32	2	**	27.8	**	18.1	**	25.1	**
Chemical Oxygen Demand (mg/L)	320	**	109	**	85	**	**	332	79	43	91	**	184	227	187	**	417	**	181	**	247	**
Nitrite+Nitrate (mg/L)	0.29	**	0.05	**	0.33	**	**	0.74	0.55	0.7	0.11	**	0.09	0.89	0.31	**	0.08	**	0.68	**	0.81	**
Dissolved Phosphorous (mg/L)	0.09	**	0.03	**	0.2	**	**	0.05	0.01	0.04	0.06	**	0.04	0.46	0.17	**	0.47	**	0.17	**	0.18	**
Dissolved Potassium (mg/L)	2	**	0	**	2	**	**	1	1	2	3	**	2	2	2	**	13	**	5	**	5	**
Total Phosphorous (mg/L)	0.72	**	0.28	**	0.34	**	**	0.1	0.17	0.11	0.28	**	0.48	1.48	0.49	**	1.32	**	0.59	**	0.37	**
Total Kjeldahl Nitrogen (mg/L)	3.7	**	1.4	**	2.1	**	**	1.2	1.6	1.8	2	**	2.8	3	2.8	**	6.7	**	3.3	**	3.1	**
Total Suspended Solids (mg/L)	886	**	301	**	91	**	**	24	202	40	147	**	427	666	384	**	414	**	**	**	102	**

**No Data

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

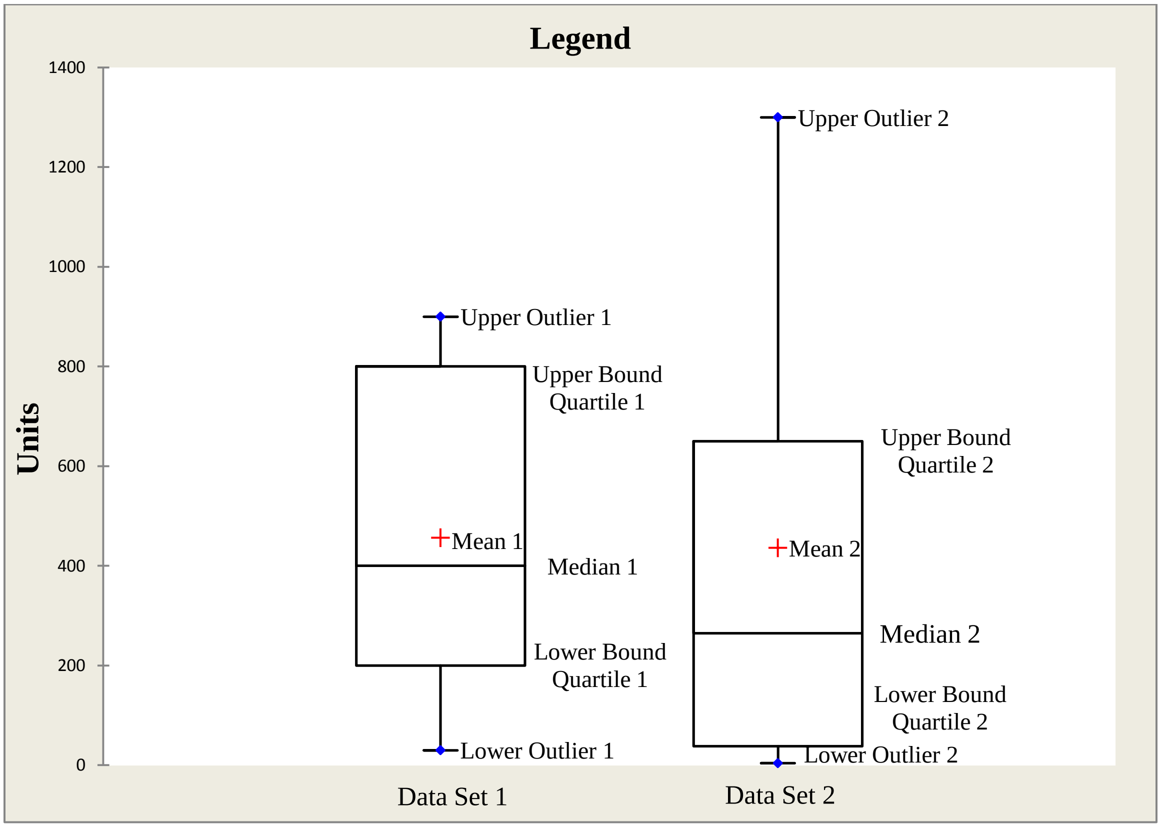


Figure 8. Legend for Box-and-Whisker Plots

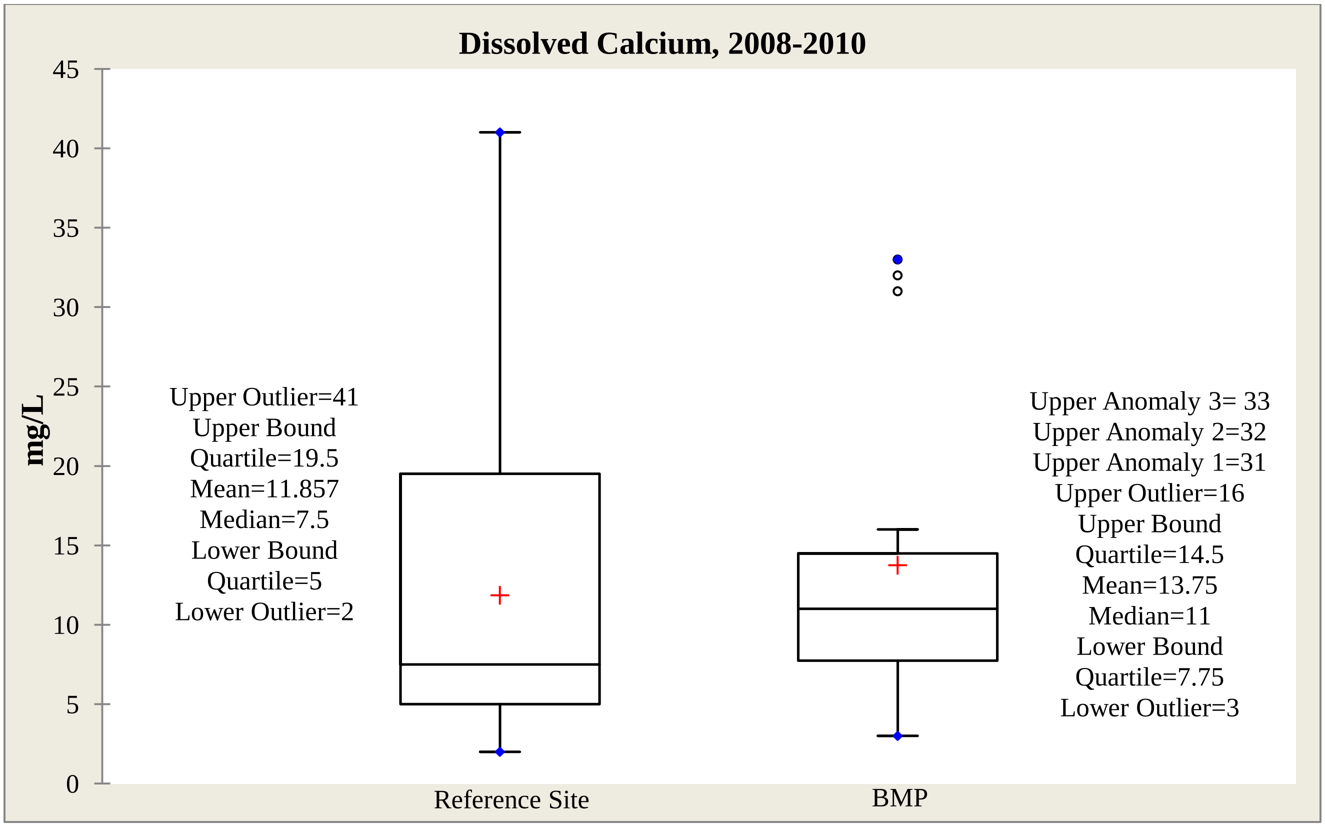


Figure 9. Dissolved Calcium Concentrations at the Reference Site and BMP

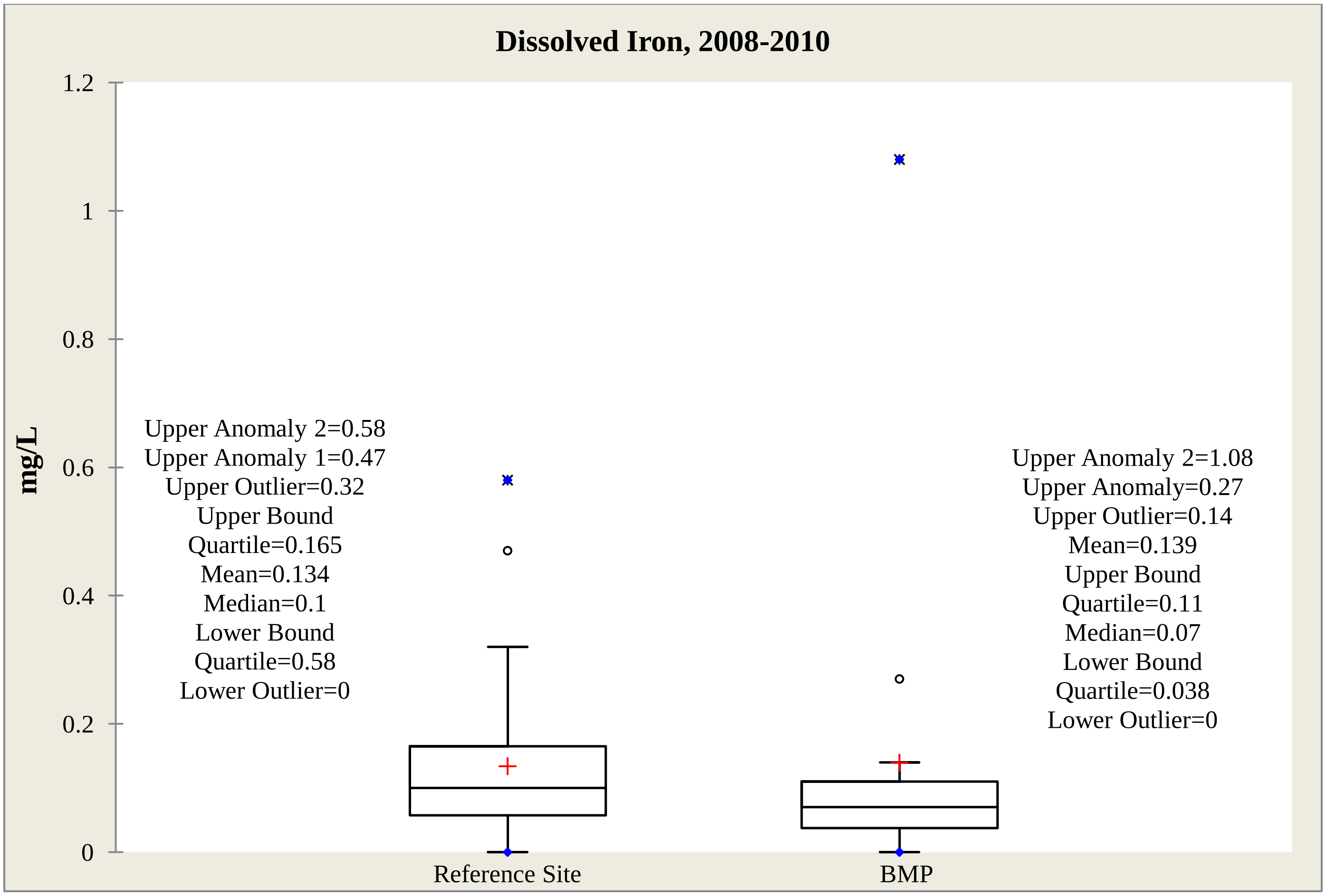


Figure 10. Dissolved Iron Concentrations at the Reference Site and BMP

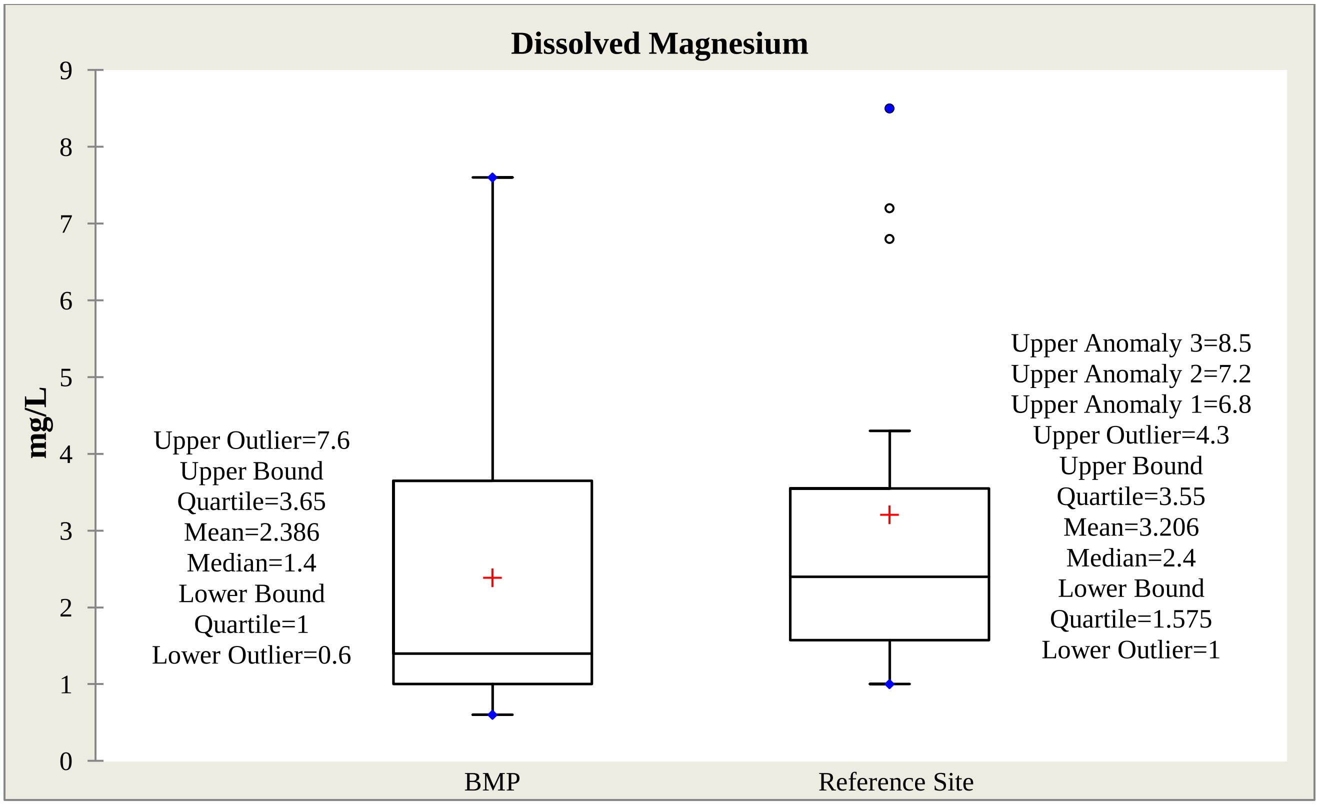


Figure 11. Dissolved Magnesium Concentrations at the Reference Site and BMP

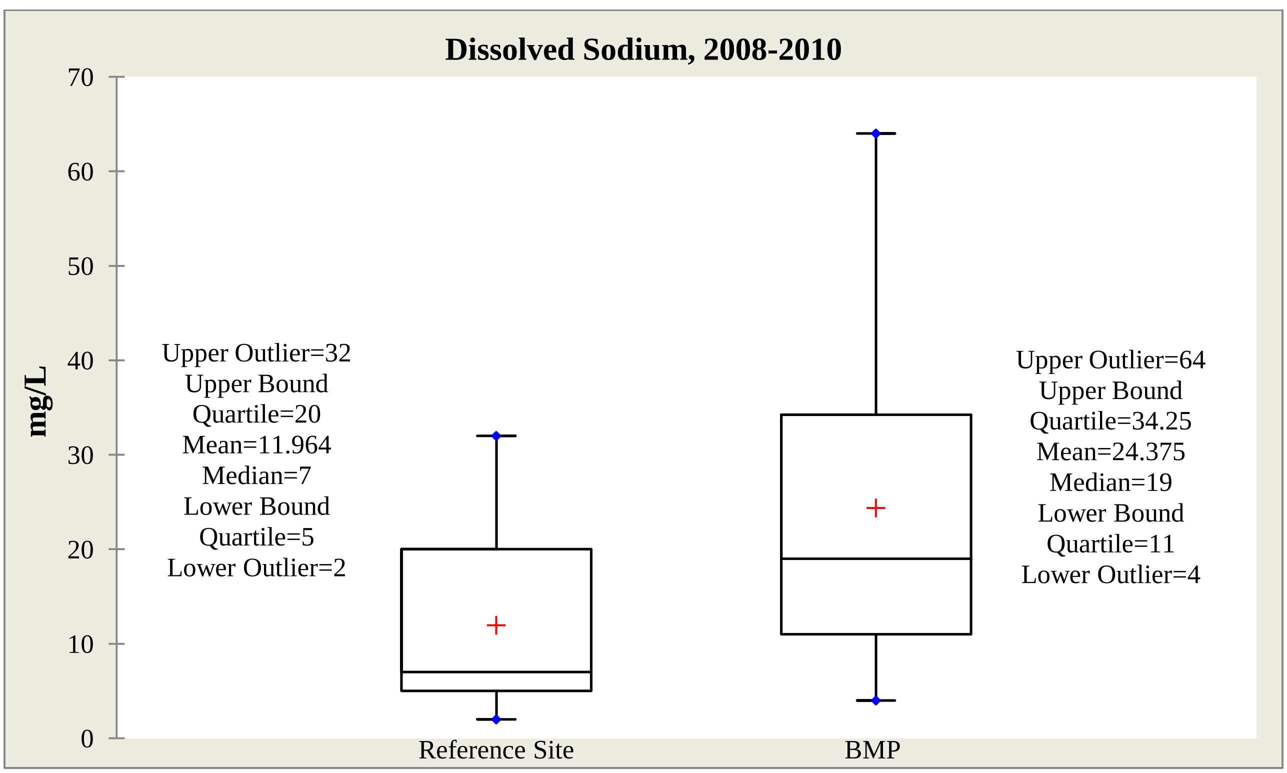


Figure 12. Dissolved Sodium Concentrations at the Reference Site and BMP

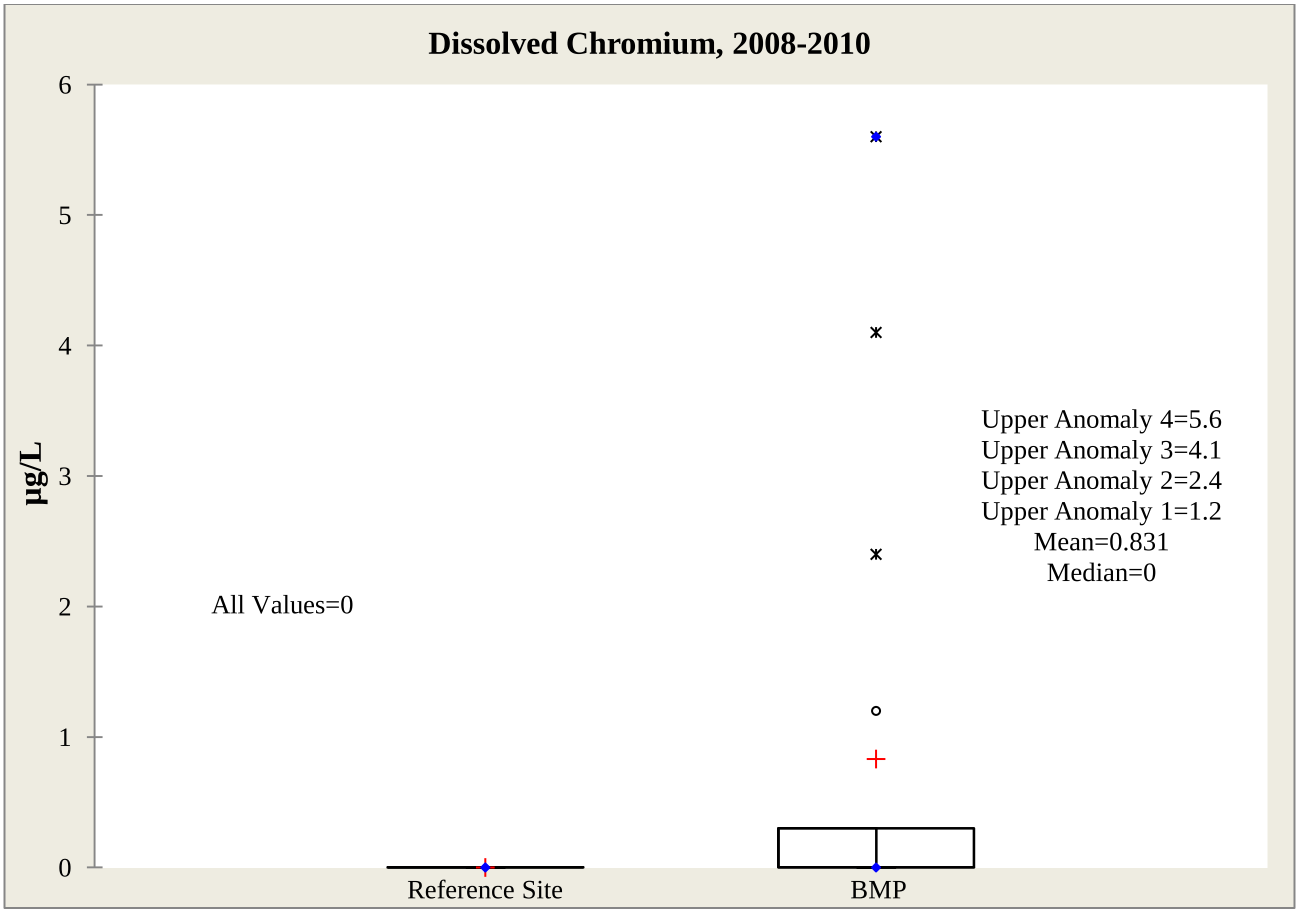


Figure 13. Dissolved Chromium Concentrations at the Reference Site and BMP

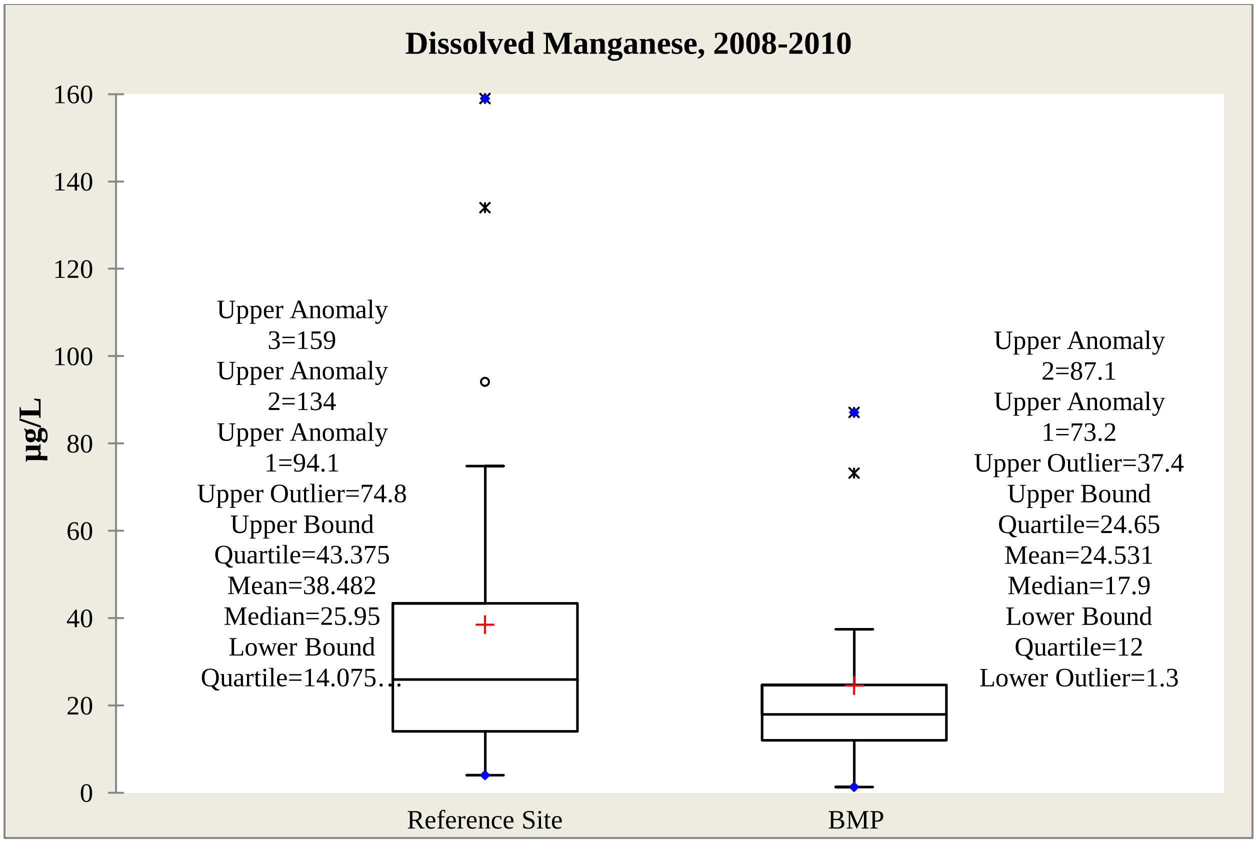


Figure 14. Dissolved Manganese Concentrations at the Reference Site and BMP

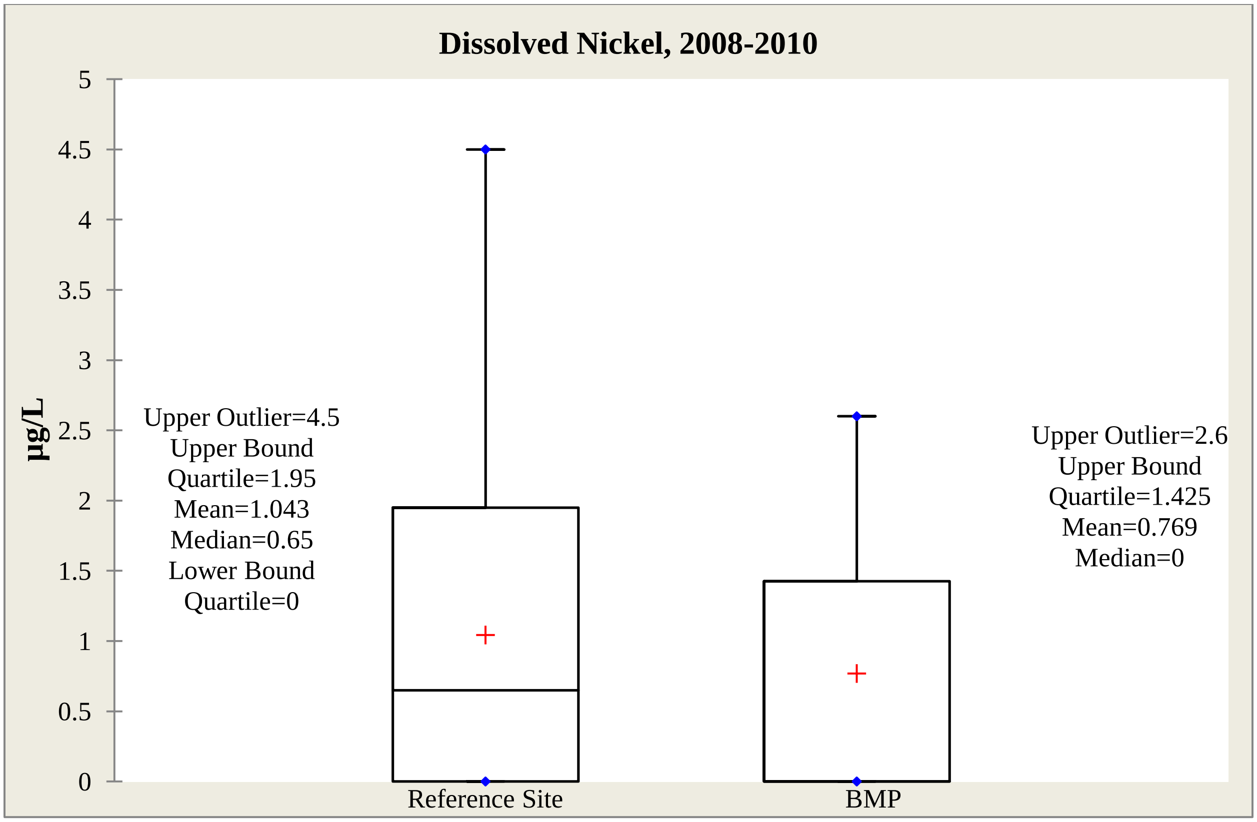


Figure 15. Dissolved Nickel Concentrations at the Reference Site and BMP

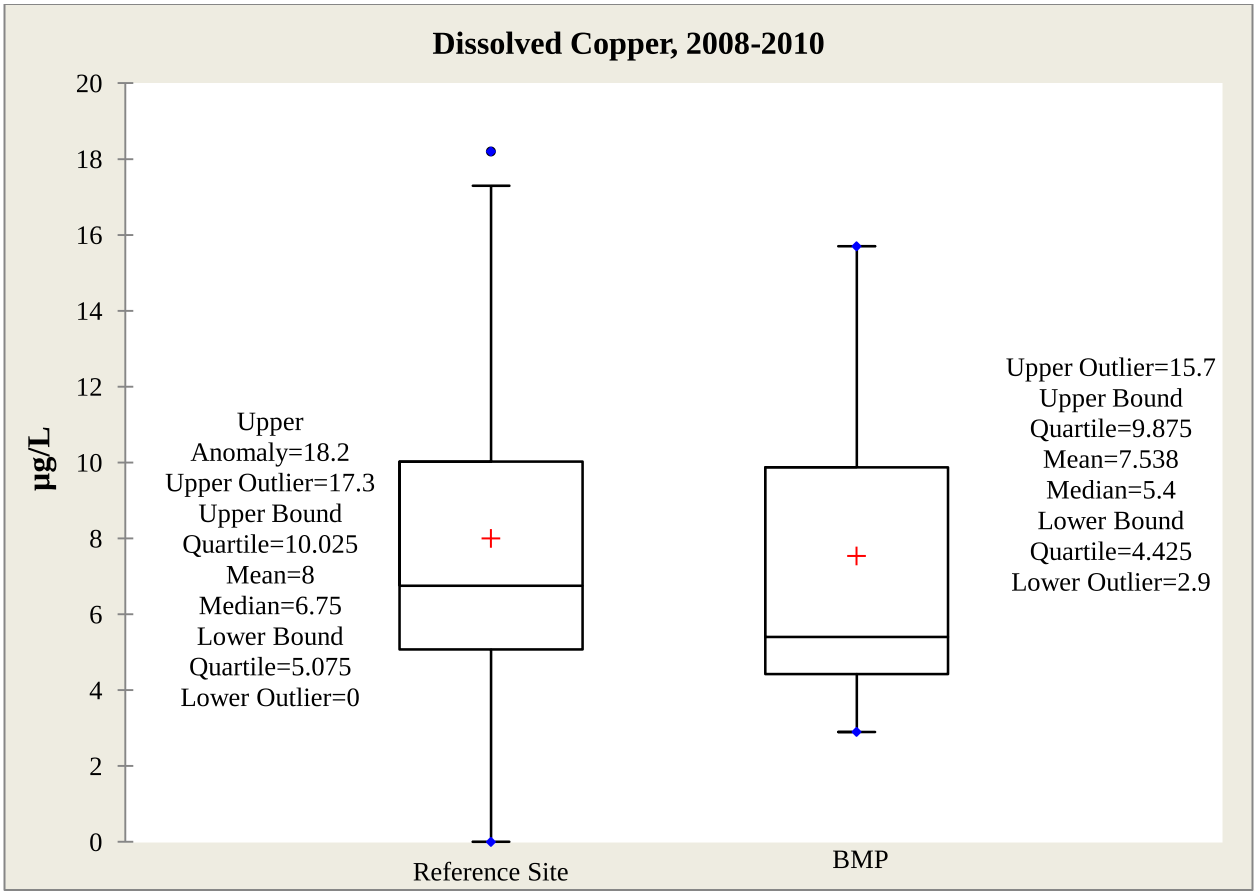


Figure 16. Dissolved Copper Concentrations at the Reference Site and BMP

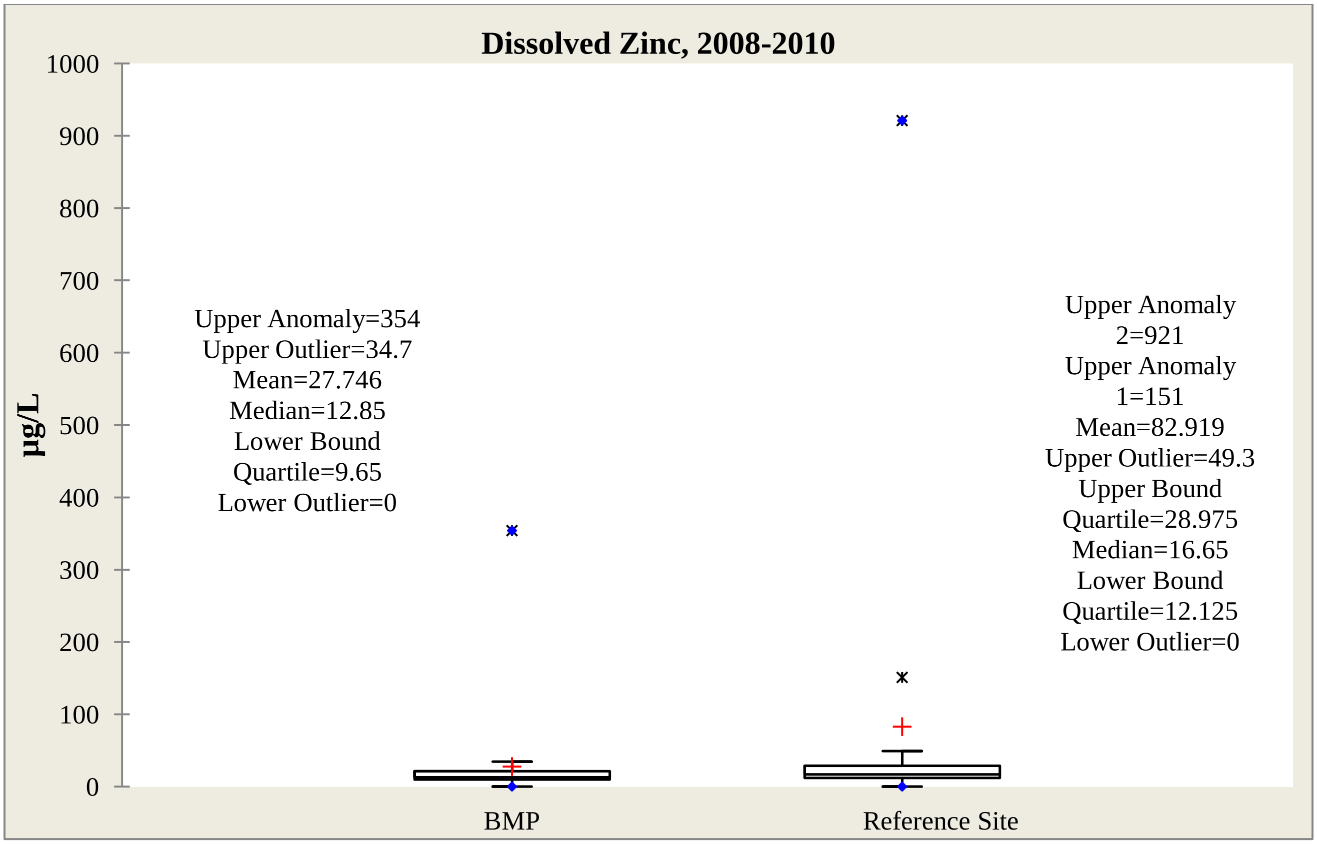


Figure 17. Dissolved Zinc Concentrations at the Reference Site and BMP

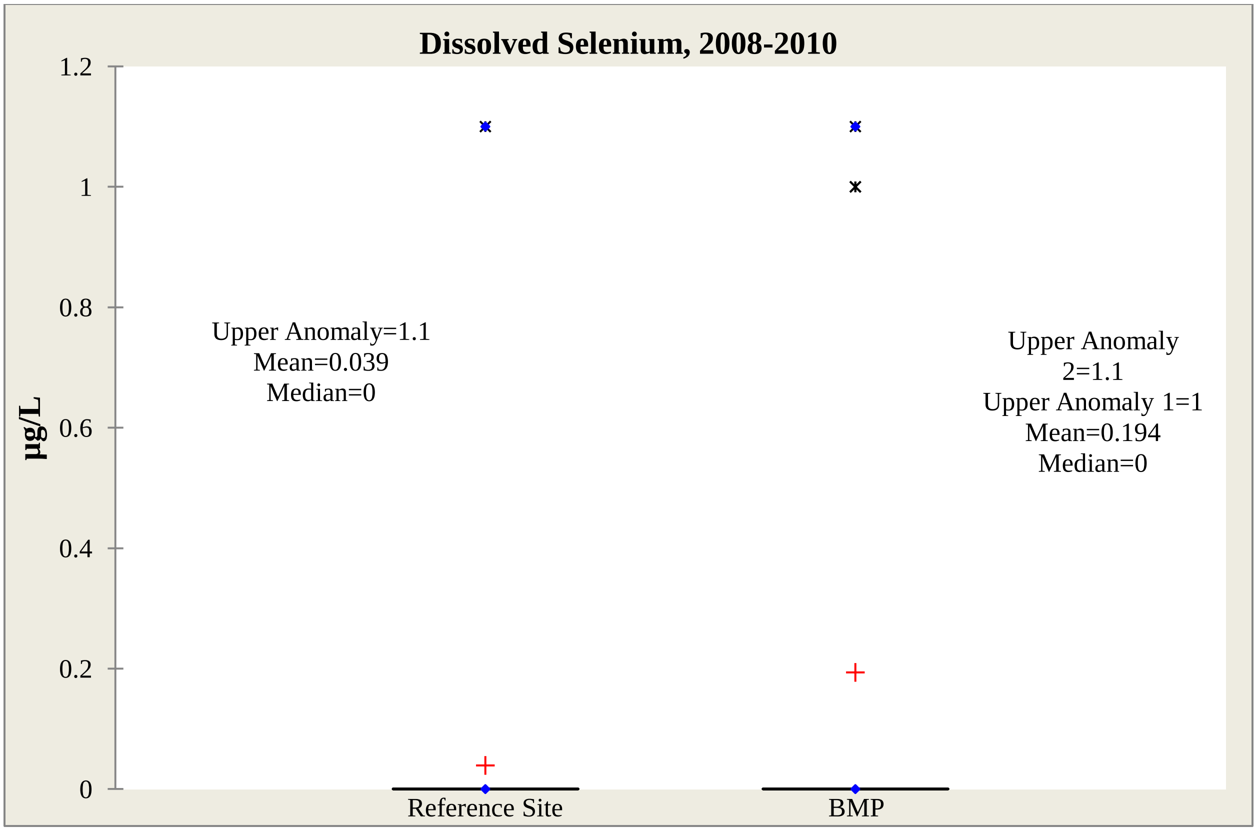


Figure 18. Dissolved Selenium Concentrations at the Reference Site and BMP

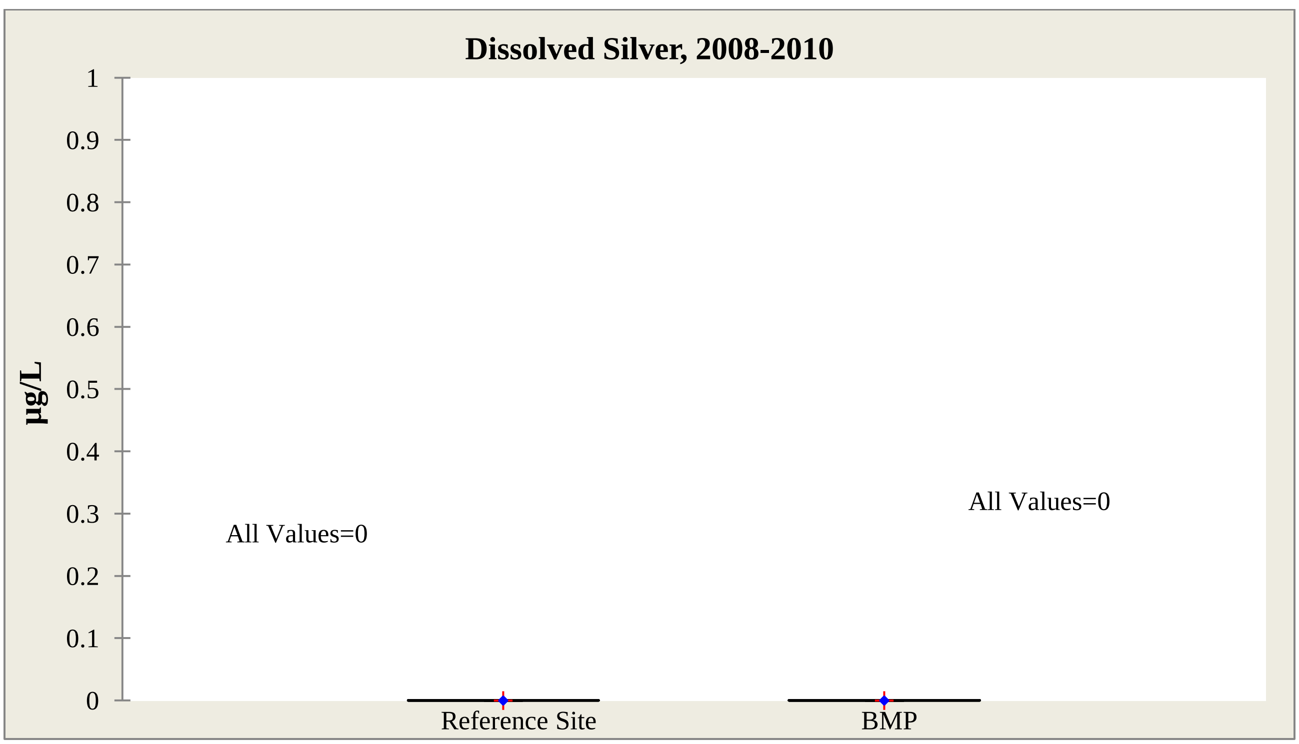


Figure 19. Dissolved Silver Concentrations at the Reference Site and BMP

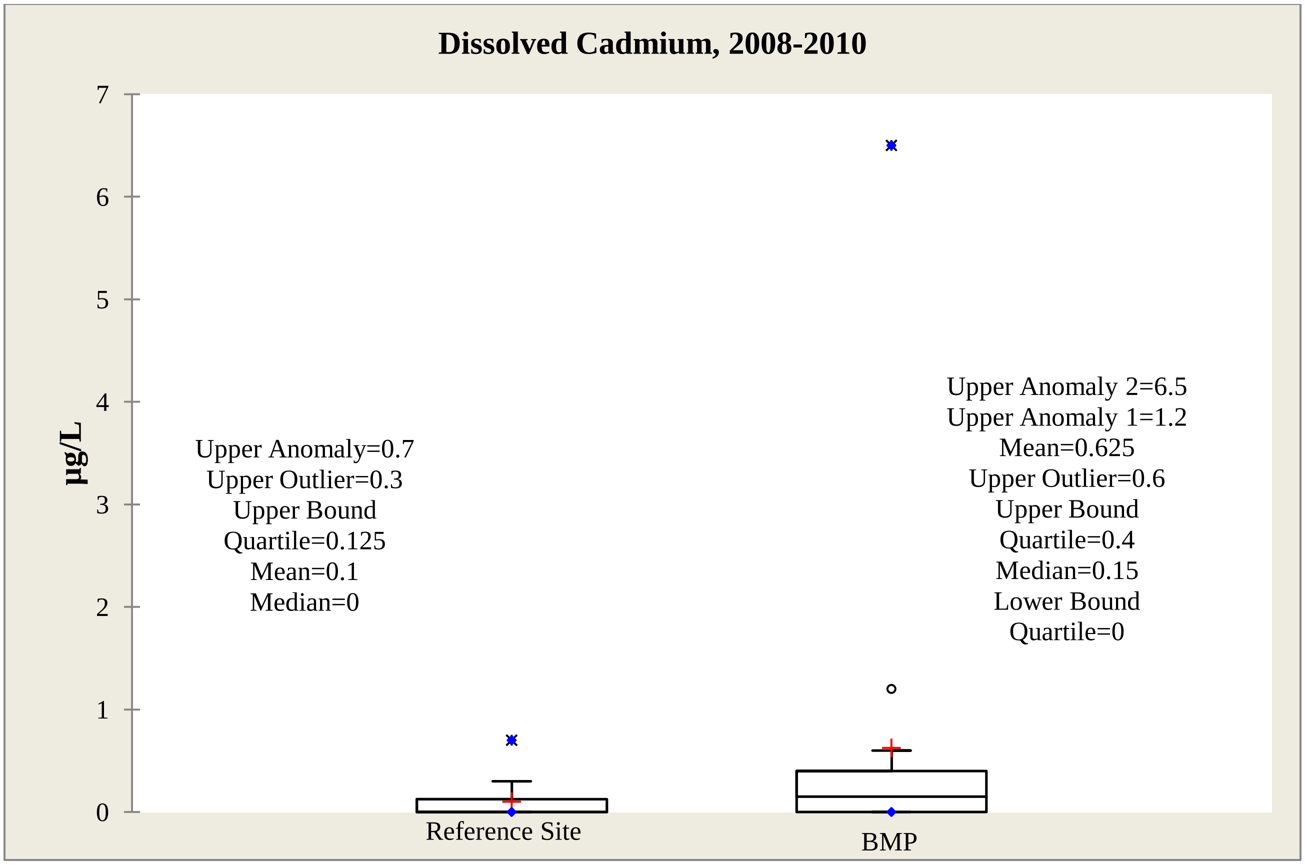


Figure 20. Dissolved Cadmium Concentrations at the Reference Site and BMP

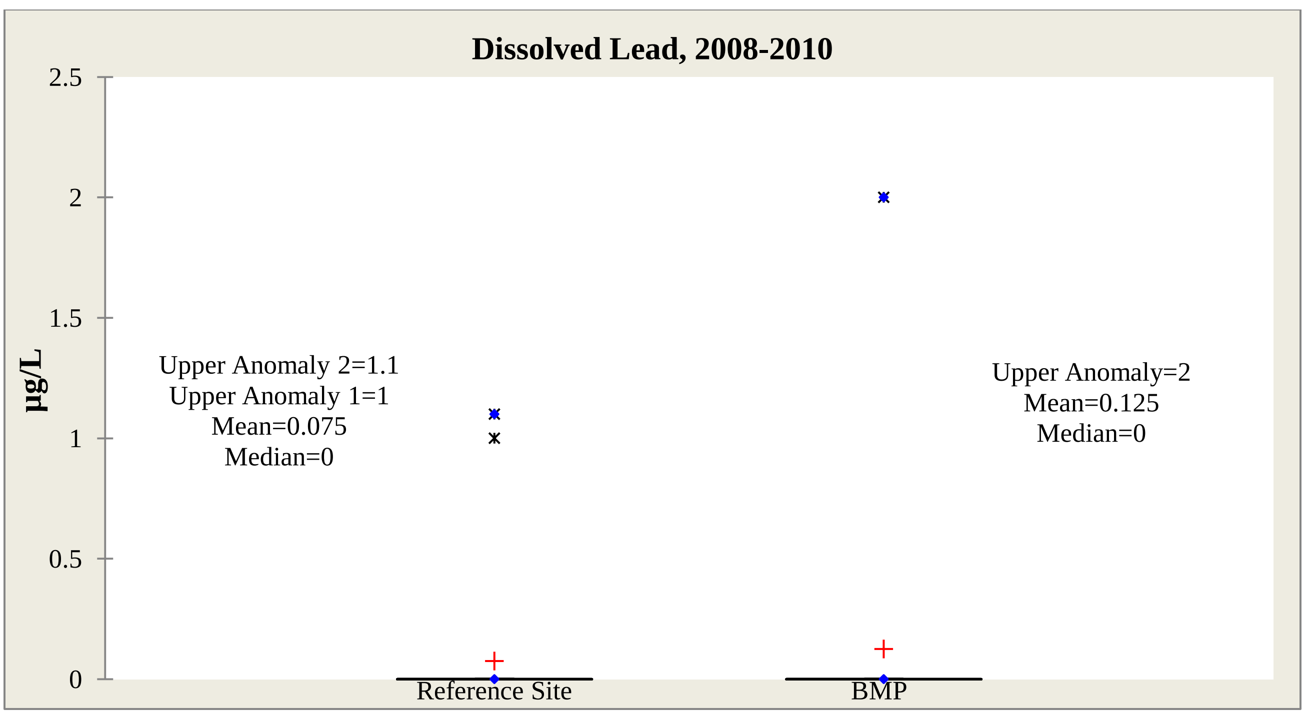


Figure 21. Dissolved Lead Concentrations at the Reference Site and BMP

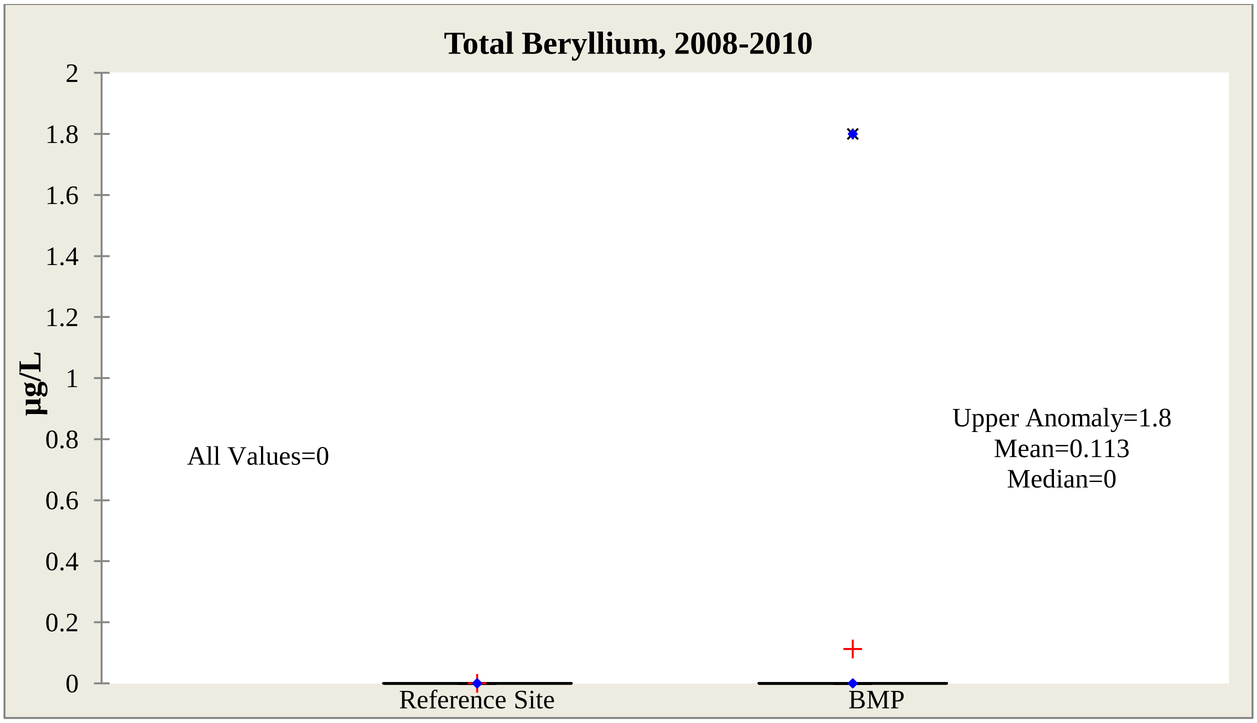


Figure 22. Total Beryllium Concentrations at the Reference Site and BMP

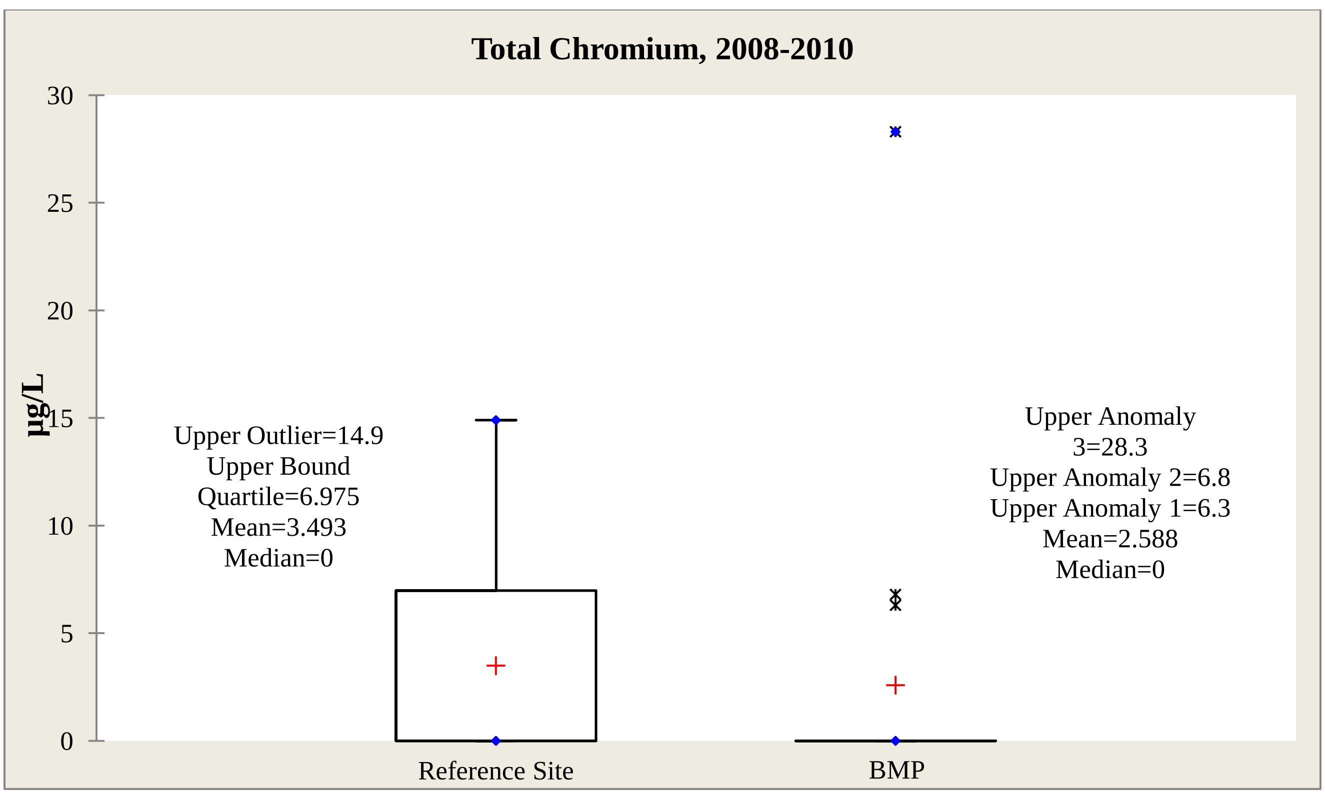


Figure 23. Total Chromium Concentrations at the Reference Site and BMP

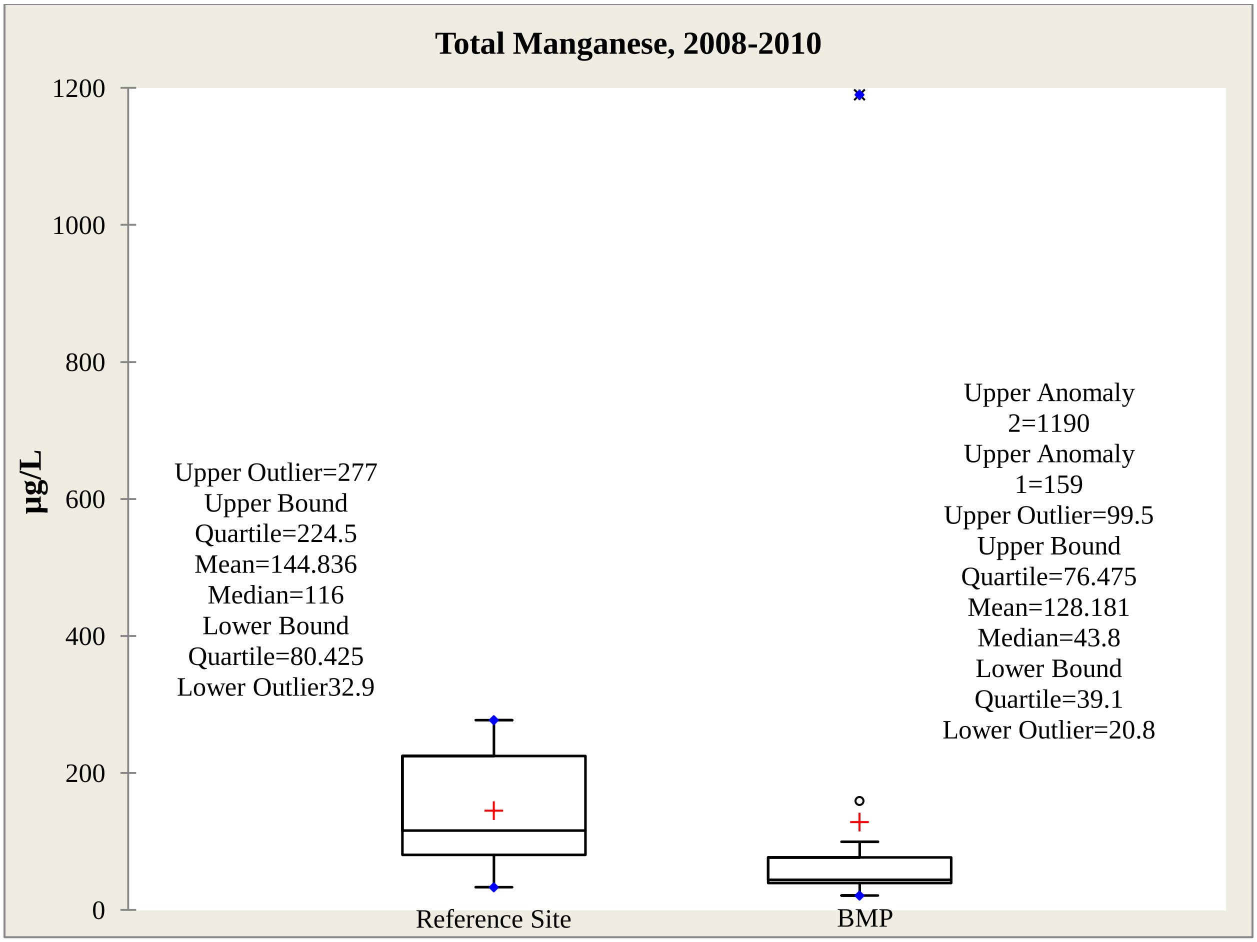


Figure 24. Total Manganese Concentrations at the Reference Site and BMP

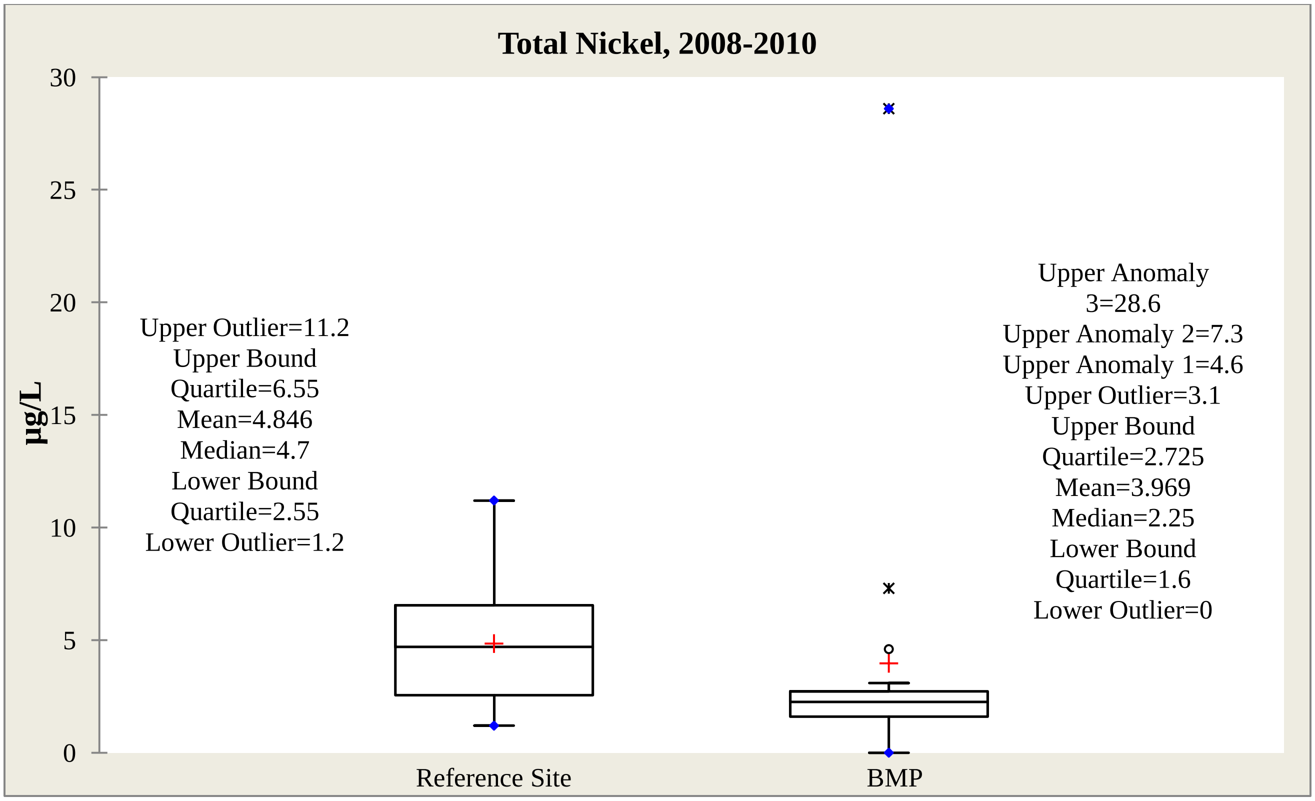


Figure 25. Total Nickel Concentrations at the Reference Site and BMP

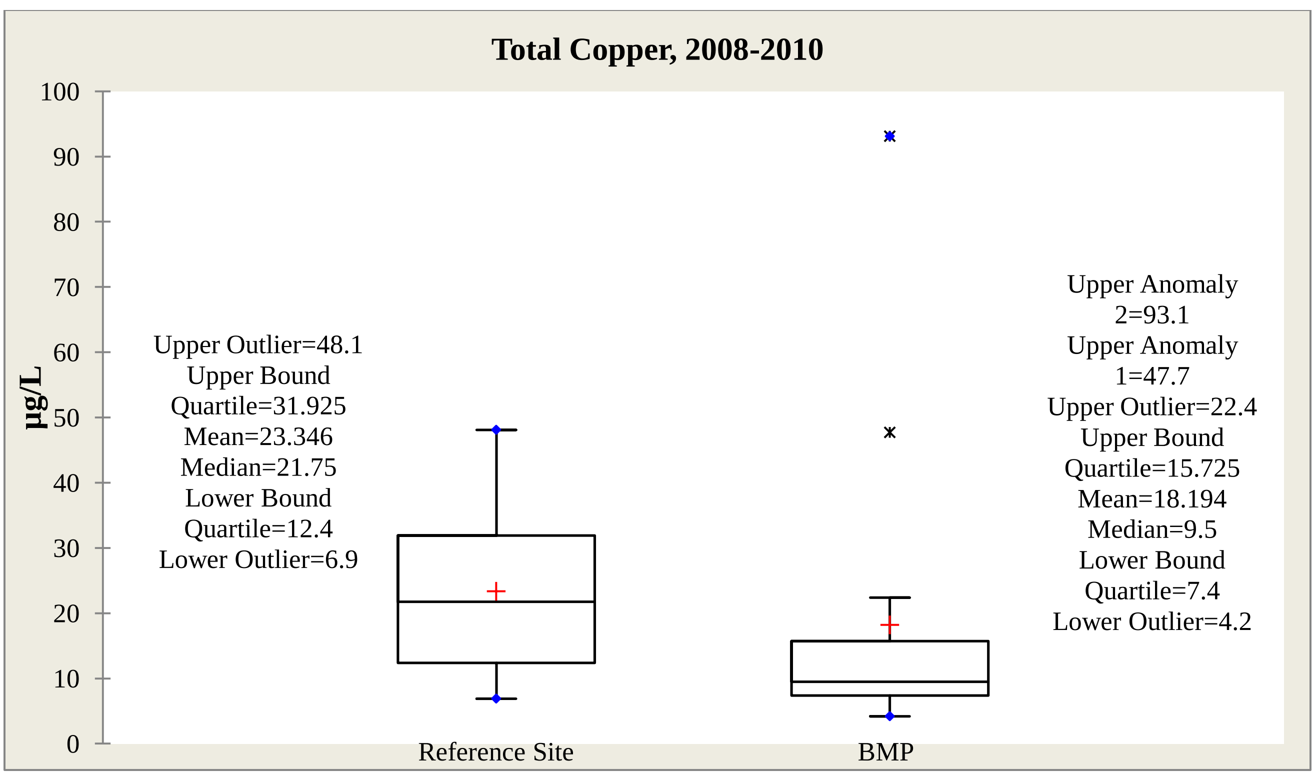


Figure 26. Total Copper Concentrations at the Reference Site and BMP

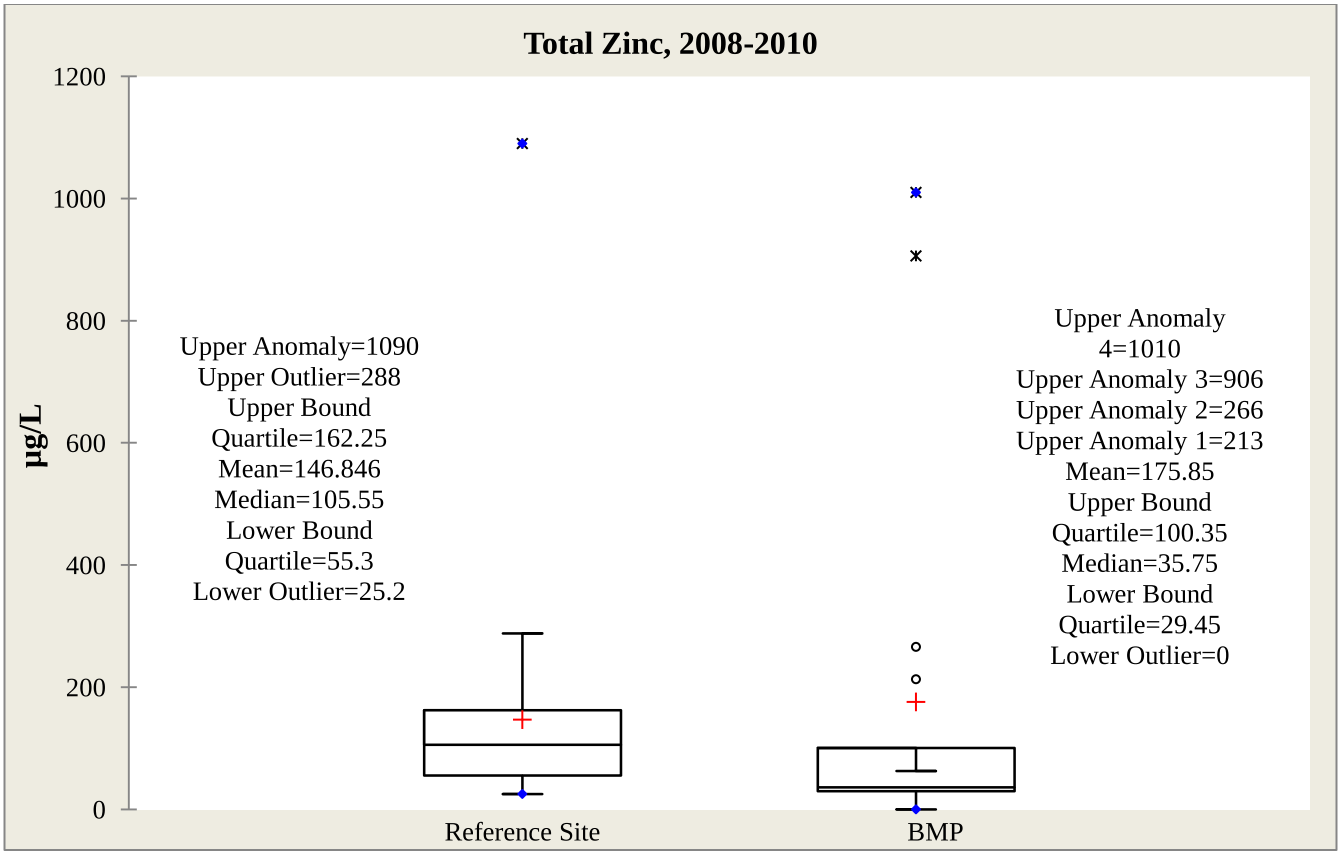


Figure 27. Total Zinc Concentrations at the Reference Site and BMP

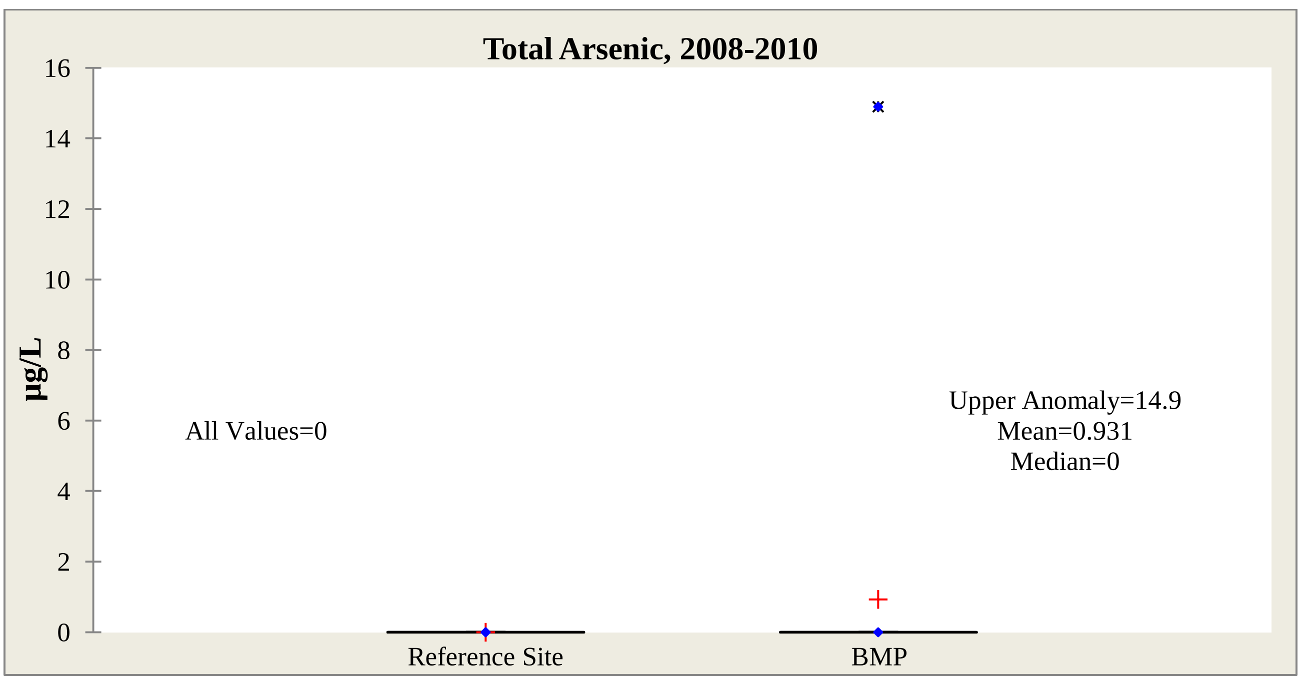


Figure 28. Total Arsenic Concentrations at the Reference Site and BMP

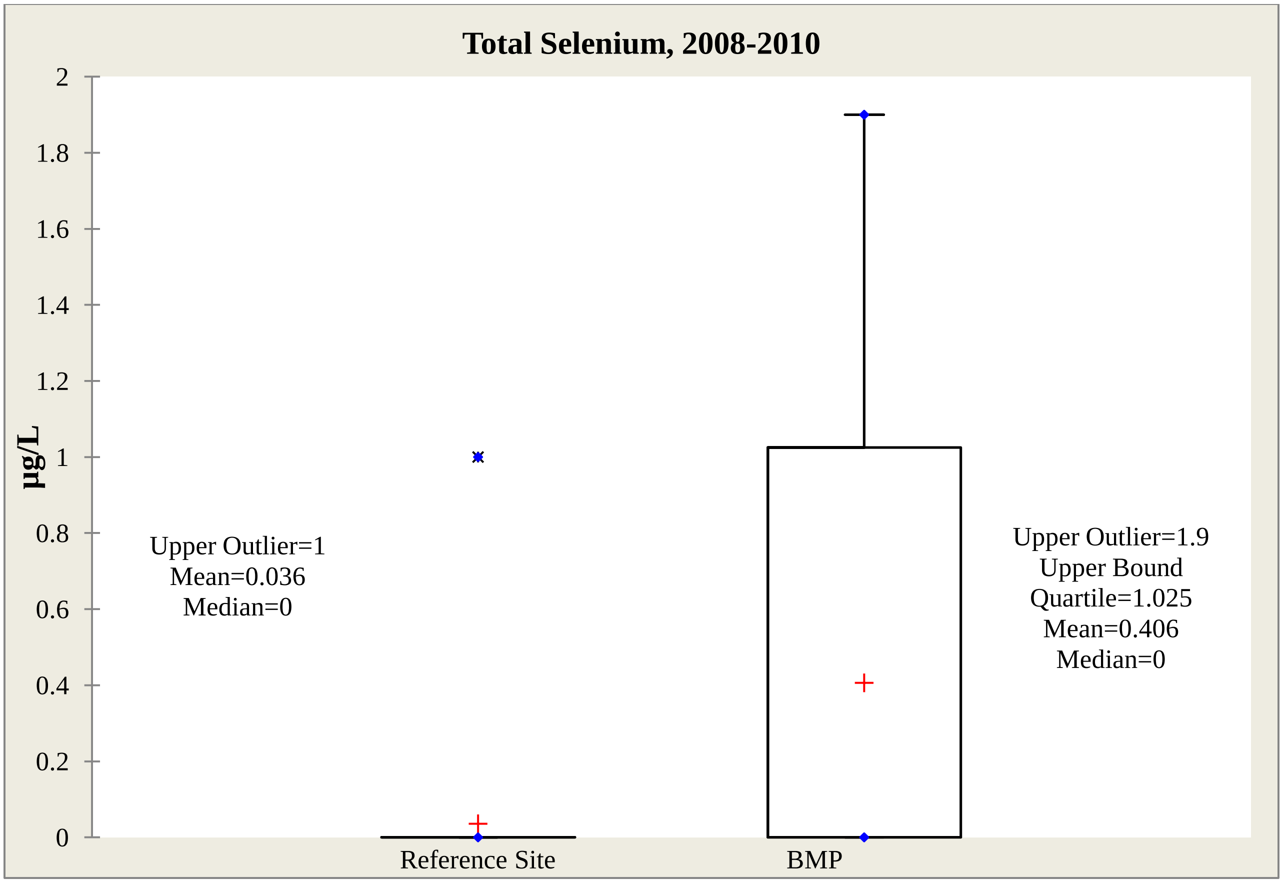


Figure 29.Total Selenium Concentrations at the Reference Site and BMP

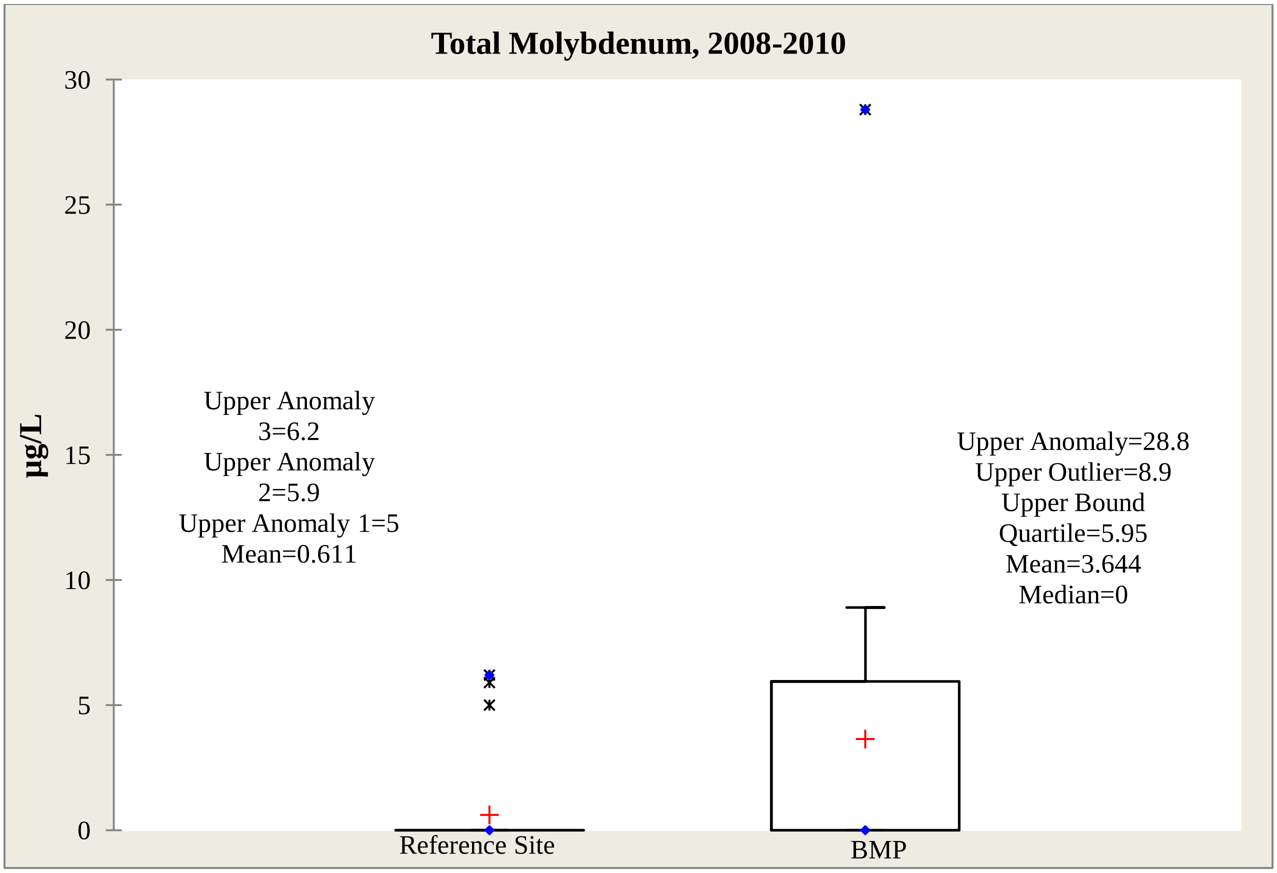


Figure 30. Total Molybdenum Concentrations at the Reference Site and BMP

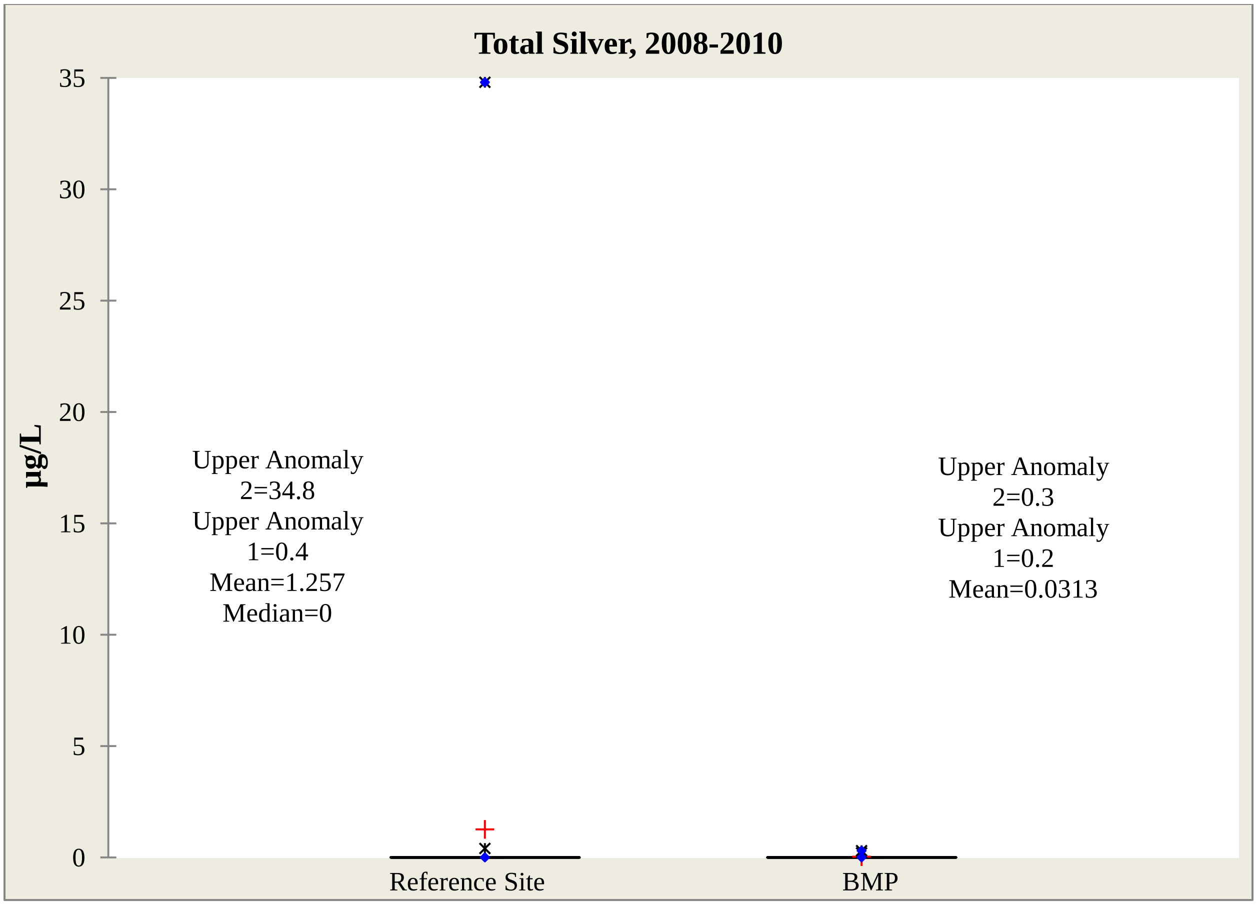


Figure 31. Total Silver Concentrations at the Reference Site and BMP

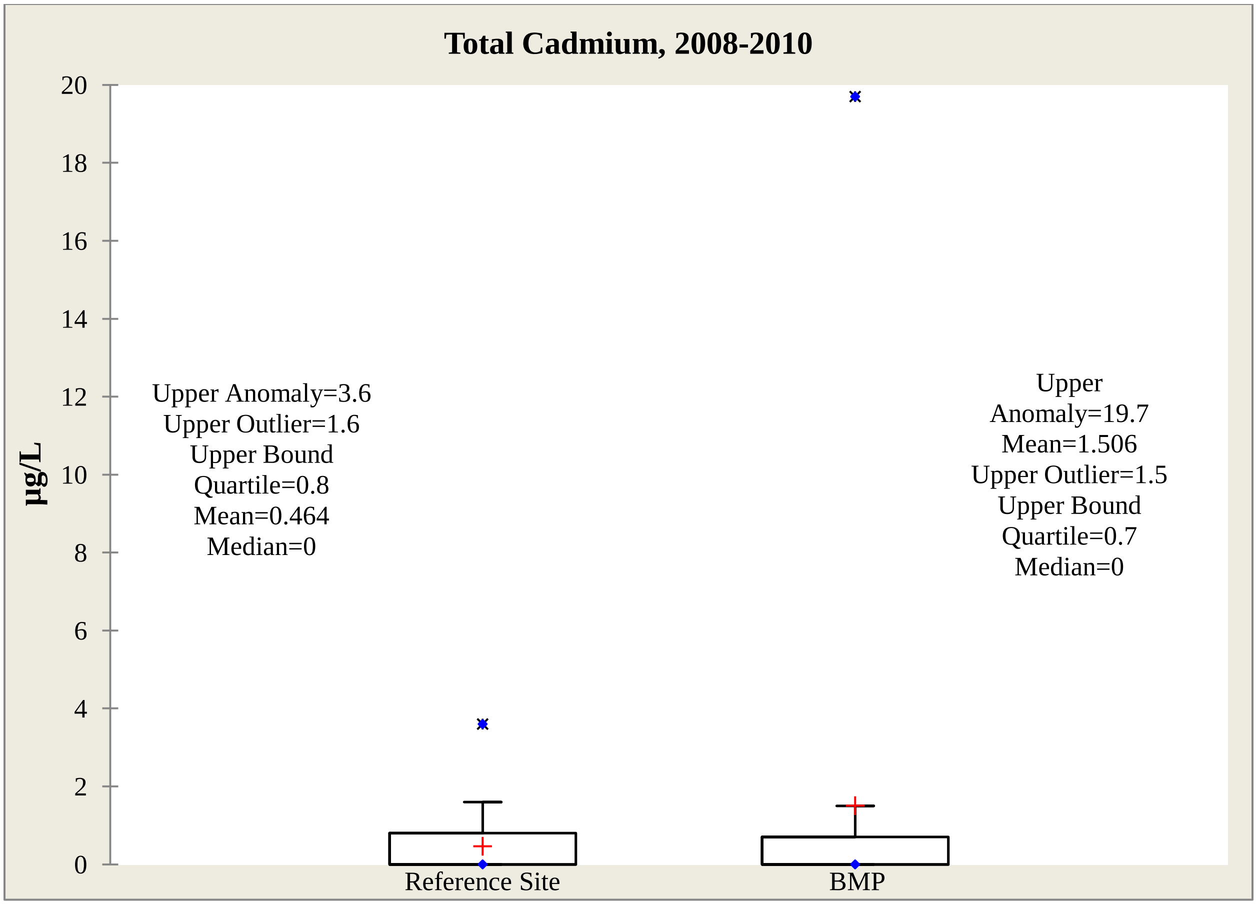


Figure 32. Total Cadmium Concentrations at the Reference Site and BMP

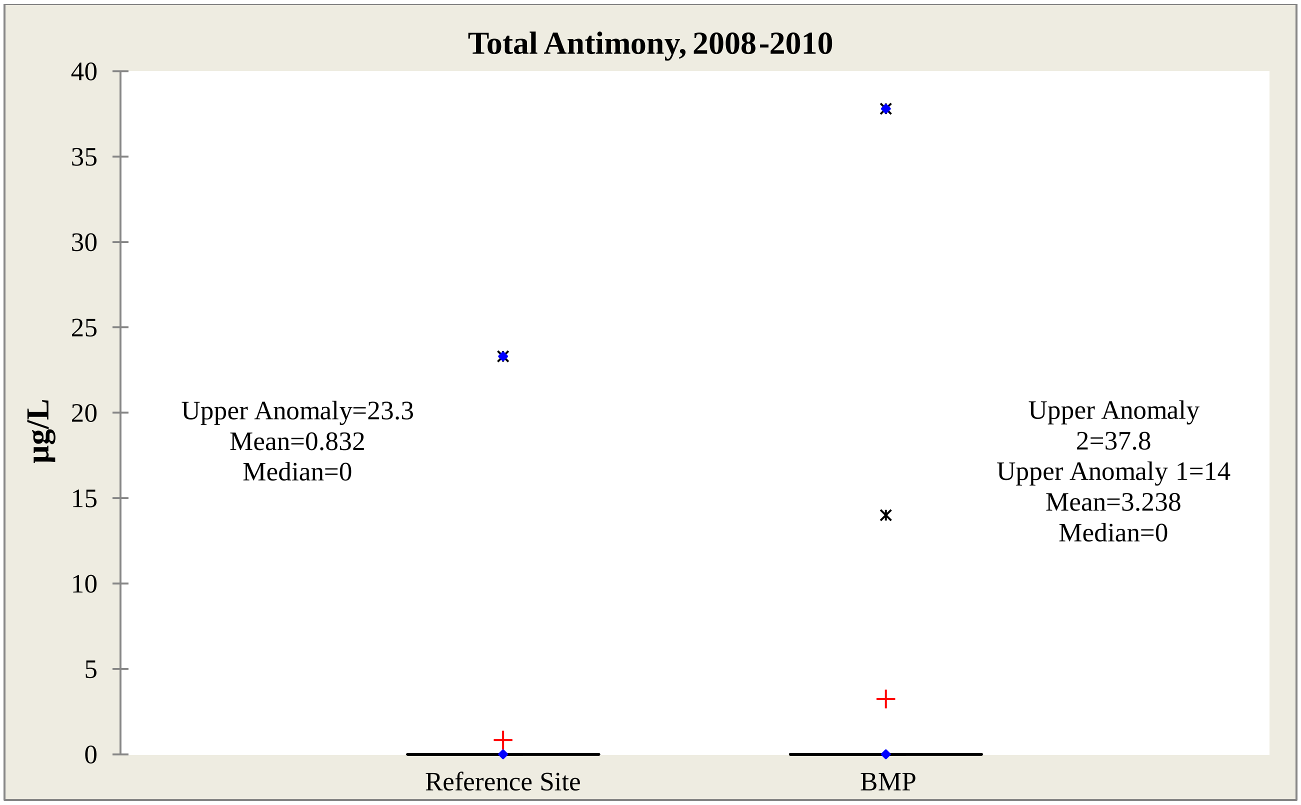


Figure 33. Total Antimony Concentrations at the Reference Site and BMP

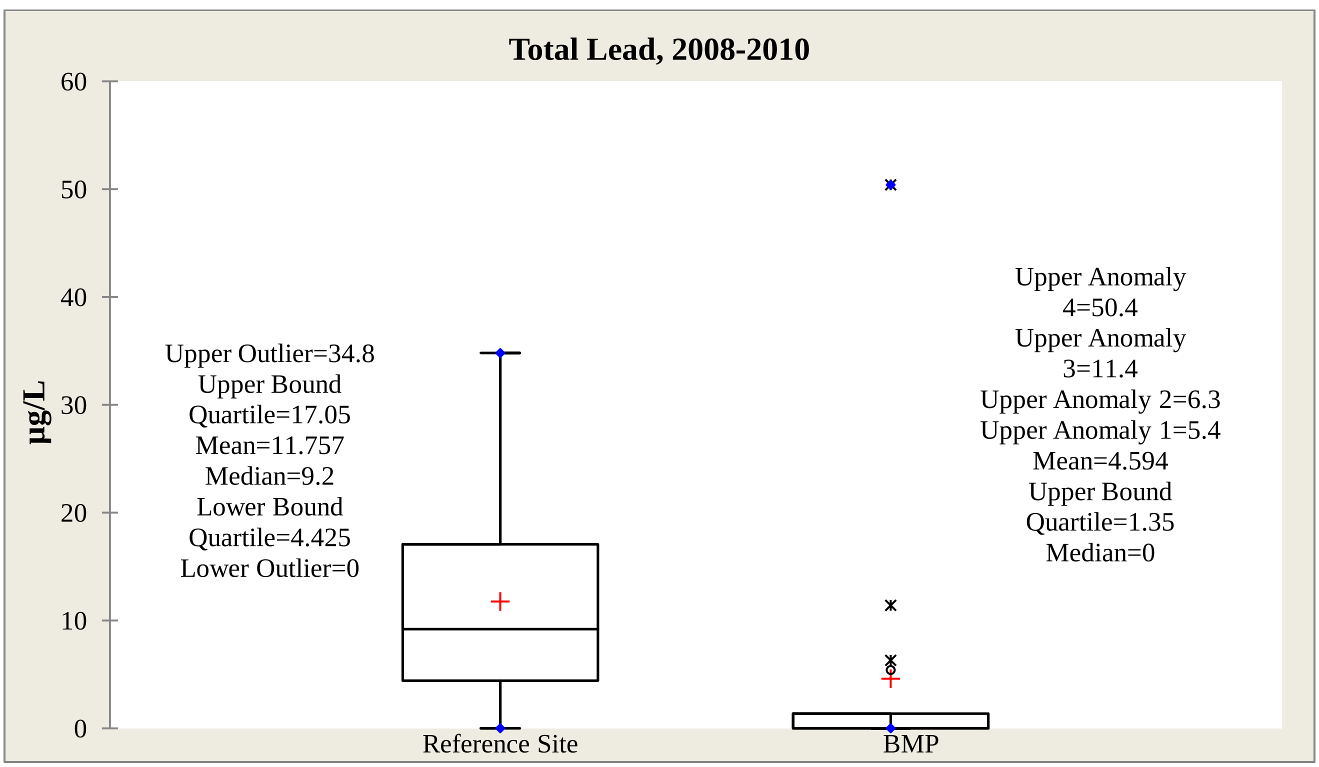


Figure 34. Total Lead Concentrations at the Reference Site and BMP

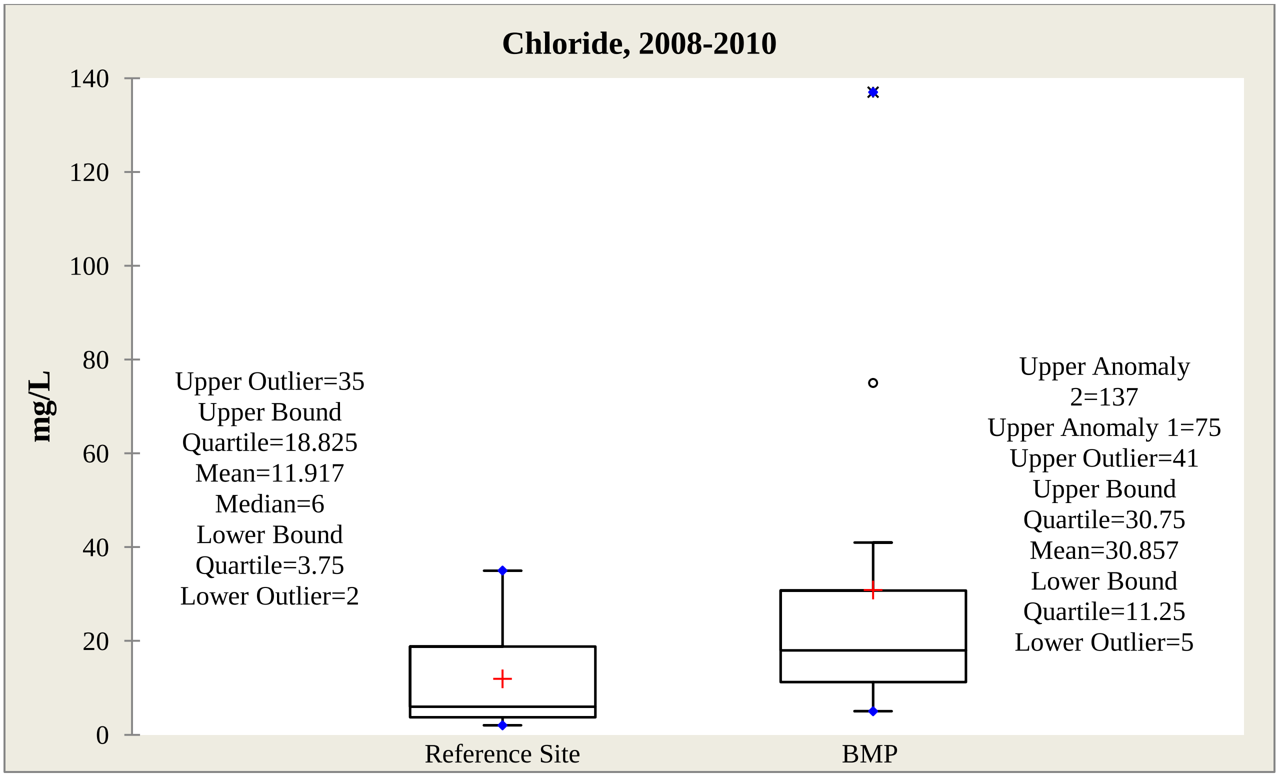


Figure 35. Chloride Concentrations at the Reference Site and BMP

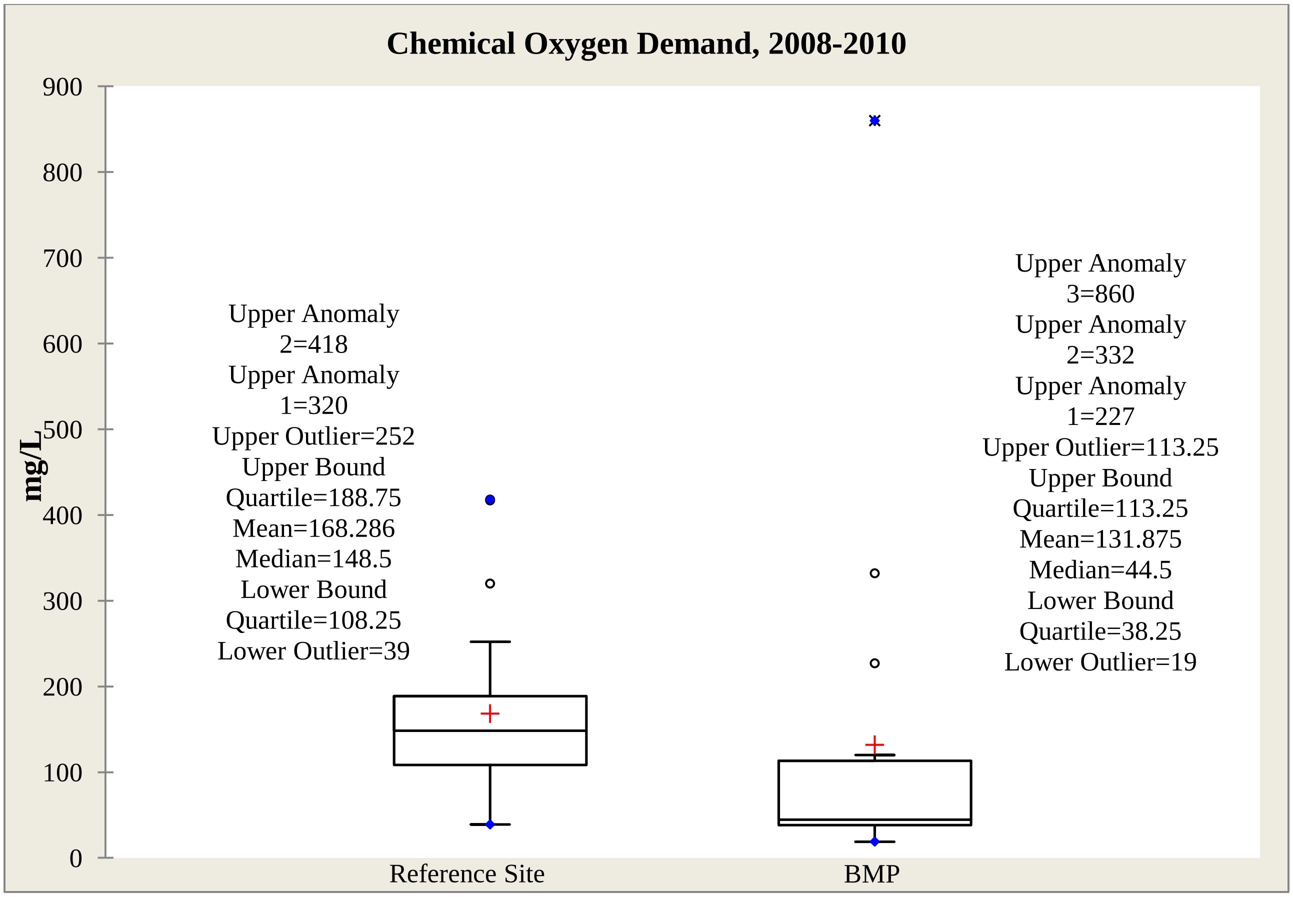


Figure 36. Chemical Oxygen Demand at the Reference Site and BMP

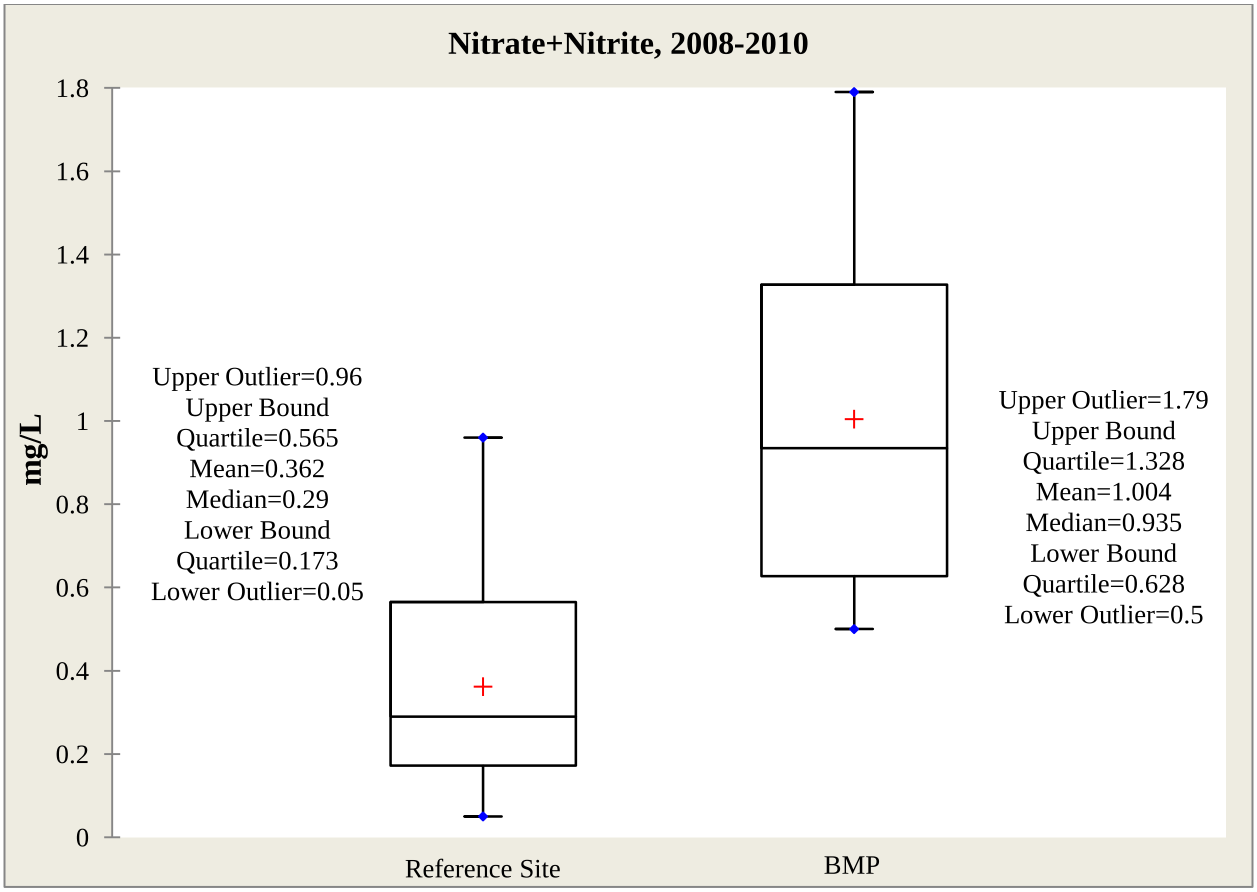


Figure 37. Nitrite+Nitrate Concentrations at the Reference Site and BMP

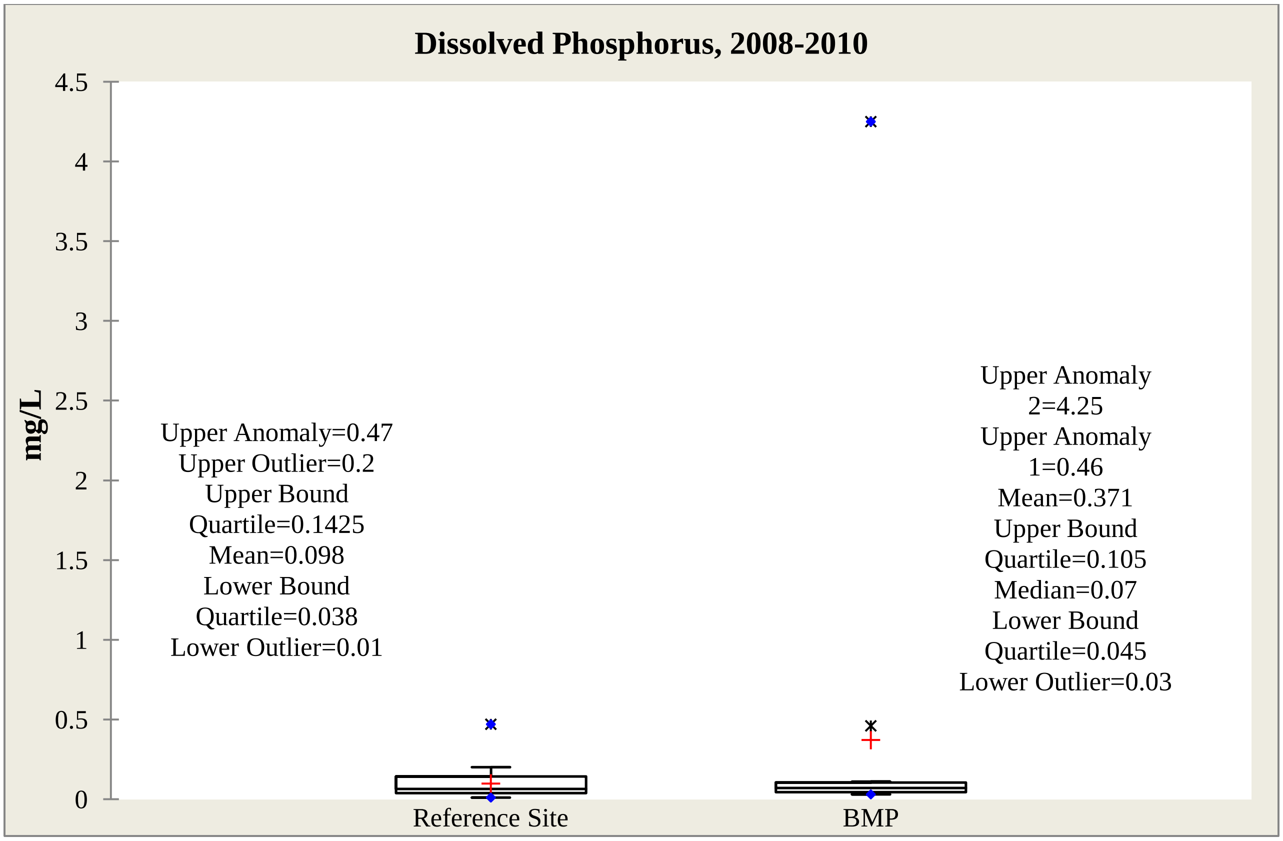


Figure 38. Dissolved Phosphorus Concentrations at the Reference Site and BMP

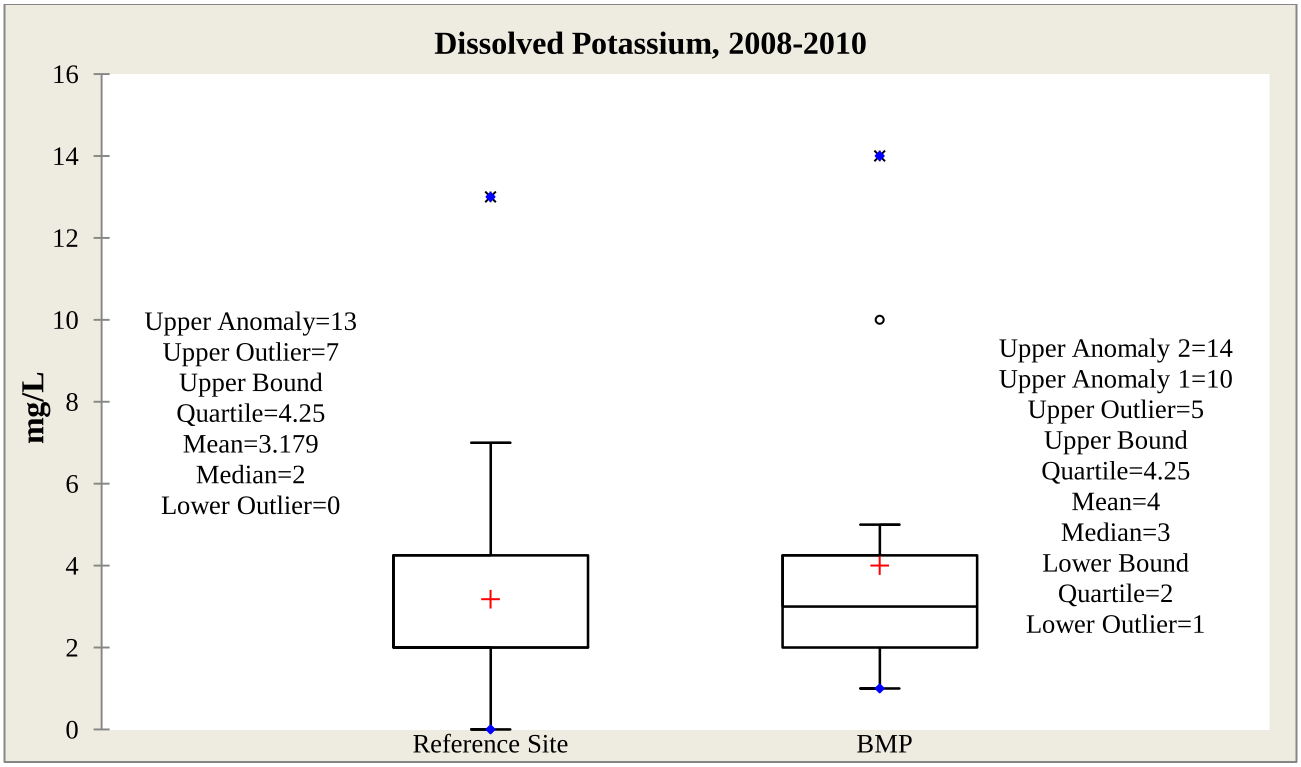


Figure 39. Dissolved Potassium Concentrations and the Reference Site and BMP

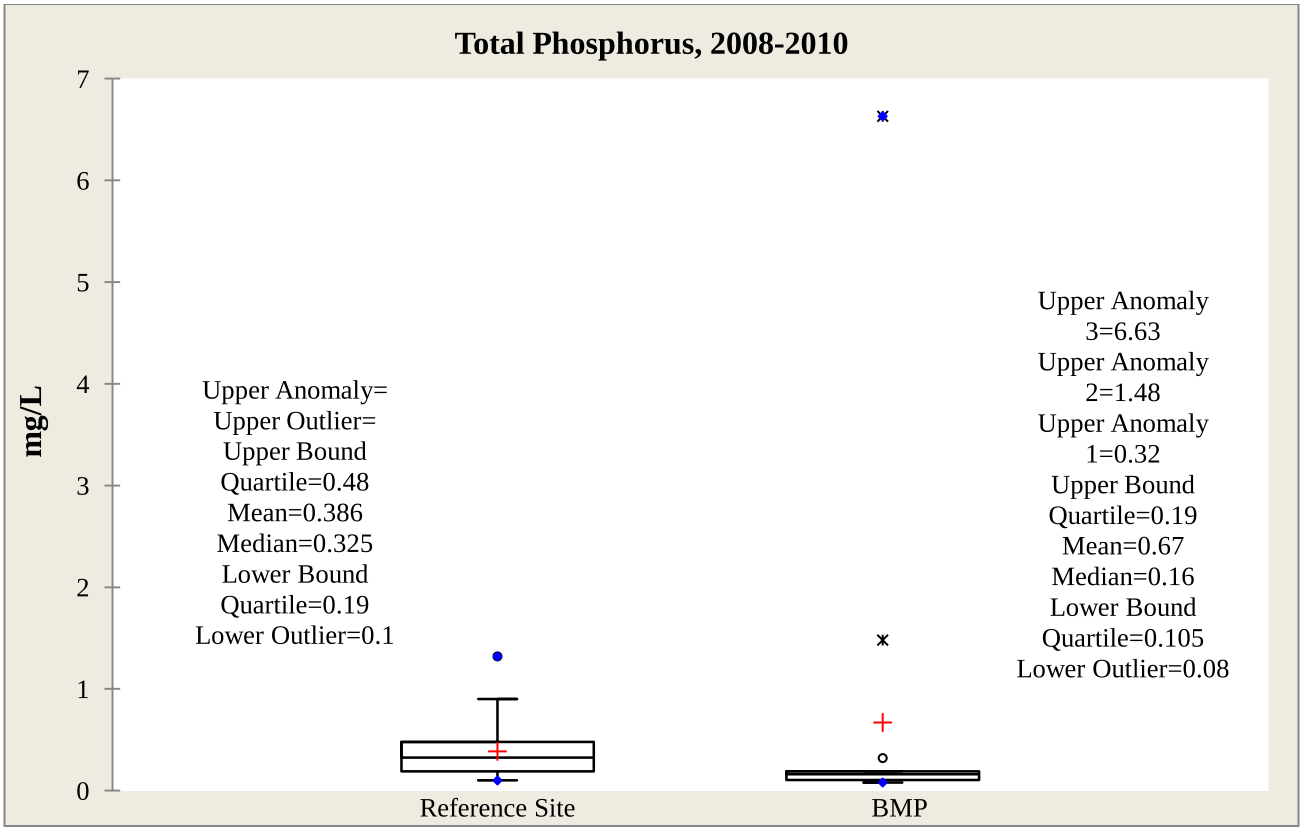


Figure 40. Total Phosphorus Concentrations at the Reference Site and BMP

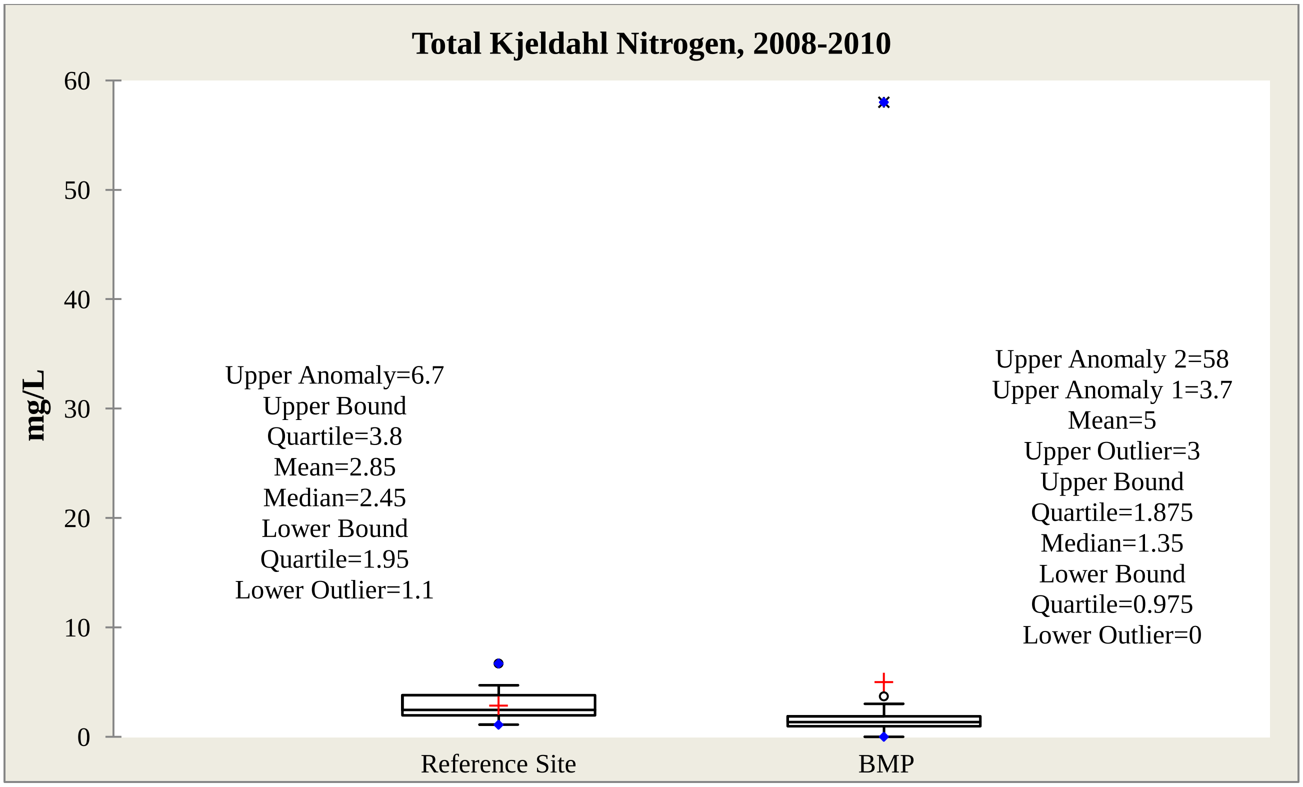


Figure 41. Total Kjeldahl Nitrogen Concentrations at the Reference Site and BMP

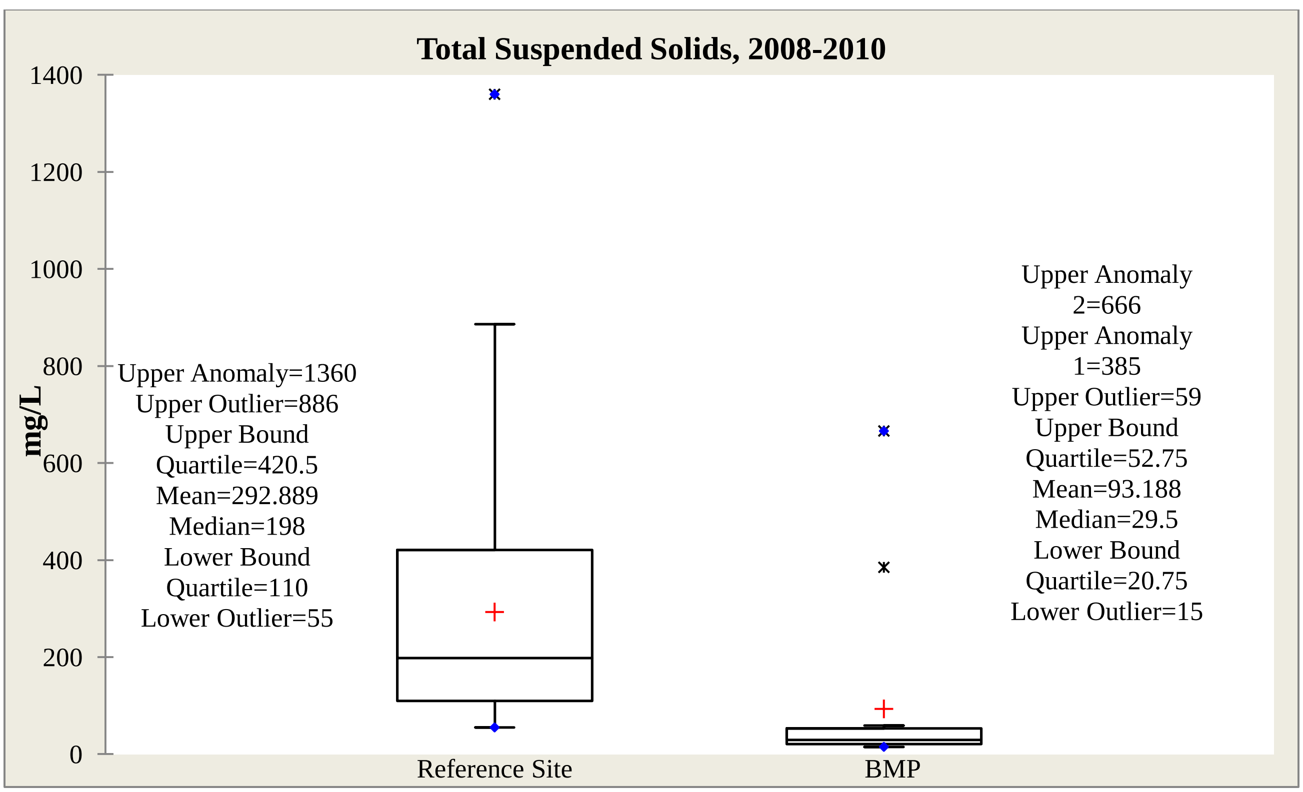


Figure 42. Total Suspended Solids at the Reference Site and BMP

V. Conclusion

Assessment of flow reduction and water quality has been difficult at this site. Equipment failures have complicated flow measurement at the porous asphalt. Improvements, namely the installation of the bubbler module, should lead to some improvement in flow readings. While methods for sample collection have been successful, it is hard to discern how the porous asphalt has impacted water quality since the water quality data, in comparison to the reference site, is in many cases not statistically significant. There were some significant differences between the reference site and the porous asphalt. Dissolved Potassium, Chloride, and Dissolved Phosphorus (according to one test) were significantly lower in the porous asphalt outflows compared to the reference site. Nitrite+Nitrate, Total Selenium, and Dissolved Sodium were all in significantly higher concentrations in the porous asphalt outflows when compared to the reference site. As noted in this report differences may be amplified by differences in site use. The reference site is in a more remote area of an employee parking lot and the BMP site is in a frequently traveled area at the entrance of the building.

Due to clogging of the wearing course, UDFCD could consider other alternatives for this site such as conventional asphalt to serve as an improved reference site for the adjacent PICP site or a difference type of permeable pavement. UDFCD continues to investigate the use of porous asphalt in the Denver metropolitan area. In 2011 UDFCD tested infiltration rates of porous asphalt installations at four other sites and continues to look for other sites in place for at least three years to determine if infiltration rates can be maintained or restored after this period of time. Results were mixed and more tests are needed before UDFCD can recommend porous asphalt per the permeable pavement design criteria in Volume 3 of the USDCM.

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 fairly consistent with the porous asphalt data produced by this study.

Table 8. Comparison of Median Constituents for the porous asphalt at Denver Waste Water and the International Stormwater BMP Database

	Data from Porous Asphalt		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	0.16	0.12	0.13
Total Suspended Solids (mg/L)	198	29.5	23.5	29.1
Total Kjeldahl Nitrogen (mg/L)	2.45	1.35	2.4	1.05
Total Cadmium (µg/L)	0	0	NA	0.3
Dissolved Copper (µg/L)	6.75	5.4	5.0	6.2
Total Copper (µg/L)	21.75	9.5	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	16.65	25	14.6
Total Zinc (µg/L)	105.55	35.75	50	22

NA=Not Analyzed

The runoff data for the reference site 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 9. Comparison of Mean Constituents for the Reference Site Inflows and the Commercial DRURP Data

Constituent	EMC Denver Commercial Land Use (DRURP)	EMC Reference Site	EMC Porous Asphalt
Total Phosphorus (mg/L)	0.42	0.39	0.67
Total Kjeldahl Nitrogen (mg/L)	2.30	2.85	5.00
Nitrate+Nitrite (mg/L)	0.96	0.36	1.00
Total Lead (µg/L)	0.06	11.76	4.59
Total Zinc (µg/L)	0.24	146.85	175.85
Total Copper (µg/L)	0.04	23.35	18.19
Total Cadmium (µg/L)	0.00	0.46	1.51
Chemical Oxygen Demand (mg/L)	173.00	168.29	131.88
Total Suspended Solids (mg/L)	225.00	292.89	93.19

ND=Not Detected

VI. References

International Stormwater Best Management Practices (BMP) data base: www.bmpdatabase.org. (June 14, 2011).

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).

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

Urban Drainage and Flood Control District (UDFCD). 2010. *Urban Storm Drainage Criteria Manual – Volume 3*. Updated and maintained by UDFCD. Denver, Colorado