Stormwater Quality Monitoring Report

Extended Detention Basin at Grant Ranch
Denver, Colorado
2009

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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 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.

Extended Detention Basin Design

At Grant Ranch, an Extended Detention Basin (EDB) is the first step in a treatment train approach used to treat stormwater from this residential development. An EDB is a sedimentation basin that was adapted from a detention basin used for flood control. EDB's are designed to intercept and slowly release stormwater runoff to improve water quality and reduce peak runoff rates. The primary difference between an EDB and a flood control detention basin is the design of the outlet: the extended detention basin uses a much smaller outlet that extends the emptying time of more frequently-occurring runoff events to facilitate pollutant removal. UDFCD recommends a 40-hour drain time for the water quality capture volume (WQCV) to remove a significant portion of suspended pollutants found in urban stormwater runoff. Many EDBs are also called "dry ponds" because they are designed to drain most of the water between storm runoff events. The EDB at Grant Ranch, however, has a 2.5-foot deep micropool at the outlet that provides some biological treatment and facilitates maintenance by reducing clogging of the outlet well screen. This micropool complies with UDFCD criteria for EDBs. The Grant Ranch EDB is shown in Photograph 1.

Photograph 1. Grant Ranch EDB with inflow sampler box shown in the foreground.

II. Site Description

Location

The Grant Ranch EDB is located within the Grant Ranch subdivision in Denver, Colorado. The basin is upstream of a constructed wetland pond that provides additional water quality treatment prior to discharge into Bowmar Lake, which is used for recreational activities such as fishing and boating. The general vicinity and location of Grant Ranch and the EDB are shown in Figures 1 and 2, respectively.

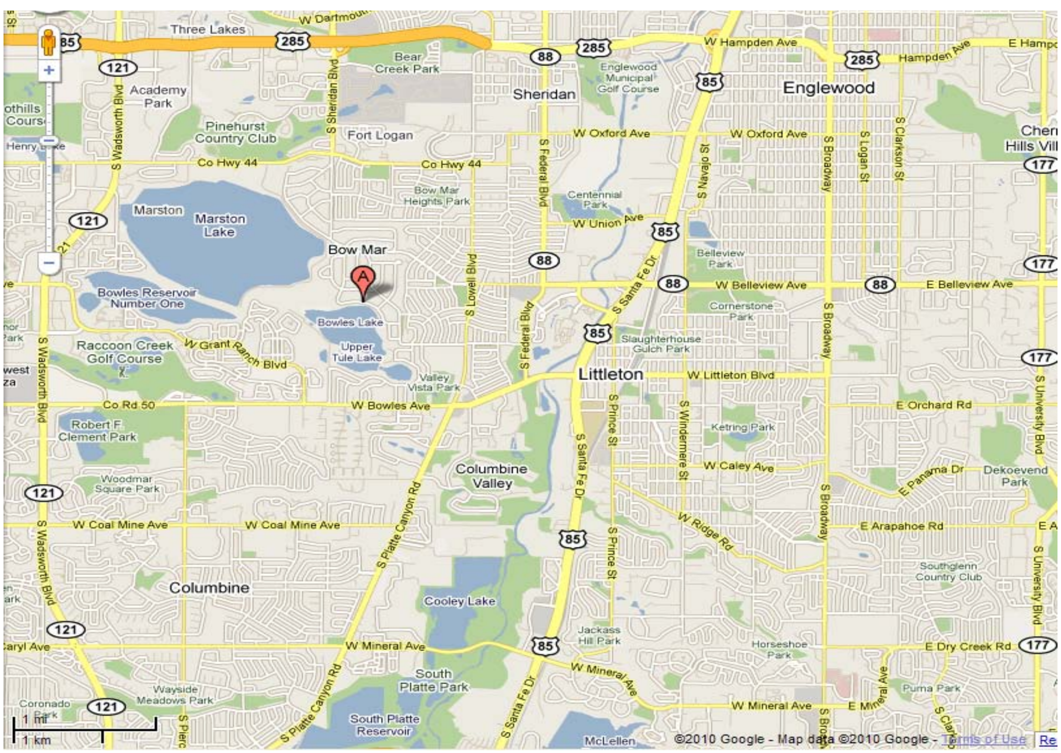


Figure 1. Vicinity Map

Figure 2. Location Map

Hydrology

Flow Characteristics:

The area of the watershed is 18.7 acres with total site imperviousness of 50.5% and NRCS Hydrologic Soil Group C. It contains single-family residential homes, paved roads and open space. The sidewalks are detached and the downspouts go underground. It is assumed that the downspouts go into a perforated drain pipe and are at least partially detached. The detached sidewalks and partially detached downspouts make this development MDCIA level 1 as described in Volume 3 of the USDCM. According to Figure 3-7 in Volume 3 of the USDCM an effective impervious value of 42%, 45%, and 47% can be assumed for the 2-year, 10-year, and 100-year storm events. See Figure 3 for the basin delineation. The watershed slope from northwest to southeast is between 1.5 and 3%. The watershed is completely built out and vegetated areas have been established. Runoff from each lot generally flows into the gutter and storm sewer system. The storm sewer collects runoff from approximately 11 acres and outlets it directly into the forebay of the EDB. The remainder of the watershed runoff enters the EDB as surface flow.

LEGEND

- BASIN BOUNDARY - 812,393 SQUARE FEET
- ROADWAYS - 116,016 SQUARE FEET; 14.3%
- SIDEWALKS - 40,677 SQUARE FEET; 5.0%
- ROOFTOPS - 126,407 SQUARE FEET; 15.6%
- DRIVEWAYS - 49,579 SQUARE FEET; 6.1%

Figure 3. Watershed Delineation

Peak Inflow:

Based on the rational method, the peak runoff from the WQCV event is 4 cubic feet per second (cfs), 2-year peak inflow to the EDB is 11 (cfs), the 10-year peak inflow is 29 cfs, and the 100-year peak is 60 cfs. Table 1 provides peak inflow calculations.

Table 1. Peak Inflow Calculations

Parameters		Equation[1]			
C_{WQCV}	0.17				
C_2	0.29	RO-3	$t_i=0.395(1.1-C_5)L_i^{0.5}/S_i^{0.33}$	8.3	min
C_5	0.36	RO-4	V_{travel} =	3.3	ft/s
C_{10}	0.46		t_t=	9.1	min
C_{100}	0.59	RO-2	$T_c=T_i+t_t$	17	min
A	18.65	RO-5	$T_c=L/180+10$	20	min
L_i	80				
s_i	0.030	RA-3	$I=28.5P_1/(10+T_c)^{.786}$		
L	1800		I_{WQCV}	1.3	in/hr
s_i	0.027		$I_{2\text{-year}}$	2.0	in/hr
C_v	20		$I_{10\text{-year}}$	3.4	in/hr
			$I_{100\text{-year}}$	5.4	in/hr
P_1(WQCV)	0.60		Q_{WQCV}=	**4**	**ft^3/s**
P_1(2-yr)	0.95		$Q_{2\text{-year}}$=	**11**	**ft^3/s**
P_1(10-yr)	1.60		$Q_{10\text{-year}}$=	**29**	**ft^3/s**
P_1(100-yr)	2.57		$Q_{100\text{-year}}$=	**60**	**ft^3/s**

1. Urban Storm Drainage Criteria Manual, Volume 1

III. Methods and Materials

EDB Components and WQCV

The EDB is designed to treat the WQCV (Water Quality Control Volume). According to UDFCD criteria, the target for the WQCV in the Denver area should be the runoff resulting from a precipitation event of 0.6 inches, which corresponds to the 80th percentile storm event. Assuming 0.1 inches of depression storage for impermeable areas, the required maximum capture volume is roughly 0.5 inches over impervious watershed area. However, the actual WQCV varies for each watershed based on the impermeability of the watershed and drain time of the BMP. Urbonas et al. (1989) found that stormwater quality can be enhanced significantly if the WQCV is effectively stored and treated. At Grant Ranch, this volume is contained between the lowest orifice, at elevation 5467.74, and the bottom of the rectangular 10-year vertical orifice, at elevation 5471.20. The 10-

year water surface elevation is 5471.71 and the 100-year water surface elevation is at elevation 5477.69. This information is provided with a picture of the EDB in Photograph 4.

The primary components of an EDB designed per UDFCD criteria include a forebay, trickle channel, initial surcharge volume, micropool, and outlet structure. The forebay allows larger particles to settle out in an area that can be easily maintained at the inlet of the basin. The trickle channel conveys low flows from the forebay to the micropool. A plan view of the Grant Ranch EDB is provided in Figure 4. The initial surcharge volume is designed to reduce the frequency of shallow ponding and resulting sedimentation in the turf area by providing volume above the micropool. The micropool is a permanent pool of water directly in front of the outlet orifice plate in the outlet structure of the EDB. Its purpose is to provide additional settling of pollutants, provide some biological uptake, and facilitate maintenance of the well screen. Micropools can also minimize mosquito production when properly designed (M. Deatrich and Brown, 2004). The well screen (trash rack) in front of the orifice plate should extend to the bottom of the micropool to allow flow through the well screen below the elevation of the lowest orifice since the portion of the well screen above the micropool will clog first. Extending the well screen to the bottom of the micropool allows the orifice plate to control outflow even if the well screen is clogged above the permanent pool elevation.

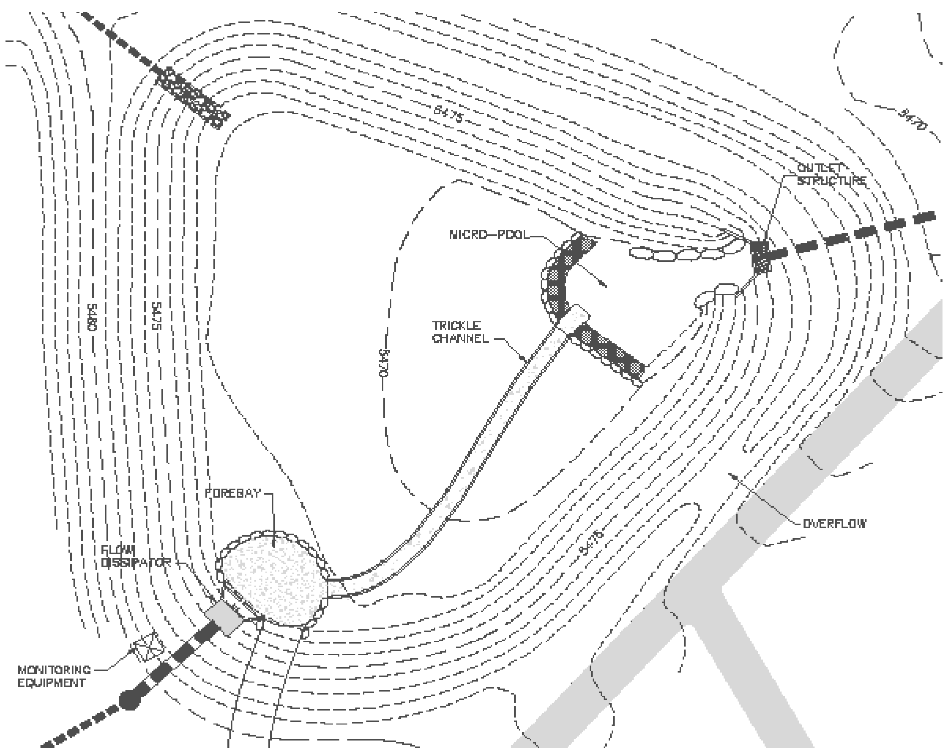
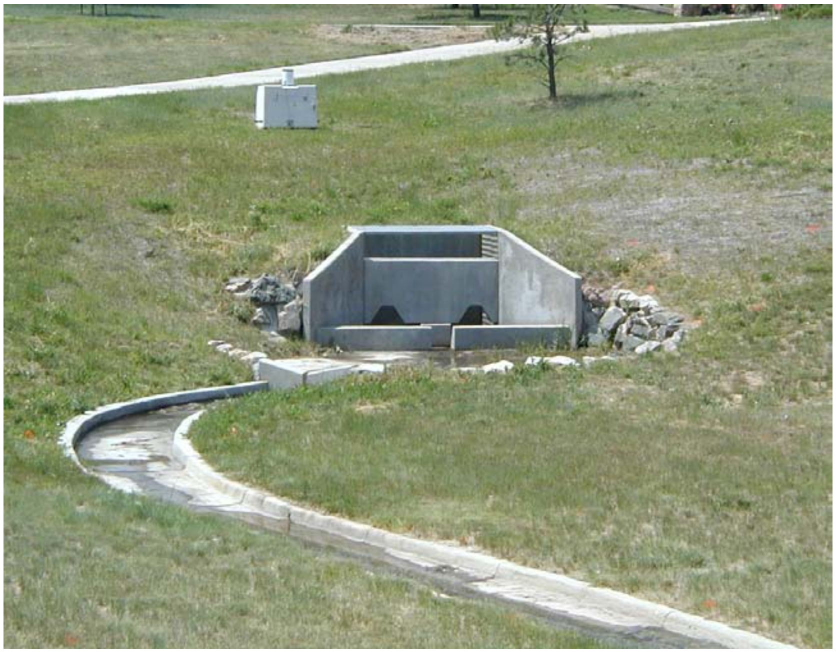


Figure 4. Plan View of the Grant Ranch EDB

The basin is made up of the following components:

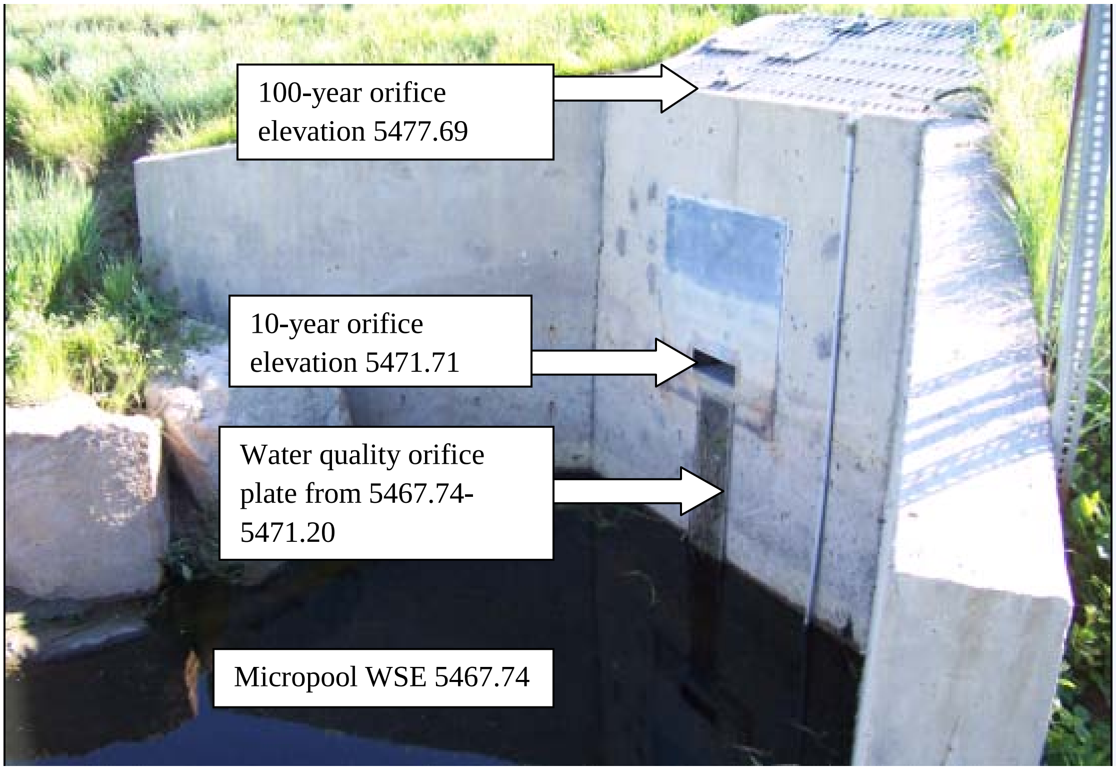
- An inlet structure with energy dissipation.
- A forebay for larger debris and coarse sediment.
- A trickle channel for small flows, shown in Photograph 2.
- A micropool, which reduces clogging of the well screen and provides some biological treatment.



Photograph 2. Energy dissipater, forebay, and trickle channel

Flow through the outlet structure is controlled by the following:

- An orifice plate for slow release of the WQCV,
- A rectangular vertical orifice to controlled release of the 10-year volume,
- A sloping overflow weir/orifice for release of volume in excess of the 10-year event, and
- A 12 inch diameter outlet pipe with restrictor plate for release of the 100-year volume.



Photograph 3. Outlet structure with micropool

Data Collection

UDFCD has been collecting data on water quality and flow from the Grant Ranch EDB since 2004. Automatic samplers (ISCO Models 6700 and 6712) are used to record inflow and outflow data throughout the runoff event. Rainfall is measured to 0.01 inches by an ISCO 674 tipping bucket rain gauge. Rainfall events are only monitored if they are separated by six or more hours of no precipitation, and samples are taken when the rain gauge indicates at least 0.01 inches of rainfall and flow is detected into the EDB. A Palmer Bowlus flume is used to measure flow into the pond. Outflow samples are taken from the outlet where a bubbler is used to measure head on the outlet orifice. Outlet flow is calculated based on the recorded head. All samples are tested for the following:

Category	Constituent	Units of Measurement
Bacteria:	E. Coli	#/100 mL
Chemical:	Alkalinity	mg/L
	Hardness	mg/L
	pH	
	Total Organic Carbon	mg/L
Metals:	Dissolved Copper	µg/L
	Total Copper	µg/L
	Dissolved Zinc	µg/L
	Total Zinc	µg/L
Nutrients:	Nitrite+Nitrate	mg/L
	Total Nitrogen	mg/L
	Dissolved Ortho-Phosphate	mg/L
	Dissolved Phosphorus	mg/L
	Total Ortho-Phosphate	mg/L
	Total Phosphorus	mg/L
Physical	Total Suspended Solids	mg/L

Inflow Monitoring and Sampling

The inlet monitoring station consists of an ISCO 6700 automated sampler which is connected to an ISCO 674 tipping bucket rain gauge, and an ISCO 730 bubbler module. Inflow is introduced to the EDB through a 24” diameter pipe which contains a Palmer Bowlus type flume (see Photograph 4). The water level upstream of the flume control section is measured using the bubbler module and this data is received by the sampler. When the level is above the crest of the Palmer Bowlus, the sampler starts recording data and converts head to flow using a series of programmed equations. The sampler takes a sample when the rain gauge detects over 0.01 inches of rainfall and 200 cubic feet of flow in a 15 minute period. The sampler continues to collect samples every 200 cubic feet and stops after the depth and flow criteria are no longer met.

The sampler tubing is connected to the automated sampler which collects up to 19 samples (500mL each) in one 20 liter bottle. Samples are pulled from a pooling cavity located in a manhole upstream from the Palmer Bowlus.

Photograph 4. Palmer Bowlus in 24" inflow pipe.

Outflow Monitoring and Sampling

The outlet monitoring station, shown in Photograph 4, consists of an ISCO 6712 automated sampler which is connected to an ISCO 730 bubbler module. Outflow leaves the EDB through an orifice plate which consists of a series of 10 vertically placed 0.69-inch diameter orifices. A well screen that extends 2.5 feet below the surface of the micropool protects the orifice pool from clogging. The orifice plate is designed to drain the WQCV in approximately 40 hours. The water level in front of the orifice plate is measured using the bubbler module and this data is received by the sampler. The sampler collects data on the water level when it surpasses the lowest orifice, and converts this data to flow through a series of programmed data points. When the bubbler module detects a rise in water level greater that 0.28ft, the sampler collects a sample after 200 cubic feet of flow has passed. The sampler continues to collect samples with 200 cubic feet of flow occurring between samples, and stops after the level drops below the original sample enabling value.

The sampler tubing is connected to the automated sampler which collects up to 19 samples (500 mL each) into one 20 liter bottle. The tubing runs from the sampler down the face of the outlet structure and draws samples from a location downstream of the orifice plate.

IV. Results and Discussion

Outflow Volume Reduction

In review of the inflow and outflow data, calculated outflow is frequently higher than calculated inflow. One explanation for this may be clogging of the lower orifices of the water quality plate at certain times during the season. Clogging results in greater head on the orifice place, and therefore overestimation of flows from the orifice plate, and late in the 2009 season it was noted that the bottom orifices had become clogged with debris. The orifice plate and bubbler were cleaned prior to the 2010 sampling season, and based on preliminary review of the 2010 data this issue has been resolved. Another cause of measurement error may be debris behind the Palmer Bowlus which can affect the accuracy of the inflow bubbler. **For these reasons the inflow and outflow data provided in this report should not be used to calculate volume reduction in the Grant Ranch EDB.** Finally, it should also be noted that a portion of the runoff from the watershed does not enter the EDB through the inflow pipe where inflow is measured. Only runoff from 11 of 18.7 acres enters the basin via the storm sewer.

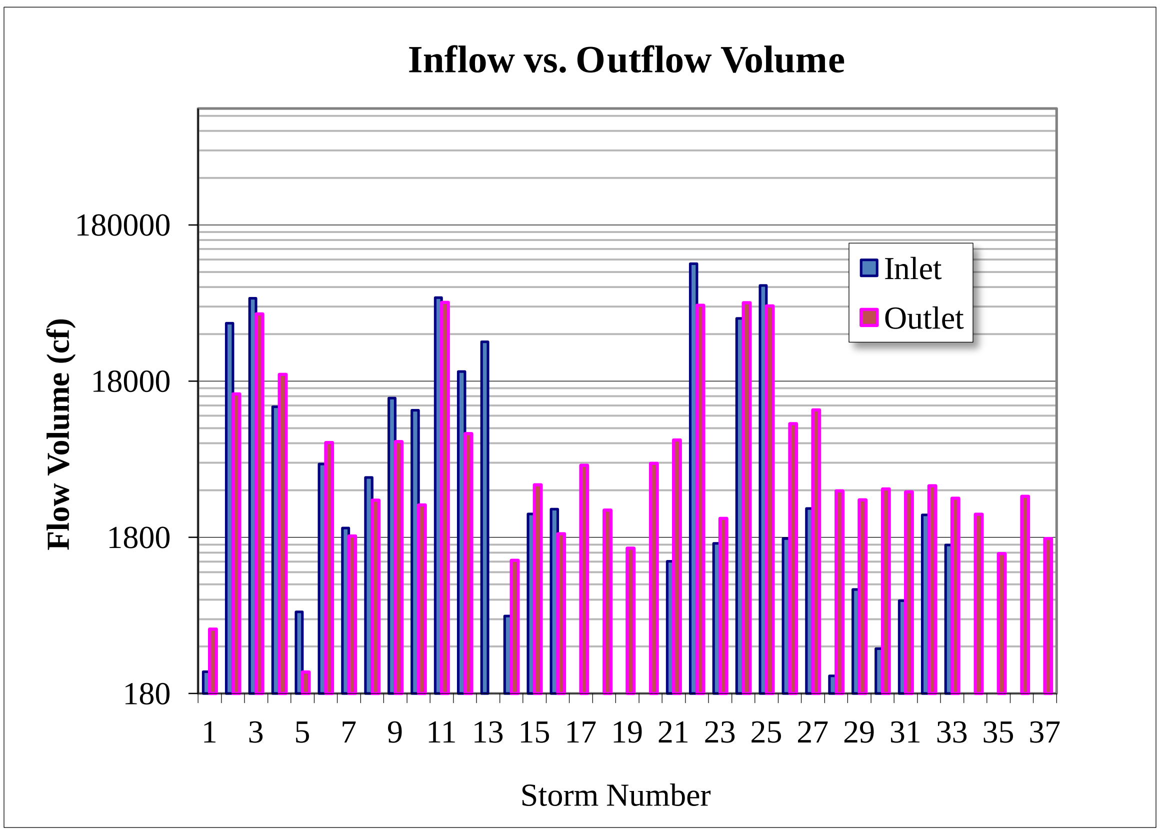


Figure 5. EDB Inflow and Outflow Volumes

Table 2. Flow Volume and Rainfall Data

2009 Storm Event	Inlet Flow Start Date	Inlet Flow Start Time	Inlet Flow End Date	Inlet Flow End Time	Outlet Flow Start Date	Outlet Flow Start Time	Outlet Flow End Date	Outlet Flow End Time	Rainfall (in)	Total Inflow Volume (cf)	Total Outflow Volume (cf)	Peak Inflow Rate (cfs)	Peak Outflow Rate (cfs)
1	4/12/2011	15:05	4/12/2011	15:30	4/12/2011	15:20	4/14/2011	1:45	0.03	249	466	0.207	0.006
2	4/16/2011	17:00	4/18/2011	6:50	4/16/2011	17:10	4/18/2011	7:10	0.48	42341	14935	1.166	0.134
3	4/18/2011	6:55	4/19/2011	5:50	4/18/2011	7:15	4/20/2011	13:25	0.65	60981	48546	2.442	1.307
4	4/26/2011	16:40	4/27/2011	10:15	4/26/2011	16:45	5/1/2011	6:45	0.35	12368	19902	1.158	0.137
5	5/8/2011	22:05	5/8/2011	23:00	5/8/2011	22:20	5/9/2011	20:30	0.02	601	248	0.278	0.006
6	5/9/2011	22:25	5/10/2011	4:15	5/9/2011	22:25	5/14/2011	17:45	0.21	5305	7293	0.7	0.078
7	5/22/2011	20:15	5/23/2011	2:40	5/22/2011	20:20	5/23/2011	15:50	0.08	2064	1832	0.404	0.039
8	5/23/2011	22:30	5/24/2011	2:00	5/23/2011	22:40	5/24/2011	14:45	0.13	4362	3121	2.541	0.079
9	5/24/2011	15:40	5/24/2011	23:10	5/24/2011	15:45	5/25/2011	9:40	0.33	14050	7376	7.663	0.14
10	5/25/2011	11:05	5/25/2011	15:50	5/25/2011	11:10	5/25/2011	17:10	0.18	11734	2901	4.007	0.14
11	5/25/2011	18:15	5/26/2011	9:45	5/25/2011	18:30	5/27/2011	3:40	0.85	61535	57329	6.247	1.793
12	5/31/2011	19:35	6/1/2011	13:25	5/31/2011	19:35	6/1/2011	20:00	0.37	20733	8304	3.926	0.13
13	6/1/2011	21:20	6/2/2011	18:30	**	**	**	**	0.56	32186	**	2.137	**
14	6/10/2011	15:00	6/10/2011	18:20	6/10/2011	15:10	6/11/2011	11:20	0.06	564	1283	0.581	0.021
15	6/14/2011	16:55	6/14/2011	18:00	6/14/2011	17:00	6/15/2011	10:40	0.04	2539	3914	4.111	0.079
16	6/23/2011	17:55	6/24/2011	11:00	6/23/2011	18:05	6/24/2011	18:10	0.15	2725	1896	0.91	0.032
17	**	**	**	**	6/25/2011	13:50	6/26/2011	14:10	0.31	**	5210	**	0.095
18	**	**	**	**	6/26/2011	14:40	6/27/2011	14:00	0.08	**	2689	**	0.075
19	**	**	**	**	7/2/2011	16:00	7/3/2011	15:55	0.18	**	1534	**	0.028
20	**	**	**	**	7/3/2011	17:10	7/4/2011	16:25	0.21	**	5366	**	0.097
21	7/4/2011	17:40	7/4/2011	18:40	7/4/2011	17:40	7/7/2011	1:40	0.13	1267	7559	2.453	0.089
22	7/10/2011	20:40	7/11/2011	0:20	7/10/2011	20:45	7/12/2011	18:50	0.81	101431	55034	29.459	3.082
23	7/13/2011	13:35	7/13/2011	15:05	7/13/2011	13:45	7/14/2011	21:55	0.11	1650	2385	0.519	0.047
24	7/20/2011	22:35	7/21/2011	11:30	7/20/2011	22:40	7/24/2011	19:40	0.52	45289	57216	24.087	2.484
25	7/25/2011	20:40	7/26/2011	16:35	7/25/2011	20:45	7/27/2011	19:25	0.84	73592	54561	12.016	2.638
26	7/27/2011	20:05	7/27/2011	20:35	7/27/2011	20:05	7/29/2011	15:30	0.11	1770	9611	1.979	0.103
27	7/29/2011	16:15	7/30/2011	1:15	7/29/2011	16:20	7/31/2011	20:25	0.19	2756	11766	1.377	0.097
28	7/31/2011	21:55	7/31/2011	22:15	7/31/2011	22:00	8/2/2011	18:30	0.04	234	3572	0.246	0.036
29	8/6/2011	15:55	8/6/2011	16:30	8/6/2011	16:05	8/8/2011	18:05	0.07	837	3130	0.977	0.028
30	8/13/2011	14:25	8/13/2011	14:40	8/13/2011	14:30	8/14/2011	19:05	0.06	349	3681	0.507	0.043
31	8/15/2011	13:25	8/15/2011	13:45	8/15/2011	13:30	8/16/2011	14:05	0.06	707	3521	0.828	0.051
32	8/17/2011	18:55	8/17/2011	23:30	8/17/2011	19:00	8/18/2011	12:30	0.19	2504	3853	0.668	0.08
33	8/18/2011	13:10	8/18/2011	14:05	8/18/2011	13:15	8/19/2011	5:05	0.08	1607	3199	1.64	0.079
34	**	**	**	**	9/12/2011	16:55	9/13/2011	14:20	0.16	**	2534	**	0.063
35	**	**	**	**	9/13/2011	15:10	9/14/2011	19:55	0.04	**	1417	**	0.029
36	**	**	**	**	9/21/2011	9:05	9/22/2011	20:20	0.13	**	3296	**	0.058
37	**	**	**	**	9/25/2011	2:50	9/26/2011	21:25	0.06	**	1769	**	0.026

**Equipment failure

Impact on Water Quality

Analysis of the data revealed that there were statistically significant reductions in total Nitrogen (Figure 18), Nitrite+Nitrate, and total Copper after they passed through the

EDB, but no significant changes in other constituents. Box-and-whisker plots comparing inflows and outflows for each constituent are provided within this report.

To conduct the analysis, paired t-tests were performed that compared inflow and outflow data for each constituent. In most cases, the data did not seem to fit a normal distribution, which is not unusual for such a small sample size, so a non-parametric Wilcoxon signed-rank test was performed in addition to parametric paired t-tests and two sample t-tests. Some of the constituents (total and dissolved Cadmium, total and dissolved Lead) were not analyzed because they were all non-detects or had values of 0. The p-values generated for each of the constituents (alpha=0.05) is shown in Table 3. The values that were significant, below the alpha level of 0.05, are highlighted in bold. Table 4 summarizes the median values for each constituent by storm.

Table 3. Significance of Differences in Constituent Concentrations in Outflows and Inflows

Constituent	Wilcoxon Signed Rank Test	Paired T-Test	Two Sample T-Test
E. Coli	0.7792	0.9077	0.9304
Alkalinity	0.726	0.4169	0.4693
Hardness	0.6353	0.6874	0.6628
pH	0.25	0.113	0.1618
Total Organic Carbon	0.6523	0.6914	0.7615
Dissolved Copper	0.08398	0.07173	0.163
Total Copper	**0.009766**	0.05639	**0.0366**
Dissolved Zinc	0.7893	0.8223	0.8528
Total Zinc	0.4185	0.343	0.3428
Nitrite+Nitrate	**0.04883**	**0.03012**	**0.03508**
Total Nitrogen	**0.03711**	**0.04063**	0.1296
Dissolved Ortho-Phosphate	0.8685	0.5738	0.8231
Dissolved Phosphorus	1	0.6994	0.8584
Total Ortho-Phosphate	0.9102	0.6861	0.6861
Total Phosphorus	0.8457	0.9219	0.9582
Total Suspended Solids	0.625	0.785	0.7617

Table 4. Median Values of Selected Water Quality Constituents

Water Quality Constituent	Storm Event 2		Storm Event 4		Storm Event 6		Storm Event 12		Storm Event 16		Storm Event 17		Storm Event 23		Storm Event 24		Storm Event 25		Storm Event 26	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Total Phosphorus (mg/L)	0.309	0.668	0.25	0.21	0.765	0.261	0.953	0.416	1.728	2.058	0.443	0.722	0.382	0.616	0.967	0.574	0.738	0.602	0.366	0.659
Dissolved Phosphorus (mg/L)	0.163	0.437	0.13	0.14	0.414	0.077	0.365	0.265	1.623	1.682	0.3	0.59	0.159	0.223	0.86	0.199	0.541	0.357	0.161	0.453
Total Ortho-Phosphate (mg/L)	0.212	0.472	0.17	0.15	0.483	0.091	0.282	0.271	1.82	1.868	0.322	0.613	0.145	0.317	0.845	0.203	0.489	0.4	N/A	N/A
Dissolved Ortho-Phosphate (mg/L)	0.138	0.357	0.11	0.12	0.38	0.055	0.308	0.239	1.665	1.839	0.267	0.514	0.124	0.182	0.794	0.162	0.49	0.303	N/A	N/A
Total Nitrogen (mg/L)	4.027	2.22	7.4	1.8	8.675	2.302	9.547	3.191	12.01	10.11	3.029	5.758	3.882	2.104	3.205	2.233	1.989	1.538	1.745	1.706
Nitrite+Nitrate (mg/L)	0.506	0.54	1.5	0.7	1.122	0.453	1.066	0.568	0.991	0.288	0.785	1.036	0.185	0.605	1.023	0.289	0.265	0.017	0.793	17
Dissolved Cadmium (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total Cadmium (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dissolved Copper (mg/L)	0.006	0.006	0.013	0.005	0.02	0.015	0.04	0.014	0.02	0.028	0.016	0.01	0.014	0.008	0.015	0.007	0.006	ND	0.015	0.012
Total Copper (mg/L)	0.012	0.01	0.012	0.01	0.017	ND	0.031	0.007	0.009	0.007	0.016	0.01	0.008	0.009	0.008	0.008	0.011	0.006	0.006	0.006
Dissolved Lead (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total Lead (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dissolved Zinc (mg/L)	0.039	0.036	ND	ND	ND	ND	0.045	ND	ND	ND	ND	ND	ND	ND	ND	0.034	ND	ND	ND	ND
Total Zinc (mg/L)	0.052	0.042	0.063	0	0.062	ND	0.17	0.053	ND	ND	ND	ND	ND	ND	ND	0.135	ND	ND	ND	ND
TSS (mg/L)	90.6	49.4	72	15	75	23.2	208	44	5.3	6.5	49	15.3	27	75.3	17.4	224	34.5	40.5	35.2	37
Alkalinity (mg/L)	36	44	22	40	42	42	38	60	106	114	N/A	N/A	158	64	114	34	92	48	22	62
Hardness (mg/L)	32	52	22	217	48	54	52	66	172	128	N/A	N/A	292	66	144	38	106	62	20	62
pH	7.49	7.31	7.3	7.2	7.03	7.22	6.85	7.19	8.77	7.52	N/A	N/A	8.6	7.21	7.88	7.25	7.34	6.76	6.83	7.04
Total Organic Carbon (mg/L)	7.5	20.5	15.5	9.4	25.8	12.1	N/A	N/A	27.2	22.7	9.98	15.5	15.2	13.2	22.2	13.9	27.9	33	25.1	26
E Coli (#/100mL)	0	0	900	4	80	50	500	1300	30	4	240	300	300	230	800	1100	N/A	N/A	800	500

ND = Not Detectable

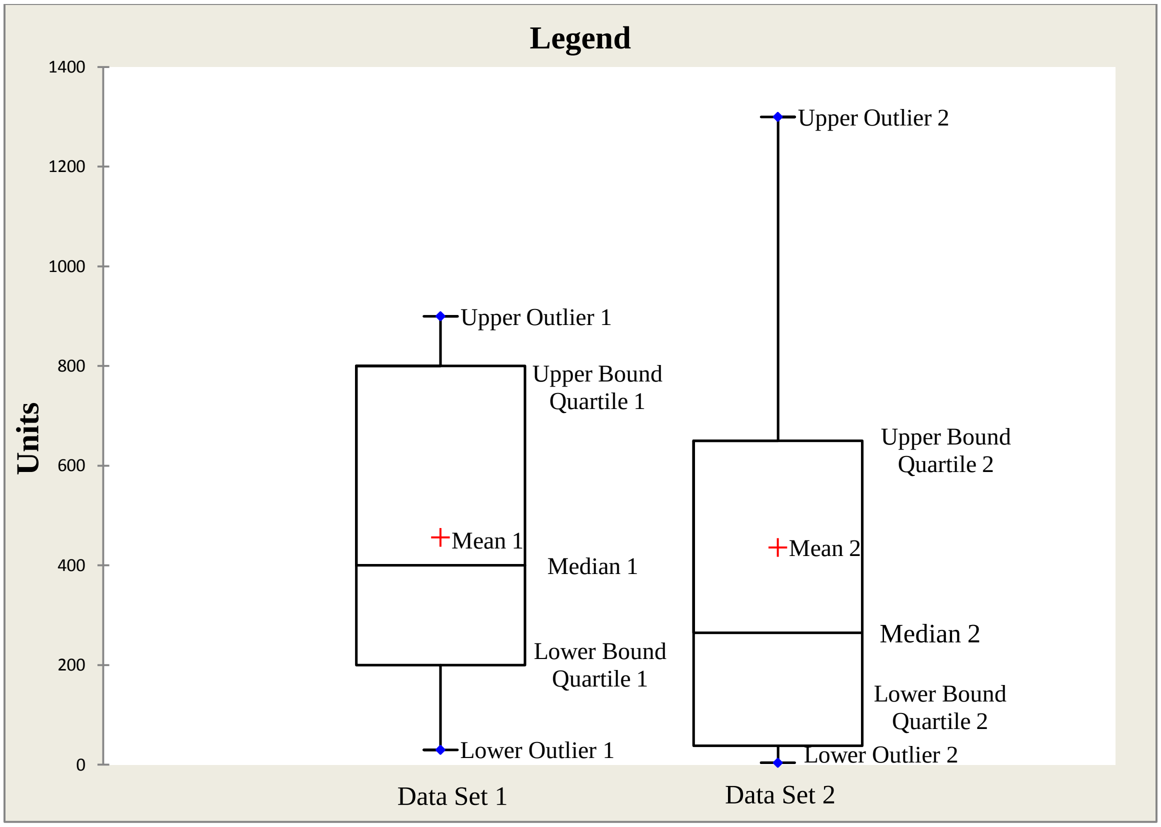


Figure 6: Legend for Box-and-Whisker Plots

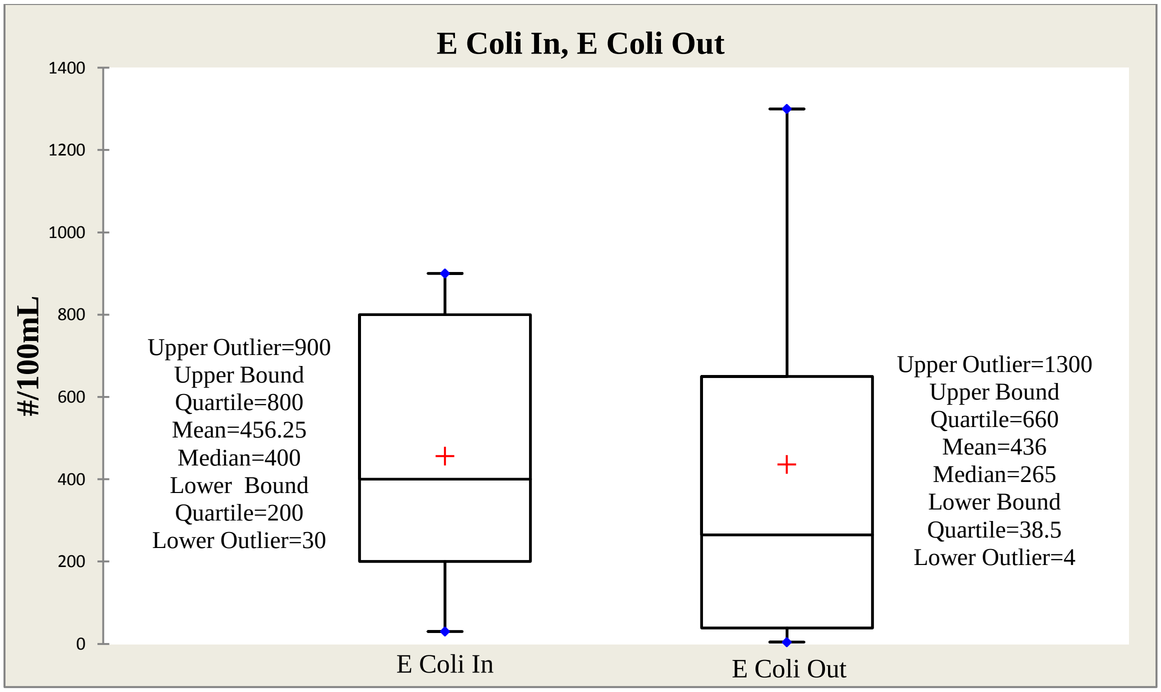


Figure 7. Inflows and Outflows of E. Coli

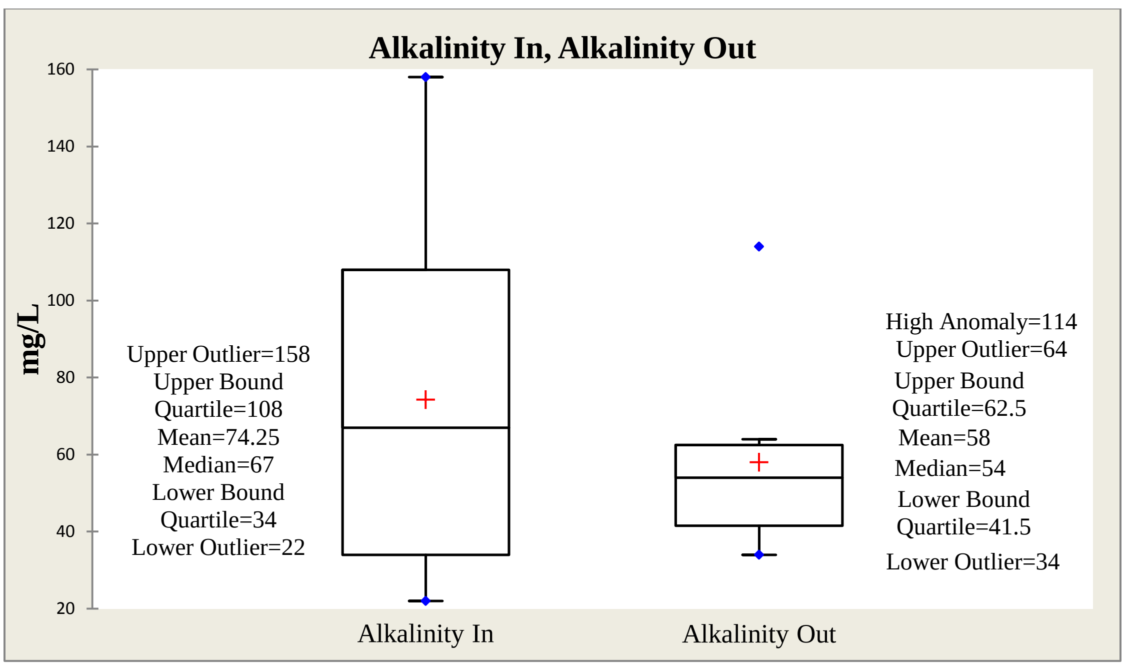


Figure 8. Inflows and Outflows for Alkalinity

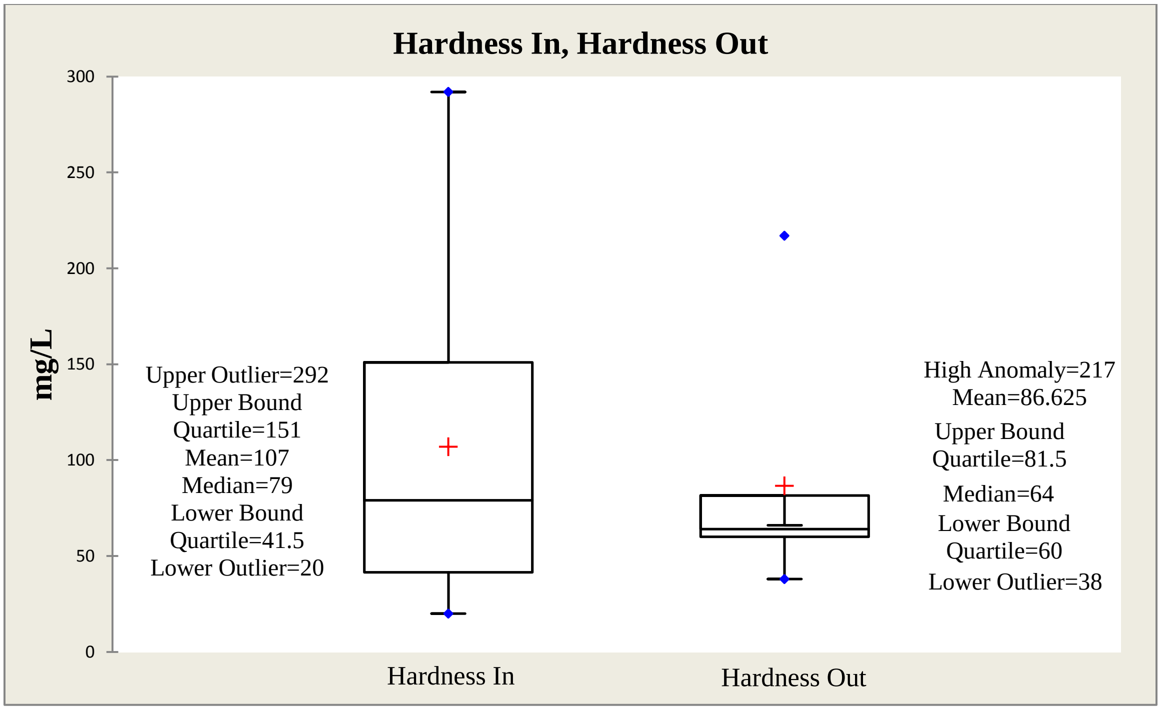


Figure 9. Inflows and Outflows for Hardness

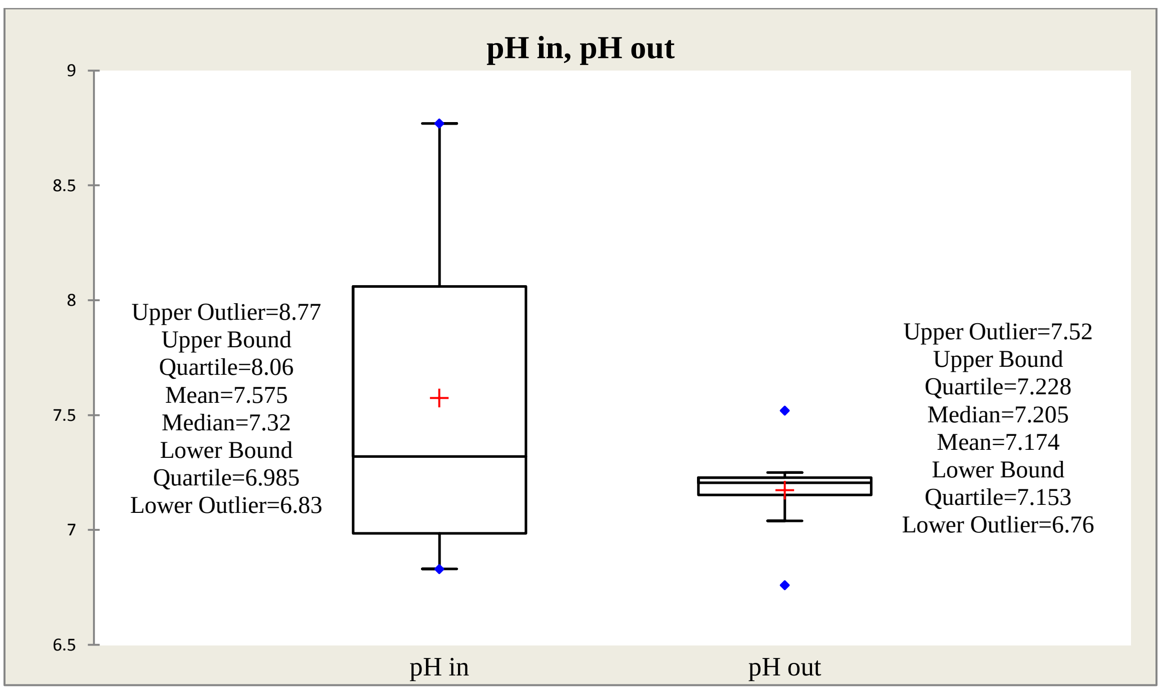


Figure 10. Inflows and Outflows for pH

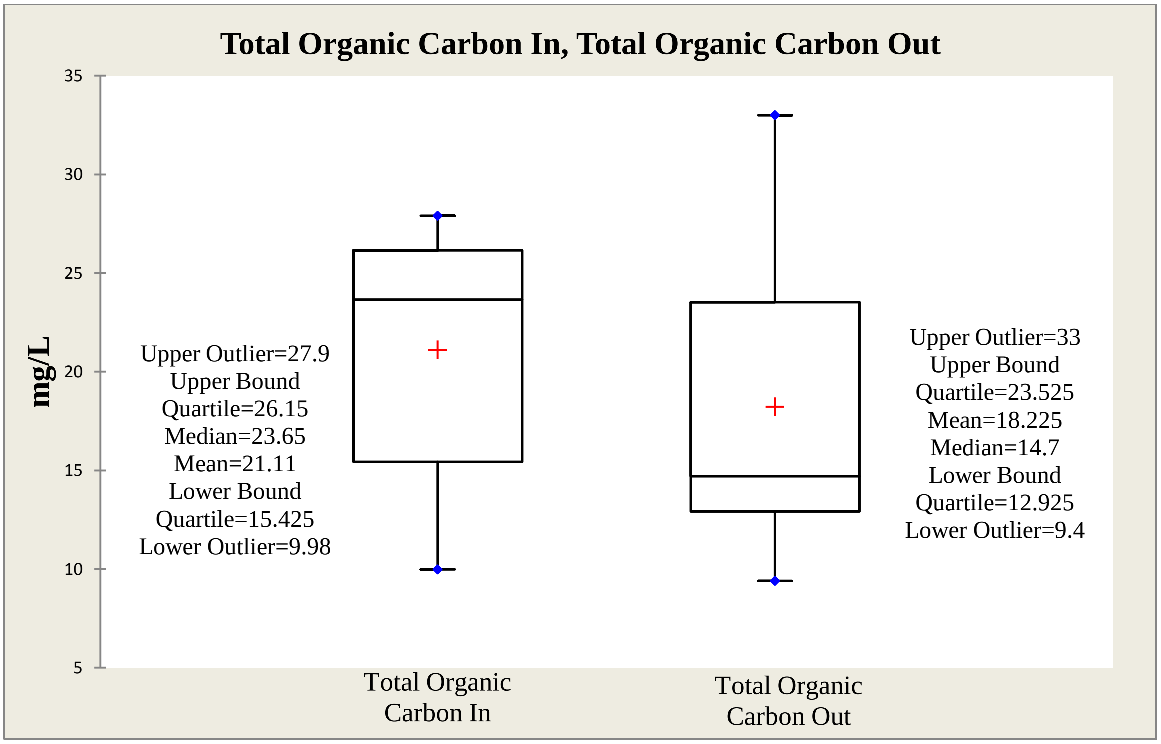


Figure 11. Inflows and Outflows of Total Organic Carbon

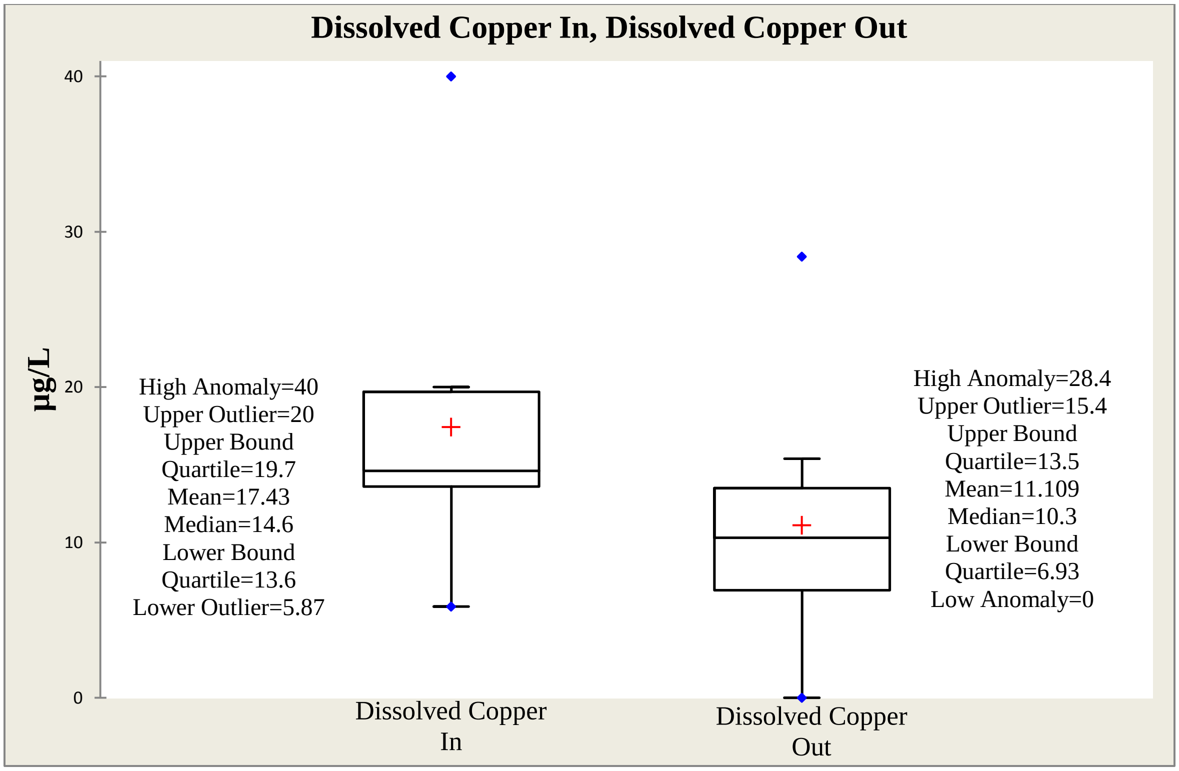


Figure 12. Inflows and Outflows of Copper (Dissolved)

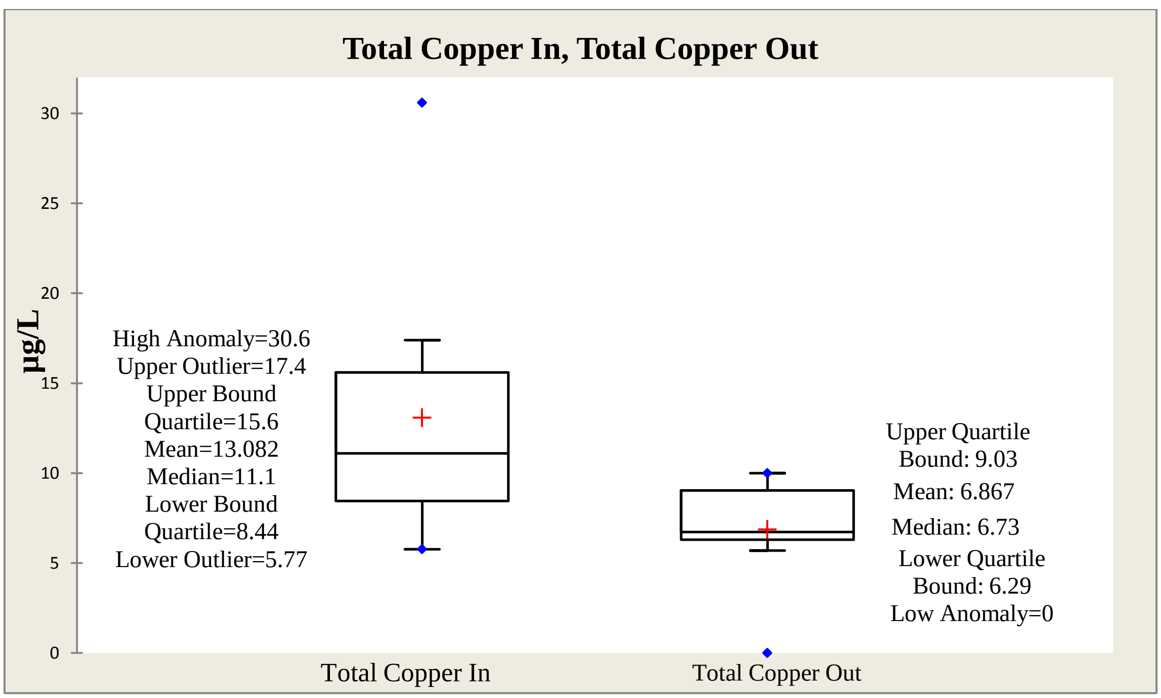


Figure 13. Inflows and Outflows of Copper (Total)

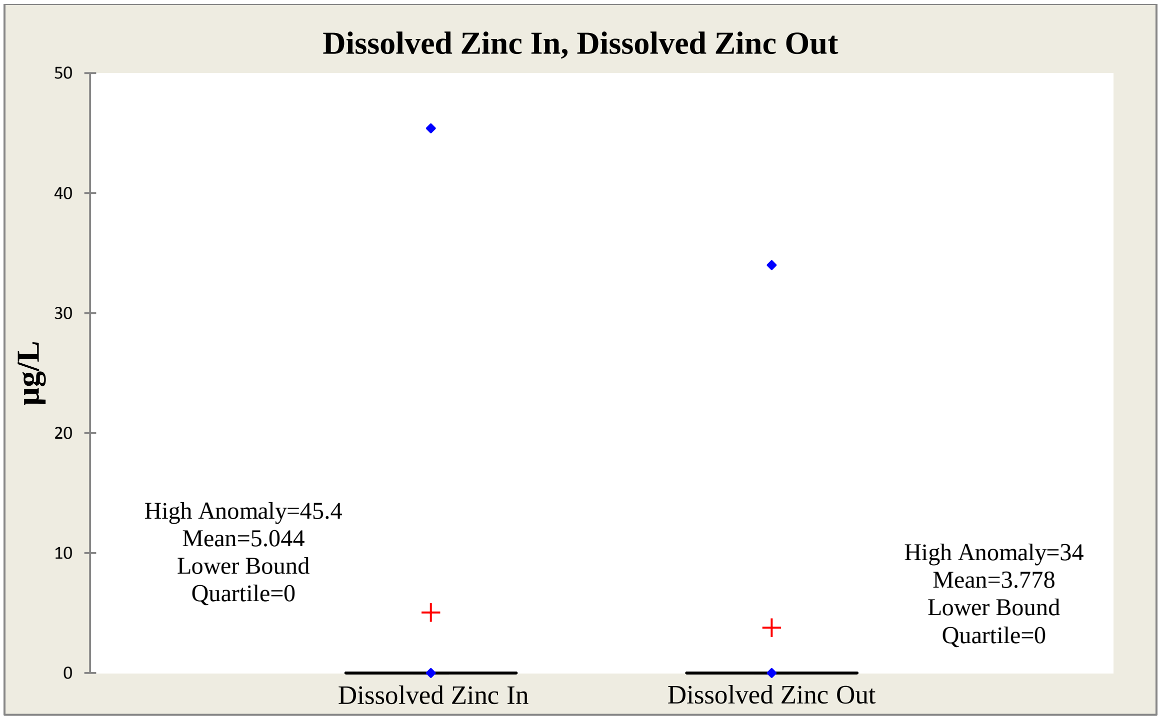


Figure 14. Inflows and Outflows of Zinc (Dissolved)

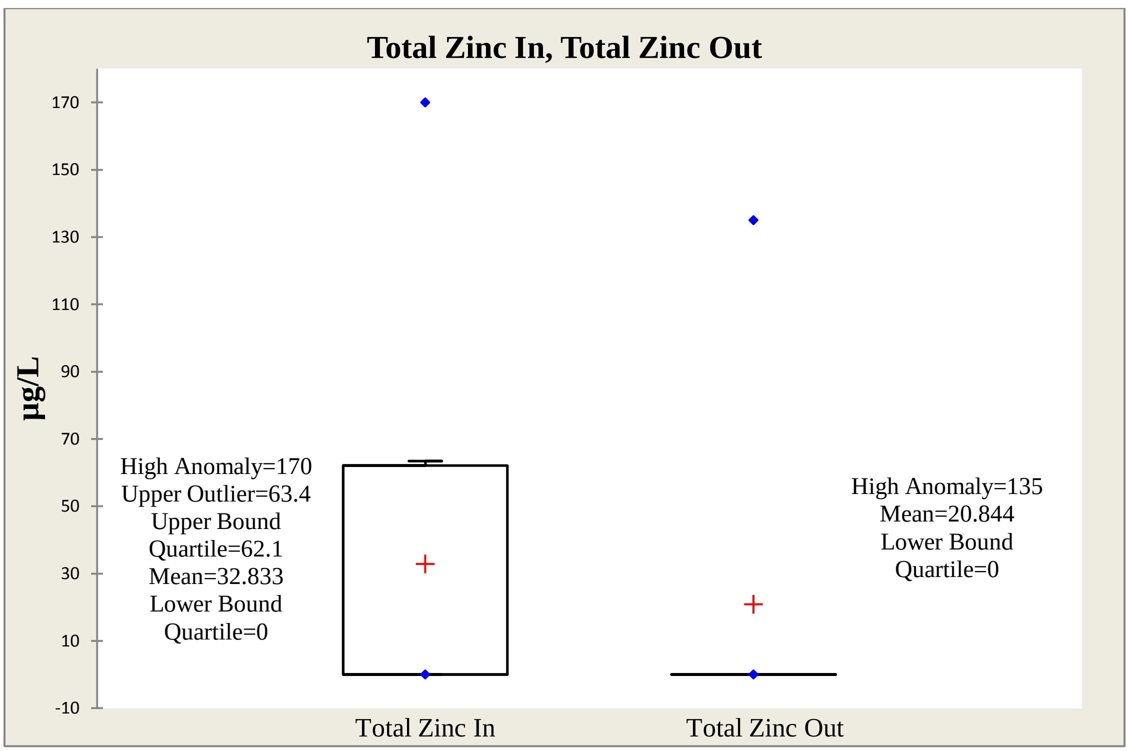


Figure 15. Inflows and Outflows of Zinc (Total)

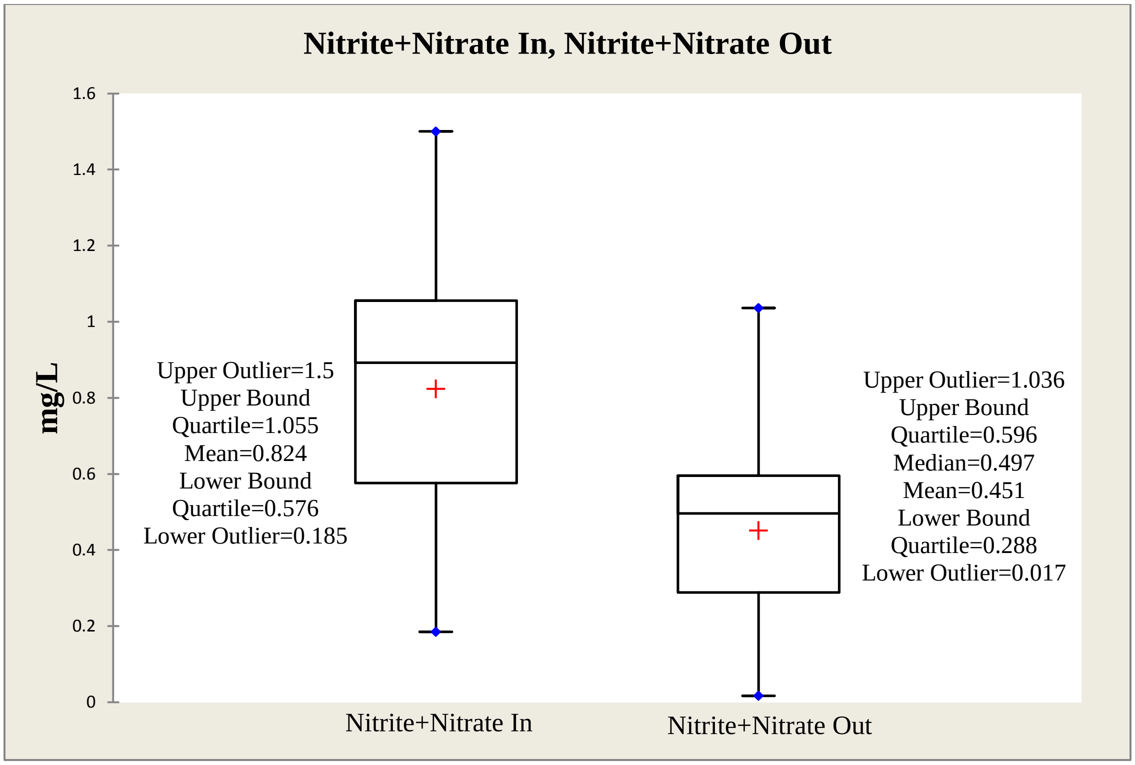


Figure 16. Inflows and Outflows of Nitrite+Nitrate

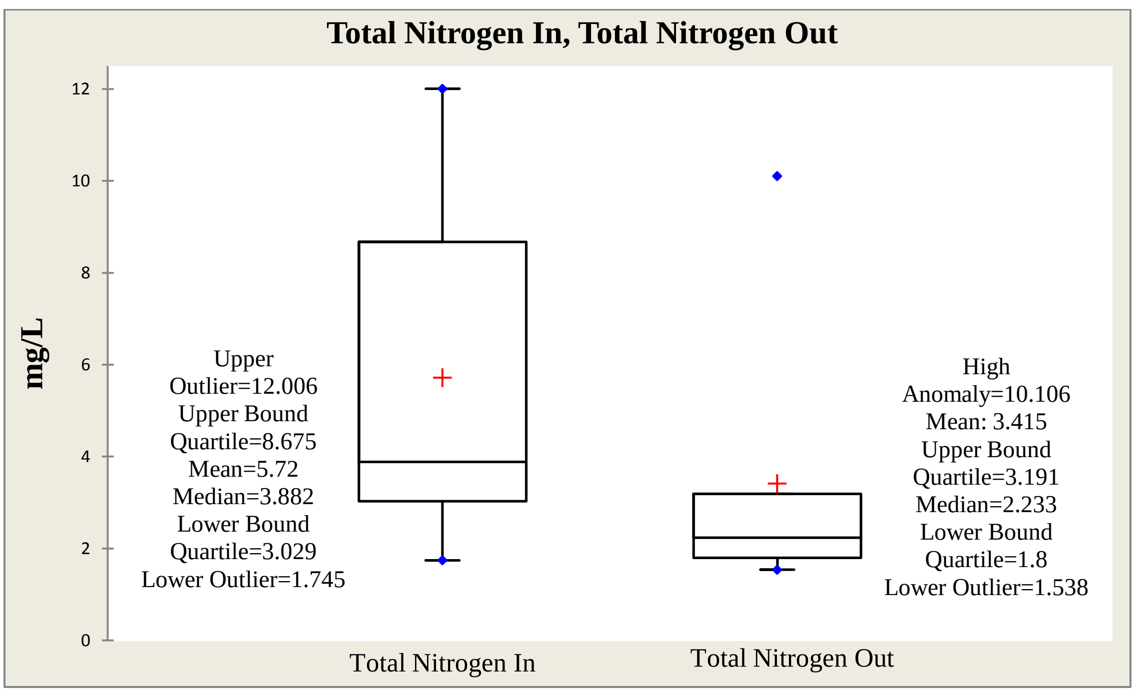


Figure 17. Inflows and Outflows of Nitrogen (Total)

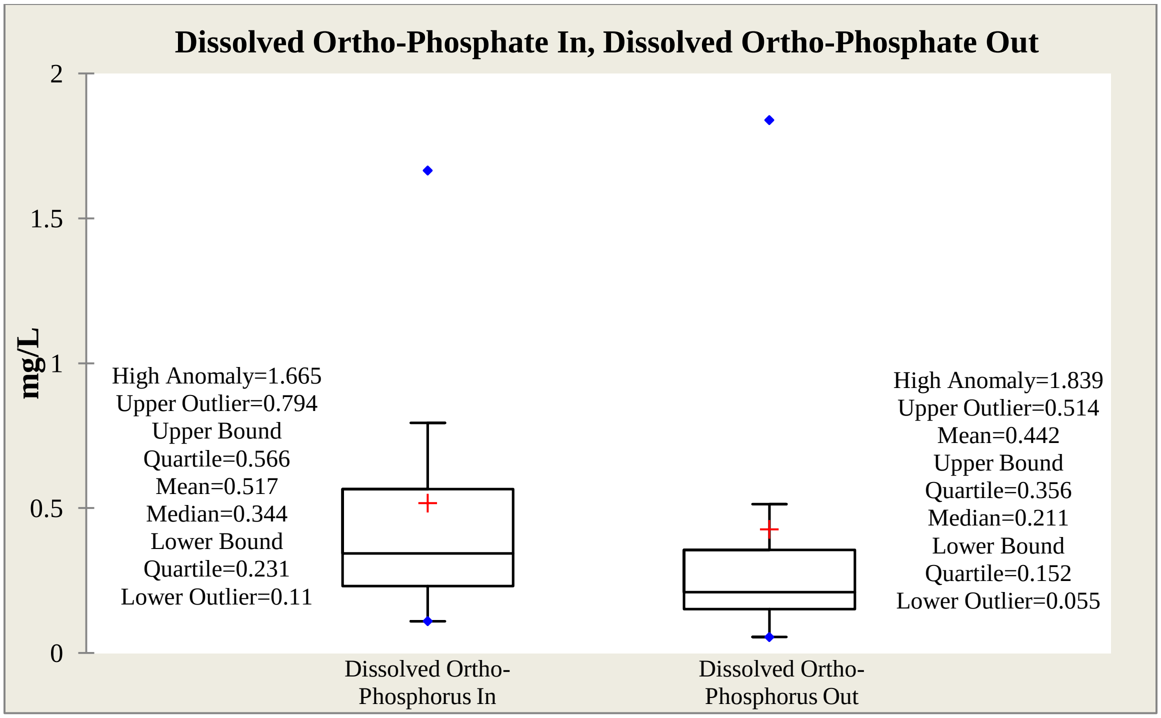


Figure 18. Inflows and Outflows of Ortho-Phosphate (Dissolved)

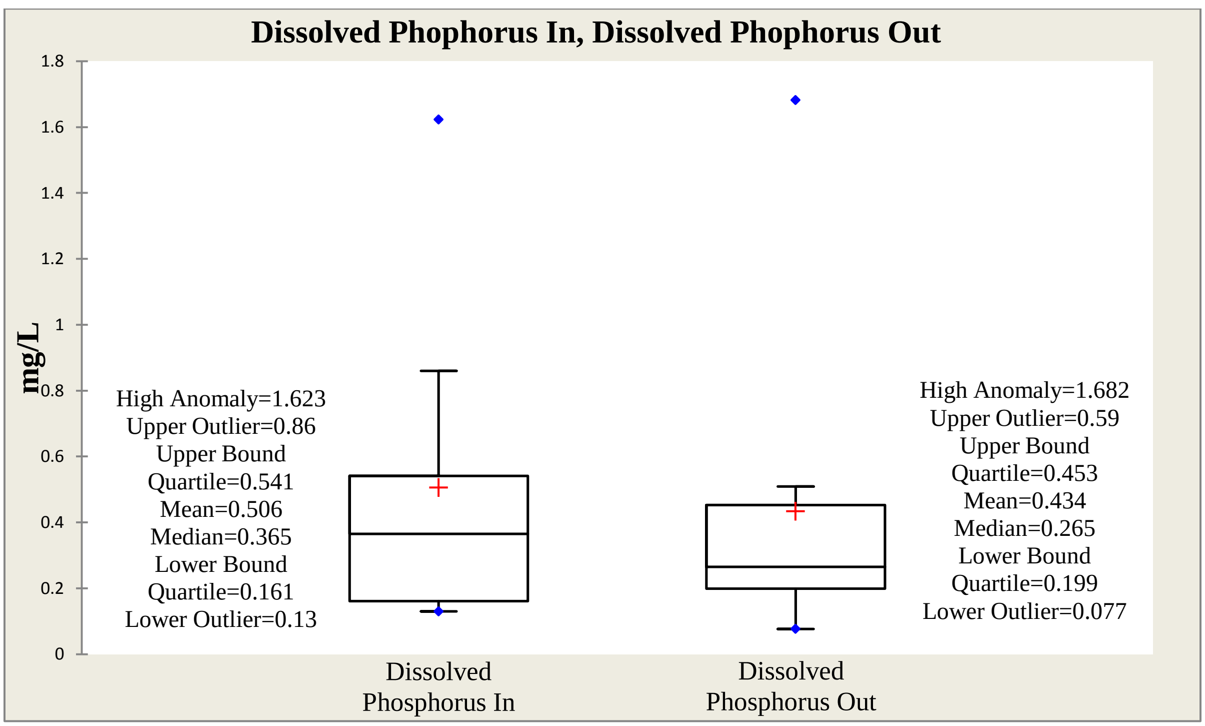


Figure 19. Inflows and Outflows of Phosphorus (Dissolved)

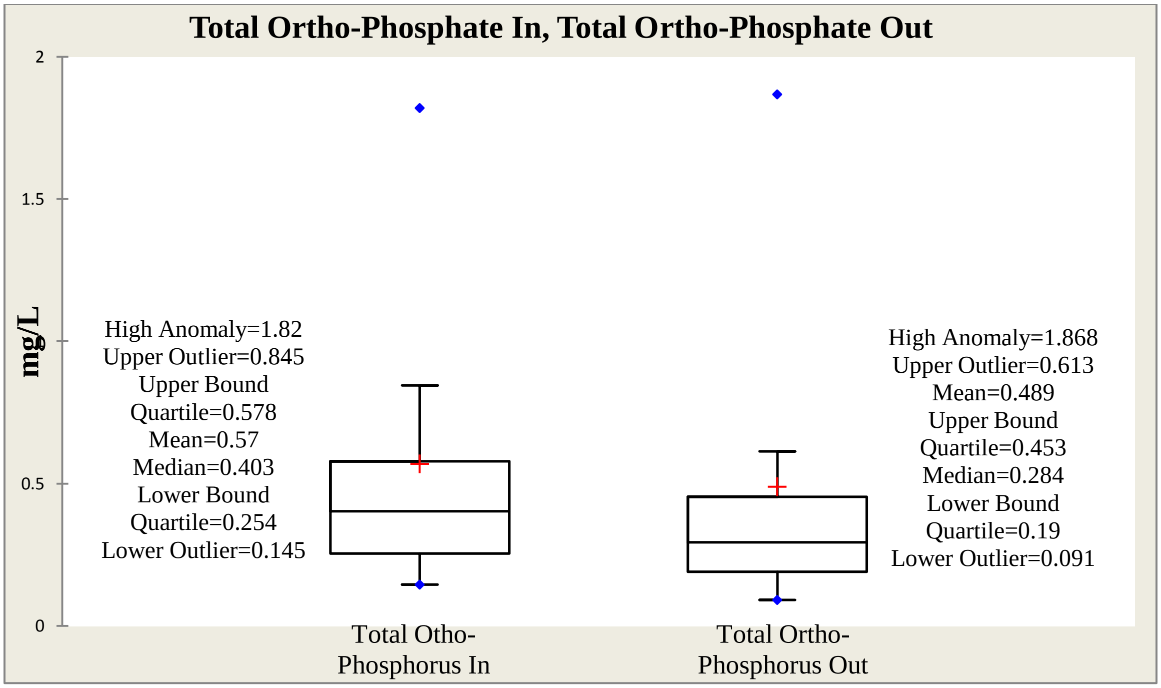


Figure 20. Inflows and Outflows of Ortho-Phosphate (Total)

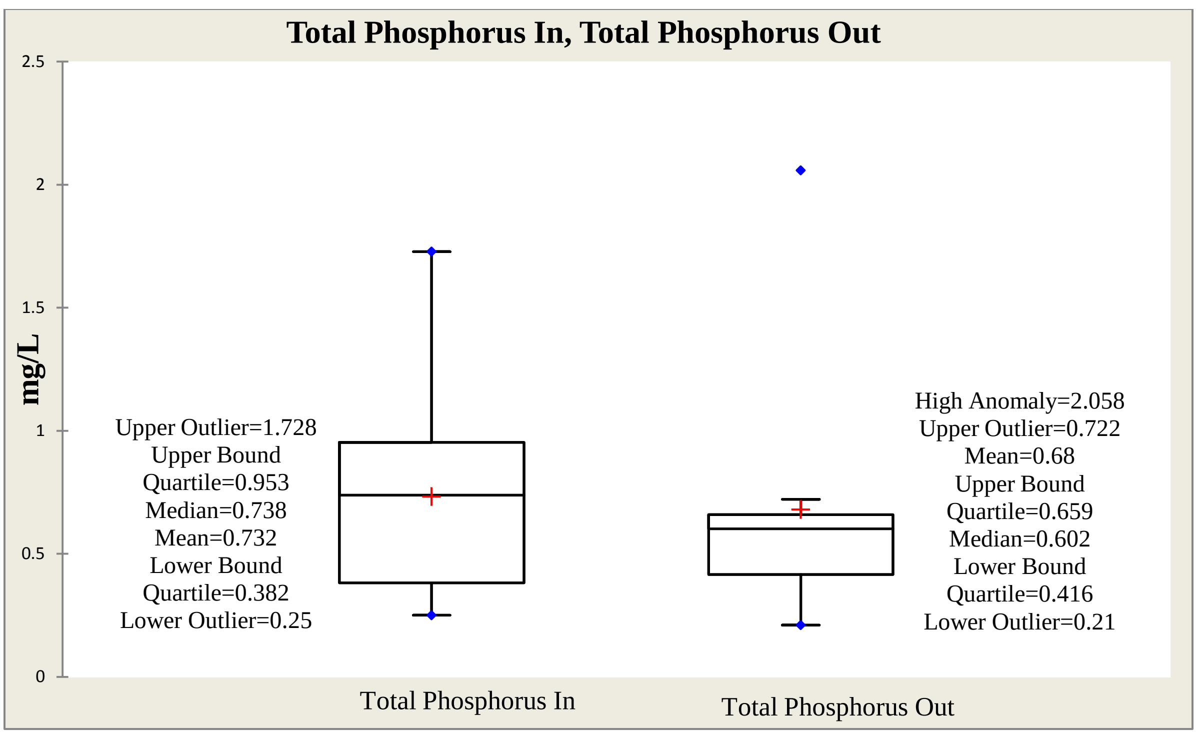


Figure 21. Inflows and Outflows of Phosphorus (Total)

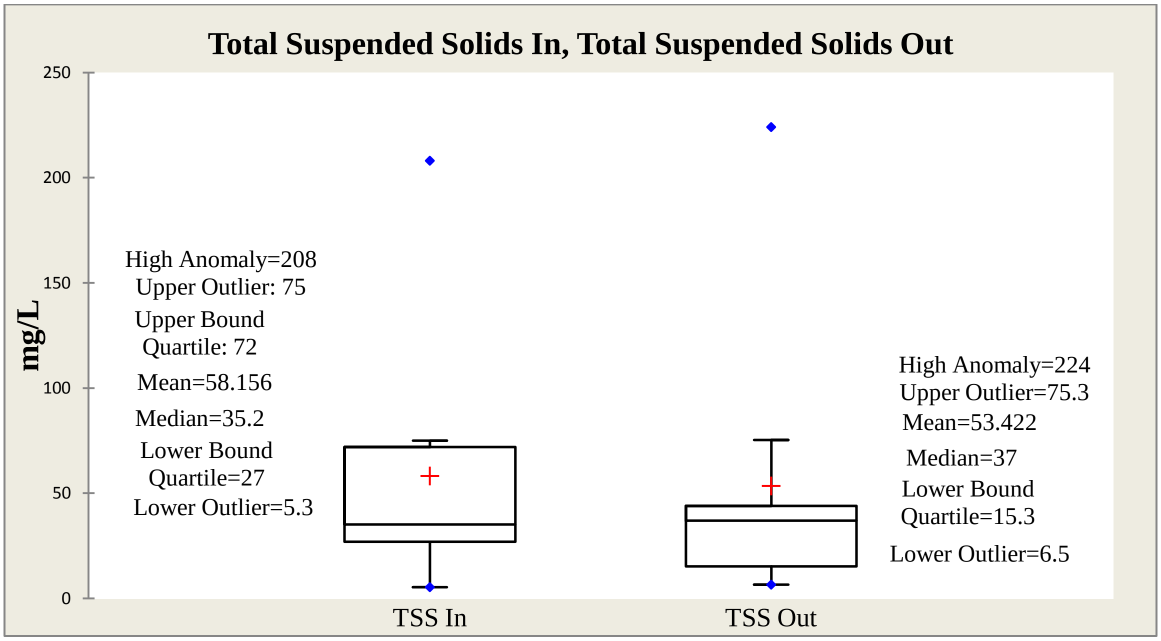


Figure 22. Inflows and Outflows of Total Suspended Solids (TSS)

V. Field Notes

The following provides a summary of field notes for 2009.

Table 5. Data Collection and Field Notes

Date	Downloaded data from samplers.	Cleaned palmer bowlus.	Cleaned bottles and reset inlet sampler	Notes
29-Jul		x	x	
30-Jul	x	x	x	
31-Jul	x	x	x	
3-Aug	x		x	Inlet weir had been ripped from the wall. Repairs need to be made.
5-Aug			x	Fixed the Pond 2 inlet weir by adding more bolts to either side of the weir and backing the weir plate with masonry caulk.
10-Aug	x	x	x	
11-Aug			x	Inlet had 3" of standing water in it and a steady stream of water from sprinklers.
13-Aug			x	Placed concrete across the bottom of the inlet weir. Put down a layer of bonding primer and placed some fast drying concrete.
14-Aug	x	x	x	Checked to see how concrete held up. Areas of concrete in front of the weir had pits. These two areas allow water to pass under the weir and need to be filled in.
17-Aug	x		x	
18-Aug	x		x	
20-Aug	x		x	
25-Aug	x		x	
26-Aug			x	Calculated data from samplers after previous night's storms.
1-Sep	x		x	
8-Sep	x		x	Found the inlet sampler to be turned off. Restarted the sampler and program.
14-Sep	x		x	Found that the inlet sampler had incorrect readings for flow and level.
15-Sep		x	x	Jack-hammered out two sampling basins in the manhole by the inlet sampler forth inlet sampler sample tubing. Patched the front of the weir with quick-crete.
17-Sep	x		x	Found the inlet sampler level reading to be inaccurate and not constant. Returned later to trouble shoot the sampler. Found that bubbler was producing bubbles in the palmer bowlus. Bought replacement tubing and placed one end in a graduated cylinder and the other on to the port in back of bubbler. Experimented and found the water level to be consistent with the with the sampler readings. Concluded that there may be a leak somewhere in the bubbler tubing, the tubing will need to be replaced.
24-Sep	x		x	
25-Sep	x		x	
2-Oct	x		x	Shut down the site for the season. Removed both samplers with bottles, removed rain gauge. Left rain gauge cable on-site with attached plastic bag on the end containing desiccant to keep it dry. Duct taped over all holes in the inlet sampler box to keep snow out over the winter.
9-Oct	x		x	Restarted the levelogger, and winterized the levelogger.

VI. Conclusion

Measurement of flow rates for both inflow and outflow has been difficult at this site. The outlet should be closely monitored and debris removed following each event for outflow measurement to be effective. The well screen at the outlet should be cleaned frequently to ensure flow through the orifice plate is accurately calculated. Alternatively, a second trash rack could be constructed to reduce debris on the well screen, which would improve confidence in the values for outflow duration, volume, and peak. The Palmer Bowlus should also be cleaned out after every storm event to ensure that inflow can be accurately measured.

Water quality constituent concentrations can be compared with other EDB studies found in the International Stormwater BMP database, as summarized in Table 6, which is adapted from Table 2-2 in Volume 3 of the Urban Storm Drainage Criteria Manual (USDCM). Database values are generally consistent with those produced by this study. However, Grant Ranch appears to have much higher levels of nutrient inflows and outflows. There were higher median phosphorus inflow and outflow concentrations in the Grant Ranch data. Inflows of total Nitrogen and were also much higher at Grant Ranch but outflow nitrogen was slightly below International BMP database levels. Nitrite+Nitrate median concentrations were much higher in inflow and outflow at Grant Ranch.

Table 6. Comparison of Water Quality Constituents for Grant Ranch and International BMP Database

	Grant Ranch				International BMP Database			
	Number of Inlet Samples	Inlet Median Value	Number of Outlet Samples	Outlet Median Value	Number of Inlet Samples	Inlet Median Value	Number of Outlet Samples	Outlet Median Value
Total Phosphorus (mg/L)	10	0.738	10	0.602	17	0.2	18	0.2
Dissolved Phosphorus (mg/L)	10	0.365	10	0.265	**	**	**	**
Total Ortho-Phosphorus (mg/L)	9	0.403	9	0.294	NC	NC	NC	NC
Dissolved Ortho-Phosphorus (mg/L)	9	0.344	9	0.211	**	**	**	**
Total Nitrogen (mg/L)	10	3.882	10	2.233	3	1.05	3	2.54
Nitrite+Nitrate (mg/L)	10	0.991	10	0.568	5	0.23	6	0.17
Dissolved Cadmium (mg/L)	10	ND	10	ND	8	0.3	9	0.3
Total Cadmium (mg/L)	10	ND	10	ND	11	0.6	12	0.4
Dissolved Copper (mg/L)	10	14.6	10	10.3	8	5.8	9	9.0
Total Copper (mg/L)	10	11.1	10	6.73	11	10.0	12	11.0
Dissolved Lead (mg/L)	10	ND	10	ND	8	1.0	9	1.0
Total Lead (mg/L)	10	ND	10	ND	11	10.0	12	9.5
Dissolved Zinc (mg/L)	10	ND	10	ND	8	16.4	9	19.0
Total Zinc (mg/L)	10	ND	10	ND	11	125	13	48.5
TSS (mg/L)	10	35.2	10	37	18	59.5	20	22
Alkalinity (mg/L)	9	67	9	54	**	**	**	**
Hardness (mg/L)	9	79	9	64	**	**	**	**
pH	9	7.32	9	7.205	**	**	**	**
Total Organic Carbon (mg/L)	9	23.65	9	14.7	**	**	**	**
ND=Not Detected								
NC= Not Calculated								
**= No Data								

The inlet data can also be compared to runoff data from the Denver Regional Urban Runoff Program (DRURP), as summarized in Table 7. This provides another way to compare the data from this study to an outside source. The mean values for Total

Organic Carbon, TSS, Copper, and Zinc were much lower at Grant Ranch compared to the mean values from DRURP data. However, mean nutrient concentrations (total Phosphorus, Total Ortho-Phosphate, total Nitrogen, and Nitrate+Nitrite) were again higher for Grant Ranch than for DRURP data.

From the data analyses, the most problematic runoff constituents at Grant Ranch are nutrients. Inflows of nutrients were greater for Grant Ranch than both the DRURP residential area data and the International BMP, and while the Grant Ranch EDB was somewhat successful at removing nutrient loads, outflow concentrations were usually higher than those for the International BMP database. Typical sources of nutrients in runoff from suburban areas include detergents, fertilizers, flame-retardants, plasticizers, cleared vegetation, human and animal waste, and corrosion inhibitors (International Stormwater BMP database). Nutrients are essential at some level to all organisms, but in excess concentrations they can lead to eutrophication from algal diebacks, increased turbidity, habitat degradation, and fish kills.

Table 7. Event Mean Concentration of Constituent Runoff Values: Residential Metropolitan Denver and Grant Ranch

Constituent	EMC DRURP Residential Concentration	EMC Grant Ranch Concentration
Total Phosphorus (mg/L)	0.65	0.732
Total Ortho-Phosphate (mg/L)	0.22	0.57
Total Nitrogen (mg/L)	3.4	5.72
Nitrate+Nitrite (mg/L)	0.65	0.859
Total Lead (mg/L)	0.053	ND
Total Zinc (mg/L)	0.18	0.033
Total Copper (µg/L)	29.0	13.082
Total Cadmium (mg/L)	ND	ND
Total Organic Carbon (mg/L)	72	21.11
TSS (mg/L)	240	58.156

ND=Not Detected

VII. References

Deatrich, Monte and Brown, Warren S., Tri-County Health Department, 2004. Stormwater Best Management Practices, Mosquitoes, and West Nile Virus

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

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