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Pre-Construction, Construction, and Post Construction Final Monitoring Report for Greenland Meadows: July 2007- November 2013

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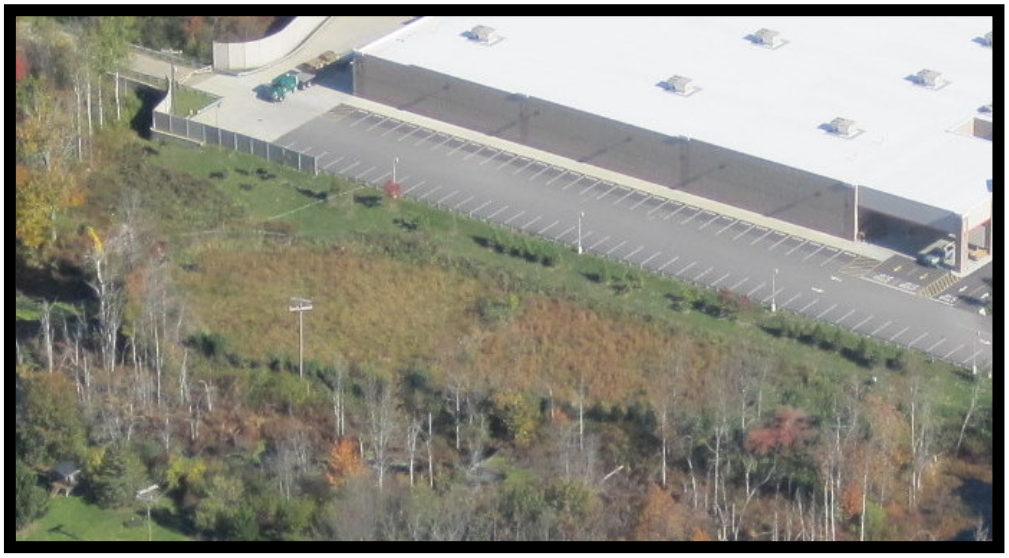

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New England Development, RT 33, Greenland, NH

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Pre-Construction, Construction, and Post-Construction Final Monitoring Report for Greenland Meadows: July 2007- November 2013, New England Development, RT 33, Greenland, NH, February 2014

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Pre-Construction, Construction, and Post-Construction Final Monitoring Report for Greenland Meadows: July 2007- November 2013

Executive Summary

Wet weather flow monitoring has been conducted at the Greenland Meadows location from July 2007 through November 2013. To date all four phases of the project are complete including pre-construction, construction, and five years of post-construction. The results to date indicate that the stormwater management systems are operating well and providing a high level of water quality treatment for the runoff from a high pollutant load commercial site and provide significant protection to the impaired receiving waters of Pickering Brook. Water quality results indicate that effluent pollutant levels as they leave the site at the gravel wetland are typically at or below ambient stream concentrations across a wide range of analytes. In addition, the baseflow benefits are observed to provide a nearly continuous source of cool clean baseflow from the site, discharging in a manner similar to shallow groundwater discharge.

Site Description

Greenland Meadows is a retail shopping center built in 2008 by Newton, Mass.-based New England Development along Route 33 in Greenland, New Hampshire that features one of the largest porous asphalt installations in the Northeast. The site is owned and operated by New England Development and is located on a 56-acre parcel that includes three, one-story retail buildings (Lowe's Home Improvement, Target, and a proposed supermarket), paved parking areas consisting of porous asphalt and non-porous pavements, landscaped areas, a large subsurface gravel wetland, as well as other advanced stormwater management systems. The total impervious area of the development – mainly from rooftops and non-permeable parking areas – is approximately 26 acres, considerably more as compared to pre-development conditions. Prior to development, the project site contained an abandoned Sylvania light bulb factory with a majority of the property vegetated with grass and trees.

The southern boundary of the development is along Pickering Brook, an impaired stream as listed by NHDES. Pickering Brook drains significant portions of Route 33 and Interstate 95 as well.

Framingham, Mass.-based Tetra Tech Rizzo provided site drainage engineering. The University of New Hampshire Stormwater Center provided design guidance and oversight with advanced stormwater management systems. The project was completed in cooperation with the Conservation Law Foundation of Concord, NH.

Project Overview

The project objective was to monitor and assess water quality impacts from stormwater runoff from the Greenland Meadows Site upon Pickering Brook from pre-construction to 5 years post-

construction. Wet weather flow monitoring was conducted to assess stormwater quality in 4 phases. The 4 phases of monitoring (see Table 1) establish water quality for background conditions (Phase 1), during construction activities (Phase 2), the immediate post-construction performance of the stormwater management systems (Phase 3), and the long-term performance of the systems (Phase 4). Real-time monitoring and water quality sampling help to assess background conditions for Pickering Brook, evaluate stormwater quality runoff from the site, and resultant water quality to Pickering Brook downstream of Greenland Meadows. During the first year of Phase 4 an additional monitoring location was installed to sample untreated parking lot runoff from a high traffic area in front of Target Retail Store. Results from this location will provide an estimate of influent concentrations into the stormwater management systems.

Table 1: Sampling Calendar and Methods

Period	Method, Site, Sampling Interval	Year
Phase 1: Pre-Construction Monitoring	Automated Sampler: 5 events, 1 site Grab samples; 3 events, 1 site	1
Phase 2: Construction Monitoring	Automated Sampler: 5 events, 1 site	1
Phase 3: Yr 1 Post-Construction Monitoring	Automated Sampler: 8 events, 2 site	2
Phase 4: Yrs 2-5 Post-Construction Monitoring	Automated Sampler: 4 events, 2 site	3-6

Methods and Sampling

Water quality samples and real-time monitoring data were collected in order to evaluate the effectiveness of the stormwater management system and the runoff water quantity and quality from Greenland Meadows. Storm event monitoring was conducted during all four seasons and over a wide range of rainfall event characteristics (i.e. rainfall depth, rainfall intensity, storm duration, antecedent dry period). Samples are taken throughout each storm event and then composited into identical 1 liter samples which are sent to a third party analytical lab for analysis of contaminant concentrations. The results are used to assess run-off water quality, stormwater management performance, and wash-off characteristics as it relates to street sweeping. System performance is examined with respect to background receiving water conditions, effluent concentrations (pre- and post-construction), and downstream receiving water conditions. Pollutant removal efficiencies were not initially calculated because no true influent monitoring was established. With the additional monitoring of direct runoff, removal efficiencies were calculated for one year of post-construction monitoring.

Pre-construction background conditions were monitored at a location in Pickering Brook over the span of seven months prior to any on-site construction activity (Table 2, Figure 1). Construction and post-construction monitoring was conducted at two primary locations during Phase 2 through Phase 4 of the project (Table 2, Figure 1). The two locations were selected to monitor treated stormwater runoff directly from the subsurface gravel wetland (SGW) as well as conditions within Pickering Brook at the confluence of treated runoff and the receiving waters. The first monitoring location was within the 36 inch effluent pipe leaving the SGW. The second monitoring location was just downstream of the outlet of the SGW effluent sedimentation basin.

During Phase 4 an additional site was selected for monitoring direct runoff to establish untreated stormwater contaminant concentrations that were entering into the stormwater management system. The direct runoff monitoring was located within an existing catch basin along a grassed median strip directly in front of the Target Retail Store (Figure 2, Figure 3). This location was selected for its high traffic count and used as a representation of the entire parking area.

Table 2: Monitoring Location Coordinates

Station ID	Latitude	Longitude
Pre-Construction Monitoring	43° 2'52.08"N	70°49'16.12"W
Construction and Post-Construction Monitoring	43° 2'54.84"N	70°49'18.68"W

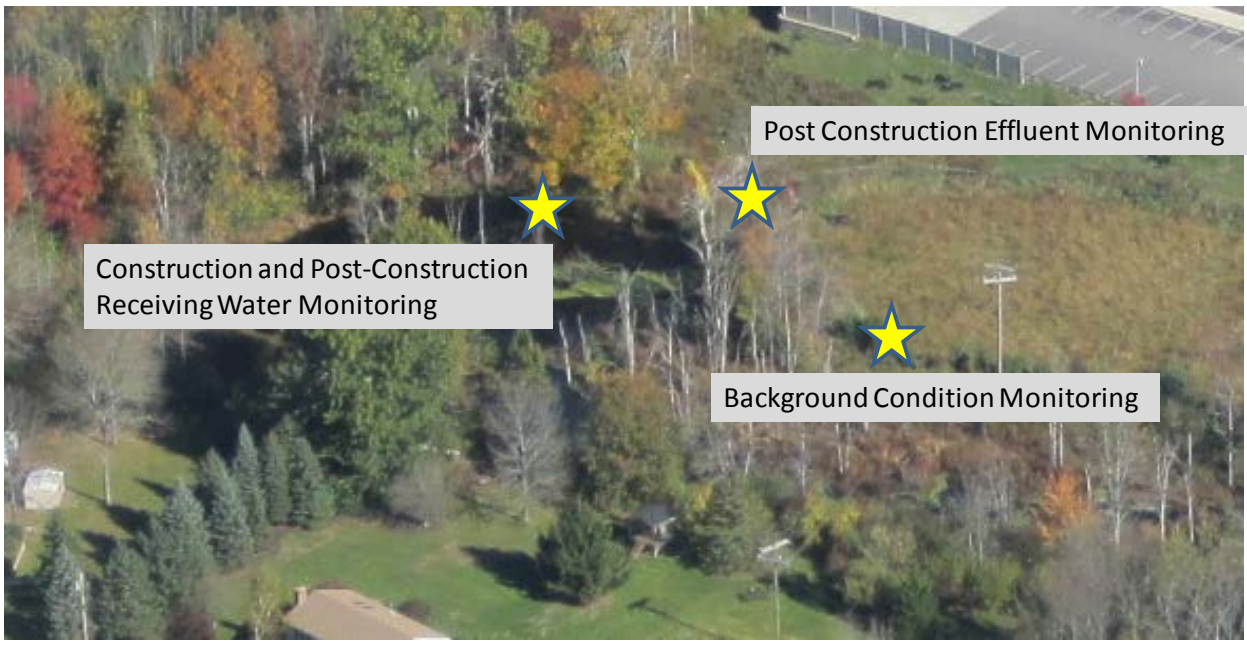


Figure 1: Pre-Construction, Construction, and Post-Construction monitoring locations for Pickering Brook

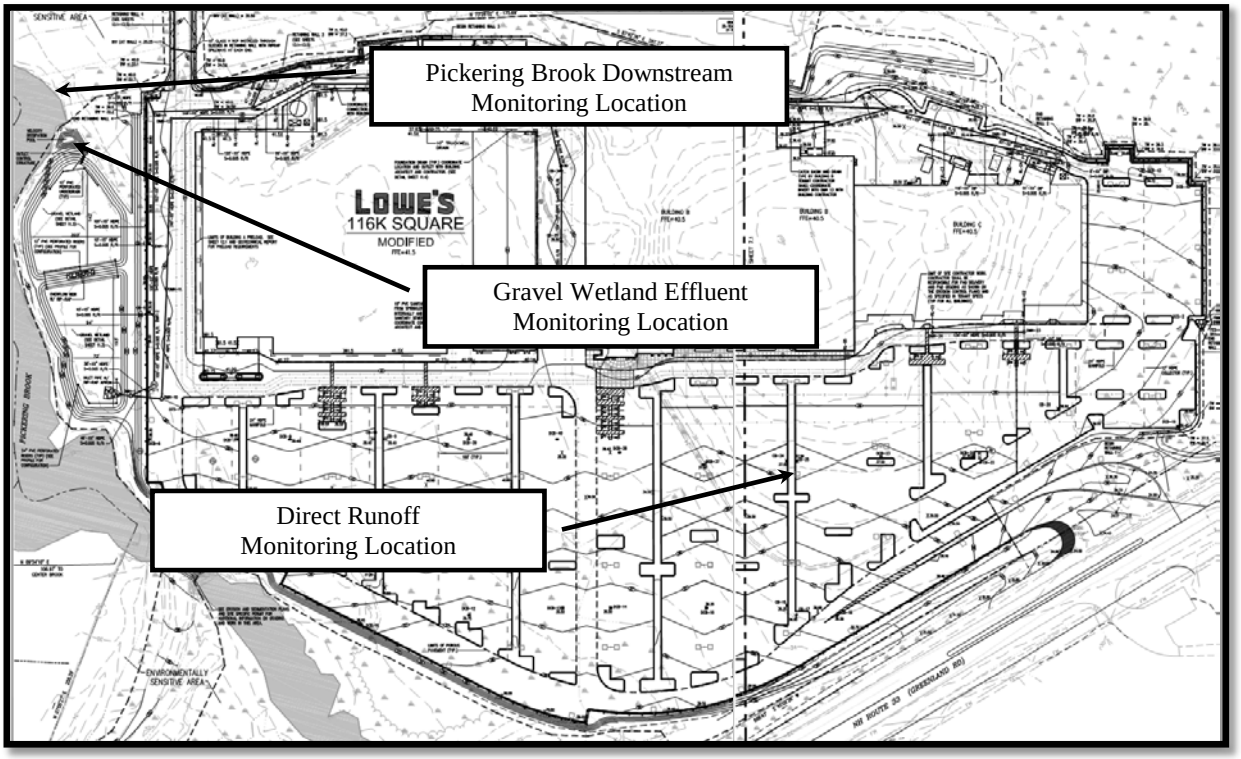


Figure 2: Phase 4 Post-Construction monitoring locations

Figure 3: Influent monitoring of direct runoff sampling installation

Equipment

Teledyne ISCO 6712 Refrigerated samplers (Figure 4) were used to monitor water quantity and water quality during storm events. Each sampler was outfitted with either an ISCO 720 Submerged Probe or ISCO 730 Bubbler module to continuously monitor water depth throughout each sampled rain event. YSI 600XL Multi-parameter Sondes are installed for real-time monitoring of pH, temperature, dissolved oxygen, and conductivity and recorded at 5 minute intervals. The samplers are equipped with twenty-four 1 liter sample bottles inside the refrigerated compartment and kept at 4°C at all times. The samplers are programmed to sample 100 milliliter aliquots at flow-weighted intervals into twenty-four 1 liter containers allowing for a maximum of 240 samples per event. The sampling program is designed to ensure adequate coverage of the storm event and is adjusted to accommodate seasonal fluctuations in rainfall patterns. Rejection criteria included minimum rainfall depth of 0.1 inches, minimum of 10 aliquots per sampling event, and at least 70% coverage of the total storm volume.

Figure 4: Teledyne ISCO 6712 Refrigerated Sampler installed at effluent location of subsurface gravel wetland.

Sample Analysis

Runoff constituent analyses routinely included; total suspended solids (TSS), total petroleum hydrocarbons- diesel (TPH-D), total nitrogen (NO3, NO2, NH4, TKN), and total Zinc (Zn). Additional analytes such as total phosphorus and ortho-phosphate were added due to their relative importance in stormwater effluent characteristics. All sample analyses listed in Table 3 were performed at an EPA and National Environmental Laboratory Accreditation Conference (NELAC) certified laboratory. UNHSC operates under a detailed quality assurance project plan, which is modeled after EPA protocols.

Table 3: Laboratory Analytical Methods and Detection Limits for Each Analyte

Analyte	Analytical Method	Sample Detection Limit (mg/L)	Method Detection Limit (mg/L)[a]
Nitrate/Nitrite in water	EPA 300.0A	0.1	0.008
TKN	ASTMD359002A	Variable	0.5
Ammonia (NH3)	SM4500NH3-D	Variable	0.5
Total Nitrogen		Variable	0.4
Total Suspended Solids	SM 2540 D	Variable, 1-10	
Suspended Sediment Concentration	ASTM D-3977	Variable, 1-2	1
Total Phosphorus	EPA 365.3	0.01	0.008
Ortho-Phosphate	EPA 300.0A	0.031	0.05
Zinc in water	EPA 200.7	0.05	0.001-0.05
Total Petroleum Hydrocarbons –Diesel Range	SW 3510C 8015B	Variable ≤ 3.5	0.1-3.0

[a]Method detection limit is different than sample detection limit which will often be higher as they are based on sample volume available for analyses.

Results

Phase 1: Pre-Construction Monitoring (Completed)

A total of 12 events were sampled including 8 rain events and 4 dry-weather grab samples. Rainfall event characteristics are included for all monitored events in Table 4. Water quality results are presented in Table 5. Background sampling occurred over the span of seven months and three seasons. Many laboratory analyses were returned below detection limit (BDL) for a variety of pollutants. In such cases a value of half of the median detection limit was employed for all BDL results in order to plot the data as well as to perform statistical analyses. This is a common approach for treatment of BDL values.

Phase 2: Construction Monitoring (Completed)

During site construction activities 8 rain events were sampled over the course of four months and two seasons. Results are presented in Table 6. Rainfall event characteristics are included for all monitored events in Table 4. Results indicate that minor elevations in sediment, nitrogen, and phosphorus were observed. It should be noted that the average concentrations of both nutrients are below any EPA action limits. Nutrient concentrations would be expected to be elevated during construction as this is a period of non-vegetation during which no plant uptake of nutrients is occurring. Once vegetation and permanent stormwater management systems are in place nutrient concentrations would be expected to decline with the stormwater management strategies employed for this site and overall site stabilization.

Phase 3: Yr 1 Post-Construction Monitoring (Completed)

Year 1 of post-construction monitoring coincided with the opening of Target in summer 2009. A total of 15 wet weather events were monitored from August 2009 through June 2010. The results are listed in Table 7 and Table 8 and plotted in Figure 5, Figure 6, and Figure 7 along with Phase 4 results. Monitoring was conducted in two locations: the primary discharge point from the SGW and in Pickering Brook where the treated runoff mixes with the receiving waters. Results indicate that effluent pollutant levels are typically at or below ambient stream concentrations across the range of contaminants. There are no water quality results for Pickering Brook during the ’09-’10 winter months due to freezing of the monitoring location. Based on the storms observed thus far, the water discharging from the Greenland Meadows site is typically lower in pollutant concentrations than the receiving waters. It is suspected that the average nutrient concentrations in Pickering Brook are in reality higher than reported here because the 3 winter months are not included. These months are typically the period of time when highest nitrogen concentrations are observed.

Phase 4: Yrs 2-5 Post-Construction Monitoring (Completed)

Long-term monitoring was conducted for an additional four years after Phase 3 monitoring was complete. A total of 25 wet weather events were monitored from July 2010 through November of 2013. Sample locations were consistent with Phase 3 with the addition of the influent runoff location in front of Target. The results are listed in Table 7 and Table 8 as well as plotted in Figure 5, Figure 6, and Figure 7 along with Phase 3 results. Results of direct runoff monitoring are listed in Table 9 and a summary of all water quality results for each project phase is presented in Table 10.

Monitoring Summary

A total of 56 wet weather events were monitored at Greenland Meadows from July 2007 through November 2013 through all four phases of the commercial site development process. Monitoring took place during all four seasons and over a wide range of rainfall characteristics. The monitoring requirements for this project have been completed on schedule with the addition of several storm events that have proven to strengthen the overall data set. The median TSS concentrations for the post-construction treated runoff (3 mg/L TSS) are below pre-construction monitoring (5 mg/L TSS), and below the receiving waters of Pickering Brook (9 mg/L TSS). The median TN concentrations for the post-construction treated runoff (0.8 mg/L TN) are above pre-construction monitoring (0.55 mg/L TN), but below the receiving waters of Pickering Brook (1.10 mg/L TN). The median TP concentrations for the post-construction treated runoff (0.01 mg/L TP) are below pre-construction monitoring (0.05 mg/L TP), and below the receiving waters of Pickering Brook (0.045 mg/L TP). The results to date indicate that the stormwater management systems are operating well and providing a high level of water quality treatment for the runoff from a high contaminant load commercial site and provide significant protection to the impaired receiving waters of Pickering Brook. This stormwater management strategy is consistently meeting or exceeding design and permitting expectations.

Of important mention is that the untreated influent monitoring location has surprisingly low levels of pollutants as compared to monitored results for untreated runoff from similar commercial land uses. This would suggest that the routine vacuum cleaning is having an impact as a pretreatment and pollutant removal strategy, reducing the mass load to the treatment systems. The influent monitoring data is being provided for informational purposes only and was not part of the original scope of work. There were only 5 storm events monitored during the fall of 2011 for influent concentrations where there were 40 storm events for the full post-construction data set. The results indicate a potential area for future research efforts. The median untreated parking lot runoff TSS concentration is 14 mg/L, just slightly above that of the receiving waters of Pickering Brook (9 mg/L TSS); the median influent TN concentration is 0.7 mg/L TN, only slightly above pre-construction monitoring (0.55 mg/L TN), but slightly below the treated effluent concentration of 0.8 mg/L; and the median influent TP concentration is 0.05 mg/L, equivalent to background but far above the treated effluent concentration of 0.01 mg/L TP. In addition, the water discharging from the subsurface gravel wetland was observed to provide a nearly continuous source of cool clean baseflow from the site, discharging in a manner similar to shallow groundwater discharge.

Lastly, in 2014 the subsurface gravel wetland basin will be entering its 6^{th} summer in operation. Maintenance recommendations for subsurface gravel wetlands are to cut and remove vegetation from the system and fore-bay areas every three years in order to physically remove nutrients that are sequestered in the vegetation. This maintenance activity was conducted in the fall of 2012 and the site has seen full grow back of all vegetation. The removal of cut biomass from the system prevents nutrients from cycling back into the system and releasing these previously removed nutrients to receiving waters. Vegetation removal should occur in the late summer, prior to plant die-off. Sampling indicates that operation and maintenance of the onsite stormwater systems is occurring as prescribed. Subsequently dissolved inorganic nitrogen (DIN = NO_3 + NO_2 + NH_3) concentrations increased in the fall of 2011 and have since returned to

below detectable limits since maintenance was conducted. Maintenance recommendations can be found online at http://www.unh.edu/unhsc/specs-and-fact-sheets-0

Table 4: Rainfall Characteristics for Background, Construction, and Post-Construction Sampling

Monitoring Period	Rainfall Event	Total Depth (in)	Peak Intensity (in/hr)	Duration (min)	Season
Phase 1: Background (Pre-development) Monitoring	7/6/2007	0.71	3.42	110	Summer
	7/12/2007	0.43	1.20	50	Summer
	7/19/2007	0.41	0.54	180	Summer
	7/28/2007	1.12	2.22	80	Summer
	9/27/2007	0.24	0.78	70	Fall
	11/6/2007	0.67	0.48	520	Fall
	11/26/2007	0.12	0.12	270	Fall
	1/11/2008	0.60	0.36	340	Winter
Phase 2: Construction Phase Monitoring	3/28/2008	0.16	0.12	180	Winter
	3/31/2008	0.24	0.12	550	Winter
	4/12/2008	0.15	0.12	170	Spring
	4/28/2008	1.84	0.30	1330	Spring
	5/27/2008	0.13	0.66	30	Spring
	6/4/2008	0.48	1.80	360	Spring
	6/6/2008	0.35	0.24	390	Spring
	6/14/2008	1.28	0.60	680	Spring
Phase 3: Post-Construction Monitoring Year 1	8/28/2009	2.17	0.72	1330	Summer
	9/12/2009	0.68	1.08	465	Summer
	10/7/2009	0.96	0.84	4390	Fall
	10/18/2009	0.58	0.12	5225	Fall
	12/2/2009	1.03	0.60	5075	Fall
	12/27/2009	0.92	0.36	6765	Winter
	1/17/2010	0.44	0.12	5650	Winter
	1/24/2010	0.96	0.36	7650	Winter
	2/24/2010	0.52	1.20	2500	Winter
	3/11/2010	0.90	0.24	12045	Winter
	5/8/2010	0.57	1.08	7545	Spring
	5/14/2010	0.20	0.48	6540	Spring
	6/3/2010	1.25	2.76	2505	Spring
	6/10/2010	0.63	0.60	6665	Spring
	6/23/2010	0.28	0.36	3535	Summer
Phase 4: Post-Construction Monitoring Year 2	7/10/2010	0.43	1.56	4525	Summer
	7/13/2010	2.09	3.00	8420	Summer
	8/9/2010	2.16	3.72	5815	Summer
	8/22/2010	3.30	1.80	5925	Summer
	10/6/2010	0.91	0.24	6040	Fall
	10/14/2010	2.53	1.32	5090	Fall
	11/4/2010	1.56	0.48	5000	Fall
	11/17/2010	1.32	0.84	6720	Fall
	12/1/2010	0.64	0.36	5120	Fall
Phase 4: Post-Construction Monitoring Year 3	10/19/2011	1.55	0.60	4340	Fall
	10/27/2011	0.93	0.24	4150	Fall
	11/10/2011	0.69	0.96	5915	Fall
	11/23/2011	1.33	0.36	5000	Fall
	11/30/2011	0.54	0.84	8565	Fall
	12/6/2011	1.69	0.36	8665	Fall
Phase 4: Post-Construction Monitoring Year 4	5/8/2013	0.76	0.48	2215	Summer
	5/21/2013	0.98	0.60	2445	Summer
	5/29/2013	0.25	0.24	2285	Summer
	6/3/2013	0.13	0.24	1900	Summer
	6/25/2013	1.22	1.08	3910	Summer
Phase 4: Post-Construction Monitoring Year 5	7/23/2013	1.22	0.96	4595	Summer
	8/1/2013	0.42	0.48	5335	Summer
	8/9/2013	1.28	0.84	5445	Summer
	11/7/2013	0.11	0.12	2060	Fall
	11/17/2013	0.25	0.24	3775	Fall

Table 5: Results for Phase 1 Pre-Construction Background Monitoring

Date	TSS	TPH-D	TZn	Nitrate-N	Nitrite-N	NH4	TKN	TN	TP	ortho- P
7/6/2007*	*5*	*160*	*0.005*	*0.05*	*0.05*	*0.25*	0.5	0.5	0.08	NA
7/6/2007	*5*	*155*	*0.005*	*0.05*	*0.05*	*0.25*	0.5	0.5	0.06	NA
7/12/2007	*5*	*170*	*0.005*	*0.05*	*0.05*	*0.25*	1.4	1.4	0.05	NA
7/19/2007	*5*	*165*	*0.005*	*0.05*	*0.05*	*0.25*	0.8	0.8	0.05	NA
7/28/2007	*5*	*135*	0.01	*0.05*	*0.05*	*0.25*	1.3	1.3	0.05	NA
8/3/2007	*5*	*175*	*0.005*	*0.05*	*0.05*	*0.25*	0.6	0.6	0.05	*0.05*
9/27/2007	*5*	*285*	0.02	*0.025*	*0.05*	*0.25*	0.8	0.8	0.07	NA
11/6/2007*	*5*	*190*	*0.005*	*0.05*	*0.05*	*0.25*	*0.25*	*0.25*	0.02	*0.05*
11/6/2007	*5*	*175*	*0.005*	*0.05*	*0.05*	*0.25*	*0.25*	*0.25*	0.03	*0.05*
11/10/2007*	*5*	*160*	*0.005*	*0.05*	*0.05*	*0.25*	0.5	0.5	0.01	*0.05*
11/26/2007	*5*	*215*	*0.005*	*0.05*	*0.05*	*0.25*	*0.25*	*0.25*	0.02	*0.05*
1/11/2008	*5*	*185*	*0.005*	0.1	*0.05*	*0.25*	0.8	0.9	0.03	*0.05*

*Denotes grab sample; values in *italics* denotes half detection limit
NA denotes where sample was not analyzed for that parameter

Table 6: Results for Phase 2 Construction Monitoring

Date	TSS	TPH-D	TZn	Nitrate-N	Nitrite-N	NH4	TKN	TN	TP	ortho-P
3/28/2008	4	*100*	*0.005*	2.50	*0.05*	*0.25*	0.8	3.30	0.020	*0.005*
3/31/2008	2	*105*	*0.005*	1.10	*0.05*	*0.25*	0.9	2.00	*0.005*	*0.005*
4/12/2008	3	*105*	*0.005*	0.70	*0.05*	*0.25*	1.0	1.70	0.020	*0.005*
4/28/2008	22	*115*	*0.025*	2.40	*0.05*	*0.25*	2.6	5.00	0.010	0.02
5/27/2008	12	*100*	*0.005*	*0.05*	*0.05*	*0.25*	1.8	*0.25*	0.140	0.04
6/4/2008	28	*185*	*0.005*	*0.05*	*0.05*	*0.25*	0.9	0.90	0.120	0.03
6/6/2008	28	NA	*0.005*	0.10	*0.05*	*0.25*	1.0	1.10	0.120	0.01
6/14/2008	16	NA	*0.005*	0.70	*0.05*	*0.25*	1.0	1.70	0.130	0.04

Values in *italics* denotes half detection limit
NA denotes where sample was not analyzed for that parameter

Table 7: **Subsurface Gravel Wetlands results for Phase 3 and Phase 4 Post Construction Monitoring**

SUBSURFACE GRAVEL WETLAND EFFLUENT

Date	TSS	SSC	TPH-D	TZn	Nitrate-N	Nitrite-N	NH4	TKN	TN	TP	ortho-P
8/28/2009	2	3	*210*	*0.025*	*0.05*	*0.05*	*0.25*	4.1	4.1	0.01	0.01
9/12/2009	1	6	*190*	*0.005*	*0.05*	*0.05*	*0.25*	0.5	0.5	*0.005*	*0.005*
10/7/2009	1	4	*160*	*0.005*	0.1	*0.05*	*0.25*	*0.25*	*0.25*	*0.005*	*0.005*
10/18/2009	2	4	*165*	*0.025*	0.1	*0.05*	*0.25*	0.7	0.8	0.02	*0.005*
12/2/2009	2	3		*0.005*	0.4	*0.05*	*0.25*	*0.25*	*0.25*	*0.005*	*0.005*
12/27/2009	13	1	*180*	*0.005*	1.2	*0.5*	*0.25*	*0.25*	1.2	0.01	*0.005*
1/17/2010	3	*0.5*	*180*	*0.005*	1.4	*0.5*	*0.25*	0.9	2.3	*0.005*	*0.005*
1/24/2010	2	3		0.01	*0.5*	*1*	*0.25*	0.6	*1*	*0.005*	0.01
2/24/2010	22	19	*145*	0.03	*0.5*	*2.5*	*0.25*	1	*2.5*	*0.005*	*0.005*
3/11/2010	4	3	*155*	*0.005*	0.4	*0.5*	*0.25*	*0.25*	*0.5*	*0.005*	*0.005*
5/8/2010	*0.5*	1	*180*	*0.025*	0.5	*0.5*	*0.25*	*0.25*	*0.5*	*0.005*	*0.005*
5/14/2010	*0.5*	2	*190*	*0.005*	0.3	*0.25*	*0.25*	0.6	0.9	*0.005*	*0.005*
6/3/2010	4	6		*0.005*	*0.05*	*0.05*	*0.25*	0.5	0.5	*0.005*	*0.005*
6/10/2010	4	3		*0.005*	*0.05*	*0.05*	*0.25*	0.7	0.7	*0.005*	*0.005*
6/23/2010	2	3		*0.005*	*0.05*	*0.05*	*0.25*	0.6	0.6	*0.005*	*0.005*
7/10/2010	3	3		*0.005*	*0.05*	*0.05*	*0.25*	*0.25*	*0.25*	0.01	*0.005*
7/13/2010	3	4	*155*	*0.005*	*0.05*	*0.05*	*0.25*	0.5	0.5	0.06	0.02
8/9/2010	5	6	*190*	*0.005*	*0.05*	*0.05*	*0.25*	1.4	1.4	0.04	*0.005*
8/22/2010	2	3	*115*	*0.005*	*0.05*	*0.05*	*0.25*	0.5	0.5	0.02	*0.005*
10/6/2010	4	3	*195*	*0.005*	*0.05*	*0.05*	*0.25*	0.5	0.5	0.02	*0.005*
10/14/2010	3	69		*0.005*	*0.05*	*0.05*	*0.25*	0.6	0.6	0.01	*0.005*
11/4/2010	2	2	*155*	*0.005*	*0.05*	*0.05*	*0.25*	*0.25*	*0.25*	0.01	*0.005*
11/17/2010	*1*	*1*	*155*	*0.005*	0.2	*0.05*	*0.25*	0.9	1.1	*0.005*	*0.005*
12/1/2010	*1*	*1*		*0.005*	0.2	*0.05*	*0.25*	0.6	0.8	*0.005*	*0.005*
10/19/2011	2	6	*135*	*0.005*	*0.05*	*0.05*	*0.25*	0.6	0.6	0.01	0.007
10/27/2011	3	3		*0.005*	0.1	*0.05*	*0.25*	0.8	0.9	0.04	0.005
11/10/2011	2	3	*180*	0.02	0.2	*0.05*	*0.25*	*0.25*	*0.25*	0.02	0.008
11/23/2011	2	3	*155*	*0.005*	0.2	*0.05*	*0.25*	0.5	0.7	0.03	0.007
11/30/2011	18	3	*190*	*0.005*	0.3	*0.05*	*0.25*	1	1.3	*0.005*	0.013
12/6/2011	2	*0.5*	*190*	*0.005*	0.2	*0.05*	*0.25*	0.7	0.9	0.01	0.01
5/8/2013	12	7	*135*	*0.005*	*0.05*	*0.05*	*0.25*	0.8	0.8	0.04	0.011
5/21/2013	3	67	*180*	*0.005*	*0.05*	*0.05*	*0.25*	0.8	0.8	0.03	0.016
5/29/2013	4	5	*140*	*0.005*	*0.05*	*0.05*	*0.25*	0.8	0.8	*0.005*	0.009
6/3/2013	4	5	*130*	*0.005*	*0.05*	*0.05*	*0.25*	0.9	0.9	0.02	0.009
6/25/2013	4				*0.05*	*0.05*	*0.25*	0.9	0.9	*0.005*	
7/23/2013	4				*0.05*	*0.05*	*0.25*	1	1	0.11	
8/1/2013	4				*0.05*	*0.05*	0.7	0.8	0.8	0.02	
8/9/2013	3				*0.05*	*0.05*	*0.25*	0.7	0.7	*0.005*	
11/7/2013	41				*0.05*	*0.05*	*0.25*	1.1	1.1	0.06	
11/17/2013	23				*0.05*	*0.05*	*0.25*	1.6	1.6	0.01	

Values in *italics* denotes half detection limit

The detection limit for ortho-P was reduced from 0.01mg/l to 0.001mg/l for samples from 10/19/2011 to present. Due to the consistent trend of low concentrations, SSC, TPH, TZn, and OrthoP was discontinued in year 5.

Table 8: Pickering Brook results for Phase 3 and Phase 4 Post Construction Monitoring

PICKERING BROOK

Date	TSS	SSC	TPH-D	TZn	Nitrate-N	Nitrite-N	NH4	TKN	TN	TP	ortho-P
8/28/2009	5	6	*220*	*0.025*	0.2	*0.05*	*0.25*	3.7	3.9	0.05	0.04
9/12/2009	6	*0.5*	*155*	*0.005*	0.2	*0.05*	*0.25*	0.7	0.9	0.04	*0.005*
10/7/2009											
10/18/2009	10	8	*165*	*0.025*	0.1	*0.05*	*0.25*	1.2	1.3	0.03	*0.005*
12/2/2009											
12/27/2009											
1/17/2010											
1/24/2010											
2/24/2010											
3/11/2010	13	14	*165*	*0.005*	*0.05*	*0.05*	*0.25*	0.5	0.5	0.01	*0.005*
5/8/2010	93	120	*190*	*0.025*	0.1	*0.5*	1	3.2	3.3	0.81	0.03
5/14/2010	40	42	*170*	*0.005*	*0.05*	*0.25*	0.6	1.8	1.8	0.23	0.03
6/3/2010	64	74	*155*	*0.005*	*0.05*	*0.05*	*0.25*	0.8	0.8	0.16	0.01
6/10/2010	38	34	*165*	*0.005*	*0.05*	*0.05*	*0.25*	*0.25*	*0.25*	0.07	0.01
6/23/2010	300	310	*195*	0.02	*0.05*	*0.05*	*0.25*	2.2	2.2	0.6	0.07
7/10/2010	120	140	*155*	*0.005*	0.1	*0.05*	2.4	4.1	4.2	0.44	0.04
7/13/2010	86	100	*150*	0.01	*0.05*	*0.05*	*0.25*	1.5	1.5	0.23	0.03
8/9/2010	42	45	*180*	*0.005*	*0.05*	*0.05*	*0.25*	1.2	1.2	0.11	*0.005*
8/22/2010	1100	1600	*175*	0.07	0.3	*0.05*	*0.25*	7	7.3	1.5	0.03
10/6/2010	9	7	*160*	*0.005*	*0.05*	*0.05*	*0.25*	0.9	0.9	0.02	*0.005*
10/14/2010	65	1	*170*	*0.005*	0.1	*0.05*	*0.25*	1.1	1.2	0.13	*0.005*
11/4/2010	2	2	*170*	*0.005*	*0.05*	*0.05*	*0.25*	0.8	0.8	0.02	*0.005*
11/17/2010	6	7	*145*	*0.005*	*0.05*	*0.05*	*0.25*	1.1	1.1	0.02	*0.005*
12/1/2010	8	6	*175*	*0.005*	*0.05*	*0.05*	*0.25*	0.8	0.8	0.01	*0.005*
10/19/2011	10	8	*170*	*0.005*	*0.05*	*0.05*	*0.25*	1.4	1.4	0.05	0.017
10/27/2011	3	2	*180*	*0.005*	*0.05*	*0.05*	*0.25*	1.1	1.1	0.02	0.012
11/10/2011	2	4	*180*	*0.005*	0.1	*0.05*	*0.25*	*0.25*	*0.25*	0.02	0.011
11/23/2011	7	9	*180*	*0.005*	0.1	*0.05*	*0.25*	0.6	0.7	0.03	0.011
11/30/2011	4	8	*190*	*0.005*	*0.05*	*0.05*	*0.25*	1	1	0.02	0.024
12/6/2011	5	5		*0.005*	0.2	*0.05*	*0.25*	1	1.2	0.03	0.016
5/8/2013	7	6	*100*	*0.005*	*0.05*	*0.05*	*0.25*	0.9	0.9	0.09	0.021
5/21/2013	4	58	*150*	*0.005*	*0.05*	*0.05*	*0.25*	0.8	0.8	0.02	0.015
5/29/2013	3	3	*175*	*0.005*	*0.05*	*0.05*	*0.25*	1.1	1.1	0.02	0.004
6/3/2013	9	3	*120*	*0.005*	*0.05*	*0.05*	*0.25*	1.4	1.4	0.08	0.023
6/25/2013	10				*0.05*	*0.05*	*0.25*	1	1	0.01	
7/23/2013	8				*0.05*	*0.05*	*0.25*	1.2	1.2	0.07	
8/1/2013	6				*0.05*	*0.05*	*0.25*	0.8	0.8	0.04	
8/9/2013	6				*0.05*	*0.05*	*0.25*	*0.25*	*0.25*	*0.005*	
11/7/2013	26				*0.05*	*0.05*	1	4.2	4.2	0.25	
11/17/2013	15				*0.05*	*0.05*	*0.25*	3	3	0.16	

Values in *italics* denotes half detection limit

The detection limit for ortho-P was reduced from 0.01mg/l to 0.001mg/l on 10/19/2011. Due to the consistent trend of low concentrations, SSC, TPH, TZn, and OrthoP was discontinued in year 5.

***** Note: Gaps in data for TPH-D indicate inadequate sample volume to meet the minimum laboratory detection limit.

** Note: Large data gaps in the winter '09-'10 for outfall sampling is due to frozen and unmonitorable conditions.

Table 9: Direct Runoff results for Phase 3 and Phase 4 Post Construction Monitoring

DIRECT RUNOFF - UNTREATED

Date	TSS	SSC	TPH-D	TZn	Nitrate-N	Nitrite-N	NH4	TKN	TN	TP	ortho-P
10/27/2011	14	6	*145*	0.02	0.1	*0.05*	*0.25*	0.8	0.9	0.05	0.01
11/10/2011	16	18	*170*	0.03	*0.05*	*0.05*	*0.25*	*0.25*	*0.25*	0.05	0.015
11/23/2011	9	10		0.02	*0.05*	*0.05*	*0.25*	0.7	0.7	0.06	0.019
11/30/2011	29	35	*165*	0.05	*0.05*	*0.05*	*0.25*	1.2	1.2	0.07	0.02
12/6/2011	13	11	*160*	0.02	*0.05*	*0.05*	*0.25*	0.5	0.5	0.02	0.004

Values in *italics* denotes half detection limit

Table 10: Comparison of Pre-Construction, Construction, and Post-Construction Monitoring Results for Influent Runoff, Effluent Discharge and Pickering Brook Receiving Waters

	TSS	SSC	TPH-D	TZn	Nitrate-N	Nitrite-N	NH4	TKN	TN	TP	ortho- P
Background											
average	5		181	0.007	0.05	0.05	0.25	0.66	0.67	0.043	0.050
median	5		173	0.005	0.05	0.05	0.25	0.55	0.55	0.050	0.050
Construction											
average	14		118	0.008	0.95	0.05	0.25	1.25	1.99	0.071	0.018
median	14		105	0.005	0.70	0.05	0.25	1.00	1.70	0.070	0.015
Post-Construction Subsurface Gravel Wetland Effluent *											
average	5	8	165	0.008	0.20	0.19	0.26	0.76	0.91	0.018	0.007
median	3	3	165	0.005	0.05	0.05	0.25	0.65	0.80	0.010	0.005
Post-Construction Pickering Brook *											
average	63	94	170	0.010	0.08	0.07	0.37	1.55	1.60	0.159	0.017
median	9	8	170	0.005	0.05	0.05	0.25	1.10	1.10	0.045	0.012
Post-Construction Direct Runoff - Untreated Influent *											
average	16	16	163	0.028	0.06	0.05	0.25	0.69	0.71	0.050	0.014
median	14	11	163	0.020	0.05	0.05	0.25	0.70	0.70	0.050	0.015

* Note: BDL values reported as 0.5 of the median DL value. Untreated influent is provided as reference only as the sample size was very small (5 storms) compared to other data sets.

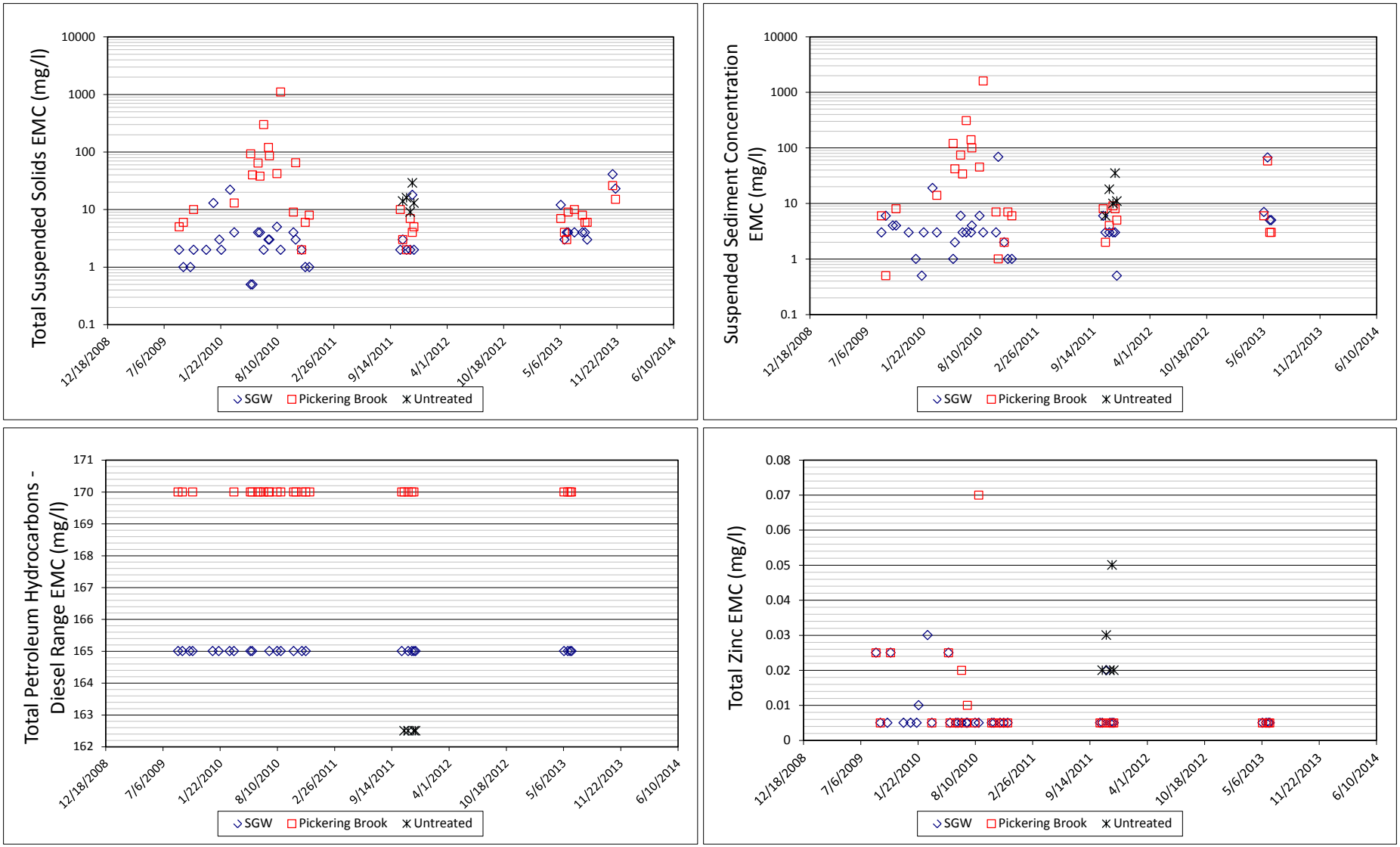


Figure 5: Influent, Effluent, and Receiving Water Contaminant Concentration Time Series Plots for the Range of Post-Construction Monitoring Data.

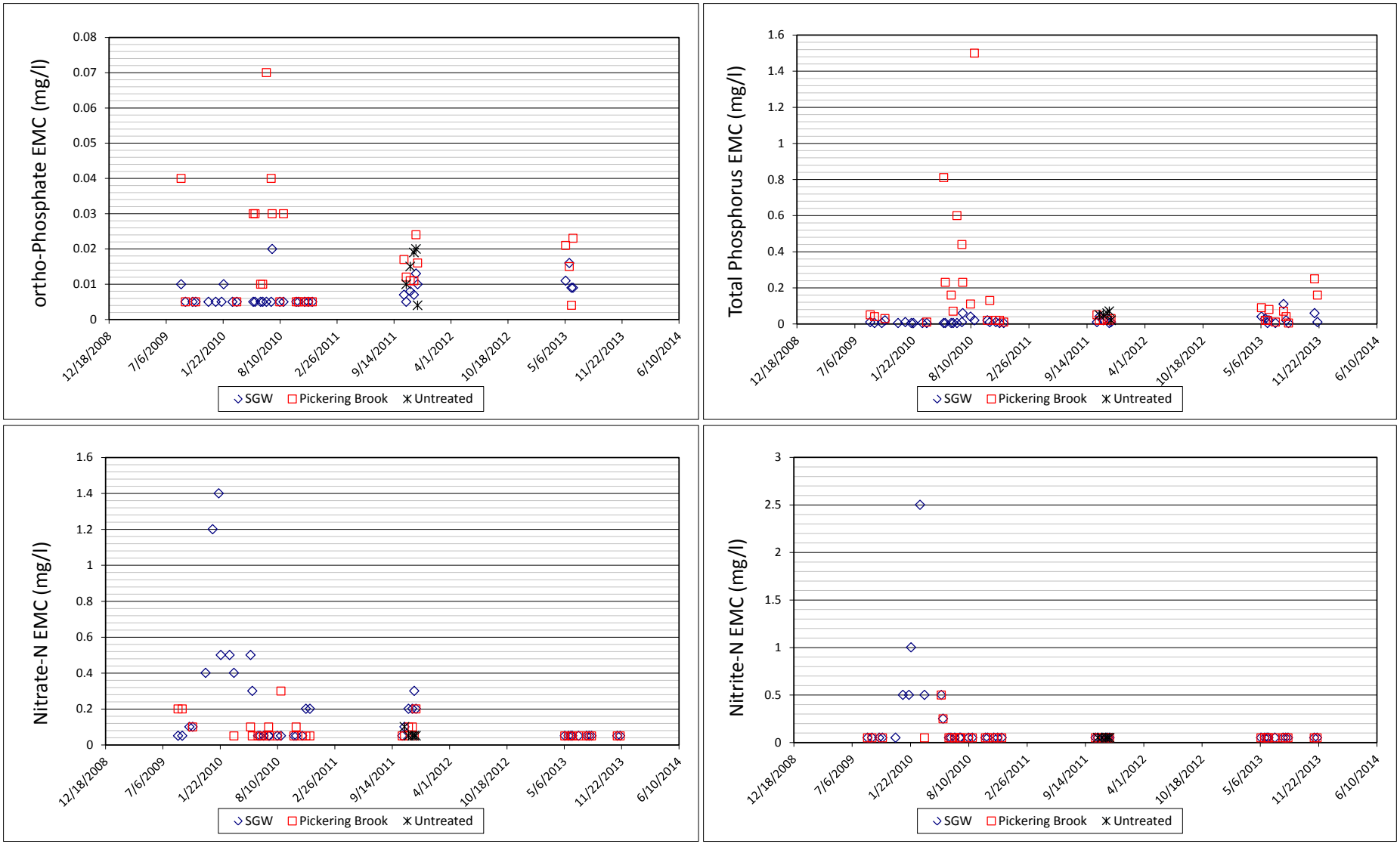
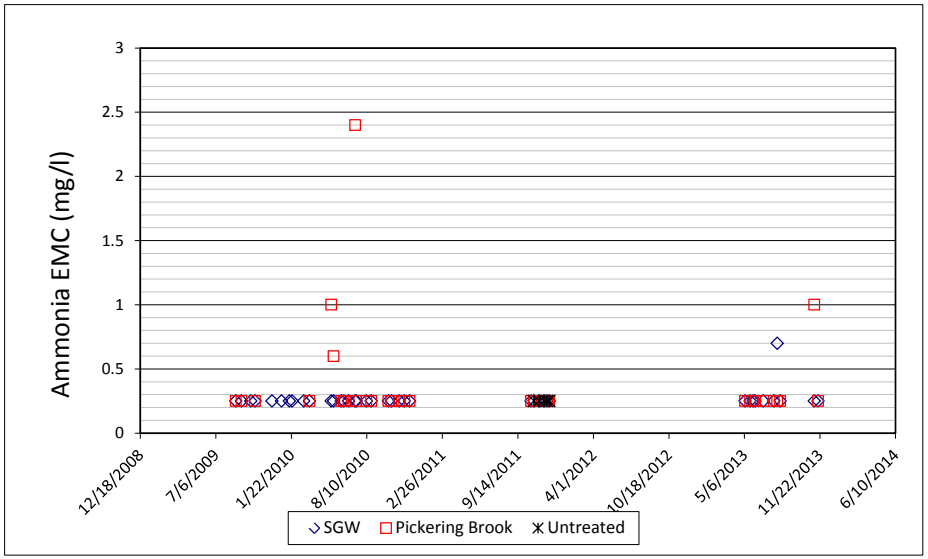
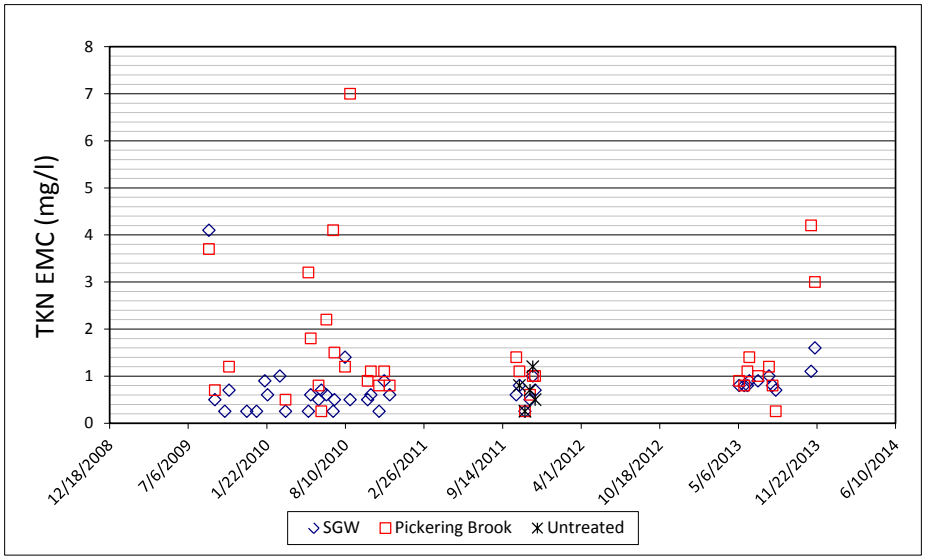


Figure 6: Influent, Effluent, and Receiving Water Contaminant Concentration Time Series Plots for the Range of Post-Construction Monitoring Data (cont).





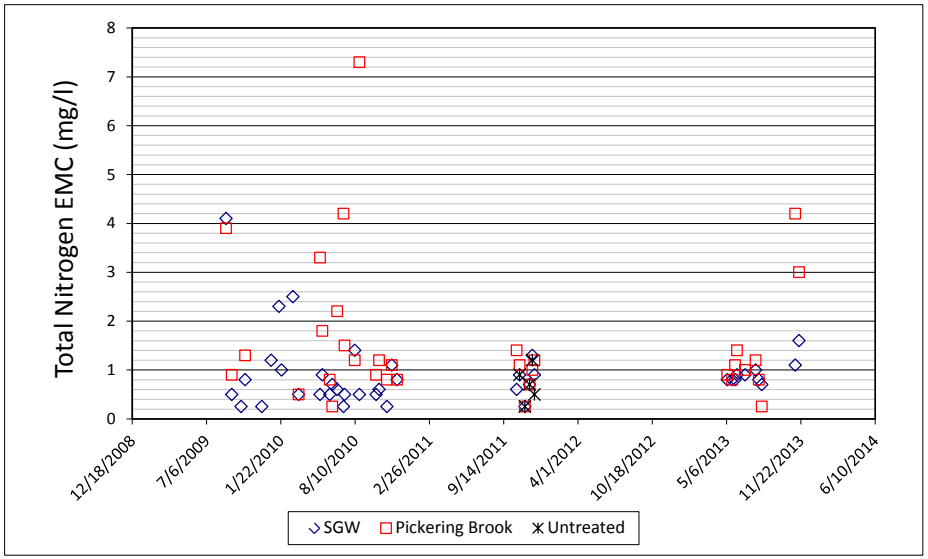


Figure 7: Influent, Effluent, and Receiving Water Contaminant Concentration Time Series Plots for the Range of Post-Construction Monitoring Data (cont).

Figure 8: Box & Whisker plot of Total Suspended Solids and Suspended Sediment Concentration

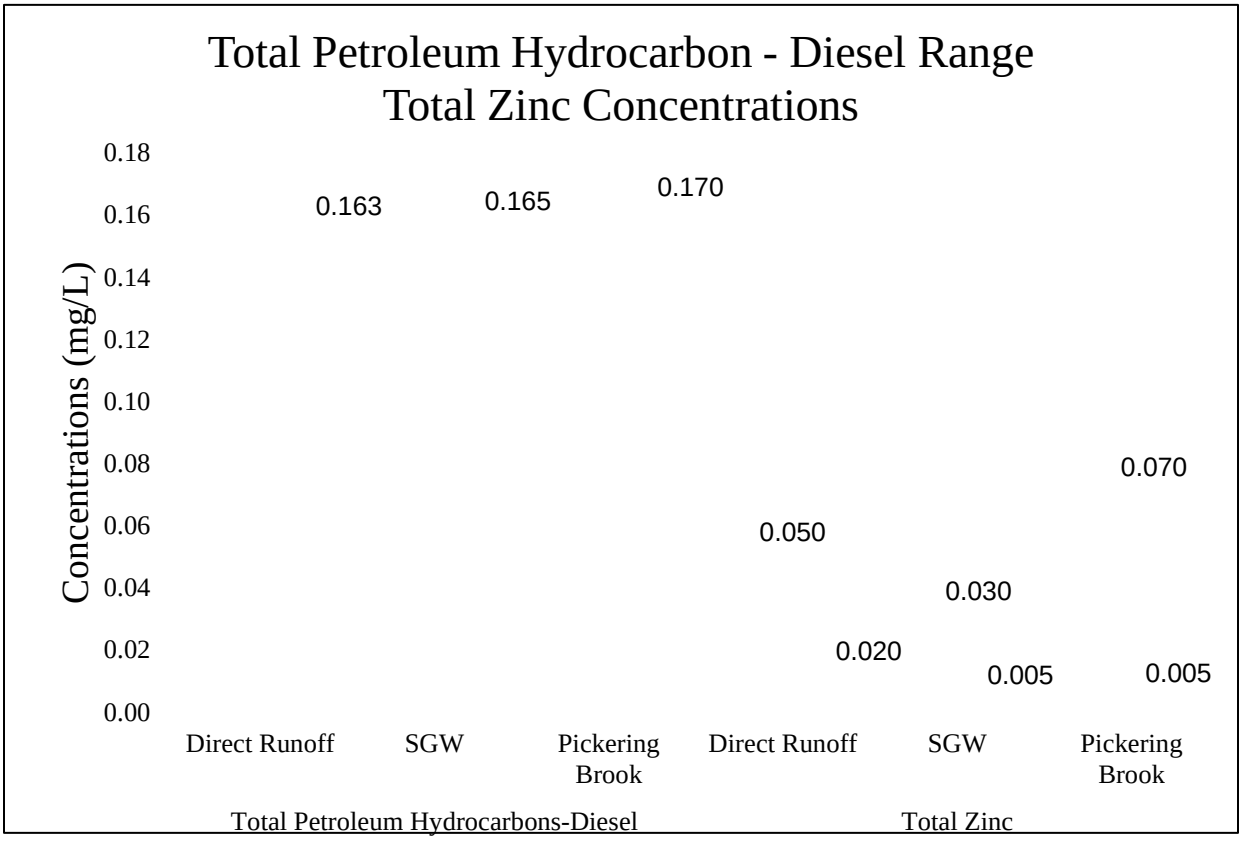


Figure 9: Box & Whisker plot of Total Petroleum Hydrocarbons-Diesel Range and Total Zinc. All TPH-D results were returned below detection limit from the lab, therefore values reported are half of the median detection limit.

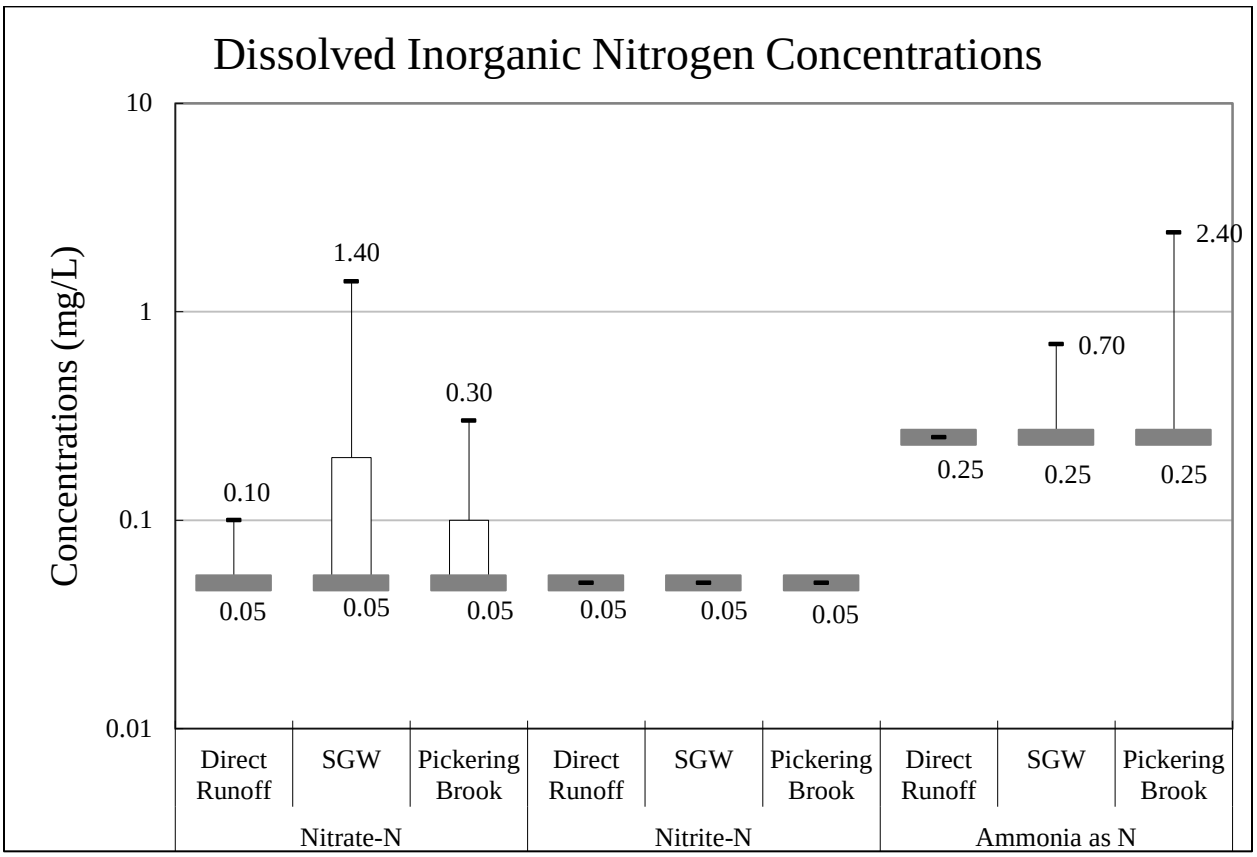


Figure 10: Box & Whisker plot of Dissolved Inorganic Nitrogen Concentrations.

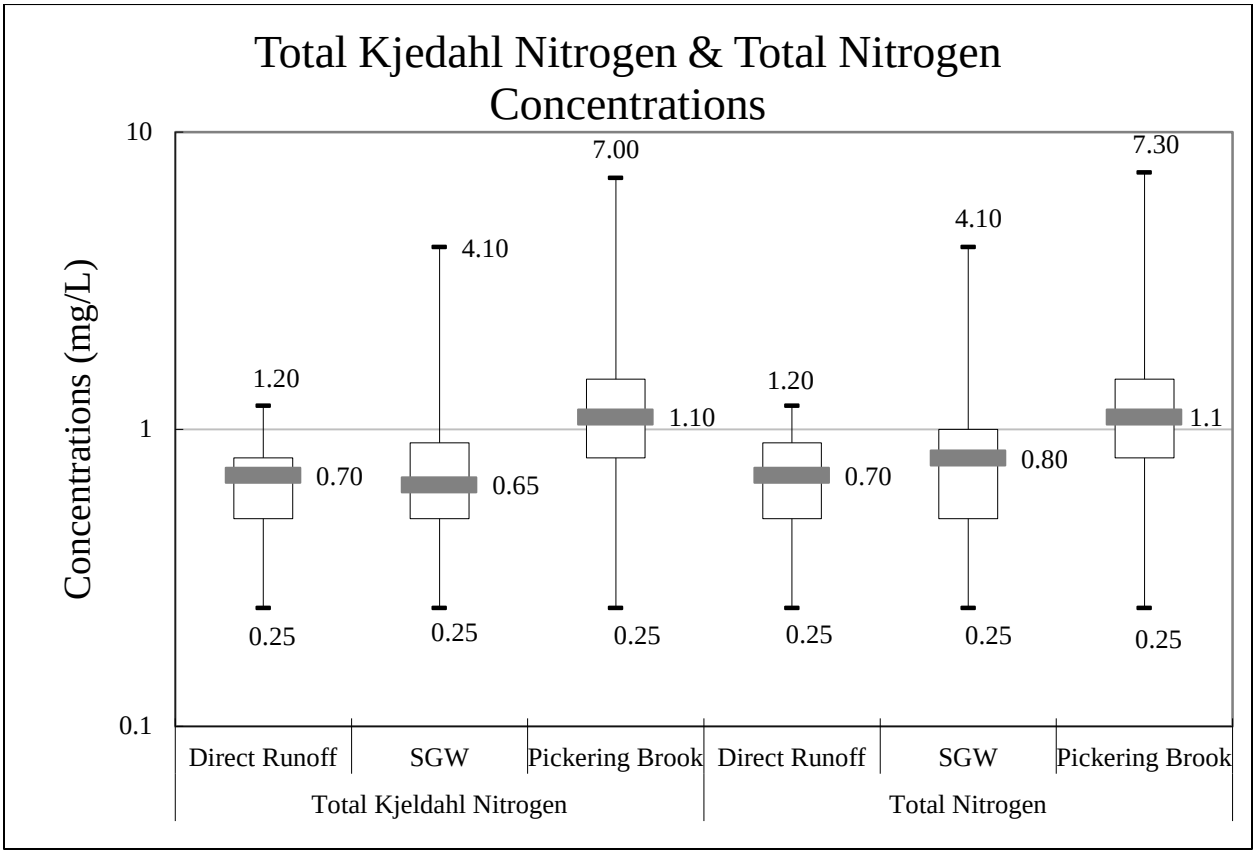


Figure 11: Box & Whisker plot of Total Kjedahl Nitrogen & Total Nitrogen Concentrations.

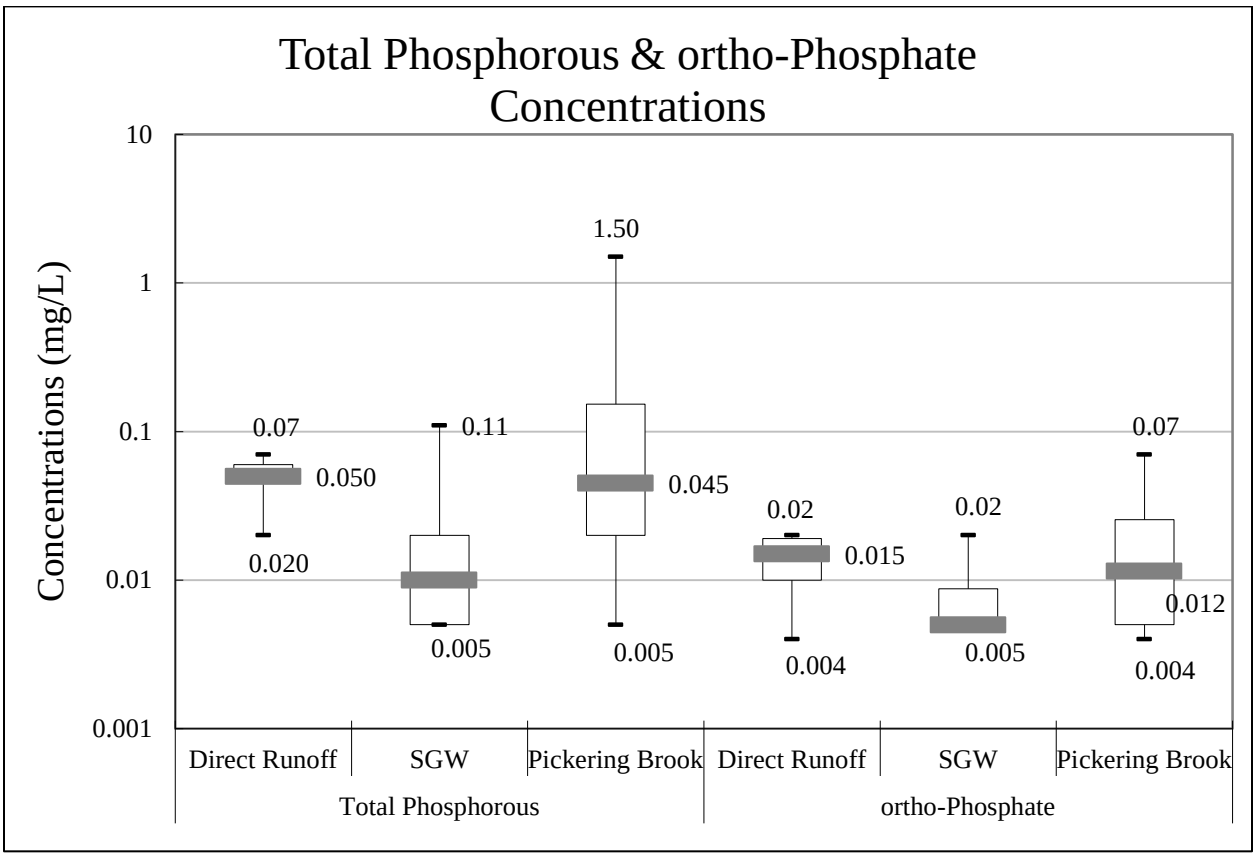


Figure 12: Box & Whisker plot of Total Phosphorous and ortho-Phosphate Concentrations.