Storm Water Management Complex
2012 Monitoring
Final Report

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Table of Contents

Executive Summary

Over the summer of 2012, a high resolution monitoring program was implemented to evaluate the overall efficiency of the newly constructed detention pond system to remove suspended solids and contaminants following precipitation events. Emphasis of the study was on assessing water quality, in particular the amounts of nonpoint source pollutants, and runoff dynamics within the storm water management area. A generally dry summer (3.11 inches of rain during the sampling period) and infrequent small rain events hampered the measurement of Total Suspended Sediments (TSS), contaminants, and water flow through the pond system. In general, average water quality parameters for the storm water management complex were within the ranges found for nearby rivers with a few notable exceptions. Most notably were the total suspended solids and turbidity values for Little Mac; which were significantly higher than values reported for nearby rivers. Based on 2012 measured events, average TSS for Little Mac ravine was roughly 18 times greater than average TSS values measured in the ponds (LM = 676.4 ppm; Ponds = 36.8 ppm)

Evaluation of results from 936 samples and 9 precipitation events indicates that, in general, the water quality in the system is good and the system is efficient at removing suspended solids and contaminants. Inflow to the SWMC during measured events ranged from 43-630 liters per second. Based on the amount of TSS measured, approximately 424 kilograms of suspended sediment entered the ponds during measured events. Barring major changes to the system and watershed, it will be decades before sediment filling would be an issue of concern for the ponds. The pond system is very effective at slowing and decreasing peak runoff during precipitation events. Many of the precipitation events were hydrologically undetectable beyond the second pond, and the time required to pass through all the ponds during 2012 was on the order of 5 days.

Nutrient levels (nitrate and phosphate) were elevated (pond event average was 0.4 ppm and 0.1 ppm for nitrate and phosphate, respectively) above background levels during precipitation events; however, there is no clear indication that fertilizer-derived nutrients are adversely affecting water quality. SWMC chlorine levels are also elevated likely due to de-icing practices and warrant further monitoring. Ponds S1, S2, and S3 had baseline water quality descriptions of “excellent”, while Little Mac and pond #4 had descriptions of “good.” Nearly every parameter for pond #4 showed irregularities when compared to the other ponds, which is of concern since this pond should be the healthiest in the system. The small pond, which flows into the last pond in the system (pond #4), from the nearby turf fields had very high pH, low bacterial counts, elevated ammonia concentrations, and is likely adversely affecting the effluent water quality in pond #4.

Introduction

Natural wetlands have been documented to play an important role in storing water (flood prevention), capturing sediments and contaminants, and providing habitats for wildlife (Bavor et al., 2001; Hammer and Bastian, 1989; Mitsch and Gosselink, 2000). Constructed wetlands and detention ponds have also been documented to provide many of the same benefits (Bavor et al., 2001; Birch et al., 2004). This is because when water enters a wetland system (natural or constructed) the velocity decreases, resulting in the removal of larger particles suspended in the water. In addition, wetland plants and sediments serve as filters which remove nutrients and contaminants from the water. This results in the water at the wetland outlet, which typically drains to another part of the watershed, having less sediment and contaminants than water at inlet.

Urbanization can profoundly alter infiltration, runoff, contaminant loading, and erosion within drainage basins (Jacobson, 2011; Sciera et al., 2009). Erosion of the beds and banks of stream channels, due to increased storm water, can increase Total Suspended Solids (TSS) and turbidity in receiving streams (Shammaa and Zhu, 2001). Constructed wetlands have been utilized in many locations to decrease sediment loads due to urbanization. Constructed wetlands have been shown to reduce TSS concentrations by as much as 92% (Abou-Elela and Hellal, 2012).

Construction of the Grand Valley State University (GVSU) Allendale, MI campus began in the 1960s. Since then, GVSU has installed over 48.6 hectares (120 acres) of impermeable surfaces (Womble and Wampler, 2006). As impermeable surface area increased; runoff, erosion, and other runoff-related problems occurred in the ravines immediately east of the campus. The emphasis has changed over the last several years toward an ultimate goal of reducing runoff into the ravines to pre-1960's levels by increasing detention and infiltration (FTCH, 2007; Wampler, 2009). In 2009, construction was started on a 44-acre storm water detention pond complex. The ponds were completed in the summer of 2011 GVSU with the diversion of the final 12.9 hectares (33 acres) of runoff from impermeable parking lots into the SWMC (Simonson et al., 2011).

The development of alternatives that support a sustainable approach for long-term management of storm water runoff on GVSU's Allendale campus has been at the forefront of management initiatives (FTCH, 2007). This is in large part due to problems associated with development of impervious building, roads, and parking areas. Problems related to development typically include: degradation of water quality, reduced groundwater recharge, stream channel instability, increased flooding, and degraded natural habitats. Both reversing and preventing future impacts to the natural environment related to development and campus activities is the basis for the implementation of alternative storm water management practices on the GVSU campus. Because the drainage patterns on campus are connected to the Lower Grand River Watershed, which discharges to Lake Michigan, any changes in water quality or runoff patterns have an impact far beyond the campus. Primary issues and concerns in the Lower Grand River Watershed include: nutrient-loading, increased turbidity and increased total suspended solids, all of which contribute to reduced water quality within the system (FTCH, 2004). The major source of nutrients and contaminants in runoff water on the GVSU campus is the application of fertilizer, deicing compounds, fluids leaked from parked cars, and orthophosphate added to irrigation water at the Grand Rapids water filtration plant to maintain compliance with the EPA Lead and Copper Rule (EPA. Control of Lead and Copper." Code of Federal Regulations, 40 C.F.R. 141.86). The major sources of sediments include parking lot accumulations derived from tires and cars, stream bank erosion, hill slope erosion, and construction activity. To minimize impacts to the campus system and the larger watershed, efforts have been put into place to restore drainage of storm water on the campus to historic, predevelopment patterns. A significant step in accomplishing this goal was the design and implementation of the constructed storm water management area.   The detention pond complex consists of two constructed wetland complexes west of the Laker Village Apartments (Figure 1) – one completed summer 2009, the other summer 2011 (Simonson et al., 2011).

Figure 1. Sampling and monitoring locations in the Pierce Street Storm Water Management Complex.

This study was designed to evaluate TSS and contaminant removal efficiency of the newly constructed storm water management area located along Pierce Street on the southern portion of Grand Valley State University's (GVSU) Allendale Campus. Emphasis was on assessing water quality, in particular the amounts of nonpoint source pollutants, and runoff dynamics within the storm water management area. The condition of the waterways from which the water is being diverted, as well as effects on the larger, natural watershed, were also evaluated.

Methods

Sampling Protocol

During the summer of 2012, water flow and water levels were recorded at 6 locations (FM1-FM6) and water samples were collected from 5 sites (S1-S4 and LM). Four of these sites were in the GVSU wetland complex and the other site was in Little Mac Ravine at the same location as previous work in 2011 (Simonson et al., 2011) (Figure 1; Figure 2).

Figure 2. Little Mac Ravine sampling and monitoring location. Colored area is the area of parking lots diverted into the pond complex show in brown.

Water flow and water level data were collected at storm water control structures located at the entry of pond #1 and the exit of ponds 2-4 using Odyssey water level data loggers. These loggers automatically correct for atmospheric pressure changes and record water temperature as well. All water samples were collected using ISCO 6712 automated samplers (see Figure 3) set to collect 500 ml samples at roughly 5 minute intervals during precipitation events.

Figure 3. Wetland Sample Site S1 (pond #1). The Isco sampler is in the blue barrel and the rain gage trigger is on the post.

Automated sampling was triggered either by a rain gage sensor, a change in water level, or manually. Water samples were collected during an extended period with no precipitation in late June and early July, to establish baseline parameters, and during nine precipitation events between July 13th and August 10th (Table 1).

Table 1. Summer 2012 Precipitation Events Sampled

#	Event Date	Approx. Trigger Time	Precipitation (in)
1	7/13/2012	1:59 pm	0.11
2	7/19/2012	1:50 am	0.13
3	7/19/2012	2:10 pm	0.50
4	7/26/2012	5:03 am	0.28
5	7/27/2012	3:10 pm	1.00
6	7/31/2012	2:11 am (S4, 10:11 am)	0.44
7	8/9/2012	8:24 pm	0.11
8	8/10/2012	3:53 am	0.44
9	8/10/2012	8:59 am	0.10
	Total		**3.11**

All water samples were collected in 500 ml bottles and transferred to plastic bottles or sealed bags, preserved and stored for later laboratory analyses. A total of over 936 water samples were collected and analyzed for a full suite of water quality parameters (Table 2). Precipitation amounts were also documented for each sample location and sampling event. Throughout the duration of the study the only physical intervention to the SWMC made during the sampling interval was the adjustment of pond levels in ponds 2, 3, and 4 at the control structures by Fishbeck, Thompson, Carr and Huber (FTCH). This adjustment was made August 7, 2012 at 4:30 pm, in an effort to better distribute flow and water level between the ponds.

Table 2. Summary of Analyses Performed and Samples Collected.

Parameter	Number of Analyses
Total Samples Collected	936
Suspended Solids (mg/L)	841 (90%)
Turbidity (NTU)	936 (100%)
Specific Conductivity (mS)	936 (100%)
Total Dissolved Solids (mg/L)	936 (100%)
pH	934 (99%)
Total Phosphate (mg/L)	311 (33%)
Orthophosphate (mg/L)	271 (29%)
Nitrate (mg/L)	239 (26%)
Sulfate (mg/L)	230 (25%)
Chloride (mg/L)	230 (25%)

Laboratory Analysis

Samples were analyzed for total suspended solids (TSS), turbidity, specific conductivity, total dissolved solids (TDS), and pH. In addition, chemical analyses for nutrients and salts (total phosphate, orthophosphate, nitrate, sulfate, and chloride) were done on a subset of the water samples for each precipitation event. Samples were obtained from the ISCO sampler immediately following the completion of a triggered sampling event. Once in the lab, they were subdivided for determination of the different analytes and preserved and stored following standard protocols. Because pH is sensitive to changes in temperature and environmental conditions, it was determined immediately upon arrival in the laboratory. For total phosphate and orthophosphate samples, 100 ml of sample water was poured into a clean (acid washed) 100 ml bottle and refrigerated at 4^{o}C until analysis. For nitrate samples, 25-

30 ml of sample water was vacuum filtered through a pre-rinsed 0.45 µm filter into a clean (acid washed) 25 ml scintillation vial and stored in the freezer. All remaining water was retained in a Whirlpack plastic bag or a clean 250 ml Nalgene bottle for later analysis of TSS, turbidity, specific conductivity, TDS, and salinity.

TSS was measured using a modified EPA method ESS 340.2 that is commonly used at wastewater treatment plants (EPA, 1993). This method involved using fiberglass filters, crucibles, and a vacuum to quantify sediment in water samples. Turbidity, specific conductivity, TDS, pH and salinity were measured using handheld water quality meters. Total phosphate and orthosphosphate were determined colorimetrically with a spectrophotometer (Spectronic 20D+, Thermo Fisher Scientific) following a commonly used EPA method (ESS 365.3) for specified forms of phosphorus in drinking, surface and saline waters, domestic and industrial wastes (EPA, 1978). Samples for nitrate, sulfate, and chloride were determined using ion chromatography by Annis Water Research Institute (AWRI).

Sediment Yield Determination

TSS data for all sampled storm events in the wetland complex were combined to create a rating curve which relates wetland pond #1 inflow (in liters) to TSS concentration. Determination of the relationship between flow and TSS concentration in the other ponds was not possible due to: 1) lack of good hydrologic data due to equipment malfunction; 2) lack of large rain events which propagated through the ponds; 3) problematic data from pond #4 due to direct runoff from turf fields and unvegetated areas which resulted in anomalously high TSS in pond #4; and 4) generally low TSS values in pond #2 and pond #3 which were near detection limits for the analysis method.

Sediment yield in Little Mac was more straight forward because a discharge rating curve was available from previous research (Simonson et al., 2011). Data from storm events in 2011 and 2012 were used to calculate the total suspended sediment load for the Little Mac at the same location. Discharge was estimated using water level, channel slope, and the Manning equation (Manning et al., 1890; Simonson et al., 2011). The same rating curve for relating water level to discharge was used for both 2011 and 2012 data. The discharge for discrete TSS samples was taken from the discharge rating curve and used to construct sediment rating curves for 2011 and 2012. The total sediment load for Little Mac was then determined by using the sediment rating curve and the continuous (one minute interval) water level data.

Water Level Measurement

Water levels were measured using two methods: 1) Odyssey water level data loggers installed in Storm Drain Catch Basins and flow control structures between ponds; and 2) a water level sensor attached to the ISCO 6712 auto sampler. The Odyssey recorders recorded water level and water temperature data every 5-minutes (wetland ponds) and required data to be downloaded manually. The ISCO water level module recorded data at 1-minute intervals and data was stored with sample collection data.

Results and Discussion

Hydrologic Parameters

Input hydrology (water flow) was measured from June 15, 2012 to October 4, 2012 using a water level and temperature data recorder located near the inlet pipe to the fore bay (S1; FM3) (Figure 3). The water level in the pond rose in response to precipitation events (Figure 4). Pond temperature generally decreased during times without input from precipitation. This reduction in temperature was interpreted as input of colder irrigation water during dry periods.

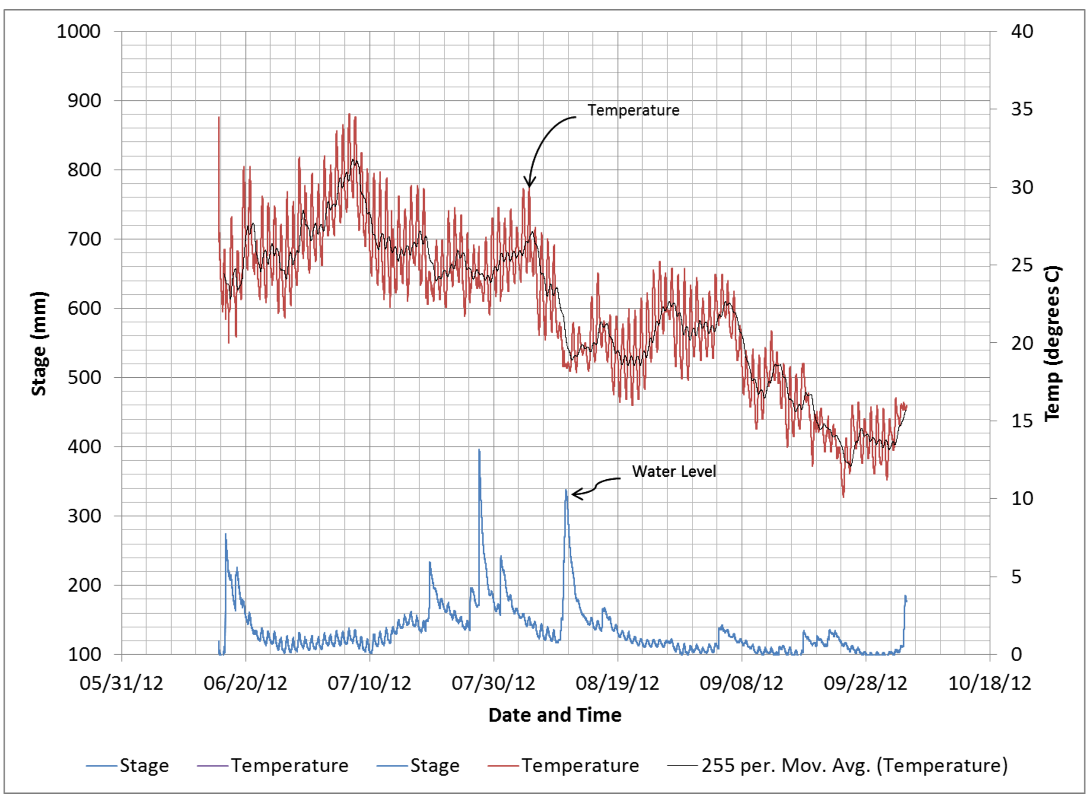

Figure 4. Hydrograph and Thermograph for pond #1 near the inlet to the wetland complex for 2012.

The increase in pond height was used to estimate the amount of storm water entering and exiting the pond system. The volume of water entering the pond system ranged from 43 to 630 liters per second for the events studied. A hydrologic budget and sediment yields were calculated based on the individual event flow into pond #1 due to precipitation events (Table 3).

Table 3. Summary of water inflow from pond #1 water level data.

Date	Time to Peak (seconds)	Rain (in)	Pond inflow Volume[1] (Gallons)	Pond inflow Volume (liters)	Inflow Rate (L/s)	Avg TSS (mg/L)	Total Sediment Input (Kg)[2]
7/13/2012	ND	0.11	122,899	465,223	ND	49	22.8
7/19/2012	4800	0.63	406,233	1,537,758	320	80[3]	123.0
7/26/2012	7200	0.28	293,020	1,109,202	154	23	25.5
7/27/2012	5400	1.00	898,131	3,399,797	630	48	163.2
7/31/2012	6600	0.44	432,265	1,636,303	248	23	37.6
8/9/2012	14400	0.11	162,251	614,186	43	5	3.1
8/10/2012	43200	0.54	719,837	2,724,880	63	18	49.0
Totals	N/A	3.11	3,034,636	11,487,349	N/A	N/A	424.3

[1] *Estimated volumes based on changes in pond height after rain events*
[2] *Estimated based on average event TSS for the input storm water into pond #*
[3] *Weighted average for two events*

Lag time for peak runoff through the pond system increased several orders of magnitude over Little Mac Ravine lag times. Lag times between the arrival of peak runoff at pond #1 and pond #2 in late July varied from 30-39 hours (Figure 5). At the sample site in Little Mac ravine, lag time between peak rainfall and peak runoff is approximately 30-45 minutes. The detention time of all four of the ponds was difficult to quantify due to: 1) the large lag time between ponds, 2) the attenuation of flows, 3) the small magnitude of 2012 precipitation events; and 4) direct runoff into pond #4 from the turf fields. Assuming the lag time for ponds 2-4 is comparable to the lag time measured between pond #1 and pond #2, the estimated detention for all ponds is approximately 5 days. However, the duration of detention would depend on: 1) antecedent pond water levels and soil moisture; and 2) rainfall amount and intensity.

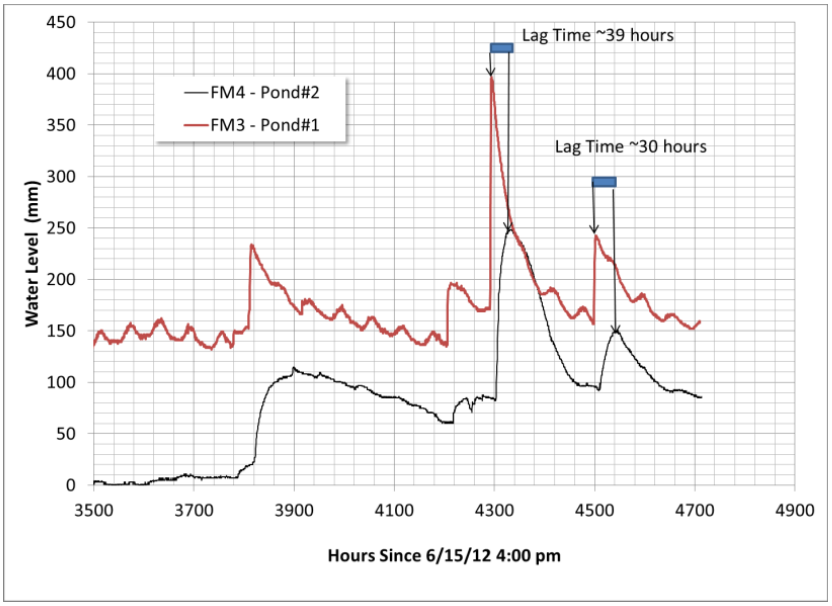

Figure 5. Lag times for July 27, 2012 and July 31, 2012 precipitation events as measured by water level gages in pond #1 and pond #2.

Water Quality Parameters

The ISCO samplers were manually triggered to collect water samples every hour for 24 hours on two occasions (June 25, 2012 and July 11, 2012) during extended periods with no precipitation to establish baseline values for each of the 5 sample locations (Little Mac and ponds 1-4). In addition, the ISCO samplers were triggered by precipitation events of greater than a tenth of an inch per hour on 9 occasions between July 13, 2012 and August 10, 2012 (Table 1). Samples collected during baseline and precipitation events were analyzed for total suspended solids (TSS), turbidity, specific conductivity, total dissolved solids (TDS), and pH. In addition, chemical analyses for nutrients and salts (total phosphate, orthophosphate, nitrate, sulfate, and chloride) were done on a subset of the water samples from each sampling event. Using averages for the baseline and event parameters, each sample location was scored using a water quality index calculator (Table 4 and Table 5) (Oram, 2013). Ponds S1, S2, and S3 had baseline water quality descriptions of “excellent”, while Little Mac and pond 4 had baseline water quality descriptions of “good.” Evaluating each sample location using average event parameters, resulted in the water quality index number being lowered for each sample location; ponds S1, S2, S3, and S4 had water quality descriptions of “good” and Little Mac had a water quality description of “medium”.

Table 4. Water Quality Index Values and Descriptions Based on Average Baseline and Event Sample Parameters.				
Site	**Baseline Samples**		**Event Samples**	
	Water Quality Index	**Water Quality Description**	**Water Quality Index**	**Water Quality Description**
LM	89	Good	63	Medium
S1	91	Excellent	86	Good
S2	95	Excellent	87	Good
S3	91	Excellent	88	Good
S4	84	Good	72	Good

Table 5. Water Quality Index Legend[1].	
Range	**Quality**
90-100	Excellent
70-90	Good
50-70	Medium
25-50	Bad
0-25	Very Bad

[1] *(Oram, 2013)*

Average values for each baseline parameter were similar between all sample locations (Table 6) with a couple of exceptions; Little Mac and S1 had comparatively higher total suspended solids during baseline conditions than the other locations and S4 had significantly higher baseline turbidity then other locations. All baseline values were within acceptable water quality limits. All of the ponds exhibited some slight variability in baseline parameters (Figure 6) over the course of the 24 hour baseline sampling events. This is attributed to both natural changes in the system (ex. daily fluctuations in temperature and evaporation), and to daily campus activities (ex. runoff following irrigation on campus grounds). Ponds 2 and 3 (S2 and S3) had the least amount of variability in all parameters over the 24 hour baseline sampling period, indicating they are, under normal conditions, the most stable of the ponds (Figure 6). Ponds 1 and 4 (S1 and S4) and to some extent Little Mac (LM) exhibited the greatest amount of variability over the 24 hour sampling period (Figure 6). In general, S4 and LM had the highest baseline turbidity values and were on average about an order of magnitude higher than values determined for S1, S2, and S3. S4 and LM turbidity baseline turbidity values also exhibited more variability over the course of the 24 hour sampling events then the others, which were relatively constant.

Table 6. Average Water Quality Parameters for Baseline Samples for Each Sample Location.						
Water Quality Parameters	**LM**	**S1**	**S2**	**S3**	**S4**	**Average for All Ponds[1]**
Suspended Solids (mg/L)	15.0	26.7	ND	3.3	3.3	11.1
Turbidity (NTU)	13.3	6.3	3.2	7.0	42.6	14.8
Specific Conductivity (mS)	1163.3	1039.3	1113.8	1196.3	1009.4	1089.7
Total Dissolved Solids (mg/L)	581.3	529.8	556.8	598.8	503.1	547.1
pH	7.6	7.7	7.6	7.8	7.7	7.7
Total Phosphate (mg/L)	0.0	0.0	0.0	0.1	0.1	0.1
Orthophosphate (mg/L)	0.1	0.2	0.0	0.1	0.2	0.1
Nitrate (mg/L)	0.6	2.0	0.6	0.6	0.4	0.9
Sulfate (mg/L)	42.0	59.3	54.0	52.0	53.5	54.7

[1]*Does not include Little Mac Ravine data*.

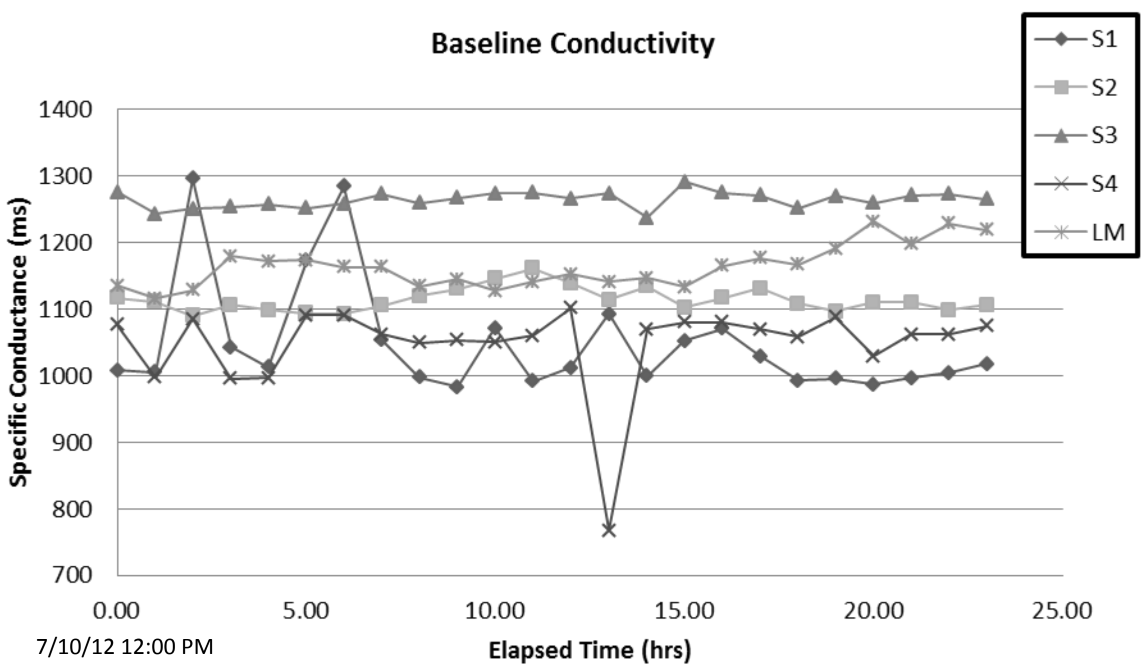

Figure 6. Baseline conductivity for all sites on July 11, 2012 dataset as an example of variability differences between sample locations.

Some other interesting trends can be seen in evaluating the baseline data. For example, in examining conductivity and total dissolved solids, ponds 2 and 3 are higher in both then ponds 1 and 4. This difference in dissolved components is likely due to evaporation, and thus concentration, of dissolved species in ponds 2 and 3. This concentrating effect isn't as evident in ponds 1 and 4 because they are regularly diluted with runoff water from irrigation, thus masking the effects of evaporation. In addition, noticeable increases in concentrations of orthophosphate, total phosphate, nitrate and sulfate all occur at the same time (from around 2pm to 6pm) in pond 1 (S1). This is coincident with increases in pH, total dissolved solids, conductivity, and suspended solids in pond 1; suggesting that the change in baseline conditions is due to irrigation on campus during that time. Further, the presence of nutrients (phosphate and nitrate) is likely being introduced from fertilizers and as residual orthophosphate from irrigation on campus. The amount of residual orthophosphate introduced from this source is not known, however the Grand Rapids introduces approximately 1.8 ppm (mg/L) at the filtration plant to remain in compliance with the EPA Lead and Copper rule (John Allen, personal communication). The presence of sulfate may also be coming from fertilizers used on campus or possibly from the dissolution of gypsum or other sulfur-bearing minerals in sediments.

Results from precipitation events showed more variability in parameters due to the introduction of runoff water (Table 7). In general, Little Mac and pond 1 (S1) showed dilution effects during and immediately following precipitation events with all parameters on average decreasing concentration with the exception of turbidity and TSS, which increased in concentration. The other ponds (S2 and S3) didn't demonstrate as much variability in parameters during events, with the exception of pond 4 which had significant increases in turbidity, total suspended solids and pH.

Table 7. Average water quality parameters for the 9 precipitation events for each sample location.						
Water Quality Parameters	**LM**	**S1**	**S2**	**S3**	**S4**	**Average for All Ponds[1]**
Suspended Solids (mg/L)	676.4	36.0	20.3	10.8	80.0	36.8
Turbidity (NTU)	480.8	23.4	24.9	13.8	143.9	51.5
Specific Conductivity (mS)	352.6	261.5	996.1	1216.7	739.8	803.5
Total Dissolved Solids (mg/L)	176.2	130.8	498.0	609.0	369.6	401.9
pH	7.3	7.2	7.6	7.6	8.1	7.6
Total Phosphate (mg/L)	0.4	0.2	0.1	0.3	0.3	0.2
Orthophosphate (mg/L)	0.0	0.2	0.0	0.1	0.0	0.1
Nitrate (mg/L)	0.5	0.6	0.3	0.5	0.4	0.4
Sulfate (mg/L)	15.8	17.7	45.3	54.3	54.9	43.0
Chloride (mg/L)	30.3	20.0	163.6	231.4	124.4	134.8

[1]*Does not include Little Mac Ravine data*.

The highest orthophosphate concentrations observed over the course of the summer sampling events were during event 1 (7/13/12) in pond 1 with concentrations around 1 ppm. Since this was the first significant rain event of the season, it is assumed these higher than average concentrations were due to a flushing out of the system. The highest total phosphate concentrations were observed during event 2 in pond 3 (which is the first time pond 3 was sampled during an event). Concentrations during this event ranged from 1.2 to 2.9 ppm total phosphate and were over an order of magnitude higher than concentrations observed in any other event. Total phosphate is phosphate that is stored in sediments so these higher concentrations in pond 3 indicate a store of phosphate in the sediments that might have been released as a result of physical perturbations to the sediments or chemical transformations by water chemistry changes during subsequent events. It is also possible that if a significant avian population (especially geese) inhabits the ponds, their waste may be contributing to phosphates in the system. The EPA water quality criteria state that phosphates should not exceed 0.05 ppm if water discharges into lakes or reservoirs, 0.025 ppm within a lake or reservoir, and 0.1 ppm in streams or flowing waters not discharging into lakes or reservoirs to control algal growth (USEPA, 2013). Surface waters that are maintained at 0.01 to 0.03 ppm of total phosphorus tend to remain uncontaminated by algal blooms. Approximately 74.4% of the samples analyzed during this study (Table 8) had concentrations of phosphate above what is recommended to control algal growth (0.1 ppm).

Generally, concentrations of nitrate were highest in ponds 1 and 4. However, nitrate was measured in all ponds at concentrations of greater than 0.5 ppm at some point over the summer. The highest concentrations of nitrate observed were in pond 1 during event 1 and event 2 with concentrations reaching 2.0 and 1.5 ppm, respectively. Pond 4 also had higher than average concentrations of nitrate (~1.1 ppm) during event 6. No limits currently exist for nitrate concentrations in surface waters so nitrate concentrations were evaluated in comparison with drinking water nitrate limits (10 ppm maximum). Nitrate concentrations were well below this standard (Table 8). However, nitrogen will contribute to undesirable algae growth, especially in the presence of phosphate, so it should be monitored.

The source of nitrate to the system is somewhat unclear. This is because nitrate can be introduced from several sources; including, the atmosphere via natural chemical reactions or from the combustion of fossil fuels (ex. coal and gasoline), or it can be formed in water bodies through the oxidation of other forms of nitrogen, including nitrite, ammonia, and organic nitrogen compounds such as amino acids. Nitrate may also be introduced by waste products from avian populations (especially geese) inhabiting the ponds. In urban or agricultural areas, nitrate can also get into water directly as the result of runoff of fertilizers containing nitrate, or other forms of nitrogen. Given the recent bans on phosphate-based fertilizers, it is also possible the campus and surrounding areas are using nitrate/nitrogen-based fertilizers as a replacement. At GVSU, on some occasions (amount or frequency of use is unknown), the natural turf areas south of the soccer fields, and in and around LAX (including Throws), receive Milorganite fertilizer. The Milorganite is an organic nitrogen fertilizer that contains 6% total nitrogen, as a well as 2% phosphate, iron chloride, and iron sulfate. As such, it is possible that the application of fertilizer may be contributing to the nitrate and phosphate concentrations, as well as chloride and sulfate concentrations, in the system.

Table 8. Summary of Nutrient Concentrations above Recommended limits.

Nutrient	# samples analyzed during events	# of samples above recommended concentration limits	% of samples above recommended concentration limits
Total Phosphate	277	206	74.4%[1]
Nitrate	214	179	83.6%[2]
Nitrate (drinking water)	214	0	0%[3]

[1]*Based on recommended limit (0.1 ppm) to minimize algal growth*
[2]*Based on recommended limit (0.1 ppm) to minimize algal growth*
[3]*Based on EPA drinking water limit (10 ppm)*

Based on geochemical data, several conclusions can be made. As expected, samples from the Little Mac ravine, during precipitation events, had much higher TSS, turbidity, and total dissolved solids then the ponds. What was not expected was the discovery that the pond 4 physical and chemical parameters indicate that it is not working as was intended. Nearly every parameter for pond 4 showed discrepancies/irregularities when compared to the other ponds, which is especially concerning since this pond should be the healthiest in the system. Most notably are the high turbidity and exceptionally high pH values observed in pond 4. pH regularly was over 8.5 in pond 4 and, during one event, the pH was over 10 during the entire sampling period. pH's of this magnitude are not normal in surface water systems and are indicative that pond 4 is not healthy.   Follow up studies have indicated several factors might be at play; including, erosion of the unstable/un-vegetated hillside adjacent to the pond as well as the diversion of runoff from the adjacent turf field pond being introduced into pond 4. Analyses conducted on water from the turf field pond during the Fall of 2012 indicate that pH, nitrate, and ammonia are quite high.   This suggests that the drainage of the turf field pond into pond 4 is playing a significant role in its water quality. In conclusion, runoff, fertilization and irrigation of campus grounds, and possibly avian inhabitants, are currently the largest contributors to water quality conditions in the stormwater management system.

Comparison of Results to Nearby Rivers

Averages values for Little Mac, baseline pond values, and event pond values were compared with ranges of data reported for rivers in Western Michigan (Table 9).   In general averages were within the ranges found for nearby rivers with a few notable exceptions. Most notably were the total suspended solids and turbidity values for Little Mac; which were significantly higher than values reported for nearby rivers. Total phosphate was also higher in Little Mac than typical ranges. Total dissolved solids and conductivity values higher than nearby waterways was likely due to lack of flow and evaporation in the ponds. Chloride levels were elevated above nearby rivers in both baseline and event samples, likely as a result of de-icing compounds used on parking lots. Continuous monitoring of conductivity in Pond#1 would allow more definitive analysis of the impact of de-icing compounds on the SWMC.

Table 9. Comparison of Sample Averages to Ranges Found in Western Michigan Rivers				
Water Quality Parameters	**Average for LM**	**Baseline Average for All Ponds**	**Event Average for All Ponds**	**Range of Typical Values[1]**
Suspended Solids (ppm)	676.4	11.1	36.8	0-70
Turbidity (NTU)	480.8	14.8	51.5	0-45
Specific Conductivity (mS)	352.6	1089.7	803.5	Data not available
Total Dissolved Solids (ppm)	176.2	547.1	401.9	175-500
pH	7.3	7.7	7.6	Data not available
Total Phosphate (ppm)	0.4	0.1	0.2	0-0.25
Orthophosphate (ppm)	0.0	0.1	0.1	Data not available
Nitrate (ppm)	0.5	0.9	0.4	0-5.5
Sulfate (ppm)	15.8	54.7	43	Data not available
Chloride (ppm)	30.3	193	148	0-75

1 (MDEQ, 2013)

Bacterial Contamination

Bacterial sampling of the SWMC was performed on three dates in October 2012 to evaluate the amount of *Escherichia coli (E. coli)* and coliform bacteria in the water (Table 10). Both *E. coli* and coliform are strong indicators of recent sewage or animal waste contamination. Results show evidence that the ponds have significant bacterial loading, especially after rain events. This is likely due to the heavy avian use of the ponds and pond banks. The lack of vegetation near the pond margins may be contributing to elevated levels after rain events as feces are easily washed into the ponds from unvegetated areas. This source of bacteria may be attenuated over time as vegetation becomes established along the pond banks. Continued monitoring and evaluation of bacterial loading is recommended.

Table 10. *E. coli* colonies per 100 ml sample[1].			
Sample Site	**10/4/2012**	**10/11/2012**	**10/18/2012**
Pond 1	113.4	9.8	26.5
Pond 2	142.1	275.5	816.4
Pond 3	272.3	686.7	51.2
Pond 4	2419.6	224.7	1732.9

[1]The Michigan maximum value for body contact is 129.

Overall wetland efficiency

The efficiency of the detention pond complex was evaluated using the measured water quality data for 6 events as measured in pond #1 and pond #3. Pond #4 was not used as the detention pond outlet for overall efficiency calculations due to the previously discussed problems with direct runoff from the turf fields. Efficiency for TSS removal ranged from 37.9% to 94.7% with an average efficiency of 67.5% (Table 11). The average efficiency is skewed toward lower values since the input of TSS to the detention pond system is quite low relative to typical stream runoff (for example Little Mac Ravine). Removal efficiency for chemical components and ions in solution generally have very low or negative efficiencies. This is likely due to evaporation as the water moves through the pond system. This effect was likely more pronounced during 2012 due to the low amounts of precipitation.

Table 11. Event Efficiencies for Total Suspended Solids and Contaminant Removal							
	Event 2[1] (7-19-12)	Event 3 (7-19-12)	Event 4 (7-26-12)	Event 5 (7-27-12)	Event 6 (7-31-12)	Event 9 (8-10-12)	Average Efficiency
Suspendid Solids (mg/L)	81.3%	94.7%	50.0%	37.9%	50.0%	90.9%	67.5%
Turbidity (NTU)	81.9%	76.0%	77.2%	30.8%	-32.4%	30.7%	44.0%
Specific Conductivity (mS)	-394.3%	-584.5%	-468.7%	-460.8%	-349.5%	-533.5%	-465.2%
pH	-8.6%	-7.0%	-5.5%	-0.6%	-0.4%	0.6%	-3.6%
TDS (mg/L)	-396.6%	-588.4%	-468.8%	-449.8%	-350.1%	-535.4%	-464.9%
Orthophosphate (mg/L)	100.0%	N/A	N/A	70.1%	100.0%	93.7%	-91.0%
Total Phosphate (mg/L)	-434.8%	73.9%	70.8%	49.0%	-17.6%	36.2%	-37.1%
Chloride (mg/L)	-990.1%	N/A	N/A	-2582.4%	-1877.8%	N/A	-1816.7%
Sulfate(mg/L)	-151.0%	N/A	N/A	-399.0%	-438.8%	N/A	-329.6%
Nitrate (mg/L)	25.6%	N/A	N/A	43.7%	99.3%	N/A	56.2%
[1]*Events 1, 7, and 8 didn't have enough data to calculate efficiencies.*							

Recommendations and Management Implications

Based on the data collected we recommend the following action items related to monitoring, configuration, and maintenance of the Pierce Street SWMC:

1. In order to evaluate the variations and nitrate loading due to fertilizers it will be necessary to sample at least three precipitation events at the inlet of the pond system, ideally one at the beginning of the summer, one midway through the summer, and one at the end of the summer. In order to thoroughly evaluate nutrient dynamics, samples should be taken and analyzed at 5 minutes during these events.
2. Pond #4 remains problematic in terms of the direct runoff that this pond receives from the turf fields. Pond #4 should be isolated from this runoff source so that it can function as part of the pond system. This could be accomplished by diverting runoff from turf fields to a smaller ancillary pond system before discharge into the wetland system below pond #4.
3. The amount of sediment entering the pond system, measured in 2012, is not significant and unless sedimentation patterns are much higher than in 2012 it will be many decades before there is a measureable filling of pond #1 due to suspended sediment.
4. Continued refinement of pond levels in response to revegetation success is needed to provide the correct hydrology for wetland species which are part of the revegatation plan.

5. Further sampling and analysis of the impact of residual orthophosphate in irrigation water due to compliance with the EPA Lead and Copper rule is needed. This could be accomplished by sampling and analyzing several irrigation points to determine residual orthophosphate levels. Combined with irrigation volumes and residual levels in pond#1 inflow a phosphate budget could be developed.
6. Chlorine levels are clearly elevated and further monitoring of the effects of de-icing compounds is warranted. This could be accomplished by retasking the continuous water quality equipment currently installed at Calder Arts Center. This would require some additional infrastructure at pond#1 including 110 power and Ethernet connectivity.
7. Additional bacterial analysis, evaluation of ammonia cycling in ponds, continued TSS sampling during spring snow melt and runoff, and analysis of a full suite of chemicals in the small turf runoff pond near pond #4.

While nutrient levels were elevated above baseline levels during precipitation events, there is no clear indication that fertilizer-derived nutrients are adversely affecting water quality in the SWMC. The small pond which flows into pond #4 from the nearby turf fields has very high pH, low bacterial counts, elevated ammonia concentrations, and is adversely affecting the effluent water quality in pond #4. It is recommended that additional chemical analysis of this influent to pond #4 be conducted. If adverse impacts to water quality continue, it may become necessary to divert or treat this water prior to incorporating this water into the pond system.

Previous discussions with facilities indicated a concern that the ponds will fill with sediment being delivered with runoff water. Based on data from the 2012 sampling, sediment filling of the ponds due to the introduction of total suspended solids (TSS) during precipitation events does not appear to be an issue. Calculations using 2012 TSS values, indicate that it would take 100's of years for appreciable (> 1 ft) of sediment to accumulate in pond #1. It is likely that spring runoff into the ponds will contain more TSS due to debris and sediment carried onto parking lots by vehicles. This could result in significantly higher sedimentation rates in the spring. Accumulation of organic matter from dead vegetation will also contribute to higher sedimentation rates. Therefore, sediment sampling in spring is recommended to further quantify the overall sedimentation rates for a complete seasonal cycle.

Over the course of the summer 2012 sampling period, it was noted that vegetation growth was limited in some areas and that vegetation growth was related to water levels in the ponds. In order to best facilitate growth of vegetation flow adjustments to the ponds were made mid-summer, which improved pond flow and will ideally help stabilize vegetation. It is recommended that pond levels are checked periodically to ensure that they remain optimal for vegetation growth.

Further Analysis and Future Work

In order to better understand the 2012 nutrient and sediment data it is recommended that monitoring be continued and perhaps expanded to include the older ponds in the system. The frequency of sampling could be reduced.

A detailed evaluation of runoff and erosion in Little Mac ravine is ongoing and will be provided once the analysis is complete. Additional Little Mac samples would improve our understanding of the response of Little Mac to the diversion of storm water which occurred in 2011.

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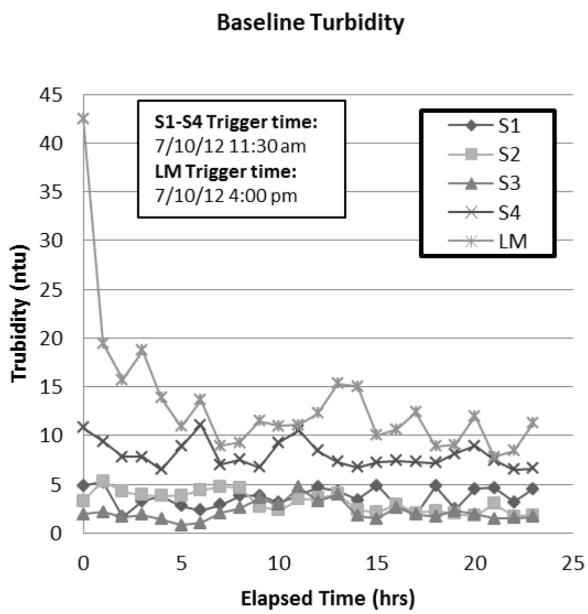
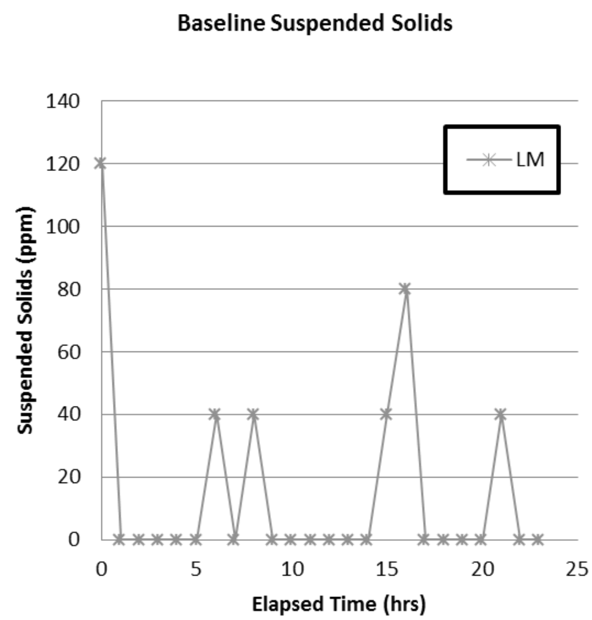
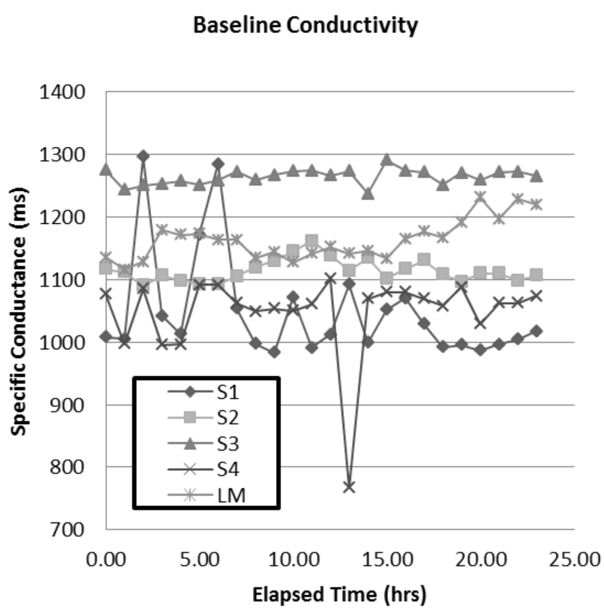
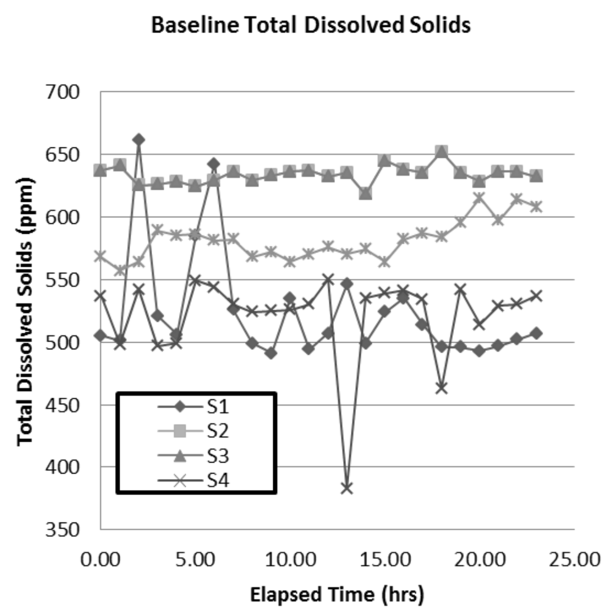
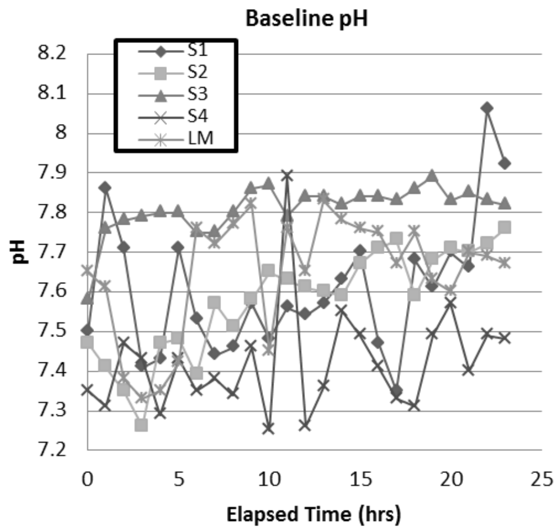
Appendix 1. Baseline and Event Graphs

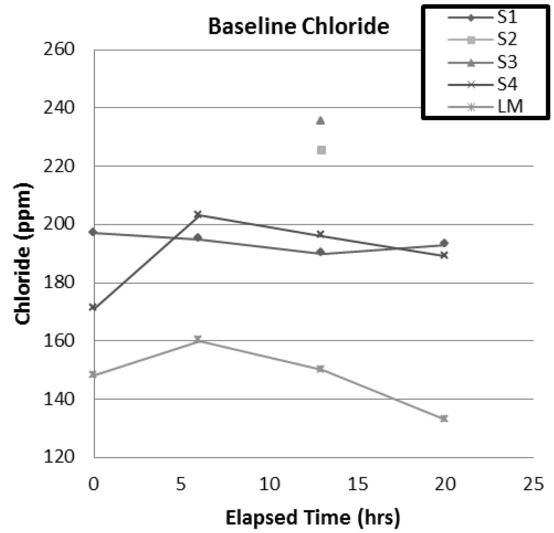


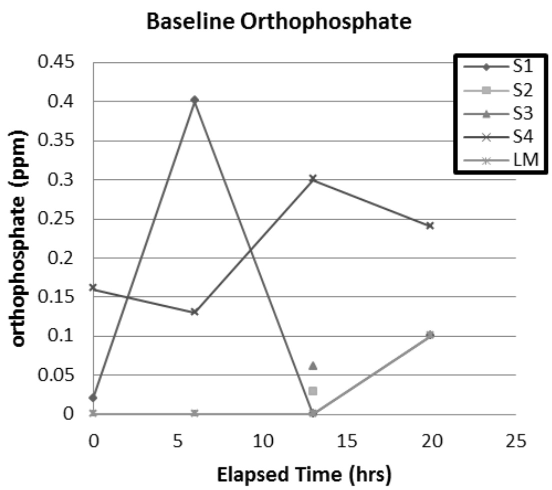


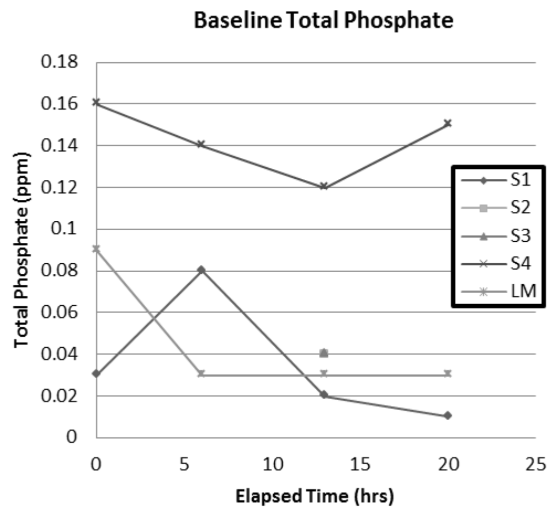


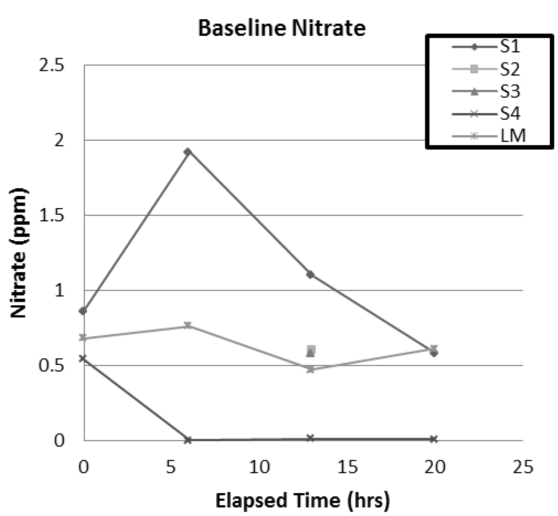


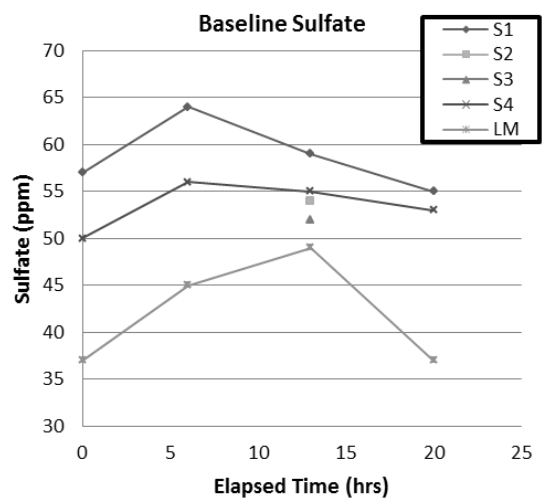

Baseline pH
pH
Elapsed Time (hrs)
S1
S2
S3
S4
LM


Baseline Chloride
Chloride (ppm)
Elapsed Time (hrs)
S1
S2
S3
S4
LM

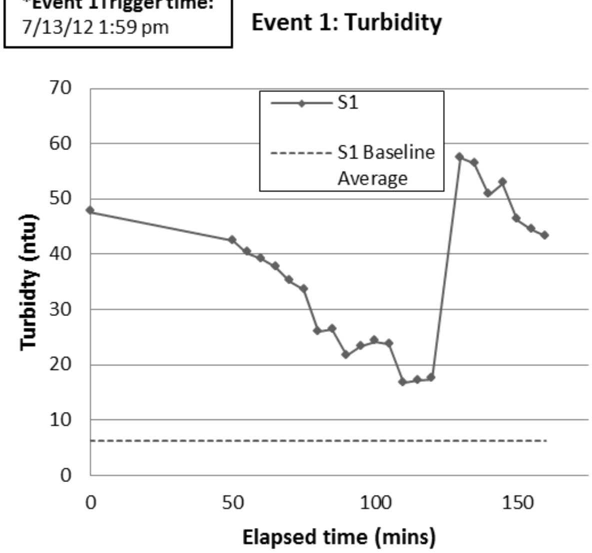

Baseline Orthophosphate
orthophosphate (ppm)
Elapsed Time (hrs)
S1
S2
S3
S4
LM

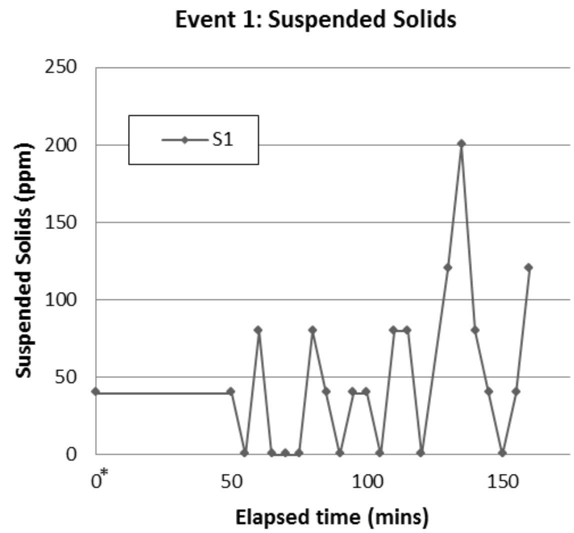

Baseline Total Phosphate
Total Phosphate (ppm)
Elapsed Time (hrs)
S1
S2
S3
S4
LM

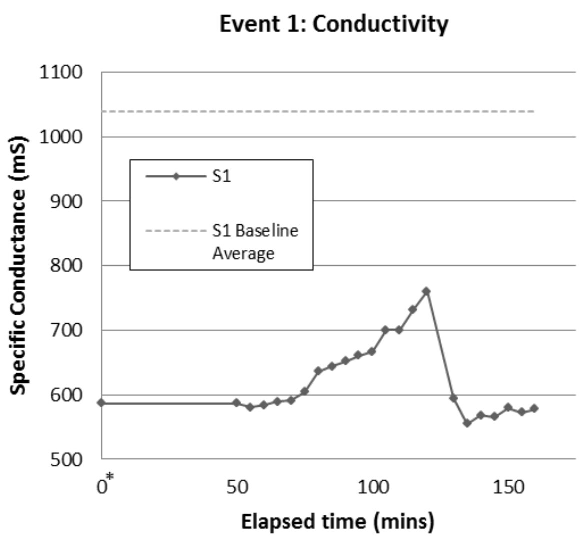

Baseline Nitrate
Nitrate (ppm)
Elapsed Time (hrs)
S1
S2
S3
S4
LM

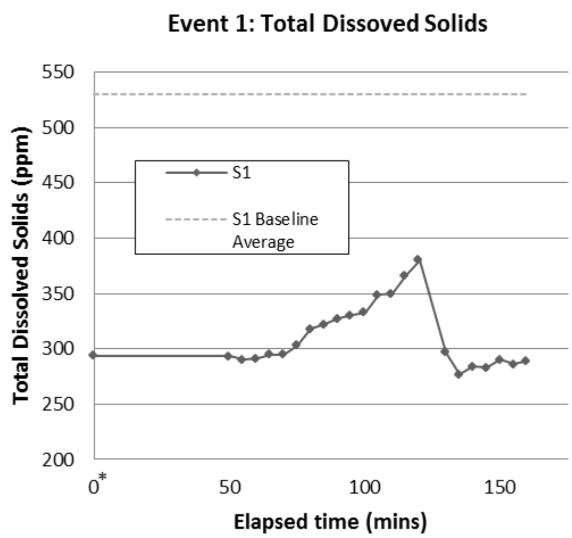

Baseline Sulfate
Sulfate (ppm)
Elapsed Time (hrs)
S1
S2
S3
S4
LM

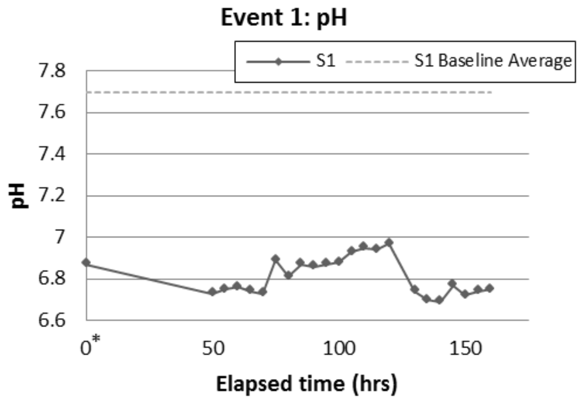
***Event 1Trigger time:**
7/13/12 1:59 pm

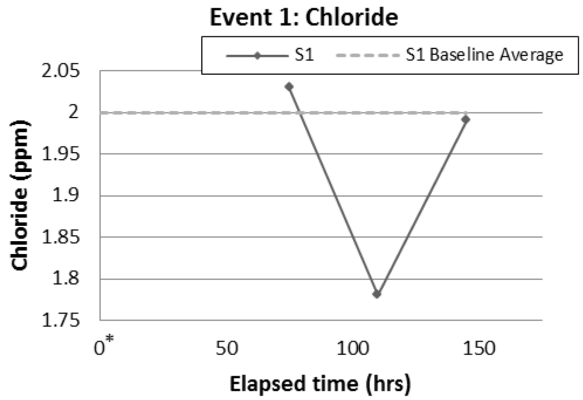


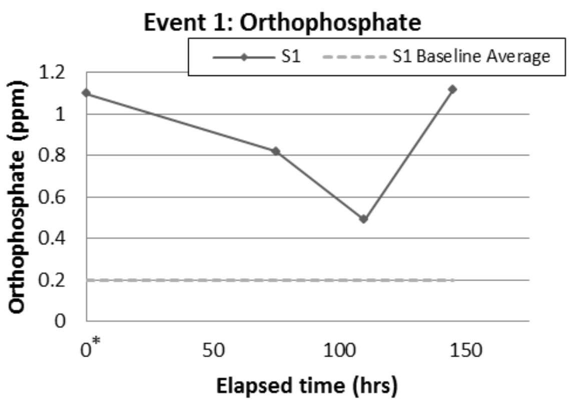


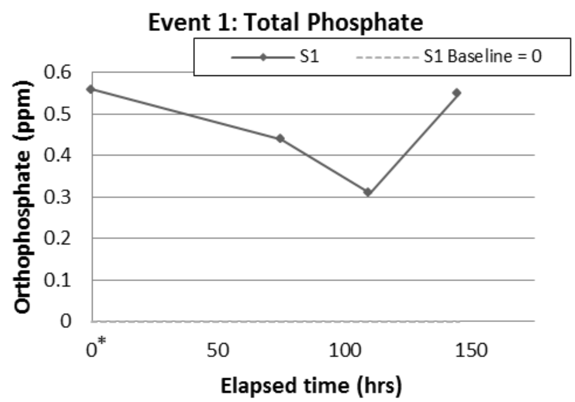


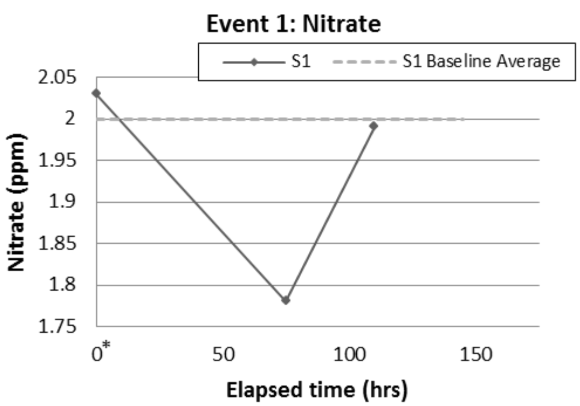


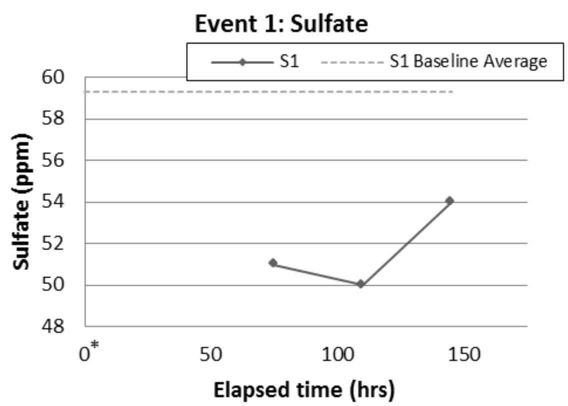

Event 1: pH
S1
S1 Baseline Average
pH
7.8
7.6
7.4
7.2
7
6.8
6.6
0*
50
100
150
Elapsed time (hrs)

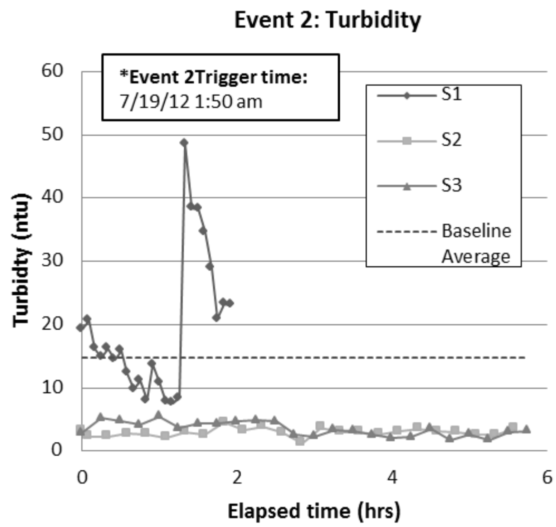

Event 1: Chloride
S1
S1 Baseline Average
Chloride (ppm)
2.05
2
1.95
1.9
1.85
1.8
1.75
0*
50
100
150
Elapsed time (hrs)

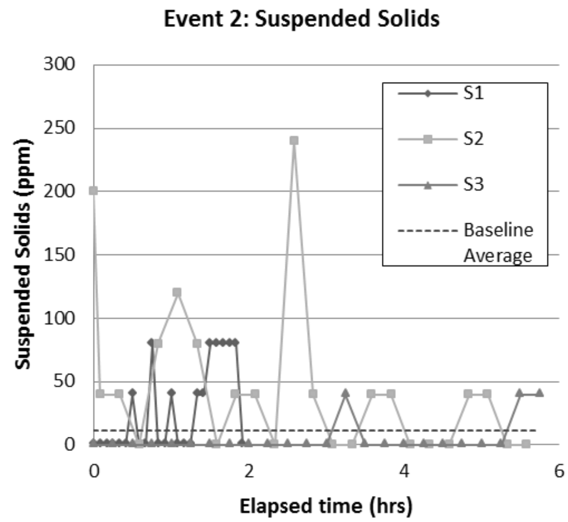

Event 1: Orthophosphate
S1
S1 Baseline Average
Orthophosphate (ppm)
1.2
1
0.8
0.6
0.4
0.2
0
0*
50
100
150
Elapsed time (hrs)

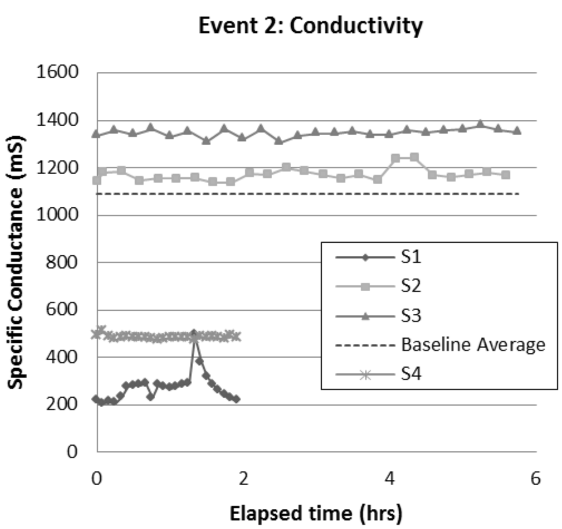

Event 1: Total Phosphate
S1
S1 Baseline = 0
Orthophosphate (ppm)
0.6
0.5
0.4
0.3
0.2
0.1
0
0*
50
100
150
Elapsed time (hrs)

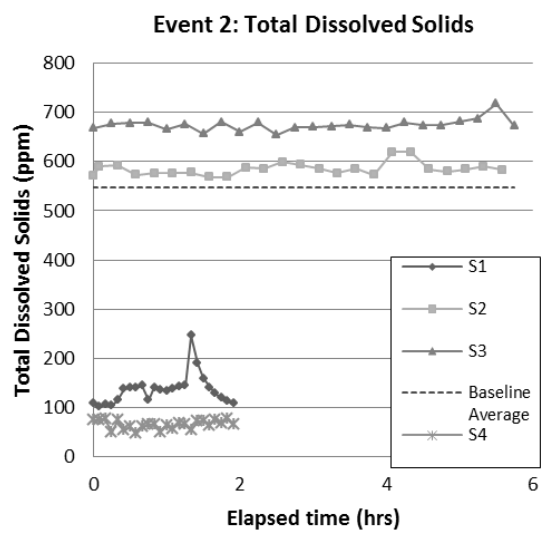

Event 1: Nitrate
S1
S1 Baseline Average
Nitrate (ppm)
2.05
2
1.95
1.9
1.85
1.8
1.75
0*
50
100
150
Elapsed time (hrs)

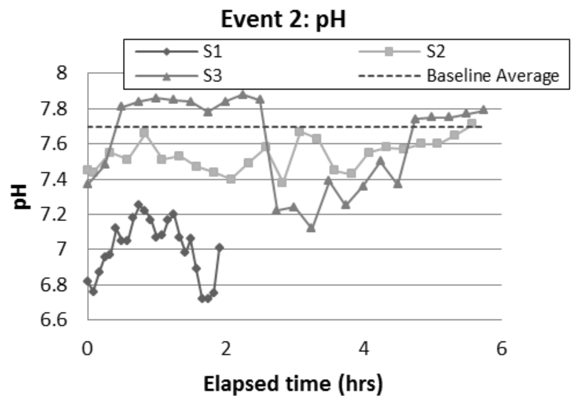

Event 1: Sulfate
S1
S1 Baseline Average
Sulfate (ppm)
60
58
56
54
52
50
48
0*
50
100
150
Elapsed time (hrs)

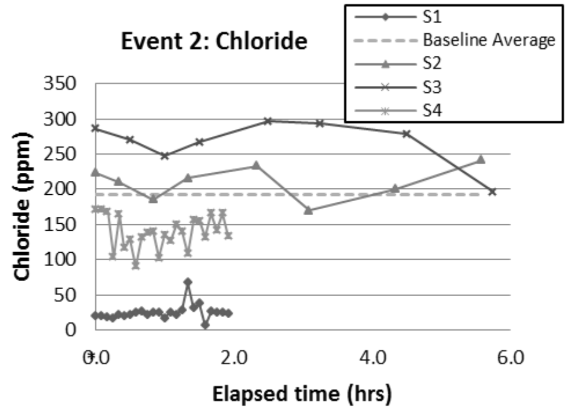

Event 2: Turbidity
*Event 2Trigger time:
7/19/12 1:50 am
Turbidty (ntu)
Elapsed time (hrs)
S1
S2
S3
Baseline Average

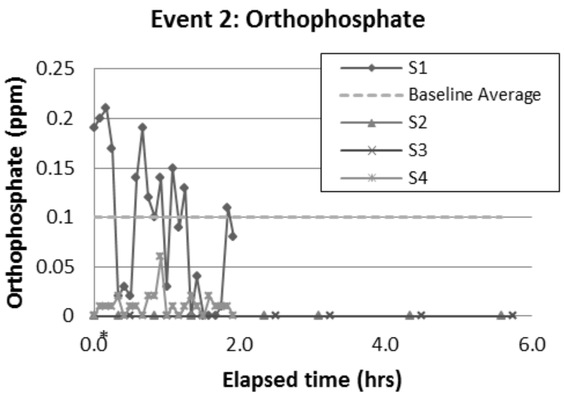

Event 2: Suspended Solids
Suspended Solids (ppm)
Elapsed time (hrs)
S1
S2
S3
Baseline Average

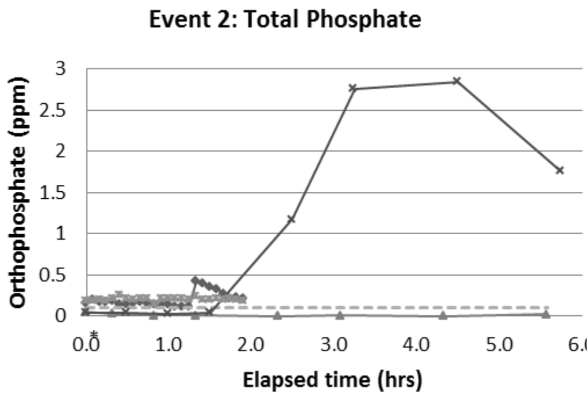

Event 2: Conductivity
Specific Conductance (mS)
Elapsed time (hrs)
S1
S2
S3
Baseline Average
S4

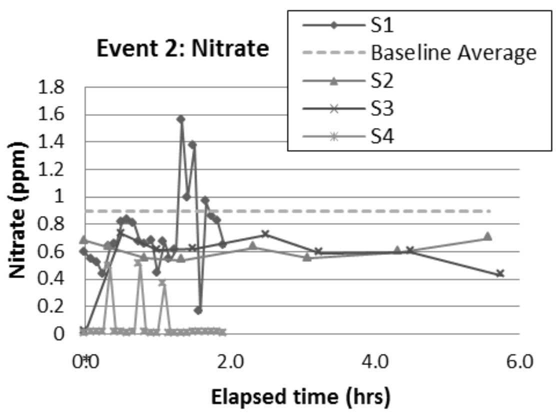

Event 2: Total Dissolved Solids
Total Dissolved Solids (ppm)
Elapsed time (hrs)
S1
S2
S3
Baseline Average
S4

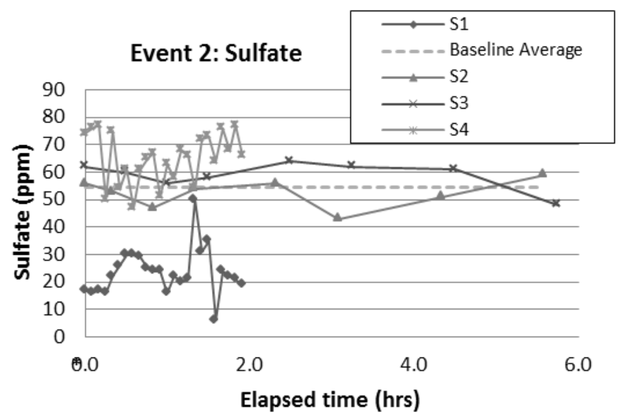

Event 2: pH
S1
S2
S3
Baseline Average
pH
Elapsed time (hrs)


Event 2: Chloride
S1
Baseline Average
S2
S3
S4
Chloride (ppm)
Elapsed time (hrs)

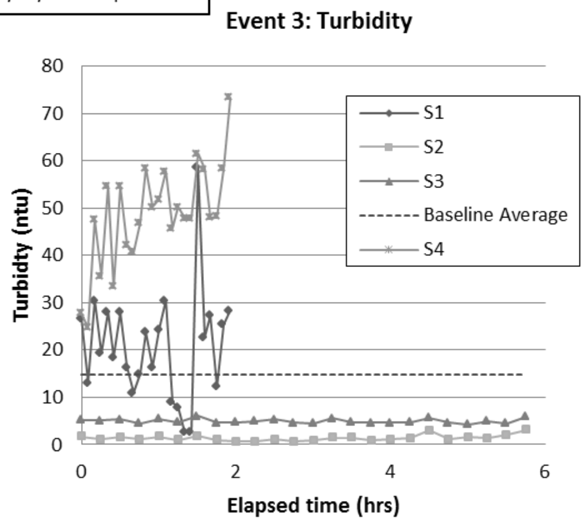

Event 2: Orthophosphate
S1
Baseline Average
S2
S3
S4
Orthophosphate (ppm)
Elapsed time (hrs)

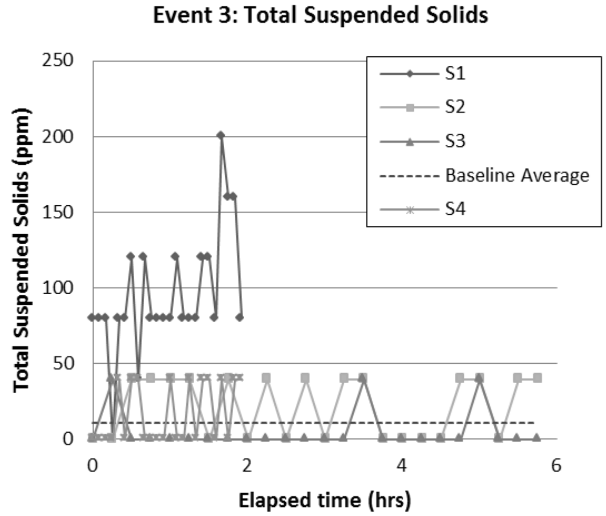

Event 2: Total Phosphate
Orthophosphate (ppm)
Elapsed time (hrs)

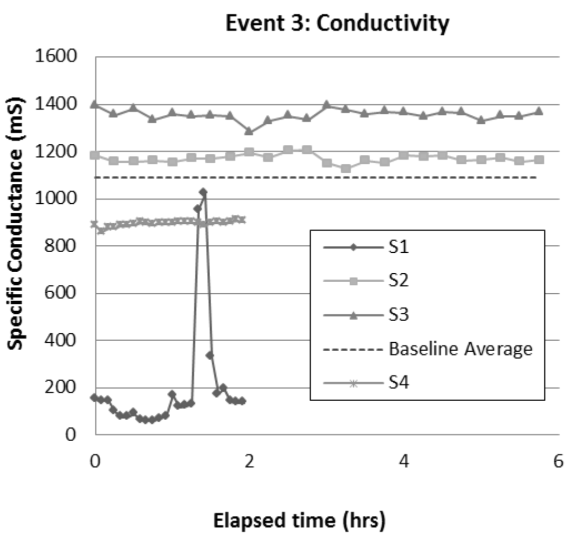

Event 2: Nitrate
S1
Baseline Average
S2
S3
S4
Nitrate (ppm)
Elapsed time (hrs)

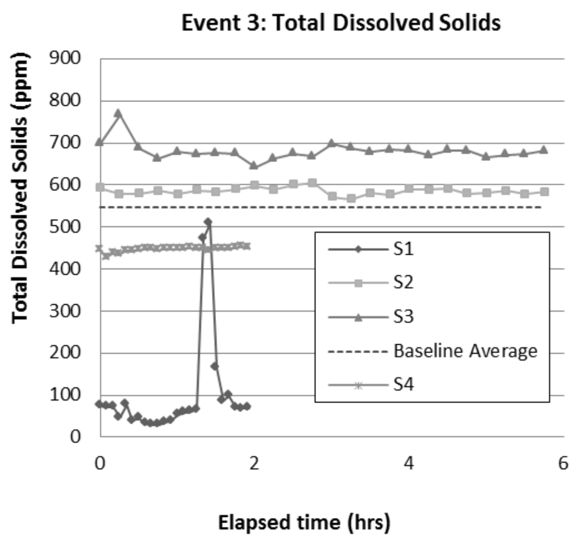

Event 2: Sulfate
S1
Baseline Average
S2
S3
S4
Sulfate (ppm)
Elapsed time (hrs)

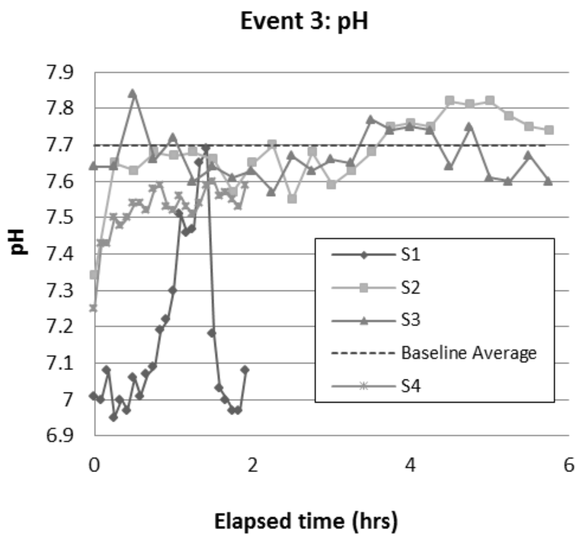
***Event 3Trigger time:**
7/19/12 2:10 pm

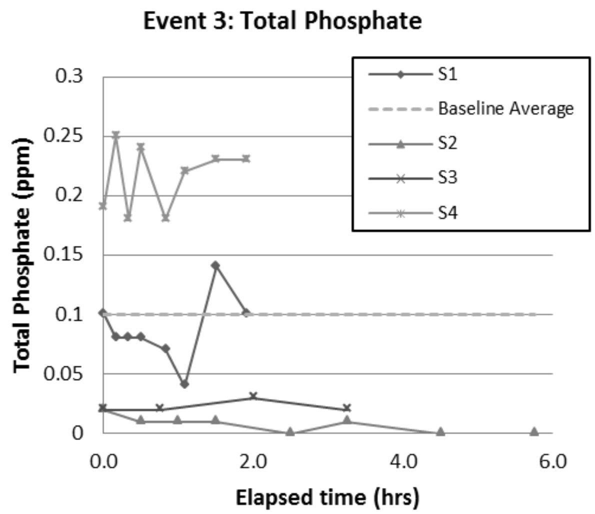




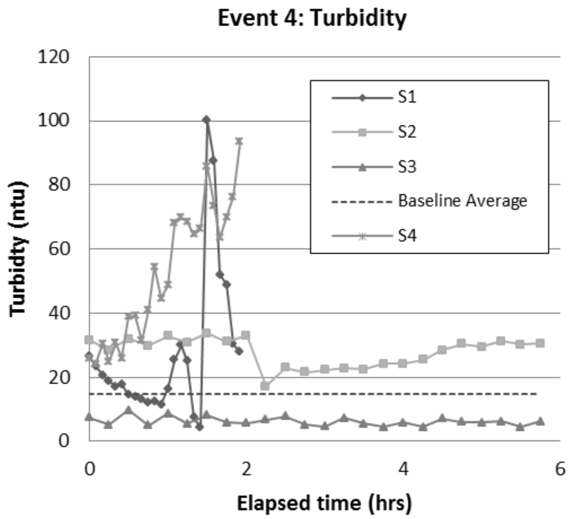


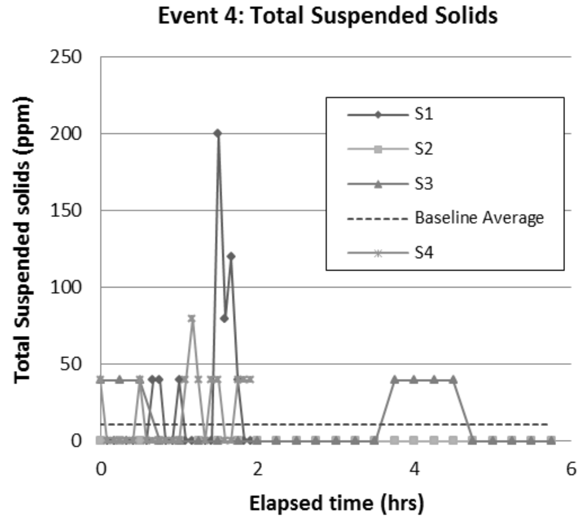


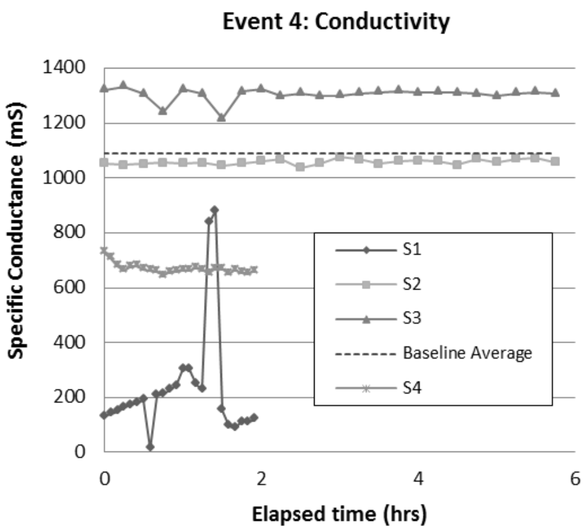

Event 3: pH
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7
6.9
pH
0
2
4
6
Elapsed time (hrs)
S1
S2
S3
Baseline Average
S4

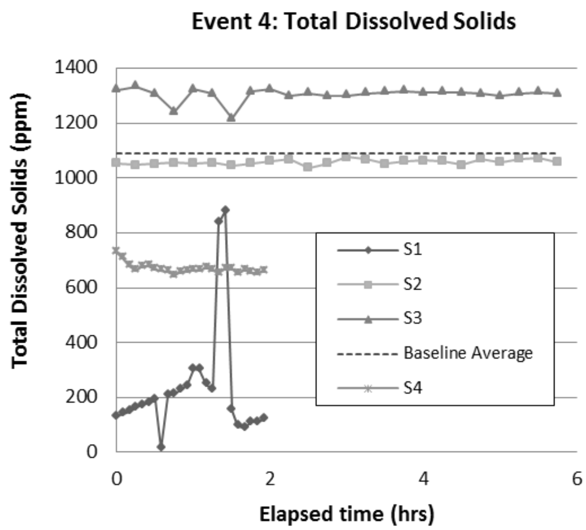

Event 3: Total Phosphate
0.3
0.25
0.2
0.15
0.1
0.05
0
Total Phosphate (ppm)
0.0
2.0
4.0
6.0
Elapsed time (hrs)
S1
Baseline Average
S2
S3
S4

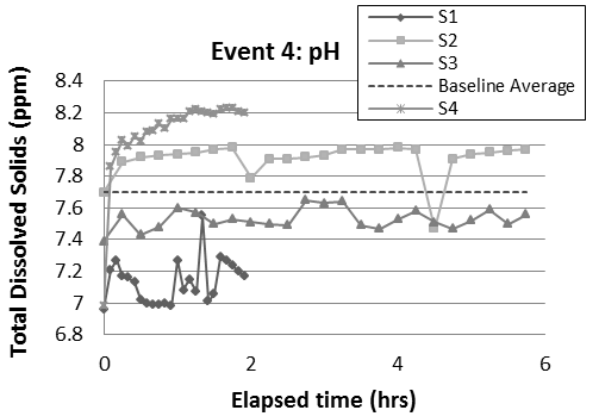
***Event 4Trigger time:**
7/26/12 5:03 am

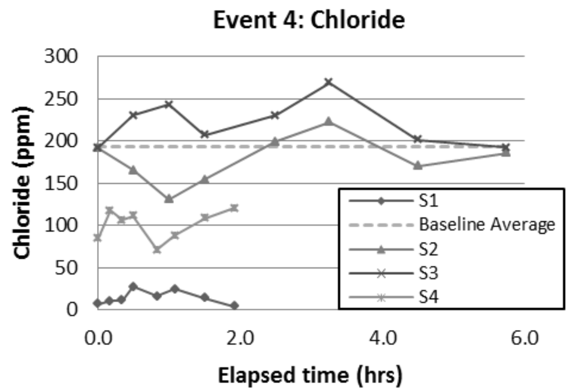


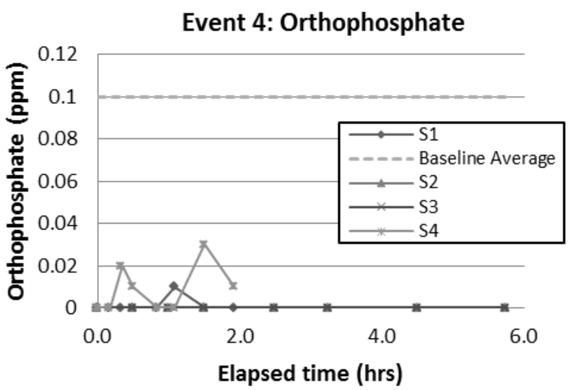


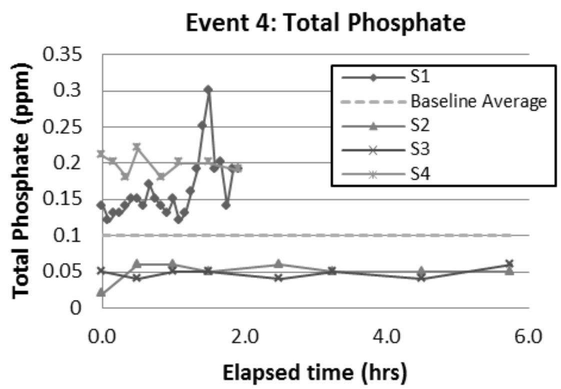


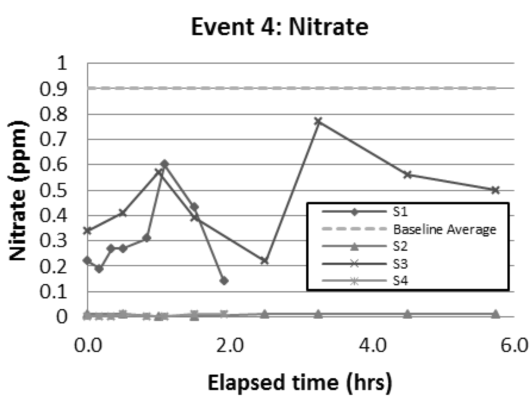


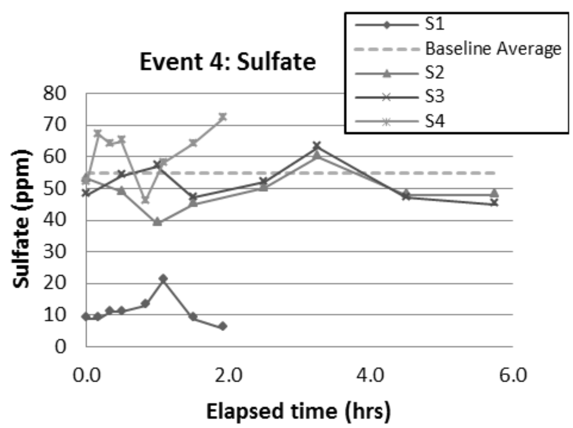

Event 4: pH
Total Dissolved Solids (ppm)
Elapsed time (hrs)
S1
S2
S3
Baseline Average
S4


Event 4: Chloride
Chloride (ppm)
Elapsed time (hrs)
S1
Baseline Average
S2
S3
S4

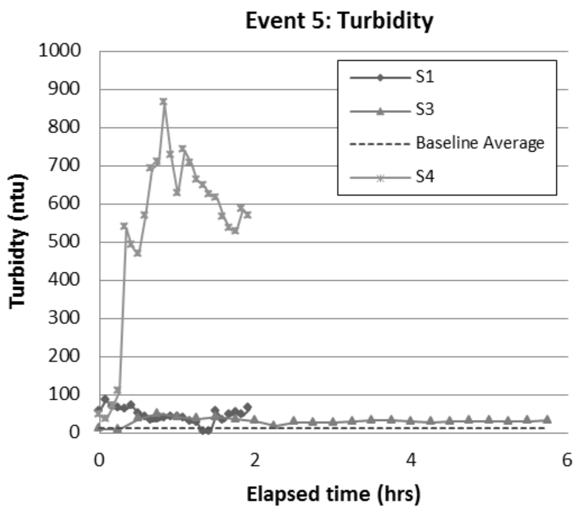

Event 4: Orthophosphate
Orthophosphate (ppm)
Elapsed time (hrs)
S1
Baseline Average
S2
S3
S4

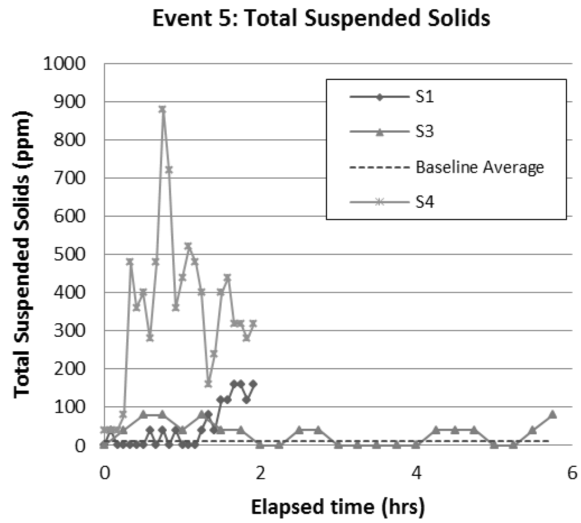

Event 4: Total Phosphate
Total Phosphate (ppm)
Elapsed time (hrs)
S1
Baseline Average
S2
S3
S4

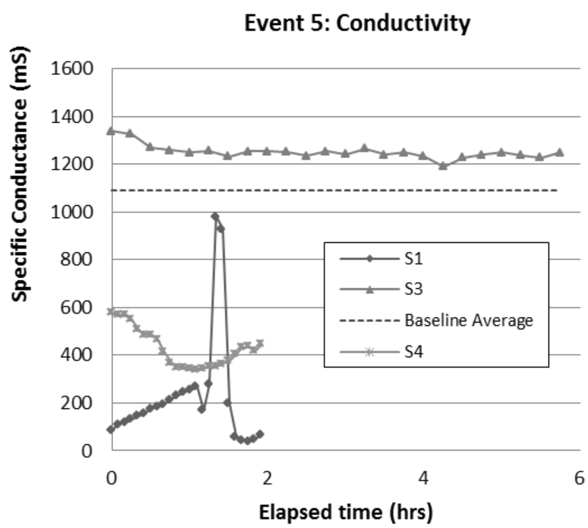

Event 4: Nitrate
Nitrate (ppm)
Elapsed time (hrs)
S1
Baseline Average
S2
S3
S4

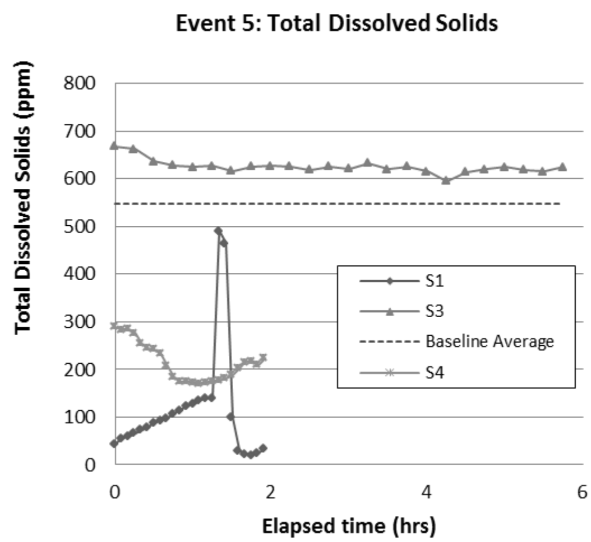

Event 4: Sulfate
Sulfate (ppm)
Elapsed time (hrs)
S1
Baseline Average
S2
S3
S4

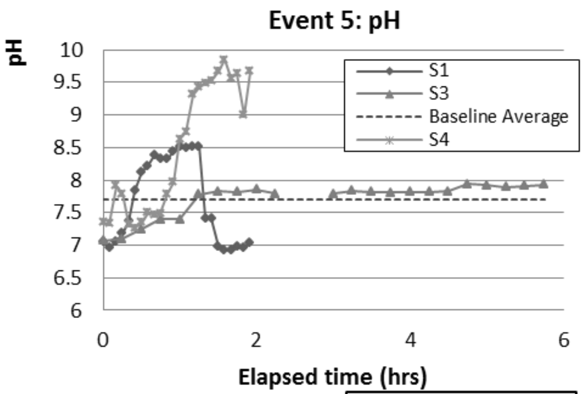
*Event 5 Trigger time:
7/27/12 3:11 pm

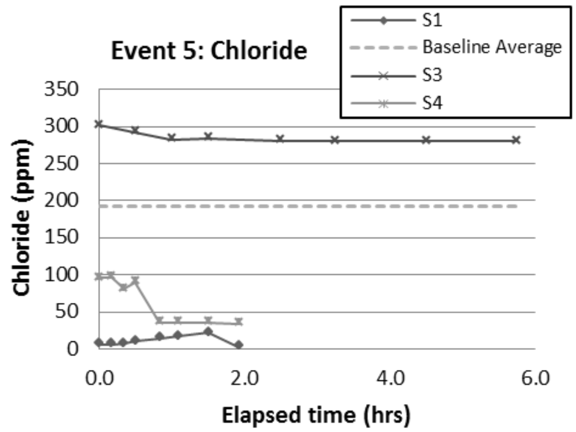


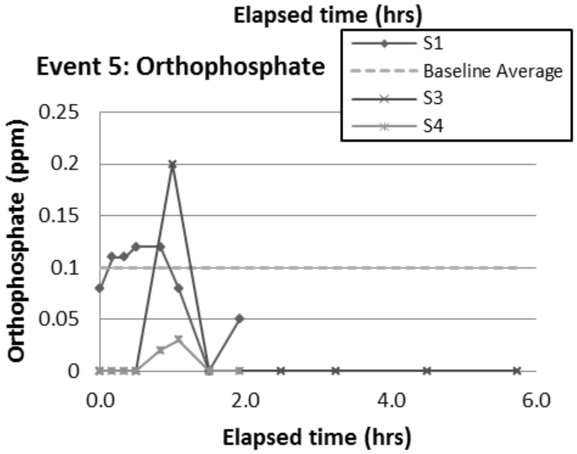


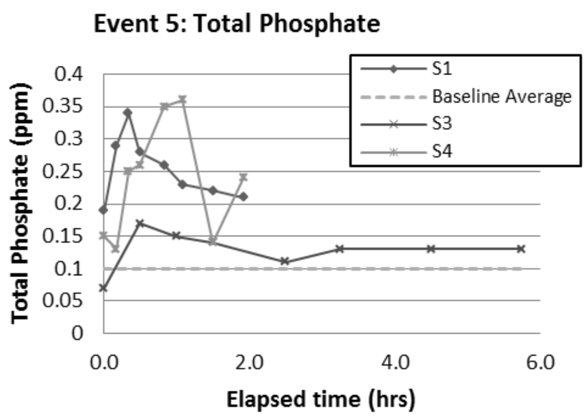


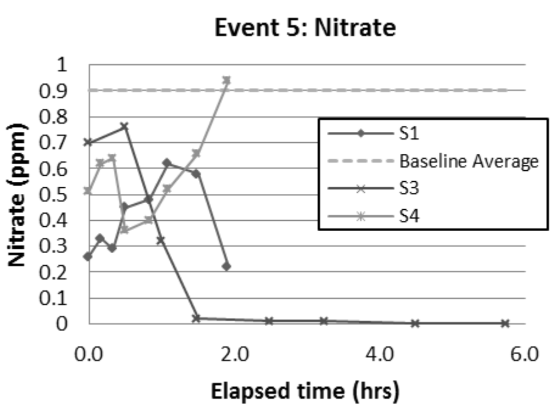


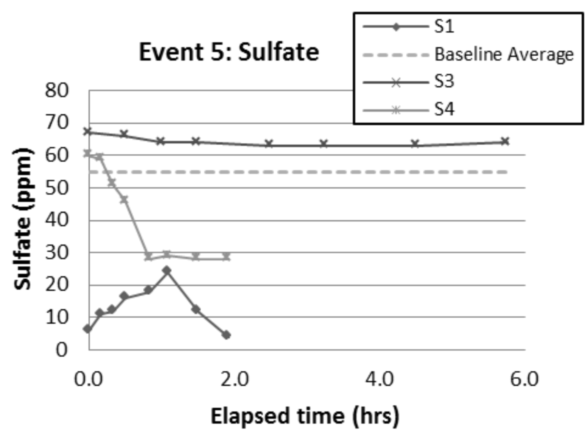

Event 5: pH
pH
Elapsed time (hrs)
S1
S3
Baseline Average
S4


Event 5: Chloride
Chloride (ppm)
Elapsed time (hrs)
S1
Baseline Average
S3
S4


Event 5: Orthophosphate
Orthophosphate (ppm)
Elapsed time (hrs)
S1
Baseline Average
S3
S4

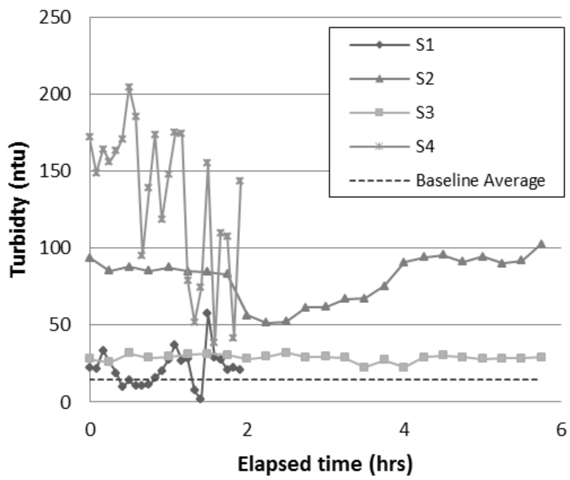

Event 5: Total Phosphate
Total Phosphate (ppm)
Elapsed time (hrs)
S1
Baseline Average
S3
S4


Event 5: Nitrate
Nitrate (ppm)
Elapsed time (hrs)
S1
Baseline Average
S3
S4

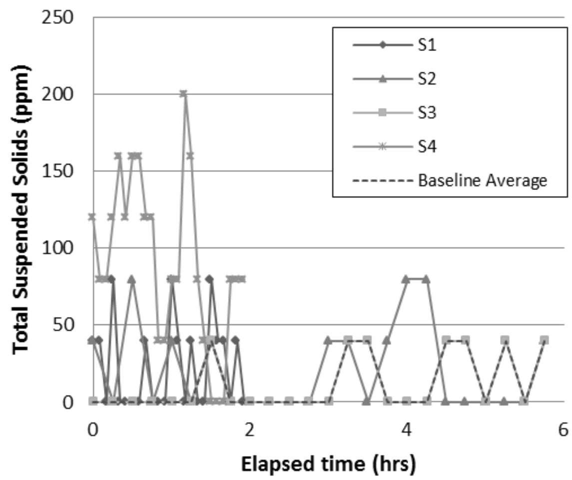

Event 5: Sulfate
Sulfate (ppm)
Elapsed time (hrs)
S1
Baseline Average
S3
S4

*Event 6 Trigger time: 7/31/12
S1-S3 2:11 am
S4 10:11 am

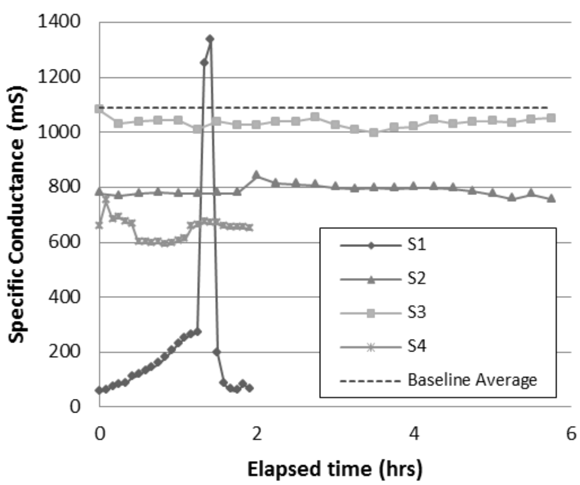
Event 6: Turbidity



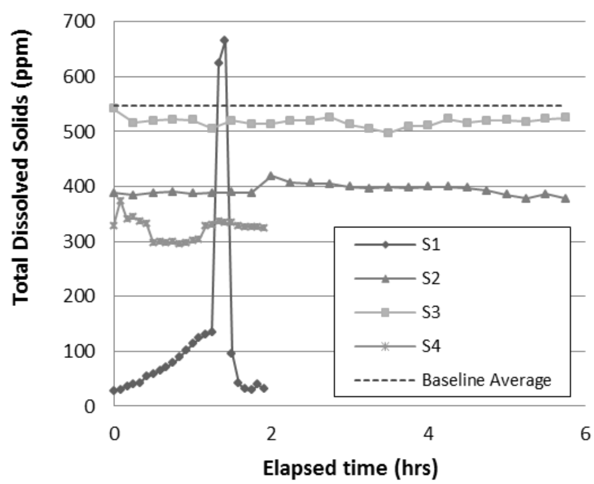
Event 6: Total Suspended Solids

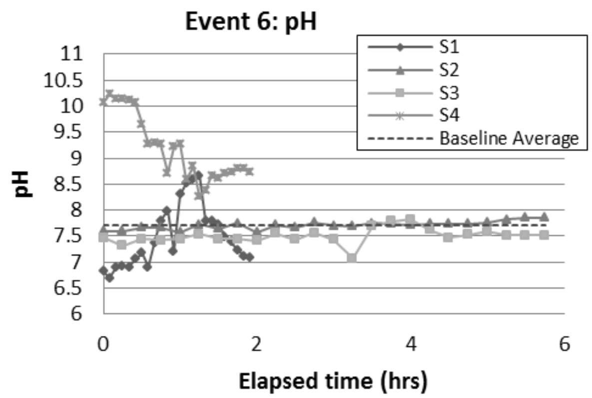


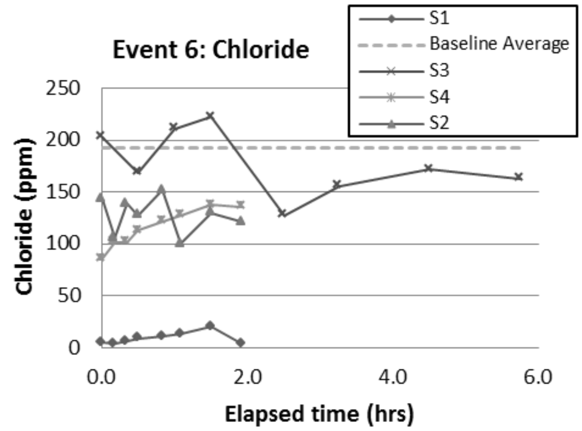
Event 6: Conductivity

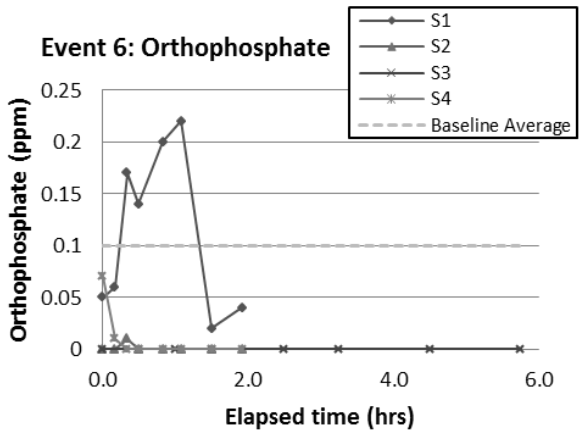


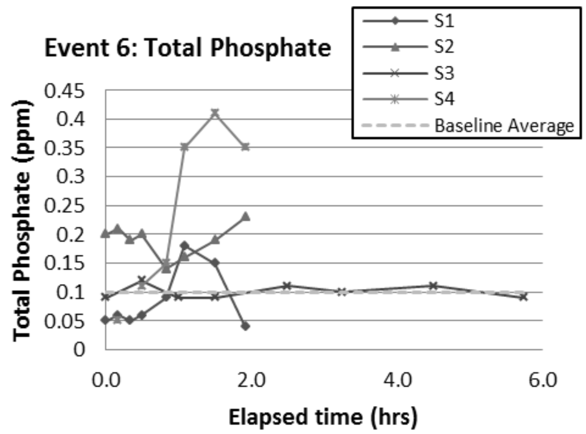
Event 6: Total Dissolved Solids

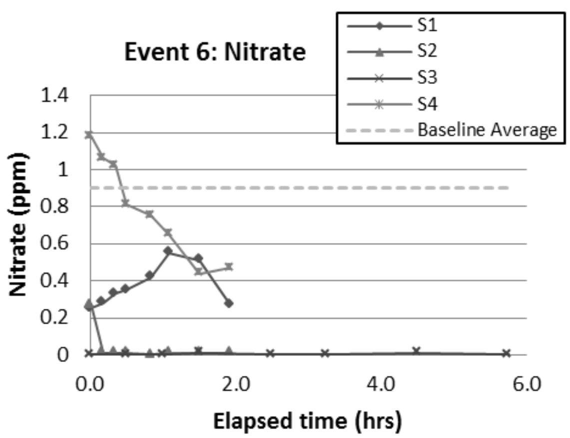


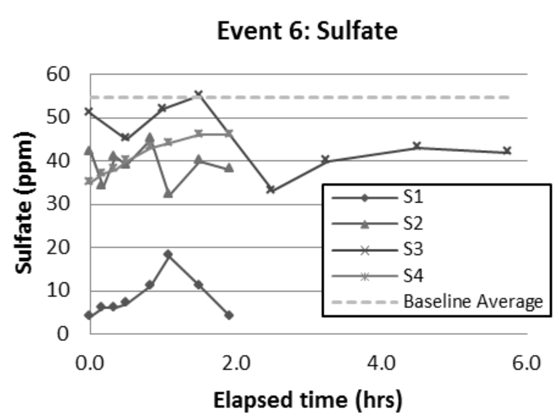

Event 6: pH
S1
S2
S3
S4
Baseline Average
pH
11
10.5
10
9.5
9
8.5
8
7.5
7
6.5
6
0
2
4
6
Elapsed time (hrs)


Event 6: Chloride
S1
Baseline Average
S3
S4
S2
Chloride (ppm)
250
200
150
100
50
0
0.0
2.0
4.0
6.0
Elapsed time (hrs)


Event 6: Orthophosphate
S1
S2
S3
S4
Baseline Average
Orthophosphate (ppm)
0.25
0.2
0.15
0.1
0.05
0
0.0
2.0
4.0
6.0
Elapsed time (hrs)

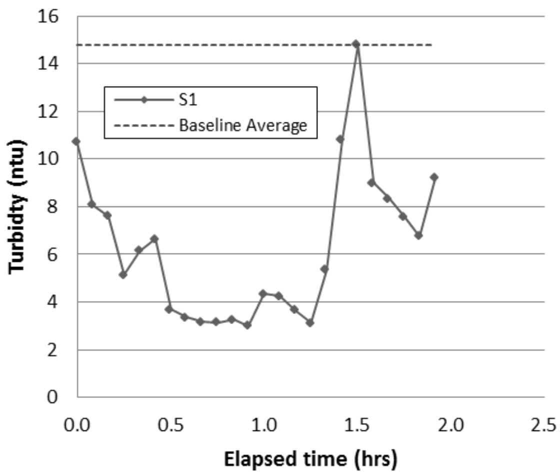

Event 6: Total Phosphate
S1
S2
S3
S4
Baseline Average
Total Phosphate (ppm)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.0
2.0
4.0
6.0
Elapsed time (hrs)


Event 6: Nitrate
S1
S2
S3
S4
Baseline Average
Nitrate (ppm)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.0
2.0
4.0
6.0
Elapsed time (hrs)

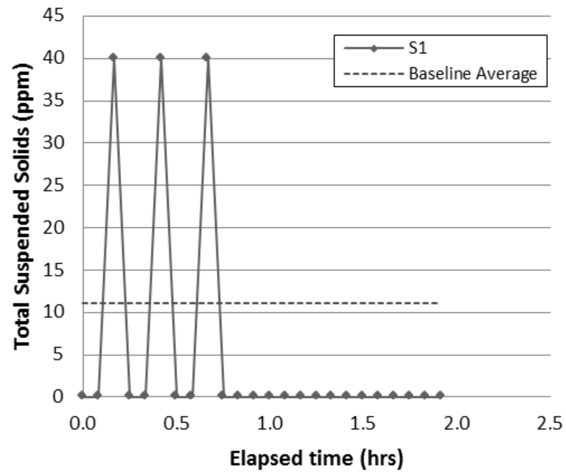

Event 6: Sulfate
S1
S2
S3
S4
Baseline Average
Sulfate (ppm)
60
50
40
30
20
10
0
0.0
2.0
4.0
6.0
Elapsed time (hrs)

***Event 7 Trigger time:** 8/9/12
8:24 pm

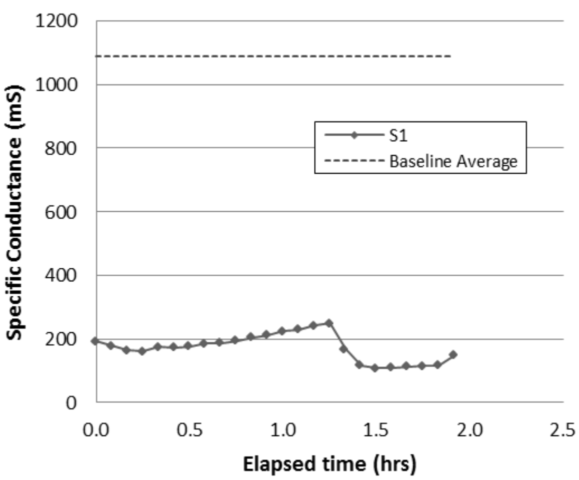
Event 7: Turbidity



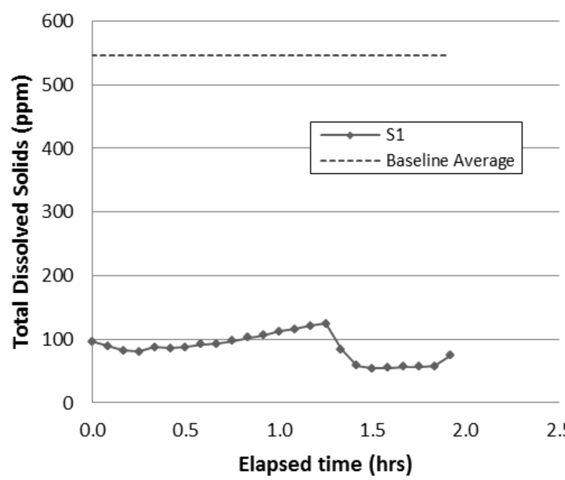
Event 7: Total Suspended Solids

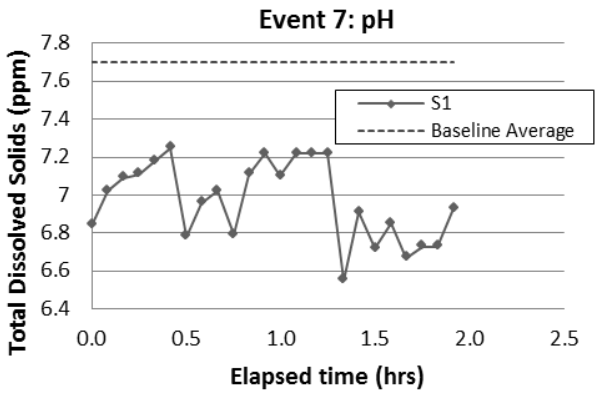


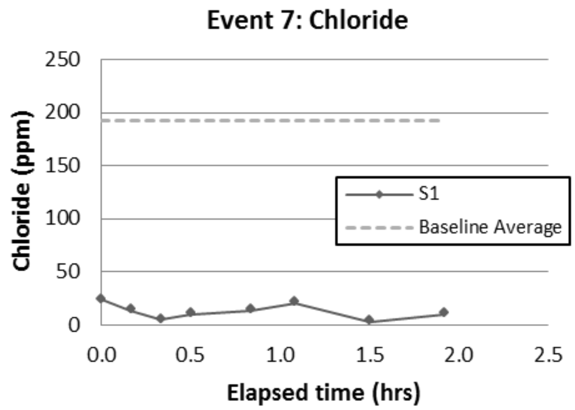
Event 7: Conductivity

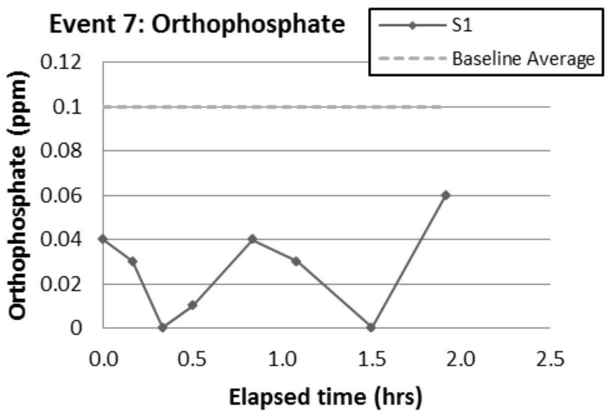


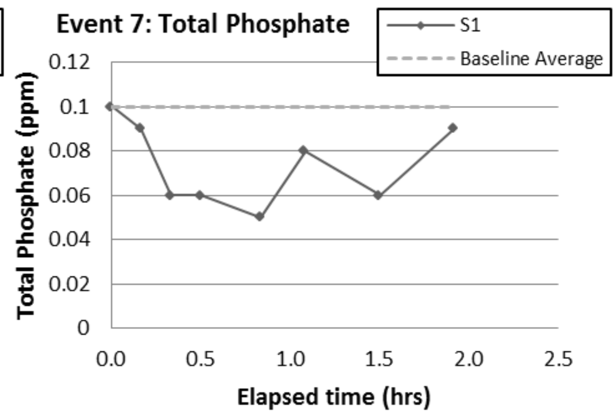
Event 7: Total Dissolved Solids

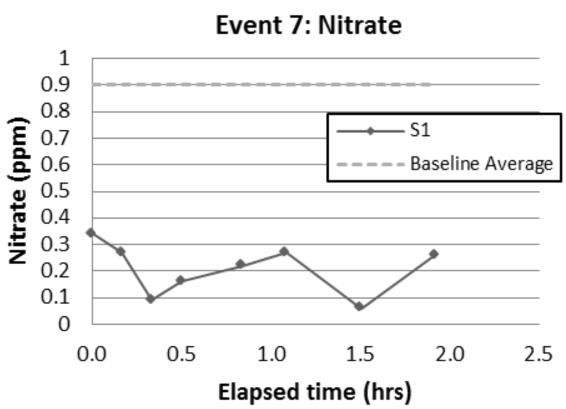


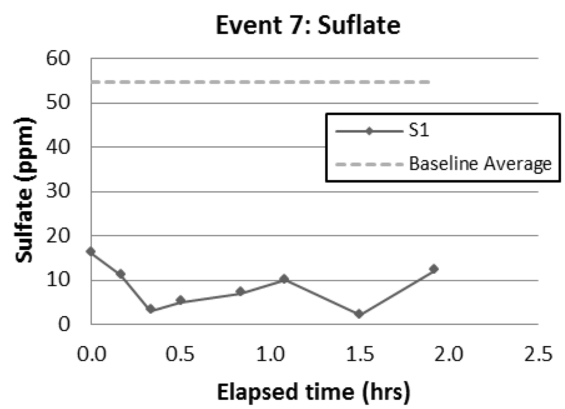

Event 7: pH
Total Dissolved Solids (ppm)
7.8
7.6
7.4
7.2
7
6.8
6.6
6.4
0.0
0.5
1.0
1.5
2.0
2.5
Elapsed time (hrs)
S1
Baseline Average


Event 7: Chloride
Chloride (ppm)
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
Elapsed time (hrs)
S1
Baseline Average

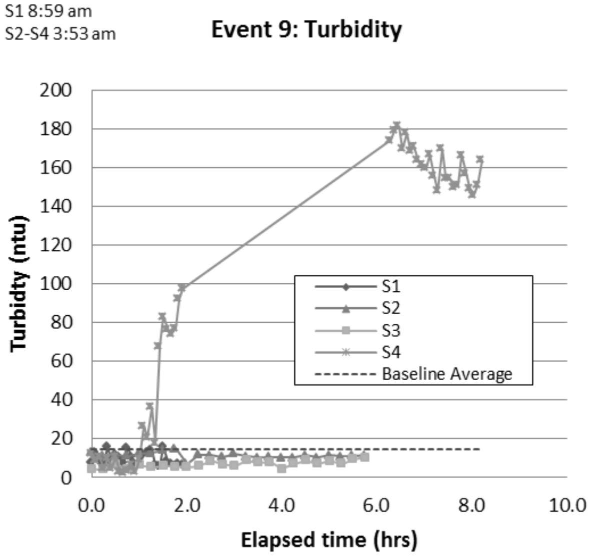

Event 7: Orthophosphate
Orthophosphate (ppm)
0.12
0.1
0.08
0.06
0.04
0.02
0
0.0
0.5
1.0
1.5
2.0
2.5
Elapsed time (hrs)
S1
Baseline Average

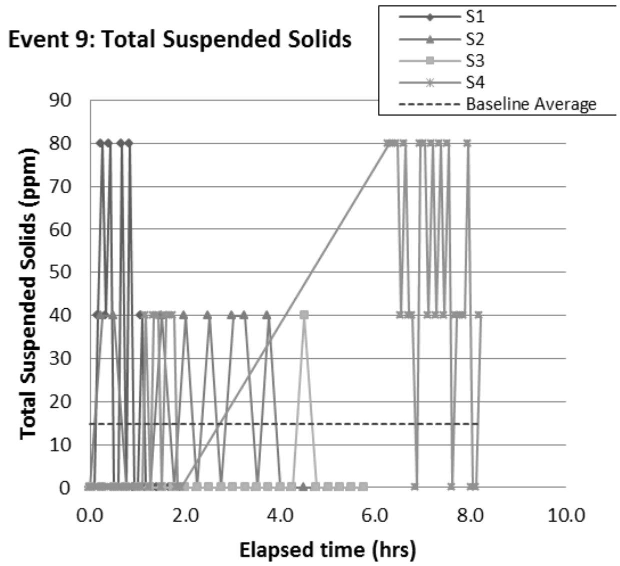

Event 7: Total Phosphate
Total Phosphate (ppm)
0.12
0.1
0.08
0.06
0.04
0.02
0
0.0
0.5
1.0
1.5
2.0
2.5
Elapsed time (hrs)
S1
Baseline Average

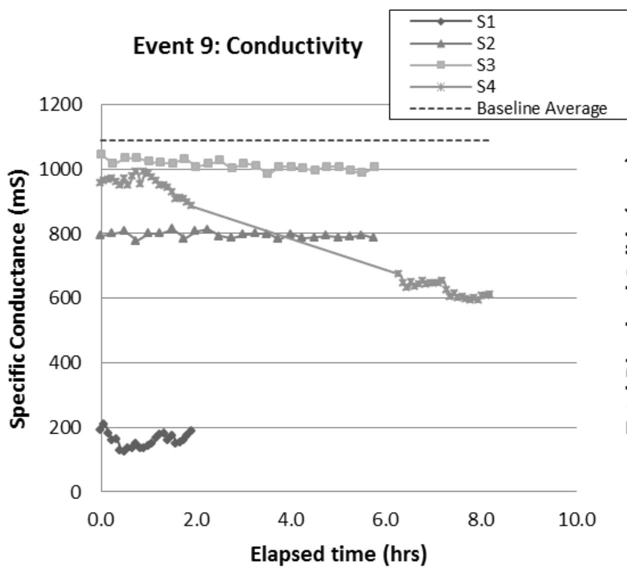

Event 7: Nitrate
Nitrate (ppm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.0
0.5
1.0
1.5
2.0
2.5
Elapsed time (hrs)
S1
Baseline Average

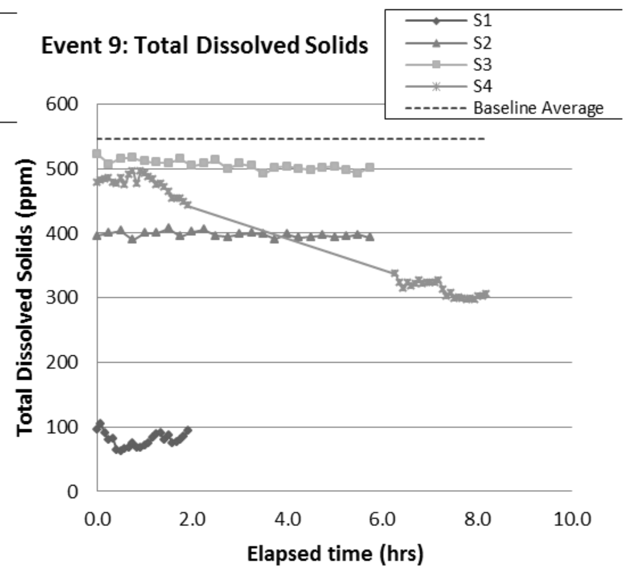

Event 7: Suflate
Sulfate (ppm)
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
2.5
Elapsed time (hrs)
S1
Baseline Average

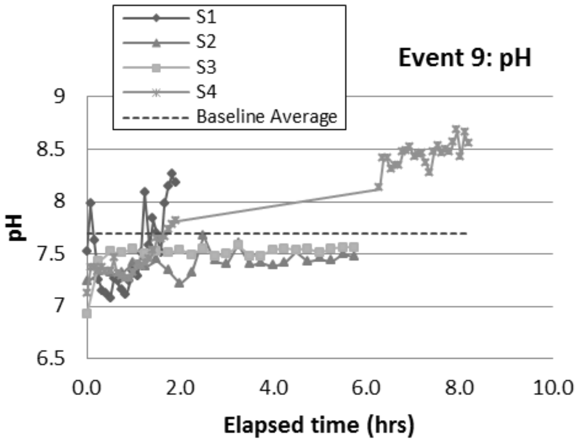
***Event 9 Trigger time:** 8/10/12
S1 8:59 am
S2-S4 3:53 am

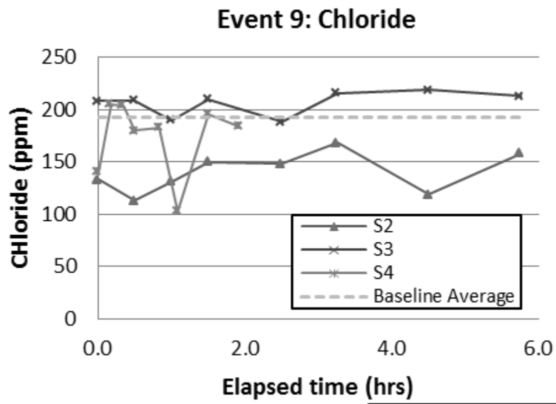


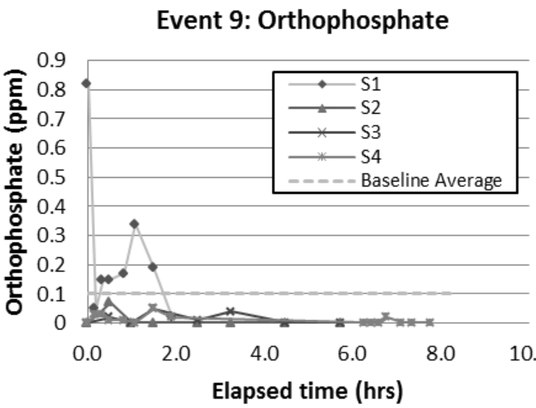


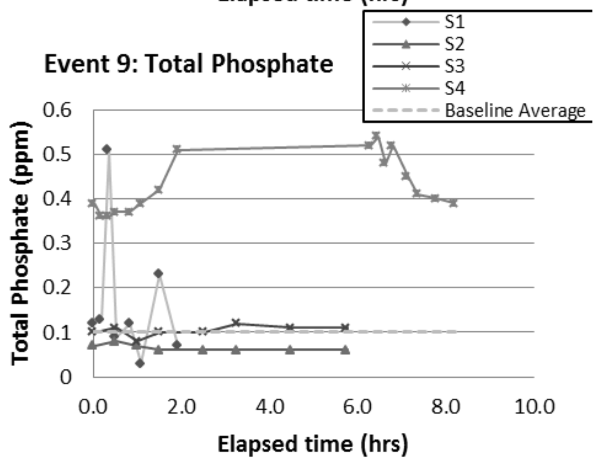


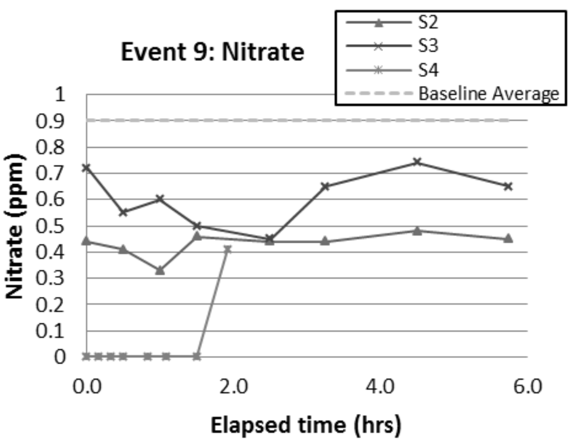


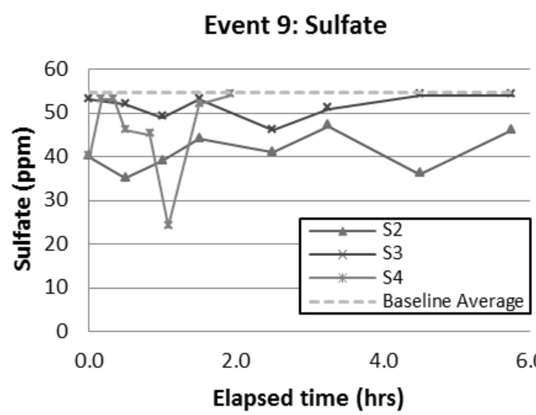

Event 9: pH
S1
S2
S3
S4
Baseline Average
pH
9
8.5
8
7.5
7
6.5
0.0
2.0
4.0
6.0
8.0
10.0
Elapsed time (hrs)

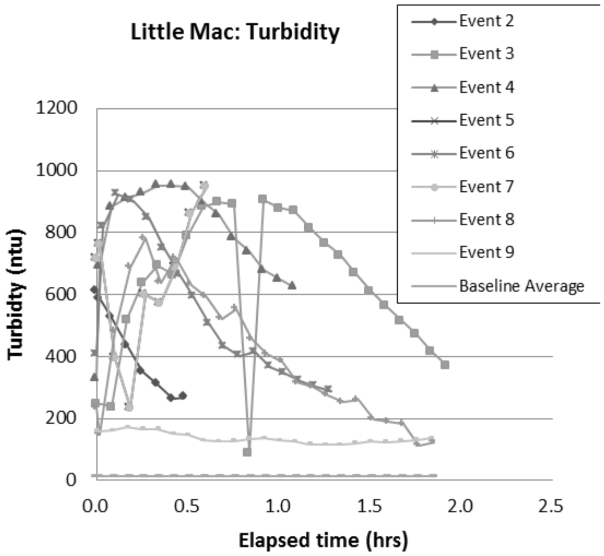

Event 9: Chloride
CHloride (ppm)
250
200
150
100
50
0
S2
S3
S4
Baseline Average
0.0
2.0
4.0
6.0
Elapsed time (hrs)

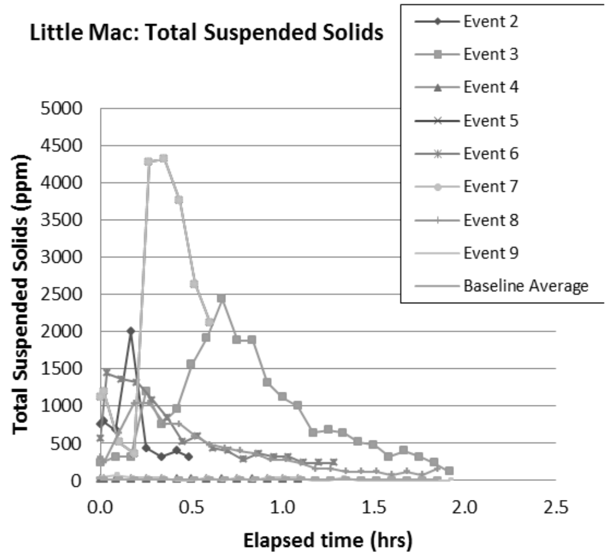

Event 9: Orthophosphate
Orthophosphate (ppm)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
S1
S2
S3
S4
Baseline Average
0.0
2.0
4.0
6.0
8.0
10.0
Elapsed time (hrs)

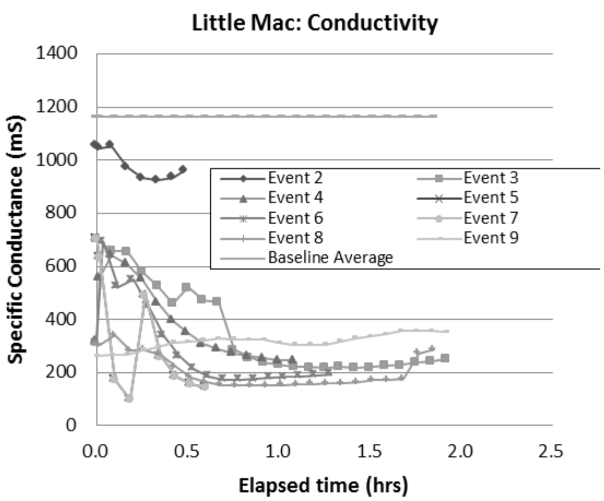

Event 9: Total Phosphate
S1
S2
S3
S4
Baseline Average
Total Phosphate (ppm)
0.6
0.5
0.4
0.3
0.2
0.1
0
0.0
2.0
4.0
6.0
8.0
10.0
Elapsed time (hrs)

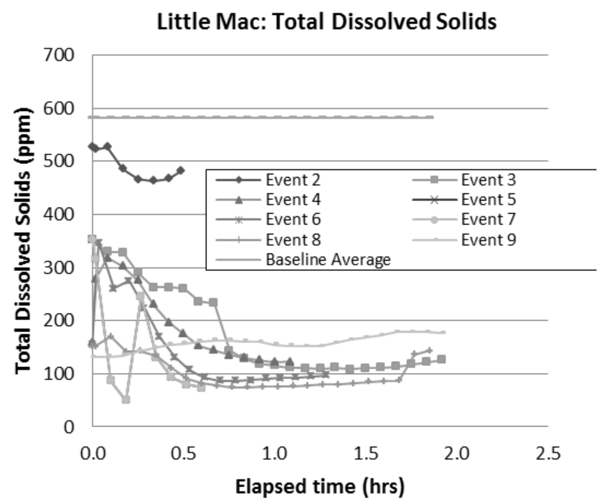

Event 9: Nitrate
S2
S3
S4
Baseline Average
Nitrate (ppm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.0
2.0
4.0
6.0
Elapsed time (hrs)

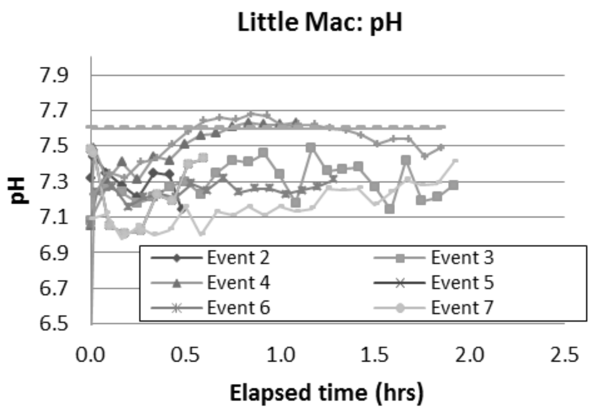

Event 9: Sulfate
Sulfate (ppm)
60
50
40
30
20
10
0
S2
S3
S4
Baseline Average
0.0
2.0
4.0
6.0
Elapsed time (hrs)

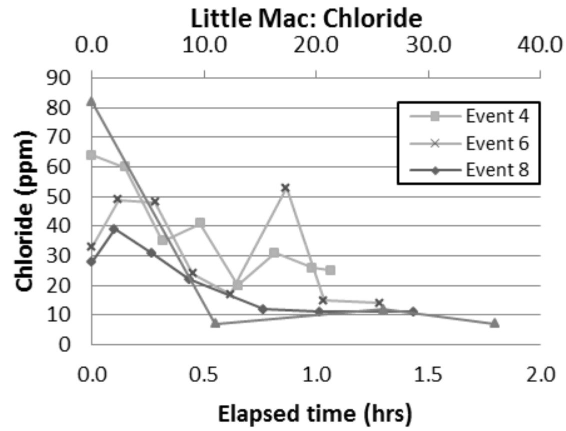

Little Mac: Turbidity
Turbidty (ntu)
Elapsed time (hrs)
Event 2
Event 3
Event 4
Event 5
Event 6
Event 7
Event 8
Event 9
Baseline Average

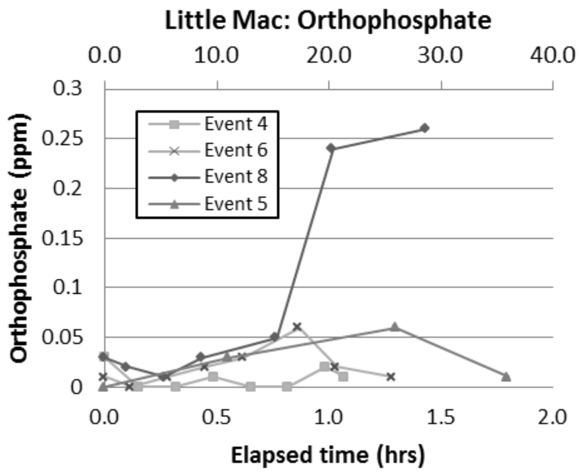

Little Mac: Total Suspended Solids
Total Suspended Solids (ppm)
Elapsed time (hrs)
Event 2
Event 3
Event 4
Event 5
Event 6
Event 7
Event 8
Event 9
Baseline Average

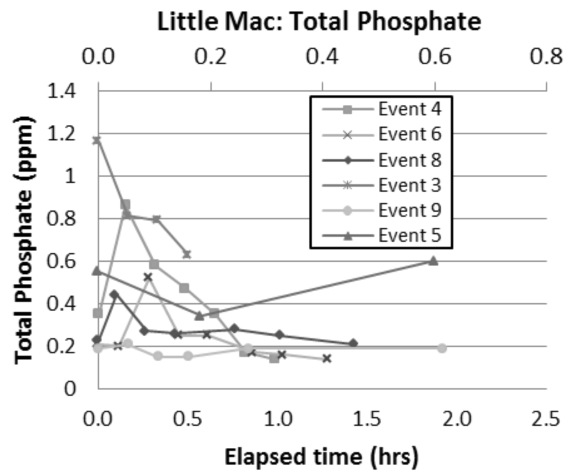

Little Mac: Conductivity
Specific Conductance (mS)
Elapsed time (hrs)
Event 2
Event 3
Event 4
Event 5
Event 6
Event 7
Event 8
Event 9
Baseline Average

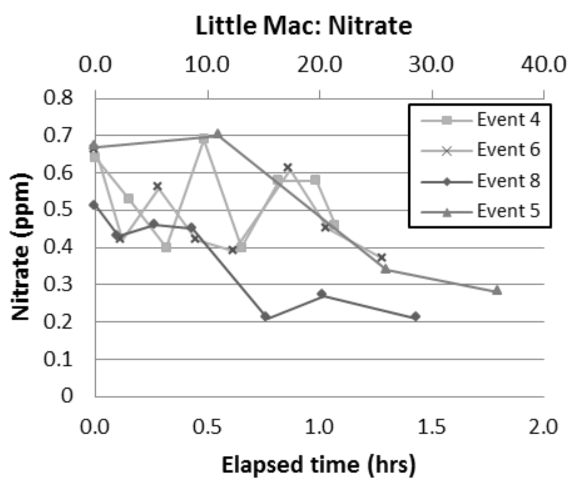

Little Mac: Total Dissolved Solids
Total Dissolved Solids (ppm)
Elapsed time (hrs)
Event 2
Event 3
Event 4
Event 5
Event 6
Event 7
Event 8
Event 9
Baseline Average

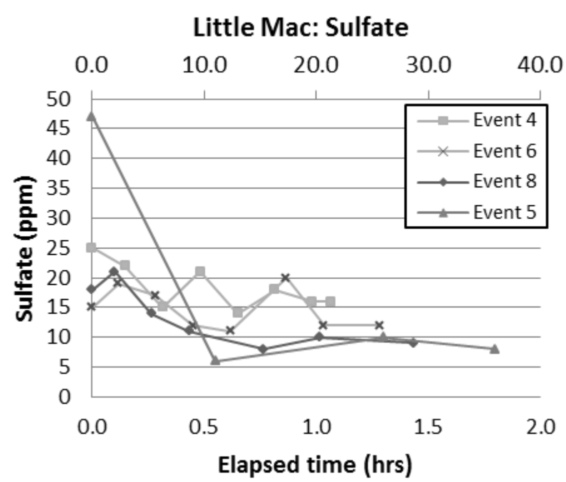

Little Mac: pH
pH
Elapsed time (hrs)
Event 2
Event 3
Event 4
Event 5
Event 6
Event 7


Little Mac: Chloride
Chloride (ppm)
Elapsed time (hrs)
Event 4
Event 6
Event 8


Little Mac: Orthophosphate
Orthophosphate (ppm)
Elapsed time (hrs)
Event 4
Event 6
Event 8
Event 5


Little Mac: Total Phosphate
Total Phosphate (ppm)
Elapsed time (hrs)
Event 4
Event 6
Event 8
Event 3
Event 9
Event 5


Little Mac: Nitrate
Nitrate (ppm)
Elapsed time (hrs)
Event 4
Event 6
Event 8
Event 5


Little Mac: Sulfate
Sulfate (ppm)
Elapsed time (hrs)
Event 4
Event 6
Event 8
Event 5