2018 WATER QUALITY MONITORING REPORT FOR

# SAGAMORE CREEK

FOR THE CITY OF PORTSMOUTH, NH

[June 2019]

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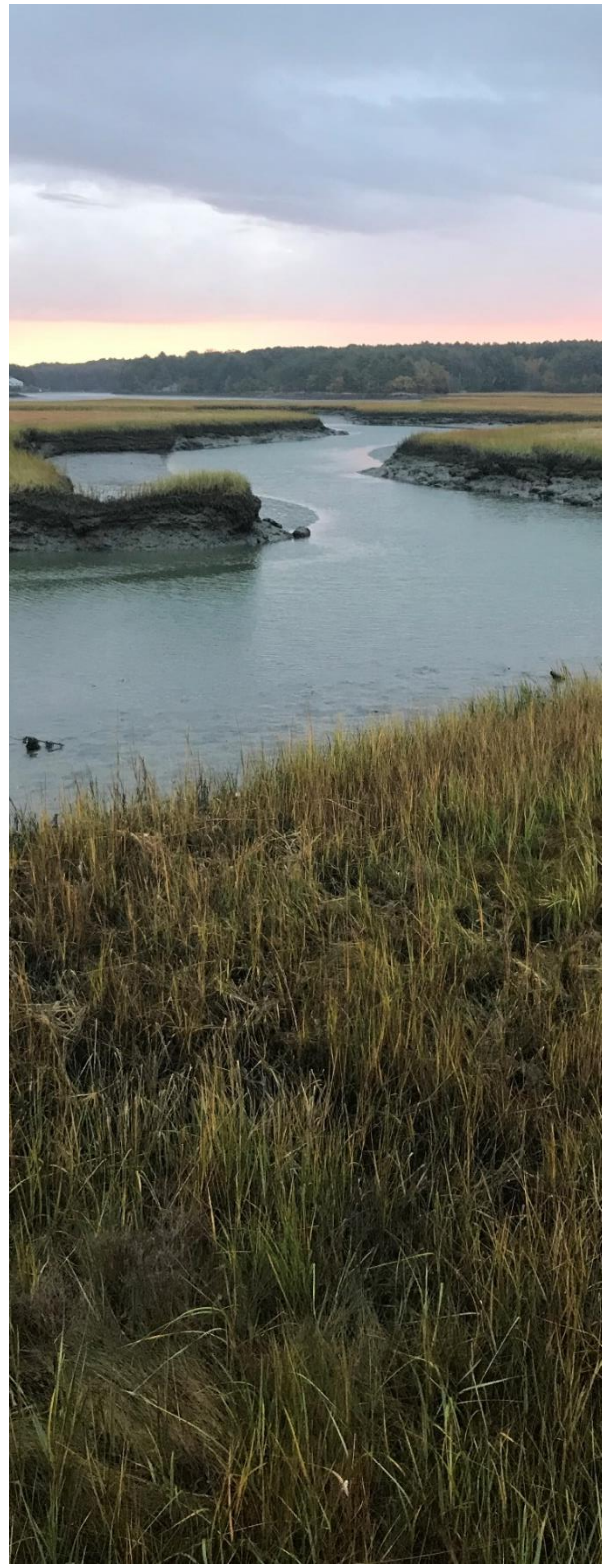
**Foggy morning on Sagamore Creek at LHB19.** Photo credit: FBE.

# BACKGROUND



Located along the New Hampshire coastline near the outlet of the Piscataqua River, Sagamore Creek is a tidally-influenced waterbody, largely characterized by its salt marshes and mudflats that serve as critical habitat for numerous and diverse aquatic and terrestrial species (Figure 1). The Creek is enjoyed by boaters and paddlers alike with several public access points and recreational opportunities along the shoreline.

Although large tracts of conserved land exist within the watershed and help protect important natural resources, the Creek is also intersected by multiple high-traffic roads, including Route 1 and 1A, which are lined with a dense mix of residential, commercial, and industrial buildings largely serviced by municipal separate storm sewer systems. Septic systems are also used at some residences and businesses in the area. Because of the diffuse pollution coming from these developed areas and from legacy human activities in the watershed, the freshwater and estuarine portions of Sagamore Creek are currently listed on the final 2016 and draft 2018 303(d) list of impaired waters in the State of New Hampshire by the New Hampshire Department of Environmental Services (NHDES, 2016, 2018). The estuarine portion of Sagamore Creek is separated into upper and lower sections as designated by the Route 1A bridge. Based on current data, Sagamore Creek does not meet state water quality criteria for the designated uses of aquatic life, fish consumption, and shellfishing due to elevated levels of fecal indicator bacteria, various contaminants in sediment[1] and shellfish tissue[2], and/or poor estuarine bioassessments[3]. The freshwater portion of Sagamore Creek is also listed as impaired for aquatic life use due to elevated chloride and low pH. The draft 2018 303(d) list tentatively added the estuarine portion of Sagamore Creek as impaired for the designated use of aquatic life due to low dissolved oxygen[4]. Other assessment units include Elwyn Brook, a headwater tributary to Sagamore Creek, along with its one-acre impoundment bordering the Department of Public Works (DPW) lot, and an unnamed brook draining to the lower portion of the Creek, crossing under Wentworth Road. Not included in the NHDES assessments are two unnamed freshwater, headwater tributaries: one originating just east of Route 1 and entering the upper salt marsh to the west after flowing under Greenleaf Avenue and the other originating from Portsmouth High School and flowing south past the Winchester Place Apartments to the upper estuary of Sagamore Creek.

In 2018, the City of Portsmouth hired FB Environmental Associates (FBE) to collect data for a multi-year water quality sampling program to further characterize and quantify the type, amount, and location of pollutant input sources to Sagamore Creek and provide a broader understanding of the water quality of Sagamore Creek (Figure 1; FBE, 2018). The work accomplished for the program, including continuous water quality monitoring, synoptic grab sampling, automated 24-hour sampling, and database management, will help inform NHDES 303(d) listing assessments, achieve Great Bay 2020 vision goals, and develop a long-term watershed management plan for Sagamore Creek.

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[1] Sediment samples were collected from the upper estuary at NH00-0021A in 2000, NH04-0221A in 2004, and NH06-0039A in 2006.

[2] Tissue samples were collected from blue mussels and softshell clams from two sites at the mouth of Sagamore Creek from 2003-2013.

[3] Lack of eelgrass habitat.

[4] The City of Portsmouth, along with its Great Bay Municipal Coalition Partners, Dover and Rochester, has advocated for an update of the state's dissolved oxygen criteria to bring them in line with EPA guidance and national standards.

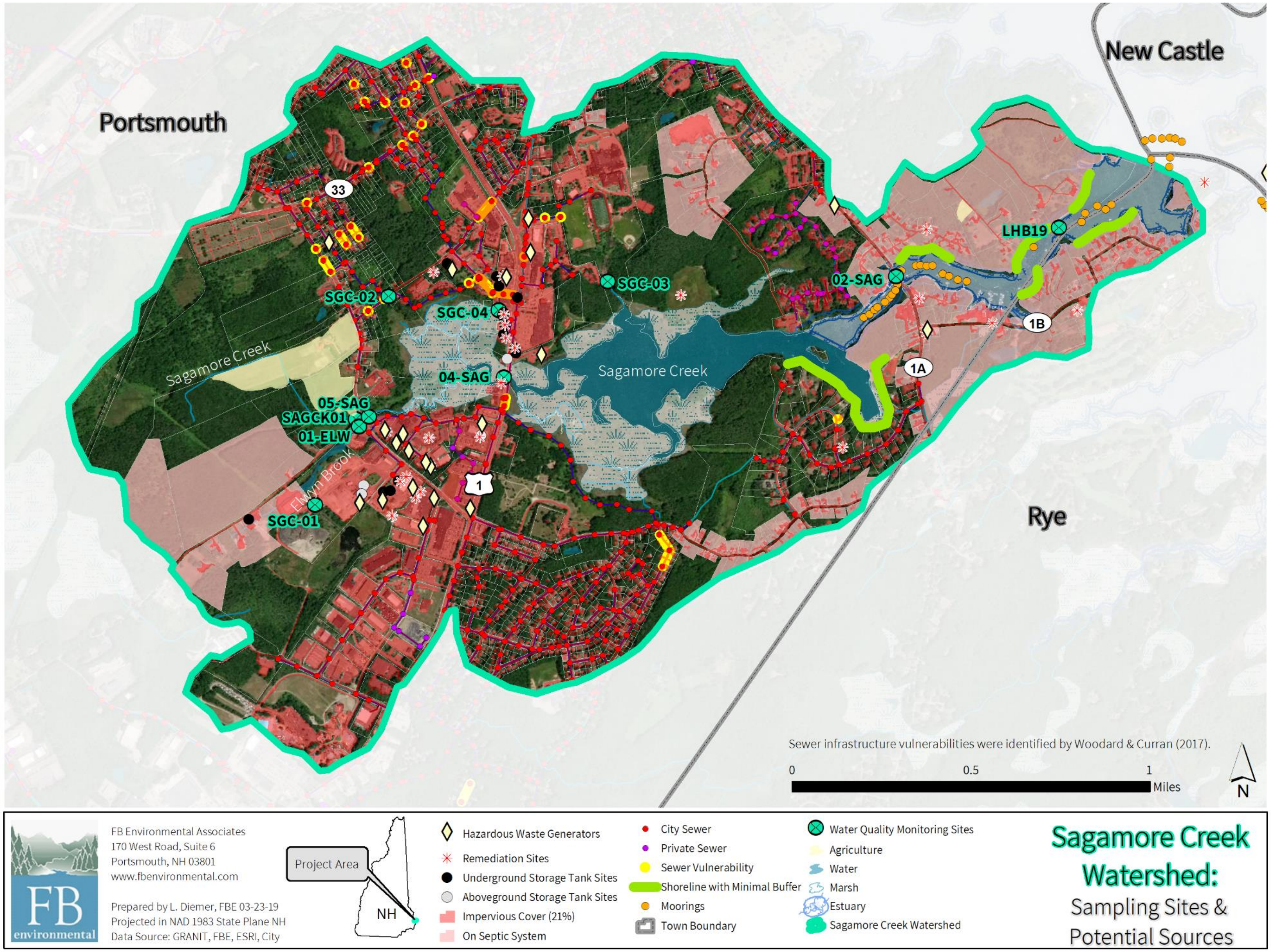


FIGURE 1. Location of 2018 sampling sites and potential contamination sources in the Sagamore Creek watershed.

# WATER QUALITY RESULTS

In 2018, FBE completed the first of two years collecting robust baseline water quality data to better inform the development of a watershed management plan for Sagamore Creek. The baseline water quality sampling builds upon existing datasets at sites that have multiple years of data, adds new sites that provide better spatial coverage of the watershed, expands the type of parameters measured, and extends the temporal coverage of collected data to account for intra- and inter-annual variation because of seasonal and annual patterns.

**TOP:** 04-SAG on 8/1/18 during logger deployment. The anchor line can be seen connecting the loggers underwater to the telephone pole. Photo: FBE.

**BOTTOM:** FBE Scientist, Amanda Gavin, deploying a data sonde at 02-SAG via kayak. Photo: FBE.

## CONTINUOUS MONITORING (DATA SONDES)

Continuous data provide valuable baseline information that can capture nuanced changes in water chemistry because of precipitation events, seasonal or daily fluctuations, tidal inundation, etc. Continuous data can also inform interpretation of grab sampling results. Two sites (04-SAG and 02-SAG) were monitored continuously at 15-minute intervals from 8/1/18 to 10/16/18 for dissolved oxygen, conductance, water level, temperature, pH, and turbidity using AquaTROLL 600 multiparameter data sondes rented from US Environmental. Water level was relative and served only to assign tidal position to any given point. Data sondes were secured to weighted crates so that the sondes sat in place above bottom sediments, and the crates were tethered to a solid land-based object (e.g., tree). Data sondes were maintained bi-weekly by taking in-field readings with calibrated field meters before and after sensor cleanings and were swapped out once with freshly-calibrated data sondes. Quality assurance and quality control of the data followed the USGS Guidelines and Standard Procedures for Continuous Water-Quality Monitors (http://pubs.usgs.gov/tm/2006/tm1D3/), as well as the AquaTROLL 600 user manual and best professional judgement.

The upper estuary (04-SAG) of Sagamore Creek experienced large swings in daily dissolved oxygen, specific conductance, pH, and temperature compared to the lower estuary (02-SAG) due to the combined influence of both freshwater and marine waters to the upper estuary and the dominance of marine waters to the lower estuary (Figures 2-3). Moderate to large precipitation events caused dilution of specific conductance in both the upper and lower estuaries as freshwater runoff contributed significant inflows to the Creek. Conversely, turbidity generally spiked following significant precipitation events and was consistently higher and more variable in the upper estuary than the lower estuary. Boating activities in the lower estuary may help explain elevated turbidity not associated with precipitation events. Specific conductance and pH were higher at high tide and lower at low tide for both the upper and lower estuaries though not as strongly at low tide in the lower estuary, likely due to the weaker influence of freshwater inputs (Appendix A). Temperature was highly related to tides (cooler at high tide and warmer at low tide) in the lower estuary; temperature was more variable in the upper estuary (but was generally cooler during high tide). Dissolved oxygen was variable and not highly related to tides (but was generally higher during high tide).

Dissolved oxygen at 04-SAG exceeded the current state criterion of 5 mg/L for 65% of days (using minimum daily value) and 10% all sonde data points collected every 15 minutes in the state-defined critical period (May 24-Sept 15) in 2018 (Figure 2). Dissolved oxygen at 02-SAG exceeded 5 mg/L on 12 days in the critical period but only exceeded the magnitude of exceedance threshold (MAGEX) of 4.5 mg/L on one day (13 sonde data points), suggesting that these exceedances were within the reasonable variability of measurement error and likely do not reflect an aquatic life use impairment (Figure 3). Low dissolved oxygen measured in the upper estuary may indicate excess nutrients and/or organic matter entering the Creek. Excess nutrients can stimulate rapid growth of algae and other aquatic plants; excess organic matter has a high potential biological oxygen demand as its decomposition can deplete oxygen in the water column, creating stressful conditions for aquatic organisms. Both the upper and lower estuaries also regularly fell below the state criterion of 8-8.5 pH for tidal waters.

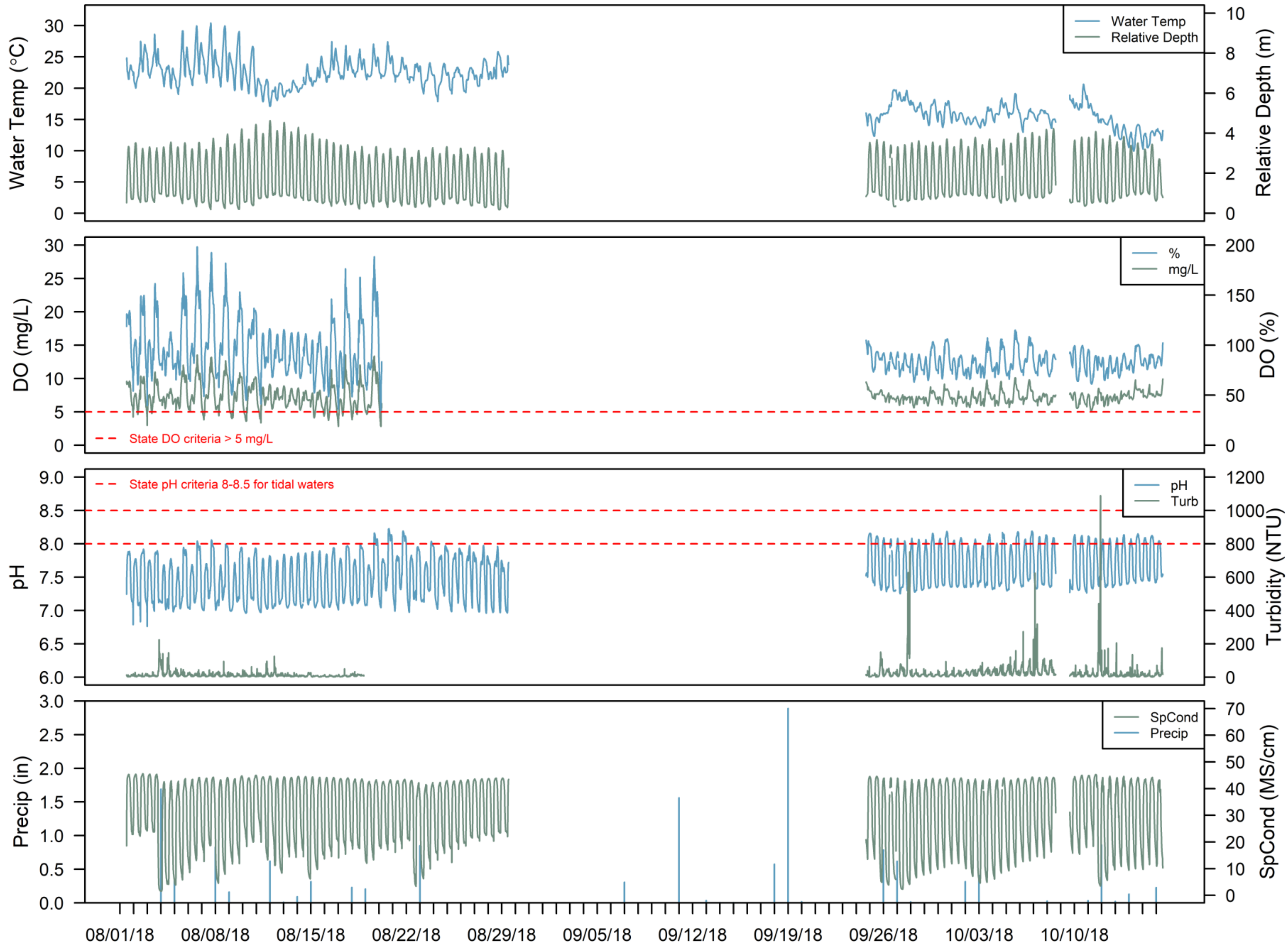


FIGURE 2. Continuous sonde data collected in the upper estuary of Sagamore Creek at Route 1 (04-SAG).

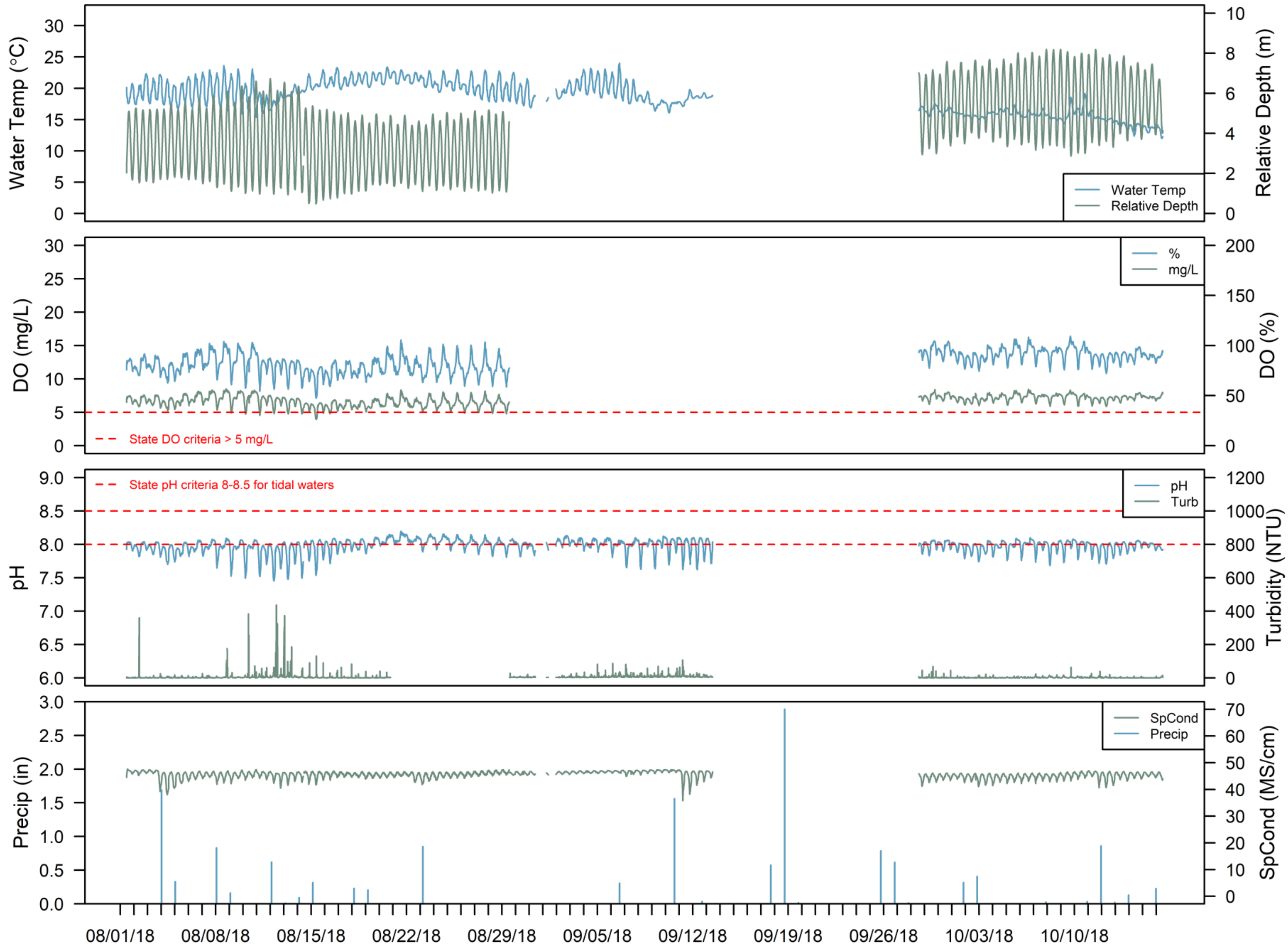


FIGURE 3. Continuous sonde data collected in the lower estuary of Sagamore Creek at Route 1A (02-SAG).

## SYNOPTIC SAMPLING (GRAB SAMPLES)

FBE conducted sampling at ten sites throughout the Sagamore Creek watershed on six dates (four dry and two wet weather events[5]) from July-December 2018. Sampling of tidal sites (SGC-04, 04-SAG, SGC-03, 02-SAG, and LHB19) occurred within ±2 hours of both high and low tide; sampling of freshwater sites (SGC-01, 01-ELW, SAGCK01, 05-SAG, and SGC-02) occurred during low tide only. Samples collected from tidal and freshwater sites were analyzed for Enterococci and *E. coli,* respectively, by Absolute Resource Associates (ARA), except for samples collected on 7/2-3/18, which were analyzed at Nelson Analytical Laboratory due to the holiday laboratory schedule of ARA. Samples were also analyzed for dissolved organic carbon (DOC), particulate carbon (PC), particulate nitrogen (PN), total dissolved nitrogen (TDN), nitrate-nitrite, ammonium, ortho-phosphate, and total suspended solids (TSS) by the University of New Hampshire (UNH) Water Quality Analysis Laboratory (WQAL). Chlorophyll-a was analyzed by the UNH Jackson Estuarine Laboratory (JEL). Temperature, dissolved oxygen, salinity, and specific conductivity were collected using a YSI handheld meter, pH using an Oakton pH Testr®30, and chloride using HACH Chloride QuanTab test strips. Refer to Appendix B for a review of quality assurance and quality control procedures and adherence.

Refer to Tables 1 and 2 for a summary of grab sample results, which include all 2018 data from both synoptic and 24-hour sampling. Additional figures can be found in Appendix C. The following summarizes general observations from 2018 grab sample results:

- **SGC-01** had elevated nutrients (TDN and nitrate-nitrite), as well as chloride concentrations that exceeded the state chronic criterion of 230 mg/L both for overall average (246 mg/L) and for four out of six single-samples (SGC-01 reached a maximum single-sample of 363 mg/L on 8/29/18 during baseflow conditions). Downstream of SGC-01, **01-ELW** also had elevated nutrients (TDN only) and chloride concentrations that exceeded the state chronic criterion not for overall average (190 mg/L) but for three out of six single-samples (01-ELW reached a maximum single-sample of 296 m/L on 8/29/18 during baseflow conditions). The lower nutrient and chloride levels at 01-ELW compared to SGC-01 are likely due to both dilution effects and storage within the impoundment of Elwyn Brook, just before it crosses under Banfield Rd and joins with Sagamore Creek. These high levels of chloride in Elwyn Brook are fatal for many sensitive aquatic species. Salinization of freshwater streams can mobilize nutrients and thus may be the cause of elevated TDN and nitrate-nitrite in Elwyn Brook. We recommend that the drainage area to Elwyn Brook be investigated for road salt application areas and rates, as well as possible road salt storage or staging areas, to reduce or minimize chloride runoff to surface waters.
- **SAGCK01** exceeded the state geomean criterion of 126 mpn/100mL for *E. coli* (driven by a high single-sample of >2,419 mpn/100mL following wet weather on 7/18/18) and had elevated nutrients (TDN and ammonium), particulates (carbon and nitrogen), and suspended solids. SAGCK01 also had the highest single-sample phosphate concentration at 47 µg/L on 8/29/18 during baseflow conditions. These elevated parameters are likely generated by upstream agricultural land use. A portion of Sagamore Creek flows through agricultural fields with minimal buffer near several horse paddocks. We recommend that a comprehensive nutrient management plan be completed for the horse farm in coordination with the Natural Resources Conservation Service (NRCS).
- **SGC-02** exceeded the state geomean criterion of 126 mpn/100mL for *E. coli* (driven by four out of six samples exceeding the single-sample criterion of 406 mpn/100mL) and had elevated chloride (one sample of 296 mg/L on 7/3/18 exceeded the state chronic criterion) and nutrients (TDN and nitrate-nitrite). Generally, and in contrast to patterns observed at most other sites, more dry-weather exceedances for *E. coli* were observed (similarly for nitrate-nitrite), suggesting possible groundwater fecal contamination sources. Residential development serviced by sewer with identified vulnerabilities (refer to FBE (2018) for more details) drain to SGC-02 and may be a possible source of contamination. Further investigation is required.
- **SGC-04** and **SGC-03** exceeded the state geomean criterion of 35 mpn/100mL for Enterococci (driven by high single-samples near or >2,419 mpn/100mL following wet weather on 7/18/18) and had elevated nutrients (TDN and nitrate-nitrate for both sites, plus ammonium for SGC-04 with a maximum observation of 657 µg/L on 7/3/18 at low tide). SGC-04 also had the highest chlorophyll-a concentrations (and the warmest temperatures) of the sampled sites, likely due to the elevated nutrients and warm waters stimulating biological growth; a bloom (110 µg/L) was observed at the site on 8/28/18 during baseflow conditions. Both sites drain highly-urban areas that are serviced by sewer with identified vulnerabilities (refer to FBE (2018) for more details) and that contain large expanses of impervious surfaces (e.g., roads, buildings, parking lots, etc.)

[5] Conditions were considered "wet" if nearby weather stations recorded any of the following: >0.1" of precipitation in the prior 24 hours; or >0.25" in the prior 48 hours; or >2.0" in the prior 96 hours. Larger precipitation events were sampled when possible. Dry weather conditions were defined as periods when precipitation was less than 0.1" for each day within 72 hours.

conveying stormwater runoff to surface waters. Stormwater runoff from highly-urban areas can contain nutrients and other harmful pollutants from atmospheric deposition, vehicle exhaust and fluids, hazardous waste spills or leaks, pet waste, chemical fertilizers, and concentrated grass clippings or leaf litter. We recommend completing a retrofit survey of the drainage areas to SGC-04 and SGC-03 to identify possible remediation sites that would disconnect impervious surfaces and treat stormwater runoff prior to entering Sagamore Creek. SGC-03, which was consistently elevated for Enterococci regardless of tides, may also be impacted by fecal contamination introduced by Canada geese observed in the summer or possibly from known homeless camps in the area; further investigation is required.

**SGC-03** was often observed being used by a flock of Canada geese (**Left:** 7/2/18). Canada geese are a notorious source of fecal contamination to waterways. SGC-03 is also influenced by tidal cycles and can be seen at low tide on 7/18/18 (**Center**) and high tide on 12/3/18 (**Right**). During the 12/3/18 high tide following a rain event, water can be seen rising up over the bank and flooding the grassy area where the Canada geese once grazed. Photos: FBE.

- **04-SAG** exceeded the state geomean criterion of 35 mpn/100mL for Enterococci (driven by high single-samples near or >2,419 mpn/100mL following wet weather on 7/18/18 and a maximum of 19,863 mpn/100mL following a storm event on 9/26/18) and had the greatest range in chlorophyll-a concentrations (high range associated with warm temperatures during low tide, baseflow conditions) of the sampled sites. There are multiple potential sources contributing pollutants to 04-SAG, including sources to the six previously-described sites upstream of 04-SAG, with SGC-04 likely the most significant contributor. An inverted syphon to 04-SAG also connects a low-lying sewer line through the Urban Forestry Center; the sewer line needed regular clean-outs after heavy rains up until about six years ago. A small, uncapped and unlined landfill was used in the 1950's and 1960's in the area around Mirona Road and the former Iafolla property (currently owned by the Portsmouth DPW and PIKE Industries); soil tests and groundwater monitoring have since revealed soil contamination from sludge and other refuse disposal that may also be contaminating the marsh area draining to 04-SAG.

**04-SAG** is influenced by tidal cycles and regularly overflows into an ajacent parking lot during spring or king tides and storm events, possibly carrying pollutants from paved areas into the Creek. **Left:** following a storm event on 12/3/18. **Center**: high tide on 8/28/18. **Right:** low tide on 8/29/18. Photos: FBE.

- **02-SAG** and **LHB19** are both situated within the lower estuary near the outlet to the Piscataqua River between Back Channel and Little Harbor and both exhibited significantly different (generally better) water quality from the next most upstream site in the upper estuary (04-SAG), likely due to the diluting effects of the large volume of water passing through the lower estuary. 02-SAG marginally exceeded the state geomean criterion of 35 mpn/100mL for Enterococci (driven by high single-samples of 1,414 mpn/100mL during high tide and 1,986 mpn/100mL during low tide following wet weather on 7/18/18). The lower estuary is or was impacted by malfunctioning septic systems in both Rye and Portsmouth near Route 1A and Shaw Road; several businesses adjacent to 02-SAG have holding tanks and/or grease traps that must be pumped out twice per week. Historical records also showed at least seven known septic system failures that have deposited raw sewage to the Creek within the last decade or two. There are 38 moorings in the lower estuary that also pose a risk of overboard discharge of sewage or spilled fuel from boats during the boating season. Several areas along the shoreline of Sagamore Creek between 04-SAG and 02-SAG have minimal buffer with a high potential for untreated stormwater runoff, possibly carrying fertilizers or other chemicals to the Creek. As part of a Consent Decree, the City of Portsmouth will be undertaking sewer system improvements and extending the sewer system to areas along Route 1A.

TABLE 1. Average 2018 field measurements for Sagamore Creek. Bold, italicized red or orange text indicates results exceeding state criteria and natural background or suggested levels, respectively.

| Site ID | Temp (°C) | DO Sat (%) | DO (mg/L) | pH | Salinity (PSU) | Specific Cond (µS/cm) | Chloride (mg/L) |
|---|---|---|---|---|---|---|---|
| Freshwater | 24-28 | 75 | 5.0 | 6.5-8.0 | 0.5 | 835 | 230 |
| **SGC-01** | 15.9 | ***67*** | 6.9 | 8.0 | ***0.6*** | ***1,136*** | ***246*** |
| **01-ELW** | 15.2 | ***57*** | 6.2 | ***8.1*** | 0.5 | ***895*** | 190 |
| **SAGCK01** | 13.6 | ***51*** | 6.0 | 7.2 | 0.1 | 130 | 14 |
| **05-SAG** | 15.0 | ***58*** | 6.3 | 7.8 | 0.4 | 762 | 156 |
| **SGC-02** | 13.7 | 85 | 9.1 | ***8.4*** | 0.4 | ***916*** | 181 |
| Tidal | 24-28 | 75 | 5.0 | 8.0-8.5 | NA | NA | NA |
| **SGC-04** | 18.1 | 75 | 7.1 | ***7.8*** | 6.8 | 11,683 | |
| **04-SAG** | 16.8 | ***61*** | 6.0 | ***7.9*** | 17.9 | 28,619 | |
| **SGC-03** | 16.3 | 79 | 7.8 | 8.2 | 9.3 | 14,463 | 409 |
| **02-SAG** | 15.4 | ***61*** | 6.2 | 8.3 | 28.3 | 43,860 | |
| **LHB19** | 14.7 | ***66*** | 6.7 | 8.6 | 29.5 | 45,798 | |

TABLE 2. Average 2018 laboratory analysis results for Sagamore Creek. Bold, italicized red or orange text indicates results exceeding state criteria and natural background or suggested levels, respectively. DOC = dissolved organic carbon; PC = particulate carbon; PN = particulate nitrogen; TDN = total dissolved nitrogen; $NO_3$+$NO_2$ = nitrate and nitrite; $NH_4$ = ammonium; $PO_4$ = ortho-phosphate; TSS = total suspended solids; Chl-a = chlorophyll-a.

| Site ID | Entero (MPN /100mL) | *E. coli* (MPN /100mL) | DOC (mg C/L) | PC (mg C/L) | PN (mg N/L) | TDN (mg N/L) | $NO_3$+$NO_2$ (mg N/L) | $NH_4$ (µg N/L) | $PO_4$ (µg P/L) | TSS (mg/L) | Chl-a (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Freshwater** | NA | 126 | NA | NA | 0.20 | 0.20 | 0.20 | 200 | 24 | 30 | 15.00 |
| **SGC-01** | | 49 | 4.68 | 1.61 | 0.12 | ***0.49*** | ***0.26*** | 71 | 5 | 7 | 2.93 |
| **01-ELW** | | 56 | 6.46 | 0.91 | 0.12 | ***0.39*** | 0.08 | 16 | 7 | 4 | 2.69 |
| **SAGCK01** | | ***133*** | 14.85 | 4.55 | ***0.43*** | ***0.67*** | 0.03 | 9 | 20 | 21 | 2.17 |
| **05-SAG** | | 31 | 7.32 | 0.72 | 0.16 | ***0.38*** | 0.06 | 17 | 10 | 8 | 2.85 |
| **SGC-02** | | ***592*** | 6.10 | 0.42 | 0.05 | ***0.64*** | ***0.39*** | 15 | 18 | 4 | 0.31 |
| **Tidal** | 35 | NA | NA | NA | 0.57 | 0.57 | 0.31 | 310 | 24 | 30 | 20.00 |
| **SGC-04** | ***106*** | | 4.21 | 1.53 | 0.21 | ***0.96*** | ***0.62*** | 208 | 10 | 21 | 11.92 |
| **04-SAG** | ***118*** | | 4.96 | 1.40 | 0.18 | 0.42 | 0.11 | 75 | 20 | ***37*** | 6.62 |
| **SGC-03** | ***164*** | | 4.97 | 0.77 | 0.10 | ***0.60*** | ***0.34*** | 32 | 16 | 11 | 5.63 |
| **02-SAG** | ***36*** | | 2.22 | 0.62 | 0.09 | 0.21 | 0.07 | 25 | 19 | 18 | 3.56 |
| **LHB19** | 24 | | 2.09 | 0.37 | 0.05 | 0.19 | 0.05 | 25 | 20 | 14 | 1.34 |

## 24-HOUR SAMPLING (GRAB SAMPLES)

Collecting samples over a lunar day (just over 24 hours) that captures two or more full tidal cycles can highlight changes in water quality because of both tide and daily fluctuations that would otherwise be missed during regular sampling. Following protocols set forth in the Great Bay Estuary Water Quality Monitoring Program QAPP 2018 and the National Estuarine Research Reserves System Wide Monitoring Program (SWMP), an automated sampler (ISCO6700) was deployed at 04-SAG and was set to collect 48 one-liter samples every 2 hours, 4 minutes over the course of eight full tidal cycles from 9/24-28/18 before, during, and after two small rain events (0.90” on 9/25/18 and 0.70” on 9/26/18). Samples were analyzed for the same parameters and by the same laboratories as for the synoptic sampling for tidal sites. A subset of 30 out of the 48 samples were analyzed for Enterococci due to conflicts with maximum hold times (6 hours) and laboratory operation hours.

**Automated sampler deployed at 04-SAG from 9/24-28/18**. Photo: FBE.

Refer to Appendix D for time-series figures. The following summarizes general observations from 2018 automated grab sample results:

- The timing and magnitude of storm events play important roles in water quality response. For instance, the first storm on 9/25/18 occurred over low tide, while the second storm on 9/26/18 occurred over high tide (causing a delay in the response signal) and after system flushing from the first storm (causing a dampening in the response signal).
- Most water quality parameters were higher during low tide and wet weather, likely due to a combination of freshwater inputs (landscape flushing), bank “sloughing”, and reduced flow volume (concentration). For chlorophyll-a, low tide generally exhibits low turbidity and high potential light penetration that can increase primary production or biological growth. One exception to the pattern of higher observed concentrations during low tide was ortho-phosphate, which showed a reverse pattern of higher during high tide and lower during low tide and increased in concentration from upstream to downstream, suggesting a marine source of phosphorus. One exception to the pattern of higher observed concentrations during wet weather was TDN, which generally diluted following both storm events and increased or concentrated with each subsequent low tide until baseflow conditions were achieved. Baseflow is the dry-weather period when streamflow is largely supplied by groundwater, wetlands, impoundments, or other forms of stored water within the watershed. During baseflow, waterborne pollutants may become concentrated by evaporation and transpiration, and contaminated groundwater or impounded water may become more pronounced in the absence of diluting precipitation.
- Most water quality parameters showed near-full recovery to baseflow conditions by 9/28/18 following the two storm events (48-hr recovery window). Exceptions included nitrate-nitrite and ammonium which had minimal response to both storm events, as well as chlorophyll-a and ortho-phosphate (at low tide).
- Before the first storm event, turbidity was largely controlled by mechanical action of tides (seen by increases during high to slack tides), but after the first and second storm events, turbidity was largely controlled by landscape flushing of materials to the Creek (seen by increases during low tides).
- A significant increase in particulate carbon was observed on the second low tide following the first storm event, suggesting a delayed input from the upstream headwaters of Sagamore Creek (likely from sources to SAGCK01).
- The amplitude of change in chlorophyll-a from low to high tide greatly diminished after the first storm, likely from the flushing of algae and plant material, as well as the increase in turbidity and suspended materials that blocked sunlight

needed for growth. Dissolved oxygen collected by the data sonde also showed a gradual decline in dissolved oxygen over the course of the two storm events, with peaks in oxygen correlated to peaks in chlorophyll-a at low tide.

- 04-SAG experienced dead low tide at variable points in time closer or further from the transition to ebbing tides, depending on the lunar phase. Low tide range was also truncated compared to the open waters of Portsmouth Harbor due to the higher elevation of 04-SAG. This has important flushing implications for the upper estuary.

# DATABASE MANAGEMENT

A database was created for the Sagamore Creek watershed to house relevant data collected by various groups. FBE first obtained validated data through 2018 from the NHDES Environmental Monitoring Database (EMD) for incorporation to the database. Water quality measurements were collected in 2018 by the NHDES at the Witch Cove Marina (LHB8). Data collected by FBE in 2018 were quality assured and quality controlled before being submitted to the NHDES for final review and validation. FBE also completed the following actions to add to the database:

- FBE contacted Andrew Chapman of NHDES to schedule a fish survey of the freshwater portion of Sagamore Creek (05-SAG) in summer 2019.
- FBE compiled avian wildlife data (including the date, count, and species) from the eBird online database for locations (notably the Urban Forestry Center and Creek Farm) within the Sagamore Creek watershed. Most records were collected from 2015 to 2019, but some records extended back to 1997. A total of 190 different avian species were reported.
- FBE obtained water level and temperature data from Deirdre Barrett, a teacher at Portsmouth High School through the Department of Life Sciences. Pressure and temperature measurements were recorded at 30-minute intervals from 12/23/16 through 5/23/17 using an Onset® HOBO water level data logger deployed off a dock piling near the Elks Lodge.

FBE will continue to compile existing data to better inform new monitoring data and maintain an ongoing database for the Creek. The database will be housed and maintained by FBE and will be made available upon request by the City.

**Fall foliage at Sagamore Creek. View from 02-SAG.** Photo credit: FBE.

# CONCLUSIONS AND NEXT STEPS

## CONCLUSIONS

- Continuous data collected during the critical period (May 24-Sept 15) in 2018 showed an aquatic life use impairment due to low dissolved oxygen in the upper estuary, but likely not the lower estuary, of Sagamore Creek. Low dissolved oxygen measured in the upper estuary may indicate excess nutrients and/or organic matter entering the Creek.
- SGC-01 and 01-ELW both had elevated levels of nutrients and chloride. These high levels of chloride in Elwyn Brook are fatal for many sensitive aquatic species. Salinization of freshwater streams can mobilize nutrients and thus may be the cause of elevated TDN and nitrate-nitrite in Elwyn Brook.
- SAGCK01 had elevated levels of fecal indicator bacteria, nutrients, particulates, and suspended solids. These elevated parameters are likely generated by upstream agricultural land use. A portion of Sagamore Creek flows through agricultural fields with minimal buffer near several horse paddocks.
- SGC-02 had elevated levels of fecal indicator bacteria, nutrients, and chloride. Generally, and in contrast to patterns observed at most other sites, more dry-weather exceedances for *E. coli* were observed (similarly for nitrate-nitrite), suggesting possible groundwater fecal contamination sources. Residential development serviced by sewer with identified vulnerabilities (refer to FBE (2018) for more details) drain to SGC-02 and may be a possible source of contamination.
- SGC-04 and SGC-03 had elevated levels of fecal indicator bacteria, nutrients, and/or chlorophyll-a. Both sites drain highly-urban areas that are serviced by sewer with identified vulnerabilities (refer to FBE (2018) for more details) and that contain large expanses of impervious surfaces (e.g., roads, buildings, parking lots, etc.) conveying stormwater runoff to surface waters. Stormwater runoff from highly-urban areas can contain nutrients and other harmful pollutants from atmospheric deposition, vehicle exhaust and fluids, hazardous waste spills or leaks, pet waste, chemical fertilizers, and concentrated grass clippings or leaf litter.
- 04-SAG had elevated levels of fecal indicator bacteria and chlorophyll-a. There are multiple potential sources contributing pollutants to 04-SAG, including sources to the six sites upstream of 04-SAG, with SGC-04 likely the most significant contributor. An inverted syphon to 04-SAG also connects a low-lying sewer line through the Urban Forestry Center; the sewer line needed regular clean-outs after heavy rains up until about six years ago. A small, uncapped and unlined landfill was used in the 1950's and 1960's in the area around Mirona Road and the former Iafolla property (currently owned by the Portsmouth DPW and PIKE Industries); soil tests and groundwater monitoring have since revealed soil contamination from sludge and other refuse disposal that may also be contaminating the marsh area draining to 04-SAG.
- 02-SAG and LHB19 exhibited generally better water quality compared to the upper estuary (04-SAG). 02-SAG marginally exceeded the state geomean criterion for fecal indicator bacteria due to elevated counts during wet weather. The lower estuary is or was impacted by malfunctioning septic systems in both Rye and Portsmouth near Route 1A and Shaw Road; several businesses adjacent to 02-SAG have holding tanks and/or grease traps that must be pumped out twice per week. Historical records also showed at least seven known septic system failures that have deposited raw sewage to the Creek within the last decade or two. There are 38 moorings in the lower estuary that also pose a risk of overboard discharge of sewage or spilled fuel from boats during the boating season. Several areas along the shoreline of Sagamore Creek between 04-SAG and 02-SAG have minimal buffer with a high potential for untreated stormwater runoff, possibly carrying fertilizers or other chemicals to the Creek.
- The timing and magnitude of tides and storm events play important roles in water quality response. Most water quality parameters were higher during low tide and wet weather, likely due to a combination of freshwater inputs (landscape flushing), bank "sloughing", and reduced flow volume (concentration). For chlorophyll-a, low tide generally exhibits low turbidity and high potential light penetration that can increase primary production or biological growth. One exception to the pattern of higher observed concentrations during low tide was ortho-phosphate, which showed a reverse pattern of higher during high tide and lower during low tide and increased in concentration from upstream to downstream, suggesting a marine source of phosphorus. Ortho-phosphate concentrations in Sagamore Creek reflect the typical range of ortho-phosphate concentrations observed in the tidal portion of the Piscataqua River to Portsmouth Harbor (see pg. 67-74 in PREP, 2017), suggesting that phosphorus is likely from the downstream accumulation of inland watershed sources.

### NEXT STEPS

- **Continue the second year of baseline monitoring for Sagamore Creek to replicate 2018 efforts.**
- **Complete a watershed management plan for the Sagamore Creek watershed** that includes the following actions:
  - → Devise and implement a long-term monitoring program for Sagamore Creek that will track improvement or degradation to water quality because of remediation efforts or land use changes.
  - → Develop and implement a robust community education and outreach program for the watershed that addresses possible residential or commercial sources of contamination such as septic systems, fertilizers, trash/litter, buffers, pet waste, etc.
- **Investigate portions of the watershed with degraded water quality** based on 2018 results:
  - → Investigate the drainage area to Elwyn Brook for road salt application areas and rates, as well as possible road salt storage or staging areas, to reduce or minimize chloride runoff to surface waters.
  - → Complete a comprehensive nutrient management plan for the horse farm in coordination with the Natural Resources Conservation Service (NRCS).
  - → Investigate the drainage area to SGC-02 for sewer vulnerabilities (refer to FBE (2018) for more details) that may be contaminating groundwater and review road salt application practices generating chloride contamination to surface and groundwater.
  - → Complete a retrofit survey of the drainage areas to SGC-04 and SGC-03 to identify possible remediation sites that would disconnect impervious surfaces and treat stormwater runoff prior to entering Sagamore Creek.

## REFERENCES

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NHDES. (2016). Final 2016 Section 305(b) and 303(d) Consolidated Assessment & Listing Methodology. R-WD-17-08, November 30, 2017; accessed at: https://www.des.nh.gov/organization/divisions/water/wmb/swqa/2016/documents/r-wd-17-08.pdf.

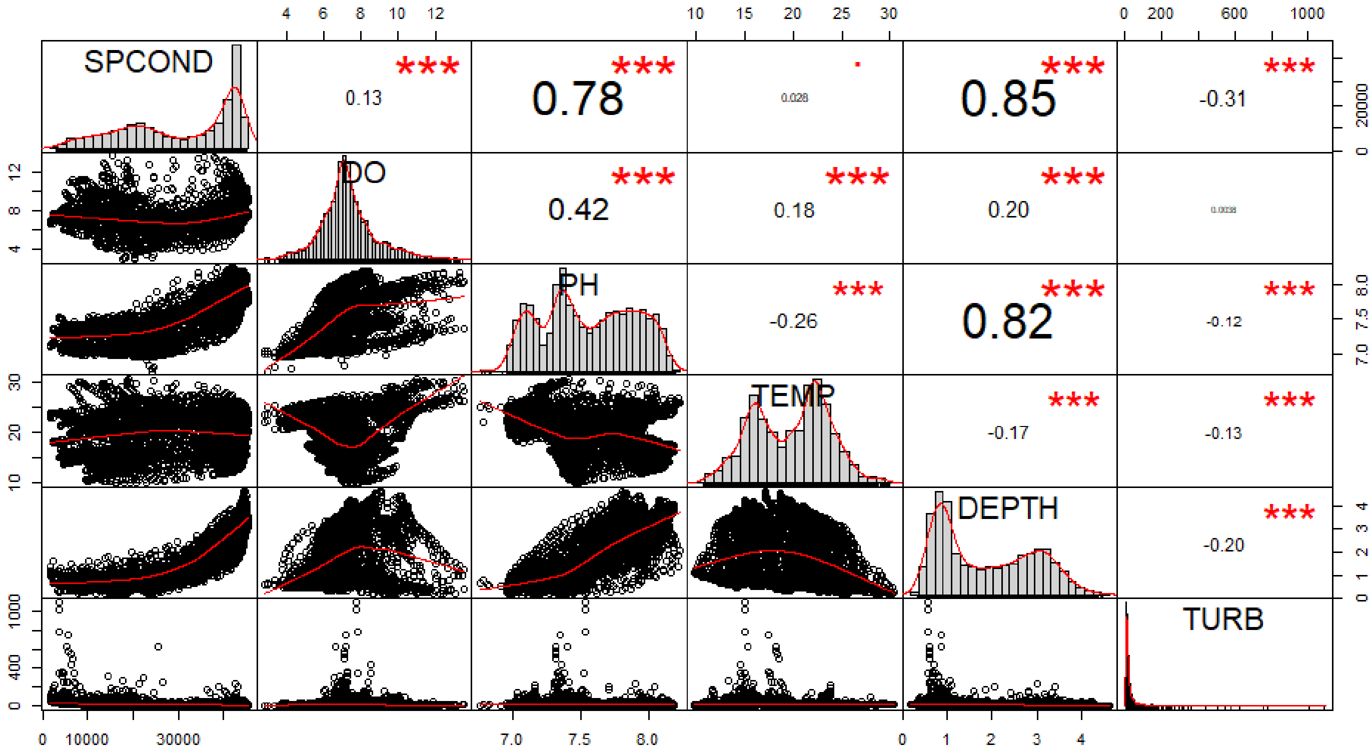
NHDES. (2018). Draft 2018 Section 305(b) and 303(d) Consolidated Assessment & Listing Methodology. R-WD-19-04, January 24, 2019; accessed at: https://www.des.nh.gov/organization/divisions/water/wmb/swqa/2018/documents/r-wd-19-04.pdf.

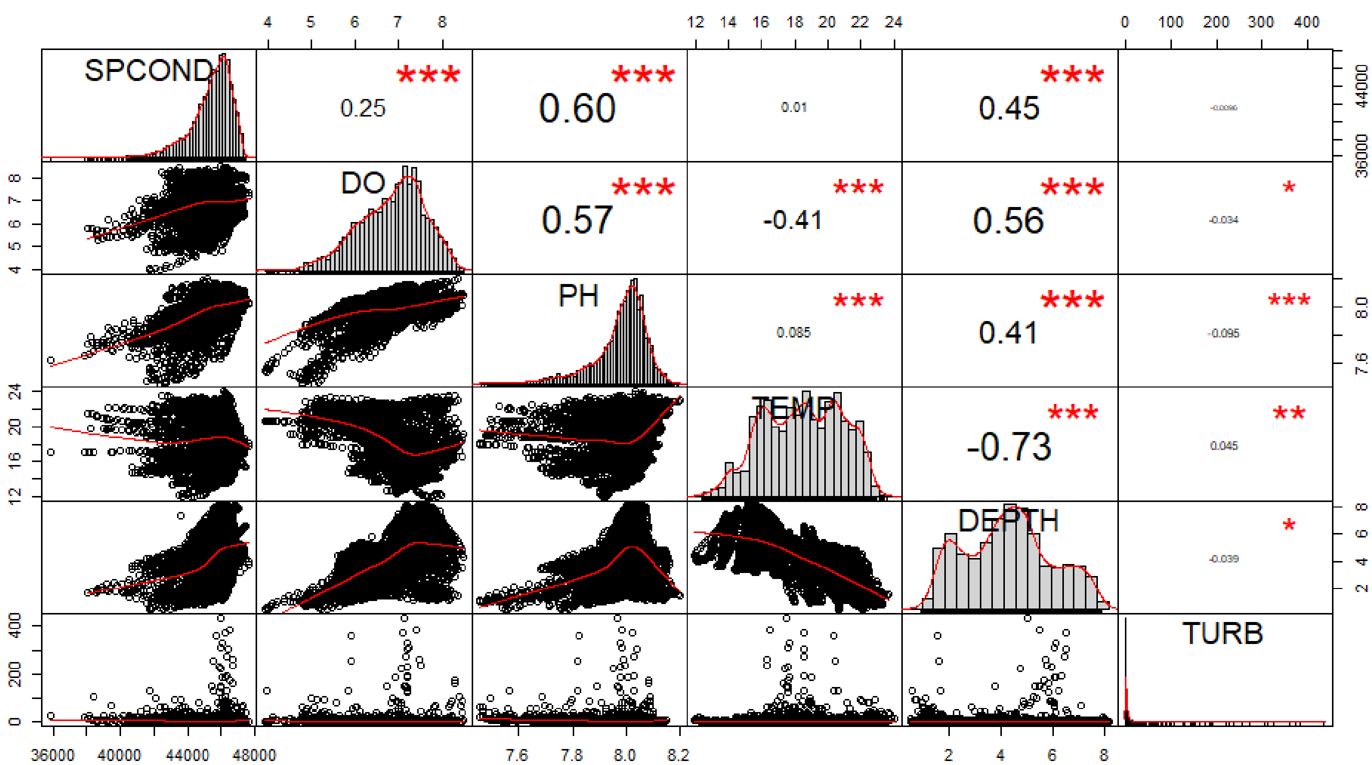
PREP. (2017). Environmental Data Report: Technical Support Document for the 2018 State of Our Estuaries Report. Piscataqua Region Estuaries Partnership, December 2017; accessed at file:///C:/Users/asus/Downloads/a-full-data-report-2018.pdf.

Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A. (2006). Guidelines and standard procedures for continuous water-quality monitors-Station operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods 1–D3, 51 p. + 8 attachments; accessed at http://pubs.water.usgs.gov/tm1d3.

# APPENDIX A: Correlation matrices for continuous data at 04-SAG and 02-SAG

The correlation matrices shown below for 04-SAG (top) and 02-SAG (bottom) were generated in R statistical programming using the package *PerformanceAnalytics.* The distribution of each variable is shown on the diagonal. The bivariate scatterplots with fitted lines are shown below the diagonal. The value and significance of the correlation are shown above the diagonal. Significance levels by symbol are as follows: "***" = <0.001, "**" = 0.001, "*" = 0.01, "-" = 0.05, " " = >0.05.



# APPENDIX B: QA/QC REVIEW

Baseline monitoring conducted in 2018 followed protocols detailed in the Sagamore Creek Water Quality Sampling Program (FBE, 2018). A summary of those protocols and any deviations are described below.

1) A mix of weather conditions across seasons were sampled.
2) All field measurements for dissolved oxygen (mg/L and % saturation) with salinities greater than 9 PSU were corrected.
3) Five samples collected from freshwater sites on 11/2/18 were analyzed by Absolute Resource Associates for Enterococci instead of *E. coli*. Due to this laboratory error, FBE resampled the five freshwater sites on 11/12/18 for *E. coli* and field parameters (not including chloride).
4) Five samples for particulate carbon and nitrogen, one sample for total suspended solids, one sample for nitrate-nitrite, and one sample for dissolved organic nitrogen and total dissolved nitrogen were missing from UNH WQAL results due to misplaced sample bottles or filters and/or broken equipment in need of repair. Some of these missing results will be added to the database later and included in the 2019 analysis.
5) Samples from three tidal sites were collected up to 33 minutes past the 2-hour window surrounding the head of tide on 7/18/18. All fecal indicator bacteria samples were delivered to Absolute Resource Associates within the 6-hour holding time limit. Most samples were delivered to the labs below 10°C. Delivery temperatures above 10°C were acceptable because sample temperatures at the time of collection were greater than 10°C and did not have time between collection and laboratory drop-off to decrease in temperature.
6) All COC forms were complete. FBE used tablets with fulcrum app field forms to complete in the field.
7) Field duplicates for fecal indicator bacteria should attempt to yield a relative percent difference (RPD) <30%, but five out of six duplicate samples resulted in RPDs >30% (Table B1). RPDs >30% can be deemed acceptable given the inherent variability of collecting and measuring biological communities. Typically, higher bacteria counts will be less variable than lower bacteria counts of <200 mpn/100mL. As such, 2018 RPDs ranging from 0-120% were acceptable and reflected a consistent field sampling procedure by personnel.
8) Field duplicates for all other laboratory parameters should attempt to yield an RPD <20% or relative standard deviation (RSD) <30% (Table B1). RPD and RSD values greater than these limits were flagged, and FBE staff contacted laboratory personnel to confirm these values were entered or analyzed properly. Discussions with laboratory personnel determined that there were no transcription errors and analysis reflected a consistent laboratory analysis and field sampling procedure by personnel.

TABLE B1. Summary of relative percent difference (RPD) or relative standard deviation (RSD) between duplicate field samples. One duplicate field sample was taken during each round of low tide sampling.

| Date | Dry/ Wet | Site | Entero (MPN/ 100mL) | *E. coli* (MPN/ 100mL) | RPD | DOC (mg C/L) | RPD | TDN (mg N/L) | RPD | NO3+NO2 (mg N/L) | RPD | PO4 (µg/L) | RPD | TSS (mg/ L) | RPD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/3/2018 | Dry | 04-SAG | 199 | | 80% | 4.73 | 3% | 0.58 | 9% | 0.19 | 1% | 15 | 5% | 33 | 16% |
| | | | 85 | | | 4.58 | | 0.53 | | 0.19 | | 15 | | 28 | |
| 7/18/2018 | Wet | SGC-02 | | >2,419.6 | 0% | 8.61 | 0% | 0.78 | 8% | 0.37 | 4% | 21 | 10% | 7 | 7% |
| | | | | >2,419.6 | | 8.62 | | 0.72 | | 0.35 | | 19 | | 8 | |
| 8/29/2018 ** | Dry | 02-SAG | 20 | | 120% | 2.19 | 48% | 0.20 | 19% | 0.03 | 28% | 25 | 16% | 10 | 16% |
| | | | 5 | | | 3.58 | 34% | 0.25 | | 0.04 | 20% | 22 | | 9 | |
| 10/11/2018 | Dry | SGC-03 | 201 | | 70% | 5.86 | 7% | 0.80 | 9% | 0.59 | 2% | 25 | 35% | 11 | 5% |
| | | | 97 | | | 6.32 | | 0.88 | | 0.58 | | 17 | 25% | 11 | |
| 11/5/2018 * | Dry | SGC-01 | 171 | | 13% | 4.01 | 13% | 0.38 | 9% | 0.15 | 8% | 6 | 6% | 3 | 92% |
| | | | 195 | | | 4.58 | | 0.42 | | 0.14 | | 6 | | 8 | |
| 12/3/2018 | Wet | SGC-04 | 20 | | 67% | 2.44 | 8% | 1.03 | 5% | 0.96 | 1% | 1 | 67% | 3 | 27% |
| | | | 10 | | | 2.66 | | 1.08 | | 0.96 | | 3 | | 3 | |

Note: All duplicate samples were collected during low tide

* Analyzed for Enterococci instead of *E. coli*

** Lab reported <10; FBE used half the reporting limit for calculations

Cells indicating RPD > 20%, but values are below 5 times the method detection limit; therefore, data are acceptable.

Cells indicating RSD <30% or values are low (near 5 x MDL); therefore, data are acceptable

Cells indicating data flagged for elevated field duplicates

TABLE B1 (continued). Summary of relative percent difference (RPD) or relative standard deviation (RSD) between duplicate field samples. One duplicate field sample was taken during each round of low tide sampling.

| Date | Dry/ Wet | Site | PC (mg/L) | RPD | PN (mg/L) | RPD | NH4 (µg/L) | RPD | Chl-a (µg/L) | RPD |
|---|---|---|---|---|---|---|---|---|---|---|
| 7/3/2018 | Dry | 04-SAG | 1.89 | 0% | 0.33 | 5% | 89 | 2% | 44 | 33% |
| | | | 1.89 | | 0.34 | | 91 | | 32 | 24% |
| 7/18/2018 | Wet | SGC-02 | 0.61 | 1% | 0.07 | 1% | 31 | 41% | | |
| | | | 0.62 | | 0.07 | | 47 | 29% | | |
| 8/29/2018 ** | Dry | 02-SAG | 0.66 | 9% | 0.12 | 2% | 28 | 17% | | |
| | | | 0.72 | | 0.12 | | 24 | | | |
| 10/11/2018 | Dry | SGC-03 | 0.75 | 4% | 0.08 | 2% | 42 | 9% | | |
| | | | 0.78 | | 0.07 | | 46 | | | |
| 11/5/2018 * | Dry | SGC-01 | 0.57 | 1% | 0.08 | 1% | 25 | 23% | | |
| | | | 0.57 | | 0.08 | | 31 | | | |
| 12/3/2018 | Wet | SGC-04 | 0.45 | 8% | 0.02 | 46% | 86 | 4% | | |
| | | | 0.49 | | 0.04 | 32% | 89 | | | |

Note: All duplicate samples were collected during low tide

* Analyzed for Enterococci instead of *E. coli*

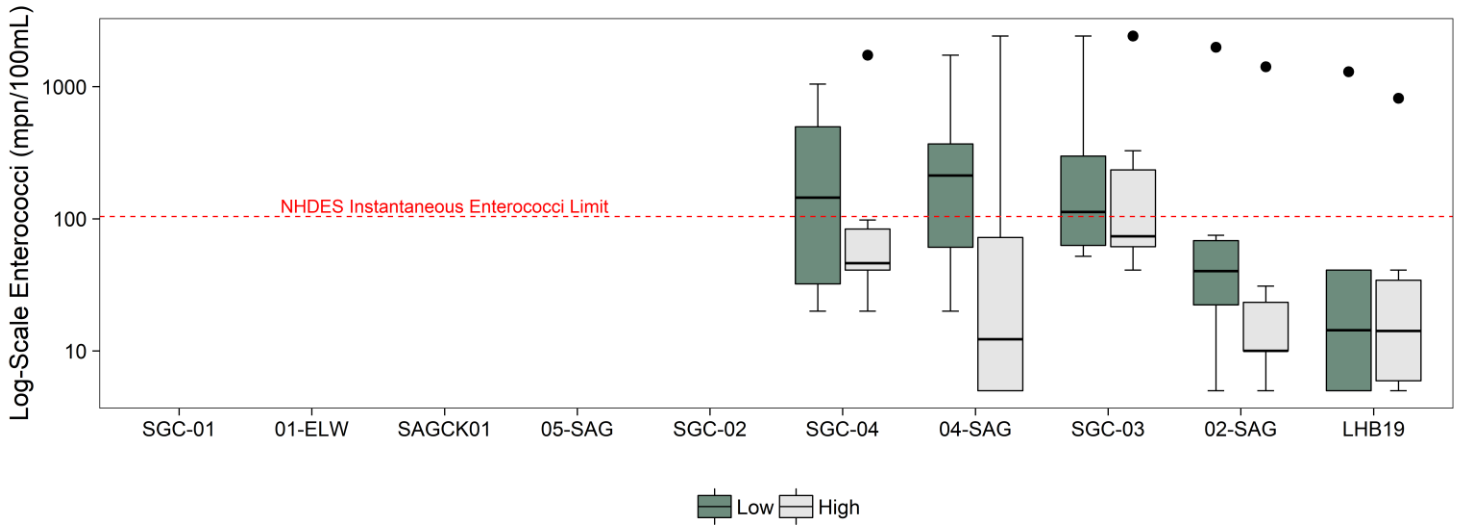
** Lab reported <10; FBE used half the reporting limit for calculations

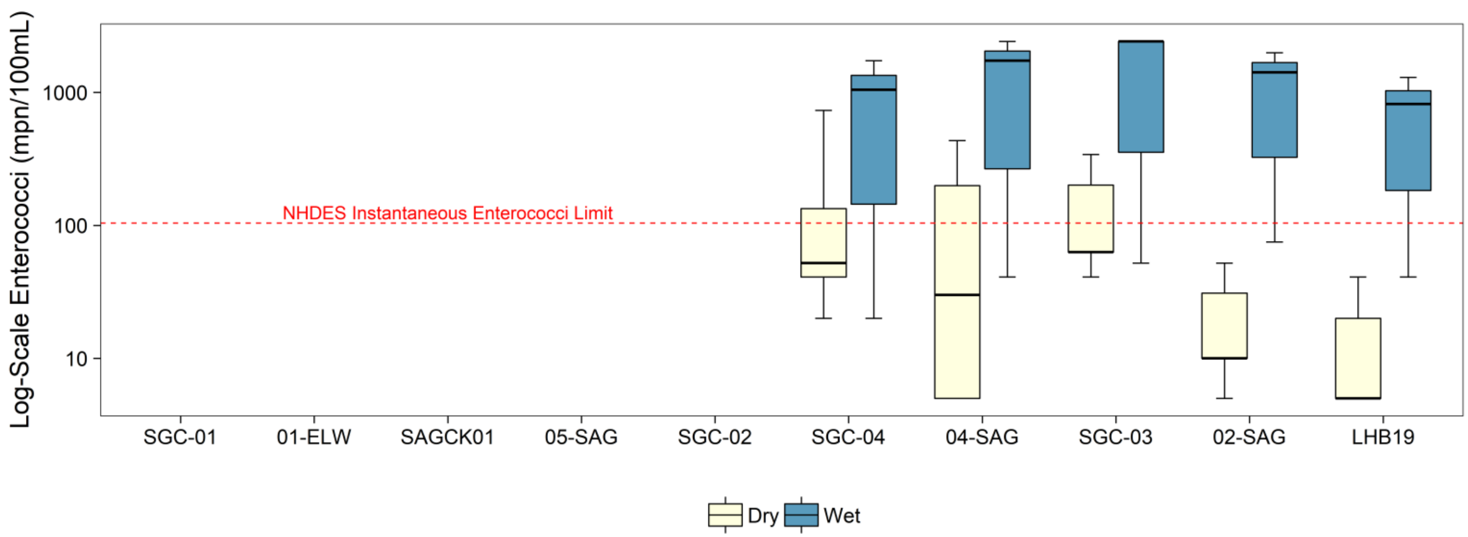
Cells indicating RPD > 20%, but values are below 5 times the method detection limit; therefore, data are acceptable.

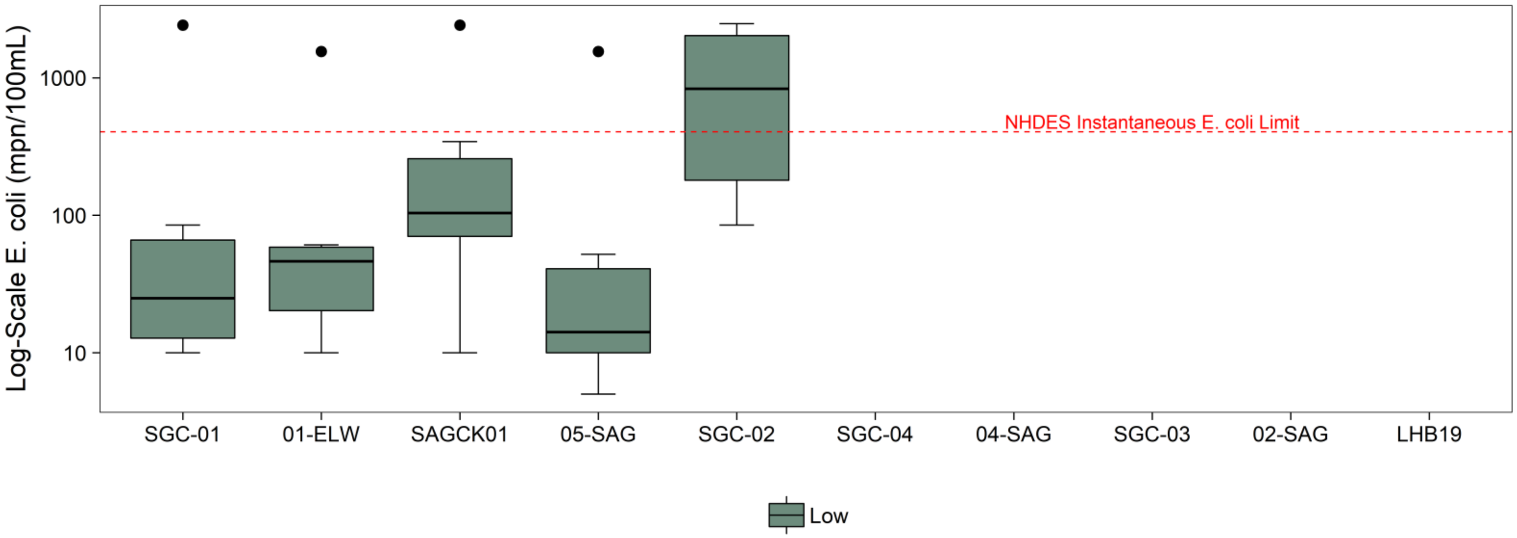
Cells indicating RSD <30% or values are low (near 5 x MDL); therefore, data are acceptable

Cells indicating data flagged for elevated field duplicates

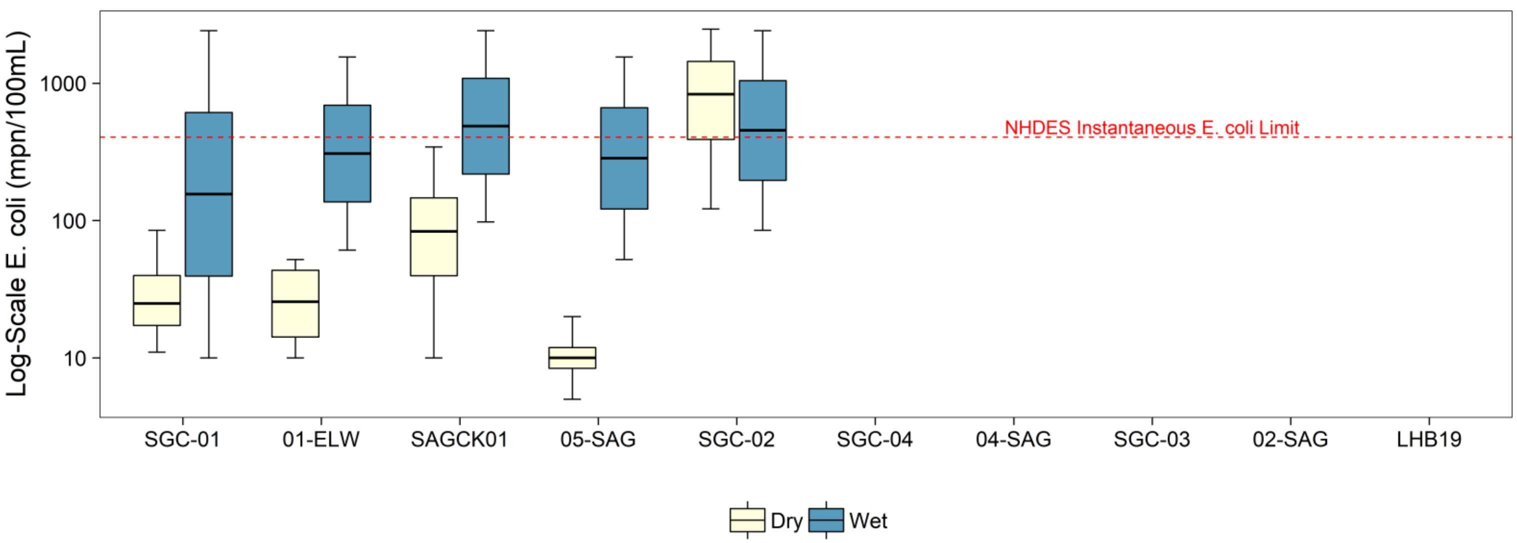
# APPENDIX C: Data figures by tide and weather for Sagamore Creek sites



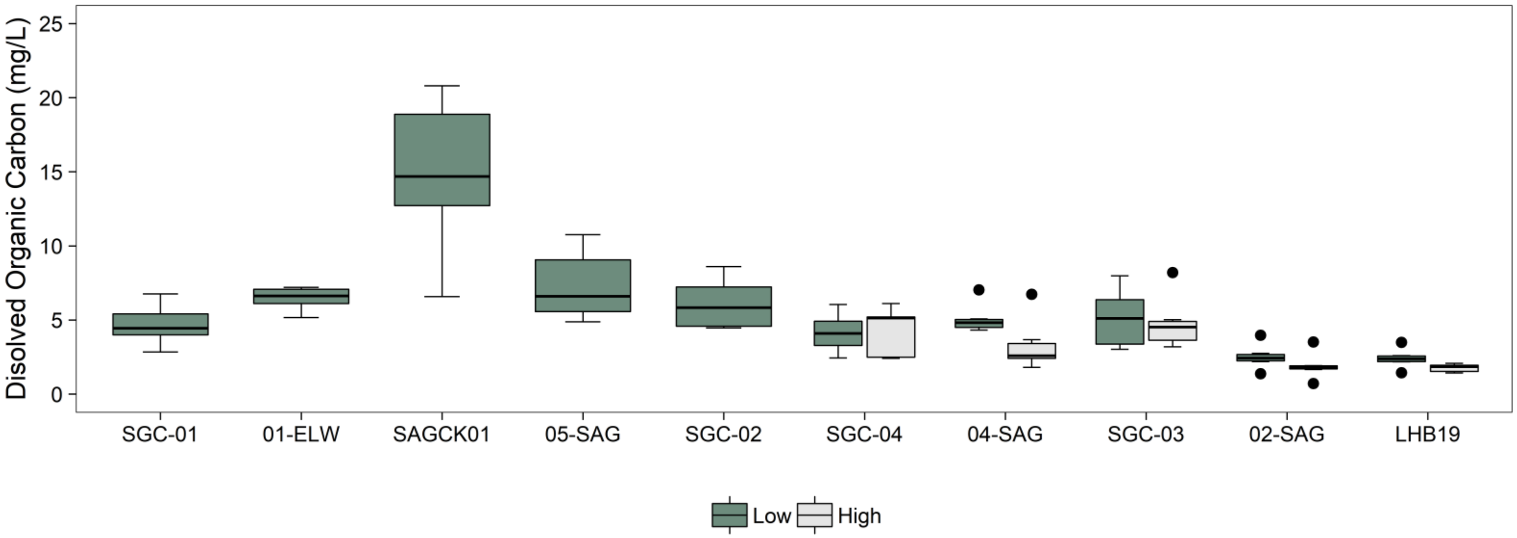





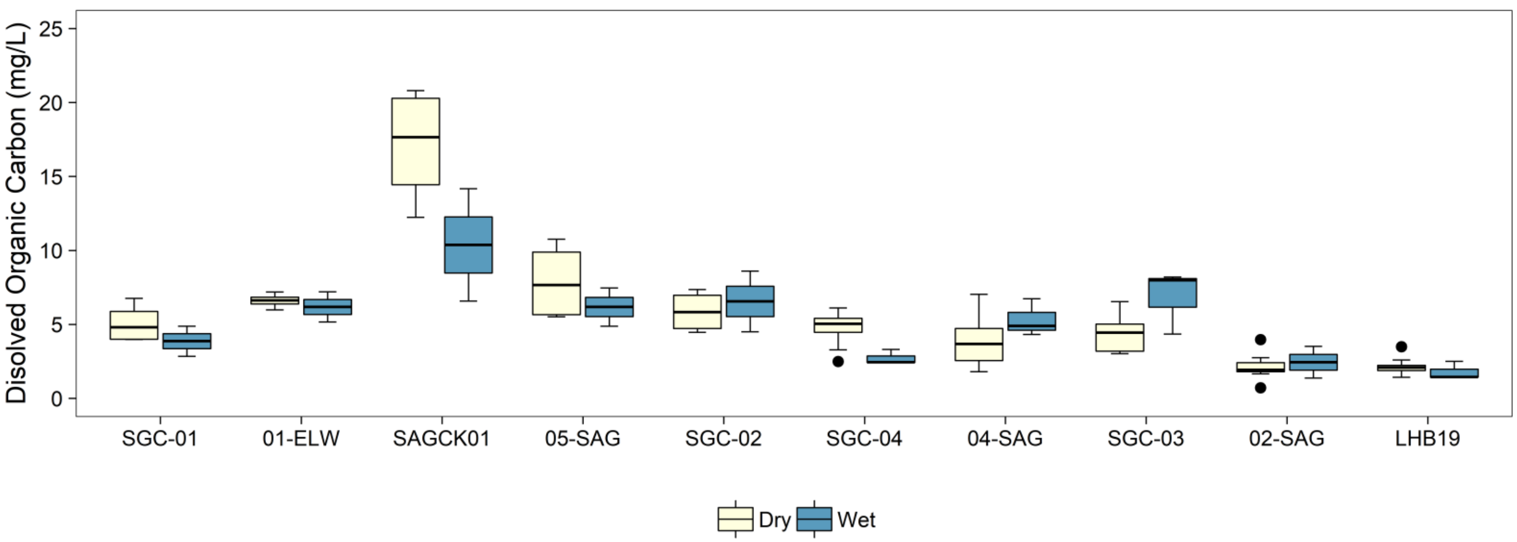
Log-Scale E. coli (mpn/100mL)
1000
100
10
NHDES Instantaneous E. coli Limit
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Low

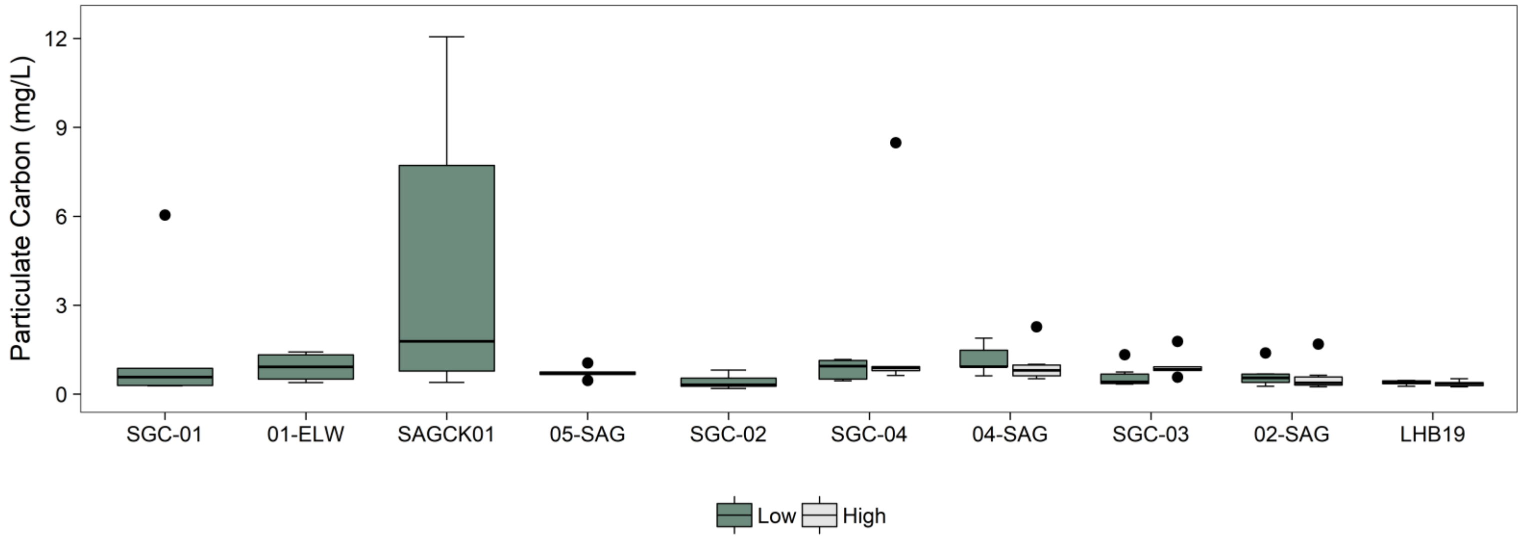
Log-Scale E. coli (mpn/100mL)
1000
100
10
NHDES Instantaneous E. coli Limit
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Dry
Wet

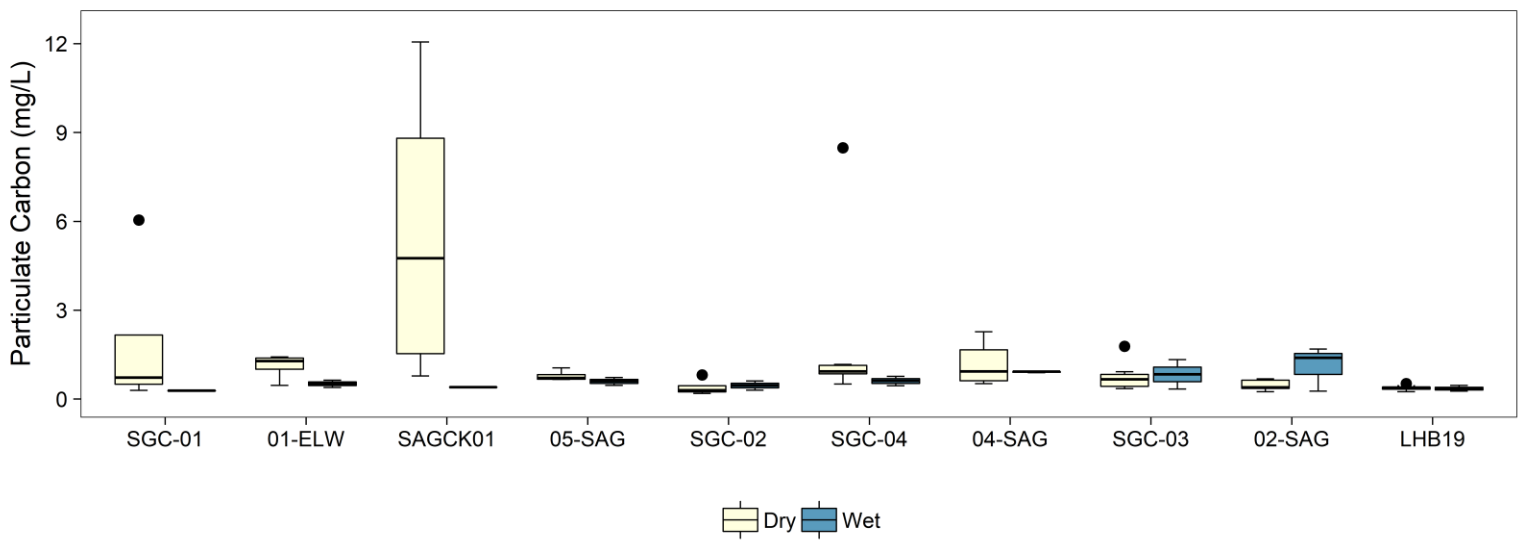


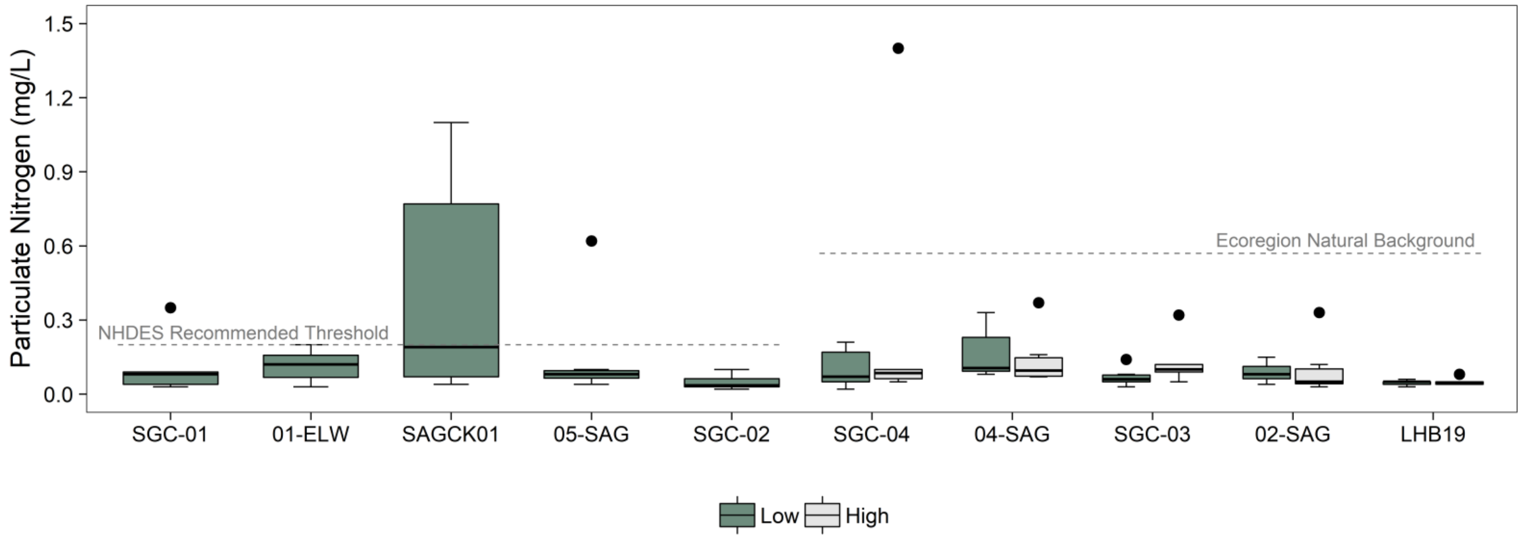
Disolved Organic Carbon (mg/L)
25
20
15
10
5
0
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Low
High

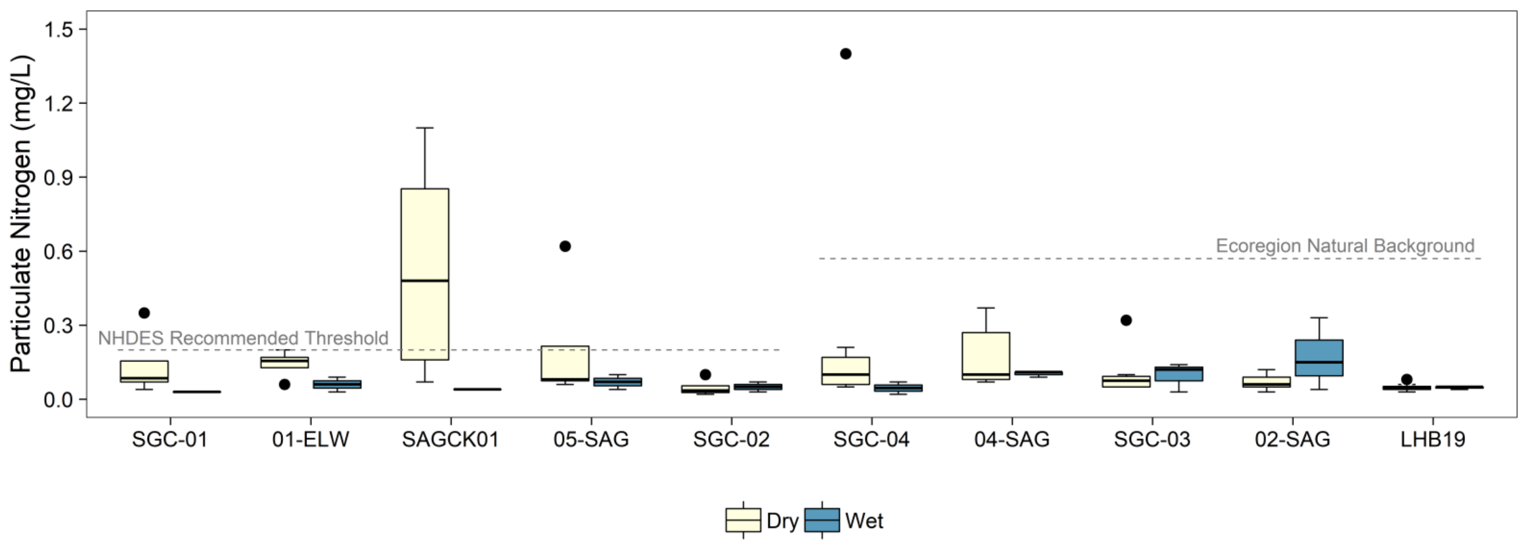



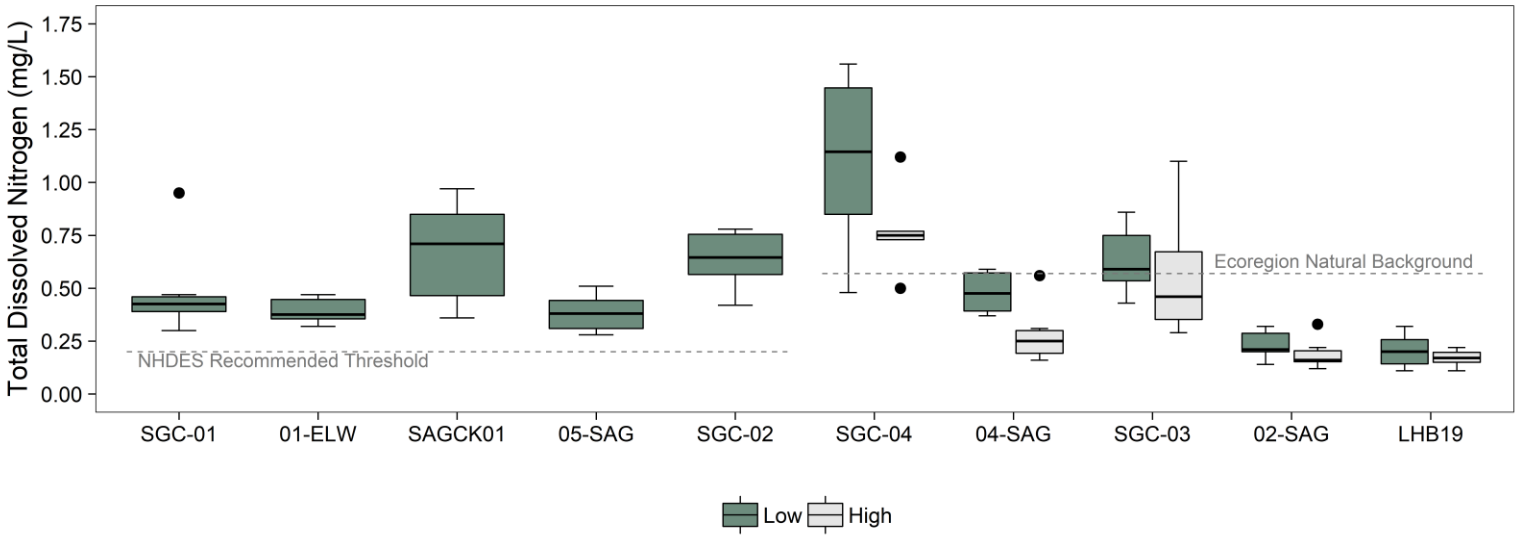
Disolved Organic Carbon (mg/L)
25
20
15
10
5
0
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Dry
Wet

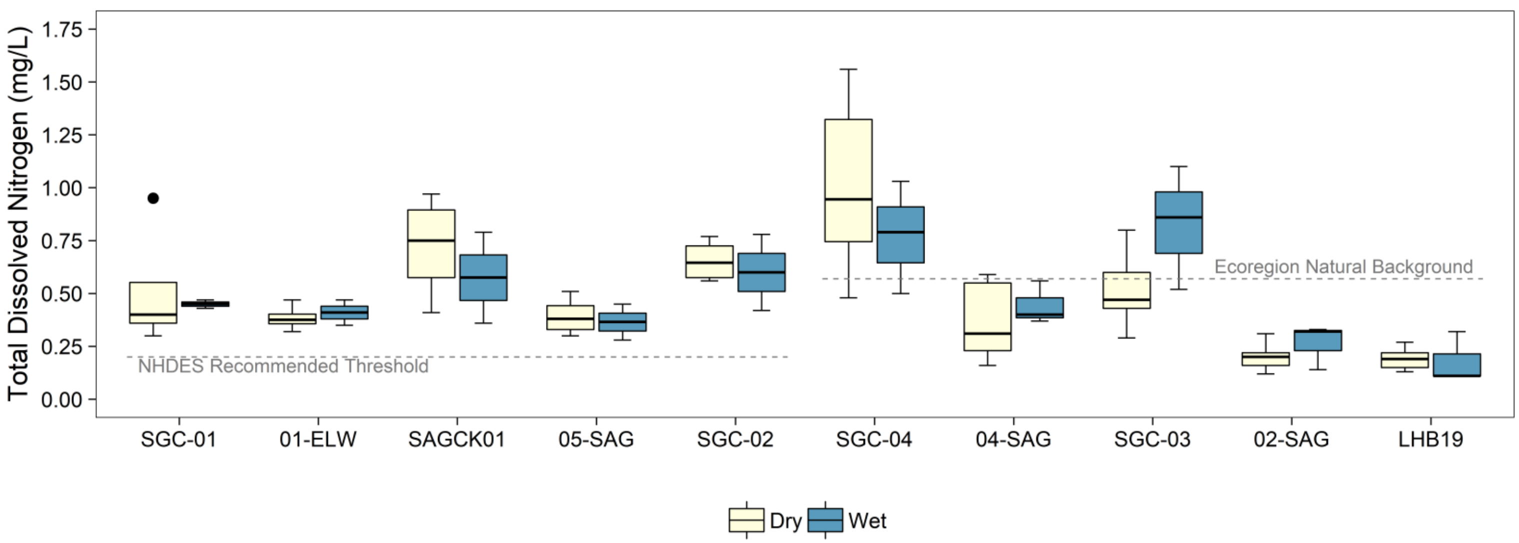

Particulate Carbon (mg/L)
0
3
6
9
12
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Low
High

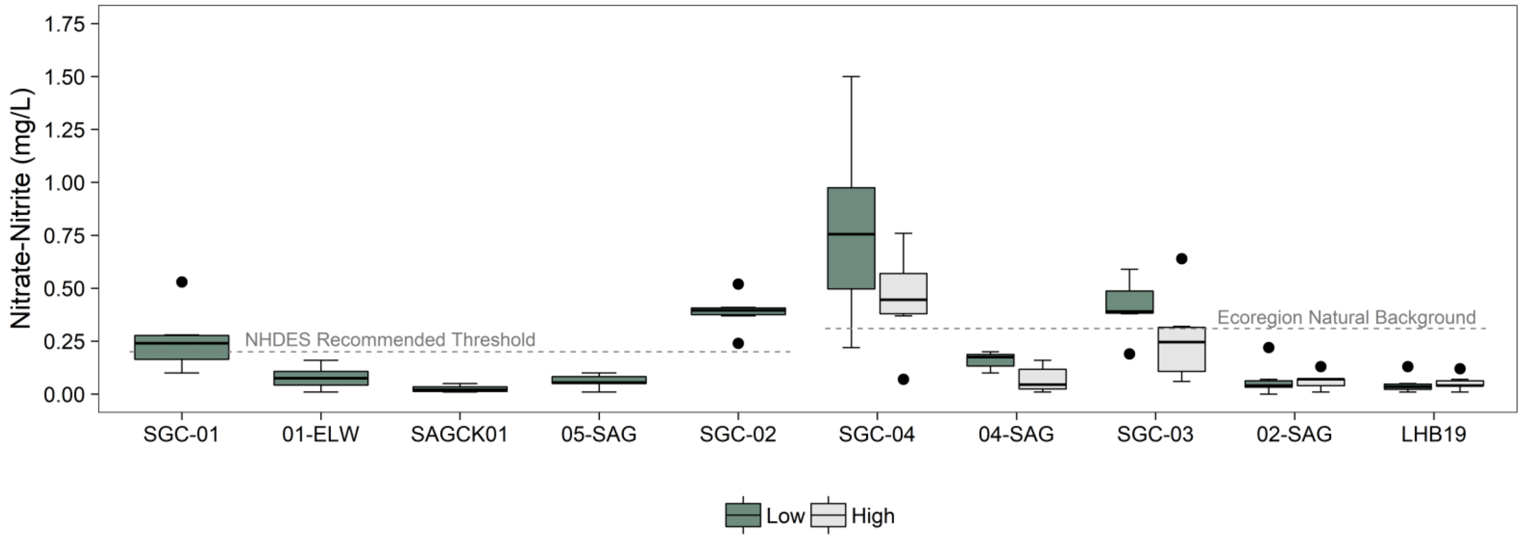

Particulate Carbon (mg/L)
0
3
6
9
12
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Dry
Wet


Particulate Nitrogen (mg/L)
1.5
1.2
0.9
0.6
0.3
0.0
NHDES Recommended Threshold
Ecoregion Natural Background
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Low
High

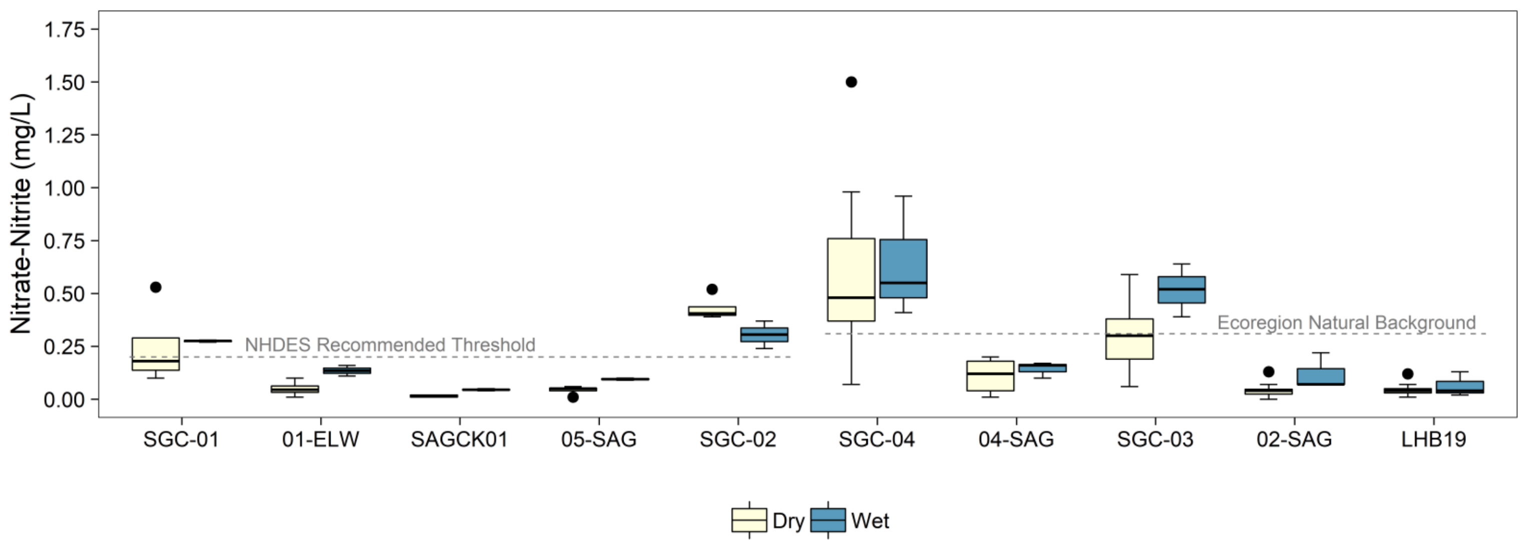

Particulate Nitrogen (mg/L)
1.5
1.2
0.9
0.6
0.3
0.0
NHDES Recommended Threshold
Ecoregion Natural Background
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Dry
Wet


Total Dissolved Nitrogen (mg/L)
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Ecoregion Natural Background
NHDES Recommended Threshold
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Low
High


Total Dissolved Nitrogen (mg/L)
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Ecoregion Natural Background
NHDES Recommended Threshold
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Dry
Wet



Nitrate-Nitrite (mg/L)
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
NHDES Recommended Threshold
Ecoregion Natural Background
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Low
High

Nitrate-Nitrite (mg/L)
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
NHDES Recommended Threshold
Ecoregion Natural Background
SGC-01
01-ELW
SAGCK01
05-SAG
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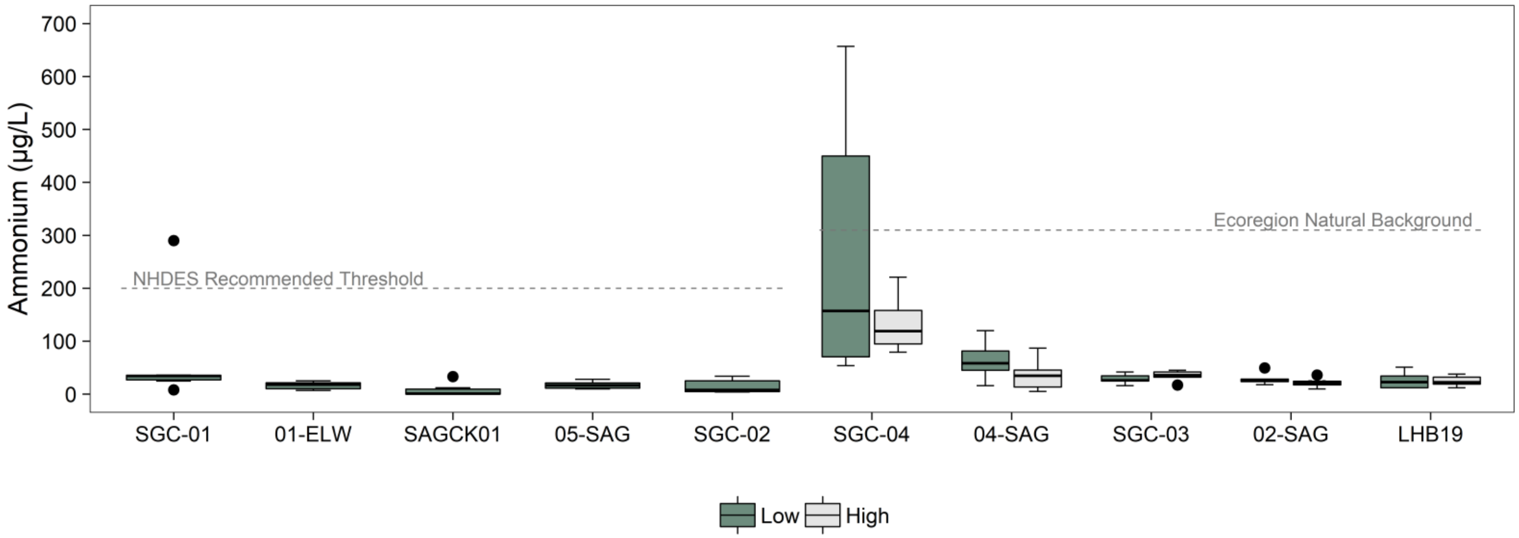
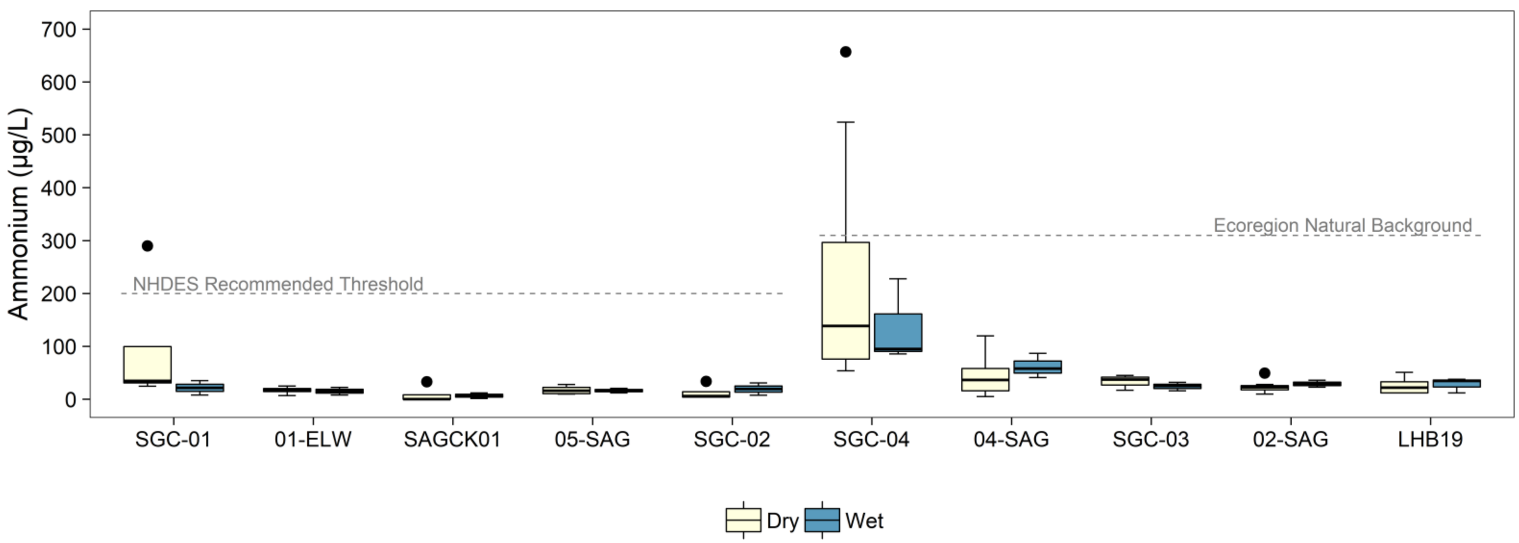
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Dry
Wet


Ammonium (µg/L)
700
600
500
400
300
200
100
0
NHDES Recommended Threshold
Ecoregion Natural Background
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Low
High


Ammonium (µg/L)
700
600
500
400
300
200
100
0
NHDES Recommended Threshold
Ecoregion Natural Background
SGC-01
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SGC-04
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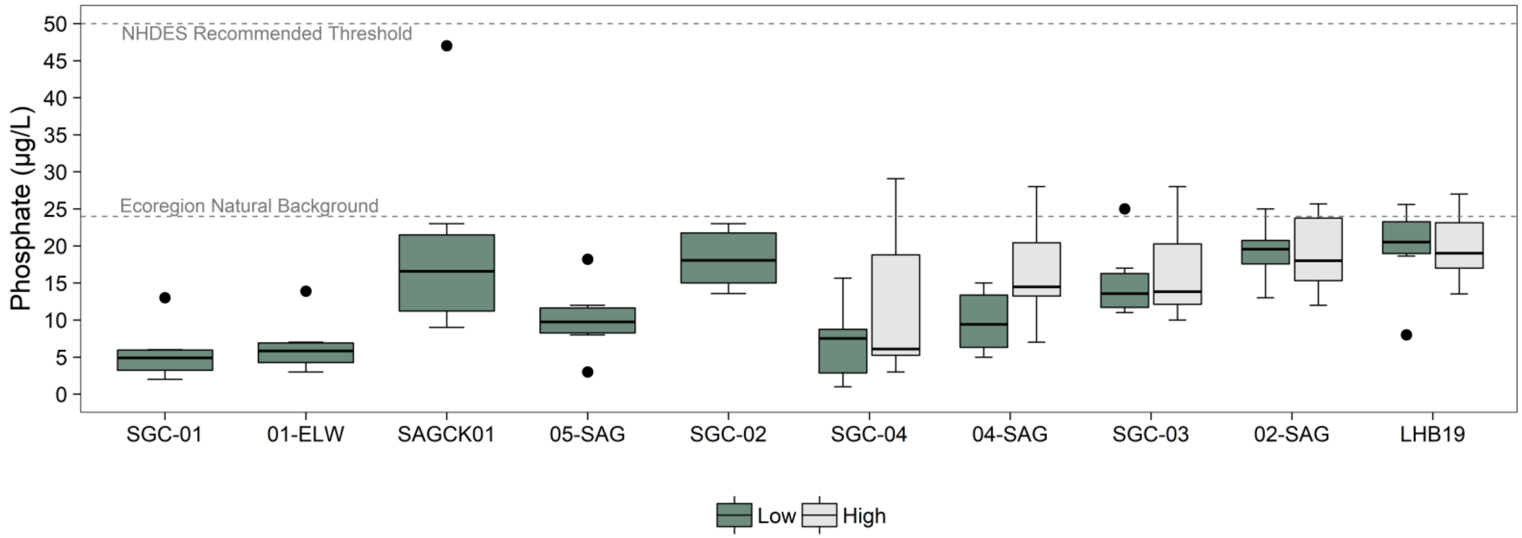
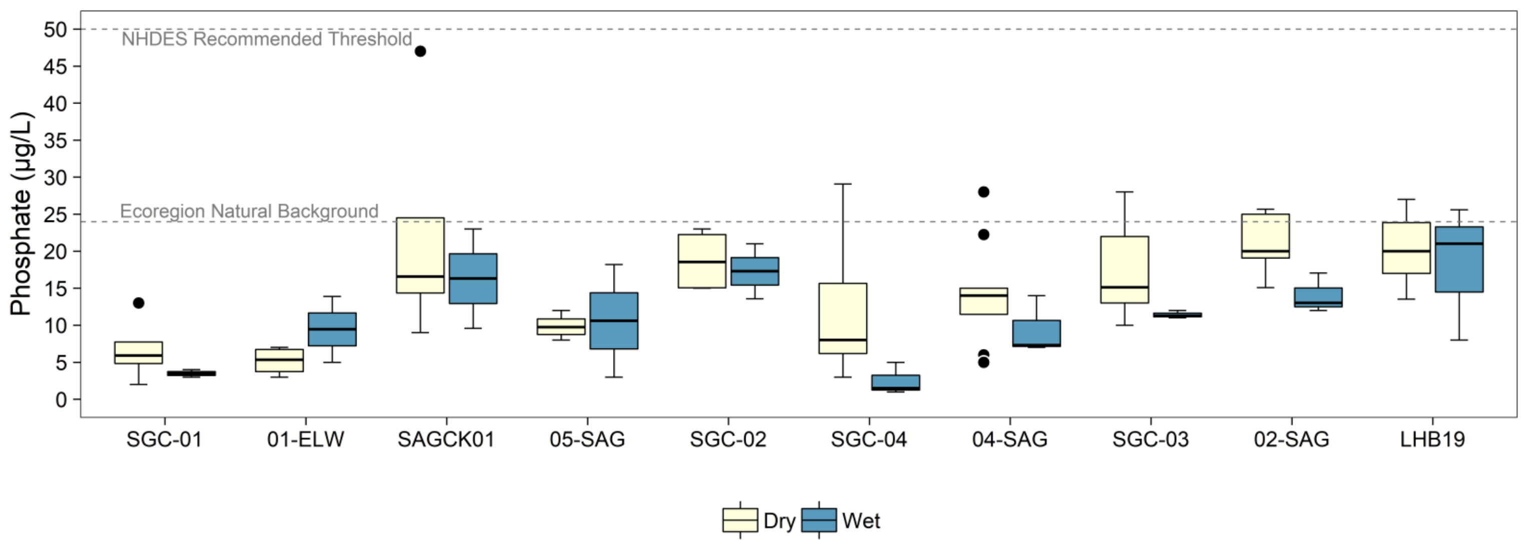
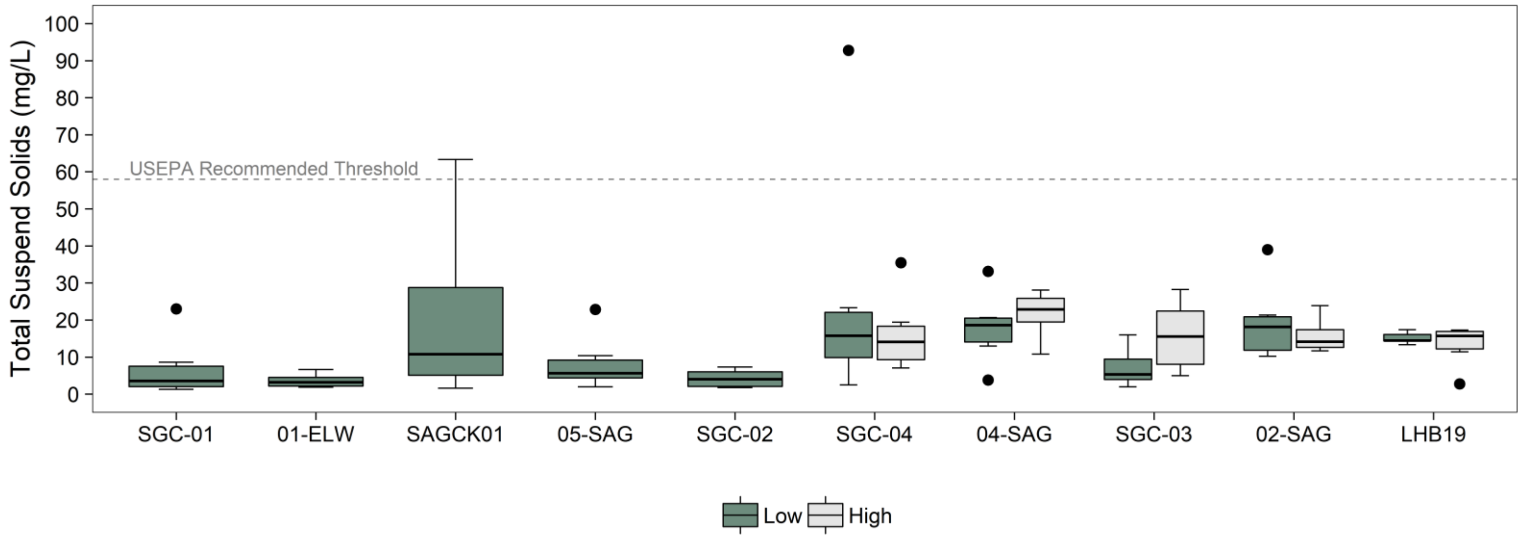
02-SAG
LHB19
Dry
Wet

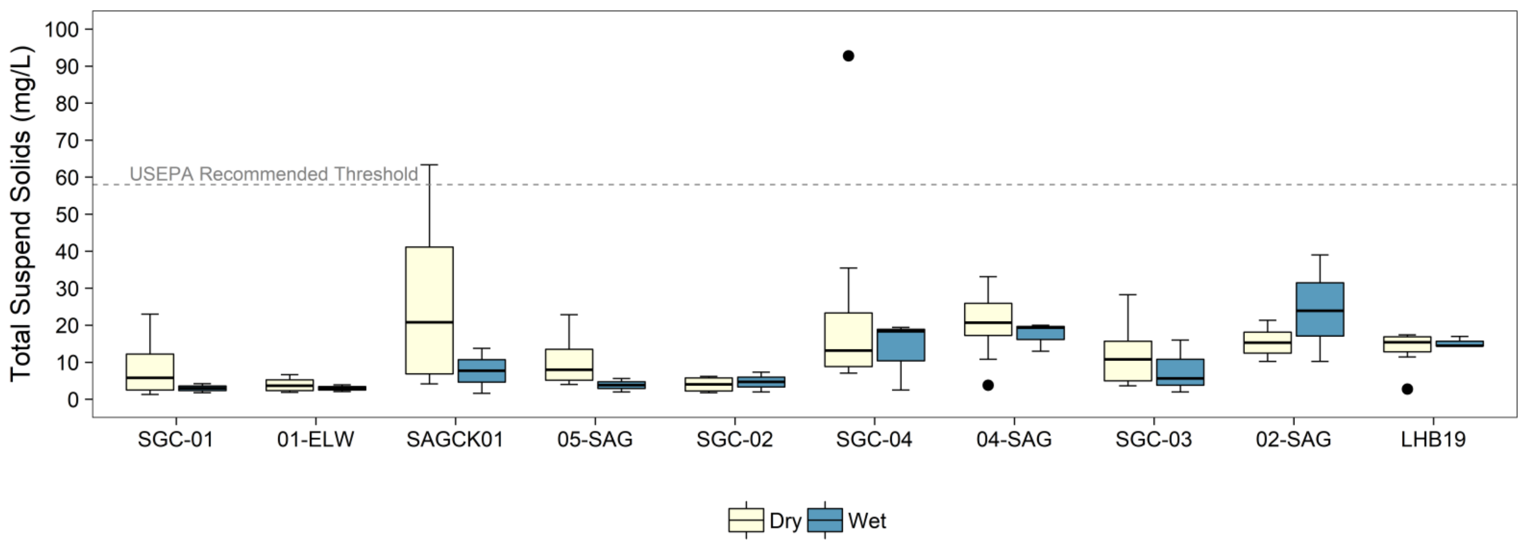


NHDES Recommended Threshold
Ecoregion Natural Background
Phosphate (µg/L)
50
45
40
35
30
25
20
15
10
5
0
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Low
High

NHDES Recommended Threshold
Ecoregion Natural Background
Phosphate (µg/L)
50
45
40
35
30
25
20
15
10
5
0
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Dry
Wet


Total Suspend Solids (mg/L)
100
90
80
70
60
50
40
30
20
10
0
USEPA Recommended Threshold
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Low
High


Total Suspend Solids (mg/L)
100
90
80
70
60
50
40
30
20
10
0
USEPA Recommended Threshold
SGC-01
01-ELW
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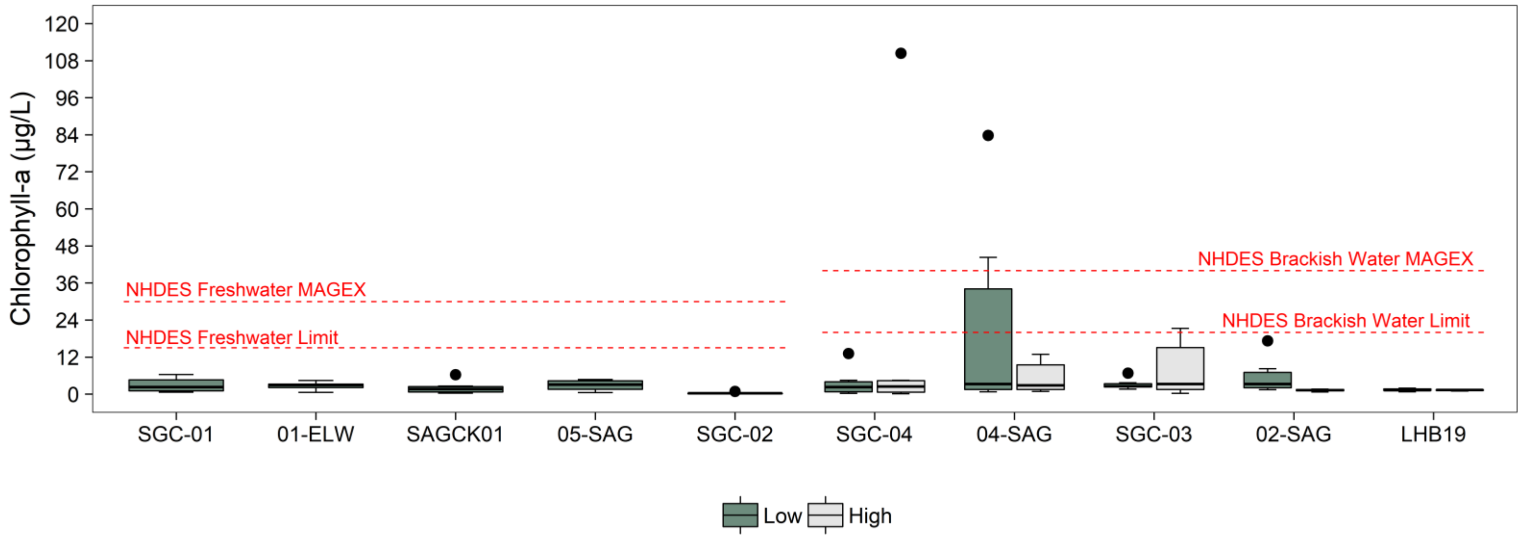
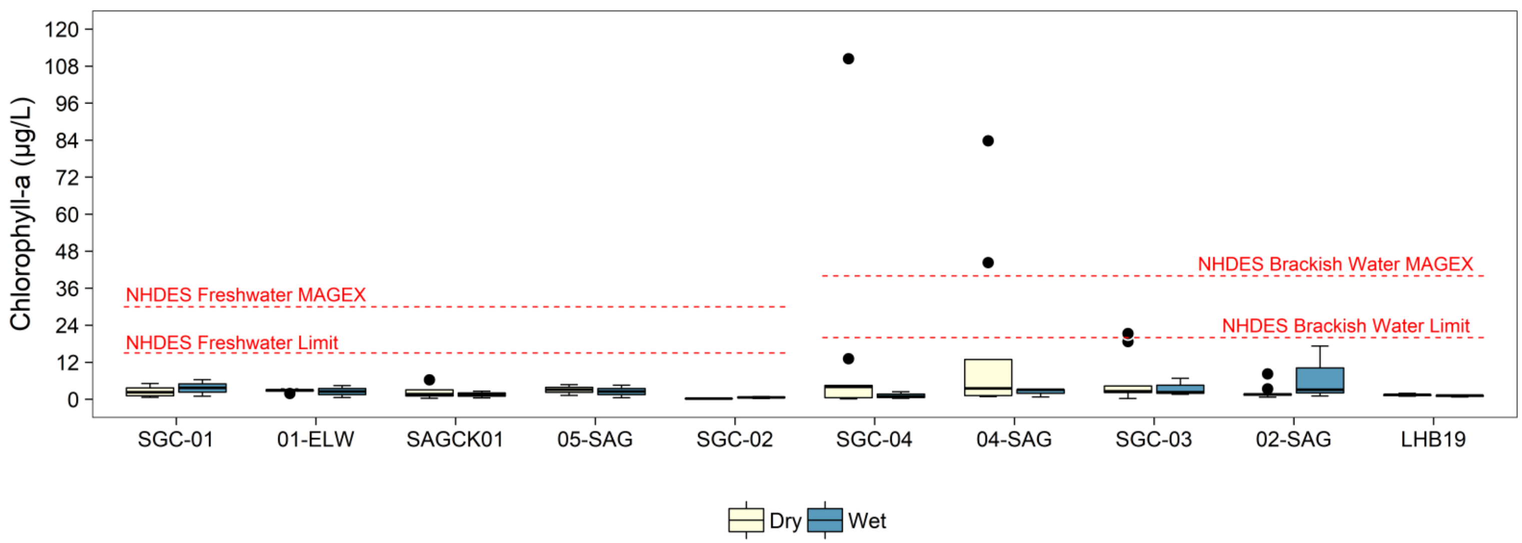
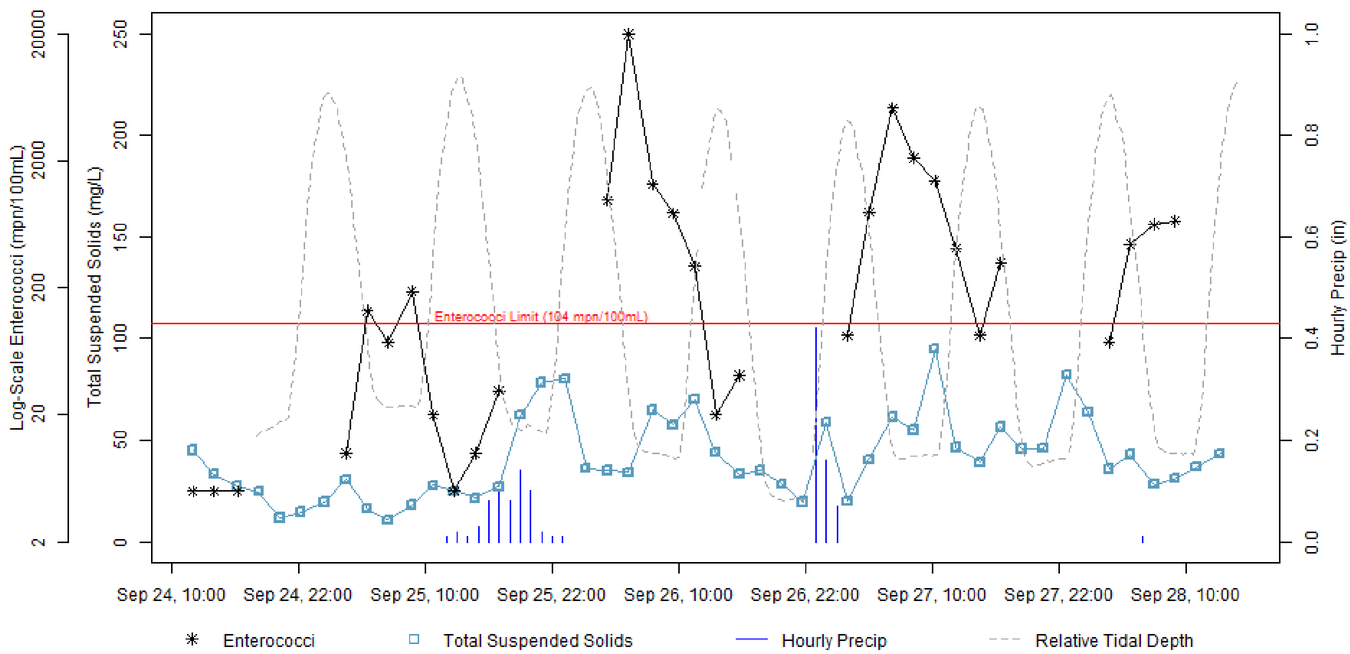
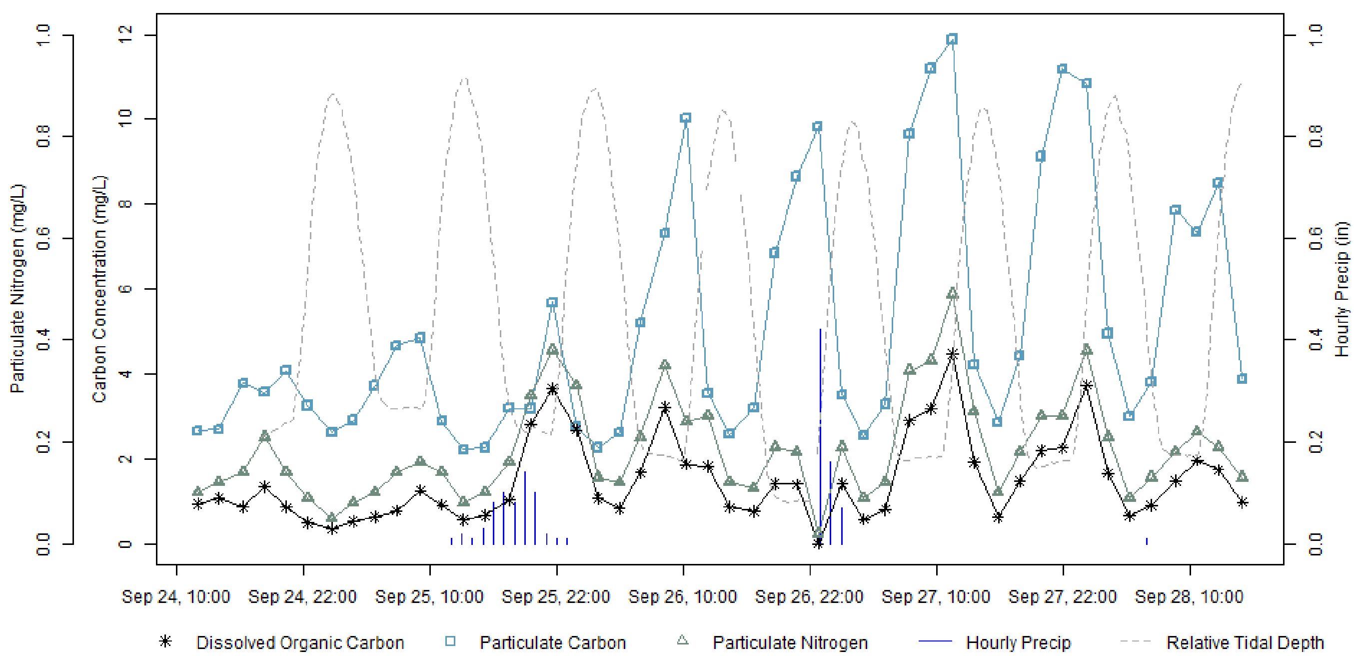
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Dry
Wet

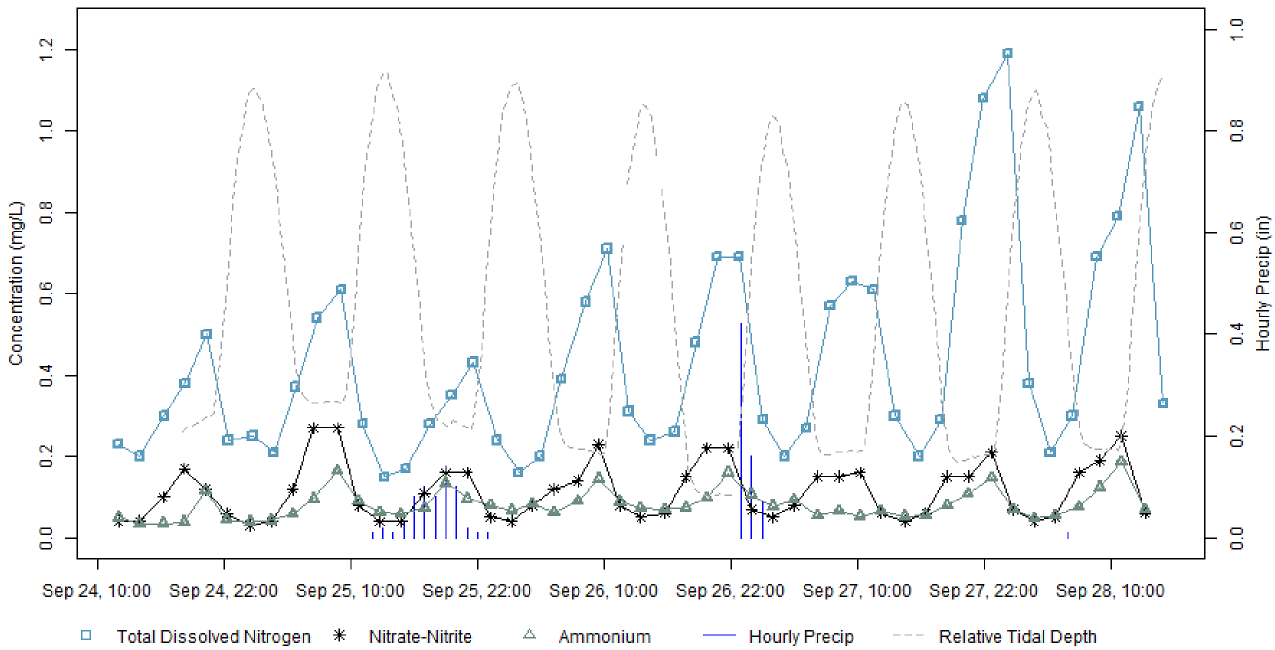

Chlorophyll-a (μg/L)
120
108
96
84
72
60
48
36
24
12
0
NHDES Freshwater MAGEX
NHDES Freshwater Limit
NHDES Brackish Water MAGEX
NHDES Brackish Water Limit
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Low
High

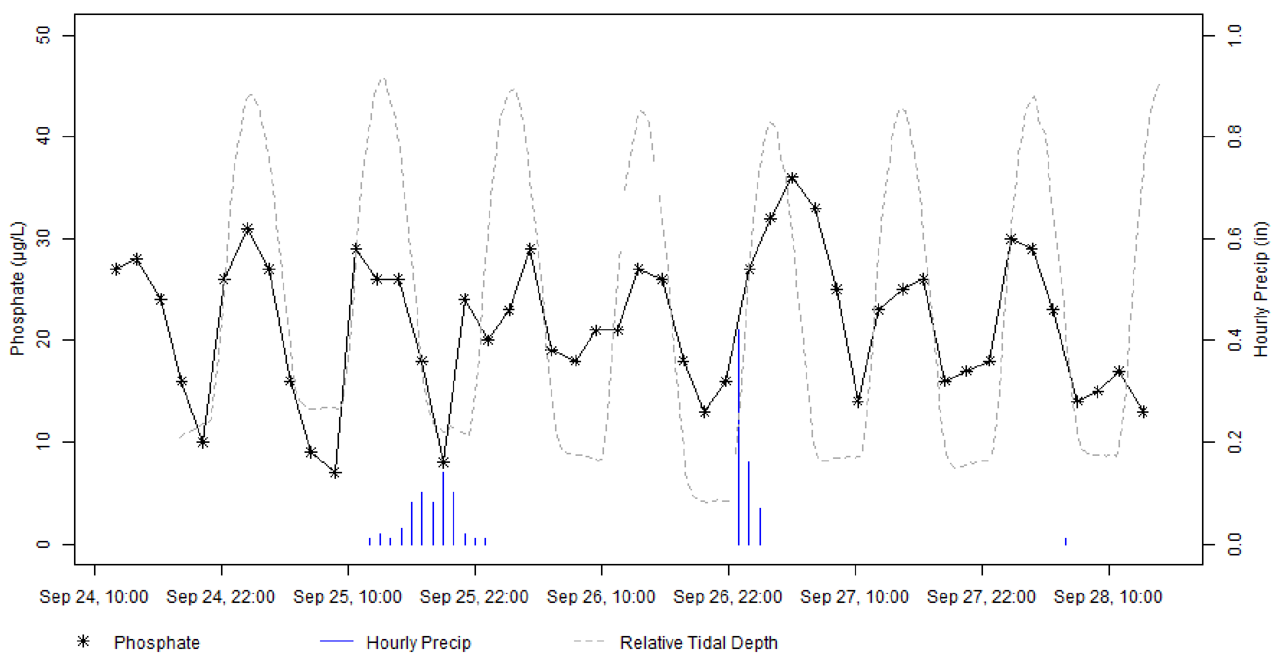

Chlorophyll-a (μg/L)
120
108
96
84
72
60
48
36
24
12
0
NHDES Freshwater MAGEX
NHDES Freshwater Limit
NHDES Brackish Water MAGEX
NHDES Brackish Water Limit
SGC-01
01-ELW
SAGCK01
05-SAG
SGC-02
SGC-04
04-SAG
SGC-03
02-SAG
LHB19
Dry
Wet

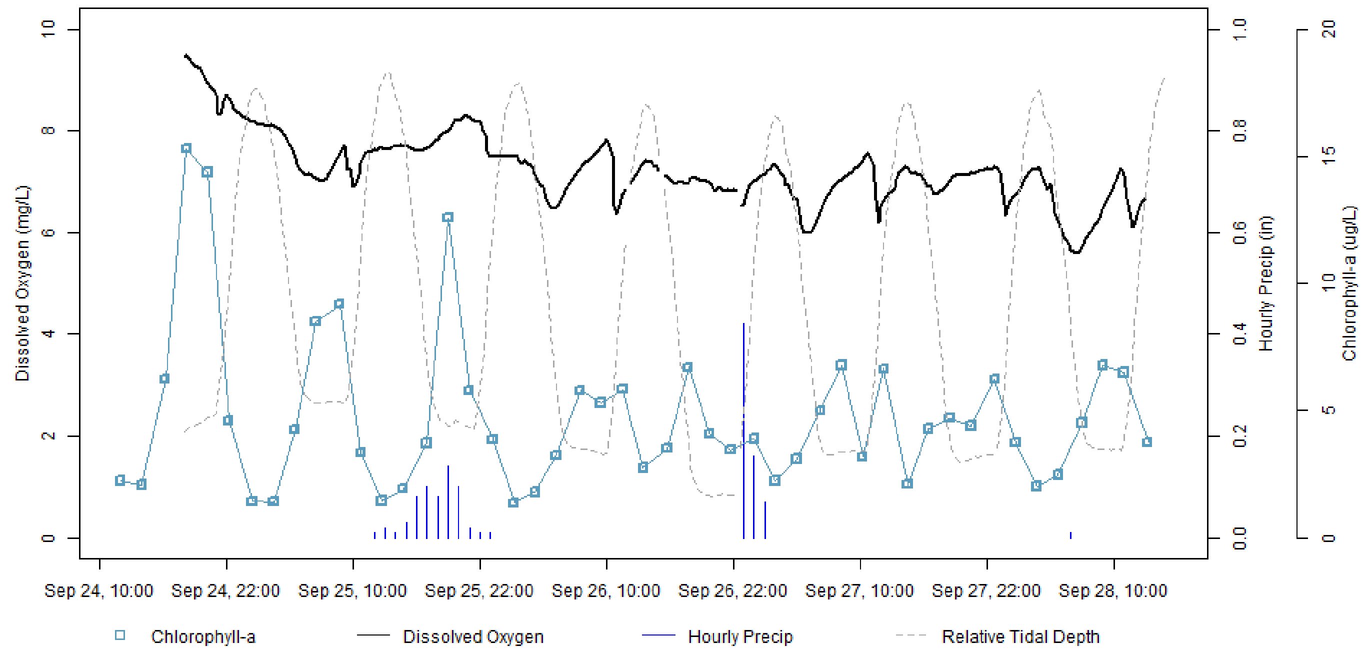
# APPENDIX D: Data figures for 24-hour sampling at 04-SAG

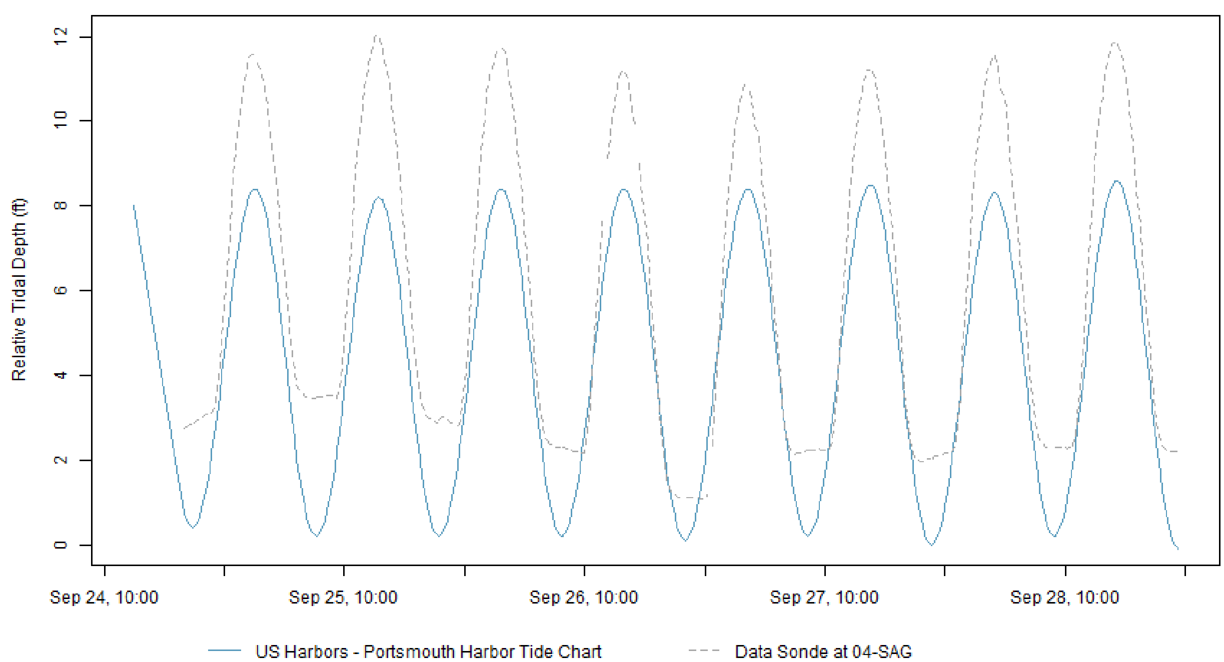



Concentration (mg/L)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Hourly Precip (in)
0.0
0.2
0.4
0.6
0.8
1.0
Sep 24, 10:00
Sep 24, 22:00
Sep 25, 10:00
Sep 25, 22:00
Sep 26, 10:00
Sep 26, 22:00
Sep 27, 10:00
Sep 27, 22:00
Sep 28, 10:00
Total Dissolved Nitrogen
Nitrate-Nitrite
Ammonium
Hourly Precip
Relative Tidal Depth


Phosphate (µg/L)
0
10
20
30
40
50
Hourly Precip (in)
0.0
0.2
0.4
0.6
0.8
1.0
Sep 24, 10:00
Sep 24, 22:00
Sep 25, 10:00
Sep 25, 22:00
Sep 26, 10:00
Sep 26, 22:00
Sep 27, 10:00
Sep 27, 22:00
Sep 28, 10:00
Phosphate
Hourly Precip
Relative Tidal Depth


Dissolved Oxygen (mg/L)
Hourly Precip (in)
Chlorophyll-a (ug/L)
Sep 24, 10:00
Sep 24, 22:00
Sep 25, 10:00
Sep 25, 22:00
Sep 26, 10:00
Sep 26, 22:00
Sep 27, 10:00
Sep 27, 22:00
Sep 28, 10:00
Chlorophyll-a
Dissolved Oxygen
Hourly Precip
Relative Tidal Depth


Relative Tidal Depth (ft)
Sep 24, 10:00
Sep 25, 10:00
Sep 26, 10:00
Sep 27, 10:00
Sep 28, 10:00
US Harbors - Portsmouth Harbor Tide Chart
Data Sonde at 04-SAG