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THINK BIG WE DO℠

URI Watershed Watch Program
Bristol Harbor Monitoring Results 2009 - 2021

May 2022

Elizabeth Herron, URI Watershed Watch

Water Quality Summary: Continued and expanded monitoring of Bristol Harbor and Mt Hope Bay sites, strengthens our understanding of conditions in these important local waters during all weather patterns. As in previous years, both the on-site monitoring and laboratory analyses indicate that except for the Silver Creek outlet (#3), Bristol Harbor *itself* is in generally good condition. Nutrients were low to moderate, although in some cases quite variable between years and even sampling months. Dissolved oxygen levels were usually sufficient for most aquatic life; although since 2011 there have been periods of low dissolved oxygen at several sites, which creates stressful conditions for species such as clams. Algae levels were generally in the low to moderate range, but algal blooms were noted at several sites. Mill Pond (#5) has had extended periods of elevated algae combined with higher bacteria levels, limiting recreational usage of the pond for several seasons. In the harbor, bacteria levels were often within both acceptable shellfishing and swimming criteria. Stormwater often raises bacteria concentrations to unacceptable levels, suggesting the need for more stormwater management efforts in the watershed.

Save Bristol Harbor (SBH) continues to use the data generated through this monitoring effort to target upstream sources by including upstream monitoring sites. The need to better understand the Silver Creek watershed developed after the 2009 results identified the creek as a source of excess nitrogen and bacteria. Monitoring at the upstream sites strengthens the indications that the sources are upstream of where Silver Creek enters the harbor, but SBH hasn't quite "nailed down" specific sources yet. Efforts have begun to reduce sources at upstream sites.

The dynamic nature of the harbor ensures that there will be fluctuations in water quality from year to year particularly in response to variable weather patterns. The commitment of Save Bristol Harbor to comprehensive, long-term water quality monitoring in order to establish and confirm baseline conditions and track trends is commendable and vital for protecting this important resource. With more than the ten years of monitoring data that are typically needed to develop good baseline data, and years beyond that to identify trends, the monitoring by SBH is growing more valuable with each season. Climate change impacts complicate our understanding of how weather impacts water quality, requiring additional seasons of data under current conditions to assess. Continued expanded monitoring in the Silver Creek watershed to better bracket current problem areas is critical to identify sources and to affect solutions. Visible water quality improvement from watershed remediation efforts often lag the actual work, so there is a lot of work ahead for the members of this dedicated organization and its partners. With eleven years of monitoring data now available, Bristol Harbor and its watershed are becoming better understood.

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Introduction: Save Bristol Harbor (SBH) has monitored water quality in the Bristol Harbor watershed and nearby coastal waters since 2009. The Predictive Habitat Model Committee, composed of scientists from Roger Williams and Brown Universities, SBH volunteers, and local students, sought to assess all factors of harbor conditions, including currents, water quality, and habitat. The water quality data collection phase of the model development process was with eight (8) monitoring sites around the perimeter of Bristol Harbor for monitoring initially. Dock and shoreline sites allowed easy and safe access for volunteers and good distribution around the harbor (see Table and Figure 1a for harbor site information). Because of finding high nitrogen and bacteria at #3 Silver Creek outlet, in 2010 three upstream sites were added, as well as a shoreline site closer to Narragansett Bay (#12 Herreshoff Dock). Two more upstream sites (#14 and #15) were added in 2012 to better target potential contamination sources. Successful monitoring efforts fostered town wide interest in water quality. Thus in 2014 shoreline sites on Mt Hope Bay were added, increasing understanding of local coastal conditions (see Table and Figure 1b for Mt Hope Bay site information). Sites #15 and #16 were not monitored after 2015. Additional sites in the Bristol Golf Course (#19 and #20) were added in 2019 to provide information for developing and implementing effective restoration projects.

Table 1a: Bristol Harbor Water Quality Monitoring Site Information (2009 – 2021 sites)

Site ID	Site Description
BH 1	Elks Club Dock
BH 2	BH Inn Dock
BH 3	Silver Creek Outlet
BH 4	Windmill Point Dock
BH 5	Mill Pond
BH 7	BH Yacht Club Dock
BH 6	Sanroma
BH 8	Brito Dock
BH 9	Silver Bridge
BH 10	Silver East Branch
BH 11	Silver West Branch
BH 12	Herreshoff Dock
BH 13	Mack's Dock ('13 only)
BH 14	DaPonte P/Wood St
BH 15	Silver @ Gooding (not >'14)
BH 19	Bristol GC North
BH 20	BH GC Site B

Figure 1a. Bristol Harbor Monitoring Sites

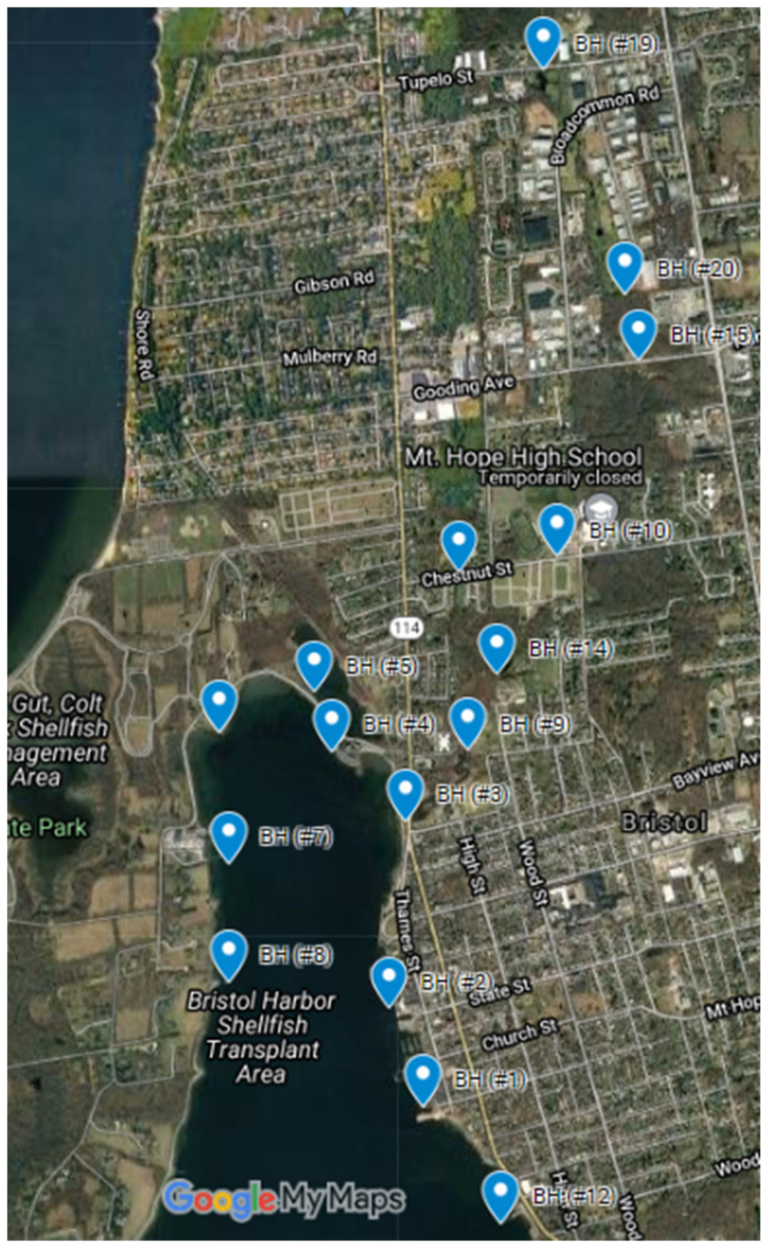


Figure 1b. Mt Hope Bay Monitoring Sites

Table 1b: Mt Hope Bay Water Quality Monitoring Site Information (2014 - 2021 sites)

Site ID	Site Description
BH 16	RWU Dock ('14 only)
BH 18	Annaswamscutt Dr
BH 17	Kickemuit

Brief descriptions of key parameters monitored, the criteria used to assess conditions, data summaries, including charts and discussions of the results, follow. An overview of the SBH monitoring program and parameters not discussed in this report can be found in the Appendices.

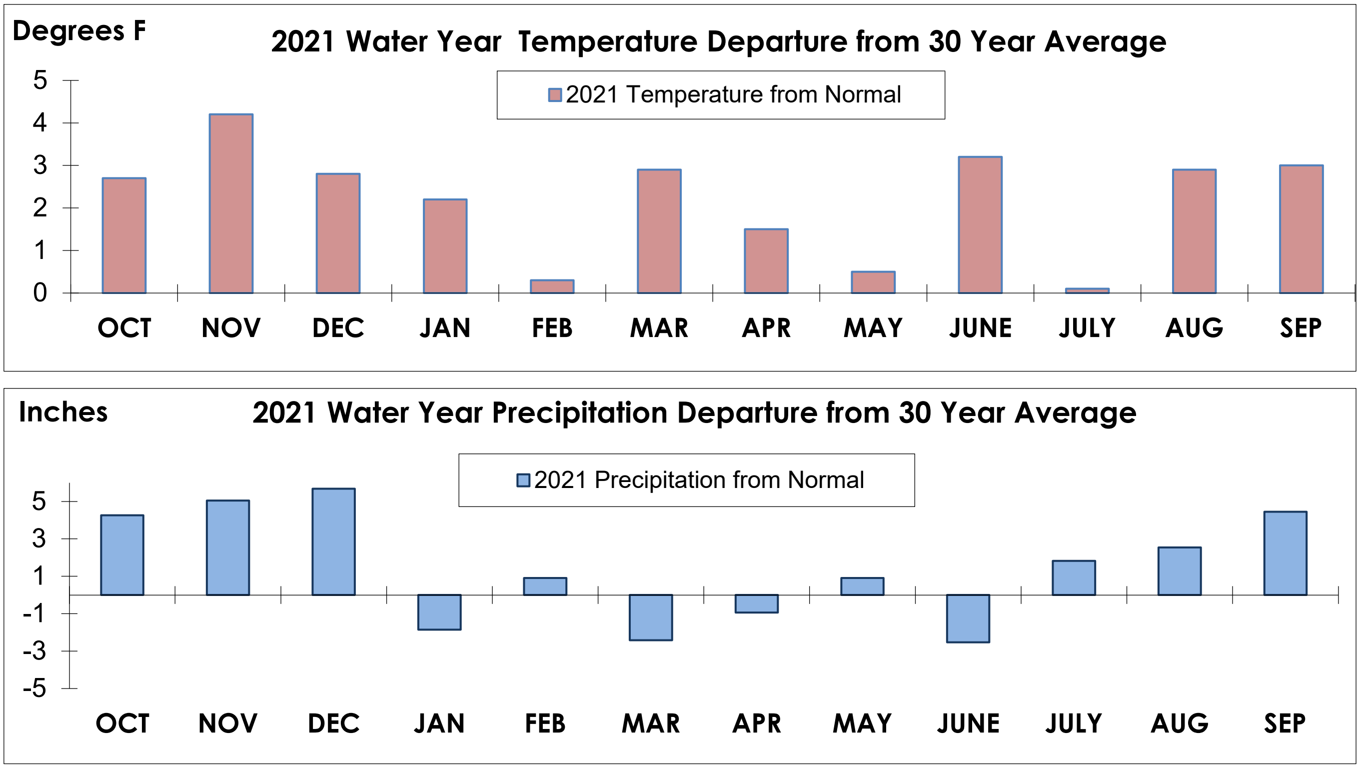
Weather summary: Weather can significantly affect water quality, often confounding the assessment of water quality trends. Dry periods reduce stream flow, which can concentrate pollutants due to the loss of dilution. Alternatively, dry weather can reduce pollutants washed off the landscape by stormwater. Intense storms can dramatically increase runoff, often resulting in flooding or scouring of stream beds, both of which can increase movement of contaminants. These short-term events can result in significant variation of water quality conditions both between sites and over time. This summary is based on weather data from the URI Weather Station in Kingston, RI, which may not exactly represent conditions in Bristol, but provides a good overview. Departures from normal were in relation to average temperature and precipitation values over the past thirty (30) years.

When assessing water quality for a particular time period, we are most concerned with the months that make up the associated water year, in this case October 2020 through September 2021. The new water year starts with an expectation for new recharge to groundwater, streams and lakes as monthly precipitation finally becomes larger than monthly evapotranspiration from plants after typical precipitation deficits in the heat of summer with plants growing rapidly.

The fall of 2020 was warm and wet, with monthly average temperatures ranging from about 2.7 to 4.2 degrees above normal from October through December. The winter of 2021 was also quite warm, with above normal temperature averages about 2-3 degrees warmer January through March, although February was just slightly warmer (+0.3 degrees). Spring 2021 continued above average, followed by a warm June, August, and September. This continued a pattern of extended the growing season at all the sites.

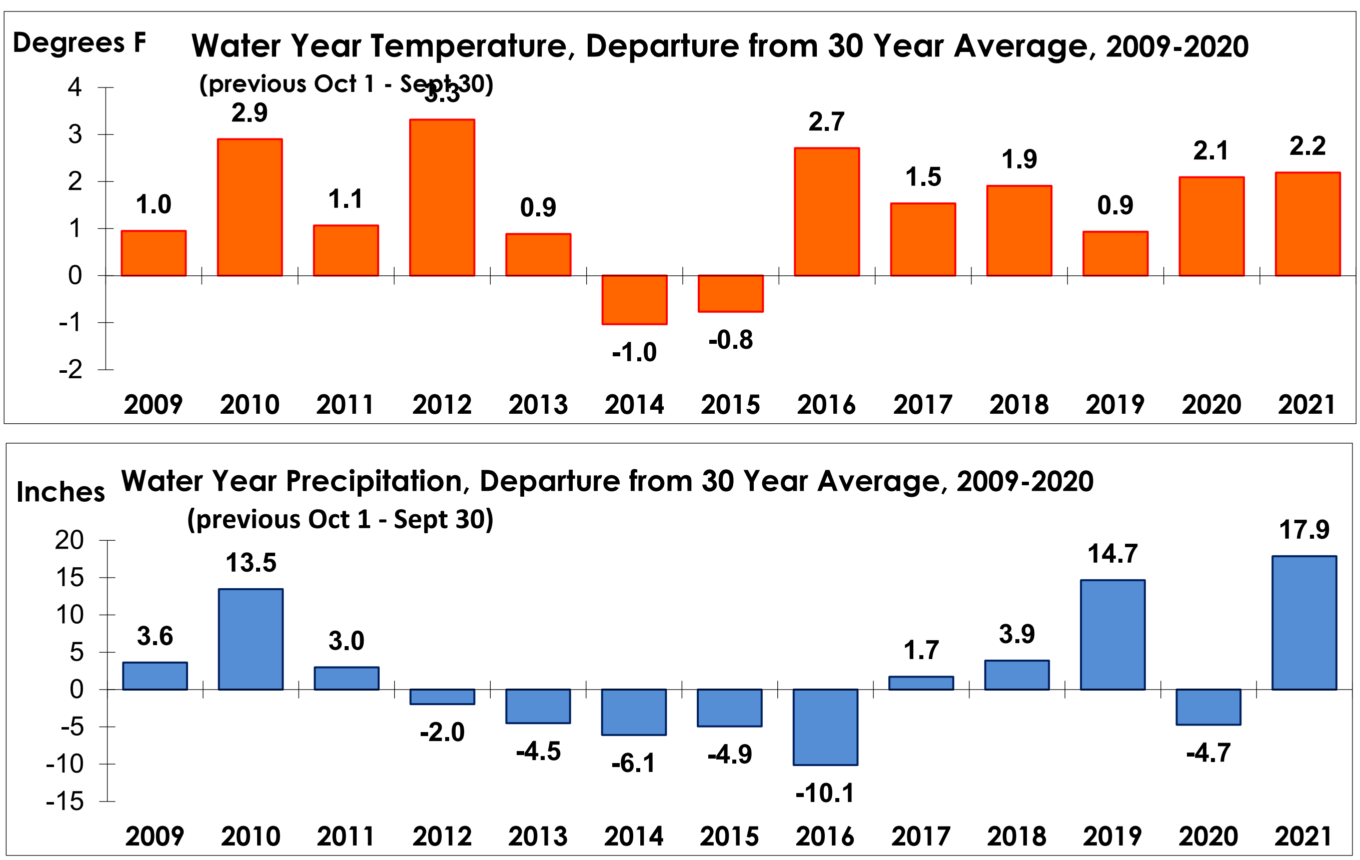
Precipitation was more variable. Fall of 2020 was increasingly wet, ranging from 4.3 – 5.7 inches above normal October through December wet. But the winter was generally dry, with little snowfall and precipitation ranging from less than an inch above normal to nearly 2.5 inches below normal for the months of January through June. The remainder of the water year saw above normal precipitation. In fact, samples were not able to be collected from several sites in September of 2021 because of flooding. Overall, the 2021 water year finished out almost 18 inches ABOVE normal, but only about 9 inches above normal for calendar year (figure 2).

Figure 2. 2021 Weather Summary Charts



Above average temperatures in 2021 continued a trend of warmer than normal temperatures seen during most of the time since monitoring began. It was the wettest year recorded since monitoring began, creating significant runoff throughout the watershed (Figure 3).

Figure 3. Long-term Water Year Summary Charts



Field monitoring descriptions and summaries: Volunteers measured several key water quality indicators using field kits and instruments. These field measurements included temperature, dissolved oxygen (DO), salinity and also processing of samples for subsequent URIWW laboratory analysis of chlorophyll. Water samples were taken from a depth of half a meter (0.5m) from the surface or midway to the bottom using either a sampling pole or the “one arm sampler.” Except for temperature, duplicate samples were collected, and then replicate measurements were made for each of the field parameters, with the average reported in Figures 4 a-d and 6 a-d.

Dissolved oxygen and water temperature data tell us quite a bit about the health of the harbor. Oxygen is critical to the survival of most of the animals and plants that live in the water; generally, the more oxygen, the healthier the ecosystem. Dissolved oxygen levels below 5 milligrams of oxygen per liter of water (mg/L) can be stressful to many forms of life, particularly at the juvenile life stage. Dissolved oxygen (DO) levels below 2 mg/L, also known as hypoxic or low oxygen, are lethal for many species. When DO concentrations fall below 0.5 mg/L, the water is called anoxic, and plants or animals that require oxygen can’t survive in that area. Oxygen enters the water through two natural processes: (1) diffusion from the atmosphere and (2) photosynthesis by aquatic plants, including algae. The mixing of surface waters by wind and waves increases the rate at which oxygen from the air can be dissolved or absorbed into the water.

Temperature and salinity dictate the maximum DO that water can hold. As the temperature increases, the amount of oxygen water can hold decreases. Higher salinity and suspended solids also reduce the amount of oxygen. These factors combine to affect DO levels. For example, saltwater at 5°C can contain up to 10.5 mg/L, but at 25°C it can only hold 7.0 mg/L, whereas freshwater at 5°C can hold up to 12.8 mg/L, and 8.3 mg/L DO at 25°C.

Wind, waves and daytime photosynthesis add oxygen to water, usually more than is used by the aquatic animals in the water, including the decomposers. But after the sun sets photosynthesis stops, and all the organisms, including plants and algae keep using oxygen through respiration. Thus, DO is typically lowest early in the morning before the rising sun starts photosynthesis. Therefore, SBH volunteers typically monitor around 6:00 am. Algal blooms often create very low minimum DO levels because bacteria, fungi, and other decomposer organisms consume oxygen while breaking down organic matter, such as dead algae.

Figure 4a. Bristol Harbor Sites (Arranged from Southeast to Northwest)
2021 Field Dissolved Oxygen and Temperature Data Charts

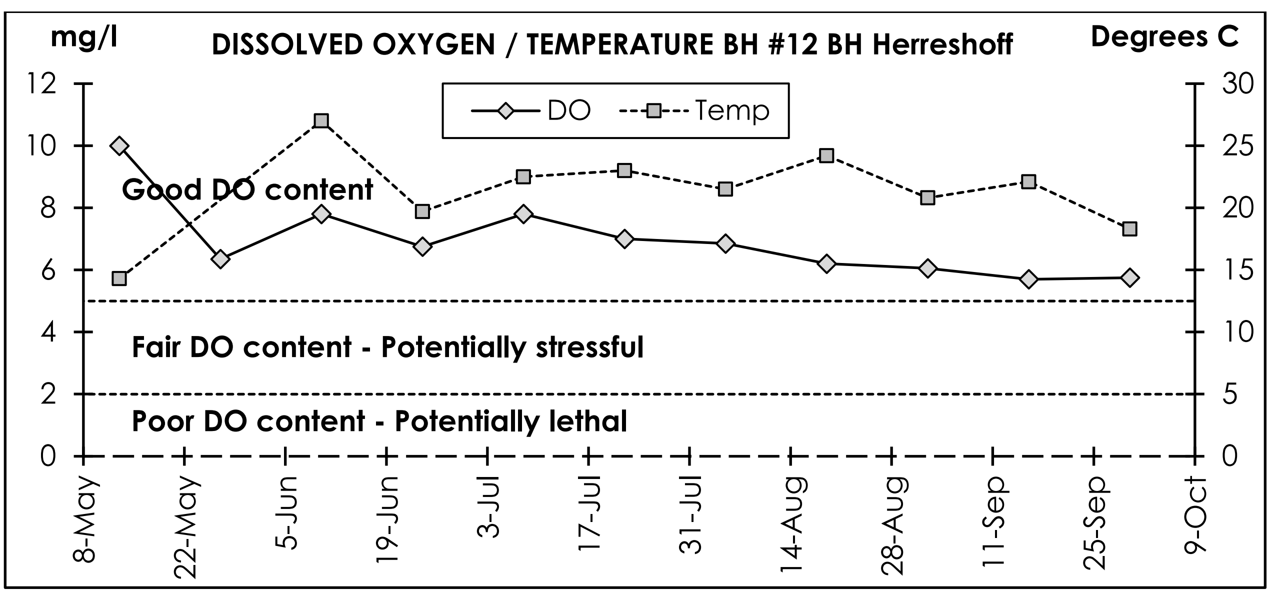
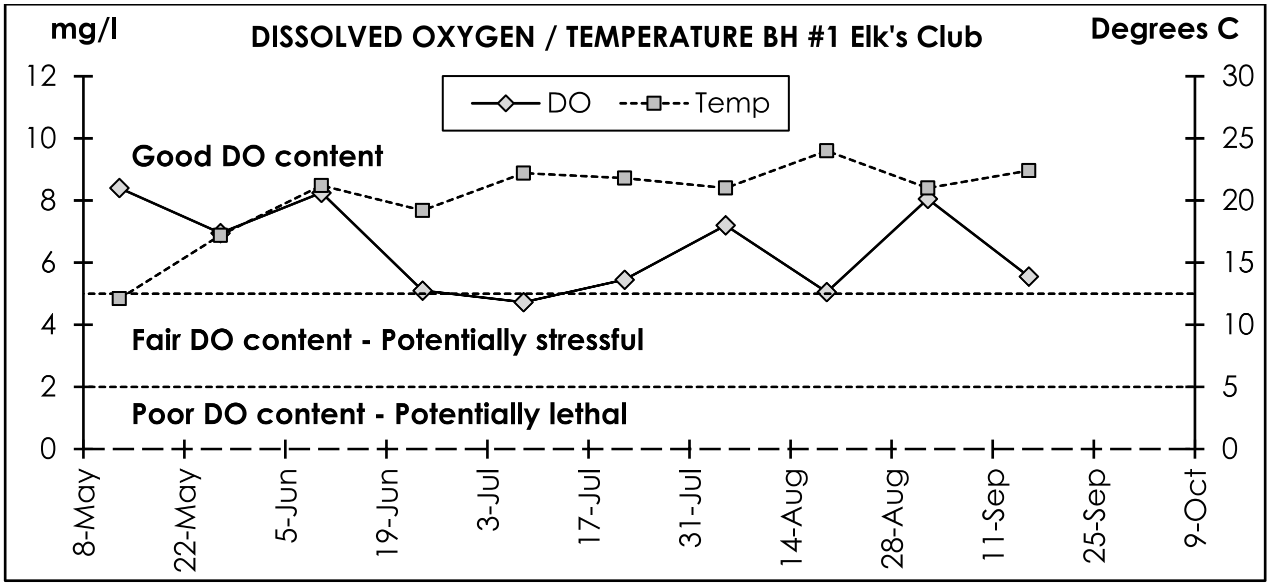
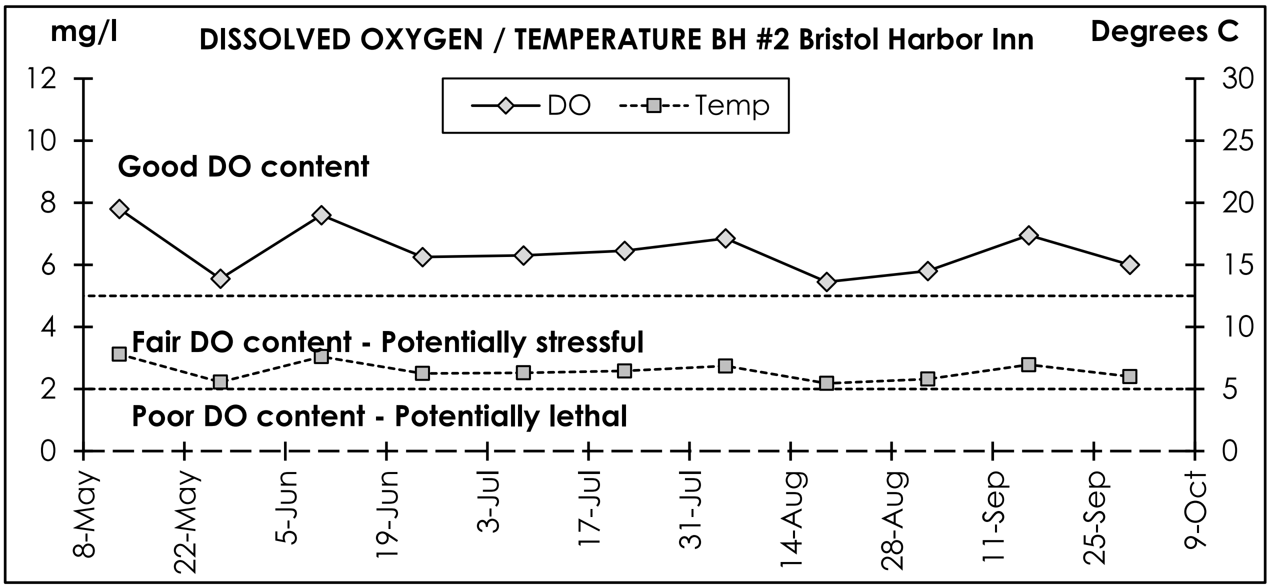


Figure 4a (cont'd.). 2021 Bristol Harbor Dissolved Oxygen and Temperature Data Charts
(Silver Creek #3 included in Figure 4b – Silver Creek sites





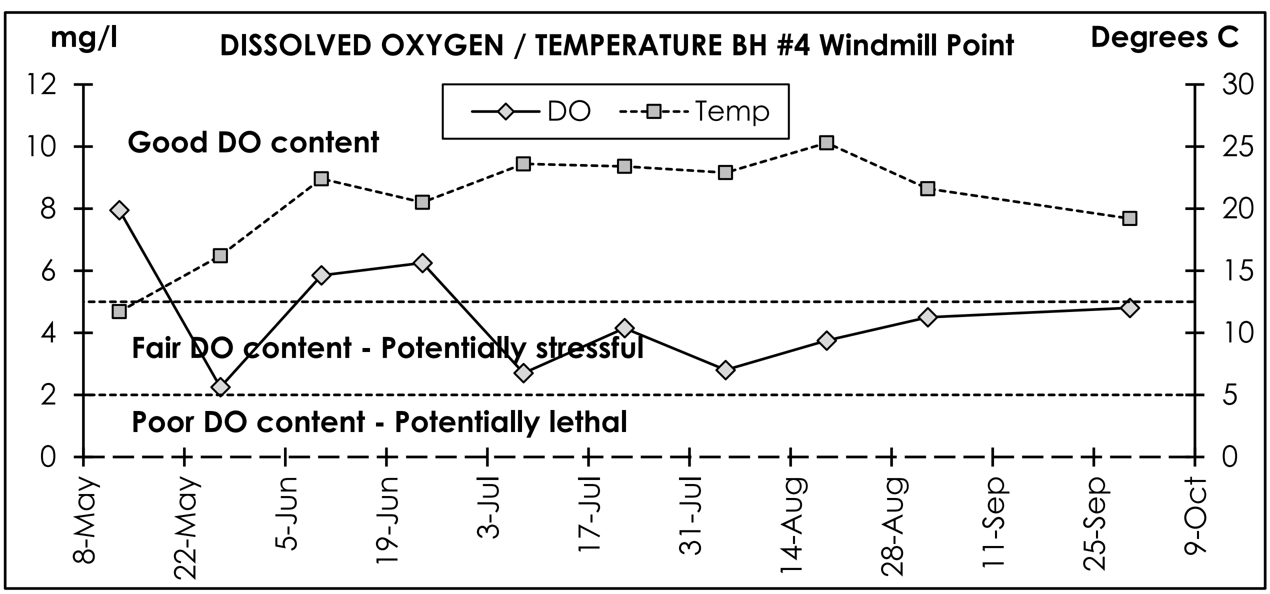
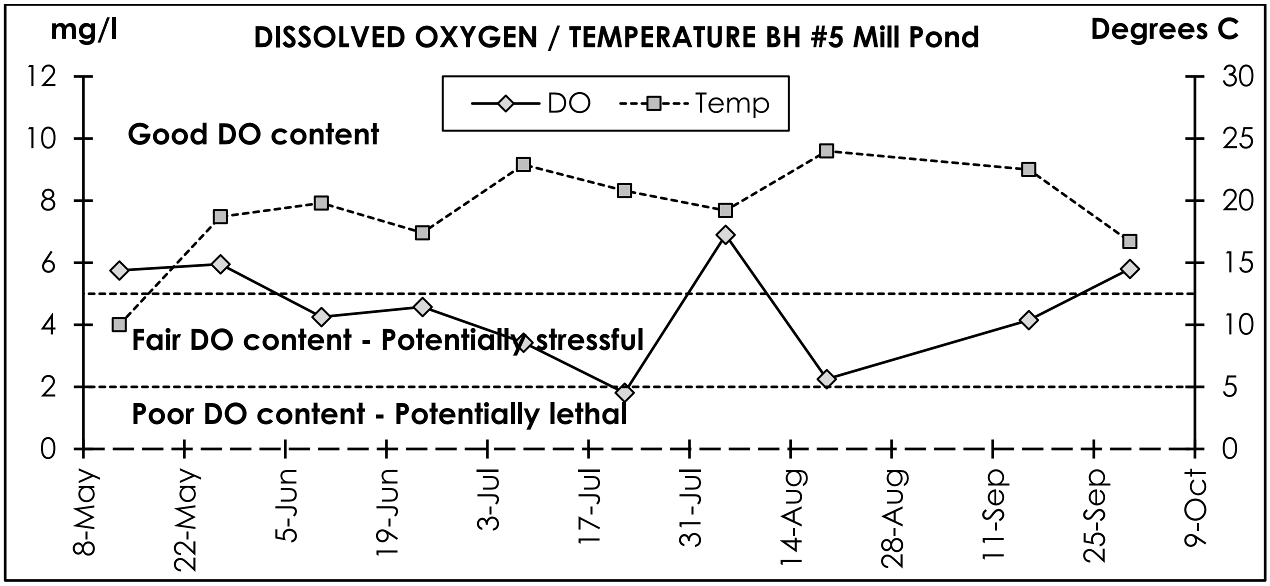
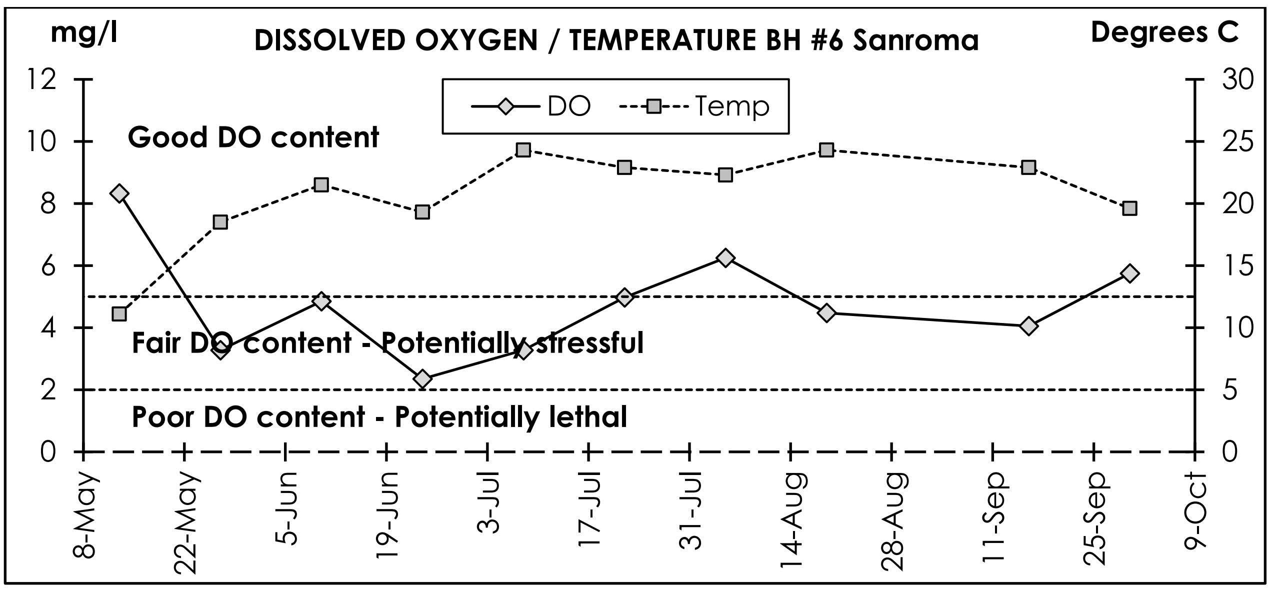


Figure 4a (cont'd.). 2021 Bristol Harbor Dissolved Oxygen and Temperature Data Charts





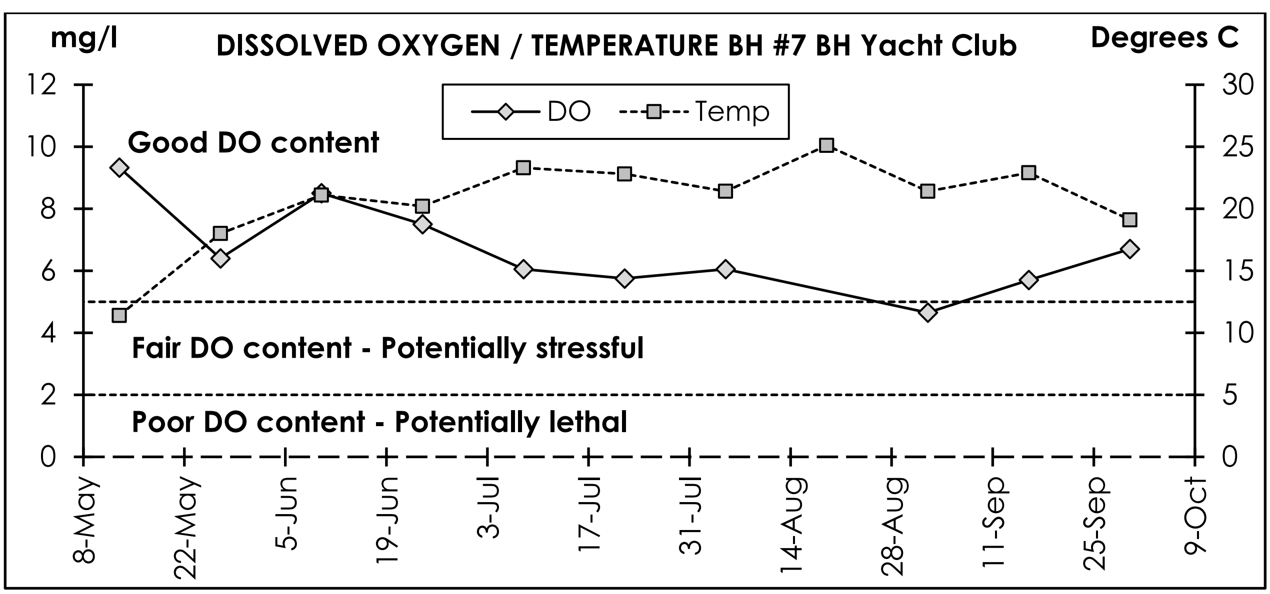
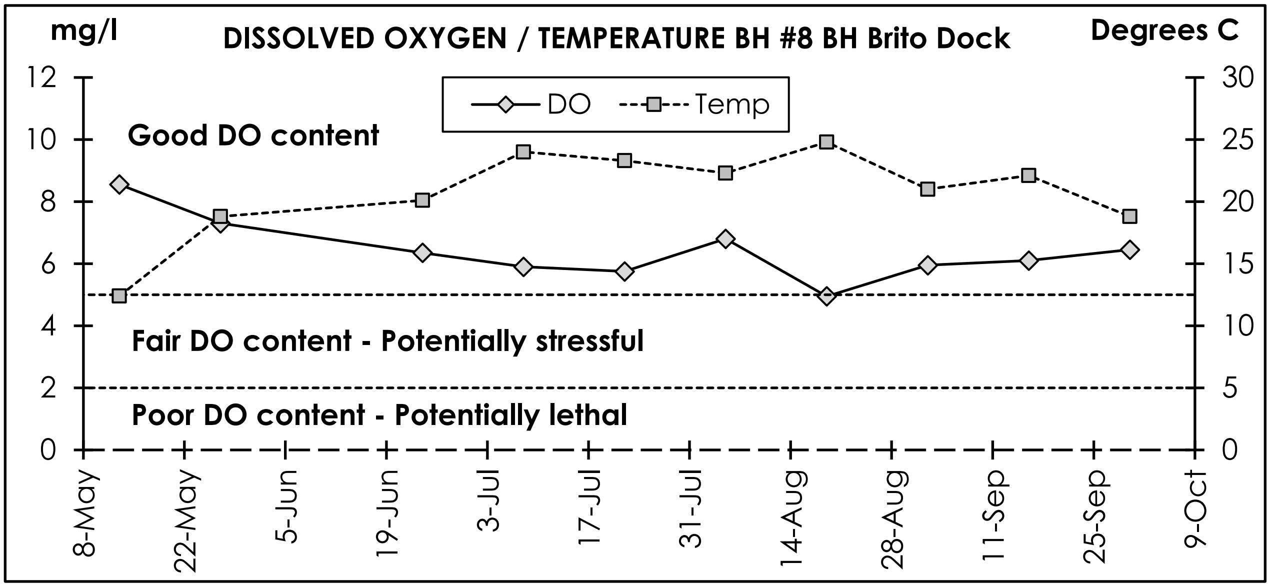


Figure 4a (cont'd.). 2021 Bristol Harbor Dissolved Oxygen and Temperature Data Charts



In 2021, many sites in the harbor areas recorded periods of DO in the stressful range. But only site, #5 Mill Pond, recorded DO levels in the lethal range in 2021, and then only briefly (figure 4a). Increased precipitation may have helped keep the waters moving bringing in more oxygen. These values reflected an improvement compared to the previous year.

Sites associated with Silver Creek (#3, #9, #10, #11 and #14) regularly recorded stressful DO values (5 - 2 mg/L range). Some sites had periods when that declined below the 2 mg/L range, into potentially lethal to some organisms (figure 4b).

Figure 4b. 2021 Silver Creek Dissolved Oxygen and Temperature Data Charts
(Upstream to downstream)

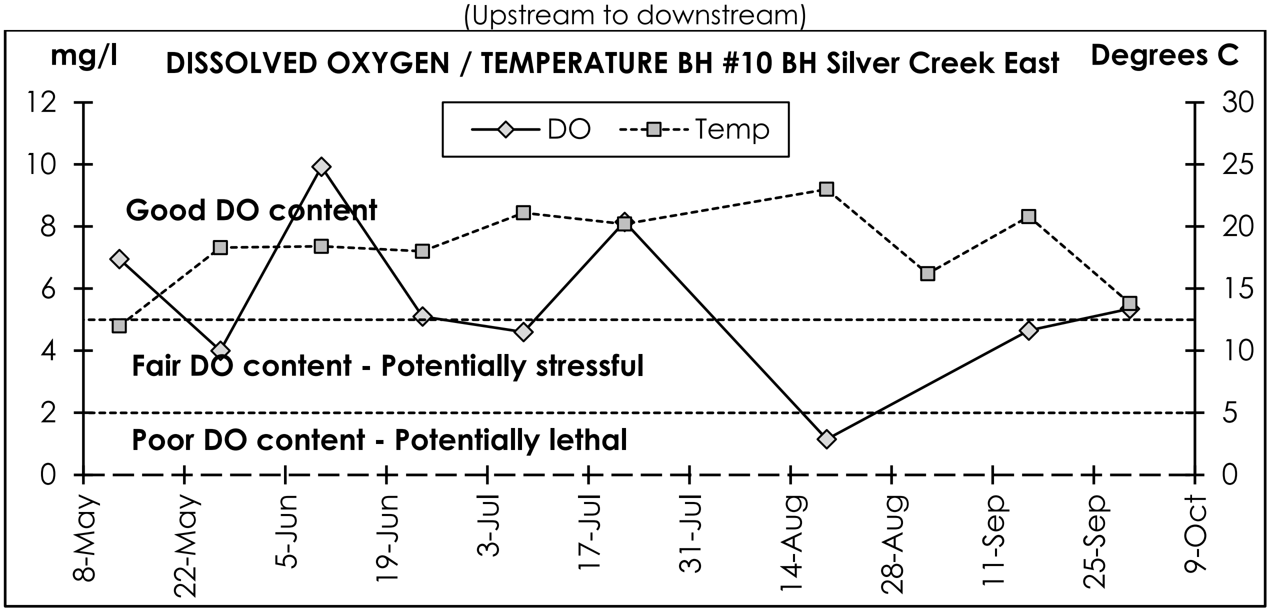
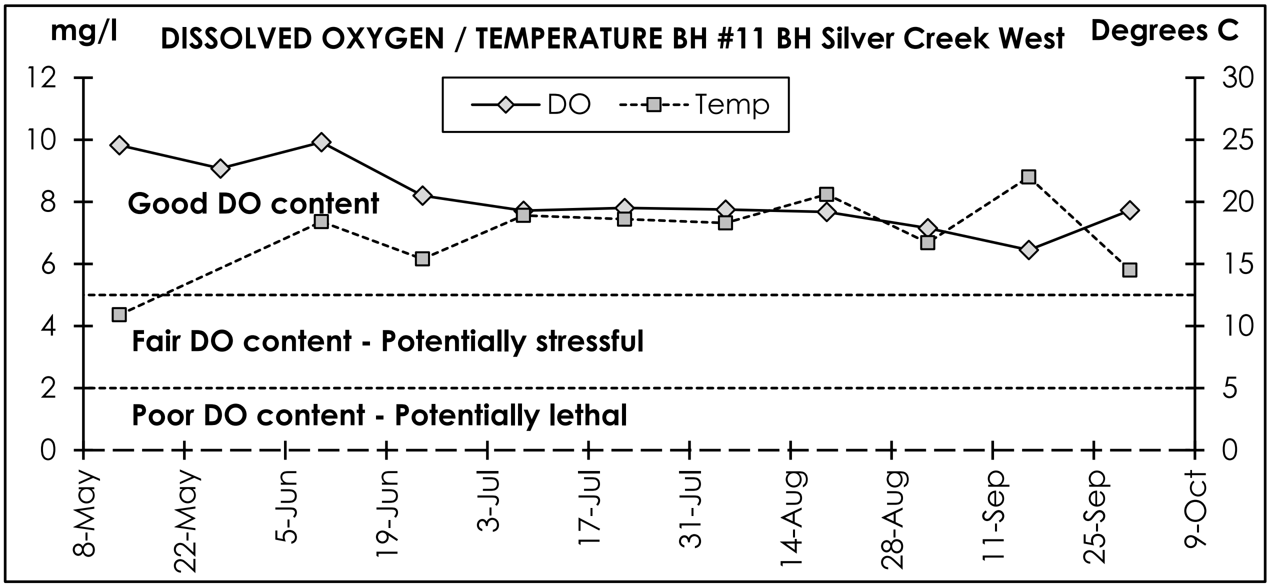
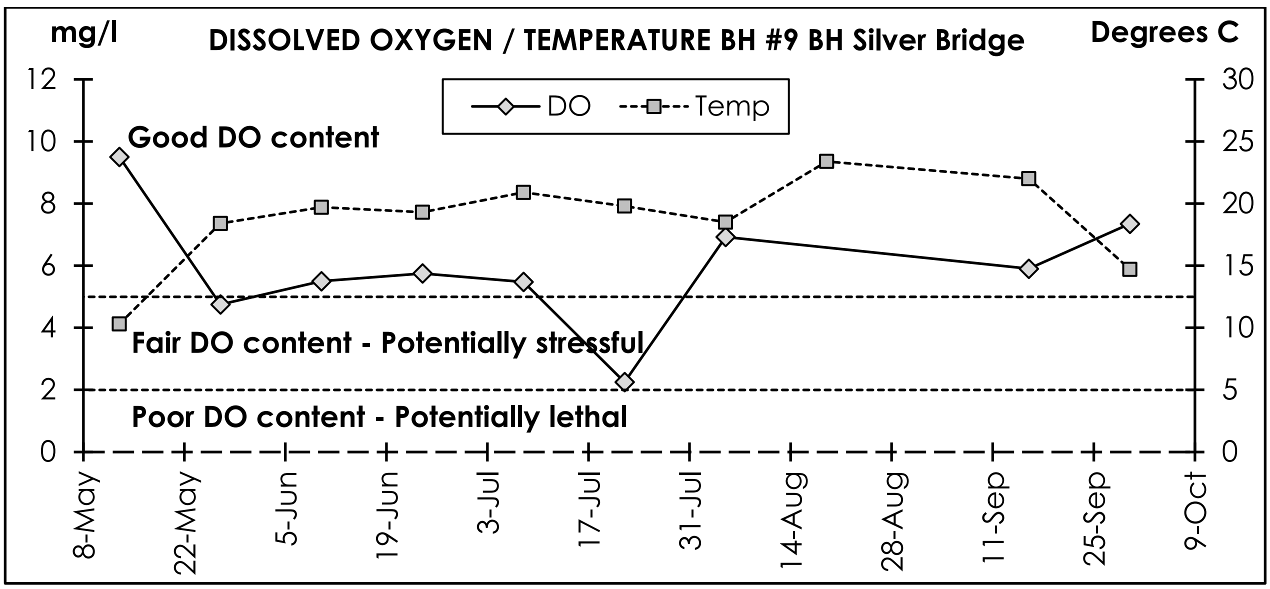


Figure 4b (continued). 2021 Silver Creek Dissolved Oxygen and Temperature Data Charts
(Upstream to downstream)





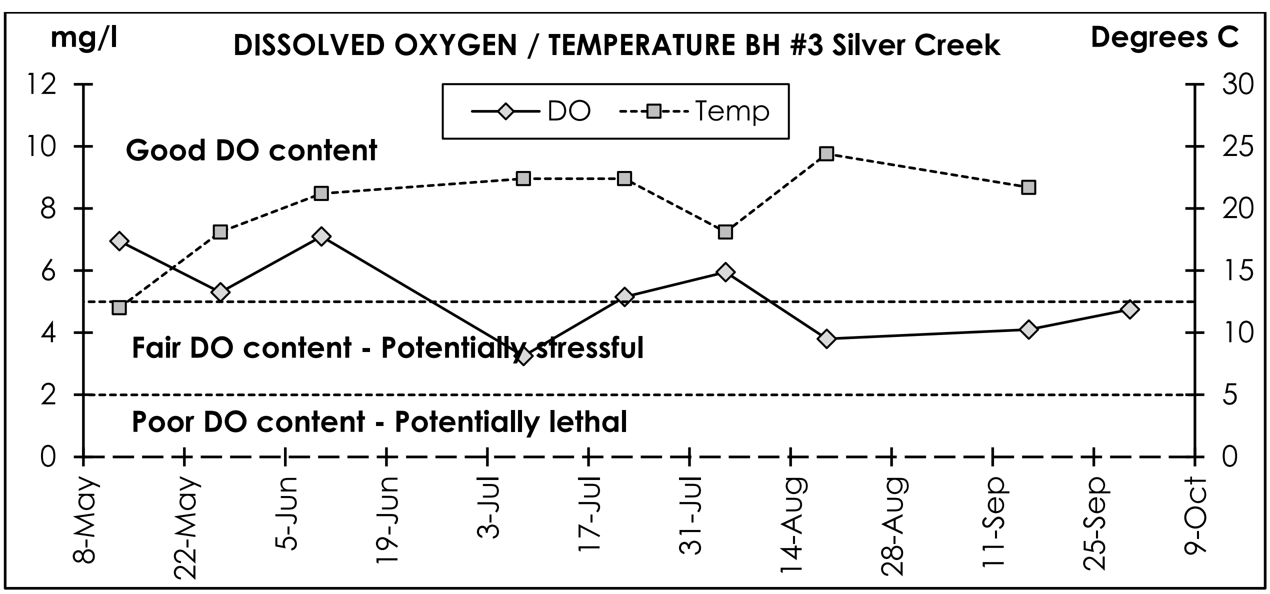


Figure 4b (continued). 2021 Silver Creek Dissolved Oxygen and Temperature Data Charts
(Upstream to downstream)

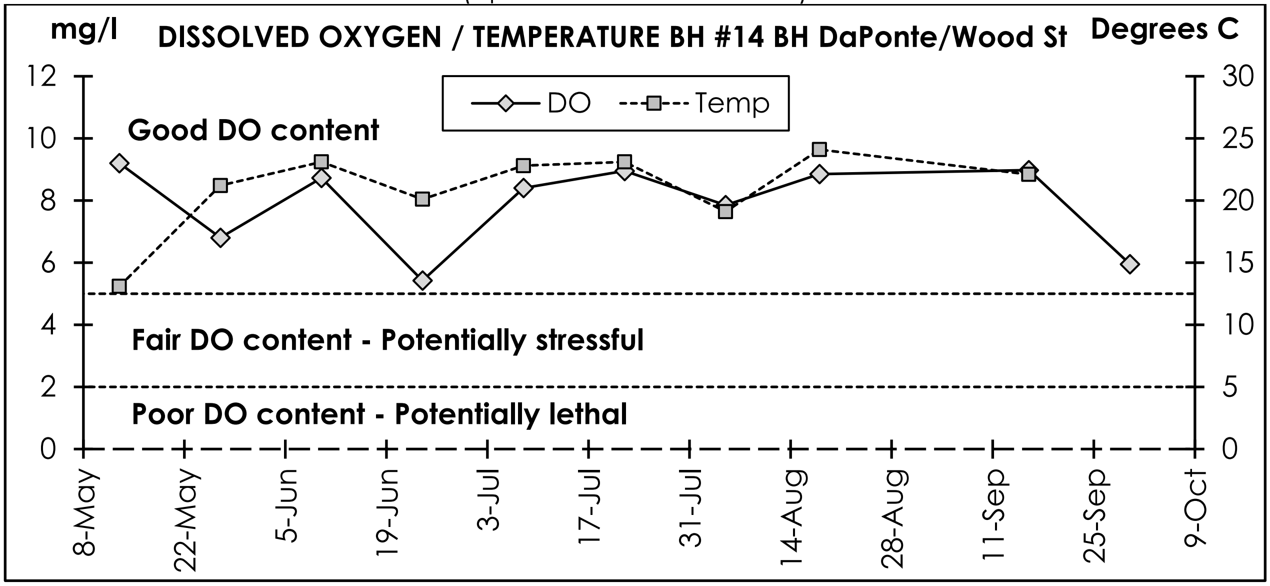
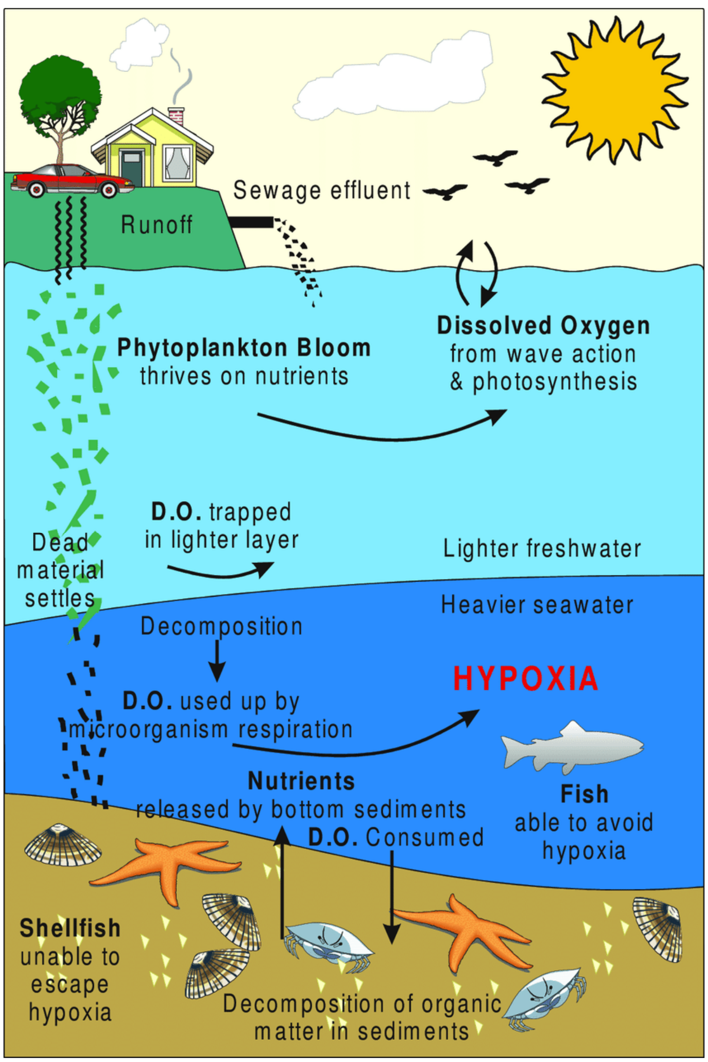


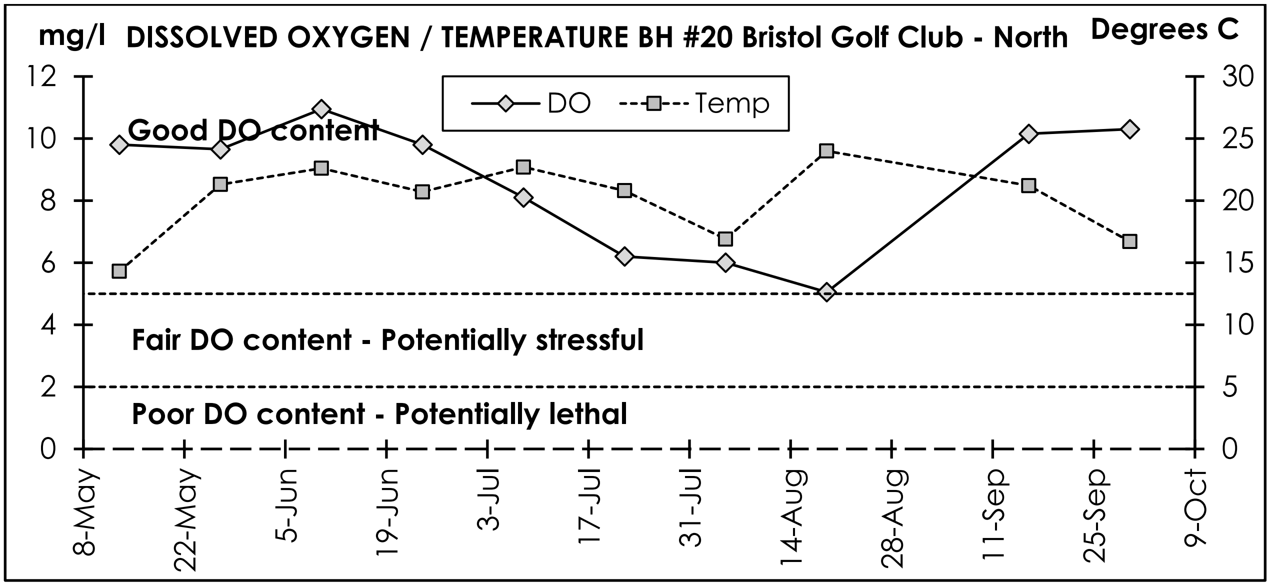
Figure 5.Ecological relevance of dissolved oxygen concentration in estuarine water (Image from https://www.researchgate.net/publication/26991140_Evaluation_Guidelines_for_Ecological_Indicators_EPA 620R-99005/figures?lo=1)

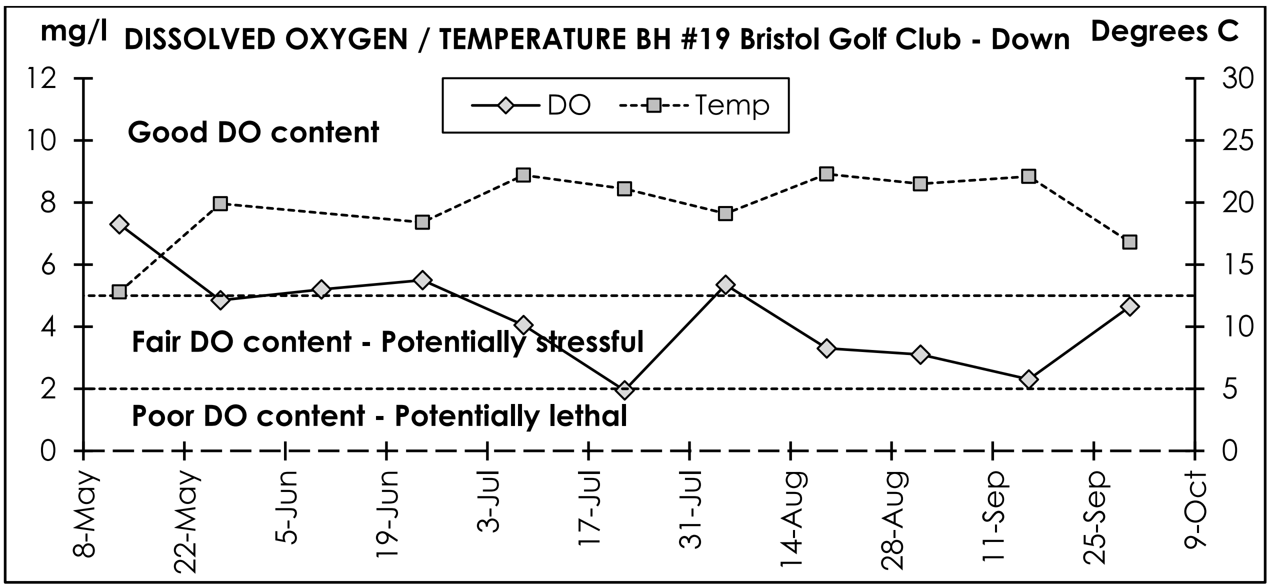


The Golf Course sites are located on a shallow stream in an altered environment, which creates frequent low flow and even dry conditions. When there is water, the DO levels at the downstream site were within the stressful and even lethal levels throughout much of the summer (figure 4c). Streams without vegetative cover frequently are quite warm, which reduces its ability to hold DO. They are also often nutrient enriched due to fertilizer runoff and/or goose droppings, which increases algal growth and decomposition, and reduces DO. Additional vegetative buffers could provide shade and perhaps improve DO levels in the stream. The DO levels further downstream at the Silver Creek East site were highly variable. Stormwater runoff likely affected the DO levels in the stream as 2021 was a somewhat wet year.

Conditions at the Kickemuit (#17) were generally good for much of the summer, an improvement compared to previous years (figure 4d). Further down bay at Annaswanscutt (#18) DO was often lower, with DO levels in the stressful range occasionally in later summer. This is interesting as Annaswanscutt is a more open site with more tidal and wind activity.

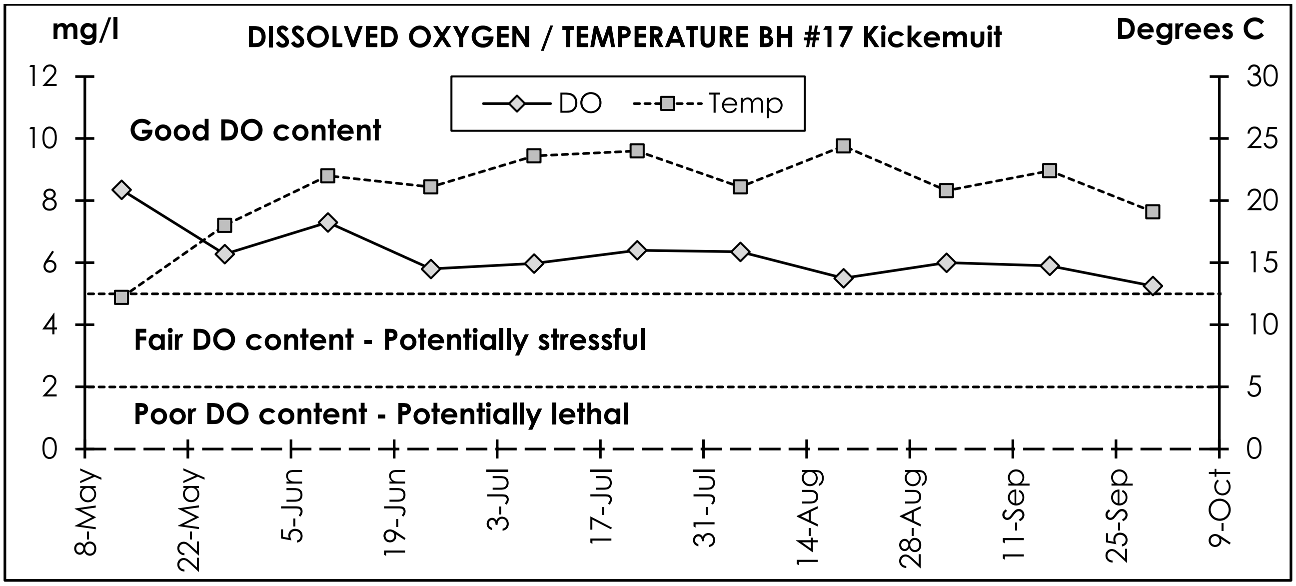
Figure 4c. Dissolved Oxygen and Temperature Silver Creek Golf Course Sites

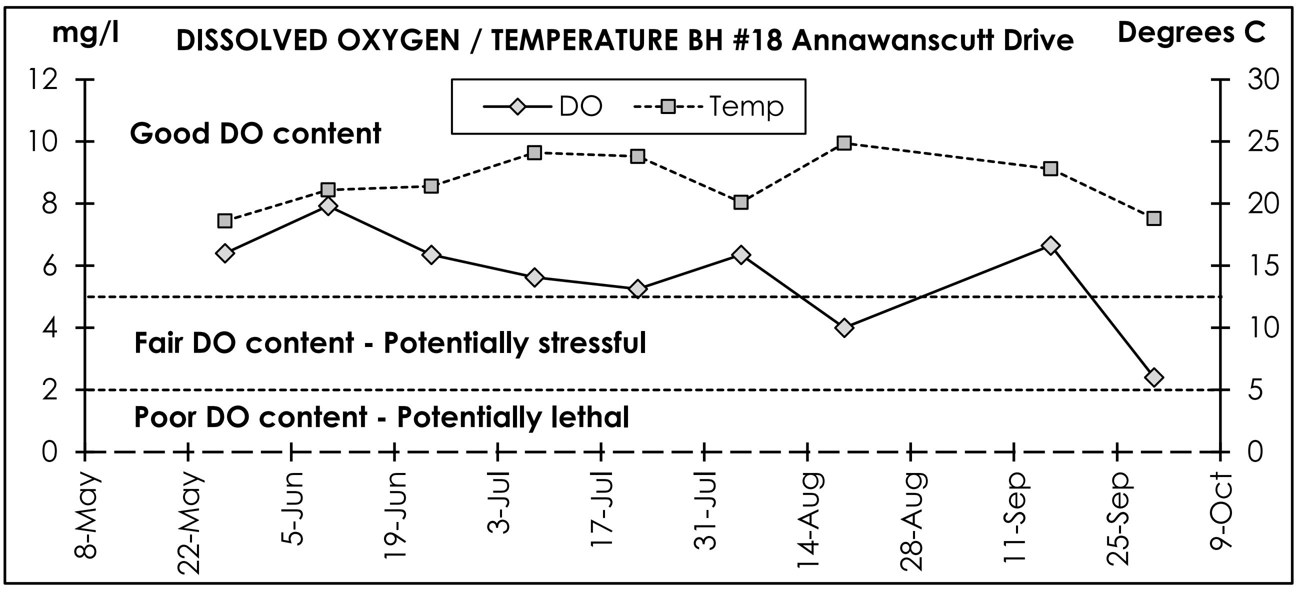




(Bristol Harbor Golf Course)

Figure 4d. 2021 Dissolved Oxygen and Temperature Mt Hope Bay Sites

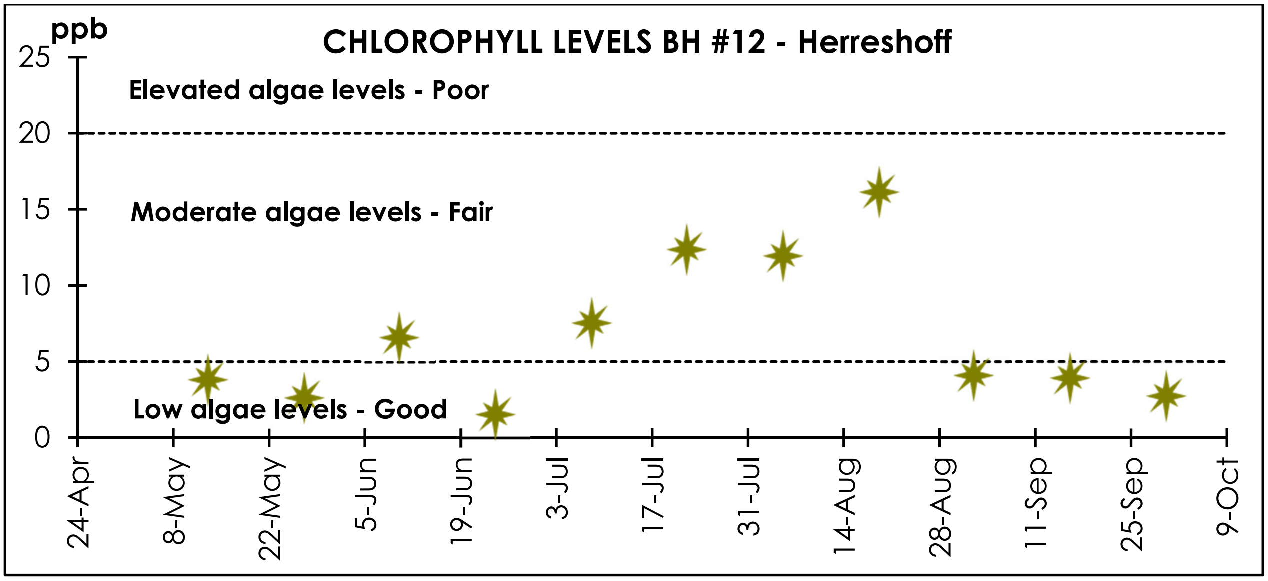


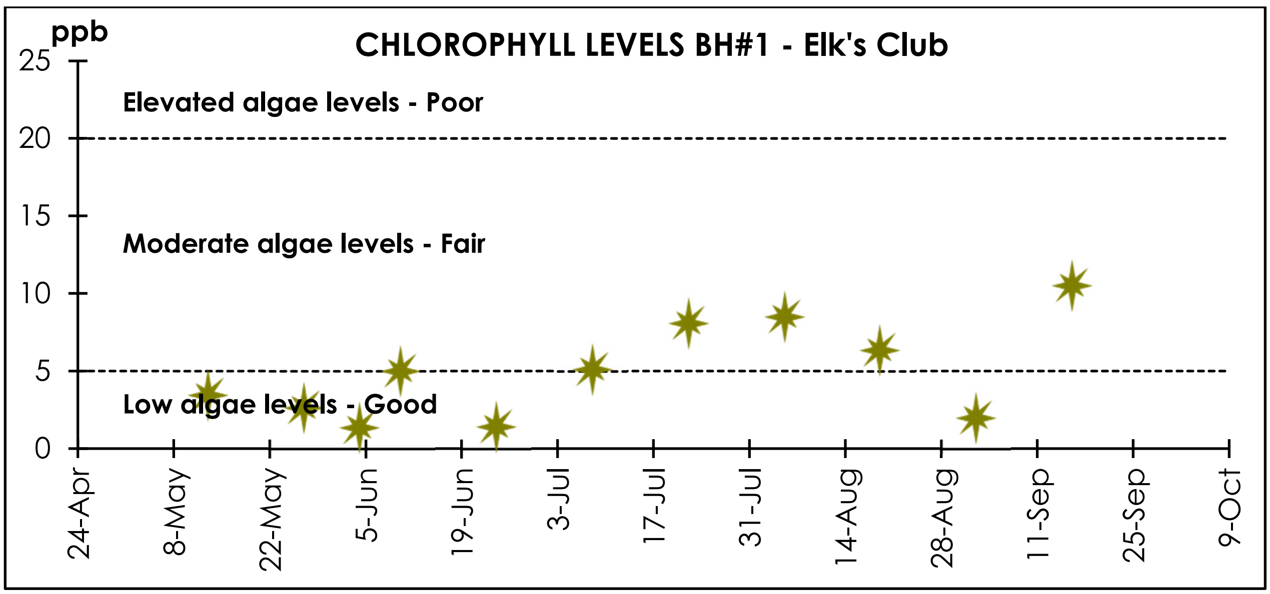


Chlorophyll is a photosynthetic pigment found in all plants, including algae. Chlorophyll-a (chl-a) is the most common form and is analyzed by URIWW to estimate the abundance of algae in the water; the higher the chl-a level, the more algae. Like all plants, algae need sunlight to convert energy and nutrients (nitrogen and phosphorus) into food via photosynthesis. But algae are sensitive to harmful ultraviolet rays in sunshine. Thus chl-a levels tend to be higher just below the surface where they still have access to sunlight, but the water filters out harmful wavelengths.

Algae are essential for a healthy harbor. They form the base of the aquatic food web and are eaten by zooplankton (microscopic animals) and small fish, which are eaten by larger animals. Animal abundance in an estuary often depends on the concentration of algae, or amount of food available. Too much algae, visible as green blooms or cloudy water, can result in poor water clarity, unpleasant odors, and lead to low oxygen particularly in bottom waters, and sometimes even fish kills. The USEPA's National Coastal Assessment (NCA) program criteria for chl-a in northeastern estuaries are: <5 ppb (low) – Good; 5 – 20 ppb (moderate) – Fair; and > 20 ppb (elevated) – Poor (USEPA 2008).

Figure 6a. 2021 Bristol Harbor Sites Chlorophyll Data Charts (Arranged from Southeast to Northwest)





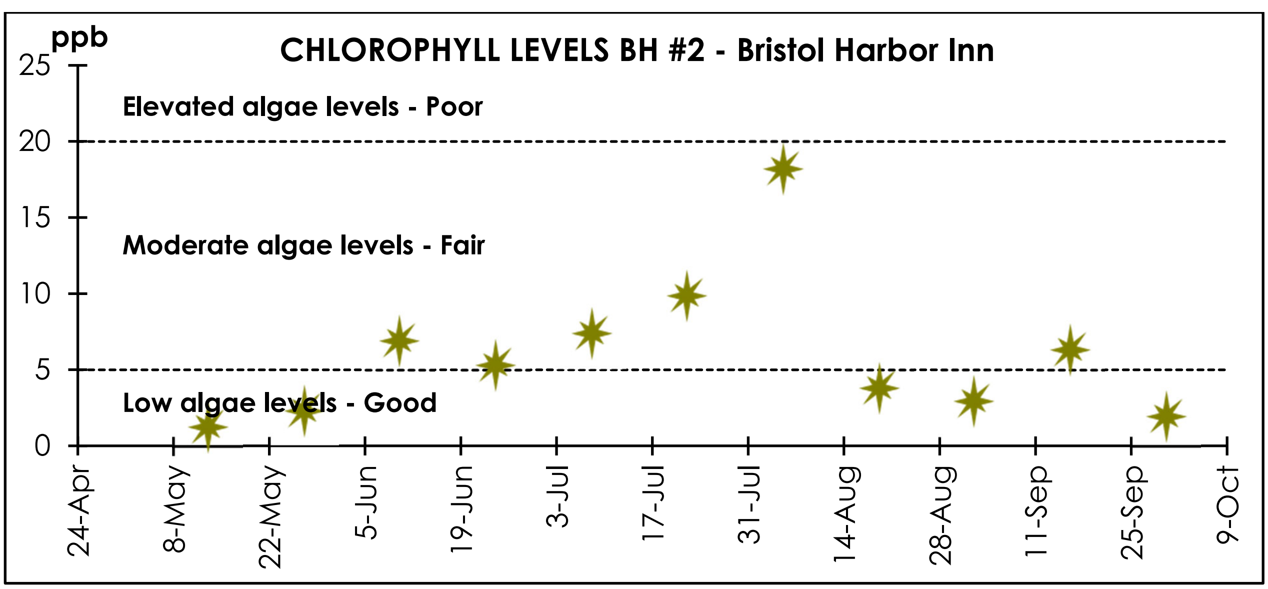
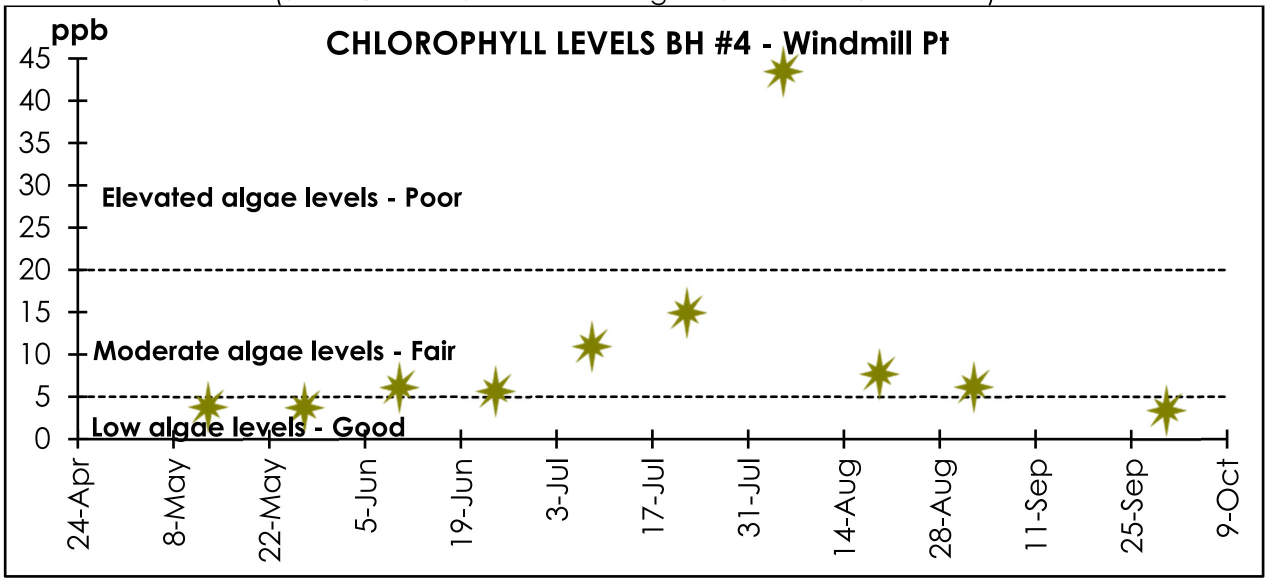
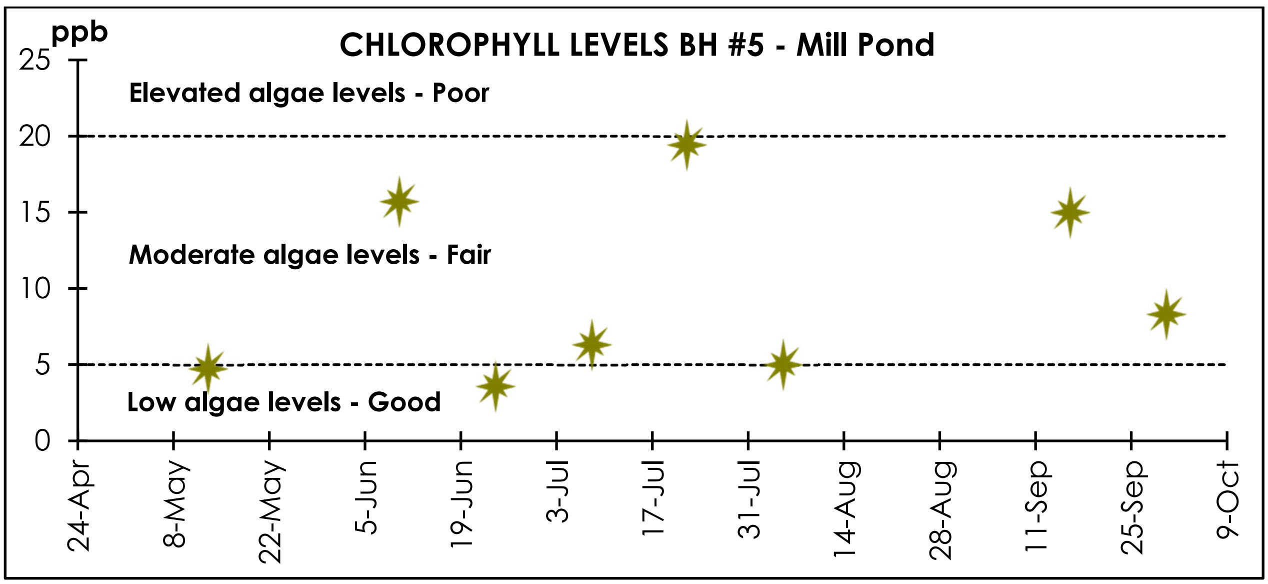


Figure 6a (cont'd.). 2021 Bristol Harbor Chlorophyll Data Charts

(Silver Creek #3 included in Figure 6b – Silver Creek sites)





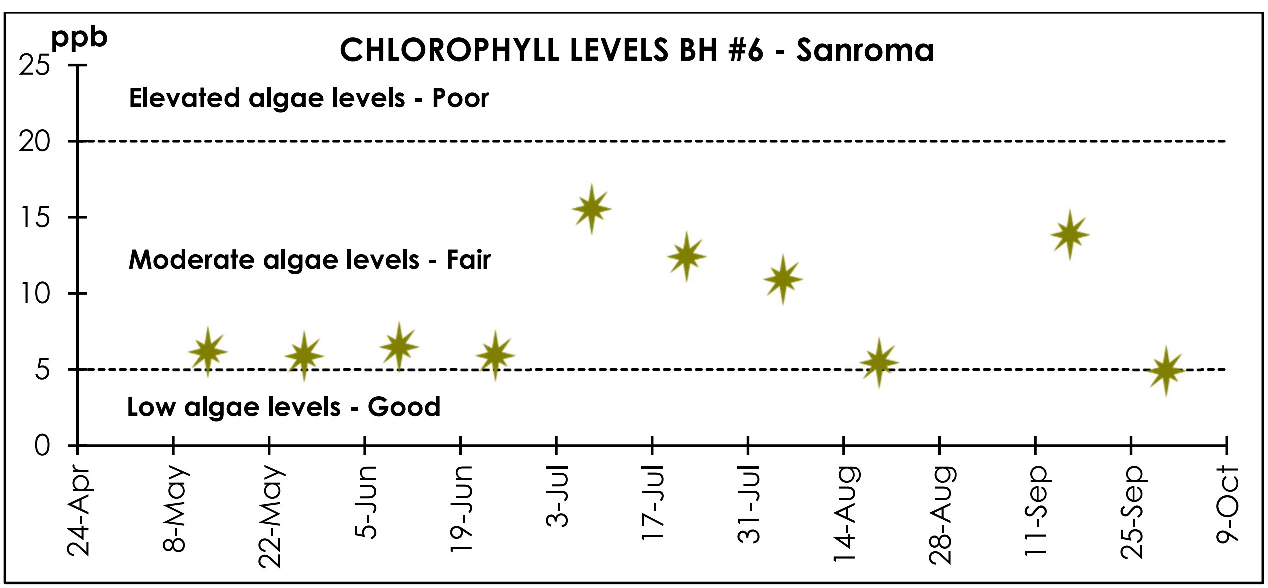
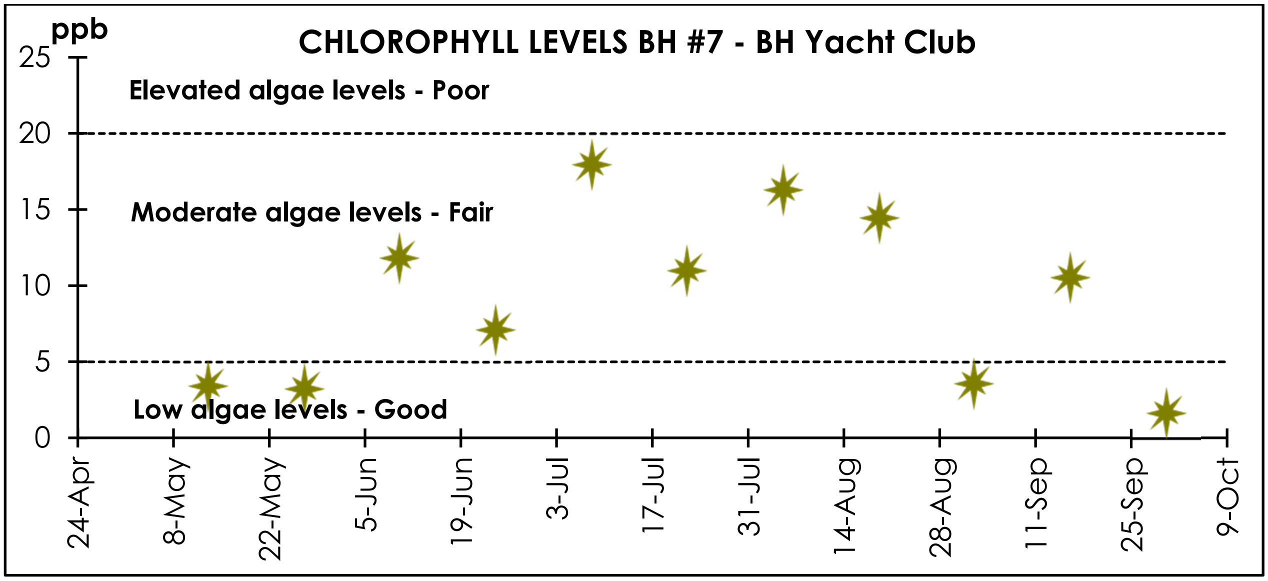
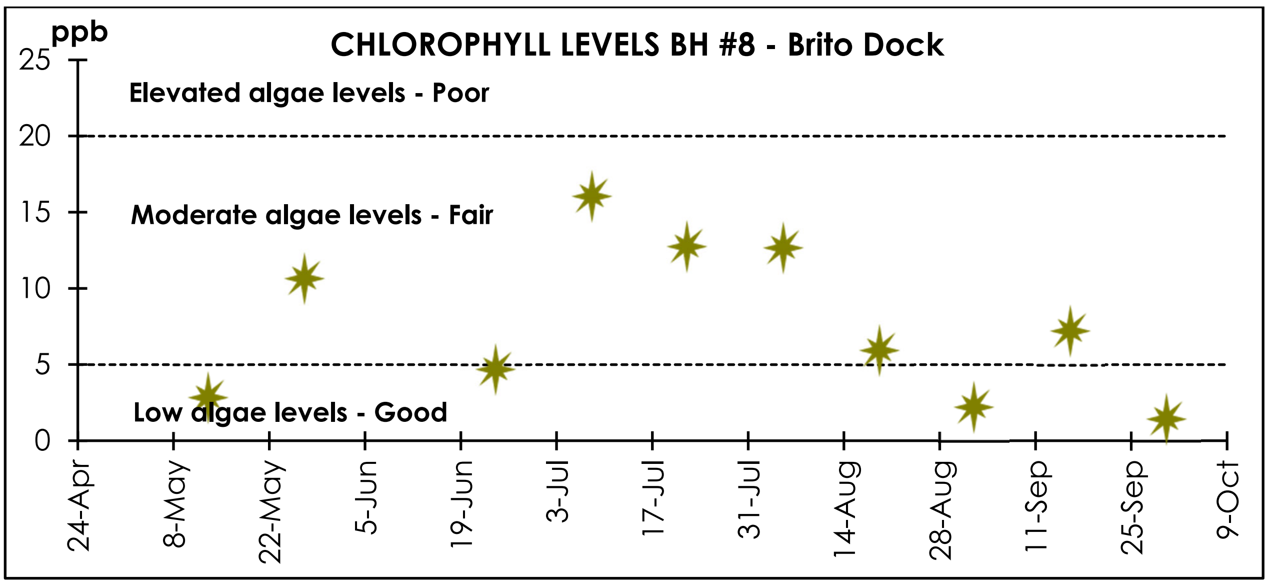


Figure 6a (cont'd.). 2021 Bristol Harbor Chlorophyll Data Charts

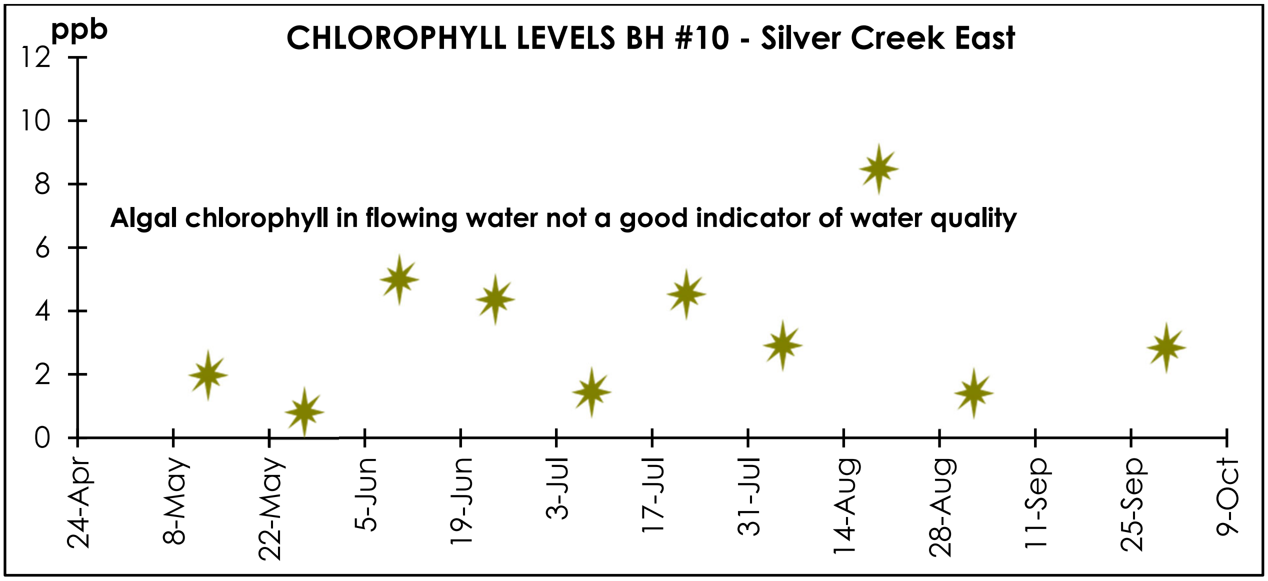


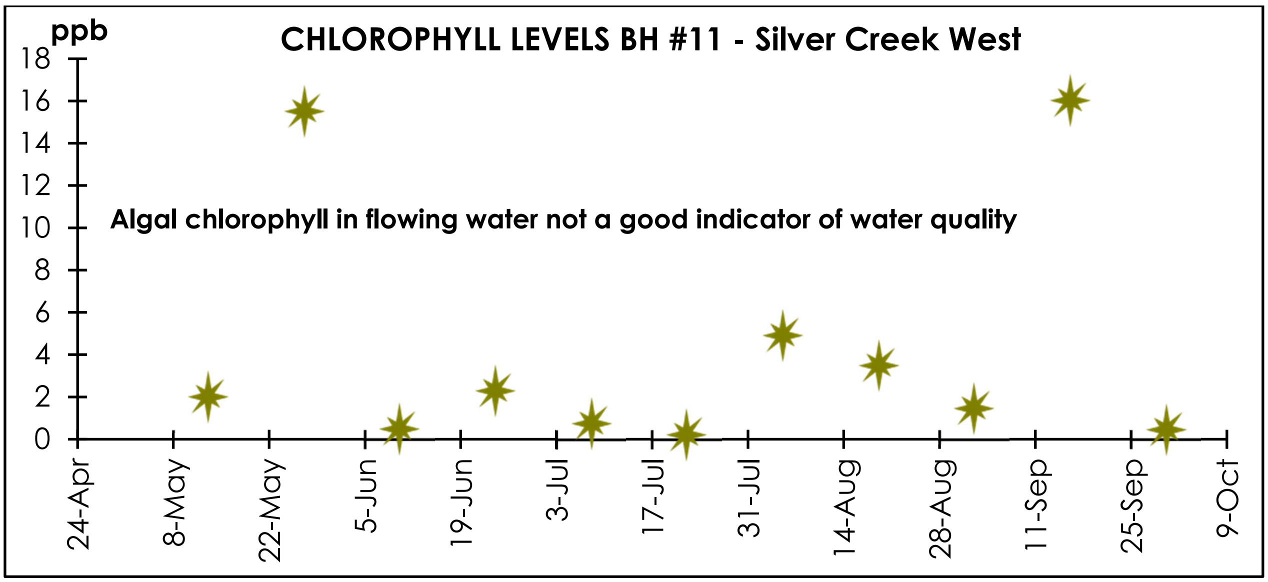


Bristol Harbor sites generally had good to fair algae levels throughout much of the summer of 2021, an indicator of a relatively healthy aquatic ecosystem (figure 6a). However, algal blooms were evident in July and again in September at many of the sites in the northern part of the harbor (Wind Mill Pt #4 through Brito Dock #8).

Figure 6b shows that very significant algal blooms were again experienced at Silver Creek #9 requiring a change in scale to display the data in that chart. Much reduced levels compared to 2020 values of chlorophyll were recorded at Daponte/Wood St (#14) in 2021. The Silver Creek East site (BH#10) recorded generally low values, but quite variable. The Silver Creek West site had generally lower levels, but included several higher spikes, suggesting runoff washing increased nutrients or even algae from upstream areas into the stream. Those algae would continue downstream with the increased flow that existed throughout much of 2021.

Figure 6b. 2021 Silver Creek and Upstream Sites Chlorophyll Data Charts





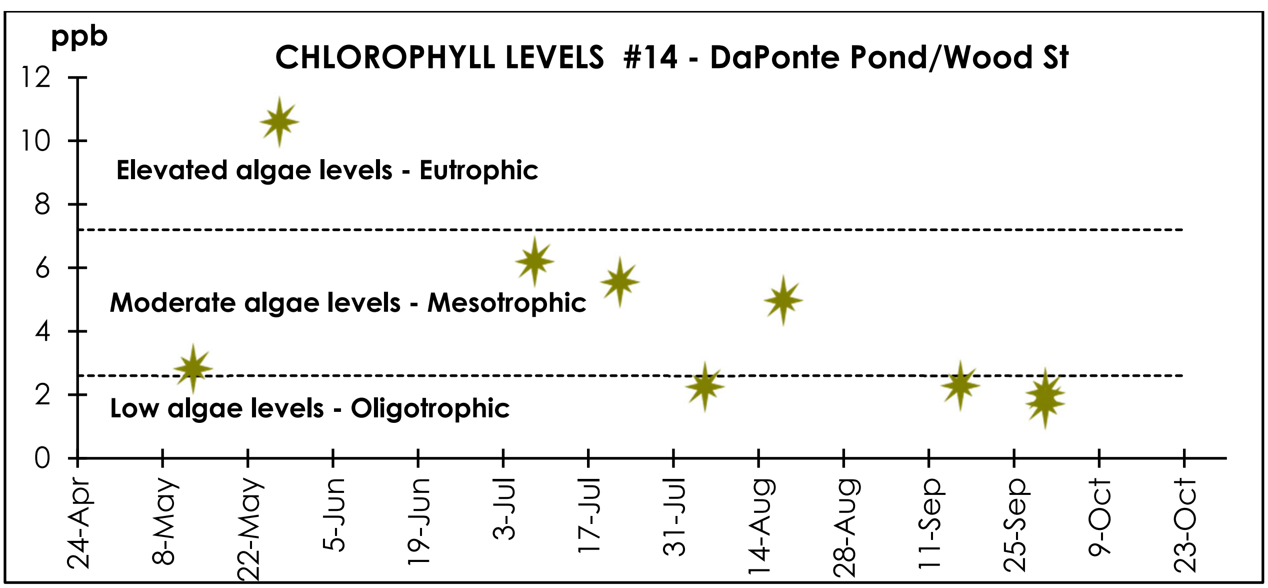
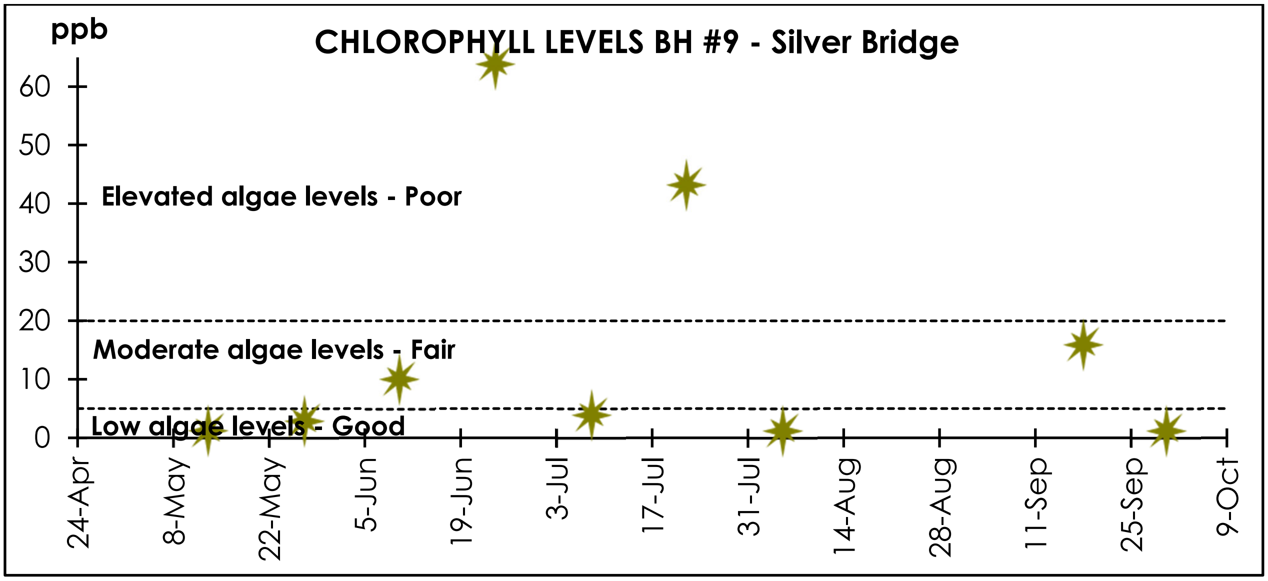
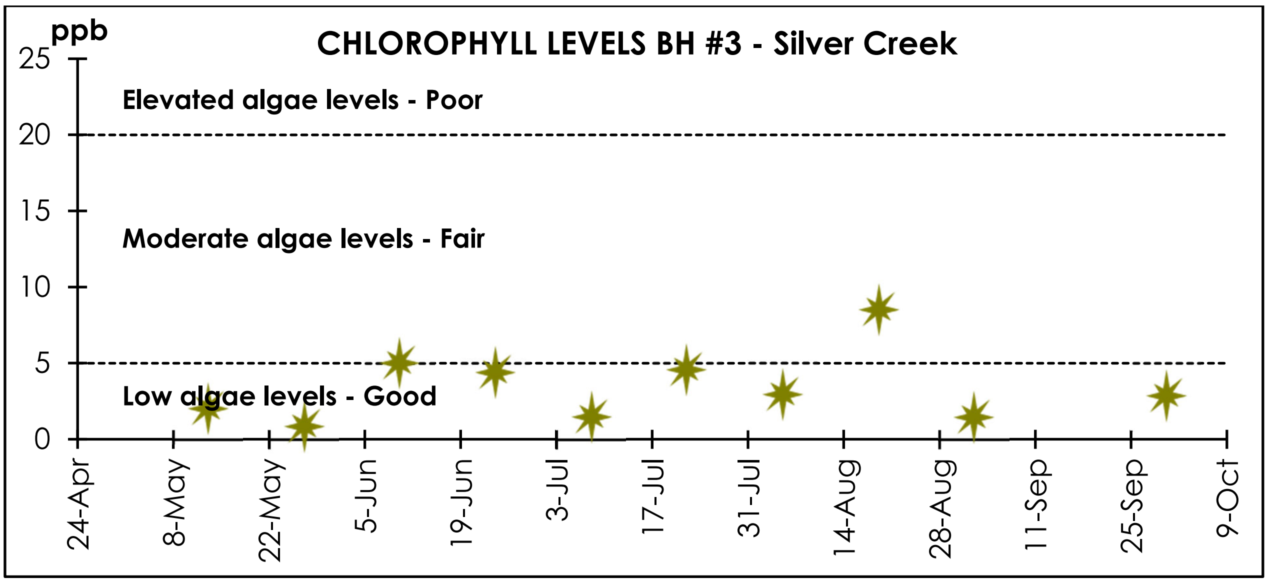


Figure 6b. 2021 Silver Creek and Upstream Sites Chlorophyll Data Charts (Cont.)

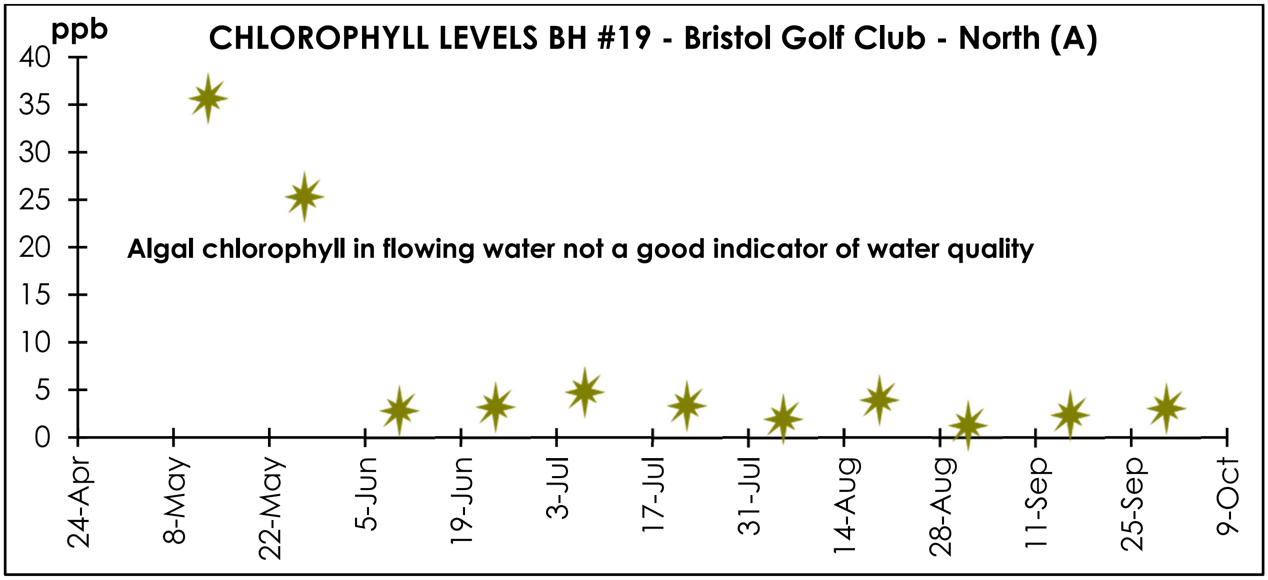


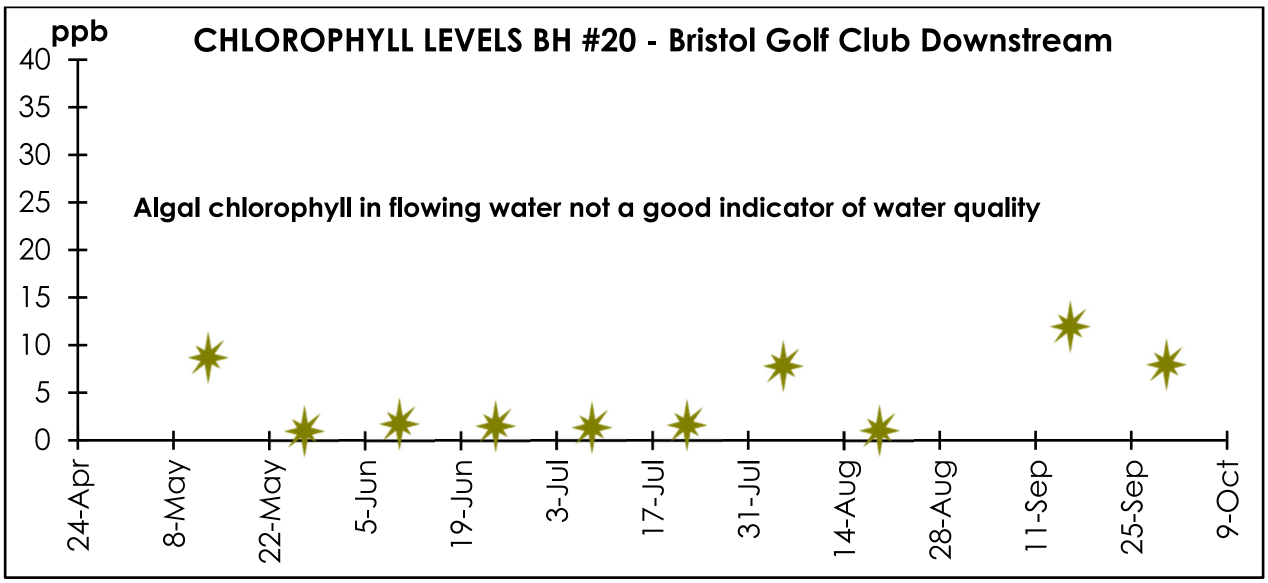


At Bristol Golf Club in Rhode Island, one hole is in sight of a blue metal warehouse building. (Image from https://onpar.blogs.nytimes.com/2011/05/22/when-a-bad-golf-course-edges-into-goodness/)

The Golf Course North (BH #19) had generally very low levels of algae, as we often expect inflowing water (figure 6c). The downstream site, Golf Course B had more variable levels of algae, but generally low levels.

Figure 6c. 2021 Silver Creek Golf Course Sites Chlorophyll Data Charts

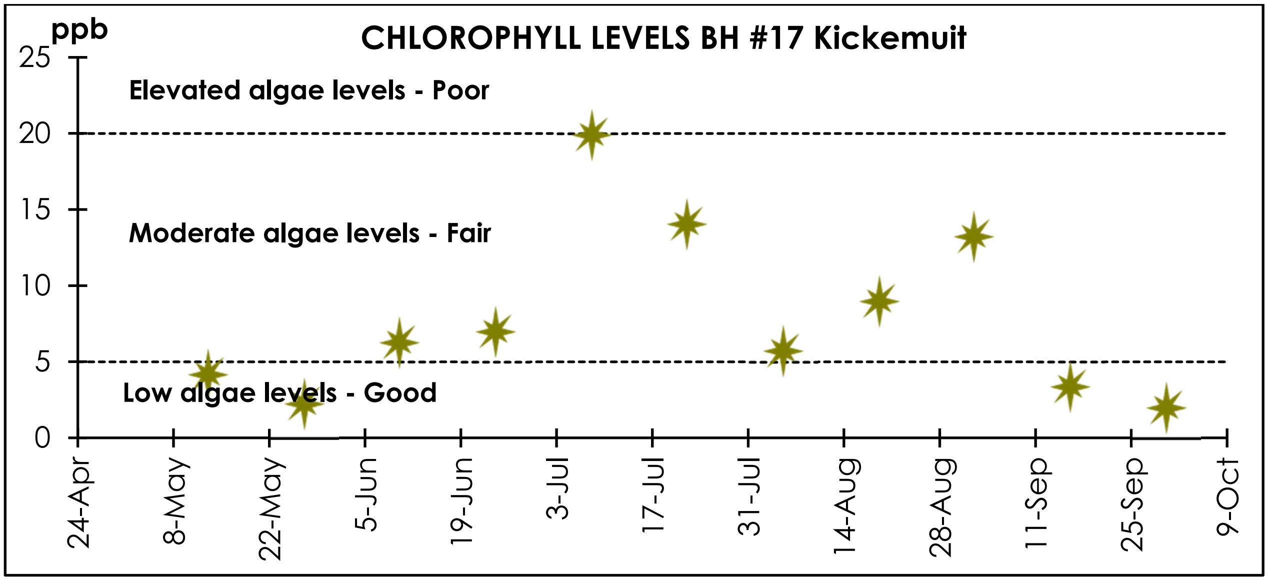




The Mt Hope Bay sites had algal levels in the moderate to low range throughout most of the monitoring season (figure 6d). Increased algal levels were present at the Mount Hope Bay sites during the same period that the Bristol Harbor sites were experiencing algal blooms (July and later summer (late August/September), suggesting this was due to particularly good weather conditions for algal productivity, and not something happening at these specific sites.

Cruising Mt Hope Bay (Image from https://www.trashpaddler.com/2013/09/a-day-in-mt-hope-bay.html)

Figure 6d. 2021 Mt Hope Bay Sites Chlorophyll Data Charts



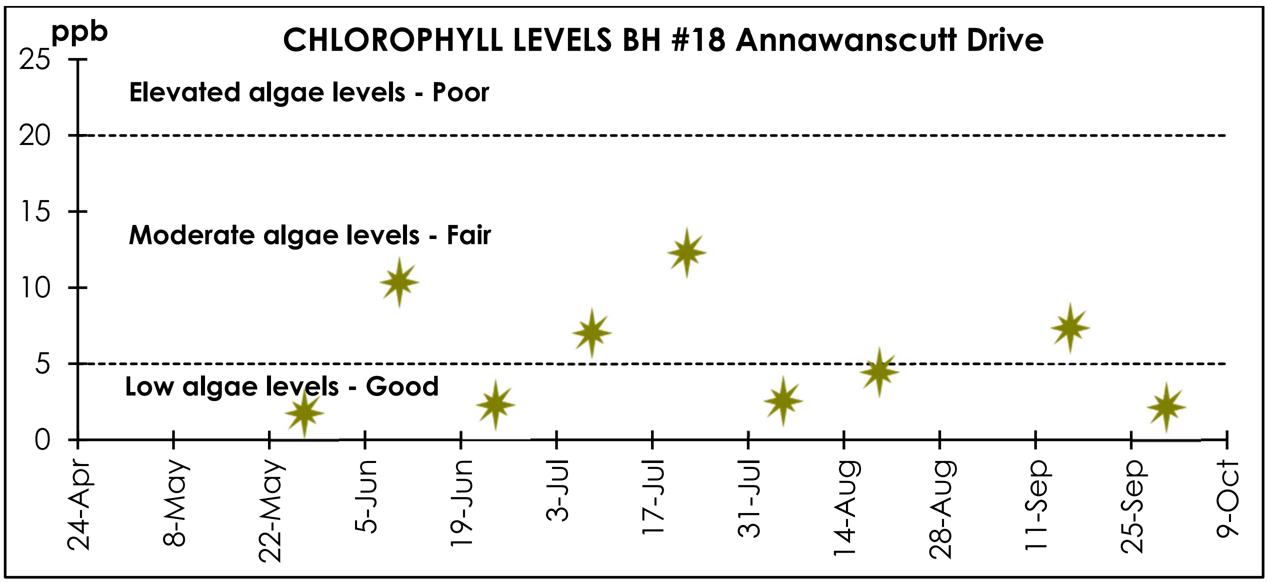


Figure 7. Sources of Fecal Bacteria (from https://www.slideshare.net/fatooo1/microbial-source-tracking-markers-for-detection-of-fecal-contamination)

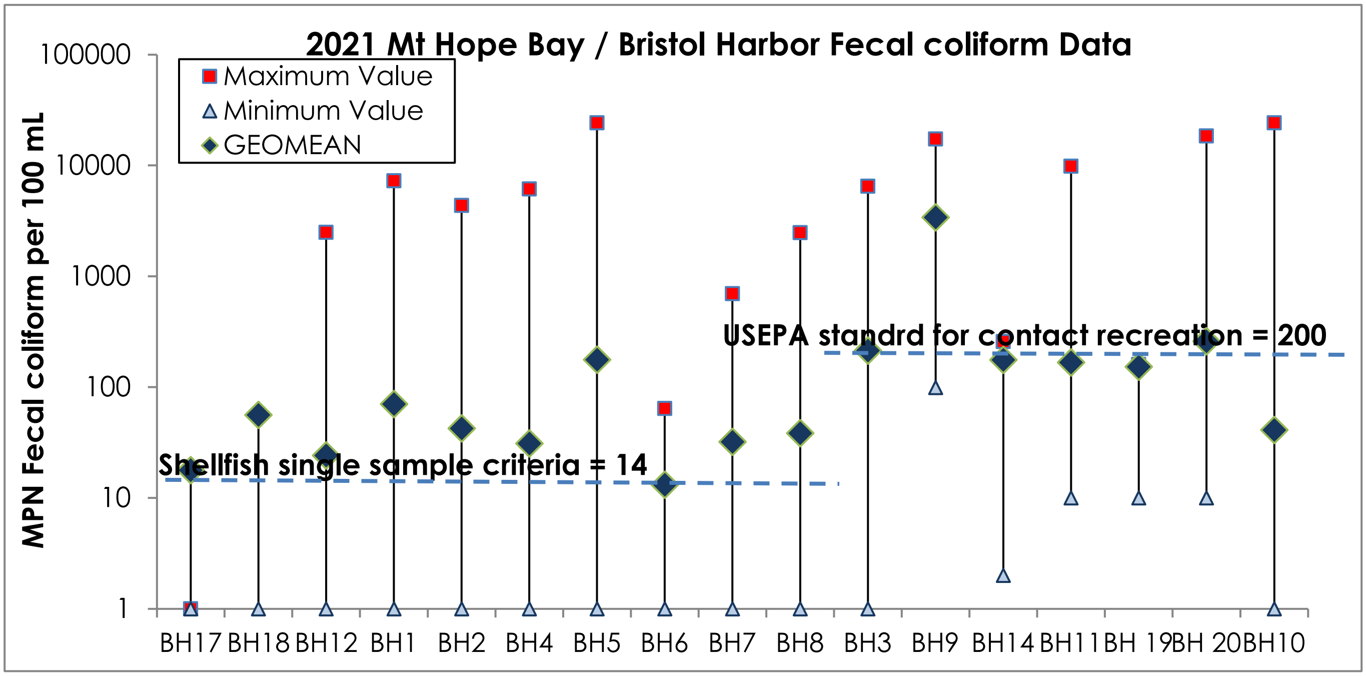
Shellfish Waters Bacteria Monitoring: Fecal coliform bacteria are an indicator of fecal contamination and potentially disease-causing organisms or pathogens. The National Shellfish Sanitation Program has established the maximum acceptable level at 14 fecal coliform per 100 mL for waters from which shellfish can be harvested. The standard was designed to prevent human illness associated with the consumption of fresh and frozen shellfish, and thus is quite conservative. Because bacteria levels can fluctuate dramatically and be impacted by short-term intermittent, localized sources such as waterfowl droppings, bacteria averages are typically reported as the geometric mean (geomean). This statistical method transforms a set of highly variable data (as bacteria can be) in order to better represent an average level. Thus, a single very high sample will not overwhelm routine low or below detection values as might happen with arithmetic averaging.

Table 2. 2021 Shellfish Bacteria Indicator Data – Fecal Coliform Bacteria

Site ID	13-May	10-Jun	9-Jul	5-Aug	2-Sep	30-Sep	Geomean
	----- Most Probable Number of Fecal coliforms per 100 mL -----						
BH17	<10	10	**52**	**3448**		<10	**18**
BH18		10	41	**>24196**		<10	**56**
BH12	**64**	20	<10	**63**	2489	<10	**24**
BH1	<10	<10	**233**	**1017**	**7270**		**70**
BH2	<10	**20**	**158**	**4352**		10	**42**
BH4	<10	**64**	31	**74**	**6131**	<10	**31**
BH5	<10	**1437**	41	**14136**		**211**	**177**
BH6	<10	**64**	20	10		31	**13**
BH7	<10	**697**	20	**309**	**253**	<10	**32**
BH8	10		31	**109**	**2475**	<10	**38**
BH3	<10	**504**	**233**	**6488**		**583**	**214**
BH9	99	**15531**	**17329**	**2238**		**7701**	**3407**
BH14	2	**77.2**	**176.4**	**>24196**		**257.6**	**>176**
BH11	<10	**185**	**134**	**9830**		**538**	**167**
BH 19	41	10	**52**	**>24196**		**160**	**>153**
BH 20	10	31	**594**	**18416**	**2187**	41	**259**
BH10	<10		**121**		**24196**	<10	**41**
Fecal coliform shellfish waters maximum = 14 CFU (or MPN)							

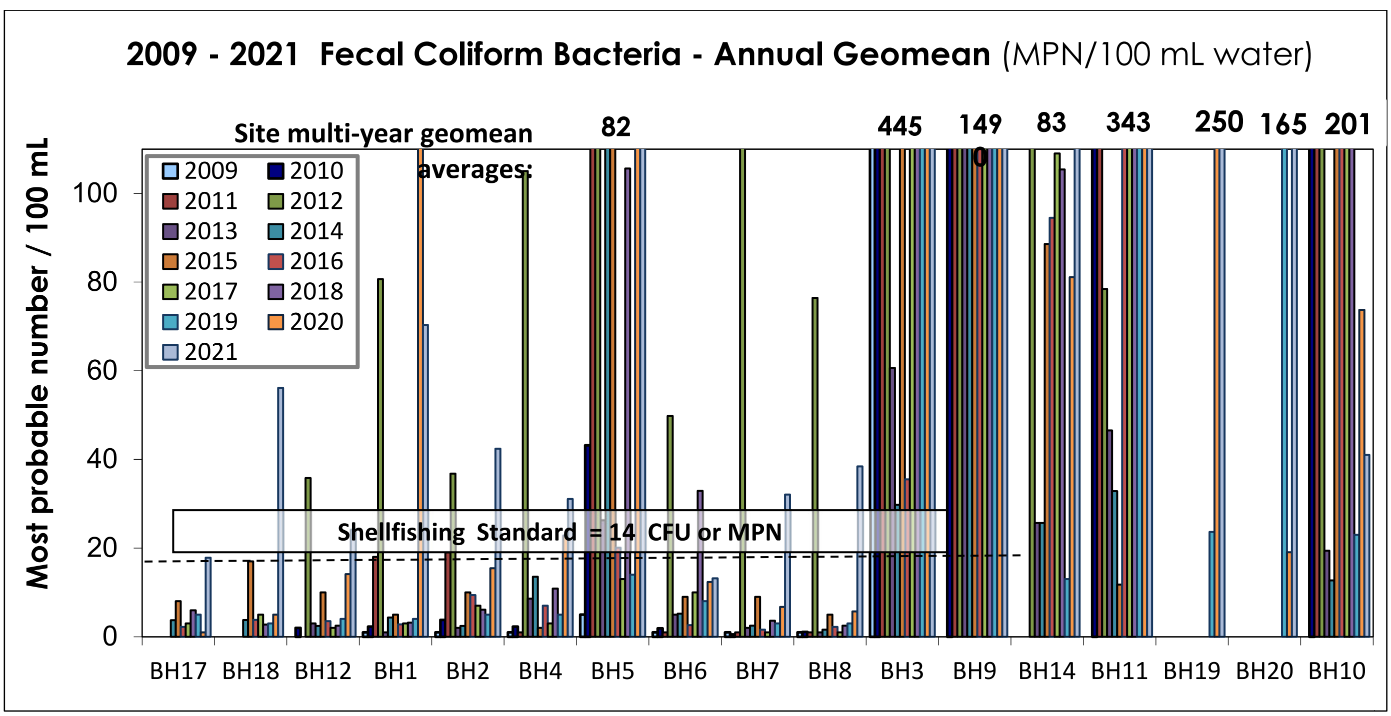
Fecal coliforms at the in-harbor sites continued to be variable in 2021, with all of the sites exceeding the shellfish criteria at least once (table 2). This reflects the regular doses of stormwater associated with the increased rains. The Sanroma #6 site, which regularly exceeded the shellfishing standard, had a geometric mean that was just below standard because its values were relatively low compared to several of the other harbor sites. The Elks Club #1 continues to have high fecal coliform levels compared to previous years in 2021. This is the second year that the site has recorded regular exceedences, in another wet year. This suggests that stormwater is a major bacterial contributor to this site, and frankly the harbor overall. Most other Bristol Harbor sites had annual geometric means that also exceeded the shellfishing standards (figure 8) confirming the impact of increased precipitation on shell fishing waters in the area.

Figure 8. 2021 Shellfish Bacteria Indicator Data – Fecal Coliform Bacteria Chart



The Silver Creek sites continued to have extended periods of high fecal coliform levels throughout much of the monitoring season (Table 2). The bacteria data supported the belief that stormwater is a significant source of bacteria since high levels were most frequently noted at the stream sites expected to carry runoff (figure 9).

Figure 9. Multi-year Shellfish Bacteria Indicator Data Chart



Swimming Waters Bacteria Monitoring: *Enterococcus spp.* is the indicator bacteria for water quality at public beaches. The Rhode Island Department of Environmental Management (RIDEM) has a primary contact (swimming) water quality standard for saltwaters of a geometric mean of 35 *enterococcus*/100 mL for five or more samples, and 33 *enterococcus*/100 mL for freshwater. Geometric means for non-swimming fresh waters is 54 *enterococcus*/100 mL. In response to new recommendations from the USEPA, the Rhode Island Department of Health (RIHealth) adopted new more consistent *single sample standard* for swimming advisories at licensed beaches. As of 2015 the RIHealth beach standard is 60 most probable number (MPN - a statistically based reporting method) *enterococci*/100 mL for both fresh and saltwater sites.

All of the harbor sites experienced at least one, and often more, events that exceeded the swimming criteria in 2021 (Table 3). The Silver Creek sites and Mill Pond (#5) routinely had elevated enterococci values, indicating ongoing sources. With the exception of Mill Pond and the Silver Creek sites (#3 and upstream) values were seldom exponentially high, suggesting localized, short-term sources. Overall, in 2021, *Enterococci* values in the harbor were usually at levels considered safe for swimming, except for after rainfall.

The Silver Creek sites continued to regularly exceed standards (table 3), with most sites exceeding exceeding criteria for nearly all of the water collections in 2021 (no swimming, especially after rain please). Elevated values in the Silver Creek systems were consistent with overall long-term conditions (figure 10). The remainder of the harbor and bay sites had seasonal geometric means generally within the safe swimming criterion (figure 11). As with fecal coliform these results confirm that the creek and its watershed are a significant source of bacteria to the harbor.

Table 3. 2021 Swimming Bacteria Indicator Data: *Enterococcus* Bacteria

Site ID	**13-May**	**10-Jun**	**9-Jul**	**5-Aug**	**2-Sep**	**30-Sep**	**Geomean**
	- - - - - Most Probable Number of Enterococci per 100 mL - - - - - -						
BH17	<10	10	<10	**6131**		<10	**<10**
BH18	no sample	10	41	**>24196**		<10	**56**
BH12	<10	<10	<10	20	**6488**	<10	**<10**
BH1	20	<10	**211**	**12033**	**5172**		**192**
BH2	31	<10	20	**5475**		10	**32**
BH4	<10	10	<10	**379**	**19893**	<10	**21**
BH5	42	**6867**	31	**>24196**		**211**	**>539**
BH6	<10	31	52	41		31	**18**
BH7	<10	53	<10	**318**	**733**	<10	**15**
BH8	<10		<10	**213**	**12997**	<10	**19**
BH3	**75**	**75**	10	**>24196**		**583**	**>240**
BH9	**111**	**1137**	**3654**	**>48392**		**7701**	**>2799**
BH14	30	29.6	**83.6**	**>24196**		**257.6**	**>215**
BH11	**254**	**301**	**1334**	**41060**		**538**	**1176**
BH 19	31	10	20	**36540**		**160**	**129**
BH 20	<10	**908**	**480**	**31062**	**588**	41	**262**
BH10	31	no sample	**317**		**>24196**	<10	**>124**
Single sample swimming maximum = 60 MPN (33 geomean)							
Freshwater geomean = 33 MPN; Salt water geomean = 35 MPN							

Figure 10. 2021 Bristol Harbor Sites – *Enterococci* Bacteria Data Chart

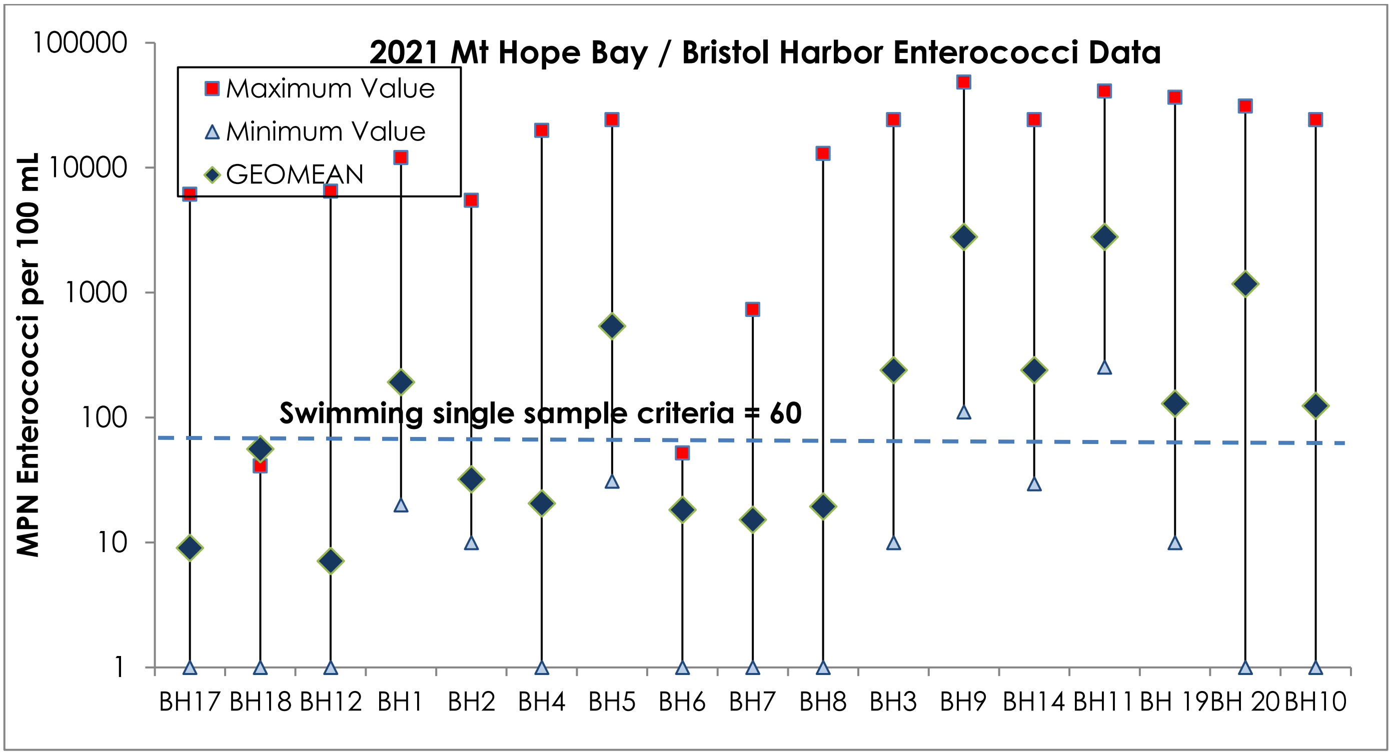
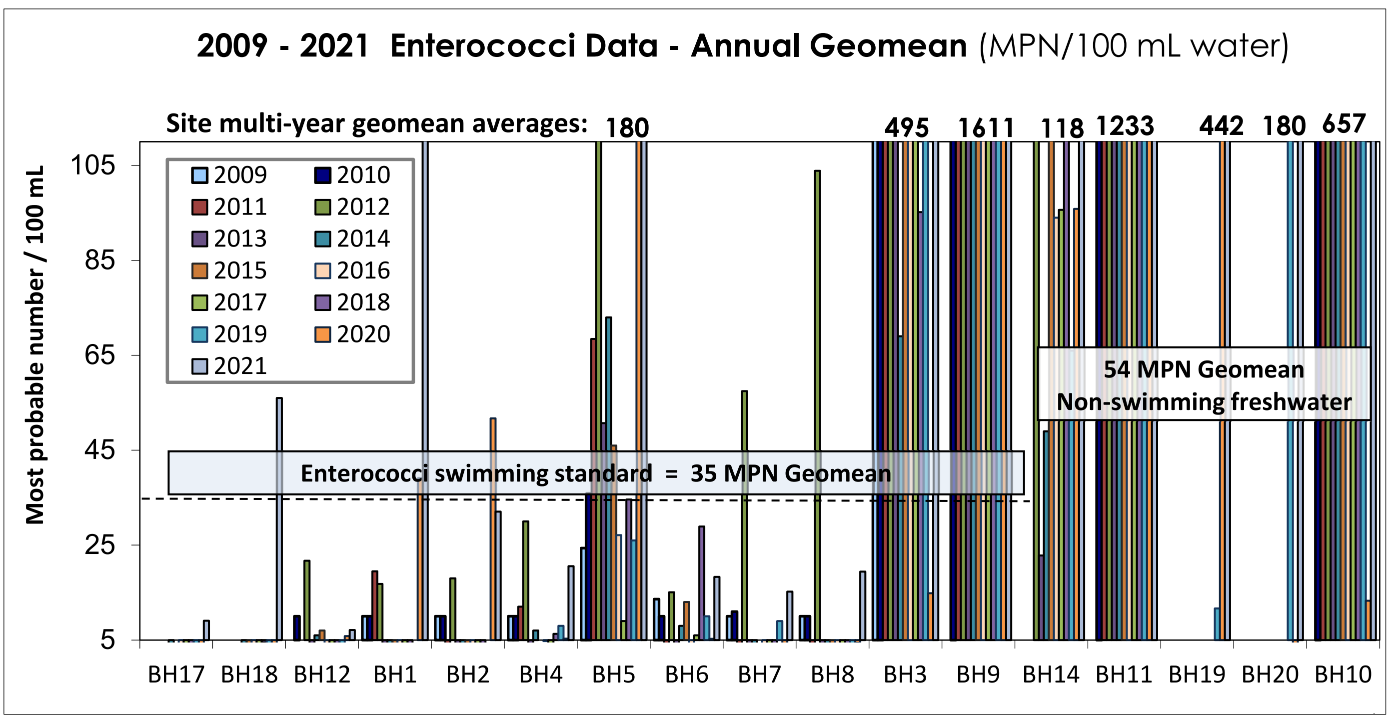


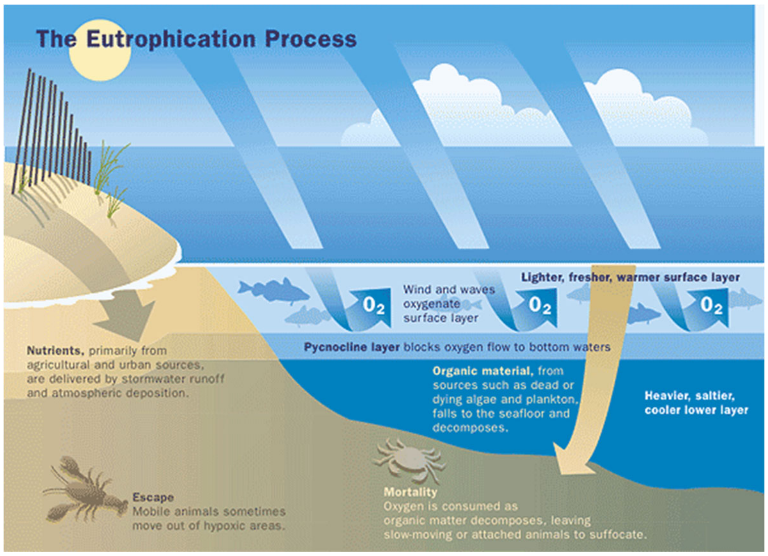
Figure 11. Multi-year Swimming Bacteria Indicator Chart



Bristol Harbor Nutrients, 2009 – 2021:

Nitrogen is a natural and essential part of all marine ecosystems, as it is required for the growth of algae or phytoplankton, the primary producers that form the base of the harbor's food web (USEPA 2008; figure 12.) Excess nitrogen (N) adversely affects water quality and degrades habitat, ultimately impacting a wide range of marine organisms including fish and shellfish. Nutrient overloading in marine ecosystems over-stimulates the growth of algae. Too much algae blocks sunlight to eelgrass, reducing the quality and area of this valuable nursery habitat and feeding ground. In addition, living and dying algae consume oxygen, leading to hypoxic (low oxygen) and anoxic (no oxygen) conditions. This process of water quality decline creates a chain reaction of negative impacts known as eutrophication. Poor water clarity, bad odors, stressed marine organisms and even fish kills are all symptoms of eutrophic conditions marine organisms including fish and shellfish (Howes et al. 1999).

Figure 12. Nutrients in the Coastal Zone (from http://www.treehugger.com/clean-water/phosphorus-pollution-poses-major-threat-worlds-lakes.htmll)



Total nitrogen, which includes both organic nitrogen (the N found in live, dead or decomposing plants and animals) as well as inorganic (the N that is dissolved into solution or bound to sediments, etc.) is widely used by scientists as an indicator of eutrophication or nutrient enrichment in marine waters. Levels below 350 parts per billion (ppb) are characteristic of low nutrient waters, while values above 600-700 ppb indicate nitrogen enrichment (Howes et al. 1999).

Total nitrogen (TN) levels in most of the Bristol Harbor sites have been at low to moderate levels throughout most of the seasons since 2009, with the exception of Silver Creek outlet (#3), upstream sites and Mill Pond (#5). At most of the sites, except Mill Pond and Sanroma (#6) sites which have been highly variable, annual TN averages have decreased or remained stable since monitoring began (figure 13a). Mt Hope Bay sites were typically in the low to moderate range in 2021 (figure 13b).

Figure 13a. Mt Hope Bay / Bristol Harbor Annual Total Nitrogen Data Chart

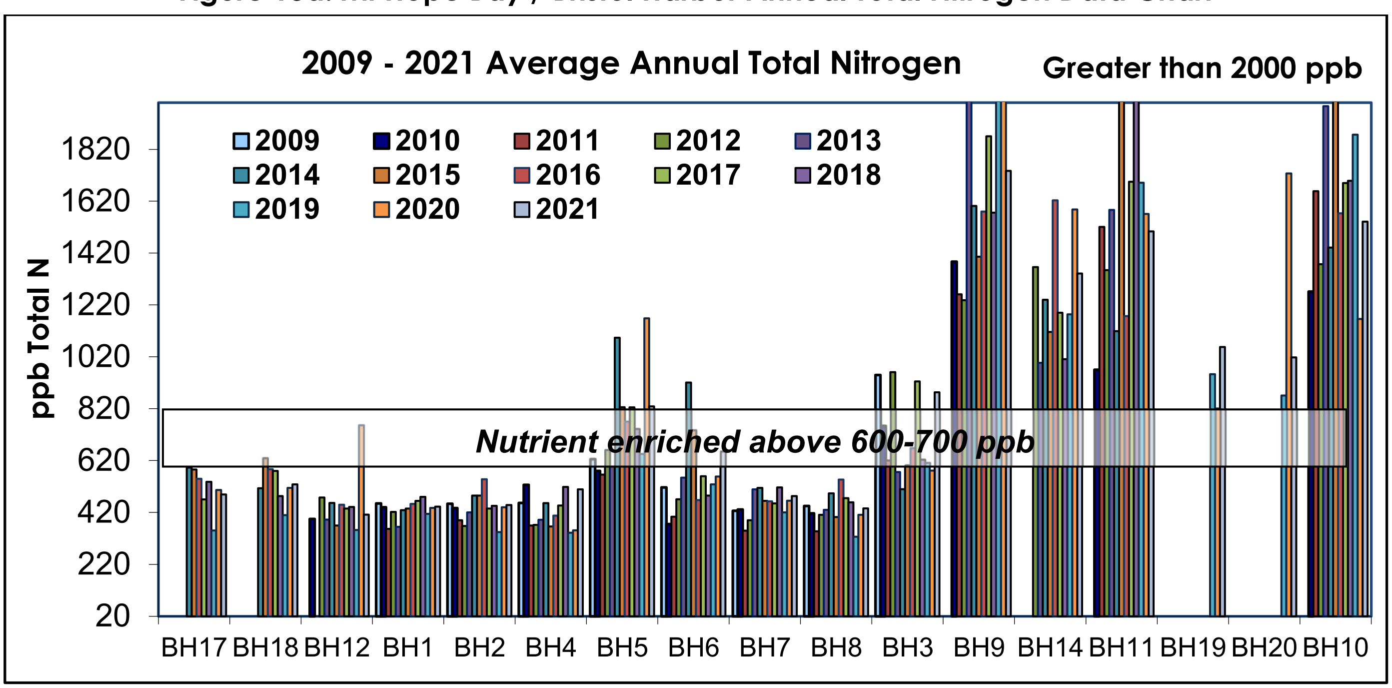
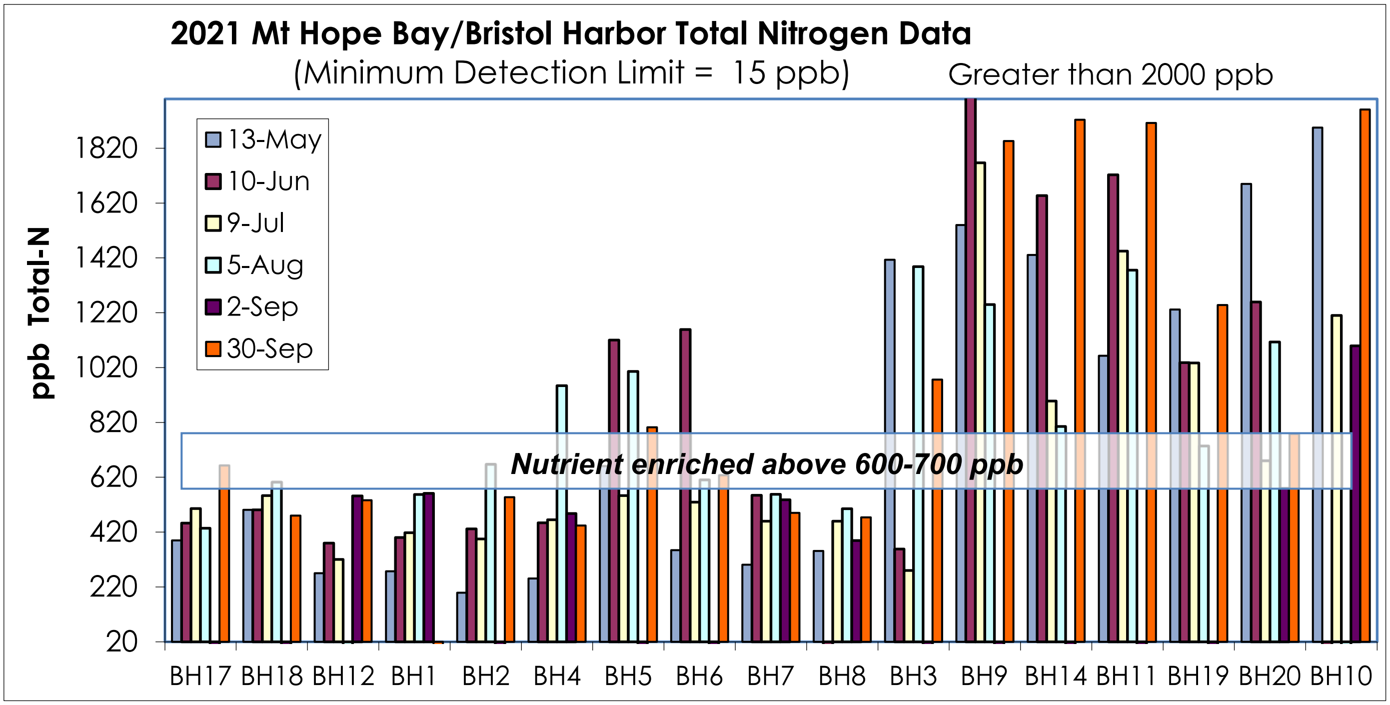


Figure 13b. Mt Hope Bay / Bristol Harbor 2021 Total Nitrogen Data Chart



Total nitrogen values in the harbor and bay sites in 2021 were generally low. The TN levels in the upstream tributaries (Silver Creek sites #9 - #20) continued to be very high, on average more than double the harbor sites (figure 13b). Concentrations of TN at the downstream site of Silver Creek (#3) were typically lower than the significantly high upstream sites. This suggests that the nitrogen sinks were again effective in 2020.

A nitrogen sink is a wetland or other feature where biological activity captures N and converts to its atmospheric form of nitrogen gas (N_2 or N_2O) by microbes, keeping it from flowing downstream. These sinks apparently functioned well at lower flow conditions but were less effective under higher flows permitting more TN to move downstream. Enhancing stormwater reduction efforts, as well as protecting or restoring associated wetland areas might help reduce impacts from stormwater runoff. Maintaining the expanded monitoring upstream on Silver Creek will be important for tracking changes in incoming nitrogen, and perhaps to identify potential nitrogen sinks that should be protected and expanded if possible.

Ammonia-nitrogen (NH_3-N) is the most reactive form of N in aquatic systems. It is soluble, readily adheres to soils and sediments, and is converted to nitrate-N by microbes when oxygen is present through a process called nitrification. Nitrification requires a substantial amount of oxygen and carbonate, thus can reduce both DO levels and pH slightly. In excess, NH_3-N can be toxic, particularly to early life stages of a variety of aquatic species. The level at which it becomes lethal is dependent on water temperature, pH, and salinity, so site specific criteria are applied (see http://www.dem.ri.gov/pubs/regs/regs/water/h20q09a.pdf for more information).

In general, given the pH and dissolved oxygen conditions in Bristol Harbor, the chronic exposure critical ammonia level would be >650 ppb, much higher than the levels found at any Save Bristol Harbor site (Figure 14a). Interestingly, NH_3-N levels in Silver Creek (#3) have been declining and are now nearly as low as other harbor sites. The Silver Bridge site (#9) continues to have the highest NH_3-N levels. Typically, NH_3-N starts out low each season, peaking in mid-summer or early autumn, as reflected in the 2021 monthly results (figure 13b). A flooding event in early September had very high levels of NH_3-N. Much of the high levels Mt Hope Bay sites were similar to the Bristol Harbor sites, and well below the critical ammonia level.

Figure 14a. My Hope Bay / Bristol Harbor Annual Ammonia-Nitrogen Data Chart

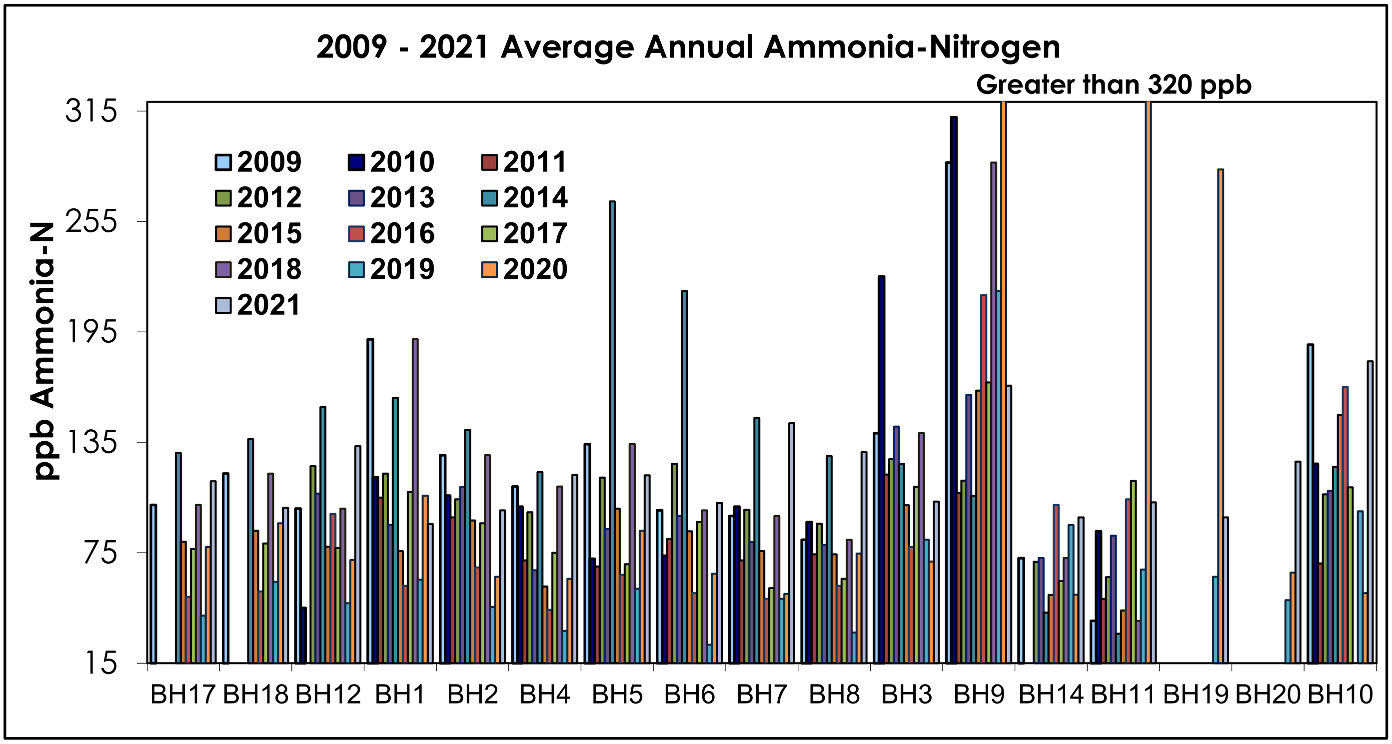
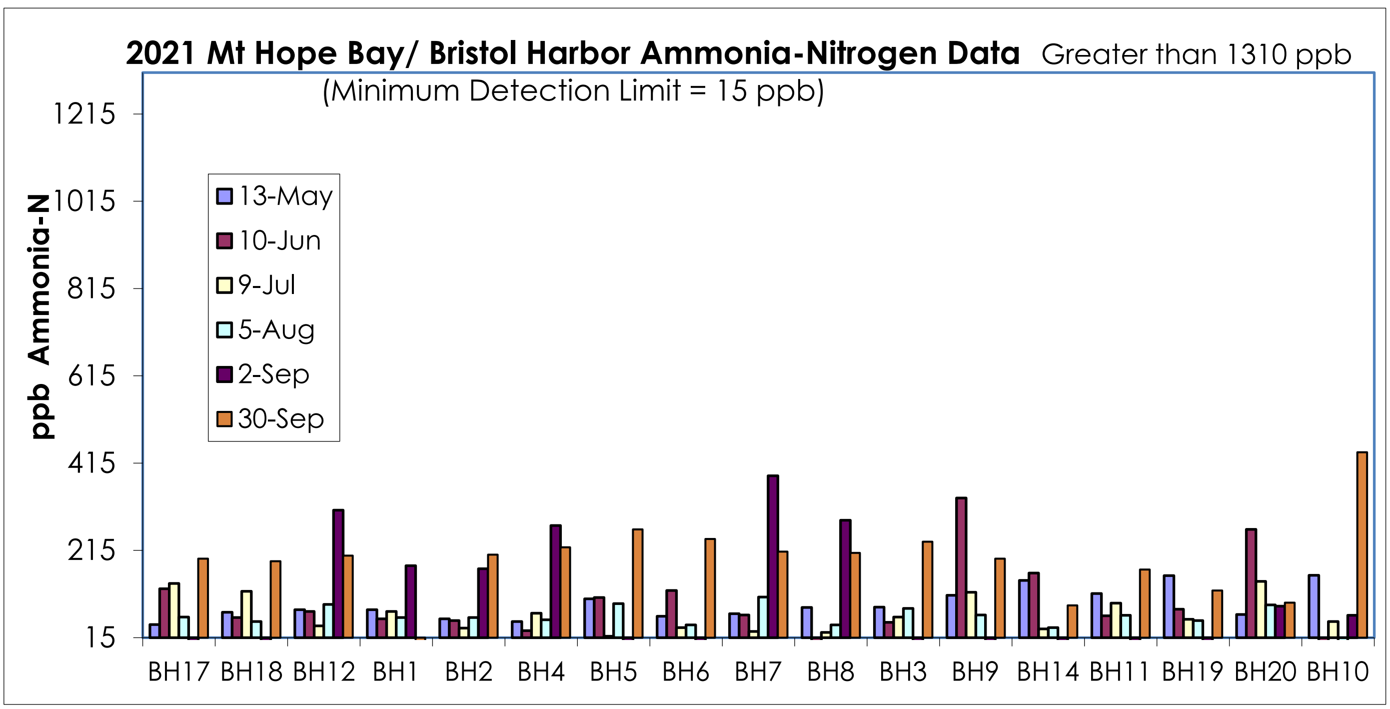


Figure 14b. Mt Hope Bay / Bristol Harbor 2021 Ammonia-Nitrogen Data Chart



Nitrate + nitrite-nitrogen (NO_3-N) is also a soluble form of N and is readily taken up for use by algae and submerged vegetation during their growing season. When oxygen is absent (anoxic conditions), bacteria convert nitrate-N to gaseous N (N_2 or N_2O) through a process called denitrification, which removes N from the soil-water environment. In 2021 NO_3-N levels were generally higher than in recent years. In general, most harbor sites were typically near or below the 15 - 20 ppb minimum detection level for most sites, except the Silver Creek sites, as well as Mill Pond. The Mt Hope Bay sites were also generally low. Results for the harbor sites have been relatively consistent since 2009. Figure 15a and 15b show the comparatively high levels in the upstream Silver Creek sites (#9 - #20). Nitrate + nitrite-N levels in these sites were high throughout most of the 2021 monitoring season (figure 15b).

Figure 15a. Mt Hope Bay / Bristol Harbor Annual Nitrate + nitrite-Nitrogen Data Chart

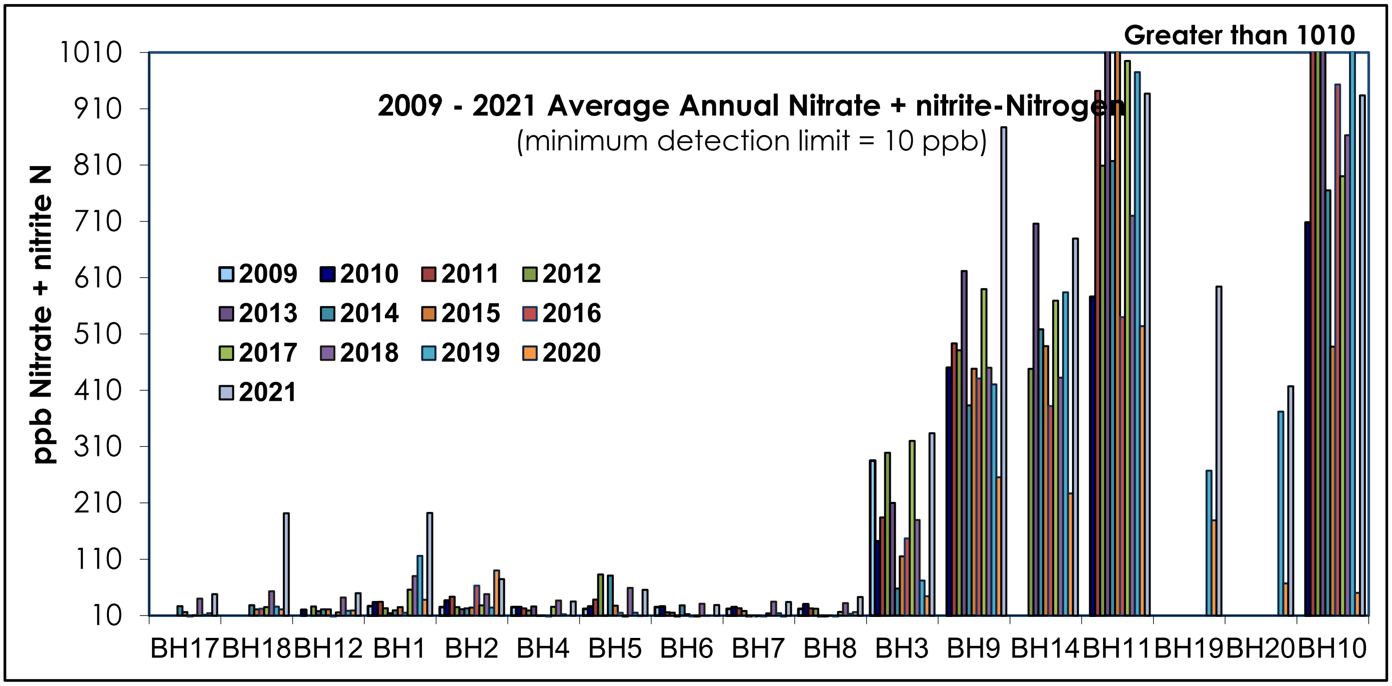
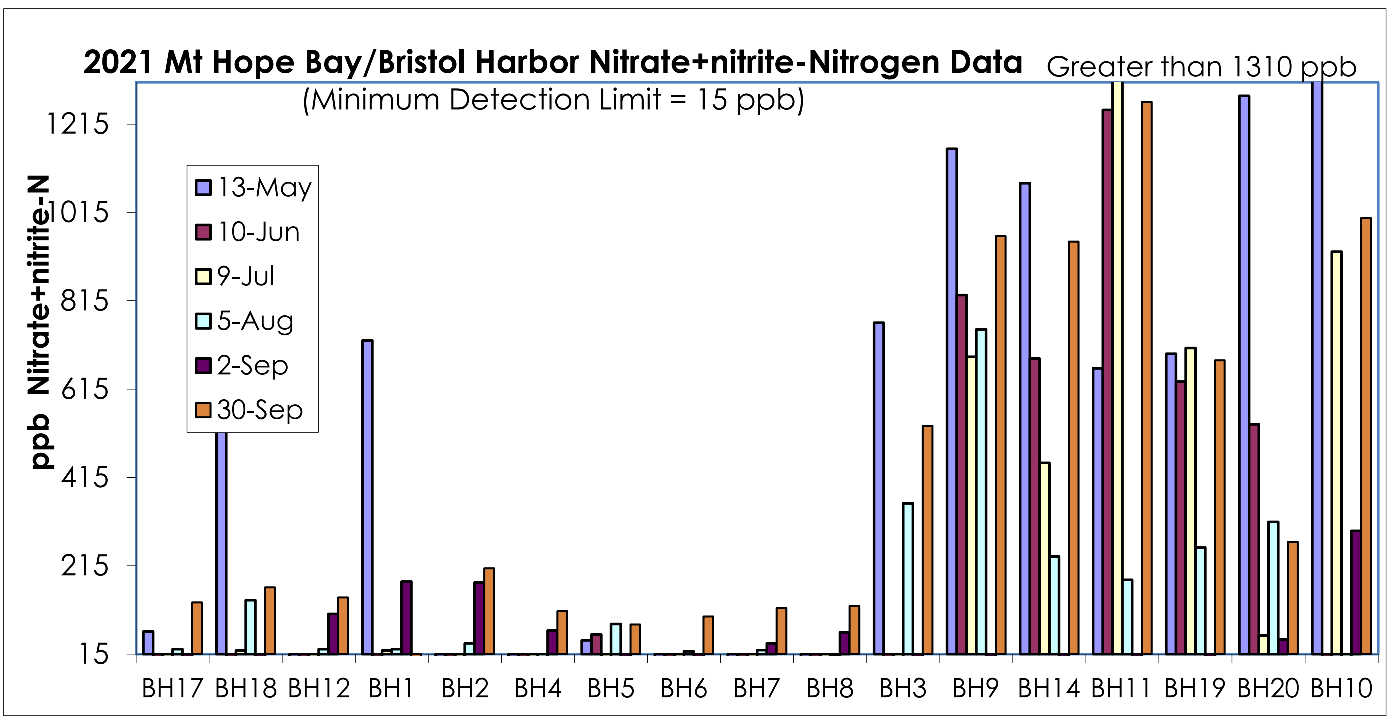


Figure 15b. Mt Hope Bay / Bristol Harbor 2021 Nitrate + nitrite-Nitrogen Data Chart



Dissolved Inorganic Nitrogen (DIN): The National Coastal Assessment program uses dissolved inorganic nitrogen (DIN), is the sum of ammonia-N (NH_3-N) and nitrate + nitrite-N (NO_3-N), as a key component in its coastal conditions' assessment. For northeastern estuaries, DIN levels <100 ppb are considered *Good*, 100 – 500 ppb considered *Fair*, and > 500 ppb considered *Poor* water quality (USEPA 2008).

All the harbor sites had DIN levels in 2021 that were consistent with previous years (figure 15a). The DIN levels in the upstream sites were much higher than down steam (figure 16a). The DIN levels in the harbor and Mt Hope Bay sites were in the moderate or good range in 2021 (figure 16b).

Figure 16a. Mt Hope Bay / Bristol Harbor Sites – Annual Dissolved Inorganic Nitrogen Data Chart

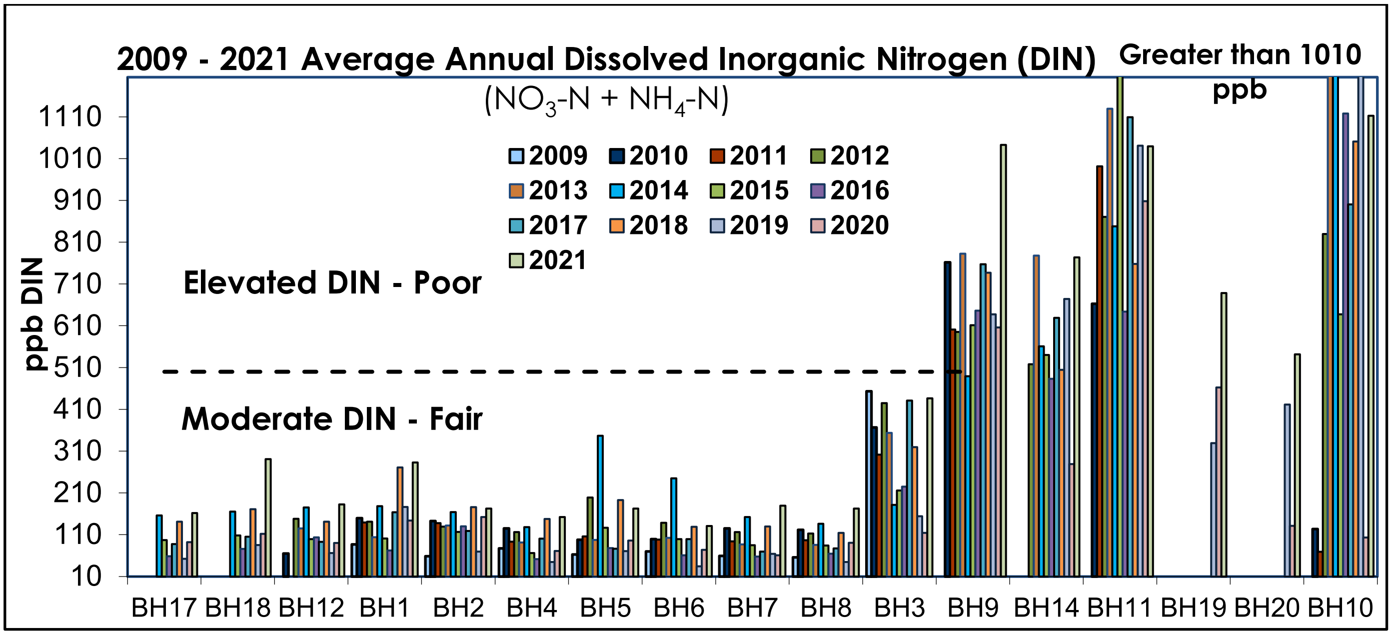
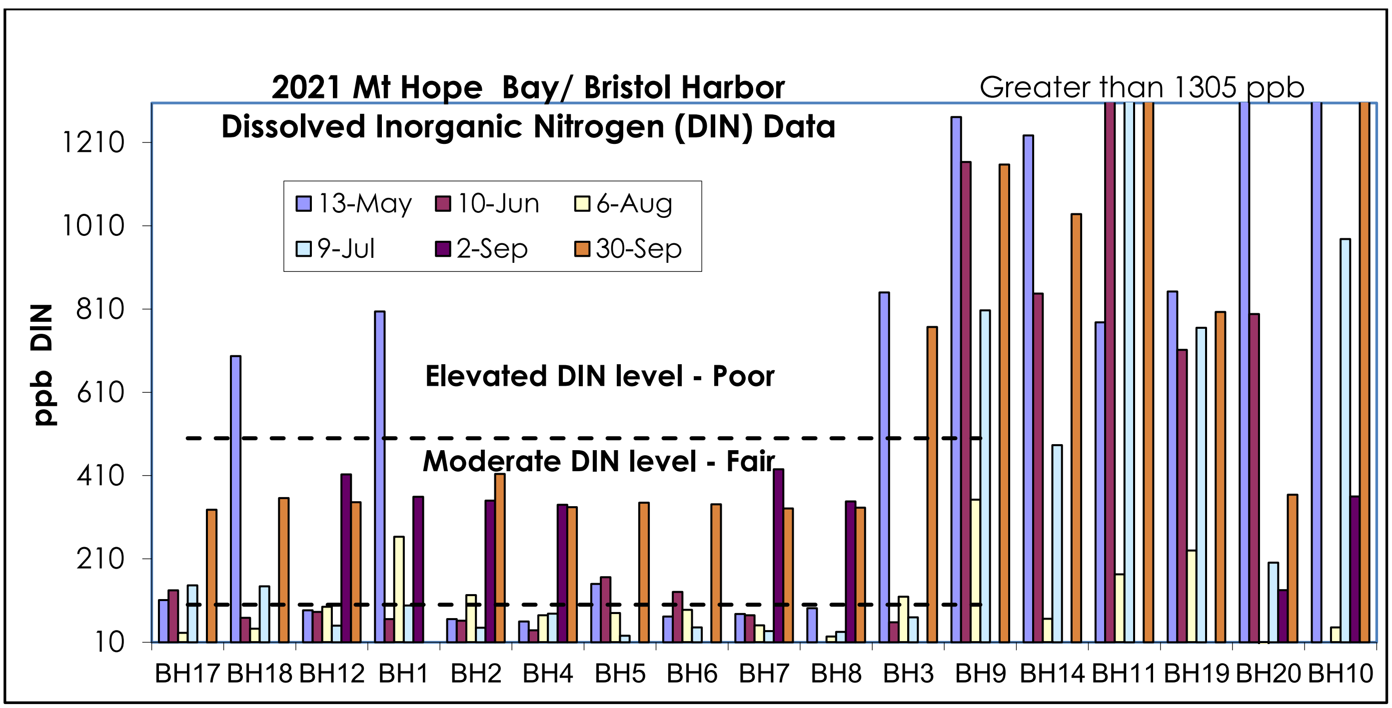
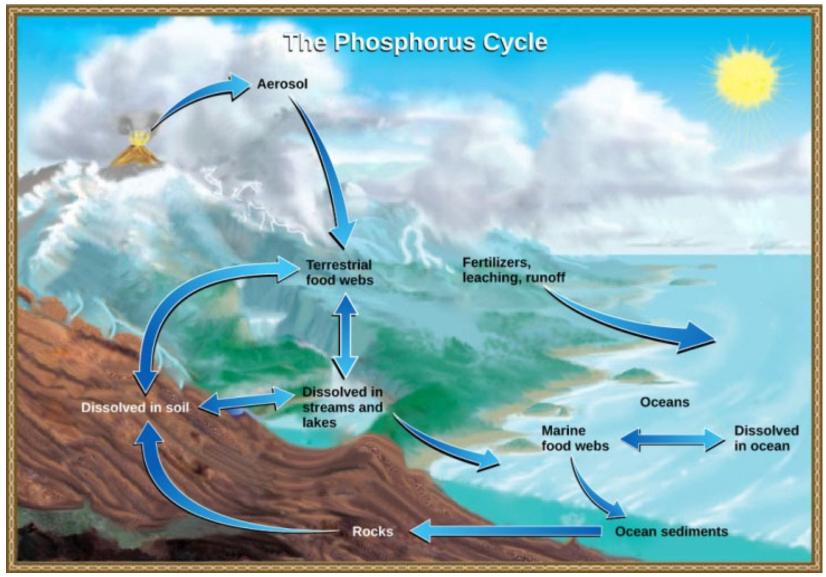


Figure 16b. Mt Hope Bay / Bristol Harbor Sites – 2021 Dissolved Inorganic Nitrogen Data Chart



Phosphorus: In most estuaries such as Bristol Harbor, nitrogen is the primary nutrient that controls algal and plant growth. However, phosphorus (P) is also essential for life, and in saltwater environments P levels are considered in relationship to N levels. Typically, a 10 to 1 N:P concentration ratio is considered appropriate to support sustainable marine systems. If large amounts of nitrogen are available, with adequate phosphorus present, algal blooms can occur. Phosphorus was analyzed as the total form, which includes P bound in particulate (organic and inorganic) matter, and soluble or dissolved forms which are readily used by algae. Dissolved inorganic P (known as dissolved P (DIP) or orthophosphate P) has been analyzed in Bristol Harbor since 2010.

Figure 17. Phosphorus Cycle (https://www.khanacademy.org/science/biology/ecology/biogeochemical-cycles/a/the-phosphorous-cycle



Total Phosphorus: Except for the Silver Creek sites, annual total phosphorus (TP) values have generally been below 100 ppb, the level of concern based on the amount of nitrogen typically found in estuaries (Figure 17a). Total phosphorus levels in the harbor reflect the relatively low TN levels. Annual TP concentrations have been somewhat variable, and several sites have had some years with high levels. Total phosphorus averages at Silver Creek upstream site East (#10) were generally much lower than the downstream sites, except for 2015. It is possible that it is taking time for phosphorus to move through the system, particularly if it being absorbed to sediments before being released under low oxygen conditions associated with stagnation. In general, 2021 TP concentrations were well below 100 ppb at nearly all sites (harbor or stream), and often followed a similar pattern as did the bacteria suggesting the strong influence of stormwater on TP values (figure 18b).

Figure 18a. Bristol Harbor Annual Total Phosphorus Data Chart

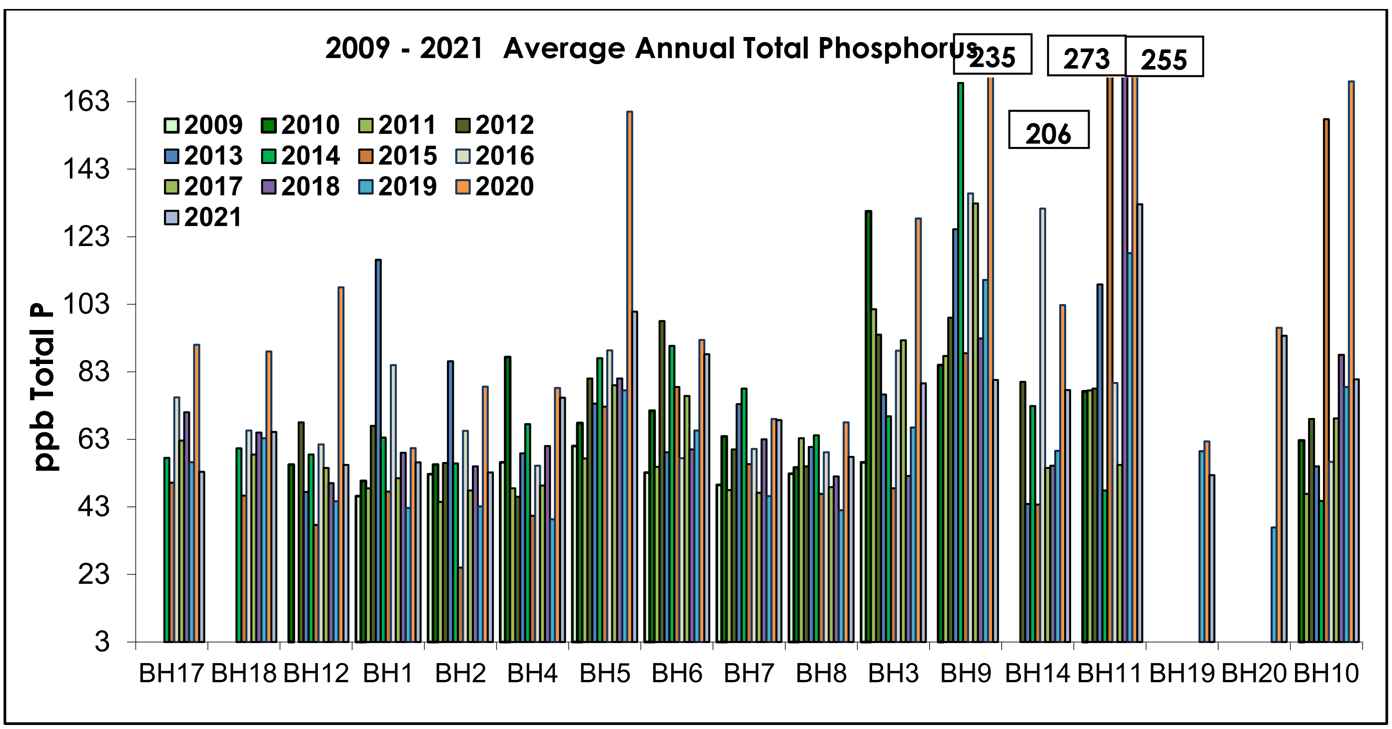
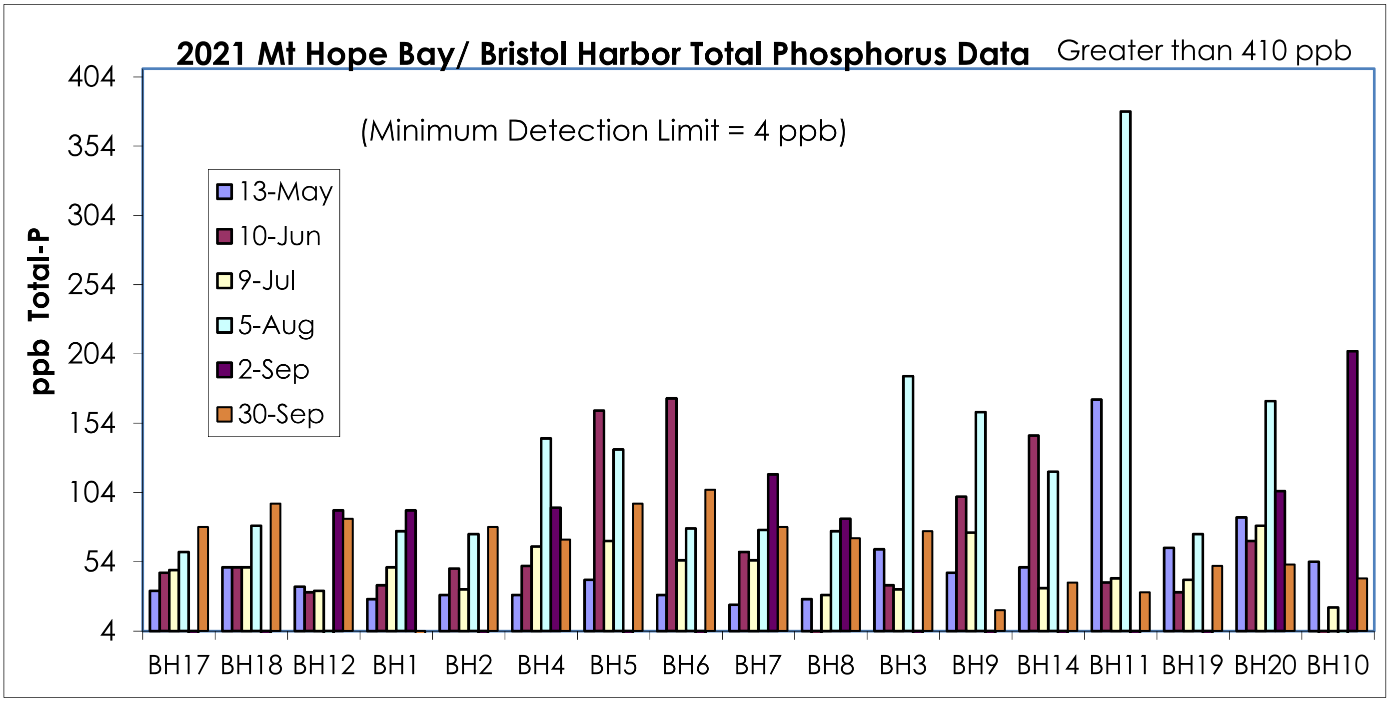
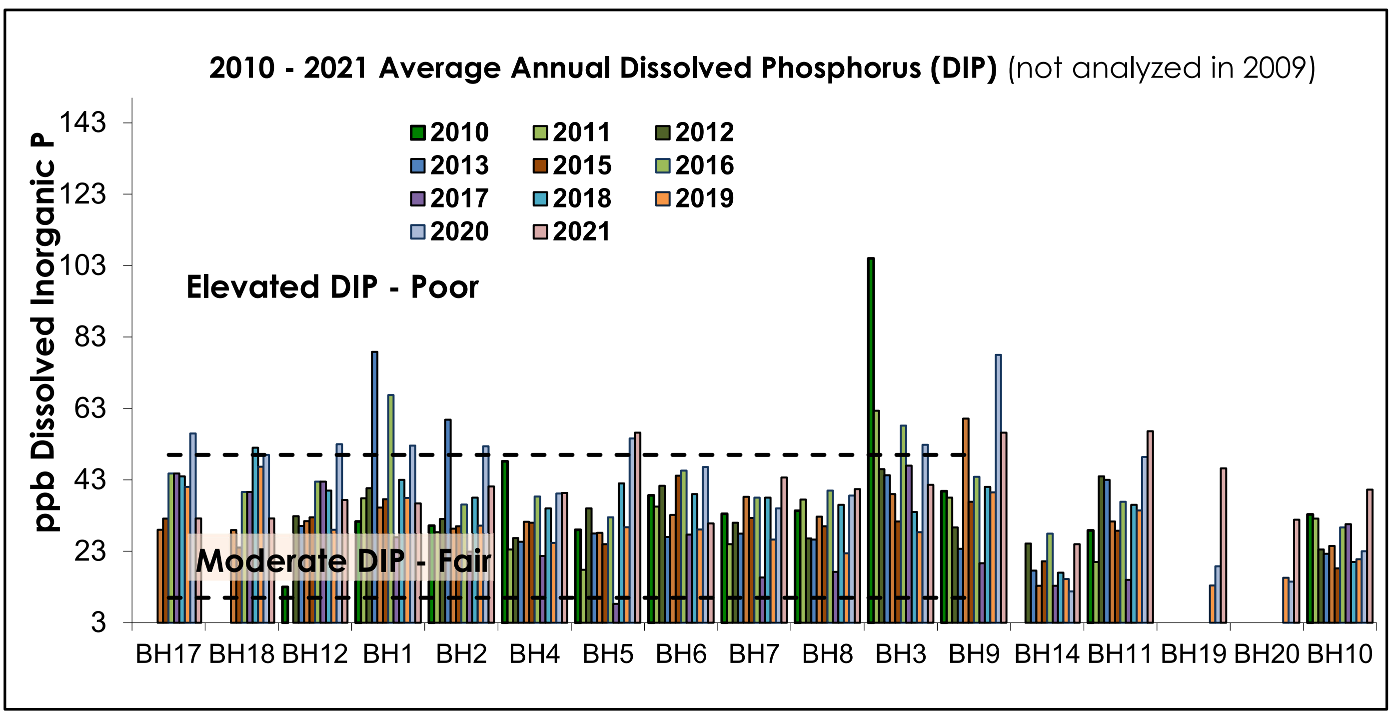


Figure 18b. Mt Hope Bay / Bristol Harbor 2021 Total Phosphorus Data Chart



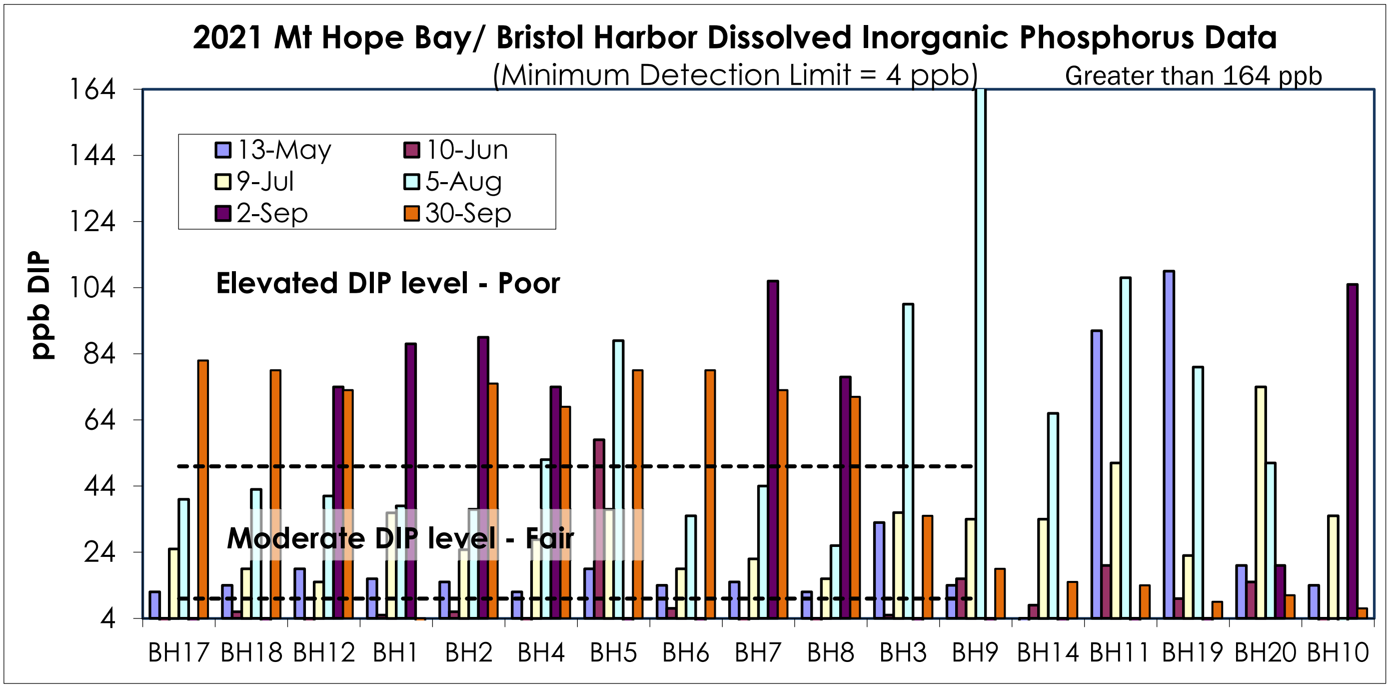
Dissolved Phosphorus: Dissolved inorganic phosphorus (DIP) is the portion of P readily available for use by aquatic organisms and is analogous to DIN. The National Coastal Assessment program uses DIP as a key component in its coastal conditions assessment. DIP surface concentrations <10 ppb are considered *Good*, 10-50 ppb considered *Fair*, and >50 ppb considered *Poor*. Rhode Island doesn't have criteria for DIP but maintaining low stream P levels reduces harbor inputs.

Figure 19a. Mt Hope Bay / Bristol Harbor Annual Dissolved Phosphorus Data Chart



Annual DIP levels have generally been in the moderate or fair range at nearly all the sites, including most of Silver Creek and Mt Hope Bay since monitoring began (Figure 19a). However nearly all the Bristol harbor and Mt Hope Bay sites recorded at least one, and up to four samples in the poor DIP range again in 2021.

Figure 19b. Mt Hope Bay / Bristol Harbor 2021 Dissolved Phosphorus Data Chart



Acknowledgements:

Hats off to these *exceptional* water quality volunteers who braved Covid-19 restrictions and requirements to add to this extraordinary dataset … Bob and Denise Arsenault, J. Barker, Lily Barker, Kevin Beaulieu, Terry and Pat Belcher, Bethany Borgia, Kyra and Mackenzie Boucher, Matt Calderiso, Janet Christopher, D. Cobery, Susan and Glenn Donovon, Carly Ferreira, Barbara and James Geehan, Rob and Gwen Hancock, Nate Januario, Valerie Malone, Anna Malone Oliver, Keith & Luna Maloney, Juan Mariscal, Sarina Olson, Gregory Rego, S. Sousa, Ed Tanner, Laura Thurber, and Hope Tyska.

These outstanding individuals got up *very* early sampling morning throughout the 2021 season, rain and shine (some even braving flood waters) working in teams to monitor their site. They successfully got their samples to their local coordinators for transportation to URI where they were delivered to a cart with a cooler located outside of the Coastal Institute Building in Kingston.

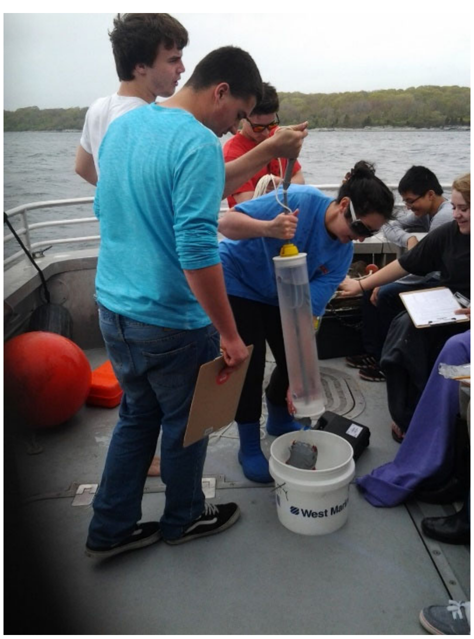
… and especially to their long-term, resolute and exceptional local coordinators (and fellow dedicated water quality monitors): Bob Aldrich, Barbara Healy and Caroline Calia. They tirelessly and cheerfully recruit volunteers, coordinate training sessions, manage monitoring supplies, keep in touch with everyone, ensure that volunteers have any resources they need. They also act as couriers, delivering samples on a monthly basis with cheery greetings to the URI Watershed Watch staff and student interns. In 2021 this meant continued adaptations to Covid-19.

We can't thank all of these folks enough for persevering throughout the ongoing pandemic and stormy weather to both give our volunteers an outdoor activity to participate in and kept the critical data coming in!

Please see the Save Bristol Harbor website (http://www.savebristolharbor.com/) to learn more about their efforts and how you can help.

Thank you to the Town of Bristol as well. They have been stalwart supporters of the monitoring program. They have used the data to secure funds to implement stormwater management and other initiatives to restore water quality in the watershed. They have been great partners for SBH and URIWW.

Save Bristol Harbor works with Mt Hope High School and Save the Bay to get students engaged



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Howes, Brian, Tony Williams and Mark Rasmussen, 1999. *BayWatchers II Nutrient related water quality of Buzzards Bay embayments: a synthesis of Baywatchers monitoring 1992-1998* http://www.savebuzzardsbay.org/bayinfo/publications/BaywatchersII/baywaters-pages3-34.pdf.

Olli, Kalle. 2004. Drainage basin nutrient inputs and eutrophication: an integrated approach. eBook, University of Tartu, Institute of Botany and Ecology, Tartu, Estonia - http://kodu.ut.ee/~olli/eutr/html/htmlBook.html

National Oceanic and Atmospheric Administration's (NOAA) Ocean Service Education Monitoring Estuaries website http://oceanservice.noaa.gov/education/kits/estuaries/estuaries10_monitoring.html

Russian River Pathogen Project (RRPP) Working Draft Report, Updated 01/28/2008 http://rrpp.ice.ucdavis.edu/node/7

United States Environmental Protect Agency (EPA), 2008. National Estuary Program Coastal Condition Report Introduction http://www.epa.gov/owow/oceans/nepccr/pdf/nepccr_intro.pdf

University of Rhode Island (URI) Office of Marine Programs' Discovery of Estuarine Environments website http://omp.gso.uri.edu/ompweb/doee/science/intro.htm)

University of Rhode Island Watershed Watch website (includes monitoring manual, data, fact sheets, and links to local, regional and national information) http://web.uri.edu/watershedwatch/

Appendix A. Volunteer Monitoring Overview

Volunteer Monitoring: Save Bristol Harbor volunteers were trained by URI Watershed Watch (URIWW) staff to conduct water quality monitoring. The volunteer monitors were provided with equipment and supplies as well as detailed, written monitoring procedures manuals. Monitoring followed a schedule designed to cover the period of peak biological activity in the harbor - from mid-May through mid-October. The schedule consisted of biweekly early morning on-site monitoring of water temperature, salinity, dissolved oxygen and chlorophyll sample collection and processing. (See https://web.uri.edu/watershedwatch/resources/training-manuals/ for URIWW monitoring manuals and https://web.uri.edu/watershedwatch/resources/quality-assurance/ for field and laboratory quality assurance project plans for more specific information.) All on-site monitoring data was submitted to URIWW on monitoring postcards or online. Data submitted online is available almost immediately in provisional form.

In addition to the bi-weekly on-site monitoring, once a month the volunteers also collected a suite of water samples, which were brought to a central collection point in Bristol. There samples were packed on ice in a cooler and brought to the state-certified URIWW Analytical Laboratory in Kingston. Bacteria, pH, nitrogen, phosphorus, and chlorophyll were analyzed according to standard URIWW laboratory procedures. The sampling schedule was designed to ensure that monitoring occurred early in the morning to measure the lowest daily dissolved oxygen, and that the samples would reach the URIWW laboratory within acceptable hold times. In 2021, the monitoring season returned to its usual May start (schedule below).

URI WATERSHED WATCH
2021 WATER QUALITY BIWEEKLY MONITORING SCHEDULE
Bristol Harbor System Water Sampling Sites

All nutrient, bacteria and water-quality monitoring for all **Bristol Harbor sampling will take place between 6 and 8:30 am on Thursday mornings**. Please contact Barbara Healy (401-258-6297) or Caroline Calia (401-451-8919) Bristol Harbor Monitoring Coordinators for local coordination and sample pick-up and delivery information, questions or concerns. Please contact Elizabeth Herron, URI Watershed Watch, 874-4552 for sampling and testing methods questions or concerns. Or try our website http://web.uri.edu/watershedwatch/ .

2021 Thursday Dates	SIMPLE monitoring: Collect & run samples in "WORK HORSE" BOTTLES for temperature, chlorophyll, dissolved oxygen (DO). Collect and refrigerate tightly capped salinity bottle.	COMPLEX monitoring: SAMPLES COLLECTED & DELIVERED TO BHPHM COORDINATOR including all salinity bottles *AND* collect & run samples in "WORK HORSE" BOTTLES for temperature, chlorophyll, DO.
April 24	New volunteer field training and equipment pick-up	
May 13		FIRST COLLECTION: May 13th All water sample bottles, chl-a filters
May 20		
May 27	Temperature, DO, salinity into frig chl-a filters into freezer	
June 3		
June 10		SECOND COLLECTION: June 10th All water sample bottles, chl-a filters
June 17		
June 24	Temperature, DO, salinity into frig chl-a filters into freezer	
July 1	*Happy 4th Enjoy the parade (virtually?)!*	*Participate in the Dip-in… www.secchidipin.org*
July 8		THIRD COLLECTION: July 8th All water sample bottles, chl-a filters
July 15		
July 22	Temperature, DO, salinity into frig chl-a filters into freezer	
July 29		
August 5		FOURTH COLLECTION: August 5th All water sample bottles, chl-a filters
August 12		*Victory Day is August 9th*
August 19	Temperature, DO, salinity into frig chl-a filters into freezer	
August 26		
Sept 2		FIFTH COLLECTION: September 2nd All water sample bottles, chl-a filters
Sept 9		*Labor Day is September 6th*
Sept. 16	Temperature, DO, salinity into frig chl-a filters into freezer	
Sept. 23		
Sept. 30	End of monitoring season Return all monitoring equipment	SIXTH COLLECTION September 30th All water sample bottles, chl-a filters

2021 Bristol Harbor Monitoring Schedule

Appendix B. Additional Water Quality Results

2021 pH Data:

Bristol Harbors Sites	Site ID	13-May	10-Jun	9-Jul	5-Aug	2-Sep	30-Sep	MEAN
			- - - - - - - - - - - - Standard pH Units - - - - - - - - - - - -					
BH17 - Kickemuit	BH17	7.9	8.1	7.7	7.8	-	7.7	**7.8**
BH18 - Annawanscutt Drive	BH18	-	8.3	7.7	7.6	-	7.8	**7.9**
BH12 - Herreshoff	BH12	8.0	8.2	7.9	7.9	7.8	7.9	**7.9**
BH01 - Elks Club	BH1	7.9	8.1	7.4	7.9	7.7	-	**7.8**
BH02 - Bristol Harbor Inn	BH2	7.9	8.0	7.9	8.0	-	7.8	**7.9**
BH04 - Windmill Pt	BH4	8.0	8.1	7.8	7.9	7.7	7.9	**7.9**
BH05 - Mill Pond	BH5	7.6	7.7	7.8	7.7	-	7.8	**7.7**
BH06 - Sanroma	BH6	8.0	8.0	7.7	8.0	-	7.9	**7.9**
BH07 - Bristol Yacht Club	BH7	8.0	8.1	7.9	8.0	7.7	7.9	**7.9**
BH08 - Brito Dock	BH8	8.0	-	8.0	8.1	7.8	7.9	**7.9**
BH03 - Silver Creek	BH3	7.3	8.0	7.6	7.1	-	7.3	**7.5**
BH09 - Silver Bridge	BH9	7.3	7.3	7.4	7.0	-	7.3	**7.2**
BH14 - DaPonte/Wood	BH14	7.4	7.6	7.8	7.1	-	7.2	**7.4**
BH11 - Silver West	BH11	7.5	7.2	7.2	6.9	-	7.4	**7.2**
BH 19 - Bristol Golf Club - A (North)	BH19	7.1	9.2	7.5	6.6	-	6.8	**7.5**
BH 20 - Bristol Golf Club - B	BH20	7.0	7.2	7.0	6.6	7.0	7.1	**7.0**
BH10 - Silver East	BH10	7.1	-	7.0	-	6.7	6.9	**6.9**

2009 – 2021 pH Data Chart