Harbor Watch, a Program of Earthplace
Report on Dissolved Oxygen Conditions in Norwalk Harbor
May – October 2015

High School Interns gather data in Norwalk Harbor

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Introduction:
The mission of Harbor Watch is to provide the people of Connecticut with the data, knowledge, and field expertise necessary to safeguard our waterways, educate our communities about watershed issues, and train volunteers and student interns through hands-on research. Harbor Watch has conducted monitoring of Norwalk Harbor (Norwalk, CT) for the past 29 years from May through October. Here, we present a study of dissolved oxygen at multiple sites in the inner and outer harbor (Figure 1).

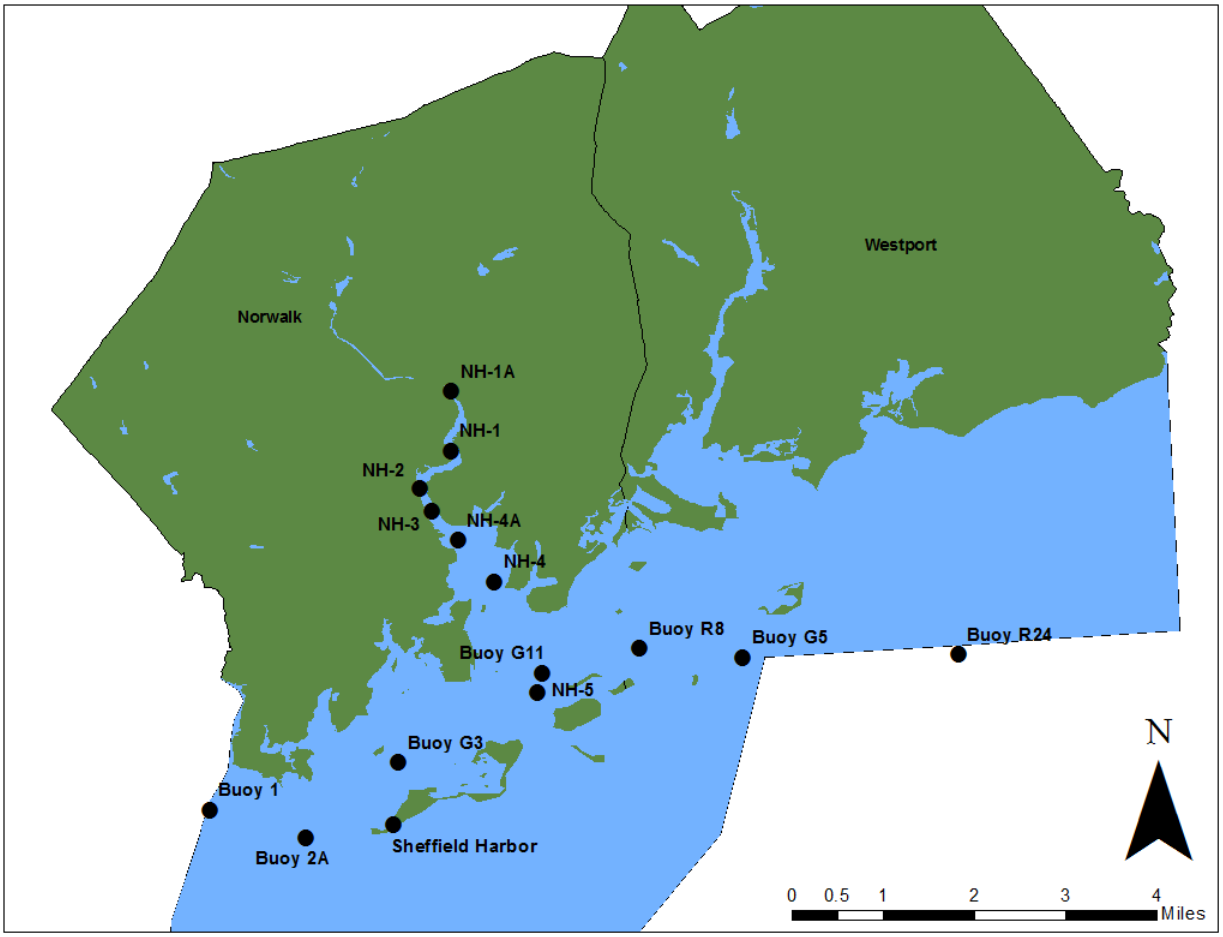


Figure 1. Map of Norwalk Harbor showing the locations of the inner harbor monitoring stations (NH1A-5) monitored by Harbor Watch staff and volunteers and the outer harbor stations (Buoys 1, 2A, G3, R8, G5, R24, and Sheffield Harbor) monitored by volunteers from the US Coast Guard Auxiliary Flotilla 72.

Methods:
Weekly Harbor Surveys
Seasonal monitoring was conducted in Norwalk Harbor from 5/21/2015 - 10/1/2015. A total of 20 dissolved oxygen survey trips were completed by Harbor Watch staff, high school and college interns, and volunteers. Additional dissolved oxygen surveys were conducted by members of Coast Guard Auxiliary Flotilla 72 on the areas outside Norwalk Harbor in partnership with

Harbor Watch (Figure 1). Physical monitoring of Norwalk Harbor was conducted using protocols and procedures contained in EPA Quality Assurance Project Plan RFA#14057 as approved on 5/30/14 for five years. Seven established harbor monitoring stations (Figure 1, sites NH-1A-NH-5) were visited weekly by Harbor Watch and crew where profiles of the water column for dissolved oxygen, salinity and water temperatures were taken at surface, half meter and full meter lengths to the bottom. Ancillary data collection included readings for barometric pressure (first and last station only), wind speed and direction with a Dwyer wind speed gauge, water clarity with a Secchi disk, air temperature with a Fisher brand pocket thermometer and a visual estimate of wave height.

Harbor Watch staff members and volunteers departed the Copps Island Oysters facility dock (home port for the RV Annie) at 7 Edgewater place in Norwalk at approximately 7:30 AM on Thursday of each sampling week. The vessel proceeded to the northern most station (NH1A) in the harbor to begin testing. Probes were lashed to a weighed PVC platform to facilitate lowering the probes through the water column perpendicularly. Monitoring was conducted sequentially downstream at all stations until all 7 had been profiled. The calibration was checked on the dissolved oxygen meter at the end of the run to assure that significant calibration drift ($\pm$ 5%) did not occur. The time to complete each sampling cycle for this estuary was approximately 2 hours. The Coast Guard Flotilla volunteers followed the same protocols for data collection, except their departure times and vessel differed.

Continuous-Recording Probe Deployment

Harbor Watch received reports that dissolved oxygen levels were occasionally approaching 2 mg/L or less during the early morning hours in July and August usually on ebb tides near the Norwalk Maritime Aquarium. To better understand this situation, Harbor Watch deployed its own continuously-recording probe at a nearby location across the harbor (east side, between Station NH-2 and Station NH-3) for two time periods. The first period was from 8/12 through 8/18/15 with a recording interval set at every three hours and the second period was from 8/31 through 9/6/15 with the recording interval set at two hours. A YSI Sonde Model 600 XLM data logger (dissolved oxygen, salinity, pH, and temperature) was deployed to a depth of 0.5 meters off a dock piling located at the Coastwise Marina (11 Goldstein Place, Norwalk CT) to verify these reports of hypoxic conditions occurring overnight on periods of ebb tide.

Results and Discussion:

Hypoxic conditions (< 3 mg/L) were observed at Stations NH-1A, NH-1, NH-2 and NH-3 as early as 5/28/15 (Figure 4, Appendix 1). Observed conditions of low dissolved oxygen were acute at Stations NH-1A ranging from 0.1 mg/L to 0.3 mg/L (Figure 3, Appendix 1) at a half meter below the surface from 7/1 through 9/9. Observed dissolved oxygen values at Station NH1, while still hypoxic, were in the range of 0.3 mg/L to 4.5 mg/L for the same period (Figure 3, Appendix 1). Hypoxic conditions were also observed at Station NH-2A, where the continuous-recording data logger documented dissolved oxygen concentrations as low as 1 mg/L on 8/12 to 8/15/15 (Figure 4 and Figure 5). It is important to note that the relatively lower concentrations observed at more inland sites are likely to be an artifact of sampling design, as stations were sampled in order from inland (NH-1A) outward (to NH-5) beginning early in the morning and continuing into the late morning. As a result, bottom water concentrations may have been lower

at the stations further downstream than what was observed in this study due to the impact of daylight on dissolved oxygen (via photosynthesis).

On 9/9/15, the lowest dissolved oxygen values of the season were observed on a rising tide at 8:00 AM at Station NH-1A. The surface dissolved oxygen concentration was 2.7 mg/L in the overlying water from the Norwalk River, however, at a depth of one-half meter the dissolved oxygen concentration dropped to 0.3 mg/L and concentrations continued to decline all the way to the bottom (Appendix 1). The summer of 2015 was noteworthy for its lack of rainfall (Figure 2), elevated water temperatures (reaching 26 ^{o}C) at several stations, and an influx of filter-feeding menhaden (also known as bunker).

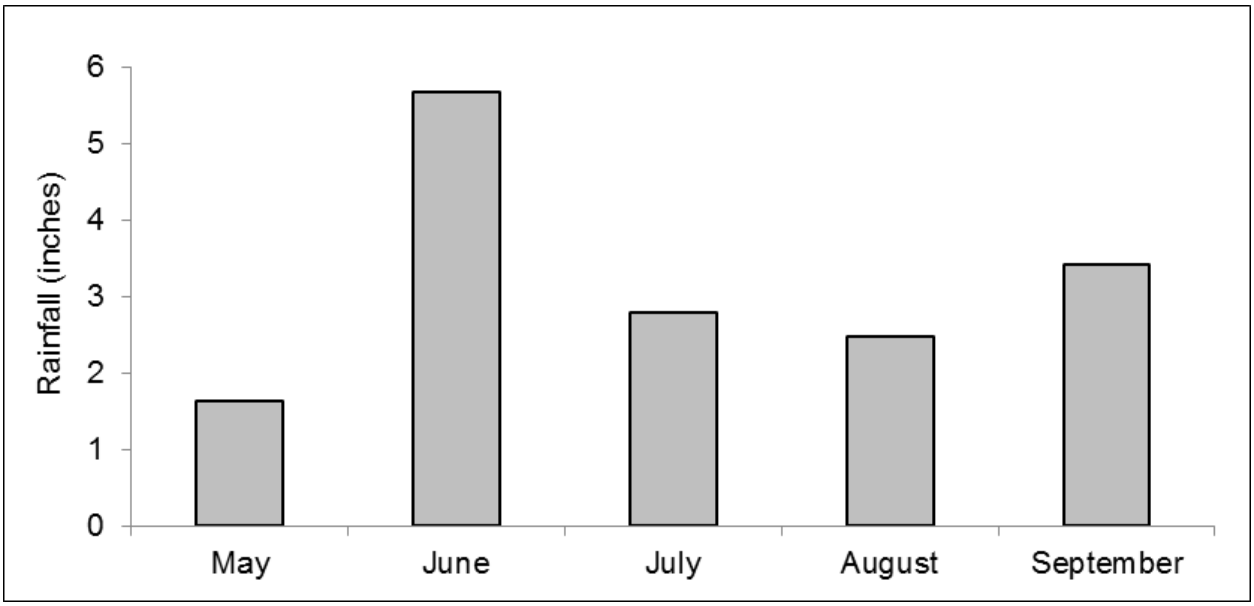


Figure 2. Rainfall (inches) for the months of May through September 2015.

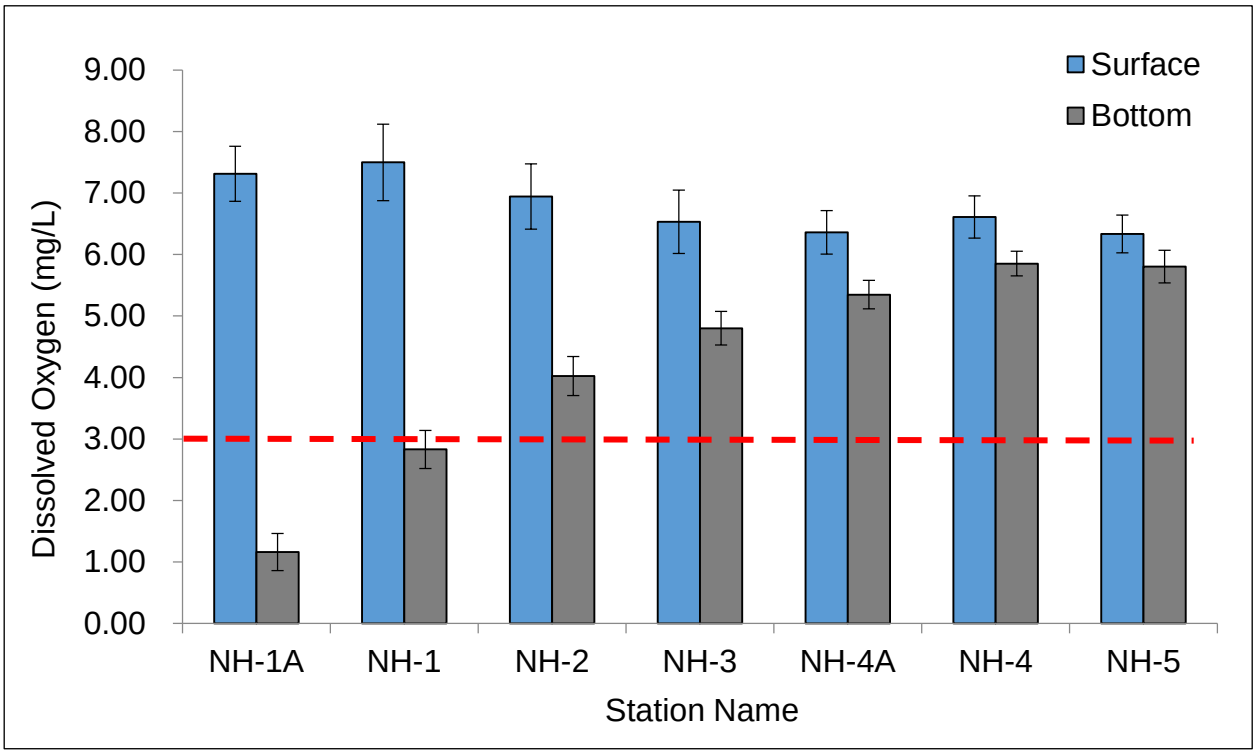


Figure 3. Mean surface dissolved oxygen concentrations and mean bottom dissolved oxygen concentrations at seven stations in the Norwalk Harbor from May 21, 2015 to October 1, 2015. Error bars represent standard error. **Please note that the relatively lower concentrations observed at more inland sites are likely to be an artifact of sampling design, as stations were sampled in order from inland (NH-1A) outward (to NH-5) beginning early in the morning and continuing into the late morning. As a result, bottom water concentrations may have been lower at the stations further downstream than what was observed in this study due to the impact of daylight on dissolved oxygen (via photosynthesis).**Values below the red dashed line indicate hypoxic conditions (below 3 mg/L).

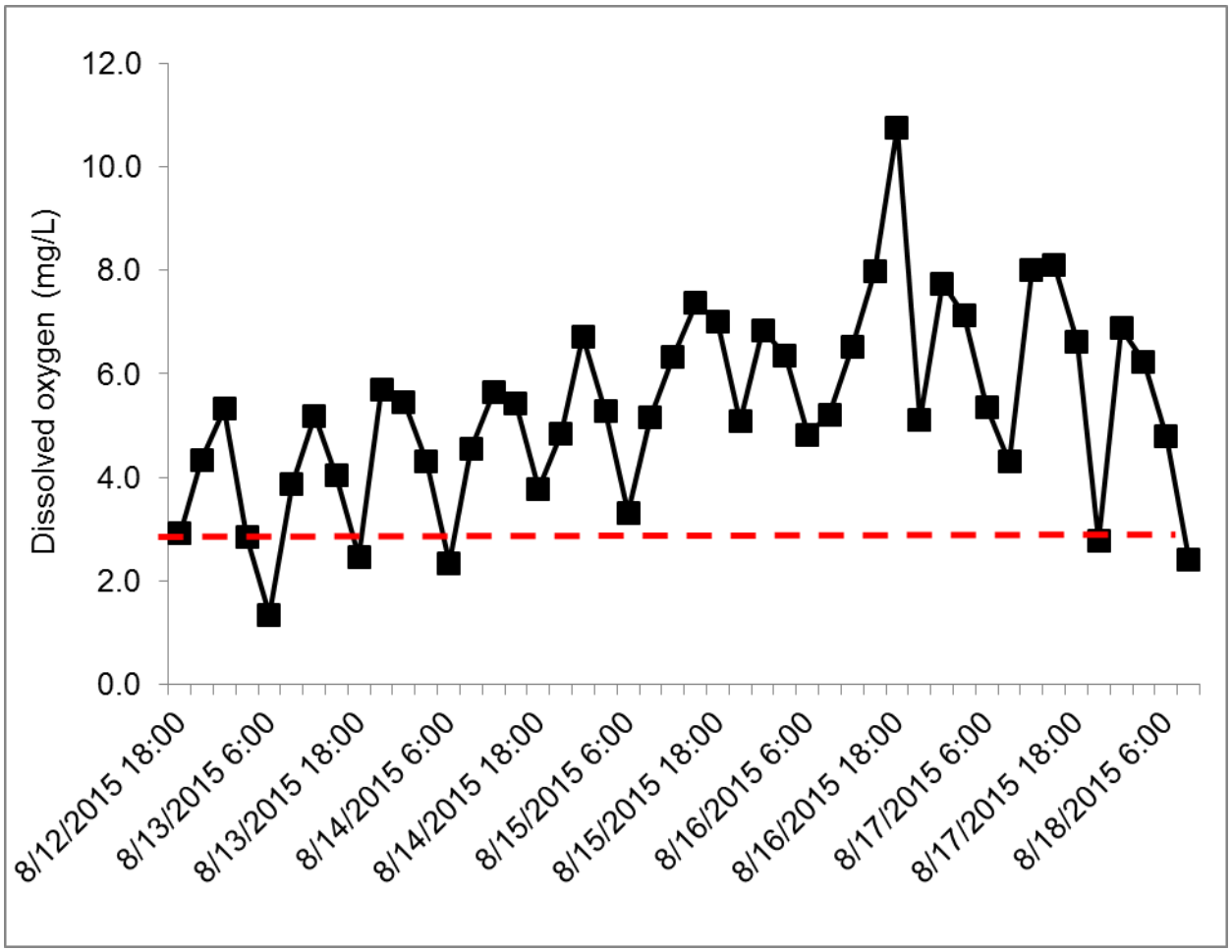


Figure 4. Continuous dissolved oxygen concentrations (mg/L) recorded from August 12, 2015 to August 18, 2015 at three hour intervals with a YSI Sonde 600 XLM at the Coastwise Marina dock piling, which is located between Station NH-2 and NH-3 in the Norwalk Harbor. Values below the red dashed line indicate hypoxic conditions (below 3 mg/L).

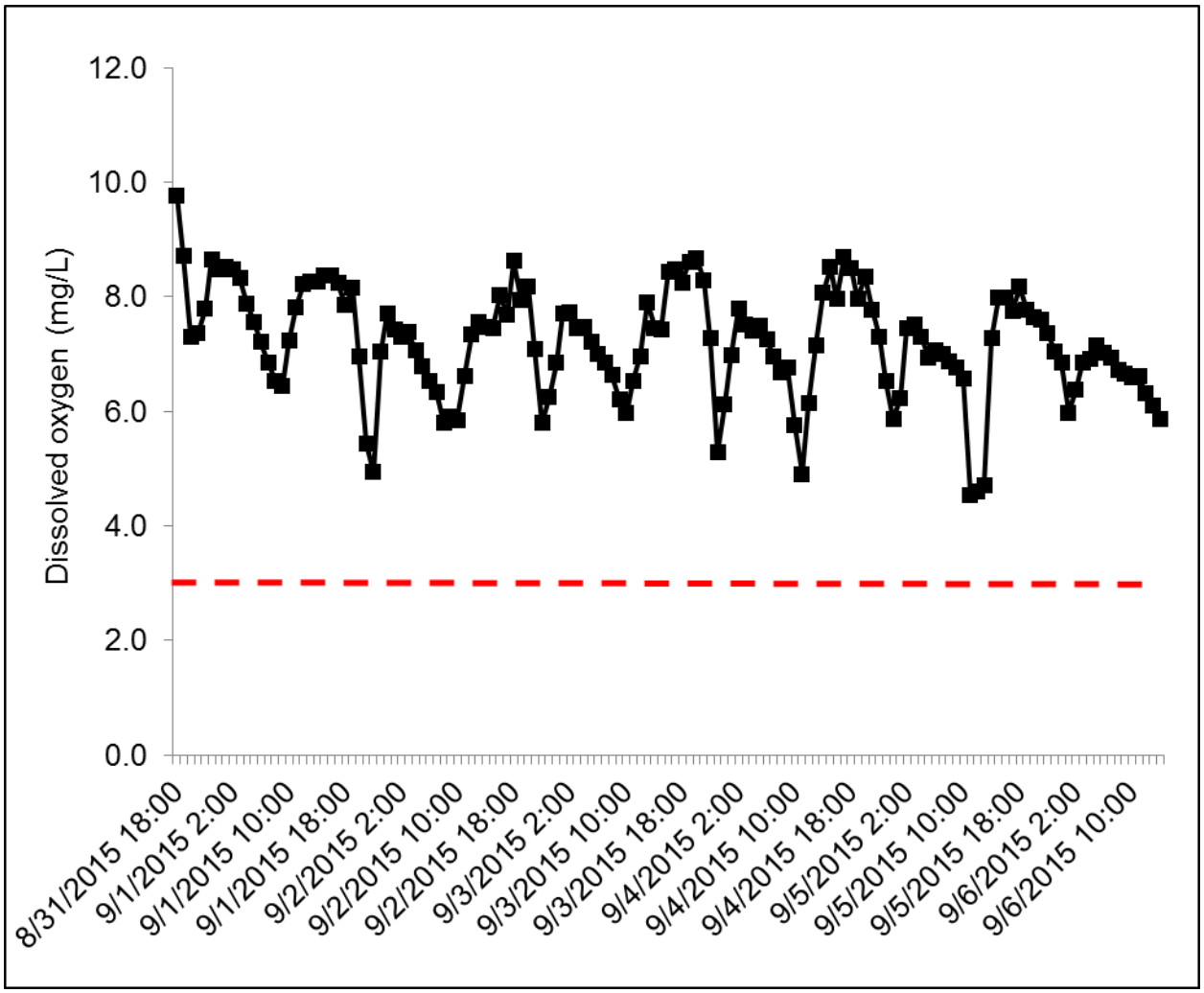


Figure 5. Continuous dissolved oxygen concentrations (mg/L) recorded from August 31, 2015 to September 6, 2015 at two hour intervals with a YSI Sonde 600 XLM at the Coastwise Marina dock piling, which is located between Station NH-2 and NH-3 in the Norwalk Harbor.

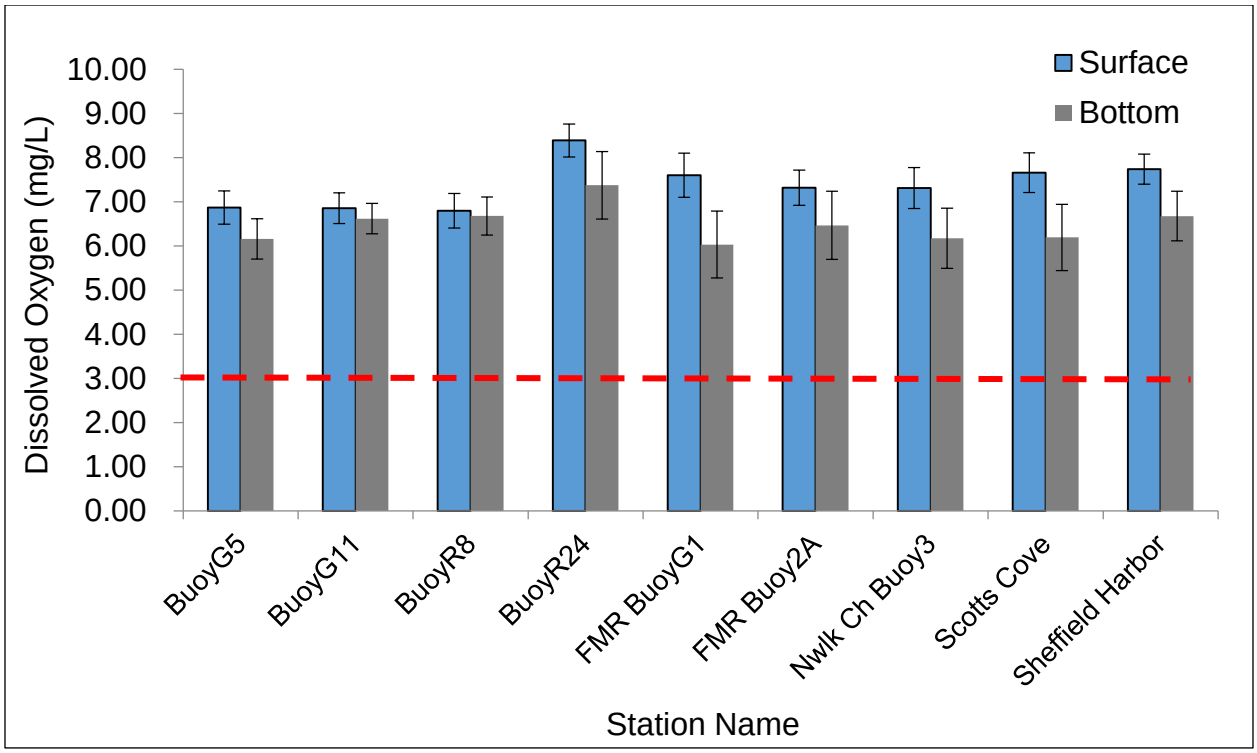


Figure 6. Mean surface dissolved oxygen concentrations and mean bottom dissolved oxygen concentrations at nine stations in the outer Norwalk Harbor between June 13, 2015 and August 26, 2015. Error bars represent standard error.

Observations of dissolved oxygen, salinity, and temperature by Coast Guard Auxiliary Flotilla 72 showed good quality marine waters (dissolved oxygen >5 mg/L) at all their monitoring stations throughout their testing cycle (Figure 6).

Norwalk Harbor suffers from poor flushing as well as other environmental problems, which often leads to poor water quality. The harbor once had extensive acres of wetlands along both banks which may have helped reduce the impact of people on water quality (Figure 7), but these valuable ecosystems were replaced beginning in the early 1800's to accommodate shipping, industry, and private homes. As a result, the upper harbor is now a long ditch flanked by extensive bulk heading and landfills. The original commercial aspects of the harbor are now giving way to marinas and new housing developments built along its banks.

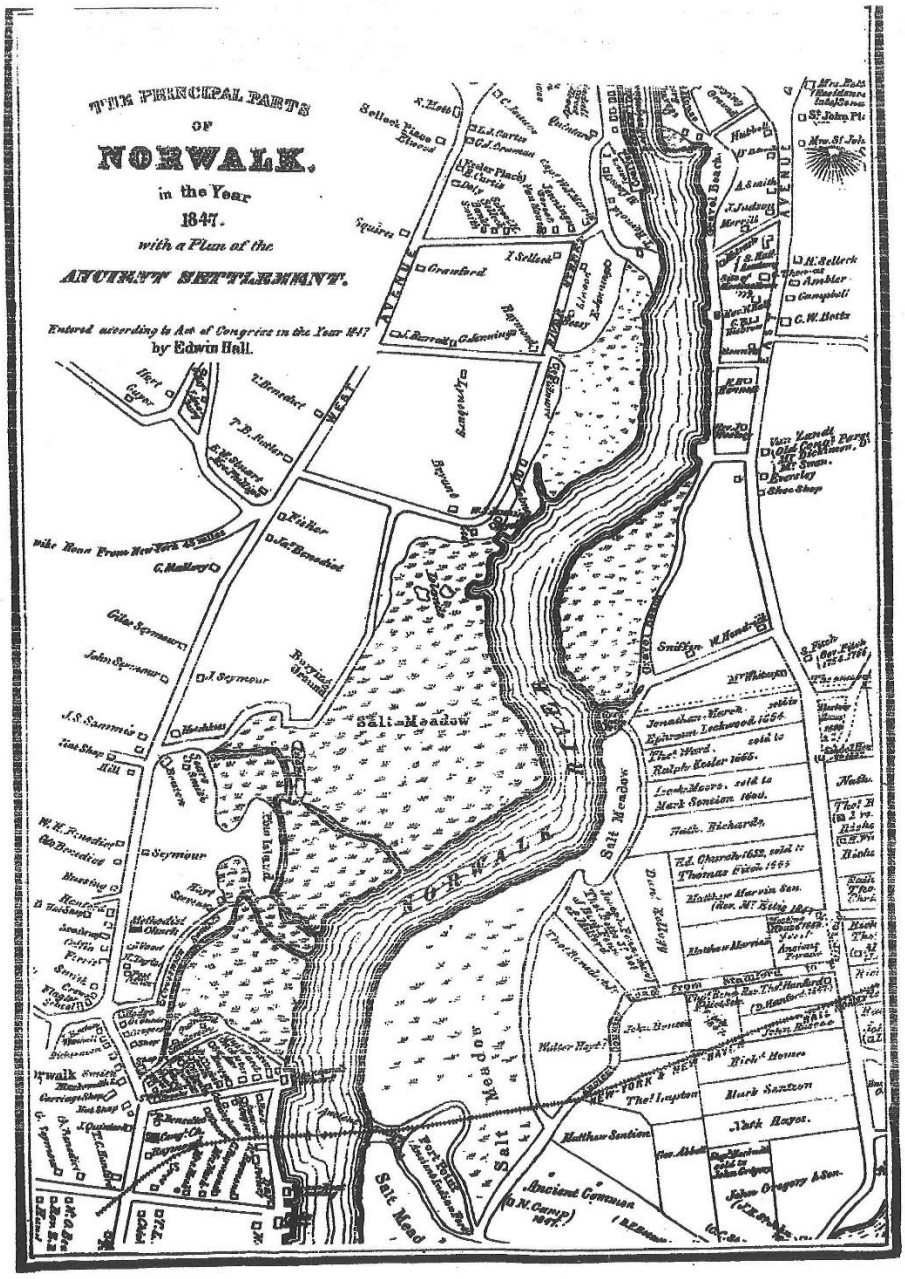


Figure 7. Norwalk Harbor estuary in 1847 showing extensive wetlands on both sides of the harbor. Image Credit: Norwalk Historical Society.

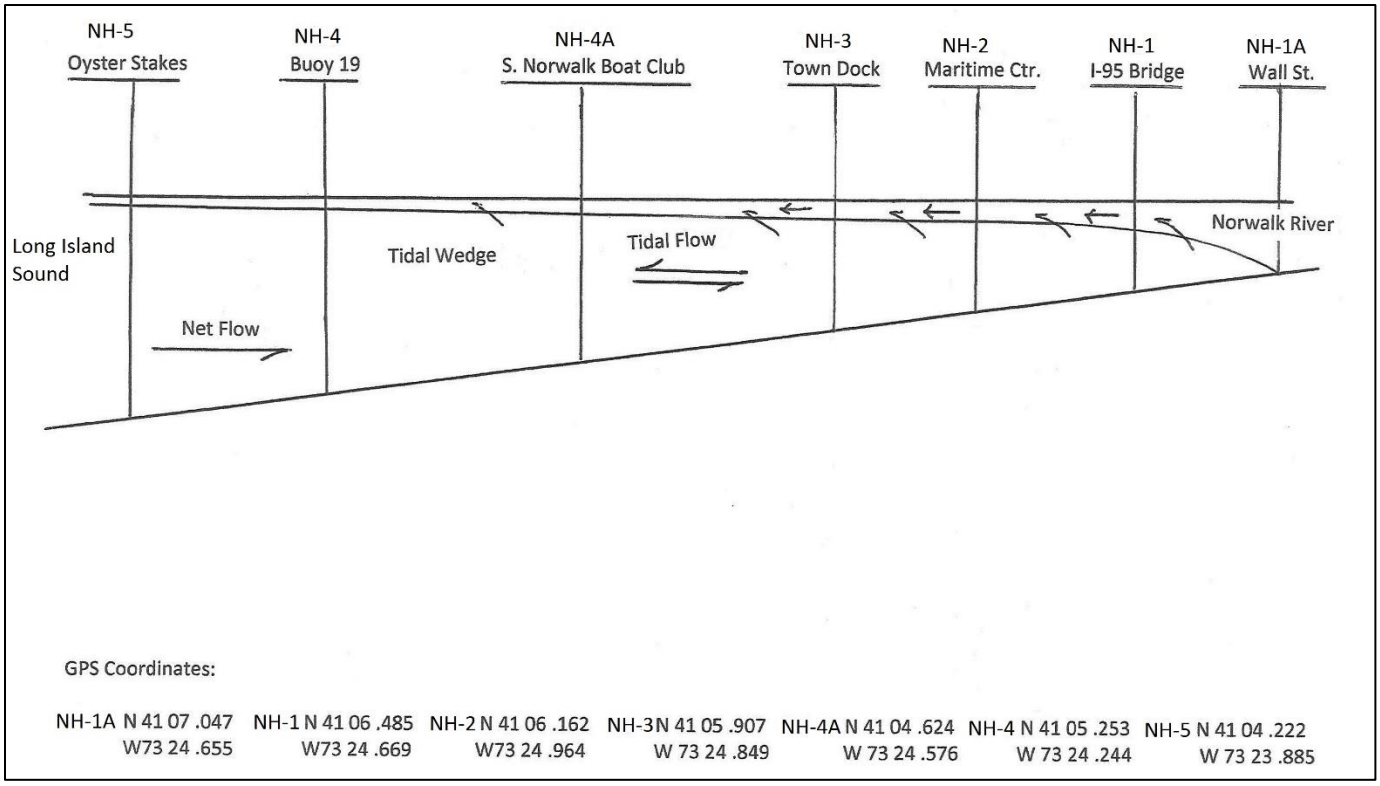


Figure 8. Lateral diagram of Norwalk Harbor from the toe of the estuary (right) to the harbor mouth a showing highly stratified tidal wedge and overlying Norwalk River flow.

With the filling in of the wetlands, flood tides can no longer spread the millions of gallons of incoming salt water over the surrounding landscape to provide the extensive volume needed on ebb tide to help flush the estuary. As a result, the underlying tidal wedge is almost totally dependent on the freshwater flow from the Norwalk River to move the underlying marine water masses seaward by frictional drag (Figure 8). This process is occasionally augmented by a seasonal drop in air temperature which can cause downwelling in the water column to restore dissolved oxygen at the bottom. Evidence of downwelling has been observed on some past Harbor Watch monitoring trips.

This harbor as restructured by man has developed a perpetual, seasonal zone of hypoxia at its northern end at Harbor Watch Station NH-1A (Appendix 1) which is typically observed each summer. Elevated water temperatures, dry weather and the presence of large schools of menhaden seeking refuge from predation in the harbor waters can accelerate this hypoxia. This oxygen-depleted water serves as a trap for schools of fish and can lead to large fish kills. Station NH-1A marks the toe of the tidal wedge and is at the entry point of the Norwalk River (Appendix 1). One of the last in a series of large fish kills occurred in the summer of 2005, when up to two million fish perished in the upper estuary after consuming the remaining dissolved oxygen available in the surface layer (mostly brackish river water).

Unfortunately, Norwalk Harbor did experience another large fish kill in the summer of 2015. As surface and bottom water temperatures became elevated over 26 ^{o}C in combination with greatly reduced rainfall during the summer months (Figure 9), the hypoxia spread downstream toward the I-95 Bridge at Station NH-1. By the end of August, available dissolved oxygen in the water column was reaching critically low levels (Figure 3, Appendix 1). Very large schools of menhaden were seen from south of the Bascule road bridge moving slowly upstream towards the I-95 Bridge in early August. A large school of peanut bunker (juvenile menhaden) moved into the hypoxic zone at Station NH-1A on 9/9 at 8:00 AM. This happened to be the very moment when the Harbor Watch vessel was on site taking dissolved oxygen readings and observing the most advanced case of hypoxia at Station NH-1A during the entire season (Figure 3 and Appendix 1). Within minutes, dead menhaden started floating to the surface. Fifty dead fish became hundreds, and hundreds became thousands within 20 minutes. Harbor Watch reported the event to the Connecticut Department of Energy and Environmental Protection (CT DEEP) Fisheries Bureau.

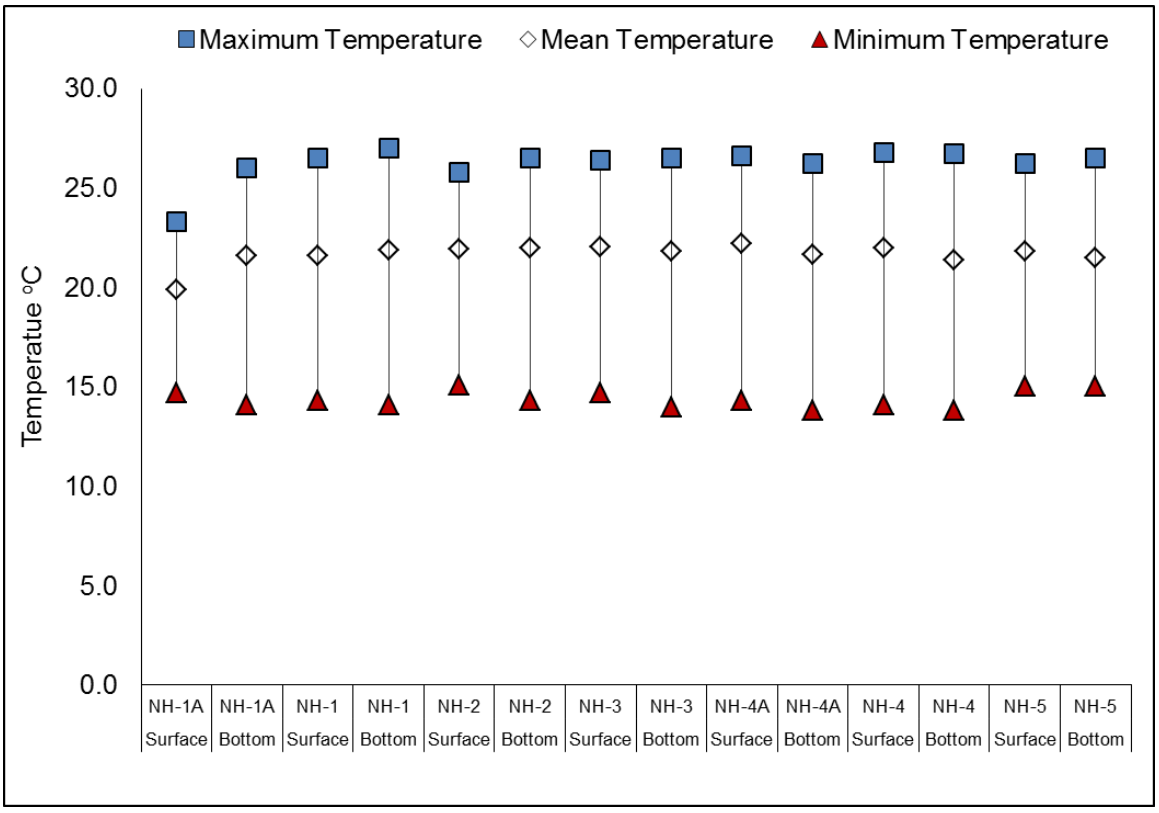


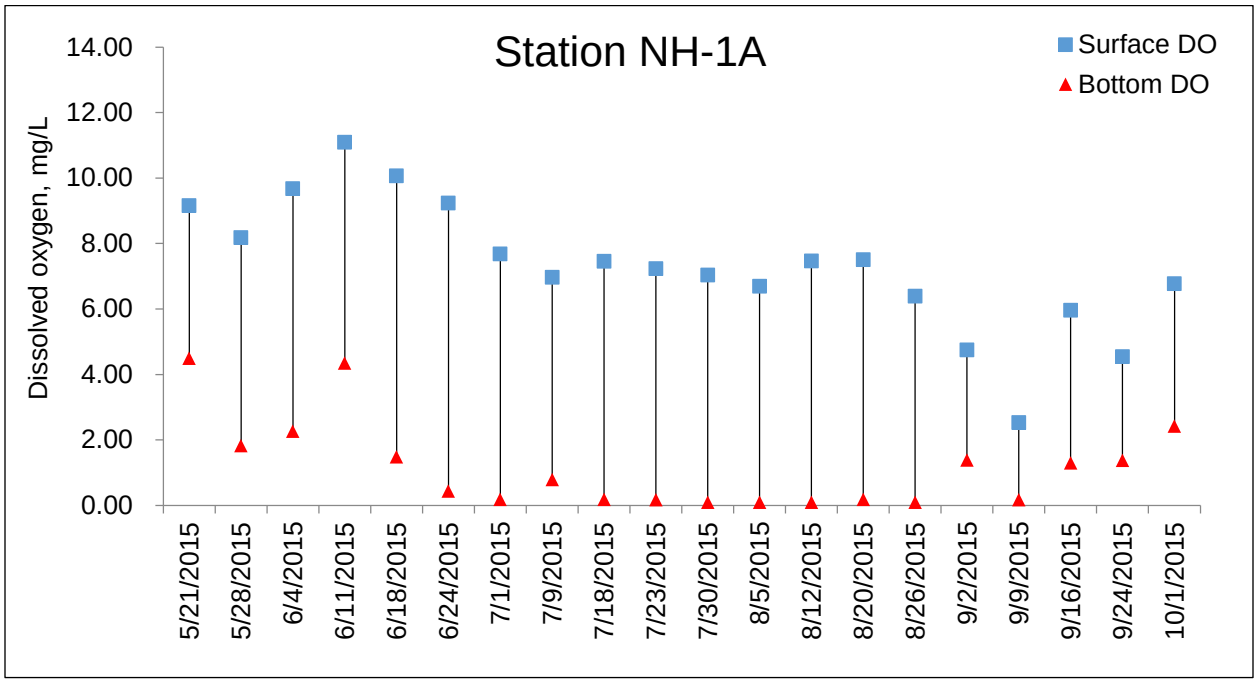
Figure 10. Maximum, mean, minimum surface and maximum, mean, and minimum bottom temperatures at the seven monitoring stations in Norwalk Harbor

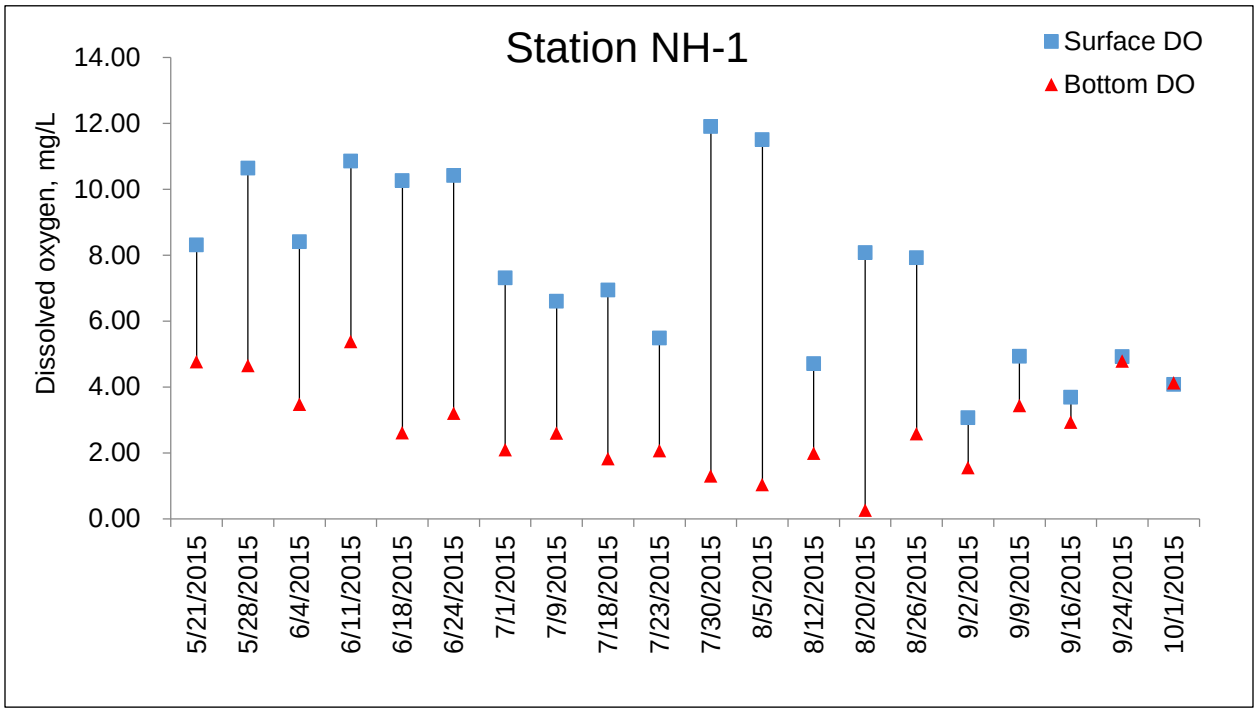
The first period of continuously-recorded dissolved oxygen values showed four episodes of hypoxia from 8/12 through 8/15 with two more hypoxic events occurring on 8/18 (Figure 5). The second recording period showed no hypoxic events with most observed dissolved oxygen concentrations above 5 mg/L (Figure 6). We hypothesize that potential causes of the observed low dissolved oxygen values could include rainfall impacts, sewage pollution, eutrophication, or other ecosystem-scale drivers. For example, a period of heavy rainfall on 8/11 (2.1 inches) may have impacted the dissolved oxygen levels observed on 8/12 and 8/13. The Norwalk River's flow increased with heavy rain and may have increased movement of the underlying tidal wedge seaward with frictional drag. More of the oxygen-depleted mass of marine water at Station NH1A could have been shifted downstream on ebb tide and may have led to hypoxic water passing the more downstream stations. However, there is no rainfall event to support the hypoxia observed on 8/18. Rainfall can also flush land-derived fertilizer into the river, which can increase hypoxia by the stimulation and subsequent decomposition of algal growth. Episodes of illegal sewage dumping from septic tank maintenance trucks or boats have occurred in the past and can decrease dissolved oxygen. However, no visible signs of human waste were found in the harbor. More research will be needed to locate the causes of hypoxia in this system which may prove to be difficult based on the seemingly random nature of these events. Additional data collection through long term deployment of the continuously-recording probe may to elucidate these drivers. Considering the elevated water temperatures (Figure 10), the atypically low rainfall, and the presence of large schools of menhaden, the Norwalk Estuary fared about as well as could be expected with respect to hypoxia this season.

Acknowledgements:
We thank Norm Bloom and Son LLC (Copps Island Oysters) for dock space for our research vessel, laboratory space, funding, and donations of scientific equipment. We also thank the many volunteers who participated in monitoring the Norwalk Harbor this season, including Joe Racz, Dick Auber, Betsy Burleson, Julian Garrison, Corrine Vietorisz, Claire Musico, Zachary Azadlian, Jeremy Philbrick, Meggy Adorno, and Tom Kelley. Also we extend our thanks to Steve Schmidt, doctoral candidate at the University of Connecticut for his help on several monitoring trips.

Appendix

Surface and bottom dissolved oxygen levels at each of six stations in Norwalk Harbor during the 2015 monitoring season. **Please note that the relatively lower concentrations observed at more inland sites are likely to be an artifact of sampling design, as stations were sampled in order from inland (NH-1A) outward (to NH-5) beginning early in the morning and continuing into the late morning. As a result, bottom water concentrations may have been lower at the stations further downstream than what was observed in this study due to the impact of daylight on dissolved oxygen (via photosynthesis).**




Station NH-1
Surface DO
Bottom DO
Dissolved oxygen, mg/L
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
5/21/2015
5/28/2015
6/4/2015
6/11/2015
6/18/2015
6/24/2015
7/1/2015
7/9/2015
7/18/2015
7/23/2015
7/30/2015
8/5/2015
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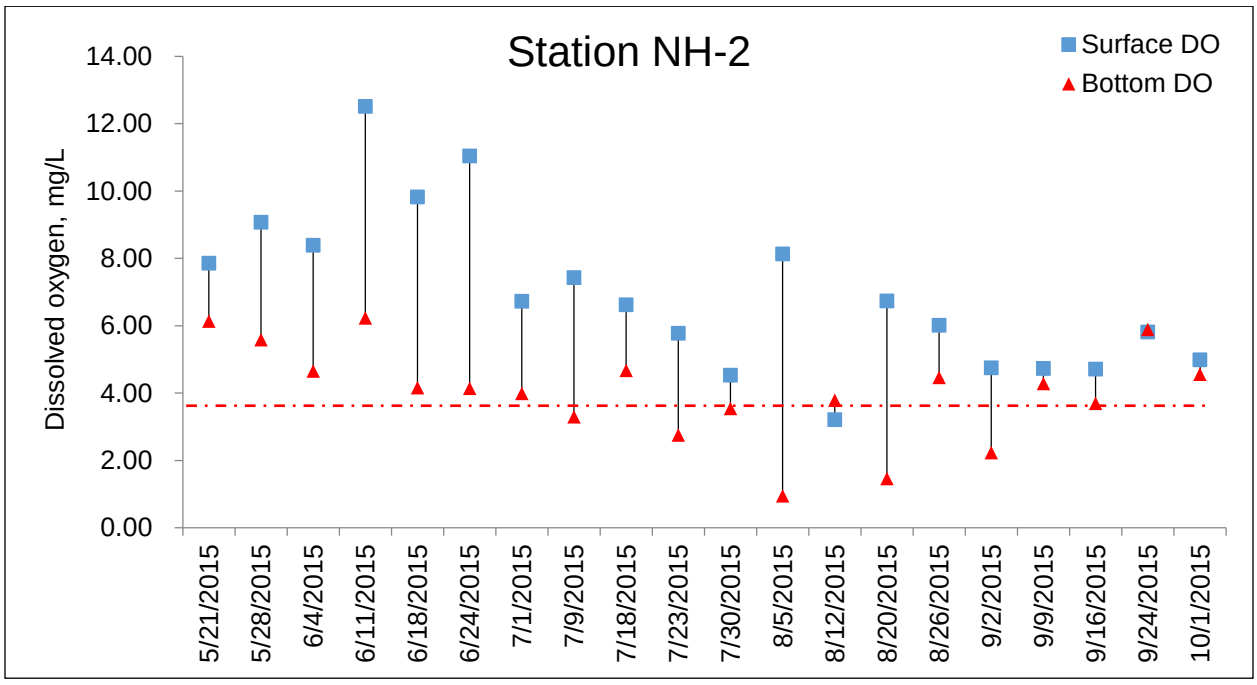
9/2/2015
9/9/2015
9/16/2015
9/24/2015
10/1/2015


Station NH-2
Surface DO
Bottom DO
Dissolved oxygen, mg/L
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
5/21/2015
5/28/2015
6/4/2015
6/11/2015
6/18/2015
6/24/2015
7/1/2015
7/9/2015
7/18/2015
7/23/2015
7/30/2015
8/5/2015
8/12/2015
8/20/2015
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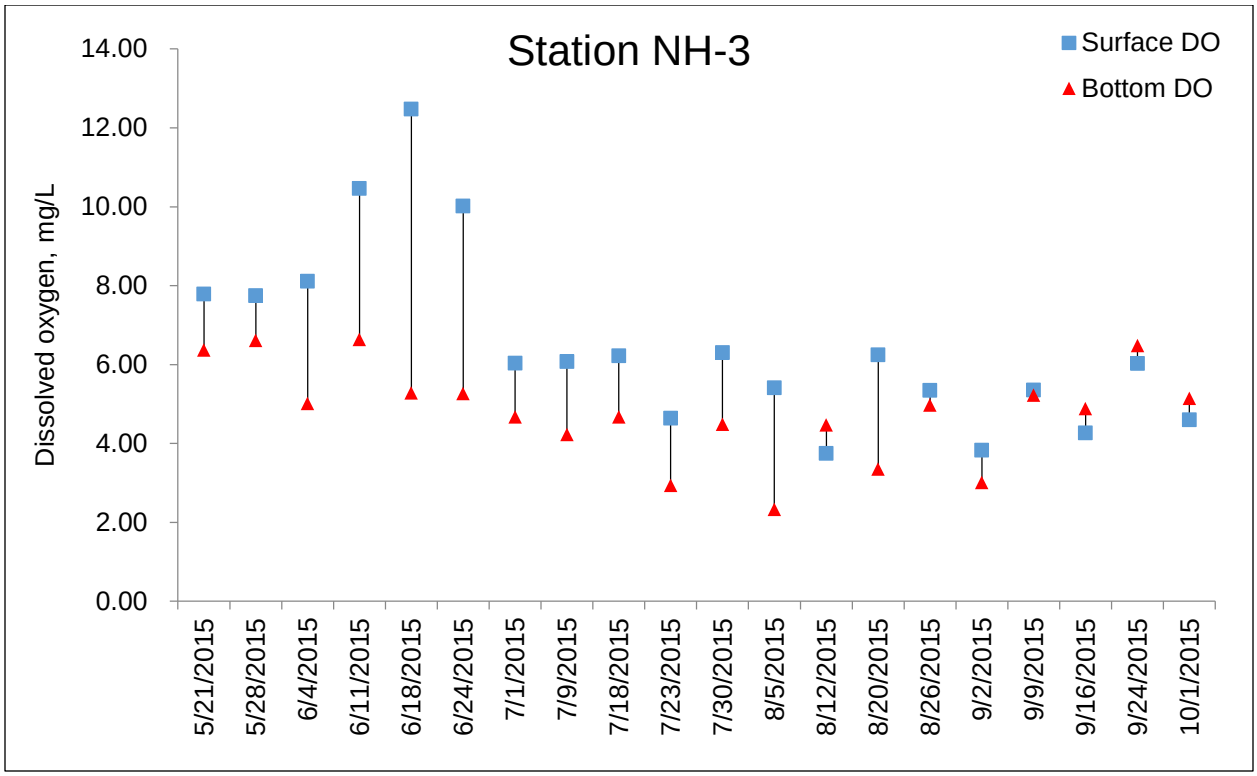
9/9/2015
9/16/2015
9/24/2015
10/1/2015


Station NH-3
Surface DO
Bottom DO
Dissolved oxygen, mg/L
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
5/21/2015
5/28/2015
6/4/2015
6/11/2015
6/18/2015
6/24/2015
7/1/2015
7/9/2015
7/18/2015
7/23/2015
7/30/2015
8/5/2015
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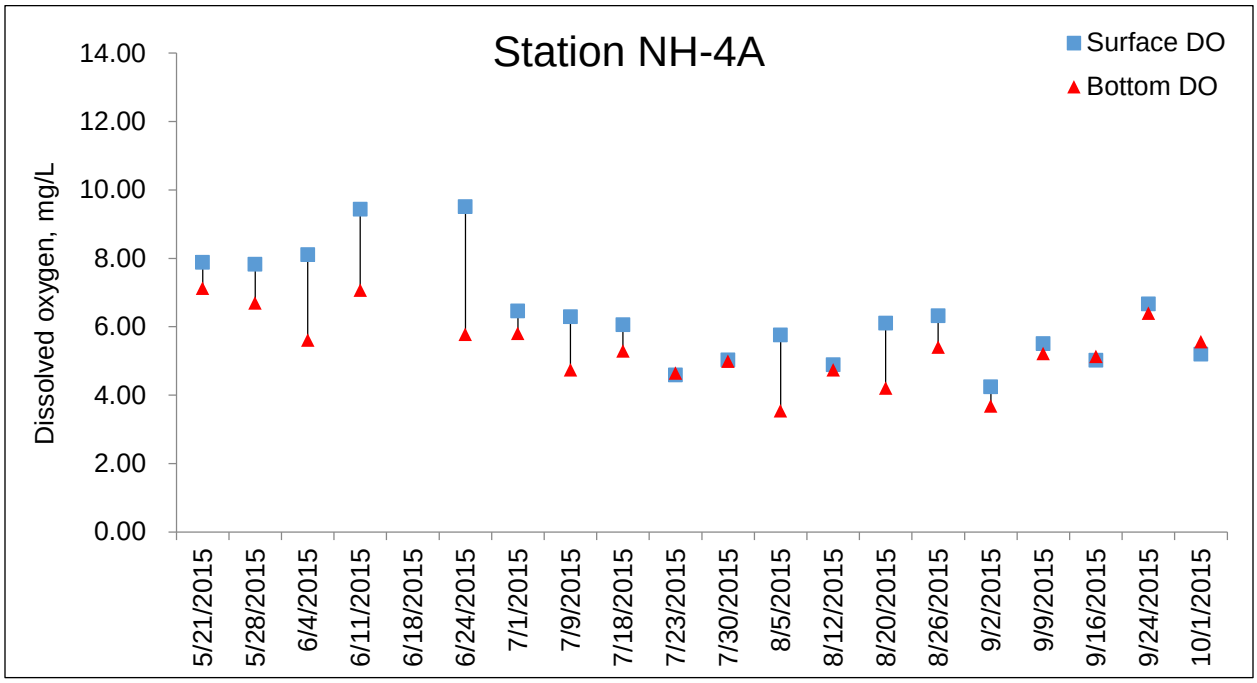
8/26/2015
9/2/2015
9/9/2015
9/16/2015
9/24/2015
10/1/2015


Station NH-4A
Surface DO
Bottom DO
Dissolved oxygen, mg/L
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
5/21/2015
5/28/2015
6/4/2015
6/11/2015
6/18/2015
6/24/2015
7/1/2015
7/9/2015
7/18/2015
7/23/2015
7/30/2015
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9/9/2015
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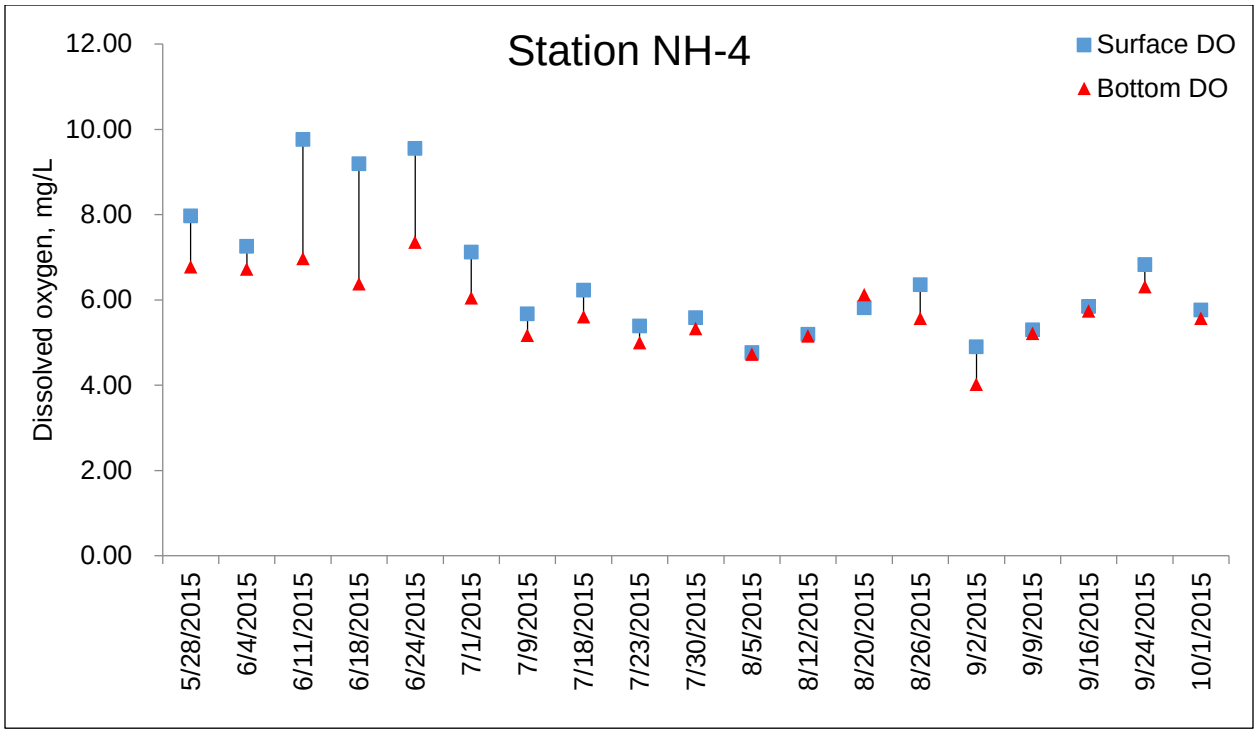
9/24/2015
10/1/2015


Station NH-4
Surface DO
Bottom DO
Dissolved oxygen, mg/L
12.00
10.00
8.00
6.00
4.00
2.00
0.00
5/28/2015
6/4/2015
6/11/2015
6/18/2015
6/24/2015
7/1/2015
7/9/2015
7/18/2015
7/23/2015
7/30/2015
8/5/2015
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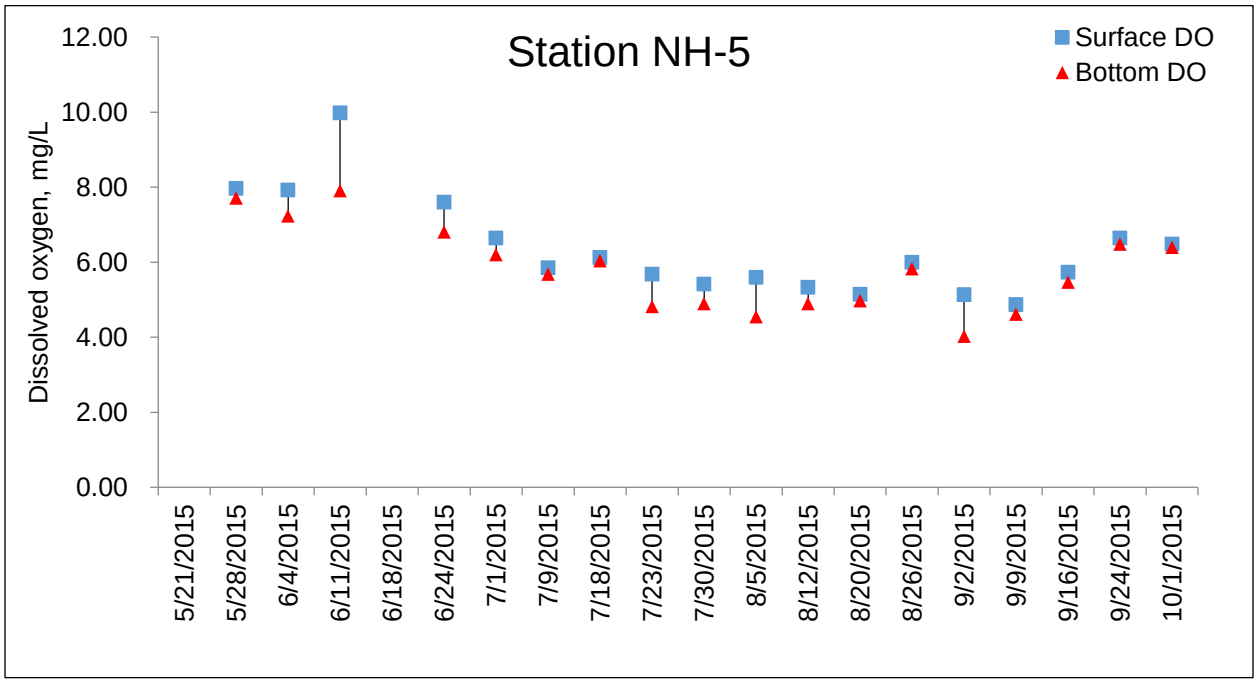
10/1/2015


Station NH-5
Surface DO
Bottom DO
Dissolved oxygen, mg/L
12.00
10.00
8.00
6.00
4.00
2.00
0.00
5/21/2015
5/28/2015
6/4/2015
6/11/2015
6/18/2015
6/24/2015
7/1/2015
7/9/2015
7/18/2015
7/23/2015
7/30/2015
8/5/2015
8/12/2015
8/20/2015
8/26/2015
9/2/2015
9/9/2015
9/16/2015
9/24/2015
10/1/2015