Technical Memorandum

Westport River Watershed Alliance
Cockeast Pond Assessment Project
(Phase 1 and Phase 2)

2015-2017

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Re: Summary of Scientific Support Services: Ecological Assessment of Cockeast Pond (Phase 1 + Phase 2). Period of Performance: December 10, 2014 – December 31, 2018

Date: June 13, 2018 DRAFT FINAL

Overview:
Cockeast Pond (92 acres) is a salt pond, tributary to the Westport River Estuary (Westport Harbor) at the southern region of the Town of Westport, near the Rhode Island border and Buzzards Bay. Cockeast Pond is separated from Buzzards Bay by a barrier beach and exchanges water with the Westport River Estuary via a culvert passing under River Road. The culvert is placed in a manner whereby tidal inflows have been significantly restricted and the pond now contains brackish rather than marine waters, as the inflowing marine waters are diluted with freshwater entering via direct groundwater discharge and a small intermittent stream. Cockeast Pond is the only brackish pond in the Westport River watershed and provides a unique and diverse habitat for numerous species of plants and animals. However, past years of nutrient related water quality and macroalgal observations indicate a system that is currently showing clear signs of nutrient related habitat impairment from nitrogen enrichment and its restricted tidal exchange.

The Westport River Watershed Alliance (WRWA), in partnership with the Coastal Systems Program (CSP) at the University of Massachusetts-Dartmouth, School for Marine Science and Technology (SMAST-UMass Dartmouth), has had in place a nutrient related water quality monitoring program for Cockeast Pond for the past seven years in order to assess the degree to which the habitat of Cockeast Pond may be affected by nutrient concentrations and incoming nitrogen load from the watershed. Water quality monitoring was specifically undertaken to establish baseline water quality conditions and assess linkages to observed levels of habitat impairment.

Cockeast Pond has a relatively small watershed that includes a nine-hole golf course, a number of single family homes and some agriculture that contribute to the level of nitrogen enrichment observed by the monitoring program in this small coastal salt pond. However, due to the restricted tidal exchange this salt pond is more sensitive to nitrogen inputs than the adjacent estuary, so that the relatively low levels of watershed nitrogen input are still sufficient to cause habitat impairment as seen in the levels of macroalgal accumulation and phytoplankton blooms. Based on the water quality monitoring, it appears that long-term increases in nitrogen loads to the poorly flushed Cockeast Pond from activities within its associated watershed are creating adverse impacts to the ecosystem, limiting its value as an estuarine resource.

At present, the level of nitrogen enrichment can be reduced either by lowering the loading from the watershed or by increasing the tidal volume exchanged (increased flushing). Within the overall Westport River Estuary, Cockeast Pond is a net contributor of nitrogen to Westport Harbor/West Branch. The pond was included in the in-depth nutrient threshold assessment of the Westport River Watershed under the Massachusetts Estuaries Project ({MEP}[1]) and has a specific nitrogen threshold as established under the MEP. The Pond and both the West Branch and the East Branches currently exceed their nitrogen thresholds and therefore the Westport River Estuary is on the USEPA List of Impaired Waters for nitrogen. The Town of Westport has received its final MEP report and is awaiting the release of the ensuing TMDLs issued MassDEP and USEPA under the Federal Clean Water Act.

In order to establish the potential for restoring the nutrient impaired habitats within Cockeast Pond and improving the West Branch of the River, soft solutions (non sewering) need to be investigated, as the housing density is insufficient to support a large sewer collection system. However, this effort requires a higher level assessment of the Cockeast Pond system beyond the quantification of its nutrient related water quality. For restoration of Cockeast Pond, the potential for enhanced tidal exchange, watershed source reduction or in pond aquaculture to remove nitrogen directly from the pond waters need to be evaluated in order to guide management action to improve habitat quality within this unique salt pond as well as to improve the downstream waters of the West Branch.

To that end, a multi-step assessment approach was initiated in December 2014 to better understand how Cockeast Pond functions in relation to Westport Harbor. Phase 1 of this multi-step assessment focused primarily of the volumetric exchange between Cockeast Pond and Westport Harbor as well as the influx/efflux of nutrients into and out from the pond.

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[1] Howes B., E. Eichner, R. Acker, R. Samimy, J. Ramsey, and D. Schlezinger (2011). Massachusetts Estuaries Project Linked Watershed-Embayment Approach to Determine Critical Nitrogen Loading Thresholds for the Westport River Embayment System, Town of Westport, MA & Massachusetts Department of Environmental Protection. Boston, MA.

Additionally, benthic infaunal habitat characterization was completed under Phase 1 as an important additional indicator of the degree of habitat impairment. Phase 1 of the overall assessment of Cockeast Pond was completed in the context of the entire Westport River estuary analyzed by the MEP Technical Team and is consistent with the analytical approaches utilized in the MEP study of the Westport River Estuary. Therefore results from the investigation of Cockeast Pond are directly comparable to results from the MEP evaluation of the Westport River.

The overall analysis of Cockeast Pond (Phase 1 completed summer 2016 and Phase 2 summarized herein), represents a detailed accounting of the nitrogen sources, mass balance and dynamics, as well as the nutrient and hydrologic characteristics of Cockeast Pond with direct linkage to indicators of habitat impairment. The complete analysis presents the sensitivity and assimilative capacity of the pond for nitrogen and allows for the evaluation of potential soft solutions for water quality and habitat restoration. It is critical to note that the necessary land use based nitrogen loading analysis needed to undertake such a study of Cockeast Pond was completed under the MEP land use nitrogen load modeling, but was revisited and completely updated including more current information on agricultural land use and site specific data on nutrient application values from the Axocet Golf Club. The updated land use analysis specific to the Cockeast Pond watershed and consistency with the MEP analytical approach for the Westport River allows for the linkage of watershed nitrogen loads to observed levels of habitat and water quality impairment and comparison to the state of the broader estuarine system.

This Cockeast Pond Habitat Assessment Project (Phase 1) was strictly limited to: 1) hydrodynamic data collection (stage and bathymetry to determine pond volume), 2) completion of three tidal flux experiments to measure volumetric exchange and associated influx/efflux of nutrients to and from the pond and 3) characterization of the benthic infaunal community as an additional gauge of habitat health/impairment. Phase 2 of the assessment was focused on extending the characterization of habitat health/impairment using dissolved oxygen and chlorophyll data, refining the watershed loading, quantifying the nutrient regeneration from pond sediments, quantifying the stream load to the pond, monitoring the water column nutrient concentrations, developing a box model of the system and relating all data sets on the nutrient dynamics and habitat quality to generate first order management recommendation to guide restoration of the Cockeast Pond System.

While there are a variety of indicators (DO, CHLA, seagrasses, macroalgal density/distribution) that can be used in concert with water quality monitoring data for evaluating the ecological health of salt ponds and embayment systems, the best biological indicators are those species which are non-mobile and which persist over relatively long periods (benthic infauna), if environmental conditions remain constant. The concept is to use species which integrate environmental conditions over seasonal to annual intervals. The approach is particularly useful in environments where high-frequency variations in structuring parameters (e.g. light, nutrients, dissolved oxygen, etc.) are common, making adequate field sampling difficult.

In areas that do not support eelgrass beds, benthic animal indicators are used to assess the level of habitat health from “healthy” (low organic matter loading, high D.O.) to “highly stressed” (high organic matter loading-low D.O.). The concept is that certain species or species assemblages reflect the quality of their habitat. Benthic animal species from sediment samples are identified and the environments ranked based upon the fraction of healthy, transitional, and stressed indicator species. These data are coupled with the level of diversity (H’) and evenness

(E) of the benthic community and the total number of individuals to determine the infaunal habitat quality.

For continuity, the current Technical Memorandum begins with the previously reported findings of the Phase 1 portion of the overall assessment and continues with the summary of data collection and synthesis of the Phase 2 portion of the project.

The Technical Memorandum is organized as follows:

PHASE 1 (Previously Submitted)

- Summary of 2015 Water Quality Results for Cockeast Pond Sampling and a comparison to the 2008-2014 results as well as Pond Trophic Status,
- Results of Hydrodynamic Field Collection (Stage and Bathymetry),
- Results of Tidal Exchange Experiments (3) Summer 2015,
- Results of Benthic Infaunal Analysis,
- Results of the Dissolved Oxygen / Chlorophyll-a Characterization,

PHASE 2

- Benthic Flux Experiments for Nutrient Regeneration from Sediments,
- Update of the Cockeast Pond Watershed Loading Analysis,
- Summary of Stream Flow and Loading,
- Summary of Summer 2016 Water Quality,
- Development of a Cockeast Pond System Box Model,
- Conclusions and Recommended Management Options.

It should be noted that nutrient samples collected at each sampling station (2015 and 2016) as well as during the three tidal flux experiments were assayed at the Coastal Systems Analytical Facility at SMAST. All samples were analyzed for ammonium (NH_4), nitrate+nitrite (NO_3+NO_2), dissolved organic nitrogen (DON), particulate organic nitrogen (PON), ortho-phosphate (PO_4), particulate organic carbon (POC), total phosphorus (TP), Chlorophyll-*a*, Pheophytin-*a*, pH and alkalinity. All samples were collected and analyzed in a manner consistent with the Massachusetts Estuaries Project QAPP and as such are directly comparable to both the baseline water quality assessment of the Westport River Estuary as well as threshold findings. Moreover, hydrodynamic data collection, tidal flux experiments and benthic infaunal sampling were also undertaken consistent to the MEP approach.

COCKEAST POND ASSESSMENT - PHASE 1 SUMMARY

Summary of Summer 2015 Water Quality Monitoring:

The Westport River Watershed Alliance (WRWA) Pond Water Quality Monitoring Program was continued through the summer of 2015 following the previously developed protocols and sampling locations to ensure comparability. It should be noted that sampling procedures utilized in Cockeast Pond are consistent with water quality sampling undertaken in other Westport Ponds such as Forge Pond and Adamsville Pond making results directly comparable. Moreover, Cockeast Pond samples collected and analyzed in collaboration with CSP-SMAST are comparable to the entirety of the CSP nutrient related water quality data for estuaries and salt ponds of southeastern Massachusetts. The 2015 program included a total of six (6) sampling events (June, July, August, September) at station CP1 (Figure 1) with samples being collected at both surface and bottom depths. As in previous years, sampling took place during the warmer summer months when water quality conditions in southeastern Massachusetts estuaries are typically lowest.

Figure 1 – Aerial photograph of Cockeast Pond depicting the 2 locations at which nutrient samples were collected from 2007 to 2016.

Total nitrogen levels showed water column enrichment in Cockeast Pond (1.44mg N/L). Although the dominant forms of nitrogen entering streams and ponds is typically nitrate and ammonium (DIN), organic forms of nitrogen (DON, PON) dominated the water column nitrogen pool. This results from the transformation of inorganic forms to organic forms by aquatic plants, algae and phytoplankton.

DON was the dominant form of nitrogen in Cockeast Pond. The average DON concentration in the water column across the 6 sampling dates was 0.97mg/L, accounting for approximately 67.4% of the TN pool (Table 1). PON comprised almost all of the remaining TN and was composed primarily of phytoplankton and some organic detritus. The combined DON+PON (organic nitrogen pool) accounted for 97.9% of the total nitrogen (TN) pool in Cockeast Pond.

COCKEAST POND										
Date	PO4 (mg/L)	TP (mg/L)	NH4 (mg/L)	Nox (mg/L)	DON (mg/L)	POC (mg/L)	PON (mg/L)	TN (mg/L)	Chla (ug/L)	Salinity (ppt)
6/5/2015	0.00	0.06	0.03	0.01	0.86	3.26	0.52	1.42	10.94	6.55
6/18/2015	0.00	0.07	0.03	0.01	1.00	2.19	0.41	1.44	3.25	8.10
7/24/2015	0.00	0.06	0.01	0.01	1.04	3.00	0.40	1.45	10.41	10.53
8/31/2015	0.00	0.03	0.00	0.01	0.83	1.70	0.22	1.06	4.19	13.30
9/9/2015	0.00	0.04	0.00	0.01	0.84	2.00	0.28	1.14	5.35	15.65
9/22/2015	0.00	0.04	0.02	0.01	0.58	1.83	0.30	0.91	4.18	14.23
AVERAGE	**0.00**	**0.05**	**0.02**	**0.01**	**0.86**	**2.33**	**0.35**	**1.24**	**6.39**	**11.39**

Table 1. Summary of nutrient concentrations for samples collected in Cockeast Pond.

The dominance of organic nitrogen is fairly typical of estuarine systems. Dissolved organic nitrogen, a by-product of the decomposition of plant material, enters from the upland stream and pond sediments and is not readily available to plants or bacteria. It tends to remain in the water column until transported out in outflowing tidal waters. In contrast, the inorganic nitrogen released during plant decay (or that enters in groundwater, surface water, or rainfall) is readily available to algae, phytoplankton and plants. It is rapidly taken up and converted to organic nitrogen within streams, ponds and estuaries. The PON level within the pond is primarily a result of this uptake and growth by phytoplankton. The predominance of organic forms within Cockeast Pond indicates that these transformations are occurring. A coupled land-use analysis such as that prepared by the MEP (and conducted under the Phase 2 of the Cockeast Pond Assessment) yields the definitive evaluation of nutrient sources, total nitrogen load to the pond, and the rate of water turnover (flushing/exchange) between the pond and Westport Harbor and how pond nitrogen levels and habitat quality may change with changing nitrogen inputs and/or the rate of tidal exchange.

While nitrogen is critical in determining the health of estuaries and salt ponds and is an important nutrient supporting their productivity, phosphorus appears to be the immediate nutrient causing eutrophic conditions in fully freshwater ponds. The ratio of N/P can be used as an approximate gauge of the relative importance of N or P to the nutrient related health of aquatic systems. While this is a more robust analysis in salt water compared to freshwater basins, generally N/P ratios less than 16 indicate that the nutrient to manage is nitrogen. In salt ponds such as Cockeast Pond (10-13 ppt), the molar ratio DIN/DIP (ratio of dissolved inorganic N to dissolved inorganic P) is sometimes used for the evaluation. However, the concentrations of the nutrients also need to be taken into account. In Cockeast Pond both the DIN and DIP levels are very low. Therefore, it appears from this preliminary analysis that both nitrogen and phosphorus inputs will result in increased phytoplankton growth. A direct assessment of N or P limitation of phytoplankton growth was conducted in 2016, using experimental nutrient additions and direct measures of phytoplankton photosynthesis and is included in the Phase 2 section of this tech memo.

Comparison of 2015 Data with Previously Collected Water Quality Results

TN values have been variable in Cockeast Pond over the 8 sampling years (2008-2015). There is no clear trend in average summer TN levels (Figure 2). It is likely that the variation results in part from inter-annual changes in tidal exchange at the culvert. Over this 8 year period, 2015 has the highest TN concentration (1.23 mg/L). For all 8 years, organic forms of nitrogen dominated the total nitrogen pool, with DIN contributing only a small fraction (Figure 3).

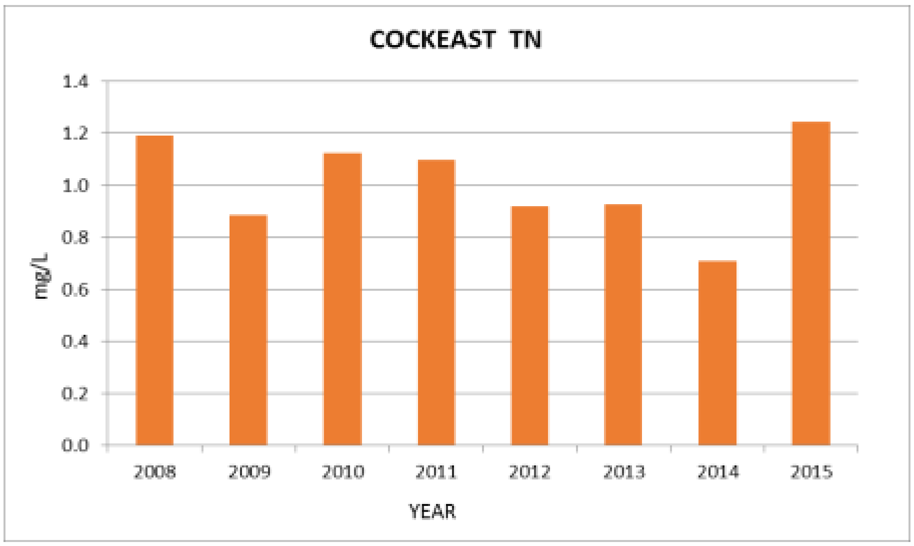

Figure 2. Comparison of Cockeast Pond water column Nitrogen concentrations from 2008-2015. 2008 values (mg/L) are means of 4 monthly samplings, June-September; 2009 values are from a single sampling in September, and 2010, 2012, 2013, 2014 values are means of 3 samplings, July-September and 2015 is the mean of 6 samplings (June-September).

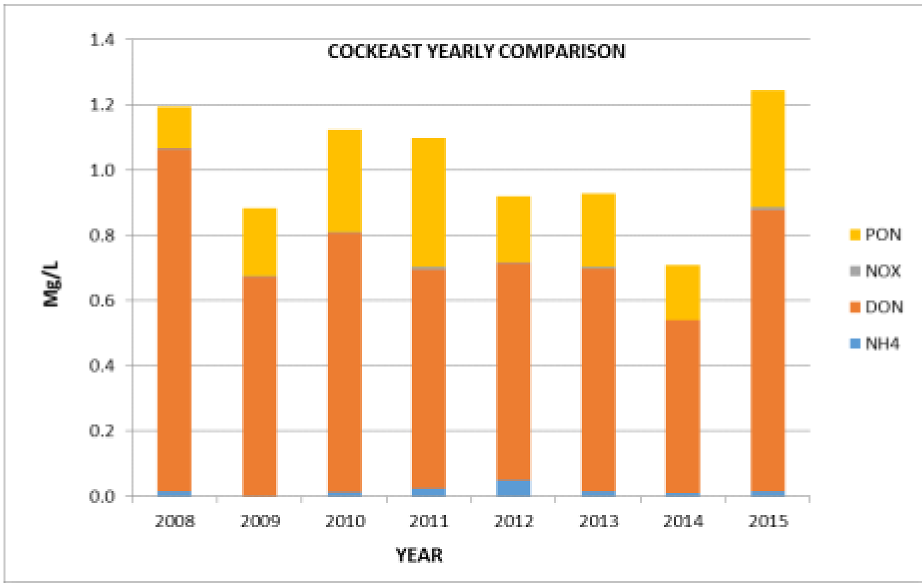

Figure 3. Comparison of water column Nitrogen concentrations from 2008-2015. 2008 values (mg/L) are means of 4 monthly samplings, June-September; 2009 values are from a single sampling in September, and 2010, 2012, 2013, 2014 values are means of 3 samplings, July-September and 2015 is the mean of 6 samplings (June-September).

Pond Trophic Status

Based upon the summer 2015 water quality survey results it is possible to conduct a two basic assessments of the nutrient related health of Cockeast Pond. Cockeast Pond is brackish so that both freshwater and estuarine assessments are included.

The first assessment uses Total Phosphorus, Chlorophyll-*a* pigment levels and water clarity (secchi depth), all of which are interrelated parameters that focus on nutrient enrichment in phosphorus controlled aquatic systems. The freshwater index of choice is the Carlson Trophic State Index, which is based upon comparisons to a large number of U.S. freshwater lakes and ponds (Table 2)[2]. The data used in the index was the averaged over the sampling period from the mixed layer of each pond. While the index needs to be used with other biotic indicators, it does provide a general assessment tool where calculated index levels are correlated with different Trophic States:

- TSI >50: Eutrophic (highly nutrient enriched)
- TSI 40-50: Mesotrophic (moderately nutrient enriched)
- TSI <40: Oligotrophic (low level of nutrient enrichment)

It appears that Cockeast Pond is continuing to show clear signs of eutrophication (Table 3). Eutrophic conditions are those that exist under high nutrient inputs and are characterized by algal and phytoplankton blooms, low water clarity and sometimes low oxygen in bottom waters. Nutrient enrichment can be seen in the poor water clarity. Cockeast Pond showed an average

[2] http://www.epa.gov/bioiweb1/aquatic/carlson.html

secchi depth value of only 1.04 meters. A moderately enriched pond would support Secchi depths of 2-4 meters. The "cloudiness" of the water column is mainly caused by phytoplankton biomass, measured by Chlorophyll-*a* concentrations which were moderate to high in summer in Cockeast Pond, 8.2 ug/L. TP levels in Cockeast were high with an average concentration of 70 ug/L. These 3 indicators together yield the high TSI values in Table 2 and the status designation of Eutrophic. The brackish waters of Cockeast Pond continue to vary between Eutrophic (2010, 2011, 2013, 2014, 2015) and a Meso/Eutrophic State (2009, 2012).

TSI	Secchi Depth (m)	Epilimnion Total P (ug/L)	Epilimnion Chlorophyll *a* (ug/L)	Trophic State
0	63.98	0.75	0.04	Oligotrophic
10	32.00	1.5	0.12	Oligotrophic
20	16.00	3	0.34	Oligotrophic
30	7.99	6	0.94	Oligotrophic
40	3.99	12	2.6	Mesotrophic
50	2.01	24	6.4	Eutrophic
60	1.01	48	20	Eutrophic
70	0.49	96	56	Eutrophic
80	0.24	192	154	Eutrophic
90	0.12	384	427	Eutrophic
100	0.06	768	1183	Eutrophic

Table 2. The Carlson Trophic Status Index (TSI) scores for Secchi Depth, Total Phosphorus and Chlorophyll a.

Pond	Secchi (m)	Secchi TSI	Chl a (ug/L)	Chl a TSI	TP (ug/L)	TP TSI	2015 Trophic State
Cockeast	1.04	55	8.2	55	70	65	**Eutrophic**

Table 3. Assessment of Trophic State of Cockeast Pond within the Town of Westport, based upon average values of summer 2015 surveys and a freshwater TSI.

The second assessment uses the Trophic Health Index Scores for estuarine water quality based upon open water embayment (not salt marsh) habitat quality scales (described in Howes et al. 1999 found at www.savebuzzardsbay.org). The Bay Health Index was developed for Buzzards Bay embayments based upon levels of nitrogen (inorganic and organic), chlorophyll-a, bottom water oxygen and the depth of light penetration (Secchi depth). While the index does not provide a quantitative assessment of habitat health and is not suitable for salt marsh dominated systems, it does give a useful picture of the general level of estuarine water quality and spatial gradients within estuaries. Since it is not yet possible to develop temporal trends from the available monitoring data, the average summer conditions throughout Cockeast Pond were used to parameterize the Bay Health Index and the Scores calculated (Table 4). It should be understood that the Bay Health Index and the designation of acceptable ranges for each parameter are approximate and provide less certainty than site-specific analysis of habitat quality. However, the Index does provide a convenient tool for comparing regions within an estuary and between estuaries. Cockeast Pond fell into the “moderate/fair” (meso-eutrophic) category for 2015 with an index score of 37.5 on a scale of >69 is high quality and <31 is poor quality.

	%Sat					Low20%				
Secchi m	DO	DIN	TON	T-Pig	Secchi	Oxsat	DIN	TON	T-Pig	EUTRO
All	20%	ppm	ppm	ug/L	SCORE	SCORE	SCORE	SCORE	SCORE	Index
1.0	79.0%	0.030	1.410	9.44	31.7	83.9	66.9	0.0	4.8	37.5

Table 4. Assessment of Trophic State of Cockeast Pond within the Town of Westport, based upon average values of summer 2015 surveys.

Recommendations Based on 2015 Water Quality Monitoring
Efforts such as reducing nitrogen levels within Cockeast Pond should be encouraged for the restoration of the impaired habitats within the pond and lower the nitrogen discharge to Westport Harbor and the West Branch of the Westport River Estuary. Moreover, protecting the health of the pond will protect the health of the river herring population, which in turn serves to support numerous bird, fish and mammal species. A comprehensive study of Cockeast Pond (such as the present Cockeast Pond Assessment {Phase 2}) will provide the necessary information from which to derive management options and plans.

It is recommended that a full sampling schedule (3-4 sampling events) be maintained to support adaptive management of this salt pond in coming years. An ongoing monitoring program allows for the continued tracking the health of Cockeast Pond. In Phase 2 monitoring was continued and used as part of the overall assessment of the system. Phase 2 (below) assessment of the Pond consider all the collected data and particularly watershed delineation/land use info, water and nutrient budgets as well as biological indicators of habitat impairment such as dissolved oxygen and chlorophyll-a (which built on the trophic status analysis above). Based on Phase 1 assessment results (see below), it appears that watershed nitrogen loading and tidal flushing are the primary controls on the water quality and habitat health of this small coastal salt pond.

Results of Hydrodynamic Field Data Collection (Stage + Bathymetry):

Critical to the completion of a detailed assessment of the nutrient and habitat characteristics of Cockeast Pond is having an accurate measure of the volume of water in Cockeast Pond as well as the rate of tidal exchange between the pond and Westport Harbor. This information combined with water quality characteristics of water in the pond allows for the calculation of residence time of that water and the level of nutrients available in the pond for stimulating plant productivity. The MEP Project Technical Team used a complex hydrodynamic model (RMA-2) to understand residence time and volumetric exchange in the Westport River Estuary. These variables were determined by the same approach (RMA2) and using a box model in Phase 2. Since no clear gradients are apparent within the pond waters and given the simple basin structure of the Pond, it was possible to build a box model initially and use it as a base of comparison to the numerical model. Both models provide different levels of sensitivity in relating watershed nitrogen inputs, nutrient concentrations in the pond and volume of tidal exchange to biological indicators of habitat health/impairment. Both models require detailed bathymetry, tide stage records, freshwater inflows (stream, groundwater, atmospheric deposition. Nitrogen water quality models then build on the hydrodynamic models and require additional data on the salinity of inflowing water and of the central basin, quantification of all nitrogen sources, sinks and the regeneration from the bottom sediments.

Bathymetric surveying of Cockeast Pond was completed in November 2015. As described in the scope of work, transect lines were surveyed as depicted in Figure 4. Proposed survey lines are depicted in red whereas actual survey lines are depicted in varying colors related to depth. Some deviation from the proposed survey lines was necessary due to extensive shallows in the near shore areas of the pond (particularly in the southern portion) as well as patches with excessive macroalgal accumulation. Nevertheless, the bathymetry survey was successfully completed and is presented in Figure 5. The volume of Cockeast Pond was determined through a measure of water levels (stage) in the pond as well as depth (bathymetry) throughout the Pond. Based on stage and bathymetry, volume was calculated for each depth interval and summed to determine the total volume of Cockeast Pond (210,046 m^3). More than half the pond volume is represented by area that is in marginal shallows, 0.0 to 0.5 meter depth range.

Cockeast Pond		
Depth (meters)	**Volume (m3)**	**Surface Area (m2)**
0-0.5	149639	185898
0.5-1.0	49968	165885
1.0-1.5	6477	12430
1.5-2.0	3066	5280
2.0-2.5	889	3413
2.5	6.25	267
Total	210046	373173

Table 5. Calculated pond volumes based on depth intervals derived from the bathymetry surveying effort. Bathymetry was corrected for the "tide" as well as atmospheric pressure.

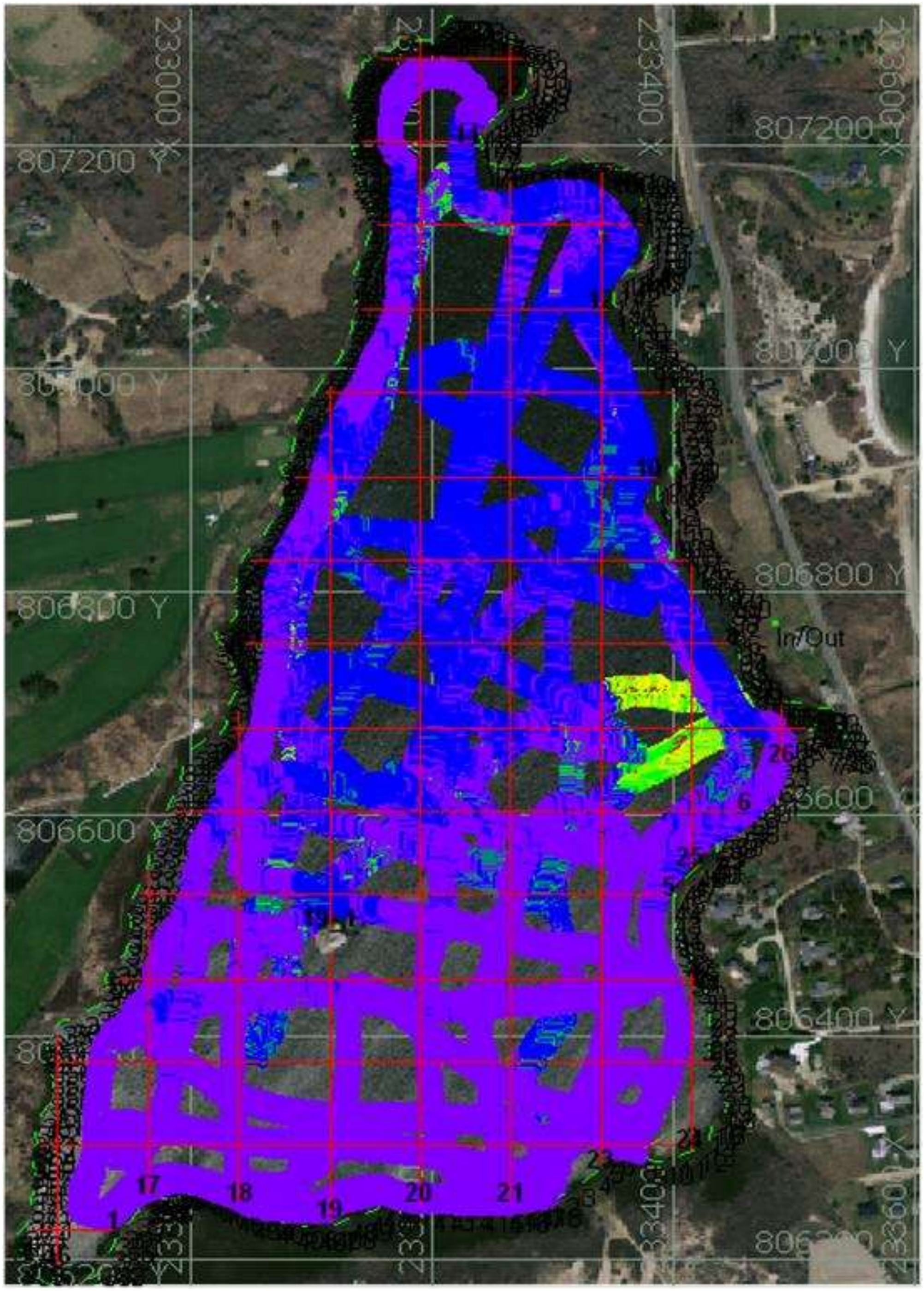

Figure 4. Map of Cockeast Pond showing proposed survey cruise tracks for bathymetry survey (red lines) compared to actual survey cruise tracks (colored). Depth along the survey lines depicted have been tide corrected to a common datum (NAVD88). Planned survey lines at spacing of 75 meters were modified due to depth constraints and field conditions.

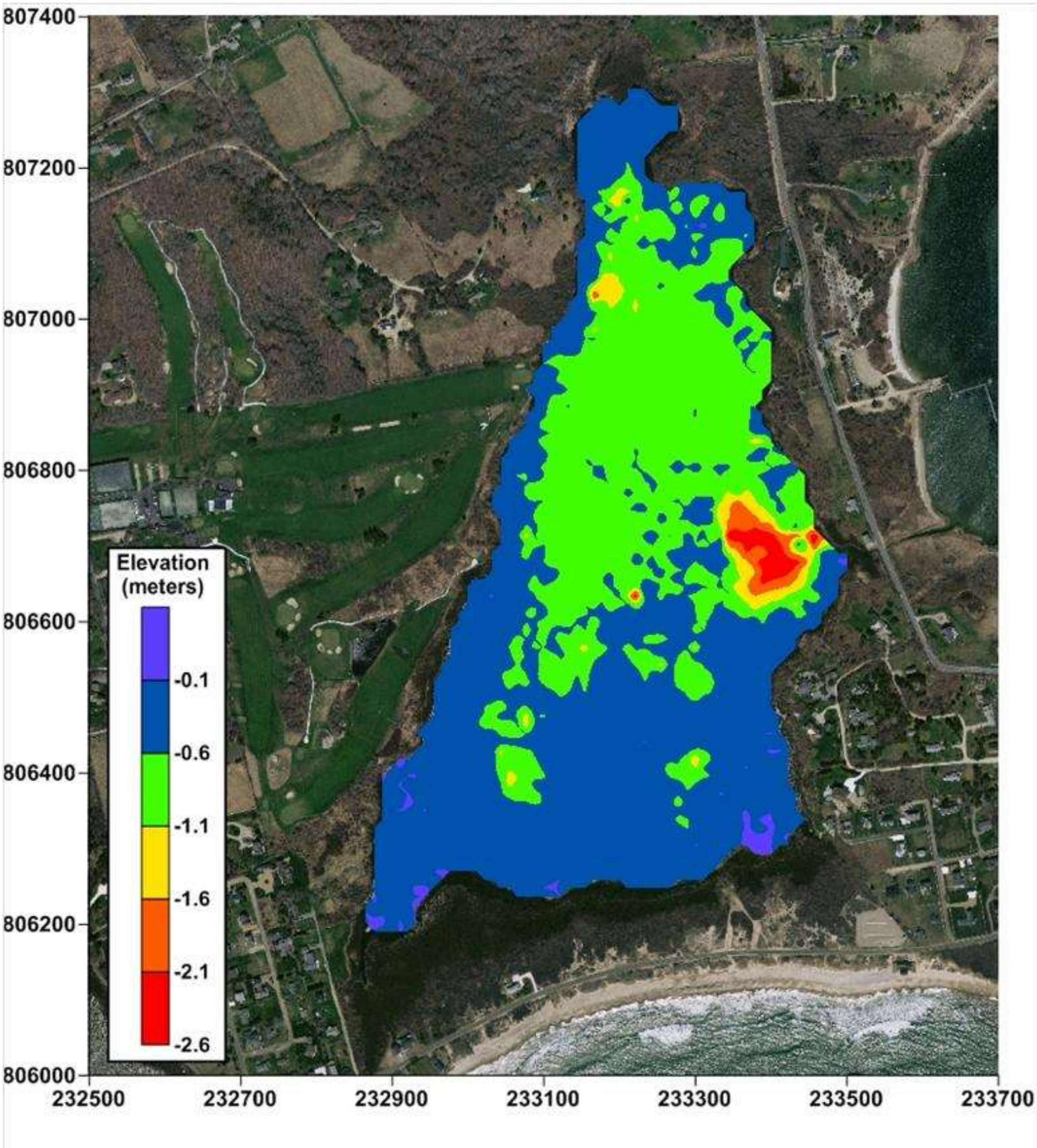

Figure 5. Bathymetric map of Cockeast Pond. Water depth is tide corrected to NAVD88 datum. Note that contours are bottom elevations relative to the NAVD88 datum.

Summer 2015 Tidal Flux Experiments (1-3) June, July, September

Measurements of tidal inflow and outflow through the herring creek connecting Cockeast Pond to Westport Harbor was undertaken to provide direct measurements of tidal volume exchange as well as to estimate residence time of water in the pond given the pond volume calculated from the bathymetry data. The tidal flux experiments were also undertaken to determine the degree to which Cockest Pond is actually influenced by tidal changes in Westport Harbor. A total of 3 tidal nutrient tidal flux samplings (includes determination of freshwater flow and salt water flow) were conducted in the summer 2015 (Table 6). The June tidal flux (1) was conducted on a neap tide whereas the July and September tidal fluxes (2, 3) were completed on a spring tide. In this manner it was possible to observe the degree of tidal exchange under both maximum and minimum tidal forcing conditions (exclusive of storm events).

Table 6. Dates when the tidal flux experiments were conducted along with the times of high and low tide as well as the associated moon phase.

COCKEAST TIDAL FLUX				
Date	**LOW TIDE**	**HIGH TIDE**	**LOW TIDE**	**MOON PHASE**
6/8/2015	6:42am	12:48pm	7:02pm	half moon
7/16/2015	3:04am	8:55am	2:25pm	new moon
9/1/2015	4:04am	10:32am	4:41am	full moon

Each sampling took place over a single complete tidal cycle beginning approximately 1 hour before low tide, continuing through high tide and ending approximately 1 hour after the following low tide. Before each tidal flux, precipitation amounts were checked for at least one complete tidal cycle prior to the first sample to ensure that water and nutrient flux data would not be biased by rain-related flows. Wind conditions (strength and direction) were also noted for potential influence on inflowing/out-flowing water. Water samples were collected at the culvert passing under River Road (Figure 6) at nearly hourly intervals over the course of the tidal cycle. All samples were analyzed for temperature, pH, salinity, Chlorophyll a and total nitrogen, comprised of ammonium, nitrate/nitrite, Dissolved Organic Nitrogen (DON), and Particulate Organic Nitrogen (PON).

Flood and ebb current velocity measurements and channel cross-section water depths were made concurrently with each water sample collection in the inlet channel to determine volumetric flow through the channel (River Road culvert) over complete flood and ebb tides. These flow data were applied to the period between each time point to yield a detailed record of total volumetric flow into (flood) and out of (ebb) Cockeast Pond. Total flow into Cockeast Pond was calculated between slack low tide and slack high tide. Total flow out was calculated from slack high tide to the point at which the tidal height during ebb reached the same level as that recorded at the previous slack low tide, as measured by tide gauges deployed up-gradient (in the pond) and down-gradient (in Westport Harbor). Flows were then combined with sample nutrient concentrations to calculate the mass flux of a specific constituent into or out of the pond via the herring creek.

Figure 6. Location of the transect along which velocity measurements and water sampling was conducted for calculation of flow and mass influx/efflux of nutrients in/out of Cockeast Pond.

Results of Tidal Flux Experiment 1 - June 8, 2015

Tidal flux experiment 1 was completed on approximately a neap tide (half moon) in that the day of the tidal flux was June 8 and the true neap tide occurred on June 9. Tidal stage in the pond and in the harbor was measured simultaneously (Figures 7 and 8) to determine the degree to which the pond is tidally influenced (magnitude of stage increase) and how that corresponds to volumetric flow and nitrogen load in (flood) and out (ebb) of the pond. Simultaneous measurements of stage were also made in combination with observations of wind strength and direction to gauge the degree to which stage changes in Cockeast Pond are affected by wind conditions as opposed to tidal strength (spring vs. neap).

Interestingly, during tidal flux 1, while the tidal signal is very clear in the record from the gage deployed in Westport Harbor, little to no change in tidal stage was observed in Cockeast Pond. In fact water levels in Cockeast Pond showed a gradual decline over the two day window during which tidal flux 1 was completed (Figure 8). This is consistent with flow measurements made during the tidal flux where the "flood" phase of the experiment was approximately 1 hour in duration (not including the time when the tide appeared slack) followed by approximately a 9-10 hour ebb during which water was leaving Cockeast Pond. This would indicate that during a neap tide, only a small volume of "clean" low nitrogen water enters Cockeast Pond from Westport Harbor during a short interval at peak high tide. Further, taking into consideration wind direction and strength during the tidal flux (10-15 mph from the ssw during the flood, 15-20 mph ssw during the ebb, Figure 9) suggests that under neap tide conditions, water levels in Cockeast Pond are effected by wind forcing and that tidal forcing is low. A strong wind out of the south-southwest effectively impedes water trying to push into the pond from the harbor during the flooding tide while amplifying the amount of water leaving the pond during the ebb portion of the tidal cycle.

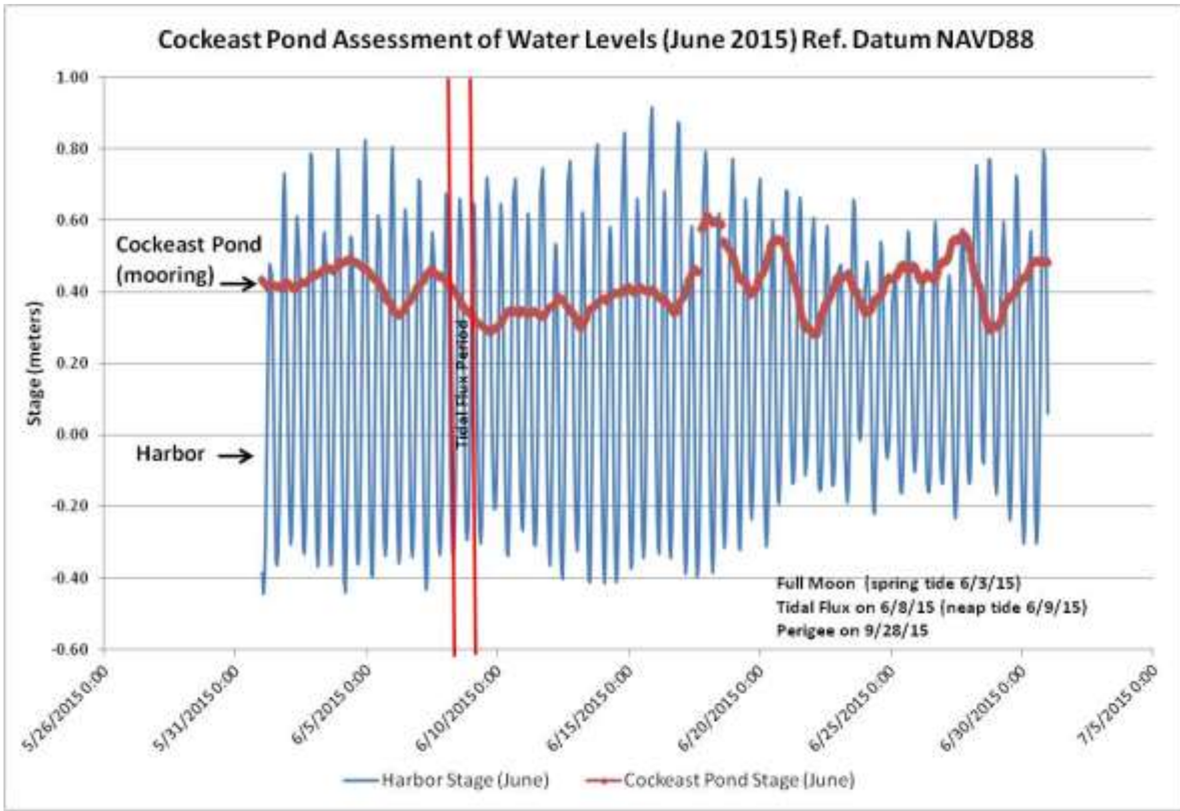

Figure 7. Record of tidal stage in Cockeast Pond (red) and Westport Harbor (blue) during the month of June 2015. Spring tide occurred on 6/3/15 and 6/16/15. Neap tide was on 6/9/15.

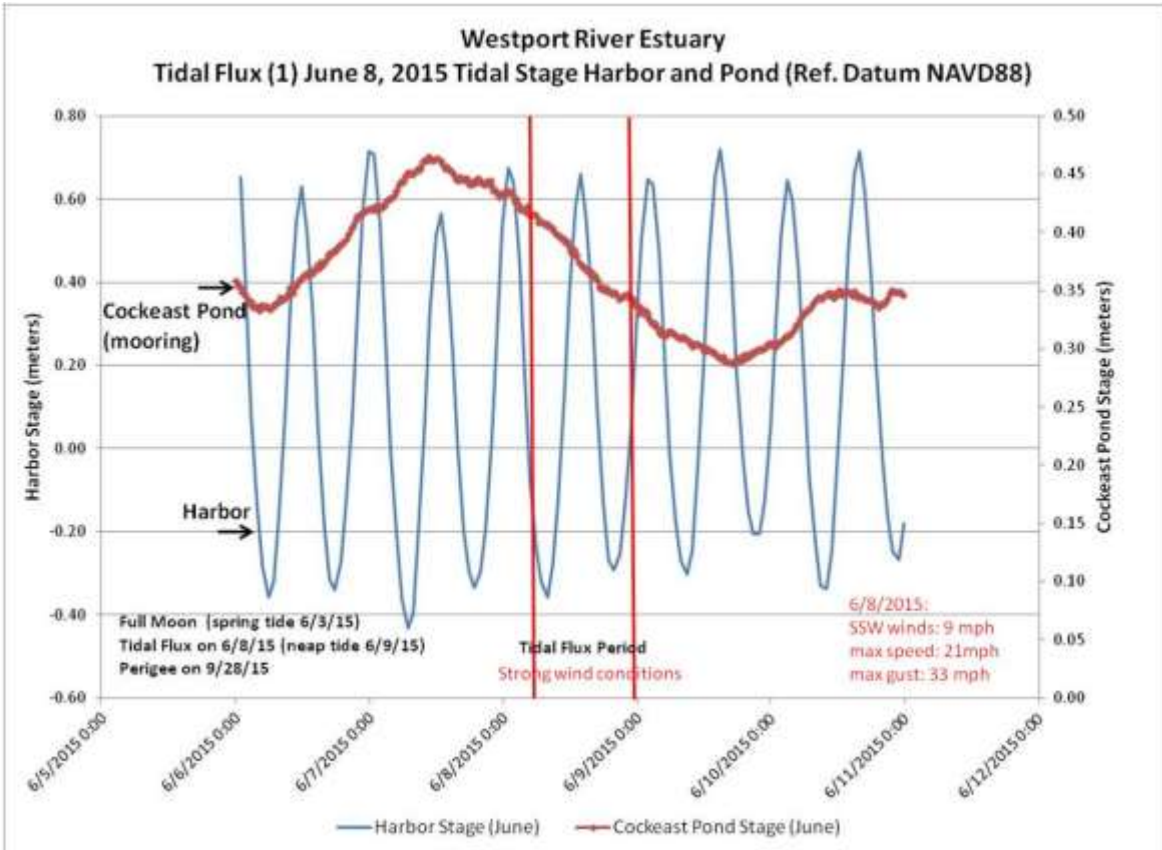

Figure 8. Tidal stage in Cockeast Pond (red line) and Westport Harbor (blue line) prior to and after completion of tidal flux 1. Of note is the steady decline of water level in Cockeast Pond over the two day period during which tidal flux was measured. Approximately a 0.18m drop in the pond over two days versus 1.0+ meter change in water levels in the harbor every tidal cycle.

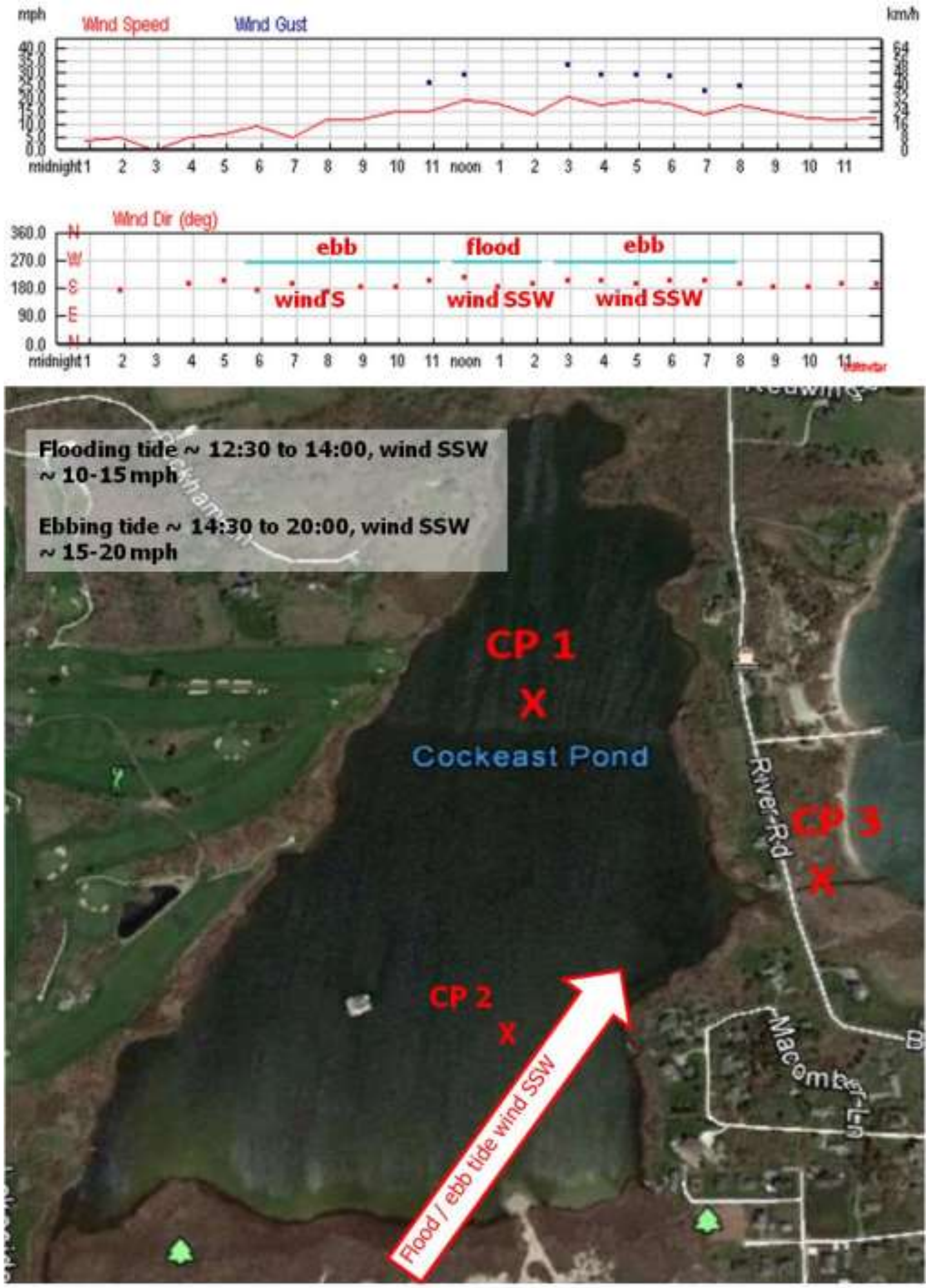

Figure 9. Wind direction and strength during the June 8, 2015 tidal flux. Wind from the SSW appears to push water out of Cockeast Pond making the ebb tide dominant.

Flow measurements and water quality samples taken at near hourly intervals during the tidal flux studies correspond to the short flood and long ebb phases observed in the tidal stage record (Figures 10). Under neap tide conditions with a moderate SSW wind more water tends to leave Cockeast Pond then enters on the flood tide leading to the gradual drop in water levels observed in the pond (Figure 8). These findings were used to refine the hydrodynamic models in Phase 2.

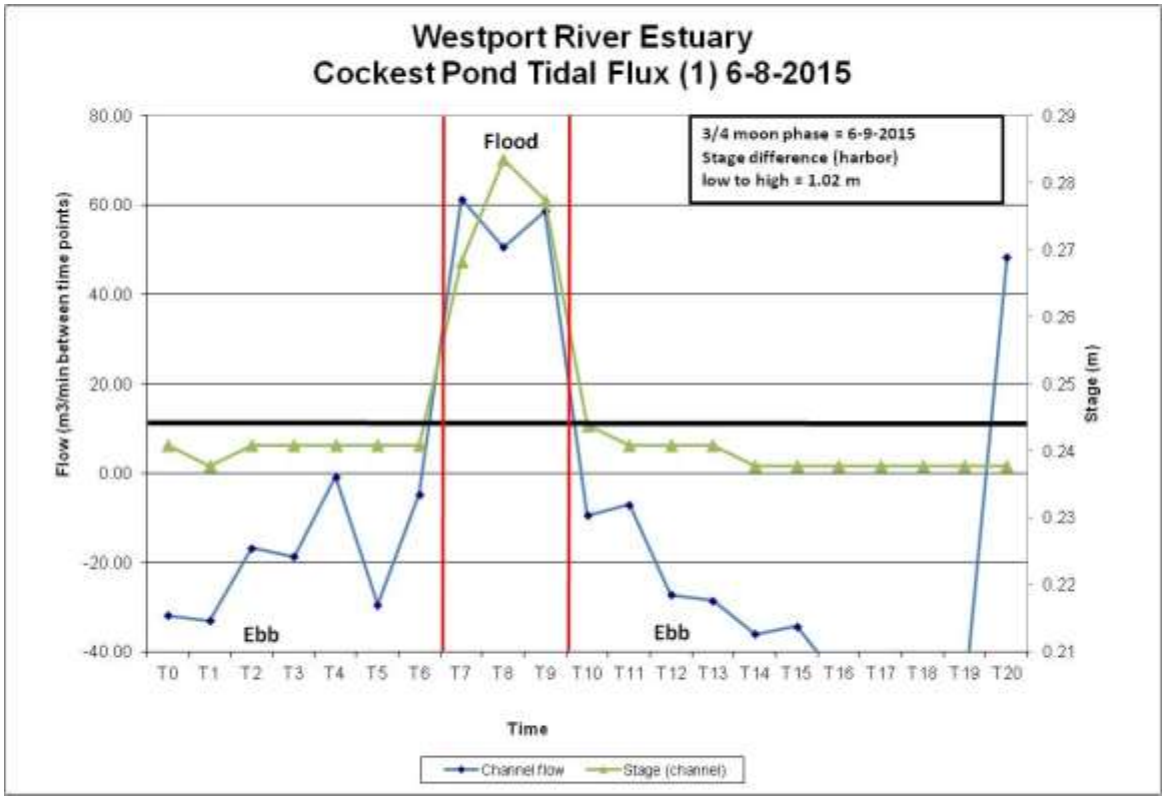

Figure 10. Plot of flood and ebb tide flows under neap tide conditions compared to measured stage in the channel leading into Cockeast Pond.

The influx of high quality water from Westport Harbor during the short flood tide is seen in the chlorophyll-a (CHLA) and total nitrogen (TN) concentrations of samples collected during the flood tide (Figures 11 and 12). The proximity of the inlet to Buzzards Bay provides the high quality water from Buzzards Bay to enter the pond near the peak flood period. As salinity increases (representative of the water flowing into Cockeast Pond from the Westport Harbor), there is a clear decrease in both the CHLA and TN concentrations. Conversely, as salinity drops during the ebb tide (representative of water leaving Cockeast Pond) both CHLA and TN concentrations increase significantly representative of the impaired water quality in Cockeast Pond. The completion of flow and water quality measurements during a complete tidal cycle (flood through ebb) further confirmed that Cockeast Pond generally acts as an exporter of lower quality, high nutrient (flood TN load = 0.112 kg, ebb TN load=0.461 kg) water to the Westport River estuary (Table 7). Given the short flood tide and the much longer ebb tide, freshwater entering the pond from the watershed via groundwater as well as the small surfacewater flow entering on the northern shore results in a greater volume of water leaving the pond with associated higher nutrient load when compared to the what enters the system on the flood tide. To the extent the duration of the flood tide into Cockeast Pond can be extended allowing more low nutrient, low CHLA water from the Westport Harbor to flood into Cockeast Pond and nutrient load entering the Cockeast Pond system from the watershed can be reduced, the greater the chance of improvement in overall water quality of the pond as well as the discharge to the Westport River.

Table 7. Summary of flow and nutrient fluxes during tidal flux experiment 1. Flood is represented by (+) values and ebb is represented by (-) values.

Mass Flux	Flow (m3)	Salt (kg)	PO4 (kg)	TP (kg)	NH4 (kg)	NOx (kg)	DON (kg)	TN (kg)	POC (kg)	PON (kg)
Flood (+)	170.5	4907.2	0.002	0.000	0.002	0.000	0.073	0.112	0.239	0.036
Ebb (-)	-341.4	-2988.7	-0.001	0.000	-0.002	-0.001	-0.302	-0.461	-0.971	-0.157
Ebb Salt Corr	-560.6	-4907.2	-0.002	0.000	-0.003	-0.001	-0.496	-0.757	-1.595	-0.257
Net Flux	-390.1	0.03	0.000	0.000	-0.001	0.000	-0.422	-0.644	-1.356	-0.221

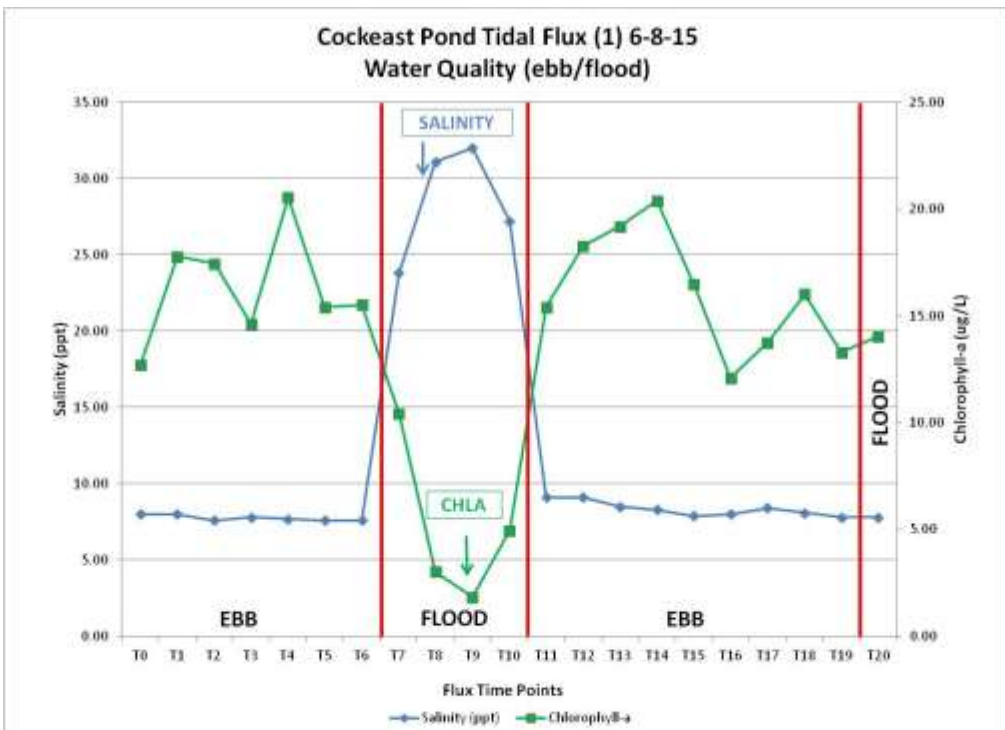

Figure 11. Plot of flood and ebb tide Chlorophyll-a and salinity concentrations under neap tide conditions.

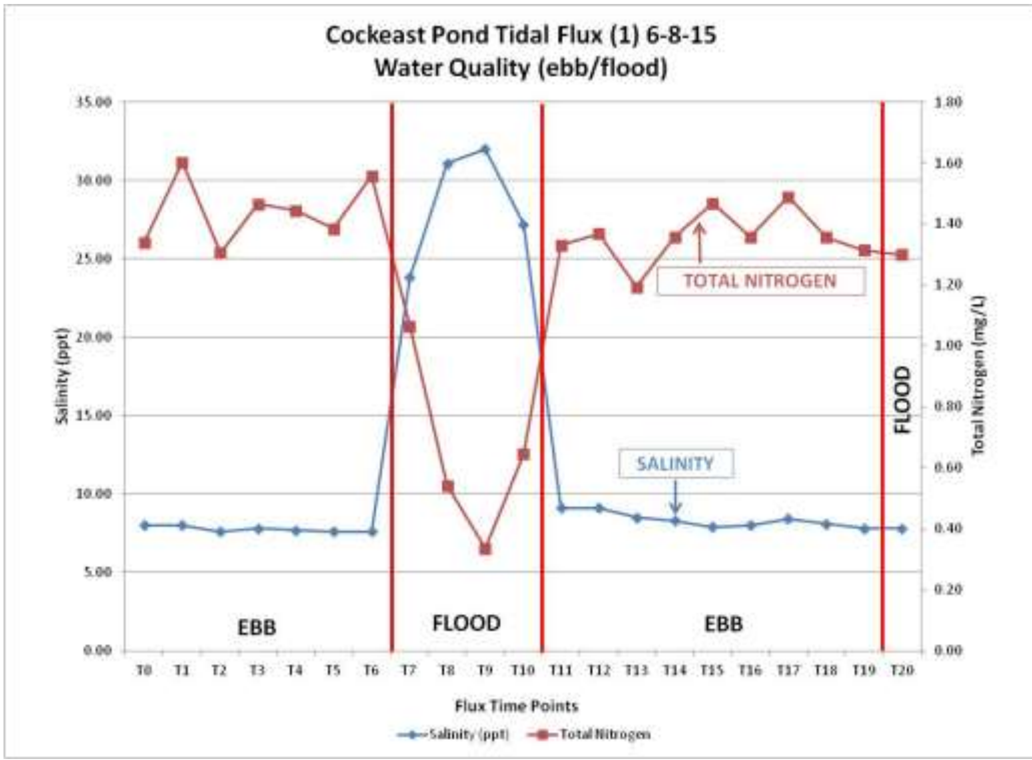

Figure 12. Plot of flood and ebb tide total nitrogen (TN) and salinity concentrations under neap tide conditions.

Results of Tidal Flux Experiment 2 - July 16, 2015

Unlike tidal flux experiment 1, tidal flux experiment 2 was completed on a spring tide (full moon) as the July 16 tidal flux study was the day after the maximum spring tide (July 15). As in tidal flux 1, tidal stage in the pond and in the harbor was measured simultaneously (Figures 13 and 14) to determine the degree to which the pond is tidally influenced (pond tide range) and how that corresponds to volumetric flow and nitrogen load in (flood) and out (ebb) of the pond. The second flux study (#2) was during the full moon when exchange should be at its greatest within the lunar cycle. Simultaneous measurements of stage were also made in combination with observations of wind strength and direction to gauge the degree to which volumetric exchange with Westport Harbor is driven by wind conditions as opposed to tidal gradients under spring vs. neap tidal conditions.

Unlike tidal flux 1, during tidal flux 2, the tidal signal is very clear in the record from the gage deployed in Westport Harbor and there is a clear and gradual increase in tidal stage observed in Cockeast Pond. The increase occurs over approximately a two day period of maximum spring tides, during which the flux study was conducted. Interestingly, a slight tidal signal in the Cockeast Pond water level record and the stage increase was steady during the flood phase of the tides which flattens out during the ebb phase of the tide and then resumes increasing during the subsequent flood phase (Figure 14). As in tidal flux 1, flow measurements indicate that the flood phase when water is entering the pond is much shorter than the ebb phase when water is trying to leave the pond, however, the flow rate is significantly greater. This disparity between flooding and ebbing tides is directly related to the elevation of the culvert within the inlet channel. It is placed such that only the highest portion of flooding tides is higher than the culvert level and can pass water into the pond. Whereas, shortly after high slack tide, the level in the inlet channel drops below the culvert bottom resulting in a long ebb tide. Similarly, during the lunar cycle, spring tides support more "clean" low nitrogen tidal water entering from Westport Harbor on a given tidal cycle (low-high-low) compared to a neap tide. Furthermore, it also appears that other than for spring tides, there are few periods where low nutrient water from Westport Harbor can make it into the pond and this is confounded by wind conditions (strength and direction). Taking into consideration wind direction and strength during tidal flux 2 (10-15 mph from the NNE during both the flood and the ebb) suggests that even during spring tide conditions, wind can play an important role in the amount of water exchanged through the culvert. A strong wind out of the north-northeast amplifies water trying to push into the pond from the Harbor during the flood tide while damping the amount of water leaving the pond during the ebb portion of the tidal cycle (Figure 14 and 15).

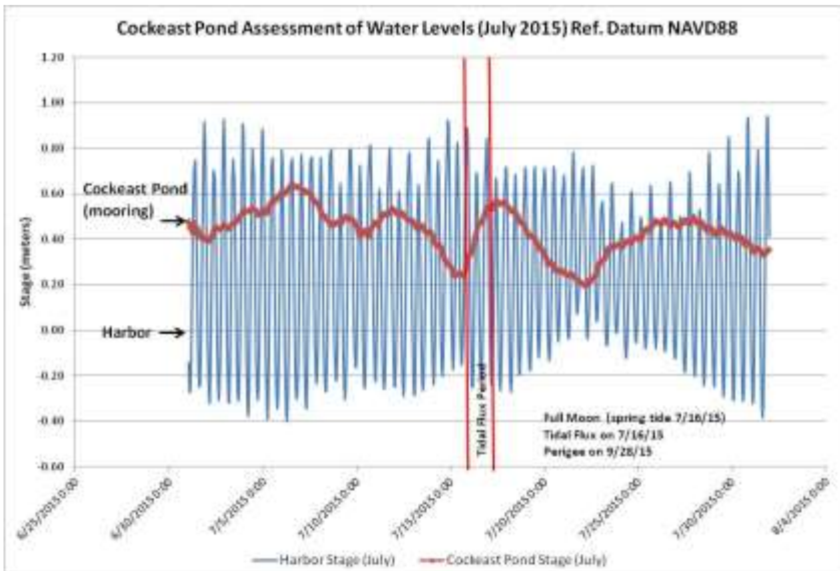

Figure 13. Record of tidal stage in Cockeast Pond (red) and Westport Harbor (blue) during the month of July 2015. Spring tide occurred on 7/16/15 during the tidal flux to capture max flushing. The highly restricted nature of the tidal inlet can be seen in the large difference in tide range within the pond versus within Westport Harbor.

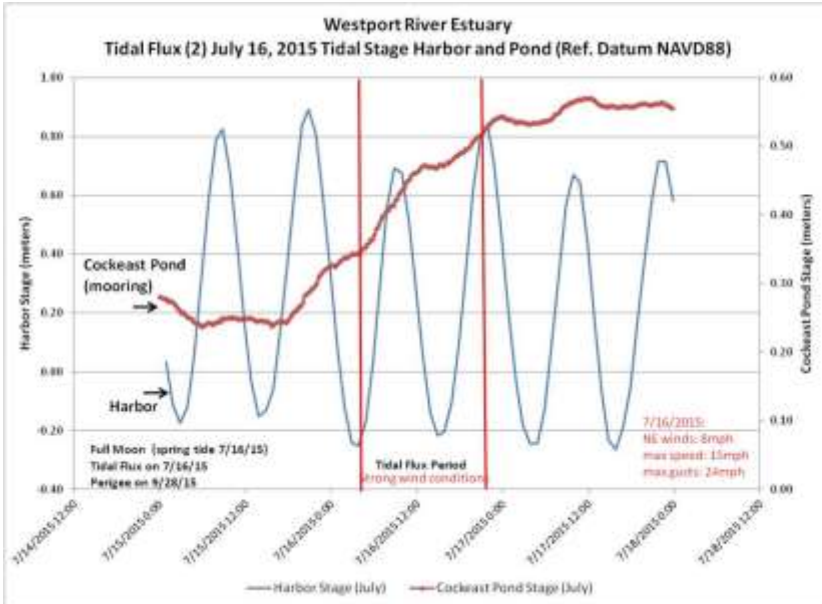

Figure 14. Tidal stage in Cockeast Pond (red line) and Westport Harbor (blue line) prior to and after completion of tidal flux 2. Of note is the steady increase of water level in Cockeast Pond over the two day period during which tidal flux was measured. Approximately a 0.3 m rise in the pond over two days versus 1.0 meter change in water levels in the harbor every tidal cycle. Corresponds to the prevailing NE wind helping to push water into the pond from Westport Harbor during the flood tide.

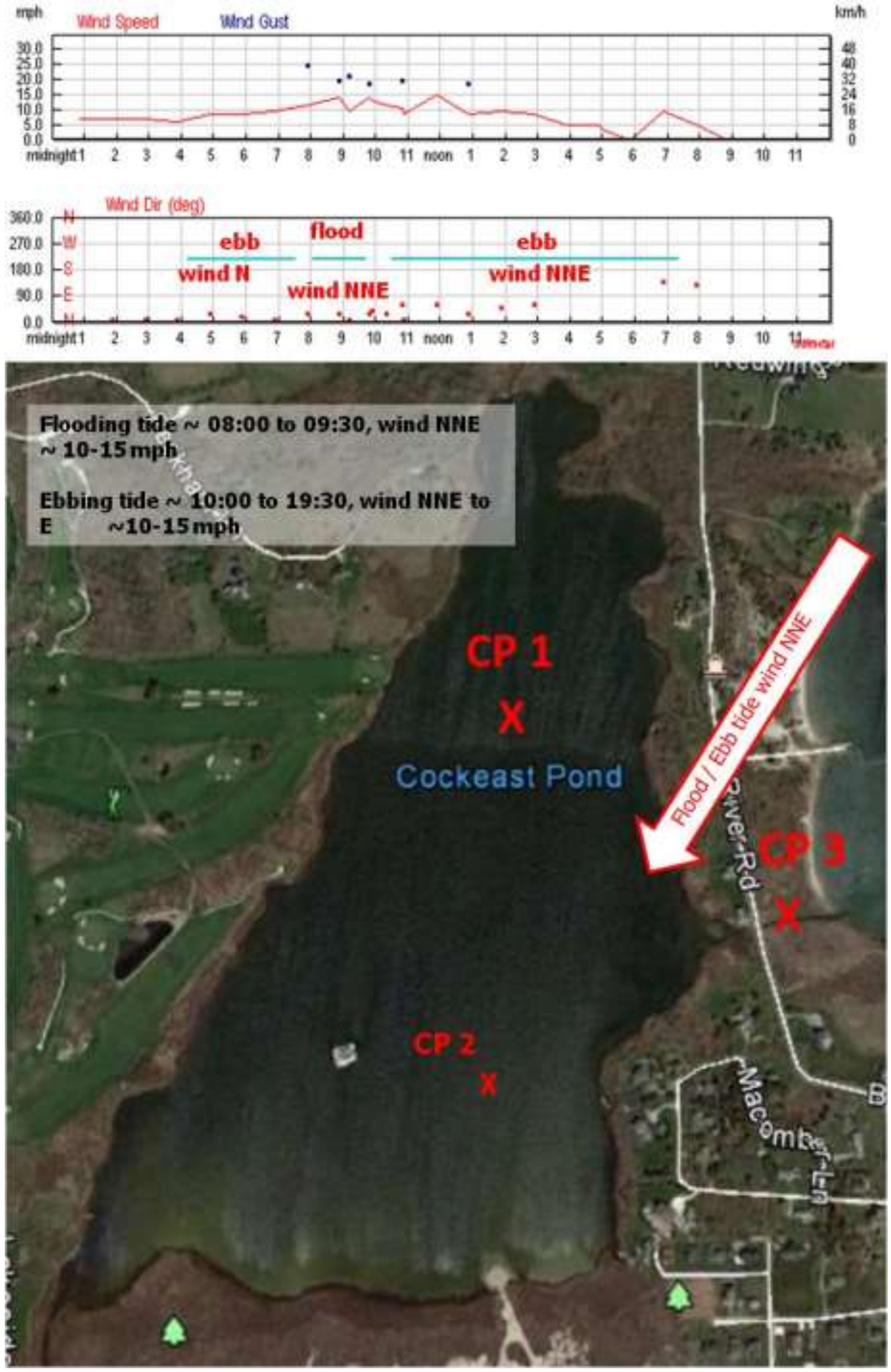

Figure 15. Wind direction and strength during the July 16, 2015 tidal flux (2). Wind from the NE during both the flood and ebb tide appears to push water into Cockeast Pond making the flood tide dominant. Water level increase in Cockeast Pond diminishes during ebb tide as water tries to exit pond but it opposed by the NE wind.

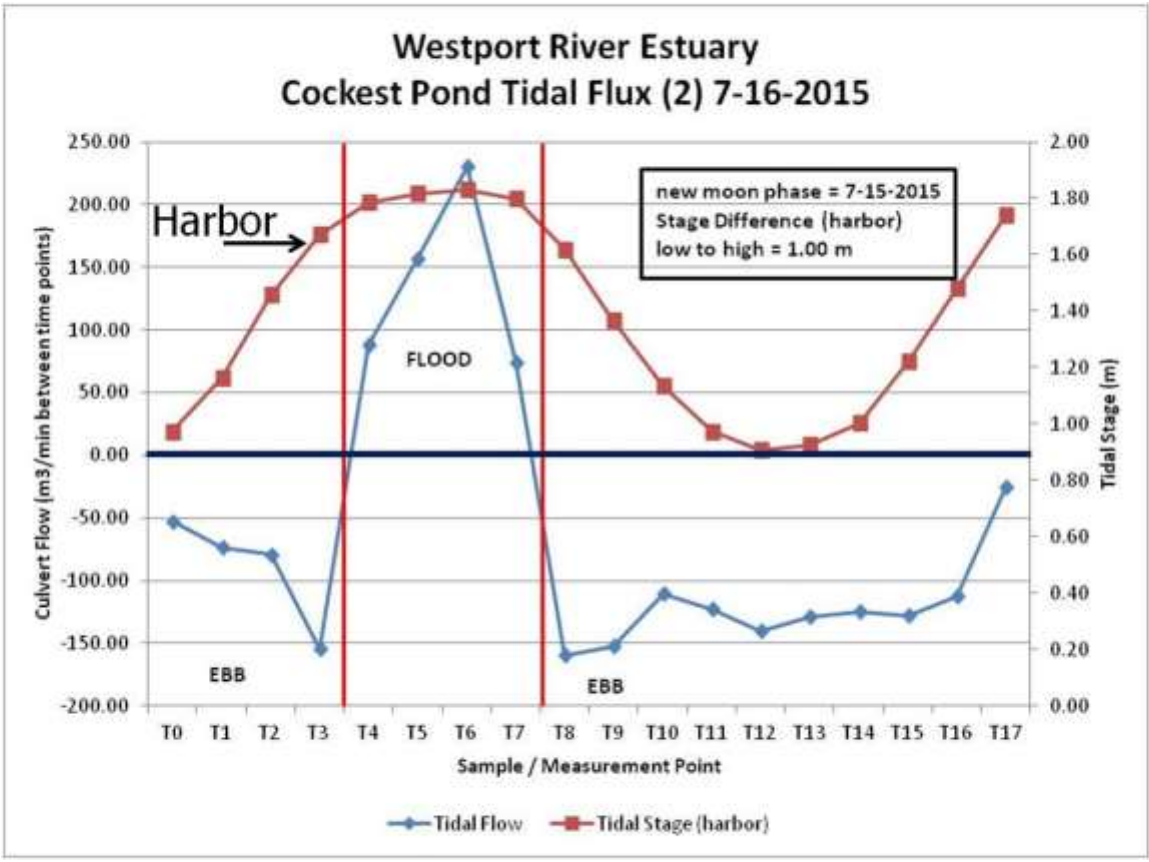

Figure 16. Plot of flood and ebb tide flows under spring tide conditions compared to measured stage in Westport Harbor. It is clear that the ebb flows greater than the flood flow, and that only when water levels in the Harbor approach 1.8 m, is water able to enter the pond.

As was observed during tidal flux 1, the influx of higher quality water entering the pond from Westport Harbor during the short flood tide is seen clearly where significantly lower concentration water is flooding versus ebbing for chlorophyll-a (CHLA) and total nitrogen (TN) (Figures 17 and 18). As salinity increases when water flows into Cockeast Pond from Westport Harbor, there is a clear decrease in both the chlorophyll a and total nitrogen concentrations with the opposite being seen in the ebbing water. Both chlorophyll a and total nitrogen concentrations increase significantly as the poor quality waters of Cockeast Pond are discharged to the Harbor on the ebbing tide. The completion of flow and water quality measurements during a complete tidal cycle (flood through ebb) further confirmed that Cockeast Pond generally acts as a net exporter of lower quality, high nutrient (flood TN load = 0.364 kg N, ebb TN load=1.61 kg N) water to the Westport River Estuary (Table 8). Similar to tidal flux experiment 1 described above, given the short flood tide and the much longer ebb tide, freshwater entering the pond from the watershed via groundwater as well as the small surfacewater inflow entering on the northern shore results in a greater volume of nitrogen rich water leaving the pond compared to what enters on the flood tide. Additionally and as would be expected, the magnitude of the exchange under spring tides is greater than during neap tides as observed during tidal flux experiment 1. To the extent the duration of the flood tide into Cockeast Pond can be extended allowing more low nutrient, low CHLA water from the Westport Harbor to flood into Cockeast Pond, the higher the overall water and habitat quality of the pond.

Table 8. Summary of flow and nutrient fluxes during tidal flux experiment 2. Flood is represented by (+) values and ebb is represented by (-) values.

FLOW (m3)	Salt (kg)	PO4 (kg)	NH4 (kg)	Nox (kg)	DON (kg)	POC (kg)	PON (kg)	TN (kg)
548.9	13895.2	0.004	0.004	0.001	0.259	0.772	0.101	0.364
-1205.8	-12671.6	-0.001	-0.018	-0.006	-1.071	-4.654	-0.514	-1.609
-656.9	1223.6	0.004	-0.014	-0.006	-0.812	-3.882	-0.413	-1.245

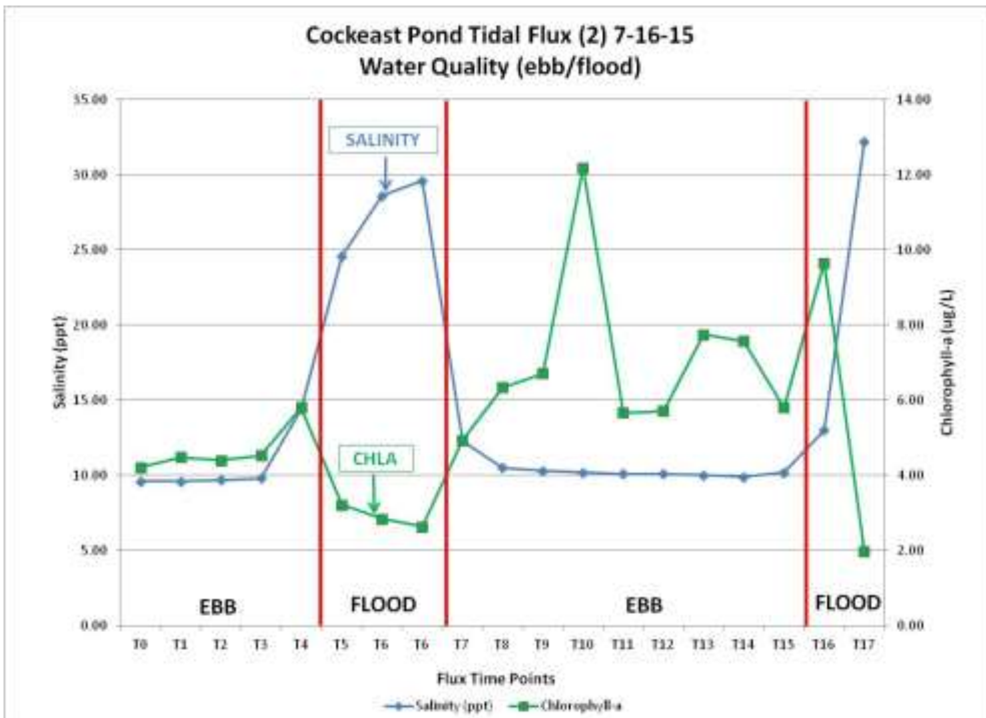

Figure 17. Time-series of chlorophyll-a and salinity concentrations through flood and ebb tides under spring tide conditions on July 16, 2015 within the Cockeast Pond inlet.

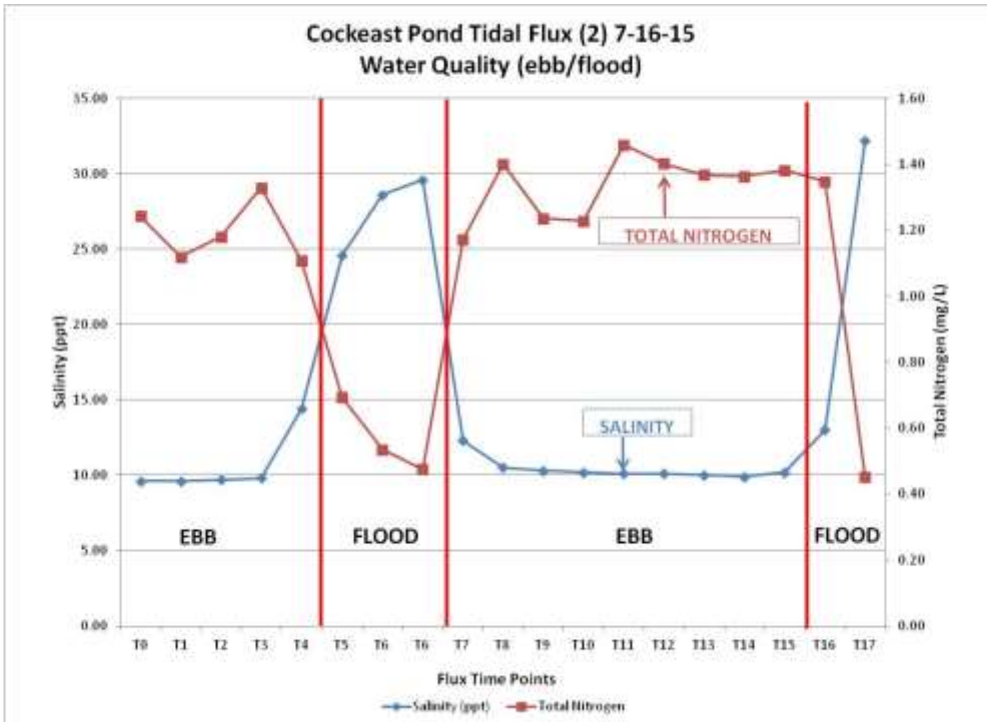

Figure 18. Time-series of total nitrogen (TN) concentrations through flood and ebb tides under spring tide conditions on July 16, 2015 within the Cockeast Pond inlet.

Results of Tidal Flux Experiment 3 - September 1, 2015

Similar to tidal flux study 2, tidal flux 3 was also completed on a spring tide (full moon), the peak spring tides occurred 2 days prior to the flux study of September 1, 2015. As in tidal fluxes 1 and 2, tidal stage in the pond and in the harbor were measured simultaneously (Figures 19 and 20) to determine the degree to which the harbor tides influence pond levels (magnitude of tide range) as related to volumetric exchange and nitrogen loads entering (flood) and leaving (ebb) the pond. Similar to flux study 2, flux 3 was conducted very near to full moon conditions when exchange should be at its greatest. It is important to also note that this specific spring tide was additionally amplified by the fact that the full moon coincided with lunar perigee (when the moon is closest to the earth during its monthly orbit). As such the tidal range in Westport Harbor would be at its greatest (excluding during storm surges). Simultaneous measurements of tide stage were combined with observations of wind strength and direction to gauge the degree to which water levels in Cockeast Pond are affected by wind conditions as opposed to tidal forcing (spring vs. neap).

During tidal flux study 3, the tidal signal in the pond is clear in the record when superimposed on the tidal stage record in Westport Harbor, more so than in the two prior flux studies. Similar to tidal flux 2, there is a clear increase in tidal stage observed in Cockeast Pond during the flood tide with an associated decrease during the ebb tide. This occurs during an overall increase in pond water level (Figure 20) that is likely associated with the wind speed and direction during the measurement period. Interestingly, the tidal signal in the Cockeast Pond stage stands out as a steady increase during the flood phase of the tide, dips during the ebb phase of the tide and then resumes increasing during the subsequent flood phase (Figure 20).

As in tidal flux 2, flow measurements indicate that the period of flood water entry to the pond during flood tide is of much shorter duration than the duration of outflow, although the flow rate is significantly greater on the flood. This would indicate that during a spring tide, more "clean" low nitrogen water enters Cockeast Pond from Westport Harbor on a given tidal cycle (low-high-low) compared to a neap tide. Furthermore, it would appear that water levels in the Harbor are high enough to enter the culvert and pond only during a short period around high tide. Therefore, other than for spring tides, little low nutrient water from Westport Harbor reaches the pond and this can be confounded by wind conditions (strength and direction). Taking into consideration wind direction and strength during tidal flux 3 (~5 mph from the NNE during the flood and ~10 mph from the SSW during the ebb) suggests that even during spring tide conditions, water levels in Cockeast Pond are influenced to a degree by wind forcing. However, during tidal flux 3 it appears that tidal forcing was the primary driver of exchange between the pond and harbor particularly since measurements were conducted during "king tide" conditions (spring tide close to lunar perigee). A wind out of the north-northeast amplifies water trying to push into the pond from the harbor during the flood tide. When the wind shifted direction to the SSW during the ebb tide, the outflow of water was also enhanced translating to a more obvious lowering of water level in Cockeast Pond (Figure 20 and 21). Even so, the light wind conditions were not sufficient to drive more water out of the pond on the ebb compared to the volume that was pushed in on the flood due to the strength of the king tide.

It should be noted that even while a clear tidal signal was measured in Cockeast Pond during tidal flux 3, the overall change in water level in the pond was merely 0.10 meters, small compared to the ~1.4 meter change in water level as measured by the "offshore" gauge deployed in Westport Harbor. Over the three tidal fluxes, the change in pond water level ranged from 0.10 m to 0.30 m. This is important as it indicates low exchange of water between the harbor and the pond, a critical finding in assessing alternatives for improving water quality in Cockeast Pond.

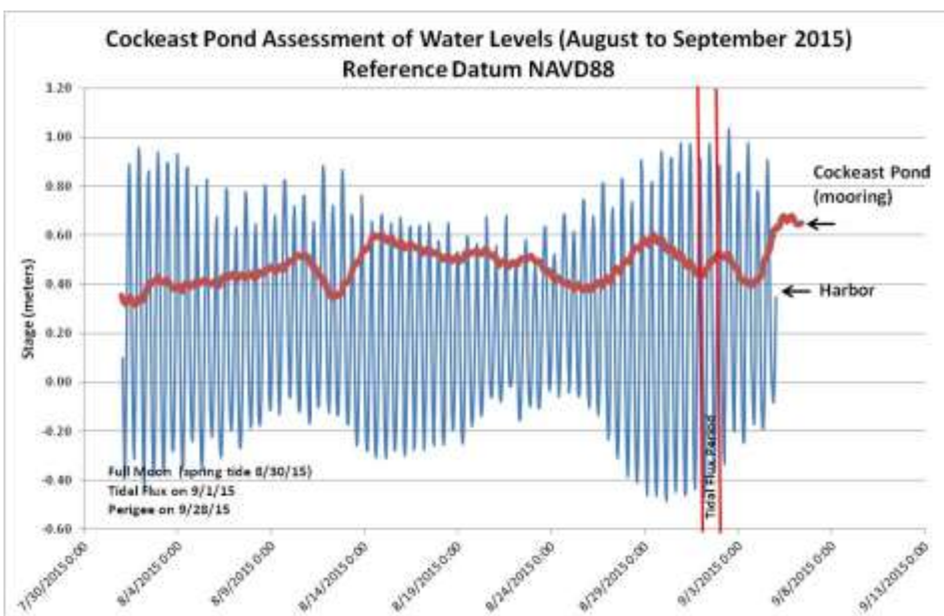

Figure 19. Record of tidal stage in Cockeast Pond (red) and Westport Harbor (blue) during the month of August-September 2015. Spring tide occurred on 8/29/15, 2 days before the tidal flux to capture maximum flushing.

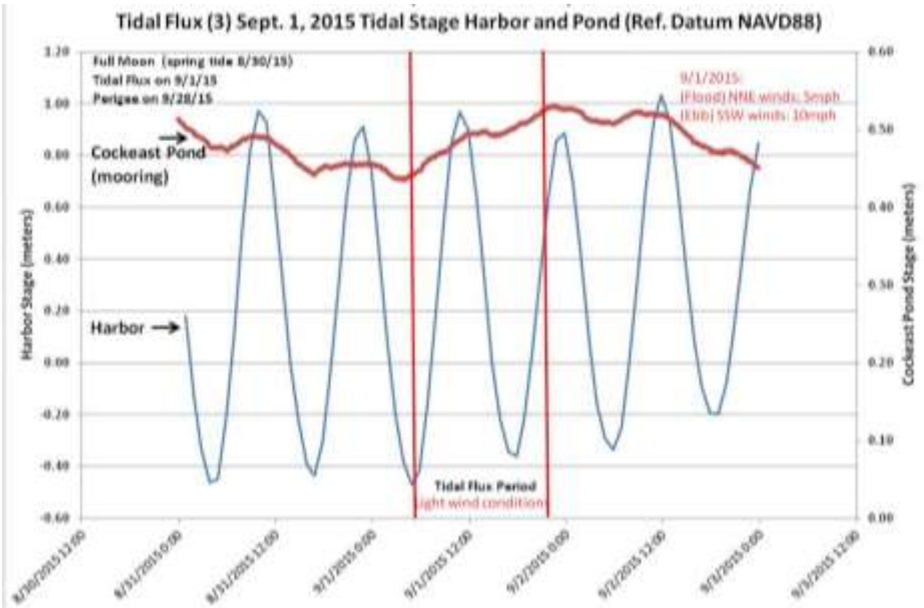

Figure 20. Tidal stage in Cockeast Pond (red line) and Westport Harbor (blue line) during the 3 days centered on tidal flux 3. Of note is the steady increase of water level in Cockeast Pond over the one day period during which tidal flux was measured. Approximately a 0.1 m rise in the pond over one day versus ~1.5 meter change in water levels in the harbor every tidal cycle. During the study period the prevailing NE wind helped to push water into the pond during the flood tide and the SW wind during the ebb aided outflow. Also moon at perigee 8/30/15 and 9/28/15 corresponding to spring tide.

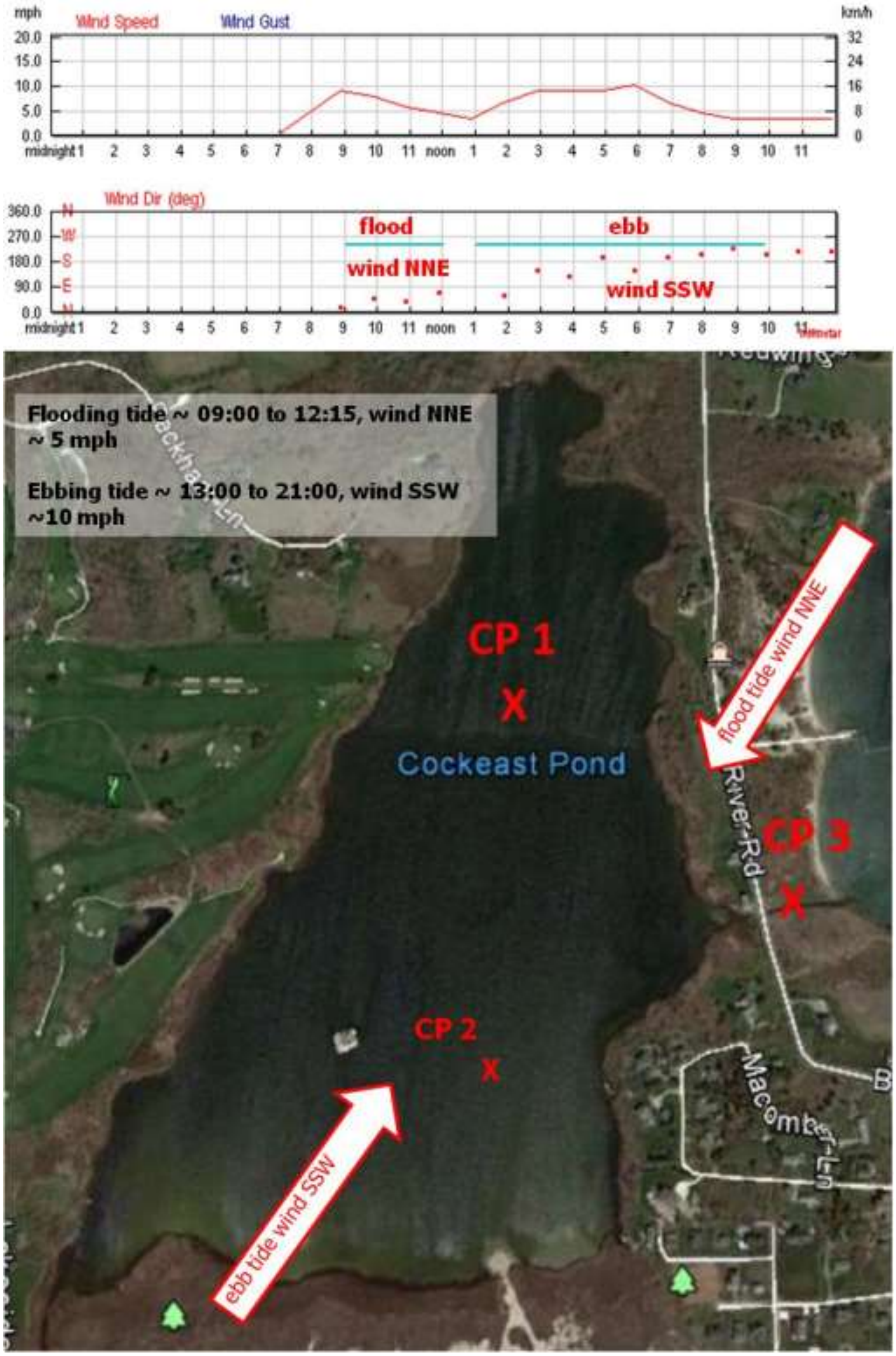

Figure 21. Wind direction and strength during the September 1, 2015 tidal flux 3. Wind from the NE during the flood increased water inflow to Cockeast Pond while wind from the SW during the ebb tide pushes water out of the pond. Strength of the spring tide is maximized due to moon being at perigee (8/30/15) and full moon one day before (8/29/15).

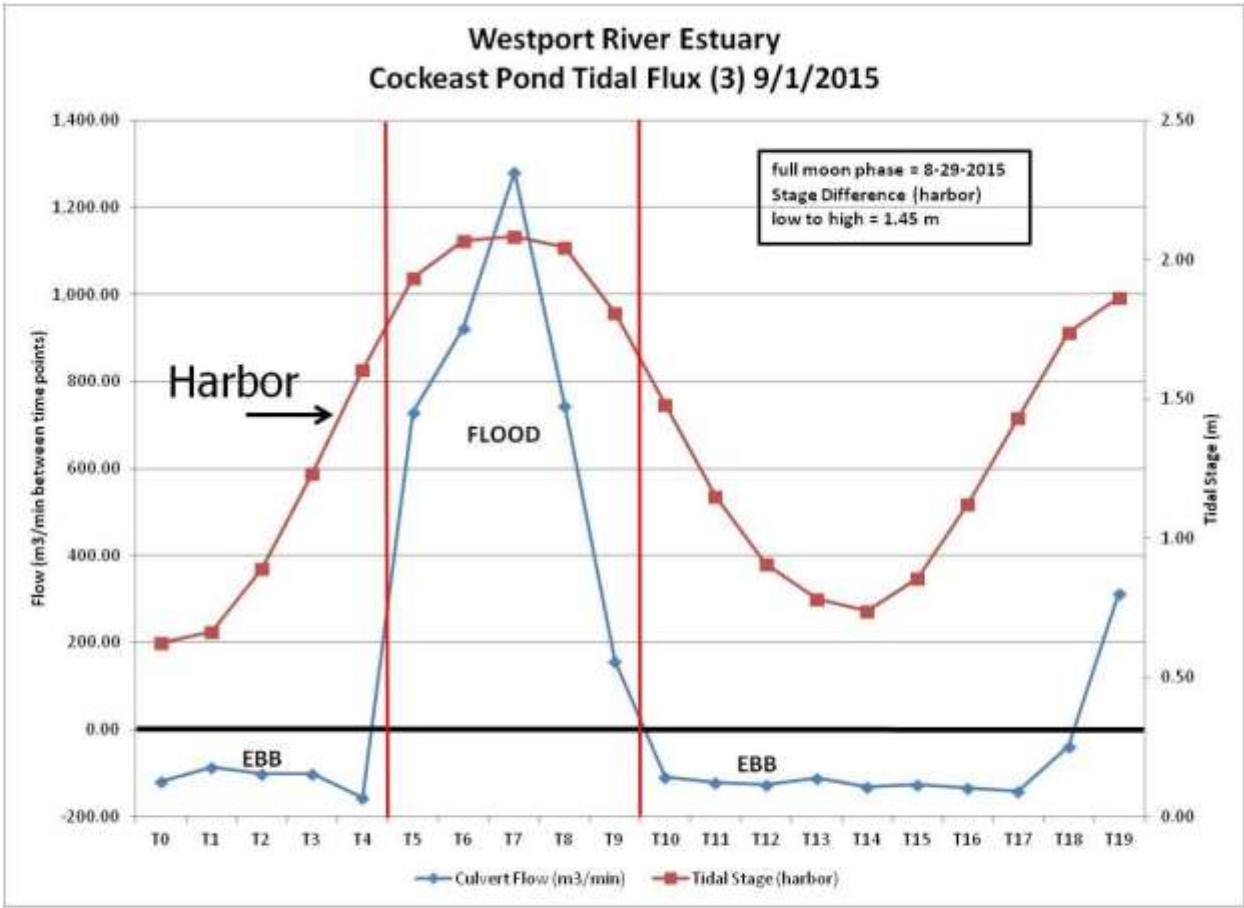

Figure 22. Flux study 3 time-series of volumetric flow at the Cockeast Pond inlet and stage in Westport Harbor over flood and ebb tide under spring tide and lunar perigee conditions.

As was observed during tidal flux 2, the influx of higher quality water from Westport Harbor during the short flood tide is seen in the significantly lower chlorophyll-a (CHLA) and total nitrogen (TN) concentrations during the flood versus ebb tide (Figures 23 and 24). The difference in chlorophyll and TN associated with Westport Harbor water is clearly seen in its association with the salinity increase in flooding water from the high salinity Harbor. Conversely, as the salinity of outflowing water drops during the ebb tide, both CHLA and TN concentrations increase reflecting the lower salinity nitrogen enriched waters of Cockeast Pond. Unlike tidal flux experiments 1 and 2 described above, the completion of flow and water quality measurements during a complete tidal cycle (flood through ebb) for tidal flux experiment 3 showed that Cockeast Pond was an importer of high quality water and in the case of total nitrogen the pond was in balance over the tidal cycle (flood TN load = 1.28 kg, ebb TN load=1.24 kg), but this results more so from the exceptional flow conditions; high volume of flood water compared to volume of ebbing water (flood volume=3,834 m^3, ebb volume=1,040 m^3, Table 9a) than a difference in pond conditions. While this pattern (flood volume > ebb volume) is reversed compared to the two previous tidal flux experiments (ebb volume>flood volume), a few environmental factors are worth considering when interpreting these results. The first significant consideration is the strength of the flood tide currents observed during this flux event. Field notes indicated that tidal stage and measured tidal current in the inlet channel (herring run) connecting Westport Harbor to Cockeast Pond were highest measured of the three tidal fluxes. This is completely reasonable in that tidal flux 3 was completed on a spring tide (as was tidal flux 2) however, the annual cycle of the moon (perigee vs. apogee) was much closer to perigee (when the moon is closest to earth in its orbit) than the earlier tidal fluxes (1 and 2). Tidal flux 3 was completed on September 2, 2015 approximately 25 days from the highest and lowest tides of the year (e.g. king tides). As such the spring tide measured in September would be measurably greater than the spring tide in July thus driving more water into Cockeast Pond on the flood portion of the tidal cycle. Wind conditions during tidal flux 3 were light therefore wind was a minor factor compared to the previous tidal flux experiments. The second significant consideration is that tidal flux 3 took place during the period of lowest freshwater inflow to the Pond. As such, freshwater flow into the pond from direct groundwater discharge or from the small stream discharging to the northern shore of the pond would be smaller than at any other time of the year resulting in lower volume for ebb flows. Putting these two points together, one would expect a large flood tide volume and reduced ebb tide volume compared to average conditions. This is also consistent with the salinity data that indicates that ebb tide pond salinity was higher during tidal flux 3 compared to tidal flux 1 and 2. It is also important to note that tidal flux 1 (June 8) showed the lowest salinity at a time when freshwater inflow to the pond during the spring early summer period of the hydrologic cycle is greater than in tidal flux 2 (July 16) which is lower still by tidal flux 3 (September 1). Late summer is when the low freshwater inflow period of the annual hydrologic cycle is reached.

Table 9a. Summary of flow and nutrient fluxes during tidal flux experiment 3. Flood is represented by (+) values and ebb is represented by (-) values.

MASS FLUX	FLOW (m3)	Salt (kg)	PO4 (kg)	NH4 (kg)	Nox (kg)	DON (kg)	POC (kg)	PON (kg)	TN (kg)
Flood (+)	3834.3	121173.7	0.072	0.010	0.002	0.968	2.175	0.299	1.279
Ebb (-)	-1040.4	15096.3	-0.002	-0.012	-0.002	-0.892	-2.626	-0.334	-1.240
Net Flux	2793.9	106077.4	0.070	-0.002	0.000	0.076	-0.451	-0.035	0.039

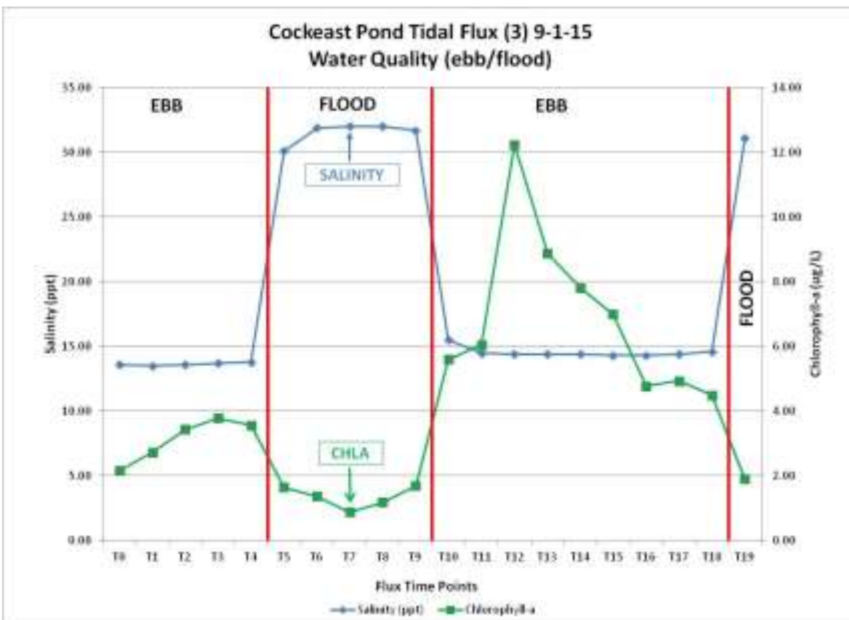

Figure 23. Tidal flux study 3 time-series of chlorophyll-a and salinity concentrations through flood and ebb tides under spring tide conditions on September 1, 2015 within the Cockeast Pond inlet.

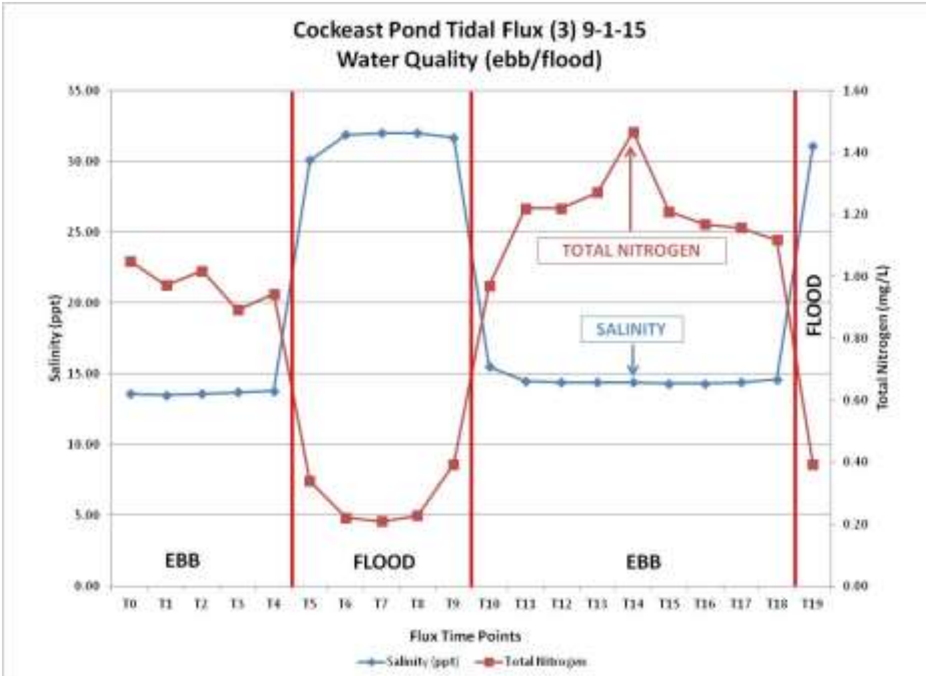

Figure 24. Tidal flux study 3 time-series of total nitrogen (TN) concentrations through flood and ebb tides under spring tide conditions on September 1, 2015 within the Cockeast Pond inlet.

Due to the extreme tide conditions and associated results obtained from tidal flux study 3, a fourth tidal flux was undertaken on April 6, 2016 during what is typically the high flow portion of the hydrologic year. This fourth tidal flux experiment was undertaken by UMD-SMAST graduate students, under CSP supervision, as part of using Cockeast Pond as a natural laboratory for a class in Estuarine Dynamics. Tidal flux 4 was completed by several of the same people who participated in tidal fluxes 1, 2, 3 and followed the same procedures to maintain cross comparability of data sets. Results of tidal flux 4 in spring 2016 are provided in Table 9b along with results of the three previous tidal fluxes completed in the summer 2015. Not surprisingly, tidal flux 4 was completed under typical spring tide conditions and as typical for Cockeast Pond, the ebb tide volume was significantly larger than the flood tide volume, due to the longer ebb flow period and the high spring freshwater inflow during the high flow period of the hydrologic year. The significant inflow of freshwater is manifest in the measured ebb tide salinity recorded during tidal flux 4 which averaged ~5 ppt (the lowest observed salinity of the four tidal flux experiments completed to date).

Looking at the results from all four tidal fluxes in aggregate (Table 9b), it would appear that Cockeast Pond generally functions as an exporter of freshwater and nutrient loads to the larger Westport Harbor system. As tidal flux 3 indicates, there are times during the year when very specific conditions exist which result in higher inflows to Cockeast Pond from the Harbor relative to what is discharged on the ebb tide, thereby increasing the pondwater salinity and lowering TN levels, however, these are not typical conditions. Based on the results of all four tidal flux experiments, it appears that to the extent the duration of the flood tide into Cockeast Pond can be extended allowing more low nutrient, low chlorophyll-a water from the Westport Harbor to flood into Cockeast Pond on typical tides, the greater the resulting water and habitat quality within the pond.

The small stream flow into Cockeast Pond was not discovered until February 2016, therefore summer data representing stream flow into the pond is not available to compare the effects of stream flow on summer and spring tidal fluxes. Gauging of the stream began in February 2016 and continues to date. Based on data collected during the MEP Westport River Embayment Project, the majority of stream flow in two streams, Adamsville Brook and Angeline Brook, located northeast of Cockeast Pond contribute approximately 50% of their total annual flow to the Westport River Embayment during March and April (Howes et al, 2006). This information indicates that highest volumes of stream input (and groundwater discharge) into Cockeast Pond is more likely to occur during March and April than the summer months, consistent with the large ebb tide volumes observed during tidal flux 4 compared to tidal fluxes 1, 2 and 3 conducted in summer 2015.

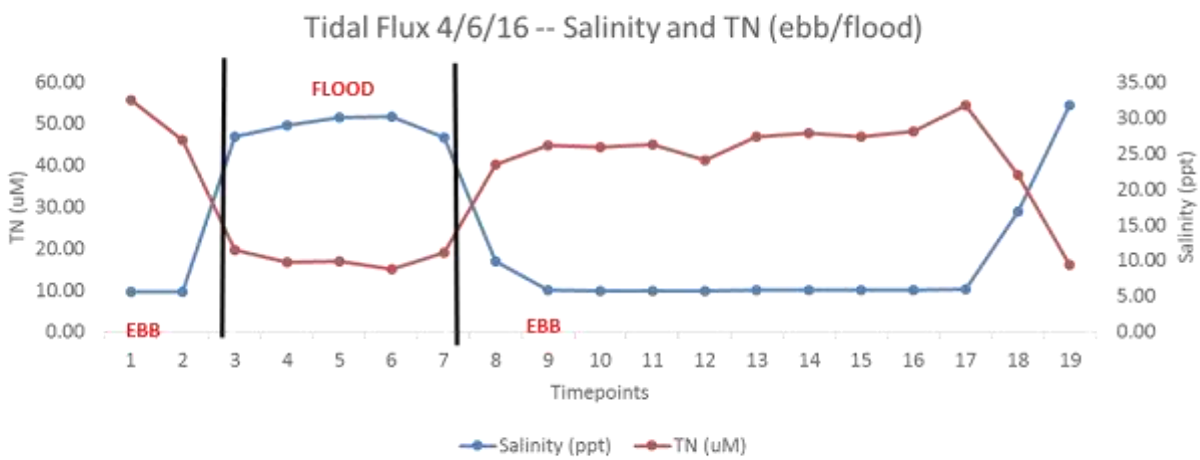

Figure 25a. Tidal flux 4 time series of salinity and total nitrogen (TN) concentration over both flood and ebb tides April 6, 2016.. Note the inverse relationship between TN and salinity as the low TN high salinity water enters on the flood and the low salinity high TN waters of Cockeast Pond leave on the ebb.

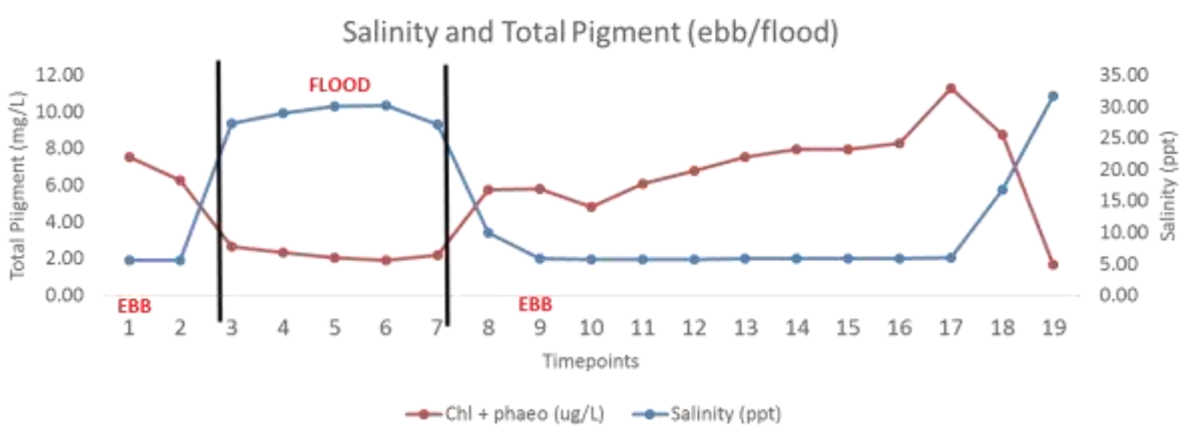

Figure 25b. Tidal flux 4 time series of salinity and chlorophyll-a levels over both flood and ebb tides April 6, 2016. Note the inverse relationship between chlorophyll-a and salinity as the low

chlorophyll-a high salinity water enters on the flood and the low salinity high TN waters of Cockeast Pond leave on the ebb.

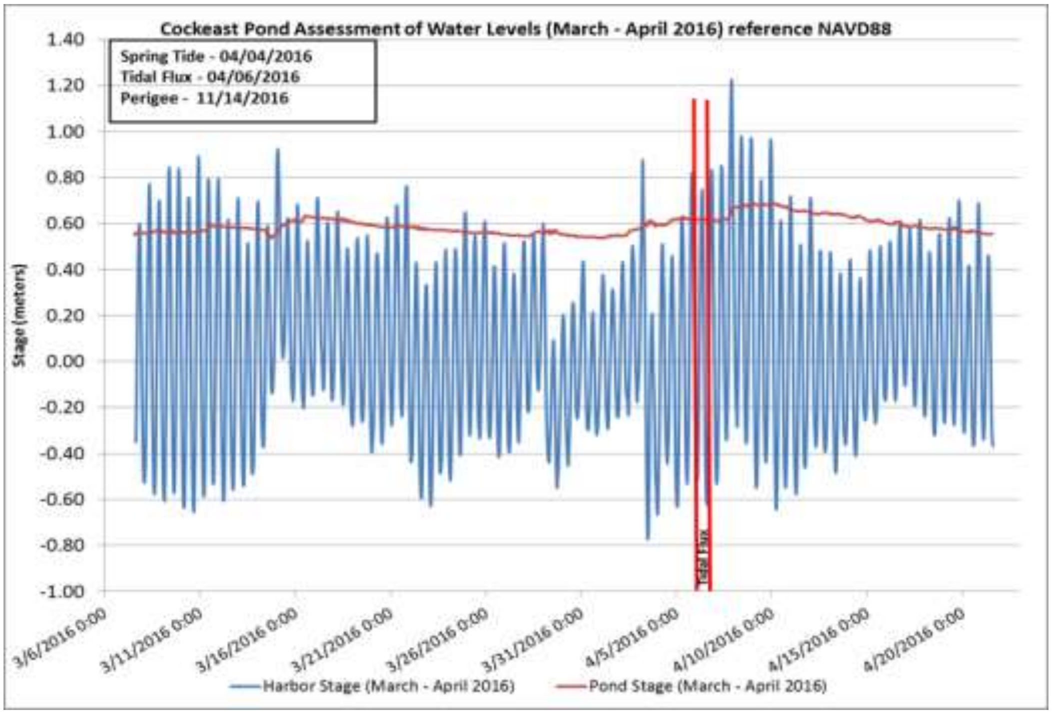

Figure 25c. Time-series of Westort Harbor and Cockeast Pond water levels (relative to NAVD88) for March and April 2016. The period of flux 4 measurements is shown by the vertical red lines.

Table 9b. Nearest spring tide, nearest perigee, max harbor stage, inflow volume, outflow volume, and pond stage for each tidal flux completed at Cockeast Pond.

Date of Flux	Nearest Spring Tide	Nearest Perigee	Max Harbor Stage (m)	Inflow m3/tide	Outflow m3/tide	Pond Height (m)
06/08/2015	06/03/2015	09/28/2015	0.66	171	-341	0.38
07/16/2015	07/16/2015	09/28/2015	0.69	549	-1206	0.44
09/01/2015	08/30/2015	09/28/2015	0.97	3834	-1040	0.48
04/06/2016	04/04/2016	11/14/2016	0.74	923	-5365	0.62

Summary of Benthic Infaunal Analysis:

Coastal Systems Program Scientific Staff have not been able to find any evidence of historical eelgrass habitat in Cockeast Pond in the modern era, 1951 to present. This is consistent with inlet restrictions over the past several decades and current water quality (past 8 years). As previously mentioned, in areas that do not support eelgrass beds, benthic animal community indicators are used to assess the level of habitat health. This approach was therefore used to assess Cockeast Pond habitat quality.

Benthic animal species from sediment samples collected in November 2015 from Cockeast Pond (8 sites, Figure 26) were identified and the environment ranked based upon the fraction of the community represented by healthy, transitional, and stressed indicator species. The analysis is based upon life history information on the species and a wide variety of field studies within southeastern Massachusetts waters, including the Wild Harbor oil spill, benthic population studies in Buzzards Bay (Woods Hole Oceanographic Institution) and New Bedford (SMAST), and more recently the Woods Hole Oceanographic Institution Nantucket Harbor Study (Howes et al. 1997). These data were coupled with the level of diversity (H') and evenness (E) of the benthic community and the total number of individuals to determine the infaunal habitat quality throughout the Cockeast Pond system. This ecological assessment approach is completely consistent with the benthic infaunal analysis completed for the Westport River Estuary under the Massachusetts Estuaries Project and as such is directly comparable to the MEP findings in the Westport River Estuary as well as all other estuarine systems evaluated by the MEP across all of southeastern Massachusetts.

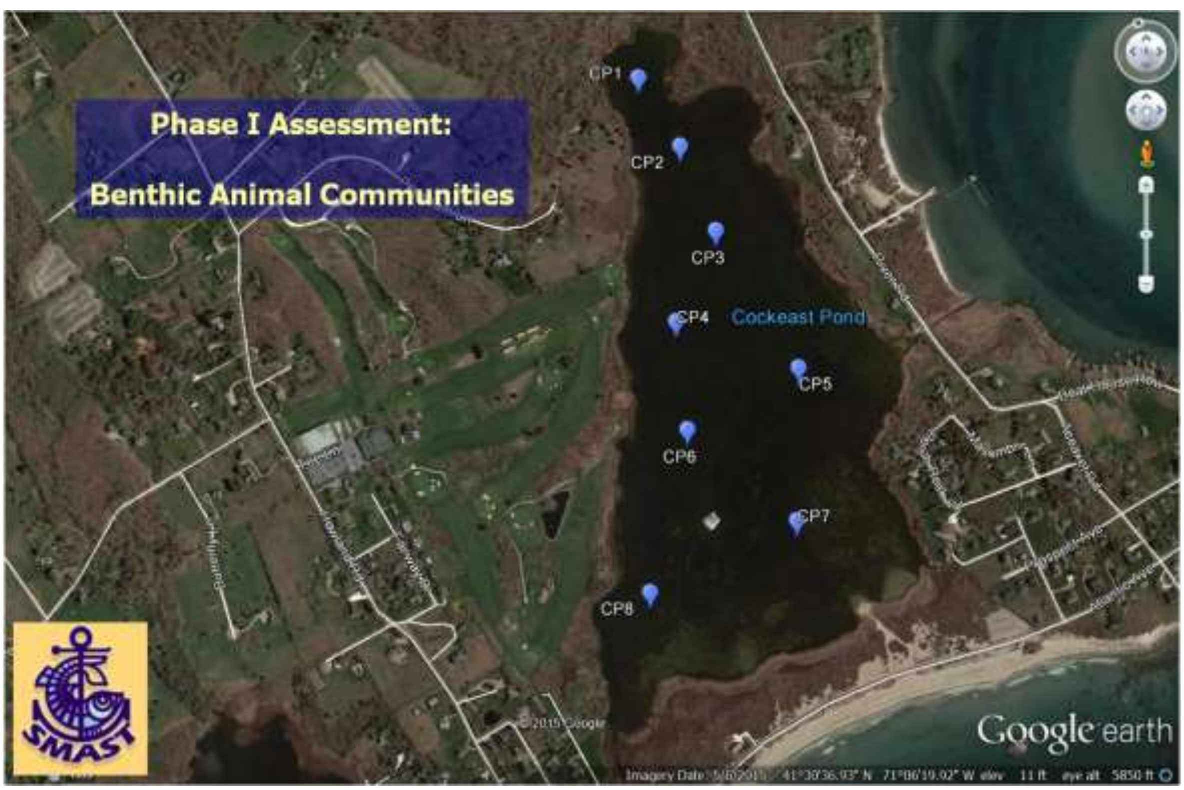

Figure 26. Aerial photograph of the Cockeast Pond system showing location of benthic infaunal sampling stations (blue symbol).

Analysis of the evenness and diversity of the benthic animal communities was also used to support the density data and the natural history information. The evenness statistic can range from 0-1 (one being most even), while the diversity index does not have a theoretical upper limit. The highest quality habitat areas in southeastern Massachusetts estuaries have the highest diversity (generally >3) and evenness (~0.7). The converse is also true, with poorest habitat quality found where diversity is <1 and evenness is <0.5.

Two grabs were collected at each site (Figure 26). Samples were analyzed for number of species and number of individuals to determine species diversity and abundance in Cockeast Pond. The benthic community in both northern and southern basins is dominated by insect larvae (Chirinomidae or non-biting flies) with estuarine species of crustaceans, mollusks and polychaetes. Very low numbers of pollution indicator species were observed (*Capitella, Tubificoides*), consistent with impairment through nutrient enrichment. The Chirinomidae and more marine species serve as prey for a variety of fish species.

Overall, the benthic community indicates nitrogen severely impaired habitat quality that is in low salinity brackish waters. The community has very low Diversity and generally low Evenness in addition to very low species numbers. In the northern stations the number of individuals is so low that the contribution to secondary production and as a food source for fish is minimal. The higher numbers in the southern basin are indicative of a moderate level of productivity, but the other metrics clearly indicate impaired habitat. While the species were generally similar from the north to the south basin, the number of individuals in the north basin was very low, less than 1/10th of the southern basin. Based on preliminary field observations, it appears that this difference in communities may be related to the distribution of macroalgal accumulations within the Pond (which can smother benthic organisms). Restoration of benthic habitat will require a lowering of the current level of nitrogen enrichment throughout the pond waters and if possible a modest increase in salinity.

Table 10. Summary of benthic infaunal community metrics for Cockeast Pond (November 2015). Estimates of the number of species adjusted to the number of individuals and diversity (H') and Evenness (E) of the community allow comparison between locations (Samples represent surface area of 0.0625 m2). Stations refer to map in Figure VII-8, duplicate samples were obtained for each site.

Sub-Embayment	Total Actual Species	Total Actual Individuals	Species Calculated @75 Indiv.	Weiner Diversity (H')	Evenness (E)	Sta. i.d. CP-#
COCKEAST POND						
Northern Basin	**3.6**	**61**	**4**	**0.99**	**0.58**	**1,2,3,4**
Southern Basin	**3.4**	**675**	**3**	**0.49**	**0.30**	**5,6,7,8**

* Station i.d.'s in Table 10 refer to stations shown in Figure 26 above.

COCKEAST POND ASSESSMENT - PHASE 2 SUMMARY

Summary of Dissolved Oxygen and Chlorophyll Conditions

In support of the benthic infaunal data described above and as an extension of the baseline habitat assessment of Cockeast Pond, autonomous time-series moorings were deployed within Cockeast Pond to measure critical habitat structuring parameters (dissolved oxygen and chlorophyll, as a measure of phytoplankton abundance and surrogate for water clarity). Dissolved oxygen (DO) and chlorophyll-a (CHLA) are indicators of the nutrient related health of a water body and were measured 30cm off the bottom of Cockeast Pond. One mooring was deployed in 2015 (station CP-1) and two moorings were deployed in 2016 and 2017 at water quality monitoring stations CP-1 and 2 (Figure 27).

Dissolved oxygen levels near atmospheric equilibration are important for maintaining healthy animal and plant communities. Short-duration oxygen depletions can significantly affect communities even if they are relatively rare on an annual basis. For example, for the Chesapeake Bay it was determined that restoration of nutrient degraded habitat requires that instantaneous oxygen levels not drop below 4 mg L^{-1}. Massachusetts State Water Quality Classification indicates that SA (high quality) waters be able to maintain oxygen levels above 6 mg L^{-1}. The tidal waters of the west branch of the Westport River Estuary are classified as SA (as are the waters of Cockeast Pond as the pond is tidally connected to the west branch), therefore, the analysis of oxygen data collected from Cockeast Pond was undertaken relative to assessing an SA classification as a conservative goal for restoration. It should be noted that the present Classification represents the water quality that the embayment should support, not the actual existing level of water quality and that it is the designated water quality that is the target of TMDL's generated under the U.S. Clean Water Act.

Dissolved oxygen levels in temperate embayments vary seasonally, due to changes in oxygen solubility, which varies inversely with temperature. In addition, biological processes that consume oxygen from the water column (water column respiration) vary directly with temperature, with several fold higher rates of oxygen uptake in summer than winter (Figure 28). It is not surprising that the largest levels of oxygen depletion (departure from atmospheric equilibrium) and lowest absolute levels (mg L^{-1}) are found during the summer in southeastern Massachusetts embayments when water column temperatures and respiration rates are greatest. Since oxygen levels can change rapidly, several mg L^{-1} in a few hours, traditional grab sampling programs typically underestimate the frequency and duration of low oxygen within shallow embayments. The use of continuously recording oxygen and chlorophyll-a sensors captures these high frequency variations and provides an accurate assessment of environmental conditions, not possible with traditional grab sampling. The dissolved oxygen sensors (YSI 6600) were first calibrated in the laboratory and then checked with standard oxygen mixtures at the time of initial instrument mooring deployment. In addition periodic calibration samples were collected at the sensor depth and assayed by Winkler titration (potentiometric analysis, Radiometer) during each deployment (2015, 2016, 2017). Each instrument mooring was serviced and calibration samples collected at least biweekly and sometimes weekly during a typical deployment of 30 days within the interval from July through mid-September.

Figure 27. Location of water quality monitoring stations paired to mooring deployments for measuring dissolved oxygen and chlorophyll-a (2015, 2016, 2017). Only one mooring was deployed in 2015 at location CP-1.

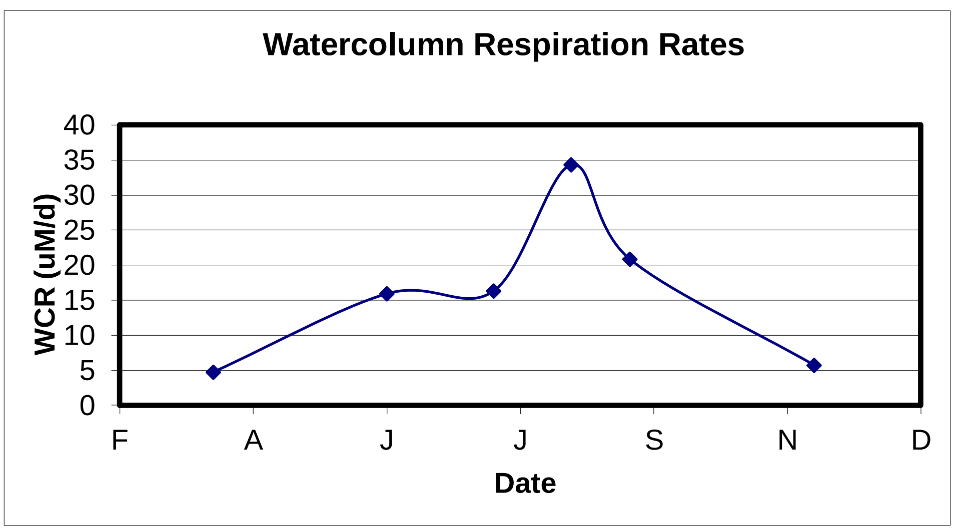

Figure 28. Example of typical average water column respiration rates (micro-Molar/day) from water collected throughout the Popponesset Bay Estuarine System, Cape Cod (Schlezinger and Howes, unpublished data). Rates vary ~7 fold from winter to summer as a result of variations in temperature and organic matter availability.

Similar to other embayments in southeastern Massachusetts, Cockeast Pond has shown high frequency variation in all mooring deployment periods (2015 - 2017). Nitrogen enrichment of embayment waters generally manifests itself in the dissolved oxygen record, both through oxygen depletion and through the magnitude of the daily excursion. The high degree of temporal variation in bottom water dissolved oxygen concentration at each mooring site indicates the clear nitrogen enrichment and underscores the need for continuous monitoring within these systems.

Dissolved oxygen and chlorophyll a records were examined both for temporal trends and to determine the percent of the total deployment period that these parameters were below/above various benchmark concentrations (Tables 11, 12). These data indicate both the temporal pattern of minimum or maximum levels of these critical nutrient related constituents, as well as the intensity of the oxygen depletion events and phytoplankton blooms.

Summer 2015 (July) Dissolved Oxygen and Chlorophyll-a:

CP-1: The northern mooring in Cockeast Pond was centrally located within the upper basin area and down gradient of the small stream flowing into the pond along the northern most shoreline (Figure 27). The CP-1 mooring was deployed in the same area as the long-term water quality monitoring station and was centrally located specifically so that it would not be significantly affected by the stream inflow. Unlike in 2016 and 2017 the 2015 mooring was deployed May through July to coincide with the sediment regeneration survey (see below) while overlapping with the period of highest ecological stress which occurs in the mid to late summer months. As a consequence diurnal variation is much lower than in later years owing to lower chlorophyll concentrations and average oxygen levels are higher owing to average cooler temperatures in the late spring/early summer. Daily excursions (maximum to minimum) in oxygen levels at this location were 2-3 mg L^{-1} or less (Figure 29) and the magnitude was generally positively correlated with the measured chlorophyll concentrations (Figure 30). Oxygen levels varied primarily with the photocycle as there is minimal tidal (semi-diurnal cycle) influence in Cockeast Pond. Lowest oxygen was generally observed in the early morning. Highest dissolved oxygen was observed towards the end of the photocycle (ca. 1500 hrs). Maximum oxygen levels exceeding air equilibration (% air saturation), which occurs when nitrogen enrichment has stimulated phytoplankton production and oxygen release, was seen during phytoplankton blooms around June 9 and July 9. Corresponding minimum oxygen levels below air equilibration were observed approximately a week following the collapse of both phytoplankton blooms. While the diurnal oxygen excursions, oxygen concentration deviations from air equilibration and chlorophyll concentrations were less extreme in 2015 than observed in 2016 and 2017, considering the differing time of year and lower water temperatures the system still exhibited the hallmarks eutrophic conditions.

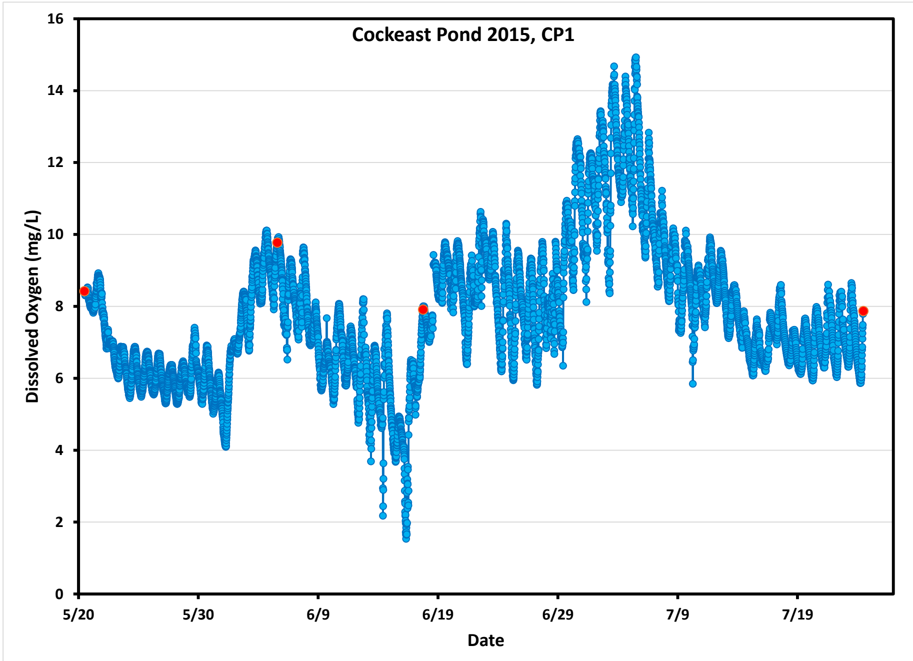

Figure 29. Bottom water dissolved oxygen levels in Cockeast Pond during summer 2015 deployment (mid May - July). Mooring deployed at water quality station CP-1. Calibration samples represented as red dots.

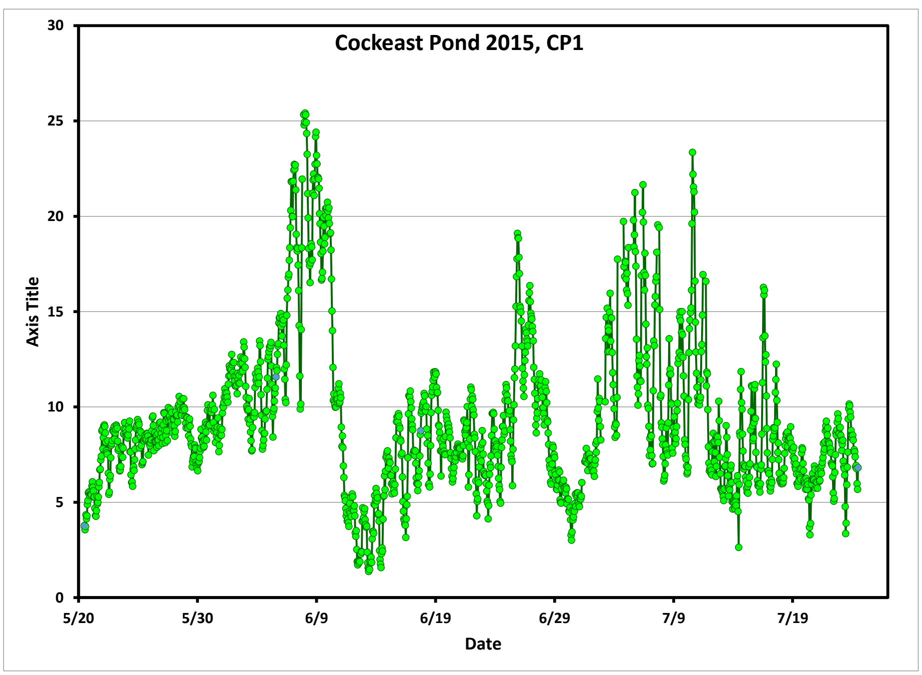

Figure 30. Bottom water record of Chlorophyll-a in Cockeast Pond at water quality monitoring station CP-1, Summer 2015 (mid May - July). Calibration samples represented as red dots. Chlorophyll-a levels >10 ug L^{-1} indicate enriched conditions.

Table 11. Days and percent of time during deployment Summer 2015 (mid-May-July) of in situ sensors that bottom water oxygen levels were below various benchmark oxygen levels within Cockeast Pond (CP-1) tributary to the West Branch of the Westport River Estuary. Mean" represents the average duration of each event over the benchmark level and "S.D." its standard deviation. Data collected by the Coastal Systems Program, SMAST.

MOORING LOCATION	Start Date	End Date	Total Deployment (Days)	<6 mg/L Duration (Days)	<5 mg/L Duration (Days)	<4 mg/L Duration (Days)	<3 mg/L Duration (Days)
Cockeast Pond CP1	**5/20/2015**	**7/24/2015**		**15%**	**4%**	**1%**	**0.5%**
			65.0	**9.49**	**2.48**	**0.61**	**0.30**
			Mean	0.32	0.31	0.12	0.08
			Min	0.01	0.01	0.01	0.02
			Max	1.73	1.48	0.39	0.20
			S.D.	0.36	0.49	0.15	0.08

Table 12. Duration (days and % of deployment time) that chlorophyll a levels exceed various benchmark levels within the Cockeast Pond (CP-1) system Summer 2015 (mid-May-July). "Mean" represents the average duration of each event over the benchmark level and "S.D." its standard deviation. Data collected by the Coastal Systems Program, SMAST.

MOORING LOCATION	Start Date	End Date	Total Deployment (Days)	>5 ug/L Duration (Days)	>10 ug/L Duration (Days)	>15 ug/L Duration (Days)	>20 ug/L Duration (Days)	>25 ug/L Duration (Days)
Cockeast CP1	**5/20/2015**	**7/24/2015**		**23%**	**8%**	**2%**	**1%**	**0.03%**
Mean Chl Value = 9.3 ug/L			**63.2**	**14.33**	**4.77**	**1.29**	**0.48**	**0.02**
			Mean	0.45	0.10	0.07	0.05	0.02
			Min	0.01	0.01	0.01	0.01	0.01
			Max	4.29	0.67	0.60	0.16	0.02
			S.D.	0.81	0.15	0.14	0.05	0.01

Summer 2016 (July) Dissolved Oxygen and Chlorophyll-a (CP-1 and CP-2)

CP-1: The northern mooring in Cockeast Pond was centrally located within the upper basin area and down gradient of the small stream discharging to the pond along its northern most shoreline (Figure VII-2). The CP-1 mooring was deployed in the same area as the long-term water quality monitoring station and was centrally located specifically so that it would not be significantly affected by the stream inflow. Daily excursions (maximum to minimum) in oxygen levels at this location were large >3 mg L^{-1}. Oxygen levels varied primarily with the photocycle as there is minimal tidal (semi-diurnal cycle) influence in Cockeast Pond. Lowest oxygen was generally observed in the early morning. Highest dissolved oxygen was observed towards the end of the photocycle (ca. 1500 hrs). Maximum oxygen levels exceed air equilibration (% air saturation), which occurs when nitrogen enrichment has stimulated phytoplankton production and oxygen release. Both the presence of high oxygen levels (>10 mg L^{-1}), the large daily excursion and the periodically low (<2-3 mg L^{-1}) overall oxygen concentrations indicate that significant organic matter enriched conditions are extant in this region of the basin during the measurement period (July – September).

Oxygen levels were above 6 mg L-1 (69% of record) but periodically declined to hypoxic levels (below 2 mg L^{-1}), during the 85 day record during summer 2016 (July-September) (Figure 31). Oxygen levels at this site in the upper portion of the Cockeast Pond system were <4 mg L^{-1} 4% of the deployment period and almost 6% of record in July and August, the critical threshold for oxygen stress in an estuarine system (Table 13). The high oxygen levels (above air equilibration) were consistent with the moderate to high levels of phytoplankton biomass as measured by chlorophyll-a. Chlorophyll-a averaged 15.8 ug L^{-1} over the time-series record and exceeded 15 ug L^{-1} for 10% of the deployment period. The chlorophyll-a levels were elevated at the beginning of the deployment period, but steadily declined showing a second increase potentially indicative of a small bloom towards the middle of the deployment with a subsequent decrease and then a third large peak towards the end of the 85 day record. Average summer chlorophyll levels over 10 ug L^{-1} have been used to indicate impaired nitrogen related water quality in temperate embayments. Average chlorophyll-a measurements from the mooring (CP-1) within the northern portion of Cockeast Pond (averaging 15.8 ug/L with maxima >40 ug L^{-1}) indicate a basin with high phytoplankton levels. These levels of chlorophyll-a are indicative of an open water basin with moderate to high nitrogen and organic matter enrichment (Table 14, Figure 32), which is resulting in wide ranging oxygen levels. All of these metrics are consistent with nitrogen related impairment, as seen in the benthic community survey results (above).

CP-2: The southern mooring in Cockeast Pond was centrally located within the mid/lower basin area and slightly below the area of the pond that is connected to Westport Harbor via a culvert and tidal channel (Figure 27). The CP-2 mooring was deployed in the same area as the long-term water quality monitoring station and was centrally located specifically so that it would not be significantly affected by the inflowing waters through the tidal inlet. Similar to the oxygen data collected at CP-1 in the upper portion of the pond, daily excursions (maximum to minimum) in oxygen levels at the CP-2 were large, 3-4 mg L^{-1}. Oxygen levels varied primarily with the photocycle as there is minimal tidal (semi-diurnal cycle) influence in Cockeast Pond. Dissolved oxygen dropped lower and more frequently compared to data collected at CP-1. But the temporal pattern was similar with lowest oxygen generally observed in the early morning and highest dissolved oxygen observed towards the end of the photocycle (ca. 1500 hrs). Maximum oxygen levels did exceed air equilibration (% air saturation), which occurs when nitrogen enrichment has stimulated phytoplankton production and oxygen release. Both the presence of high oxygen levels (>12 mg L^{-1}), the large daily excursion and the periodically low

(<2 mg L^{-1}) oxygen levels indicate that significant organic matter enriched conditions are extant in this region of the basin during measurement in 2016, July-September period (more so than observed at CP-1 over the same time period).

Oxygen levels were above 6 mg L-1 (only 54% of record) and declined to below 3 and even 2 mg L^{-1} during the 85 day record (Figure 33). Oxygen levels at this site in the mid to lower portion of the Cockeast Pond system were <4 mg L^{-1} 17% of the deployment period, the critical threshold for oxygen stress in an estuarine system (Table 13). The high oxygen levels (above air equilibration) were consistent with the high levels of phytoplankton biomass as measured by chlorophyll-a. Chlorophyll-a averaged 16.3 ug L^{-1} over the time-series record and exceeded 15 ug L^{-1} for 12% of the deployment period. The chlorophyll-a levels were elevated at the beginning of the deployment period (beginning of July to beginning of August), showing a series of peaks in chlorophyll levels and then steadily declined during the middle portion of the deployment (beginning August to beginning September) followed a second series of increases potentially indicative of more bloom activity towards the end of the 85 day record (primarily the month of September). Average summer chlorophyll levels over 10 ug L^{-1} have been used to indicate impaired nitrogen related water quality in temperate embayments. Average chlorophyll-a measurements from the mooring (CP-2) within the mid to lower portion of the Cockeast Pond system (averaging 16.3 ug/L with maxima >40 ug L^{-1}) were similar to those at CP-1 and both indicate a basin with high phytoplankton levels. These levels of chlorophyll-a are indicative of an open water basin with moderate to high nitrogen and organic matter enrichment (Table 14, Figure 34), which is resulting in wide ranging oxygen levels and habitat impairment.

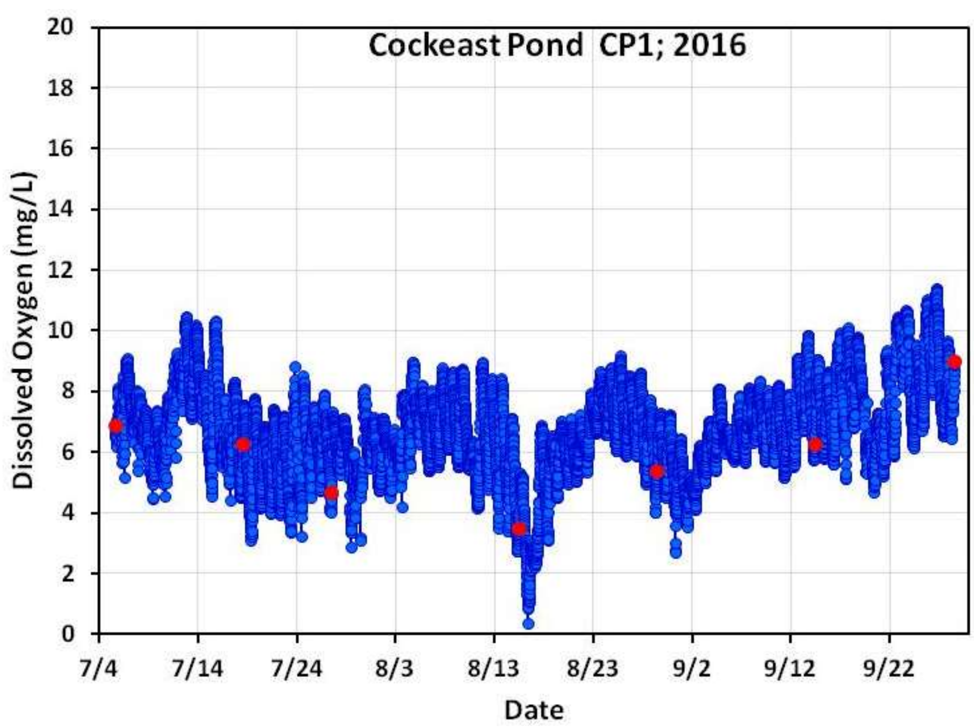

Figure 31. Bottom water dissolved oxygen levels in Cockeast Pond during summer 2016 deployment (July-September). Mooring deployed at water quality station CP-1. Calibration samples represented as red dots.

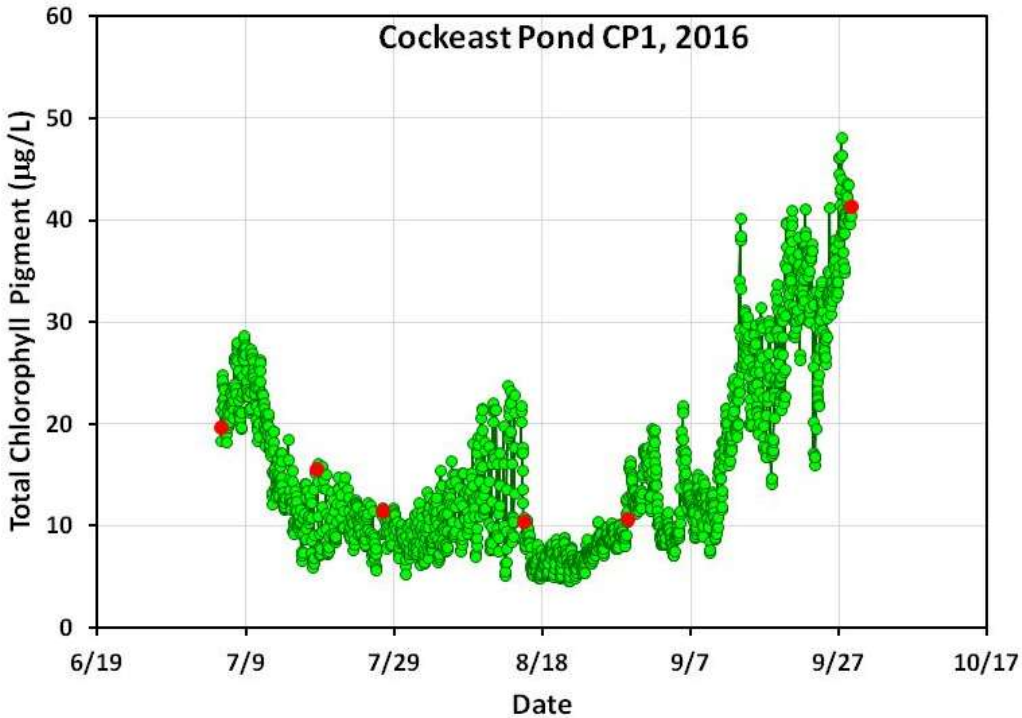

Figure 32. Bottom water record of Chlorophyll-a in Cockeast Pond at water quality monitoring station CP-1, Summer 2016 (July - September). Calibration samples represented as red dots.

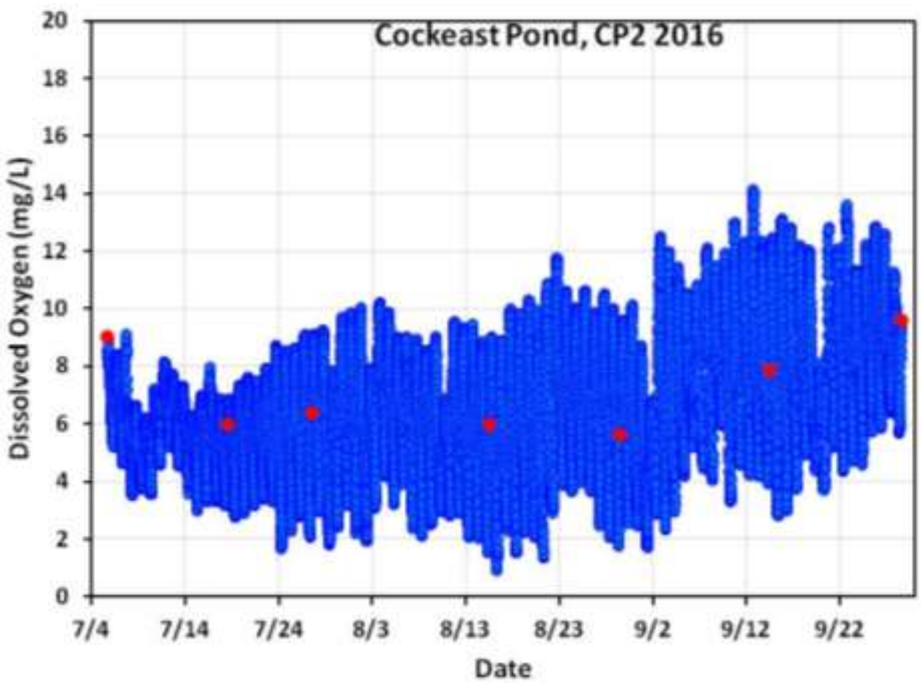

Figure 33. Bottom water dissolved oxygen levels in Cockeast Pond during summer 2016 deployment (July-September). Mooring deployed at water quality station CP-2. Calibration samples represented as red dots.

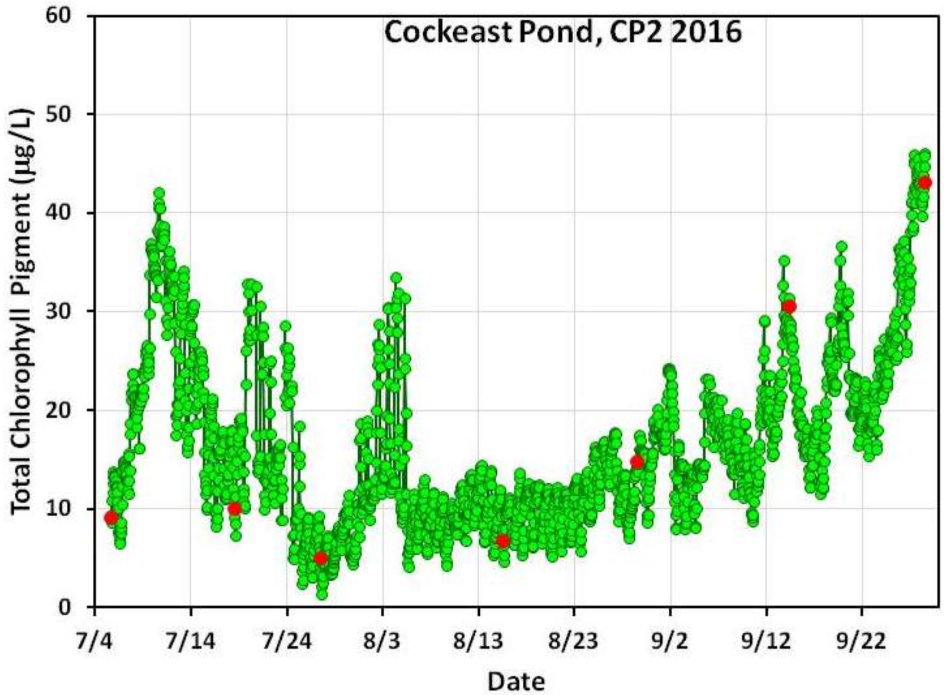

Figure 34. Bottom water record of Chlorophyll-a in Cockeast Pond at water quality monitoring station CP-2, Summer 2016 (July - September). Calibration samples represented as red dots.

Table 13. Days and percent of time during deployment in Summer 2016 (July-September) of in situ sensors that bottom water oxygen levels were below various benchmark oxygen levels within Cockeast Pond tributary basin to the West Branch of the Westport River Estuary. Mean" represents the average duration of each event over the benchmark level and "S.D." its standard deviation. Data collected by the Coastal Systems Program, SMAST.

MOORING LOCATION	Start Date	End Date	Total Deployment (Days)	<6 mg/L Duration (Days)	<5 mg/L Duration (Days)	<4 mg/L Duration (Days)	<3 mg/L Duration (Days)
Cockeast Pond CP1	**7/5/2016**	**9/28/2016**		**31%**	**12%**	**4%**	**2%**
			84.8	**26.48**	**9.81**	**3.13**	**1.40**
			Mean	0.22	0.16	0.14	0.23
			Min	0.01	0.01	0.01	0.01
			Max	2.69	1.72	1.49	0.61
			S.D.	0.37	0.25	0.32	0.29
Cockeast Pond CP2	**7/5/2016**	**9/28/2016**		**46%**	**31%**	**17%**	**6%**
			84.8	**38.59**	**26.63**	**14.82**	**5.48**
			Mean	0.45	0.32	0.23	0.15
			Min	0.01	0.01	0.01	0.01
			Max	0.80	0.66	0.47	0.32
			S.D.	0.19	0.15	0.12	0.09

Table 14. Duration (days and % of deployment time) that chlorophyll a levels exceed various benchmark levels within the Cockeast Pond system in Summer 2016 (July-September). "Mean" represents the average duration of each event over the benchmark level and "S.D." its standard deviation. Data collected by the Coastal Systems Program, SMAST.

MOORING LOCATION	Start Date	End Date	Total Deployment (Days)	>5 ug/L Duration (Days)	>10 ug/L Duration (Days)	>15 ug/L Duration (Days)	>20 ug/L Duration (Days)	>25 ug/L Duration (Days)
Cockeast CP1	**7/5/2016**	**9/28/2016**		**25%**	**16%**	**10%**	**7%**	**4%**
Mean Chl Value = 15.8 ug/L			**75.3**	**18.74**	**12.00**	**7.57**	**5.28**	**3.25**
			Mean	0.31	0.13	0.17	0.18	0.22
			Min	0.01	0.01	0.01	0.01	0.03
			Max	6.39	2.88	2.66	1.35	1.06
			S.D.	0.92	0.41	0.50	0.32	0.33
Cockeast CP2	**7/5/2016**	**9/28/2016**		**24%**	**19%**	**12%**	**7%**	**4%**
Mean Chl Value = 16.3 ug/L			**83.7**	**20.47**	**15.74**	**9.72**	**5.64**	**3.23**
			Mean	1.14	0.29	0.24	0.14	0.12
			Min	0.01	0.01	0.01	0.01	0.01
			Max	5.65	4.48	2.64	1.24	0.96
			S.D.	1.79	0.67	0.53	0.25	0.22

Summer 2017 (July-September) Dissolved Oxygen and Chlorophyll-a:

CP-2: As in the summer of 2016, a mooring was deployed in the southern region of the pond (CP-2) to record dissolved oxygen and chlorophyll-a levels at high frequency (15 minute intervals) over an extended duration (~114 days). The southern mooring location in Cockeast Pond was centrally located within the mid/lower basin area and slightly below the area of the pond that receives direct inflows from Westport Harbor via a culvert and tidal channel (Figure 27). As in previous years, the CP-2 mooring was deployed in the same area as the long-term water quality monitoring station and was centrally located specifically so that it would not be significantly affected by the inflowing waters from Westport Harbor. It was also positioned at the same coordinates as the 2016 mooring, such that the dissolved oxygen and chlorophyll-a records from both years would be directly comparable. Unlike the 2016 mooring deployment, a second mooring was not deployed at station CP-1 during the summer 2017 season.

Similar to the oxygen data collected at both stations in 2016, the 2017 record for CP-2 showed large daily oxygen excursions (maximum to minimum), 4-12 mg L^{-1}. As previously observed in 2016, oxygen levels varied primarily with the photocycle as there is minimal tidal (semi-diurnal cycle) influence in Cockeast Pond. Dissolved oxygen dropped as low and as frequently as it did at CP-2 during the summer 2016 deployment. Lowest oxygen was generally observed in the early morning. Highest dissolved oxygen was observed towards the end of the photocycle (ca. 1500 hrs). Maximum oxygen levels did exceed air equilibration (% air saturation), which occurs when nitrogen enrichment has stimulated phytoplankton production and oxygen release. Both the presence of high oxygen levels (>12 mg L^{-1}), the large daily excursion and the periodically low (<2 mg L^{-1}) overall oxygen concentrations suggest that significant organic matter enrichment is occurring in this region of the basin during the measurement period (as also found at CP-2 in 2016).

Oxygen levels were above 6 mg L^{-1} (76% of record) and periodically declined to below 3 mg L^{-1} (1% of the deployment period) and even <2 mg L^{-1} during the 114 day record (Figure 35). These results are comparable to the long-term Water Quality Monitoring Program sampling in the main basin (CP-1, CP-2) that showed a minimum oxygen level of ~1 mg L^{-1} and <4 mg L^{-1} in 4% of grab samples (June – October) over 10 years of monitoring. Oxygen levels at this site in the mid to lower portion of the Cockeast Pond system were <4 mg L^{-1} 5% of the deployment period (17% of the deployment period in 2016). The apparently shorter % of record below 4 mg L^{-1} in 2017 is somewhat misleading as the record continued much later into the fall when oxygen conditions improve. Correcting for this, the records from the 2 years show generally similar significant periods of low oxygen. Four (4) mg L^{-1} is the critical threshold for oxygen stress in an estuarine system (Table 15). The high oxygen levels (above air equilibration) were consistent with the high levels of phytoplankton biomass as measured by chlorophyll-a. Chlorophyll-a averaged 7.5 ug L^{-1} (16.3 ug L^{-1} in 2016) over the time-series record and exceeded 15 ug L^{-1} for 9% (12% in 2016) of the deployment period. The chlorophyll-a levels were elevated at the beginning of the deployment period (mostly august), showing a clear peak in chlorophyll levels indicative of a bloom event and then steadily declined during the middle and end portion of the 114 day deployment. Average summer chlorophyll levels over 10 ug L^{-1} have been used to indicate impaired nitrogen related water quality in temperate embayments. Average chlorophyll a measurements from the mooring (CP-2) within the mid to lower portion of the Cockeast Pond system (averaging 7.5 ug/L with maxima >20 ug L^{-1} and >10 ug L^{-1} in August) indicate a basin with high phytoplankton levels. These levels of chlorophyll-a are indicative of an open water basin with moderate to high nitrogen and organic matter enrichment (Table 16, Figure 36), which is resulting in wide ranging oxygen levels and habitat impairment. It should be noted that chlorophyll-a conditions in 2017 did appear only slightly better than conditions observed in 2016 when adjusting for the different periods of record. However, annual monitoring will capture any interannual changes in water quality within Cockeast Pond to support future management actions.

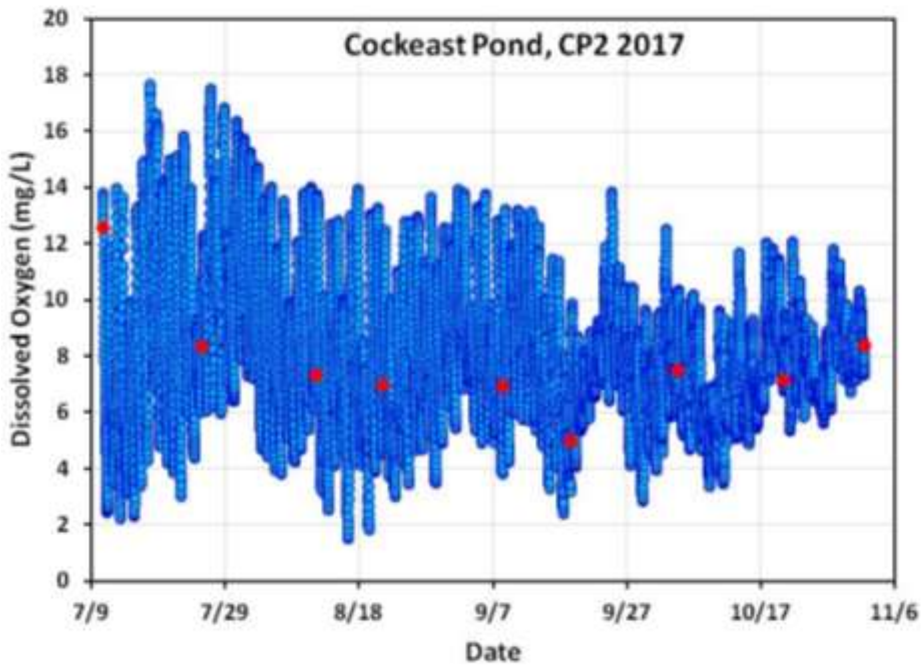

Figure 35. Bottom water dissolved oxygen levels in Cockeast Pond during summer 2016 deployment (July-September). Mooring deployed at water quality station CP-2. Calibration samples represented as red dots.

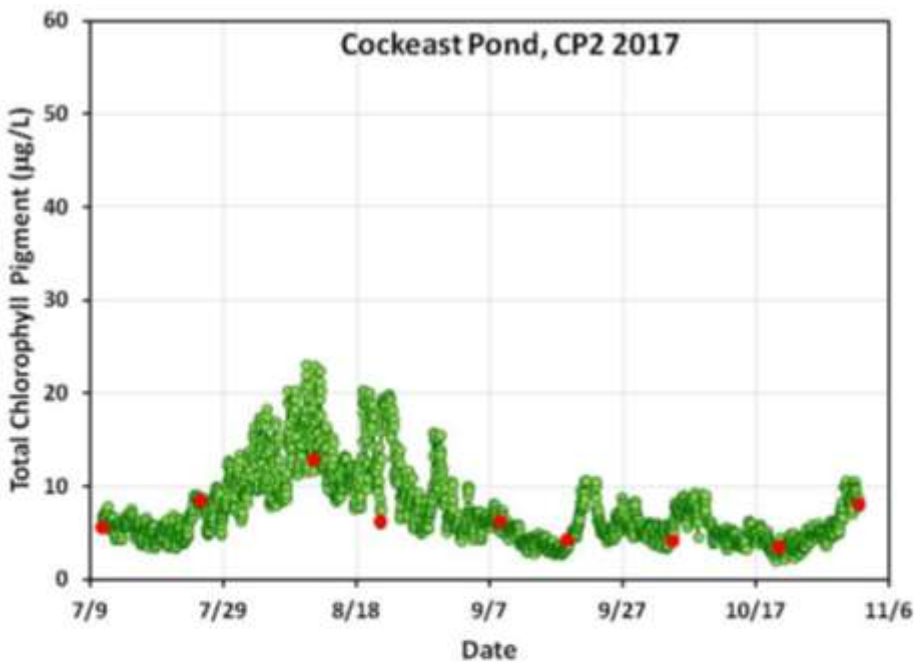

Figure 36. Bottom water record of Chlorophyll-a in Cockeast Pond at water quality monitoring station CP-2, Summer 2016 (July - September). Calibration samples represented as red dots.

Table 15. Days and percent of time during deployment (Summer / Fall 2017) of in situ sensors that bottom water oxygen levels were below various benchmark oxygen levels within Cockeast Pond, tributary to the West Branch of the Westport River embayment system. Mean" represents the average duration of each event over the benchmark level and "S.D." its standard deviation. Data collected by the Coastal Systems Program, SMAST.

MOORING LOCATION	Start Date	End Date	Total Deployment (Days)	<6 mg/L Duration (Days)	<5 mg/L Duration (Days)	<4 mg/L Duration (Days)	<3 mg/L Duration (Days)
Cockeast Pond CP2	**7/10/2017**	**11/1/2017**		**24%**	**12%**	**5%**	**1%**
			113.8	**27.25**	**13.65**	**5.24**	**1.38**
			Mean	0.31	0.22	0.18	0.15
			Min	0.01	0.01	0.02	0.02
			Max	0.84	0.56	0.38	0.27
			S.D.	0.18	0.14	0.12	0.07

Table 16. Duration (days and % of deployment time) that chlorophyll a levels exceed various benchmark levels within the Cockeast Pond system (Summer / Fall 2017). "Mean" represents the average duration of each event over the benchmark level and "S.D." its standard deviation. Data collected by the Coastal Systems Program, SMAST.

MOORING LOCATION	Start Date	End Date	Total Deployment (Days)	>5 ug/L Duration (Days)	>10 ug/L Duration (Days)	>15 ug/L Duration (Days)	>20 ug/L Duration (Days)	>25 ug/L Duration (Days)
Cockeast CP2	**7/10/2017**	**11/1/2017**		**18%**	**5%**	**2%**	**0%**	**NA**
Mean Chl Value = 7.5 ug/L			**108.8**	**19.86**	**5.34**	**1.70**	**0.17**	**NA**
			Mean	0.22	0.10	0.05	0.02	NA
			Min	0.01	0.01	0.01	0.01	NA
			Max	2.49	0.58	0.23	0.04	NA
			S.D.	0.39	0.11	0.06	0.01	NA

Benthic Flux Experiment for Nutrient Regeneration from Sediments

The overall objective of the sediment nutrient regeneration surveys is to quantify the summertime exchange of nitrogen, between the sediments and overlying waters throughout the Cockeast Pond system. The flux of nutrients from embayment sediments can serve as a source or a sink of nutrients needed for plant production. While these are regenerated nutrients, they play the same role as the "new" nutrients that enter from outside the pond. This summer regenerated load must be accounted for accurately in concert with all other sources of load, be it the inflowing waters from the harbor, precipitation directly to the surface of Cockeast Pond or what is entering the pond from the watershed via ground or surface water. Benthic nutrient flux can be a critical input term to a water quality model as it can represent upwards of 50 percent of the nutrient load to the water column during summer and failure to account for it can result in errors in developing nutrient management options.

The summer (July 2016) nutrient regeneration characterization was complemented by a spring (April 2016) flux experiment that was undertaken by Coastal Systems Program scientists and graduate students in conjunction with a graduate level course in estuarine dynamics which used the Cockeast Pond as a natural laboratory. Both the spring and summer flux experiments were completed using the same experimental protocols to ensure cross comparability of results. The mass exchange of nitrogen between water column and sediments is a fundamental factor in controlling nitrogen levels within coastal waters. These fluxes and their associated biogeochemical pools relate directly to carbon, nutrient and oxygen dynamics and the nutrient related ecological health of these shallow marine ecosystems. In addition, these data are required for the proper modeling of nitrogen in shallow aquatic systems, both fresh and salt water, including Cockeast Pond.

Sediment-Water Column Exchange of Nitrogen:
As stated in the above section summarizing results from Phase 1 of the Cockeast Pond assessment, nitrogen loading and resulting levels within coastal embayments are the critical factors controlling the nutrient related ecological health and habitat quality within a salt pond. Nitrogen generally enters Cockeast Pond waters predominantly in highly bio-available inorganic forms from the surrounding upland watersheds and in primarily refractory forms in the inflowing tidal waters. If all of the nitrogen remained within the water column (once it entered) then predicting water column nitrogen levels would be simply a matter of determining the watershed and tidal loads, dispersion, and hydrodynamic flushing. However, as nitrogen enters the embayment from the surrounding watersheds it is predominantly in the bio-available form, nitrate. This nitrate and other bio-available forms are rapidly taken up by phytoplankton for growth, i.e. it is converted from dissolved inorganic nitrogen into phytoplankton “particles”. Many of these “particles” remain in the water column for sufficient time to be flushed out to a down gradient larger water body (like the Westport Harbor and Buzzards Bay). However, some of these phytoplankton particles are grazed by zooplankton or filtered from the water by shellfish and other benthic animals and deposited on the bottom. Also, in longer residence time systems (greater than 8 days) these nitrogen rich particles may die and settle to the bottom. In both cases (grazing or senescence/death), a fraction of the phytoplankton with their associated nitrogen “load” become incorporated into the surficial sediments of the embayments.

In general the fraction of the phytoplankton population which enters the surficial sediments of a shallow embayment: (1) increases with decreased hydrodynamic flushing, (2) increases in low velocity settings, (3) increases within enclosed tributary basins, particularly if they are deeper than the adjacent embayment. To some extent, the settling characteristics can be evaluated by observation of the grain-size and organic content of sediments within an estuary. Once organic particles become incorporated into surface sediments they are decomposed by the natural animal and microbial community. This process can take place both under oxic (oxygenated) or anoxic (no oxygen present) conditions. It is through the decay of the organic matter with its nitrogen content that bio-available nitrogen is returned to the embayment water column for another round of uptake by phytoplankton.

In shallow water systems like Cockeast Pond, sinking particulate organic matter reaches the sediment surface before it can be remineralized completely within the water column. The sediment remineralization rate is based on the amount of organic matter received by the sediments. The majority of remineralization occurs in the upper 10 cm of the sediments because it contains the largest concentration of labile organic matter. In addition, typically only the surface 0-6 mm of sediment are aerobic, except proximal to burrows, which can extend the oxygenated volume (Figure 37). Ammonia is the dominant nitrogen remineralization product released from sediments. Heterotrophic bacteria break-down the organic matter and release excess ammonia; this occurs within the aerobic and anaerobic sediment layers. Ammonia produced through remineralization can remain in the anaerobic layer where it sorbs onto clay and humic material or it can diffuse upward. Ammonia diffusing upward in the sediments can be oxidized to nitrite and then nitrate – a microbial process called nitrification – in oxygenated sediments or it can diffuse out of the sediments into the water column where is available for primary production. Nitrate produced through nitrification can diffuse into the water column, or it can be denitrified by heterotrophic bacteria to nitrogen gas in sediments with low to no oxygen. Nitrogen gas produced through denitrification escapes to the atmosphere, thus denitrification permanently removes nitrogen from the aquatic system. If denitrification occurs, then the sediments are a net sink for fixed nitrogen.

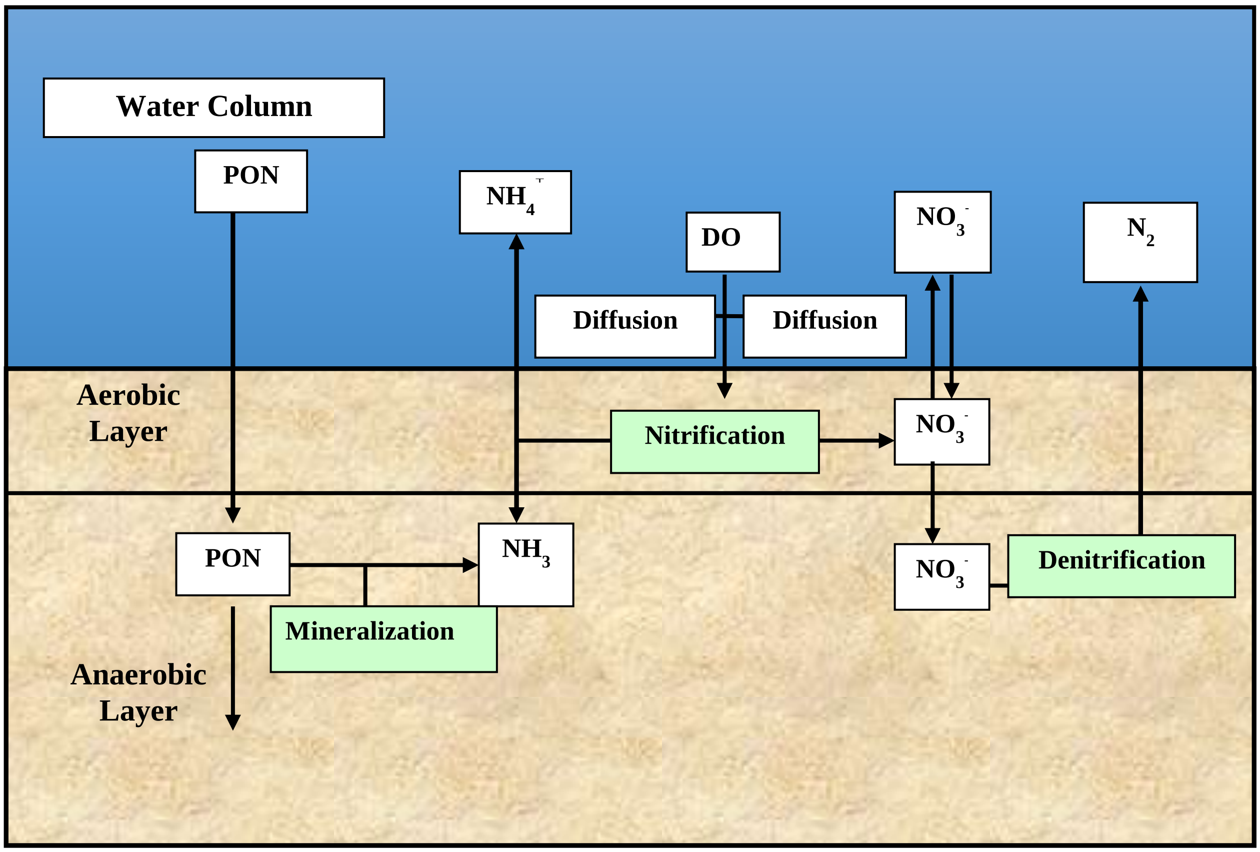

Figure 37: Schematic of sediment – water column nitrogen cycling in aquatic systems.

Recycled nitrogen adds directly to the eutrophication of the estuarine waters in the same fashion as watershed inputs. In some systems that have been investigated by SMAST and the MEP, recycled nitrogen can account for about one-third to one-half of the nitrogen supply to phytoplankton blooms during the warmer summer months. It is during these warmer months that estuarine waters are most sensitive to nitrogen loadings from all sources. In contrast in some systems, with deep depositional basins or salt marsh tidal creeks, the sediments can be a net sink for nitrogen even during summer (e.g. Mashapaquit Creek Salt Marsh, West Falmouth Harbor; Centerville River Salt Marsh or Sesachacha Pond on the Island of Nantucket). Embayment basins can also be net sinks for nitrogen to the extent that they support relatively oxidized surficial sediments, for example in the margins of the main basin to Lewis Bay (Town of Barnstable, Cape Cod). In contrast, most embayments show low rates of nitrogen release throughout much of a basin's area and, in regions of high deposition, typically support anoxic sediments with high release rates during summer months. The consequence of high deposition rates is that the basin sediments are unconsolidated, organic rich and sulfidic in nature and very poor benthic animal habitat (MEP field observations).

Failure to account for the site-specific nitrogen balance of the sediments and its spatial variation will result in significant errors in determination of the threshold nitrogen loading to the Cockeast Pond system. In addition, since the sites of recycling can be different from the sites of nitrogen entry from the watershed, both recycling and watershed data are needed to determine the best approaches for nitrogen mitigation.

Method for Determining Sediment-Watercolumn Nitrogen Exchange:
For the Cockeast Pond system, in order to determine the contribution of sediment regeneration to nutrient levels during the spring (April) as well as the most sensitive summer interval (July-August), sediment samples were collected and incubated under in situ conditions.

For the spring 2016 flux experiment, six intact sediment cores (15.24 cm diameter) were collected by SCUBA diver on 4/21/2016, including one field duplicate (Figure 38, Table 17).

Table 17: Summary of benthic core locations and depths (SPRING 2016).

Site ID	Date	Latitude	Longitude	Total Depth (m)
C1	4/21/16	41 30’50.2”	-70 06’ 08.3”	1.05
C2	4/21/16	41 30’46.1”	-70 06’.07.3”	1.2
C3	4/21/16	41 30’40.3”	-70 06’05.5”	1.2
C4	4/21/16	41 30’35.7”	-70 06’12.7”	1.2
C5	4/21/16	41 30’29.1”	-70 06’03.5”	0.65
C6	4/21/16	41 30’23.9”	-70 06’13.7”	0.75

Figure 38: Core locations for sediment regeneration determinations in Cockeast Pond, April 21, 2016 (spring). Numbers relate to station i.d.'s referenced in Table 17 above.

During the summer flux experiment (07/27/2016), a total of 8 cores were collected from 8 sites (Figure 39), focusing on obtaining a spatial distribution that would be representative of nutrient fluxes throughout the system. As was done for the spring 2016 flux, sediment cores (15.24 cm inside diameter) were collected by SCUBA divers and cores transported back to the Coastal Systems Program analytical facility. Cores were maintained from collection through incubation at in situ temperatures. Bottom water was collected and filtered from each core site to replace the headspace water of the flux cores prior to incubation. Rates of nitrogen release were determined through time-series measurements in the headspace water over the undisturbed sediment cores over 24 hours in temperature-controlled baths. Measurements of total dissolved nitrogen, nitrate + nitrite, ammonium and dissolved organic nitrogen were made at each time point. The summer sampling locations and numbers of cores collected are listed in Table 18, below. The spatial distribution of the stations is presented in Figure 39. Sampling was distributed throughout the system such that the results for each site could be combined to calculate the net nitrogen regeneration rates for the water quality modeling effort.

Table 18: Summary of summer benthic core locations and depths (SUMMER 2016).

Site ID	Date	Latitude	Longitude	Total Depth (m)
C1	7/27/16	41.51395	71.10239	0.90
C2	7/27/16	41.51279	71.10200	1.20
C3	7/27/16	41.51120	71.10158	1.00
C4	7/27/16	41.50990	71.10355	1.00
C5	7/27/16	41.50883	71.10099	0.80
C6	7/27/16	41.50845	71.10387	0.80
C7	7/27/16	41.50704	71.10186	0.70
C8	7/27/16	41.50663	71.10471	0.45

Specifically, the sediment-water column exchange measurements follow the methods of Jorgensen (1977), Klump and Martens (1983), and Howes et al. (1998) for nutrients and metabolism. Upon return to the field laboratory (SMAST), the cores were transferred to pre-equilibrated temperature baths. The headspace water overlying the sediment was replaced, magnetic stirrers emplaced, and the headspace enclosed. Periodic 60 ml water samples were withdrawn (volume replaced with filtered water), filtered into acid leached polyethylene bottles and held on ice for nutrient analysis. Ammonium (Scheiner 1976) and orthophosphate (Murphy and Reilly 1962) assays were conducted within 24 hours and the remaining samples frozen (-20^{o}C) for assay of nitrate + nitrite (Cd reduction: Lachat Autoanalysis), and DON (D'Elia et al. 1977). Rates were determined from linear regression of analyte concentrations through time.

For both the spring and summer flux experiments, chemical analyses were performed by the Coastal Systems Analytical Facility at the School for Marine Science and Technology (SMAST) at the University of Massachusetts in New Bedford, MA [508-910-6325]. The laboratory follows standard methods for saltwater analysis and sediment geochemistry.

Figure 39. Cockeast Pond system 2016 summer (7/27/16) benthic core locations (yellow symbols). Numbers relate to station i.d.'s referenced in Table 18 above. Long-term Water Quality Monitoring stations (CP-1, CP-2) are represented by red symbols.

Rates of Spring 2016 / Summer 2016 Nitrogen Regeneration from Sediments:
Water column nitrogen levels are the balance of inputs from direct sources (land, rain etc), losses (denitrification, burial), regeneration (water column and benthic), and uptake (e.g. photosynthesis). As stated above, during the warmer summer months the sediments of shallow embayments typically act as a net source of nitrogen to the overlying waters and help to stimulate eutrophication in organic rich systems. However, some sediments may be net sinks for nitrogen and some may be in “balance” (organic N particle settling = nitrogen release). Sediments may also take up dissolved nitrate directly from the water column and convert it to dinitrogen gas (termed “direct denitrification”), hence effectively removing it from the ecosystem. This process is typically a small component of sediment denitrification in embayment sediments, since the water column nitrogen pool is typically dominated by organic forms of nitrogen, with very low nitrate concentrations. However, this process can be very effective in removing nitrogen loads in some systems, particularly in streams, ponds and salt marshes, where overlying waters support high nitrate levels.

In addition to nitrogen cycling, there are ecological consequences to habitat quality of organic matter settling and mineralization within sediments, these relate primarily to sediment and water column oxygen status. However, for the modeling of nitrogen within an embayment it is the relative balance of nitrogen input from water column to sediment versus regeneration which is critical. Similarly, it is the net balance of nitrogen fluxes between water column and sediments during the modeling period that must be quantified. For example, a net input to the sediments represents an effective lowering of the nitrogen loading to down-gradient systems and net output from the sediments represents an additional load.

The relative balance of nitrogen fluxes ("in" versus "out" of sediments) is dominated by the rate of particulate settling (in), the rate of denitrification of nitrate from overlying water (in), and regeneration (out). The rate of denitrification is controlled by the levels of organic matter within the sediments, whether the sediments are oxic or anoxic and the concentration of nitrate in the overlying water. Organic rich sediment systems with high overlying nitrate frequently show large net nitrogen uptake throughout the summer months, even though organic nitrogen is being mineralized and released to the overlying water as well. The rate of nitrate uptake, simply dominates the overall sediment nitrogen cycle.

Overall, coastal sediments are not overlain by nitrate rich waters and the major nitrogen input is via phytoplankton grazing or direct settling. In these systems, on an annual basis, the amount of nitrogen input to sediments is generally higher than the amount of nitrogen release. This net sink results from the burial of reworked refractory organic compounds, sorption of inorganic nitrogen and some denitrification of produced inorganic nitrogen before it can "escape" to the overlying waters. However, this net sink evaluation of coastal sediments is based upon annual fluxes. If seasonality is taken into account, it is clear that sediments undergo periods of net input and net output. The net output is generally during warmer periods and the net input is during colder periods. The result can be an accumulation of nitrogen within late fall, winter, and early spring and a net release during summer. The conceptual model of this seasonality has the sediments acting as a battery with the flux balance controlled by temperature (Figure 40).

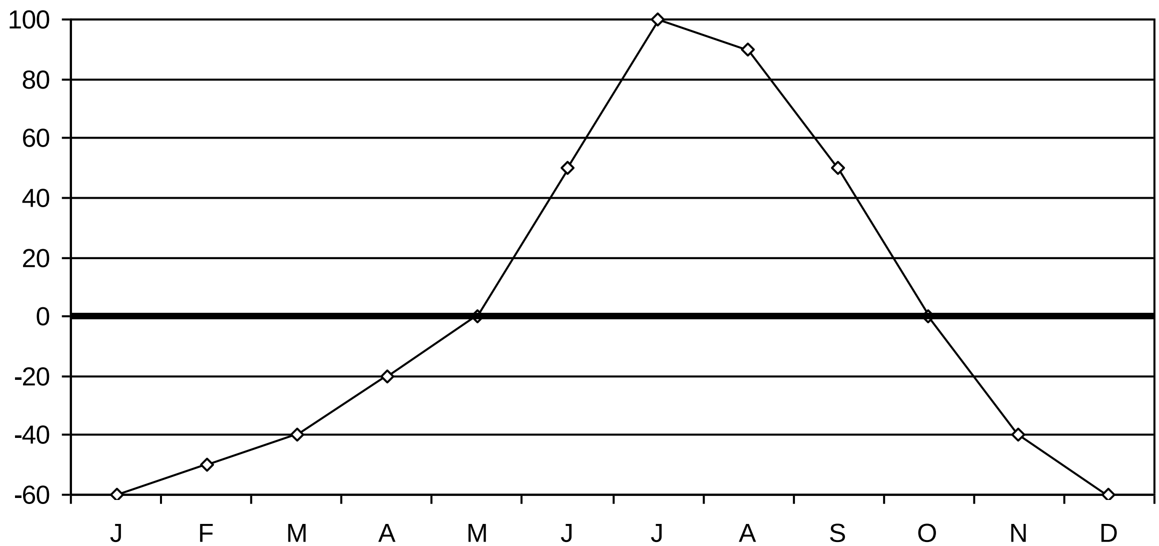

Figure 40. Conceptual diagram showing the seasonal variation in sediment N flux, with maximum positive flux (sediment output) occurring in the summer months, and maximum negative flux (sediment up-take) during the winter months.

Unfortunately, the tendency for net release of nitrogen during warmer periods coincides with the periods of lowest nutrient related water quality within temperate embayments. This sediment nitrogen release is in part responsible for poor summer nutrient related health. Other major factors causing the seasonal water quality decline are the lower solubility of oxygen during summer, the higher oxygen demand by marine communities, and environmental conditions supportive of high phytoplankton growth rates.

In order to determine the net nitrogen flux between water column and sediments, all of the above factors were taken into account. The net input or release of nitrogen within Cockeast Pond was determined based upon the measured total dissolved nitrogen uptake or release, and estimate of particulate nitrogen input.

During both the spring and summer flux experiments, sediment sampling was conducted throughout the upper and lower portions of the Cockeast Pond system. Generally, the distribution of cores was established to cover gradients in sediment type, flow field and phytoplankton density. For each core the nitrogen flux rates (described in the section above) were evaluated relative to measured sediment organic carbon and nitrogen content, as well as sediment type and an estimate of the tidal velocity at each core location. Based on the previously discussed tidal exchange experiments, low flow velocities were selected throughout the Cockeast Pond system, which has been more recently confirmed by direct field measurements of velocity. Flow estimates were then used to determine the sediment nitrogen balance across the system.

The magnitude of the settling of particulate organic carbon and nitrogen into the sediments was accomplished by determining the average depth of water within each sediment site, the average spring and summer particulate carbon and nitrogen concentrations within the overlying water and an estimate of the tidal velocities across the pond. Depositional areas were also determined from an analysis of the sediment type. Based upon the low velocities, a water column particle residence time of ~8 days was generally used (based upon phytoplankton and particulate carbon studies of poorly flushed basins). Adjusting the measured sediment releases was essential in order not to over-estimate the sediment nitrogen source and to account for those sediment areas that are net nitrogen sinks for the aquatic system. This approach has been previously validated in outer Cape Cod embayments (Town of Chatham) by examining the relative fraction of the sediment carbon turnover (total sediment metabolism) which would be accounted for by daily particulate carbon settling. This analysis indicated that sediment metabolism in highly organic rich sediments of wetland dominated areas and depositional basins is driven primarily by stored organic matter (ca. 90%). Also, in more open lower portions of larger embayments, storage appears to be low and a large proportion of the daily carbon requirement in summer is met by particle settling (approximately 33% to 67%). This range and distribution of values is consistent with ecological theory and field data from shallow embayments.

Spring (2016) Nitrogen Flux

Spring rates of net nitrogen release or uptake (nutrient flux) from the sediments within the Cockeast Pond system were averaged based on sediment type. Cores 1-4 were collected in mud / fluid mud, whereas cores 5 and 6 were collected in sand. The flux rates of ammonium, nitrate + nitrite, dissolved organic nitrogen, ortho-phosphate, and dissolved organic phosphorus between the two sediment types differed by at least 20% (Table 19).

Table 19: Summary of nutrient fluxes from sediment (SPRING 2016).

Sediment Type	SOD (mMol•m^{-2}•d)	NH_4^+ (μMol•m^{-2}•d)	NO_3^- (μMol•m^{-2}•d)	PO_4^{3-} (μMol•m^{-2}•d)	TDP (μMol•m^{-2}•d)
(Fluid) Mud (C1-C4)	44.0	393.3	-16.6	-221.3	-93.0
Sand (C5 & C6)	51.3	634.8	-9.0	-268.9	-142.0

Based on the spring flux experiment, ammonia was the dominant form of nitrogen released (+) from the sediments. Ammonium is readily incorporated into plant biomass. Benthic regeneration of ammonium varied throughout Cockeast Pond (Figure 41). Also a low level of direct denitrification was found at both sites (nitrate uptake).

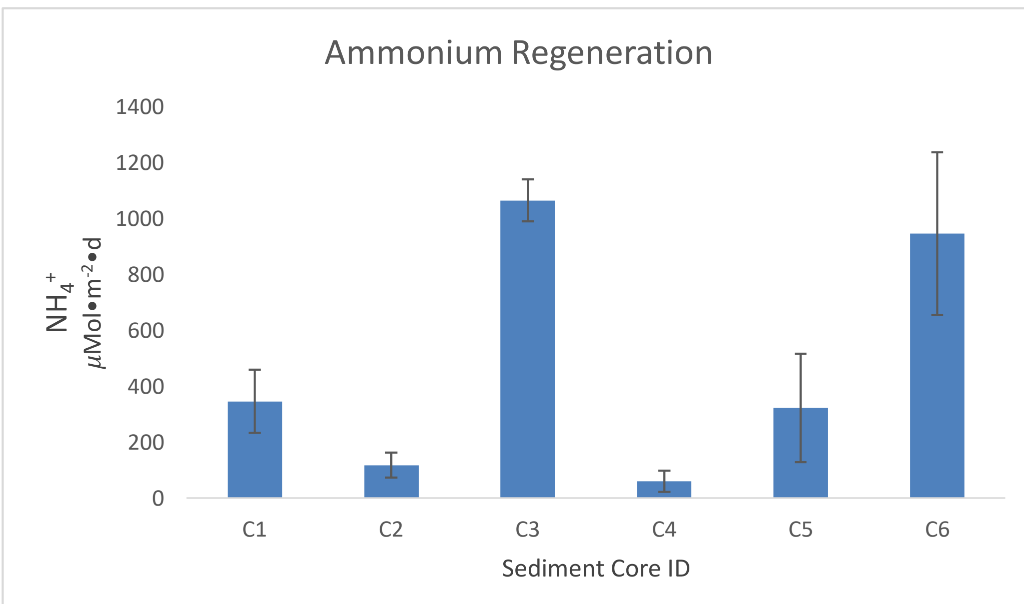

Figure 41. Core specific ammonium regeneration rates in Cockeast Pond (April 2016).

Spring benthic regeneration of nitrate was low and variable, with most sites showing a low level of uptake of nitrate, only one site (3) showed a net release from the sediment (Figure 42).

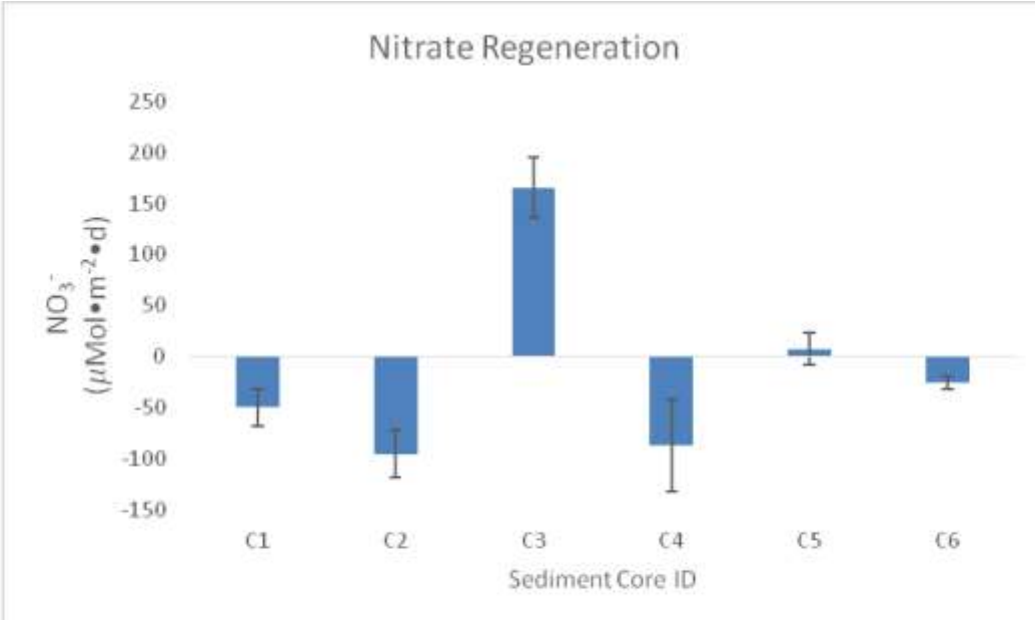

Figure 42. Core specific Nitrate (+ nitrite) regeneration rates in Cockeast Pond (April 2016).
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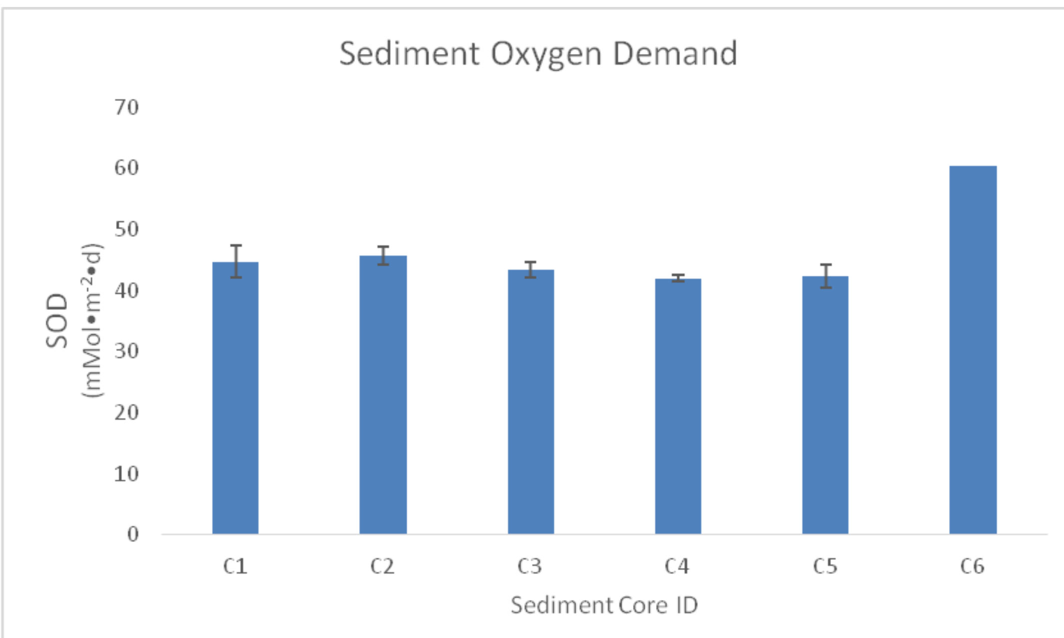


Figure 43. Core specific sediment oxygen demand in the Cockeast Pond system (April 2016).

Oxygen is used by bacteria in the sediments for aerobic mineralization of organic matter and chemoautotrophic processes, e.g. nitrification. Uptake of oxygen by the sediments was generally constant for each core site throughout the pond (Figure 43). This most likely results from the non-tidal nature of the pond which tends to result in a relatively uniform deposition of organic matter to the sediments and therefore oxygen uptake.

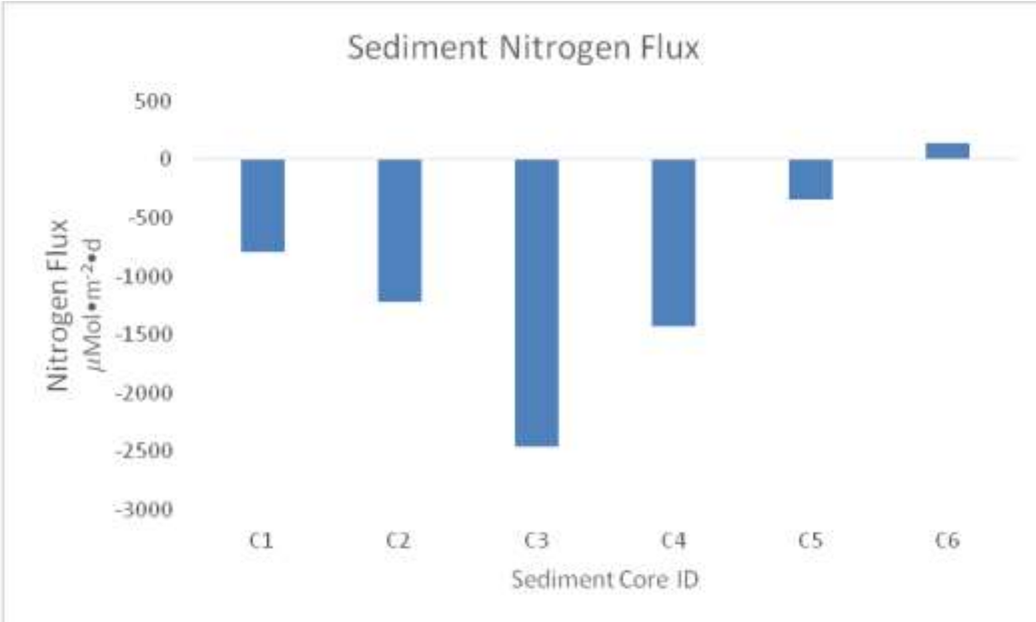


Figure 44. Rates of net nitrogen fluxes across the sediment – water column interface. Dissolved inorganic nitrogen flux rates were combined with particulate organic nitrogen settling rates which shows a net nitrogen uptake by the sediments in early spring.

Net nitrogen release or uptake rates in the spring (April 2016) from the sediments within Cockeast Pond are shown in Figure 44. In the spring, a general trend of nitrogen uptake by the sediments was observed. As expected, variation in nitrogen uptake rates between the sediment cores was also observed as some cores varied in grain-size, but have relatively similar organic contents. The net nitrogen flux rates were determined by combining the measured dissolved inorganic nitrogen uptake or release with an estimate of particulate nitrogen input. Particulate organic nitrogen input was estimated by determining the water depth at each core site and the average particulate nitrogen concentration within the water column. The water column concentration was multiplied by a settling rate to determine the amount of nitrogen input through settling. The net deposition of nitrogen is expected due to the low water temperatures resulting in low rates or remineralization. Under these conditions, deposition is occurring but the regeneration of nitrogen is low, so the net is dominated by deposition.

Summer (2016) Nitrogen Flux

A detailed survey of the nitrogen balance of Cockeast Pond sediments was conducted during the critical summer management period in 2016. In this analysis 3 major components of the sediment nitrogen balance were determined: (a) net sediment exchange between overlying water and sediments, (b) measurements of denitrification (as N_2 production), and (c) change in sediment storage of nitrogen.

Summer rates of net nitrogen flux from the sediments to the water column throughout Cockeast Pond were found to be negative, indicating that overall the sediments were receiving more nitrogen in deposition or in nitrate uptake than was being released in dissolved forms after decomposition (Table 20). While this is not always the case, it is typical of shallow brackish salt ponds throughout the region. The rates of net N uptake (in) was negative in both the northern region of the main basin and the deeper southern region, although there was a clear pattern. The northern region (-15.0 mg N m^{-1} d^{-1}) has more organic rich sediments which were soft, anoxic and contained some free sulfides compared to the southern region which generally supported less organic rich find sands with an oxic surface. The more oxic nature of the southern surficial sediments is likely the reason for the higher rate of net nitrogen uptake (-36.1 mg N m^{-1} d^{-1}) due the better conditions for coupled nitrification-denitrification.

The net uptake rates in summer in Cockeast Pond sediments are comparable to other tidally restricted salt ponds on Cape Cod surveyed by the Massachusetts Estuaries Project. For example, the upper brackish tidally restricted basins of Rushy Marsh (Barnstable), Swan Pond (Swan Pond River System, Dennis), Seine Pond (Parkers River System, Dennis), and Farm Pond (on Martha's Vineyard) with summer rates of sediment net nitrogen uptake of -19.0 mg N m^{-1} d^{-1}, -8.0 mg N m^{-1} d^{-1}, -16.9 mg N m^{-1} d^{-1}, and -25.7 mg N m^{-1} d^{-1}, respectively. They were also similar to enclosed brackish upper basins of estuaries, such as Childs River (-45.2 mg N m^{-1} d^{-1}) and Eel River (-29.2 mg N m^{-1} d^{-1}) in the Waquoit Bay Estuarine System.

Overall, the summer sediment nitrogen release from the sediments within the northern and southern regions of the Cockeast Pond main basin are comparable to other similarly configured enclosed basins, are consistent with basin morphology, sediment type, sediment oxidation levels and water depth. The sediments appear to be in balance with the overlying waters and uptake rates are consistent with the level of nitrogen loading to this salt pond with its limited tidal exchange. Net nitrogen flux rates for use in the water quality modeling effort are presented in Table 20.

Table 20. Summer rates of net nitrogen exchange from sediments to the overlying waters of the Cockeast Pond system. These values are combined with the basin areas to determine total nitrogen mass in water quality models. Measurements represent July rates.

	Sediment Nitrogen Flux (mg N m-2 d-1)			
Location	Mean	S.E.	N	Core i.d. *
Cockeast Pond System				
Main Basin – North	-15.0	18.7	4	CP-1, 2, 3, 4
Main Basin – South	-36.1	10.9	4	CP-5, 6, 7, 8

* Station i.d. numbers refer to Figure 39.

In addition to determining the net sediment-water column exchange, the total of direct and coupled denitrification was determined with a membrane injection mass spectrometer to yield highly accurate rates of increase in N_2 during the core incubations. These data were consistent with the sediment properties discussed above where the anoxic sediments in the northern basin have reduced coupled nitrification-denitrification as it requires oxygen in surficial sediments to oxidize ammonium produced by decomposition in the sediments to form nitrate to support denitrification. In contrast, the more oxidized sediments of the southern region appear to have supported 6 fold higher rates of denitrification, due to higher rates of coupled nitrification-denitrification, hence higher overall denitrification (removal of fixed N as N_2 gas). These results strongly support that the storage of nitrogen (as organic and inorganic forms) within the sediments throughout Cockeast Pond in July is ~12 mg N m^{-1} d^{-1} (difference between efflux and denitrification). It should be noted that this “stored N” contains short and long-term N pools. Much of this nitrogen in organic forms will be decomposed and either released to the overlying water or denitrified. The long-term pool is what eventually is “permanently” buried in the pond sediments. The relatively high proportion of the total nitrogen cycled 24% and 65% of cycled N (non-stored) that is denitrified is well within the range for brackish sediments in natural systems, and forms a nitrogen removal pathway which is currently lowering the level of nitrogen enrichment in pond waters. Further organic enrichment of Cockeast Pond resulting in bottom water hypoxia will reduce the extent of this denitrification pathway resulting in a significant increase in water column nitrogen levels and further degradation of Cockeast Pond. Maintaining oxygen levels is therefore a management concern relative to nitrogen loading, not just benthic animal habitat in this system.

Cockeast Pond Nutrient Balance (Watershed Loading, Stream Loading, Water Column Nutrient Concentrations)

Updated Cockeast Pond Watershed Land-use Based Loading Analysis:

Watershed Delineation Background

During the Westport River MEP assessment (2012), project staff completed watershed delineations of the overall Westport River Estuarine System, as well as the its various subwatersheds, including Cockeast Pond (Figure 45). The overall watershed is primarily composed bedrock geology overlain with various glacial till deposits and stratified drift deposits down the main river valley (Bent, 1995). Cockeast Pond is located in an area that is primarily till deposits, which tend to be unsorted, unstratified mixtures of clay, silt, sand, cobbles, and boulders and with varying composition from location to location. Review of surficial soils within the Cockeast Pond subwatershed reflect this diverse mixture with a variety of fine sandy loams interspersed with stony pockets (USDA, 2016).

Till materials tend to have relatively low permeability compared to drift materials and, as such, tend to favor stormwater runoff more than percolation into the soils and subsurface recharge. In these types of settings, precipitation tends to form runoff streams. Smaller streams may be ephemeral and, because of this, are often altered by land use developments, sometimes resulting in wet depressions or runoff crossing lawns or roads. Because of these characteristics, watershed delineations in these types of areas, such as the Cockeast Pond watershed, are generally based on topography and the tendency of surface water and groundwater to flow downhill perpendicularly to the topographic contour lines. Watershed delineation of the Cockeast Pond watershed focused on determining the pattern of local maximum elevations, which function as watershed divides, based upon US Geological Survey 1:25,000 topographic maps. These divides can be confirmed by observing general patterns of groundwater flow and surface water flow during rainfall or snow melt or by measuring the flow of water in streams over a hydrologic cycle.

Using the watershed delineation and a region-specific recharge rate, MEP staff developed an estimate of the annual freshwater input to Cockeast Pond of 4,726 cubic meters per day. Additionally, a delineation was created for the sub-watershed to the small groundwater fed stream discharging into the head of Cockeast Pond. Given the area of the stream subwatershed and an average recharge rate (30.46 inches per year), an estimate of stream discharge was calculated to be 2,122 m^3/day (Figure 45). Development of the MEP recharge rate for the Westport River watershed was based on a review of available regional precipitation datasets and estimates of recharge rates based on both modeling and measurements. Precipitation data was primarily based on readings since 1961 at the National Oceanic and Atmospheric Administration (NOAA) gauge at New Bedford. These readings generally show an increasing precipitation rate, but MEP staff utilized a rate of 50.77 inches per year, which is the average between 1971 and 2000. Review of transpiration and recharge rates resulted in the use of a 60% recharge rate, which combined with the precipitation rate resulted in an MEP recharge rate of 30.46 inches per year. Use of this recharge rate with the MEP stream subwatershed areas in the 6 gauged streams within the overall Westport River Estuary watershed resulted in good agreement with the predicted and measured stream flows suggesting that the modeled stream flows are accurate in this setting.

Watershed Land use and Nitrogen loading Factors (Update)
As a result of the current project, CSP/SMAST staff and our partners (WRWA) had the opportunity to update and refine the MEP watershed land use analysis and nitrogen loading to Cockeast Pond. During the Westport River MEP assessment, project staff worked with the towns in the watershed, including the Town of Westport, to develop parcel-by-parcel nitrogen loads throughout the watershed. This effort included characterization of each parcel based on town assessor land use information, incorporation of available water use information, review of household occupancy rates, golf course fertilizer rates, and review of agricultural land uses.

During the current Cockeast Pond assessment project, project staff reviewed all of these factors and updated those where additional watershed-specific information was needed. With assistance of staff from the Westport River Watershed Alliance (WRWA), a land use survey was prepared and mailed to all properties within the Cockeast Pond watershed. The survey included questions about seasonality, lawn sizes, fertilizer use, and agricultural uses. Although the response to the survey was low, information developed during the survey and subsequent follow-up visits to individual properties helped to provide updated information for the development of the revised Cockeast Pond watershed nitrogen loading model. The details of these updates and others are summarized below.

Land Use and Water Use Database Preparation
Development of the MEP watershed nitrogen loading model is based on the identification of individual parcels within the watershed (Figure 46) followed by assignment of parcel based nitrogen loads, watershed, and regionally-specific loading factors. Individual parcels are typically identified through the use of town assessor's parcel delineations and records of parcel use. For the update of the Cockeast Pond watershed loads, project staff reviewed current town assessor and MassGIS parcel delineations and compared these results to the town assessor information supplied to MEP in 2008. Comparison of parcel counts from the various sources resulted in the addition of one parcel to the total of 172 parcels within the Cockeast Pond watershed.

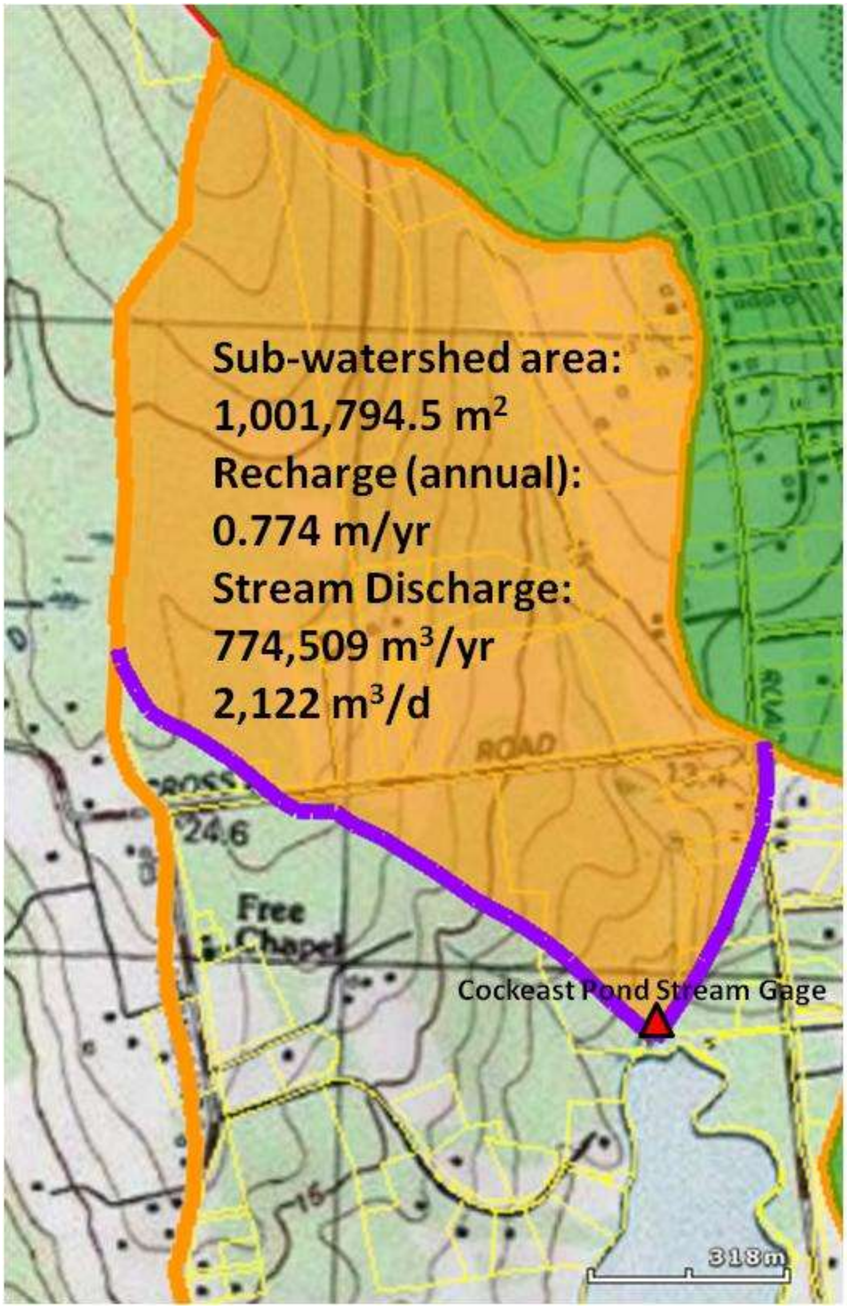


Figure 45. Topographically delineated sub-watershed to the groundwater fed stream discharging into Cockeast Pond. Modeled discharge is based on the average recharge rate and the subwatershed surface area. Measured discharge can be higher or lower depending on whether precipitation conditions are above or below average for a given year.

Water use is used as a proxy for wastewater generation in MEP assessments. The individual parcel water use rates are adjusted to account for irrigation and other consumptive uses. Most of the Westport River Estuary watershed relies on private on-site wells for drinking water; therefore individual parcel water uses were generally not available for the original MEP analysis. As a result, MEP staff consulted with all of the towns in the watershed and decided to utilize the available Town of Dartmouth water use database (8,184 accounts) to assign an average water use of 188 gallons per day to most developed properties within the Westport River watershed. Properties with multiple residential units were assigned a rate twice as large (Figure 46). MEP staff compared the average rate for single family residences and were based on average residential occupancy values from the US Census. It was determined that this water use was likely conservative, but generally reasonable for the Westport River Estuary watershed.

For the current Cockeast Pond specific assessment project, staff was able to contact one of the public water suppliers within the Cockeast Pond watershed. During the MEP assessment, staff had identified four potential public water supply wells near Cockeast Pond, but had not been successful in contacting any of the purveyors. As a result of the current project, technical staff were able to contact Woody Underwood, Past President of the Westport Harbor Aqueduct Company (WHAC). Based on conversations with Mr. Underwood (November, 2016), WHAC supplies 53 customers, which have been the same for approximately 10 years and are located to the southeast of Cockeast Pond in the area bisected by Acoaxet Road. Mr. Underwood could not supply information for individual parcels in the area, but reviewed his records and provided average monthly pumping rates from the past 10 years (**Figure 47**). Using this information with additional insights from Mr. Underwood regarding summer usage of properties, types of use for selected properties and lawn irrigation practices, staff developed a site specific average water use of 113 gpd for the WHAC, representing about 1/3 of the residences in the subwatershed. After unsuccessful attempts to contact any of the other water suppliers near Cockeast Pond, this average water use was used as the average water use for all developed properties within the Cockeast Pond watershed.

Fertilized Turf Areas

Within estuary watersheds with predominantly residential development, fertilizer turf areas of residential lawn and golf courses are typically the second largest source of nitrogen loading. The MEP assessments generally use turf loading rates based on regional assessments of homeowner application rates (White, 2003; Howes, *et al.*, 2015), nitrogen leaching rates (*e.g.*, HWG, 2009), and lawn sizes. For the current project, staff from the Westport River Watershed Alliance (WRWA) reviewed aerial photographs and conducted windshield surveys to measure lawn areas and estimate whether turf fertilizers were used for each property within the Cockeast Pond watershed. In addition, project staff consulted with Acoaxet Club staff to determine average nitrogen fertilizer applications and understand how residual nitrogen might be recirculated on the site through the Club's irrigation system.

Based on the WRWA lawn review, 77 properties in the Cockeast Pond watershed were identified as having fertilized lawns for a total fertilized lawn area of 1,321,567 square feet (or an average of 17,163 square feet per property). During the MEP assessment, average fertilized lawn area for residential dwellings was assumed to be 5,000 square feet based on previous in-depth reviews of residential lawn areas with the region. Additional observations by WRWA staff noted that lawn services maintained 60-70% of the lawns. CSP/SMAST staff analysis of fertilizer application practices differ substantially between lawn services and homeowners; homeowners fertilize an average of 1.08 lbs of nitrogen per 1,000 square feet of turf, while lawn services apply an average of 3 lbs of nitrogen per 1,000 square feet per year. Using these factors with observations of practices within the Cockeast Pond watershed, staff assumed that 65% of the fertilized turf was managed by lawn services and the remaining 35% was fertilized by property owners. The net result was that the fertilizer application rate was increased from the 1.08 lbs of nitrogen per 1,000 square feet of turf used in the MEP assessment to 2.33 lbs of N per 1,000 sq ft due to the high fraction of lawns using commercial lawn services. Based on all of the gathered information, lawn fertilizers were estimated to contribute a combined total of 279 kg of nitrogen per year.

The golf course at the Acoaxet Club is the only golf course in the Cockeast Pond watershed. As is typically done in MEP assessments, golf course turf areas were digitized and categorized based on their use: tees, greens, fairways, and rough. Working with the Town of Westport Estuaries Project Committee, fertilizer application rates were obtained from the club and a total turf nitrogen load from the golf course was determined. During the current project, technical staff met with Acoaxet Club staff and obtained site-specific fertilizer application rates, layout of the course irrigation system, and insights into Club turf management practices. Based on these conversations, the range of nitrogen applications for the various turf types (all in lbs of N per 1,000 sq ft) at the course were: 1.5 to 2.5 for greens, 2 to 3 for tees and fairways, and no applications on roughs (Keith Kruger, Superintendent, December 2016 personal communication). Project staff digitized the turf areas again based on updated aerial photographs and generally found that the total turf area was similar to the 17 acres of fertilized area digitized for the MEP assessment.

Mr. Kruger also provided project staff with additional information on the irrigation practices at the course. The Club has installed an irrigation system that allows targeted distribution of water to the greens, tees, and fairways (**Figure 48**). This system draws water from the approximately 25,000 sq ft fresh pond located to the east of the 7th hole green and approximately 80 m west of Cockeast Pond. Based on irrigation records maintained by the Club, 4.6 to 5.3 million gallons were annually pumped from the pond between 2014 and 2016. Based on annual monitoring data provided by the Club, the pond water averaged 1.45 mg/L nitrate-N between 1985 and 2009. Using this concentration with the measured irrigation flows results in annual nitrogen load of between 25 and 32 kg that was captured by the pond and distributed back on to the course through the irrigation system. This load would not be new load, but would essentially represent a closed nitrogen loop on the golf course site. It is also likely that some portion of the nitrogen captured in the irrigation pond is denitrified, but quantitative data is not available. More refined monitoring of the nitrogen loads on the site would be necessary to further characterize the golf course nitrogen loads. Overall, the present best estimate of nitrogen load from the golf course to Cockeast Pond was 162 kg per year, based upon the new golf course specific information.

Agricultural Areas

During the development of the MEP Westport River watershed nitrogen loading model, MEP staff coordinated development of agricultural loads with town, state, and federal staff regarding animal counts and nitrogen fertilizer use. For the Town of Westport, this coordination included the Estuaries Project Committee and Agricultural Committee. Since the completion of the MEP report, staff have held a number of follow-up meetings and encouraged the Town to refine these loads for the overall Westport River Estuary watershed. During the current project, WRWA staff discussed agricultural practices within the watershed with individual property owners who responded to the land use survey. WRWA staff also developed information about farm animals from survey follow-ups and review of multiple historic aerial photos available through Google Earth. These updates are summarized below and were incorporated in the update to the Cockeast Pond watershed nitrogen loading model.

Through the efforts of WRWA staff, three properties with farm animals were identified within the Cockeast Pond watershed. These three properties support horses, steer, sheep, and chickens. One of the property owners covered its accumulated animal manure and removed it from the site annually; based on this manure management practice, this property was assigned no nitrogen load from the farm animals on the site. As a result of the animal counts and nitrogen loading factors developed during the MEP, the net result was that farm animals were assigned a total annual nitrogen load of 310 kg N per year within the Cockeast Pond subwatershed in the updated Cockeast Pond watershed loading model.

Based on further discussions and aerial photo analysis, WRWA staff surveys confirmed that there were no agricultural crops other than hay within the Cockeast Pond watershed. In addition, it was noted that none of the hay was harvested or fertilized. Hay tended to be mowed annually and left in place. As such, no nitrogen loading from agricultural fertilizers was assigned within the Cockeast Pond watershed in the updated Cockeast Pond watershed loading model.

Freshwater Wetlands

During the course of the Westport River MEP assessment, it was noted that nitrogen loading was likely occurring from freshwater wetlands within the watershed due to the interaction of the hydrogeology of the watershed system with the wetlands near the rivers, streams and the estuary. The combination of these factors reduced the residence time of precipitation within these wetlands and as such did not attenuate the deposited atmospheric load as much as in other wetlands in other geologic settings (e.g. Cape Cod) where precipitation infiltrates. Within the Cockeast Pond watershed, there is a freshwater wetland area of 42 acres. This area was assigned a nitrogen load of 215 kg N per year in the Cockeast Pond subwatershed of the MEP Westport River Estuary watershed nitrogen loading model and this load is also assigned to Cockeast Pond in the current project.

Other Nitrogen Loading Factors

Other nitrogen loading factors used the current Cockeast Pond watershed nitrogen loading model update remain unchanged from the MEP Westport River Estuary assessment. These factors include those for atmospheric deposition, impervious surfaces and natural areas (Howes, *et al.*, 2012). The factors are similar to those utilized by the Cape Cod Commission Nitrogen Loading Technical Bulletin (Eichner and Cambareri, 1992) and the MassDEP Nitrogen Loading Computer Model Guidance Document (1999).

Road areas are based on MassHighway GIS information, which provides road width for various road segments. MEP staff utilized GIS to sum these segments and their various widths by sub-watershed. Project staff also checked this information against parcel-based rights-of-way.

Updated Cockeast Pond Watershed Nitrogen Loading

All of the updated nitrogen loading information for Cockeast Pond was linked to the updated parcel coverages and an overall watershed nitrogen load to Cockeast Pond was determined. The overall watershed nitrogen load (Table 21) based upon all of the updated information is 1,689 kg N per year. The largest component of the watershed load (30%) was wastewater from Title 5 septic systems with nitrogen loads from farm animals (18%) and residential lawn fertilizers (16%) representing the next largest components (**Figure 49**).

The total watershed nitrogen load from the updated watershed N loading model for the current project is approximately the same as the loading estimate from the MEP assessment, but loads were attributed to the various sources slightly differently. The MEP Cockeast Pond watershed nitrogen load was 1,746 kg per year (or 3% higher than the current updated load). In the MEP estimate, the largest watershed nitrogen loading component was wastewater from Title 5 septic systems (48%) with nitrogen loads from agriculture as the next largest component (26%). Comparison of the loads from the MEP assessment to the current project show that the wastewater and agricultural loads were lower in the updated model, while the fertilizer load was greater due to updates in both residential lawn areas and golf course application rates. The agricultural load also changed from crop fertilizers in the MEP assessment to farm animal loads in the current project.

Figure 46. Cockeast Pond watershed. Parcels are outlined in yellow and are from the town assessor's database and are included in the 2012 MEP report. Review of updated parcel coverages for the current project showed the addition of one additional parcel.

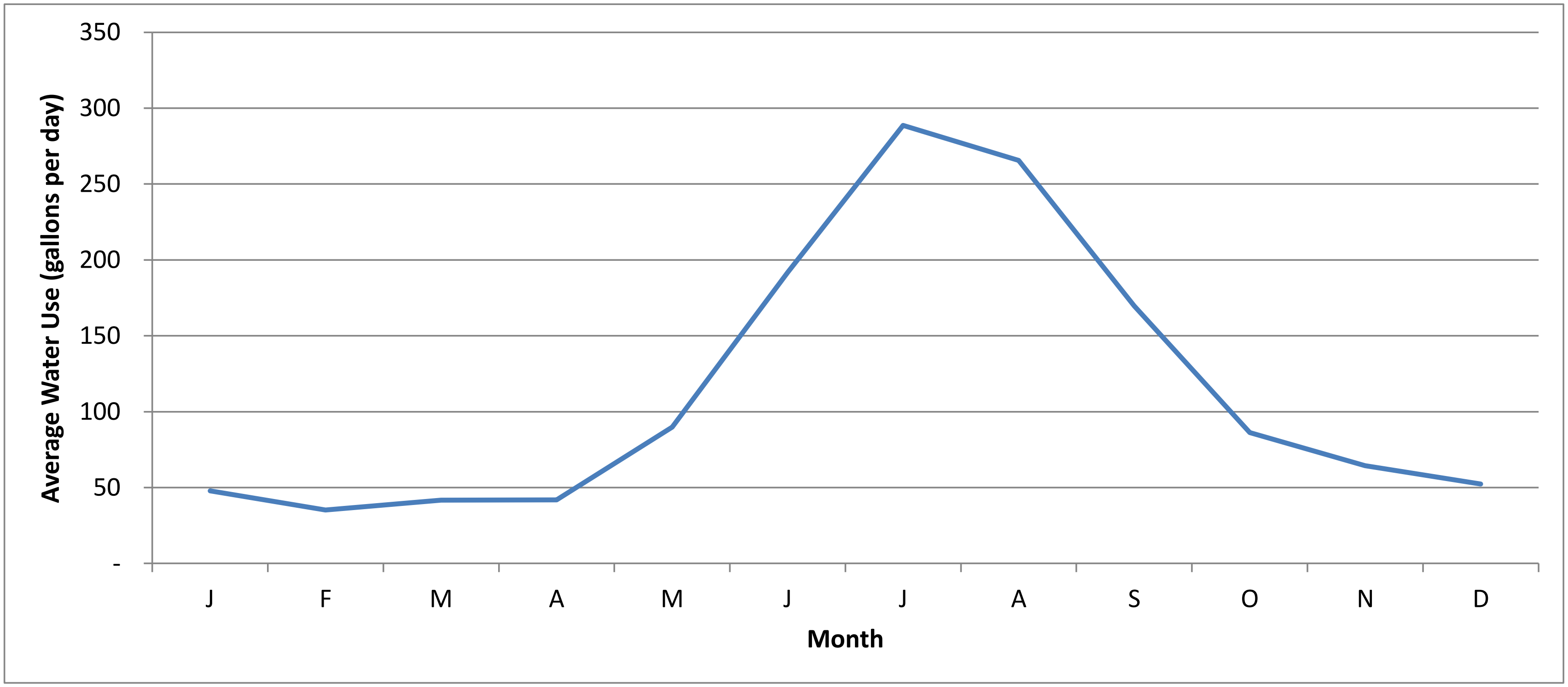


Figure 47. Average Water Use for Westport Harbor Aqueduct Company. Based on 10 year average pumping rates and customer counts provided by Woody Underwood, past company president (November, 2016). Some of the summer increase in use was due to irrigation of residential lawns, but observations of suggest that the majority of the increase was due to increases in summer occupancy. Average annual water use is 113 gpd per property.

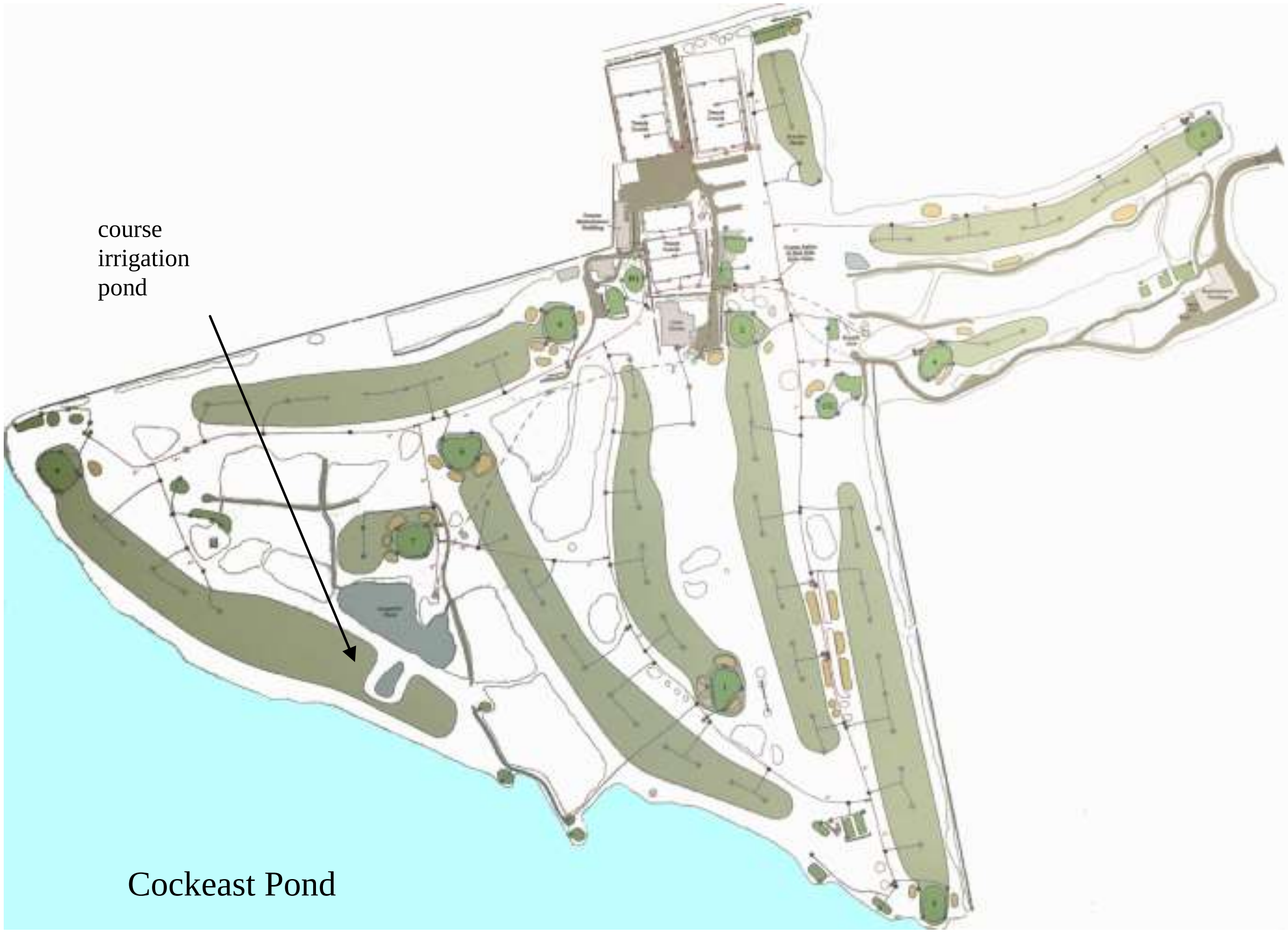
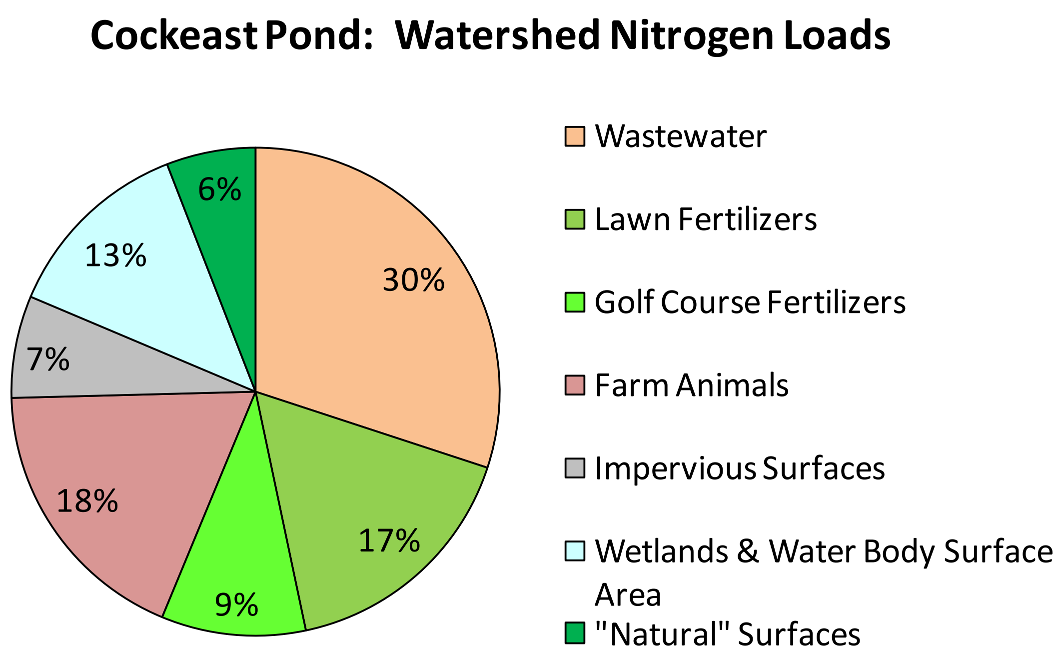
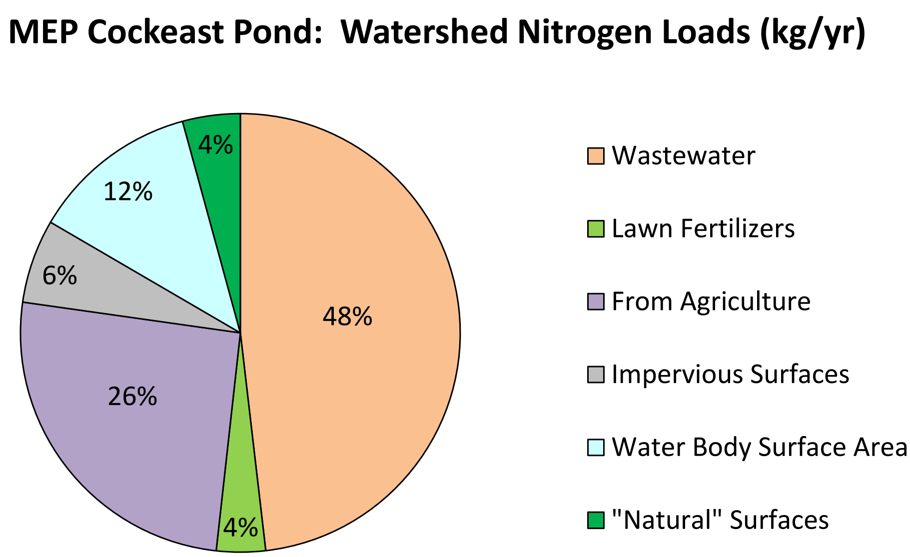


Figure 48. Irrigation system at Acoaxet Club golf course. Sprinkler heads are located to irrigate only the greens, tees, and fairways of the golf course. Irrigation water is withdrawn from the course irrigation pond. Water quality monitoring data from the pond suggests that it captures some of the nitrogen used as fertilizers on the course and returns it to the irrigated turf areas. Modified from an irrigation system map provided by the course superintendent (K. Kruger, personal communication).



a. Current updated watershed nitrogen load (%) by source



b. 2012 MEP watershed nitrogen load (%) by source.

Figure 49. Cockeast Pond watershed nitrogen load by source category with comparison between (a) current updated watershed modeled load and (b) the watershed load from the 2012 MEP. The total loads were approximately the same 1,692 kg/yr and 1,746 kg/yr, respectively, but the distribution among sources was slightly different. The largest source in both estimates was wastewater from Title 5 septic systems, but this source is somewhat smaller in the update because of a reduced wastewater flow. Lawn fertilizer loads were significantly increased in the update by closer inspection of lawn areas and fertilizer practices. Agricultural loads were significantly altered from crop fertilizers to farm animals. Most of the loads from other sources were relatively similar in both estimates.

		Cockeast Pond N Loads by Input (kg/y):							Present N Loads		
Watershed Name	shed ID#	Waste Water	Lawn Fertilizers	Golf Course Fertilizers	Farm Animals	Impervious Surfaces	Wetlands & Water Body Surface Area	"Natural" Surfaces	UnAtten N Load	Atten %	Atten N Load
Cockeast Pond TOTAL	**14**	508	282	162	310	114	216	100	1,692		1,692
Cockeast Pond Salt		420	200	162	-	97	204	45	1,127	0	1,127
Cockeast Pond Stream		88	82	-	310	18	12	55	565	0%-40%	565
Cockeast Pond Surface	14						526		526	0	526

Table 21. Nitrogen loads to Cockeast Pond by source for the overall watershed as well as the stream and groundwater watersheds separately. Note that due to the low flow year it was not possible to determine an accurate N attenuation rate for the stream. The stream measured load was 325 kg/yr discharging to the pond in 2015, a drought year, an attenuation rate of 42%. However, to be conservative (until additional stream data is available) for the present an attenuation rate of 0% was used.

Streamflow and Nutrient Loading Analysis:

Modeling and predicting changes in coastal embayment nitrogen related water quality is based, in part, on determination of the inputs of nitrogen from the surrounding contributing land or watershed relative to the tidal flushing and nitrogen cycling within the embayment basins. This watershed nitrogen input parameter is the primary term used to relate present loads to changes in water quality and habitat health. Therefore, nitrogen loading is the primary threshold parameter for protection and restoration of estuarine systems such as Cockeast Pond and the broader Westport River estuary. Rates of nitrogen loading to Cockeast Pond were based upon the delineated watersheds established under the Massachusetts Estuaries project analysis of the Westport River described above and a refined analysis of the land-uses within the watershed to Cockeast Pond with specific attention to the nutrient loads associated with the residential water-use, Acoaxet Golf Club and agricultural practices.

If all of the nitrogen applied or discharged within a watershed reaches an embayment the watershed land-use loading rate represents the nitrogen load to the receiving waters. This condition exists in watersheds where nitrogen transport from source to estuarine waters is through groundwater flow in sandy outwash aquifers (such being the case in the developed region of southeastern Massachusetts but more so on Cape Cod). The lack of nitrogen attenuation in these aquifer systems results from the lack of biogeochemical conditions needed for supporting nitrogen sorption and denitrification. However, in most watersheds in southeastern Massachusetts, nitrogen passes through a surface water ecosystem (pond, wetland, stream) on its path to the adjacent embayment. Surface water systems, unlike sandy aquifers, do support the conditions needed for nitrogen retention and denitrification. The result is that the mass of nitrogen passing through lakes, ponds, streams and marshes (fresh and salt) can be diminished by natural biological processes that represent removal (not just temporary storage). However, this potential natural attenuation of nitrogen during transport is not uniformly distributed within the watershed, but is associated with ponds, streams and marshes to varying degrees based on habitat and residence time. For example, in the watershed for the Westport River Estuary, a portion of the freshwater flow and transported nitrogen passes through several surface water systems (e.g. the Westport River discharging to the head of the East Branch from the up-gradient Lake Noquachoke, Kirby Brook discharging to the East Branch, Snell Creek discharging to the East Branch, Adamsville Brook discharging to the head of the West Branch and Angeline Brook discharging to the West Branch) prior to entering the estuary, producing the opportunity for significant nitrogen attenuation under appropriate conditions. This is similarly the case with the small un-named stream that flows into Cockeast Pond along its northern shore.

Failure to determine the attenuation of watershed derived nitrogen discharging to Cockeast Pond overestimates the nitrogen load to its waters thereby greatly affecting the accuracy of any nutrient balances being developed for this salt pond. Fundamentally, proper development and evaluation of nitrogen management options requires accurate determination of the nitrogen loads reaching an embayment, not just loaded to the watershed, because the difference between the land use based load and the attenuated load can be significant. Whereas some systems have high attenuation rates, others like Kirby Brook, Snell Creek and Angeline Brook have attenuation rates that are quite small (0.2%, 6%, 3% respectively).

Given the importance of determining accurate nitrogen loads to embayments for developing effective management alternatives and the potentially large errors associated with ignoring natural attenuation, direct integrated measurements of upper watershed attenuation were undertaken as part of the Cockeast Pond assessment. To this end, the CSP technical team conducted long-term measurements of flow and nitrogen load in the single significant surface water discharge to the Cockeast Pond basin (Figure 50). A stream gauge was deployed in the small stream just upstream of where the stream discharges into Cockeast Pond. The goal is to capture at the gauge the full flow and N load to determine the nitrogen load to the Pond which also includes the biological functions within the watershed that attenuate nitrogen load during transport.

Measurement of the flow and nutrient load associated with the freshwater streams discharging to the pond provides a direct integrated measure of all of the sources of N input and processes presently attenuating nitrogen in the contributing area up-gradient from the gauging site. Flow and nitrogen load were measured in the Cockeast Pond stream for one year (12 months from March 2016 to March 2017). During the stream flow study period, volumetric discharge measurements were completed every two weeks and annualized using the continuous stage record.

Volumetric discharge measurements are based upon the summation of the products of stream subsection areas of the stream cross-section and the respective measured velocities which yield the instantaneous stream volumetric flow (Q). Stream discharge was represented by the summation of individual discharge calculations for each stream subsection for which a cross sectional area and velocity measurement were obtained. Velocity measurements across the entire stream cross section were not averaged and then applied to the total stream cross sectional area.

The formula that was used for calculation of stream flow (discharge) is as follows:

$$Q = \Sigma(A * V)$$

where by:

Q = Stream discharge (m^3/s)
A = Stream subsection cross sectional area (m^2)
V = Stream subsection velocity (m/s)

Thus, each stream subsection will have a calculated stream discharge value and the summation of all the sub-sectional stream discharge values will be the total calculated discharge for the stream.

Periodic measurement of flows over the entire stream gauge deployment period allowed for the development of a stage-discharge relationship (rating curve) that could be used to obtain flow volumes from the detailed record of stage measured by the continuously recording stream gauges (Figure 51). Water level data obtained every 10-minutes was averaged to obtain hourly stages for the stream into Cockeast Pond. These hourly stage values were then entered into the stage-discharge relation to compute hourly flow. Hourly flows were summed over a period of 24 hours to obtain daily flow and further, daily flows summed to obtain annual flow. A complete annual record of stream flow (365 days) was generated for the stream discharge to the pond and that was used as an input term to the models developed for the Cockeast Pond system.

Figure 50. Locations and ID's of Cockeast Pond water quality sampling sites, stage recorder sites, and flow measurement locations. Stream flow and load determined for "Station CP Stream Inlet".

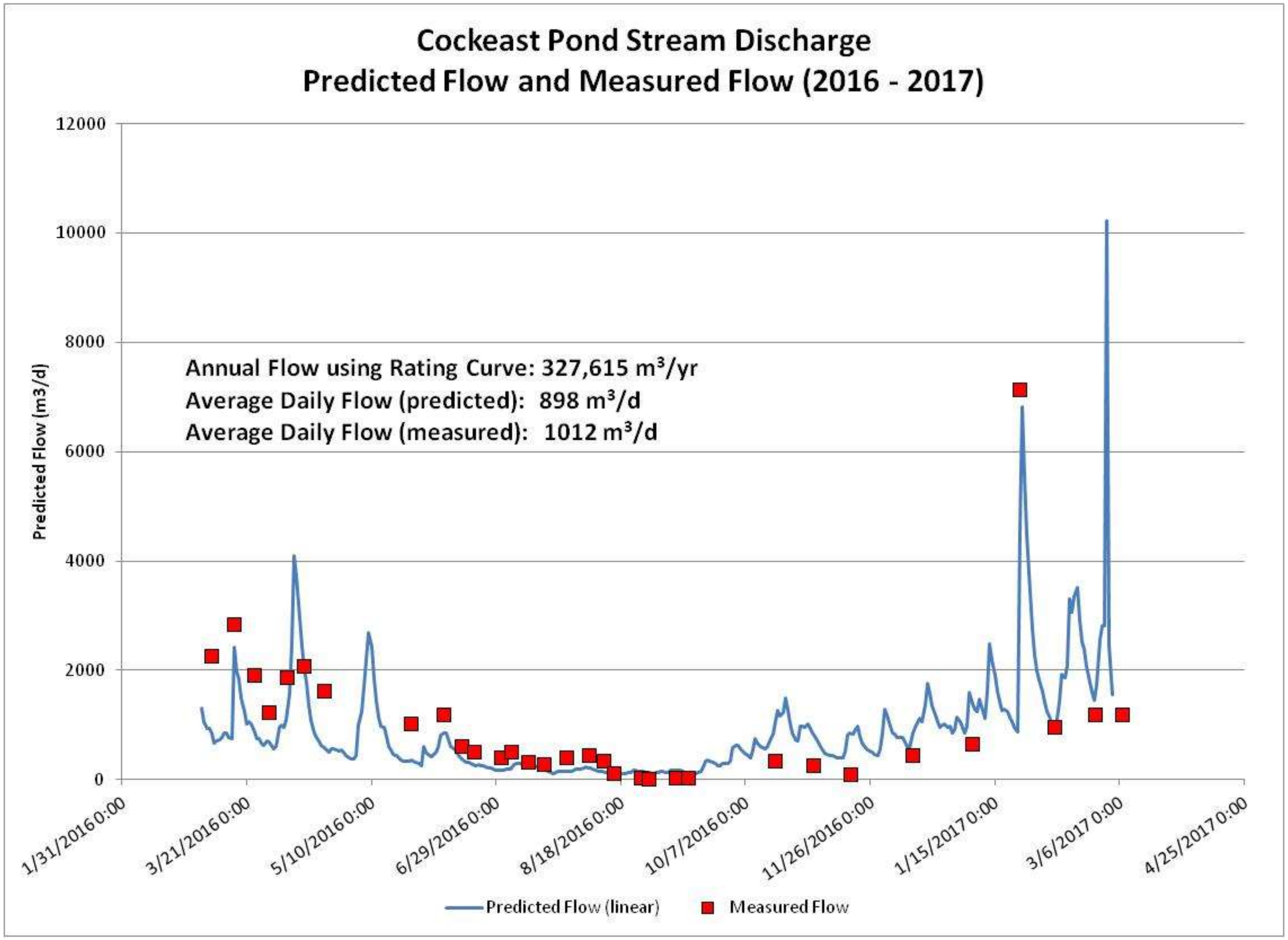


Figure 51. Predicted daily flows generated from the stage record and rating curve compared to point flow measurements.

The annual flow record for the surface water flow at each gauge was merged with the nutrient data from the weekly to bi-weekly water quality sampling performed at the gauge location to determine surfacewater related nitrogen loading rates to the Pond. The nitrogen load discharged from the stream was calculated using the paired daily volumetric discharge and daily nitrogen concentration measurements to determine the mass flux of nitrogen through each specific gauge site. For the stream gauge locations, weekly water samples were collected in order to determine nutrient concentrations from which nutrient load was calculated. In order to pair daily flows with daily nutrient concentrations, interpolation between weekly nutrient data points was necessary. These data are expressed as nitrogen mass per unit time (kg/d) and can be summed in order to obtain weekly, monthly, or annual nutrient loads to the Pond as appropriate.

Unlike many surface water features in the southeastern MA. region that typically emanate from a specific pond, the un-named stream which discharges into the upper portion of Cockeast Pond does not have an up-gradient pond from which that stream discharges. Rather, this small stream appears to be groundwater fed and emanates from a wooded area up-gradient and down-gradient of Cross Road. The stream outflow leaving the areas up-gradient and down gradient of Cross Road travels through a wooded upland area just prior to discharging directly into Cockeast Pond. The stream outflow from the wooded area up-gradient of the gauge may serve to contribute to the attenuation of nitrogen as groundwater flows through the riparian zone into the stream channel and also provides for a direct measurement of the "attenuated" nitrogen load to the pond.

The freshwater flow carried by the stream flowing into Cockeast Pond was determined using a continuously recording vented calibrated water level gauge. As this surface water system was potentially tidally influenced (Cockeast Pond salinity {summer 2015} ranged from ~6.5 ppt to 15.7 ppt, average = 11.4 ppt), the stream discharge was checked to confirm the extent of tidal influence and whether freshwater flow could be measured at low tide in Cockeast Pond. To confirm that freshwater was being measured, salinity measurements were conducted on weekly / bi-weekly water quality samples collected from the gauge site. Average measured stream sample salinity was found to be near zero ppt (0.1) ppt, clearly not tidally influenced, consistent also with the minimal tide range in Cockeast Pond.. As such, a salinity adjustment was not necessary in order to determine daily flows using the MEP developed stage-discharge relation. The stream gauge location was deemed acceptable for making flow measurements and obtaining an estimate of annual freshwater flow. Calibration of the gauge was checked monthly when the instrument was being downloaded. The gauge was installed on March 2, 2016 and was set to operate continuously for 12 months such that at least one summer season would be captured in the flow record. Stage data collection continued until March 1, 2017 for a total deployment of 12 months.

Stream flow (volumetric discharge) was measured every 2 to 4 weeks using a Marsh-McBirney electromagnetic flow meter. A rating curve was developed for the gauge site based upon these flow measurements and the measured water levels at the gauge site. The rating curve was then used to convert the continuously measured stage data to daily freshwater flow volume. Integrating the flow and nitrogen concentration datasets allows for the determination of nitrogen mass discharge from the stream to Cockeast Pond while also reflective of the biological processes occurring in the stream channel and wooded areas potentially contributing to nitrogen attenuation. In addition, a water balance was constructed based upon the U.S. Geological Survey/Buzzards Bay Project/MEP defined watershed delineations to determine long-term average freshwater discharge expected at the stream gauge site based on area and average recharge.

The annual freshwater flow record for the stream into Cockeast Pond as measured by the CSP technical team was compared to the long-term average flows determined by the MEP modeling effort while undertaking the analysis of the Westport River Estuary. The measured freshwater discharge from the stream at the CP Stream Inlet gauge location was 57% below the long-term average modeled flows. The average daily flow based on the CSP measured flow data for the hydrologic year beginning March 2, 2016 and ending in March 1, 2017 was 898 m^3/day compared to the long term average flows determined by the watershed modeling effort (2,122 m^3/day). The significant difference between the long-term average flow based on recharge rates over the watershed area and the CSP measured flow in the stream discharging from the sub-watershed is attributable to the below average precipitation during the stream monitoring period. Whereas average annual precipitation based on the long term record obtained from New Bedford Regional Airport (1971-2000) is 50.77 inches/year, during the stream monitoring year precipitation was 36.03 inches (approximately 30% below the long-term average). This indicates that the stream was discharging at a below average rate with a potentially lower associated nutrient loading compared to more average years.

Total nitrogen concentrations within the Cockeast Pond stream outflow were moderate, 0.986 mg N L^{-1} yielding an average daily total nitrogen discharge to the estuary of 0.89 kg/day and a measured total annual TN load of 325 kg/yr. Interestingly, TN concentrations in the Cockeast Pond stream was very similar to that measured in nearby Adamsville Brook and Kirby Brook, both of which had TN concentrations of 0.980 and 0.903 mg N L^{-1}, respectively, and discharges from sub-watersheds with similar land use characteristics. In the Cockeast Pond stream, nitrate made up well less than half of the total nitrogen pool (29%) and in Adamsville Brook and Kirby Brook nitrate as percent of TN was (22% and 28%, respectively), indicating that groundwater nitrogen (typically dominated by nitrate) discharging to the stream from the upland wooded areas, riparian zones and stream bed up-gradient of the gauge was partially taken up by plants within these different ecosystems. Given the relatively low levels of remaining nitrate in the stream discharge, the possibility for additional uptake by any freshwater systems upstream in the watershed is limited in the Cockeast Pond stream sub-watershed (Figure 52).

As expected, the annual load of total nitrogen entering Cockeast Pond from the stream represented only a small fraction of the total nitrogen entering the pond from its watershed based on the land use analysis. As a point of comparison, TN load from the groundwater watershed was 1,127 kg yr^{-1} compared to 325 kg/yr discharging from the stream during the 2015 gauge period and 565 kg yr^{-1} under more typical rainfall conditions. The stream discharged TN load represents 19% of the total 2015 watershed load and 22% of the average watershed load to Cockeast Pond showing the potential variation with drought and normal rainfall years. It should be noted that the stream load in 2015 drought year was 42% lower than might be expected in a typical year. The stream gauge has been continued in an attempt to develop a typical attenuation rate for the stream.

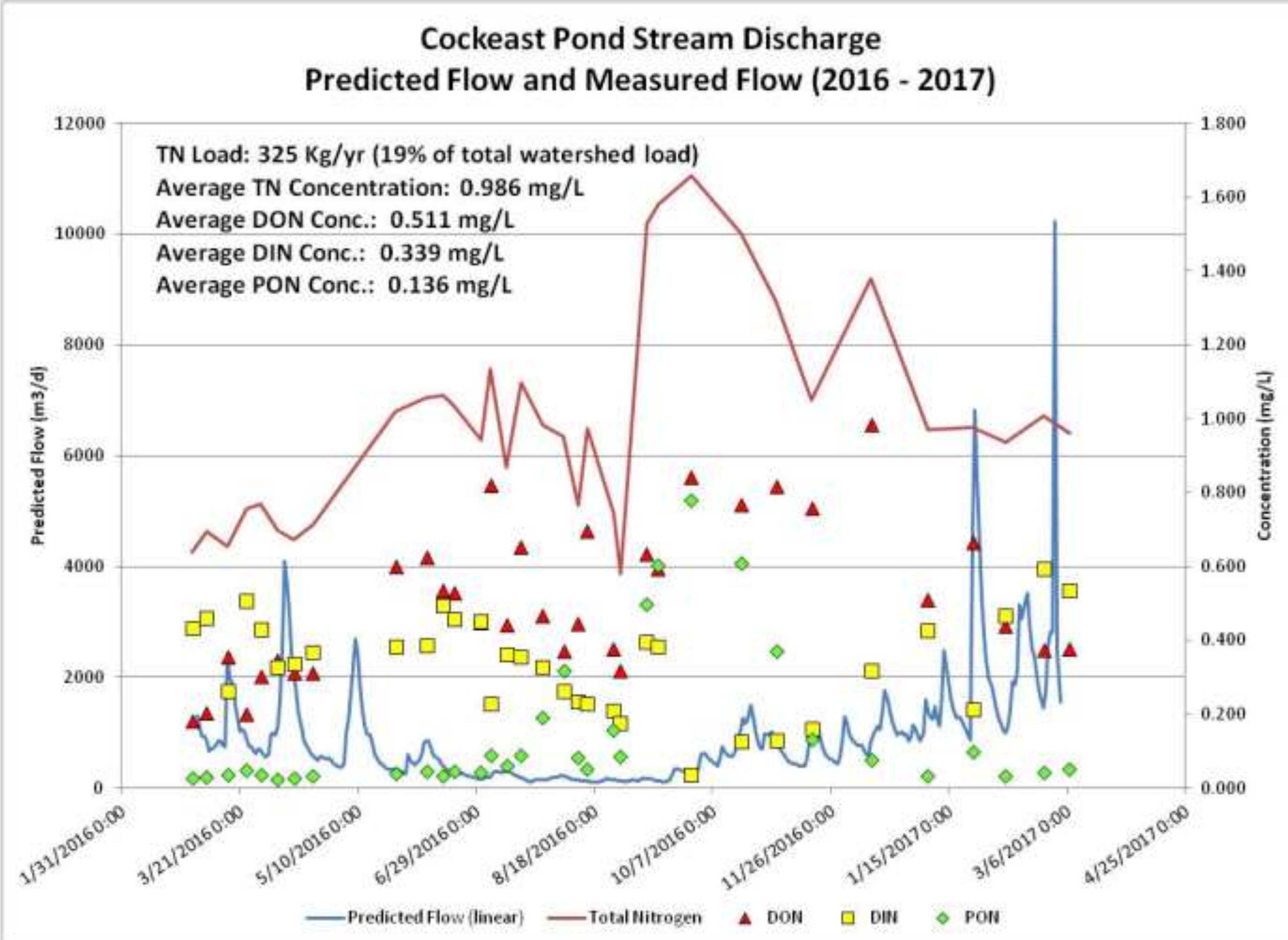


Figure 52. Discharge from un-named stream flowing into Cockeast Pond(solid blue line). Total Nitrogen (TN, brown line), Dissolved Organic Nitrogen (DON, red symbol), Dissolved Inorganic Nitrogen (DIN, yellow symbols) and Particulate Organic Nitrogen (PON, green symbols) concentrations are used for determination of total attenuated nitrogen load discharged by the stream.

Water-column Nutrient Concentrations (summer 2016):
In conjunction with the extended data collection on dissolved oxygen and chlorophyll as well as stream discharge/loading and benthic nutrient flux, nutrient related water quality was monitored during the summer 2016 field season to characterize nutrient concentrations in the water column and compare 2016 conditions to previous years data. Samples were collected from two previously established monitoring stations (CP-1 and CP-2) over the course of 9 sampling events during June through September (2 events in June, 3 events in July, 2 events in August and 2 events in September). All sampling completed in 2016 followed the same field and analytical protocols as in prior monitoring, such that all data would be cross comparable. Given the limited historic water quality data available for station CP-2, the water quality data from CP-1 was the primary focus for comparison with previous years. It was determined that CP-1 is representative of Cockeast Pond as whole because of the horizontally well mixed condition of waters in the main basin as seen in the salinity data from both CP-1 and CP-2 (Figure 53). Additionally, salinity from CP-1 and CP-2, while similar, show that water in Cockeast Pond is distinctly different than inflowing tidal water from Westport Harbor (Figure 54).

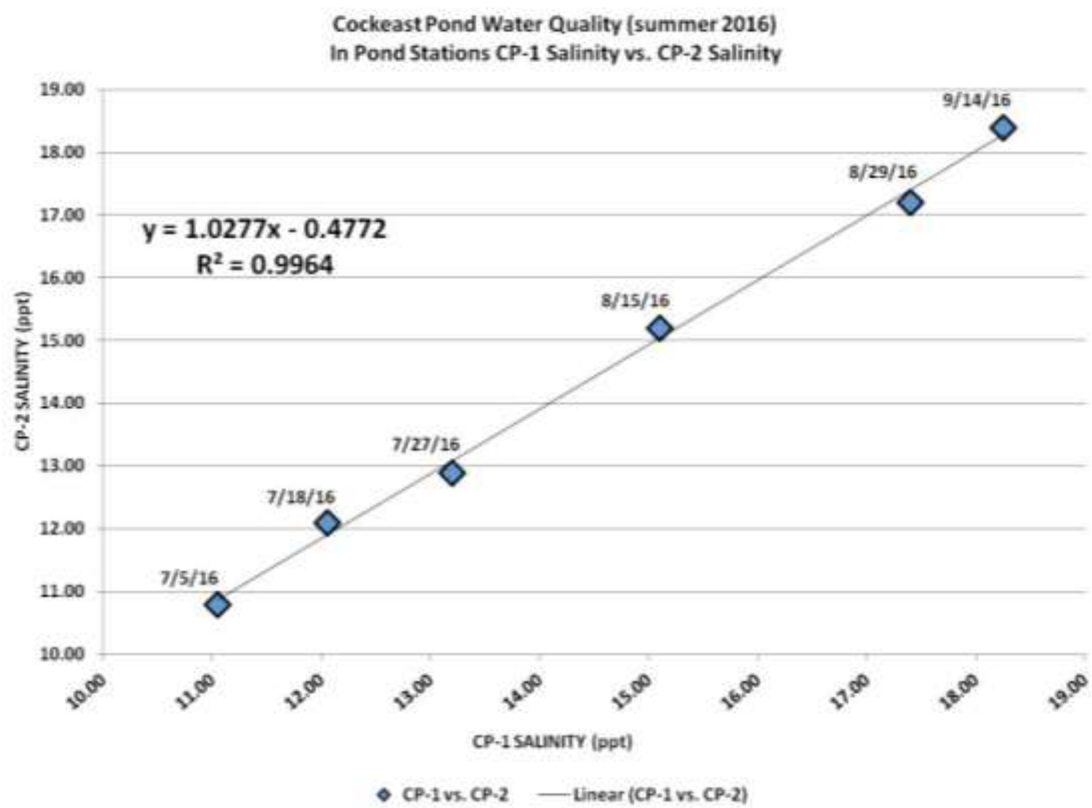


Figure 53. Plot of salinity data (ppt) collected from both CP-1 and CP-2 over summer 2016. Points falling on the 1:1 line indicates perfect agreement between the stations on that sampling event. The good agreement throughout the summer results from the dominance of wind driven horizontal mixing within Cockeast Pond and supports the use of either station, being representative of Cockeast Pond as whole.

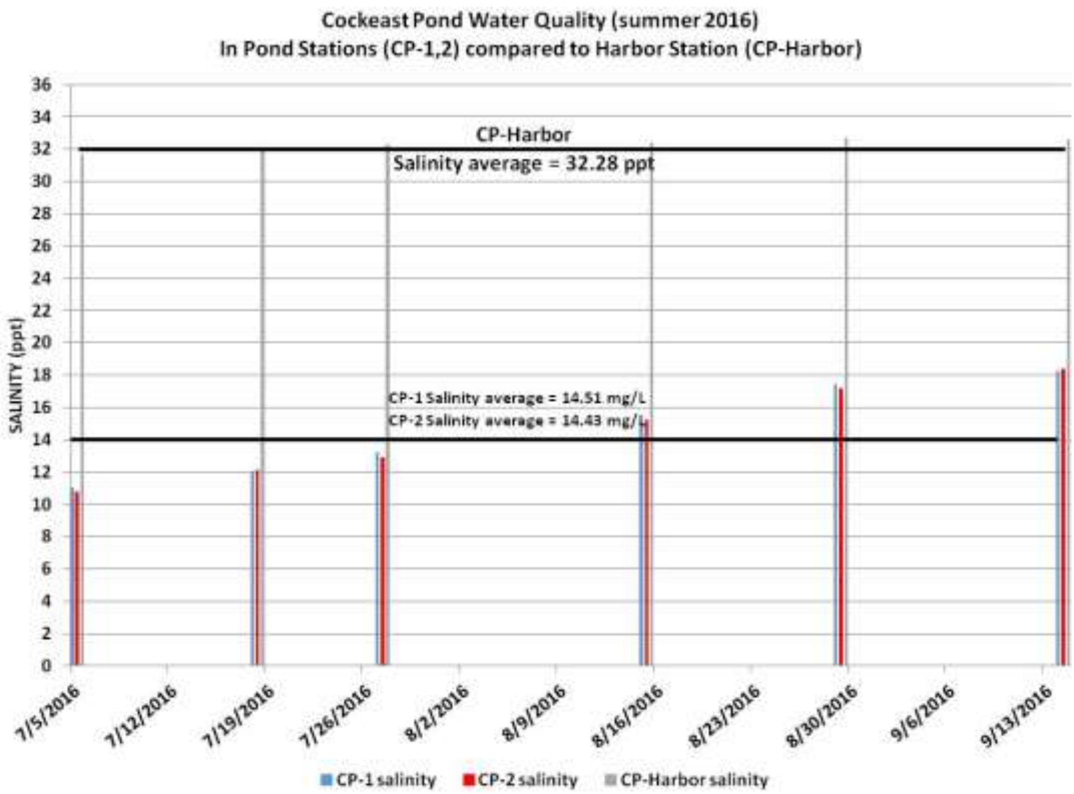


Figure 54. Summer 2016 salinity concentrations by date at CP-1, CP-2 compared to average salinity in the Westport Harbor (CP-Harbor), the source for tidal inflows (top horizontal line).

Based on the summer 2016 nutrient related water quality data compared to summer 2015, it appears that nutrient concentrations as well as chlorophyll-*a* concentrations (as a measure of phytoplankton biomass in the water column) were noticeably higher relative to each other but also significantly higher compared to concentrations in the tidal source waters of Westport Harbor (Tables 22a,b,c, Figures 55a,b,c).

Date	PO4 (mg/L)	TP (mg/L)	NH4 (mg/L)	NOx (mg/L)	DIN (mg/L)	DON (mg/L)	TDN (mg/L)	POC (mg/L)	PON (mg/L)	TON (mg/L)	TN (mg/L)	Chla (ug/L)	Salinity (ppt)
6/8/2016	0.001	0.036	0.000	0.004	0.005	0.886	0.891	3.442	0.565	0.157	1.456	12.36	9.30
6/20/2016	0.013	0.039	0.011	0.008	0.019	1.029	1.048	2.565	0.422	0.134	1.470	13.00	10.10
7/5/2016	0.002	0.032	0.005	0.005	0.010	0.937	0.946	2.902	0.449	0.175	1.395	13.19	11.10
7/18/2016	0.007	0.061	0.004	0.003	0.007	1.019	1.027	6.336	0.842	0.615	1.869	8.88	12.10
7/27/2016	0.003	0.057	0.005	0.004	0.009	1.026	1.035	8.080	1.102	1.587	2.138	97.59	13.20
8/15/2016	0.009	0.070	0.025	0.004	0.029	1.183	1.212	4.433	0.682	0.571	1.894	7.23	15.10
8/29/2016	0.005	0.051	0.007	0.003	0.011	1.172	1.183	3.941	0.702	0.683	1.884	5.85	17.40
9/14/2016	0.003	0.036	0.010	0.000	0.011	1.187	1.197	3.560	0.607	0.350	1.804	19.67	18.20
9/28/2016	0.005	0.067	0.023	0.002	0.026	1.039	1.064	7.205	0.991	0.405	2.055	35.58	
Average	0.01	0.05	0.01	0.00	0.01	1.05	1.07	4.72	0.71	0.52	1.77	23.71	13.31
Average excluding 7/27 and 9/28 dates	0.006	0.046	0.009	0.004	0.013	1.059	1.072	3.883	0.610	0.384	1.682	11.45	13.33

Table 22a. Summer 2016 Cockeast Pond nutrient concentrations from monitoring station CP-1.

COCKEAST POND													
Date	PO4 (mg/L)	TP (mg/L)	NH4 (mg/L)	Nox (mg/L)	DIN (mg/L)	DON (mg/L)	TDN (mg/L)	POC (mg/L)	PON (mg/L)	TON (mg/L)	TN (mg/L)	Chla (ug/L)	Salinity (ppt)
6/5/2015	0.00	0.06	0.03	0.01	0.04	0.86	0.90	3.26	0.52	1.38	1.42	10.94	6.55
6/18/2015	0.00	0.07	0.03	0.01	0.03	1.00	1.03	2.19	0.41	1.41	1.44	3.25	8.10
7/24/2015	0.00	0.06	0.01	0.01	0.01	1.04	1.05	3.00	0.40	1.44	1.45	10.41	10.53
8/31/2015	0.00	0.03	0.00	0.01	0.01	0.83	0.84	1.70	0.22	1.05	1.06	4.19	13.30
9/9/2015	0.00	0.04	0.00	0.01	0.01	0.84	0.85	2.00	0.28	1.13	1.14	5.35	15.65
9/22/2015	0.00	0.04	0.02	0.01	0.03	0.58	0.61	1.83	0.30	0.88	0.91	4.18	14.23
AVERAGE	**0.00**	**0.05**	**0.02**	**0.01**	**0.02**	**0.86**	**0.88**	**2.33**	**0.35**	**1.21**	**1.24**	**6.39**	**11.39**

Table 22b. Summer 2015 Cockeast Pond nutrient concentrations from monitoring station CP-1.

CP-Harbor Date	PO4 (mg/L)	TP (mg/L)	NH4 (mg/L)	NOx (mg/L)	DIN (mg/L)	DON (mg/L)	TDN (mg/L)	POC (mg/L)	PON (mg/L)	TON (mg/L)	TN (mg/L)	Chla (ug/L)	Salinity (ppt)
6/8/2016	0.016	0.030	0.024	0.002	0.027	0.256	0.283	0.333	0.048	0.304	0.331	1.619	32.000
6/15/2016	0.015	0.027	0.019	0.003	0.022	0.353	0.375	0.345	0.058	0.410	0.433	2.465	32.000
6/20/2016	0.014	0.041	0.019	0.003	0.021	0.251	0.272	0.437	0.057	0.308	0.329	1.006	32.200
7/1/2016	0.014	0.034	0.014	0.002	0.016	0.288	0.304	0.381	0.053	0.341	0.357	1.296	32.100
7/5/2016	0.012	0.028	0.021	0.000	0.021	0.182	0.203	0.718	0.112	0.294	0.315	1.631	31.700
7/12/2016	0.016	ND	0.045	0.002	0.047	0.348	0.394	0.347	0.046	0.394	0.440	1.359	31.900
7/18/2016	0.019	0.030	0.030	0.004	0.034	0.259	0.293	0.622	0.080	0.339	0.373	1.477	32.000
7/27/2016	0.020	0.044	0.031	0.003	0.033	0.456	0.489	0.616	0.098	0.554	0.587	1.982	32.300
8/5/2016	0.019	0.034	0.036	0.003	0.039	0.345	0.384	0.269	0.037	0.383	0.422	1.039	32.300
8/11/2016	0.025	0.040	0.011	0.006	0.016	0.315	0.331	0.485	0.074	0.389	0.405	2.248	32.600
8/15/2016	0.037	0.048	0.056	0.003	0.059	0.313	0.372	0.521	0.081	0.394	0.453	1.486	32.400
8/26/2016	0.019	0.038	0.056	0.006	0.062	0.429	0.491	0.649	0.099	0.528	0.591	2.492	32.900
8/29/2016	0.019	0.038	0.035	0.005	0.039	0.251	0.290	0.520	0.086	0.337	0.376	3.166	32.700
9/9/2016	0.025	0.040	0.028	0.006	0.033	0.362	0.396	0.458	0.073	0.436	0.469	2.148	32.200
9/14/2016	0.022	0.039	0.012	0.005	0.017	0.315	0.332	0.437	0.073	0.387	0.404	1.595	32.600
9/28/2016	0.003	0.087	0.294	0.003	0.297	0.155	0.452	7.692	1.245	1.400	1.697	20.411	ND
Average	0.02	0.04	0.05	0.00	0.05	0.30	0.35	0.93	0.15	0.45	0.50	2.96	32.26

Table 22c. Summer 2016 Westport Harbor tidal source waters for Cockeast Pond. Nutrient concentrations from monitoring station CP-Harbor located in Westport Harbor..

This is particularly evident in the total nitrogen concentrations as well as the chlorophyll-*a* concentrations. Whereas total nitrogen (TN) concentrations at CP-1 in 2015 averaged 1.24 mg/L, during the summer 2016 sampling season, TN concentrations at CP-1 averaged 1.68 mg/L, excluding two sampling dates with very high concentrations. If those two outliers are included in the calculation of the average, the 2016 concentration would be 1.77 mg/L. The 2016 average TN concentration at CP-1 is approximately 35%-40% higher than the average 2015 concentrations and is approximately 3x higher than the TN concentration of the source of inflowing tidal waters of (CP-Harbor) Westport Harbor (1.68 mg/L vs. 0.50 mg/L respectively). Looking in more detail at the fractionation of TN at station CP-1 in 2016, it appears that 64% of the total nitrogen in Cockeast Pond was composed of Total Dissolved Nitrogen (TDN), which in turn was primarily Dissolved Organic Nitrogen (DON), the remainder being particulate nitrogen (PON) composed primarily of phytoplankton. In 2016, DON was 99% of TDN at station CP-1. This is consistent with the previous 9 years of nutrient related water quality data collected on Cockeast Pond.

Generally, in saltwater systems, nitrogen is the nutrient that limits plant (phytoplankton, seagrass, macroalgal) growth and it therefore the nutrient which controls water and habitat quality. In contrast, phosphorus is the limiting nutrient in freshwater systems (lakes, ponds streams, rivers). Based on previous years of water quality monitoring, Cockeast Pond has an average salinity of ~10 ppt in the summer but 6.5 ppt in the spring. Nutrient data from previous years indicates that the Cockeast Pond appears to be mainly limited by nitrogen, but might also have some phosphorus limitation. This is determined by comparing the dissolved inorganic nitrogen to phosphate. When N:P ratios are less than 16:1 the system is nitrogen limited. Conversely, systems with N:P ratios greater than 16:1, the system is considered P limited (Vince and Valiela 1973). Analysis of Dissolved Inorganic Nitrogen (DIN) and Dissolved Inorganic Phosphorous (DIP, aka PO4) was used to generate DIN/DIP molar ratios for the summer 2016 for CP-1. The DIN/DIP ratio at station CP-1 averaged only 3.1 with a range of 1.1 - 5.5, clearly well below the Redfield Ratio value of 16, indicating that nitrogen additions will increase phytoplankton production in this system and that nitrogen is the nutrient for management planning (Ryther and Dunstan 1971).

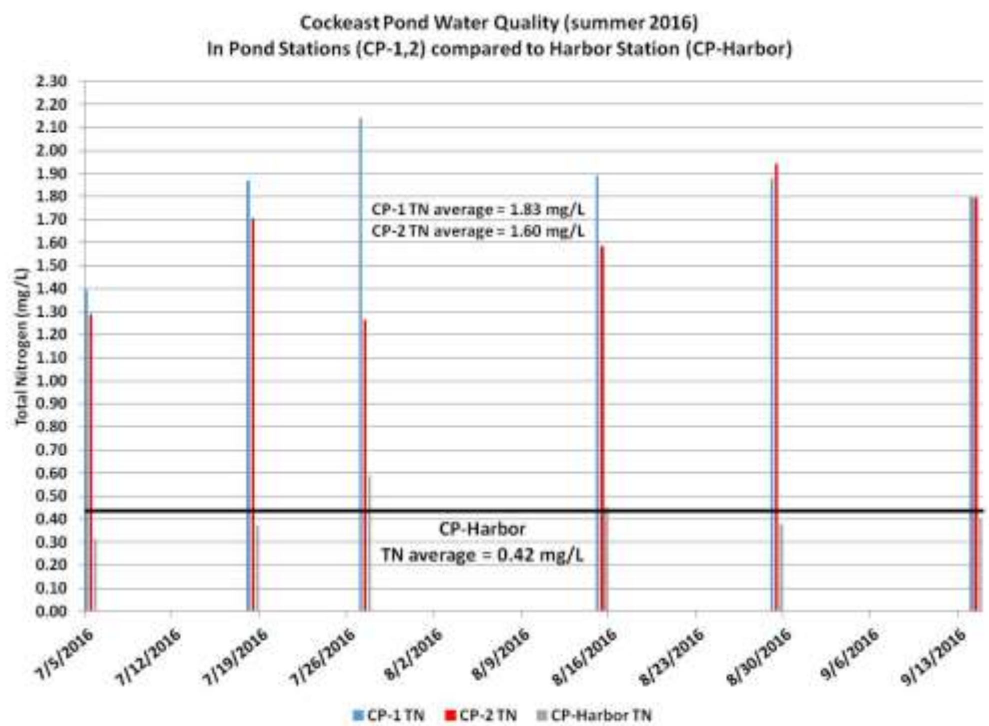


Figure 55a. Total Nitrogen (TN) concentrations (mg/L) within the main basin of Cockeast Pond (CP-1) compared to station CP-Harbor located in Westport Harbor. TN at CP-1 significantly higher than at CP-Harbor.

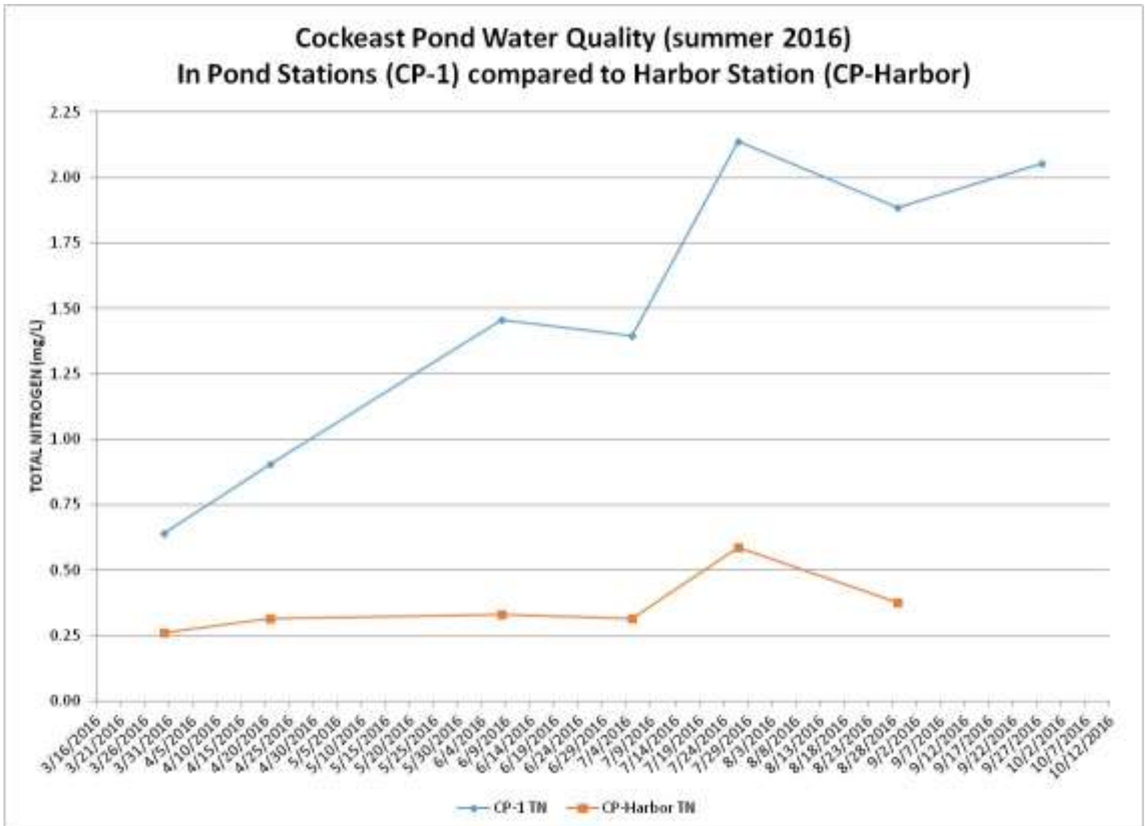


Figure 55b. Total Nitrogen (TN) concentrations (mg/L) at station CP-1 in Cockeast Pond compared to station CP-Harbor located in the Westport River. TN at CP-1 significantly higher than at CP-Harbor and increased over the course of ~7 months of sampling in 2016.

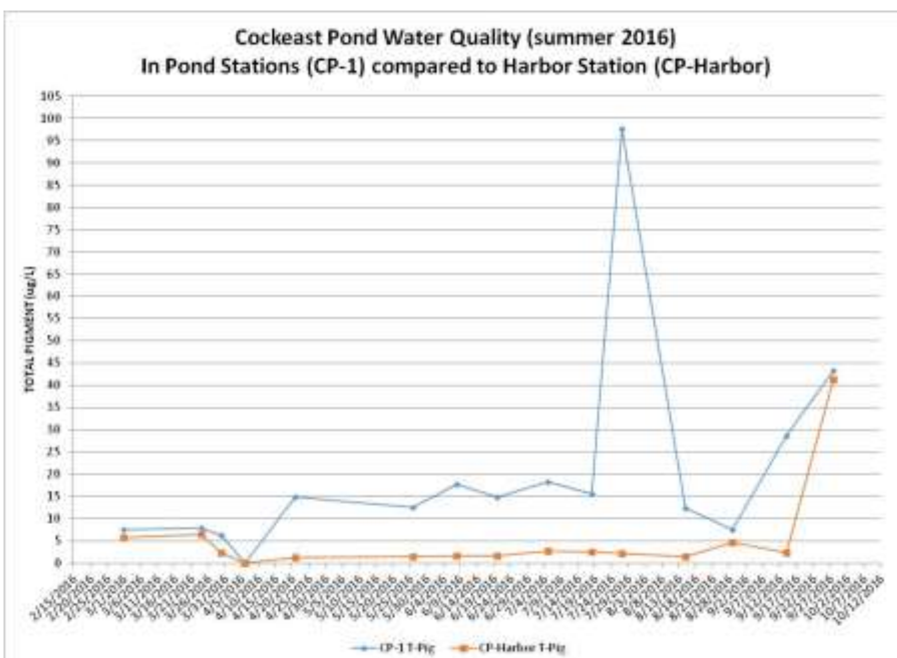


Figure 55c. Total Pigment concentrations (mg/L) at station CP-1 in Cockeast Pond compared to station CP-Harbor located in the Westport River. T-pig at CP-1 significantly higher than at

CP-Harbor and increased dramatically in the spring (April) with a big bloom observed in Cockeast around the month of August and a bloom observed at both CP-1 and CP-Harbor in September.

In addition to the general analysis of nutrient limitation based on the 2016 DIN/DIP ratios, an experiment was conducted in the spring of 2016 by Coastal Systems Program graduate students to determine which nutrient, nitrogen or phosphorus, is limiting in Cockeast Pond. The experiment consisted of a series of bottle incubations under a variety of nutrient addition conditions to determine which nutrient stimulated photosynthesis in phytoplankton.

At Cockeast Pond, two carboys were filled with water at 0.5 meter depth from CP1 using a Niskin sampler. In situ temperature measurements were recorded using a YSI DO probe and light intensity was recorded using a Li-Cor 4 pi PAR[3] sensor. The carboys were held in the dark for transport back to the SMAST lab. Immediately, thirty-nine Winkler bottles were filled as a series of six replicates for each of the following conditions: initial (T0), control, phosphorus enrichment (1P), nitrogen enrichment (5N), nitrogen and phosphorus enrichment (5N:1P), and dark respiration with an additional three bottles for BOD determination. Clear bottles were used, except for the respiration determination, which was incubated in dark bottles. Simultaneously, the initial condition Winkler bottles were fixed with reagents and processed by potentiometric titration to measure initial dissolved oxygen concentration, while the phosphorus enrichment, nitrogen enrichment, and nitrogen and phosphorus enrichment Winkler bottles were enriched with phosphate and ammonia. The phosphate enriched Winkler bottles (300 mL) received a one-milliliter addition of 0.3mM PO4, setting a minimum concentration of 1 µg/L PO4 in the Winkler. The N enriched bottles received a one-milliliter addition of 1.5mM NH_4^+, setting a minimum concentration of 5 µg/L N in the Winkler. Since the Cockeast Pond water contained N and P at collection, analysis of the spiked water showed concentrations of 1.0 uM PO_4 and 5.24 µM NH_4^+, respectively. The control and respiration Winkler bottles were "enriched" with one milliliter additions of 16 ppt seawater. For incubation the bottles were randomly placed in a temperature controlled water bath, grouped by their respective replicates. Bottles were incubated for approximately two days under in-situ light and temperature conditions. In-situ light conditions of Cockeast Pond were determined from surface light using a light attenuation equation, Id = I0*e-kd.

After 2 days oxygen levels in each bottle were determined as well as for the initial conditions. Based on the averages of the replicates, each condition showed a significant change in DO concentration compared to the initial conditions (Figure 56). The significance of change was determined using the standard deviation of each condition to assess any potential overlap in the samples. A comparison of the PO_4^{3-} enrichment, NH_4^+ enrichment, and NH_4^+:plus PO_4^{3-} enrichment to the control conditions, indicated no significant difference in DO production in the PO_4^{3-} enrichment compared to the control, but a significant difference in DO production of the NH_4^+ enrichment and NH_4^+:PO_4^{3-} enrichment compared to the control. This difference indicated that biological production in Cockeast Pond for the month of March 2016 was mainly driven by available nitrogen and not available phosphorus. A comparison of the DO production of the NH_4^+ enrichment to the NH_4^+:PO_4^{3-} enrichment revealed that the rate of DO production is significantly higher in the NH_4^+:PO_4^{3-} enrichment then the NH_4^+ only enrichment. The DO production rate in the control condition, containing only the in-situ nutrients, was 0.73 mg/L/day. The NH_4^+ only enrichment DO production was significantly higher than the PO_4^{3-} only enrichment, consistent with N limitation. In contrast, NH_4^+, and NH_4^+:plus PO_4^{3-} enrichments,

[3] Photosynthetically Active Radiation

showed significant DO production from photosynthesis at rates of 0.79, and 1.10 mg/L/day (Figure 56), respectively..

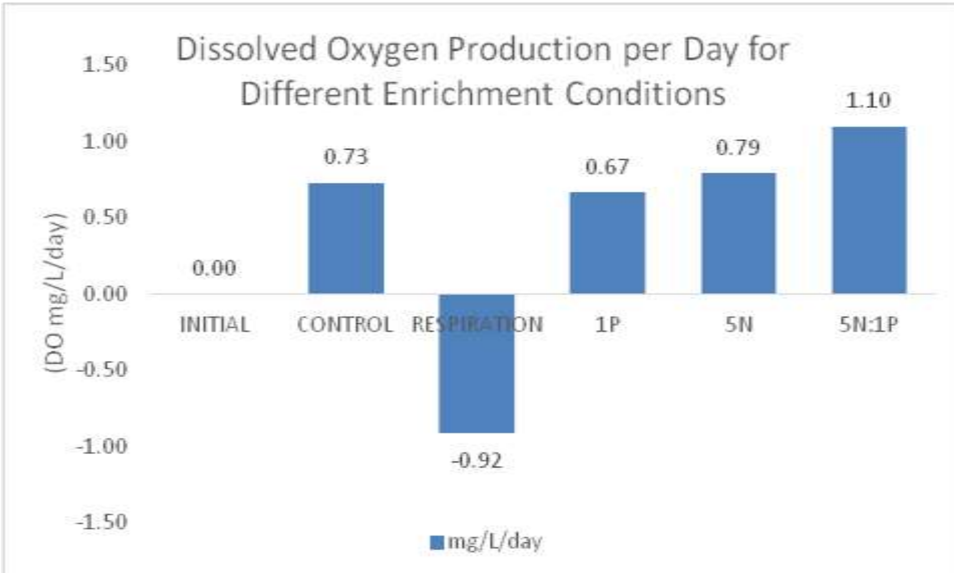


Figure 56: Rate of dissolved oxygen production in each enrichment condition.

The spring 2016 nutrient addition experiment indicated that plant production in Cockeast Pond was most affected by the input of nitrogen and that nitrogen was the nutrient responsible for habitat quality in this salt pond. It should be noted that combined inputs of nitrogen and phosphorus will cause the greatest negative impacts. This result is common in that with the initial input and uptake of N for growth also draws down the existing P, such that addition of P, with the remaining N, allows production to continue. It appears that the focus of water and habitat management should target nitrogen levels within Cockeast Pond, if the pond becomes increasingly fresh (low salinity), attention should also be given to phosphorus.

Cockeast Pond Modeling of Nutrients and Volumetric Exchange for Initial Evaluation of Management Alternatives

As originally proposed, the wide ranging data collection effort undertaken in Cockeast Pond was completed to ultimately understand the linkage between nutrients generated in the watershed and the pond itself and the habitat it supports. The link between land based sources of nutrients (load) and nutrient concentrations in Cockeast Pond can be quantified using modeling tools of varying degrees of complexity and accuracy (e.g. a steady state box model vs. time varying hydrodynamic model). The original Cockeast Pond Assessment (Phase 1 + Phase 2) specified that a simple box model would be developed to examine various nutrient management scenarios. The box model that was developed for Cockeast Pond showed clearly that a more complex numerical model was needed due to the importance of temporal variations in freshwater input (greatest in spring and fall, lowest in summer), sediment nutrient regeneration rates (strong seasonal temperature effect), tidal exchange (spring/neap tides) and very long residence time. While the box model indicated that watershed and regenerated nitrogen inputs, under the limited tidal exchange were key to the poor habitat health of Cockeast Pond, for the above stated reasons the results were mainly qualitative. Fortunately, CSP-SMAST established

Cockeast Pond as a natural laboratory in 2016 to support further research activities and therefore the CSP technical team was able to access additional resources external to the Town of Westport or WRWA to upgrade the modeling approach from the simple box model to a state-of-the-art time varying hydrodynamic/water quality model.

Nutrient loads in the watershed as described in previous sections of this report were characterized in detail such that the hydrodynamic/water quality model could be used to predict changes in water and habitat quality resulting from reducing loads from various sources in the watershed, increasing flushing rates and deploying oyster aquaculture for in situ nitrogen removal. The model output yield pond-wide nitrogen concentrations under present and implemented management alternatives for comparison to the nitrogen level supportive of healthy habitat. The use of a properly parameterized calibrated and validated time varying hydrodynamic/water quality model is the best way to conduct what-if scenarios to get a realistic sense of management effects. The RMA2/RMA4 numerical model, an industry standard developed by the U.S. Army Corps of Engineers, was used to test different management scenarios for reducing TN in the Cockeast Pond system. RMA2 is used to characterize the hydrodynamics of the system (water circulation and velocities) whereas RMA4 is used to characterize the distribution of nitrogen concentrations based on nitrogen loads and the RMA2 derived circulation. Both RMA2 and RMA4 are structured around a grid that captures bathymetric details of the pond and is used to represent the pond in a numerical space. It is also important to note that RMA2/RMA4 was also used to complete the MEP nutrient threshold analysis for the larger Westport River Estuary. The numerical modeling work summarized herein was completed in partial fulfillment of the University of Massachusetts-Dartmouth Masters Degree thesis (January 2018) by Ranjoy Barua and titled *Assessing Water Quality Improvement Strategies for Cockeast Pond, Westport, MA Using RMA2/RMA4*. All the modeling work undertaken in completing the thesis was under the supervision of Dr. Miles Sundermeyer (Director, Ocean Mixing and Stirring Laboratory, UMD-SMAST) and Dr. Brian Howes (Director, Coastal Systems Program, UMD-SMAST).

Following model calibration and validation using previously collected water quality data, a series of 1-year simulations were conducted removing components of anthropogenic watershed load individually to determine the effect on water column nutrient concentrations in Cockeast Pond. Components of watershed load that were removed in the numerical model included:

1) wastewater,
2) farm animals,
3) lawn fertilizer,
4) golf course fertilizer

Additionally, model runs were completed to test the effect of increased tidal flushing. In these scenarios, tidal flushing was increased by widening the channel two times (Vx*2) and four times (Vx*4), respectively. The Vx*2 and Vx*4 channel widenings increased the volumetric flooding by 195% and 267% respectively compared to the existing conditions. Of the altered N loading scenarios, removing wastewater was most effective among all other single source watershed scenarios, reducing pond TN by 6.5% at the summer peak and 43.8% at the end of the 1-year simulation run. At the other extreme, removing only the golf course fertilizer associated load had the least impact among the four single source watershed load reduction scenarios, reducing pond TN by 2.2% at the summer peak and 13.7% at the end of the model simulation run. Removal of either lawn fertilizer or farm animals had approximately equal effects, as their TN load was similar throughout the year – both reduced TN by ~4% at the summer peak, and by 23.3% and 26.3%, respectively, at the end of the annual run. Notable is that none of the reduced watershed loading scenarios were able to reduce TN significantly in the summer season compared to that achieved by increasing tidal flushing. These findings result from the large seasonality in nitrogen regeneration, with high summertime rates and much lower rates in winter which is the opposite timing of groundwater and stream discharge of watershed derived nitrogen. It is possible that over several years that the sediment regeneration of nitrogen will decline, but the long residence time of pond waters appear to be allowing the buildup of nitrogen within the pond as winter and spring particulates are stored in the sediments for summer release.. This also helps to explain the large effect of increasing tidal exchange, as particulate nitrogen is removed from the pond with a lesser fraction being stored in the sediments. This is consistent with the effect of widening the channel connecting Cockeast Pond to Westport Harbor by a factor of two and four which reduced pond TN at the summer peak by 16.1% and 25.8%, respectively, and 30.1% and 43.8%, respectively at the end of the run.

In addition to scenarios oriented around reducing nutrient loading from the watershed or increasing flushing of Cockeast Pond, a set or scenarios were run integrating the effect of deploying oyster aquaculture in the pond *without* reductions in watershed loads or increases in flushing. For these scenarios, the hydrodynamic/water quality model was run for two successive 1-year periods to capture aquacultural practices, incorporating oyster aquaculture into the pond as first and second year-class deployments in respective years. Three scenarios were examined, representing a total of 500,000 (1/2 M), 1,000,000 (1 M), and 2,000,000 (2 M) oysters. For each scenario, half the total number of oysters were deployed at the start of the first year and remained through the end of the second year and then harvested, while the other half were deployed at the start of the second year, anticipating they too will remain for two years before harvest, and so on. As in all time dependent simulations reported here, observed TN from spring 2016 was used as the initial condition for the first year of each of the two-year oyster scenario runs. For the second year, however, the final TN of the first-year run was used to initiate the second-year run, effectively creating a two-year simulation with identical forcing from all sources except oyster aquaculture, which has a one-year spin-up.

Results of the oyster scenario runs show that for 1/2 M oysters, TN was reduced by 9.1% at the summer peak in the first year, and 21.5% at the summer peak in the second-year compared to current conditions. For 1 M oysters, TN was reduced by 17.2% at the summer peak in the first year, and 41.9% in the second year compared to current conditions. Finally, for 2 M oysters, TN was reduced by 35.0% at the summer peak in the first year, and 62.4% in the second year compared to current conditions. As could have been anticipated, the highest TN reduction rate relative to current conditions was the second year of the 2 M oysters' scenario. Given that the highest nitrogen removal by the oysters is in the late summer and early fall, it is anticipated that the largest N reduction would be at the end of the run.

The final set of scenarios that were evaluated involved combining oyster aquaculture with decreased watershed loading and increased tidal flushing. Increased flushing was achieved by widening the channel to twice its original size plus 100% reduction of lawn fertilizer and reducing wastewater N discharge by 50%. Subsequently, the reduced loading scenario was repeated with the addition of 1/2 M, 1 M, and 2 M oysters, each for two years as previously described above. Results show that relative to current conditions, the combined reduction in watershed only loading (i.e., without oysters) reduced TN by 20.3% at the summer peak and 67.1% at the end of the one year model run. With oysters, both summer peak and end of run TN were additionally reduced relative to current conditions, with 2 M oysters resulting in a TN reduction of 76.3% at the summer peak and 98.1% at the end of the run during the second year. Summer TN levels currently were found to range between 1.31 and 1.68 mg L^{-1} (June-early September the critical period for water quality management). Based upon the results of the watershed load reduction

+ tidal flushing improvement + 2 M oysters, this would result in a summer TN of 0.31 to 0.40 mg L^{-1} mean summertime TN. The target for restoration of Cockeast Pond is <0.5 mg L^{-1} in summer. However, given the current uncertainties in the model, a safety factor is needed. To lessen the safety factor and bring the target equal to 0.5 mg L^{-1} in summer, additional model refinements are needed. These refinements are underway at present, but are well beyond the scope of the present effort. None-the-less when these refinements are completed, the scenarios will be rerun to refine more accurately the amount of watershed N reduction and tidal flushing and oyster deployment needed for restoration. The refined model will also be calibrated and validated with ongoing water quality monitoring results.

Conclusions and Recommended Management Options

At present, Cockeast Pond is a highly nitrogen impaired salt pond, as seen in its high TN levels, large phytoplankton blooms, accumulations of macroalgae and severely impaired benthic animal habitat quality, in low salinity brackish waters. The community has very low Diversity and generally low Evenness in addition to very low species numbers. In the northern region of the pond, the number of individuals is so low that the contribution as a food source for fish is minimal, while the southern region supports similarly impaired habitat but with moderate numbers of individuals. This trend parallels the distribution of sediment quality with the northern region supporting soft anoxic organic rich muds and the southern region having fine sands with oxic surface layer. The higher numbers of animals in the southern basin are indicative of a moderate level of productivity, but the other metrics clearly indicate impaired habitat. While the species were generally similar from the north to the south basins, the number of individuals in the north basin was very low, less than $1/10^{th}$ of the southern basin. Based on preliminary field observations, it appears that this difference in benthic animal communities may be related to sediment quality and the distribution of macroalgal accumulations within the Pond, which can smother benthic organisms, Restoration of benthic habitat is a target for TMDL's under the Clean Water Act and will require a lowering of the current level of nitrogen enrichment throughout the pond waters and if possible a modest increase in salinity. As part of the management analysis, water sampling and phytoplankton productivity studies were conducted, which again confirmed that nitrogen is the nutrient controlling phytoplankton blooms and habitat quality in Cockeast Pond and therefore is the correct target nutrient for restoring the impaired habitats within the pond.

Annual field measurements and subsequent water quality modeling of Cockeast Pond clearly show that the extremely tidally restricted nature (e.g. poor tidal flushing) of Cockeast Pond makes this system very sensitive to watershed nitrogen inputs resulting in habitat impairment. The very low volumetric tidal exchange allows nitrogen levels to become significantly enriched over incoming tidal waters from Westport Harbor and supports the development of large phytoplankton blooms and accumulations of macroalgae.

A result of the poor tidal exchange in Cockeast Pond, the freshwater inflow through the stream and groundwater discharge have a much larger impact on the pond than in the adjacent well flushed Westport Harbor basin and most estuaries in the region. This can be seen in the seasonal cycle of water column salinity where high freshwater inflows in winter and spring result in reduced salinities which then rise in late spring and summer as freshwater decreases and tidal inflows remain constant. Since most of the nitrogen load is carried by freshwater the high inflow, low salinity winter and early spring period sees both a drop in salinity and a significant rise in TN levels which support the large spring bloom in Cockeast Pond. In contrast, with the dominance of tidal inflows in late spring and summer comes a rise in salinity and drop in TN as the salinity of the inflowing Westport Harbor water is ~30 ppt and the TN is only ~0.3 mg N L^{-1}, compared to the Pond at ~6 ppt and 1.2 mg N L^{-1}. The seasonality of freshwater inflow under conditions of restricted tidal flow creates a highly variable environment with significant nitrogen enrichment and impaired water and habitat quality. To restore the impaired conditions nitrogen levels need to be lowered.

Nitrogen enrichment occurs when the rate of nitrogen input to a salt pond is higher than the rate of output through tidal flushing and removals from within the pond itself. Generally as watersheds become developed the N load from the watershed to the pond is increased and the nitrogen levels within the pond water increases as the tidal flushing remains constant. This is the case for Cockeast Pond. There are only 3 options for lowering the nitrogen levels to restore Cockeast Pond: (1) reduce the amount of nitrogen entering from the watershed, (2) increase the rate at which nitrogen leave the pond via tidal flushing, (3) increase the rate of nitrogen removal within the pond through direct removals (plant or animal harvest) or enhanced denitrification.

Management Options:

(1) Cockeast Pond is currently hydraulically connected to Westport Harbor via a culvert passing underneath River Road. Relieving the tidal restriction to restore tidal exchange to more natural levels becomes a significant management consideration for lowering nutrient concentrations in the water column and improving impaired habitat. Though within the last decade the culvert was redesigned and rebuilt to try and improve flushing, it appears that the placement was at a higher elevation than needed such that tidal inflows are restricted to all but the highest tides in Westport Harbor, resulting in very little flushing most of the time. Based on the detailed loading analysis, sampling program and hydrodynamic modeling, it has become apparent that enhancing flushing (exchange with higher quality water from Westport Harbor/Buzzards Bay) of Cockeast Pond should be a top priority in the sequence of steps that can be taken to manage nitrogen concentrations in the system. Of the various nitrogen management options, increasing tidal exchange is the most direct and least expensive. However, Cockeast Pond is a herring spawning area, so preliminary discussions were conducted with MassDMF. It appears that the present culvert not only is restricting tidal flows, but also is impeding herring migration. **Therefore, for both lowering the level of nitrogen enrichment for habitat restoration and to support the herring run, it is recommended that the inlet culvert be redesigned to improve tidal exchange with Westport Harbor.** However, care must be taken to maintain pond salinity within acceptable ranges to support herring spawning.

(2) Since redesign of the tidal culvert will likely be inadequate to fully restore the impaired habitats within Cockeast Pond, reductions in watershed N source loads needs to be considered for implantation after enhancing tidal exchange. The land use analysis shows the majority of the Cockeast Pond nitrogen load coming from agriculture, septic systems, and fertilizers (residential and golf course). While, these three inputs are difficult to reduce, long-term community and commercial practices in the Cockeast Pond watershed will have a positive impact when implemented. Agricultural operations should continue to implement Best Management Practices (BMP's) and in cases where BMPs have not been implemented, these should be integrated as appropriate. Similarly, the high quality fertilizer, turf and water management practices associated with the Axocet Club's golf course need to be sustained. During the present assessment if was clear that the grounds keeper is already aggressively managing its fertilization practice and water management. While continuing these practices will maintain current N loading, it will not reduce watershed N loading to the pond.

(3) There are a limited number of practical options for lowering watershed nitrogen loads, if enhanced tidal exchange is insufficient to restore the pond, as projected. Among the various options, the most practical approach to lowering existing nitrogen loading to the pond relates to residential areas. Many towns in s.e. Massachusetts have implemented lawn fertilizer by-laws targeted at lowering (not preventing) nitrogen applications to lawns. However, fertilizer education programs for home owners can also be effective without implementing a new regulation. The greatest practical option is to consider requiring installation of on-site denitrifying septic systems as older systems need to be replaced or in new homes within the watershed. Some communities have also considered making these installations necessary with the sale of a property, although this would have to have significant support within the Town.

4) Finally, if further nitrogen mitigation is needed for full habitat restoration, the Town should consider implementing shellfish aquaculture within the pond as a final step to decrease TN concentrations in the pond. Shellfish deployments will be most successful after re-establishing tidal exchange and increasing the pond salinity to $\geq$15 ppt.

An overall management plan is based upon a temporally staggered implementation approach combining increased flushing as a top priority, followed by nitrogen load reducing measures (septic system upgrades and fertilizer reduction) and oyster aquaculture will be necessary to restore Cockeast Pond to a non-eutrophic state. This phased approach will required continued low level monitoring to determine the necessity and/or magnitude of each successive management option. At present, USEPA has deemed such “adaptive management” an efficient approach to restoration.

The Coastal Systems Program (SMAST-UMassD) is continuing to work with WRWA on analysis monitoring and assessment of Cockeast Pond to further refine the recommended specific management options presented above.

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