Introduction

In recent decades, increasing worldwide attention has been paid to the issue of anthropogenic nutrient inputs and their associated ecological effects in coastal ecosystems. Coastal productivity is strongly influenced by nutrient supply, especially nitrogen (Oviatt et al. 1995), and increased fertilizer and sewage inputs often result in undesirable effects (Nixon 1995). High nutrient supply often increases frequency and severity of algal blooms, which can result in chronic hypoxia (low dissolved oxygen levels), loss or decline of seagrass, shifts in community composition, loss of biodiversity, and anoxic events that can cause fish kills (e.g., Duarte 1995, Valiela et al. 1997, Smith et al. 1999, Anderson et al. 2002).

In recent years, concerns regarding anthropogenic nutrients in Narragansett Bay, Rhode Island have risen, mainly in response to summer hypoxia and anoxic events, and especially the macroalgae blooms and fish kill of 2003 (RIDEM 2003). As a result, efforts to survey and monitor physical parameters around the bay have increased, and plans to upgrade Rhode Island sewage treatment plants (to remove more nitrogen) have been accelerated.

The data from these surveys and monitoring programs provide excellent opportunities to quantify the Bay’s spatial heterogeneity and track changes over time in nutrient concentrations, dissolved oxygen, temperature, and other ecologically important parameters. For example, numerous studies have observed that a north-south gradient exists with high concentrations near the Providence River that decreases southward towards the mouth (Pratt 1965, Kremer and Nixon 1978, Oviatt et al. 2002). Evidence for east-west differences in nutrients has also begun to emerge (Oczkowski et al. 2008). Another study by Nixon et al. (2005) quantified nutrient inputs by measuring concentrations at the mouths of rivers that flow into Narragansett Bay.

These measurements were made over one annual cycle in the 1970's, 80's, 90's and 00's. By tracking trends over the last 40 years, the study concluded that nitrogen inputs have essentially remained constant while phosphorus inputs have declined. Currently many other regular monitoring programs are in place to assess nutrient inputs and concentrations around the Bay. As data continue to be collected, there remain rich opportunities for further analysis and reporting.

The objective of this study was to synthesize and make available recent nutrient data from two distinct sources, the Narragansett Bay National Research Reserve (NBNERR or Reserve) and the Graduate School of Oceanography (GSO) at the University of Rhode Island (URI). In 1995, NBNERR began to monitor sites year-round at Prudence Island (where the Reserve is located) for salinity, turbidity, temperature, depth, dissolved oxygen, and pH as part of the national protocol established for all reserves in the National Oceanic and Atmospheric Administration's (NOAA) NERR system. In 2002, NBNERR added inorganic nutrients to the monitoring program. In the West Passage, GSO has been monitoring nutrients since 2003 as part of an effort to continue work by D. Pratt and T.J. Smayda that monitored phytoplankton populations and nutrients from 1959-1996. Also included in this study are nutrient data in the Providence River collected from 2005-2007 by the Narragansett Bay Commission (NBC).

Comparisons between such data sets are intended to illustrate recent trends over time in nutrient concentrations in the mid-Bay, as well as any differences or similarities between sites.

Methods - Site and Monitoring Program Description

T-wharf

T-wharf is a station that is monitored by NBNERR, stationed on Prudence Island in the geographic center of Narragansett Bay, RI (Figure 1). The sampling station is located on the south end of the island at the end of a long wharf facing the open water. Depth at the sampling site ranges from 4.6-6.9 m. Boat traffic is minimal at T-wharf, and the nearby land is protected within NBNERR's boundaries.

Starting in July 2002, water samples have been collected monthly around low tide.[1] Samples are taken in duplicate at the surface (~0.5 m from the surface) and bottom (~0.5 m from the bottom), filtered through a Whatman nuclepore polycarbonate track-etched membrane filter (0.45 µm pore size), and subsequently analyzed for phosphate (PO_4), ammonium (NH_4), nitrate (NO_3), nitrite (NO_2), and dissolved silica (DSi). Through 2006, nutrients were analyzed at GSO on a Technicon Autoanalyzer using U.S. Environmental Protection Agency (EPA)-approved methods (indophenol method for ammonia, cadmium reduction method for nitrite plus nitrate, and antimony-phospho-molybdate method for orthophosphate; Table 1). Since 2007, nutrient analyses have been completed on a Lachat Instruments Quik Chem 8000 flow injection analyzer (Lachat Instruments/Hach, Loveland, Colorado, USA) at GSO also using the U.S. EPA-approved methods (Table 1).

Salinity is measured from two fixed YSI (Yellow Springs Instruments) EDS (Extended Deployment System) sondes attached to the wharf at surface and bottom depths (Table 1). Measurements are automatically taken every 15 minutes along with temperature, dissolved oxygen, water depth, turbidity, chlorophyll, and pH.

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[1] Data are available at http://cdmo.baruch.sc.edu.

Station 2

Station 2 is monitored by the Graduate School of Oceanography (GSO) at URI, and is located in the middle of the West Passage, ~4 km west of T-wharf (Figure 1). The average depth is 8.2 m. Station 2 typically receives water from the Upper Bay and Providence River that moves along the Bay's western edge as it flushes out to Rhode Island Sound (Kincaid et al. 2008).

Two data sets exist for Station 2. The primary data set analyzed in this report is from the most recent and ongoing monitoring program at GSO for nutrients at Station 2.[2] Nutrients have been collected weekly since May 2003. Samples (with no replicates) are taken near the surface (~0.5 m from the surface) and bottom (~0.5 m from the bottom), filtered through a Supor nitrocellulose membrane filter (0.45 μm pore size), and subsequently analyzed for PO_4, NH_4, NO_3, NO_2, and DSi on the same instrument using the same methods as the most current T-wharf nutrient analyses (Table 1). Salinity is measured concurrently using an optical refractometer (Table 1). Unlike T-wharf, samples were taken without regard to tidal stage.

The second data set from Station 2 provided this study with a historical context for recent nutrient data.[3] The original monitoring program established by D. Pratt and continued by T.J. Smayda and his students at GSO began in 1959 and ended in 1996, using similar sampling methods as described above, with a few differences. Nitrite was not analyzed, and ammonium analysis did not begin until 1972.[4] Also, no data were collected from 1963 – 1972; therefore the only data from 1973 – 1996 are included in this report.

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[2] Data are available at http://www.gso.uri.edu/phytoplankton.

[3] Data are available at http://www.narrbay.org/d_projects/plankton-tsv/plankton-tsv.htm.

[4] Metadata for historical Station 2 sampling, including methods for nutrient analyses, are not currently available.

Though not used for the purposes of this report, it is worthwhile to note that historical and current monitoring efforts at Station 2 include the collection of phytoplankton data to document changes in abundance and species composition over time.

Conimicut Point

The Conimicut Point station, located in the middle of the Providence River mouth (near Conimicut Point), is monitored by the Narragansett Bay Commission (Figure 1). The Providence River receives a large portion of the Bay's nutrient inputs and experiences chronic bottom water hypoxia and anoxia. Starting in May 2005, water samples have been taken every two weeks during the period of May-December. Samples are filtered using Jensen disposable groundwater filter cartridges (0.45 µm pore size) and subsequently analyzed for PO_4, NH_4, NO_3, NO_2, and DSi on a Lachat Instruments Quik Chem 8000 flow injection analyzer at NBC using the U.S. Environmental Protection Agency (EPA)-approved methods (Table 1). These data were used in this report for spatial context by showing how mid-Bay nutrient concentrations compare to those from the Upper Bay and Providence River, where high nutrients inputs are located. Because samples were not taken year-round only seasonal means were included in this report.

Methods – Data Analysis

Annual means of salinity and all five nutrient species were calculated for T-wharf and Station 2 at surface and bottom depths. Annual means are reported only if data were available for an entire year. Therefore annual means from 2003-07 for T-wharf and 2004-07 for Station 2 are included for all nutrients (except silica which was incomplete during the winter of 2007 at Station 2). Annual means were also calculated for Station 2 historical data (1973-1996).

Seasonal means were calculated based on the following: Winter (Jan, Feb, Mar); Spring (Apr, May, Jun); Summer (Jul, Aug, Sep); Fall (Oct, Nov, Dec). For simplicity, only surface means are reported in the results section; comparisons of seasonal surface and bottom means at each site are included in Appendix A. If data gaps spanned a period over one month, the corresponding seasonal mean was excluded from the analysis. Means are reported for T-wharf, Station 2, and Conimicut Point. Nitrogen to phosphorus (N:P) and nitrogen to silica (N:Si) ratios were calculated from seasonal means at all three sites. A comparison of these ratios to the Redfield ratio indicated which nutrients were limiting for phytoplankton growth each season.

All statistics were run using JMP Statistical Software v. 7.0.2 (SAS Institute Inc.). A repeated measures analysis of variance (ANOVA) was performed for each nutrient species on T-wharf and Station 2 data spanning from 2003-2007. Data were grouped by season and year (e.g. winter 2003, spring 2003, summer 2003, etc.) for the analyses. The two samples collected each month at T-wharf were used (6 data points per season). Station 2 had varying number of sampling dates each season, mainly due to missing data. The analysis requires that all seasons have the same number of samples. Therefore at Station 2 only two data points from each month were included to match the two samples collected at T-wharf. The two data points chosen from Station 2 to be included were from dates closest to T-wharf monthly sampling dates. This ensured that the data included data taken around the same time of the month at both T-wharf and Station 2, in order to prevent any bias from samples collected at Station 2 during the rest of the month.

Linear regressions and one-way ANOVAs were also used to look for significant differences in annual means between Station 2 historical (1973-1996) and current (2003-2007) data sets in order to identify any changes in nutrient concentrations over time.

Results

Salinity

T-wharf is generally more saline than Station 2, indicating that the waters near lower Prudence Island receive more oceanic inputs than the upper West Passage (Figure 2). A circulation model of Narragansett Bay also indicates that water flows year-round along the western edge of the Bay carrying freshwater from the Providence River Estuary to the Bay's mouth (Kincaid et al. 2008), with Station 2 intercepting some of this freshwater. A repeated measures analysis, however, resulted in no significant differences between the two sites (Table 2). Salinity varied significantly over time, and behaved similarly between Station 2 and T-wharf (Table 2).

Narragansett Bay is described as a well-mixed estuary, which can be seen by the general similarity between annual means of surface and bottom water at both sites, though bottom waters were slightly more saline than surface waters (Figure 2). Annual means also fluctuated year to year, likely influenced by variation in precipitation. Dry years occurred in 2004 and 2007 (Figure 2). Seasonal cycles also show a general trend with more saline conditions during the summer, fall, and winter, and freshwater inputs peaking during the spring (Figure 3).

Nutrients

Annual means of all five nutrients (PO_4, NH_4, NO_3, NO_2, and DSi) generally followed a similar pattern over time. In 2005 and 2006 annual means were high, and low in 2004 and 2007, corresponding with wet and dry years respectively. Seasonal cycles for each nutrient were generally similar between T-wharf and Station 2. Conimicut seasonal means also seemed to follow a similar cycle, though generally in much higher concentrations than the mid-Bay sites. Results for each nutrient are discussed in more detail in the sections below.

Phosphate

Annual PO_4 means at T-wharf were higher than Station 2 surface water, but similar to bottom water (Figure 4). Seasonal means at T-wharf were almost always higher than or similar to Station 2, with concentrations at both sites peaking during the fall and lowest at springtime (Figure 5). Suspect data (12 data points) from the summer and fall of 2002 at T-wharf, which had anomalously high concentrations, were removed. The missing data can be found in the original databases for both stations. Conimicut seasonal means were similar to mid-Bay stations from summer 2006 through spring 2007, but were otherwise at elevated levels (1.5 – 3.5x higher than mid-Bay; Figure 5).

A repeated measures ANOVA showed a significant difference in PO_4 concentrations between sites and over time (2003-2007). Concentrations, however, behaved similarly over time between sites (Table 2).

Both a linear regression and a one-way ANOVA show a significant decline over time from 1973-1996 levels current PO_4 concentrations at Station 2 (2003-2007) ($p = 0.0106$ and $p<0.0001$, respectively) (Figure 6, Table 3).

Ammonium

Annual NH_4 means at Station 2 were higher than T-wharf at both surface and bottom (Figure 7). In 2007 surface water means at both sites were lower than bottom water, whereas in past years they had been generally similar. Seasonal cycles of NH_4 occurred similarly between stations, peaking during the fall and were often nearly depleted in the winter, spring and summer months. Similar to PO_4, suspect data (12 data points) were removed from the summer and fall of 2002 at T-wharf. (Figure 8). Throughout seasons when mid-Bay stations were extremely low in NH_4, Conimicut concentrations remained at relatively high levels, with the exception of spring 2006. When NH_4 peaked seasonally in the fall, Conimicut concentrations were approximately 2-6x higher than T-wharf and Station 2 (Figure 8).

A repeated measures ANOVA resulted in a significant difference in NH_4 between sites and over time, as well as a significant difference in how concentrations changed over time at each site (Table 2).

A one-way ANOVA between NH_4 data from 2003-2007 and those from 1973-1996 at Station 2 show a nearly significant difference between data sets ($p = 0.0556$) (Figure 9, Table 3). However, a linear regression analysis shows no changes over time ($p = 0.6818$).

Nitrate

In 2004 and 2006 T-wharf average NO_3 concentrations were higher than Station 2, and similar in 2005 and 2007, with higher levels in surface water compared to bottom water at both sites (Figure 10). Seasonally, NO_3 peaked in fall or winter, with T-wharf concentrations higher than or similar to Station 2. Concentrations declined to near-depletion at both mid-Bay sites during spring and summer months (Figure 11). Similar to NH_4, Conimicut NO_3 remained at high levels when mid-Bay sites became nearly depleted in NO_3. During peak months Conimicut NO_3 levels were 2-4x higher than those at T-wharf and Station 2 (Figure 11).

A repeated measures ANOVA showed that NO_3 concentrations were not statistically different between T-wharf and Station 2 and behaved similarly over time between sites. Concentrations, however, varied significantly over time between sampling dates (Table 2).

Using a linear regression and a one-way ANOVA, current NO_3 concentrations at Station 2 from 2003-2007 show no significant changes over time from 1973-1996 levels ($p = 0.7385$ and $p = 0.5119$, respectively) (Figure 12, Table 3).

Nitrite

Annual and seasonal means of NO_2 followed a similar pattern to NO_3, and with the exception that concentrations were fairly similar between T-wharf and Station 2 (Figures 13 and 14). Nitrite levels at Conimicut Point remained high during periods of near-depletion seen at mid-Bay sites. When NO_2 concentrations peaked, Conimicut Point levels were 1.5 – 2.5x higher than T-wharf and Station 2 (Figure 14).

A repeated measures ANOVA showed that NO_2 concentrations were significantly different between sites, though they behaved similarly between sites. Concentrations also varied significantly between sampling dates (Table 2).

Long-term monitoring data for NO_2 were not available and comparisons between recent years and past decades were not possible to make.

Silica

Note: Data from Station 2 January-March 2007 were missing and therefore no annual mean for 2007 was calculated for that site.

Surface water at Station 2 had lower annual means of DSi than bottom water, whereas T-wharf concentrations were generally similar between depths, with the exception of 2006. Comparisons between sites were variable and no particular site had consistently higher or lower annual means over time (Figure 15). Dissolved silica was typically low during spring, increased during summer, with a fall peak and a decrease in winter. Again, no particular site had predictably higher or lower concentrations of DSi (Figure 16). During summer, fall, and winter Conimicut concentrations were similar or up to 2.5x higher than mid-Bay stations, compared to the summer low when Conimicut DSi ranged from 2-8x higher (Figure 16).

A repeated measures ANOVA resulted in a significant difference in DSi concentrations between sites and over time. Concentrations, however, behaved similarly over time among the two sites (Table 2).

A one-way ANOVA data from 2003-2007 and those from 1973-1996 at Station 2 shows a significant difference ($p = 0.0012$) (Figure 17, Table 3). However, a linear regression showed no significant changes over time ($p = 0.2472$).

Nutrient Ratios

At T-wharf and Station 2, nitrogen to phosphorus ratios (N:P) remained under or near 16:1, which is the Redfield Ratio that determines the ratio of N and P needed for plant and algal growth in marine systems (Redfield 1958). In most temperate coastal waters, N:P is typically below 16:1 and therefore plants and algae are N-limited for growth (Granéli et al. 1990, Oviatt et al. 1995). Conimicut Point in the Providence River however became P-limited during the fall of 2006 and spring (and presumably winter) of 2007 as N:P reached 22.0 and 44.6 (Table 4).

Silica (Si) is biologically important for diatom growth and is needed in a 1:1 ratio with N. T-wharf and Station 2 remained N-limited during the period analyzed. Conimicut Point became Si-limited in the spring of 2005 and summer of 2007 and at other times was limited by N or neither (Table 5).

Discussion

Spatial Trends

The results from this study indicate that although nutrient concentrations between T-wharf and Station 2 are distinct, trends over time are similar enough that each site is fairly representative of the other, with the exception of NH_4.

Comparisons with the Providence River Estuary station, Conimicut Point, show that the magnitude of difference in nutrient levels on a north-south gradient greatly outweigh those from east-to-west. Other studies have established the existence of a north-south gradient with high concentrations of nutrients and phytoplankton in the Providence River gradually decreasing down-Bay towards the mouth (Pratt 1965, Kremer and Nixon 1978, Oviatt et al. 2002, Rhode Island Sea Grant 2005, Oviatt 2008, Smayda and Borkman 2008). This gradient persists even amid interannual variability (Smayda and Borkman 2008) and the seasonal variability observed between T-wharf, Station 2, and Conimicut Point. Forty-nine percent of Narragansett Bay's total N inputs originate from wastewater treatment facilities (WWTF) discharges and riverine inputs to the Providence River Estuary (Rhode Island Sea Grant 2005). These high concentrations decrease southward towards the Bay's mouth by processes of dilution and phytoplankton uptake.

In addition to north-south gradients, questions regarding differences in the east-west direction are being currently studied. Circulation patterns in the Bay, though seasonally variable and driven by wind and tides, are generally characterized by water flowing southward along the western shore of the Bay, and flowing in from Rhode Island Sound in the East Passage and bottom eastern half of the West Passage (Kincaid et al. 2008). Station 2, located at the mid-West Passage, receives water from the Upper Bay and Providence River Estuary, while the circulation patterns affecting T-wharf are less well-characterized (though studies are currently underway - C. Kincaid *personal communication*). The WWTF signal is seen at Station 2 by the higher concentrations of NH_4 compared to those at T-wharf (NH_4 is the primary form of sewage derived nitrogen released into Narragansett Bay). This signal also is likely responsible for the difference in how NH_4 concentrations changed over time between the two sites. Lower levels of PO_4 at Station 2 could possibly be explained by higher phytoplankton productivity, resulting in increased PO_4 uptake. The seasonally high concentrations of NO_3 seen at T-wharf in some years are likely due to a higher input of seawater-derived NO_3 which primarily enters Narragansett Bay through the East Passage. Patterns of NO_3 and other nutrients at T-wharf are also possibly complicated by the influence of Upper Bay and Mount Hope Bay water.

In addition to nutrient levels, N:P and N:Si ratios were similar between T-wharf and Station 2. Though the ratios varied over time, both sites were always N-limited. This was not case, however, at Conimicut Point where at times P- or Si-limitation occurred due to extremely high levels of N. Silica-limitation in particular has the potential to influence selection of phytoplankton functional groups (Smayda and Borkman 2008). During periods of Si-limitation flagellates have an advantage over diatoms, which comprise the annual winter-spring bloom in Narragansett Bay. However, phytoplankton are also light-limited – even when in the presence of excess nutrients they may not take up nutrients and grow due to shading from high densities in the water column. Smayda and Borkman (2008) also found that sites in the Upper Bay were more sensitive to P than N, and that this trend reversed down-Bay as N became comparatively less available. This is supported by the results of this report showing, at times, P-limitation or a lack of N-limitation near Conimicut Point.

Short-term Trends

During the recent time period analyzed (2003-2007) annual nutrient means varied with wet and dry years. Wet years, as indicated by low annual salinities, produced high nutrient levels, while dry years with higher salinities resulted in low nutrient concentrations. Smayda and Borkman (2008) found that dissolved inorganic nitrogen (DIN), PO4, and DSi inversely correlated to salinity among stations sampled in the Upper Bay from 1986-1987. Though trends were apparent, significant correlations were not observed at T-wharf and Station 2 in this study. The difference in findings may be attributed to differences in sampling design. Correlations between nutrients and salinity found by Smayda and Borkman (2008) may be more evident when sampling along the north-south salinity and nutrient gradient. Processes that alter nutrient and salinity levels (i.e. phytoplankton uptake, nutrient cycling, and circulation patterns) are likely more influential when comparing data over time from two stations with similar salinity regimes, such as in this study.

The same may be true for comparisons to other studies that analyze nutrient inputs (as opposed to within-Bay concentrations) and/or river flow. For example, Nixon et al. (2008) found significant regressions between nutrient inputs and flow in a number of rivers that enter Narragansett Bay. An analysis for this study, however, between annual river flow into

Narragansett Bay (from Pilson 2008) and Station 2 historical nutrients (1973-1996) did not yield any significant correlations (see Appendix B).

General seasonal cycles of nutrient concentrations followed a pattern with peak concentrations in the fall (Oct-Dec) and near-depletion in the spring and summer (April-Sept). This pattern is consistent with the large input of nutrients during periods of heavy precipitation in the fall, and the development of high phytoplankton abundances in winter and early spring that subsequently deplete nutrients through the spring and summer (Pratt 1965). Other processes such as biogeochemical cycling can also influence nutrient dynamics. The specific timing of nutrient maximums and minimums, which were similar between T-wharf and Station 2, could be particular to the mid-Bay. For example, Smayda and Borkman (2008) found that peak concentrations of NH_4 and NO_3 varied from September to December, from July to December for PO_4, and summer or winter for DSi, depending on the location along the north-south gradient.

The similar trends in annual concentrations and seasonal cycles at T-wharf and Station 2 indicate both sites are representative of general nutrient dynamics in mid Narragansett Bay.

Long-term Trends

Comparisons of recent nutrient concentrations (2003-2007) at Station 2 to those from previous decades (1973-1996) revealed no changes over time in nutrient trends, with the exception of PO_4. The significant decrease of PO_4 found in this study is matched by previously documented declines of PO_4 inputs (Rhode Island Sea Grant 2005, Nixon et al. 2005, Nixon et al. 2008), and is likely due to the regulation of detergent phosphates beginning in the 1980's and 1990's.

Long-term trends in N are particularly important to document and understand, especially as recent and future WWTF upgrades reduce DIN discharges into Narragansett Bay. Anthropogenic N was introduced to Narragansett Bay 120 years ago and concentrations rapidly increased around the turn of the 20th century (Hamburg et al. 2008), though Nixon et al. (2005) calculated that N inputs from 1975-2004 have remained constant. This study, however, observed an almost significant increase in NH_4 (but not NO_3) at Station 2 between recent years and past decades. Due to the WWTF upgrades, a decrease in N concentrations would be expected in the near future. Fulweiler et al. (2007) found that in the summer of 2006 net nitrogen-fixation occurred in the sediments of mid-Narragansett Bay, resulting in the sediments acting as a source of N (particularly NH_4) rather than a sink. Such reversals in nutrient cycling could potentially impact nutrient dynamics within the Bay. More in-depth analyses of long-term trends are needed before conclusions are drawn.

Additional Remarks

Ample opportunity exists to further explore these data sets, and to include other parameters such as chlorophyll, dissolved oxygen, and temperature, and other data from additional stations. NBNERR monitors two other sites around Prudence Island in Potter Cove and Nag Marsh. GSO has an additional long-term monitoring station located at the GSO dock run by C. Oviatt that dates back to 1976. NBC also monitors other sites stationed within the Providence and Blackstone Rivers. Information regarding additional programs in Narragansett Bay can be found at http://www.narrbay.org.

The results of this particular report add value to the existing body of literature regarding nutrients in Narragansett Bay and can be applied in a variety of ways. For example, despite the observation that east-west differences in nutrient concentrations exist between T-wharf and Station 2, data from either site can be extrapolated for the general mid-Bay region when considering general trends and temporal dynamics. Some caution might be prudent, however, when considering dynamics of NH_4, which clearly delineates some difference between the eastern and western parts of the mid-Bay. Similarity between the two sites will likely increase in the near future as Station 2 N-concentrations drop due to the planned WWTF N-removal, especially for NH_4. Additional studies such as this can help to inform the scientific and management community of to implement and increase monitoring efforts, and where others could be potentially combined or discarded.

An additional value of this report is that by analyzing nutrient concentrations at sites in the mid-Bay, this study captures a picture of nutrient dynamics that incorporate ecological processes such as uptake and transformation within Narragansett Bay as apposed to analyses of nutrient inputs. This report is particularly useful to understand the magnitude of influence these processes have on nutrients entering the Bay. To gain such insight, future studies could compare the mid-Bay concentrations to nutrient inputs. Such analyses would be timely as WWTF upgrades have the potential to significantly alter the Bay's nutrient dynamics and general ecology. The availability of these long-term data sets provides a unique opportunity to track changes over years and decades, and advance our understanding of historic and current impacts to Narragansett Bay such as eutrophication and climate change.

Finally, it is imperative that not only should the scientific and management communities continue and expand nutrient monitoring in Narragansett Bay, equal efforts should be made to make publicly available and report on the data collected. As this study and others have shown, the nutrient dynamics of the Bay are neither spatially homogenous nor static. Overarching analyses that synthesize data from various monitoring programs would be extremely useful to identify where gaps exist and collaboration would be most beneficial.

On the basis of the findings of this report, some general recommendations are listed below:

1) Due to the likelihood of east-west differences, sampling in the middle of the East Passage near Prudence Island should be implemented. Surface water samples could be collected off of the Prudence Island Ferry. For budgeting needs, surface sampling in the East Passage could replace bottom sampling at T-wharf. Though surface-bottom comparisons at T-wharf show some trends, spatial differences along an east-west gradient would be more valuable to understanding nutrient dynamics in the Bay.
2) A co-sponsorship by GSO and NBNERR for current or additional sites would efficiently combine monitoring efforts and resources.
3) Additional analyses of long-term data at Station 2 in comparison to other parameters (such as river flow and phytoplankton abundance) are needed to improve understanding of changes in nutrient trends over the last five decades.
4) The incorporation of nutrient data from other locations around the Bay into future analyses would further contextualize mid-Bay nutrient dynamics.

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Tables and Figures

Table 1. Methods for nutrient analyses and salinity measurements.

Parameter	Method reference	Instrument
Salinity		Optical refractometer (A) YSI Extended Deployment System sonde (calculated from temperature & conductivity) (B, C)
Nitrite and nitrate	U.S. EPA Method 353.4, Ortner and Fischer (1997); Grasshoff (1976)	Lachat Instruments Quik Chem 8000 Flow Injection Analyzer (A, C, D) Technicon Autoanalyzer (B)
Ammonia	U.S. EPA Method 365.3, U.S. EPA (1997); Grasshoff (1976)	Same as above
Orthophosphate	U.S. EPA Method 365.5, Zimmerman and Keefe (1997); Grasshoff (1976); Murphy and Riley (1962)	Same as above

A: Station 2 (2003 – present)
B: T-wharf (2002 – 2006)
C: T-wharf (2007 – present)
D: Conimicut Point

Table 2. Two-way repeated measures ANOVA for salinity and nutrients concentrations, looking at differences between sites (“Site”), over time (“Time”), and if sites behaved similarly or differently over time (‘Site*Time”). Significant differences are highlighted where $p < 0.05$. For all “Within” tests, Univariate G-G Epsilon test results were used rather than the F-test, if $p < 0.5$ for sphericity (not reported).

	Test	**Type**	**Source**	**D.F.**	**F-Value**	**Prob>F**
Salinity	F-Test	Between	Site	1	0.57	0.4598
	Univariate G-G Epsilon	Within	Time	3.75	9.44	<.0001
	Univariate G-G Epsilon	Within	Site*Time	3.75	1.90	0.1266
Phosphate	F-Test	Between	Site	1	12.0292	0.0022
	Univariate G-G Epsilon	Within	Time	2.9474	55.5537	<.0001
	Univariate G-G Epsilon	Within	Site*Time	2.9474	1.5515	0.2103
Ammonium	F-Test	Between	Site	1	79.8607	<.0001
	Univariate G-G Epsilon	Within	Time	2.4798	27.2033	<.0001
	Univariate G-G Epsilon	Within	Site*Time	2.4798	3.1938	0.0388
Nitrate	F-Test	Between	Site	1	0.0006	0.9802
	Univariate G-G Epsilon	Within	Time	1.5798	41.1414	<.0001
	Univariate G-G Epsilon	Within	Site*Time	1.5798	0.7272	0.4598
Nitrite	F-Test	Between	Site	1	10.6697	0.0035
	Univariate G-G Epsilon	Within	Time	2.0395	60.3461	<.0001
	Univariate G-G Epsilon	Within	Site*Time	2.0395	1.3641	0.2662
Silica	F-Test	Between	Site	1	13.5192	0.0013
	Univariate G-G Epsilon	Within	Time	2.2164	32.2186	<.0001
	Univariate G-G Epsilon	Within	Site*Time	2.2164	2.4303	0.0932

Table 3. One-way ANOVA for nutrient concentrations, comparing differences between historical (1973-1996) and recent (2004-2007) data at Station 2. Significant differences are highlighted where $p < 0.05$.

	D.F.	**F Ratio**	**Prob > F**
Phosphate	1	60.46	<.0001
Ammonium	1	3.67	0.0556
Nitrate	1	0.43	0.5119
Silica	1	10.48	0.0012

Table 4. Nitrogen to phosphorus ratios (N:P) of seasonal means at T-wharf, Station 2, and Conimicut Point. Limiting nutrients are based on the Redfield ratio (16N: 1P) required for marine plant growth.

		T-wharf		**Station 2**		**Conimicut Pt.**	
Year	**Season**	**N:P Ratio**	**Limiting Nutrient**	**N:P Ratio**	**Limiting Nutrient**	**N:P Ratio**	**Limiting Nutrient**
2003	Spring	4.6	N	10.9	N		
	Summer	3.3	N	2.7	N		
	Fall	9.3	N	13.5	N		
2004	Winter	3.3	N	17.9	neither		
	Spring	0.8	N	4.7	N		
	Summer	0.5	N	0.8	N		
	Fall	8.2	N	7.9	N		
2005	Winter	13.2	N	13.5	N		
	Spring	1.8	N	8.0	N		
	Summer	0.5	N	2.3	N	8.0	N
	Fall	12.3	N	13.0	N	17.8	neither
2006	Winter	16.6	neither	19.8	P		
	Spring	1.1	N	12.8	N		
	Summer	1.1	N	1.1	N	11.2	N
	Fall	8.5	N	8.1	N	22.0	P
2007	Winter	17.5	neither	13.8	N		
	Spring	2.8	N	2.8	N	44.6	P
	Summer	0.8	N	0.7	N	6.3	N
	Fall	6.9	N	8.4	N	12.7	N

Table 5. Nitrogen to silica ratios (N:Si) of seasonal means at T-wharf, Station 2, and Conimicut Point. Limiting nutrients are based on the Redfield ratio (1N: 1Si) required for marine diatom growth.

		T-wharf		**Station 2**		**Conimicut Pt.**	
Year	**Season**	**N:Si Ratio**	**Limiting Nutrient**	**N:Si Ratio**	**Limiting Nutrient**	**N:Si Ratio**	**Limiting Nutrient**
2003	Spring	0.29	N	0.20	N		
	Summer	0.16	N	0.08	N		
	Fall	0.59	N	0.54	N		
2004	Winter	0.74	N	1.10	neither		
	Spring	0.10	N	0.29	N		
	Summer	0.11	N	0.17	N		
	Fall	0.54	N	0.78	N		
2005	Winter	0.50	N	0.53	N		
	Spring	0.69	N	0.38	N		
	Summer	0.08	N	0.20	N	1.39	Si
	Fall	0.65	N	0.58	N	0.66	N
2006	Winter	0.68	N	0.61	N		
	Spring	0.11	N	0.48	N		
	Summer	0.09	N	0.13	N	0.94	neither
	Fall	0.53	N	0.56	N	0.75	N
2007	Winter	0.53	N				
	Spring	0.10	N	0.06	N	1.40	Si
	Summer	0.03	N	0.02	N	0.33	N
	Fall	0.55	N	0.41	N	0.85	neither

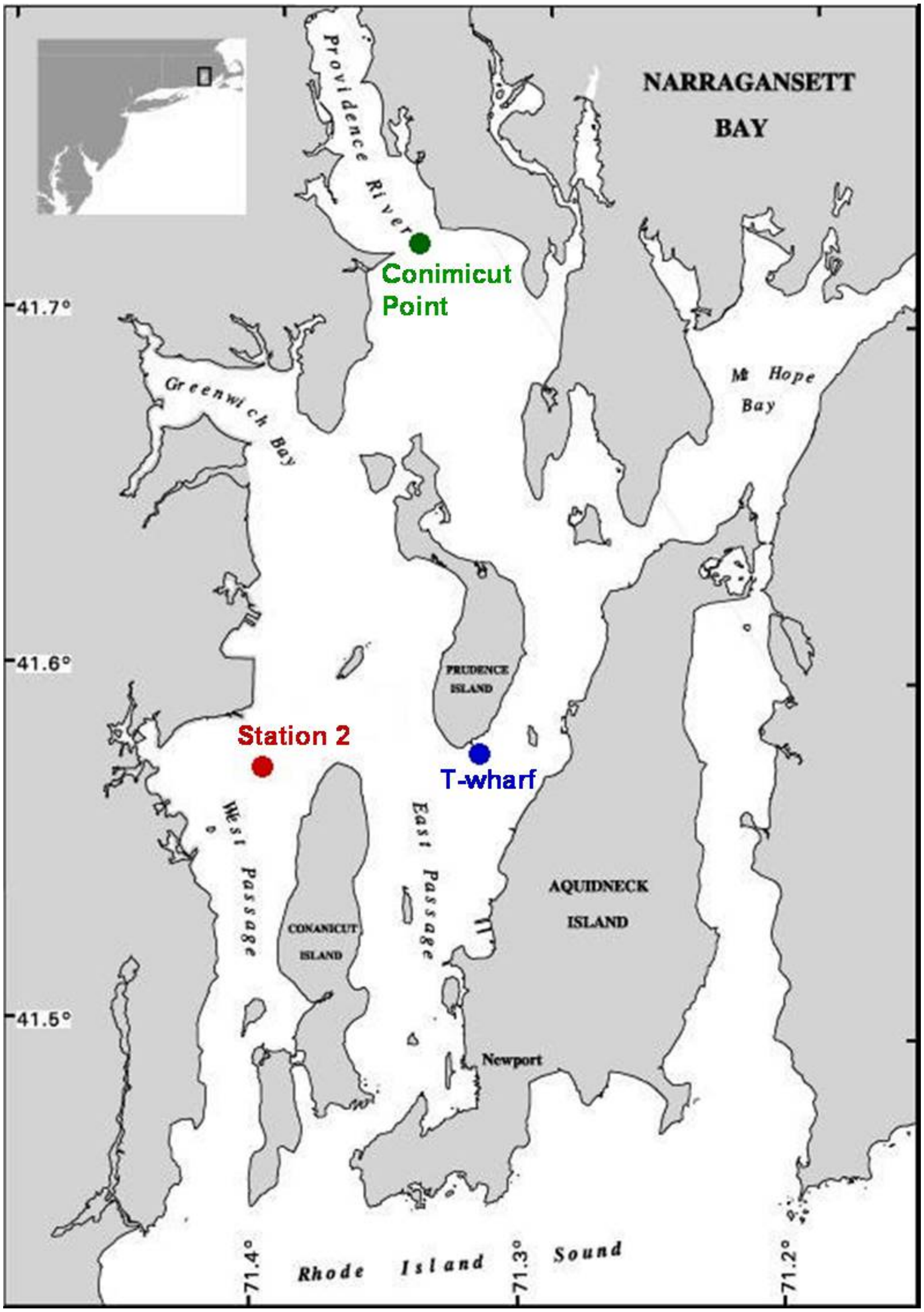


Figure 1. Map of Narragansett Bay and location of the sampling stations.

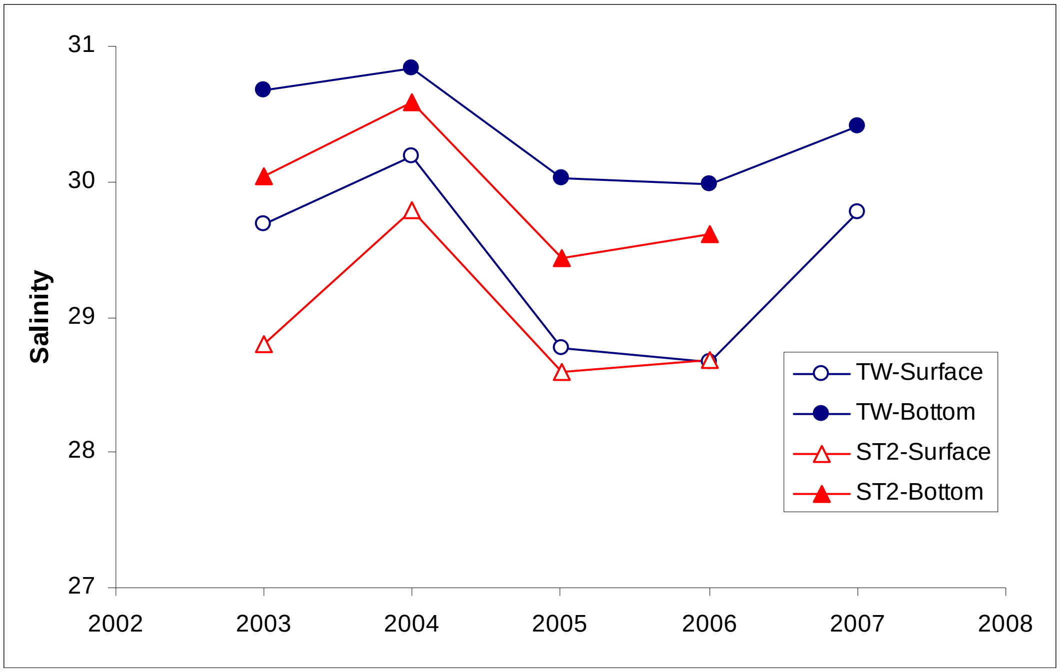
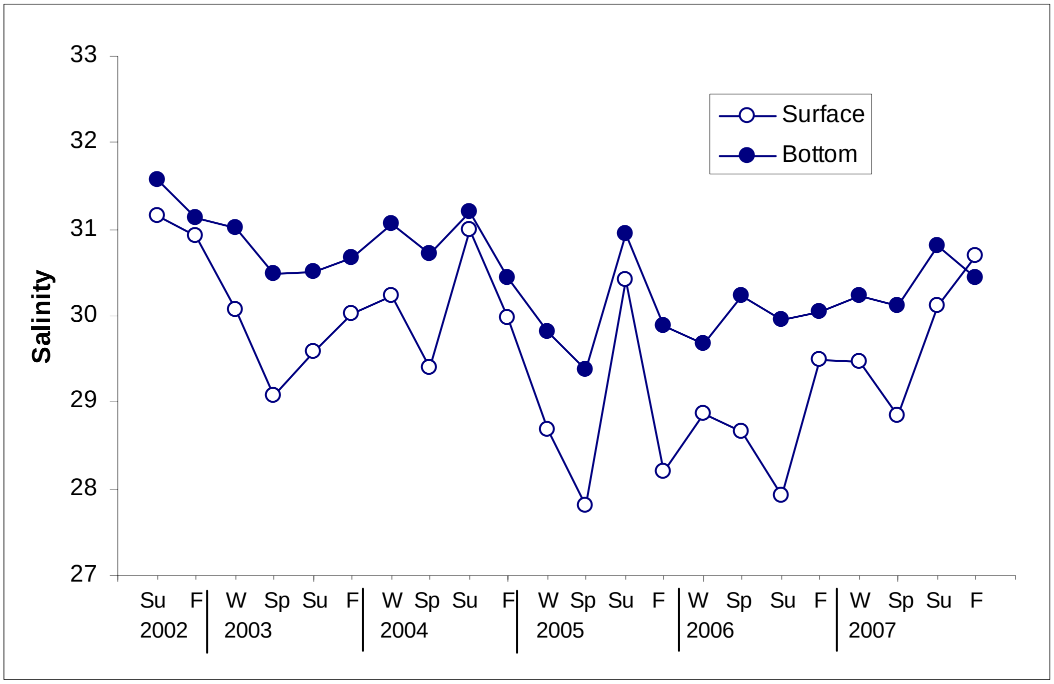


Figure 2. Annual salinity means for surface and bottom water at T-wharf (TW) and Station 2 (ST2). Coefficients of variation generally ranged from 2-7% at both sites.

3a.



3b.

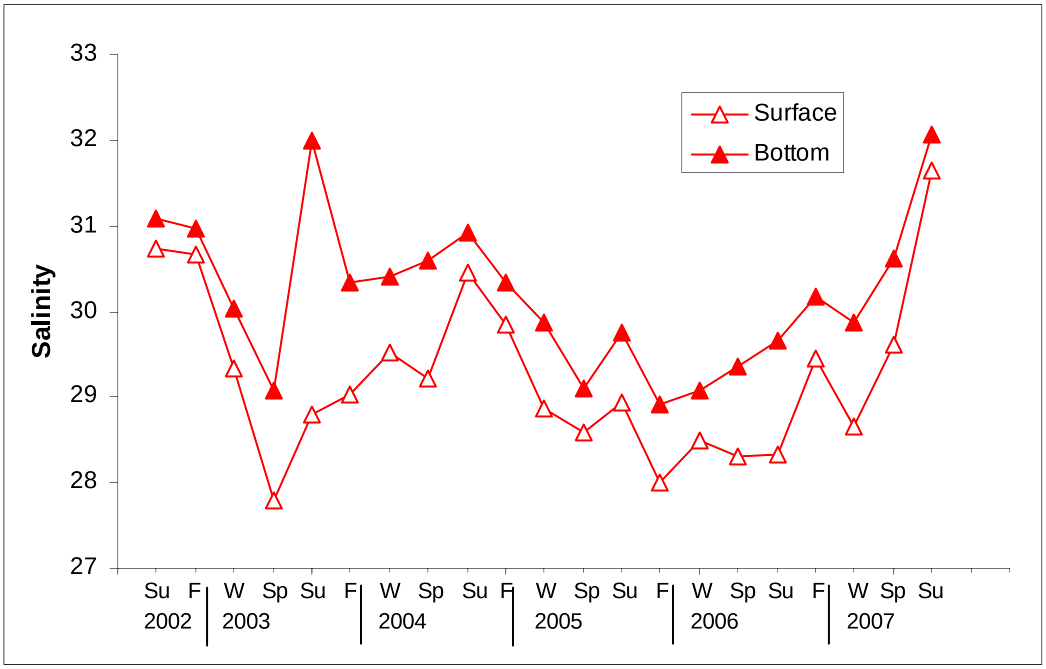


Figure 3. Seasonal means of salinity in surface and bottom waters at T-wharf (3a) and Station 2 (3b) (W = winter, Sp = spring, Su = summer, F = fall). Coefficients of variation generally ranged from 1-8% at both sites.

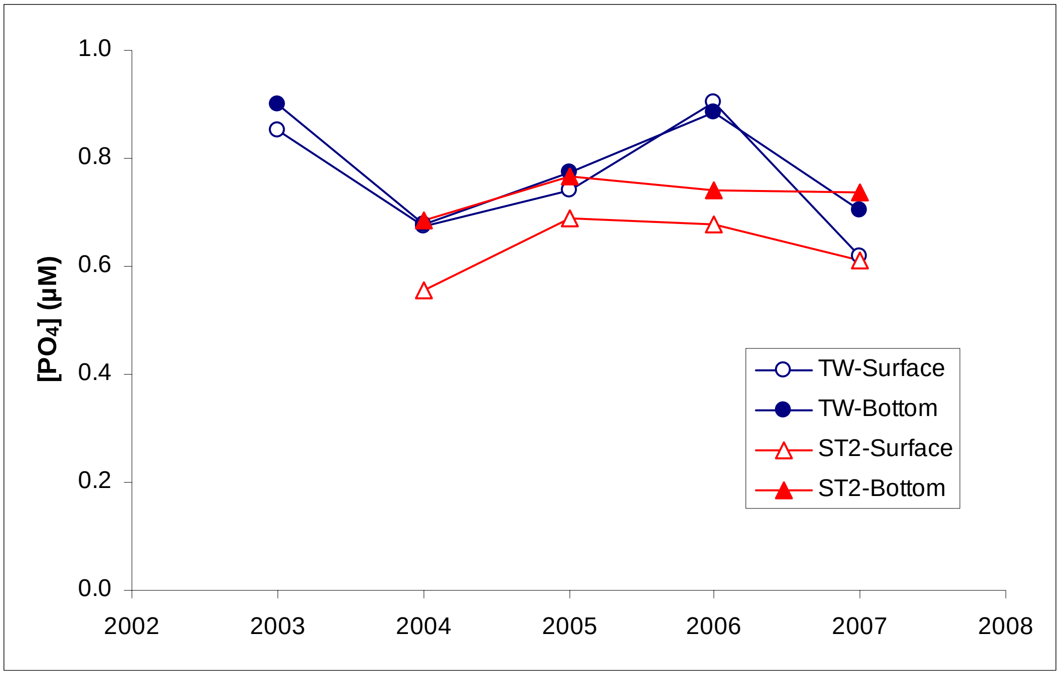


Figure 4. Mean annual phosphate concentrations for surface and bottom water at T-wharf (TW) and Station 2 (ST2). Coefficients of variation ranged from 50-75% at T-wharf and 55-75% at Station 2.

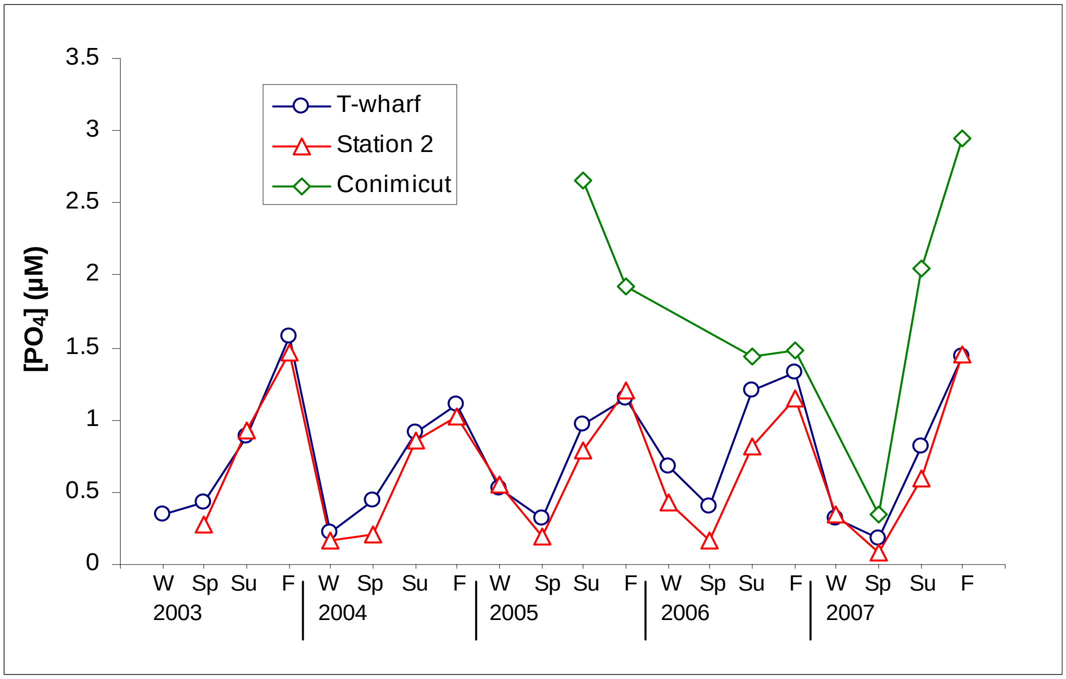


Figure 5. Mean seasonal phosphate concentrations for surface and bottom waters at T-wharf and Station 2 (W = winter, Sp = spring, Su = summer, F = fall). Suspect data at T-wharf from summer and fall of 2002 are not included. Coefficients of variation generally ranged from 5-40% at T-wharf, 10-75% at Station 2 and 0-50% at Conimicut Point.

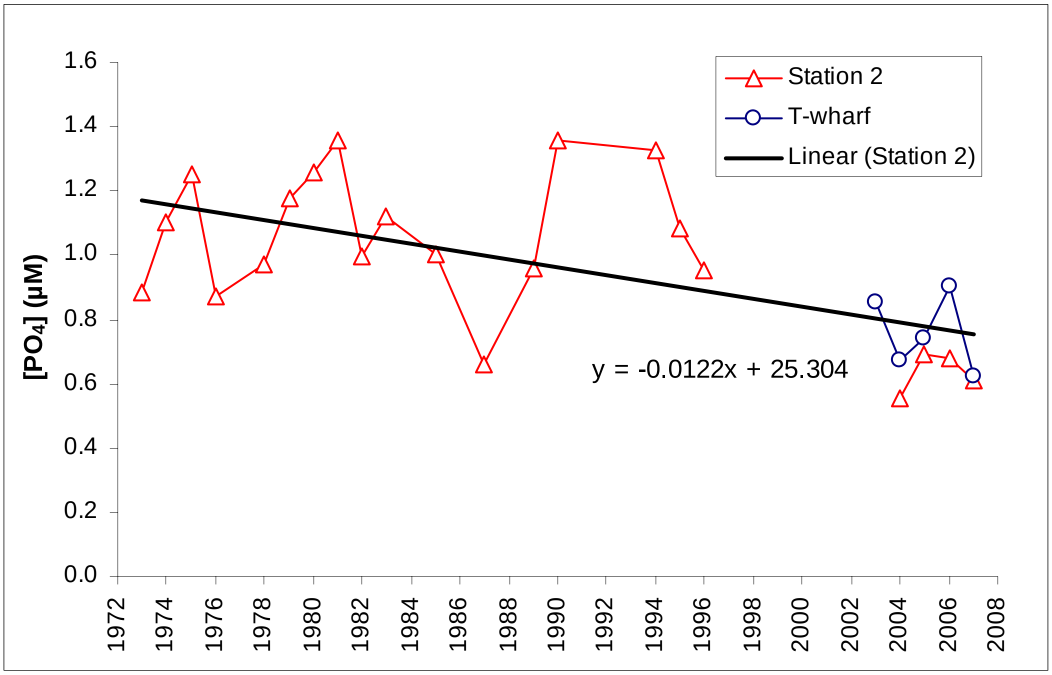


Figure 6. Mean annual phosphate concentrations from Station 2 historical data (1973-1996) and recent Station 2 and T-wharf data (2003/4-2007). A linear regression line for the Station 2 values shows a significant decline over time ($p = 0.0106$).

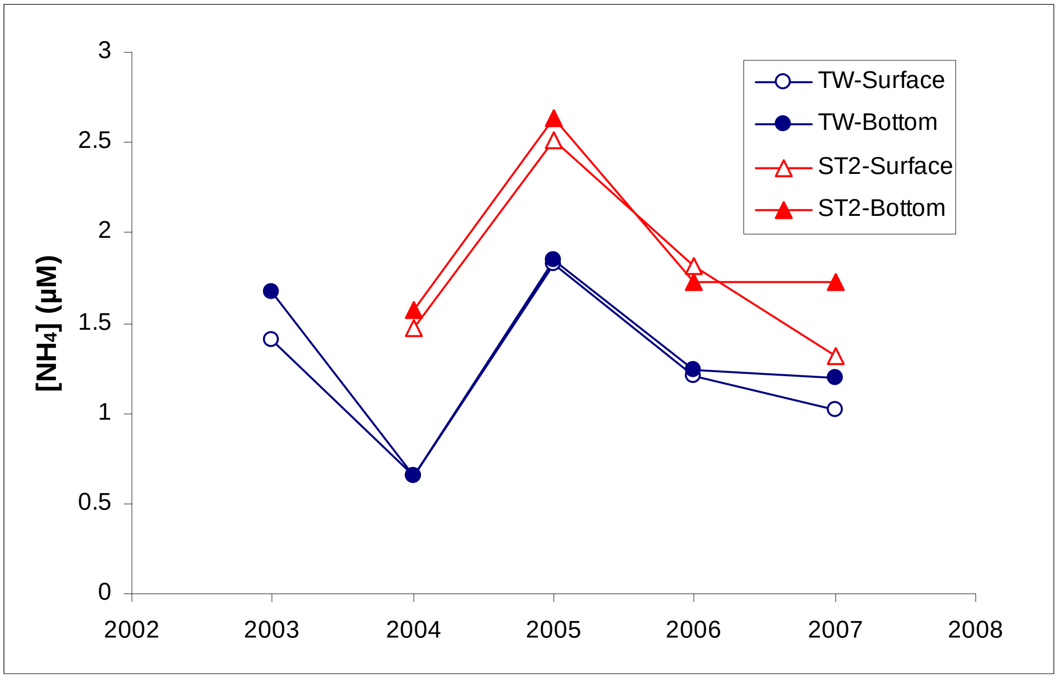


Figure 7. Mean annual ammonium concentrations for surface and bottom water at T-wharf (TW) and Station 2 (ST2). Coefficients of variation ranged from 70-200% at T-wharf and 125-235% at Station 2.

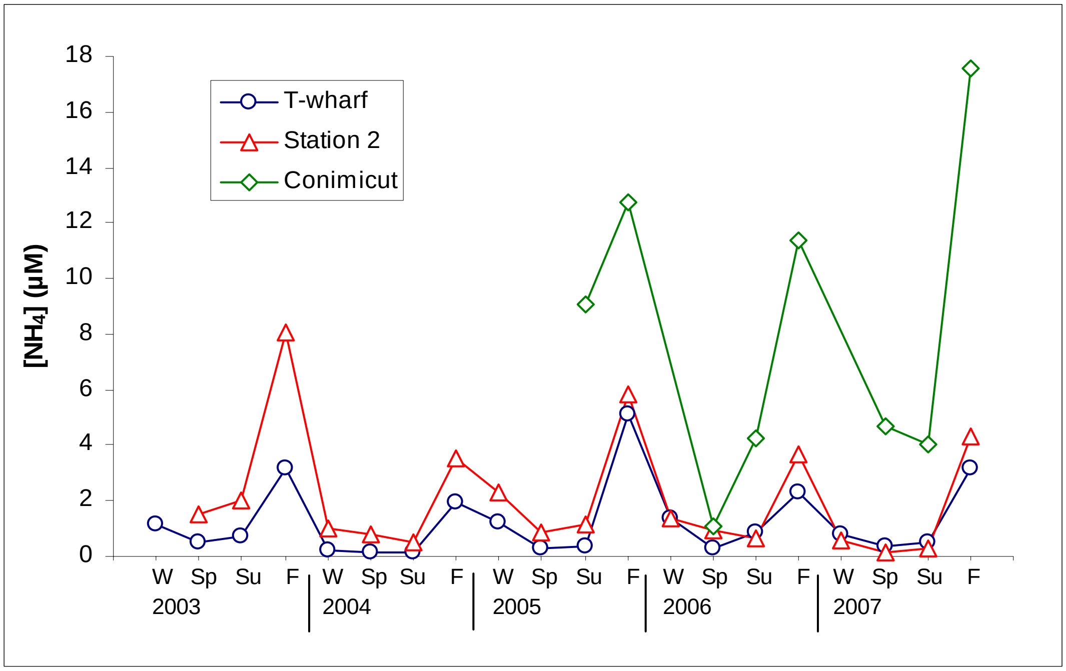


Figure 8. Mean seasonal ammonium concentrations for surface and bottom waters at T-wharf and Station 2 (W = winter, Sp = spring, Su = summer, F = fall). Suspect data at T-wharf from summer and fall of 2002 are not included. Coefficients of variation generally ranged from 5-170% at T-wharf, 5-150% at Station 2 and 10-80% at Conimicut Point.

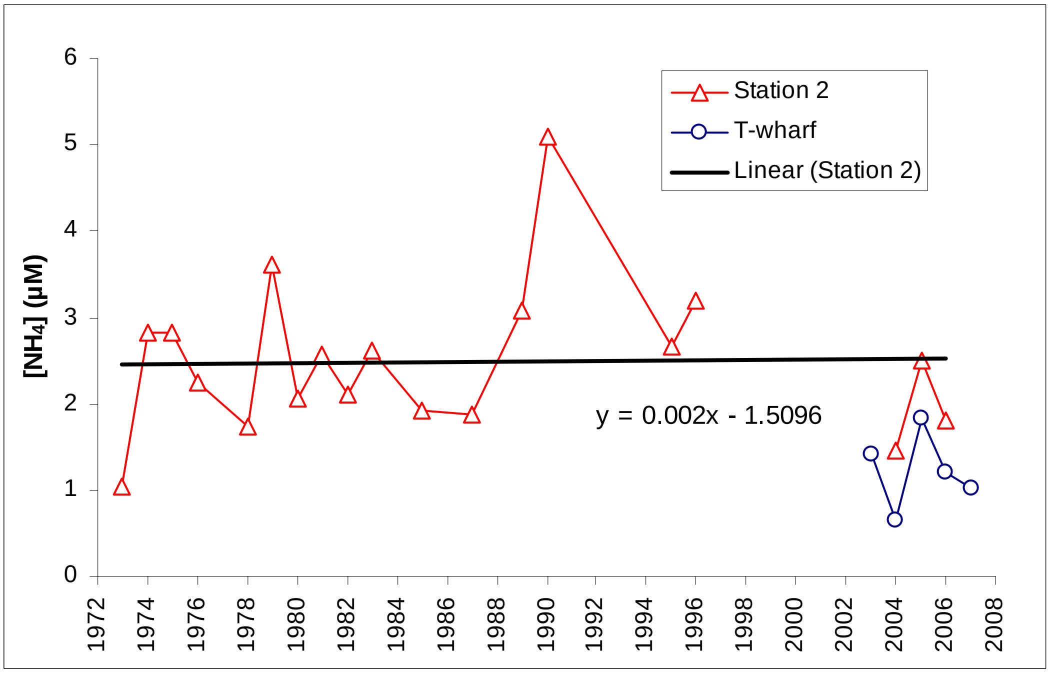


Figure 9. Mean annual ammonium concentrations from Station 2 historical data (1973-1996) and recent Station 2 and T-wharf data (2003/4-2007). A linear regression line for the Station 2 values shows no changes over time (p = 0.6818).

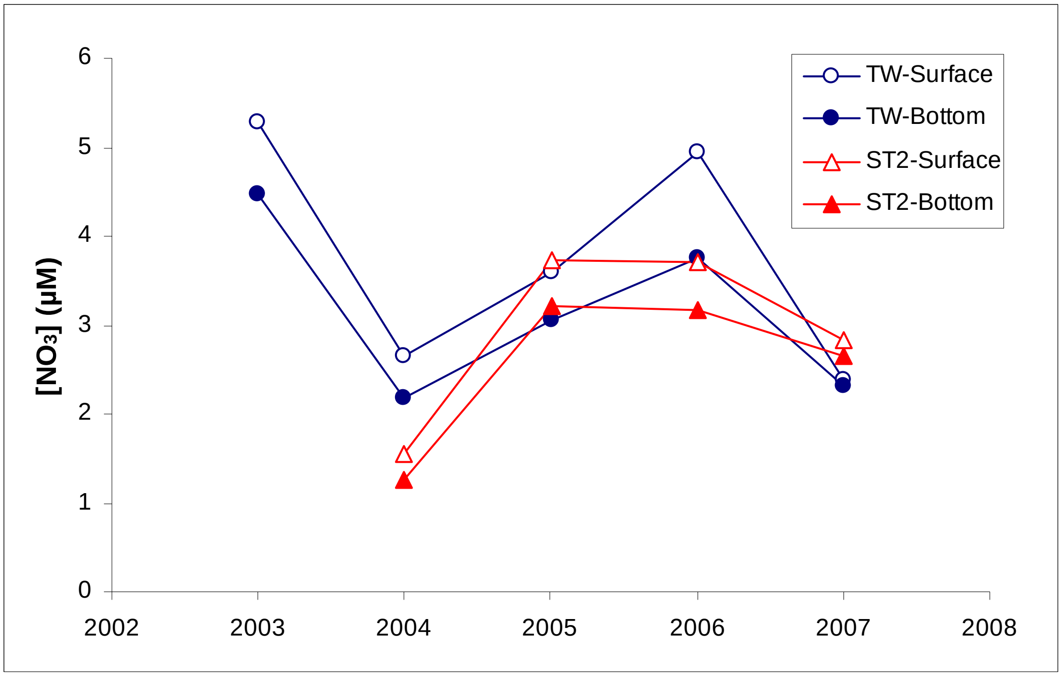


Figure 10. Mean annual nitrate concentrations for surface and bottom water at T-wharf (TW) and Station 2 (ST2). Coefficients of variation ranged from 70-170% at T-wharf and 70-125% at Station 2.

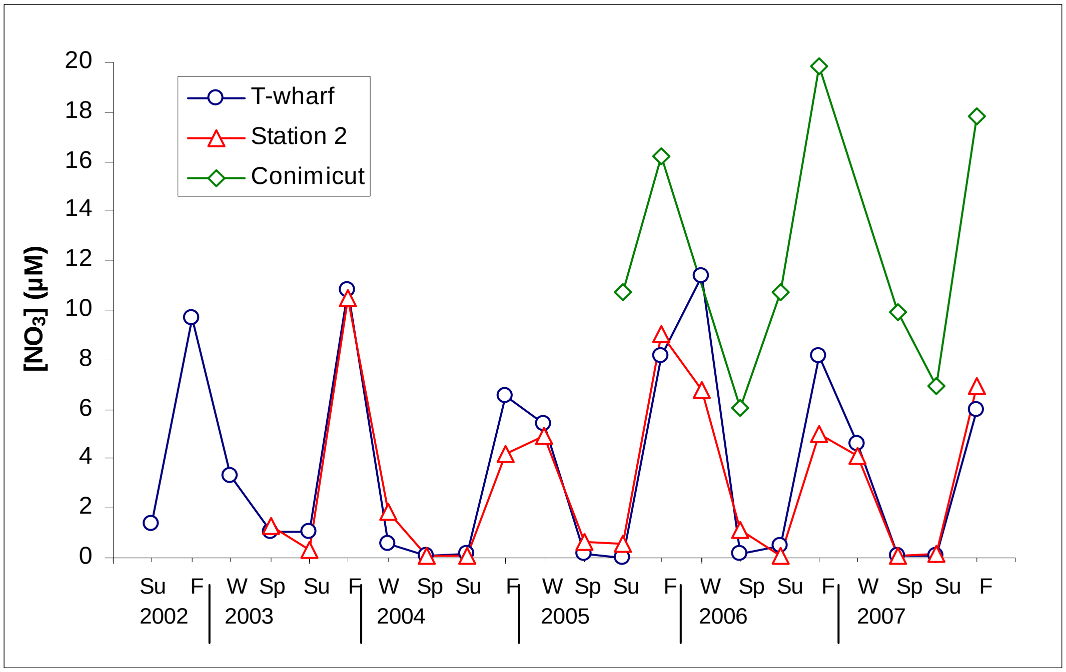


Figure 11. Mean seasonal nitrate concentrations for surface and bottom waters at T-wharf and Station 2 (W = winter, Sp = spring, Su = summer, F = fall). Coefficients of variation generally ranged from 0-210% at T-wharf, 2-200% at Station 2 and 25-95% at Conimicut Point.

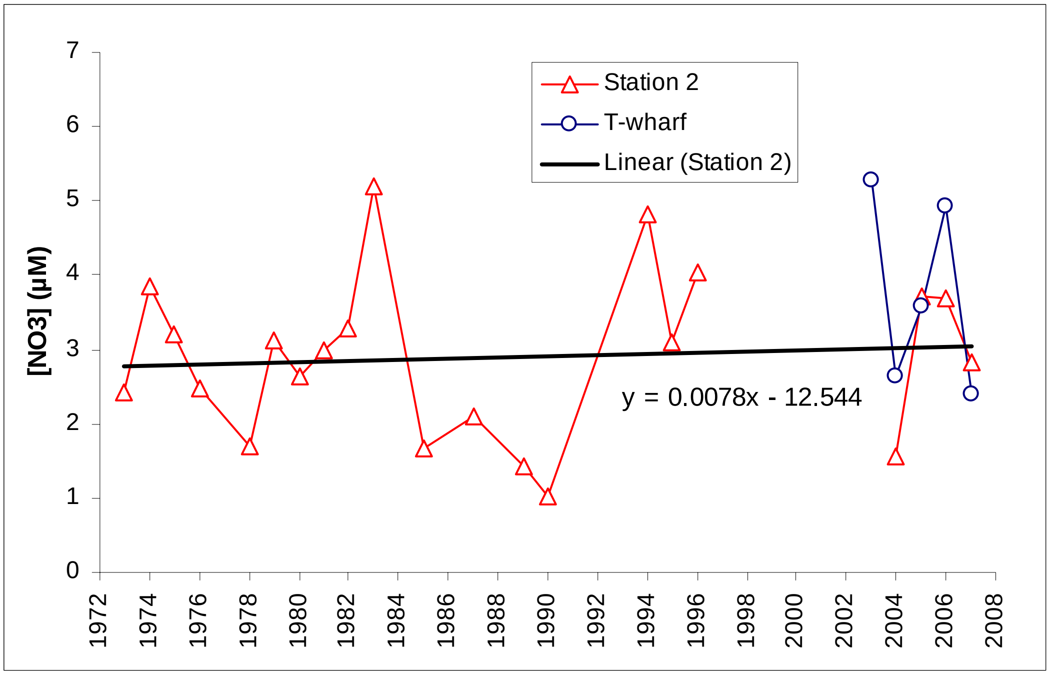


Figure 12. Mean annual nitrate concentrations from Station 2 historical data (1973-1996) and recent Station 2 and T-wharf data (2003/4-2007). A linear regression line for the Station 2 values shows no changes over time (p = 0.7385).

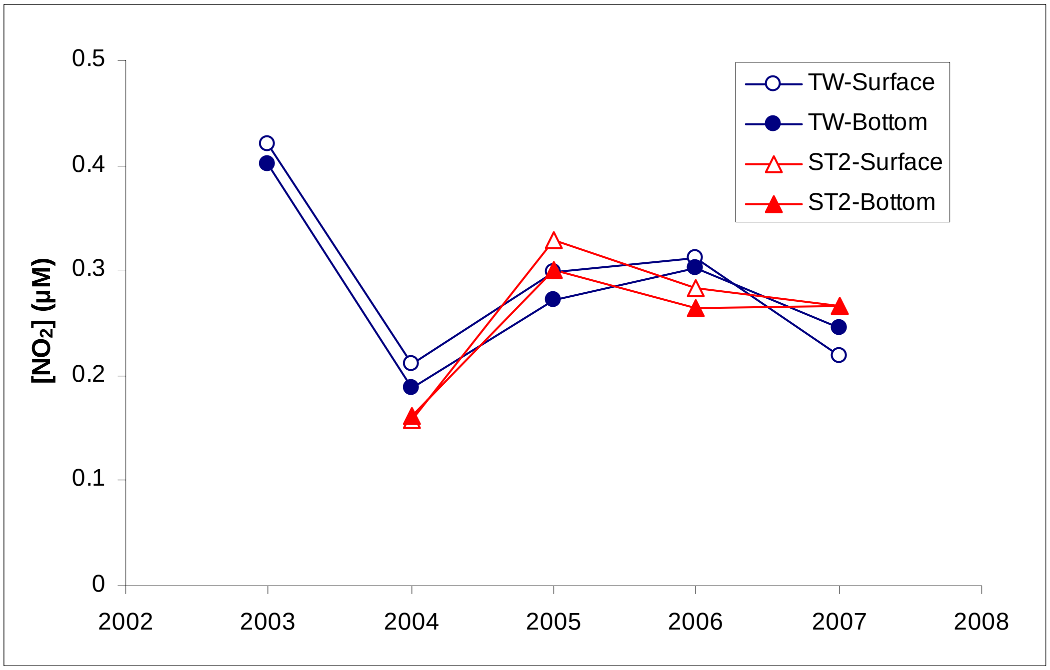


Figure 13. Mean annual nitrite concentrations for surface and bottom water at T-wharf (TW) and Station 2 (ST2). Coefficients of variation ranged from 80-140% at T-wharf and 80-135% at Station 2.

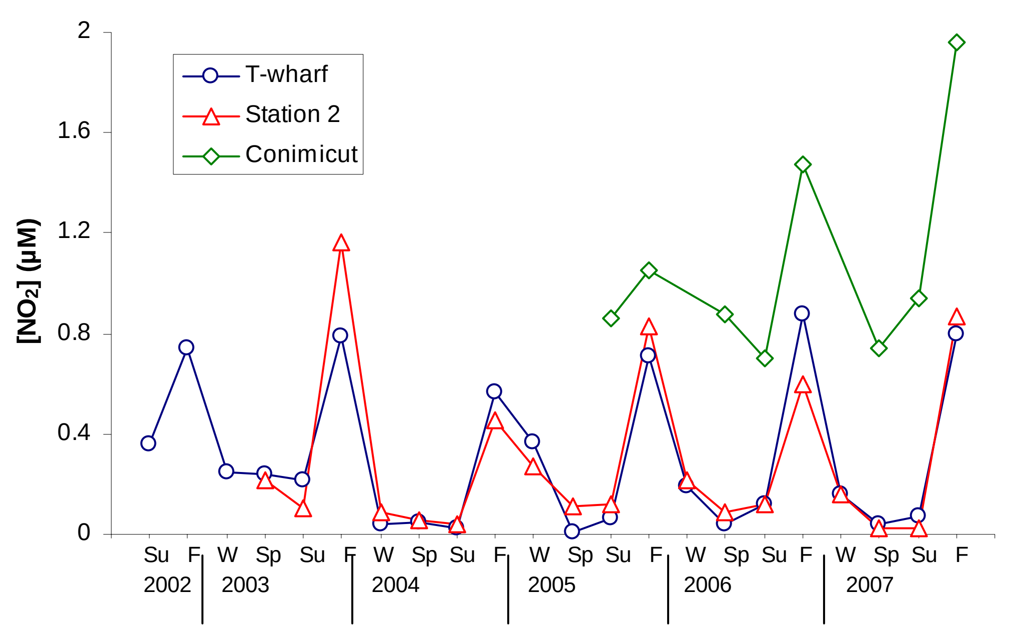


Figure 14. Mean seasonal nitrite concentrations for surface and bottom waters at T-wharf and Station 2 (W = winter, Sp = spring, Su = summer, F = fall). Coefficients of variation generally ranged from 0-150% at T-wharf, 5-150% at Station 2 and 10-95% at Conimicut Point.

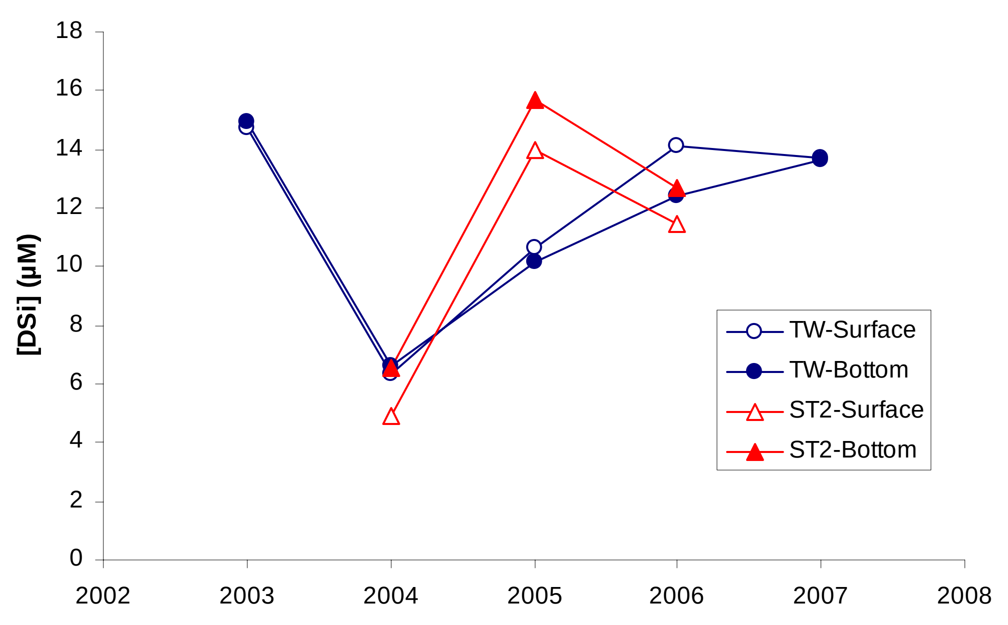


Figure 15. Mean annual dissolved silica concentrations for surface and bottom water at T-wharf (TW) and Station 2 (ST2). Coefficients of variation ranged from 65-140% at T-wharf and 85-140% at Station 2.

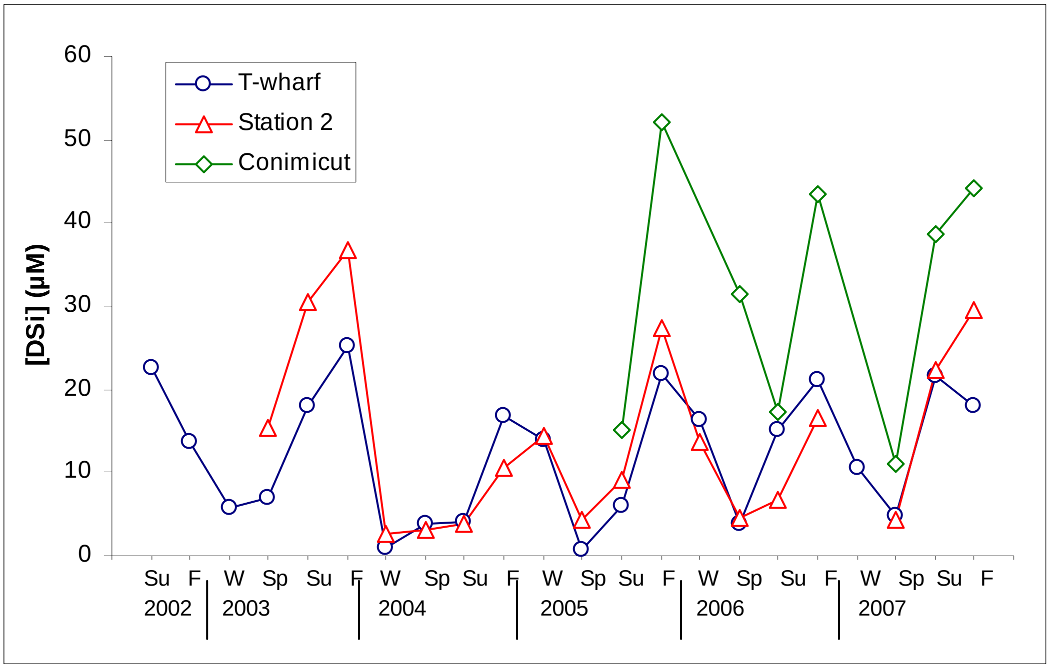


Figure 16. Mean seasonal dissolved silica concentrations for surface and bottom waters at T-wharf and Station 2 (W = winter, Sp = spring, Su = summer, F = fall). Coefficients of variation generally ranged from 5-125% at T-wharf, 0-190% at Station 2 and 5-60% at Conimicut Point.

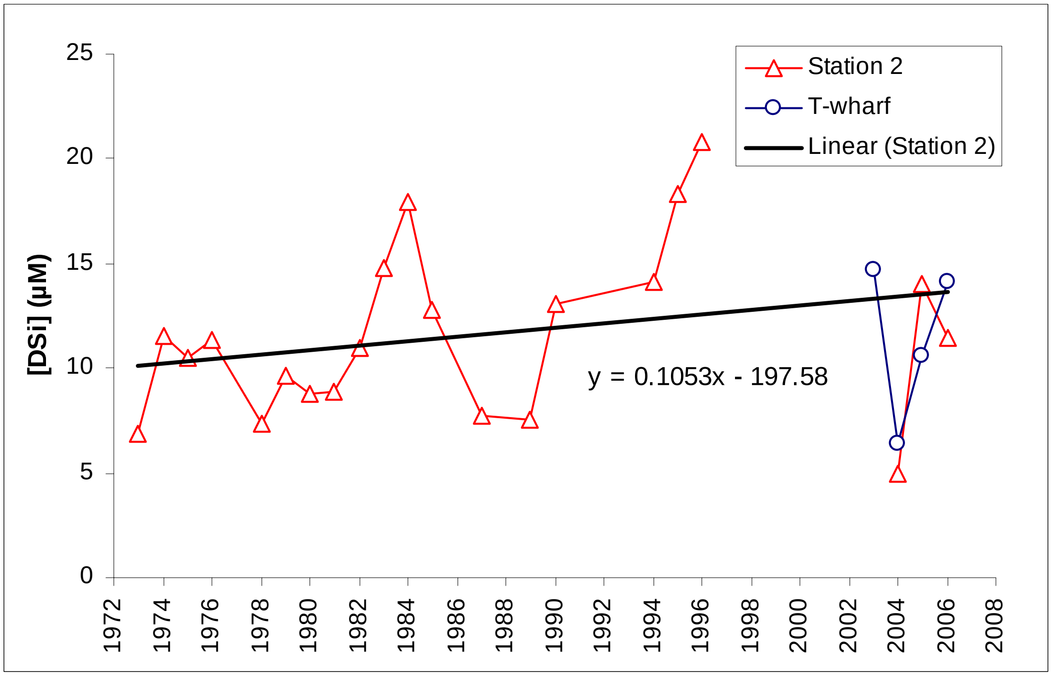
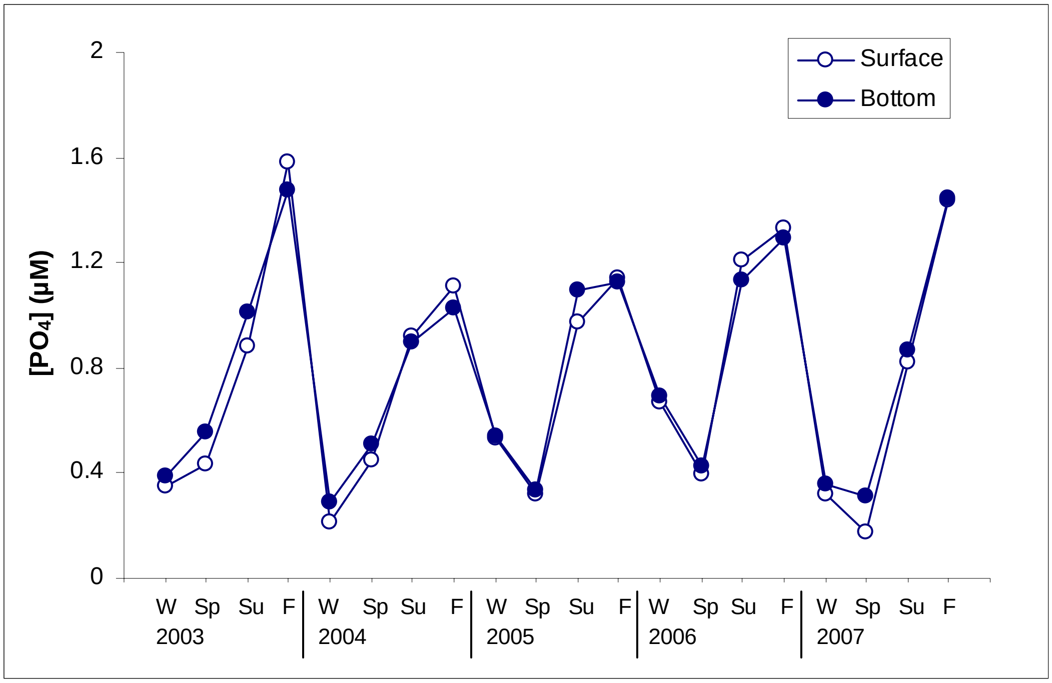


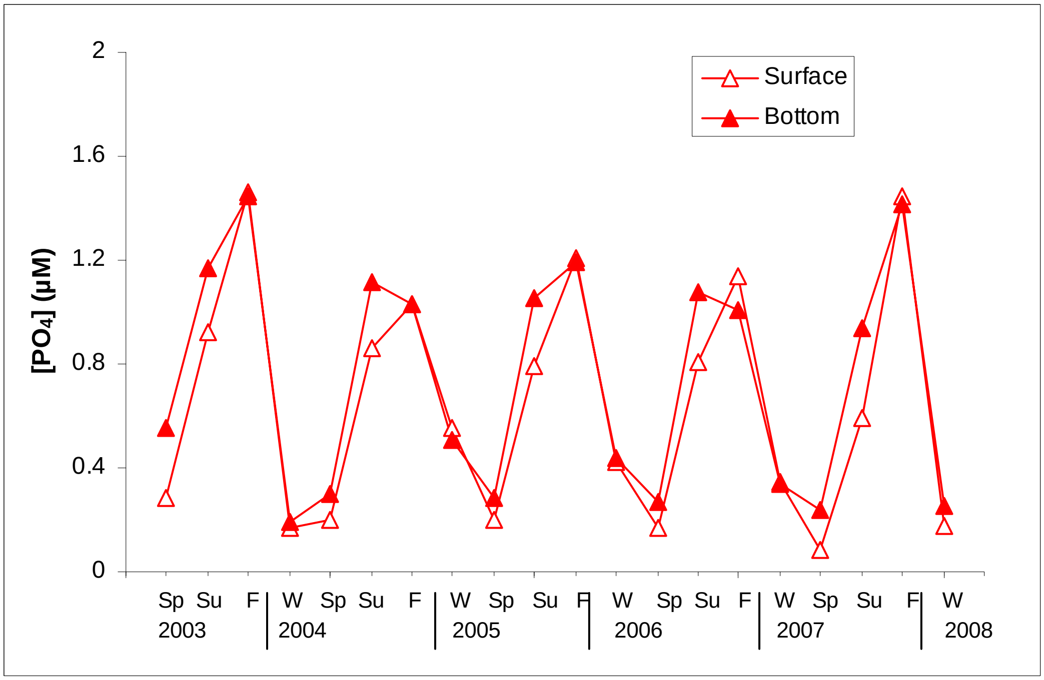
Figure 17. Mean annual dissolved silica concentrations from Station 2 historical data (1973-1996) and recent Station 2 and T-wharf data (2003/4-2007). A linear regression line for the Station 2 values shows no changes over time ($p = 0.2472$).

<u>Appendix A</u>: *Seasonal nutrient concentrations at T-wharf and Station 2 – comparisons between surface and bottom waters. (W = winter, Sp = spring, Su = summer, F = fall)*

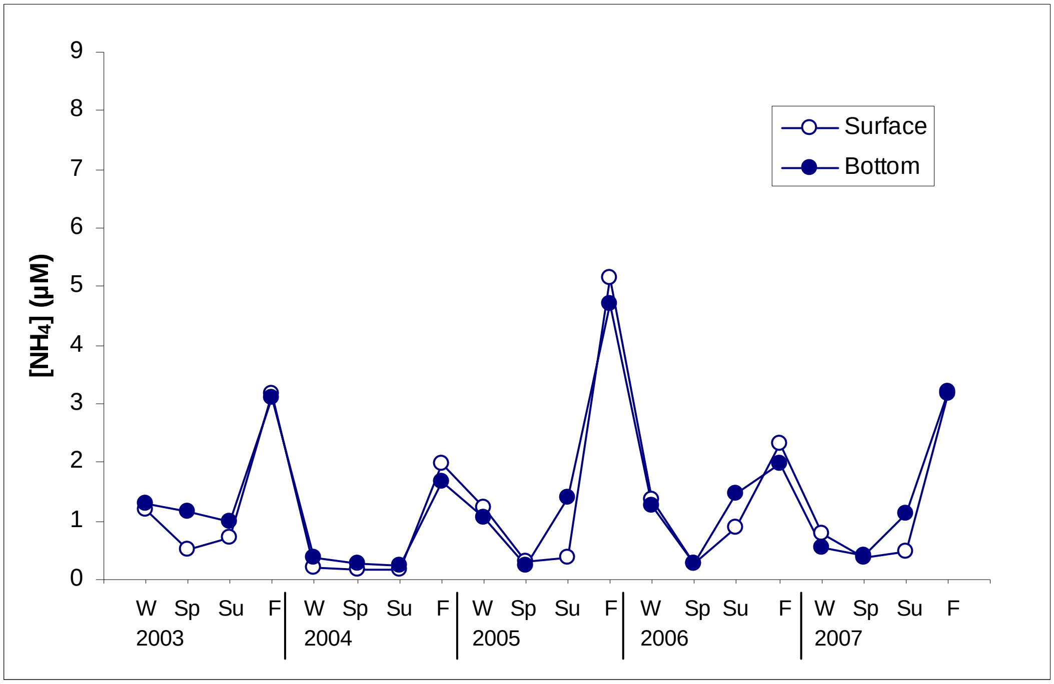
T-WHARF – PHOSPHATE



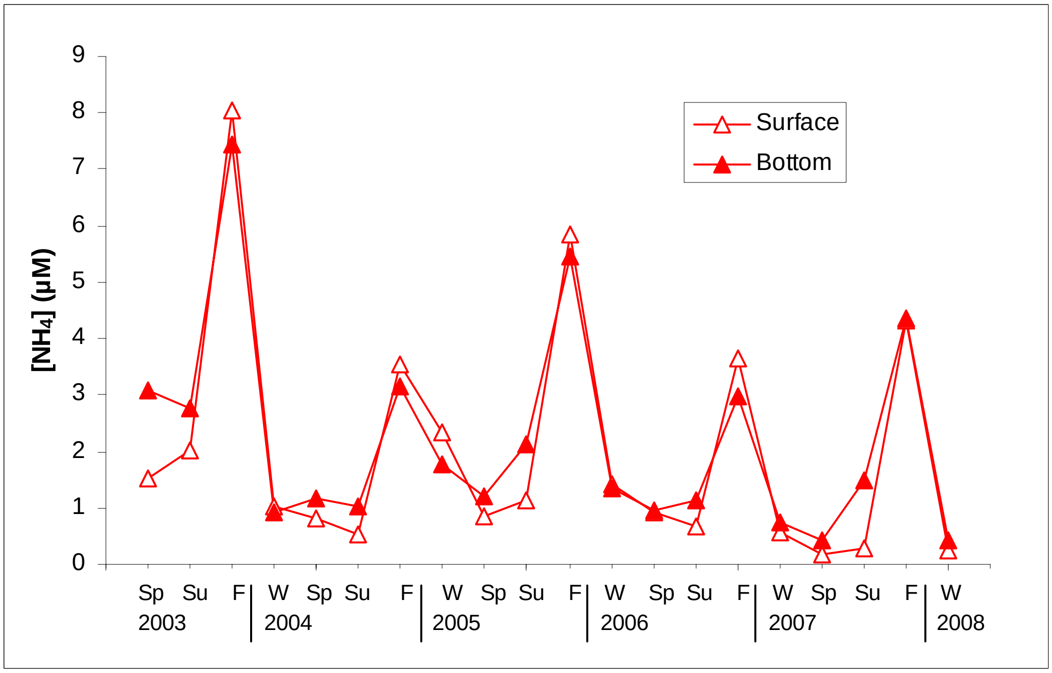
STATION 2 - PHOSPHATE



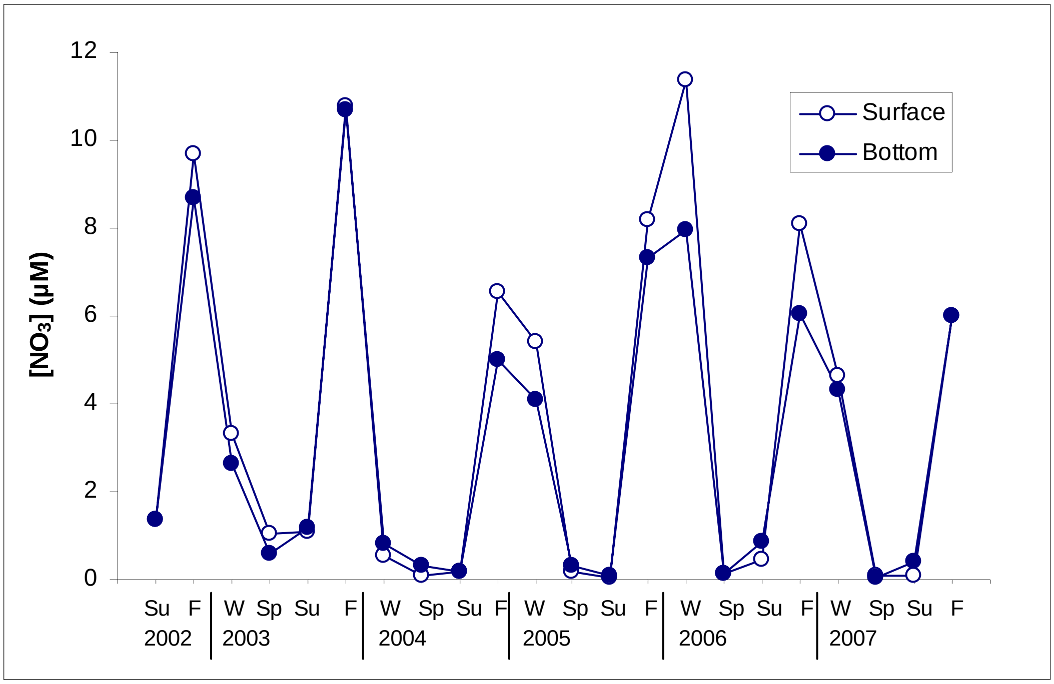
T-WHARF – AMMONIUM



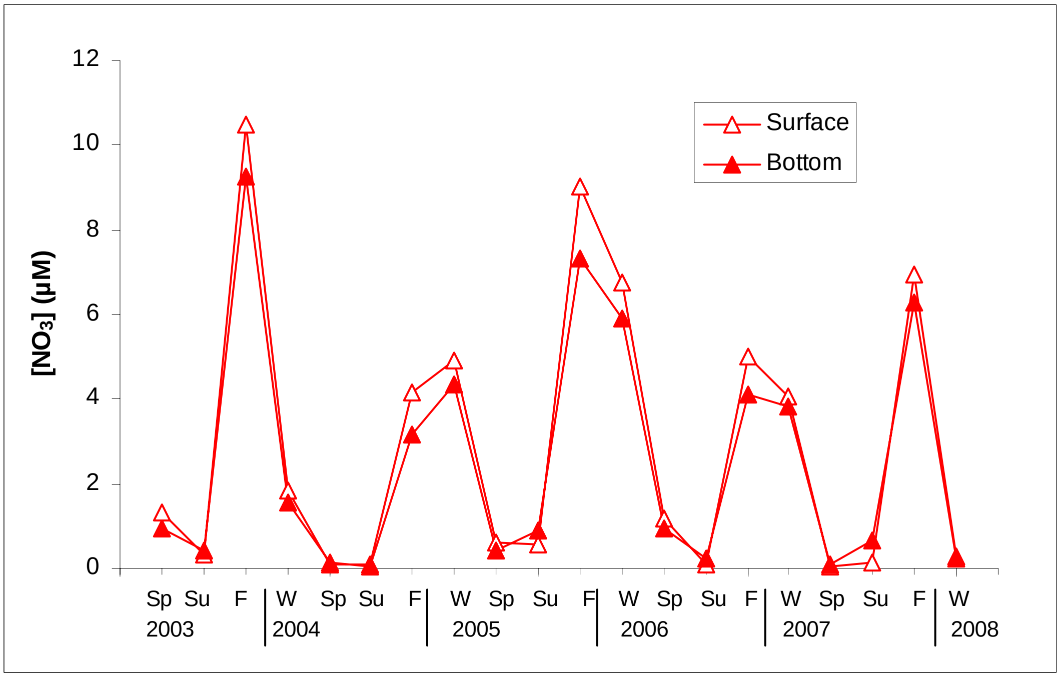
STATION 2 – AMMONUIM



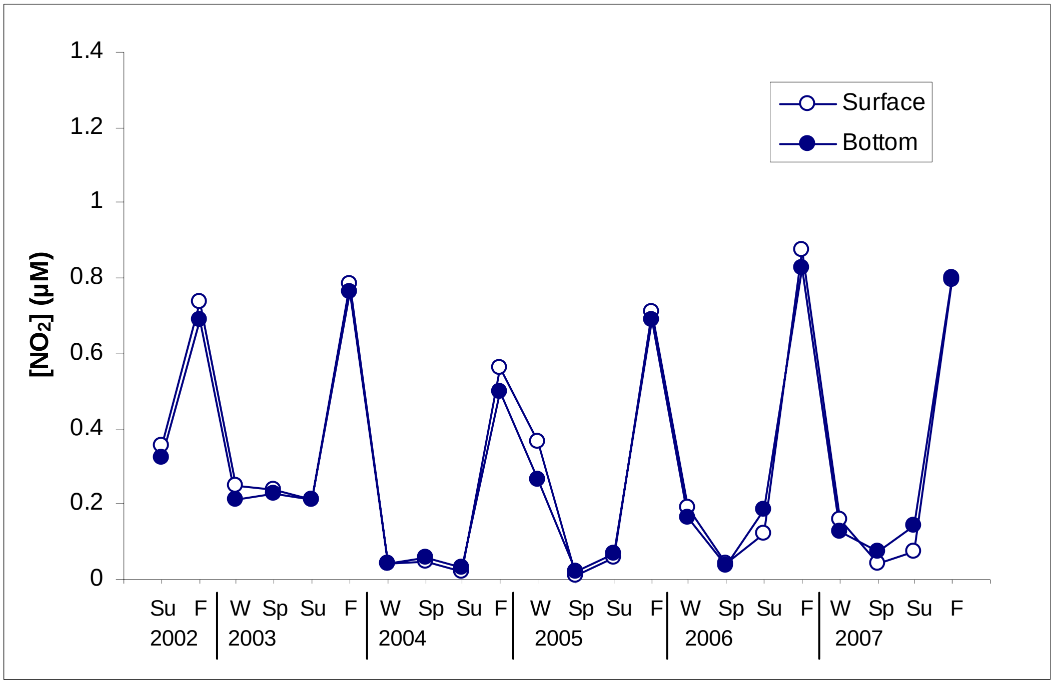
T-WHARF – NITRATE



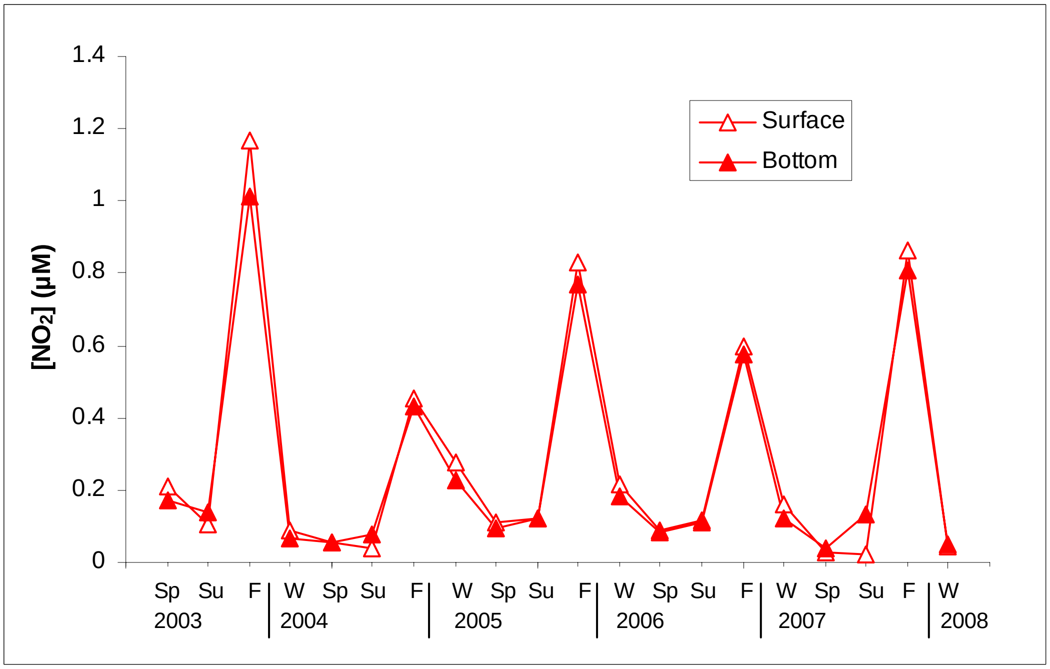
STATION 2 - NITRATE



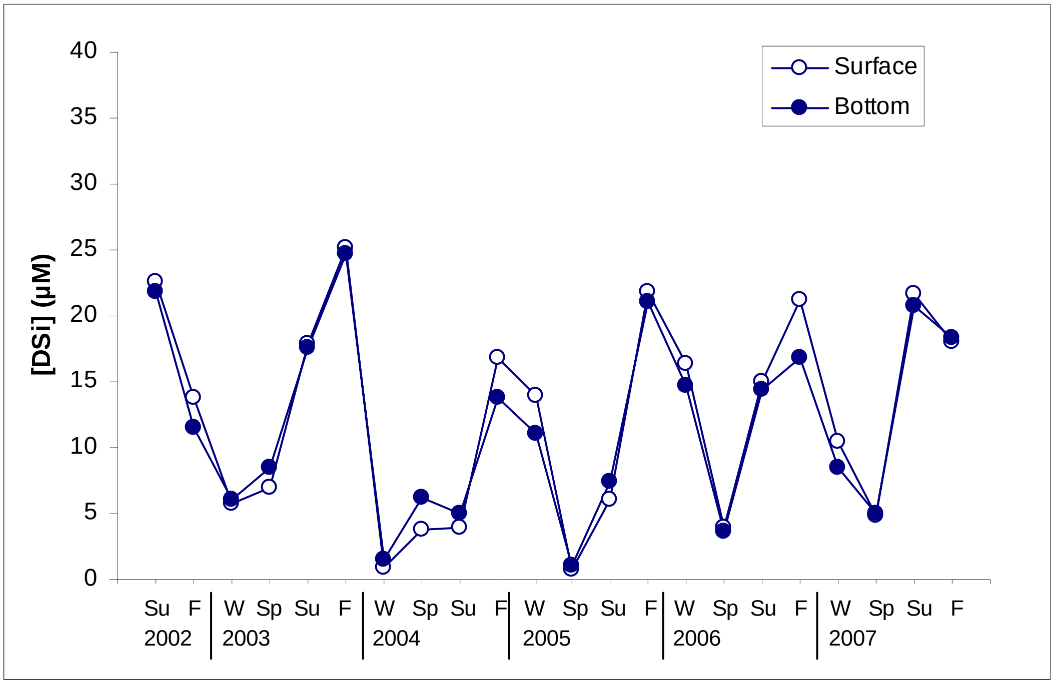
T-WHARF – NITRITE



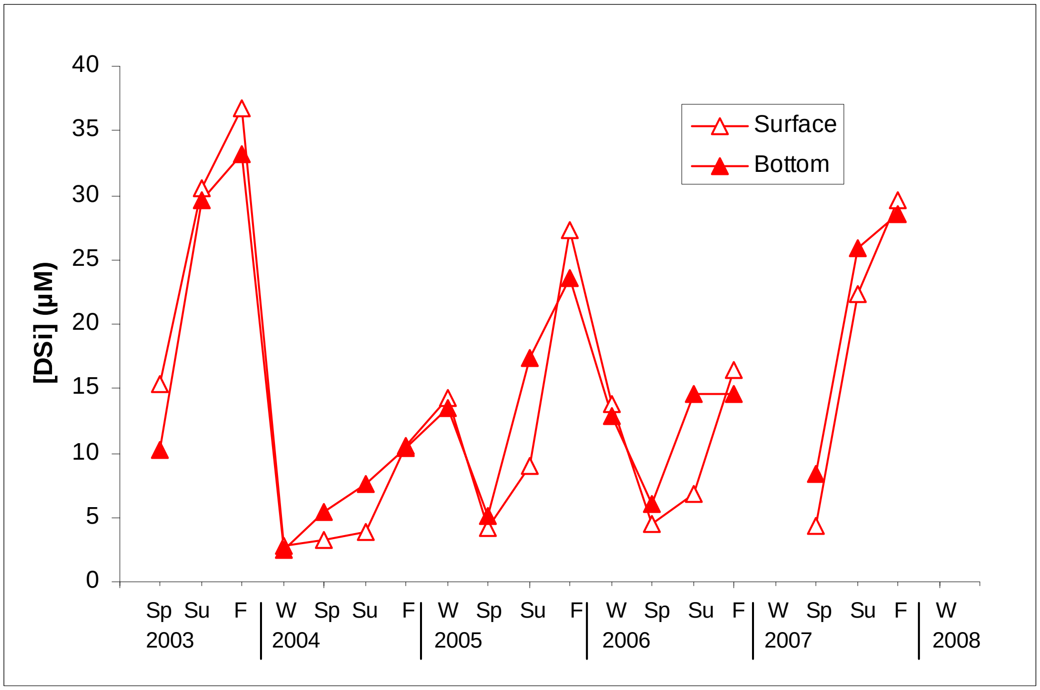
STATION 2 - NITRITE



T-WHARF – DISSOLVED SILICA



STATION 2 – DISSOLVED SILICA



Appendix B: *Regression analyses of annual river flow into Narragansett Bay (from Pilson 2008) vs. annual nutrient means at Station 2 (1973-1996)*

PHOSPHATE

PO4 = 1.190149 - 0.0011585*River Flow

Summary of Fit

RSquare	0.021382
RSquare Adj	-0.04386
Root Mean Square Error	0.197645
Mean of Response	1.077059
Observations (or Sum Wgts)	17

Analysis of Variance

Source	DF	F Ratio	Prob > F
Model	1	0.3277	0.5755
Error	15		
C. Total	16		

AMMONIUM

NH4 = 1.7924521 + 0.0066804*River Flow

Summary of Fit

RSquare	0.065054
RSquare Adj	-0.00686
Root Mean Square Error	0.66282
Mean of Response	2.430667
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	F Ratio	Prob > F
Model	1	0.9045	0.3589
Error	13		
C. Total	14		

NITRATE

NO3 = 1.0275666 + 0.0190434*River Flow

Summary of Fit

RSquare	0.162616
RSquare Adj	0.10679
Root Mean Square Error	1.089725
Mean of Response	2.886471
Observations (or Sum Wgts)	17

Analysis of Variance

Source	DF	F Ratio	Prob > F
Model	1	2.9129	0.1085
Error	15		
C. Total	16		

DISSOLVED SILICA

Silica = 8.3258912 + 0.035399*River Flow

Summary of Fit

RSquare	0.04425
RSquare Adj	-0.01548
Root Mean Square Error	4.095169
Mean of Response	11.82056
Observations (or Sum Wgts)	18

Analysis of Variance

Source	DF	F Ratio	Prob > F
Model	1	0.7408	0.4021
Error	16		
C. Total	17		

Appendix C: *Annual and seasonal means (+ standard error) for nutrients and salinity. Means for years with incomplete data were not calculated. Nutrient means are expressed in µM and salinity means are in ppt.*

ANNUAL MEANS: T-WHARF

Surface

	PO_4		NH_4		NO_3		NO_2		DSi		Salinity	
Year	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
2003	0.85	0.12	1.41	0.28	5.27	1.09	0.42	0.07	14.71	3.14	29.68	0.01
2004	0.67	0.09	0.65	0.19	2.64	0.76	0.21	0.06	6.36	1.30	30.19	0.01
2005	0.74	0.09	1.83	0.51	3.59	0.80	0.30	0.07	10.62	2.17	28.78	0.01
2006	0.90	0.09	1.21	0.23	4.94	1.29	0.31	0.08	14.12	2.88	28.66	0.01
2007	0.62	0.11	1.02	0.29	2.39	0.98	0.22	0.06	13.73	2.80	29.78	0.01

Bottom

	PO_4		NH_4		NO_3		NO_2		DSi		Salinity	
Year	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
2003	0.90	0.10	1.67	0.27	4.47	1.08	0.40	0.07	14.94	3.19	30.67	0.01
2004	0.68	0.07	0.65	0.17	2.19	0.54	0.19	0.05	6.61	1.35	30.83	0.01
2005	0.77	0.09	1.85	0.47	3.06	0.70	0.27	0.07	10.15	2.07	30.02	0.01
2006	0.89	0.08	1.24	0.18	3.76	0.96	0.30	0.08	12.41	2.53	29.98	0.01
2007	0.71	0.10	1.20	0.27	2.31	0.83	0.25	0.06	13.65	2.79	30.42	0.00

ANNUAL MEANS: STATION 2 – RECENT

Surface

	PO_4		NH_4		NO_3		NO_2		DSi		Salinity	
Year	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
2003											28.80	0.22
2004	0.56	0.07	1.47	0.29	1.55	0.46	0.16	0.04	4.93	0.71	29.79	0.14
2005	0.69	0.07	2.51	0.41	3.72	0.66	0.33	0.05	14.01	1.98	28.59	0.19
2006	0.68	0.07	1.81	0.34	3.70	0.72	0.28	0.05	11.46	1.73	28.68	0.25
2007	0.61	0.08	1.32	0.30	2.82	0.62	0.27	0.06				

Bottom

	PO_4		NH_4		NO_3		NO_2		DSi		Salinity	
Year	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
2003											30.05	0.21
2004	0.69	0.08	1.57	0.26	1.26	0.41	0.10	0.04	6.54	1.00	30.59	0.13
2005	0.77	0.07	2.64	0.36	3.21	0.52	0.15	0.05	15.69	2.24	29.43	0.12
2006	0.74	0.06	1.72	0.23	3.16	0.60	0.14	0.05	12.69	1.91	29.61	0.14
2007	0.74	0.08	1.72	0.27	2.66	0.53	0.16	0.05				

ANNUAL MEANS: STATION 2 – HISTORIC

Surface Only (No Bottom)

	PO_4		NH_4		NO_3		DSi	
Year	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
1973	0.88	0.10	1.04	0.24	2.43	0.57	6.84	0.96
1974	1.10	0.10	2.83	0.46	3.85	0.63	11.52	1.18
1975	1.25	0.08	2.83	0.52	3.20	0.60	10.46	1.26
1976	0.87	0.09	2.26	0.40	2.48	0.51	11.33	1.34
1977								
1978	0.97	0.09	1.73	0.23	1.71	0.37	7.39	0.71
1979	1.18	0.12	3.62	0.60	3.13	0.54	9.68	0.87
1980	1.26	0.12	2.07	0.39	2.63	0.72	8.81	1.13
1981	1.36	0.12	2.57	0.49	2.98	0.60	8.84	0.98
1982	1.00	0.06	2.12	0.33	3.30	0.63	10.95	1.07
1983	1.12	0.09	2.63	0.32	5.19	0.88	14.76	0.98
1984							17.91	1.89
1985	1.00	0.10	1.93	0.29	1.66	0.40	12.77	1.51
1986								
1987	0.66	0.09	1.88	0.41	2.10	0.62	7.75	1.21
1988								
1989	0.96	0.07	3.08	0.73	1.42	0.32	7.51	1.23
1990	1.35	0.09	5.10	0.37	1.02	0.30	13.09	4.02
1991								
1992								
1993								
1994	1.32	0.12			4.82	0.62	14.08	1.64
1995	1.08	0.08	2.66	0.31	3.11	0.67	18.28	1.86
1996	0.95	0.09	3.21	0.38	4.04	0.72	20.80	2.49

SEASONAL MEANS: T-WHARF

Surface

* Denotes bad data that were removed from the analysis

		PO_4		NH_4		NO_3		NO_2		DSi	
Year	Season	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
2002	Summer	3.13 *	0.12 *	2.55 *	0.93 *	1.34	0.71	0.36	0.14	22.54	5.06
	Fall	3.08 *	0.33 *	9.85 *	2.70 *	9.69	0.97	0.74	0.04	13.71	1.56
2003	Winter	0.35	0.02	1.18	0.41	3.32	1.38	0.25	0.06	5.75	1.51
	Spring	0.43	0.15	0.50	0.21	1.05	0.50	0.24	0.06	6.98	2.06
	Summer	0.88	0.09	0.70	0.29	1.07	0.00	0.21	0.00	17.93	4.93
	Fall	1.58	0.06	3.18	0.31	10.79	1.39	0.79	0.11	25.18	0.81
2004	Winter	0.22	0.03	0.20	0.02	0.57	0.24	0.04	0.01	0.96	0.22
	Spring	0.45	0.09	0.18	0.05	0.10	0.02	0.05	0.01	3.73	0.69
	Summer	0.92	0.12	0.18	0.06	0.16	0.04	0.02	0.01	3.97	0.62
	Fall	1.11	0.11	1.97	0.43	6.54	1.43	0.56	0.07	16.78	3.59
2005	Winter	0.53	0.09	1.23	0.29	5.40	0.60	0.37	0.04	13.90	0.96
	Spring	0.32	0.09	0.30	0.09	0.18	0.04	0.01	0.00	0.81	0.18
	Summer	0.97	0.14	0.38	0.08	0.04	0.01	0.06	0.01	6.01	2.22
	Fall	1.14	0.10	5.14	1.16	8.18	1.24	0.71	0.17	21.75	1.98
2006	Winter	0.67	0.14	1.38	0.43	11.38	3.06	0.19	0.05	16.33	5.38
	Spring	0.40	0.07	0.27	0.05	0.13	0.03	0.04	0.01	3.94	0.94
	Summer	1.21	0.07	0.88	0.30	0.46	0.12	0.12	0.03	15.05	6.05
	Fall	1.33	0.04	2.32	0.46	8.11	1.86	0.88	0.18	21.15	3.60
2007	Winter	0.32	0.16	0.79	0.25	4.63	2.90	0.16	0.07	10.52	6.14
	Spring	0.18	0.05	0.38	0.08	0.07	0.03	0.04	0.01	4.80	0.78
	Summer	0.82	0.04	0.47	0.10	0.07	0.04	0.07	0.03	21.60	2.24
	Fall	1.44	0.14	3.16	1.03	5.98	1.87	0.79	0.01	18.00	5.87

SEASONAL MEANS: T-WHARF

Bottom

* Denotes bad data that were removed from the analysis

		PO_4		NH_4		NO_3		NO_2		DSi	
Year	Season	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
2002	Summer	3.33 *	0.25 *	4.56 *	1.89*	1.37	0.65	0.32	0.13	21.84	4.78
	Fall	2.90 *	0.92 *	8.84 *	6.94 *	8.67	0.61	0.69	0.05	11.58	0.92
2003	Winter	0.39	0.02	1.30	0.34	2.64	1.28	0.21	0.04	6.06	1.01
	Spring	0.55	0.13	1.17	0.52	0.57	0.29	0.23	0.04	8.47	1.43
	Summer	1.01	0.10	0.98	0.36	1.18	0.02	0.21	0.00	17.52	4.72
	Fall	1.47	0.03	3.11	0.29	10.69	1.37	0.76	0.11	24.76	0.84
2004	Winter	0.29	0.05	0.38	0.21	0.82	0.32	0.04	0.01	1.45	0.44
	Spring	0.51	0.12	0.27	0.07	0.32	0.09	0.06	0.02	6.15	1.49
	Summer	0.89	0.04	0.22	0.04	0.20	0.02	0.03	0.01	5.02	0.35
	Fall	1.02	0.10	1.66	0.41	5.02	0.90	0.50	0.05	13.83	2.30
2005	Winter	0.54	0.09	1.06	0.31	4.10	0.91	0.27	0.04	11.02	1.93
	Spring	0.34	0.11	0.25	0.05	0.32	0.08	0.02	0.00	1.07	0.18
	Summer	1.10	0.17	1.40	0.50	0.07	0.03	0.07	0.01	7.37	2.36
	Fall	1.13	0.12	4.69	1.16	7.30	1.02	0.69	0.16	21.11	1.55
2006	Winter	0.69	0.11	1.26	0.33	7.96	2.54	0.16	0.05	14.64	4.43
	Spring	0.43	0.07	0.26	0.03	0.13	0.03	0.04	0.01	3.69	0.83
	Summer	1.13	0.05	1.46	0.38	0.88	0.33	0.19	0.02	14.44	3.93
	Fall	1.29	0.06	1.97	0.22	6.05	1.28	0.83	0.17	16.85	1.93
2007	Winter	0.36	0.12	0.56	0.22	4.34	2.25	0.13	0.05	8.43	4.70
	Spring	0.31	0.05	0.41	0.06	0.05	0.01	0.08	0.05	5.05	0.64
	Summer	0.87	0.08	1.13	0.23	0.42	0.17	0.15	0.06	20.77	1.89
	Fall	1.45	0.11	3.20	0.74	5.99	1.82	0.80	0.01	18.36	5.63

SEASONAL MEANS: STATION 2 – RECENT

Surface

		PO_4		NH_4		NO_3		NO_2		DSi	
Year	Season	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
2003	Spring	0.28	0.07	1.52	0.53	1.32	0.30	0.21	0.04	15.31	4.54
	Summer	0.92	0.13	2.02	0.67	0.34	0.14	0.11	0.04	30.59	7.52
	Fall	1.46	0.07	8.04	0.79	10.51	0.98	1.17	0.11	36.78	3.42
2004	Winter	0.17	0.05	1.03	0.38	1.86	1.17	0.09	0.03	2.72	1.59
	Spring	0.20	0.06	0.80	0.07	0.08	0.03	0.05	0.01	3.19	1.17
	Summer	0.86	0.09	0.54	0.13	0.08	0.02	0.04	0.01	3.95	0.77
	Fall	1.03	0.09	3.54	0.86	4.17	1.08	0.45	0.11	10.53	2.50
2005	Winter	0.56	0.11	2.34	0.58	4.91	1.30	0.27	0.06	14.31	2.51
	Spring	0.20	0.03	0.86	0.15	0.62	0.16	0.11	0.02	4.21	0.88
	Summer	0.79	0.10	1.14	0.25	0.59	0.10	0.12	0.02	9.03	2.49
	Fall	1.21	0.11	5.83	1.05	9.03	1.19	0.83	0.12	27.25	2.99
2006	Winter	0.42	0.08	1.40	0.42	6.75	1.59	0.22	0.04	13.79	2.71
	Spring	0.17	0.07	0.93	0.57	1.16	0.60	0.09	0.03	4.54	1.56
	Summer	0.81	0.10	0.68	0.19	0.08	0.03	0.12	0.03	6.75	1.94
	Fall	1.14	0.07	3.64	0.80	4.99	1.21	0.60	0.12	16.47	2.96
2007	Winter	0.35	0.10	0.58	0.17	4.08	1.31	0.16	0.04		
	Spring	0.09	0.02	0.18	0.03	0.04	0.02	0.03	0.01	4.30	0.48
	Summer	0.59	0.08	0.27	0.10	0.14	0.09	0.02	0.01	22.30	2.98
	Fall	1.45	0.08	4.32	0.65	6.93	1.36	0.86	0.10	29.63	1.34

SEASONAL MEANS: STATION 2 – RECENT

Bottom

		PO_4		NH_4		NO_3		NO_2		DSi	
Year	Season	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
2003	Spring	0.56	0.09	3.07	0.69	0.95	0.24	0.17	0.04	10.28	3.46
	Summer	1.17	0.11	2.78	0.61	0.40	0.12	0.14	0.04	29.56	5.18
	Fall	1.44	0.08	7.43	0.80	9.25	0.91	1.02	0.09	33.23	2.73
2004	Winter	0.19	0.07	0.91	0.28	1.58	1.04	0.07	0.02	2.45	1.41
	Spring	0.30	0.07	1.17	0.25	0.12	0.05	0.06	0.01	5.48	2.24
	Summer	1.11	0.10	1.02	0.18	0.06	0.03	0.08	0.01	7.53	0.99
	Fall	1.03	0.07	3.16	0.78	3.18	1.03	0.43	0.10	10.35	2.51
2005	Winter	0.51	0.08	1.78	0.45	4.37	1.14	0.23	0.03	13.48	2.04
	Spring	0.28	0.04	1.20	0.27	0.45	0.09	0.09	0.01	5.16	1.00
	Summer	1.05	0.08	2.14	0.34	0.88	0.16	0.12	0.02	17.38	2.74
	Fall	1.20	0.10	5.47	0.94	7.32	0.77	0.77	0.11	23.61	1.91
2006	Winter	0.44	0.07	1.36	0.27	5.89	1.32	0.18	0.03	12.93	2.04
	Spring	0.27	0.08	0.97	0.53	0.95	0.35	0.09	0.03	6.02	1.43
	Summer	1.08	0.06	1.14	0.26	0.22	0.06	0.11	0.01	14.60	2.27
	Fall	1.01	0.05	2.99	0.50	4.12	1.02	0.57	0.12	14.58	2.15
2007	Winter	0.34	0.09	0.74	0.19	3.82	1.20	0.12	0.03		
	Spring	0.24	0.06	0.44	0.18	0.10	0.03	0.04	0.01	8.33	1.18
	Summer	0.94	0.11	1.47	0.29	0.65	0.28	0.13	0.05	25.91	2.56
	Fall	1.42	0.07	4.37	0.60	6.29	1.14	0.81	0.09	28.52	1.16

SEASONAL MEANS: CONIMICUT POINT

Surface

		PO_4		NH_4		NO_3		NO_2		DSi	
Year	Season	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
2005	Summer	2.65	1.01	9.05	6.01	10.73	8.21	0.86	0.50	15.22	2.40
	Fall	1.93	0.19	12.74	1.33	16.24	4.47	1.05	0.35	52.16	5.48
2006	Spring			1.06	0.66	6.01	5.17	0.87	0.15	31.51	13.71
	Summer	1.43	0.40	4.27	1.16	10.75	4.12	0.70	0.35	17.23	6.69
	Fall	1.49	0.01	11.39	1.11	19.83	3.08	1.48	0.17	43.44	1.42
2007	Spring	0.34	0.21	4.67	4.54	9.93	2.09	0.74	0.09	10.99	5.73
	Summer	2.05	0.34	4.05	1.67	6.92	2.48	0.94	0.29	38.73	4.59
	Fall	2.95	0.30	17.55	2.31	17.82	3.17	1.96	0.23	44.08	2.33