Marine Conditions 2008–2019 Report Series: Nutrients in Beach Waters

December 2022

King County

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1.0 INTRODUCTION

For over 50 years, King County has conducted extensive water quality monitoring to assess conditions in King County marine waters within the Central Puget Sound. The King County Marine Monitoring Program is managed by scientists in the Water and Land Resources Division within the Department of Natural Resources. The program includes two types of monitoring (1) baseline monitoring to assess background conditions (ambient monitoring) and (2) monitoring to assess conditions near King County's wastewater treatment plant (TP), combined sewer overflow (CSO), and CSO wet weather treatment station (TS) marine outfalls (outfall monitoring).

The goals of the Marine Monitoring Program are to characterize water quality and food web (phytoplankton and zooplankton) conditions in King County receiving waters, provide information for management decisions, and evaluate the status and trends of marine waters within King County. These data provide insight into both short and long-term variations and form a baseline from which water quality and food web conditions can be assessed on multiple temporal and spatial scales. Please see *Marine Conditions Report Series 2008-2019: Marine Monitoring Program Overview* (King County, 2022) for a more detailed description of the background and purpose of the Marine Monitoring Program.

The Marine Monitoring Program collects data for multiple types of media and parameters. This report presents results for the beach nutrient monitoring component collected between 2008 -2019 as well as long-term trend analysis for specific nutrients. Beach water nutrient data are used to:

- Assess potential water quality impacts following wastewater treatment plant upset discharges by comparing against historical data.
- Assist in special studies such as siting new wastewater treatment plant outfalls (King County, 2001) and evaluating dynamics in specific areas with known water quality issues (King County, 2014).
- Assess influences of large-scale and regional climate patterns on riverine and freshwater inputs and nearshore nutrient concentrations.
- Support regional efforts and collaborations such as the Puget Sound Ecosystem Monitoring Program (PSEMP) Marine Waters Workgroup, Puget Sound Marine Waters Annual Report (PSEMP Marine Waters Workgroup, 2019), Washington Dept. of Ecology's Nutrient Reduction Effort, and regional modeling efforts.

Nutrients are important to monitor as they can affect aquatic plant growth, with nitrogen being the primary limiting nutrient in marine waters. This is particularly true in nearshore areas where nutrient inputs from rivers and streams, stormwater, and groundwater can have a considerable effect on nearshore vegetation, such as seaweeds. All nutrient data (nitrogen and phosphorus compounds) are measured and reported in the dissolved inorganic form, except total nitrogen (includes both inorganic and organic forms). Dissolved nutrients are readily available for uptake by aquatic plants and the form most

often measured in marine waters. King County reports dissolved ammonia concentrations (ammonium ion that has been converted to ammonia) and the sum of nitrate and nitrite (nitrate+nitrite) concentrations. Nitrite concentrations are naturally low compared to nitrate, so nitrate+nitrite concentrations represent almost entirely nitrate.

Samples for multiple parameters were collected concurrently with nutrient samples. A summary of all data collected at each station is provided in *Marine Conditions Report Series 2008–2019: Marine Monitoring Program Overview* (King County, 2022). Results for other Marine Monitoring Program components sampled between 2008 – 2019 (except pH and thermosalinograph data), are provided in separate reports. These data summary reports are provided in separate reports with hyperlinks (click on titles to access reports) below and include the following topics:

- Marine Monitoring Program overview
- Nutrients in offshore waters
- Dissolved oxygen in offshore waters
- Temperature, salinity, and density in offshore waters
- Temperature and salinity in beach waters
- Water clarity in offshore waters
- Fecal indicator bacteria in beach and offshore waters
- Chlorophyll in offshore waters
- Phytoplankton
- Zooplankton
- Chemical and physical parameters and benthic infauna in beach (intertidal) and offshore (subtidal) sediments
- Chemical parameters in clam tissues.

2.0 METHODS

The following sections describe the sampling locations, field and laboratory methods used to assess nutrients in beach waters. A summary of the data analysis methods is also included. A more detailed description of the sampling and analysis methods can be found in the *Marine Offshore and Beach Water Monitoring: Sampling and Analysis Plan* (King County, 2020).

2.1 Sampling Locations

Beach nutrient sampling locations are located within the Puget Sound Central Basin, extending south to Dumas Bay and north to Edwards Point. Elliott Bay, a large urban embayment, which includes the City of Seattle waterfront, is located within the monitoring area (Figure 1). The eastern shoreline of Vashon Island and Quartermaster Harbor, an embayment between Vashon and Maury Islands, are also included in the sampling area.

Stations are designated as either "outfall" or "ambient". Beach outfall stations are located along the shoreline in the vicinity of a wastewater treatment plant (TP), CSO wet weather treatment station (TS), or combined sewer overflow (CSO) discharge point. Ambient beach stations are located along the shoreline away from a treatment plant outfall to assess background conditions. However, stormwater outfalls are located about every 15 meters (m) along the shoreline within the City of Seattle limits and as such, beach water quality may be affected by stormwater input.

Samples from 8 outfall and 12 ambient long-term offshore monitoring stations were collected between 2008 – 2019. Five additional beach stations were sampled 2008 – 2010, including one site in the Duwamish River. Monitoring results for those five sites are not included in this report; however, prior results can be found in water quality status reports for marine waters (King County, 2001, 2005, 2006, 2009). Table 1 provides station information.

Table 1. Beach monitoring stations, region, and first year of nutrient data collection. Data from stations sampled 2008 – 2010 (marked with an asterisk) are not included in this report.

Station Name	Station Description	Region	Station Type	First Year of Record
*ITEDWARDSPT	Edwards Point	North	ambient	2000
JSVW04	Pt. Wells/Richmond Beach	North	ambient	1999
ITCARKEEKP	Carkeek Park	North	ambient	2000
*KSQU01	Mouth of Lake WA Ship Canal	North	ambient	1998
KSHZ03	Carkeek Park-Piper's Creek outflow	North	outfall	1984
KSLU03	Golden Gardens Park	North	ambient	1998
KSSN04	West Point north beach	North	outfall	1998
KSSN05	West Point south beach	North	outfall	1998
KSYV02	Magnolia CSO	Middle	outfall	1998
LTBD27	SAM Sculpture Park	Middle – Elliott Bay	ambient	2007
*LTEH02	Seattle Waterfront -ferry terminal	Middle – Elliott Bay	ambient	1998
LSGY01	Seacrest Park	Middle – Elliott Bay	ambient	1998
LSHV01	Alki beach	Middle	ambient	1989
LSKR01	Alki TS outfall	Middle	outfall	1999
LSKS01	Constellation Park-Alki TS outfall	Middle	outfall	1998
*LTTL02	Duwamish Park	Duwamish	ambient	2007
LSVW01	Fauntleroy Cove	Middle	ambient	1999
*MTEC01	Seahurst Park	South	ambient	2007
MSJL01	Vashon TP outfall	South	outfall	2002
MTLD03	Normandy Park	South	outfall	2006
MSSM05	Tramp Harbor	South	ambient	2006
MTUJ01	Des Moines Creek Park	South	ambient	2007
MSXK01	Burton Acres Park	South – Quartermaster Harbor	ambient	2007
NTFK01	Redondo Beach	South	ambient	2007
NSJY01	Dumas Bay	South	ambient	2007

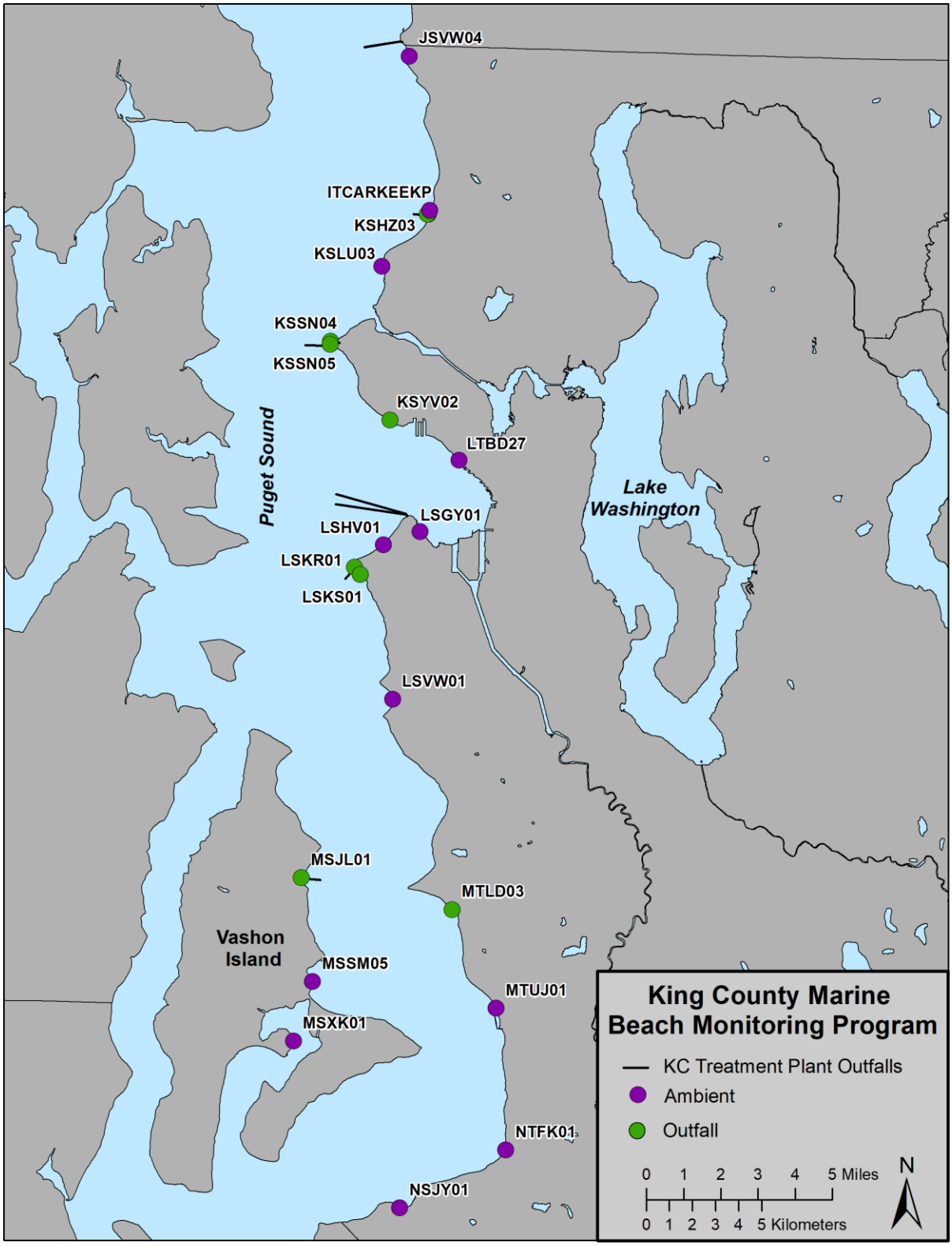


Figure 1. Beach water nutrient monitoring sampling locations.

2.2 Sampling and Analysis Methods

Samples for nutrient analyses were collected monthly from a single depth at each station. Samples were collected for dissolved ammonia-nitrogen (ammonia) and nitrate+nitrite-nitrogen (nitrate+nitrite) at all sites during the reporting period (2008 – 2019). Prior to June 2010, total phosphorus was measured at all sites until the analysis was changed to measure dissolved orthophosphate-phosphorus (orthophosphate), the form that is readily bioavailable. Total nitrogen, the sum of organic and inorganic nitrogen and ammonia, was analyzed at a subset of six stations 2010 -2019.

2.2.1 Field Methods

Beach nutrient samples were collected by the King County Environmental Laboratory (KCEL) in accordance with the *Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissues in Puget Sound* (PSEP; 1991, 1997) and the Standard Operating Procedure (SOP) for each parameter (King County, 2016). Samples were collected in approximately knee-deep water by wading into the water and inverting each sample container just above the water surface, then sinking the bottle down to approximately three to six inches below the surface. No specific tidal height or tidal stage were targeted in order to collect samples from a variety of conditions.

Dissolved nutrients were filtered in the field within 15 minutes after the sample was collected using a 0.45µm filter. The total nitrogen samples were unfiltered. Samples were stored on ice until transported to the laboratory.

Field quality control (QC) measures included use of a field filtration blank and a field blank. Detailed information regarding field methods is provided in the *Marine Offshore and Beach Water Monitoring: Sampling and Analysis Plan* (King County, 2020; https://your.kingcounty.gov/dnrp/library/2020/kcr3135/kcr3135.pdf).

2.2.2 Analytical Methods

Nutrient concentrations were measured in the laboratory using an automated analysis (Astoria2 segmented flow analyzer) for the simultaneous assessment of ammonia, nitrite + nitrate, and orthophosphate. Analyses were conducted according to Standard Methods (APHA, 2017) and *Standard Operating Procedure for Ammonia-Nitrogen, Nitrate-Nitrogen, Nitrite-Nitrogen, Orthophosphate Phosphorus and Silica in Liquid Matrices* (King County, 2016). Total nitrogen analysis was also conducted according to Standard Methods (APHA, 2017) and the KCEL SOP.

All analyses were performed using appropriate QC procedures for each parameter. QC measures included use of method blanks, laboratory control samples, matrix spikes, and laboratory duplicates. Detailed information regarding analytical methods is provided in the *Marine Offshore and Beach Water Monitoring: Sampling and Analysis Plan* (King County, 2020).

Laboratory analytical methods and method detection limits (MDL) are shown in Table 2. The MDL is defined as the minimum concentration that can be reliably detected by a particular method. MDLs for most nutrients were consistent between 2008 – 2019. However, the ammonia MDL decreased substantially in 2014. The MDL was 0.01 mg/L in 2008, decreased to 0.005 mg/L in 2009, and then decreased to 0.002 mg/L in 2014. The MDL for nitrate + nitrite was 0.02 mg/L from 2008 – 2009 and then subsequently decreased to 0.01 mg/L.

Table 2. Nutrient analytical methods and method detection limits (MDL).

	Method Detection Limit (mg/L)	Method
Ammonia-nitrogen	0.002*	Kerouel & Aminot 1997
Nitrate + nitrite-nitrogen	0.01**	SM 4500 NO3-F-S
Total nitrogen	0.05	SM 4500 N-C-S
Orthophosphate-phosphorus	0.005	SM 4500 P-F-S

*2008: 0.01 mg/L; 2009-2013: 0.005 mg/L
**2008-2009: 0.02 mg/L

2.2.3 Data Analysis Methods

Data validation was conducted on all sample results included in this report prior to data analysis. Laboratory QC checks were reviewed, including data qualifiers. Data that were assigned a "B" or "B3" (blank contamination), "SH" (sample handling criterion not met), or "J" (estimated value) qualifier were assessed for usability. Data that were deemed suspect or unusable were removed prior to data analysis.

Concentrations over the entire 2008 – 2019 period for each month were used to calculate a single average. When concentrations were < MDL, the MDL value was used to calculate both monthly and annual averages for all data analyses, except trend analysis.

Nitrate+nitrite and ammonia data monthly anomalies (departure from a long-term baseline average) were calculated for all stations by comparing each monthly concentration to the long-term baseline average (1997–2013) for that month. Monthly results that are higher than the baseline average concentration are considered positive anomalies and concentrations lower than the baseline average are considered negative anomalies. Anomalies were not calculated for total nitrogen or orthophosphate due to the short data record.

To assess long-term nitrate+nitrite and ammonia trends, a non-parametric Seasonal Kendall (SK) test was conducted using R and the censeaken function (NADA2 package) using months as a season. Rather than use the MDL if a concentration was < MDL, the censeaken function estimates concentration based on the entire data set for a given month. The SK test provides a *p* value and the Thiel-Sen slope. The *p* value is the probability of describing how likely the data would have occurred by random chance. A *p* value < .05 is typically considered a significant trend and the smaller the *p* value, the less likely to have

occurred by chance. The Thiel-Sen slope is an estimator of the magnitude and direction of change from year to year, with higher values indicating a greater amount of change.

Trends during two different time periods were assessed to account for data availability; monitoring at some stations did not begin until 2007. Therefore, the SK test was conducted with data for all 20 stations collected between 2007 - 2019, and for 13 stations with data collected between 1999 - 2019. The SK test was used to assess both annual and monthly trends over each of the two data ranges. Since ammonia concentrations are typically < MDL in the winter months, trend analysis for this parameter was performed with data collected between April - October to avoid skewing results. Trends for orthophosphate and total nitrogen were not evaluated since monitoring for these parameters did not start until mid-2010, resulting in less than 10 years of data.

3.0 BEACH WATER NUTRIENT RESULTS

Samples were collected monthly from 8 outfall and 12 ambient beach stations between 2008 and 2019 (Figure 1).

This section summarizes beach water data analyzed for dissolved nitrate+nitrite, ammonia, and orthophosphate at all sites. Total nitrogen was also analyzed at a subset of six stations.

3.1 Nitrate+Nitrite-Nitrogen

Dissolved nitrate+nitrite-nitrogen (nitrate+nitrite) concentrations in beach waters at the 20 monitoring stations ranged from below the method detection limit (MDL; 0.01 mg/L) to 1.18 mg/L (2008 - 2019). The highest values were measured at the Carkeek Park/Piper's Creek outflow station (KSHZ03) in 2009. This station is influenced by freshwater outflow from Piper's Creek; the four nitrate+nitrite concentrations >1.0 mg/L were measured at this location.

Nitrate+nitrite results for all stations and years combined are summarized in Figure 2. The highest mean and median nitrate+nitrite concentrations were measured at the Carkeek Park/Piper's Creek outflow station (KSHZ03). Station MSXS01 near Jensen Point in Quartermaster Harbor had the lowest mean and median values due to very low nitrate+nitrite concentrations spring through fall. The median nitrate+nitrite concentration at this site (MSXS01) was 0.052 mg/L compared to 0.265–0.357 mg/L at the other stations.

A distinct north to south spatial pattern in nitrate+nitrite levels was not evident; however, stations located in the vicinity of a freshwater source (KSHZ03, LTBD27, and LSVW01) had higher median concentrations than other sites. As stated above, KSHZ03 is near the outflow of Piper's Creek, LTBD27 is located near Myrtle Edwards Park in Elliott Bay and influenced by the Duwamish River, and LSVW01 is located in Fauntleroy Cove and influenced by Fauntleroy Creek. Concentrations at the two stations nearshore of the West Point TP outfall (KSSN04 and KSSN05) were similar to other sites.

Some interannual variation was evident, particularly in 2008, 2009, and 2016 (Figure 3). The highest annual mean concentrations occurred at most sites in both 2008 and 2009 and the lowest or second lowest values of all years were seen in 2016, except at KSHZ03 (Carkeek Park/Piper's Creek outflow) and MSXK01 (Quartermaster Harbor). Low annual means were also seen in 2015 and 2017. Beach water nitrate+nitrite concentrations can reflect macroalgae (seaweed) abundance; low values can indicate high macroalgae production. Years with warm air and water temperatures during the growing season (e.g., 2015–2017), tend to have higher macroalgae abundance and low nitrate+nitrite values due to nutrient uptake. Macroalgae abundance along some beaches was especially high in 2015 and led to odor problems when the seaweed decayed.

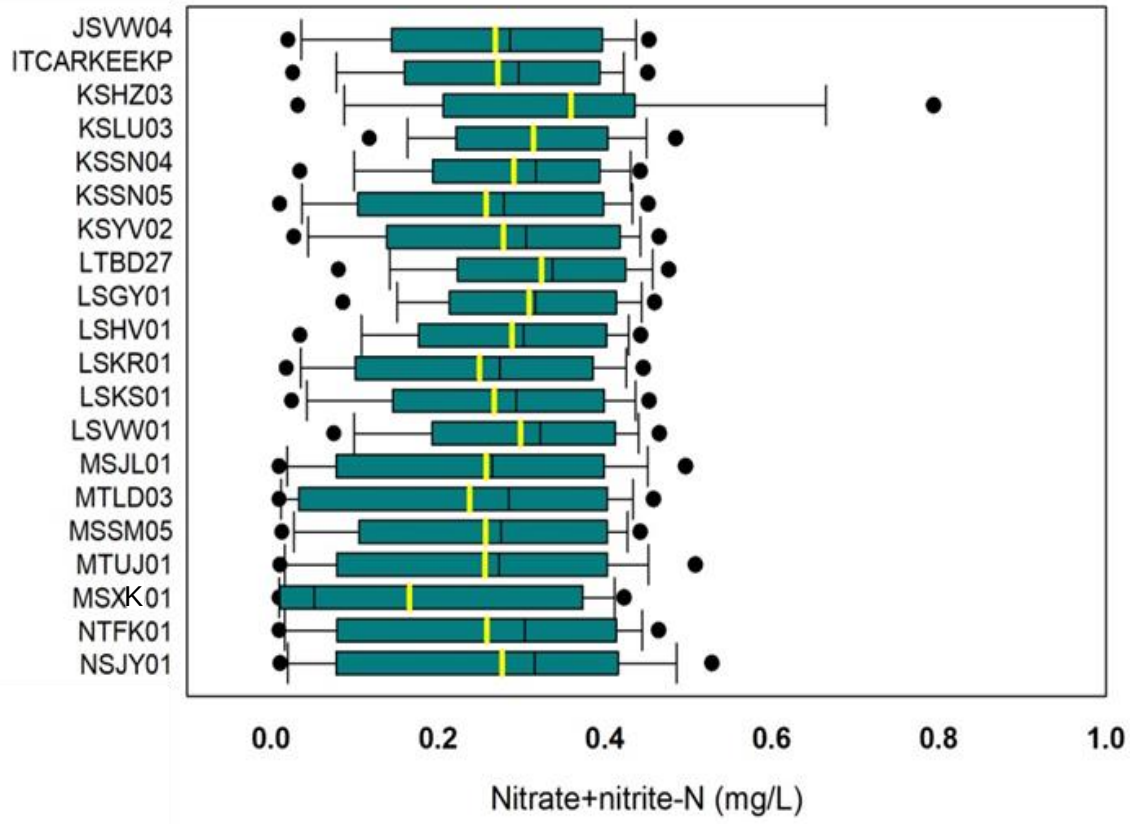


Figure 2. **Nitrate+nitrite concentrations in beach waters by station (north to south), all data (2008–2019) combined. Mean and median are represented by the yellow and black lines within the box, respectively. Box edges represent 25th and 75th percentile, whiskers represent 10th and 90th percentile, and black dots represent 5th and 95th percentile.**

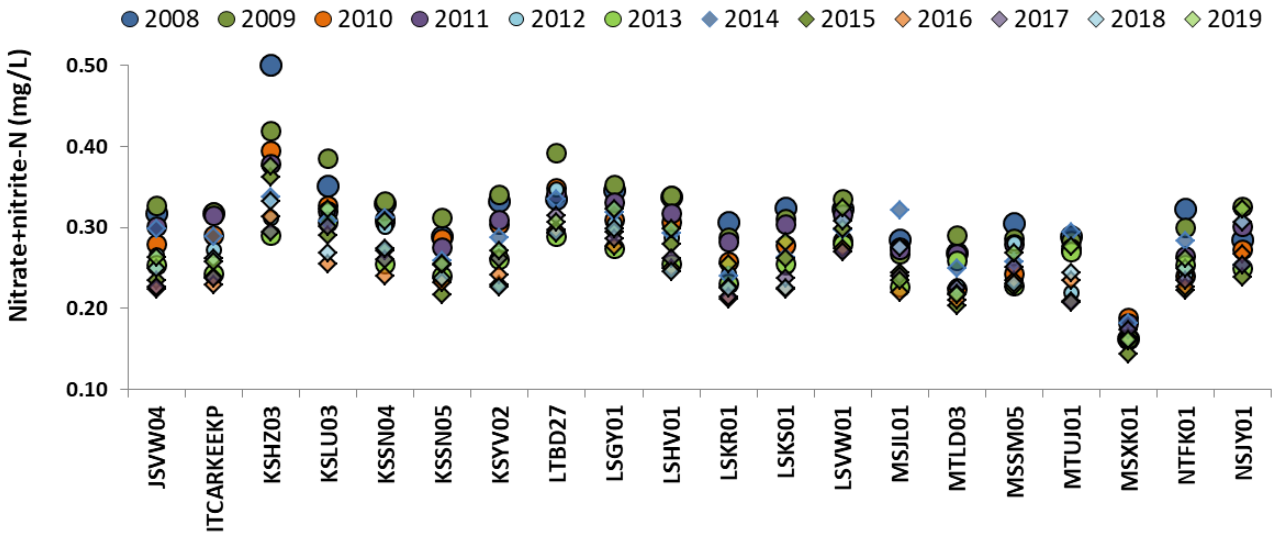


Figure 3. **Nitrate+nitrite annual mean concentration in beach waters by station and year (2008 – 2019). Stations are ordered north to south.**

Seasonal variation was evident at all stations, with higher concentrations occurring in the late fall and winter months (Figure 4). The lowest concentrations of the year were seen in late spring through summer when macroalgal growth is highest and freshwater inputs are low. Nitrate+nitrite was very low, often below detectable levels, in Quartermaster Harbor (MSXK01) between May and September and moderately low (< 0.2 mg/L) in April and October. Twenty-seven percent of all measurements at MSXK01 were below detectable levels during May and October. Station MTLD03 at Normandy Park also had low nitrate+nitrite concentrations in the summer months compared to other sites.

Nitrate+nitrite concentrations during winter months, when biological uptake is limited, were similar for all sites except at Carkeek Park/Piper's Creek outflow (KSHZ03) where levels in January and February were higher than at other sites. The high nitrate+nitrite levels in February 2008 (1.14 mg/L) at this site coincided with a high ammonia concentration, as well as high ammonia at the freshwater Piper's Creek site (KTHA01) (upstream of Carkeek Wet Weather TS). A high nitrate+nitrite concentration in November 2009 (1.18 mg/L) at KSHZ03 also coincided with a high value at station KTHA01. However, high nitrate+nitrite concentrations were not seen at the Carkeek Park beach station (ITCARKEEKP) north of KSHZ03 and outside the direct influence of Piper's Creek. No discharges from the Carkeek Wet Weather TS offshore outfall occurred on or near the dates when high nitrate+nitrite values were observed, other than in November 2009 when a small discharge occurred two days prior to sampling. The high nitrate+nitrite levels at the Piper's Creek stream station KTHA01, coupled with typical concentrations at ITCARKEEKP, indicate the high KSHZ03 concentrations are likely due to a watershed source via Piper's Creek.

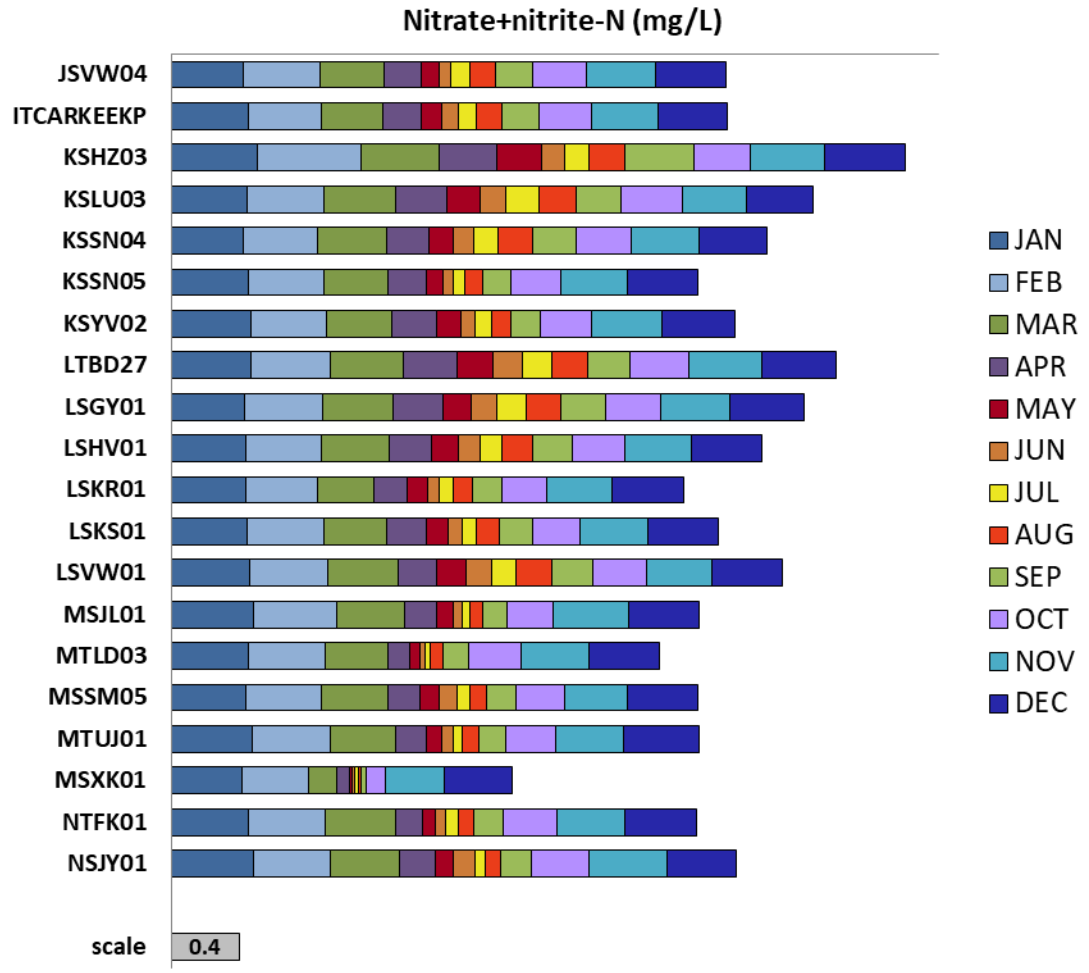


Figure 4. Monthly mean nitrate+nitrite concentrations in beach waters by station, all data (2008-2019) combined. Stations are ordered north to south.

3.1.1 Nitrate+Nitrite Anomalies

Monthly nitrate+nitrite anomalies (departure from long-term mean) were calculated for all stations by comparing each monthly value to the long-term mean for each site. While the data record started in December 1998 for most sites, monitoring at five additional sites was initiated in 2007 (LTBD27, MTUJ01, MSXK01, NTFK01, and NSJY01). Figure 5 shows the monthly anomalies for six representative stations. The patterns exhibited at stations JSVW04 (Richmond Beach/Pt. Wells), KSSN05 (West Point south), and MTLD03 (Normandy Park) are representative of those seen at other stations not shown.

Although some variation was seen, concentrations at most stations were generally higher than the long-term mean from 2008 to the fall of 2011 and then again for a short period from early spring 2014 until summer 2014. Concentrations were generally lower than normal from late summer 2014 through spring 2019, when a shift to higher concentrations

was seen at most sites. These results may have been influenced by lower water temperatures and macroalgae growth in addition to watershed inputs during this period. Greater variation was seen at some stations (KSHZ03 – Carkeek Park/Piper's Creek outflow, MSXK01- Quartermaster Harbor, and NSJY01-Dumas Bay), possibly due to macroalgae growth, watershed inputs, and nutrient cycling. The beaches in Quartermaster Harbor and Dumas Bay typically support high amounts of macroalgae production. The physical characteristics of Dumas Bay, a shallow embayment, in addition to watershed nutrient inputs make this site susceptible to high macroalgae growth.

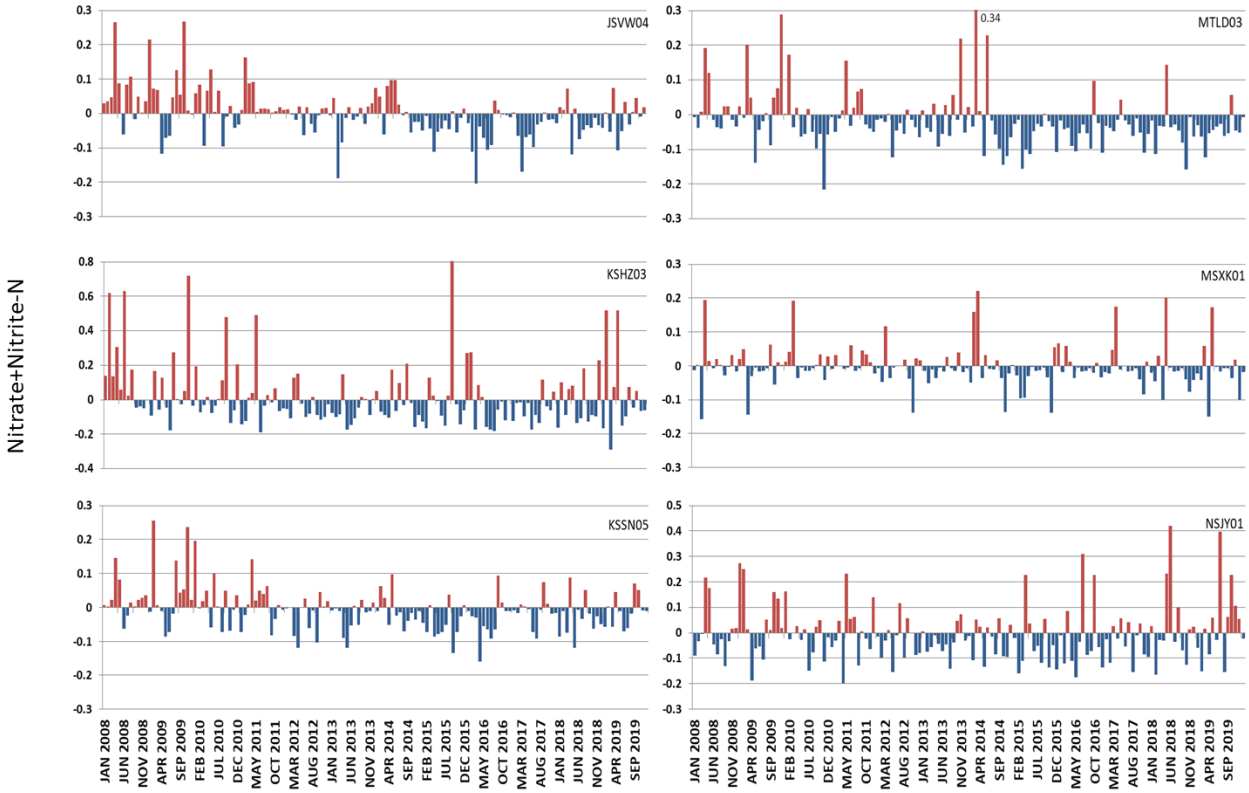


Figure 5. Monthly nitrate+nitrite anomalies for six stations (2008-2019). Note different y-axis scales for KSHZ03 and NSJY01.

3.2 Ammonia-Nitrogen

Dissolved ammonia-nitrogen (ammonia) concentrations in beach waters (2008-2019) ranged from less than the MDL (0.002 mg/L) to 3.77 mg/L. The highest value was measured at the Normandy Park station (MTLD03) in July 2012. Another very high ammonia concentration (1.54 mg/L) was measured at this station in July 2011. Elevated ammonia levels at this site may have been influenced by discharges from the Miller Creek Wastewater TP operated by the Southwest Suburban Sewer District. This TP discharges treated effluent via a marine outfall at a water depth of about 61 m offshore of this site. Ammonia levels were < 1.0 mg/L at all other sites except Tramp Harbor (MSSM05; 1.22 mg/L) in June 2011.

King County measures dissolved ionized ammonia, however, the Washington State surface water quality ammonia standard is based upon un-ionized ammonia. An EPA conversion formula based upon temperature, salinity, and pH is used to convert un-ionized to total ionized ammonia. Using the EPA conversion yields a total ionized ammonia criterion of 1.6 mg/L, which the July 2012 dissolved concentration at Normandy Park (MTLD03) surpassed. All other values were below the criterion.

Ammonia results for all locations (2008-2019 combined) and all months combined are presented in Figure 6 . The highest mean concentrations were seen at Normandy Park (MTLD03) (0.076 mg/L) and Tramp Harbor (MSSM05) (0.039 mg/L) due to the high values mentioned previously. The next highest mean concentrations were seen at MTUJ01 (Des Moines Park), LSKS01(Alki near Constellation Park), NSJY01, and MSKX01 and ranged from 0.031 to 0.037 mg/L. The lowest mean and median concentrations occurred at LSHV01 (north Alki), KSSN04 (north side of West Point), and LSVW04 (Fauntleroy Cove).

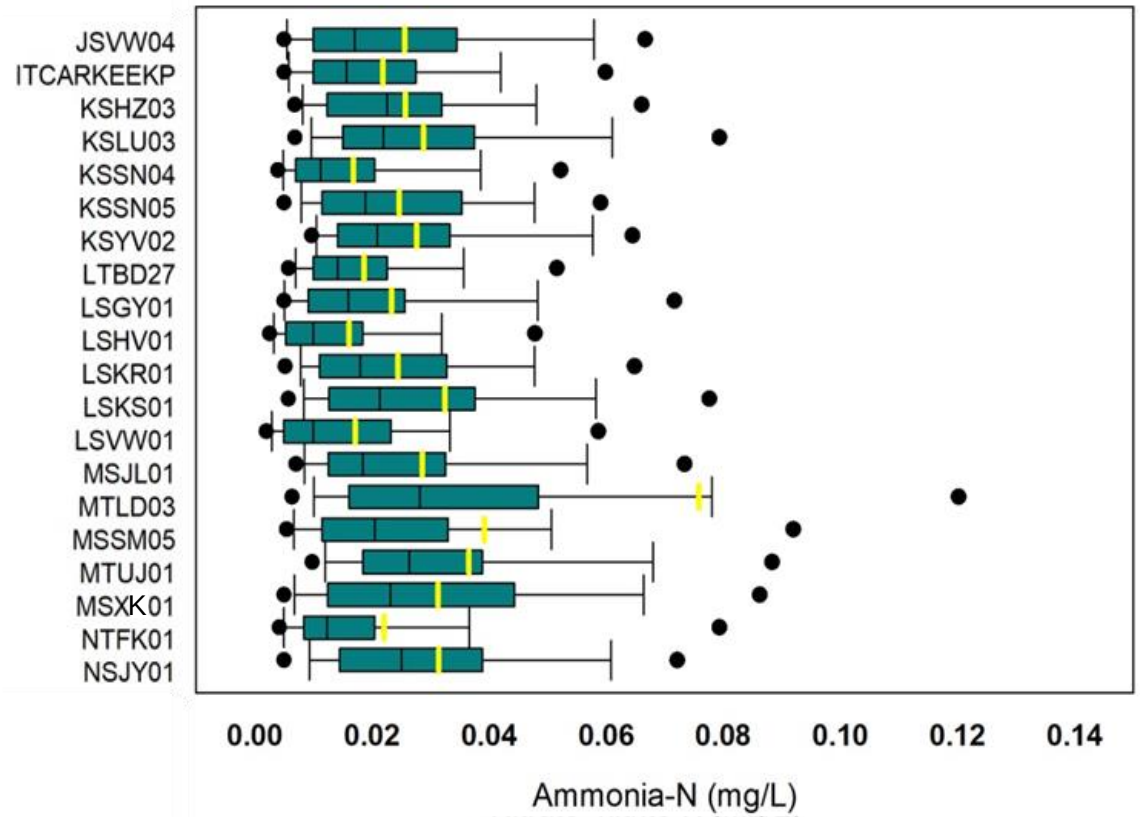


Figure 6. Ammonia concentrations in beach waters by station, all data (2008–2019) combined. Mean and median are represented by yellow and black lines within the box, respectively. Box edges represent 25th and 75th percentiles, whiskers represent 10th and 90th percentiles, and black dots represent 5th and 95th percentiles.

Little interannual variation was seen at most sites (Figure 7). The greatest variation was seen at the Normandy Park (MTLD03) and Tramp Harbor (MSSM05) locations due to the

high values mentioned above. Ammonia concentrations were highest in 2011 at several sites and varied between years for other sites.

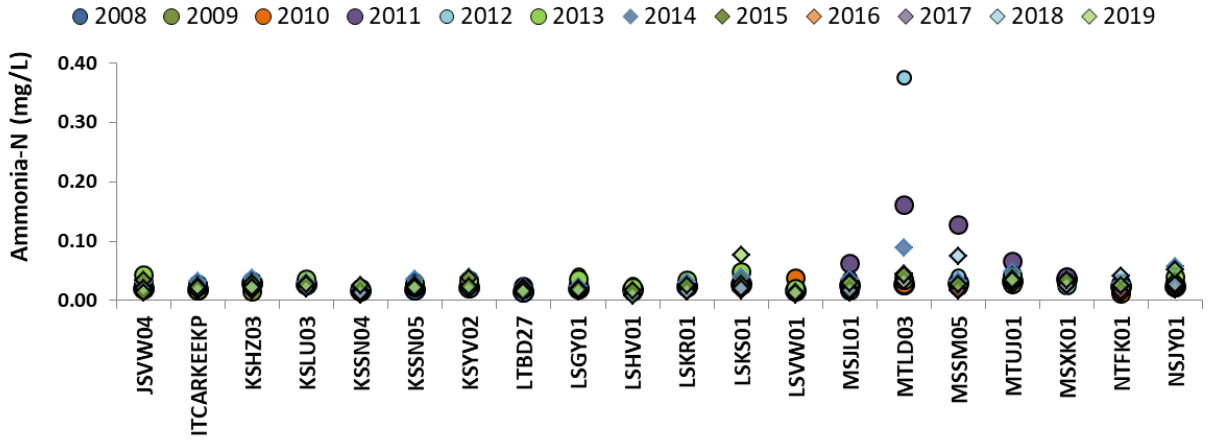


Figure 7. Mean annual ammonia concentration in beach waters by station (2008-2019). Stations are ordered north to south.

Unlike nitrate+nitrite, ammonia concentrations showed more variation between sites in the winter months (Figure 8). Concentrations were generally lowest at West Seattle beaches as well as the north side of West Point (KSSN04) in winter months. A spatial gradient was observed in terms of the northern beaches having similar concentrations in summer and winter months compared to more variation in the summer months for beaches south of Alki Point. The high monthly mean shown in Figure 8 for Normandy Park (MTLD03) in July is due to two very high values in 2011 and 2012. Overall, ammonia concentrations started increasing in April, peaked in June, and then steadily decreased through the remainder of the year. Similar to nitrate+nitrite, macroalgae abundance can influence ammonia concentrations particularly when the macroalgae decay, releasing ammonia.

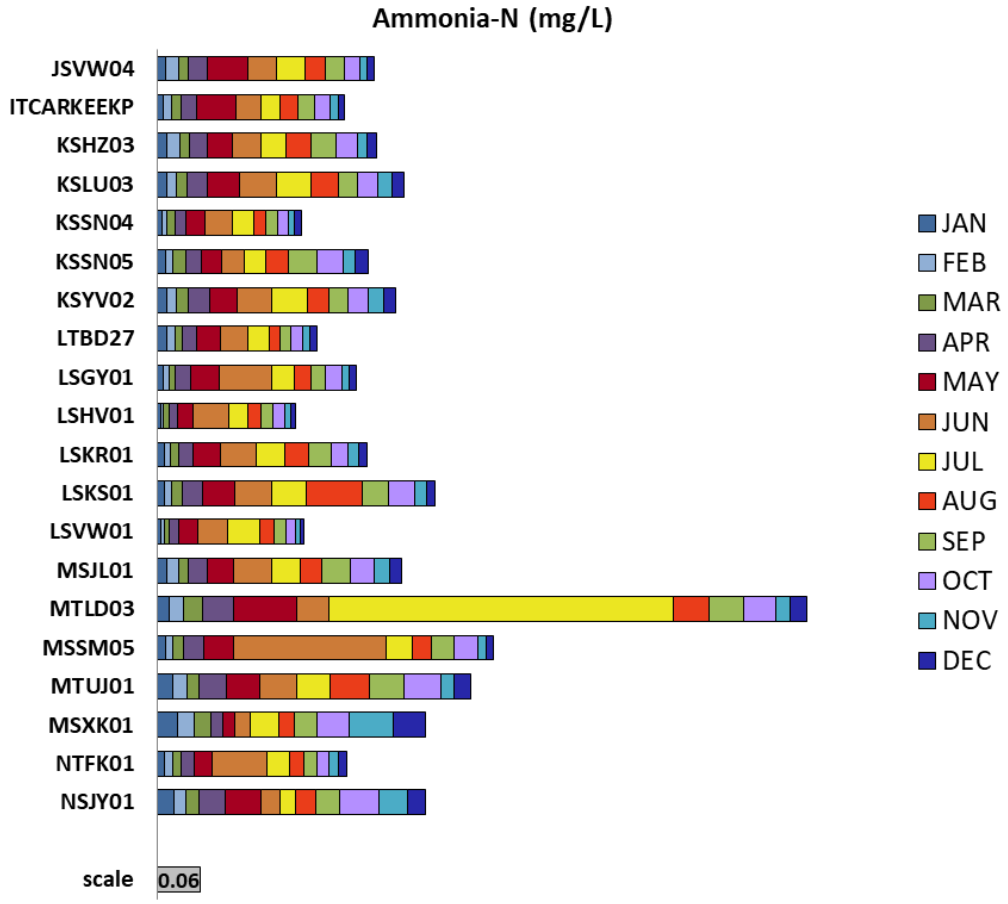


Figure 8. Monthly mean ammonia concentration by location, all data (2008–2019) combined. Stations are ordered north to south.

3.3 Total Nitrogen

Analysis of total nitrogen, (sum of dissolved inorganic nitrogen and organic nitrogen), began in September 2010 at a subset of six beach stations (JSVW04-Richmond Beach/Pt. Wells, KSHZ03-Carkeek Park/Piper's Creek outflow, LSVW01-Fauntleroy Cove, MSXK01-Quartermaster Harbor, NTFK01-Redondo Beach, NSJY01-Dumas Bay). Mean concentrations (2010-2019) ranged from 0.349 mg/L at MSXK01 to 0.545 mg/L at KSHZ03. These two sites also had the lowest and highest median concentrations, respectively. A maximum value of 4.67 mg/L was detected at NTFK01 (Redondo) in April 2011 and this site also had 4 of the highest 10 values in the period of record for all sites. Table 3 shows where and when the highest 10 results were observed.

Table 3. Ten highest total nitrogen concentrations between 2010 and 2019.

Station	Date	Total Nitrogen (mg/L)
NTFK01	4/20/2011	4.67
NSJY01	11/20/2019	3.66
NTFK01	6/27/2018	2.98
NSJY01	5/21/2014	2.88
KSHZ03	4/23/2014	1.96
NTFK01	7/23/2014	1.88
JSVW04	4/20/2011	1.72
KSHZ03	7/23/2014	1.41
NTFK01	9/20/2017	1.4
KSHZ03	9/23/2015	1.35

Four of the stations showed interannual variation with respect to annual mean concentrations, with Fauntleroy Cove (LSVW01) having the least variation (Figure 9). The two southernmost stations, Redondo Beach (NTFK01) and Dumas Bay (NSJY01), showed more interannual variation as well as having some of the highest annual means. Annual mean concentrations were highest in 2014, in part due to several high monthly values that skewed the mean. Data were only collected for four months in 2010; therefore, 2010 means were not calculated.

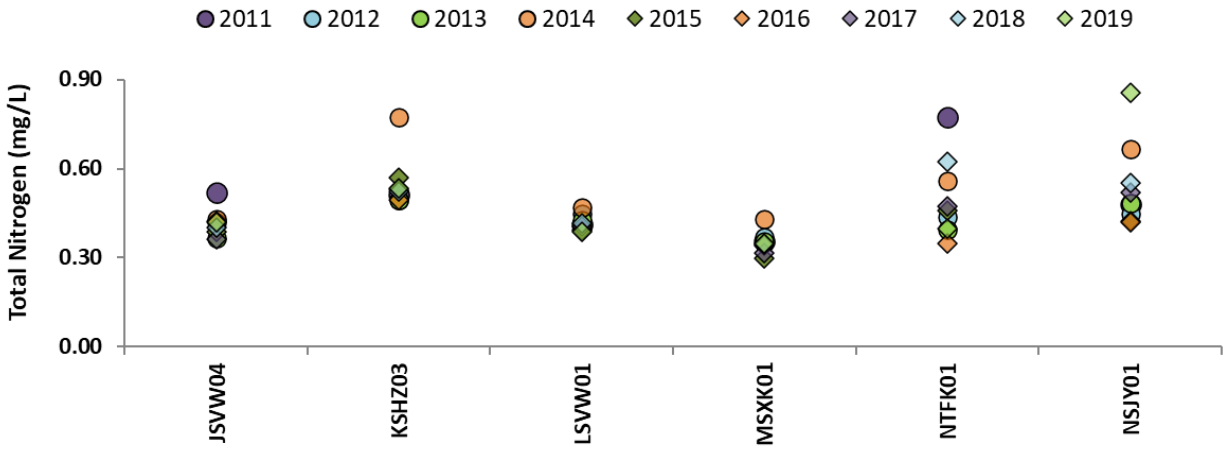


Figure 9. Annual mean total nitrogen concentrations in beach waters by station (2011-2019).

Total nitrogen monthly mean concentrations at beach locations were generally similar at all six sites during the winter but varied during spring and summer (April- July), a reflection of inputs and biological uptake. Concentrations were lowest in spring and summer (Figure 10).

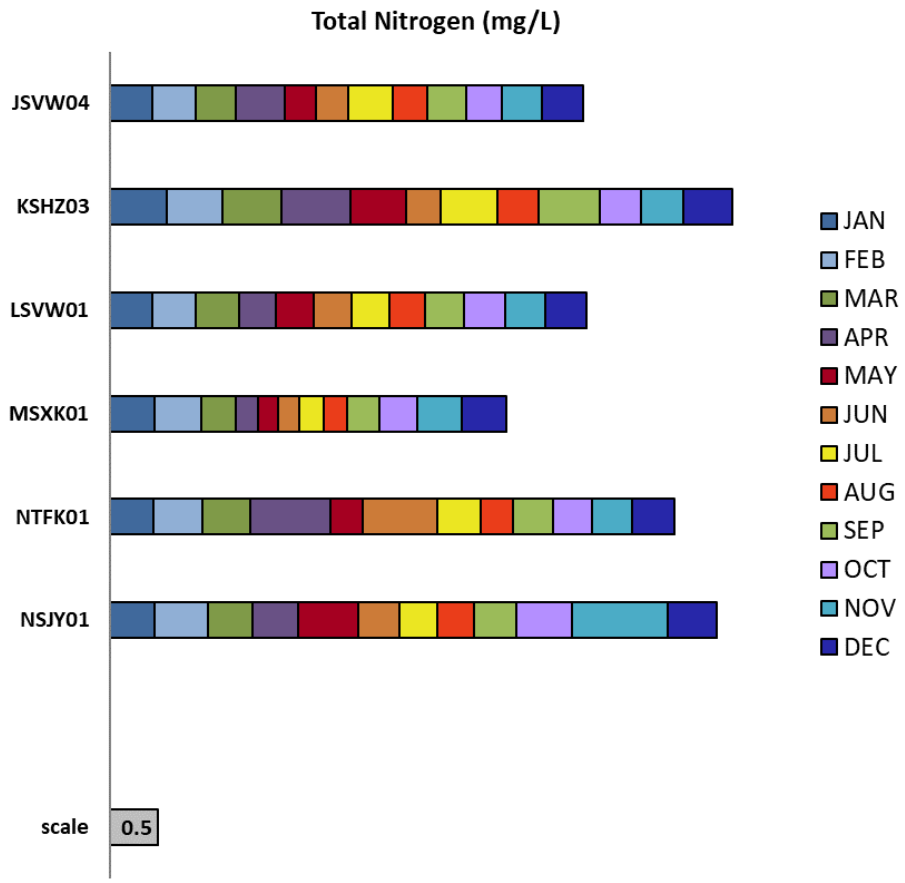


Figure 10. Total nitrogen monthly concentrations in beach waters by month and location, all data (2010–2019) combined. Stations are ordered north to south.

3.4 Orthophosphate-Phosphorus

Total phosphorus was measured in beach waters up to May 2010 when the analysis for phosphorus was changed to dissolved orthophosphate-phosphorus (orthophosphate), the form that is most bioavailable. Only orthophosphate results are presented here. Total phosphorus results (2008 - 2010) are provided in Appendix A.

Orthophosphate in beach waters (2010-2019) ranged from < MDL (0.005 mg/L) - 0.558 mg/L at Normandy Park (MTLD03). There were four samples during this time period when concentrations were below detectable levels in either May or June, three at Quartermaster Harbor (MSXK01) and the other at Dumas Bay (NSJY01). The range in monthly mean orthophosphate concentrations was greater for beaches in the southern portion of the Central Basin and near Magnolia (KSVY02), north of Elliott Bay. The highest orthophosphate values were measured at Normandy Park (MTLD03) in July 2011 and 2012 when very high ammonia values were also seen, indicating wastewater discharges as a potential source.

Mean (0.043 - 0.063 mg/L) and median (0.043 - 0.064 mg/L) ammonia concentrations for all years combined were similar(Figure 11). The lowest overall concentrations were seen in Quartermaster Harbor (MSXK01), similar to nitrate+nitrite. Quartermaster Harbor has high primary productivity and an extended growing season compared to other areas in the Central Basin, resulting in lower nutrient concentrations due to biological uptake.

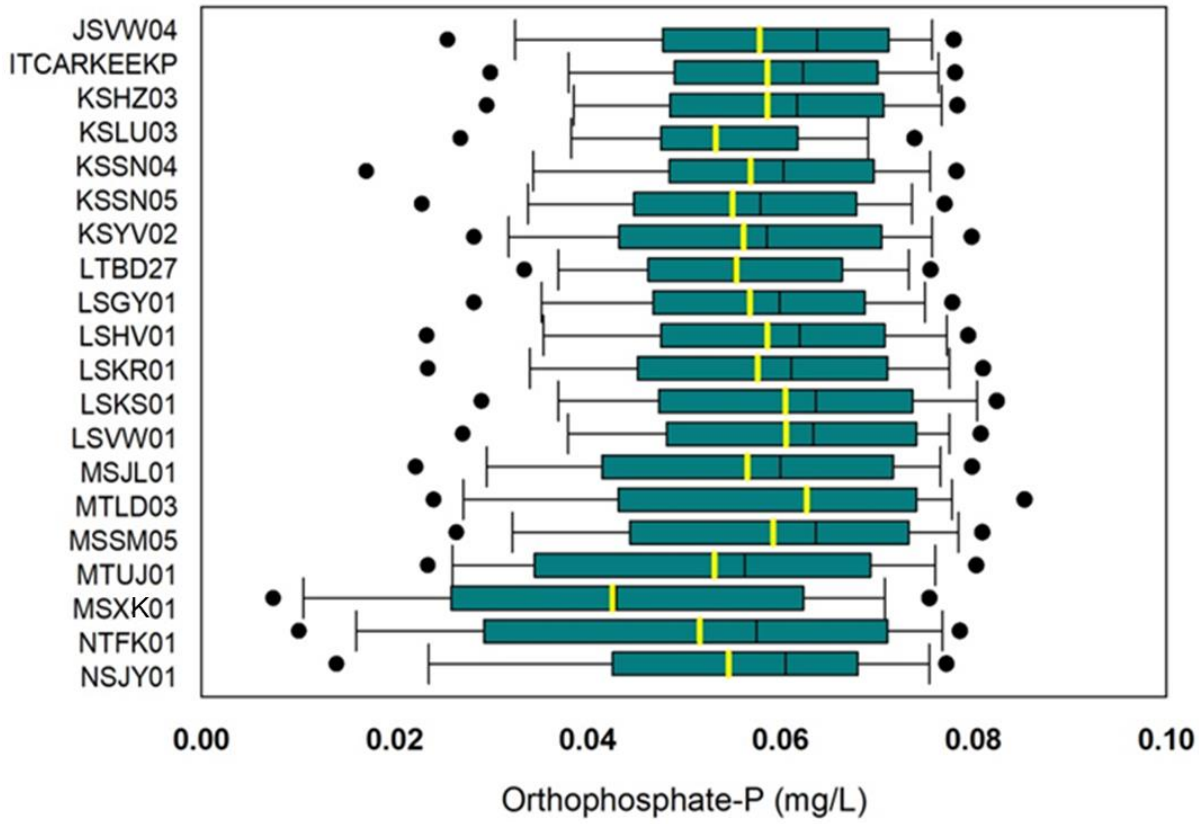


Figure 11. Orthophosphate concentrations in beach waters by station, all data (2010–2019) combined. Mean and median are represented by yellow and black lines within the box, respectively. Box edges represent 25th and 75th percentiles, whiskers represent 10th and 90th percentiles, and black dots represent 5th and 95th percentiles.

Some interannual variation in orthophosphate was evident, although the range of variation was narrower than for other nutrients (Figure 12). Orthophosphate concentrations at most sites 2015 - 2017 were lower than other years, particularly during the growing season spring through summer months. Water temperatures were warmer than normal during those years due to the marine heat wave. As a result, more biological uptake occurred due to high macroalgae abundance. Conversely, concentrations in 2011 were relatively high at most sites due to lower biological uptake associated with historic climate anomalies that brought very cold and wet conditions during spring and early summer.

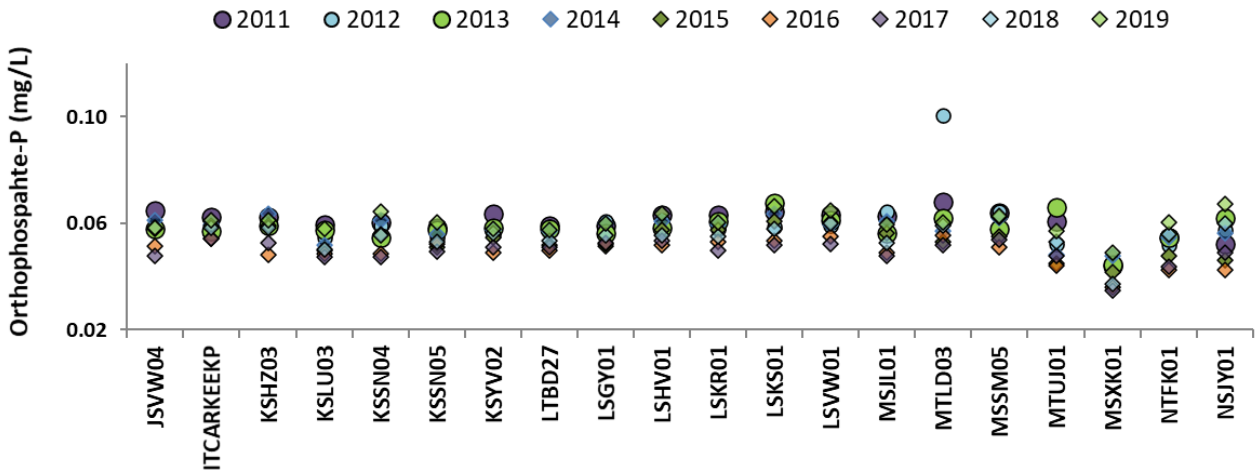


Figure 12. Orthophosphate annual mean concentration in beach waters by station and year (2011-2019). Stations are ordered north to south.

Similar to nitrate+nitrite, orthophosphate concentrations were lower during the spring and summer months (Figure 13). Concentrations were similar between sites, except for Quartermaster Harbor (MSXK01) which had lower concentrations from March - October due to the extended growing season in this area. The high mean orthophosphate concentration in July at Normandy Park (MTLD03) was skewed by the two high (0.142 and 0.558 mg/L) concentrations detected in 2011 and 2012 as described above.

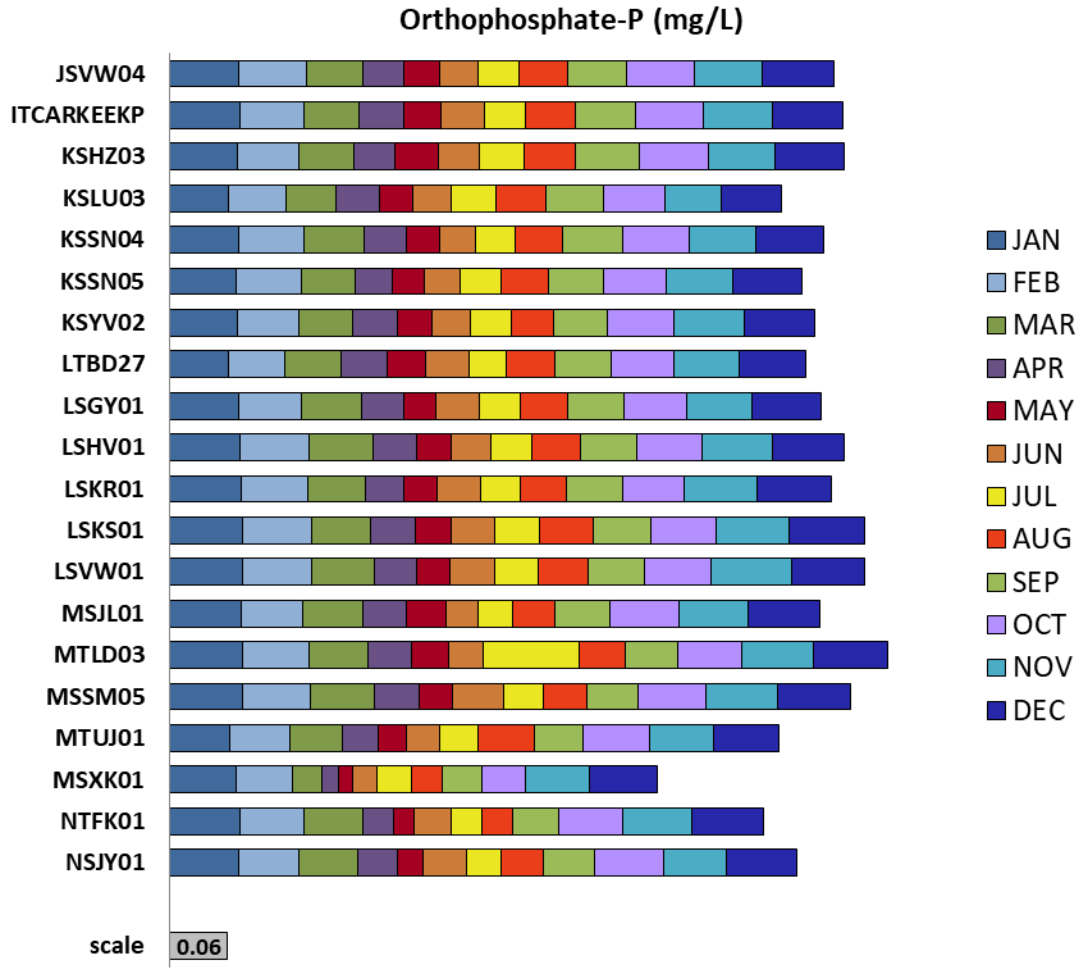


Figure 13. Orthophosphate monthly mean concentrations in beach waters by location, all data (2010–2019) combined. Stations are ordered north to south.

3.5 Trend Analysis

To assess long-term nitrate+nitrite and ammonia trends, a non-parametric Seasonal Kendall (SK) test was conducted in R using the censeaken function in the NADA2 package using months to group data. Trends for two different time periods were assessed since sampling did not begin at some stations until 2007. The SK test was conducted on results for 20 beach stations collected between 2007 and 2019 and for 13 stations collected between 1999 and 2019. Since ammonia concentrations were typically < MDLs in winter, annual trend analysis was performed with results for April - October to avoid skewing results. Trends for orthophosphate and total nitrogen were not evaluated as monitoring for these parameters did not start until mid-2010, resulting in less than 10 years of data.

Annual Trends

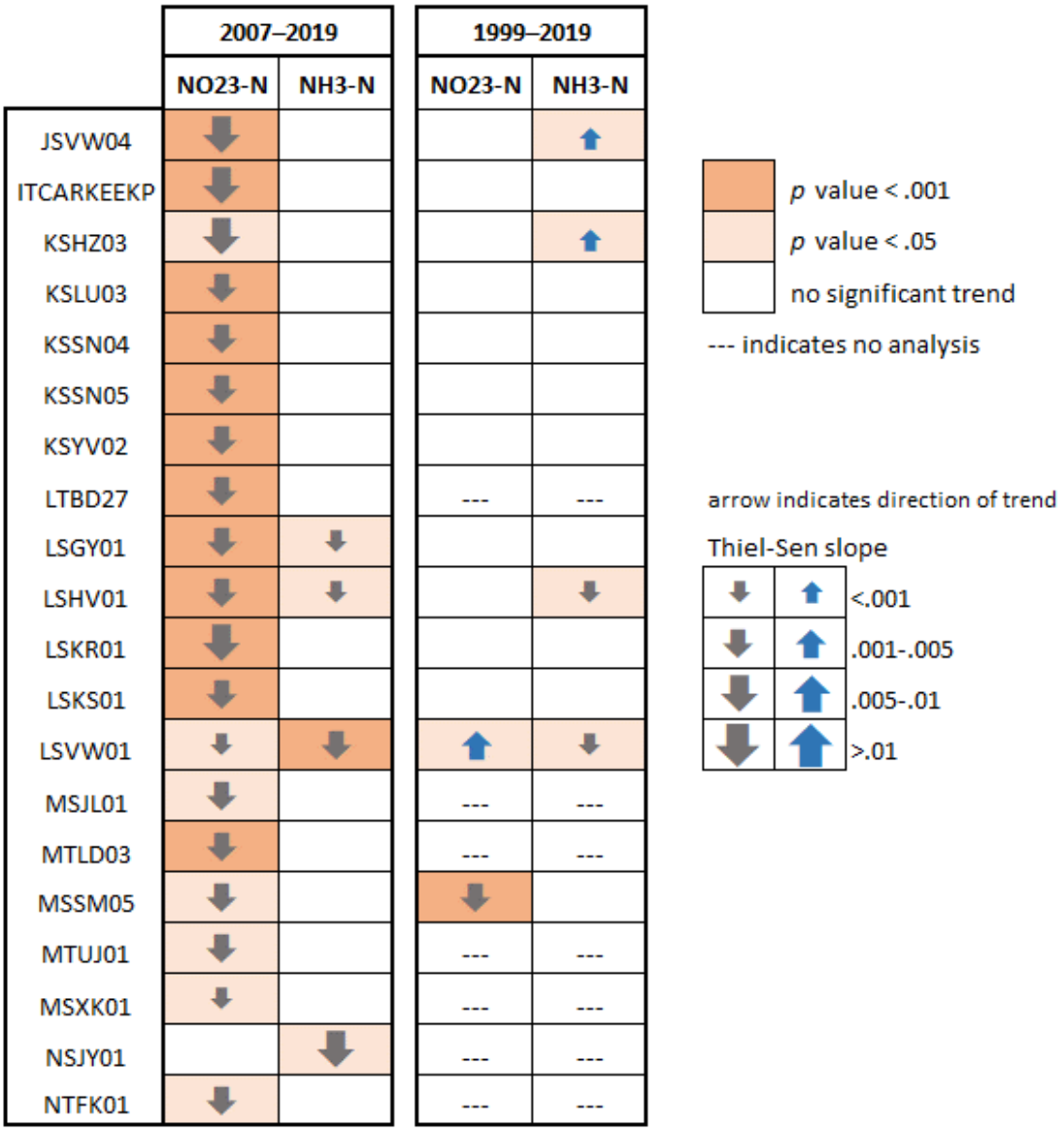
Trend analysis results for nitrate+nitrite and ammonia are presented in Table 4. Results (2007 – 2019) for all but one station (NSJY01-Dumas Bay) showed a significant decreasing trend for nitrate+nitrite ($p < .05$ is typically considered a significant trend).

Significant ($p < .001$*)* decreasing trends (2007-2019) in nitrate+nitrite were detected at all stations from Point Wells south to Alki, except the Carkeek Park/Piper's Creek outflow site (KSHZ03). Significant decreasing trends ($p < .05$) were also seen at stations from Fauntleroy Cove south to Dumas Bay, except at Normandy Park (MTLD03) which had a significance level of $p < .001$. The magnitude of decrease in nitrate+nitrite levels between 2007–2019 varied by station, but generally indicated a greater annual decrease at northern stations than the southern stations.

Of the 13 stations with nitrate+nitrite data from 1999 - 2019, only two showed statistically significant trends. An increasing trend ($p < .05$) was seen at Fauntleroy Cove (LSVW01), while a decreasing trend ($p < .001$) was observed at Tramp Harbor (MSSM05). These results highlight the influence of the data period when determining trends, particularly as results for Fauntleroy Cove (LSVW01) showed opposite trend directions between the two data periods. Differences in rainfall patterns, both timing and magnitude, over the last 10 years of the data set may have influenced trend results for 2007 - 2019, including the higher nitrate+nitrite concentrations measured in 2008 and 2009, and lack of trends during the longer time period.

Compared to nitrate+nitrite trends, fewer sites showed significant decreasing trends (2007-2019) for ammonia (Table 2). Significant decreasing trends ($p < .05$) were detected at stations on the east and west side of Duwamish Head (LSGY01 and LSHV01), Dumas Bay (NSJY01), and at Fauntleroy Cove (LSVW01) ($p < .001$). The magnitude of change was greatest at LSVW01 and NSJY01. A significant ($p < .05$) ammonia trend was measured at 4 of 13 stations for 1999 - 2019. A slight increasing trend was seen for Point Wells (JSVW04) and Carkeek Park/Piper's Creek outflow (KSHZ03), while a slight decreasing trend was seen at LSHV01 and LSVW01.

Table 4. **Annual trends in nitrate+nitrite (NO23-N) and ammonia (NH3-N) concentrations in beach waters by station and date range (2007-2019 and 1999- 2019). The arrow indicates trend direction and magnitude of change from year to year.**



Monthly Nitrate+Nitrite Trends

Trend results for nitrate+nitrite concentrations by month (2007 - 2019) for 20 beach stations are summarized in Table 5. A significant decreasing trend ($p < .05$) was measured at many stations during the winter (November. – January). A decreasing trend in March concentrations was observed at most northern stations, and at Tramp Harbor (MSSM05) and Redondo Beach (NTFK01). The largest significant decrease in March concentrations was seen at the Carkeek/Piper's outflow site (KSHZ03). A decreasing trend in nitrate+nitrite concentrations was seen in more than half the stations in July. The magnitude of the decrease varied by station and month, but generally showed that the

largest decrease was in July over this time period. The decreasing annual trend reflects the decreasing trends observed during these months.

Table 5. Monthly trends in nitrate+nitrite concentrations in beach waters by station (2007 - 2019). The arrow indicates trend direction and magnitude of change from year to year.

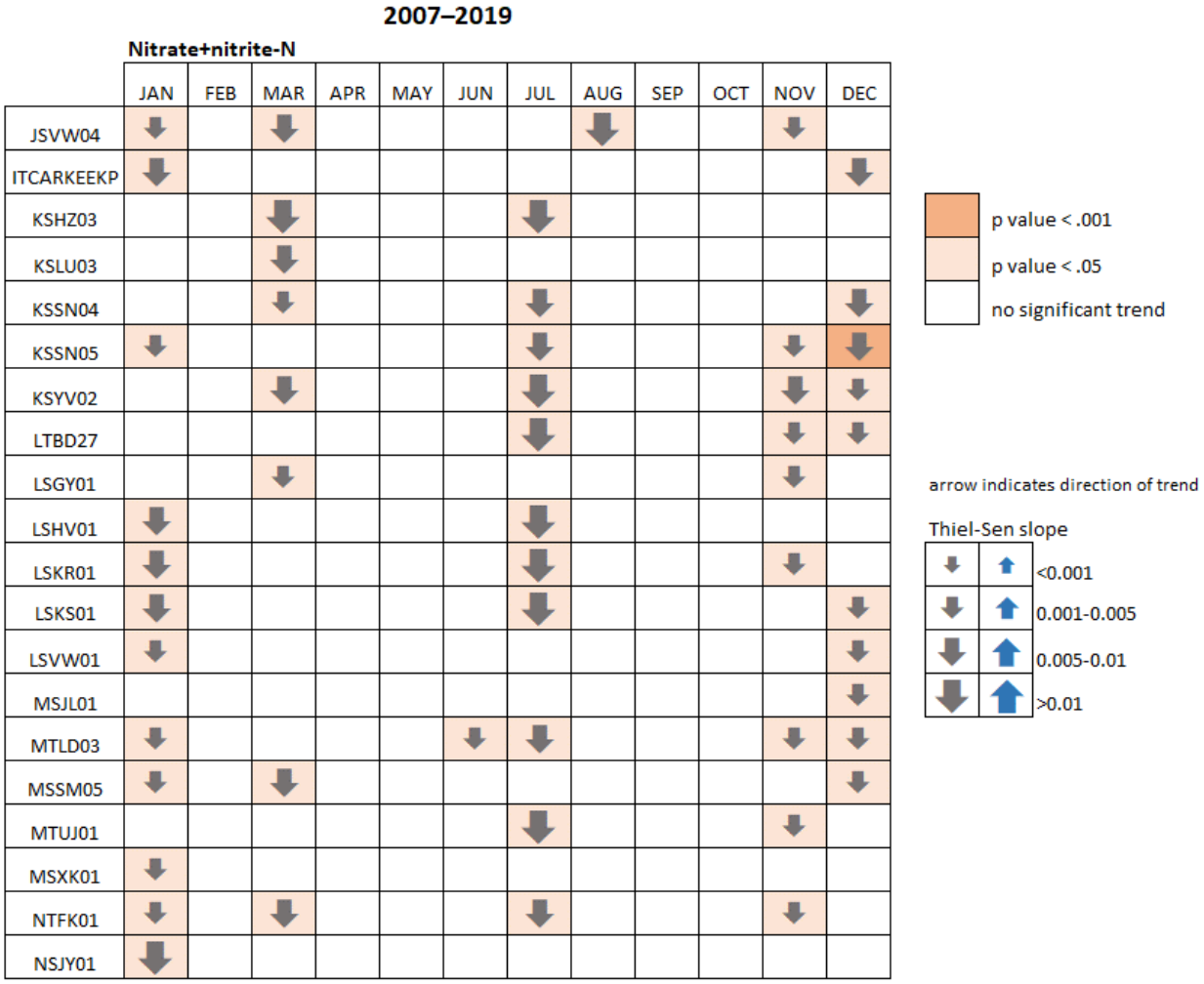
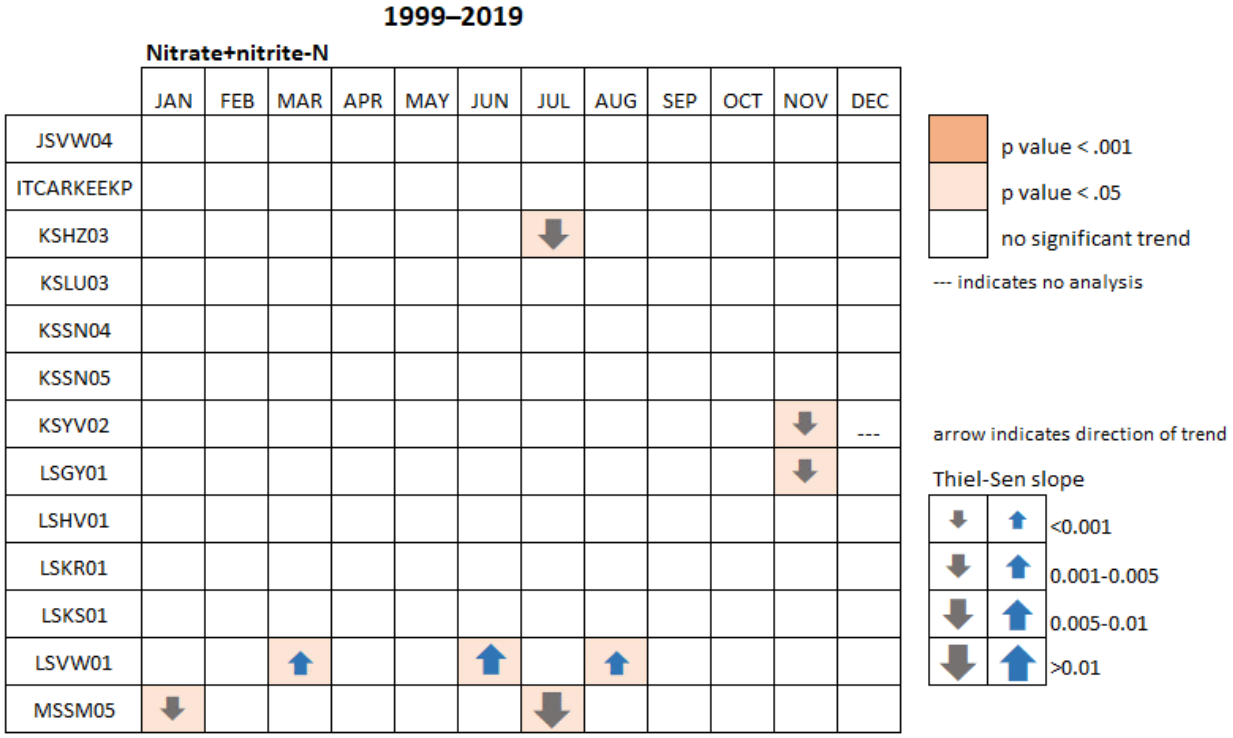


Table 6 provides results for nitrate+nitrite trend analysis by month (1999 – 2019) for 13 beach stations. Trend analysis for this time period resulted in fewer significant trends, compared to the annual trend results. An increasing trend in nitrate+nitrite was seen in March, June, and August at Fauntleroy Cove (LSVW01), with the largest year to year increase in June. A significant decrease in nitrate+nitrite at Tramp Harbor (MSSM05) in January and July was observed, while a decrease was seen at Carkeek/Piper's outflow site (KSHZ03) and Seacrest Park (LSGY01) in November. The differing trend results between the two time periods may be influenced by the higher nitrate+nitrite values measured in 2008 and 2009, as well as 2010 to 2012 to a lesser extent (Figure 3 and Figure 5), which may be influencing the trend results over a shorter time period. For the longer time period, the higher concentrations measured in 2008 and 2009 likely have less influence on the trend results.

Table 6. **Monthly trend results for nitrate+nitrite concentrations in beach waters by location (1999 - 2019). The arrow indicates trend direction and magnitude of change from year to year.**



Monthly Ammonia Trends

Table 7 shows results for ammonia trends by month (April – October) between 2007 and 2019 for 20 beach stations. A slight increasing trend was seen for April at Carkeek Park (ITCARKEEKP), the only month to show an increasing trend. A significant decreasing trend was seen at almost half the stations for July, similar to that seen for nitrate+nitrite. All observed trends were significant at $p < .05$. The magnitude of the trend was similar across stations and months, except a slightly larger decrease was seen in October at Dumas Bay (NSJY01) over this time period.

Table 7. Monthly (April-October) trends in ammonia concentrations in beach waters by location (2007 - 2019). The arrow indicates trend direction and magnitude of change from year to year.

2007–2019

Ammonia-N

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSVW04	---	---	---								---	---
ITCARKEEKP	---	---	---	↑							---	---
KSHZ03	---	---	---				↓				---	---
KSLU03	---	---	---								---	---
KSSN04	---	---	---								---	---
KSSN05	---	---	---								---	---
KSYV02	---	---	---								---	---
LTBD27	---	---	---				↓				---	---
LSGY01	---	---	---				↓		↓		---	---
LSHV01	---	---	---				↓				---	---
LSKR01	---	---	---				↓				---	---
LSKS01	---	---	---								---	---
LSVW01	---	---	---				↓	↓			---	---
MSJL01	---	---	---								---	---
MTLD03	---	---	---								---	---
MSSM05	---	---	---								---	---
MTUJ01	---	---	---				↓				---	---
MSXK01	---	---	---								---	---
NSJY01	---	---	---							↓	---	---
NTFK01	---	---	---				↓		↓		---	---

p value < .001
p value < .05
no significant trend
--- indicates no analysis

arrow indicates direction of trend

Thiel-Sen slope
<0.001
0.001-0.005
0.005-0.01
>0.01

Results for ammonia trends by month (April – October) (1999 – 2019) for 13 beach stations are summarized in Table 8. Similar to results discussed above, trends for this longer time period varied from the shorter time period. Only one significant trend ($p < .05$) was observed for July: an increasing trend at Richmond Beach/Pt. Wells(JSVW04). The most significant trends ($p < .05$; all decreasing) were seen in September, followed by April, with decreasing trends at two stations. The magnitude of the trends varied between stations and months.

Table 8. Trends in monthly (April – October) ammonia concentrations in beach waters by location (1999 -2019). The arrow indicates trend direction and magnitude of change.

1999–2019

Ammonia-N

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSVW04	---	---	---				↑				---	---
ITCARKEEKP	---	---	---								---	---
KSHZ03	---	---	---					↑			---	---
KSLU03	---	---	---						↓		---	---
KSSN04	---	---	---								---	---
KSSN05	---	---	---								---	---
KSYV02	---	---	---								---	---
LSGY01	---	---	---	↓					↓		---	---
LSHV01	---	---	---						↓		---	---
LSKR01	---	---	---								---	---
LSKS01	---	---	---								---	---
LSVW01	---	---	---	↓					↓		---	---
MSSM05	---	---	---								---	---

p value < .001
p value < .05
no significant trend
--- indicates no analysis

arrow indicates direction of trend

Thiel-Sen slope
<0.001
0.001-0.005
0.005-0.01
>0.01

3.6 Summary

Monitoring results from 20 beach stations sampled for nitrate+nitrite and ammonia (2008 - 2019) and orthophosphate (2010 - 2019) showed less spatial and interannual variation than seen in offshore waters. Stations located near a freshwater input, such as a creek outflow, showed the most variation. Interannual variation was more pronounced for nitrate+nitrite, which may be influenced by higher macroalgae abundance in some years, as seen in 2015. Specific results include:

- no spatial gradient was evident for nitrate+nitrite, and median concentrations at stations near a freshwater input were higher than at other sites,
- the lowest annual mean nitrate+nitrite and orthophosphate concentrations were measured at the Quartermaster Harbor site,
- the lowest nitrate+nitrite and orthophosphate concentrations occurred between late spring and summer when macroalgae growth is highest and freshwater inputs are lowest, in contrast to ammonia when concentrations were generally highest during this period,
- results for locations nearshore of the County's wastewater treatment plants were similar to other sites,

- the highest median and mean ammonia levels were measured at Normandy Park, driven by two very high concentrations detected in July, which may be due to the proximity of this site to the Miller Creek Wastewater Treatment Plant outfall,
- statistical trend analysis results indicated a decreasing annual trend (2007-2019) for nitrate+nitrite at all but one site, driven by decreasing nitrate+nitrite concentrations in the winter months and July. Decreasing annual trends in ammonia were seen at four sites during the same period, driven by decreasing concentrations in July, and
- fewer statistical trends were seen for both nitrate+nitrite and ammonia for results between 1999-2019, with two northern sites showing increasing ammonia annual trends and two mid-basin sites showing decreasing annual trends.

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Appendix A: Total Phosphorus 2008 – 2010 Results

Table A-1 Total phosphorus (mg/L) annual average for beach waters. This analysis was discontinued in June 2010 for 13 sites and October for 4 sites, therefore the 2010 annual average was not calculated.

Locator	2008	2009
JSVW04	0.0817	0.0774
ITCARKEEKP	0.0785	0.0878
KSHZ03	0.0875	0.0752
KSLU03	0.0696	0.0704
KSSN04	0.0981	0.0927
KSSN05	0.1324	0.1057
KSYV02	0.0878	0.0770
LTBD27	0.0708	0.0709
LSGY01	0.0727	0.0718
LSHV01	0.0793	0.0827
LSKR01	0.0832	0.0814
LSKS01	0.0860	0.0797
LSVW01	0.0935	0.0994
MSJL01	0.0897	0.0848
MSSM05	0.0899	0.1050
MSXK01	0.0661	0.0700
MTLD03	0.0840	0.0828
MTUJ01	0.0765	0.0751
NSJY01	0.0839	0.0745
NTFK01	0.0808	0.0966

Table A-2 Total phosphorus (mg/L) 2008 monthly results for beach waters.

2008	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSVW04	0.0872	0.0974	0.0805	0.0866	0.122	0.0751	0.0594	0.0689	0.0655	0.0793	0.0764	__
ITCARKEEKP	0.0921	0.0815	0.0846	0.0757	0.0765	0.0448	0.0571	0.0944	0.0734	0.0817	0.0804	0.0996
KSHZ03	0.0946	0.11	0.116	0.0777	0.0895	0.086	0.0583	0.0975	0.0672	0.0832	0.0823	0.0877
KSLU03	0.0762	0.0752	0.0711	0.06315	0.0675	0.0515	0.0606	0.06665	0.0669	0.0857	0.0766	0.0725
KSSN04	0.201	0.0946	0.107	0.0929	0.0759	0.0681	0.0636	0.0767	0.0979	0.0878	0.0812	0.13
KSSN05	0.224	0.153	0.181	0.0892	0.118	0.124	0.0816	0.255	0.089	0.087	0.0841	0.103
KSYV02	0.0901	0.0822	0.103	0.0759	0.08	0.111	0.0697	0.0917	0.0796	0.0867	0.08905	0.0905
LTBD27	0.0861	0.0752	0.077	0.065	0.0594	0.05	0.0652	0.0625	0.0715	0.0777	0.0785	0.0811
LSGY01	0.0869	0.0826	0.084	0.0736	0.0671	0.0565	0.0611	0.0659	0.0677	0.0815	0.0593	0.0863
LSHV01	0.0846	0.0847	0.0807	0.0826	0.0814	0.072	0.0643	0.0665	0.0751	0.0857	0.0822	0.0917
LSKR01	0.09985	0.0835	0.0895	0.0736	0.0743	0.06475	0.0708	0.095	0.0807	0.0876	0.0855	0.0934
LSKS01	0.106	0.0856	0.0859	0.0783	0.0692	0.0661	0.0696	0.0973	0.1	0.092	0.0864	0.095
LSVW01	0.0918	0.0834	0.0816	0.084	0.119	0.119	0.0824	0.0958	0.074	0.0826	0.0909	0.0919
MSJL01	0.0871	0.0831	0.0819	0.0814	0.0844	0.105	0.0626	0.105	0.0871	0.0812	0.115	0.103
MSSM05	0.0848	0.0828	0.11	0.0831	0.0845	0.177	0.0586	0.0685	0.0727	0.0876	0.0804	0.0883
MSXK01	0.0861	0.088	0.0366	0.0834	0.0361	0.0417	0.0719	0.0536	0.0652	0.0952	0.074	0.091
MTLD03	0.102	0.0895	0.0872	0.0757	0.0714	0.0852	0.0809	0.0892	0.08135	0.0804	0.0798	0.0885
MTUJ01	0.0879	0.0861	0.077	0.0763	0.0721	0.0694	0.0601	0.0655	0.0657	0.08	0.09455	0.0866
NSJY01	0.0868	0.0831	0.0777	0.0765	0.0636	0.0672	0.0504	0.0628	0.0589	0.08055	0.214	0.0891
NTFK01	0.0882	0.0815	0.08	0.0917	0.0708	0.0877	0.0592	0.0612	0.0736	0.0817	0.095	0.09

Table A-3 Total phosphorus (mg/L) 2009 monthly results for beach waters.

2009	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSVW04	0.0747	0.081	0.0773	0.0714	0.0538	0.044	0.1	0.0762	0.0815	0.0853	0.0889	0.0951
ITCARKEEKP	0.0728	0.0805	0.0751	0.232	0.0553	0.0591	0.0598	0.0739	0.0786	0.0811	0.085	0.1
KSHZ03	0.0683	0.076	0.0741	0.0858	0.0433	0.045	0.0765	0.0857	0.0818	0.0806	0.0881	0.0973
KSLU03	0.0672	0.0785	0.0617	0.0845	0.0469	0.0432	0.0754	0.0853	0.0778	0.075	0.069	0.0797
KSSN04	0.0668	0.0829	0.0755	0.159	0.0508	0.0598	0.0777	0.0788	0.0808	0.0823	0.199	0.0993
KSSN05	0.0806	0.0808	0.088	0.079	0.0562	0.0547	0.0899	0.0833	0.089	0.0939	0.364	0.109
KSYV02	0.0655	0.0809	0.0722	0.0754	0.0465	0.0382	0.0848	0.0924	0.0809	0.0822	0.0912	0.125
LTBD27	0.0629	0.0701	0.0716	0.0601	0.0415	0.0421	0.0767	0.0811	0.0805	0.0812	0.0857	0.0978
LSGY01	0.063	0.082	0.0787	0.0464	0.0602	0.0497	0.0635	0.0695	0.0839	0.0777	0.0869	0.0997
LSHV01	0.074	0.0826	0.0779	0.0605	0.0596	0.126	0.068	0.0915	0.0823	0.0841	0.0872	0.0981
LSKR01	0.0803	0.0858	0.0668	0.061	0.0711	0.068	0.0712	0.105	0.0818	0.0857	0.0982	0.102
LSKS01	0.0779	0.0826	0.0673	0.0617	0.0651	0.0692	0.0749	0.081	0.0882	0.088	0.102	0.0979
LSVW01	0.0806	0.0836	0.0771	0.128	0.0775	0.0826	0.107	0.194	0.0787	0.0812	0.0999	0.102
MSJL01	0.0777	0.0808	0.0768	0.0559	0.057	0.0892	0.0925	0.0839	0.0852	0.0998	0.121	0.0976
MSSM05	0.078	0.0807	0.0804	0.219	0.15	0.071	0.107	0.13	0.0772	0.0809	0.0896	0.0964
MSXK01	0.0686	0.0702	0.0355	0.0819	0.0324	0.0434	0.0623	0.0381	0.133	0.081	0.0946	0.0988
MTLD03	0.08	0.0796	0.0781	0.0727	0.0669	0.0683	0.0746	0.0827	0.0816	0.101	0.11	0.0977
MTUJ01	0.0749	0.0806	0.0729	0.0641	0.0543	0.0435	0.0669	0.0913	0.0816	0.087	0.0812	0.103
NSJY01	0.0647	0.0889	0.0773	0.0475	0.0364	0.0383	0.0687	0.0822	0.12	0.0823	0.0906	0.0972
NTFK01	0.07565	0.0761	0.0797	0.063	0.0489	0.0369	0.152	0.281	0.0783	0.0849	0.106	0.0974

Table A-4 Total phosphorus (mg/L) 2010 monthly results for beach waters.

2010	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSVW04	__	0.0826	0.0954	0.0813	0.0702	0.0663	0.0692	0.0793	0.0823	__	__	__
ITCARKEEKP	0.0867	0.0844	0.081	0.0772	0.0723	__	__	__	__	__	__	__
KSHZ03	0.0878	0.0815	0.0801	0.0916	0.0572	0.0537	0.0621	0.0865	0.0773	__	__	__
KSLU03	0.0619	0.0631	0.0763	0.0679	0.0533	0.0624	0.0582	0.0672	0.0615	__	__	__
KSSN04	0.0968	0.086	0.0841	0.0759	0.0558	__	__	__	__	__	__	__
KSSN05	0.0965	0.253	0.1	0.17	0.0761	__	__	__	__	__	__	__
KSYV02	0.0869	0.0784	0.0809	0.0678	0.0451	__	__	__	__	__	__	__
LTBD27	0.0776	0.0825	0.0777	0.0683	0.0501	__	__	__	__	__	__	__
LSGY01	0.084	0.0825	0.0763	0.0567	0.046	__	__	__	__	__	__	__
LSHV01	0.0877	0.0831	0.0826	0.0782	0.0586	__	__	__	__	__	__	__
LSKR01	0.0845	0.0883	0.0743	0.0861	0.0577	__	__	__	__	__	__	__
LSKS01	0.094	0.0876	0.0799	0.0796	0.0599	__	__	__	__	__	__	__
LSVW01	0.0926	0.0899	0.0811	0.0756	0.0564	0.0979	0.141	0.0753	0.127	__	__	__
MSJL01	0.0813	0.0865	0.0758	0.0824	0.0567	__	__	__	__	__	__	__
MSSM05	0.0846	0.0844	0.0901	0.066	0.0626	__	__	__	__	__	__	__
MSXK01	0.0872	0.0862	0.0781	0.0346	0.0637	__	__	__	__	__	__	__
MTLD03	0.0981	0.0852	0.0784	0.0501	0.0497	__	__	__	__	__	__	__
MTUJ01	0.0585	0.0721	0.08	0.0619	0.0497	__	__	__	__	__	__	__
NSJY01	0.0876	0.0896	0.0734	0.0652	0.0572	__	__	__	__	__	__	__
NTFK01	0.0857	0.0911	0.0823	0.0712	0.044	__	__	__	__	__	__	__