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

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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, 2022a) 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 offshore nutrient monitoring component collected between 2008 -2019 as well as long-term trend analysis for specific nutrients. Offshore 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 nutrient concentrations.
- Evaluate how primary producers (phytoplankton) respond to nutrients and potential effects to the Puget Sound food web.
- Support regional efforts and collaborations such as the Puget Sound Ecosystem Monitoring Program (PSEMP) Marine Waters Workgroup marine conditions monthly update meetings, 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. 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. Water column nitrite concentrations are naturally low compared to nitrate, so nitrate+nitrite concentrations represent almost entirely nitrate.

Samples for multiple parameters were collected concurrently with offshore 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 beach 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 provide an overview of the sampling and analysis methods used to assess nutrients. Also presented are the data analysis methods used to interpret results. Detailed information regarding methods is provided in the Sampling and Analysis Plan (SAP) (King County, 2020).

2.1 Sampling Locations

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

Four sampling sites in the Duwamish River sub-estuary (Duwamish River) are located between the East Waterway upstream to river mile 6.5. Salinity conditions at these sites are brackish (a mix of saltwater and freshwater). The highest salinity is found at the furthest downstream location closest to Elliott Bay.

The term ‘mainstem’ is used to refer to all sampling areas except Elliott Bay, Quartermaster Harbor, and the Duwamish River, while ‘offshore’ refers to all locations. Stations are designated as either “outfall” or “ambient”. Outfall stations are located at/near the end of a wastewater treatment plant (TP), CSO wet weather treatment station (TS), or combined sewer overflow (CSO) discharge point. Samples from 8 outfall (including 1 Duwamish River) and 10 ambient (including 3 Duwamish River) long-term offshore monitoring stations were collected between 2008 – 2019. Table 1 provides station information and Figure 1 shows station locations.

Table 1. Offshore monitoring stations, depths, and first year of nutrient data collection.

Station	Central Basin Region	Station Rationale	Station Type	First Year of Record	Average Station depth (m)
JSUR01	North	**Brightwater TP** outfall diffuser	outfall	2005	178
KSBP01	North	**Point Jefferson** -represents conditions in the northern Central Basin	ambient	1994	262
CK200P	North	**Carkeek Wet Weather TS** outfall	outfall	2000	63
KSSK02	North	**West Point TP** outfall diffuser	outfall	1997	65
LTBC43	Middle – Elliott Bay	**Denny Way/Elliott West Wet Weather TS** outfall	outfall	2005	17.5
LTED04	Middle – Elliott Bay	**Inner Elliott Bay -** represents Elliott Bay conditions	ambient	1997	85
LSEP01	Middle	**South Plant TP** north outfall diffuser	outfall	1997	185
HNFD01	Duwamish	**Duwamish River** - East Waterway, closest to Elliott Bay	ambient	1996	17
LTKE03	Duwamish	**Duwamish River** near West Waterway	ambient	2005	12.5
LSKQ06	Middle	**Alki Wet Weather TS** outfall	outfall	1997	43
LSNT01	Middle	**Point Williams** - represents conditions in mid Central Basin	ambient	1994	205
LTUM03	Duwamish	**Duwamish River** near 16th Ave South bridge	ambient	2005	7.5
LSVV01	Middle	**Fauntleroy Cove**	ambient	2007	12.5
LTXQ01	Duwamish	**Duwamish River** near Henderson/MLK Wet Weather TS outfall at Norfolk	outfall	2009	3*
MSJN02	South	**Vashon TP** outfall	outfall	2005	63
MSWH01	Quartermaster Harbor	**Inner Quartermaster Harbor -**shallow embayment	ambient	2006	5.5
NSAJ02	Quartermaster Harbor	**Outer Quartermaster Harbor -**shallow embayment	ambient	2006	9
NSEX01	South	**East Passage** - represents conditions in southern Central Basin	ambient	2003	173

*Station depth is highly variable

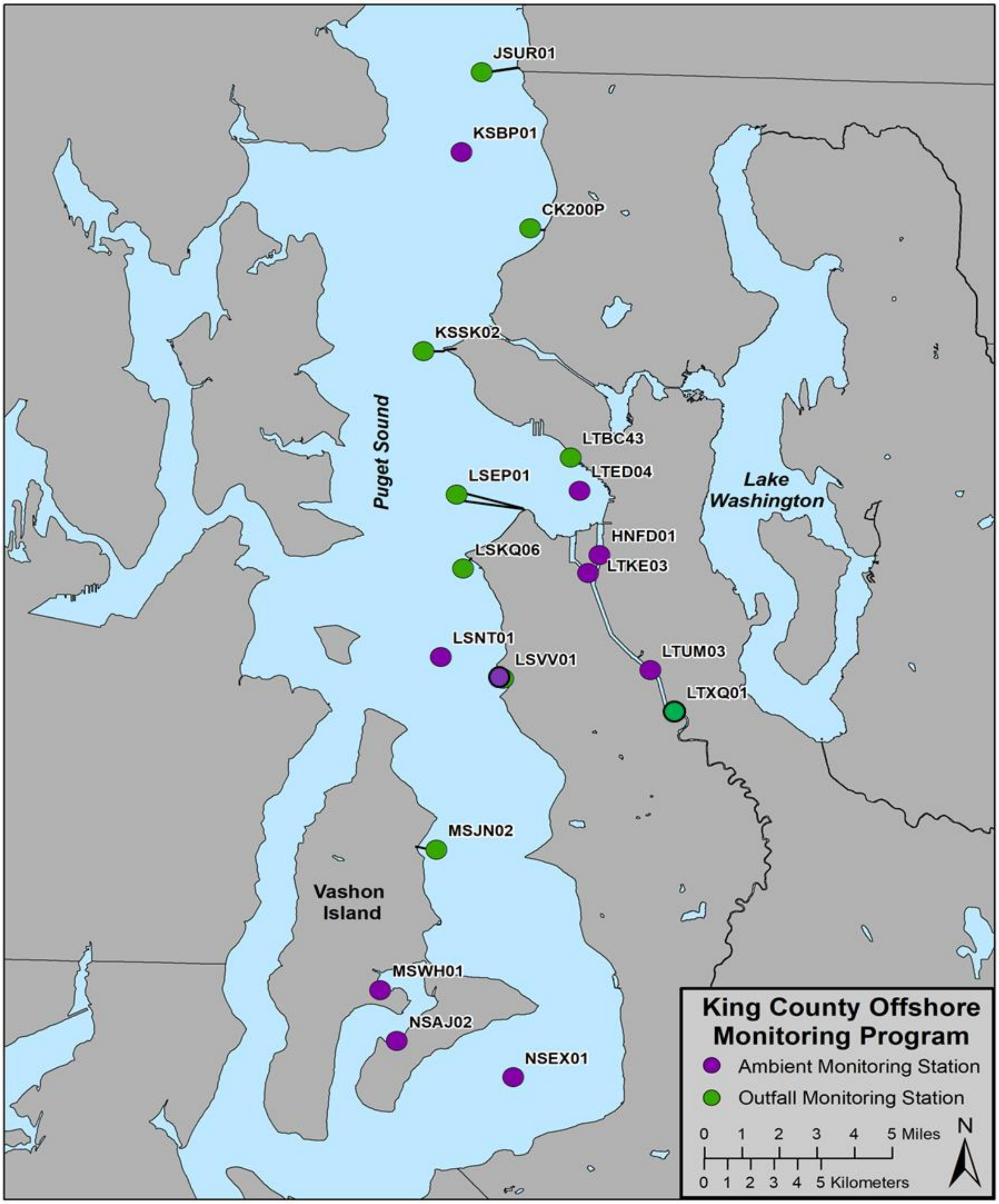

Figure 1. Offshore marine nutrient monitoring sampling locations.

2.2 Sampling and Analysis Methods

Samples for nutrient analyses were collected from up to seven depths at each station, based on water depth. Samples for ammonia-nitrogen, nitrate+nitrite-nitrogen, and silica analysis were collected at 1, 15, 25, and 35 m at the 10 stations > 50 m depth and at 55, 75, 100, or > 170 m at a subset of 7 stations. Samples were only collected from two depths at the four shallow stations < 20 m (Denny Way TS outfall, Fauntleroy Cove, and inner and outer Quartermaster Harbor) and the four Duwamish River stations.

Total nitrogen, which includes both organic and inorganic forms of nitrogen, was analyzed in the 1 m samples at a subset of nine offshore stations, three of which are outfall stations. This analysis was added to the nutrient sampling component in 2010 to measure the sum of all forms of nitrogen. A total nitrogen sample was also collected at a deeper depth at the West Point and South Plant TP outfalls (KSSK02 and LSEP01) and the two Quartermaster Harbor stations (MSWH01 and NSAJ02) (Table 2).

Prior to June 2010, total phosphorus was measured in offshore waters until the type of phosphorus analysis was changed to the measurement of dissolved orthophosphate-phosphorus (orthophosphate).

Dissolved organic carbon (DOC) and total organic carbon (TOC) were analyzed in samples from three of the four Duwamish River stations. DOC and TOC were not measured at the furthest upstream station (LTXQ01). Parameters and sampling depths for all stations are provided in Table 2.

Except for the Duwamish River stations, nutrient samples were collected monthly from 2008-2013 and then twice monthly from 2014-2019 (monthly in January and December). From April 2008 - 2014, nutrient samples at 1 m and the chlorophyll maximum depth were collected twice monthly at three stations: Point Jefferson (KSBP01), East Passage (NSEX01), and Quartermaster Harbor (NSAJ02). The phytoplankton monitoring component of the Marine Monitoring Program began in 2008 at these three sites and nutrient samples were collected concurrently with phytoplankton samples. Nutrient samples were collected monthly at the Duwamish River stations from 2008 – 2019.

Table 2. Parameters and sampling depths for all offshore stations. Stations are ordered north to south with the four Duwamish River stations at the bottom.

Station	Sample Depth (m)	Ammonia-N	Nitrite + nitrate-N	Total Nitrogen[1]	Orthophosphate-P[1]	Silica	Total organic carbon	Dissolved organic carbon
JSUR01	1	●	●	●	●	●		
	15, 25, 35, 55, 100, 175	●	●		●	●		
KSBP01	1	●	●	●	●	●		
	15, 25, 35, 55, 100, 200	●	●		●	●		
CK200P	1, 15, 25, 35, 55	●	●		●	●		
KSSK02	1, 55	●	●	●	●	●		
	15, 25, 35	●	●		●	●		
LTBC43	1, 15	●	●		●	●		
LTED04	1	●	●	●	●	●		
	15, 25, 35, 55, 75	●	●		●	●		
LSEP01	1, 100	●	●	●	●	●		
	15, 25, 35, 55, 180	●	●		●	●		
LSKQ06	1, 15, 25, 35	●	●		●	●		
LSNT01	1	●	●	●	●	●		
	15, 25, 35, 55, 100, 180	●	●		●	●		
LSVV01	1, 5	●	●		●	●		
MSJN02	1, 15, 25, 35, 55	●	●		●	●		
MSWH01	1	●	●	●	●	●		
	variable[2]	●	●	●	●	●		
NSAJ02	1	●	●	●	●	●		
	variable[2]	●	●	●	●	●		
NSEX01	1	●	●	●	●	●		
	15, 25, 35, 55, 100, 170	●	●		●	●		
LTKE03	1	●	●		●	●	●	●
	variable[2]	●	●		●	●	●	●
LTUM03	1	●	●		●	●	●	●
	variable[2]	●	●		●	●	●	●
HNFD01	1	●	●		●	●	●	●
	variable[2]	●	●		●	●	●	●
LTXQ01	1	●	●		●			

[1] Sample collection began in 2010

[2] Sample collected one meter above the bottom (depth variable with tidal height)

2.2.1 Field Methods

Offshore water column 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 nutrient analysis (KCEL, 2007) and total and dissolved organic carbon (KCEL, 2012).

All but three stations (MSWH01, NSAJ02, and LTXQ01) were collected using KCEL research vessels. Multiple five liter Niskin bottles were mounted onto the rosette containing the conductivity-temperature-depth (CTD) profiler to collect water samples on the upcast at pre-determined depths. Once the rosette was brought back on deck, samples for all nutrients, except total nitrogen, were filtered in the field using a 0.45 µm syringe filter. All results for filtered samples are reported as dissolved concentrations. Total nitrogen and TOC samples were unfiltered. Following filtration, all samples were placed into appropriate sample containers and held on ice at 4°C until they were transported to the laboratory for analyses. DOC samples were filtered in the laboratory.

Samples from the two Quartermaster Harbor (MSWH01 and NSAJ02) and one Duwamish River (LTXQ01) station were collected from docks and a bridge, respectively. Water samples for laboratory analyses were collected using a four-liter "Scott" bottle lowered by hand via a rope to the selected depth and samples placed into appropriate sample containers for laboratory analyses. Following collection, samples were placed on ice and held at 4°C and transported to the laboratory.

Field quality control (QC) measures included use of a field filtration blank. Detailed information regarding field methods is provided in the *Marine Offshore and Beach Water Monitoring: Sampling and Analysis Plan* (King County, 2020).

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-nitrogen, nitrite + nitrate-nitrogen, silica, and orthophosphate-phosphorus. Analyses were conducted according to Standard Methods (APHA, 2017) and KCEL SOPs. Total nitrogen, TOC, and DOC analyses were also conducted according to Standard Methods (APHA, 2017) and KCEL SOPs.

All analyses were performed using appropriate QC procedures for each parameter. Where appropriate, QC measures included use of method blanks, matrix spikes, check standards, 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 3. The MDL is defined as the minimum concentration that can be reliably detected by a

particular method. MDLs for most nutrients and organic carbon were consistent between 2008 – 2019. However, the ammonia-nitrogen 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-nitrogen was 0.02 mg/L from 2008 – 2009 and then subsequently decreased to 0.01 mg/L.

Table 3. Nutrient and organic carbon 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
Silica	0.05	Whitledge 1981
Orthophosphate-phosphorus	0.005	SM 4500 P-F-S
Dissolved organic carbon	0.5	SM 5310 B
Total organic carbon	0.5	SM 5310 B

* 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” (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.

To calculate monthly average concentrations for each station and year by depth, results for the two sample concentrations in a given month (when available) for each depth were averaged to obtain a single monthly average. These monthly averages were then used to calculate annual averages. Concentrations over the entire 2008 – 2019 period for each depth range 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, ammonia, and silica data monthly anomalies (departure from a long-term baseline average) were calculated for all stations by comparing each monthly average concentration at a specific depth range to the long-term baseline average (1997–2013) for that month. Monthly results that are higher than the baseline average are considered positive anomalies and 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 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 14 stations collected between 2007 - 2019, and for 7 stations with data collected between 1997 - 2019. The SK test was used to assess both annual and monthly trends over each of the two data ranges for nitrate+nitrite, ammonia, and silica. 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. Trend analyses were not conducted for DOC and TOC due to the method change in 2013 resulting in a limited set of comparable data.

3.0 RESULTS

3.1 Nitrate+Nitrite-Nitrogen

Dissolved nitrate+nitrite-nitrogen (nitrate+nitrite) concentrations in offshore waters ranged from less than the method detection limit (MDL) (0.01 mg/L) to 0.677 mg/L. The highest value was measured at Dockton in outer Quartermaster Harbor (NSAJ02) in 2009. Of the three nitrate+nitrite concentrations > 0.600 mg/L, two were measured at Dockton and the other at Carkeek Park (CK200P).

Nitrate+nitrite results for all 12 years and months combined are summarized in Figure 2. The highest mean and 95th percentile concentrations were measured at the two Elliott Bay stations (LTBC43 and LTED04), which are influenced by freshwater outflow from the Duwamish River. The lowest overall mean concentrations at mainstem (Quartermaster Harbor excluded) sites were measured at the northernmost (JSUR01 and KSBP01) and southernmost (NSEX01) stations. The two Quartermaster Harbor sites had the lowest means and percentiles of all stations.

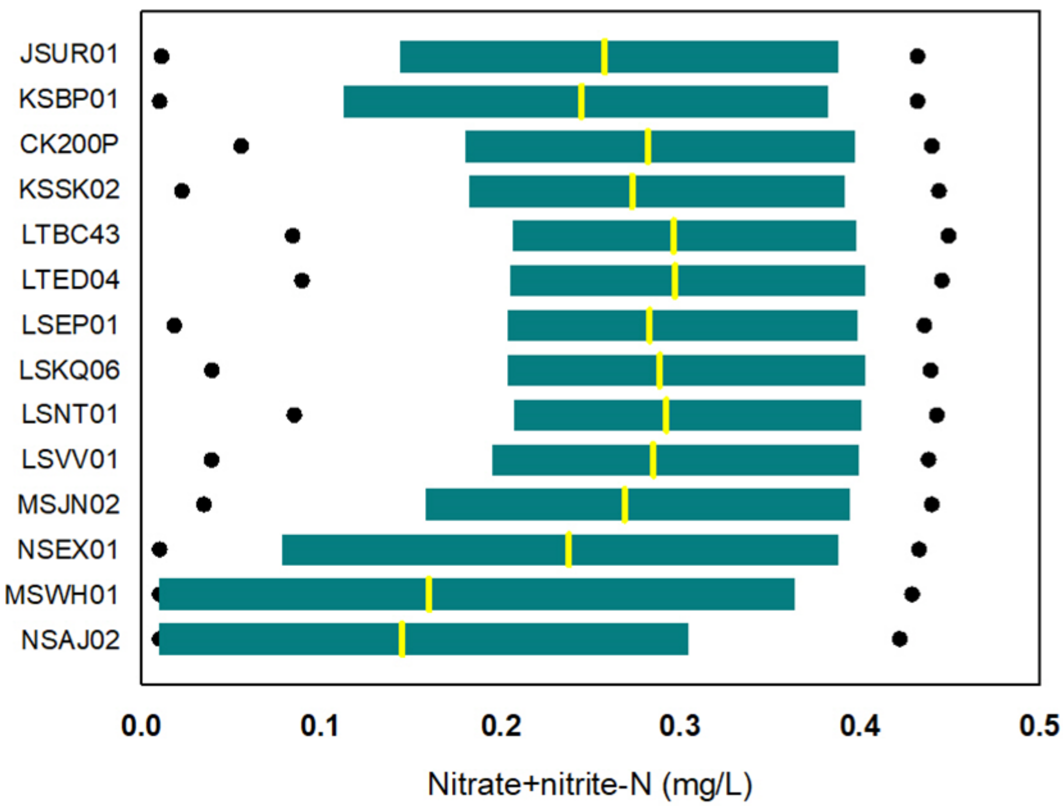

Figure 2. Surface (<2 m) nitrate+nitrite concentrations in offshore waters by location, 2008-2019 combined. Box edges represent 25th and 75th percentiles and black dots represent 5th and 95th percentiles. Yellow lines within each box represent the mean.

Nitrate+nitrite interannual variation in surface (< 2 m) water was greater than that seen for deep water due to differences in phytoplankton abundance and nutrient uptake. In general, except for Quartermaster Harbor, nitrate+nitrite annual means in surface waters at all sites were lower from 1997 - 2006 and peaked in 2008 (Figure 3). A similar pattern was observed at other depths, with a notable exception: nitrate+nitrite means at depths > 25 m dropped in 2015 and remained relatively low until 2019.

Nitrate+nitrite interannual variation in surface waters (< 2 m) was observed at Duwamish River stations (Figure 4). The lowest annual mean concentrations at the two furthest upstream locations (LTXQ01 and LTUM03) occurred in 2018. Only two Duwamish stations, LTKE03 and LTUM03, were monitored prior to 2008; the highest annual nitrate+nitrite means were measured at these sites in 2005 and 2006. Annual means were higher at the two furthest upstream locations for most years as these sites are most influenced by watershed inputs. Mean nitrate+nitrite values at the four Duwamish River sites were low in 2018 and 2019, with the lowest means in the data record occurring at LTXQ01 during this time frame. Low nitrate+nitrite concentrations may have been influenced by low river flows June - October in 2018 and 2019, compared to typical flows during these months. In 2019, the monthly mean flow in the Green River at Auburn was the lowest since 1992 and the second lowest on record since 1952 due to dry summer conditions.

Only a surface nitrate+nitrite sample is collected at station LTXQ01 but the other three sites where a near-bottom sample is also collected showed little variation in annual means both temporally and spatially (see Figure 4). However, spatial variation in nitrate+nitrite was observed in 2008 when exceptionally high Green River flows occurred in May and June. River flow in May 2008 was the highest recorded since the data record began in 1937 and the highest in June since 1974. The near-bottom annual mean at LTUM03 in 2011 is biased low as several months that typically have higher concentrations were not included in the mean due to the samples being collected too shallow.

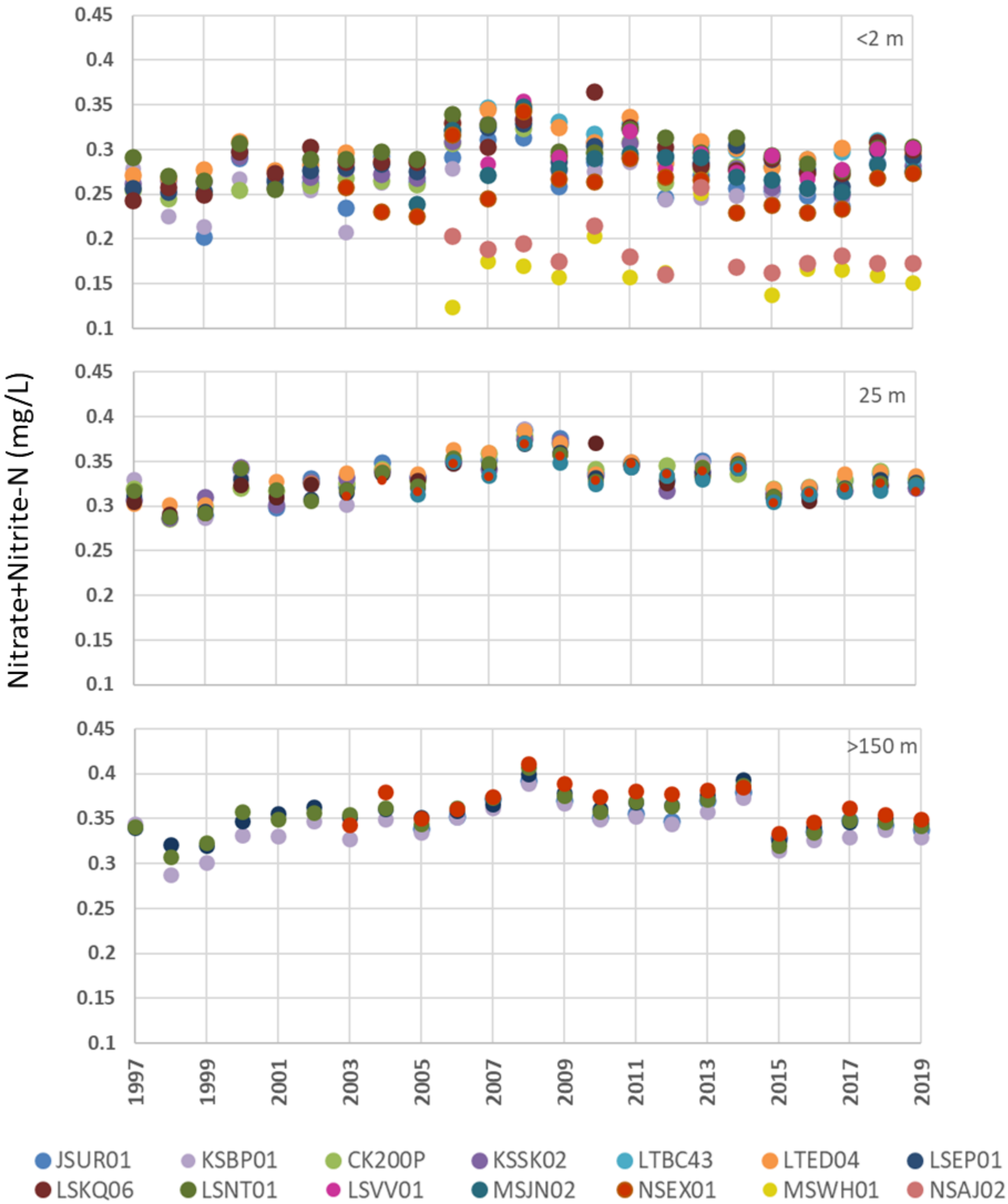

Figure 3. Mean annual nitrate+nitrite concentrations in offshore waters by depth and location (1997-2019).

Figure 4. Mean annual nitrate+nitrite concentrations in the Duwamish River sub-estuary by location and depth (2005-2019).

Seasonal variation in surface water nitrate+nitrite concentrations was evident at all offshore stations, with lower concentrations observed during months when phytoplankton abundance was highest (April - September) (Figure 5). Except for Quartermaster Harbor, little variation was seen between months and stations during winter when little or no nutrient uptake by phytoplankton occurs and the water column is well mixed. The phytoplankton growth season is longer in Quartermaster Harbor than other areas and is reflected by lower nitrate+nitrite values starting in March and persisting until November. For all years combined (2008-2019), the lowest values of the year were measured from May - August at all stations. Nitrate+nitrite concentrations were typically below detectable levels at the two Quartermaster Harbor stations during these months and levels were below detectable levels in 84-89% of samples in June and August, respectively. However, nitrate+nitrite was below detectable levels only 70-78% in July and coincided with a slight increase in ammonia, which may have been influenced by increased boating activity (and increased boat waste discharge) over the 4th of July holiday.

While there was some seasonal variation in nitrate+nitrite at all depths < 15 m in the late spring and summer months, it was much less compared to surface waters (see Figure 5).

There was also little spatial or seasonal variation at depths < 15 m and no difference between outfall and ambient stations.

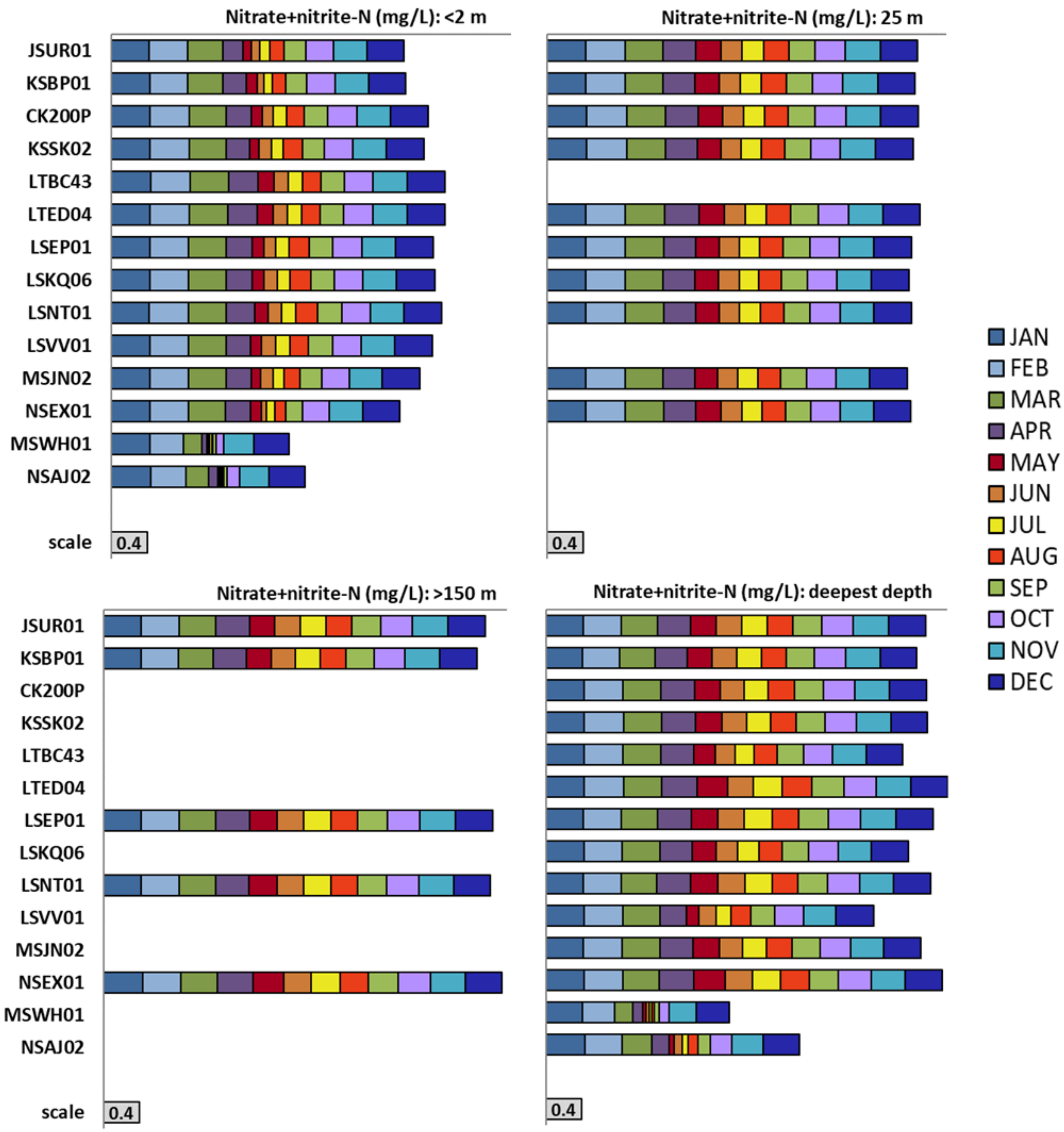

Figure 5. Mean monthly nitrate+nitrite concentrations in offshore waters by location and depth; all data (2008 – 2019) combined.

Although much less pronounced than in offshore waters, some seasonal variation was evident for nitrate+nitrite at the Duwamish River sites (Figure 6). Concentrations were highest in winter months, with little variation across sites; concentrations were lowest

from May - October. The lowest monthly means of the year at all locations occurred in July and were slightly lower at the two furthest downstream Duwamish sites.

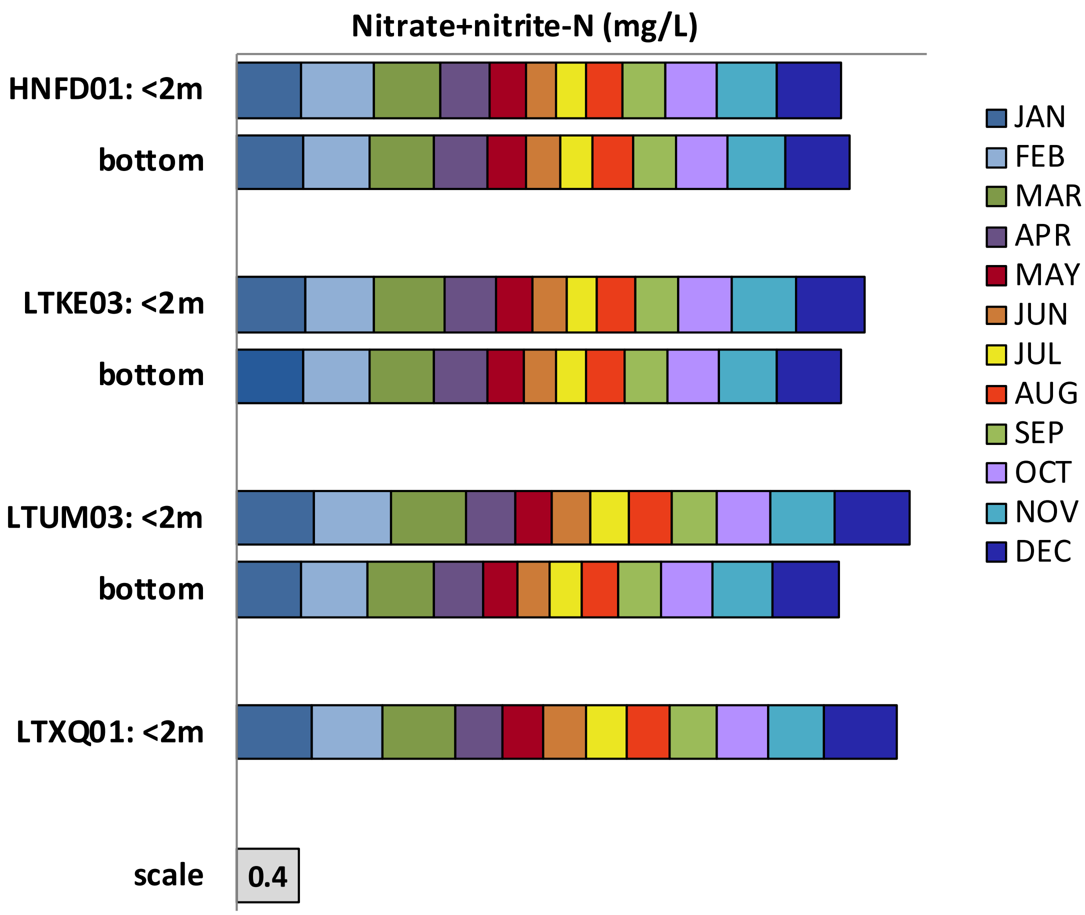

Figure 6. Duwamish River subestuary monthly mean nitrate+nitrite values by location and depth all data (2008 - 2019) combined.

3.1.1 Nitrate+Nitrite Data Anomalies

Monthly nitrate+nitrite anomalies (departure from long-term baseline average) were calculated for all stations by comparing each monthly average (mean) concentration to the long-term baseline average (1997–2013) concentration for each site. The data record began later for the following sites; therefore, the long-term baseline average spans a shorter time period:

- LTBC43—1998
- JSUR01—1999
- NSEX01—2003
- MSJN02—2005
- MSWH01, NSAJ02—2006
- LSVV01—2007

Figure 7 shows surface water (< 2 m) monthly anomalies for three stations, with blue being higher (positive) than the long-term mean and red being lower (negative). The pattern exhibited at these stations is representative of the pattern seen at other stations not shown. For most months from 2008 to 2012, monthly surface nitrate+nitrite anomalies were positive and then transitioned to a period of mixed anomalies until spring 2014. Primarily negative nitrate+nitrite anomalies occurred from spring 2014 to 2019 for most sites, with positive anomalies in the spring and fall of 2019. Negative anomalies at East Passage (NSEX01) were particularly pronounced with all but four months lower than the long-term mean between April 2014 and March 2018, with stronger negative anomalies (lower concentrations) for most months than at other sites.

Monthly nitrate+nitrite anomalies in deep water (> 150 m) for two stations (Pt. Jefferson and East Passage) are shown in Figure 8. Although the anomaly range was smaller for deep water, the overall patterns in deep water relative to long-term means were similar to surface patterns with one exception: negative anomalies in deep water began a few months later in September 2014 compared to the surface.

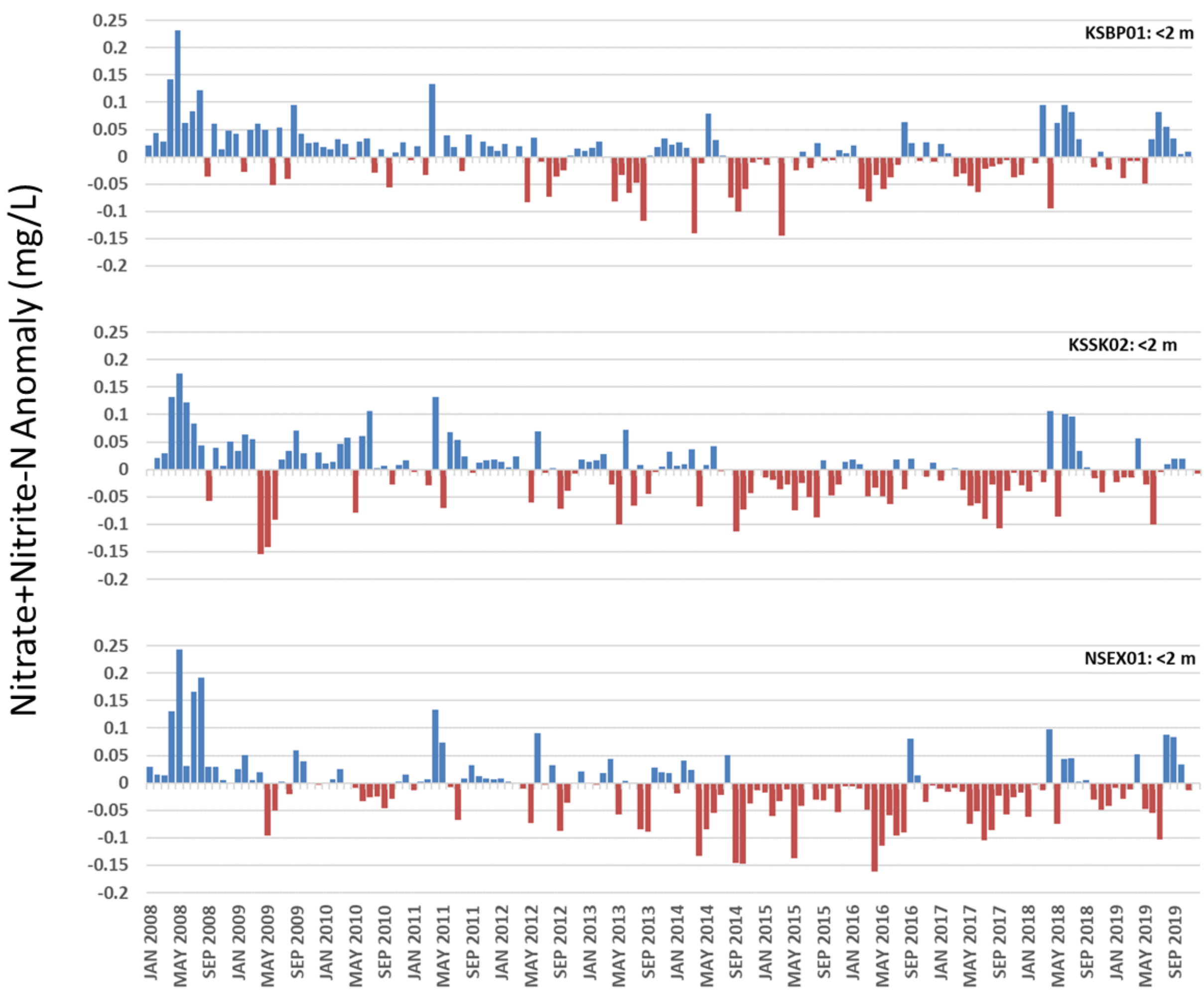

Figure 7. Monthly nitrate+nitrite surface (<2 m) anomalies for three offshore locations (2008-2019).

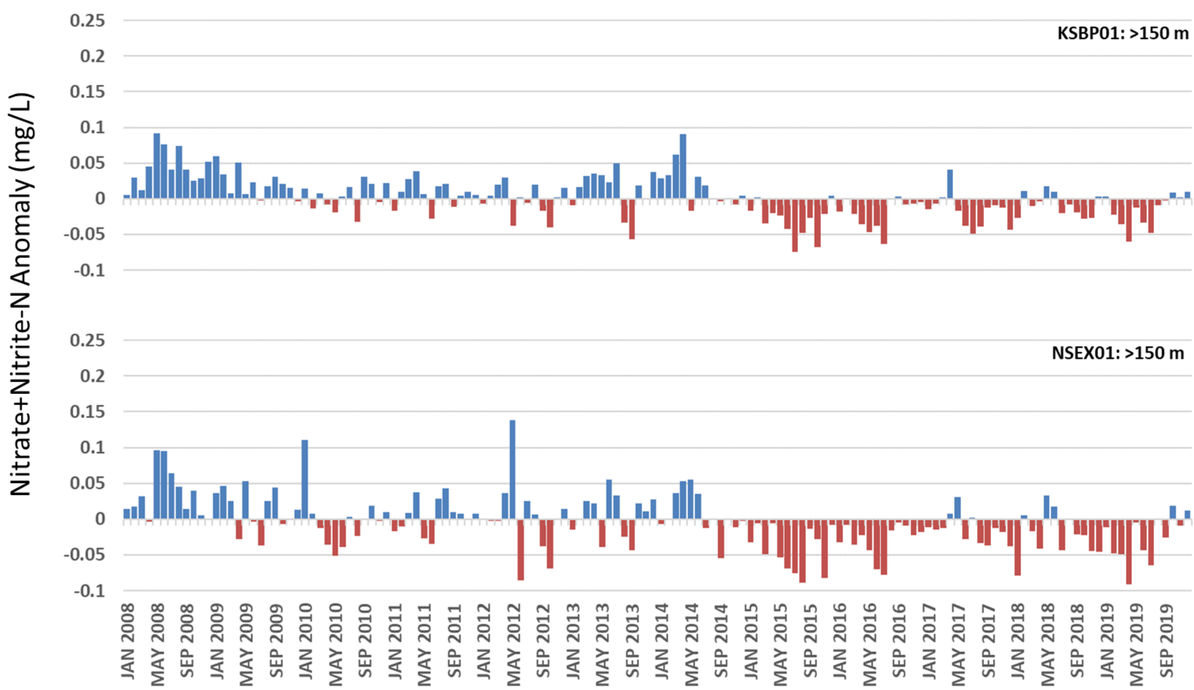

Figure 8. Monthly nitrate+nitrite deep water (> 150 m) anomalies for two locations.

3.2 Ammonia-Nitrogen

Dissolved ammonia-nitrogen (ammonia) concentrations in offshore waters ranged from < MDL (0.002 mg/L) to 0.363 mg/L between 2008 and 2019. The highest value was detected at the deepest depth at the West Point TP outfall site (KSSK02) in June 2014. The ammonia MDL decreased from 0.01 mg/L in 2008 to 0.005 mg/L, and decreased again in August 2013 (to present) to 0.002 mg/L.

Ammonia concentrations were frequently < MDLs in the winter months, particularly prior to 2013 when the MDL decreased. Table 4 shows the percentage of samples that were below detection limits for all offshore sites and depths between 2008 and 2019. To account for different MDLs and to calculate monthly and annual means, the cfit function in the R NADA2 package was applied. This function calculates the empirical cumulative distribution for censored (< MDL) data.

Table 4. Percentage (%) of ammonia samples below MDLs by month at offshore stations between 2008 and 2019.

	Method Detection Limit (mg/L)		
	2008	**2009–Jul 2013**	**Aug 2013–2019**
	0.01	**0.005**	**0.002**
JAN	92.6	86.9	68.2
FEB	92.9	85.4	73.8
MAR	91.4	62.7	43.9
APR	87.3	18.3	7.8
MAY	19.7	8.7	2.5
JUN	78.1	2.1	2.5
JUL	3.8	7.6	6.7
AUG	6.4	15.2	9.5
SEP	24.4	34.6	24.2
OCT	17.3	20.1	34.5
NOV	90.0	80.1	65.5
DEC	93.1	86.8	62.9

Some spatial variation in mean annual ammonia concentrations was evident at most depths, particularly in surface and deep (> 100 m) waters (Figure 9). In surface waters, the two southern mainstem stations at East Passage (NSEX01) and the Vashon outfall (MSJN02) generally had the lowest annual means, especially East Passage. The two Quartermaster Harbor sites (MSWH01 and NSAJ02) and the West Point outfall (KSSK02) had the highest annual means for most years. Station KSSK02 had the highest annual means at 25 m, the trapping depth of the effluent plume, while the South Plant outfall station (LSEP01) had the highest means in waters > 100 m at the effluent plume trapping depth. Other than the West Point outfall site (KSSK02), little spatial variation was observed between years at mid-depths. In surface waters to 55 m, annual means between 2016 and 2019 were lower than prior years at most sites. In deep waters, annual means were more variable between years with 2008, 2017, and 2018 the lowest and 2015 the highest at all sites.

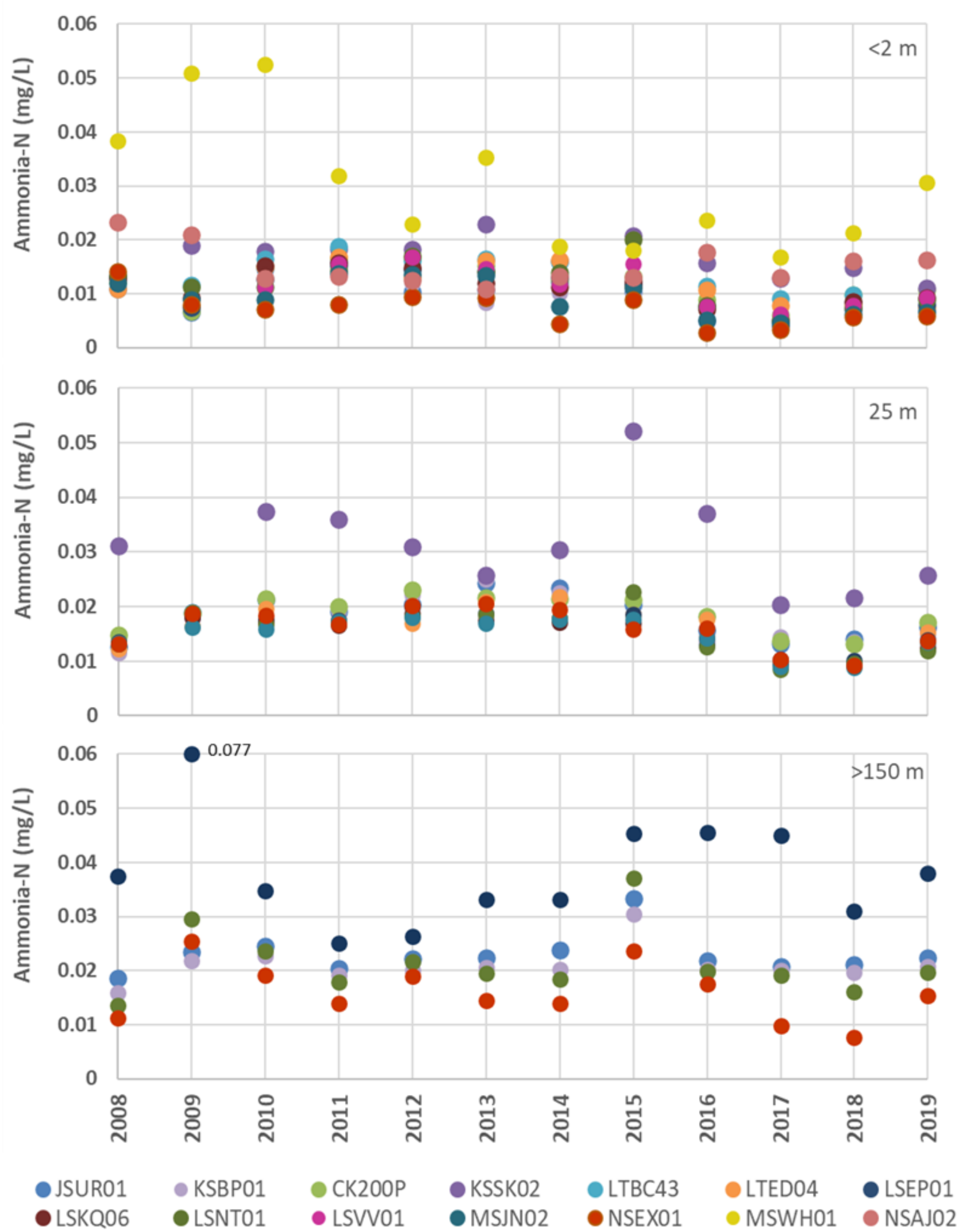

Figure 9. Mean annual ammonia concentrations in offshore waters by location and depth (2008-2019).

Ammonia concentrations in Duwamish River sub-estuary waters ranged from < MDL (0.002 mg/L) to 0.207 mg/L (2008 - 2019) (not shown). The highest concentration was measured at the furthest upstream station (LTXQ01) in 2009. As with offshore waters, the MDL changed, however, unlike offshore waters only a small percent of all concentrations (5.8%) were < MDL. All but three concentrations below the MDL were seen at the two furthest downstream stations, primarily in the winter months.

Spatial variation in mean annual ammonia concentrations was evident in both surface and near-bottom waters at the Duwamish River sites (Figure 10). In surface waters, the two furthest downstream stations (HNFD01 and LTKE03) generally had the lowest ammonia annual means, while station LTUM03 had the highest. Mean annual ammonia levels in surface waters at the furthest downstream site (HNFD01) were low in 2008 and 2009, and then increased before slightly decreasing each year starting in 2017. A similar but less distinct annual pattern was also seen at station LTKE03 but varied for the other two sites. Mean annual ammonia levels at the three Duwamish River sites where near-bottom data were collected showed spatial and annual patterns like those seen for surface waters with one exception: near-bottom annual means were lowest at station LTKE03 rather than HNFD01.

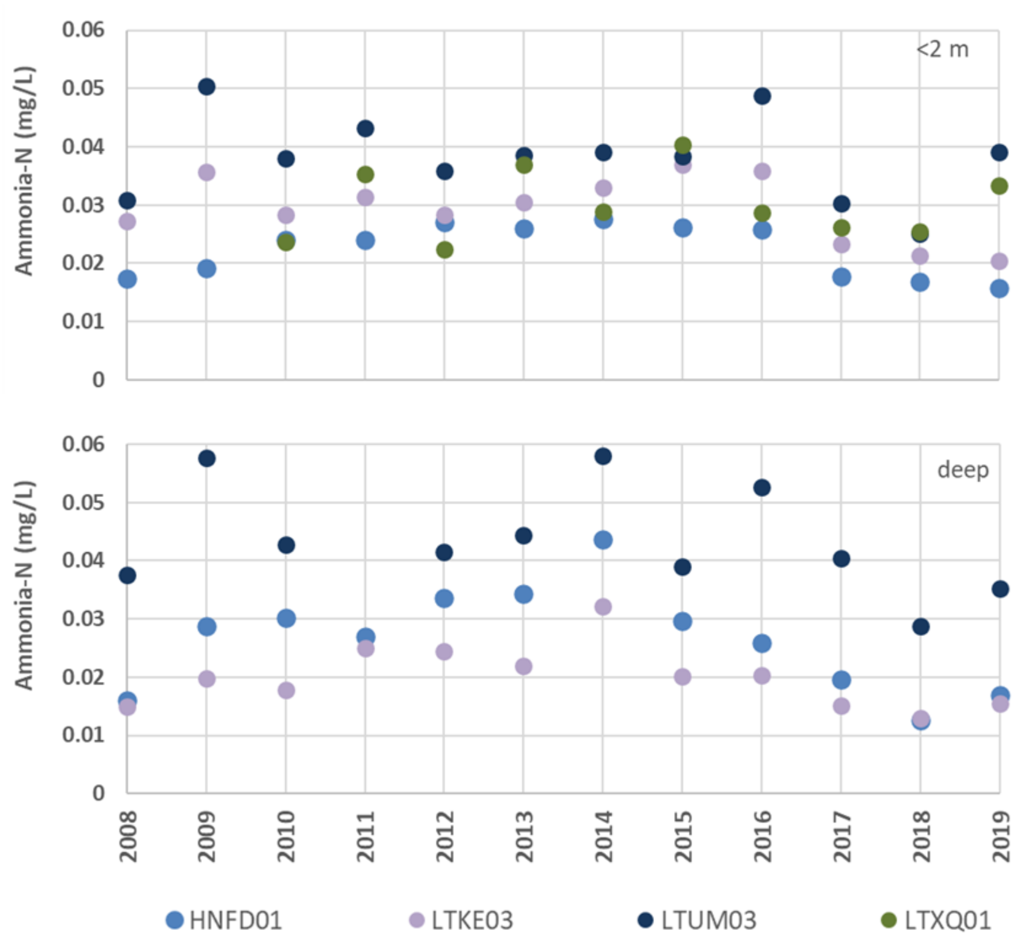

Figure 10. Mean annual ammonia concentrations in Duwamish River subestuary waters by location and depth (2008-2019).

Mean monthly ammonia concentrations in offshore waters (2008 - 2019) are shown in Figure 11 for all stations at multiple depths. The seasonal variation pattern seen at all depths was the opposite of that observed for other nutrients, with low concentrations in winter and higher levels in spring and summer.

The highest monthly ammonia means in surface waters occurred in June at most sites. The exceptions were the West Point outfall (KSSK02) and the two Quartermaster Harbor sites (MSWH01 and NSAJ02). February and December had the highest monthly means at the West Point outfall while the highest means occurred from October through December in Quartermaster Harbor. Except for the West Point outfall station (KSSK02), the highest monthly mean at each station typically occurred following the month(s) with highest phytoplankton biomass. Some spatial variation was evident with the two northernmost (JSUR01 and KSBP01) and two southernmost stations (NSEX01 and MSJN02) having the lowest monthly means in spring through fall compared to mid-basin and Elliott Bay sites. The two Quartermaster Harbor sites had substantially higher monthly ammonia means in the late fall and winter months.

Mean monthly ammonia concentrations at 25 m were more similar among stations compared to surface waters, except at the West Point outfall (KSSK02) where substantially higher ammonia concentrations were observed in winter and fall months. Monthly means at the three northern stations were slightly higher May - July than at other sites, except for the Elliott Bay (LTED04) and West Point outfall (KSSK02) stations. As described above, the West Point outfall effluent plume trapping depth is 25 m, and high monthly mean ammonia levels reflect effluent outflow.

Spatial variation in mean monthly ammonia concentrations was more evident in water depths > 150 m and the deepest sampling depth at each station. Ammonia levels in East Passage deep waters (> 150 m) in summer months were lower than levels at other deep sites, and mean concentrations at the deepest sampling depth were lower than levels at southern stations. Mean ammonia concentrations at relatively shallow sites (Elliott Bay: LTBC43, Alki: LSKQ06, and Fauntleroy Cove: LSVV01) were typically lower in spring and summer. The lowest monthly means for all sites were seen at Fauntleroy Cove (LSVV01).

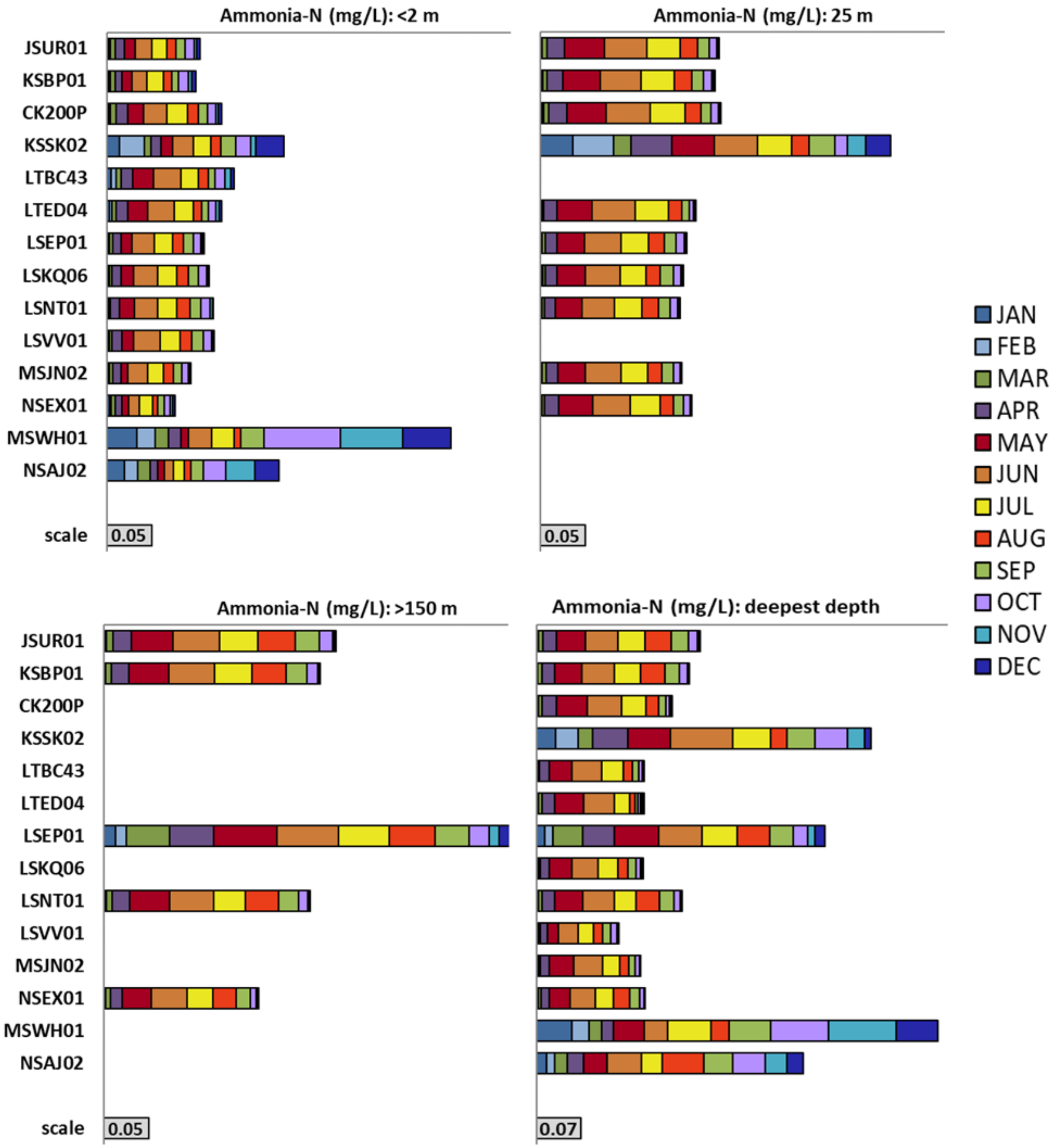

Figure 11. Mean monthly ammonia concentrations in offshore waters by location and depth; all data (2008 – 2019) combined.

Mean monthly ammonia levels (2008 - 2019) in the Duwamish River are shown in Figure 12. Ammonia concentrations in surface waters at the two furthest downstream (HNFD01 and LTKE03) sites were highest in May -July, while the highest levels at the furthest upstream sites were measured in September – October, particularly in October. Ammonia levels in near-bottom waters at stations HNFD01 and LTUM03 were higher in May - July than surface waters, unlike LTKE03 where ammonia levels in surface and near-bottom waters were similar for these months. Relative to ammonia levels at the three other

Duwamish River sites, levels at station LTUM03 (both depths) were higher throughout most of the year.

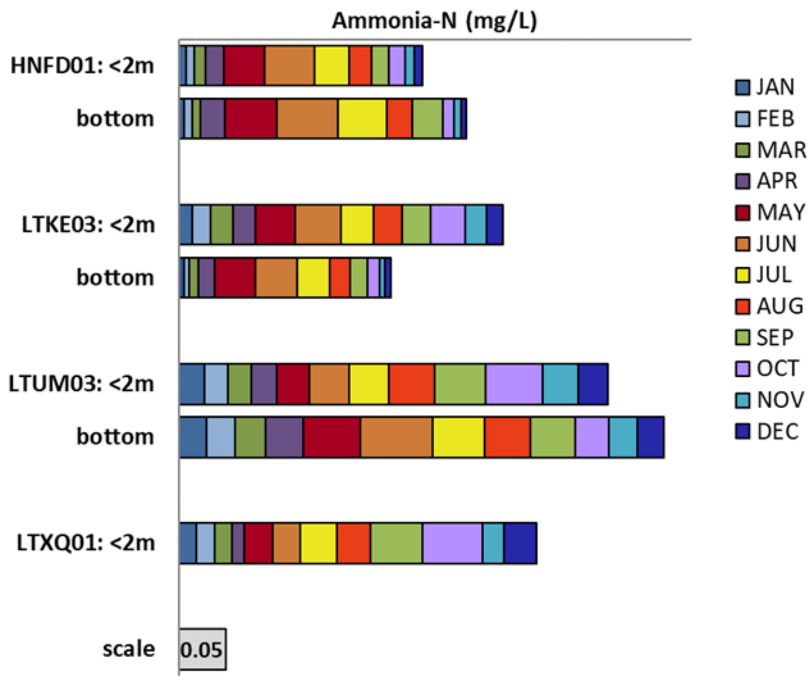

Figure 12. Mean monthly ammonia concentrations in Duwamish River subestuary waters by location and depth; all data (2008 - 2019) combined.

Figure 13 shows ammonia surface water monthly means between 2008 and 2019 for representative stations during months with a high percentage of detected values (> 70%). Patterns were similar at stations not shown. Ammonia concentrations between June and July demonstrated the most interannual variation, likely due to primary productivity dynamics. Compared to other months, ammonia levels in June were high (~ 0.02-0.07 mg/L) at most stations between 2010 and 2013 and very low (≤0.005 mg/L) in 2008 and 2017. Ammonia concentrations in both June and July were atypically high (~ 0.07-0.08 mg/L) at most sites in 2011, while in September levels varied between years, but high at all sites in 2013. Concentrations measured in April at most sites were higher in 2018 and 2019 relative to prior years.

Inner Quartermaster Harbor ammonia levels in October were high (0.11-0.28 mg/L) between 2008–2011, then subsequently decreased until moderately increasing starting in 2015. In 2015, ammonia levels in inner Quartermaster Harbor developed a pattern of decreasing summer ammonia concentrations. A similar pattern of decreasing ammonia levels was observed in East Passage starting in 2016.

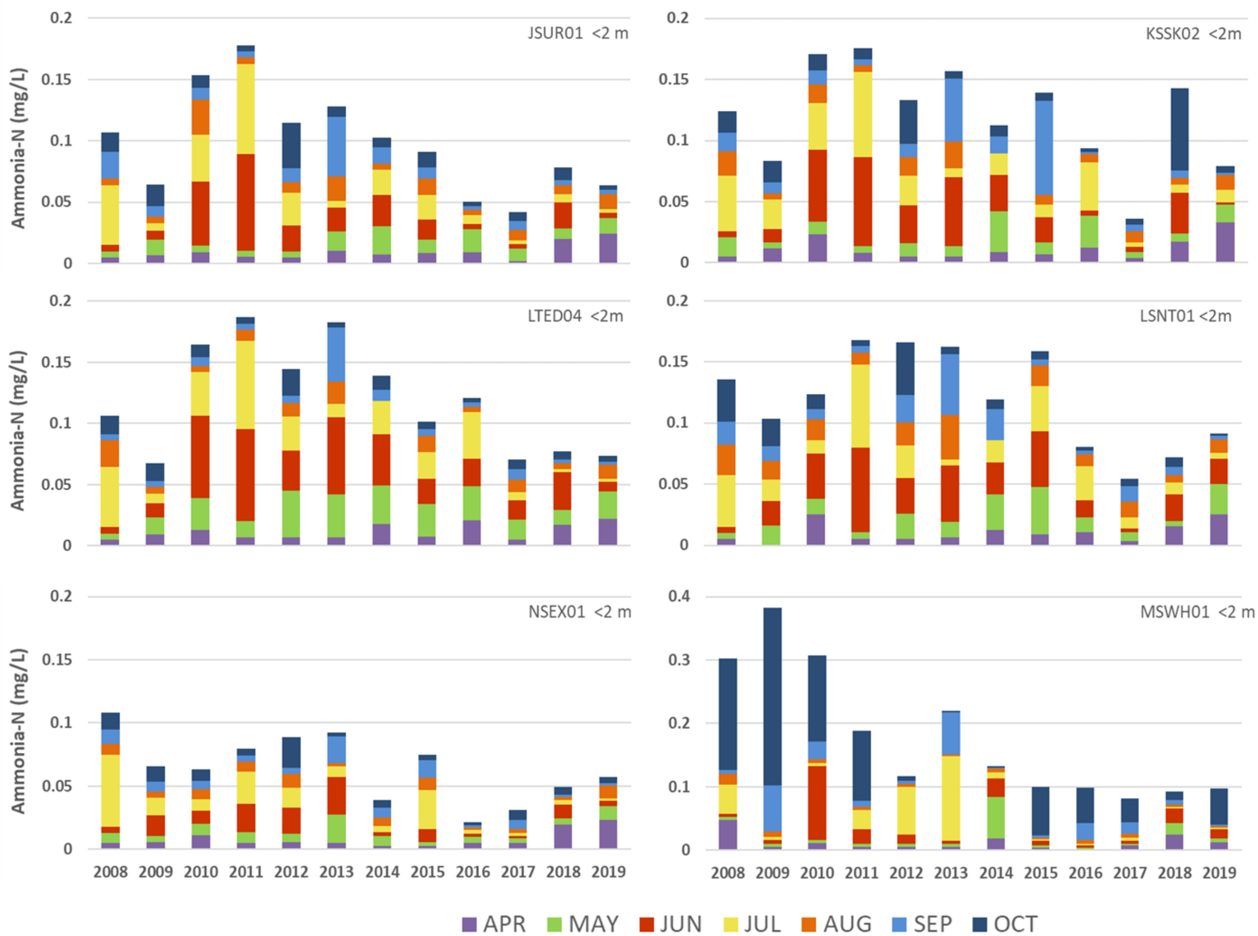

Figure 13. Mean ammonia concentrations by month (Apr – Oct) and year in surface waters at select stations (2008 - 2019).

While ammonia concentrations in waters > 150 m showed some interannual similarity to the pattern seen for surface waters, monthly variation was less distinct between years (Figure 14).

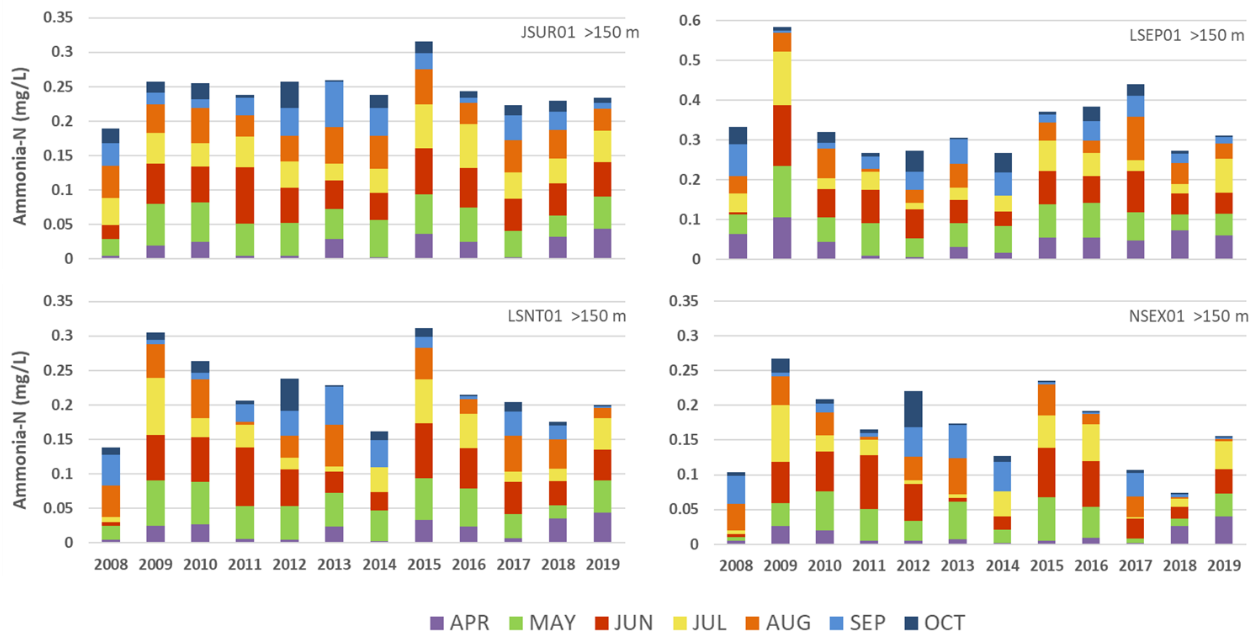

Figure 14. Mean ammonia concentrations by month (Apr-Oct) and year in deep water (> 150 m) at select stations (2008 - 2019).

3.3 Total Nitrogen

Total nitrogen is the sum of all forms of nitrogen, both inorganic (nitrate+nitrite and ammonia) and organic. Total nitrogen analysis began in September 2010 at a subset of seven offshore stations; an eighth station (South Plant outfall) was added in January 2013. Surface samples (< 2 m) were collected at all stations and an additional sample was collected at 55 m at the West Point outfall (KSSK02), 100 m at the South Plant outfall (LSEP01), and approximately 6 m at Dockton Park (NSAJ02) in Quartermaster Harbor. Overall, between 2010 and 2019, total nitrogen concentrations ranged from 0.056 (NSAJ02) to 0.941 (NSAJ02) mg/L.

Mean annual total nitrogen surface water concentrations exhibited some interannual variation; the greatest variation was seen at Dockton (NSAJ02) (Figure 15). Some of the highest total nitrogen annual means were measured at Pt. Williams (LSNT01) during most years. Mean annual total nitrogen concentrations in surface waters were generally highest in 2011-2014. Since sampling until September 2010, the mean concentrations for 2010 are biased low and are not shown in Figure 15.

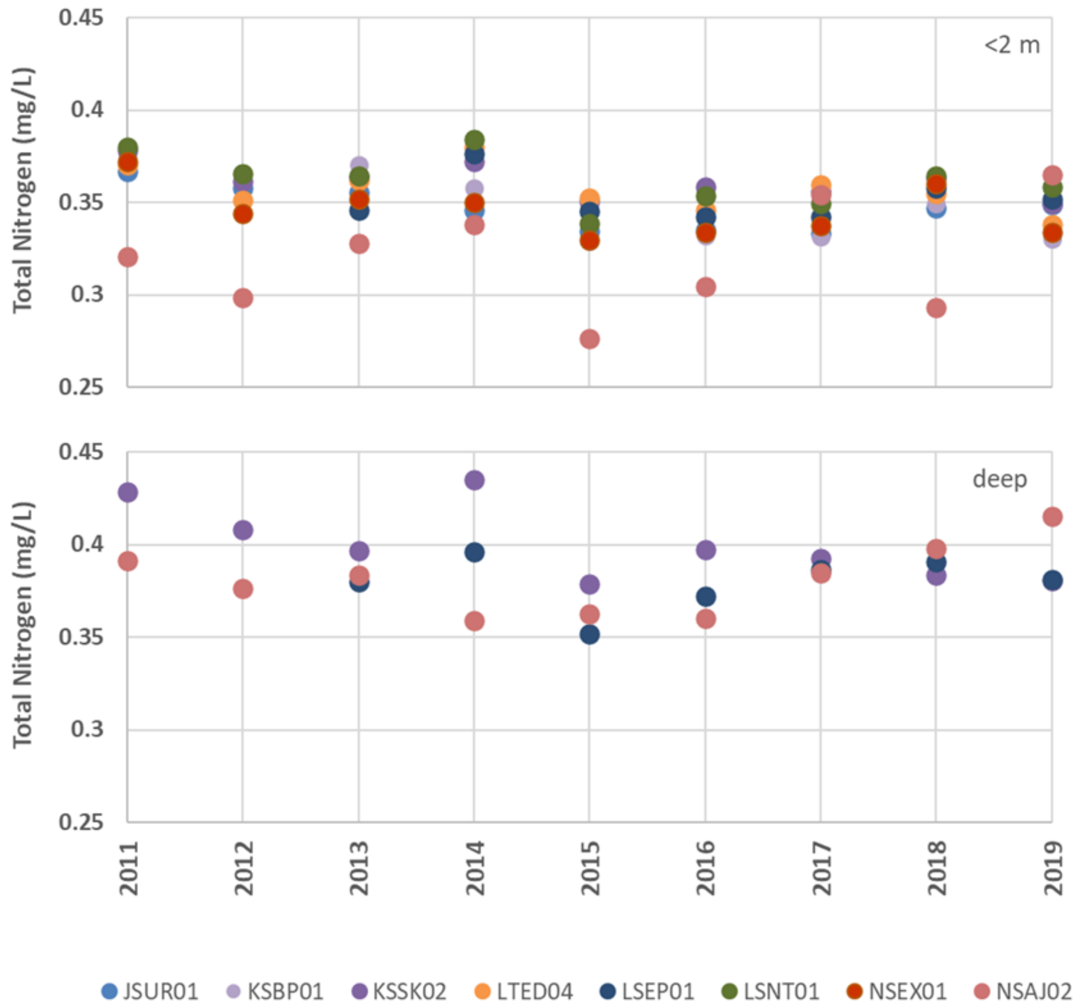

Figure 15. Mean annual total nitrogen concentrtions in offshore waters by station and depth (2011 - 2019).

Total nitrogen surface water monthly mean concentrations were generally similar at all sites in the winter months but were more varied in spring and summer months, a reflection of differences in inputs and biological uptake. Concentrations were lowest in the spring and summer months (May-August) (Figure 16).

For the three sites with total nitrogen measured in deeper waters, the most variation between surface and deeper water was seen at Dockton (NSAJ02) between April and August (Figure 17). The other two sites also exhibited monthly variation between surface and deeper waters between May and September but showed less monthly variation in deeper waters.

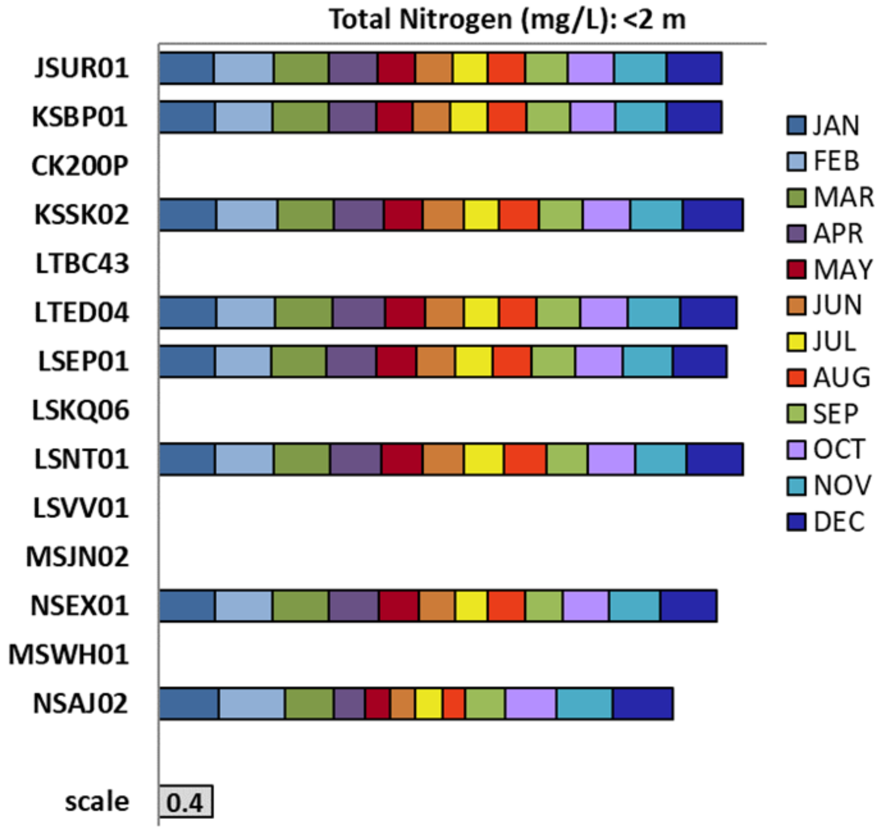

Figure 16. Mean monthly total nitrogen concentrations in offshore surface (< 2 m) waters by site; all data (2010 - 2019) combined.

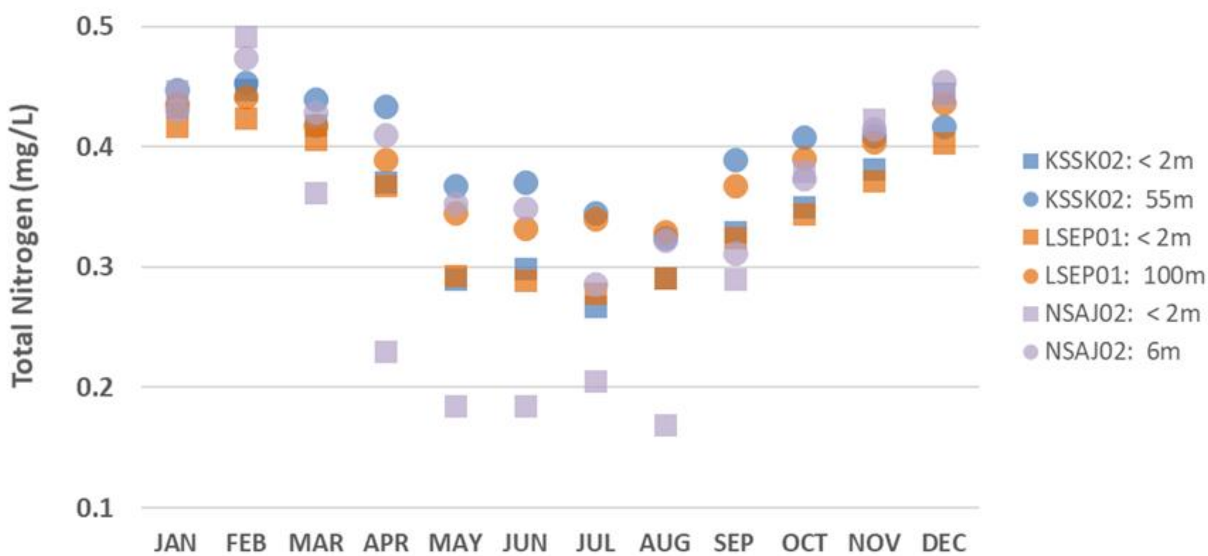

Figure 17. Mean montly total nitrogen concentrations by location and depth; all data (2010 - 2019) combined.

3.4 Silica

Dissolved silica (silica) concentrations in offshore waters (2008 - 2019) ranged from < MDL (0.05 mg/L) to 7.25 mg/L. The highest silica concentration was measured in inner Quartermaster Harbor (MSWH01) in March 2017 following very high stream flows from Judd Creek, which flows into the northwest end of the inner harbor. The second highest value of 7.21 mg/L was seen at in Elliott Bay (LTBC43) in February 2016. Between 2008 and 2019, silica concentrations at all stations have only been < MDL 8 times, with 6 of those measurements occurring at the two Quartermaster Harbor sites. Silica was < MDL at the two northernmost stations, JSUR01 and KSBP01, in June and July of 2017, respectively.

Interannual variation was more pronounced in surface waters than deeper waters due to seasonal differences in phytoplankton (diatom) abundance and freshwater input. Generally, for most stations with a data record back to 1997, silica annual means in surface waters (< 2 m) were lower from 1997-2005 and peaked in 2008 (Figure 18). A similar pattern was observed at other depths > 25 m. Silica annual means were slightly lower in waters > 25 m in 2015 compared to 2006- 2014 and 2016-2019. The range in annual means for all depths > 25 m was smaller than in surface waters.

While some silica interannual variation was observed in surface waters (< 2 m) at the Duwamish River stations, each station exhibited a different pattern (Figure 19). Annual means were highest at the furthest upstream location (Norfolk/Henderson [LTXQ01]) and subsequently decreased further downstream. The least amount of interannual variation was seen at the furthest downstream location. Although Duwamish River flows (Green River at Auburn gage) in 2019 were the second lowest on record since 1952, it did not appear to influence silica levels at the furthest upstream site (LTUM03). The silica annual mean in 2019 at LTUM03 was typical as were the monthly concentrations between June - October when river flow was very low. However, the 2019 annual mean for station LTKE03 was the lowest in the data record and was also low for HNFD01.

The furthest two downstream Duwamish River sites (HNFD01 and LTKE03) where a near-bottom silica sample was also collected, showed little variation in annual means both temporally and spatially (Figure 19). Higher silica annual means were observed at the furthest upstream site (LTUM03) relative to the other Duwamish River sites and exhibited more interannual variation. The silica annual mean for the near-bottom depth at LTUM03 in 2011 is likely biased due to several months of data were not included in calculation of the mean. Samples are collected from a bridge at this site and a few of the deeper depth samples were collected from relatively shallow depths and thus, excluded from the mean calculation.

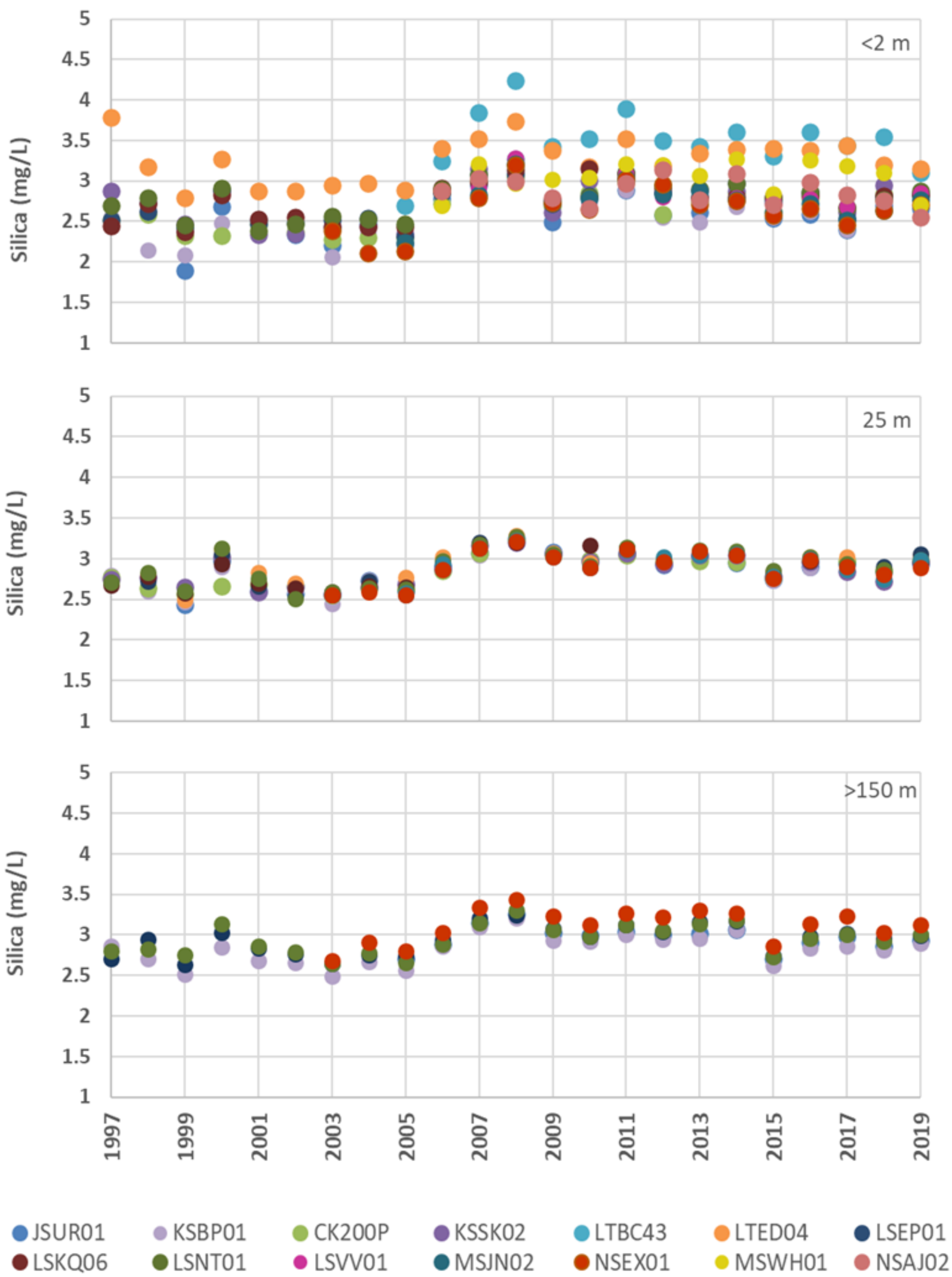

Figure 18. Mean silica concentration at offshore stations by year, location and depth (1997-2019).

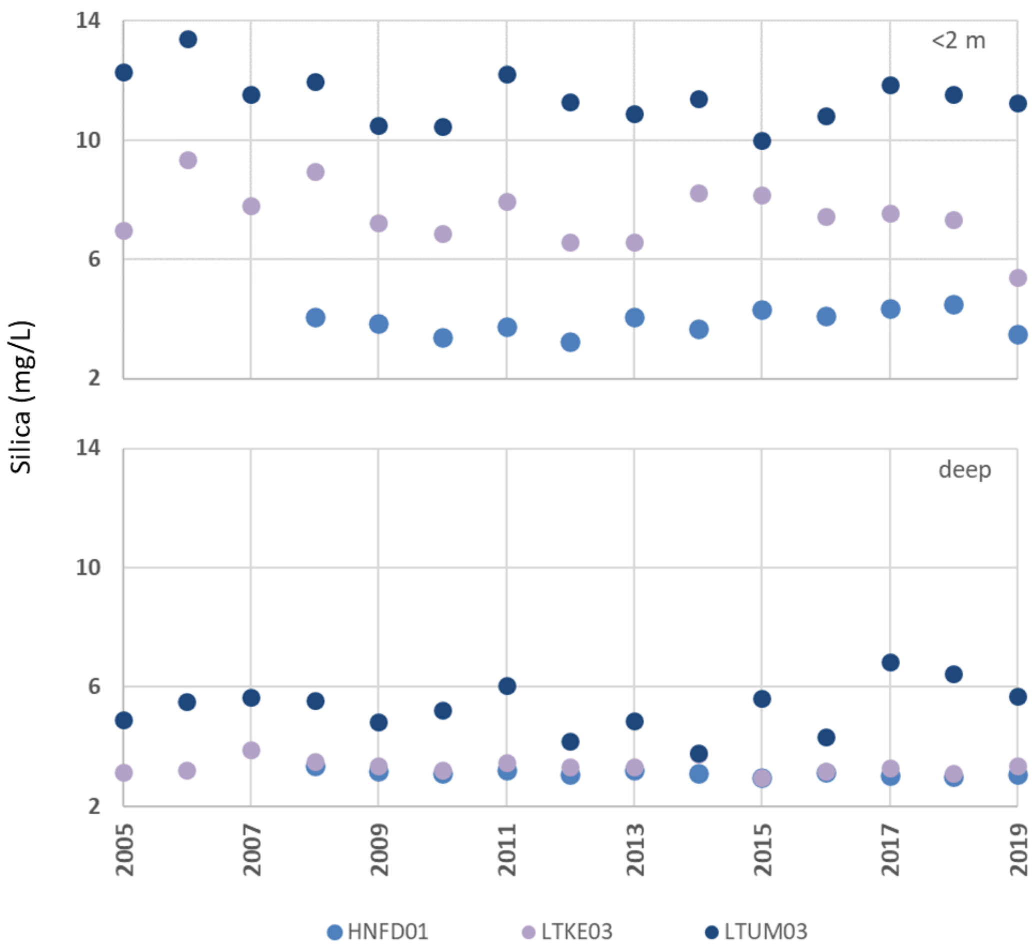

Figure 19. Mean annual silica concentrations in Duwamish River subestuary surface waters by year, location and depth (2005 – 2019).

Seasonal variation in surface water silica was evident at all stations, with lower concentrations measured during months when phytoplankton abundance was highest and freshwater input was lowest (April – September) with one exception (Figure 20). When all data (2008 - 2019) are combined, monthly silica means at the two Elliott Bay stations was higher April - May compared to other locations. Little spatial variation was seen between winter months except for the two Elliott Bay and Quartermaster Harbor stations. Monthly silica means at the two Elliott Bay and Quartermaster Harbor stations were slightly higher in January and October. The lowest values of the year were seen June and July at most stations and also in May at the two Quartermaster Harbor stations, particularly in the inner harbor. Seasonal variation was less in waters > 25 m, but slightly lower from May - September at all sites, even at depths > 150 m.

Although silica concentrations in surface waters varied between the three Duwamish River stations, all sites exhibited a similar pattern with lower monthly means June - September (2005 – 2019, all data combined) (Figure 21). The deeper sampling depth at each site exhibited seasonal variation in late spring and summer months to a lesser extent, particularly at the two furthest downstream sites.

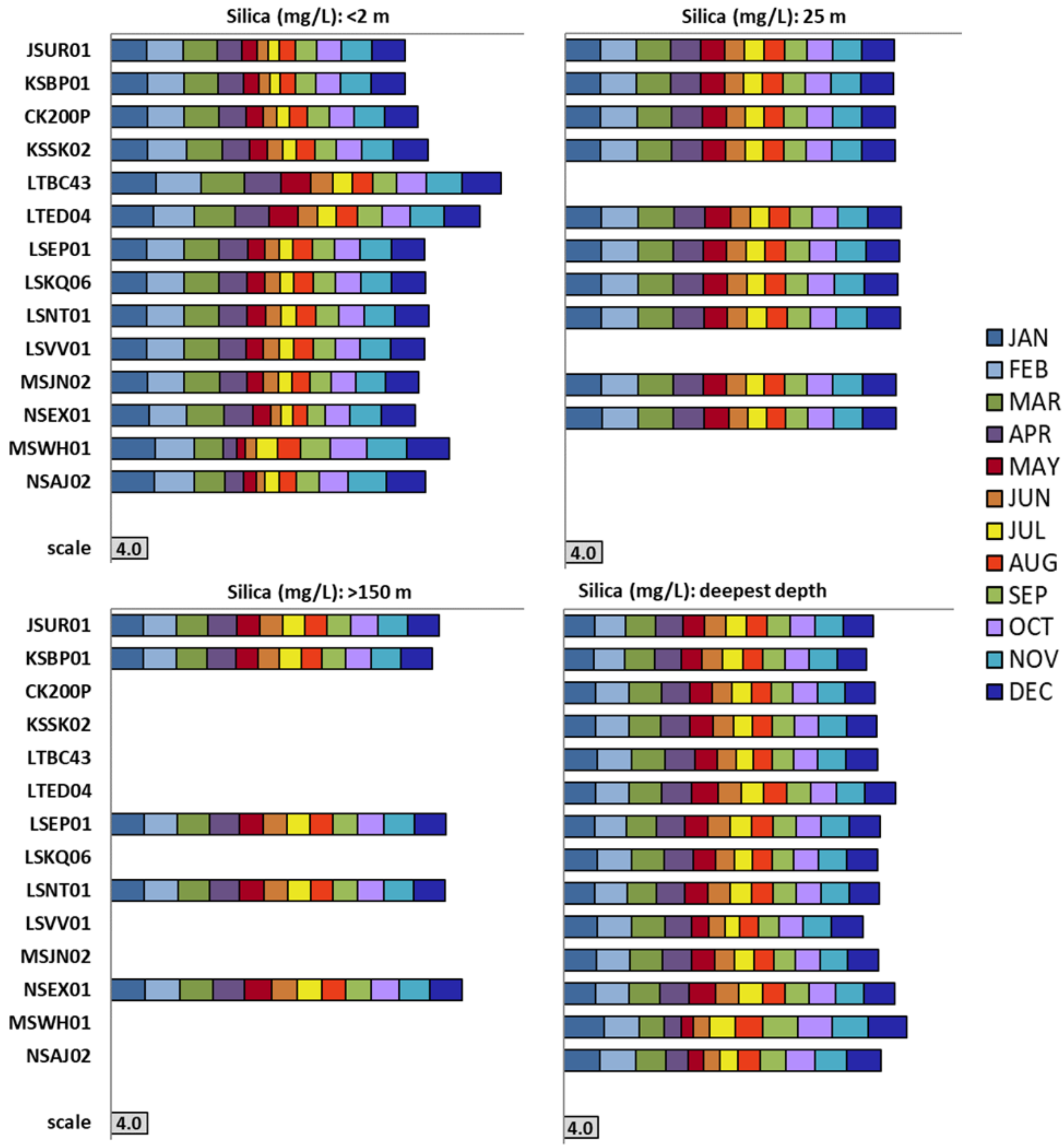

Figure 20. Mean silica concentrations in offshore waters by station, depth and month; all data (2008 - 2019) combined for multiple depths.

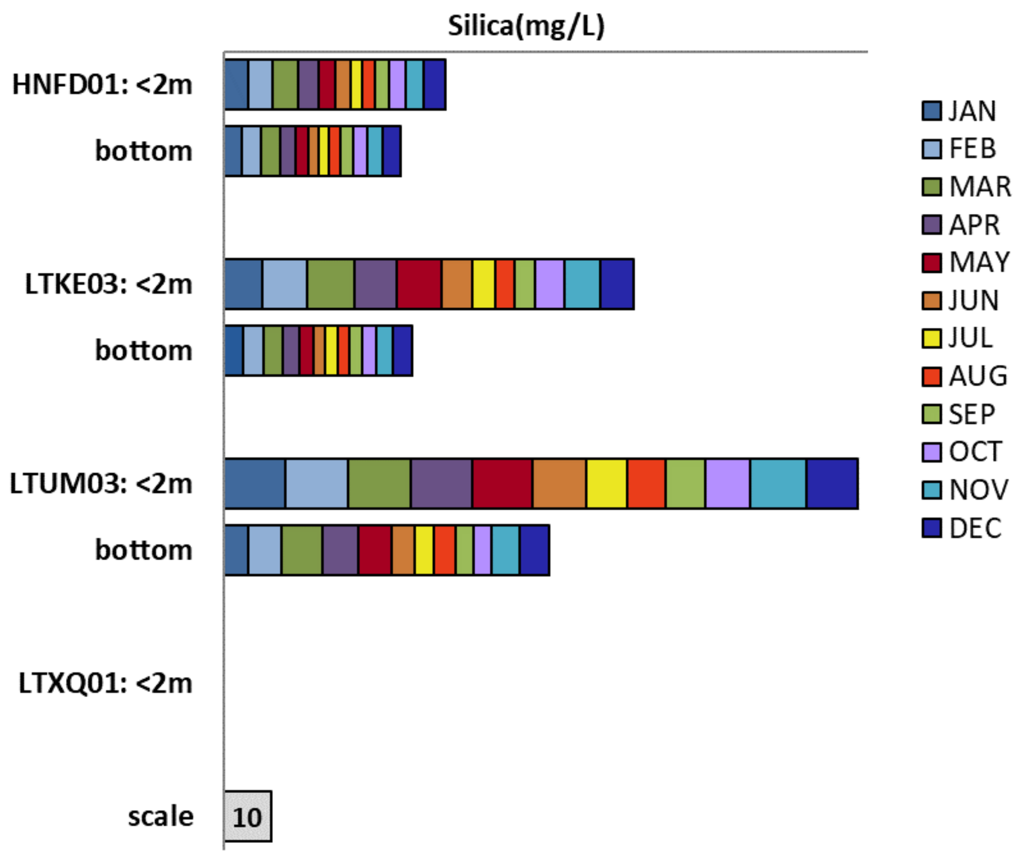

Figure 21. Mean silica concentrations in Duwamish River Subestuary waters by station, month and depth; all data (2005-2019) combined.

3.4.1 Silica Data Anomalies

Monthly silica anomalies (departure from long-term baseline average) were calculated for offshore stations by comparing each monthly value to the long-term baseline average (1997–2013) for each site. Anomalies are useful for assessing variability and trends between locations and also over both short and long time frames. A positive anomaly indicates higher silica concentrations than the long-term mean, while a negative anomaly indicates lower silica values. The data record started in 2003 for station NSEX01, therefore anomalies were calculated using a 2003-2013 baseline. Figure 22 shows surface water (< 2 m) monthly anomalies for three stations; the patterns exhibited at these stations are representative of those seen at other stations not shown. Except for the Elliott Bay stations, surface water anomalies were positive for most months from 2008 to early 2013 and then alternated between positive and negative from 2013 - 2019. Negative anomalies were most pronounced and stronger at East Passage (NSEX01), particularly between May and September each year from 2016 - 2019. Although the pattern of anomalies in surface waters at Pt. Jefferson and other stations was similar to the pattern at East Passage, the strength of the negative anomalies (lower concentrations) was greatest at East Passage. Anomalies for silica levels in surface waters varied most at the two Elliott Bay stations due

to the influence of the Duwamish River. Positive anomalies were seen at all stations in 2008 (except Elliott Bay stations) and again between September 2016 through March 2017.

Monthly silica anomalies in deep waters (> 150 m) at two representative stations are shown in Figure 23. The range of silica anomalies was smaller in deep waters and exhibited a different pattern than surface waters for most years. Although positive anomalies were seen in deep waters in 2008, and between September 2016 and March 2017, like the pattern seen in surface waters, there were fewer negative anomalies observed until fall 2014 when effects of the marine heat wave were first observed. Negative anomalies persisted for most months in deep waters from September 2014 through July 2016 at Pt. Jefferson and from September 2014 - September 2016 at East Passage. In addition to the marine heat wave in fall of 2014, the Pacific Decadal Oscillation (PDO) shifted to a positive phase in 2014 and remained strongly positive throughout 2015 and 2016. As with surface waters, the strength of positive silica anomalies in deep waters at East Passage was similar to Pt. Jefferson but the negative anomalies were typically stronger at East Passage.

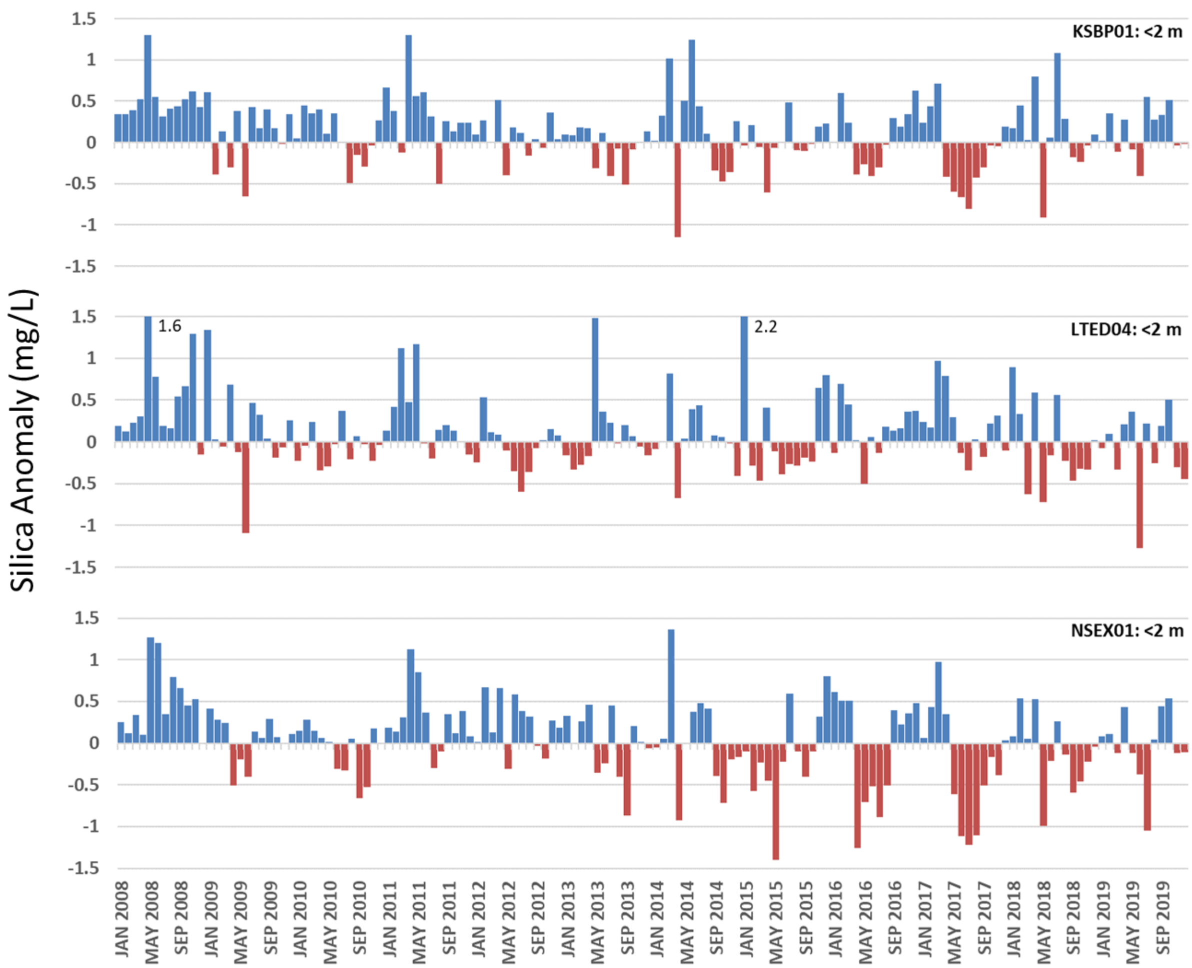

Figure 22. Anomalies in monthly silica concentration in surface (< 2 m) waters by year and month for three representative stations.

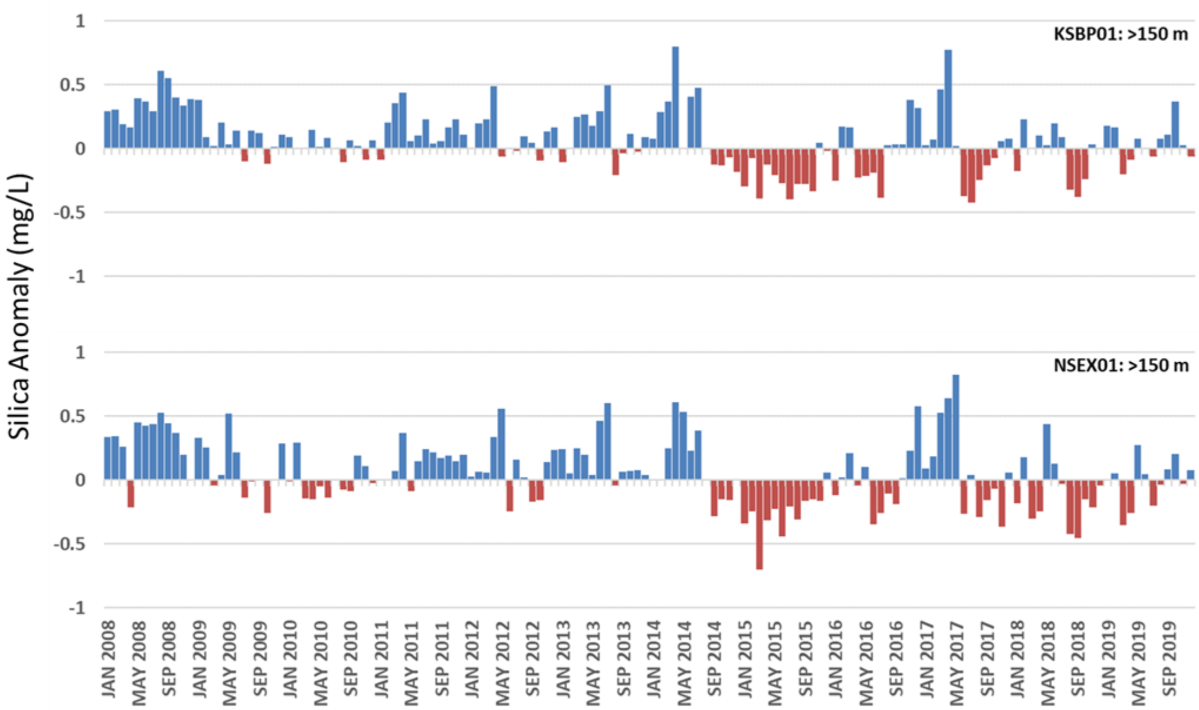

Figure 23. Anomalies in monthly silica concentrationin deep waters (> 150 m) by year and month for two representative stations.

3.5 Orthophosphate-Phosphorus

Total phosphorus was measured in offshore waters from 1994 - May 2010 and subsequently changed to measuring dissolved orthophosphate-phosphorus (orthophosphate). Only orthophosphate results are presented here; annual mean concentrations were calculated starting in 2011 due to the incomplete dataset for 2010. Orthophosphate results presented were collected between 2010 and 2019.

Orthophosphate concentrations in offshore waters ranged from < MDL (0.005 mg/L) to 0.137 mg/L. Orthophosphate concentrations were seldom < MDL, except in Quartermaster Harbor where 63% of the concentrations < MDLs occurred, particularly in April - June.

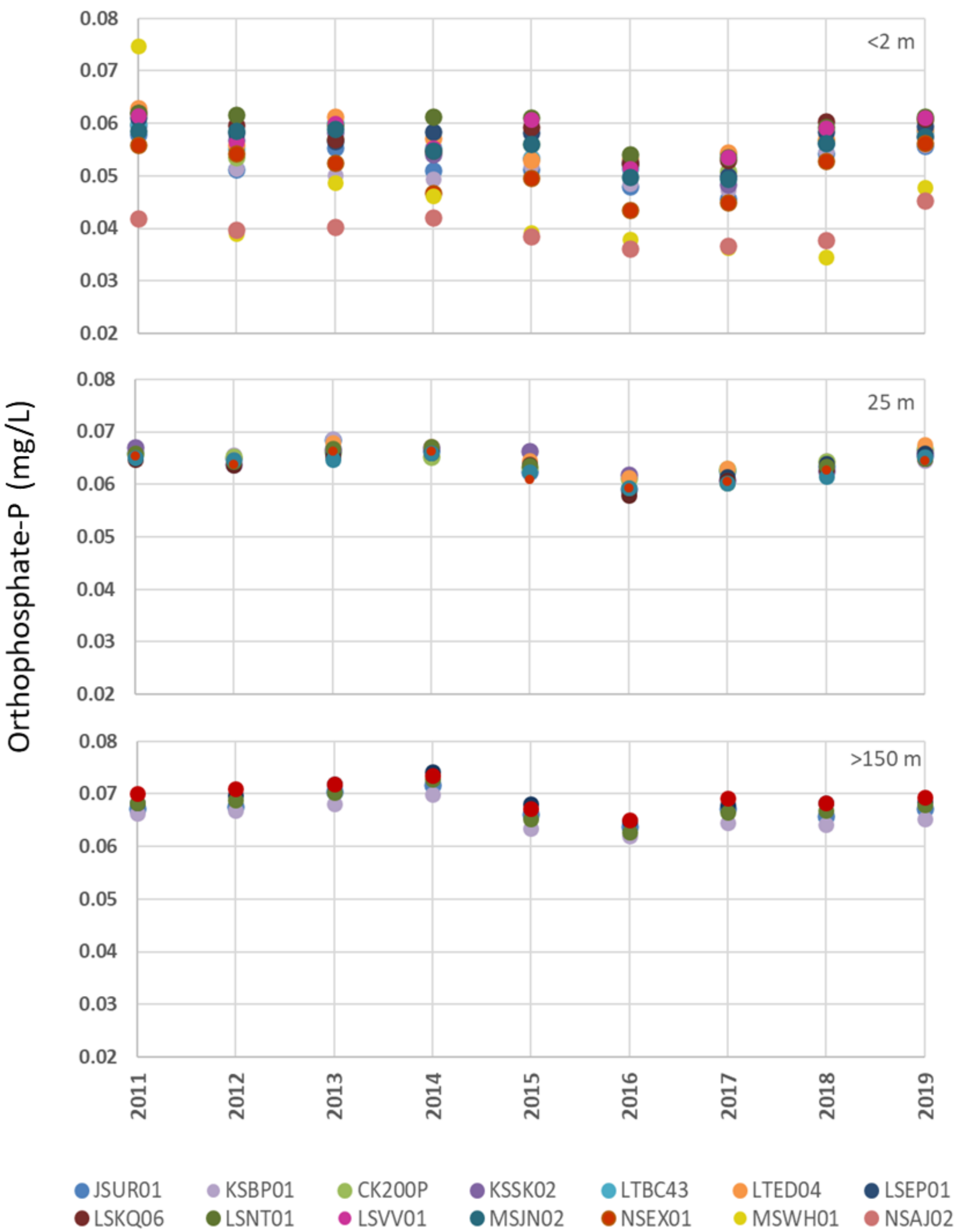

Figure 24. Mean orthophosphate concentrations in offshore waters by year and location at three depths (2011 - 2019).

Some interannual variation in orthophosphate concentrations in offshore waters was evident at all depths, more so in surface waters (Figure 24). Mean annual orthophosphate concentrations in surface waters (<2 m) at most stations were highest in 2019, and lower in 2016 and 2017. The lowest orthophosphate levels were measured at the two Quartermaster Harbor sites, although levels in East Passage (NSEX01) and Pt. Jefferson (KSBP01) were also relatively low most years. The highest orthophosphate annual means

were typically measured at mid-basin stations. The greatest spatial variation was seen in 2014, while the least variation was seen in 2011 and 2019.

Minimum orthophosphate concentrations in surface waters for any month at all offshore stations are shown in Table 5 to compare spatial and interannual differences when low values were observed. A value of 0.005 mg/L indicates the concentration was below the <MDL. Minimum values were generally below or close to the MDL in 2017. The persistent water column stratification in 2017 led to sustained phytoplankton blooms which is reflected in the low minimum values. Minimum values at the two Elliott Bay stations were higher in 2017 relative to levels measured at other sites, likely due to the lower productivity that typically occurs in Elliott Bay. The mid-basin stations had higher minimum values for several years compared to the northern and East Passage stations. Maximum values in surface waters were highest in 2013 and 2014 for most stations (not shown).

Table 5. Minimum orthophosphate concentrations measured in offshore surface waters (<2 m) by year and station (2011 - 2019). 0.005 mg/L indicates <MDL. Yellow shading indicates lower values, blue higher values.

	2011	2012	2013	2014	2015	2016	2017	2018	2019
JSUR01	0.0128	0.0125	0.0136	0.009	0.0127	0.0092	0.0054	0.01	0.007
KSBP01	0.0108	0.0112	0.0063	0.0073	0.0131	0.0073	0.005	0.0077	0.009
CK200P	0.0193	0.0254	0.0268	0.0084	0.0256	0.01	0.005	0.0088	0.008
KSSK02	0.0213	0.0264	0.0155	0.005	0.0115	0.0084	0.005	0.009	0.005
LTBC43	0.0321	0.0307	0.0292	0.0186	0.0222	0.0055	0.0195	0.0199	0.005
LTED04	0.0391	0.0304	0.0351	0.0193	0.0294	0.01	0.012	0.0187	0.005
LSEP01	0.0298	0.037	0.0107	0.0084	0.0282	0.0107	0.005	0.0084	0.0071
LSKQ06	0.0246	0.0338	0.0093	0.0102	0.0339	0.0081	0.0057	0.0223	0.0081
LSNT01	0.0268	0.0328	0.0104	0.0164	0.0346	0.0106	0.0063	0.0119	0.0305
LSVV01	0.0155	0.0245	0.0095	0.005	0.0373	0.0052	0.005	0.0167	0.0251
MSJN02	0.0184	0.0341	0.0194	0.0176	0.0184	0.0066	0.007	0.0103	0.0181
NSEX01	0.0123	0.0196	0.0051	0.005	0.0073	0.0062	0.005	0.0061	0.0093
MSWH01	0.0112	0.0052	0.005	0.0148	0.005	0.01	0.005	0.005	0.0101
NSAJ02	0.005	0.005	0.005	0.005	0.0081	0.0053	0.005	0.005	0.0053

Less annual and spatial variation in orthophosphate concentrations was observed in waters > 25 m due to less biological uptake that occurs at these depths. Orthophosphate concentrations in waters ≥ 25 m were lowest in 2016, and generally higher in 2011 to 2014.

Orthophosphate concentrations in Duwamish River waters ranged from 0.0072 to 0.0871 mg/L; concentrations were never < MDL.

Annual mean orthophosphate concentrations in the Duwamish River (2011 - 2019) surface (< 2 m) waters were similar most years but varied considerably between stations (Figure 25). Annual means showed a spatial gradient with the lowest concentrations at the furthest upstream site (LTXQ01) and highest levels at the furthest downstream site (HNFD01). The two furthest upstream sites showed a similar pattern to each other, while the two furthest downstream sites exhibited a similar pattern. The two furthest downstream sites had the lowest annual means in 2015, while the upstream sites had high or the highest means that year. The highest annual means were seen in 2019 at the two furthest downstream sites, similar to what was seen in offshore waters. For 2011 to 2019 combined, mean orthophosphate concentrations at each station ranged from 0.0179 - 0.0595 mg/L.

Mean annual orthophosphate concentrations in near-bottom samples from the three Duwamish River stations exhibited a similar spatial gradient; higher means were seen at the furthest downstream site. During most years, mean orthophosphate levels at the two furthest downstream sites were similar but exhibited the most variation in 2014. Orthophosphate was lower at station LTUM03 most years but were similar to the other two Duwamish stations in 2012 and 2016 when little variation between sites was seen. For 2011 to 2019 combined, mean values at each station ranged from 0.0540 - 0.0661 mg/L

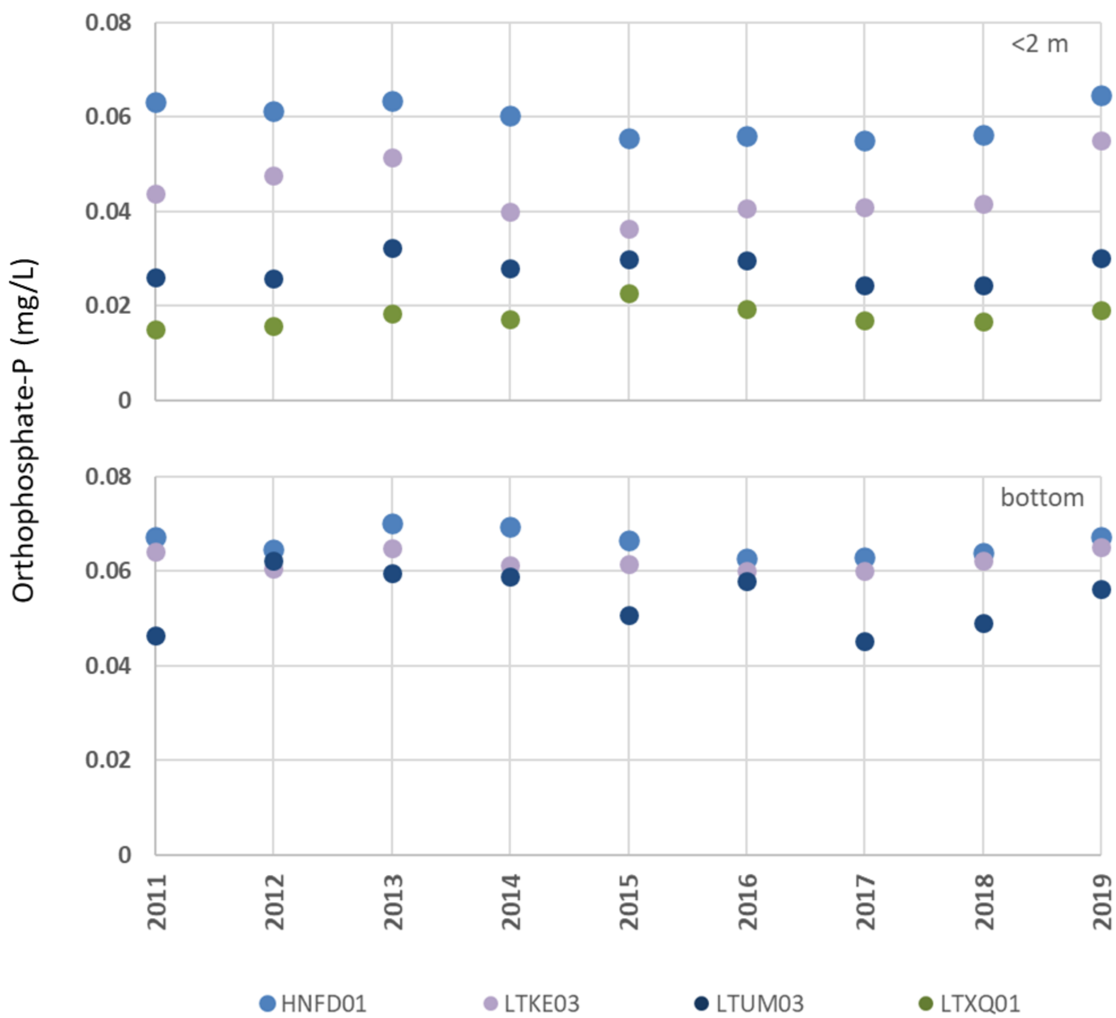

Figure 25. Mean orthophosphate concentrations in the Duwamish River subestuary by year, depth and location (2011-2019).

As with other nutrients, seasonal variation in orthophosphate concentrations in offshore surface waters (< 2 m) was evident at all stations when phytoplankton abundance was highest (April - September) (Figure 26). Orthophosphate concentrations were also lower in March and October at the two Quartermaster Harbor sites due to the extended growing season in the harbor. Orthophosphate levels were also lower in East Passage June - September relative to levels at other offshore sites. Little variation was seen between months and stations during winter months when little or no nutrient uptake by phytoplankton occurs. For all years combined, the lowest values of the year were seen from May through August at all stations.

While there was some seasonal variation in orthophosphate concentrations at depths < 15 m in the late spring and summer months, it was much less compared to variation in surface waters. There was also little spatial variation between months at depths < 15 m and no difference between outfall and ambient stations.

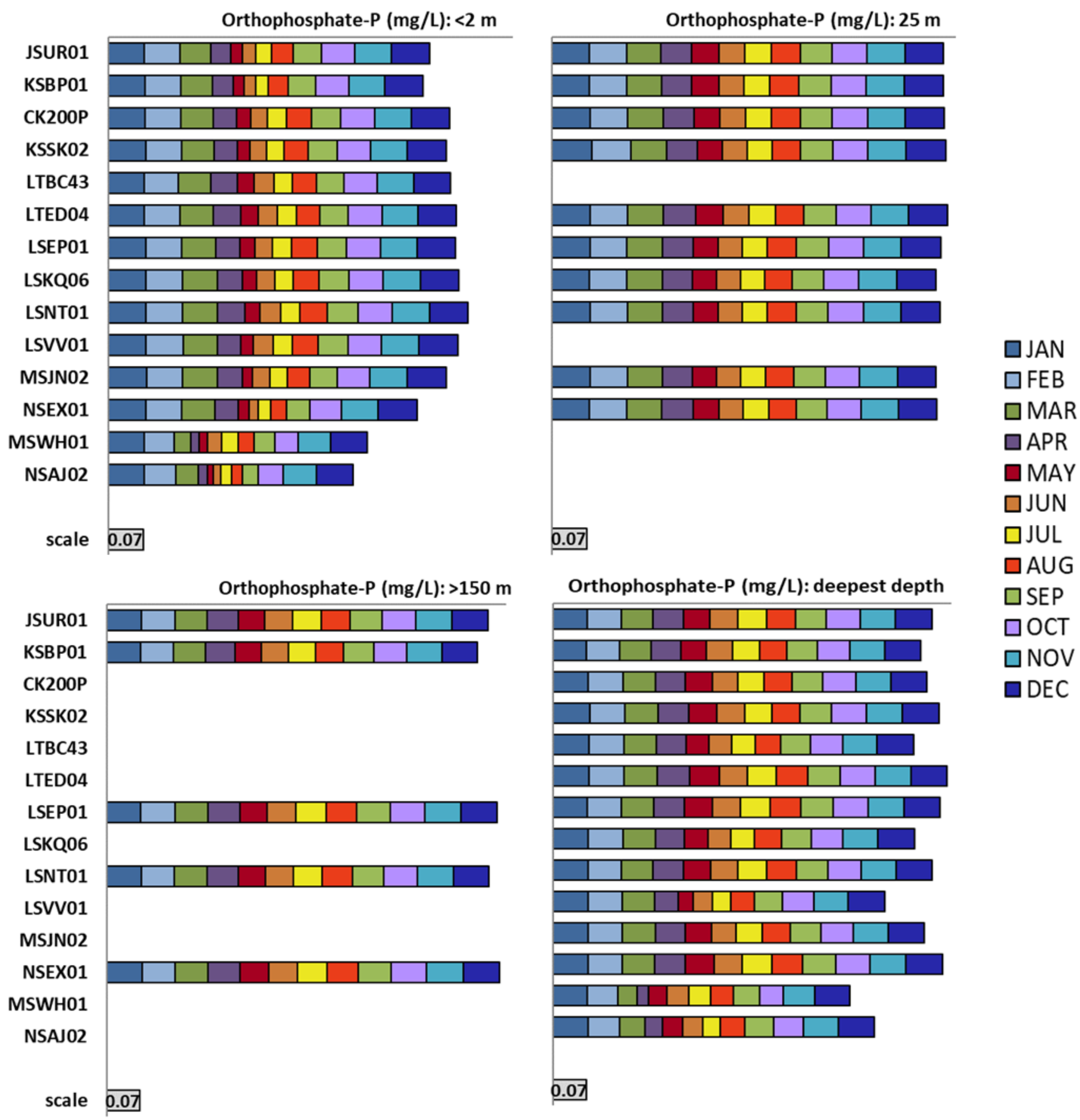

Figure 26. Mean montly orthophosphate concentrations in offshore waters by month, depth, and location; all data (2010 - 2019) combined.

Although much less than offshore waters, some seasonal variation was evident for monthly mean orthophosphate values at the Duwamish River sites (Figure 27). For 2010 to 2019 combined, the lowest surface water monthly means occurred in May at all but the furthest upstream site. The lowest monthly mean at station LTXQ01 occurred in January, although levels in February - May were also low. Station LTXQ01 had the lowest monthly means throughout the year for the Duwamish River stations. Similar to results for the offshore stations, less seasonal variation in near-bottom waters was seen at Duwamish River stations and little variation was observed during winter months.

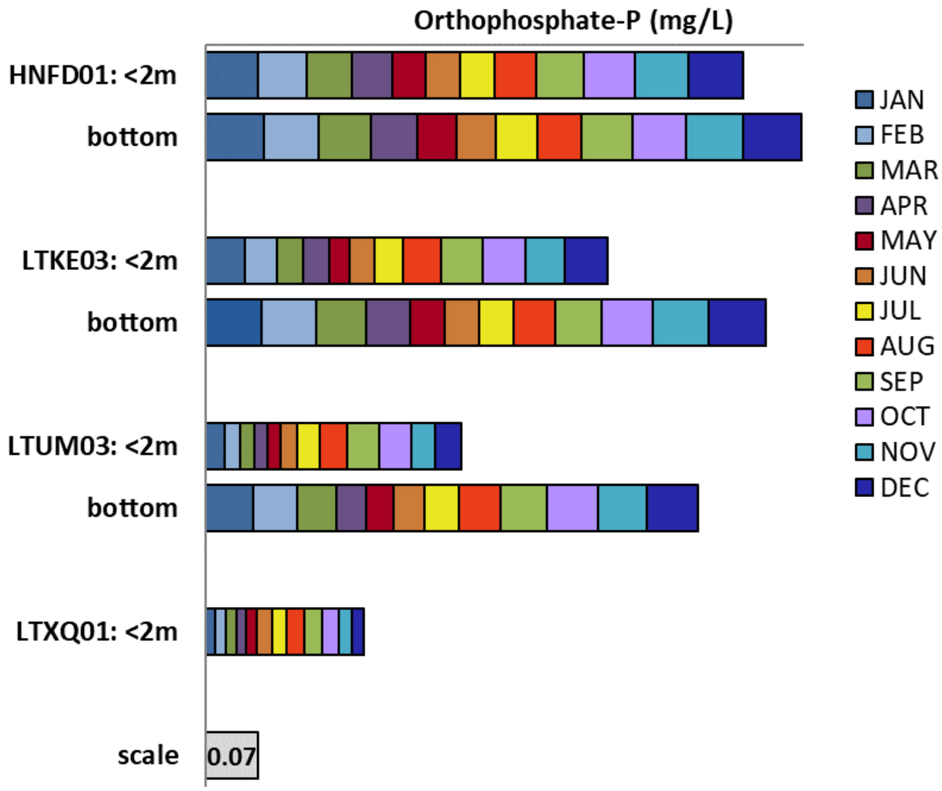

Figure 27. Mean orthophosphate concentrations in Duwamish River subestuary waters by location, depth and month; all data (2010 - 2019) combined.

3.6 Dissolved and Total Organic Carbon

Dissolved organic carbon (DOC) and total organic carbon (TOC) were only measured at the three furthest downstream Duwamish River stations 2008-2019 and not at offshore stations. A laboratory instrument change in 2013 improved detection limits and resulted in noticeably lower DOC and TOC values compared to previous data. Due to the limited data set trend analysis was not conducted on DOC and TOC.

DOC in the Duwamish River ranged from 0.69 - 6.95 mg/L and TOC from 0.67 - 30.3 mg/L at all three stations and depths (2008-2019). Little variation in levels of both DOC and TOC at each station in both surface (< 2 m) and near-bottom waters was seen. The exception was in 2012 when high TOC annual means were observed at HNFD01 and LTKE03 in both surface and near-bottom waters (Figure 28). The higher annual mean was due to very high TOC levels in June 2012 at both stations, and in November at HNFD01. Spatial variation was seen in surface water DOC and TOC levels. The highest DOC and TOC annual means were measured at the furthest upstream station (LTUM03) and the lowest levels were measured at HNFD01.

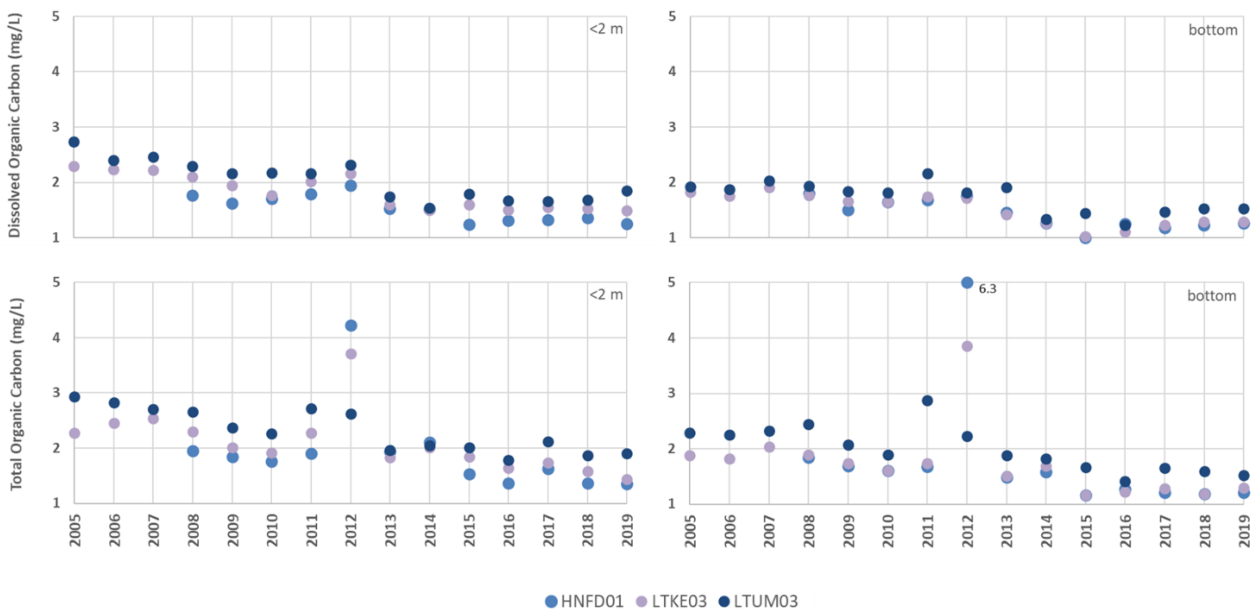

Figure 28. Mean TOC and DOC concentrations in Duwamish River subestuary waters by year, depth and location. Note: a laboratory instrument change resulted in lower DOC and TOC values after 2012.

Some spatial differences in DOC were evident seasonally (Figure 29). DOC monthly mean concentrations were slightly higher at LTUM03 in both surface and near-bottom waters, which decreased with distance downstream. A similar pattern was observed for TOC in both surface and near-bottom waters, except in June when the pattern was reversed. DOC levels at the furthest downstream station (HNFD01), were highest in June, which subsequently decreased with distance upstream. TOC means in June and November also reflect the very high values at HNFD01. If the high values at HNFD01 and LTKE03 are removed from the data set, the TOC seasonal pattern is similar to DOC.

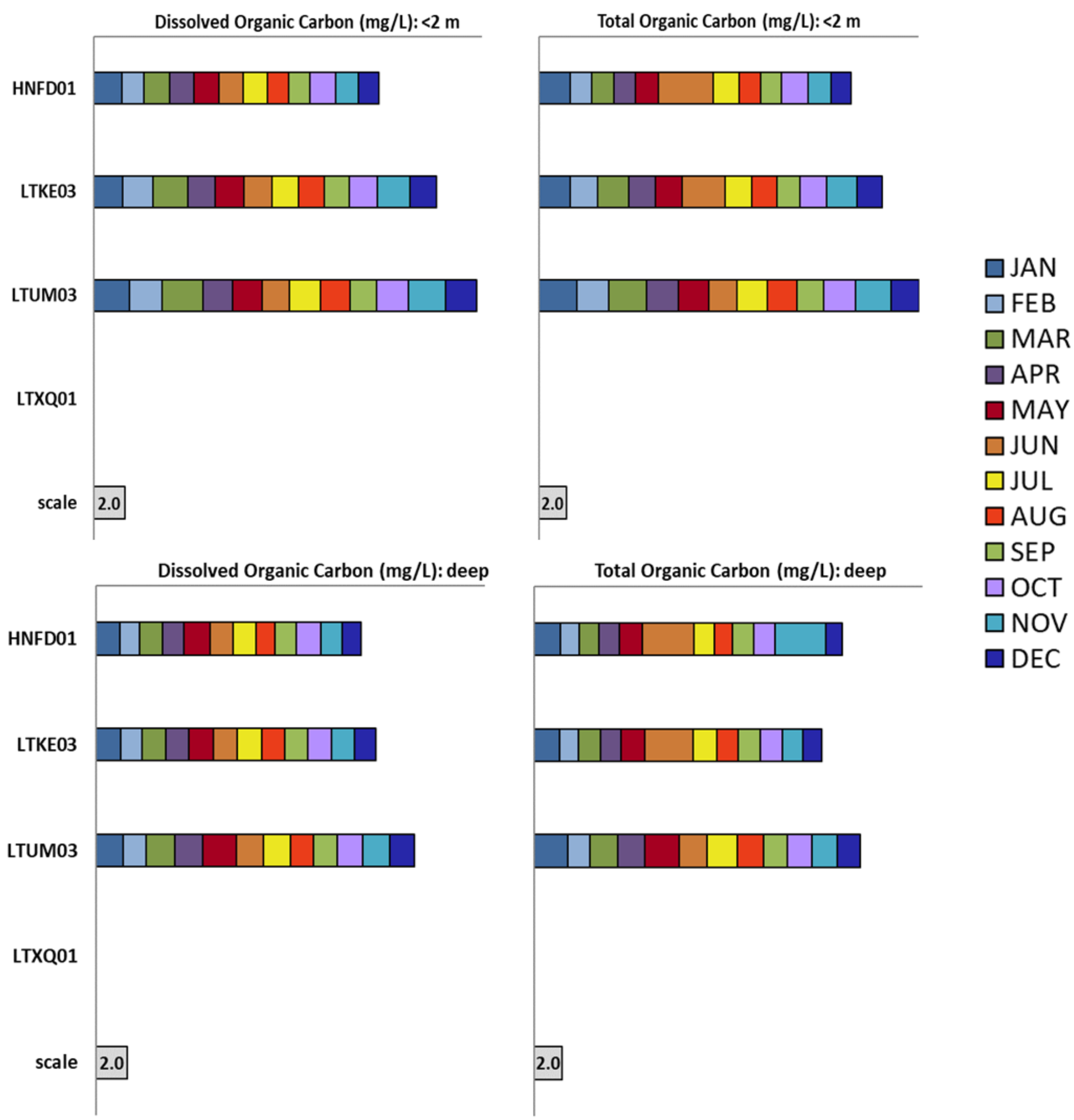

Figure 29. DOC and TOC concentrations in Duwamish River subestuary waters by month, location and depth; all data (2008 - 2019) combined.

3.7 Trend Analysis

To assess long-term trends, a non-parametric Seasonal Kendall (SK) test was conducted using months as a season. The SK test provides a *p* value and the Thiel-Sen slope, an estimator of the magnitude and direction of change from year to year. A *p* value < .05 is typically considered a significant trend. 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 14 offshore stations collected between 2007 - 2019, and for 7 stations with data collected between 1997 - 2019. The SK test was used to assess both annual and monthly trends over each of the two time periods

for nitrate+nitrite, ammonia, and silica. Since ammonia concentrations are typically < MDL in the winter months, trend analysis for this parameter was performed with data collected between April and 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. All trend analysis results are provided in Appendix A. Trend analyses were not conducted for DOC and TOC due to the method change in 2013 resulting in a limited set of comparable data.

3.7.1 Annual Trends

Table 6 provides results for annual nutrient (nitrate+nitrite, ammonia, and silica) trends for surface waters (< 2 m). Chlorophyll *a* annual trends are also included for comparison due to the relationship between chlorophyll and nutrients. More detailed chlorophyll *a* results are provided in *Marine Conditions Report Series 2008 - 2019: Chlorophyll and Pheophytin* (King County, 2022b). Table 7 shows annual trend results for stations with data > 150 m.

Annual Trends - 2007-2019

Trend results for the 14 stations (2007 – 2019 data) showed a statistically significant decreasing trend for surface nitrate+nitrite at all stations. A highly significant decreasing trend ($p < .001$) was detected for all but three stations (Carkeek Park and the two Quartermaster Harbor stations). The magnitude of the nitrate+nitrite decrease was consistent at all stations and depths. Nitrate+nitrite trend results for sites at depths between 10 and 150 m demonstrated similar significant decreasing trends (see Appendix A). A significant decreasing trend in nitrate+nitrite levels was detected at the two shallow Quartermaster Harbor stations at the deepest sampling depths (3-9 m).

A significant decreasing trend in surface ammonia concentrations was detected at 6 of 14 stations, including the West Point TP (KSSK02) and South TP (LSEP01) outfall stations. The magnitude of the decreasing trend was consistent at these stations. No trend in ammonia concentrations was seen for the three northern and three southernmost stations. Trend results for ammonia for depths between 10 and 150 m were variable, but all statistically significant trends were decreasing. At the 10 to 20 m depth range, a significant decreasing trend in ammonia was detected at the South TP outfall and all sites to the south, as well as the Brightwater TP and West Point TP outfall sites. A decreasing trend in ammonia levels at the 30 - 40 m depth was only seen at the South TP outfall and all sites to the south. A decreasing trend for ammonia levels was only seen for two stations at the 50 - 60 m depth range. Of the five sites with available data at 90 m or deeper, only the South TP outfall site showed a decreasing trend. The magnitude of the trend was consistent across stations and depths.

A significant decreasing trend in surface water silica was measured at all locations except the two Quartermaster Harbor stations. The decreasing trend was at the $p < .001$ level for most stations and the magnitude of decrease was consistent at all but one station; the decrease at the shallow Elliott Bay station (LTBC43) was larger than other sites. The magnitude of decrease in silica was higher than that observed for nitrogen compounds.

Silica results showing decreasing trends for depths between 10 and 150 m were similar to results for surface waters. All but two results at the 10 to 20 m depth range were significant, and the magnitude of the decrease was consistent across stations and depths.

Table 6. Trends in surface water (< 2 m) nutrient concentrations at offshore stations for two time periods (2007- 2019 and 1997-2019). White box indicates no statistically significant trend.

	<2 m							
	2007--2019				1997--2019			
Locator	NO23	NH3	Si	Chl-a	NO23	NH3	Si	Chl-a
JSUR01	↓		↓		--	--	--	--
KSBP01	↓		↓		↑		↑	
CK200P	↓		↓		↑		↑	
KSSK02	↓	↓	↓	↑		↓	↑	↑
LTBC43	↓	↓	↓		--	--	--	--
LTED04	↓		↓					
LSEP01	↓	↓	↓		↑		↑	
LSKQ06	↓	↓	↓		↑		↑	
LSNT01	↓	↓	↓				↑	
LSVV01	↓		↓		--	--	--	--
MSJN02	↓	↓	↓		--	--	--	--
NSEX01	↓		↓		--	--	--	--
MSWH01	↓				--	--	--	--
NSAJ02	↓				--	--	--	--

p value < .001
p value < .05
arrow indicates direction of trend
white indicates no trend
-- indicates no analysis
Thiel-Sen slope
< .01
.01 - .05
.05 - .2
.2 - 1
> 1

Annual Trends 1997-2019

Trend results differed for the seven sites with a longer data record (1997 - 2019). A slight statistically significant increasing trend for surface nitrate+nitrite levels (Table 6) was detected at four locations (Pt. Jefferson, Carkeek Park, South TP outfall, and Alki outfall). An increasing trend for sites between 10 and 40 m at all but the West Point outfall also was detected. The three stations with data for 90 m or deeper all showed a significant increasing trend, except for Pt. Williams (LSNT01).

Only one statistically significant trend was observed for ammonia based on the longer data record. A slight decreasing trend was seen at the West Point TP outfall station in surface waters.

Unlike the decreasing trend observed for silica levels for the 2007-2019 time period, an increasing trend was seen in surface waters at six of the seven stations with longer data records (1997 - 2019). An increasing trend was also seen at all stations at the ≥10 m depth, mostly at $p < .001$. The magnitude of the increase was similar between stations and depths.

Table 7. Trends in nutrient concentrations in offshore waters at deep stations (> 150 m) for two time periods (2007-2019 and 1997-2019). White box indicates no statistically significant trend.

	> 150 m							
	2007--2019				1997--2019			
Locator	NO23	NH3	Si	Chl-a	NO23	NH3	Si	Chl-a
JSUR01	↓		↓	--	--	--	--	--
KSBP01	↓		↓	--	↑		↑	--
CK200P	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--
LSEP01	↓		↓	--	↑		↑	--
LSKQ06	--	--	--	--	--	--	--	--
LSNT01	↓		↓	--			↑	--
LSVV01	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--
NSEX01	↓		↓	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--

p value < .001

p value < .05

arrow indicates direction of trend

white indicates no trend

-- indicates no analysis

Thiel-Sen slope

↓	↑	Slope
↓	↑	< .01
↓	↑	.01 - .05
↓	↑	.05 - .2
↓	↑	.2 - 1
↓	↑	> 1

3.7.2 Monthly Trends

The statistically significant decreasing nitrate+nitrite annual trends in surface waters between 2007 - 2019 and increasing trends between 1997 - 2019 were driven primarily by concentrations during the winter months (Table 8). Particularly during 2007 - 2019 and also during April at some stations between 1997 - 2019. Nitrate+nitrite levels in winter months were also driving the annual trends for depths between 10 and 40 m between 2007 - 2019, and to a lesser extent for deeper depths. Decreasing summer concentrations also influenced annual trends for the deepest depths. The annual trend for nitrate+nitrite at all

depths between 1997 - 2019 was driven by increasing concentrations in December and in April at some stations.

Table 8. Trends in nitrate+nitrite concentrations in surface waters (< 2 m) at offshore stations by month and location. White box indicates no statistically significant trend.

Nitrate+nitrite-N <2 m

2007--2019	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	↓						↓				↓	↓
KSBP01	↓				↓						↓	↓
CK200P											↓	↓
KSSK02	↓											↓
LTBC43	↓									↓	↓	↓
LTED04										↓	↓	↓
LSEP01	↓										↓	
LSKQ06	↓										↓	
LSNT01	↓										↓	
LSVV01	↓										↓	
MSJN02	↓						↓					
NSEX01	↓										↓	
MSWH01	↓							--	↓	↓	↓	
NSAJ02	↓					--		--			↓	
1997--2019												
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01												↑
CK200P												↑
KSSK02												
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04												
LSEP01												↑
LSKQ06												↑
LSNT01												↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Legend:
- *p* value < .001
- *p* value < .05
- arrow indicates direction of trend
- white indicates no trend
- -- indicates no analysis

Thiel-Sen slope (arrow size):

↓	↑	Slope
↓	↑	< .01
↓	↑	.01 - .05
↓	↑	.05 - .2
↓	↑	.2 - 1
↓	↑	> 1

Decreasing annual trends in surface water ammonia concentrations between 2007 - 2019 were driven primarily by decreasing concentrations in July and also in September for a few stations. The decreasing annual trend at the West Point TP outfall between 1997-2019 was

driven by decreasing ammonia concentrations in September and October. Decreasing ammonia concentrations at depths between 10-60 m in July were primarily driving the annual trend. Although no significant annual trends were noted for sites at depths > 2 m for the 1997 - 2019 period, significant decreasing trends were seen in October at multiple stations and depths.

The decreasing annual trends in surface water silica between 2007 - 2019 were driven primarily by decreasing concentrations in September and also in January at four stations. The increasing annual trends in surface water silica concentrations for 1997 to 2019 were primarily driven by increasing February concentrations and also in December at mid-Basin stations. For waters between 10 and 60 m, the decreasing annual trends for 2007 to 2019 were due to decreasing silica concentrations in January, August, and September at most stations and in November at many stations. Conversely, increasing annual silica trends for 1997 to 2019 in waters 10 to 60 m were due to increasing concentrations February through May (Table 9). Decreasing annual trends between 2007 and 2019 in deep waters (> 150 m) were primarily due to decreasing concentrations in August and September and increasing concentrations in March and April between 1997 and 2019.

Table 9. Trends in silica concentration at offshore locations (50–60 m) by month and location. White box indicates no statistically significant trend.

Silica 50-60 m — 2007--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	↓							↓	↓		↓	↓
KSBP01	↓							↓	↓		↓	↓
CK200P	↓								↓			↓
KSSK02	↓							↓	↓		↓	↓
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	↓							↓	↓			↓
LSEP01	↓							↓	↓		↓	
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01	↓							↓	↓			
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02								↓	↓			
NSEX01								↓	↓		↓	
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01		↑	↑	↑	↑							
CK200P		↑		↑								
KSSK02		↑		↑								
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04			↑	↑	↑							
LSEP01		↑	↑	↑	↑							↑
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01			↑	↑ (p < .001)	↑							↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Legend:
- p value < .001 (dark shading)
- p value < .05 (light shading)
- arrow indicates direction of trend
- white indicates no trend
- -- indicates no analysis

Thiel-Sen slope (arrow size):

↓	↑	
↓	↑	< .01
↓	↑	.01 - .05
↓	↑	.05 - .2
↓	↑	.2 - 1
↓	↑	> 1

4.0 SUMMARY

Due in part to the influence of phytoplankton uptake and freshwater inputs, interannual and seasonal variation in offshore waters was more pronounced in surface nutrients, than in deeper waters. The exception was more spatial variation in ammonia annual means at depths > 100 m than for other nutrients. Lower surface concentrations of most nutrients occurred during months when phytoplankton abundance was highest (April - September). Silica and orthophosphate concentrations were rarely below detectable levels in surface waters, while nitrate+nitrite levels were often below detectable levels during months with high productivity.

Except for Quartermaster Harbor, little variation in surface water nutrient levels between months and stations during the winter was observed. Minimal seasonal and spatial variation in nutrient levels was observed between months and depths < 15 m and except for ammonia, no difference between outfall and ambient stations was measured. The highest ammonia (annual and/or monthly mean) at various depths was measured at the two Quartermaster Harbor, West Point TP outfall, and South Plant TP outfall sites.

Spatial variation in surface waters was most evident at the northern and southernmost stations, as well as in Quartermaster Harbor. The Duwamish River stations also exhibited an upstream to downstream spatial gradient, with either lower or higher concentrations at the furthest upstream site dependent upon the nutrient.

Trend analysis was conducted with offshore data for two different time periods (due to data availability). Results yielded statistically significant decreasing nitrate+nitrite, ammonia, and silica concentrations for the 2007 - 2019 period for most depths and stations (only some stations for ammonia). However, results for the 1997 - 2019 period showed increasing trends for nitrate+nitrite and silica at most stations and depths, highlighting the influence of the data timeframe on trend results.

A few nutrient observations of note are provided below:

- Annual mean nitrate+nitrite concentrations in waters > 25 m were lower between 2015–2019 compared to prior years, and substantially lower in deep waters > 150 m.
- Low annual mean nitrate+nitrite levels in Duwamish River sub-estuary waters in 2018 and 2019 were reflective of low summer flow in the Green River; river flow in 2019 was the second lowest on record since 1952.
- Compared to the long-term baseline average, monthly nitrate+nitrite concentrations in surface and deep waters were higher most months from 2008 until spring 2014.
- Nitrate+nitrite and orthophosphate were often below detectable levels May - August (nitrate+nitrite) and April - June (orthophosphate) in Quartermaster Harbor, which suggests concentrations may be limiting primary production.

- Inner Quartermaster Harbor exhibited a pattern of decreasing summer ammonia concentrations starting in 2015; East Passage also showed a similar pattern of decreasing summer levels starting in 2016.
- Mean annual silica levels in surface waters were lower between 1997–2005, and peaked in 2008 with a similar pattern observed at other depths > 25 m.
- Statistically significant decreasing annual trends for nitrate+nitrite and silica were seen at almost all stations and depths; similar trends were observed for ammonia at most stations in the upper (< 20 m) water column between 2007 – 2019.
- Statistically significant increasing annual trends were seen for nitrate+nitrite and silica at most stations and all depths between 1997 – 2019.
- The decreasing trends in annual nitrate+nitrite between 2007 - 2019 were driven primarily by decreasing concentrations during the winter months, while the increasing trends seen for 1997–2019 were driven by increasing April and December concentrations.
- Decreasing trends in annual silica levels between 2007 - 2019 were driven primarily by decreasing concentrations during January, August, and September.
- Increasing trends in annual silica levels from 1997 - 2019 in waters > 10 m were due to increasing concentrations February - May, and through April at the deepest depths.

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Appendix A: Offshore Nutrient Trend Analysis

For the 10—20 m depth range, note that three stations have a shallower depth range: LSVV01 is 6-13 m, MSWH01 is 3-8 m, and NSAJ02 is 4-9 m.

Legend below applies to all tables in this appendix.

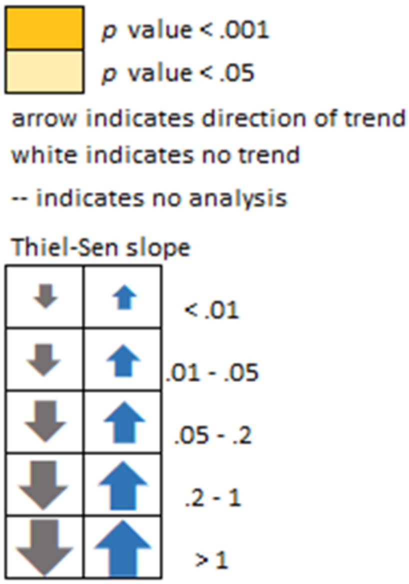

Table A-1 Annual trends.

<2 m	2007--2019				1997--2019			
	NO23	NH3	Si	Chl-a	NO23	NH3	Si	Chl-a
JSUR01	↓		↓		--	--	--	--
KSBP01	↓		↓		↑		↑	
CK200P	↓		↓		↑		↑	
KSSK02	↓	↓	↓	↑		↓	↑	↑
LTBC43	↓	↓	↓		--	--	--	--
LTED04	↓		↓					
LSEP01	↓	↓	↓		↑		↑	
LSKQ06	↓	↓	↓		↑		↑	
LSNT01	↓	↓	↓				↑	
LSVV01	↓		↓		--	--	--	--
MSJN02	↓	↓	↓		--	--	--	--
NSEX01	↓		↓		--	--	--	--
MSWH01	↓				--	--	--	--
NSAJ02	↓				--	--	--	--

10 - 20 m	2007--2019				1997--2019			
	NO23	NH3	Si	Chl-a	NO23	NH3	Si	Chl-a
JSUR01	↓	↓	↓		--	--	--	--
KSBP01	↓		↓		↑		↑	
CK200P	↓		↓		↑		↑	
KSSK02	↓	↓	↓	↑			↑	
LTBC43	↓		↓		--	--	--	--
LTED04	↓		↓		↑		↑	
LSEP01	↓	↓	↓		↑		↑	
LSKQ06	↓	↓	↓		↑		↑	
LSNT01	↓	↓	↓		↑		↑	
LSVV01	↓	↓	↓		--	--	--	--
MSJN02	↓	↓	↓		--	--	--	--
NSEX01	↓	↓	↓		--	--	--	--
MSWH01	↓				--	--	--	--
NSAJ02	↓		↓		--	--	--	--

	20 - 30 m							
	2007--2019				1997--2019			
	NO23	NH3	Si	Chl-a	NO23	NH3	Si	Chl-a
JSUR01	↓		↓		--	--	--	--
KSBP01	↓		↓		↑		↑	
CK200P	↓		↓		↑		↑	
KSSK02	↓	↓	↓	↑			↑	
LTBC43	--	--	--	--	--	--	--	--
LTED04	↓		↓	↓	↑		↑	
LSEP01	↓	↓	↓		↑		↑	
LSKQ06	↓	↓	↓		↑		↑	
LSNT01	↓	↓	↓		↑		↑	
LSVV01	--	--	--	--	--	--	--	--
MSJN02	↓	↓	↓		--	--	--	--
NSEX01	↓		↓		--	--	--	--
MSWH01	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--

	30 - 40 m							
	2007--2019				1997--2019			
	NO23	NH3	Si	Chl-a	NO23	NH3	Si	Chl-a
JSUR01	↓		↓		--	--	--	--
KSBP01	↓		↓		↑		↑	
CK200P	↓		↓		↑		↑	
KSSK02	↓		↓				↑	
LTBC43	--	--	--	--	--	--	--	--
LTED04	↓		↓		↑		↑	
LSEP01	↓	↓	↓		↑		↑	
LSKQ06	↓	↓	↓		↑		↑	
LSNT01	↓	↓	↓		↑		↑	
LSVV01	--	--	--	--	--	--	--	--
MSJN02	↓	↓	↓		--	--	--	--
NSEX01	↓	↓	↓		--	--	--	--
MSWH01	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--

	50 - 60 m							
	2007--2019				1997--2019			
	NO23	NH3	Si	Chl-a	NO23	NH3	Si	Chl-a
JSUR01	↓		↓	--	--	--	--	--
KSBP01	↓		↓	--	↑		↑	--
CK200P	↓		↓	--			↑	--
KSSK02	↓		↓	--			↑	--
LTBC43	--	--	--	--	--	--	--	--
LTED04	↓		↓	--	↑		↑	--
LSEP01	↓		↓	--	↑		↑	--
LSKQ06	--	--	--	--	--	--	--	--
LSNT01	↓	↓	↓	--	↑		↑	--
LSVV01	--	--	--	--	--	--	--	--
MSJN02	↓		↓	--	--	--	--	--
NSEX01	↓	↓	↓	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--

	90 - 110 m							
	2007--2019				1997--2019			
	NO23	NH3	Si	Chl-a	NO23	NH3	Si	Chl-a
JSUR01	↓		↓	--	--	--	--	--
KSBP01	↓		↓	--	↑		↑	--
CK200P	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--
LSEP01	↓	↓	↓	--	↑		↑	--
LSKQ06	--	--	--	--	--	--	--	--
LSNT01	↓		↓	--	↑		↑	--
LSVV01	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--
NSEX01	↓		↓	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--

	> 150 m							
	2007--2019				1997--2019			
	NO23	NH3	Si	Chl-a	NO23	NH3	Si	Chl-a
JSUR01	↓		↓	--	--	--	--	--
KSBP01	↓		↓	--	↑		↑	--
CK200P	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--
LSEP01	↓		↓	--	↑		↑	--
LSKQ06	--	--	--	--	--	--	--	--
LSNT01	↓		↓	--			↑	--
LSVV01	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--
NSEX01	↓		↓	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--

Table A-2 Nitrate+nitrite-N monthly trends.

Nitrate+nitrite-N <2 m — 2007--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	↓						↓				↓	↓
KSBP01	↓				↓						↓	↓
CK200P											↓	↓
KSSK02	↓											↓
LTBC43	↓									↓	↓	↓
LTED04										↓	↓	↓
LSEP01	↓										↓	
LSKQ06	↓										↓	
LSNT01	↓										↓	
LSVV01	↓										↓	
MSJN02	↓						↓					
NSEX01	↓										↓	
MSWH01	↓							--	↓	↓	↓	
NSAJ02	↓					--		--			↓	

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01												↑
CK200P												↑
KSSK02												
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04												
LSEP01												↑
LSKQ06												↑
LSNT01												↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Nitrate+nitrite-N 10 - 20 m **2007--2019**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	↓						↓				↓	↓
KSBP01	↓	↓									↓	↓
CK200P	↓										↓	
KSSK02						↓	↓	↓			↓	↓
LTBC43	↓									↓	↓	↓
LTED04	↓							↓		↓	↓	↓
LSEP01	↓										↓	
LSKQ06											↓	↓
LSNT01	↓							↓			↓	
LSVV01	↓						↓				↓	↓
MSJN02	↓										↓	
NSEX01	↓							↓			↓	
MSWH01	↓							--			↓	↓
NSAJ02	↓						↓					↓

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01												↑
CK200P												↑
KSSK02												
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04				↑								
LSEP01				↑								↑
LSKQ06				↑								↑
LSNT01												↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Nitrate+nitrite-N 20 - 30 m **2007--2019**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	↓	↓									↓	↓
KSBP01	↓	↓						↓			↓	↓
CK200P	↓									↓	↓	↓
KSSK02	↓										↓	↓
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	↓								↓	↓	↓	↓
LSEP01							↓				↓	
LSKQ06	↓										↓	
LSNT01											↓	↓
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	↓										↓	
NSEX01	↓										↓	↓
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01												↑
CK200P												↑
KSSK02												
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04				↑								
LSEP01				↑								↑
LSKQ06				↑								↑
LSNT01				↑								↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Nitrate+nitrite-N 30 - 40 m

2007--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	↓	↓		↓				↓		↓	↓	
KSBP01	↓	↓								↓	↓	↓
CK200P	↓										↓	↓
KSSK02											↓	↓
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	↓								↓	↓	↓	↓
LSEP01	↓										↓	↓
LSKQ06							↓				↓	
LSNT01								↓			↓	↓
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	↓										↓	
NSEX01	↓										↓	↓
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01												↑
CK200P												↑
KSSK02												
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04				↑								↑
LSEP01												↑
LSKQ06				↑								↑
LSNT01	↑											↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Nitrate+nitrite-N 50 - 60 m **2007--2019**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	↓	↓		↓					↓	↓	↓	
KSBP01	↓	↓		↓						↓	↓	
CK200P	↓			↓							↓	
KSSK02									↓		↓	↓
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	↓			↓				↓	↓		↓	↓
LSEP01	↓							↓	↓		↓	
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01	↓							↓			↓	
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	↓										↓	
NSEX01	↓								↓		↓	
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01												↑
CK200P												
KSSK02												↑
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04												↑
LSEP01												↑
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01				↑								↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Nitrate+nitrite-N 90 - 110 m **2007--2019**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	↓	↓		↓			↓	↓	↓	↓	↓	
KSBP01				↓	↓			↓		↓	↓	
CK200P	--	--	--	--	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--	--	--	--	--
LSEP01				↓					↓		↓	
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01				↓							↓	
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01							↓		↓		↓	↓
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01												↑
CK200P	--	--	--	--	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--	--	--	--	--
LSEP01												
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01												↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Nitrate+nitrite-N > 150 m

2007--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01							↓			↓	↓	
KSBP01								↓		↓	↓	
CK200P	--	--	--	--	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--	--	--	--	--
LSEP01									↓		↓	
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01						↓	↓				↓	↓
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01							↓	↓	↓		↓	
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01				↑								↑
CK200P	--	--	--	--	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--	--	--	--	--
LSEP01												↑
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01												
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Table A-3 Ammonia-N Monthly Trends.

Ammonia-N <2 m 2007--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--				↓		↓		--	--
KSBP01	--	--	--						↓		--	--
CK200P	--	--	--	↑							--	--
KSSK02	--	--	--				↓			↓	--	--
LTBC43	--	--	--				↓		↓		--	--
LTED04	--	--	--				↓				--	--
LSEP01	--	--	--				↓				--	--
LSKQ06	--	--	--				↓				--	--
LSNT01	--	--	--				↓				--	--
LSVV01	--	--	--				↓				--	--
MSJN02	--	--	--				↓				--	--
NSEX01	--	--	--				↓				--	--
MSWH01	--	--	--								--	--
NSAJ02	--	--	--						↓		--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01	--	--	--						↓	↓	--	--
CK200P	--	--	--							↓	--	--
KSSK02	--	--	--						↓	↓	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--							↓	--	--
LSEP01	--	--	--							↓	--	--
LSKQ06	--	--	--							↓	--	--
LSNT01	--	--	--							↓	--	--
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Ammonia-N 10-20 m **2007--2019**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--				↓				--	--
KSBP01	--	--	--	↑			↓				--	--
CK200P	--	--	--								--	--
KSSK02	--	--	--			↓				↓	--	--
LTBC43	--	--	--								--	--
LTED04	--	--	--								--	--
LSEP01	--	--	--				↓				--	--
LSKQ06	--	--	--			↓	↓				--	--
LSNT01	--	--	--				↓				--	--
LSVV01	--	--	--				↓				--	--
MSJN02	--	--	--				↓				--	--
NSEX01	--	--	--				↓				--	--
MSWH01	--	--	--		↑						--	--
NSAJ02	--	--	--								--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01	--	--	--								--	--
CK200P	--	--	--		↑						--	--
KSSK02	--	--	--							↓	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--								--	--
LSEP01	--	--	--							↓	--	--
LSKQ06	--	--	--							↓	--	--
LSNT01	--	--	--							↓	--	--
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Ammonia-N 20-30 m **2007--2019**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--								--	--
KSBP01	--	--	--								--	--
CK200P	--	--	--								--	--
KSSK02	--	--	--			↓	↓				--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--								--	--
LSEP01	--	--	--				↓				--	--
LSKQ06	--	--	--			↓	↓				--	--
LSNT01	--	--	--				↓				--	--
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--				↓				--	--
NSEX01	--	--	--								--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01	--	--	--								--	--
CK200P	--	--	--								--	--
KSSK02	--	--	--								--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--							↓	--	--
LSEP01	--	--	--							↓	--	--
LSKQ06	--	--	--							↓	--	--
LSNT01	--	--	--							↓	--	--
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Ammonia-N 30-40 m **2007--2019**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	↑							--	--
KSBP01	--	--	--	↑							--	--
CK200P	--	--	--								--	--
KSSK02	--	--	--								--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--							↓	--	--
LSEP01	--	--	--				↓			↓	--	--
LSKQ06	--	--	--	↑			↓				--	--
LSNT01	--	--	--								--	--
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--								--	--
NSEX01	--	--	--								--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01	--	--	--				↑				--	--
CK200P	--	--	--								--	--
KSSK02	--	--	--								--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--							↓	--	--
LSEP01	--	--	--							↓	--	--
LSKQ06	--	--	--							↓	--	--
LSNT01	--	--	--							↓	--	--
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Ammonia-N 50-60 m **2007--2019**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	↑							--	--
KSBP01	--	--	--	↑							--	--
CK200P	--	--	--							↓	--	--
KSSK02	--	--	--								--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--								--	--
LSEP01	--	--	--			↓					--	--
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01	--	--	--				↓				--	--
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--								--	--
NSEX01	--	--	--				↓				--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01	--	--	--				↑			↓	--	--
CK200P	--	--	--				↑			↓	--	--
KSSK02	--	--	--								--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--								--	--
LSEP01	--	--	--							↓	--	--
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01	--	--	--							↓	--	--
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Ammonia-N 90-110 m **2007--2019**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	↑							--	--
KSBP01	--	--	--	↑							--	--
CK200P	--	--	--	--	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--	--	--	--	--
LSEP01	--	--	--								--	--
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01	--	--	--	↑							--	--
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--								--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01	--	--	--								--	--
CK200P	--	--	--	--	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--	--	--	--	--
LSEP01	--	--	--							↓	--	--
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01	--	--	--							↓	--	--
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Ammonia-N > 150 m — 2007--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--								--	--
KSBP01	--	--	--	↑							--	--
CK200P	--	--	--	--	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--	--	--	--	--
LSEP01	--	--	--								--	--
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01	--	--	--								--	--
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--								--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01	--	--	--								--	--
CK200P	--	--	--	--	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--	--	--	--	--
LSEP01	--	--	--								--	--
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01	--	--	--							↓	--	--
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Table A-4 Silica Monthly Trends.

Silica <2 m — 2007--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01									↓			↓
KSBP01					↓							↓
CK200P									↓			
KSSK02								↓				
LTBC43	↓							↓	↓			
LTED04												
LSEP01									↓			
LSKQ06	↓								↓			
LSNT01	↓							↓	↓			
LSVV01	↓								↓		↓	
MSJN02									↓		↓	
NSEX01												
MSWH01												
NSAJ02												

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01		↑										
CK200P		↑										
KSSK02		↑										
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04												
LSEP01		↑	↑									
LSKQ06												↑
LSNT01												↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Silica 10-20 m 2007--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	↓							↓	↓			↓
KSBP01	↓								↓			
CK200P	↓								↓			
KSSK02						↓		↓	↓			↓
LTBC43	↓							↓	↓			↓
LTED04	↓							↓	↓			↓
LSEP01								↓	↓		↓	
LSKQ06	↓							↓	↓		↓	
LSNT01	↓							↓	↓			
LSVV01	↓							↓	↓		↓	
MSJN02								↓	↓		↓	
NSEX01	↓										↓	
MSWH01												
NSAJ02								↓				

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01		↑	↑	↑								↑
CK200P			↑	↑								
KSSK02		↑		↑								
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04		↑	↑	↑	↑							
LSEP01		↑	↑	↑								
LSKQ06			↑	↑	↑							↑
LSNT01			↑	↑	↑							↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Silica 20-30 m — 2007--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	↓							↓	↓			↓
KSBP01	↓							↓	↓			↓
CK200P	↓								↓			
KSSK02								↓	↓			↓
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	↓							↓	↓			↓
LSEP01								↓				
LSKQ06	↓							↓	↓		↓	
LSNT01	↓							↓	↓			
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02								↓	↓		↓	
NSEX01								↓	↓		↓	
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01		↑	↑	↑	↑							↑
CK200P		↑	↑	↑	↑							
KSSK02			↑	↑								
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04		↑		↑	↑							
LSEP01		↑	↑	↑	↑							
LSKQ06			↑	↑	↑							↑
LSNT01				↑	↑							↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Silica 30-40 m **2007--2019**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	↓							↓	↓			↓
KSBP01	↓							↓	↓			
CK200P	↓							↓	↓			↓
KSSK02								↓	↓		↓	↓
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	↓							↓	↓			↓
LSEP01	↓							↓	↓			
LSKQ06								↓	↓		↓	
LSNT01	↓							↓	↓		↓	
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02								↓	↓			
NSEX01	↓							↓	↓		↓	
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01		↑	↑	↑	↑							↑
CK200P				↑	↑							
KSSK02			↑	↑	↑							
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04		↑	↑	↑	↑							
LSEP01		↑	↑	↑	↑							↑
LSKQ06			↑	↑	↑							↑
LSNT01			↑	↑	↑							↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Silica 50-60 m **2007--2019**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	↓							↓	↓		↓	↓
KSBP01	↓							↓	↓		↓	↓
CK200P	↓								↓			↓
KSSK02	↓							↓	↓		↓	↓
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	↓							↓	↓			↓
LSEP01	↓							↓	↓		↓	
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01	↓							↓	↓			
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02								↓	↓			
NSEX01								↓	↓		↓	
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01		↑	↑	↑	↑							
CK200P		↑		↑								
KSSK02		↑		↑								
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04			↑	↑	↑							
LSEP01		↑	↑	↑	↑							↑
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01			↑	↑	↑							↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Silica 90-110 m — 2007--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	↓							↓	↓			↓
KSBP01	↓				↓			↓	↓		↓	↓
CK200P	--	--	--	--	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--	--	--	--	--
LSEP01					↓				↓		↓	
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01	↓								↓		↓	
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01								↓	↓		↓	
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01		↑	↑	↑								
CK200P	--	--	--	--	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--	--	--	--	--
LSEP01				↑								
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01				↑								
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

Silica > 150 m — 2007--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01								↓	↓			↓
KSBP01								↓	↓			↓
CK200P	--	--	--	--	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--	--	--	--	--
LSEP01									↓			
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01								↓	↓		↓	
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01								↓	↓		↓	
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--

1997--2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JSUR01	--	--	--	--	--	--	--	--	--	--	--	--
KSBP01		↑	↑	↑								
CK200P	--	--	--	--	--	--	--	--	--	--	--	--
KSSK02	--	--	--	--	--	--	--	--	--	--	--	--
LTBC43	--	--	--	--	--	--	--	--	--	--	--	--
LTED04	--	--	--	--	--	--	--	--	--	--	--	--
LSEP01			↑	↑								↑
LSKQ06	--	--	--	--	--	--	--	--	--	--	--	--
LSNT01				↑								↑
LSVV01	--	--	--	--	--	--	--	--	--	--	--	--
MSJN02	--	--	--	--	--	--	--	--	--	--	--	--
NSEX01	--	--	--	--	--	--	--	--	--	--	--	--
MSWH01	--	--	--	--	--	--	--	--	--	--	--	--
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	--