# Marine Conditions 2008–2019 Report Series: Water Clarity

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King County

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# Marine Conditions 2008–2019 Report Series: Water Clarity

## Submitted by:

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Cover photo: Bull kelp taken by Randy Shuman

King County
Department of
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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 long term data for multiple types of media and parameters. This report presents results for the offshore water clarity monitoring component of the program collected between 2008 - 2019. Water clarity 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 the amount of available light for photosynthesis by aquatic plants.
- Assess influences of large-scale and regional climate patterns on riverine and freshwater sediment inputs.
- 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), and regional modeling efforts.

Water clarity, or transparency, is an indicator of the amount of suspended particles in the water and the amount of light available for photosynthesis by phytoplankton and other aquatic plants. Water clarity measurements are used to determine the euphotic zone, the depth at which sufficient light penetrates the water column to support aquatic plant growth. Several factors affect water clarity, including the amount of suspended sediment

and phytoplankton in the water column. In addition to suspended particles, waves, and atmospheric conditions can also affect water clarity.

Soil particles from rivers and streams, particularly lighter silt and clay fractions following large rain events, enter marine waters and can reduce water clarity. Low water clarity conditions that persist over an extended time period can reduce water quality by decreasing the amount of sunlight needed for aquatic plants and primary producers which can alter the balance between nutrient uptake and phytoplankton. In addition, many marine organisms feed by filtering water and large amounts of suspended material in the water column may obstruct their filter-feeding systems. High levels of suspended particles in the water column can degrade visual clarity, decreasing the feeding ability of visual predators.

Water clarity is measured in several ways. Secchi depth and percent light transmission (transmissivity) are both transparency indicators that measure light attenuation due to absorption and scattering. Photosynthetically active radiation (PAR) is also a measure of light transmission but specific to the amount of available light for photosynthesis. Sunlight consists of a wide spectrum of wavelengths, of which only a small portion can be used for photosynthesis. The range of light available for photosynthesis is in the 400 – 700 nanometer range. Total suspended solids (TSS) concentrations represent a direct measure of the amount of suspended particles in the water.

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, 2022a). Results for other Marine Monitoring Program components sampled between 2008–2019 (except pH and thermosalinograph data), are provided in separate reports. These data summary reports are provided in separate reports with hyperlinks (click on titles to access reports) below and include the following topics:

- Marine Monitoring Program overview
- Nutrients in offshore waters
- Nutrients in beach waters
- Dissolved oxygen in offshore waters
- Temperature, salinity, and density in offshore waters
- Temperature and salinity in beach 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 water clarity. Also presented are the data analysis methods used to interpret the water clarity results. Detailed information regarding methods is provided in the Sampling and Analysis Plan (SAP) (King County, 2020; https://your.kingcounty.gov/dnrp/library/2020/kcr3135/kcr3135.pdf ).

## 2.1 Sampling Locations

Water clarity 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, is also included in the sampling area.

Four sampling sites in the Duwamish River subestuary (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 CSO discharge point. Samples from 8 outfall (including 1 Duwamish River) and 10 ambient (including 3 Duwamish River) 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 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 | 1988 | 262 |
| CK200P | North | **Carkeek Wet Weather TS** outfall | outfall | 2001 | 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 | 1987 | 43 |
| LSNT01 | Middle | **Point Williams** - represents conditions in mid Central Basin | ambient | 1985 | 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

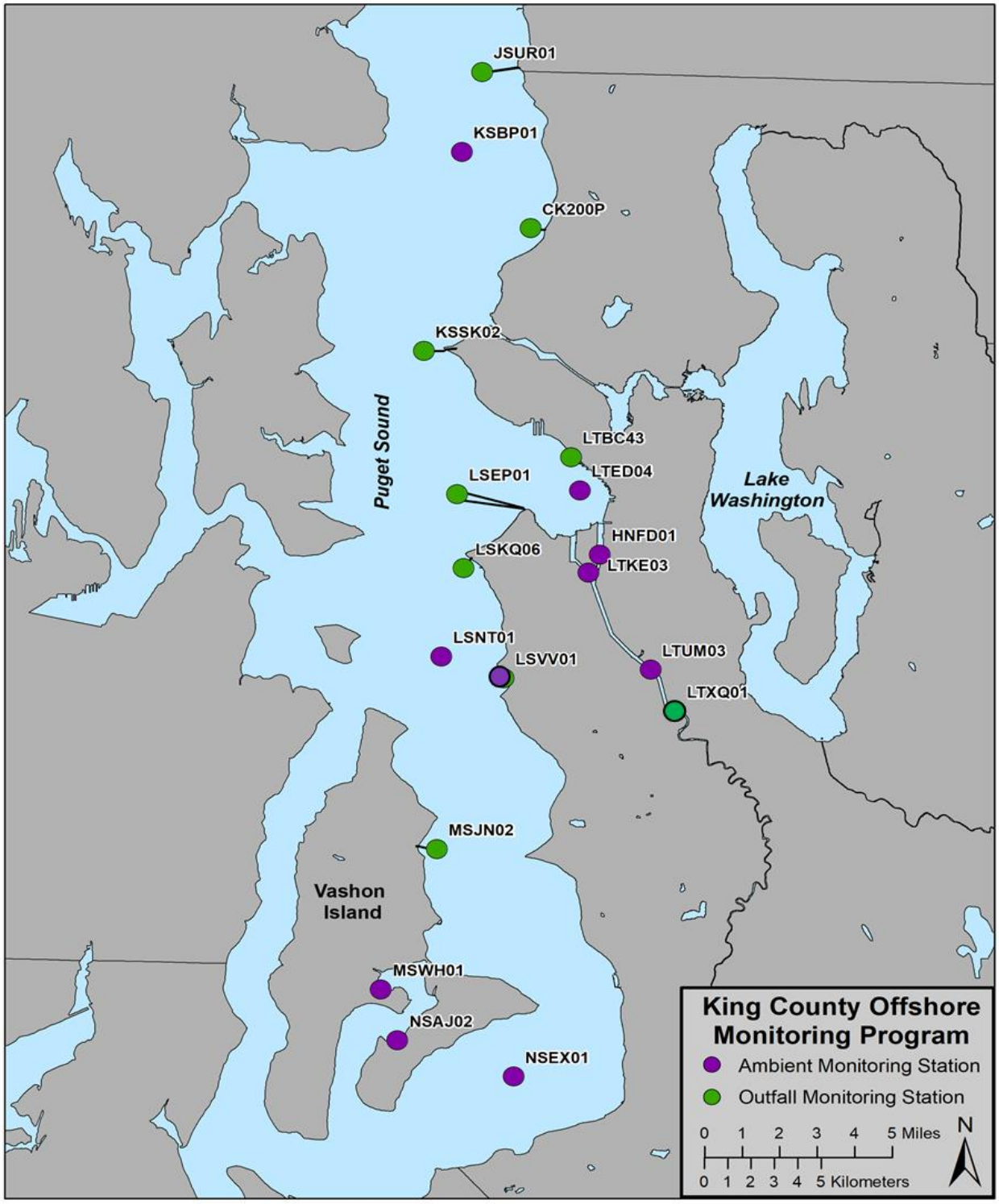


**Figure 1. Water clarity monitoring locations.**

## 2.2 Sampling and Analysis Methods

Secchi transparency, total suspended solids, in situ light transmission and PAR data were collected to assess water clarity. Secchi transparency was determined at all sampling locations except the four Duwamish River stations. The inherent turbidity in a riverine environment limits the usefulness of this measure of water clarity.

Samples for TSS analysis were collected from up to seven depths at each station, based on water depth. 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 (Table 2).

In situ measurements of light transmission and PAR were made throughout the water column at the 15 offshore stations sampled by boat (all but the two Quartermaster Harbor stations and the furthest upstream Duwamish station [LTXQ01]).

Water clarity parameters were measured monthly (2008 - 2018) at the Duwamish River stations. All other sites were monitored monthly from 2008 - 2013 and then twice monthly from 2014 - 2019 (monthly in January and December).

**Table 2. Total suspended solids sampling depths.**

| Total Suspended Solids Sample Depths (m) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Station** | **1** | **5** | **15** | **25** | **35** | **55** | **75** | **100** | **170-180** | **200** |
| JSUR01 | ● | | ● | ● | ● | ● | | ● | ● | |
| KSBP01 | ● | | ● | ● | ● | ● | | ● | | ● |
| CK200P | ● | | ● | ● | ● | ● | | | | |
| KSSK02 | ● | | ● | ● | ● | ● | | | | |
| LTBC43 | ● | | ● | | | | | | | |
| LTED04 | ● | | ● | ● | ● | ● | ● | | | |
| LSEP01 | ● | | ● | ● | ● | ● | | ● | ● | |
| LSKQ06 | ● | | ● | ● | ● | | | | | |
| LSNT01 | ● | | ● | ● | ● | ● | | ● | ● | |
| LSVV01 | ● | ● | | | | | | | | |
| MSJN02 | ● | | ● | ● | ● | ● | | | | |
| MSWH01 | ● | * | | | | | | | | |
| NSAJ02 | ● | * | | | | | | | | |
| NSEX01 | ● | | ● | ● | ● | ● | | ● | ● | |
| HNFD01 | ● | | * | | | | | | | |
| LTKE03 | ● | | * | | | | | | | |
| LTUM03 | ● | * | | | | | | | | |
| LTXQ01 | ● | | | | | | | | | |

*Sample collected 1 m above the bottom (depth variable with tide height).

## 2.2.1 Field Methods

Offshore water column data and sample collection was conducted 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 total suspended solids (KCEL, 2021) and water clarity field measurements (KCEL, 2017).

Secchi transparency was determined at each station using a standard 30 centimeter (cm) diameter black and white Secchi disk. Secchi transparency depth, reported in 0.1meter (m) increments, is determined by lowering the disk to just beyond the point where it disappears in the water, raising it until the disk is visible again, and then lowering it slightly to take an average of the two depths. Secchi transparency measurements have inherent sampling errors from sun glare on the water, weather conditions, and differences in eyesight between samplers. Wind and waves are the largest factor, with windy conditions significantly decreasing Secchi values. Due to potential variation between samplers, the

method was standardized as much as possible to minimize sampling error. Secchi measurements were taken off the shady side of the boat and the same field sampler collected the measurements on a given day.

Samples for TSS analysis were collected using the King County research vessel at all but three stations (Quartermaster Harbor [MSWH01, NSAJ02], and Duwamish River [LTXQ01]). 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. The rosette was then brought on deck and samples placed into appropriate sample containers. Quartermaster Harbor (MSWH01, NSAJ02) and Duwamish River (LTXQ01) samples were collected from docks and a bridge, respectively. Water samples for laboratory analyses were collected at these stations 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 during transport to the laboratory for analysis.

In situ water column profiles for light transmission and PAR data were collected were collected from the research vessel using a SeaBird Electronics SBE 25 SEALOGGER conductivity-temperature-depth (CTD) profiler with multiple parameter sensors. Sensor measurements were collected during both the downcast and upcast from the surface to within 1–5 m of the seafloor. Measurements were made at a rate of 2 hertz and interpolated to final values that represent 0.5 m depth increments. A LI-COR PAR sensor was used on the CTD profiler to obtain measurements within the water column. Between 2008 and July 2016, a LI-COR SPAR sensor placed above the vessel's deck was used to obtain surface (ambient) light intensity measurements. After July 2016, a Biospherical SPAR sensor was used. The surface measurements were used to standardize water measurements relative to the amount of ambient light that diffused through the water compared to surface light. Light transmission was measured using a WetLabs C-Star 0.25m transmissometer, integrated on the CTD profiler.

Field quality control (QC) measures included use of a field replicate for total suspended solids samples, and routine factory calibration of sensors.

### 2.2.2 Analytical Methods

Total suspended solids (TSS) analysis was conducted by the KCEL according to SM 2540 D (APHA, 2017) and the KCEL Standard Operating Procedure (KCEL, 2021). The method detection limit (MDL) was 0.5 mg/L. The MDL is defined as the minimum concentration that can be reliably detected by a particular method. TSS was determined by filtering a measured volume of a well-mixed water sample through a 2 µm glass fiber filter. The residue retained on the filter was dried to a constant weight at 103 to 105°C. The resulting net weight represented the TSS concentration.

All analyses were performed using appropriate QC procedures. QC measures included the use of method blanks and laboratory duplicates.).

### 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 for TSS 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 2008 – 2019 period for each depth range were used to calculate a single average.

Of 413 offshore CTD profiles conducted between 2008 – 2019, 17 were removed when surface PAR was unusually low (< 26 µmol/s/$m^2$), indicating a sampling error or PAR data collected during anomalously dark conditions. Underwater PAR values < 0 µmol/s/ $m^2$ were also removed from the dataset prior to data analysis. Monthly and yearly averages for PAR, Surface PAR, and euphotic zone depth were calculated using the remaining 396 profiles, with data averaged into 0.5 m bins.

Depth of the euphotic zone was calculated as the depth where underwater PAR reached 1% of surface PAR, from CTD data averaged into 0.5 m bins. The resulting bin depths were used to calculate monthly and annual averages.

# 3.0 WATER CLARITY MONITORING RESULTS

The following section presents monitoring results between 2008 – 2019 for total suspended solids, Secchi transparency, light transmission, and photosynthetically active radiation (PAR).

## 3.1 Total Suspended Solids.

Total suspended solids (TSS) refers to small particles in the water column and primarily consists of soil/sediment, plankton, and organic debris. As well as small living organisms, when algae and plankton decay, particles break free during the decomposition process and contribute to the number of particles in the water. A significant source of inorganic soil/sediment particles is from riverine input and other freshwater sources, particularly following large rainfall events. The more solids present in the water, the lower the water clarity. TSS affects the underwater light field and thus the amount of light available for photosynthetic phytoplankton and other aquatic plants.

TSS values in offshore waters ranged from less than the method detection limit (MDL) (0.5 mg/L) to 26.5 mg/L (2008 - 2019). The two Quartermaster Harbor stations (MSWH01 and NSAJ02) had the highest values of the marine sites. The highest TSS values at the four Duwamish River stations ranged from 38.9 (HNFD01) to 185 (LTUM03) mg/L and increased with distance upstream.

Annual average TSS concentrations for marine offshore stations by depth are shown in Figure 2. 2011 data were not included due to a methodology error through August for that year. Some TSS interannual variation was evident, with higher concentrations at most sites seen between 2012 - 2014, which was particularly apparent at all depths below the surface (> 2 m). Surface (< 2 m) values showed more variation than deeper depths due to spatial variation in phytoplankton abundance and ranged from 1.5-5.6 mg/L. Surface annual averages were highest in most years at the two Quartermaster Harbor sites (MSWH01 and NSAJ02), the locations with the highest phytoplankton abundance. Conversely, Fauntleroy Cove (LSVV01) and Pt. Williams (LSNT01) that tend to have lower phytoplankton abundance than other sites had low surface annual averages for most years.

The annual patterns for the 15, 25, 35, and 55 m depths were similar although the range for the 55 m depth was narrower. Fauntleroy Cove (LSVV01) had the highest or high TSS annual average for some years at the 15 m depth and not the surface, unlike other locations. This could be due to the influence of the location of the outflow of Fauntleroy Creek, which can change course as well as multiple stormwater pipes on the north side of the Fauntleroy Ferry Terminal. The Elliott Bay station LTED04 had the lowest or low annual average of all sites between 2014 and 2019 at the 15 m depth.

Annual average TSS levels in waters > 150 m at the five deep water stations (Table 1) ranged from 1.8-5.2 mg/L with minimum values higher than the other depths. Annual average TSS levels at the Brightwater TP outfall station (JSUR01) were considerably higher during most years at depth. Although Pt. Jefferson (KSBP01) is relatively close to JSUR01, TSS results were not similar. The Brightwater TP outfall is not the likely source of TSS due to the advanced treatment technology and the low effluent discharge flows. Although there are fast bottom currents near JSUR01, other factors are likely influencing TSS at this location. The steep bathymetry and bottom slope to the east of the outfall location and sediment transport from Possession Sound are potential sources of TSS near the seafloor.

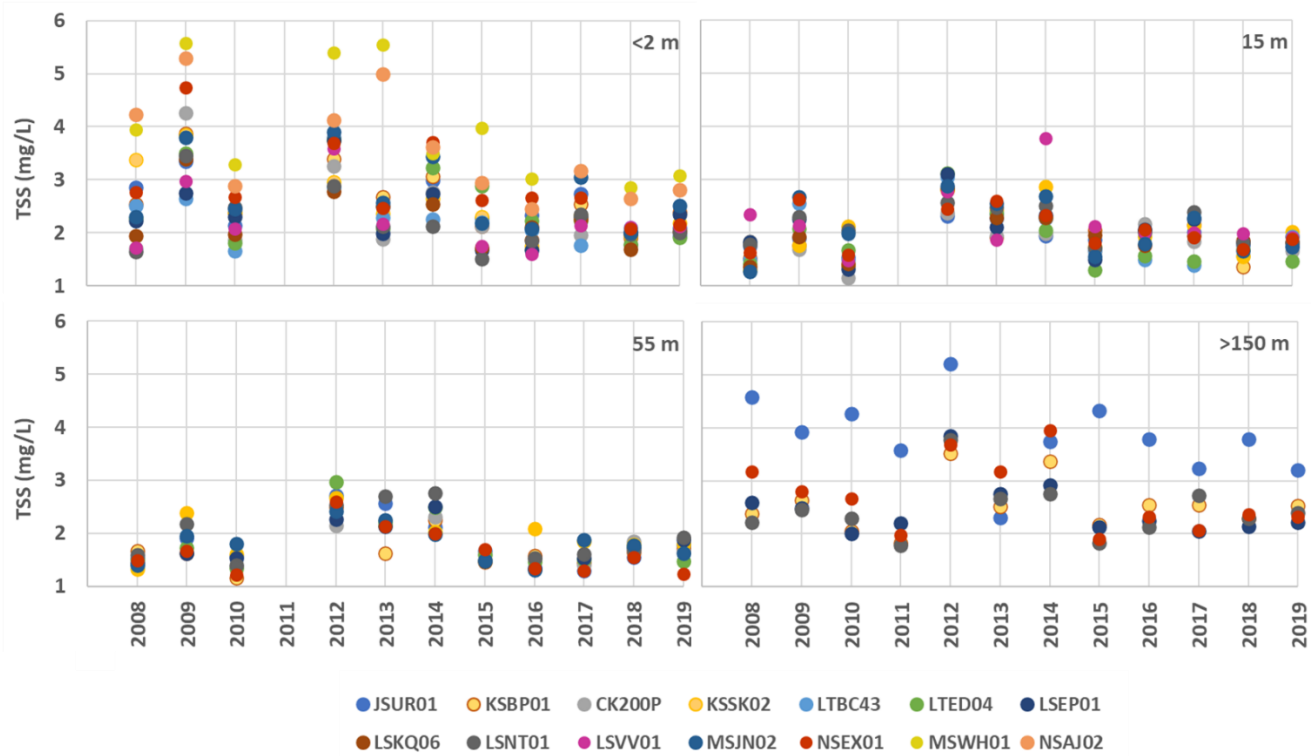


**Figure 2. Annual average TSS concentrations at offshore marine stations by depth (2008-2019).**

Annual average (2008 - 2019) TSS results for the four Duwamish sites 2008 – 2019 are shown in Figure 3 (2011 data were not included due to a methodology error through August for that year). TSS annual averages ranged from 2.6-19.0 mg/L at the surface and exhibited interannual variation. The highest annual averages were seen in 2015 at all four sites, which subsequently decreased each year thereafter. Flow in the Duwamish River (Green River gage at Auburn) was unusually low in 2015, particularly between April - July. Monthly average flow in May 2015 (577.8 $ft^3/S$) was the lowest on record since 1937 and lowest in July since 1958. Flow in April and June of 2015 were the lowest since 1992 and 1987, respectively. These low flows likely contributed to increased turbidity and suspended solids in the Duwamish River. Unusually high river flow was seen throughout most of 2017 but did not result in an overall increase in TSS. An obvious spatial pattern was observed in surface TSS levels, with highest values consistently measured at the furthest upstream location (LTXQ01) and subsequently declining downstream.

The East Waterway station, (HNFD01), is the only Duwamish River location deeper than 10 m. The range in TSS annual average values was less at the deeper 15 m depth and did not exhibit the same annual pattern as surface values.

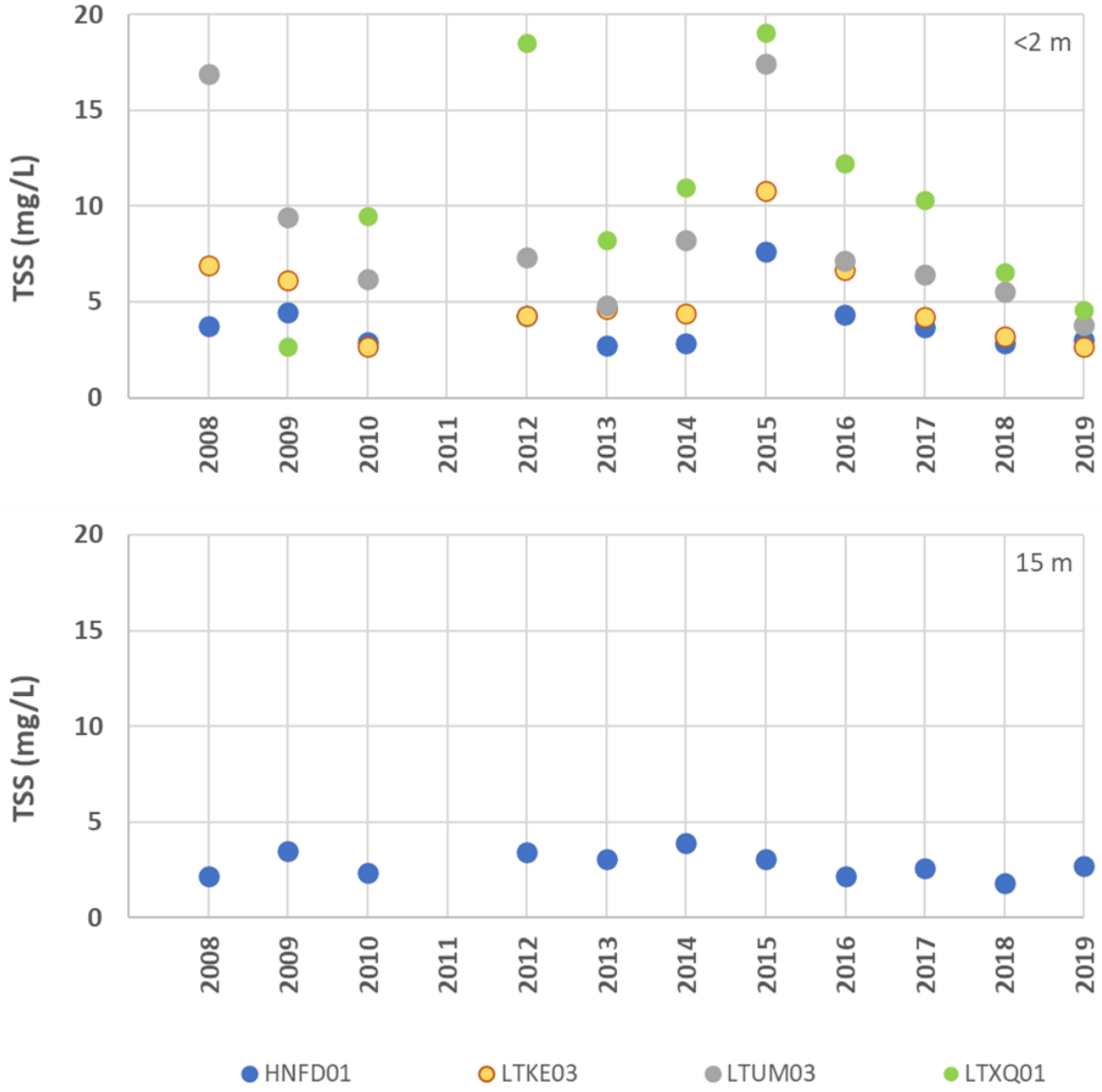


**Figure 3. Annual average TSS concentrations in the Duwamish River by station and depth (2008-2019).**

Monthly average TSS values for 2008-2019 combined are shown in Figure 4 for each marine location at multiple depths. Seasonal variation in TSS at the surface was evident at all stations, with higher concentrations measured during spring and summer months when phytoplankton growth is high. Monthly averages in surface waters ranged between 1.3-4.8 mg/L for all but the two Quartermaster Harbor sites (MSWH01 and NSAJ02) and 2.0-5.5 mg/L for the two Quartermaster Harbor sites. The highest TSS levels from spring through fall were observed at the Quartermaster Harbor sites due to the extended phytoplankton

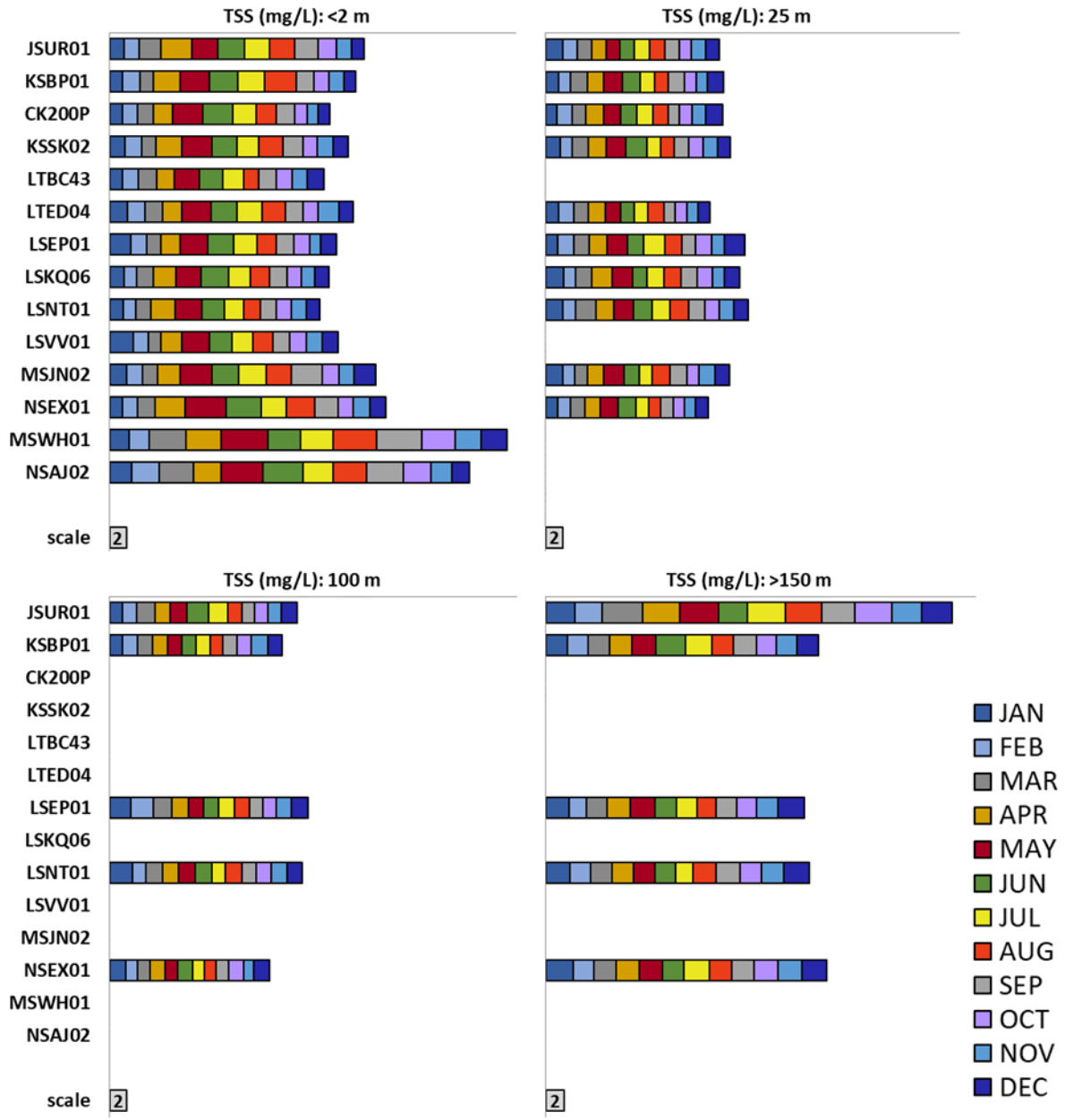


**Figure 4. Monthly average TSS concentrations in offshore marine waters by location and depth; all data (2008 – 2019) combined. Scale is in mg/L.**

growing season in the harbor. The lowest surface values of the year were seen in winter months at most stations and the lowest levels seen during the summer months were measured at the shallow Elliott Bay station (LTBC43). Some spatial variation was evident with higher TSS levels measured in April at the northern and southernmost sites and in May at the southernmost site East Passage (NSEX01). The spring phytoplankton bloom typically occurs slightly later in the spring at NSEX01 and is reflected in surface TSS values. No spatial pattern was apparent between outfall and ambient locations.

TSS values were similar at the 15, 25, 35, and 55 m depths and are represented by the 25 m graph shown in Figure 4. Monthly means at 25 m ranged between 1.3-2.5 mg/L and were less at all the mid-depths compared to surface concentrations. Less seasonal variation in TSS was seen at these mid-depths, but some spatial variation was observed. The Elliott Bay (LTED04) and southernmost (East Passage-NSEX01) sites had lower TSS values at the mid-depths, 25-55 m in particular, during late summer through fall months. The West Point TP outfall site (KSSK02) had higher TSS values at 25 m than other sites which was not seen at other mid-depths.

Monthly averages at 100 and 150 m ranged between 1.2-2.7 mg/L at 100 m and 1.9-4.5 mg/L at 150 m mg/L Some spatial variation in TSS was evident at 100 m with higher levels seen in January at the southern locations and in June at the Brightwater TP outfall site (JSUR01). Spatial variation was particularly evident at 150 m with higher TSS levels measured most months at JSUR01, as reflected in the annual averages mentioned above.

Monthly average surface values for 2008-2019 combined for the Duwamish River locations are shown in Figure 5 and ranged between 2.8-31.5 mg/L Values were highest at the furthest upstream location and decreased with distance downstream. TSS levels at the furthest Duwamish upstream site, (LTXQ01), were especially high in February and November. TSS Levels near the 16$^{th}$ Ave. S bridge (LTUM03) in January and May - August were higher than at other Duwamish River sites.

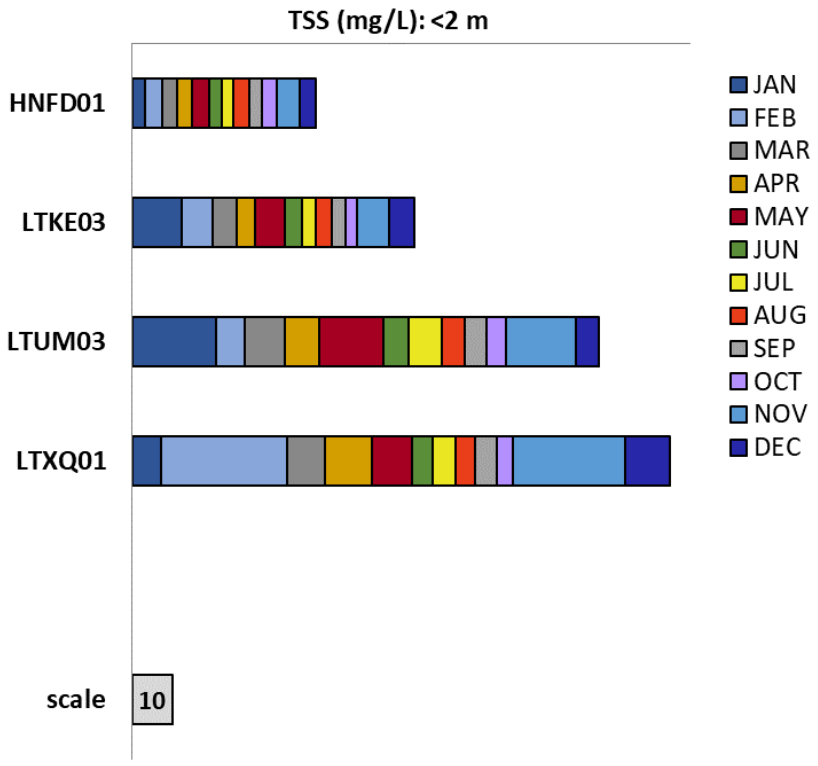


**Figure 5. Monthly average TSS concentrations for Duwamish River stations by station; all data (2009 - 2019) combined.**

## 3.2 Secchi Transparency Results

Secchi transparency is a measure of water clarity; the higher the Secchi depth, the greater the water transparency. Factors that influence Secchi transparency include turbidity, riverine and freshwater inputs, shoreline erosion, resuspension of bottom sediment, and particularly phytoplankton biomass. Secchi transparency is often used as a eutrophication indicator due to the relationship between Secchi depth and phytoplankton biomass. Secchi transparency was only measured in offshore waters; the Duwamish River is too turbid for measurements to be meaningful.

Secchi results (2008 - 2019) ranged from 0.3 m at the inner Quartermaster Harbor station (MSWH01) in 2014 to a high of 22.5 m at East Passage (NSEX01) in 2019. During most years, the lowest Secchi measurements were seen at the Elliott Bay stations (LTED04 and LTBC43) due to inputs of solids and turbidity from the Duwamish River. The two Quartermaster Harbor sites (MSWH01 and NSAJ02) also had some of the lowest values during months with high phytoplankton biomass.

Most Secchi depths at all but the three shallow stations, (LSVV01, MSWH01, and NSAJ02), ranged from 5.1 - 10 m (2008 - 2019) (Figure 6). Deeper Secchi depths occurred most often in late summer and fall/winter months when primary productivity was low and were lowest during months with high productivity (April – July) (Figure 7).

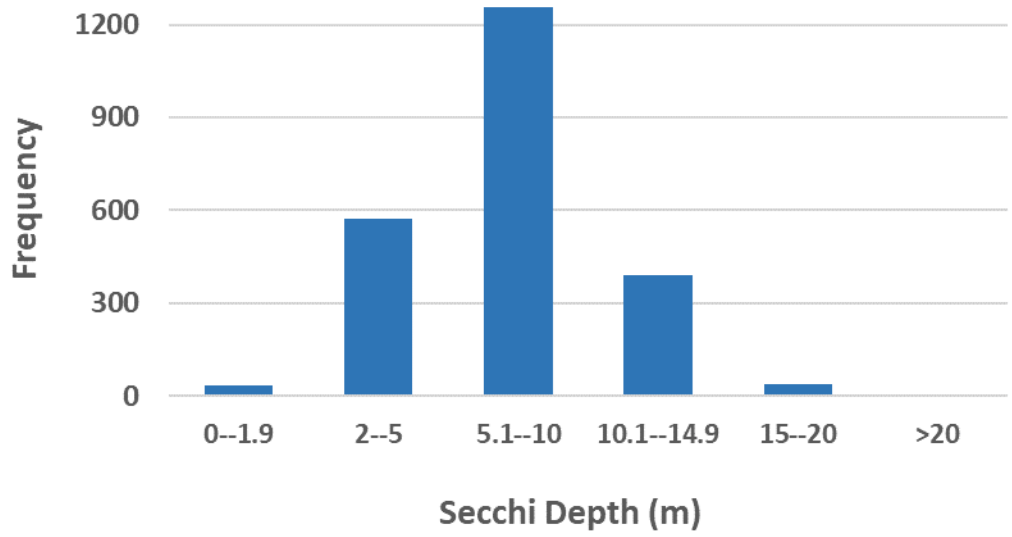


**Figure 6. Frequency of occurance for Secchi depths (m) measured at offshore stations, three shallow sites excluded; all data (2008-2019) combined.**

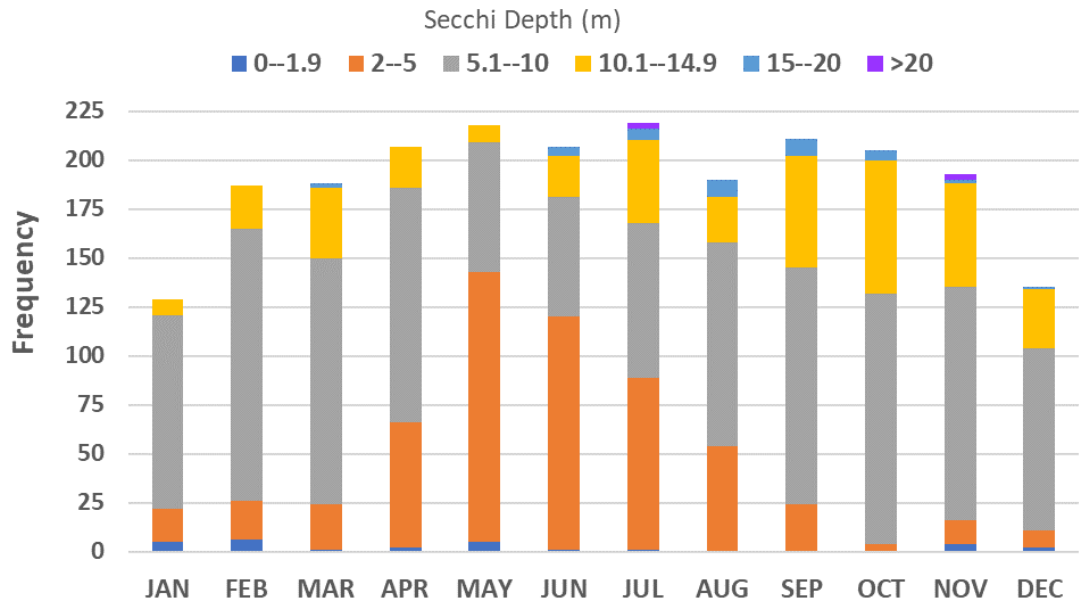


**Figure 7. Frequency of occurance of Secchi depths by month at offshore stations, three shallow sites excluded; all data (2008-2019) combined.**

Although Secchi depth varied by location, some interannual differences were evident. Annual averages at almost all stations were the lowest in 2017 and the highest in 2019. Annual averages in 2018 were also relatively high (> 7 m) at all stations except in Quartermaster Harbor (MSWH01 and NSAJ02) (Figure 8). Quartermaster Harbor is a relatively shallow embayment, especially the inner harbor where the sampling station (MSWH01) depth is only about 5 m. Therefore, values similar to other stations which are much deeper are not expected.

Water column stratification strongly affected phytoplankton biomass between 2017 and 2019, with sustained biomass in 2017 and a shortened bloom season in both 2018 and 2019. The bloom season was particularly compressed in 2019 with no fall bloom and is reflected in high annual average Secchi depths for all but the two Quartermaster Harbor stations. Secchi depths at the two Quartermaster Harbors stations had the lowest annual averages for all years due to impact of phytoplankton blooms on transparency. East Passage (NSEX01) and Elliott Bay (LTED04) stations also had low values in some years compared to other sites.

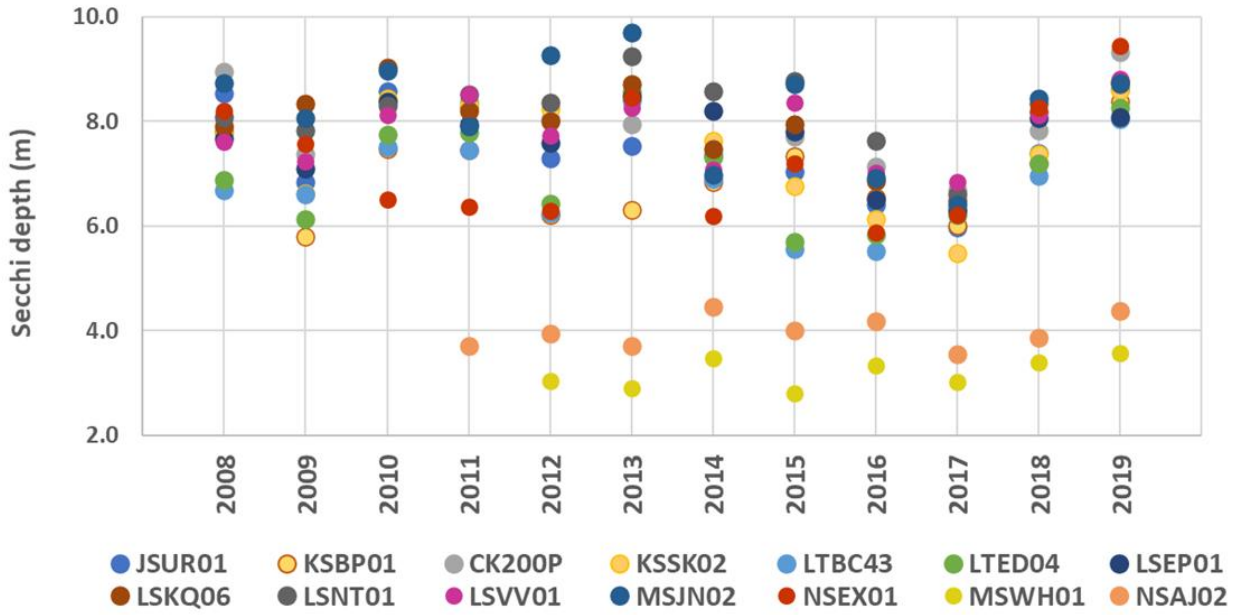


**Figure 8. Annual average Secchi depths (m) at offshore locations (2008 – 2019).**

Time series data (2008-2019) for Secchi depth at representative sites are summarized in Figure 9 and Figure 10 shows the time series for the two Quartermaster Harbor sites The seasonal pattern in monthly Secchi depth was similar across stations, with lowest depths measured during spring and summer months, reflecting phytoplankton biomass. While a great deal of variability was seen between years for each site, some spatial differences were evident besides lower overall values in Elliott Bay and Quartermaster Harbor. During some months, lower Secchi depths were measured at the northern stations compared to depths at the mid- or southern stations. High Secchi depths were measured earlier in the year through March at East Passage (NSEX01), and to a lesser extent at the Vashon TP outfall station (MSJN02), than other locations. The spatial differences are likely due to timing of phytoplankton biomass, which is typically later in the spring in the southern Central Basin, as well as the influence of the Puyallup River at East Passage. Figure 11 shows time series data for a longer date range (2000- 2019) that are grouped by location: north, central, and south area of the Central Basin. While some interannual variation is evident, Secchi depths have remained consistent over time a decreasing trend in water clarity over the 20-year data record is not apparent.

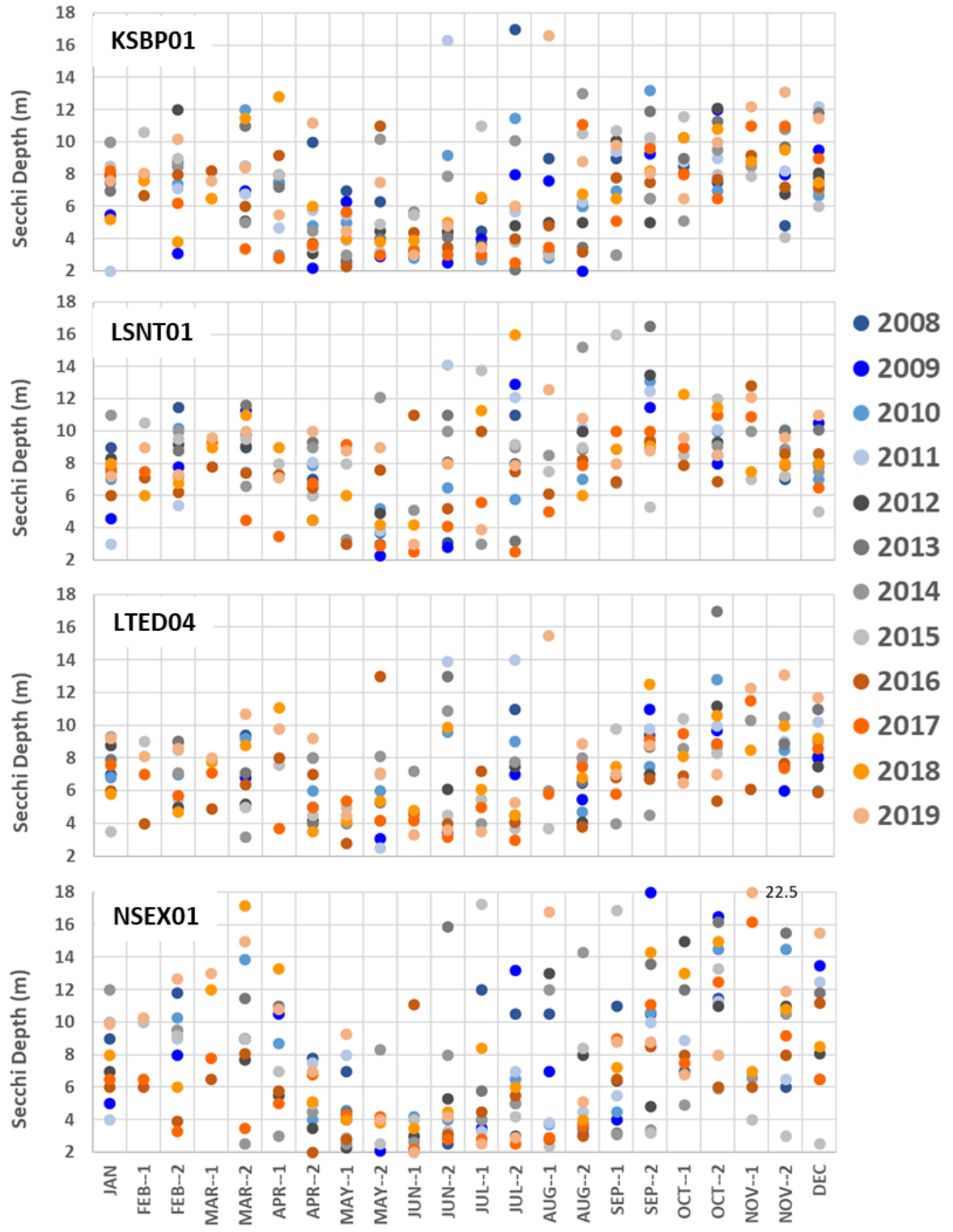


**Figure 9. Secchi depths (m) at four representative stations by year and monitoring event (2008 - 2019).**

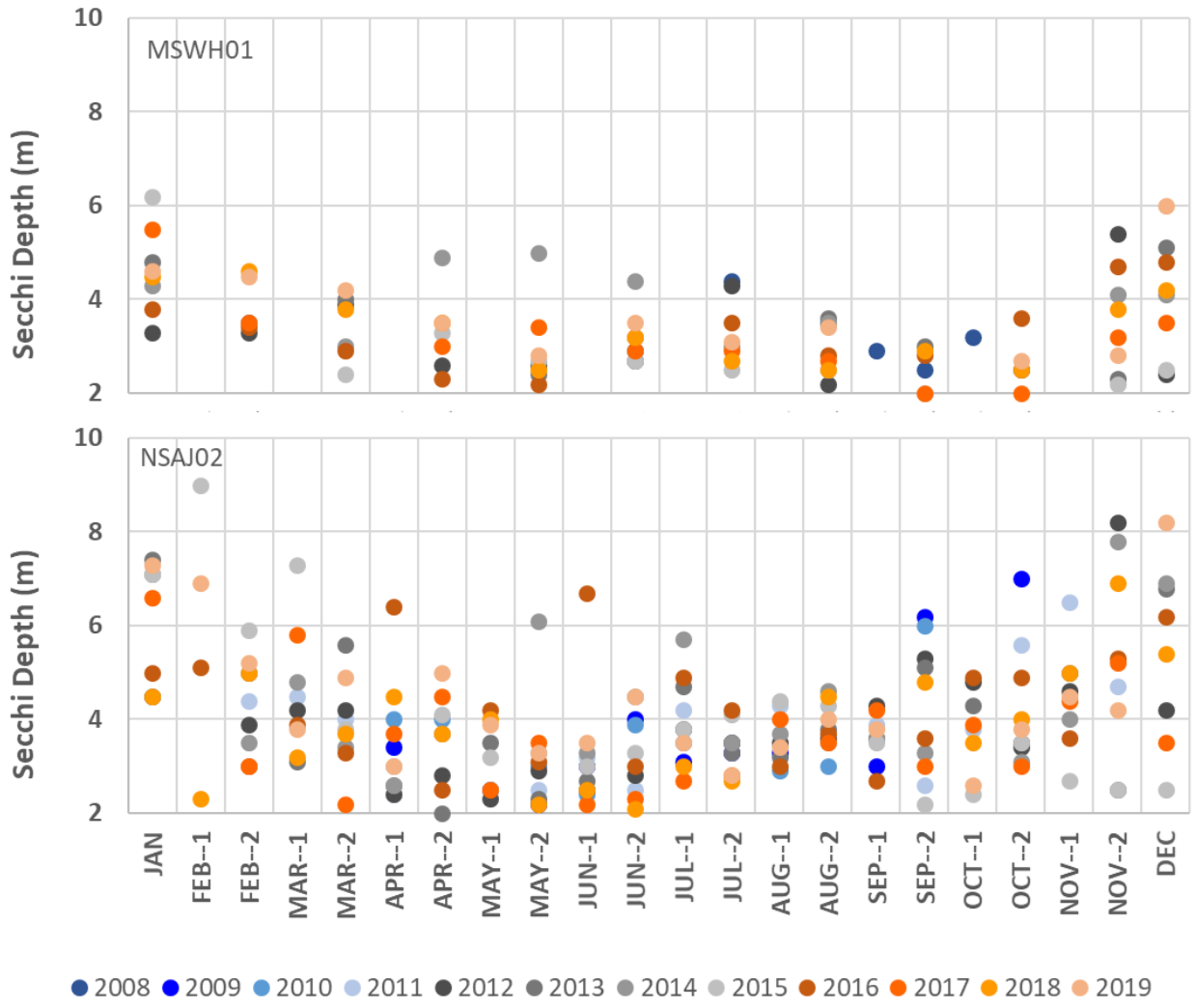


**Figure 10. Secchi results (m) for inner (MSWH01) and outer (NSAJ02) Quartermaster Harbor stations by monitoring event and year; (2008 - 2019).**

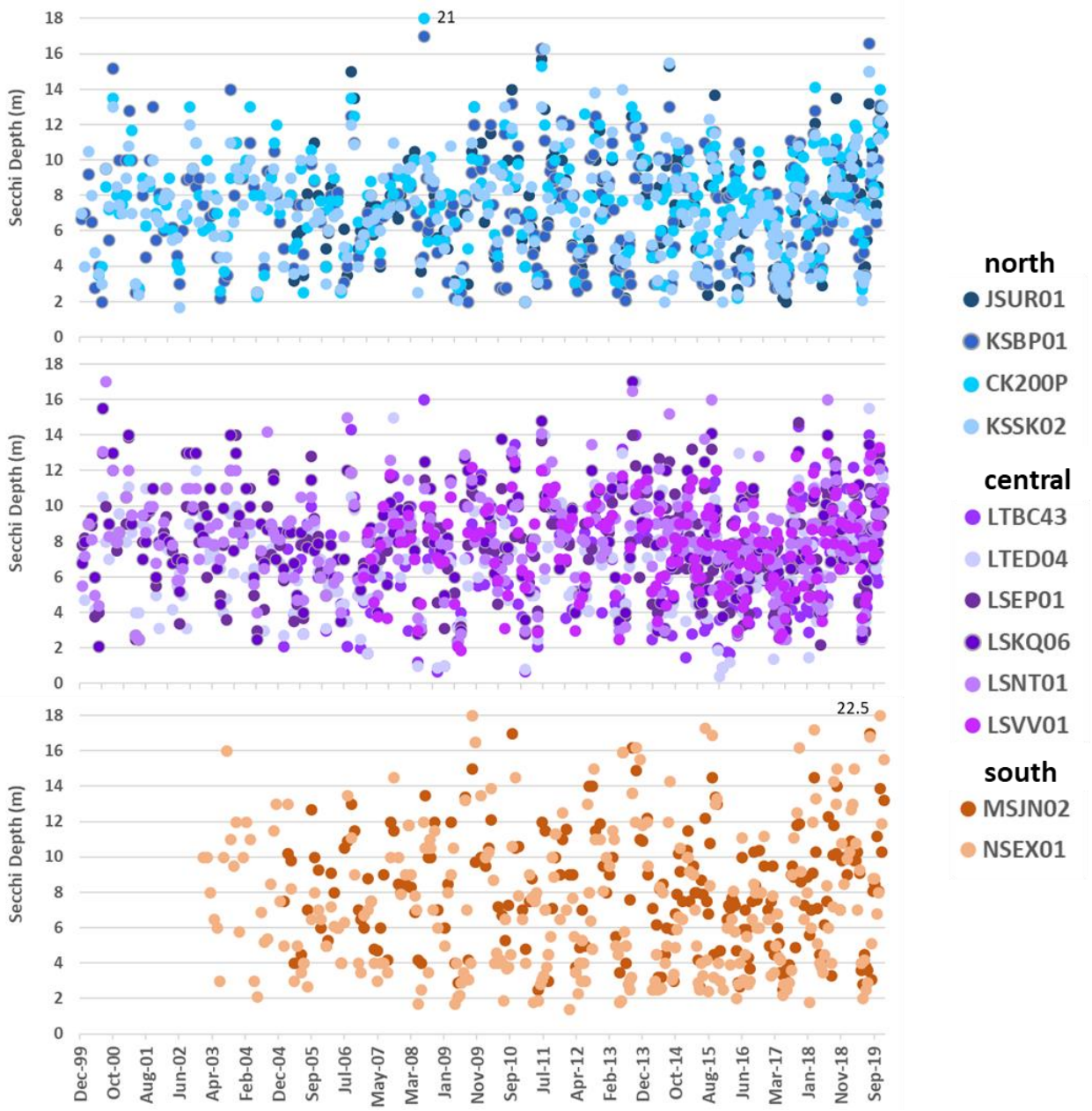


**Figure 11. Secchi results (m) by geographic area and station (2000 - 2019).**

## 3.3 Light Transmission Results

Transmissivity is the amount of light that travels through water without being absorbed or scattered. It is measured by a transmissometer and is expressed as the fraction of light that reaches a detector (% light transmission). Suspended particles reduce the amount of light that reaches the detector, while higher % light transmission corresponds with clearer water. Unlike photosynthetically active radiation (PAR), which is dependent on the amount of ambient sunlight, measurements from a transmissometer are not dependent on light already present in the water column. While transmissivity does not provide a quantitative measurement of the type, size, or number of particles in water, it is a direct measurement of how suspended particles affect the amount of light travelling through water.

At the 12 offshore stations with transmissivity data (all but the two Quartermaster Harbor and Duwamish River stations), light transmission ranged from a low of 0.66% to a high of 97.5%. Surface values in the top 2 m had the lowest transmissivity and the greatest monthly, yearly, and spatial variation. As phytoplankton biomass is a major source of light attenuation, seasonal patterns in surface transmissivity aligned with periods of high chlorophyll fluorescence and other water clarity indicators, with consistently lower light transmission and highest inter-station and monthly variability during the spring growing season. The two stations in Elliott Bay (LTBC43 and LTED04) that are affected by freshwater outflow from the Duwamish River deviated the most from seasonal patterns, with greater year-round variability and less pronounced differences between spring-summer and fall-winter. Monthly patterns in transmissivity at the surface are shown in Figure 12 for 2008-2019 combined.

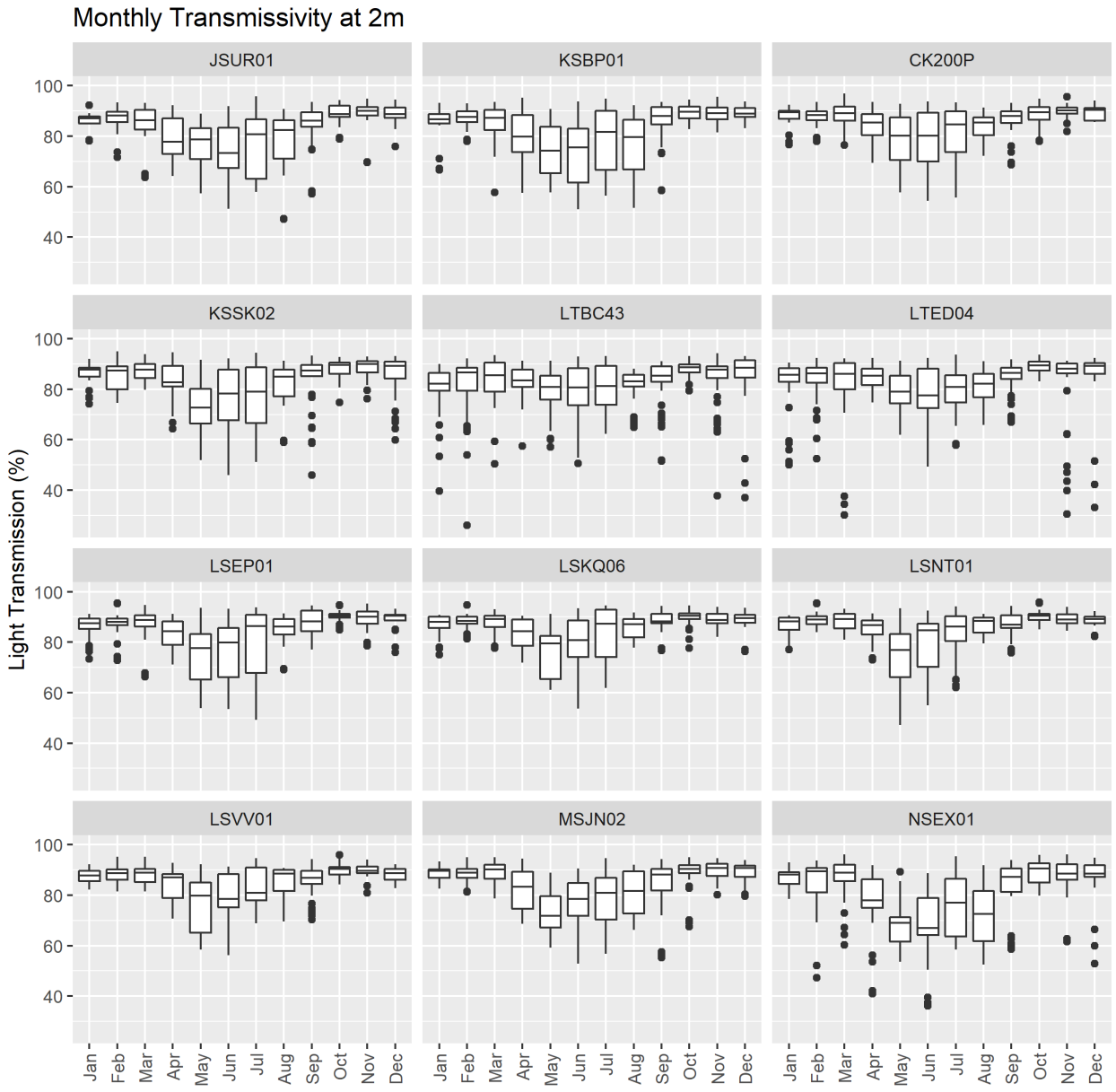


**Figure 12. Average monthly transmissivity 2008 – 2019 in top 2 m at each station. Each box represents the distribution of data aggregated for each month within 2008 – 2019 (e.g. the Jan box contains the distrubution of transmissivity data collected during every January from 2008 - 2019). Horizontal lines indicate the median % light transmission for that month, the box represents the interquartile range (IQR), the lines extend to the highest value within 1.5*IQR, and points are outliers.**

Below the surface, light transmission had lower variability and less pronounced seasonal trends. Average monthly transmissivity had low variability at most stations below 15 m with only a slight increase during the growing season. Average monthly transmissivity at the surface and near the seafloor is shown in Figure 13, with high monthly variability at 2

m at all stations. The station in Fauntleroy Cove (LSVV01) had the strongest seasonal trends near the seafloor due to its shallow depth (average depth of 12.5 m).

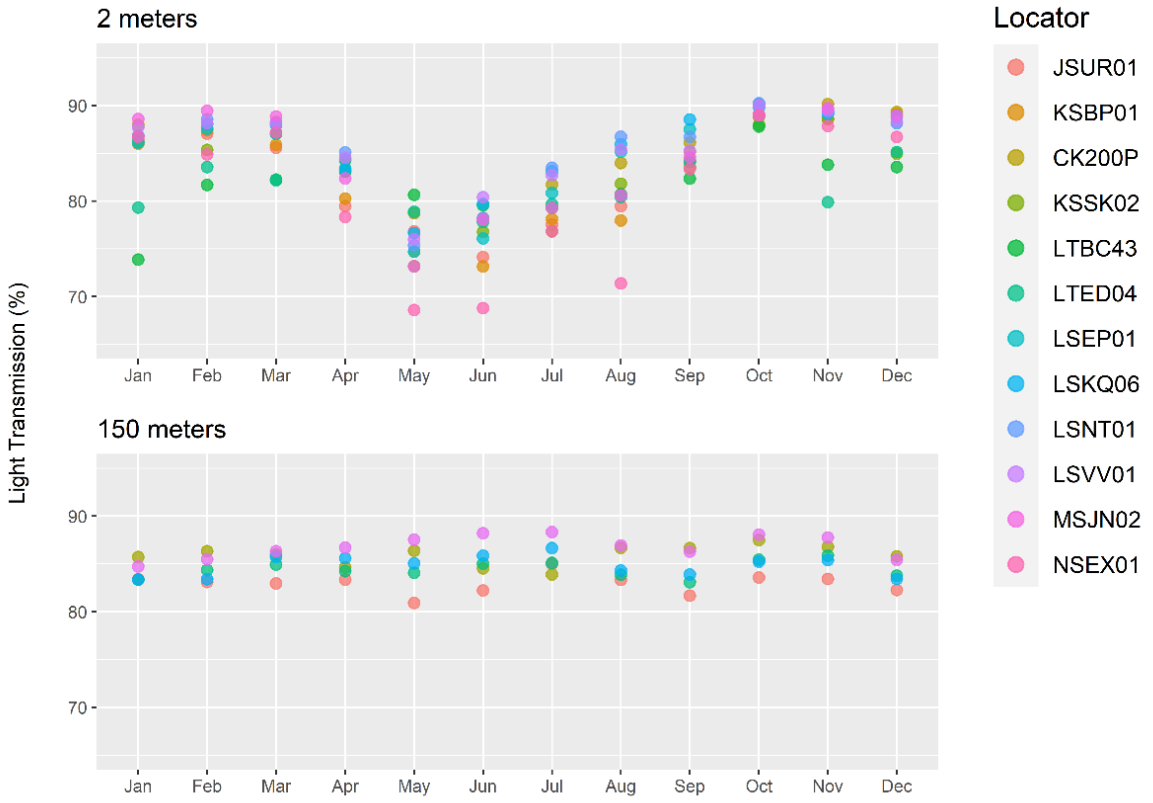


**Figure 13. Monthly averages in transmissivity at 2 meters and 150 meters. Transmissivity variability is typically highest at the surface and near the seafloor.**

Annual patterns of transmissivity remained consistent from 2008 – 2019, with the most yearly variability in the top 2 m. Surface annual averages ranged from a low of 78.7% in 2017 to a high of 87.6% in 2010. Surface transmissivity was lowest in 2009, 2016, and 2017, and highest in 2008, 2010, 2018, and 2019. The southernmost station (NSEX01) consistently had the lowest average surface transmissivity for most years, followed by the stations in Elliott Bay (LTBC43 and LTED04). Transmissivity near the seafloor showed less interannual variability, with the lowest values in 2016 and 2017. Figure 14 shows annual transmissivity in the top 2 m (black boxplots) and near the seafloor (red boxplots) at each station. Low surface light transmission during 2017 was likely due to sustained phytoplankton biomass, whereas high light transmission in 2018 and 2019 correspond to a compressed growing season, with no fall bloom in 2019.

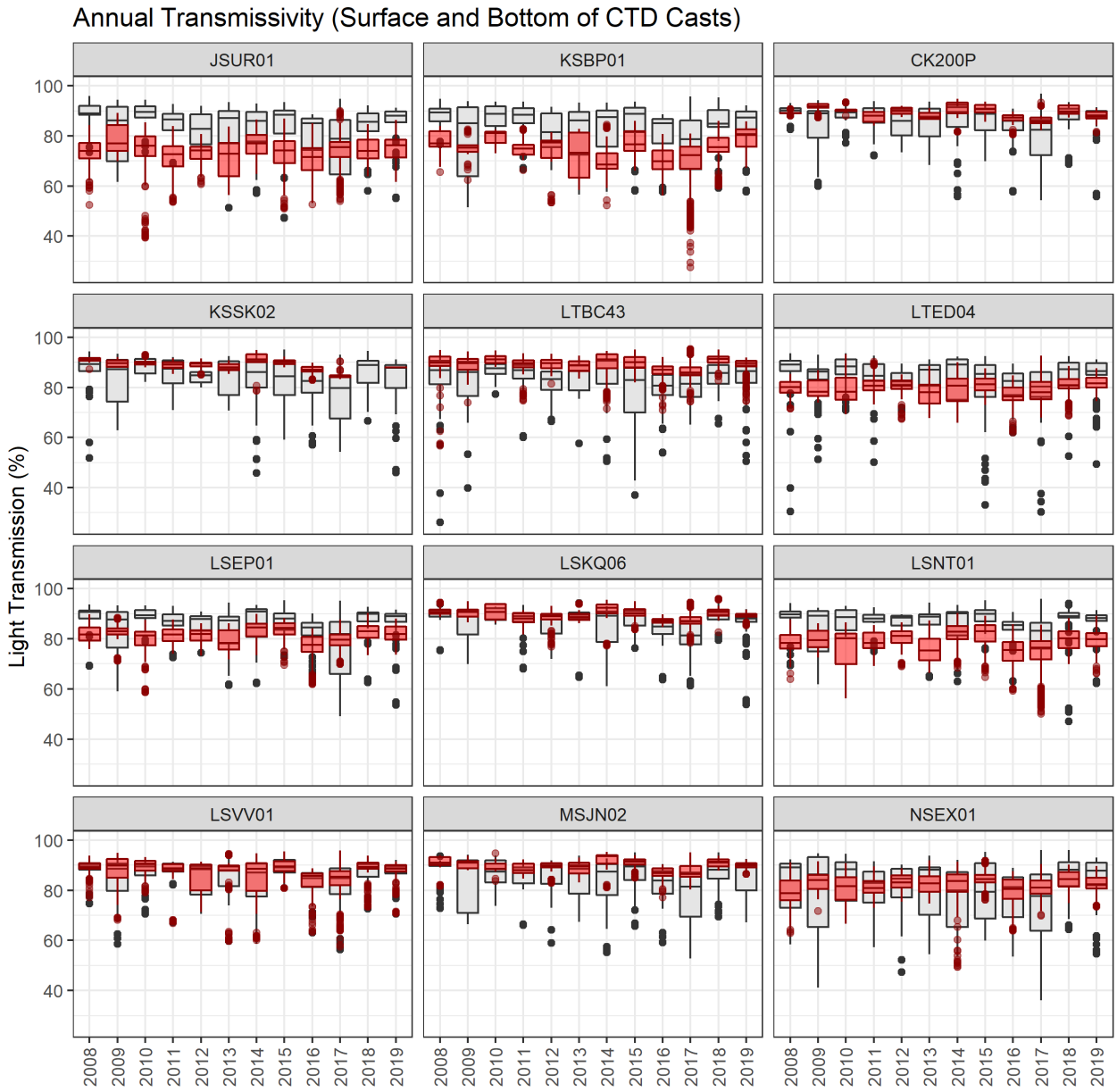


**Figure 14. Distribution of transmissivity for each year in the top 2 m (gray boxes) and bottom depth (red boxes) at each station. For a description of statistics contained within boxplots, refer to the caption in Figure 13.**

Fauntleroy Cove (LSVV01) and Pt. Williams (LSNT01) had the highest surface transmissivity for most years, matching observations of low TSS and phytoplankton abundance at these stations. Figure 15 shows the distribution of each station's yearly average transmissivity in the top two meters (black boxplots) and bottom two meters (red boxplots) of the CTD profiles, highlighting which stations had particularly low transmissivity towards the seafloor relative to transmissivity in surface waters throughout 2008 - 2019.

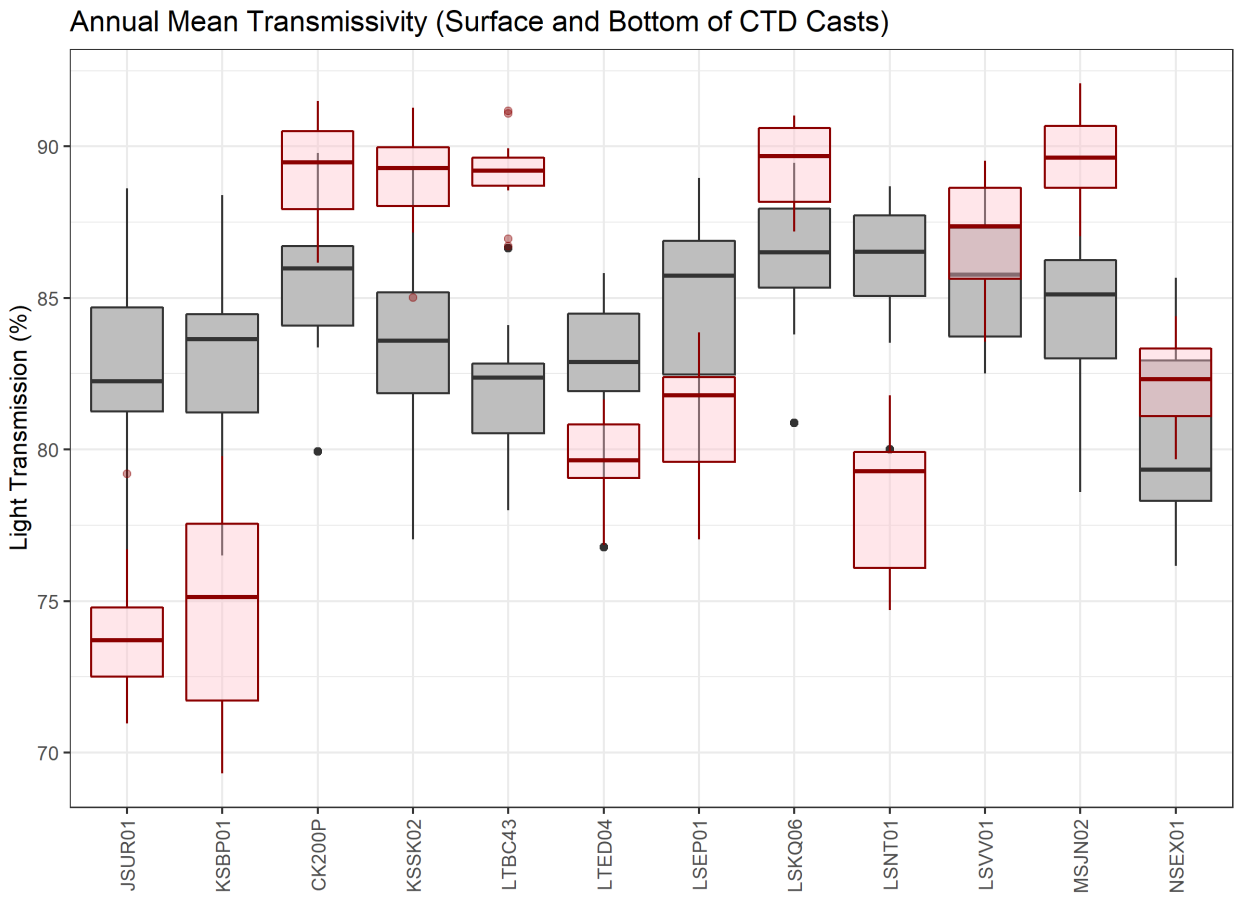


**Figure 15. Annual mean transmissivity (2008– 2019 combined) for each station in the top 2 m (gray boxes) and bottom depth (red boxes). Box boundaries represent 25th and 75th percentiles, line within the box indicates the median, whiskers represent 10th and 90th percentiles, and points are outliers.**

The two northernmost stations consistently had the lowest bottom transmissivity near the seafloor, averaging 73.8% at JSUR01 and 73.4% at KSBP01. Bottom transmissivity often contrasted the extent and timing of surface transmissivity at these stations, indicating that suspended sediment rather than phytoplankton biomass had a more consistent effect on light attenuation towards the seafloor relative to other stations. Further South, bottom transmissivity was higher while surface transmissivity was typically lower. The southernmost station (NSEX01) had periods of low surface transmissivity that extending longer into the Spring and Winter than stations further north. Figure 16 compares yearly transmissivity throughout the water column at a northern station (KSBP01), central station (LSNT01) and southern station (NSEX01).

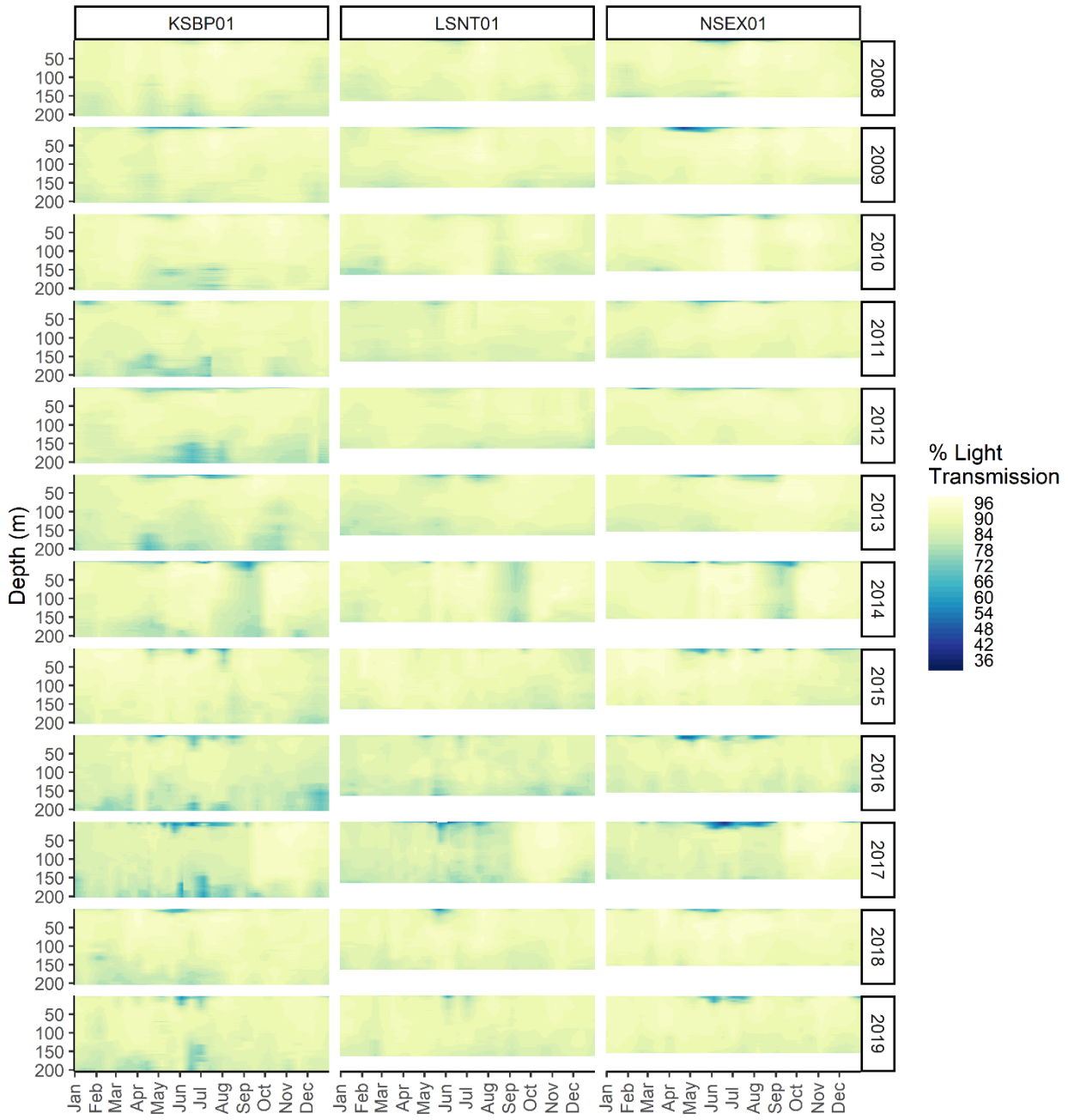


**Figure 16. Water column transmissivity by year at a northern (KSBP01), central (LSNT01), and southern station (NSEX01).**

As transmissivity is strongly affected by phytoplankton suspended in the water, bloom dynamics strongly influence light attenuation in the water column, especially in the surface. In 2014, the first year of the marine heat wave, a strong autumn bloom resulted in low transmissivity throughout the entire water column from August – October. This appeared at all stations and was followed by a period of notably high light transmission for the rest of the autumn. Sustained phytoplankton blooms in 2017 reduced surface and mid-depth

transmissivity from April – October, while a shortened growing season in 2018 and 2019 resulted in high surface and mid-depth transmissivity throughout most of the year.

## 3.4 PAR Results

Photosynthetically active radiation (PAR) refers to the amount of light energy available for photosynthesis in the spectral range of 400 – 700 nm. Ambient (surface) PAR measured above water is dependent on a variety of factors including time of year, time of day, and weather conditions during data collection. Underwater PAR is dependent on the amount of surface PAR entering the water column and water clarity factors such as turbidity, suspended sediments, particle size, and phytoplankton biomass that scatter and absorb incoming light.

The proportion of underwater PAR to ambient PAR can be used to calculate the size of the euphotic zone, which extends from the surface to the depth where light is insufficient for photosynthesis, defined as when underwater PAR is 1% of ambient PAR. This depth is an indicator of water clarity since it represents how attenuation from suspended particles in the surface affects the amount of light available for photosynthesis. Figure 17 demonstrates how sunlight entering the water column attenuates with depth in the top 20 m at station MSJN02 throughout the year.

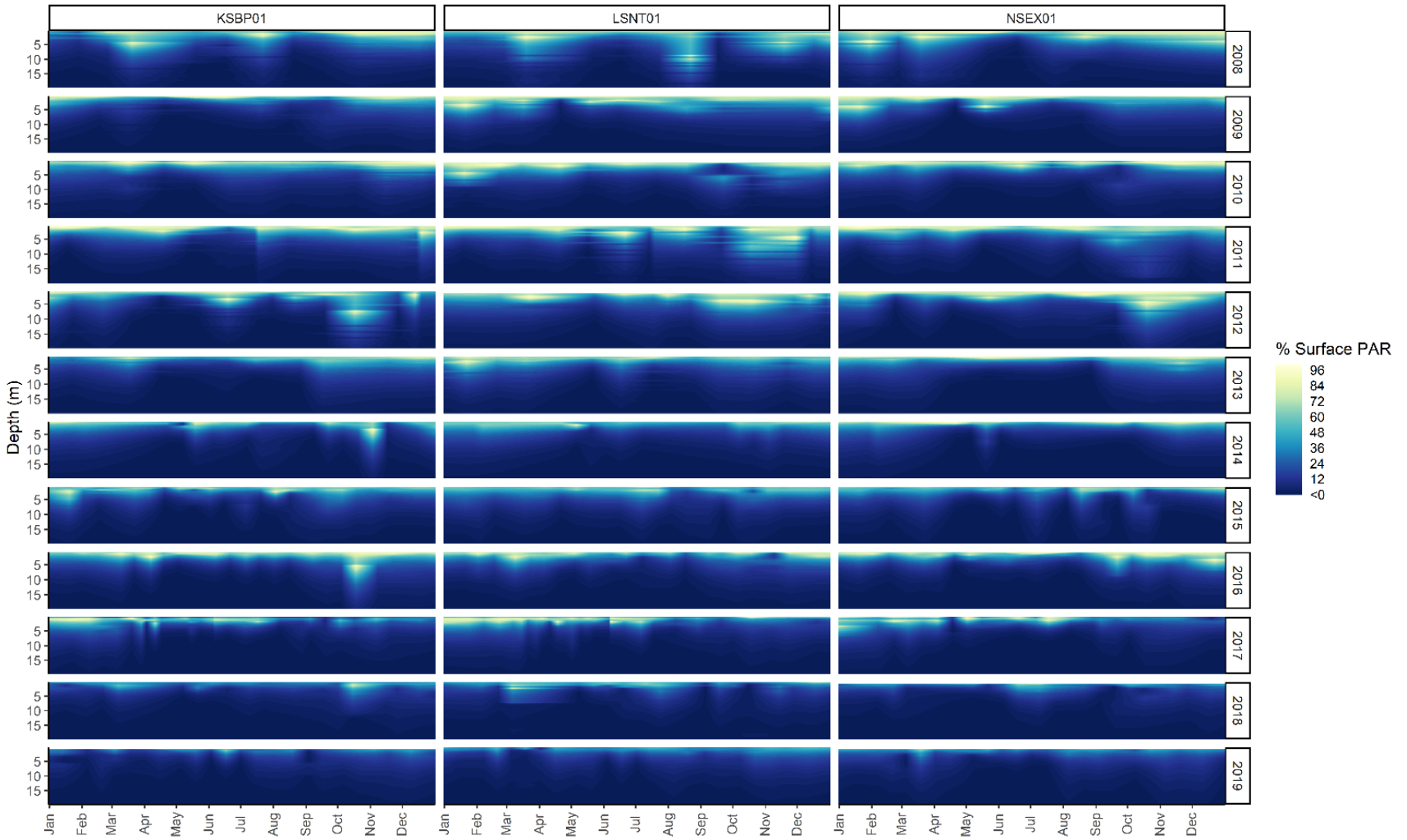


**Figure 17. Water column PAR in the top 20 m at a northern (KSBP01), central (LSNT01), and southern station (NSEX01).**

The depth of the euphotic zone followed seasonal patterns in primary productivity and varied by location, with the shallowest monthly average of 9.1 m at station LSVV01 in May, and the highest monthly average of 22.5 m at station CK200P in November. Station LSVV01 is shallow (12.5 m), therefore the euphotic zone included the majority of the water column at this location. The greatest amount of light penetration occurred outside of the growing season in October – March, reaching an average depth of 20.7 m. The euphotic zone decreased in September to an average of 15.6 m, and the shallowest depth occurs in May at all stations, averaging 12.5 meters (Figure 18).

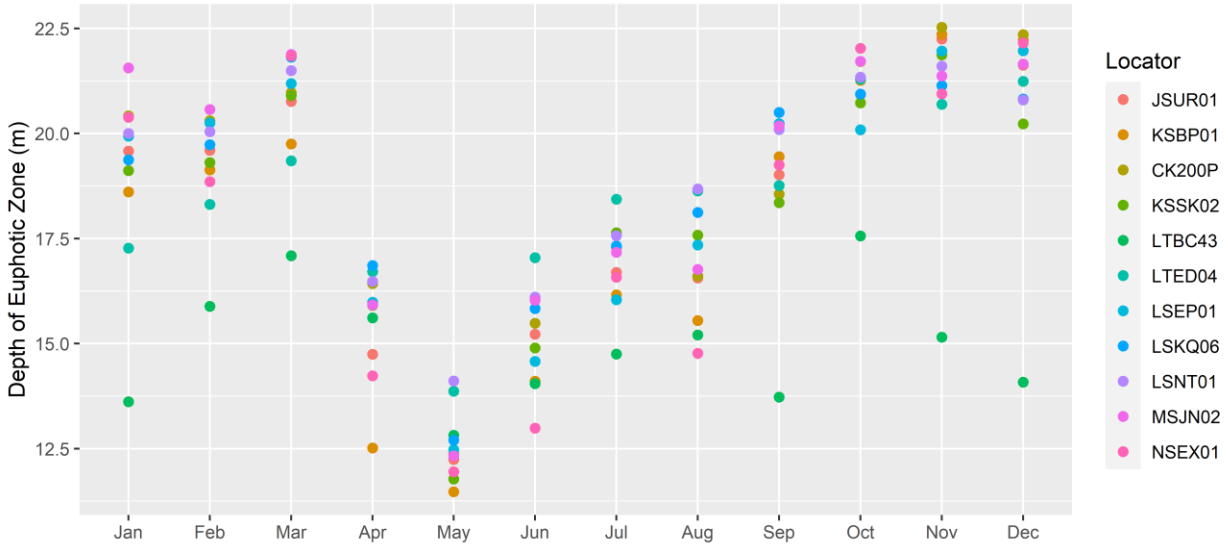


**Figure 18. Monthly average euphotic zone depth (m) at each station 2008-2019, excluding the shallow station LSVV01.**

These patterns in PAR-derived euphotic zone depth followed seasonal patterns of high primary productivity in spring and summer months and matched seasonal patterns in observed Secchi depths (Section 3.2). Stations LSVV01, LTBC43, and LTED04 deviated the most from observed seasonal patterns, with a shallower overall euphotic zone depth throughout the year and less pronounced differences between fall-winter and spring-summer. This is likely due to the shallow station depth of LSVV01 (Fauntleroy Cove) and higher turbidity in Elliott Bay (LTBC43 and LTED04) from the Duwamish River outflow.

The annual average (2008 – 2019) euphotic zone depth was 18.4 meters, with a high of 21.6 meters in 2008 and a low of 15.9 meters in 2017. Figure 19 shows the annual average at each station (black circles) alongside the combined yearly average of all stations (gray squares). Averages are calculated excluding stations LSVV01 and LTBC43.

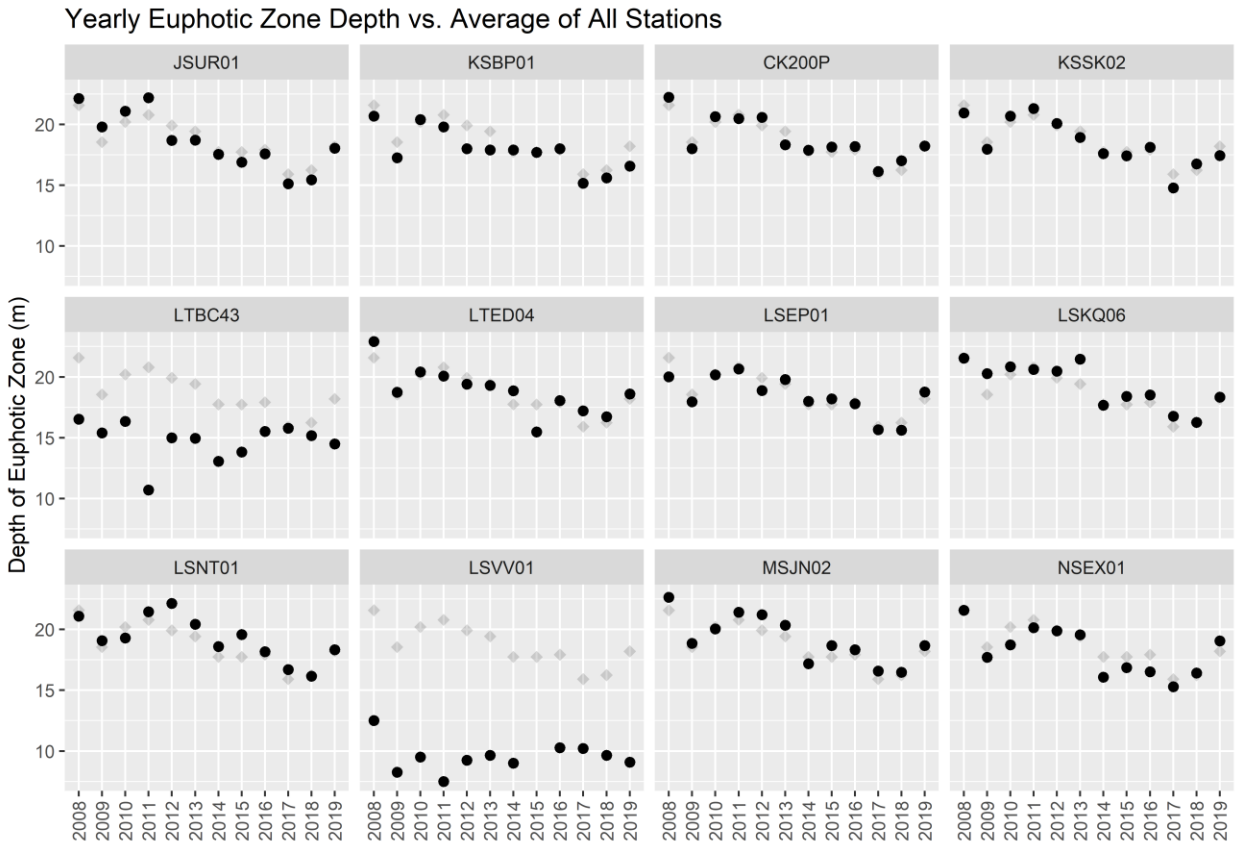


**Figure 19. Annual average euphotic zone depth at each station (black circles) compared to the average for all stations combined (gray diamonds). Averages were calculated excluding stations LTBC43 and LSVV01.**

LSVV01 located in Fauntleroy Cove had the shallowest euphotic zone depth. However, these data are skewed by the shallow depth at this station; the euphotic zone often reached the seafloor during fall and winter. The shallow Elliott Bay station (LTBC43) had the second shallowest euphotic zone depth for all years except 2017, where most other stations were unusually low due to a sustained phytoplankton bloom. All other offshore stations showed similar annual trends to one another, with an average high of 21.6 m in 2008 and an average low of 15.9 m in 2017.

While interannual variation was observed, the PAR-derived annual average euphotic zone depth shows a slight decreasing trend from 2008 – 2019 for all 12 stations. The euphotic zone depth was particularly low in 2017 and 2018, with low light penetration starting in August of 2017 at most stations. Figure 20 shows the monthly average euphotic zone depth for all stations from 2008 – 2019 against the monthly average for the 1998 – 2013 baseline. Most stations in 2008 – 2019 exhibit shallower euphotic zone depths than the monthly average from 1998 – 2013. Note that not all stations had data starting in 1998 (see Table 1).

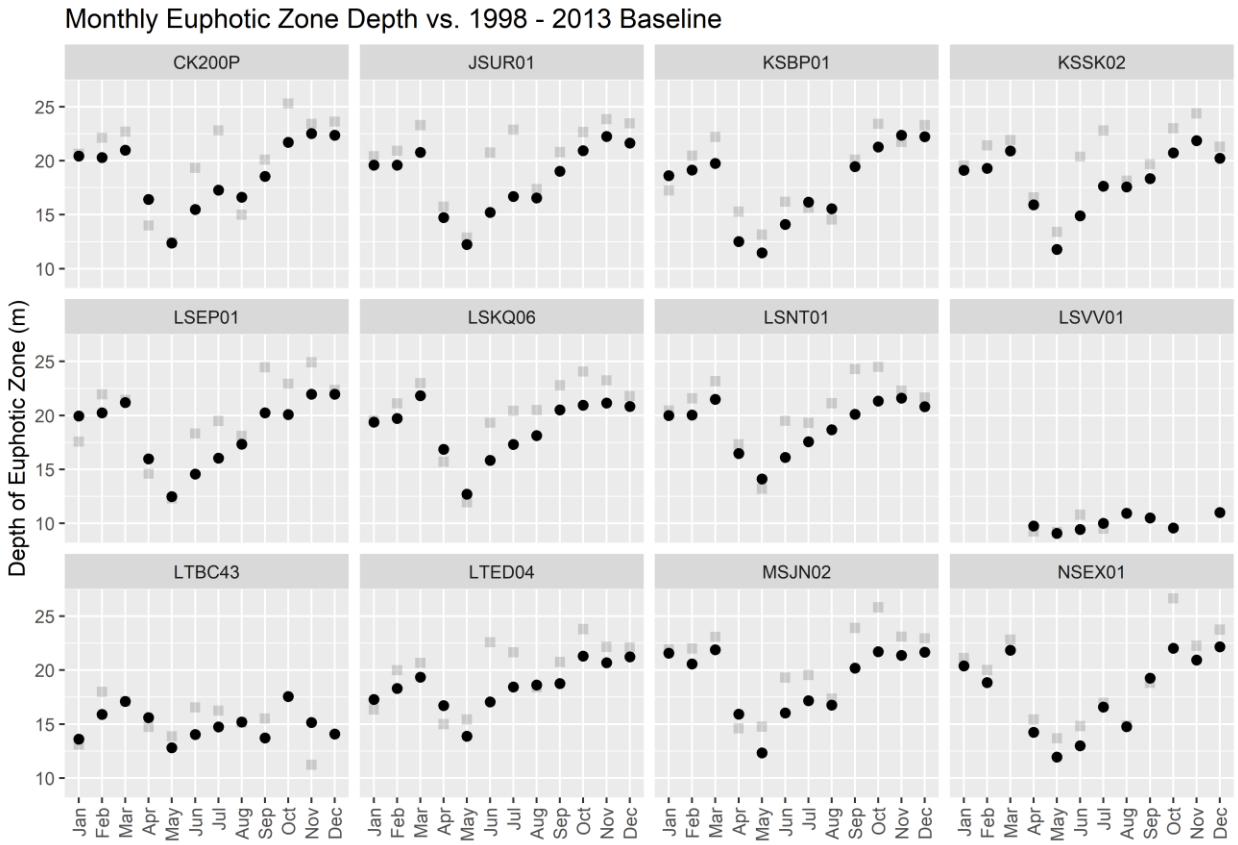


**Figure 20. Monthly average euphotic zone depth at each station (black circles) plotted against the the monthly average calculated from the 1998 – 2013 baseline (gray boxes).**

Most stations showed similar seasonal patterns. The shallowest station (LSVV01) and the two stations within Elliott Bay (LTBC43 and LTED04) showed the strongest differences in seasonality. Most other stations have very consistent seasonal and annual trends to one another

The overall depth of the euphotic zone has decreased slightly, averaging 20.4 m in 2008 – 2013 and 18.16 m in 2014 – 2019. Monthly averages compared against the 1998 – 2013 baseline show a slight decrease in depth at most stations for most months, though seasonal patterns have remained consistent.

## 3.5 Water Clarity Summary

During the reporting period 2008 - 2019, water clarity was assessed by total suspended solids (TSS), Secchi depth, light transmission, and photosynthetically active radiation (PAR) measurements.

Some TSS interannual variation was evident, with higher concentrations at most sites seen between 2012 - 2014, which was particularly apparent at all depths below the surface (> 2 m). Annual averages in surface water were highest in most years at the two Quartermaster Harbor sites (MSWH01 and NSAJ02), the locations with the highest phytoplankton abundance. Conversely, Fauntleroy Cove (LSVV01) and Pt. Williams (LSNT01) tended to have lower phytoplankton abundance than other sites and had low surface annual averages for most years. Seasonal variation in TSS at the surface was evident at all stations, with higher concentrations measured during spring and summer months when phytoplankton growth is high. The highest TSS levels from spring through fall were observed at the Quartermaster Harbor sites due to the extended phytoplankton growing season in the harbor.

Some spatial variation was evident at offshore stations with higher TSS levels measured in April at the northern and southernmost sites and in May at the southernmost site East Passage (NSEX01). The spring phytoplankton bloom typically occurs slightly later in the spring at NSEX01 and is reflected in surface TSS values. A pronounced spatial pattern was observed for the Duwamish River stations in surface TSS levels, with highest values consistently measured at the furthest upstream location (LTXQ01) and subsequently declining downstream.

Other than the two Quartermaster Harbor stations, the lowest Secchi depth measurements were seen at the Elliott Bay stations (LTED04 and LTBC43) in most years due to inputs of solids and turbidity from the Duwamish River. Higher Secchi depths occurred most often in late summer and fall/winter months when primary productivity was low. Although Secchi depth varied by location, some interannual differences were evident with annual averages lowest in 2017 and the highest in 2019.

Light transmission varied seasonally with less light penetration in the spring and summer months. Phytoplankton biomass is a major source of light attenuation and seasonal patterns in surface transmissivity aligned with the growing season and other water clarity indicators, with consistently lower light transmission in spring.

A few water clarity observations of note are provided below:

- Annual average TSS levels at the Brightwater TP outfall station (JSUR01) were considerably higher during most years in water > 150 m. The Brightwater TP outfall is not the likely source of TSS, other factors are likely influencing TSS at this location.

- The highest TSS annual averages at the four Duwamish River stations were seen in 2015, which subsequently decreased each year thereafter.
- The Duwamish River furthest upstream location (LTXQ01) had high monthly TSS averages in February and November compared to the other Duwamish River sites.
- High variability in Secchi depths was seen between years and sites, a reflection of variability in phytoplankton biomass.
- The two Quartermaster Harbor stations had the lowest Secchi depths of all sites.
- While some interannual variation was evident, Secchi depths have remained consistent over time and a decreasing trend in water clarity is not apparent.
- Transmissivity in surface waters followed seasonal trends in primary productivity (high in spring summer low in fall winter).
- The two northernmost stations (JSUR01 and KSBP01) had the lowest transmissivity near the seafloor.
- The two offshore stations in Elliott Bay (LTBC43 and LTED04) showed the most seasonal variation in transmissivity.
- The depth of the euphotic zone between 2008-2019 decreased slightly compared to the 1998 – 2013 baseline, but overall season patterns remained consistent.
- The euphotic zone was shallowest during the month of May, and highest during October – December.

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