2021–2022 SUMMARY REPORT

COLUMBIA SLOPE WATER QUALITY MONITORING PROJECT

Prepared for
City of Vancouver
Surface Water Management

Prepared by
Herrera Environmental Consultants, Inc.

Note:
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Prepared for
City of Vancouver
Surface Water Management
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July 7, 2022

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This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement RB 01J73401-0 to the City of Vancouver. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does the EPA endorse trade names or recommend the use of commercial products mentioned in this document.

EXECUTIVE SUMMARY

The Columbia Slope Water Quality Project is a US Environmental Protection Agency (EPA) grant funded project with the objective of collecting and analyzing water quality data within the Columbia Slope watershed. This report describes monitoring activities conducted from June 2021 to March 2022, characterizes the subsequent water quality results throughout the watershed, and provides a data analysis report in support of City and state activities designed to improve water quality in the Columbia Slope watershed. The report concludes with an evaluation of basins for stormwater treatment retrofitting based on an assessment of pollutants of interest discharged to the Columbia River in each basin.

The following summary describes major trends and water quality criteria exceedances observed during the monitoring period:

- **Seasonal Trends**–Warmer temperatures and low discharge rates in the summer base flow events were generally associated with lower dissolved oxygen (DO), chloride, and copper concentrations for most stations and higher total suspended solids (TSS), lead, and *Escherichia coli* (*E. coli)* concentrations.

- **Storm vs. Base Flow Comparison–**Compared to base flow, storm flow had lower temperature and pH and higher concentrations of DO, turbidity, TSS, total metals, and *E. coli*, which is expected due to the mobilization of pollutants from higher flow rates and adsorption of metals and other pollutants to fine solids. Significantly higher levels of total nitrogen and nitrate+nitrite were observed at most stations during base flow and may be a result of septic tanks providing inadequate treatment, though the positive correlations between nitrogen and septic system density were not found to be statistically significant.

- **Water Quality Criteria Comparison**–Applicable criteria for several parameters were exceeded, particularly during storm flow events. Parameters for which criteria were frequently and/or greatly exceeded include pH, nutrients, total metals, *E. coli*, several individual semivolatile organic compounds (SVOCs), and many organochlorine pesticides (including DDx isomers, alpha-benzene hexachloride [BHC], dieldrin, and aldrin). The three Washington State Department of Transportation (WSDOT) monitoring stations had the highest relative ranking in terms of water quality impairment due to frequent exceedances for metals, SVOCs, and *E. coli*. City monitoring stations CSF1 and CSJ1 had fewer water quality criteria exceedances relative to other stations.

- **Regression Analysis**–The regression model results indicate that industrial/commercial land cover (which was significantly correlated with impervious area) is a positive, explanatory variable for turbidity, TSS, total metals, bis(2-ethylhexyl)phthalate (BEHP), total phosphorus, and organochlorine pesticides. Residential area was also significantly correlated to septic density and there was some evidence of septic density predicting greater nutrient concentrations.

Prioritization of Basins I-205, P, Q, R, and J for additional stormwater treatment is recommended due to either their relatively high industrial/commercial land cover and high impervious area, or the ecological/recreational value of waterbodies contained therein. Basins with substantial highway contribution (i.e., Basins I-205 and Q) are especially of interest due to the relatively high pollutant concentrations observed at WSDOT monitoring stations.

No changes to frequency of sampling are recommended for future monitoring but we recommend relocating some of the monitoring stations to help identify local pollutant sources, provide baseline data for areas for potential retrofit projects, and/or evaluate effectiveness of existing treatment. New stations established upstream of stations with high pollutant concentrations could help locate pollutant sources. Candidates for continued monitoring include CSJ1 in Basin J (Love Creek and Columbia Springs Fish Hatchery), CSR1 in Basin R (Fisher's creek), and at least one WSDOT station (current or new) to gather a more robust dataset of highway inputs. Additional stormwater contaminants of concern and emerging pollutants should be considered for the monitoring including polychlorinated biphenyls and 6PPD-quinone, which is acutely toxic to coho salmon and prevalent in urban streams and stormwater (Tian et al, 2020). We recommend considering analysis of these parameters for a select set of stations and number of storm events as budget allows. Continued storm event monitoring of pesticides and SVOCs should be reevaluated for parameters that were largely undetected and/or not deemed a concern along with consideration of budgetary constraints and priorities.

Additional data collection will not only provide an improved understanding of water quality conditions throughout the Columbia Slope watershed but allow for a more robust statistical analysis to identify temporal trends, spatial differences, pollutant sources, and impacts of existing stormwater management practices to better inform City and other agencies of stormwater management needs in the Columbia Slope watershed.

INTRODUCTION

Water quality data for the Columbia Slope watershed have not been consistently collected and remains a significant gap in the understanding of stormwater influences that affect surface water and groundwater. The Columbia Slope Water Quality Monitoring Project is intended to begin to fill this gap and demonstrate the need to expand the City's long-term program. The project is funded by a grant from the EPA to monitor suitable stream or spring outfall basins in the Columbia Slope watershed within City limits for 12 events over a one-year period to identify areas where stormwater treatment would be most effective in reducing pollutants from City outfalls to the Columbia River.

This report describes monitoring activities performed for the Columbia Slope Water Quality Monitoring Project, characterizes the subsequent water quality results throughout the watershed, and provides a data analysis report in support of City and state activities designed to improve water quality in the Columbia Slope watershed. This report concludes with an evaluation of basins for stormwater treatment retrofitting based on an assessment of pollutants of interest discharged to the Columbia River in each basin.

BACKGROUND

The Columbia Slope watershed encompasses approximately 25 square miles of central and southeast Vancouver, Washington, including hillsides between Vancouver Lake and Lacamas Creek (Figure 1). It is part of the Columbia River Landscape Unit and is composed of riverine floodplain areas draining multiple hillside seeps and streams supplied by groundwater, surface water runoff, and infiltrated urban stormwater to the Columbia River. The reach of the Columbia River impacted by the Columbia Slope watershed is impaired by high water temperature, and dioxin according to the EPA-approved Washington State 303(d) list of parameters with TMDLs (Ecology 2016). Additional listed parameters of concern include fecal coliform bacteria, BEHP, and arsenic. The Columbia Slope area has been designated a Shoreline of Statewide Significance in Washington, with safeguards established in the City of Vancouver Shoreline Master Program.

Approximately 10,411 acres (16.3 square miles) of the watershed are within Vancouver city limits. Land use in the watershed is predominantly residential (approximately 86 percent) and commercial/industrial (approximately 13 percent), with impervious surface cover in approximately 52 percent of the watershed. Most soils within the watershed are well-drained and generally derived from their parent geologic materials, which is particularly relevant because they control infiltration from the land surface to the shallow groundwater flow system. Infiltration is the basis for groundwater recharge and availability and can carry pollutants from the land surface (or from shallow, constructed, infiltration facilities) to the water table.

In the Columbia Slope watershed, a number of small ponds, marshes, and wetland areas are sustained by groundwater spring flows. The US Geological Survey (USGS) estimated total discharge from the springs as 25 cubic feet per second (cfs) in 1949 but noted that discharge declined to 14.5 cfs in 1988, which is a 42 percent reduction between measurement events (McFarland and Morgan 1996). Two City water supply wells (WS-4 and Ellsworth WS) are located in the Columbia Slope watershed that provide approximately 7 percent of the City's annual groundwater withdrawal of 39.4 cfs (based on 2013 to 2017 data) (Herrera and Pacific Groundwater Group [PGG] 2019). For some aquifers, areas also exist where pumping near the Columbia River could capture water from the river itself; although none of the City's wells have been identified as groundwater sourced from surface water features.

Stormwater runoff from urban areas typically carries pollutants that can be harmful to human health and aquatic life. The City is responsible for vital municipal infrastructure and urban services and is regulated under the National Pollutant Discharge Elimination System (NPDES) Phase II Stormwater Permit. The City's Stormwater Management Program has evolved to include all NPDES permit requirements in addition to the tasks traditionally associated with operating a municipal stormwater utility. The City is committed to effectively managing stormwater and meeting goals established by the Federal Clean Water Act and the Water Pollution Control Act to protect surface and groundwater. Other potential pollutant sources within City limits include infiltration facilities (dry wells and perforated drainage pipes), septic tanks, underground storage tanks, older sanitary sewer installations, contaminated sites, commercial/industrial sites that store and use hazardous materials, and former landfills.

Under a separate effort, the City is working on an Ecology-funded stormwater retrofit planning evaluation for the Columbia Slope watershed designed to identify and prioritize projects that will provide stormwater runoff treatment and flow control. The phased project is underway and 12 potential projects have been identified based on desktop and field evaluations. The proposed projects are currently undergoing further evaluation and include regional treatment facilities, green streets, a potential stormwater pond outfall retrofit, and a filter vault retrofit. Water quality data will be considered and, when appropriate, be used to evaluate retrofit project priority and benefits, particularly if monitoring stations are representative of conditions at potential retrofit locations.

Objectives

The primary goal of the monitoring project described in this report is to collect credible water quality data and provide a data analysis report in support of the City and state programs and activities designed to improve water quality and protect the environment throughout the Columbia Slope watershed. Data collected during this one-year monitoring project will allow the City to assess pollutant loading to the Columbia River and identify basins of priority for stormwater treatment retrofitting. To meet this goal, the following objectives have been defined for this project:

- Identify where stormwater pollutants are being carried to the Columbia River
- Accurately characterize specific water quality parameters within the watershed

- Provide high quality data for the City and other users
- Determine whether trends or correlations are present in the water quality data
- Prioritize basins where stormwater treatment retrofits could effectively remove pollutants that currently reach the Columbia River
- Identify outfalls where stormwater treatment activities can be monitored for effectiveness over the long-term
- Provide feedback for adaptive strategies in stormwater management programs

This report describes base and storm flow monitoring conducted in WY2021 and WY2022. WY2021–WY2022 monitoring was conducted from June 2021 to March 2022 in accordance with procedures in the Quality Assurance Project Plan (QAPP; Herrera 2021a) and Addendum (Herrera 2021b). To maintain consistency and comparability with other monitoring efforts within the City, namely the Burnt Bridge Creek Water Quality Monitoring Program, monitoring procedures were generally consistent with those described in the Burnt Bridge Creek QAPP (Herrera 2019) where appropriate.

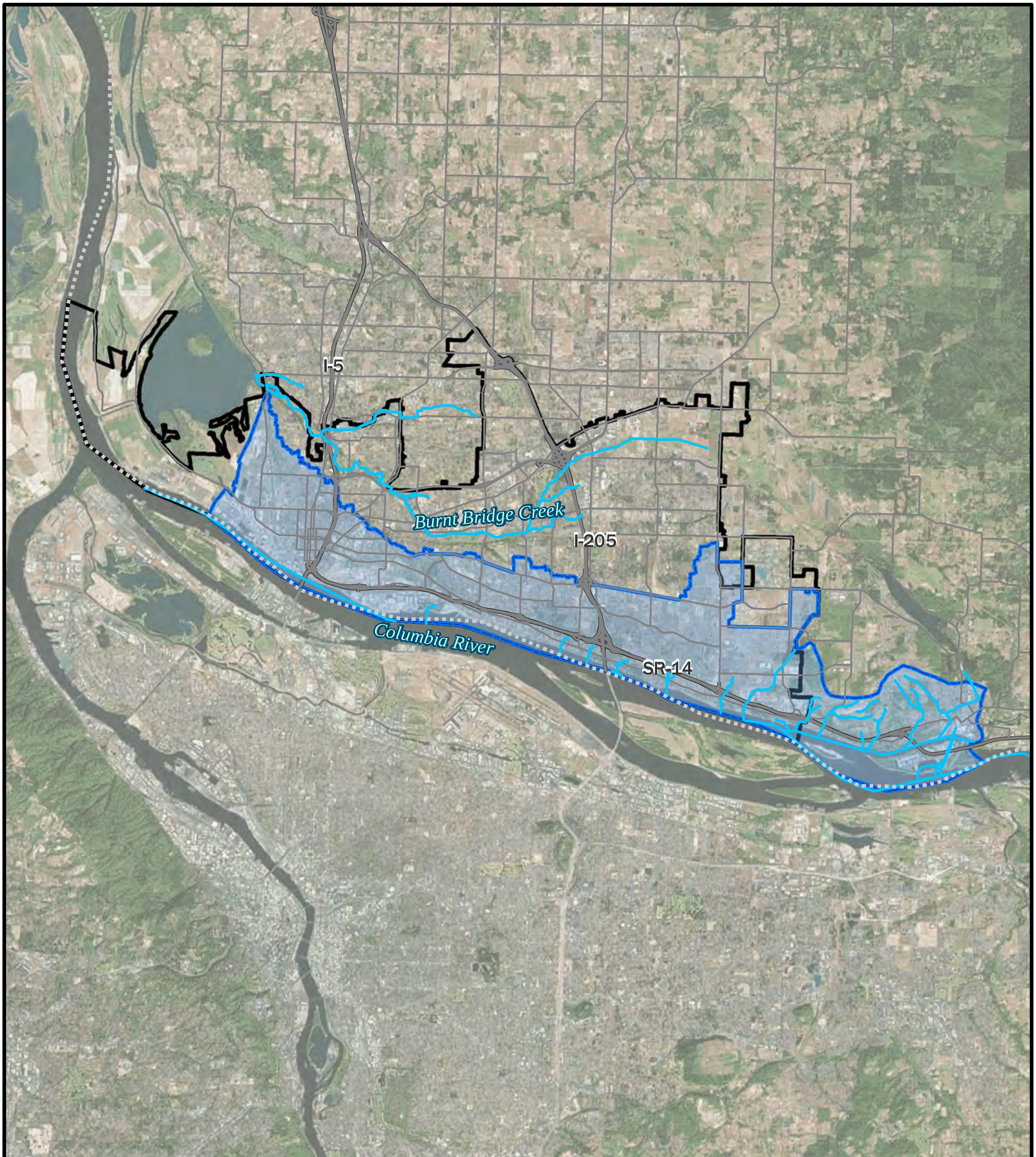

Figure 1.
Columbia Slope Watershed Vicinity Map.

0 7,125 14,250 28,500 Feet

ESRI (Aerial, 2021)

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MONITORING SUMMARY

The field monitoring, laboratory analysis, and data management and analysis methods are described below. A detailed description of these methods in provided in the QAPP (Herrera 2021a) and Addendum (Herrera 2021b).

MONITORING STATIONS

Water quality sampling and field measurement were conducted at ten stations in the Columbia Slope watershed (Figure 2). These stations included seven owned by the City and three owned by WSDOT. The seven City monitoring station locations are as follows (listed below from west to east):

- Basin E outfall (CSE1)–Upstream culvert along Southeast Evergreen Highway roughly 200 feet west of Southeast 94th Court.
- Basin F outfall (CSF1)–Upstream culvert along Southeast Evergreen Highway roughly 200 feet east of Southeast 101st Avenue.
- Basin J outfall (Biddle Lake/Love Creek; CSJ1)–Downstream culvert along Southeast Evergreen Highway east of the intersection with Schafer Road.
- Basin O outfall (CSO1)–Upstream culvert along Southeast Evergreen Highway roughly 100 feet east of Southeast 158th Avenue.
- Basin P outfall (CSP1)–Outfall accessible at the beach access roughly 50 feet south of the southern extent of Southeast 164th Avenue.
- Basin R outfall (Fisher's Creek; CSR1)–Exposed artificial channel on unnamed gravel road south of the railroad tracks adjacent to 17403 Southeast Evergreen Highway.
- Basin R upstream (Fisher's Creek; CSR2)–Upstream culvert along Southeast 192nd Avenue roughly 500 feet north of the intersection with Southeast 31st Street and adjacent to a wetland.

The three WSDOT monitoring station locations are as follows (listed below from west to east):

- I-205 outfall (CSWSDOT1)–Outfall located approximately 50 feet from the bank of the Columbia River directly beneath the western edge of the southbound I-205 bridge. Approximately 37 acres of I-205 drains to the outfall.

- SR-14 untreated highway runoff (CSWSDOT2)–The original monitoring station as described in the QAPP Addendum (Herrera 2021b) was located at the outfall on the southern shoulder of eastbound SR-14 at the wide shoulder pullout immediately preceding exit 8. There was insufficient flow at this station during storm events, so it was relocated to the outfall in the center of the grassy swale located between SR-14 and the eastbound off-ramp at exit 8.

- SR-14 treated highway runoff (CSWSDOT3)–Southernmost and largest of two outfalls located in the ditch on the southeast corner of the intersection of Southeast 164th Avenue and the SR-14 eastbound on-ramp. Approximately 5.9 acres drains to the outfall that includes 4.7 acres (80 percent) of treated highway runoff, 1.0 acres (17 percent) of untreated highway runoff, and 0.2 acres (3 percent) of City property drainage. The contributing area to this monitoring station includes the CSWSDOT2 station.

Monitoring stations were selected based on a preliminary desktop assessment and field feasibility investigation as described in the QAPP (Herrera 2021a) and Addendum (Herrera 2021b). The seven City monitoring stations were selected from 21 basins ranging in size from 31 to 942 acres. Basin size, land use, and stormwater treatment characteristics are summarized for each monitoring station in Table 1. Basin delineations are approximate and preliminary based on GIS automated delineations updated by Herrera staff.

Larger basins with substantial baseflow were prioritized to maximize the portion of the watershed monitored. Locations with safe public access and well-defined channels or pipe outfalls were selected to ensure that representative discharge measurements could be made. Beyond these metrics, basins representing a range of characteristics were prioritized in basin outfall selection. These characteristics included land use, septic and drywell density, and stormwater treatment technology density (Table 1). In addition, unique characteristics of interest were considered, such as a fish hatchery discharging to the Basin J outfall. Upstream and outfall monitoring stations were included in Basin R, which has one of the largest streams in the watershed (Fisher’s Creek), to compare water quality between the primarily undeveloped upstream basin to the primarily residentially developed lower basin. Three additional monitoring stations were added in the Addendum to characterize the water quality contributions from WSDOT facilities and included the I-205 outfall at the Columbia River, pre-treatment runoff from SR-14, and post-treatment runoff from SR-14. Further discussion of basin characteristics and their relationships to water quality within the watershed can be found in the *Data Analysis Methods* and *Regression Analysis* sections below.

Table 1. Columbia Slope Basin Characteristics.

Monitoring Station	Drainage Area (acres)	Impervious Area (%)	Residential (%)	Commercial and Industrial (%)	Agriculture (%)	Forest, Field, and Other (%)	Septic Density (count/acre)	Swale Density (count/ 10 acres)	Storm-water Pond Density (count/ 100 acres)
CSE1	144.2	42.6	98.9	0.3	0.0%	0.8	0.53	0.00	0.00
CSF1	160.8	37.7	83.6	2.5	0.7%	13.2	0.19	0.06	0.62
CSJ1	246.3	45.4	80.5	6.8	1.4%	11.3	0.03	0.12	0.41
CSO1	658.0	56.4	92.2	7.8	0.0%	0.0	0.02	0.15	0.30
CSP1	522.7	65.8	79.0	21.0	0.0%	0.0	0.18	1.49	0.00
CSR1	1152.2	37.5	55.4	11.9	11.0%	21.7	0.02	0.16	1.13
CSR2	621.5	25.1	40.8	7.6	14.9%	36.7	0.01	0.11	0.32
CSWSDOT1	427.4	60.1	73.2	25.4	0.4%	1.1	0.32	0.44	0.00
CSWSDOT2	2.0	89.0	0.0	100.0	0.0%	0.0	0.00	0.00	0.00
CSWSDOT3	12.8	72.8	62.7	37.3	0.0%	0.0	0.00	0.00	7.84

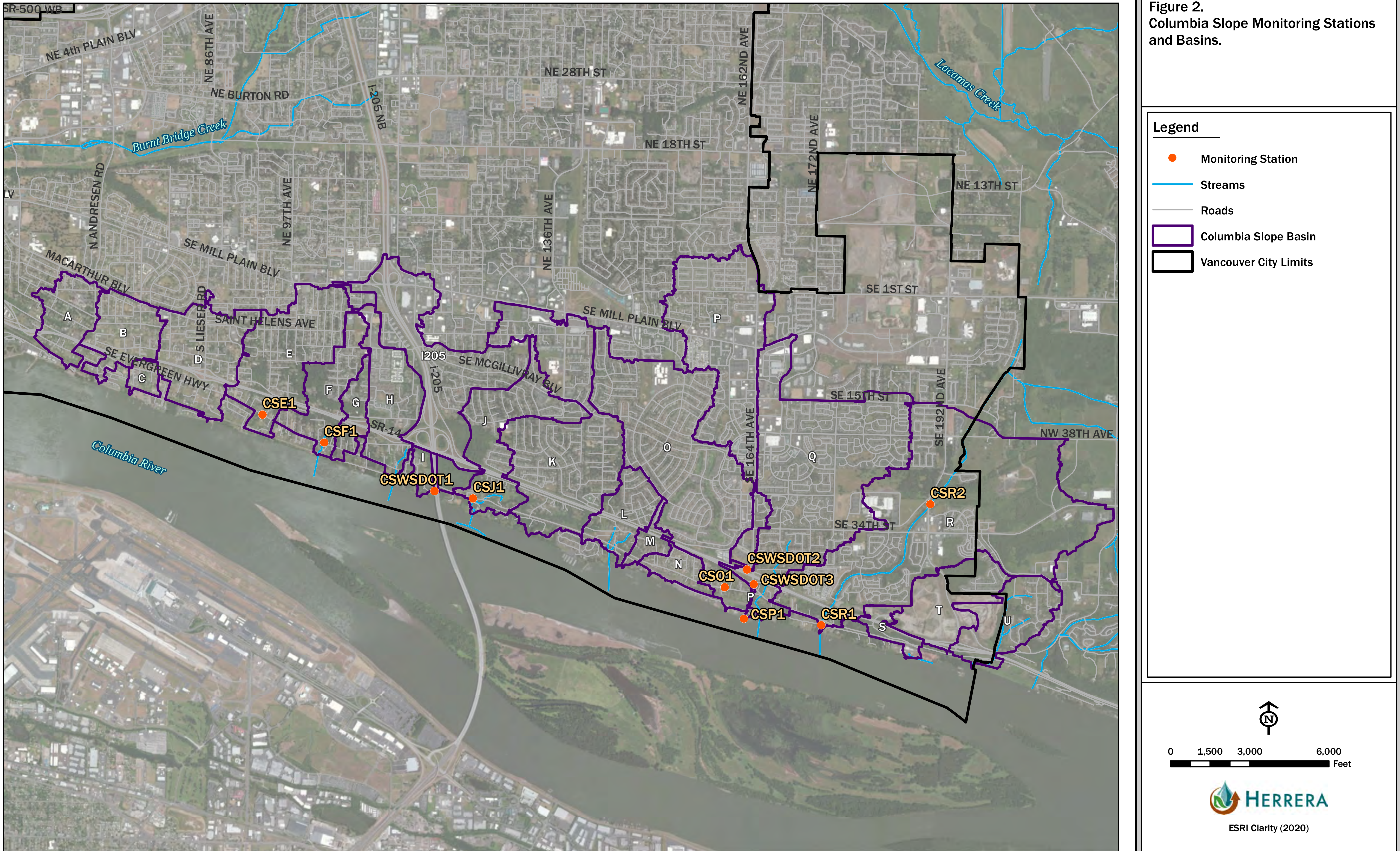

Figure 2.
Columbia Slope Monitoring Stations and Basins.

DATA COLLECTION METHODS

In situ water quality measurements were made at each of the monitoring stations by submerging the probe of a calibrated water quality multimeter. Herrera's YSI Pro DSS water quality meter was used for 11 events and a Hanna HI98194 multimeter was rented for one event. To ensure accuracy and minimize variability across multimeters, standardized field calibration procedures were followed (Herrera 2021a) including post-event calibration checks. The probe was placed in an area within the stream where the current was estimated to be at least 1 foot per second; or the probe was moved at a rate of at least 1 foot per second to avoid false low readings.

Upon arrival at a monitoring station, stream discharge measurements were made at each of the monitoring stations using a water current meter, field tape, and calibrated staff according to the Herrera Standard Operating Procedures for Instantaneous Discharge Measurement in Streams and Pipes (QAPP Appendix A; Herrera 2021a). Where possible, discharge was measured at circular pipes. The water quality probe was then submerged in the stream and left to stabilize for several minutes. The probe was placed upstream of all instream activity. When the meter's readings were stabilized, measurements were recorded for each water quality parameter on standardized field forms. Field duplicate measurements were collected once during each sampling event by re-submerging the multimeter in the stream during the sampling event.

Water samples were collected by hand from each of the monitoring stations using precleaned bottles supplied by the laboratories (ALS Environmental, and BSK Analytical Laboratories). Samples were collected from the center of the stream by wading into the channel and using an aseptic technique. Water samples were collected after the *in situ* measurements were recorded in order to ensure that both the *in situ* measurements and water sampling would occur upstream of all disturbance in the channel from monitoring activities. One field duplicate was collected from a different station during each sampling event by consecutively filling each pair of sample bottles and labeling the field duplicate samples bottles with a blind sample identification number.

The collected water samples were immediately stored in a cooler with ice at a temperature less than 6 degrees Celsius (°C). *E. coli* samples were dropped off at the BSK Analytical Laboratories location in Vancouver, Washington, immediately after the conclusion of each sampling event. All other samples were picked up by the ALS Environmental laboratory courier the morning after the sampling event. Chain-of-custody forms were completed and included with each batch of samples sent to the laboratory.

Table 2 summarizes the field and laboratory parameters and methods that were included in sampling. Sample preservation, maximum holding times, and analytical methods met federal requirements for the Clean Water Act (Federal Register 40 CFR Part 136; EPA 2011) and recommendations by Standard Methods (APHA et al. 1998).

Table 2. Field and Laboratory Parameter Methods.		
Parameter	**Method Description**	**Method Number[a] or Meter**
Field Parameters		
Water Discharge	Circular conduit, velocity-depth transect	Swoffer Model 2100-13
Temperature	*In situ* field reading	YSI ProDSS
pH	*In situ* field reading	YSI ProDSS
Specific conductance	*In situ* field reading	YSI ProDSS
Dissolved oxygen	*In situ* field reading	YSI ProDSS
Laboratory Parameters		
Turbidity	Nephelometric	EPA 180.1
Total suspended solids	Weighed filter	SM 18 2540D
Total phosphorus	Persulfate digestion, ascorbic acid	EPA 365.3
Total nitrogen	Kjeldahl digestion, ammonia-selective electrode with known addition, adding to nitrate+nitrite	EPA 351.4; SM 4500-NH3 G LL
Nitrate+nitrite nitrogen	Automated cadmium reduction	EPA 353.2; SM 18 4500-NO3 F
Hardness as CaCO3	Titrimetric	SM 2340C
Chloride	Ion chromatography	EPA 300.0
Total Cu, Pb, and Zn	Inductively coupled plasma mass spectrometry	EPA 200.8
SVOCs	Gas chromatography/mass spectrometry	EPA 8270D-LL
Organochlorine pesticides	Gas chromatography	EPA 8081B
E. coli bacteria	Quanti-Tray	SM 9223B Q-tray

[a] SM = APHA Standard Methods (APHA et al. 1998) EPA = US Environmental Protection Agency Method Code

Cu = copper Pb = lead Zn = zinc CaCO3 = calcium carbonate

SVOCs = Semivolatile organic compounds

As summarized in the QAPP (Herrera 2021a) and Addendum (Herrera 2021b), these parameters are consistent with those measured under similar City monitoring programs. Several additions to the parameter list were included in this monitoring program including SVOCs and organochlorine pesticides which were included to evaluate urban and highway runoff pollutant contribution during storm flow events.

Data Analysis Methods

This section includes a subsection describing the procedures used for the computation of summary statistics, regression analysis, and comparison of results to the applicable water quality criteria. The results from these analyses are summarized in the *Results* section.

To better evaluate and describe the concentrations and relative toxicities of certain polycyclic aromatic hydrocarbons (PAHs) and pesticides, individual parameters within each specified group were summed as follows. Per Ecology (WAC 173-340-708(8)(e)), the human health toxicity of carcinogenic PAHs (cPAHs) is evaluated using toxicity equivalency factors (TEFs), which are estimates of toxicity relative to the reference cPAH chemical, benzo(a)pyrene (Ecology 2015). For each cPAH evaluated, the concentration observed in a sample was multiplied by its listed TEF value, the product of which is considered the toxic equivalent concentration (TEQ) for that cPAH. TEQs for individual cPAHs were then summed for each sample and this total is reported as the value observed for total cPAHs (Ecology 2015). Additionally, DDx isomer totals were calculated for each sample as the sum of all isomers of dichlorodiphenyldichloroethane (DDD), dichlorodiphenyldichloroethylene (DDE), and dichlorodiphenyltrichloroethane (DDT). All summed values were calculated using only detected values (non-detect values assumed as zero), and for groups where no detected values were measured, half of the maximum reporting limit in the specified group was used instead. All final sum values were considered as 'detected' values for further calculation and presentation of summary statistics.

When the proportion of undetected values exceeded 50 percent in the data, half the reporting limit was used in calculations of summary statistics. Use of half the reporting limit for undetected values is consistent with data management practices used in other City monitoring programs and generally results in less bias than other estimation methods. When the proportion of undetected values was less than 50 percent (but greater than zero) in the data, the R statistical package NADA version 1.6-1.1 (Lee 2020) was used to estimate undetected values using the Regression on Order Statistics (RoS) method (Lee and Helsel 2005; Helsel and Cohn 1988) which has been shown to be one of the most accurate estimation techniques for left-censored analytical chemistry data. Summary statistics using these values were then calculated and compiled for each of the monitoring parameters. Minimum and maximum values were reported using either the detected value or the reporting limit if not detected (Appendix C).

Computation of Summary Statistics

In order to assess water quality conditions at each of the sample locations, R software packages (R Core Team 2021) were used to calculate the following summary statistics from the compiled data (Appendix C):

- Minimum
- Mean
- Geometric mean (*E. coli* only)
- Median
- 25th percentile
- 75th percentile
- 90th percentile
- Maximum

Seasonal and Spatial Patterns

In addition to the tabular data summaries, graphical data summaries consisting of “line” plots and “box and whisker” plots were generated. The line plots were generated to present the seasonal pattern of recent base and storm flow data collected at each station over the course of the monitoring period. The box and whisker plots were generated to present the following information for each station: the minimum and maximum values as the lower and upper whiskers, respectively; the median and mean as the black line and red point inside the box, respectively; and the 25th and 75th percentiles of the data as the lower and upper boundaries of the box, respectively. For *E. coli*, the 90th percentile of the data is also shown on the plot as a black triangle and the geometric mean is presented as a red diamond rather than the arithmetic mean for comparison to water quality criteria. Box and whisker plots displaying storm and base flow data at each station were produced for comparison.

To identify significant differences between storm and base flow concentrations, a Wilcoxon Signed Rank Test (Helsel and Hirsch 2002) was applied to the respective data for each station. Statistical significance in these tests was assessed based on an alpha level of 0.05. The p-values resulting from this test are displayed below the data in the box and whisker plots. If there was a significant difference between concentrations for base and storm events (i.e., the p-value is less than the alpha level of 0.05), the p-value is shown in red text. This indicates that the storm and base event concentrations are significantly different than one another for the given station and parameter evaluated.

Spatial patterns in parameter concentrations were evaluated using the Friedman Test along with a pairwise comparison of sampled stations. The Friedman test is a nonparametric analogue to a blocked analysis of variance (ANOVA) test that was used to determine if there were significant differences in water quality among stations (Helsel and Hirsch 2002). Using a blocked test, differences in water quality among the stations could be assessed with more statistical power because the noise (or variance) associated with sampling over a range of climatic and hydrologic conditions can be controlled for in the analysis. Only stations which were sampled for all events were analyzed. If a significant difference was detected, a nonparametric pairwise comparison test was conducted to determine which monitoring sites were significantly different from the others (Helsel and Hirsch 2002). The pairwise comparison results are shown as letters below the plotted data for each station in the box and whisker plots to the left of the page, where stations without common letters are significantly different and stations with common letters were not found to be significantly different. Statistical significance for this test was assessed at an alpha level of 0.05.

Correlation and Multiple Regression

Multiple regression was used to identify basin characteristics that have a statistically significant influence on water quality at sampled stations to inform the prioritization of basins for stormwater management. Multiple regression can be used to develop statistical models for predicting how a dependent variable (i.e., water quality parameter of interest) will vary in response to variations in one or more independent/explanatory variables (i.e., basin characteristics).

Basin attributes used for the statistical analysis included existing basin characteristics for which GIS data were available and which were expected to influence surface water quality. Basin characteristics used, methodology and data sources are listed in Table 3.

Basins draining to each outfall were delineated using a hydrologic analysis of a bare-earth LiDAR Digital Terrain Model (DTM). Sinks in the DTM were filled and flow direction was calculated based on the D8 flow method, where flow direction is assigned to the steepest downslope neighbor. The flow direction surface was used to calculate flow accumulation for each cell in the DTM and identify pour points for the basin analysis. Subsequently the basin analysis identifies the contributing area above each pour point by finding all sets of hydrologically connected cells and the ridgelines between basins. Contributing area draining to each monitoring station were delineated by hand in ArcGIS using stormwater infrastructure data, aerial imagery, and elevation data.

The 20 classes of land cover in the National Land Cover Database (NLCD) database were grouped into the four categories used by Herrera to estimate loadings of toxic chemicals in surface runoff to Puget Sound for Ecology (Herrera 2011). Impervious surfaces were added as land cover categories because they are known to affect surface water quality. Land cover categories were grouped in the following manner:

- Commercial/Industrial: NLCD 24 (developed–high intensity)
- Residential: NLCD 21–23 (developed land: open space, low intensity and medium intensity)
- Agriculture: NLCD Values 81–82 (hay/pasture and cultivated crops)
- Forest/Field/Other (all others)

Stormwater and facility density was used as the metric, rather than percent of the subbasin served by each facility group, because data on the drainage area for each facility were not available.

To identify which basin characteristics should be included in the regression analysis, a semi-variogram (correlation matrix) was produced to determine if statistically significant relationships (using Kendall's Tau) exist between basin characteristics. Significant relationships may indicate that more than one watershed attribute represents some underlying characteristic, such as the statistically significant relationship between industrial/commercial land use and impervious area (both represent urban development) found during the analysis.

Table 3. Columbia Slope Basin Characteristics Considered for Regression Analysis.			
Basin Characteristic	**Metric**	**Methodology**	**Data Source**
Contributing area draining to each monitoring station	Area	Area draining to each monitoring station was delineated by hand in GIS.	Stormwater infrastructure (City), aerial imagery, LiDar (Clark County LiDAR Project Spring 2013-Reflight)
Land cover: ● Residential ● Commercial/ Industrial ● Agriculture ● Forest/Field/ Other	Percent cover	The percentage of each landcover type was calculated for each basin. The total area of each landcover type was calculated by multiplying its percent coverage by the total area of the basin.	NLCD 2019 Land Cover Conterminous United States
Land cover: Impervious	Percent cover	The NLCD impervious area data set assigns a cell value of 0%-100% for each cell. The percent of pervious area for each basin as calculated by finding the mean values of all cells within each basin boundary.	NLCD 2019 Impervious Surface Conterminous United States
Septic system density	Number per acre	Summed for each basin and divided by basin area to calculate density.	Clark County
Stormwater treatment densities and types	Number per acre	Summed for each basin and divided by basin area to calculate density.	City of Vancouver
Drywell densities	Number per acre	Summed for each basin and divided by basin area to calculate density.	City of Vancouver
Roadway density	Linear miles	County roads reclassified into Highway and Surface streets, intersected with the watersheds layer, and then dissolved by the watershed ID and road classification. A 'Linear Miles' field was added to the dissolved road layer and populated with a calculate geometry function.	Clark County
Stream slope	Feet per mile, Percent	The highest and lowest elevations of each stream was calculated by extracting values from a LiDAR derived DEM to the stream start and end points. Stream slope was calculated by dividing the difference in elevation of the stream start and end points by the total length of the stream.	Stream layer, LiDar (Clark County LiDAR Project Spring 2013-Reflight)

Multiple regression analysis was used to assess the relationship between multiple basin characteristics and the water quality parameters. Four explanatory (predictor) variables were considered in the multiple regression analysis:

- Percent industrial and commercial areas
- Septic system density

- Density of swales, bioretention, filter strips (hereafter referred to as ‘swale density’)
- Stormwater pond density

A stepwise selection technique was used to determine which combinations of the four explanatory variables are best for predicting each of the dependent water quality parameters. A distinct model with differing explanatory variables was produced for each water quality parameter under base flow conditions and storm flow conditions. The resultant model parameters are summarized in the results section. Assumptions of normality and homoscedasticity (equal variance) were tested for each final model to check adherence to statistical requirements but corrections (i.e., data transformations or use of a different model more appropriate for data) could not be implemented for those models which did not meet the assumptions due to the limited scope of this project.

For each model, the standardized regression coefficients, or beta slopes, of the selected explanatory variables were calculated. Beta slopes are calculated by dividing the slope of the variable by its standard deviation to normalize the value. Higher magnitudes of beta slopes indicate greater relative influence of the explanatory variable within the model. Positive beta slopes indicate positive correlation with the parameter concentration, while negative beta slopes indicate negative correlation with parameter concentration. Significance of the beta slope for each explanatory variable was determined by comparison of the p-value associated with the slope with the alpha level (0.05). Explanatory variables with significant slopes are the most meaningful variables in the model for predicting the parameter concentration. In addition to the beta slope and significance of the slope, which are defined for each explanatory variable within the model, the adjusted R-squared value was calculated for each model. The adjusted R-squared value for the multiple regression model indicates the percent of variance of the median parameter concentration explained by all explanatory variables. Higher adjusted R-squared values indicate better 'goodness of fit' of the model. R software (R Core Team 2021) and related packages were used to perform and summarize these statistics from the compiled data.

There are two key limitations to the multiple regression analysis. First, the monitoring data collected for each main stem stream basin are dependent on all upstream monitoring stations. There were two sets of nested stations in the project area (CSR2 drains to CSR1 and CSWSDOT2 drains to CSWSDOT3) but a nesting evaluation determined that the impact was minimal. Second, the stormwater management predictor variables in the model are based solely on density and do not include the size of area treated; for example, the area treated by a dry well is typically much smaller than the area treated by an infiltration facility. Including the area treated in future analysis may improve predictions of water quality variables.

Comparison to Water Quality Criteria

In order to identify priority basins for stormwater retrofits within the Columbia Slope watershed, monitoring data were compared to regulatory criteria from the following sources:

- Water Quality Standards for Surface Waters of the State of Washington (WAC 173 201A, updated September 2021) (Ecology 2019)

- Ambient Water Quality Criteria Recommendations: Rivers and Streams in Nutrient Ecoregion I (EPA 2001)

Surface water quality criteria and project action limits are included in Table 4. These criteria include acute and chronic criteria that are applied to storm and base flow event samples, respectively, for project action criteria. Acute criteria are based on a 1-hour average concentration not to be exceeded more than once every three years on average for metals or an instantaneous concentration not to be exceeded at any time for other parameters. Chronic criteria are based on a 4-day average concentration not to be exceeded more than once every three years. These criteria were calculated using a hardness concentration of 50 mg/L and a pH of 7.0 from the Washington State Department of Ecology (Ecology) Water Quality Calculator. General criteria are also included to protect salmonid spawning and rearing for temperature (based on a 7-day maximum), dissolved oxygen (based on a 1-day minimum), pH, and turbidity (based on a 5 NTU increase over a background) and to protect water contact recreation for *E. coli* (based on single sample values).

Various criteria were applied to develop project action limits in the QAPP for storm and base flow event samples (Herrera 2021a). In general, chronic and acute water quality criteria were used for base and storm flow action limits, respectively. In cases where the analytical reporting limit was higher than the relevant water quality criterion, the reporting limit was used for the project action limit. Parameters analyzed for this monitoring program that did not have relevant water quality criteria or project action limits including total suspended solids and several individual SVOCs were omitted from Table 4.

Surface water quality criteria also include National Recommended Water Quality Criteria for protection of human health from consumption of water and organisms (EPA 2020). These criteria were used as project action criteria for both storm and base flow event sample values when there were no freshwater life criteria for a parameter. If the parameter reporting limit exceeds the human health criterion, then the reporting limit was used for the project action limit.

Total phosphorus and total nitrogen criteria are based on reference conditions in Ecoregion I (Willamette Valley) determined by EPA (2001) using the 25th percentile of all data collected from 1990 to 2000 in the ecoregion. This source also includes a reference condition for turbidity at 4.25 NTU, which was rounded up to 5 NTU to represent background conditions for comparison to surface water quality standards.

Table 4. Water Quality Criteria and Project Action Limits Used for Comparison to Data Collected for the Columbia Slope Water Quality Monitoring Project.

Parameter	Surface Water Quality Criteria[a]			Project Action Limit	
	Aquatic Life–Freshwater		Protection of Human Health		
	Acute	Chronic		Storm Flow	Base Flow
Field Measurements					
Temperature	17.5°	17.5°C	–	17.5°C	17.5°C
pH	6.5–8.5 S.U.	6.5–8.5 S.U.	–	6.5–8.5 S.U.	6.5–8.5 S.U.
Dissolved oxygen	8.0 mg/L	8.0 mg/L	–	8.0 mg/L	8.0 mg/L
Conventionals, Metals, and Bacteria					
Turbidity	–	–	–	10 NTU	10 NTU
Nitrate+nitrite nitrogen	–	–	10 mg/L	10 mg/L	10 mg/L
Total nitrogen (TN)	–	–	–	0.31 mg/L	0.31 mg/L
Total phosphorus	–	–	–	0.047 mg/L	0.047 mg/L
Chloride	860 mg/L	230 mg/L	–	860 mg/L	230 mg/L
Copper (total)	8.86 µg/L	6.28 µg/L	1300 µg/L	8.86 µg/L	6.28 µg/L
Lead (total)	30.14 µg/L	1.174 µg/L	–	30.14 µg/L	1.174 µg/L
Zinc (total)	63.61 µg/L	58.09 µg/L	1000 µg/L	63.61 µg/L	58.09 µg/L
E. coli bacteria	–	–	–	320 MPN/100 mL	320 MPN/100 mL
Polycyclic Aromatic Hydrocarbons (PAHs)[b]					
Acenaphthene	–	–	30 µg/L	30 µg/L	30 µg/L
Anthracene	–	–	100 µg/L	100 µg/L	100 µg/L
Benzo(a)anthracene	–	–	0.00016 µg/L	0.2 µg/L	0.2 µg/L
Benzo(a)pyrene	–	–	0.000016 µg/L	0.2 µg/L	0.2 µg/L
Benzo(b)fluoranthene	–	–	0.00016 µg/L	0.2 µg/L	0.2 µg/L
Benzo(k)fluoranthene	–	–	0.0016 µg/L	0.2 µg/L	0.2 µg/L
Chrysene	–	–	0.016 µg/L	0.2 µg/L	0.2 µg/L
Dibenz(a,h)anthracene	–	–	0.000016 µg/L	0.2 µg/L	0.2 µg/L
Fluoranthene	–	–	6 µg/L	6 µg/L	6 µg/L
Fluorene	–	–	10 µg/L	10 µg/L	10 µg/L
Indeno(1,2,3-cd)pyrene	–	–	0.00016 µg/L	0.2 µg/L	0.2 µg/L
Pyrene	–	–	8 µg/L	8 µg/L	8 µg/L
Phthalates[b]					
Bis(2-ethylhexyl) Phthalate	–	–	0.045 µg/L	1 µg/L	1 µg/L
Butyl Benzyl Phthalate	–	–	0.013 µg/L	0.2 µg/L	0.2 µg/L
Diethyl Phthalate	–	–	200 µg/L	200 µg/L	200 µg/L
Dimethyl Phthalate	–	–	600 µg/L	600 µg/L	600 µg/L
Di-n-butyl Phthalate	–	–	8 µg/L	8 µg/L	8 µg/L

Table 4 (continued). Water Quality Criteria and Project Action Limits Used for Comparison to Data Collected for the Columbia Slope Water Quality Monitoring Project.					
	Surface Water Quality Criteria[a]				
	Aquatic Life–Freshwater		Protection of Human Health	Project Action Limit	
Parameter	**Acute**	**Chronic**		**Storm Flow**	**Base Flow**
Chlorinated Organics[b]					
1,2-Dichlorobenzene	–	–	700 µg/L	700 µg/L	700 µg/L
1,3-Dichlorobenzene	–	–	2 µg/L	2 µg/L	2 µg/L
1,4-Dichlorobenzene	–	–	200 µg/L	200 µg/L	200 µg/L
2,4,6-Trichlorophenol	–	–	0.25 µg/L	0.5 µg/L	0.5 µg/L
2,4-Dichlorophenol	–	–	10 µg/L	10 µg/L	10 µg/L
2-Chloronaphthalene	–	–	100 µg/L	100 µg/L	100 µg/L
2-Chlorophenol	–	–	15 µg/L	15 µg/L	15 µg/L
3,3′-Dichlorobenzidine	–	–	0.0031 µg/L	2.0 µg/L	2.0 µg/L
4-Chloro-3-methylphenol	–	–	36 µg/L	36 µg/L	36 µg/L
Bis(2-chloroethyl) Ether	–	–	0.02 µg/L	0.2 µg/L	0.2 µg/L
Hexachlorobenzene	–	–	0.000005 µg/L	0.2 µg/L	0.2 µg/L
Hexachlorobutadiene	–	–	0.01 µg/L	0.2 µg/L	0.2 µg/L
Hexachlorocyclopenta-diene	–	–	1 µg/L	1 µg/L	1 µg/L
Hexachloroethane	–	–	0.02 µg/L	0.2 µg/L	0.2 µg/L
Pentachlorophenol	9.07 µg/L	5.73 µg/L	0.002 µg/L	9.07 µg/L	5.73 µg/L
Other Semivolatile Organic Compounds (SVOCs)[b]					
1,2-Diphenylhydrazine	–	–	0.01 µg/L	0.2 µg/L	0.2 µg/L
2,4-Dimethylphenol	–	–	85 µg/L	85 µg/L	85 µg/L
2,4-Dinitrophenol	–	–	30 µg/L	30 µg/L	30 µg/L
2,4-Dinitrotoluene	–	–	0.039 µg/L	0.2 µg/L	0.2 µg/L
2-Methyl-4,6-dinitrophenol	–	–	3 µg/L	3 µg/L	3 µg/L
Isophorone	–	–	27 µg/L	27 µg/L	27 µg/L
Nitrobenzene	–	–	30 µg/L	30 µg/L	30 µg/L
N-Nitrosodi-n-propylamine	–	–	0.0044 µg/L	0.2 µg/L	0.2 µg/L
Phenol	–	–	9000 µg/L	9000 µg/L	9000 µg/L
Organochlorine Pesticides[b]					
2,4-DDD	1100 mg/L	1 mg/L	0.0079 mg/L	1100 mg/L	1 mg/L
2,4-DDE	1100 mg/L	1 mg/L	0.00088 mg/L	1100 mg/L	1 mg/L
2,4-DDT	1100 mg/L	1 mg/L	0.0012 mg/L	1100 mg/L	1 mg/L
4,4-DDD	1100 mg/L	1 mg/L	0.0079 mg/L	1100 mg/L	1 mg/L
4,4-DDE	1100 mg/L	1 mg/L	0.00088 mg/L	1100 mg/L	1 mg/L
4,4-DDT	1100 mg/L	1 mg/L	0.0012 mg/L	1100 mg/L	1 mg/L

Table 4 (continued). Water Quality Criteria and Project Action Limits Used for Comparison to Data Collected for the Columbia Slope Water Quality Monitoring Project.					
	Surface Water Quality Criteria[a]			Project Action Limit	
	Aquatic Life–Freshwater		Protection of Human Health		
Parameter	Acute	Chronic		Storm Flow	Base Flow
Organochlorine Pesticides (continued)[b]					
Aldrin	2500 mg/L	1.9 mg/L	0.000041 mg/L	2500 mg/L	1.9 mg/L
alpha-BHC	–	–	0.048 mg/L	1 mg/L	1 mg/L
alpha-Chlordane[c]	2400 mg/L	43 mg/L	0.022 mg/L	2400 mg/L	43 mg/L
beta-BHC	–	–	1.3 mg/L	1.3 mg/L	1.3 mg/L
Organochlorine Pesticides (continued)[b]					
Chlordane	2400 mg/L	43 mg/L	0.022 mg/L	2400 mg/L	43 mg/L
Chlorpyrifos	83 mg/L	41 mg/L	–	83 mg/L	41 mg/L
Dieldrin	2500 mg/L	1.9 mg/L	0.00007 mg/L	2500 mg/L	1.9 mg/L
Endosulfan I[d]	220 mg/L	56 mg/L	–	220 mg/L	56 mg/L
Endosulfan II[d]	220 mg/L	56 mg/L	–	220 mg/L	56 mg/L
Endosulfan Sulfate	–	–	9000 mg/L	9000 mg/L	9000 mg/L
Endrin	180 mg/L	2.3 mg/L	2 mg/L	180 mg/L	2.3 mg/L
Endrin Aldehyde	–	–	34 mg/L	34 mg/L	34 mg/L
gamma-BHC (Lindane)	2000 mg/L	80 mg/L	430 mg/L	2000 mg/L	80 mg/L
gamma-Chlordane[c]	2400 mg/L	43 mg/L	0.022 mg/L	2400 mg/L	43 mg/L
Heptachlor	520 mg/L	3.8 mg/L	0.00034 mg/L	520 mg/L	3.8 mg/L
Heptachlor Epoxide	520 mg/L	3.8 mg/L	0.0024 mg/L	520 mg/L	3.8 mg/L
Hexachlorobenzene	–	–	0.005 mg/L	1 mg/L	1 mg/L
Hexachlorobutadiene	–	–	10 mg/L	10 mg/L	10 mg/L
Hexachloroethane	–	–	20 mg/L	20 mg/L	20 mg/L
Toxaphene	730 mg/L	0.2 mg/L	0.032 mg/L	730 mg/L	100 mg/L

°C degrees Celsius mg/L milligrams per liter NTU Nephelometric turbidity units µg/L micrograms per liter
ng/L nanograms per liter MPN most probable number DDD Dichlorodiphenyldichloroethane
DDE Dichlorodiphenyldichloroethylene, DDT Dichlorodiphenyltrichloroethane BHC Benzene Hexachloride

[a] Washington State human health criteria for the consumption of water and organisms, EPA-approved human health criteria under 40 CFR 131.45; National recommended water quality criteria for the protection of aquatic organisms and protection of human health based on consumption of organisms from Section 304 of the Clean Water Act; and Water Quality Standards for Surface Waters of the State of Washington, Chapter 173-201A WAC. Washington State Department of Ecology Water Quality Calculator with anticipated hardness concentration of 50 mg/L and pH of 7.

[b] SVOCs and OC Pesticides are analyzed only during storm monitoring events.

[c] Criteria for chlordane are used for alpha-chlordane and gamma-chlordane.

[d] Criteria for endosulfan are used for endosulfan I and endosulfan II.

Monitoring Activities

As specified in the QAPP (Herrera 2021a) and Addendum (Herrera 2021b), monitoring was conducted at all 10 sites during one day for each of 12 sampling events. At one site, CSWSDOT2, make-up samples were collected on separate days during two events. Sampling generally progressed from CSWSDOT2 to CSWSDOT3 and then from east to west from CSR2 to CSE1. The monitoring events are summarized in Table 5. Storm flow monitoring occurred from October to March on days when the following criteria for storm event conditions were met:

- At least 0.30 inch of rain was predicted to occur in daylight hours of the sampling date and at least 0.10 inch of rain occurred before sampling began.

Base flow sampling occurred according to schedule with the following criterion for baseflow conditions:

- Less than 0.04 inch of rain in the previous 24 hours.

Rainfall data from the Post Office Rain Gage (Portland BES 2020) was checked before monitoring to ensure criteria were met.

Table 5. Sampling Events for the Columbia Slope Water Quality Monitoring Project.

Event ID	Sample Date	Sample Event Type	Weather Season[a]	Sample Duplicate Station	Antecedent Dry Period (days)[b]	Storm Depth (inches)[c]
1	6/10/2021	Base	Dry	CSR1	3.7	0
2	7/15/2021	Base	Dry	CSJ1	31	0
3	8/26/2021	Base	Dry	CSF1	72	0
4	10/26/2021	Storm	Wet	CSP1	1.0	0.51
	11/4/2021[d]				2.1	0.51
5	11/22/2021	Base	Wet	CSE1	3.2	0
6	12/9/2021	Storm	Wet	CSO1	0.8	0.16[e]
	12/15/2021[d]				1.4	0.59
7	1/3/2022	Storm	Wet	CSWSDOT3	3.1	2.24
8	1/12/2022	Base	Wet	CSR2	1.1	0
9	1/20/2022	Storm	Wet	CSE1	1.0	0.79
10	2/17/2022	Base	Wet	CSWSDOT1	2.8	0
11	2/28/2022	Storm	Wet	CSWSDOT2	2.2	2.17
12	3/2/2022	Storm	Wet	CSWSDOT1	0.4	1.25

[a] Dry and wet weather season are defined as June through September and October through April, respectively.

[b] Antecedent dry period was defined as the number of days with less than 0.04 inch of rain in a 6-hour period that preceded the event date (Portland BES 2022).

[c] Storm depth was determined as the total precipitation amount measured over the course of the targeted storm event (as defined by storm criteria) or base flow event (as determined by base flow sampling criteria) (Portland BES 2022).

[d] Make-up storm sampling day for CSWSDOT2, due to no flow at this site on the original event sampling day.

[e] The QAPP criteria for storm monitoring were not met because only 0.07 inches or rain occurred in the previous 24 hours. Precipitation was observed by field staff in the morning and flow conditions observed in the field appeared consistent with past storm flow monitoring events, but due to the posting delay at the Post Office HYDRA rain gage field staff could not determine that the precipitation was insufficient to reach the QAPP criteria.

DATA QUALITY REVIEW

A quality assurance review was performed for all field and laboratory data collected during the monitoring period, as specified in the QAPP (Herrera 2021a). The quality assurance review findings were presented in an interim update report for each sampling event (Appendix A). In general, the data quality for all parameters was considered acceptable based on holding time, reporting limit, method blank, control standard, laboratory duplicate, and field duplicate criteria specified in the QAPP. However, as summarized below, some quality control issues were identified in the data. Measurement quality objectives established in the QAPP, data quality criteria exceedances, and laboratory quality assurance review worksheets are presented in Appendix B. Data quality review findings are summarized below for field and laboratory data.

FIELD DATA

The water quality meter was calibrated and then checked before and after each event as documented in the calibration logs provided as an attachment to the Interim Reports (Appendix A). With the exception of one discharge field measurement at station CSF1 on December 9, 2021, all field parameters were measured. In general, *in situ* measurements and continuous temperature logging met all data measurement quality objectives with a few exceptions provided in Appendix B and summarized in Table B-2. Stream discharge was the only field measurement commonly flagged as estimated due to either excessive bank vegetation or low stream flow depth interfering with accurate velocity readings.

LABORATORY DATA

All scheduled samples were collected, the laboratory reported all parameters, and all laboratory methods were consistent with those specified in the QAPP (Herrera 2021a). No method blanks analyzed contained levels of target parameters above the reporting limit with one exception. Laboratory matrix spike samples met control limits except for four chloride samples at monitoring stations CSE1 and CSO1. All laboratory duplicate samples met the established control limits with few exceptions for parameters including total copper, turbidity, and several organochlorine pesticide confirmation samples. Field duplicate samples generally met the established control limits except for a number of sample results for parameters including *E. coli*, hardness, total lead, and total nitrogen.

Exceptions to QAPP specified data quality criteria and resulting data qualifiers, if applicable, are detailed in the individual Interim Reports (Appendix A) and are presented in the Quality Assurance Review in Appendix B.

Data Quality Summary

In general, data quality criteria were met with relatively few exceptions, as detailed in the individual Interim Reports (Appendix A) and in the Data Quality Review Results (Appendix B).

The percentage of estimated (J flag) and rejected (R flag) values are summarized in Table 6 by parameter, excluding field duplicate samples. In addition to the reasons discussed in the above subsections, some results (primarily total lead and multiple SVOCs and organochlorine pesticides) were flagged as estimated due to detections below the reporting report. SVOC and organochlorine pesticide parameters are presented in Table 6 as total qualified percentage of all parameters within the respective groups.

Table 6. Percentages of Data Qualified as Estimated (J) or Rejected (R) Values.

Parameter	Base Flow		Storm Flow	
	J (%)	R (%)	J (%)	R (%)
Temperature	0	0	0	0
pH	0	0	0	0
Dissolved Oxygen	0	0	0	0
Specific Conductance	0	0	17	0
Turbidity	3	0	5	0
Total Suspended Solids	0	0	5	0
Nitrate+Nitrite Nitrogen	2	0	7	0
Total Nitrogen	3	0	8	0
Total Phosphorus	0	0	5	0
Hardness as CaCO3	2	0	7	0
Chloride	0	0	13	0
Total Copper	2	0	5	0
Total Lead	15	0	5	0
Total Zinc	20	0	20	0
E. coli Bacteria	2	0	5	0
Semivolatile Organic Compounds	NS	NS	37	0
Organochlorine Pesticides	NS	NS	12	0

NS = Not sampled. Semivolatile organic compounds and organochlorine pesticides were only sampled during storm flow events.

RESULTS

Key results are summarized below, followed by a detailed discussion by parameter. Regression analysis results are also presented and discussed.

SUMMARY OF RESULTS

Seasonal Patterns

The concentrations of many water quality parameters measured in the Columbia Slope varied seasonally over this 2021-2022 monitoring period. Key conclusions related to seasonal patterns include:

- **Relatively Consistent Seasonal Trends**–Where seasonal trends were found for a parameter, the trend was consistent among most stations with some exceptions at CSJ1, CSR2, and the WSDOT stations likely due to differing basin characteristics.

- **Summer Trends**–Warmer temperatures, low flow, and low discharge rates in the summer base flow events were generally associated with lower DO, chloride, and copper concentrations for most stations and higher TSS, lead, and bacteria concentrations.

- **Winter Trends–**In contrast, the inverse of the summer trends was observed with lower temperatures, higher flow, and greater discharge rates in the winter months. Additionally, storm flow turbidity and TSS increased over the wet season likely driven by increasing storm flow rates over this period.

- **Limited Seasonal Variation**–Parameters with relatively stable concentrations at most stations throughout the monitoring period included pH, conductivity, all nutrients, hardness, and zinc.

Storm-only parameters including SVOCs and organochlorine pesticides were not evaluated for seasonal patterns, as sampling of these parameters was restricted to one season.

Storm and Base Flow Comparison

To understand both the influence of storm flow on water quality and the relative contribution of pollutants during storm flow, base flow concentrations were compared to storm flow concentrations using the Wilcoxon Rank Sum test.

The results for most parameters reflected the inherent variability in storm and base flow contributions:

- **Storm Flow** tended to have cooler water and lower pH, with higher concentrations of DO, turbidity, TSS, all total metals, and *E. coli*. Higher concentrations are expected for these water quality indicators, due to mobilization of pollutants from higher flow rates, which are associated with greater weathering, erosion, and sediment transport capacity. TSS concentrations are positively associated with heavy metals and other pollutants due to the adsorption of metals and other pollutants to fine solids. Lower pH potentially indicates greater input of acidic pollutants during storm flow, and the naturally low pH of clean rain (5.0 to 5.5) can also be a contributing factor. *E. coli* concentrations in storm flow were significantly greater at most stations and more variable than base flow likely due to mobilization from surfaces during storm events and variable mixing of storm and base flows, respectively.

- **Base Flow** stations tended to have warmer, more basic water (higher pH), with greater measurements of conductivity, nitrate+nitrite, total nitrogen, and hardness. Higher conductivity during base flow is expected, as groundwater typically has higher conductivity and warmer temperatures cause ions to become more mobile. Similarly, increased hardness (as a measure of dissolved minerals) can be caused by warmer temperatures that increase the solubility of most salts. Significantly higher levels of total nitrogen and nitrate+nitrite at most stations during base flow may be a result of septic tanks providing inadequate treatment, though the positive correlations between nitrogen and septic system density were not found to be statistically significant.

Water quality did not differ between base and storm events at station CSR2 for many parameters, likely in part due to base flow samples taken only during the wet season which predictably compare more favorably to storm flow samples. However, the station drains a wetland and as such, with biogeochemical processes differing from other stations, this may pose a moderating role for any expected differences in water quality.

PAHs, phthalates, other SVOCs and organochlorine pesticides were not considered in this comparison since they were only sampled during storm events.

Water Quality Criteria Comparison

Water quality in the Columbia Slope watershed exceeded applicable criteria for several monitored parameters, particularly during storm flow events. Water quality standard exceedances during the monitoring period are summarized below, starting with parameters analyzed during both base and storm flow events:

- **pH**: The pH criterion (6.5 to 8.5) was not met during any base flow event at station CSR2, which was only sampled during wet season base flow events. Values below 6.5 were also measured during storm flow events at monitoring stations CSR2, CSWSDOT2, and CSWSDOT3.

- **Dissolved Oxygen:** The dissolved oxygen criterion (minimum value shall exceed 8.0 mg/L) was not met during one storm event at station CSR2, likely due to the groundwater-fed natural wetland located immediately upstream of this monitoring station. Because the dissolved oxygen criterion was met at the downstream Fishers Creek station (CSR1), the low levels are of lesser concern regarding inputs into the Columbia River, where dissolved oxygen is only a category 2 listed (water of concern) parameter on the 303(d) list.

- **Turbidity:** The turbidity criterion was not met during at least one storm flow event at all stations except CSF1 and CSJ1. It was exceeded most frequently during storm events at the CSWSDOT2 and CSWSDOT3 (6 times); CSWSDOT1 (4 times); and CSR1 (3 times). Across all stations, 40 percent of storm flow samples exceeded the turbidity criterion. No base flow samples exceeded the applicable criterion at any station.

- **Nutrients:** Nutrient criteria for total nitrogen and total phosphorus recommended by EPA (2001) for streams in the Willamette Valley were not met for any base or storm flow sample at any station, indicating potential impairment from eutrophication (nutrient enrichment) across the Columbia Slope. The EPA criterion for nitrate+nitrite was exceeded at least once at each station but never exceeded state drinking water or groundwater standards.

- **Chloride:** No chloride concentrations exceeded acute or chronic criteria at any station, but spikes were observed at WSDOT stations during cold winter storm events likely driven by highway deicer application.

- **Metals:** The acute metals criteria were not met for copper during at least one storm flow event at CSO1, CSR1, and all WSDOT stations; lead during at least one storm flow event at CSE1, CSO1, CSP1, CSR1, and all WSDOT stations; and zinc during at least one storm flow event at CSO1, CSP1, CSR2, and all WSDOT stations. No acute or chronic criteria were exceeded at any station during any base flow events.

- ***E. coli***: Storm flow *E. coli* bacteria results exceeded the state water quality standard for the geometric mean (shall not exceed 100 CFU/100 mL) and/or the 90th percentile (shall not exceed 320 CFU/100 mL) at all stations except CSJ1 and CSO1. Bacteria is category 2 listed parameter for the Columbia River. *E. coli* criteria were met at all stations during base flow events.

Water quality standard exceedances during the monitoring period are summarized below, for parameters sampled during storm flow events only:

- ***SVOCs:*** Several individual SVOCs exceeded applicable state water quality standards. Laboratory reporting limits are typically several orders of magnitude greater than the applicable criteria, so any detection of certain parameters will typically constitute an exceedance.

- **PAHs:** Several individual PAHs exceeded criteria at stations CSE1 and CSWSDOT1 during several sampling events, and one PAH exceeded criteria during one event at CSWSDOT2.
- **Phthalates:** BEHP exceeded the human health criterion at all stations at least once. The criteria were exceeded several times at all WSDOT stations. BEHP is a category 2 (water of concern) parameter identified in fish tissue from the Columbia River. Butyl benzyl phthalate criterion was exceeded at least once at all stations except CSWSDOT2.
- **Other SVOCs:** N-nitrosodi-n-propylamine exceeded the criterion at least once at CSE1 and CSWSDOT2.
- **DDTs:** Several individual organochlorine pesticides exceeded applicable state water quality standards. DDx isomers, most commonly 4,4′-DDE, were detected at concentrations exceeding criteria at least once at all monitoring stations and exceeded criteria most often at CSP1 and CSWSDOT1 (at least one isomer in 50 percent of samples).
- **Other pesticides:** Aldrin, alpha-BHC, alpha-chlordane, beta-BHC, dieldrin, heptachlor, heptachlor epoxide, hexachlorobenzene, and trans-chlordane also exceeded criteria at least once at one or more stations. Most commonly, alpha-BHC exceeded criteria at all stations, dieldrin exceeded criteria at all stations except CSWSDOT2, and aldrin exceeded criteria at CSE1, CSF1, CSJ1, CSR1, CSR2, and CSWSDOT1.

HYDROLOGY

Storm characteristics and monitoring events are presented above in Table 5. Rainfall data were collected in 1-hour intervals by Portland Bureau of Environmental Services (BES) at the Post Office Rain Gage (Portland BES 2022), which is located approximately 1.5 miles south of station CSE1. During the nine-month project monitoring period from June 10, 2021, to March 2, 2022, the gage recorded 36.5 inches of rain with a maximum daily precipitation value of 1.98 inches. There was little to no precipitation in the months of July and August in 2021.

Stream Discharge

In order to assess hydrologic conditions across the Columbia Slope during the 2021-2022 monitoring period, stream discharge measurements are summarized in the following tables and figures for each of the monitoring stations:

- “Line” plots, presenting the seasonal patterns among the sampling stations for base flow (top) and storm flow (bottom)
- “Box and whisker” plots, presenting spatial patterns among the sampling stations for base flow (top left) and storm flow (bottom left), each tested via Friedman analyses (results of which are represented by letter groups beneath boxes; see *Data Analysis Methods* section for further interpretation explanation)

- “Box and whisker” plots, presenting base and storm flow comparisons for each station (right), tested via Wilcoxon Rank Sum tests (results of which are represented by p values beneath boxes; see *Data Analysis Methods* section)

Summary statistics are presented for each parameter and station in Appendix C, and full data for each sample date, station, and parameter is provided in Appendix D.

Seasonal Patterns

As shown in Figure 3, base flow stream discharge varied seasonally with minimum discharge rates at most stations in July and August, then generally increased to maximum rates at most stations in January and February. Monitoring station CSR2 had no measurable flow during the dry season base flow events in June through August, and base flow was not observed at stations CSWSDOT2 and CSWSDOT3. Discharge during base flow events ranged from 0.03 to 7.48 cfs among all stations with flow, and median discharge rates ranged from 0.1 to 0.71 cfs at all stations except for CSF1 and CSJ1, which had much higher median discharge rates of 3.85 and 5.89 cfs, respectively (Appendix C).

Discharge during storm flow events was more variable than base flow and tended to increase from November to March. Storm flow discharge ranged from 0.002 to 14.1 cfs except at monitoring station CSP1, which had a maximum measured discharge of 30.3 cfs on February 28, 2022 (Appendix D).

Storm and Base Flow Comparison

Discharge during base flow showed significant spatial differences (Figure 4). Stream discharge at stations CSF1 and CSJ1 was significantly greater than at all other stations during base, followed by stations CSE1 and CSR1 during base flow. No discharge was measured at CSWSDOT2 or CSWSDOT3 during base flow events and these stations were predictably significantly lower than all other stations. The remaining monitoring stations generally lacked any significant spatial differences (Figure 4).

The boxplots show more variation in storm flow relative to base flow and some significant differences between sites (Figure 4). Storm flow discharge at CSF1, CSJ1, CSR1, and CSR2 were significantly higher than most other stations, while discharge at CSE1, CSWSDOT2, and CSWSDOT3 was significantly lower than at all other stations.

For all stations except CSJ1, stream discharge was significantly higher during storm flow than during base flow, as shown by significant p-values beneath all stations in the right-most plot in Figure 4. Monitoring station CSJ1 is located immediately downstream from the Biddle Lake fish hatchery, which may employ flow controls to regulate stream stage during storms.

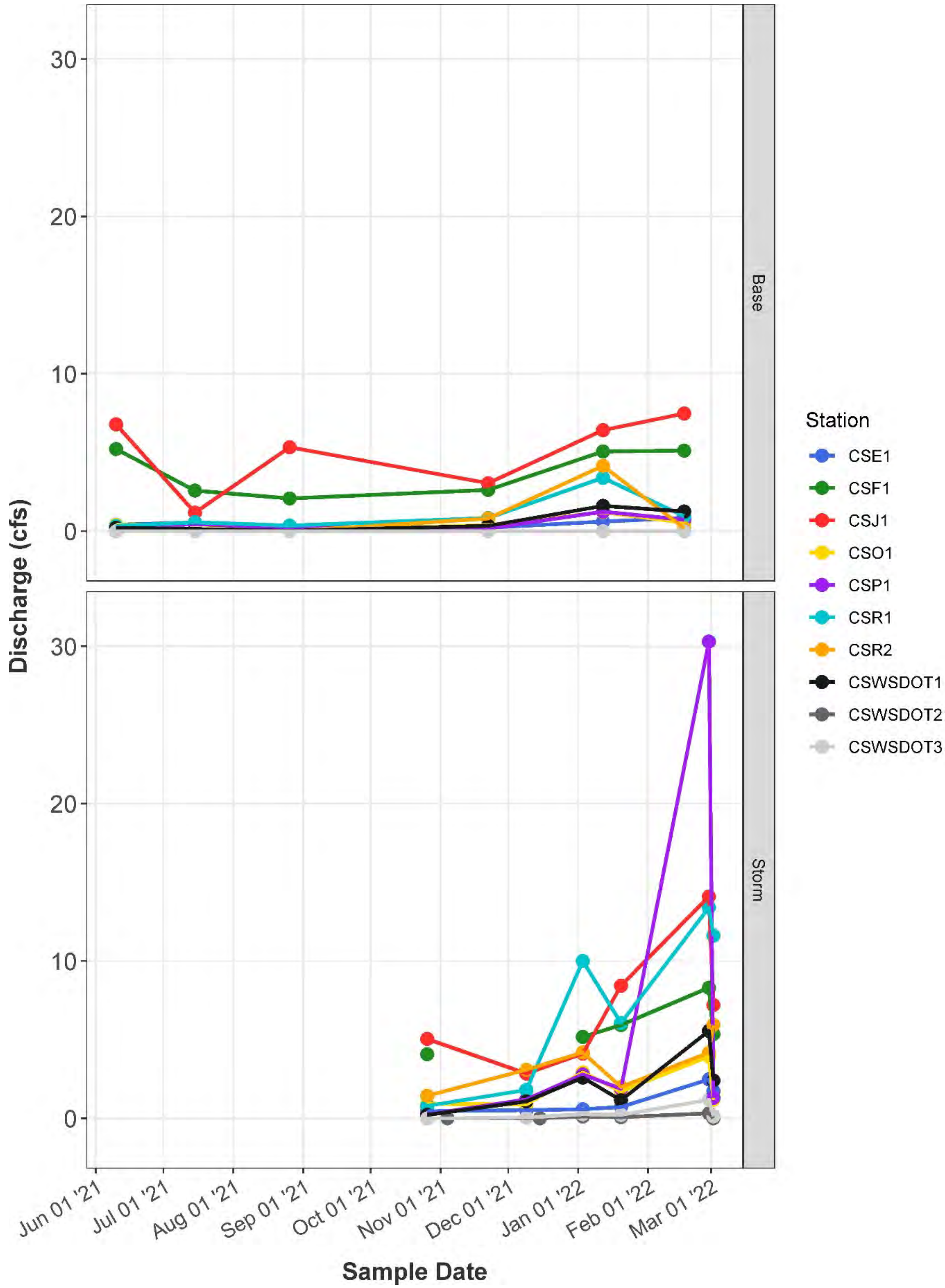

Figure 3. Stream Discharge Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

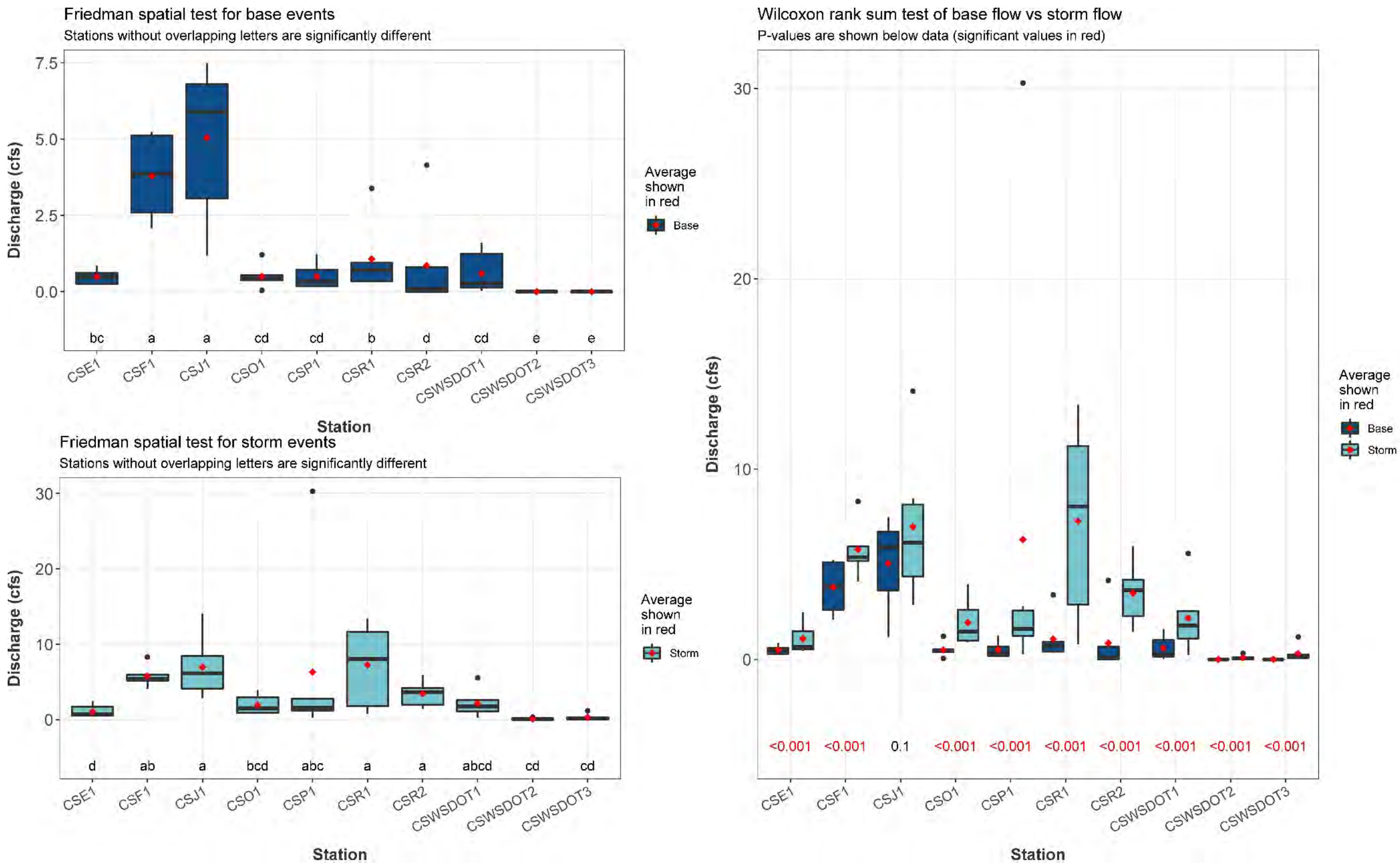

Figure 4. Stream Discharge Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope.

WATER QUALITY

In order to assess water quality conditions across the Columbia Slope during the 2021-2022 monitoring period, data are summarized in tables and figures for each of the sample locations. Water quality results are described separately for each parameter in the sections below. Where applicable, each parameter section presents results and summarizes implications of:

- "Line" plots, presenting the seasonal patterns among the sampling stations for base flow (top) and storm flow (bottom)

- "Box and whisker" plots, presenting spatial patterns among the sampling stations for base flow (top left) and storm flow (bottom left), each tested via Friedman analyses (results of which are represented by letter groups beneath boxes; see *Data Analysis Methods* section for interpretation)

- "Box and whisker" plots, presenting base/storm flow comparisons for each station (right), tested via Wilcoxon Rank Sum tests (results of which are represented by p values beneath boxes and in Table 7; see *Data Analysis Methods* section for interpretation)

- Water quality criteria comparison

Line plots and boxplots are overlain with black horizontal lines representing water quality criteria where applicable. Friedman tests for base flow data and the Wilcoxon Rank Sum tests were not applicable to stations CSWSDOT2 and CSWSDOT3 because samples could not be collected during base flow events under no flow conditions. Water quality and statistical results for these two stations are therefore not included in the base flow boxplots or the base/storm flow comparison boxplots. Similarly, CSR2 had lower base flow sample size (n=3) relative to other stations (n=6) due to lack of flow during the summer season. Friedman tests on base flow did not include CSR2 because the test requires equal sample size for all stations and discussion regarding significant spatial differences for base flow does not include CSR2.

Summary statistics are presented for each parameter and station in Appendix C, and full data for each sample date, station, and parameter is provided in Appendix D.

Table 7. Wilcoxon Signed Rank Test P-Values: Are Base and Storm Event Concentrations Significantly Different?

Parameter	Station									
	CSE1	CSF1	CSJ1	CSO1	CSP1	CSR1	CSR2	CSWSDOT1	CSWSDOT2	CSWSDOT3
Temperature	**<0.001**	**0.004**	**0.004**	**<0.001**	**<0.001**	**0.015**	0.211	**<0.001**	NA	NA
pH	**<0.001**	0.310	**0.015**	**<0.001**	**<0.001**	**<0.001**	0.059	**<0.001**	NA	NA
Dissolved Oxygen (DO)	**<0.001**	**0.008**	0.688	**0.025**	**<0.001**	**0.015**	0.351	**<0.001**	NA	NA
Conductivity	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.027**	**0.001**	NA	NA
Turbidity	**<0.001**	**0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.351	**<0.001**	NA	NA
Total Suspended Solids (TSS)	**<0.001**	0.418	0.104	0.224	**<0.001**	**0.004**	**0.011**	**<0.001**	NA	NA
Discharge	**<0.001**	**<0.001**	0.105	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Nitrate+Nitrite as Nitrogen	**<0.001**	0.224	0.224	**0.004**	**<0.001**	**<0.001**	0.353	**<0.001**	NA	NA
Total Nitrogen	**<0.001**	**0.015**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.158	**<0.001**	NA	NA
Total Phosphorus	**<0.001**	**0.004**	**<0.001**	0.155	**0.002**	**<0.001**	0.770	1.000	NA	NA
Total Hardness as CaCO3	**<0.001**	0.677	0.067	**<0.001**	**<0.001**	**<0.001**	0.346	**<0.001**	NA	NA
Chloride	**<0.001**	0.688	0.843	**0.001**	**<0.001**	**0.043**	**0.004**	**<0.001**	NA	NA
Total Copper	**<0.001**	0.068	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.059	**<0.001**	NA	NA
Total Lead	**<0.001**	0.311	**0.001**	**<0.001**	**<0.001**	**<0.001**	**0.011**	**<0.001**	NA	NA
Total Zinc	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.894	**<0.001**	NA	NA
E. coli	**0.043**	**0.025**	0.311	0.419	**<0.001**	**<0.001**	**0.027**	**<0.001**	NA	NA

Red bold text indicates significant test results.

Temperature

Water temperature is critical to the health and survival of fish and other aquatic species in many life stages including embryonic development, juvenile growth, and adult migration. The relative species composition, metabolism, and reproductive effectiveness of cold-blooded aquatic species are also regulated by the water temperature. An increase in water temperature accelerates the biodegradation of organic matter and increases the dissolved oxygen demand as well as decreasing the solubility of oxygen. The state water quality standards for temperature (see Table 4) are based on a 7-day average daily maximum (7-DADMax). The maximum allowable 7-DADMax is 17.5 °C in waters designated for salmon and trout spawning, noncore rearing, and migration. Temperature is category 5 listed (requiring an improvement project) due to state criteria exceedances, according to Washington State's 303(d) list of impaired waters (Ecology 2016).

Instream discrete water temperature data were collected at all 10 stations during sampling events to assess how they may contribute to water temperature impairment in the Columbia River. Instream temperature data results are discussed and presented graphically below.

Seasonal Patterns

As shown in Figure 5, surface water temperature varied seasonally with the warmest base flow temperatures occurring in July and August and coolest base flow temperatures in November. Temperature during base flow events ranged from 8.0 to 17.1 °C among all stations, except CSR2 which had temperatures as low as 4.3 °C (Appendix D).

For all stations, temperature was generally lower and more variable across storm events than base flow and ranged between 3.4 and 15.0 °C. The warmest storm flow temperatures were observed in November for all stations whereas the coldest storm flow temperatures were observed in early January.

Storm and Base Flow Comparison

Water temperature during base flow did not exhibit many significant spatial differences except for significantly greater temperature at CSP1 and CSO1 than CSE1, CSJ1 and CSR1 as shown in Figure 6. Although CSR2 was not included in the Friedman test due to its smaller sample size, base flow temperatures at this wetland station were substantially lower than temperatures at other stations, reflecting the naturally low water temperatures of groundwater infiltration and likely influenced by sample collection during colder months.

The spatial pattern during storm flow is similar to that observed during base flow. Many stations were not shown to be significantly different as shown by overlapping letters among many sites. Lower storm flow temperatures were usually observed at CSR1, CSR2, CSWSDOT2, and CSWSDOT3 and higher temperatures at CSF1 and CSP1 and CSWSDOT1 (Figure 6).

The Wilcoxon Rank Sum test (Figure 6) showed that water temperature was significantly lower during storm flow than base flow, likely due to the seasonality of storm events, at all stations except CSR2. One exception is that water temperature was higher (not significantly) during storm flow than base flow at CSR2 because base flow temperatures were not measured during the warm summer months due to a lack of flow at this wetland.

Water Quality Criteria Comparison

All stations met the state surface water temperature criteria (7-DADMax) of 17.5 °C, which was not exceeded by any sample.

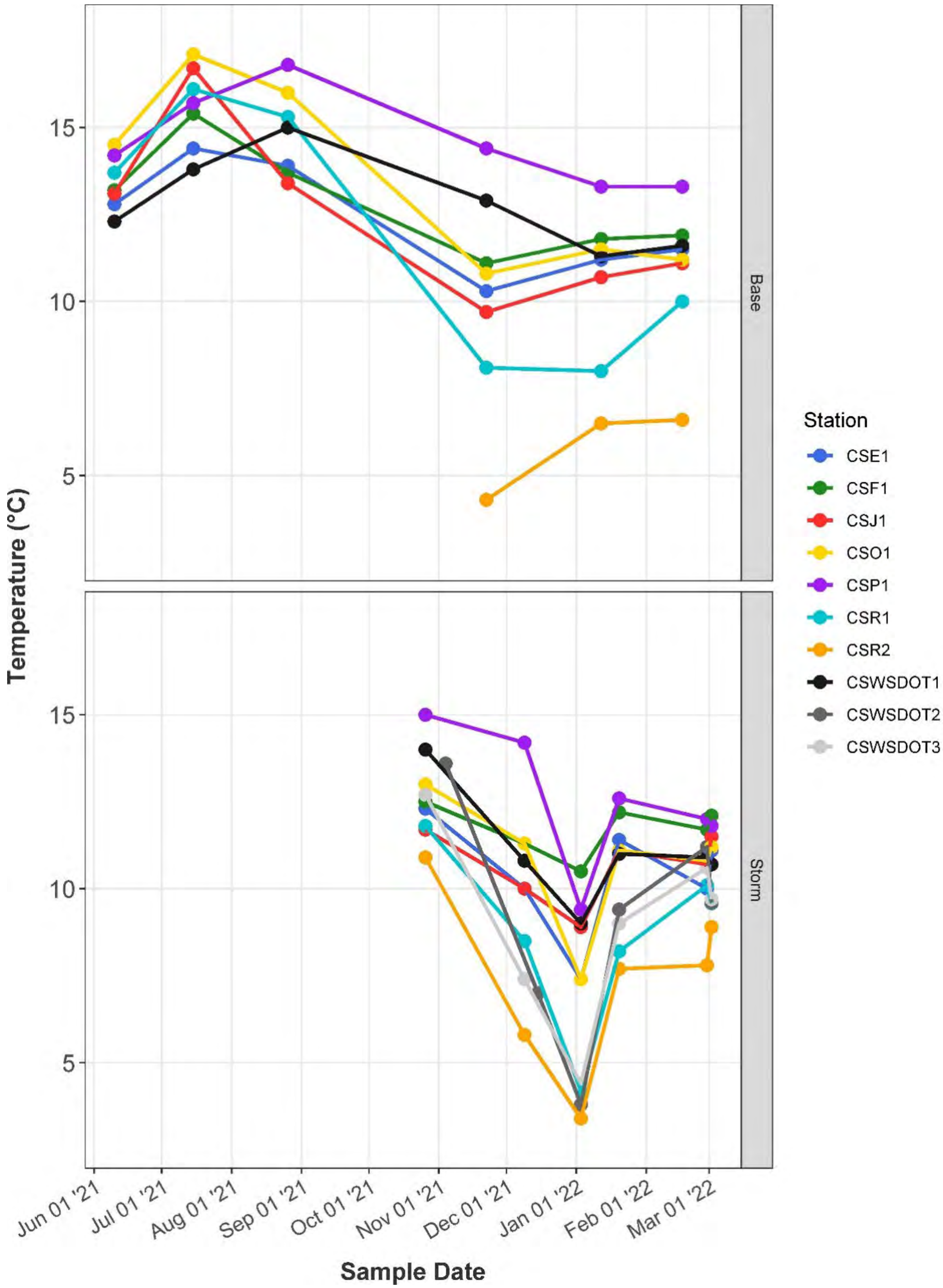

Figure 5. Temperature Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

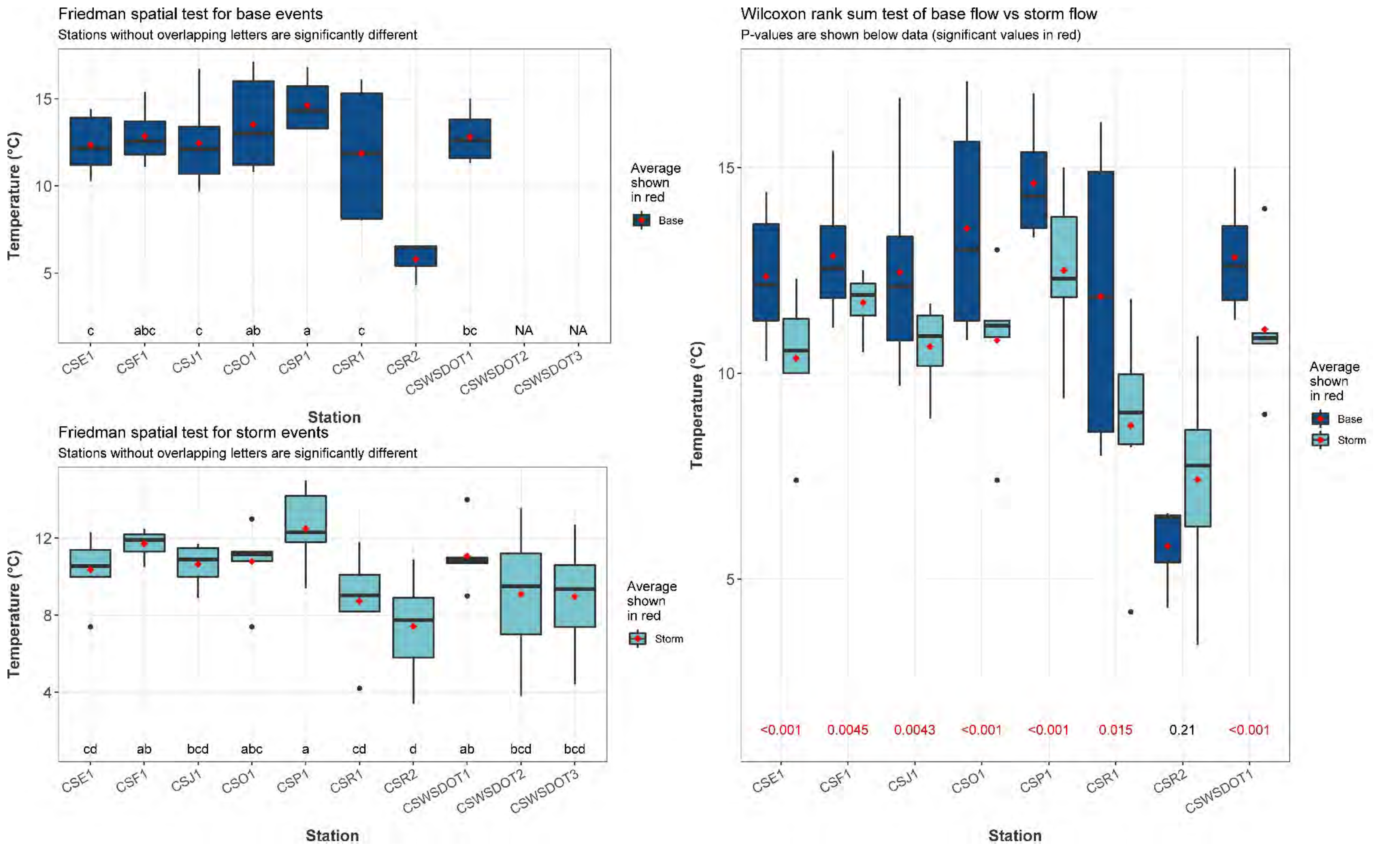

Figure 6. Temperature Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope

pH

pH is a measure of the hydrogen ion activity in water, which can have a direct effect on aquatic organisms or an indirect effect since the toxicity of various common pollutants are markedly affected by changes in pH. Waters that have pH levels ranging from 0 to 7 are considered acidic, while waters with pH levels ranging from 7 to 14 are considered alkaline. Waters that have a pH of approximately 7 are considered neutral. Washington state surface water quality standards for noncore salmonid rearing require pH to be within the range of 6.5 to 8.5 (WAC 173-201A). Some wetlands such as peat bogs are naturally acidic with a pH between 5 and 6.

To assess the pH concentrations of each monitoring basin and how they may contribute to the pH levels in the Columbia River, instream pH data results are discussed and presented graphically below.

Seasonal Patterns

As shown in Figure 7, pH was relatively stable across base flow events ranging from 7.1 to 8.1 for all stations but CSR2 (Appendix D). Minimum base flow values were observed in January and maximum values were observed July or August for most sites. The CSR2 pH values were less than the water quality criterion of 6.5 during three baseflow events in November through February. Base flow was not observed at CSR2 during summer sampling events in June through August.

For most stations, pH was lower and more variable across storm events than base flow and ranged between 6.0 and 7.9. Minimum values were observed in January and March. pH was below 6.5 for CSR2, CSWDOT1, and CSWSDOT3 during at least two of the six storm events.

Spatial Patterns

During base flow, pH was almost always lower at CSJ1 and CSR2 than other stations. Base flow pH measurements at CSJ1 were significantly lower ($p<0.05$) than other stations except CSO1 as shown in Figure 8. The Friedman test did not identify many significant differences during storm events as shown by the similar letter groups in Figure 8. Though CSR2 was not included in the Friedman test due to limited data during base flow events, it was substantially lower in pH than all other stations for both base and storm flow. This low pH at CSR2 is typical of wetland areas and reflective of natural conditions for low flow and longer retention times, which allow for increased microbial activity resulting in low pH.

The Wilcoxon Rank Sum test (see Figure 8) showed that pH was significantly lower during storm flow than base flow, due to the typically lower pH of stormwater runoff, at all stations except CSJ1 and CSR2. While not demonstrated to be significantly different, stormwater runoff at CSR2 appeared to have increased the naturally low pH at this wetland.

Water Quality Criteria Comparison

All stations met the state water quality standard for pH (6.5 to 8.5) with the following exceptions where pH was below 6.5:

- All three sampled base flow events at CSR2 (note that flow was not present during the three summer base flow events)

- Four of the six storm flow events at CSR2

- Two of the six storm flow events at CSWSDOT2 and CSWSDOT3

No values exceeded the upper criteria limit of 8.5 at any station.

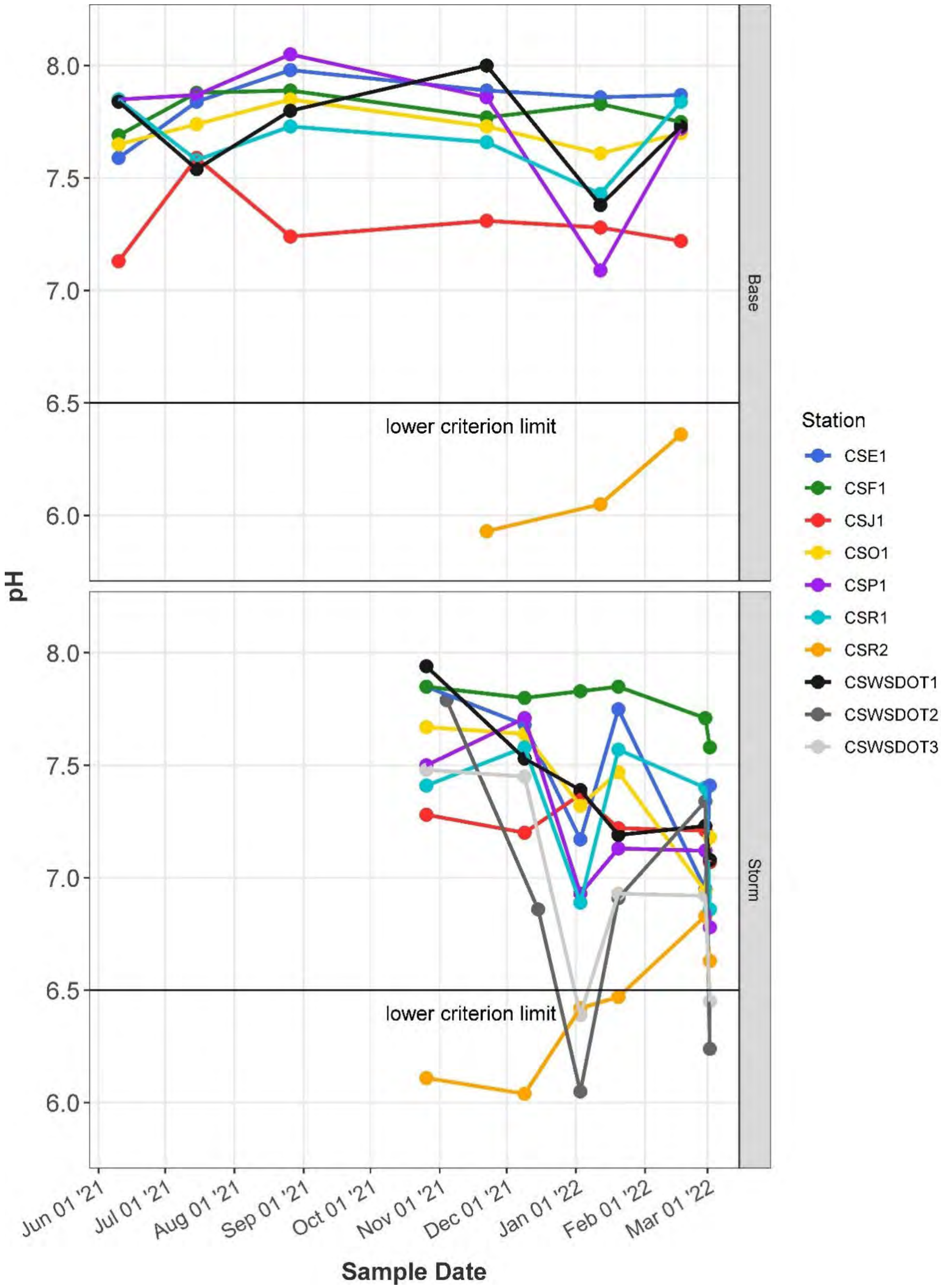

Figure 7. pH Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

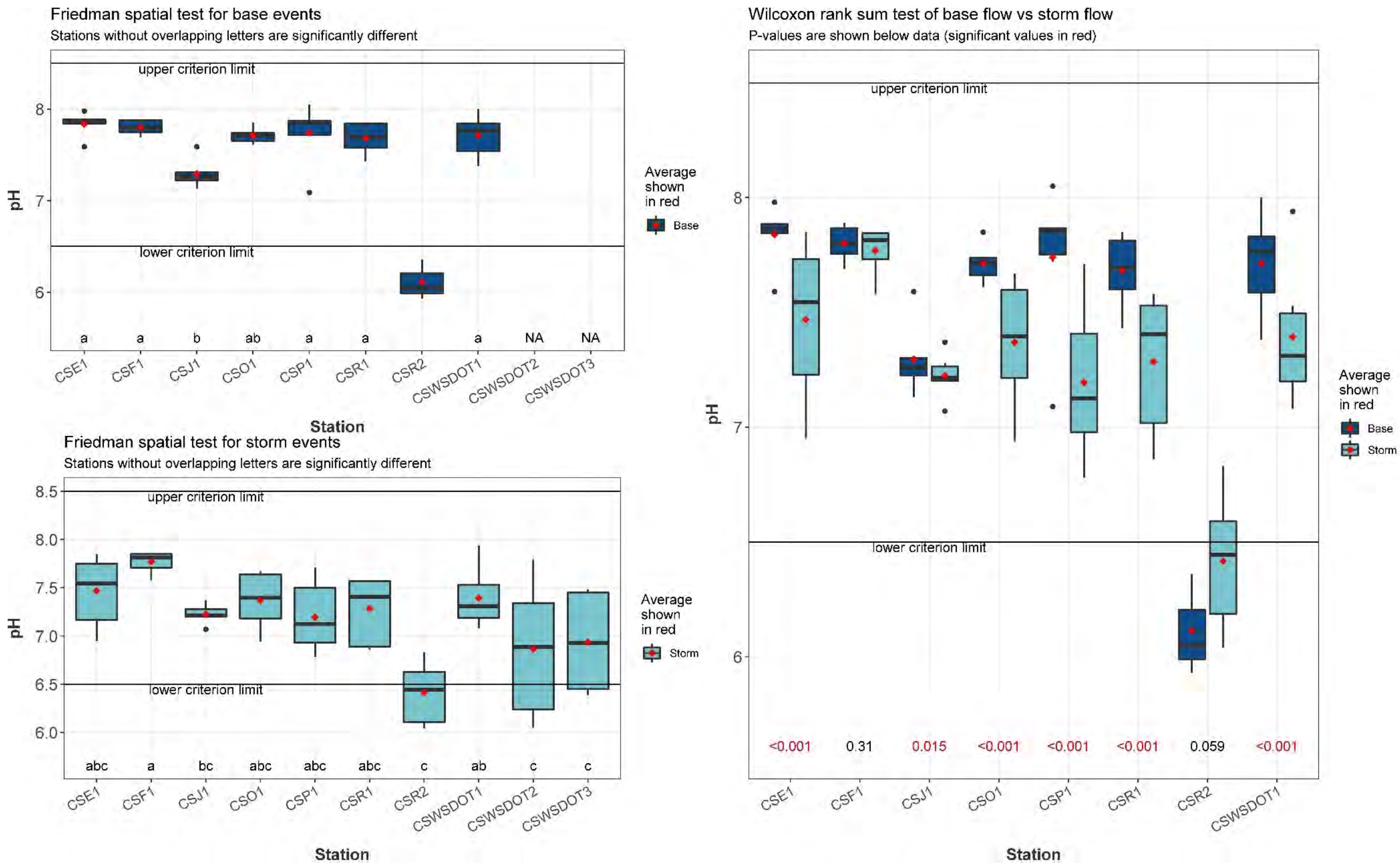

Figure 8. pH Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope.

Dissolved Oxygen

Dissolved oxygen (DO) is another important water quality parameter for salmonids and other aquatic organisms. Low dissolved oxygen levels can be harmful to larval life stages and respiration of juveniles and adults; directly affecting the survival of aquatic organisms. Depletion of oxygen in water bodies can also lead to a shift in the composition of the aquatic community. Washington state surface water quality standards require that dissolved oxygen concentrations exceed 8.0 mg/L in fresh waters designated for noncore salmonid rearing (WAC 173 201A). DO naturally decreases as waters warm because DO decreases with increasing temperature at 100 percent saturation. Higher nutrient concentrations are often found in warmer waters, so low DO is also associated with high nutrient concentrations.

Seasonal Patterns

As shown in Figure 9, minimum values under base flow conditions occurred July through August and maximum values for most stations were recorded in either November or March. This shows that DO values varied somewhat seasonally, with more DO available during the colder, wet season and less DO available during the warmer, dry season due to temperature effects on DO saturation. DO concentrations were more variable and tended to have greater maximum values under storm conditions. Minimum and maximum DO concentrations were observed in November and January respectively for storm flow.

DO percent saturation was consistent through the water year for all stations, remaining greater than 93 percent during base flow and greater than 89 percent during storm flow, except CSR2 which dropped as low as 65 and 39 percent during base and storm flow, respectively.

Storm and Base Flow Comparison

DO values during base flow were typically high, ranging from 8.5 to 12.0 mg/L, but were more variable during storm flow, ranging from 4.3 to 13.0 mg/L. The Friedman test did not identify many significant differences in DO concentration or percent saturation between stations during base or storm events as shown by common letter groups in Figure 10. One exception is significantly higher DO concentrations during storm flow at CSR1 than most stations, excluding WSDOT stations.

The Wilcoxon Rank Sum test (see Figure 10) showed that DO concentration was significantly lower during base flow than storm flow at all stations except CSJ1 and CSR2, which had similar base and storm flow values. Percent saturation was not significantly different between storm and base flow at any station except at CSJ1 where percent DO saturation was significantly greater during base flow despite significantly greater temperatures.

Water Quality Criteria Comparison

All stations met the project action limit criteria for DO (not to exceed 8.0 mg/L) except at CSR2 where DO was measured below 8.0 mg/L during one of the six storm flow events.

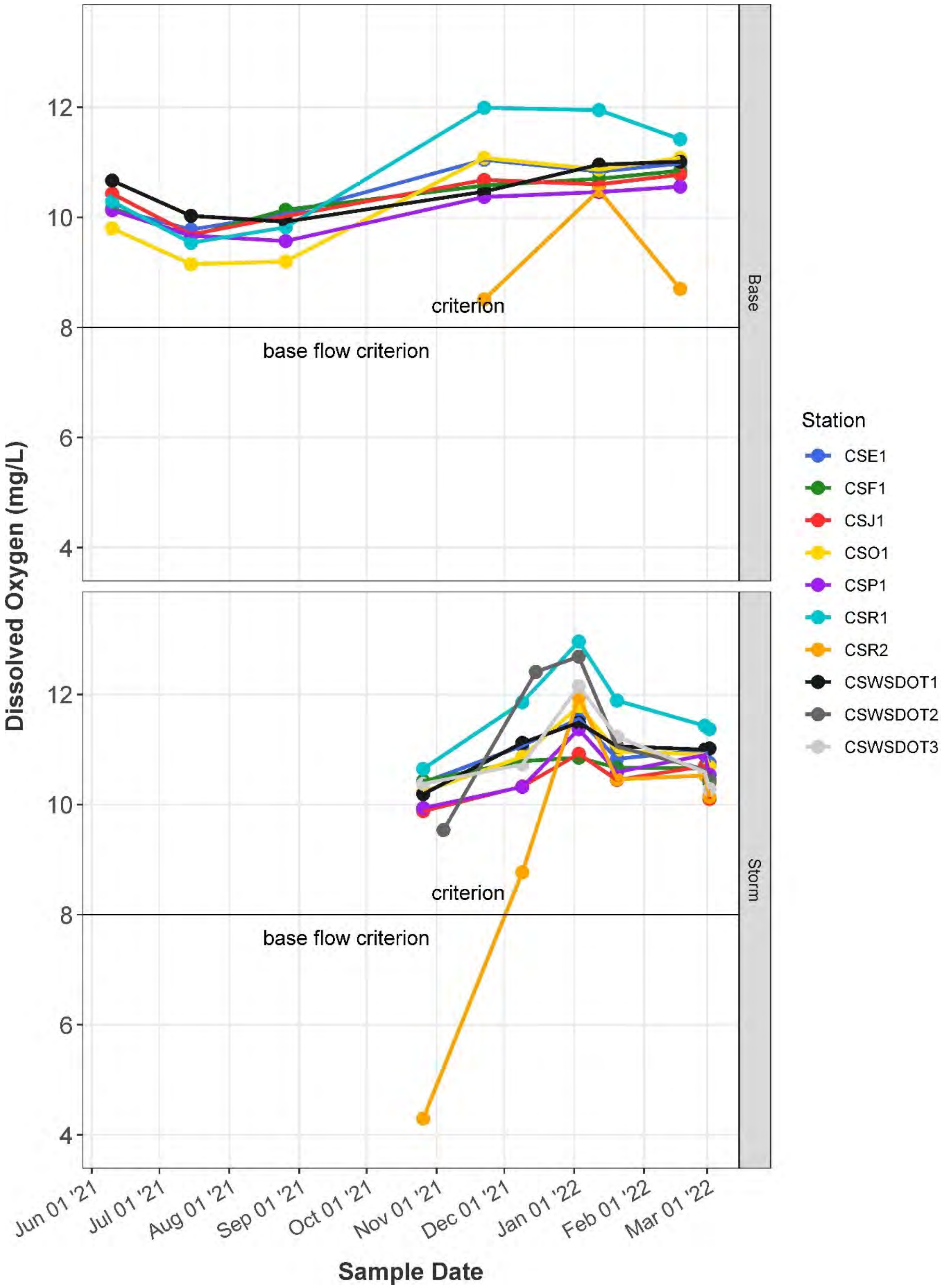

Figure 9. Dissolved Oxygen Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

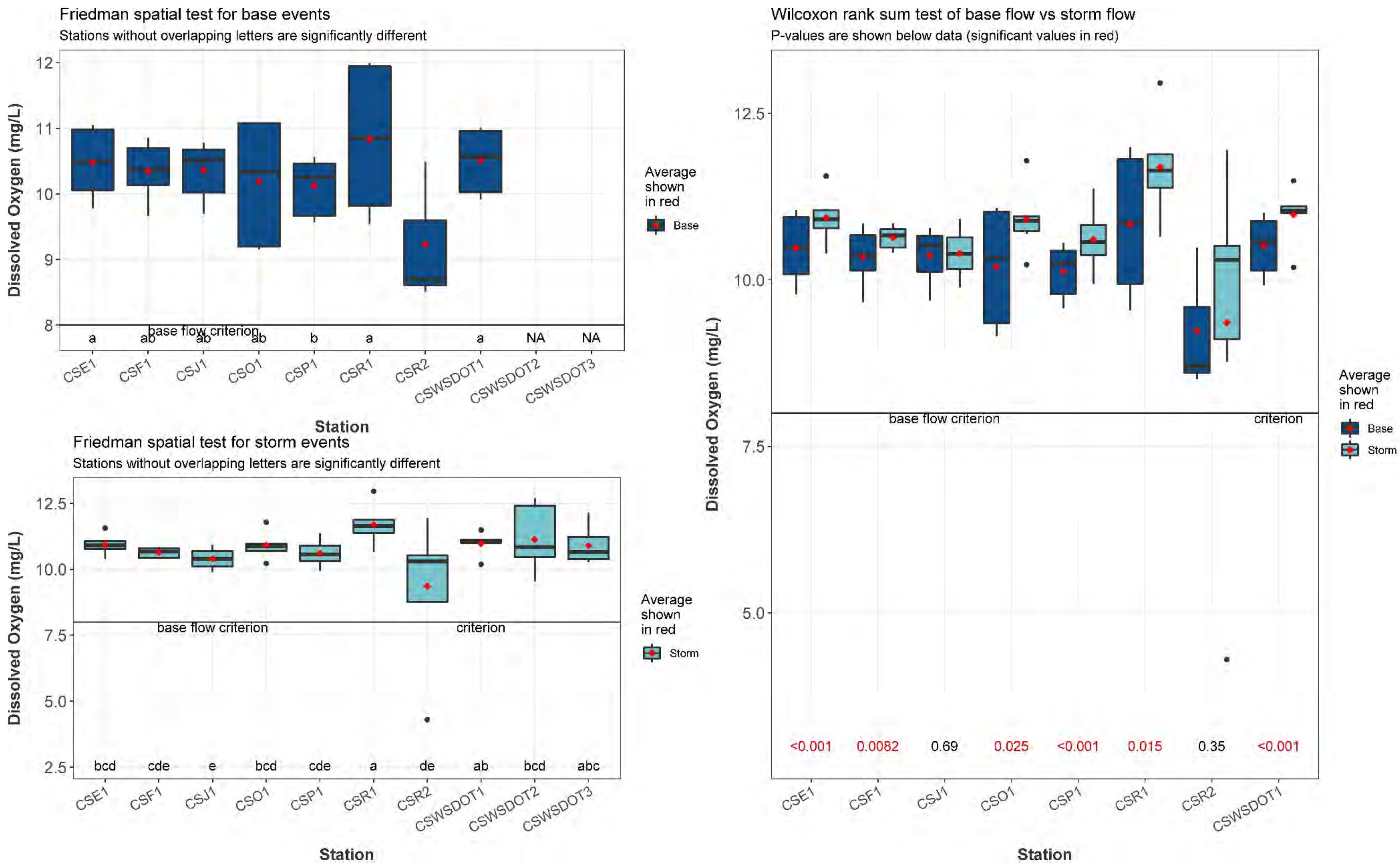

Figure 10. Dissolved Oxygen Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope.

Conductivity

Conductivity is a measure of the ability of water to conduct an electrical current, which is directly related to the content of dissolved ions in the water. Conductivity varies with temperature and is typically measured as specific conductance, which is normalized to a temperature of 25 °C. although there is no state surface water quality standard established for conductivity, this measurement is useful for identifying sources of dissolved solids (primarily salts) and for determining the relative flow contributions attributed to groundwater, since conductivity is typically higher in groundwater than in surface water.

Seasonal Patterns

As shown in Figure 11, conductivity was fairly consistent for most stations during base flow throughout the water year, ranging from 173 to 244 microsiemens per centimeter (μS/cm). An exception to this pattern was for CSR1 and CSR2 stations, where a substantial reduction in conductivity occurred during the wet season (November through January), dropping from 151 to 104 μS/cm at CSR1 and from 81 to a minimum of 63 μS/cm at CSR2, before rising again in February. Conductivity during storm flow was highly variable for each site, ranging from 14 to 253 μS/cm with no apparent seasonal pattern (Figure 11).

Storm and Base Flow Comparison

Conductivity during base flow showed significant spatial differences (Figure 12). Specific conductance was greatest at CSE1, significantly greater than at all other stations, followed next by CSF1 and CSJ1, then CSP1 and CSWSDOT1. Conductivity at CSR1 was significantly lower than all stations except CSR2, which was not tested statistically due to low sample size, exhibited conductivity values substantially lower than all other stations due to naturally low amounts of salts in the wetland soils.

Despite the larger ranges in conductivity at each station (Figure 12), the relative spatial pattern during storm flow is similar to base flow such that the western-most sites generally had greater conductivity while CSR1 and CSR2 generally had the lowest conductivity.

For all stations, specific conductivity during base flow was significantly greater than during storm flow, as observed by the significant p-values beneath all stations in the right-most plot in Figure 12. This is expected due to typically higher conductivity levels in groundwater relative to stormwater.

Water Quality Criteria Comparison

There are no water quality standards or project action limits established for this parameter.

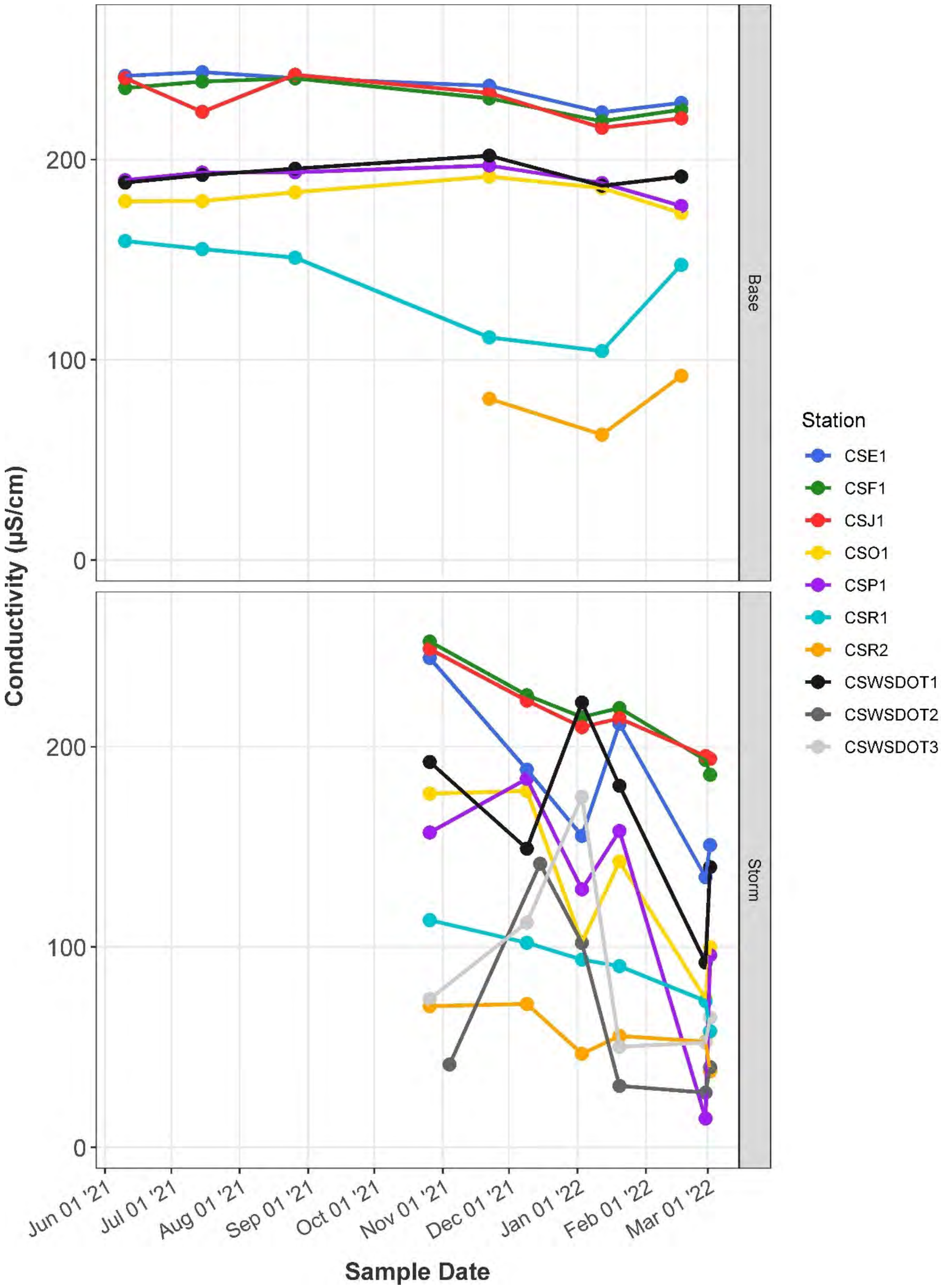

Figure 11. Specific Conductance Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

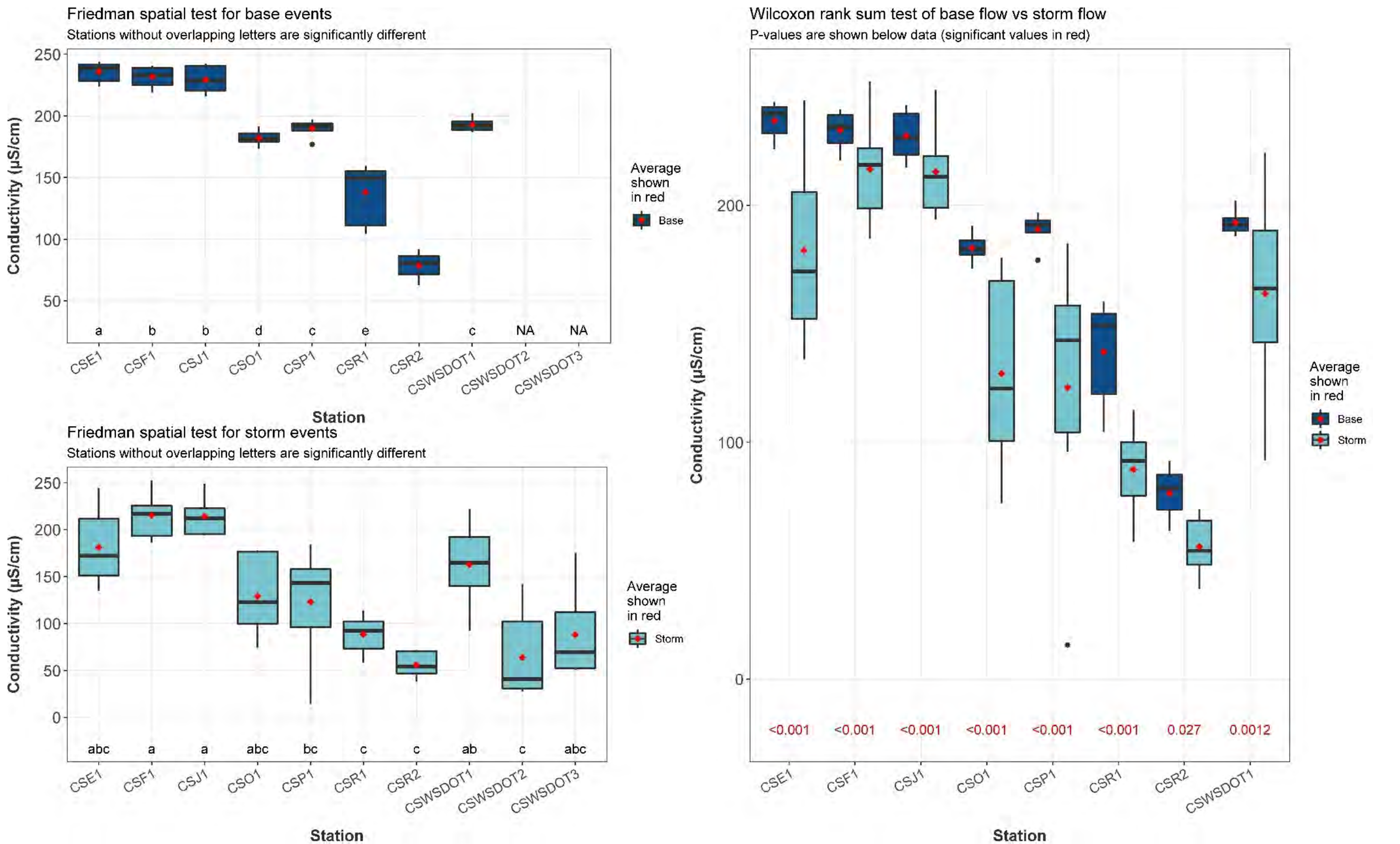

Figure 12. Specific Conductance Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope.

Turbidity

Turbidity is a measure of water clarity that is determined by how the transmission of light is scattered as it passes through water. An increase in the amount of particulate matter in water reduces clarity (or transparency) by increasing the scattering of light. Measurements of turbidity are expressed in nephelometric turbidity units (NTU). Washington state surface water quality standards restrict turbidity increases to a maximum of 5 NTU more than background when background turbidity is 50 NTU or less, and to no more than a 10 percent increase in turbidity when the background turbidity is greater than 50 NTU (WAC 173-201A). Typically, background turbidity is measured at an upstream location and turbidity criteria are applied to downstream location.

Seasonal Patterns

As shown in Figure 13, turbidity was fairly consistent among base flow events, ranging from 0.2 to 8.7 NTU for all stations, though turbidity did not exceed 3.8 NTU at any station other than CSR1 and CSR2 (Appendix C).

Turbidity during storm flow was much more varied for most stations, ranging from 0.5 to 39.4 NTU for all stations except the three WSDOT stations. Each of the City stations exhibited a seasonal pattern in which storm flow turbidity generally increased over time from October to March. No apparent seasonal pattern was observed for WSDOT stations due to the large variability per event (potentially associated with discharge or size of individual storm events), with turbidity reaching an overall maximum of 136 NTU in March 2022 at CSWSDOT2.

Storm and Base Flow Comparison

Some significant spatial differences were identified by the Friedman test (Figure 14). Stations with particularly low base flow turbidity included CSJ1, CSP1, and CSWSDOT1 (not exceeding 1.1 NTU). Base flow turbidity at CSR1 and CSR2 were typically substantially greater, representing the greatest four observations of base flow turbidity in the dataset (Appendix D). Base flow turbidity at CSE1 and CSR1 were found to be significantly greater than at the rest of the stations tested.

At WSDOT stations, storm flow turbidity was particularly varied, ranging from 1.2 to 136 NTU (Appendix C). Storm flow turbidity at CSF1 was significantly lower than turbidity at all other sites, apart from CSJ1. In contrast, turbidity values at CSWSDOT2 and CSWSDOT3 were almost always substantially greater than values observed at other stations (Figure 14).

Comparing base flow to storm flow, turbidity was significantly greater during storm flow events for all stations except CSR2, which though not significant still showed generally greater storm flow values (Figure 14).

Water Quality Criteria Comparison

The project action limit of 10 NTU (see Table 4) was not exceeded for base flow events. The project action limit was exceeded in 40 percent of storm flow samples, including at least one sample at all stations except CSF1 and CSJ1. Applying state criteria to CSR1 by using CSR2 as upstream background, average turbidity increased about 7 NTU downstream during storm flow but decreased during base flow, indicating exceedance of turbidity criteria in Fisher's Creek from stormwater runoff.

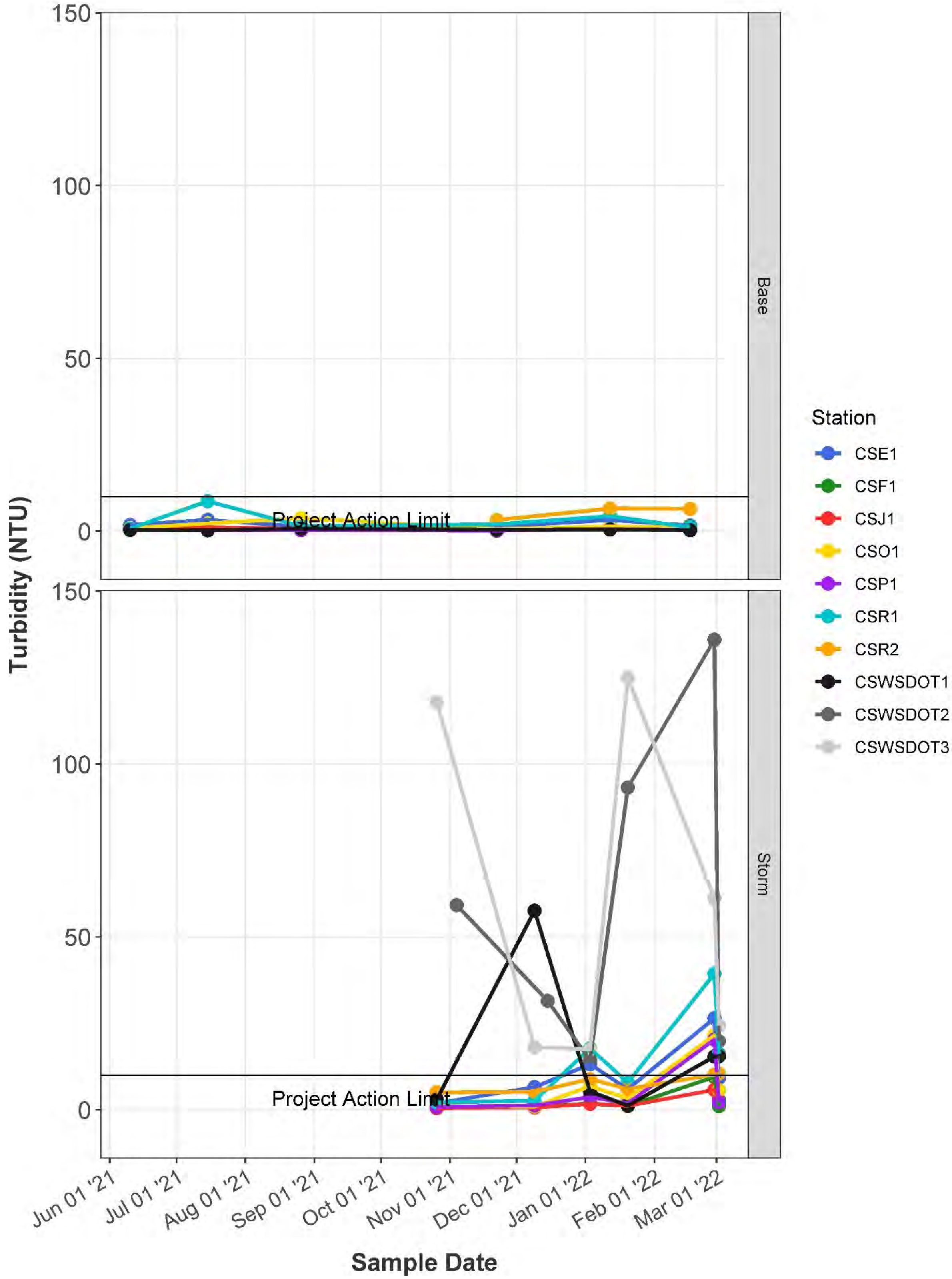

Figure 13. Turbidity Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

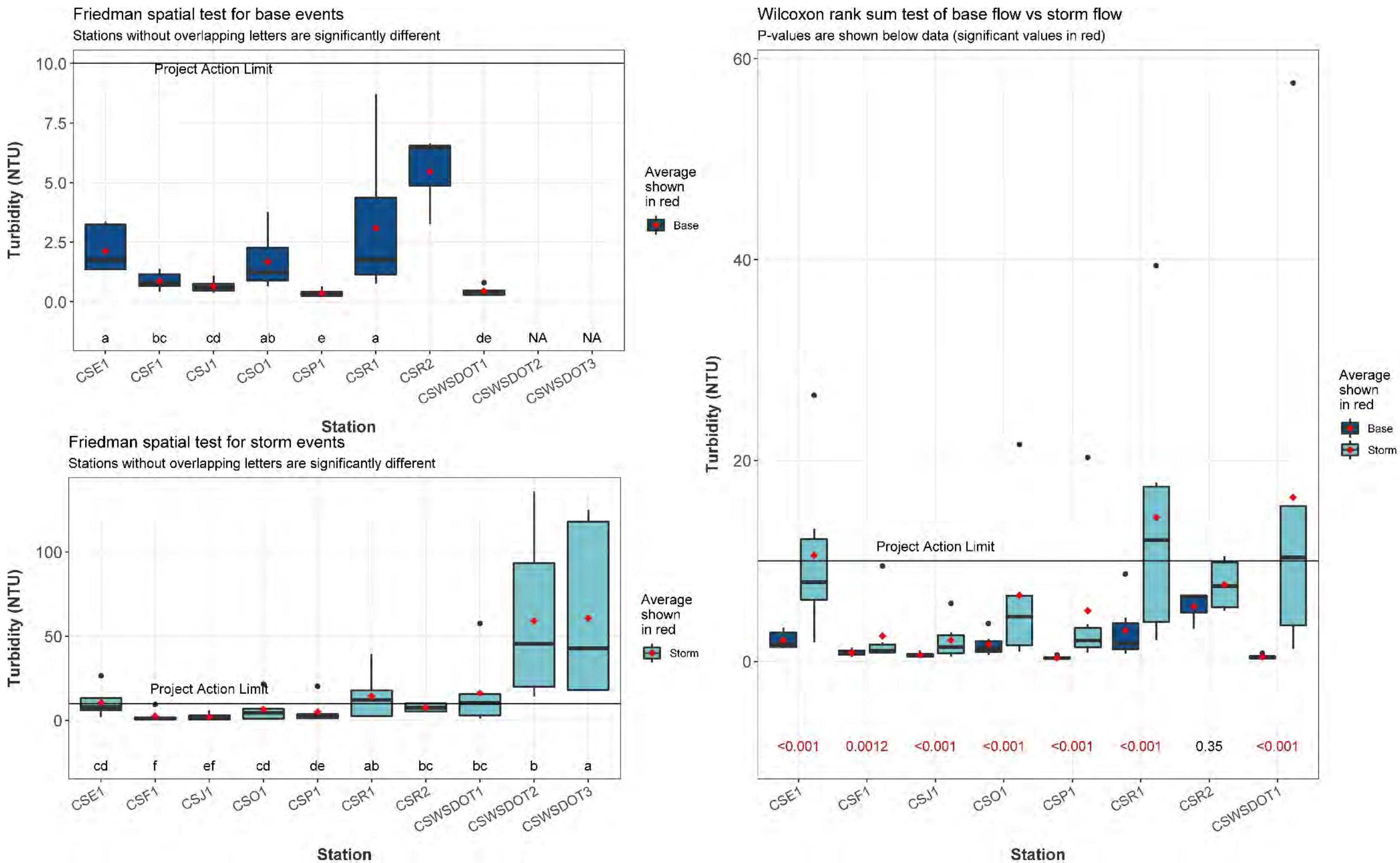

Figure 14. Turbidity Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope.

Total Suspended Solids

TSS are the most widespread pollutants entering surface waters. Solids, especially the finer fractions, reduce light penetration in water and can have a smothering effect on fish spawning and benthic biota. Suspended solids are also closely associated with other pollutants such as nutrients, bacteria, metals, and organic compounds. These pollutants tend to adsorb to the solids particles and are transported in surface runoff to receiving waters if onsite controls are not implemented for solids removal. Thus, the presence of suspended solids is used to evaluate the overall pollutant loading within a basin. No state surface water quality standards have been established for total suspended solids.

Seasonal Patterns

TSS concentrations during base flow events were consistently low, ranging only 1.0 to 9.5 mg/L and showed a modest seasonal pattern at most stations. TSS decreased over time from summer maximums to minimums in January and February (Appendix D).

Compared to base flow, storm flow TSS varied greatly (Figure 15), ranging from 1.0 to 122 mg/L among all stations except the WSDOT stations, which ranged 1.0 to 661 mg/L. Like turbidity, maximum TSS concentrations occurred in March 2022 for many City sites.

Storm and Base Flow Comparison

Some significant spatial differences in TSS during base flow were identified by the Friedman test (Figure 16) including significantly greater concentrations at CSE1 (median of 7.1 mg/L) than all other stations except CSO1. TSS at CSP1 was significantly less than at all other stations during base flow except CSWSDOT1, with 100 percent undetected values (Appendix C). Under storm flow conditions, TSS was consistently higher at CSWSDOT2 and CSWSDOT3 than all other stations (Figure 16), with medians of 45 and 42 mg/L respectively (Appendix C). However, TSS values were more widely distributed at each station during storm flow and so fewer significant spatial differences were detected (Figure 16).

TSS concentrations were significantly greater under storm flow conditions than base flow at most stations, except CSF1, CSJ1, and CSO1 (Figure 16), indicating that adsorbed pollutants may also be greater under storm flow, particularly at CSWSDOT2 and CSWSDOT3 where TSS was consistently high.

Water Quality Criteria Comparison

There are no water quality standards or project action limits established for this parameter.

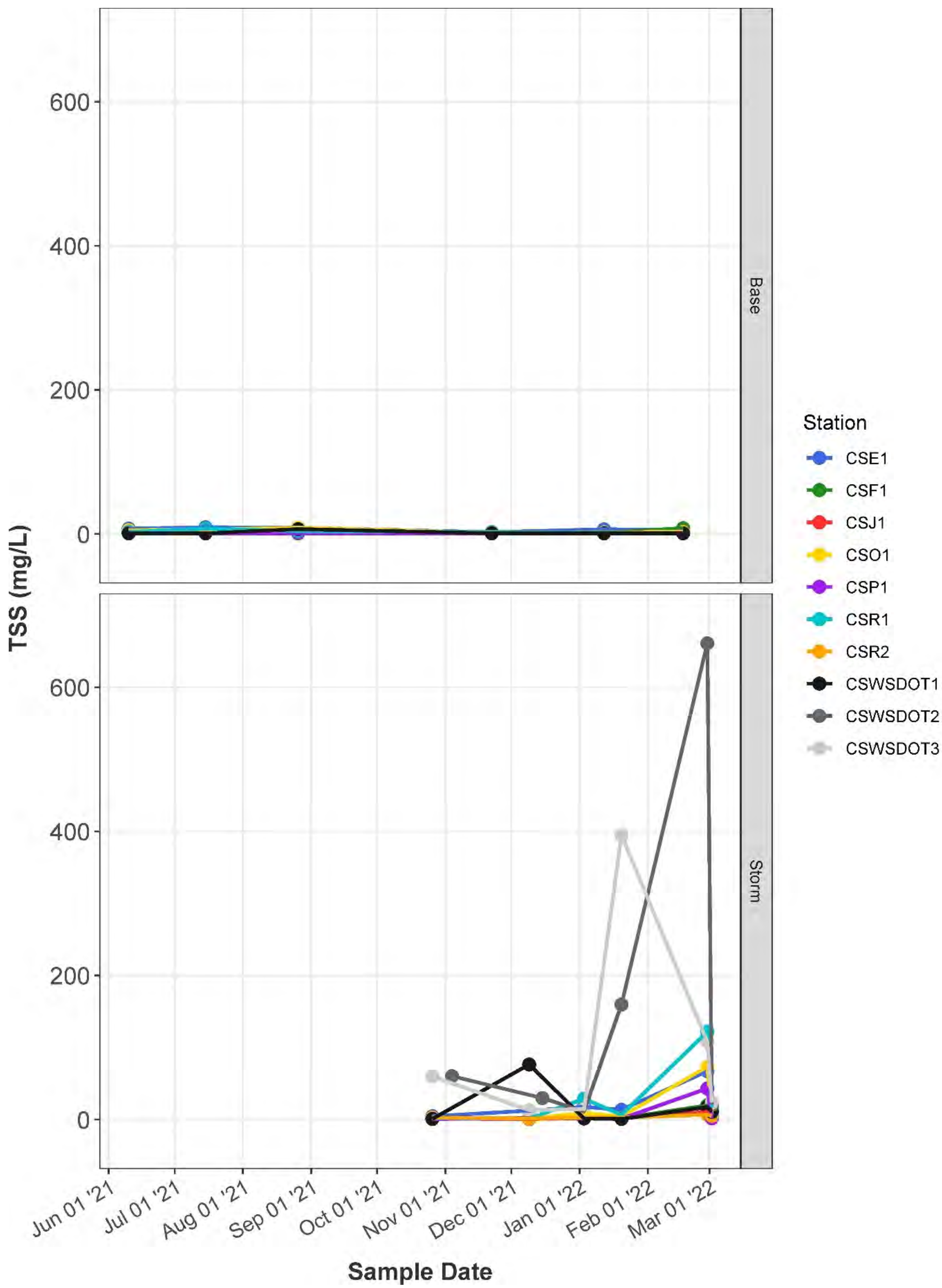

Figure 15. TSS Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

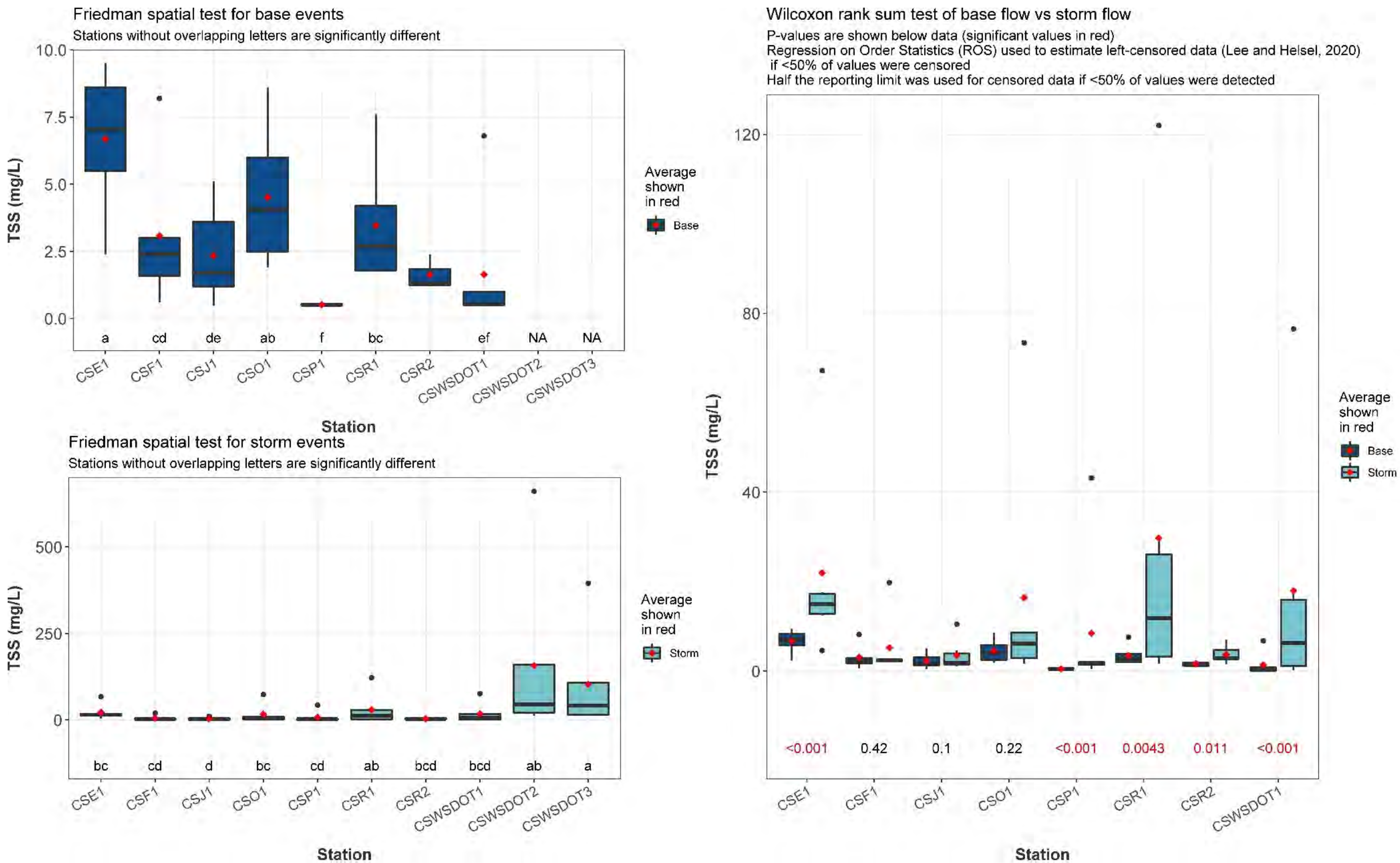

Figure 16. TSS Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope.

Nitrate+Nitrite Nitrogen

Washington State does not have a surface water quality standard for nitrate+nitrite nitrogen; however, it is a regulated parameter in the state ground water standards (WAC 173-200-040) and the state drinking water standards (WAC 246-290-310) for the protection of human health. To prevent a potentially fatal blood disorder in infants called "blue baby syndrome" as well as other human health problems, both standards specify that nitrate+nitrite nitrogen concentrations shall not exceed 10 mg/L. Nitrate+nitrite nitrogen is also a concern in freshwaters because it may contribute to an overabundant growth of algae and aquatic plants and to a decline in diversity of the biological community. The EPA recommended a nutrient criterion of 0.15 mg/L for nitrate nitrogen in rivers and streams in the Willamette Valley ecoregion. This criterion was used for comparison to the sampling results.

Seasonal Patterns

As shown in Figure 17, nitrate+nitrite concentrations ranged from 0.04 to 5.5 mg/L across all stations during base flow events (Appendix C). During storm flow, nitrate+nitrite concentrations were similar to base flow and ranged from 0.02 and 5.5 mg/L from November through March. No substantial seasonal patterns were observed.

Storm and Base Flow Comparison

For base flow, the lowest nitrate+nitrite concentrations were observed at CSR2, followed by CSR1 (Figure 18). CSR1 and CSO1 had significantly lower nitrate+nitrite concentrations than any other station during base flow. The greatest nitrate+nitrite concentrations were observed at CSE1 (median of 5.2 mg/L) and CSF1 (median of 5.0 mg/L) during base flow and were significantly greater than at other stations. These basins have high septic or dry well densities, which were strongly but not significantly associated with nitrate+nitrite concentrations, suggesting that septic systems may be a source of nitrogen pollution.

Some significant spatial differences in nitrate+nitrite concentrations were identified by the Friedman test (Figure 18) for storm flow, but many stations had overlapping letters, indicating no significant difference between those sites. Nitrate+nitrite under storm flow was greatest at CSE1, CSF1, and CSJ1 (median values greater than 3.6 mg/L) and lowest at CSR1, CSR2, CSWSDOT2, and CSWSDOT3 (median values less than 0.3 mg/L) (Appendix C).

Nitrate+nitrite concentrations were significantly greater under base flow conditions than storm flow at most stations, except CSF1, CSJ1, and CSR2 for which concentration ranges for each event type were similar (Figure 18).

Water Quality Criteria Comparison

All stations met state drinking water and groundwater standards for nitrate+nitrite (10 mg/L) for all events, never exceeding 5.5 mg/L. However, the majority of samples (88 percent) collected in the Columbia Slope exceeded the EPA-recommended nutrient criterion for the Willamette Valley ecoregion (0.15 mg/L). The only stations where nitrate+nitrite did not exceed this criterion included CSP1 (for one sample), CSR2 (for eight samples), CSWSDOT2 (for three samples), and CSWSDOT3 (for two samples), all during the wet season (October–March) (Appendix D).

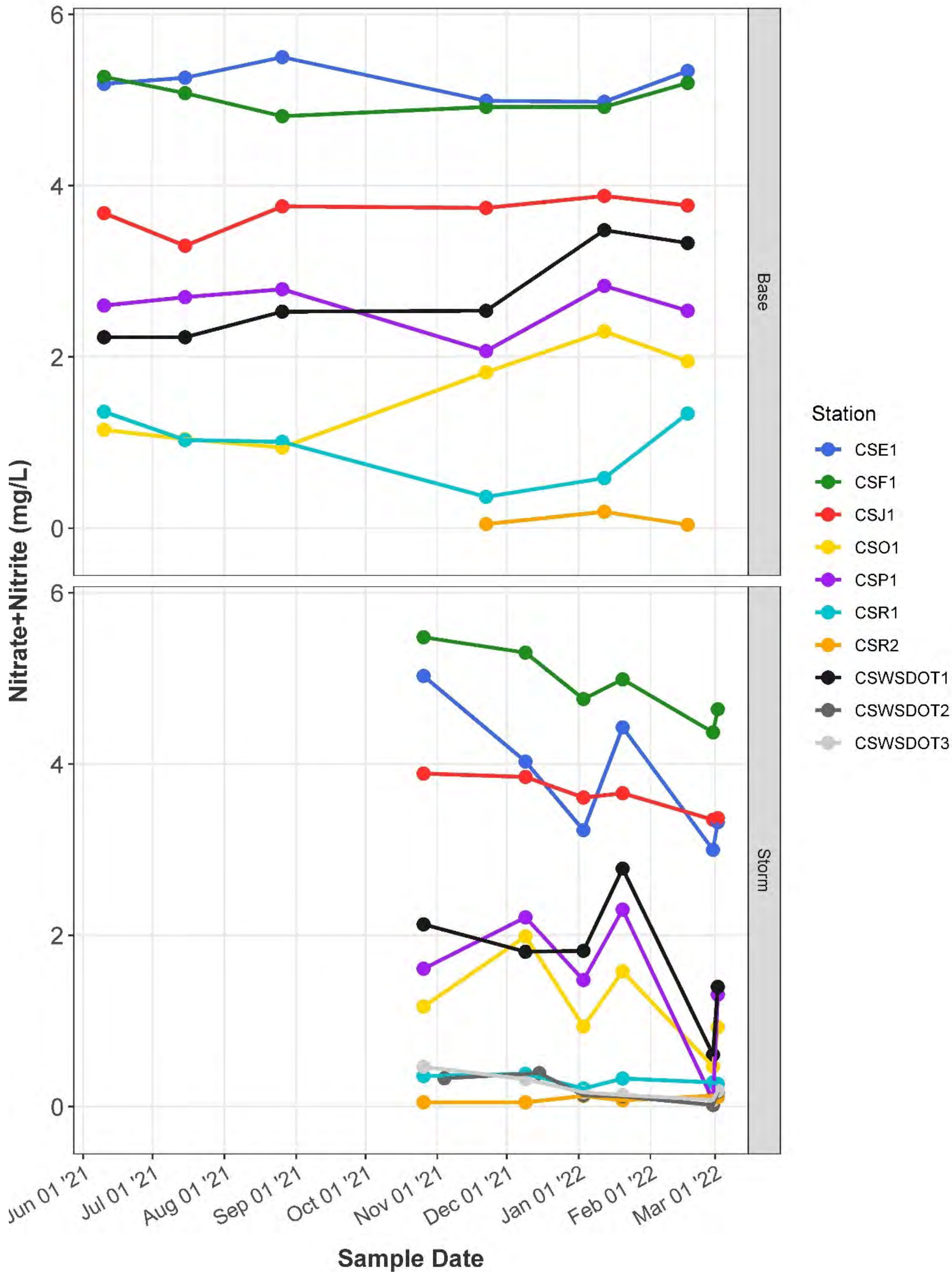

Figure 17. Nitrate+Nitrite Nitrogen Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope

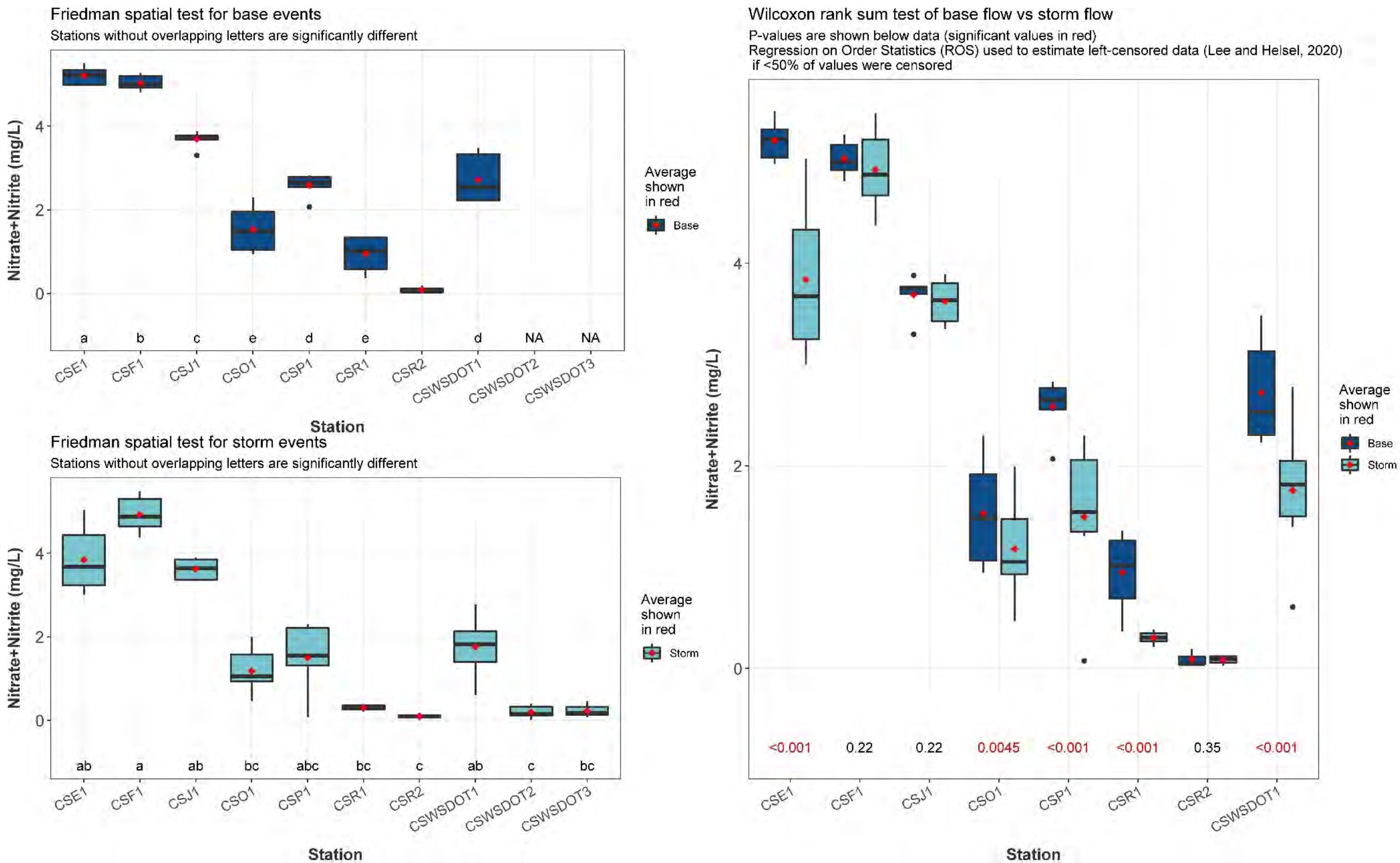

Figure 18. Nitrate+Nitrite Nitrogen Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope .

Total Nitrogen

Currently, Washington State has not established surface water quality criteria for total nitrogen. However, the EPA (2001) has established a nutrient criterion of 0.31 mg/L for total nitrogen in streams located in the Willamette Valley Ecoregion. This criterion was used for comparison to these sampling results. Nitrogen can come from natural or anthropogenic sources including atmospheric deposition, wastewater treatment plants or septic system failures, animal manure storage, and fertilizer runoff. Total nitrogen concentrations for each sample were calculated by the analytical laboratory using results from nitrate+nitrite and total kjeldahl nitrogen analyses.

Seasonal Patterns

Total nitrogen throughout the monitoring period closely echoed those patterns observed for nitrate+nitrite. Total nitrogen concentrations were relatively stable at all stations throughout base flow events, as shown in Figure 19. Total nitrogen during storm flow was more varied than base flow for most stations. No substantial seasonal patterns were observed.

Storm and Base Flow Comparison

Total nitrogen spatial patterns reflected those observed for nitrate+nitrite. Of any station, CSR2 consistently had the lowest total nitrogen concentrations during base flow, followed by CSR1 (Figure 20), with medians of 0.59 and 1.47 mg/L respectively (Appendix C). As shown in Figure 20, CSR1 and CSO1 had significantly lower concentrations than any other station during base flow. In contrast, the CSE1 and CSF1 had significantly greater concentrations than any other station (median of 5.7 mg/L at both stations). These basins have high septic or dry well densities, suggesting that septic systems may be a significant source of nitrogen and phosphorus; though nitrogen was strongly associated with septic density, only phosphorus was significantly correlated.

During storm flow, few significant spatial differences in total nitrogen concentrations were identified by the Friedman test (Figure 20). Total nitrogen under storm flow was greatest at CSE1, CSF1, and CSJ1 with medians greater than 4.0 mg/L, and was lowest at CSR1, CSR2, CSWSDOT2, and CSWSDOT3 with medians less than 1.0 mg/L (Appendix C).

The Wilcoxon Rank Sum test revealed that total nitrogen concentrations were significantly greater under base flow than storm flow conditions at all stations except CSR2 (Figure 20).

Water Quality Criteria Comparison

The EPA-recommended nutrient criterion for the Willamette Valley ecoregion (0.31 mg/L) for total nitrogen was exceeded in all samples collected during both base and storm flow monitoring (Appendix D).

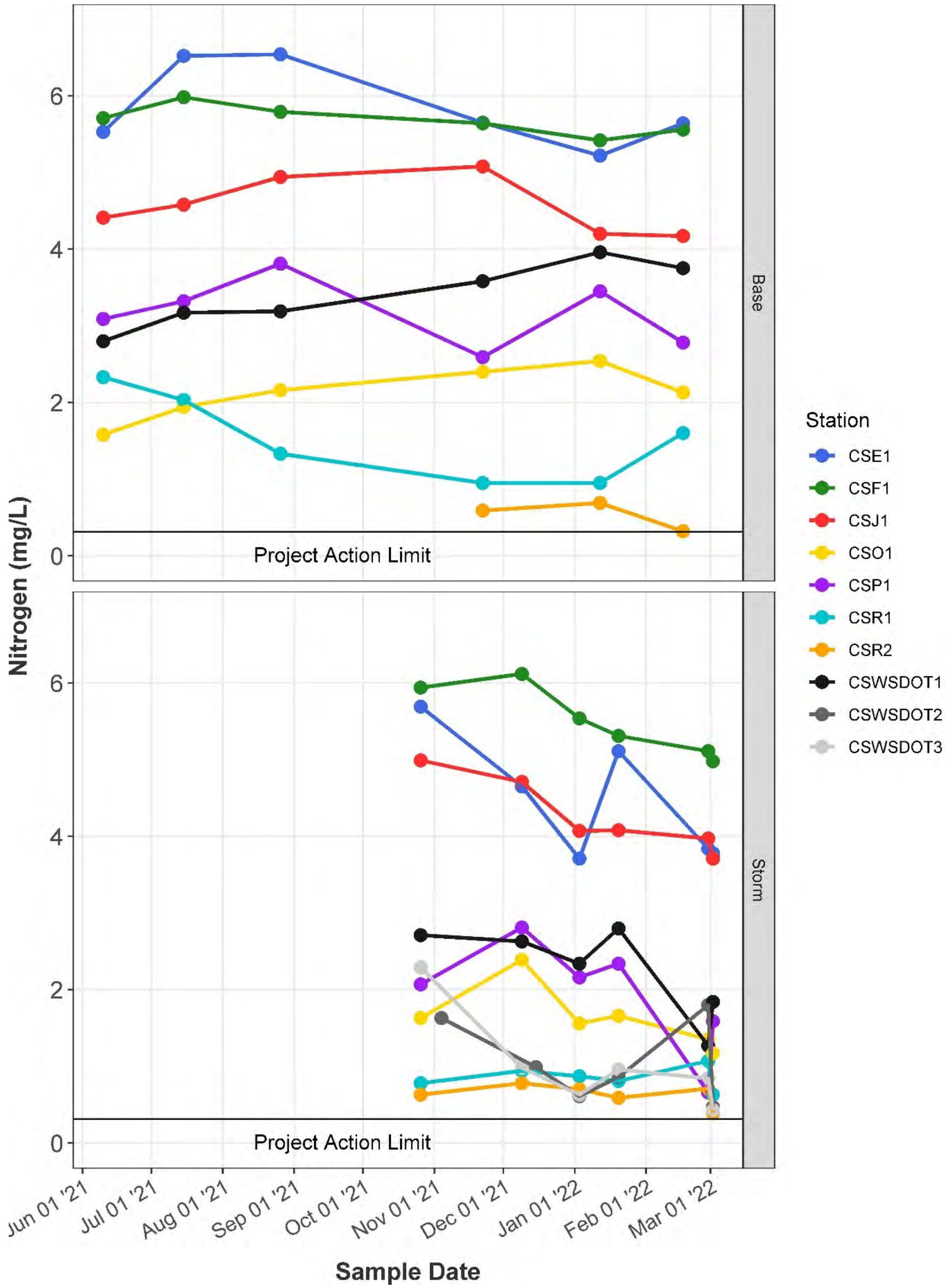

Figure 19. Total Nitrogen Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

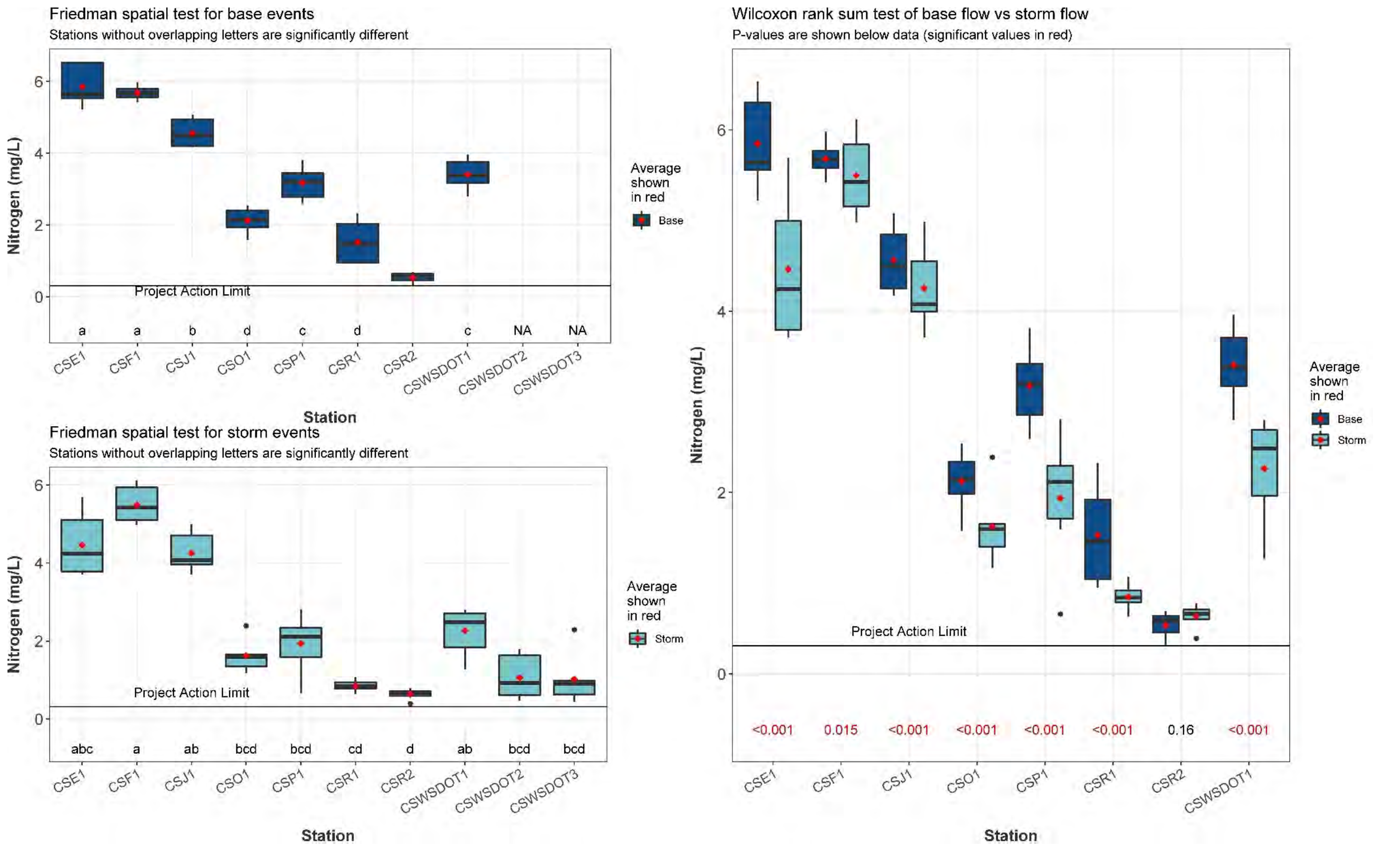

Figure 20. Total Nitrogen Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope.

Total Phosphorus

Total phosphorus is a combination of inorganic and organic forms of phosphorus, which can come from natural sources or anthropogenic sources (e.g., wastewater treatment plants, septic system failures, animal manure storage, and fertilizer runoff). Phosphorus is a concern in fresh water because high levels can lead to accelerated plant growth, algal blooms, low dissolved oxygen, decreases in aquatic diversity, and eutrophication. Currently, Washington State does not have surface water quality standards for total phosphorus in rivers and streams. The EPA recommended a nutrient criterion of 0.040 mg/L for total phosphorus in streams located in the Willamette Valley ecoregion (EPA 2001).

Seasonal Patterns

Total phosphorus concentrations were consistent throughout base flow events at all stations, as shown in Figure 21, only varying by 0.01 to 0.05 mg/L per station (Appendix C). Total phosphorus during storm flow was much more varied for most stations, with stations varying up to 0.9 mg/L from November through March. No substantial seasonal patterns were observed.

Storm and Base Flow Comparison

As shown in Figure 22, CSWSDOT1 had significantly lower total phosphorus concentrations than all other stations except CSO1 during base flow. Significantly greater concentrations were observed at CSE1 and CSF1 than all other stations, with medians of 0.16 and 0.11 mg/L respectively. High nitrogen concentrations were observed at these same stations and the basins they are located in have high septic or dry well densities which were significantly associated with higher phosphorus concentrations. This suggests that septic systems may be a significant source of phosphorus and probable source of nitrogen in these basins. During storm flow, there were few significant spatial differences in total phosphorus concentrations though the highest concentrations were observed at CSWSDOT2 and CSWSDOT3 during the January 20 and February 28, 2022, monitoring events (Figure 22).

The Wilcoxon Rank Sum test results show diverging patterns amongst stations. Phosphorus concentrations at CSE1 and CSP1 were significantly greater under base flow conditions than storm flow, while at CSF1, CSJ1, and CSR1, phosphorus was significantly greater under storm flow conditions. At CSO1, CSR2, and CSWSDOT1, no significant differences between base and storm flow were detected (Figure 22).

Water Quality Criteria Comparison

Like total nitrogen, the EPA-recommended total phosphorus criterion for the Willamette Valley ecoregion (0.040 mg/L) was exceeded in 100 percent of the samples collected in the Columbia Slope during this monitoring period (Appendix D).

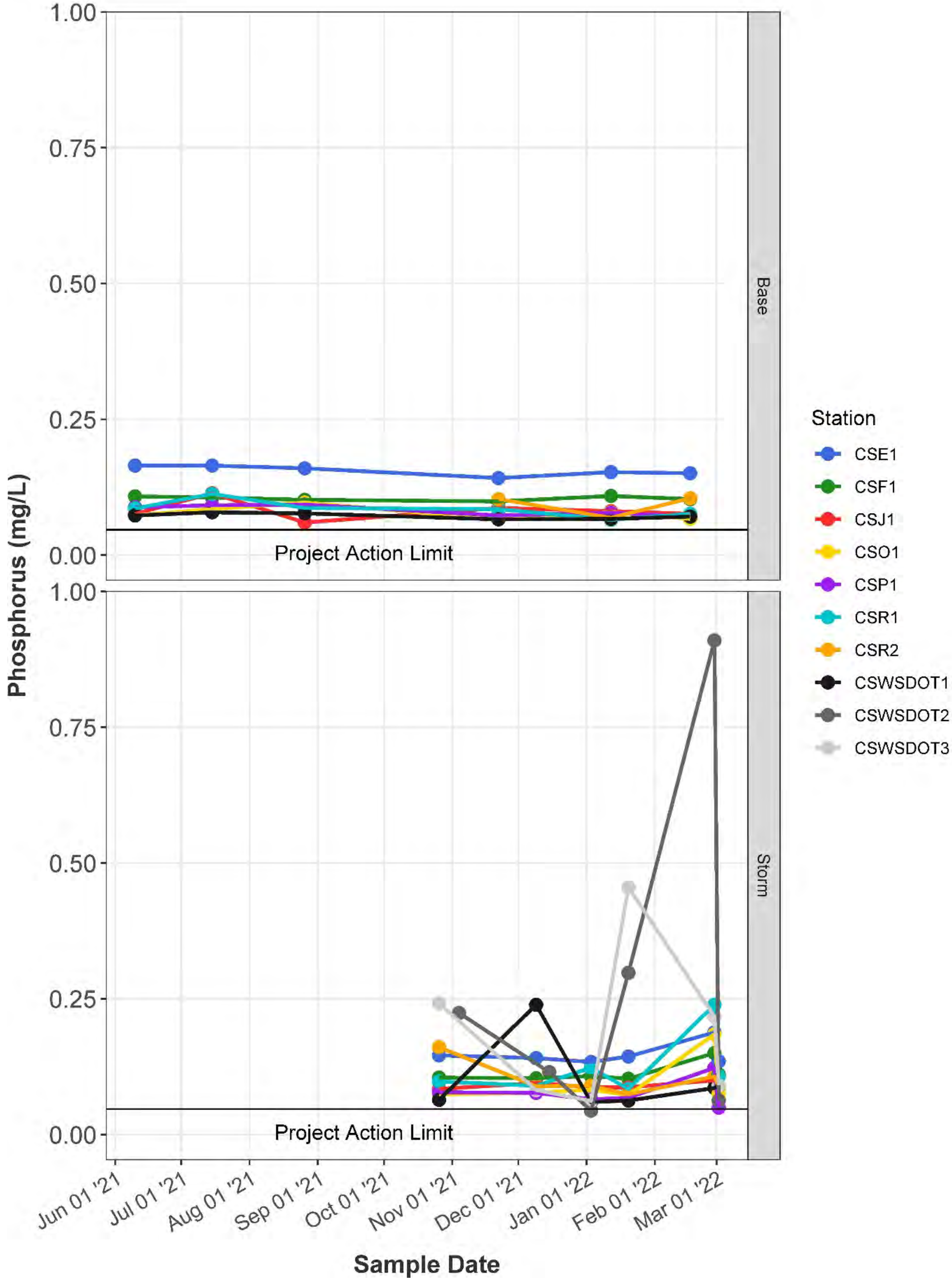

Figure 21. Total Phosphorus Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

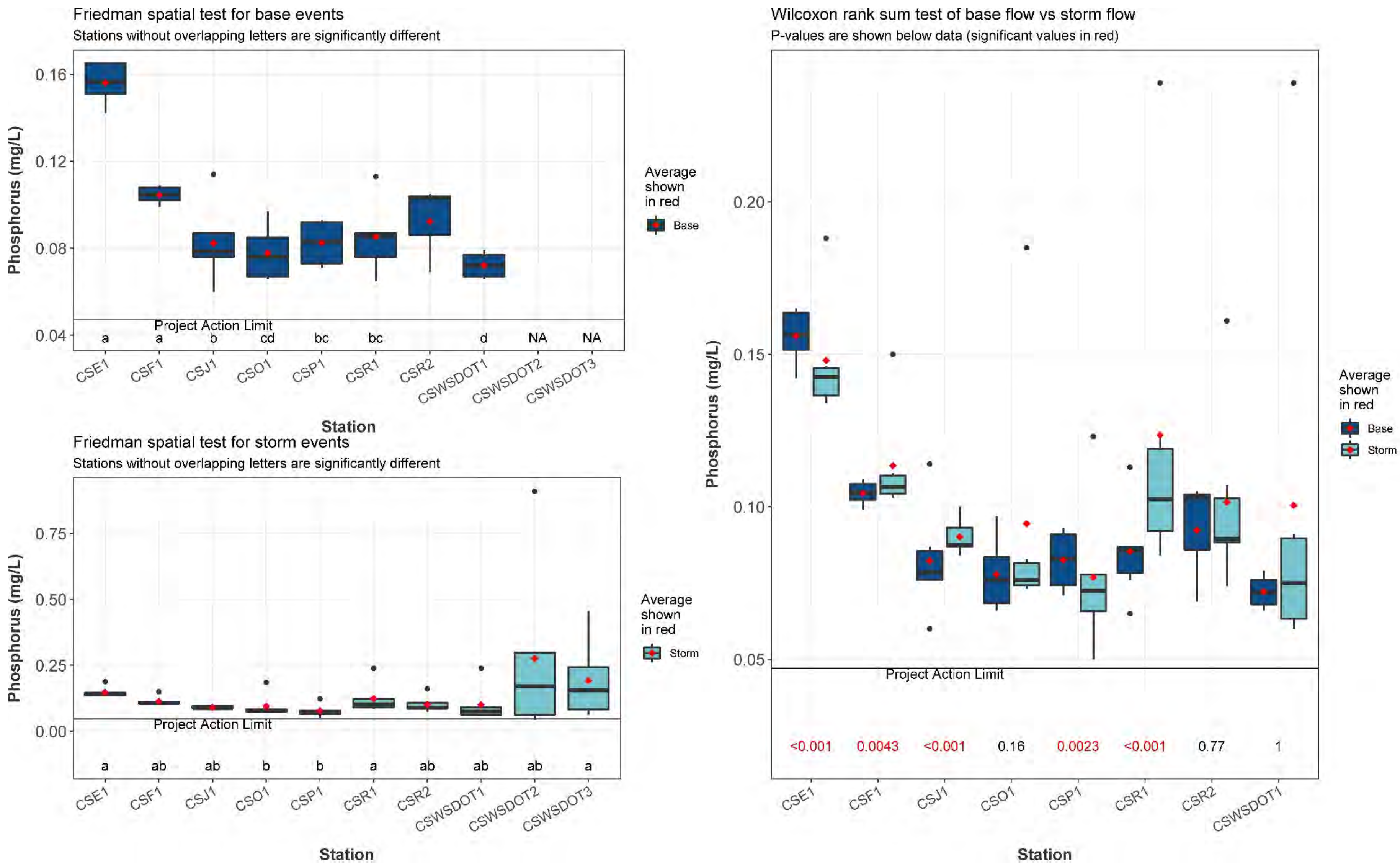

Figure 22. Total Phosphorus Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope

Hardness as $CaCO_3$

Hardness is a measurement of the dissolved mineral content (primarily calcium and magnesium) of water. Hard water contains a high mineral content and soft water contains a low mineral content. High hardness values can increase or decrease the toxicity of metals in runoff, depending on the aquatic species that is exposed. Hardness values are therefore used to calculate dissolved metals toxicity criteria. Natural sources of hardness include limestone (which introduces calcium into groundwater) and dolomite (which introduces magnesium). No state surface water quality standards have been established for hardness.

Seasonal Patterns

As shown in Figure 23, hardness during base flow was relatively stable throughout the monitoring period for most stations except CSR1, CSR2, and CSWSDOT1, for which the range of values was greater. No seasonal patterns were observed that were consistent amongst all stations; however, three stations exhibited similar patterns where a drop in hardness occurred in July with an increase in August.

For most stations, hardness was lower and more variable across storm events than base flow. Similar temporal patterns in hardness concentration were observed amongst most stations (Figure 23). Maximum hardness values were recorded at the start of the storm season for most stations, with gradual decreases before a small peak in January, followed by a dramatic decline at the end of February and an immediate increase again in March.

Storm and Base Flow Comparison

Base flow hardness concentrations at CSE1 and CSJ1 were significantly greater than any other station (Figure 24). CSR2, with a median of 33 mg/L, had substantially lower base flow concentrations than all other sites (non-overlapping interquartile ranges), and CSR1 had significantly lower base flow concentrations than any other station excluding CSR2. CSJ1 had significantly greater concentrations than most other stations and had the largest median values of all sites for storm and base flow (91 and 93 mg/L respectively).

Hardness concentrations were typically significantly greater during base flow than storm flow, except at stations CSF1 and CSJ1 where hardness was relatively high during all sampling events, and at CSR2 where hardness was low during all sampled events (Figure 24). Rainwater has a very low mineral concentration compared to groundwater, potentially increasing the toxicity of metals in stormwater runoff.

These results indicate that the toxicity of heavy metals may be lowest at CSE1 and CSJ1, while the greatest risk of metals toxicity in the Columbia Slope may be at CSR1 and CSR2, particularly during base flow.

Water Quality Criteria Comparison

There are no water quality standards or project action limits established for this parameter.

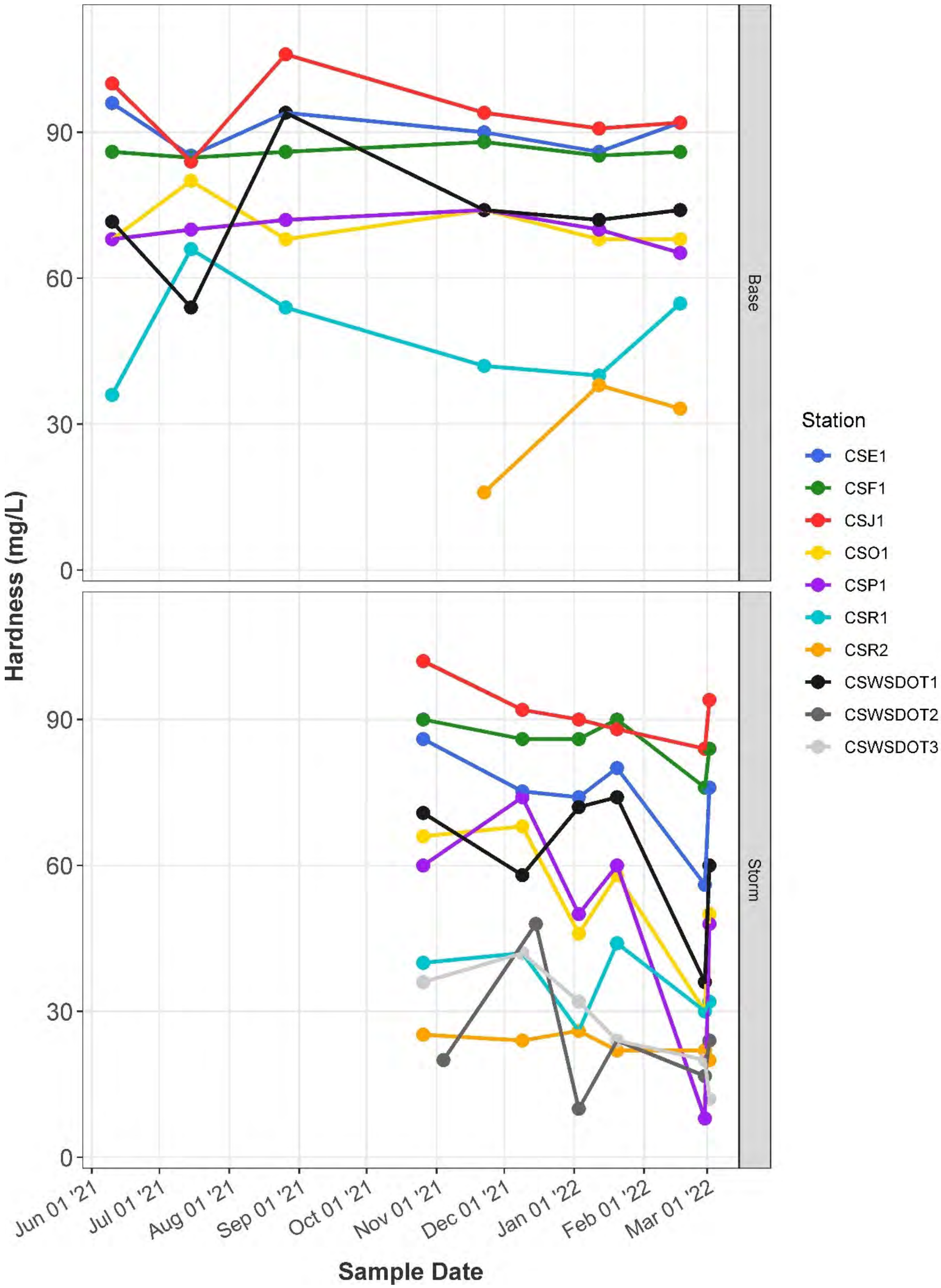

Figure 23. Hardness as CaCO3 Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

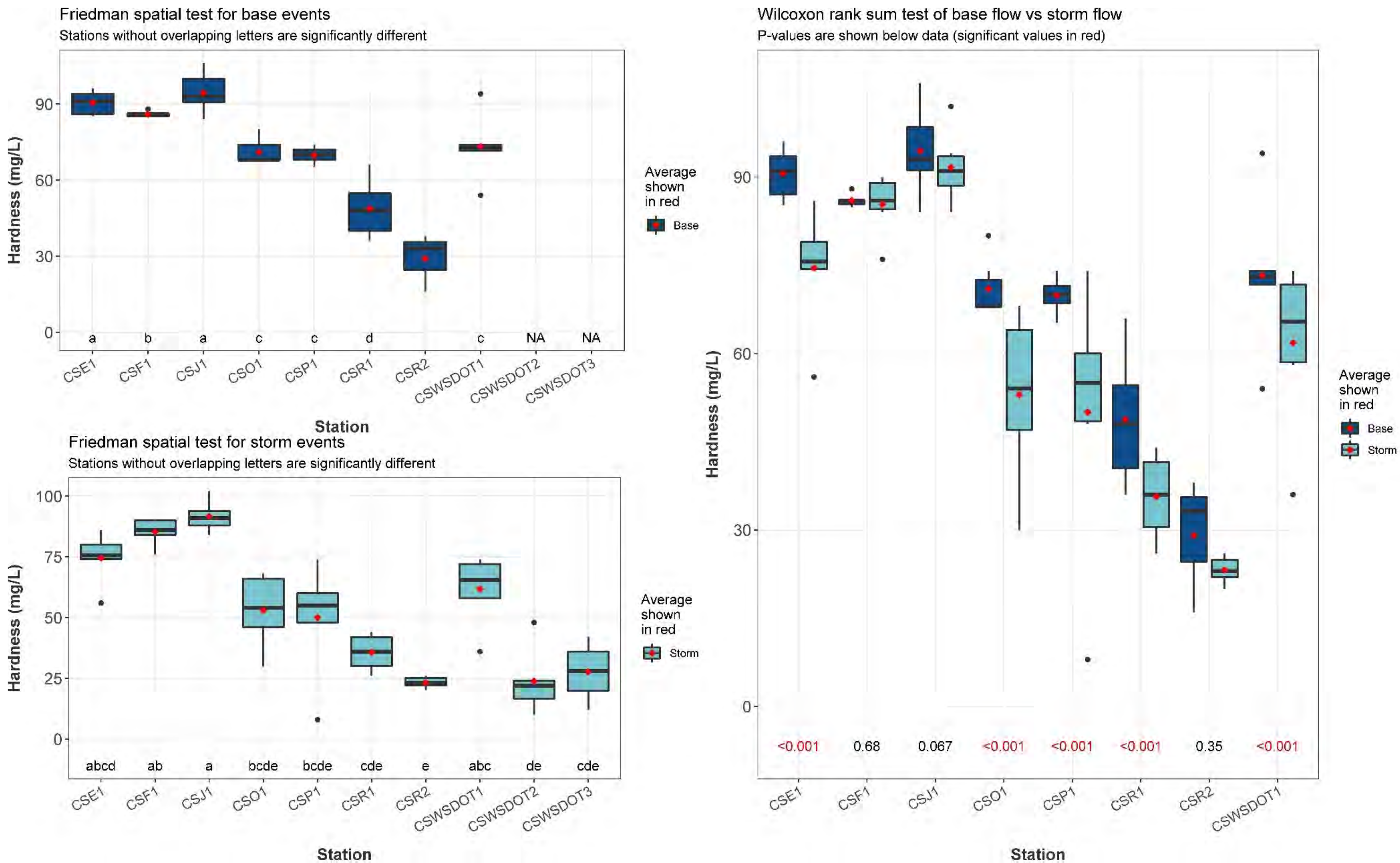

Figure 24. Hardness as CaCO3 Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope.

Chloride

Chloride is a measurement of dissolved chloride in association with sodium, potassium, calcium, and magnesium as salts. Chlorides are present in a variety of products, such as water and wastewater treatment products (i.e., chlorine, iron chloride), roadway deicing salts (e.g., sodium chloride, magnesium chloride), and fertilizers (e.g., potassium chloride). Thus, anthropogenic sources of chloride may include runoff, landfill leachate, septic tank or industrial effluent, and irrigation drainage. However, chlorides are also present naturally in surface and groundwater, originating from natural sources like seawater intrusion in coastal areas and weathering of various rocks. Additionally, chloride can increase the corrosivity of water, so as it reacts with the metal ions in pipes, this can increase the concentration of metals in drinking water or waterways. Measuring chloride in freshwater systems is thus an important indicator of impairment and is often used to specifically evaluate potential inputs from septic systems.

According to the World Health Organization (WHO) (2003), chloride levels in unpolluted waterways are often below 10 mg/L, and sometimes below 1 mg/L. There are no Washington state human health criteria for chloride. Healthy individuals can tolerate large quantities of chloride as long as it is accompanied by an intake of fresh water (WHO 2003). However, Washington state does maintain a criterion for aquatic life uses, which restricts chloride concentrations to less than 860 mg/L for acute exposure and 230 mg/L for chronic exposure (WAC 173-201A-240).

Seasonal Patterns

As shown in Figure 25, chloride during base flow was relatively stable throughout the monitoring period, varying by less than 4 mg/L for all stations. (Appendix C). Minimums, however slight relative to the rest of the datasets, were typically observed in summer months and maximums typically observed in January and February, except at CSO1 for which the opposite pattern was true.

For most stations, chloride was more variable across storm events than base flow particularly for WSDOT stations. No temporal patterns in chloride concentration were observed consistently across stations but spikes in chloride were observed at CSR1 and WSDOT stations in January and is likely related to use of deicing salts (Figure 25).

Storm and Base Flow Comparison

Station CSJ1 was found to have significantly lower base flow chloride concentrations than all stations except at CSR1 and CSR2 (Figure 26). CSF1, CS01 and CSP1 had significantly greater base flow concentrations than all other stations. For storm flow, CSWSDOT1 had significantly greater chloride concentrations than all stations except CSWSDOT3.

Patterns in chloride concentrations between base and storm flow differed among stations (Figure 26). Chloride was significantly greater during storm events at stations CSE1, CSR1, and CSWSDOT1, but was significantly greater during base events at CSO1, CSP1, and CSR2.

These results suggest the potential for pipe corrosion or contamination via septic system inputs, wastewater products, salts, or fertilizers was relatively low amongst all City stations and that the greatest contribution of chloride contamination was from WSDOT stations in January, likely due to deicers used on highways.

Water Quality Criteria Comparison

All stations met the state aquatic life use criteria of less than 860 mg/L for acute exposure to chloride and 230 mg/L for chronic exposure to chloride (WAC 173-201A-240). Additionally, compared to typical levels of chloride in unpolluted waterways (less than 10 mg/L), chloride concentrations in the Columbia Slope during base flow were often comparable at less than 10.8 mg/L, as were concentrations at City stations during storm flow. However, chloride concentrations at WSDOT stations during storm flow exceeded this general threshold, with values greater than 13 mg/L and up to 44 mg/L during a January storm event (Appendix C).

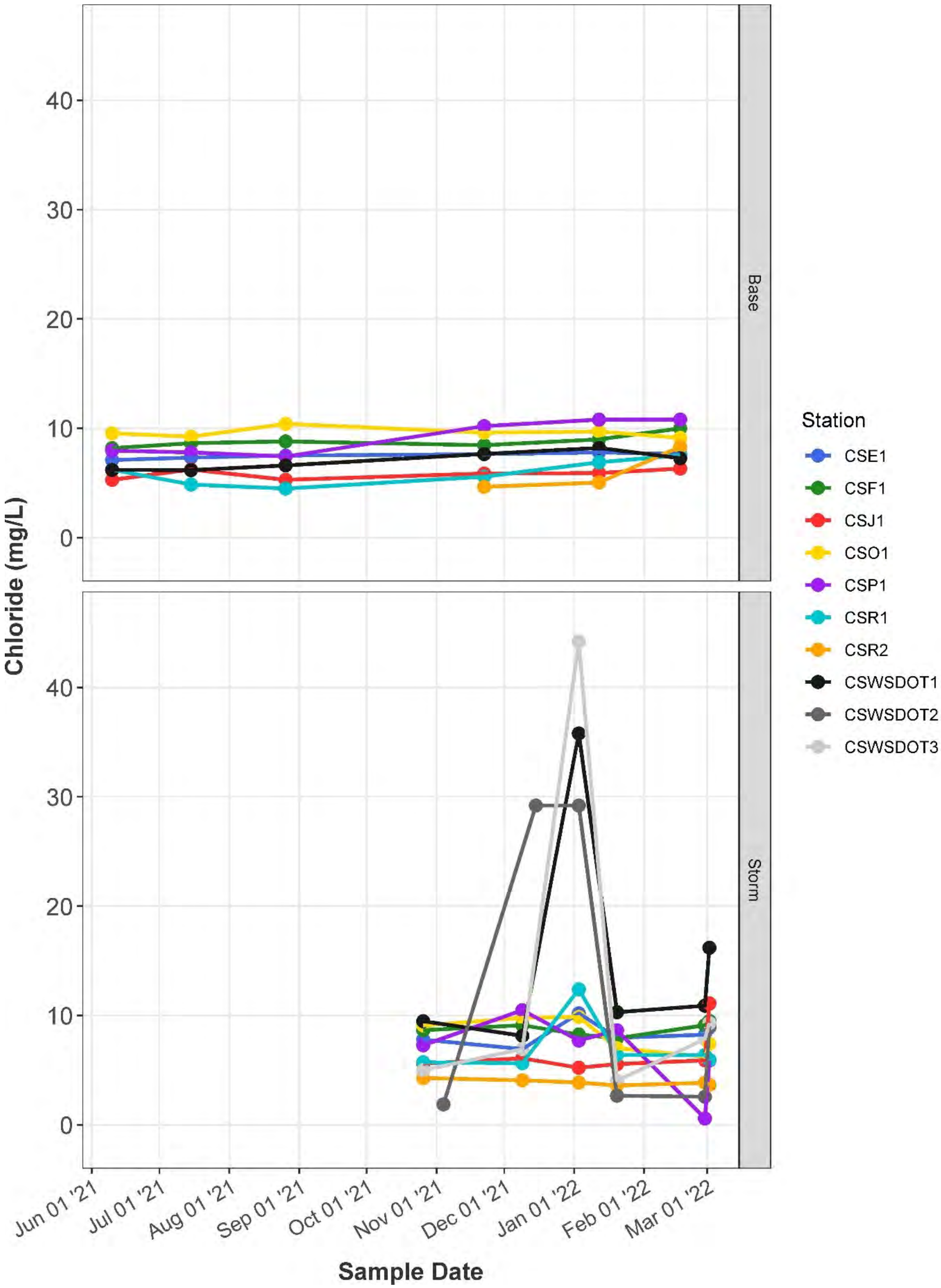

Figure 25. Chloride Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope

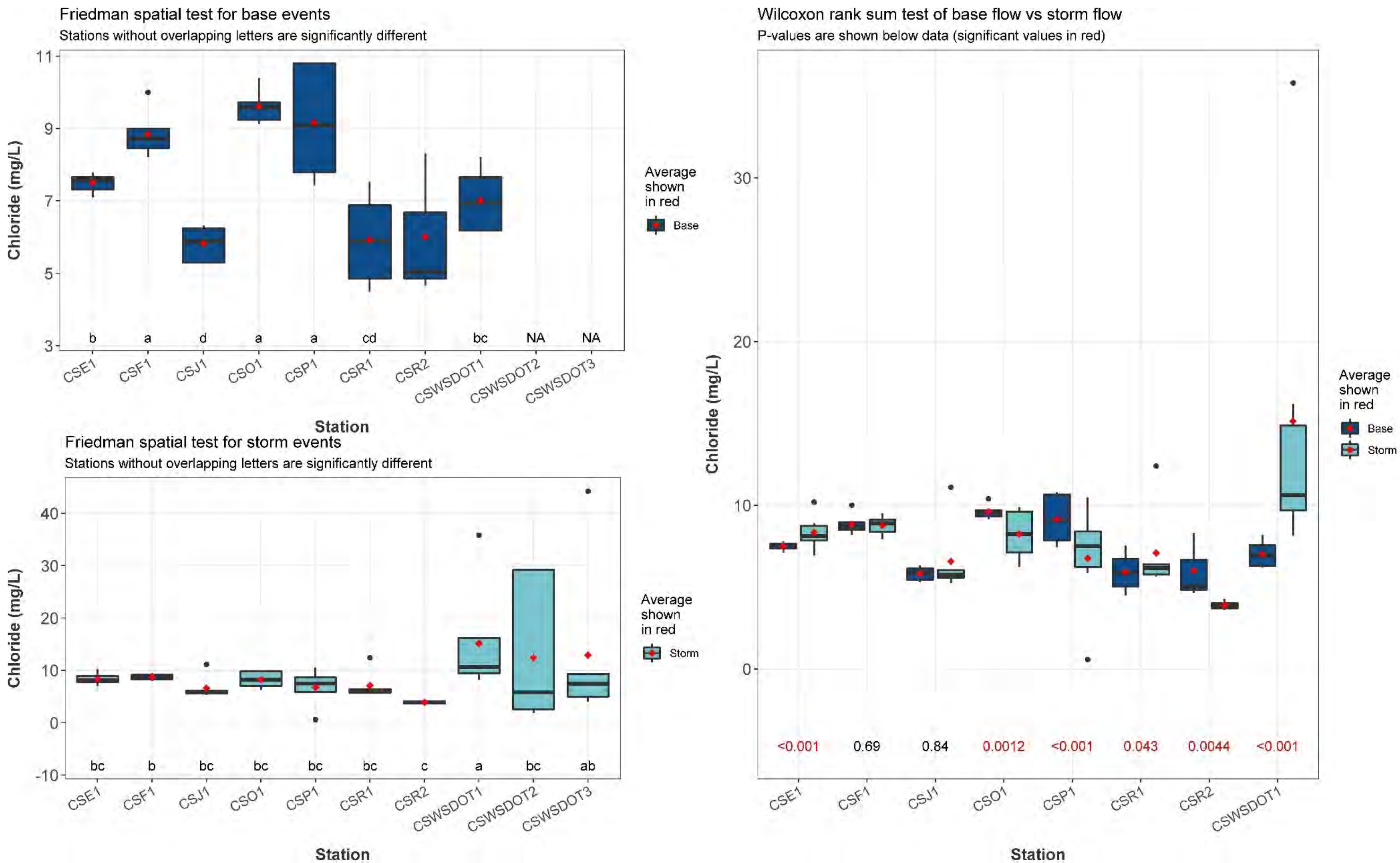

Figure 26. Chloride Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope.

Metals

Copper, lead, and zinc are some of the most common heavy metals observed in urban streams. The total fractions of these heavy metals were included in both the storm and base flow monitoring program to evaluate acute and chronic aquatic toxicity within the project area. Potential sources of these heavy metals within the Columbia Slope watershed include vehicle components, petroleum-based fuels and oil, electronics waste, metal roofs, and naturally eroding soils. Washington state surface water quality standards (WAC 173 201A) for these three heavy metals are based on the dissolved fraction and vary directly with hardness concentrations such that toxicity decreases with increasing hardness. A list of exceedances of the calculated acute and chronic water quality standards are presented in Table 8. Criteria values were calculated using hardness values reported at each station from each monitoring event. Note that the criteria lines in the figures below represent values calculated using the median hardness value for all events at all stations and are for general visual comparison only.

Results for each metal are discussed below. Summary statistics for these data are presented in Appendix C, and all data results are presented in Appendix D.

Table 8. Metals Water Quality Criteria Exceedances.

Station	Date	Type	Parameter	Result (µg/L)	Hardness (mg/L)	Criteria Type	Criteria Value (µg/L)[a]
CSO1	2/28/2022	Storm	Copper	7.01	30	Acute, Chronic	5.47, 4.06
CSP1	2/28/2022	Storm	Copper	6.63	8	Acute, Chronic	1.58, 1.31
CSR1	2/28/2022	Storm	Copper	5.95	30	Acute, Chronic	5.47, 4.06
CSR2	12/9/2021	Storm	Copper	4.18	24	Chronic	3.35
CSWSDOT1	12/9/2021	Storm	Copper	21.7	58	Acute, Chronic	10.19, 7.13
CSWSDOT1	2/28/2022	Storm	Copper	6.36	36	Chronic	4.74
CSWSDOT2	11/4/2021	Storm	Copper	25.9	20	Acute, Chronic	3.74, 2.87
CSWSDOT2	12/15/2021	Storm	Copper	15.8	48	Acute, Chronic	8.45, 6.06
CSWSDOT2	1/3/2022	Storm	Copper	8	10	Acute, Chronic	1.94, 1.59
CSWSDOT2	1/20/2022	Storm	Copper	32.5	24	Acute, Chronic	4.44, 3.35
CSWSDOT2	2/28/2022	Storm	Copper	73.4	16.7	Acute, Chronic	3.15, 2.46
CSWSDOT2	3/2/2022	Storm	Copper	10.9	24	Acute, Chronic	4.44, 3.35
CSWSDOT3	10/26/2021	Storm	Copper	36.5	36	Acute, Chronic	6.50, 4.74
CSWSDOT3	12/9/2021	Storm	Copper	7.96	42	Acute, Chronic	7.51, 5.41
CSWSDOT3	1/3/2022	Storm	Copper	6.57	32	Acute, Chronic	5.82, 4.29
CSWSDOT3	1/20/2022	Storm	Copper	50.3	24	Acute, Chronic	4.44, 3.35
CSWSDOT3	2/28/2022	Storm	Copper	19	20	Acute, Chronic	3.74, 2.87
CSWSDOT3	3/2/2022	Storm	Copper	8.83	12	Acute, Chronic	2.31, 1.85
CSE1	2/28/2022	Storm	Lead	2.16	56	Chronic	1.33
CSO1	2/28/2022	Storm	Lead	1.84	30	Chronic	0.66
CSP1	2/28/2022	Storm	Lead	1.41	8	Chronic	0.15

Table 8 (continued). Metals Water Quality Criteria Exceedances.							
Station	Date	Type	Parameter	Result (µg/L)	Hardness (mg/L)	Criteria Type	Criteria Value (µg/L)[a]
CSR1	2/28/2022	Storm	Lead	2.31	30	Chronic	0.66
CSWSDOT1	12/9/2021	Storm	Lead	4.84	58	Chronic	1.38
CSWSDOT1	2/28/2022	Storm	Lead	1.4	36	Chronic	0.81
CSWSDOT2	11/4/2021	Storm	Lead	3.28	20	Chronic	0.42
CSWSDOT2	12/15/2021	Storm	Lead	1.8	48	Chronic	1.12
CSWSDOT2	1/3/2022	Storm	Lead	0.677	10	Chronic	0.19
CSWSDOT2	1/20/2022	Storm	Lead	5.81	24	Chronic	0.52
CSWSDOT2	2/28/2022	Storm	Lead	19.5	16.7	Acute, Chronic	8.80, 0.34
CSWSDOT2	3/2/2022	Storm	Lead	1.1	24	Chronic	0.52
CSWSDOT3	10/26/2021	Storm	Lead	5.06	36	Chronic	0.81
CSWSDOT3	1/3/2022	Storm	Lead	0.858	32	Chronic	0.71
CSWSDOT3	1/20/2022	Storm	Lead	10.1	24	Chronic	0.52
CSWSDOT3	2/28/2022	Storm	Lead	4.71	20	Chronic	0.42
CSWSDOT3	3/2/2022	Storm	Lead	1.19	12	Chronic	0.24
CSO1	2/28/2022	Storm	Zinc	67.6	30	Acute, Chronic	41.26, 37.68
CSP1	10/26/2021	Storm	Zinc	100	60	Acute, Chronic	74.24, 67.79
CSP1	2/28/2022	Storm	Zinc	56.5	8	Acute, Chronic	13.46, 12.30
CSR2	12/9/2021	Storm	Zinc	196	24	Acute, Chronic	34.16, 31.19
CSWSDOT1	12/9/2021	Storm	Zinc	175	58	Acute, Chronic	72.14, 65.87
CSWSDOT1	2/28/2022	Storm	Zinc	47.4	36	Chronic	43.97
CSWSDOT2	11/4/2021	Storm	Zinc	95.4	20	Acute, Chronic	29.27, 26.72
CSWSDOT2	12/15/2021	Storm	Zinc	152	48	Acute, Chronic	61.45, 56.11
CSWSDOT2	1/3/2022	Storm	Zinc	39.7	10	Acute, Chronic	16.27, 14.85
CSWSDOT2	1/20/2022	Storm	Zinc	157	24	Acute, Chronic	34.16, 31.19
CSWSDOT2	2/28/2022	Storm	Zinc	374	16.7	Acute, Chronic	25.12, 22.94
CSWSDOT2	3/2/2022	Storm	Zinc	47.6	24	Acute, Chronic	34.16, 31.19
CSWSDOT3	10/26/2021	Storm	Zinc	239	36	Acute, Chronic	48.16, 43.97
CSWSDOT3	1/20/2022	Storm	Zinc	294	24	Acute, Chronic	34.16, 31.19
CSWSDOT3	2/28/2022	Storm	Zinc	96	20	Acute, Chronic	29.27, 26.72
CSWSDOT3	3/2/2022	Storm	Zinc	40.4	12	Acute, Chronic	18.98, 17.34

[a] Water Quality Standards for Surface Waters of the State of Washington, Chapter 173-201A WAC. Washington State Department of Ecology Water Quality Calculator with measured hardness.

mg/L = milligrams per liter

µg/L = micrograms per liter

Total Copper

Seasonal Patterns

As shown in Figure 27, total copper concentrations were fairly consistent at all stations during base flow throughout the monitoring period ranging from 0.2 to 2.2 µg/L (Appendix C).

Maximum total copper concentrations were typically observed during storm events in late February for most stations, except at CSR2, CSWSDOT1 and CSWSDOT3, for which maxima were observed in December and January. The timing of minimum total copper concentrations for each station varied; for many stations this occurred in August but for others, minima occurred during the wet season months. Total copper concentrations during storm flow for each station were more variable between monitoring events and did not appear to display temporal trends (Figure 27).

Storm and Base Flow Comparison

Total copper concentrations ranged from 0.2 to 2.2 µg/L at all stations during base flow events but were higher and more variable during storm flow events, ranging from 0.2 to 7.0 µg/L and from 1.0 to 73 µg/L at City and WSDOT stations, respectively (Appendix C). Base flow concentrations at CSE1 and CSO1 were significantly higher than all other stations except at CSR1 and CSR2. Storm flow copper concentrations at CSWSDOT3 were significantly higher than all other stations except CSWSDOT2, which also had substantially higher total copper than the remaining stations (Figure 28). Storm flow total copper concentrations at stations CSWSDOT1, CSWSDOT2, and CSWSDOT3 displayed the greatest variability.

The Wilcoxon Rank Sum test (Figure 28) showed that total copper concentrations were significantly lower during base flow than storm flow, likely due to the higher proportion of urban surface runoff during storm events, at all stations except CSF1 and CSR2 which had similar base and storm flow concentrations. Since total copper is a common urban stormwater pollutant, the increase in concentrations during storm flow events at most stations is expected.

Water Quality Criteria Comparison

All base flow total copper concentrations were below the associated water quality criteria. However, total copper concentrations during storm flow exceeded acute criteria at least once at CSO1, CSR1, and all WSDOT stations, and exceeded chronic criteria at those stations and at CSR2 as well (Table 8).

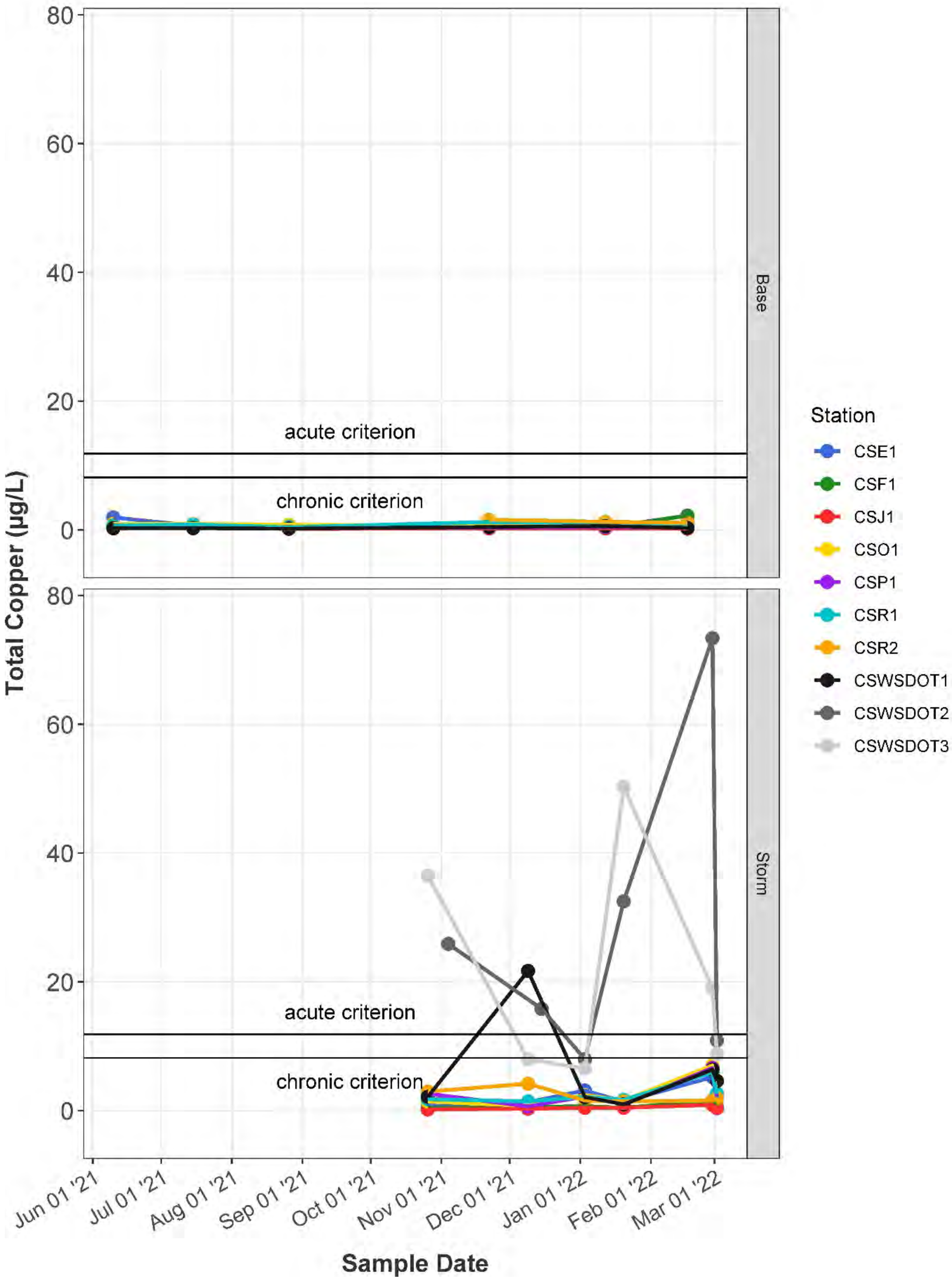

Figure 27. Total Copper Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

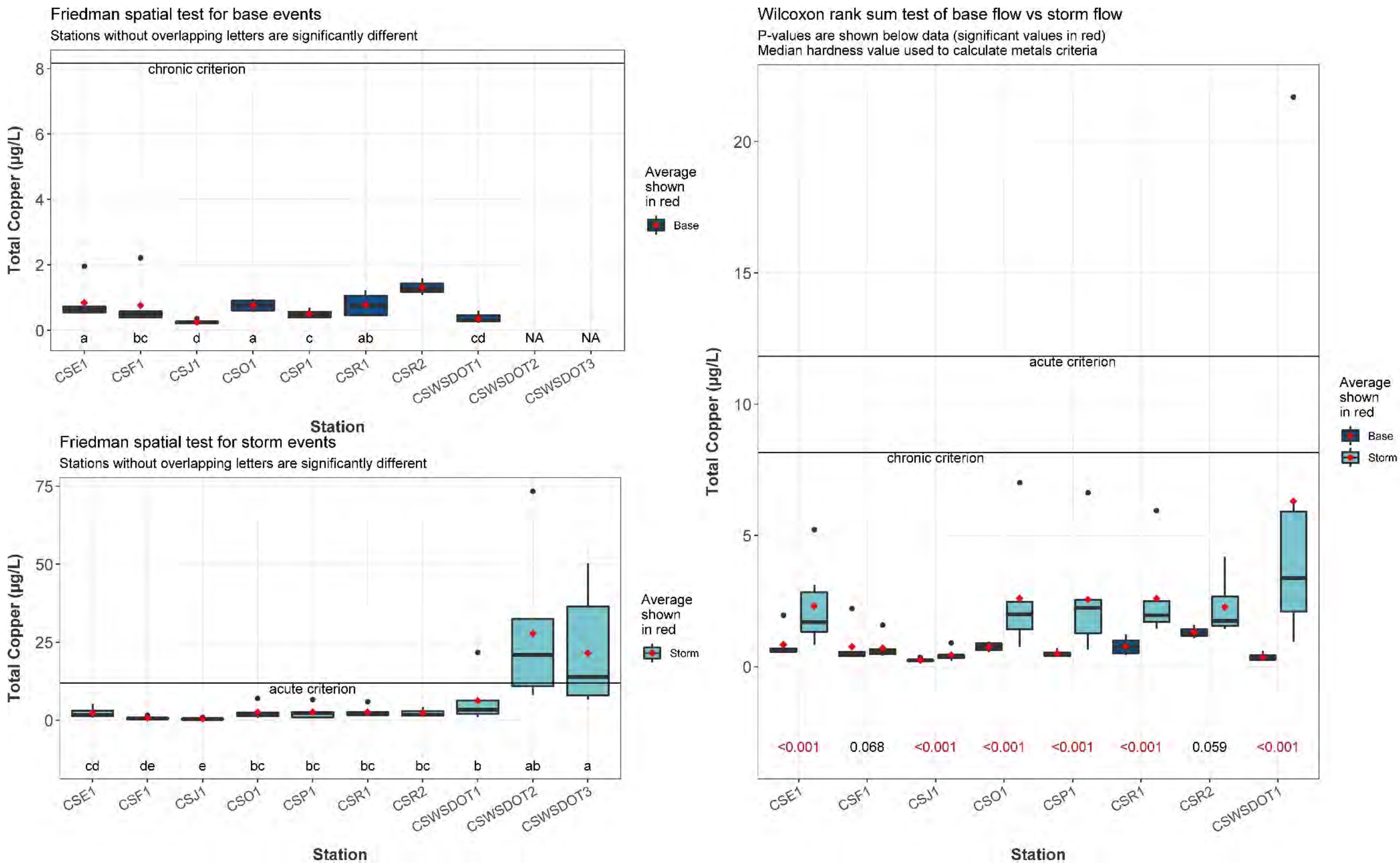

Figure 28. Total Copper Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope.

Total Lead

Seasonal Patterns

As shown in Figure 29, total lead concentrations during base flow were relatively stable throughout the monitoring period for most stations, varying from 0.01 to 0.20 µg/L for all stations except CSR1, for which the range was higher (0.06 to 0.31 µg/L) (Appendix C). Maximum base flow concentrations were observed at most stations during July and August and were generally higher during dry season events and decreased during wet season events. Storm flow concentrations ranged from 0.02 to 19.5 µg/L and did not display any clear temporal patterns (Figure 29), though maximum storm flow total lead concentrations were observed at most stations on February 28, 2022.

Storm and Base Flow Comparison

Base flow total lead concentrations at CSE1 were significantly higher than all other stations except CSR1 and CSR2. Base flow concentrations of lead were significantly lower at CSP1 and CSWSDOT1 than all other stations (Figure 30). Storm flow concentrations at CSWSDOT3 were significantly higher than all other stations except CSWSDOT2 (Figure 30). Storm flow total lead concentrations at stations CSWSDOT1, CSWSDOT2, and CSWSDOT3 displayed the greatest range.

The Wilcoxon Rank Sum test (Figure 30) showed that total lead concentrations were significantly lower during base flow than storm flow, likely due to the higher proportion of urban surface runoff during storm events, at all stations except CSF1. Since total lead is a common urban stormwater pollutant, this increase in concentrations during storm flow events at most stations is expected.

Water Quality Criteria Comparison

All base flow total lead concentrations met the associated water quality standards. However, total lead concentrations during storm flow exceeded chronic criteria at least once at each CSE1, CSO1, CSP1, CSR1, and all WSDOT stations (Table 8). Most chronic criteria exceedances occurred at CSWSDOT2 and CSWSDOT3. The acute criterion for total lead concentrations was exceeded once at CSWSDOT2 on February 28, 2022 (Table 8).

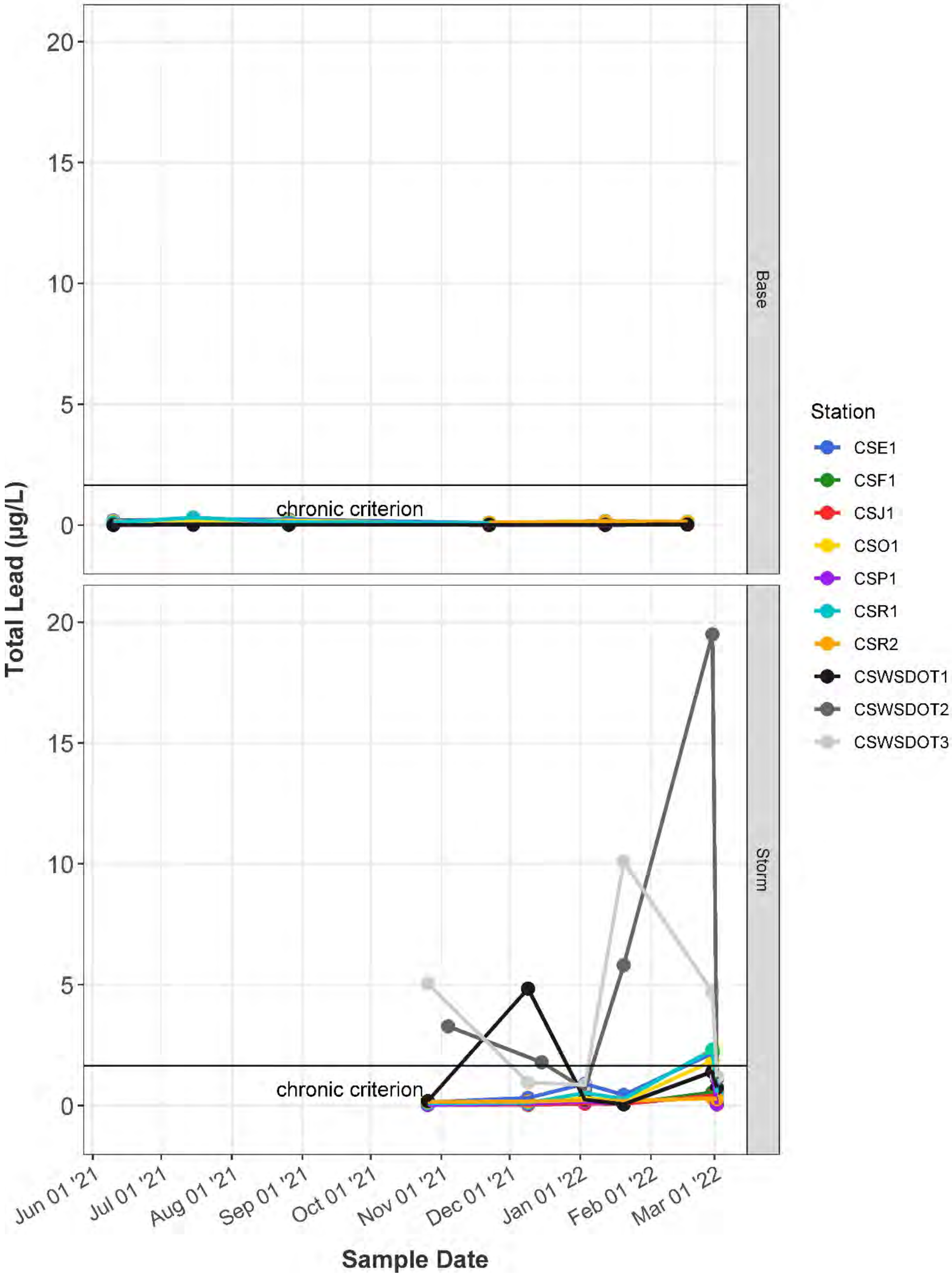

Figure 29. Total Lead Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

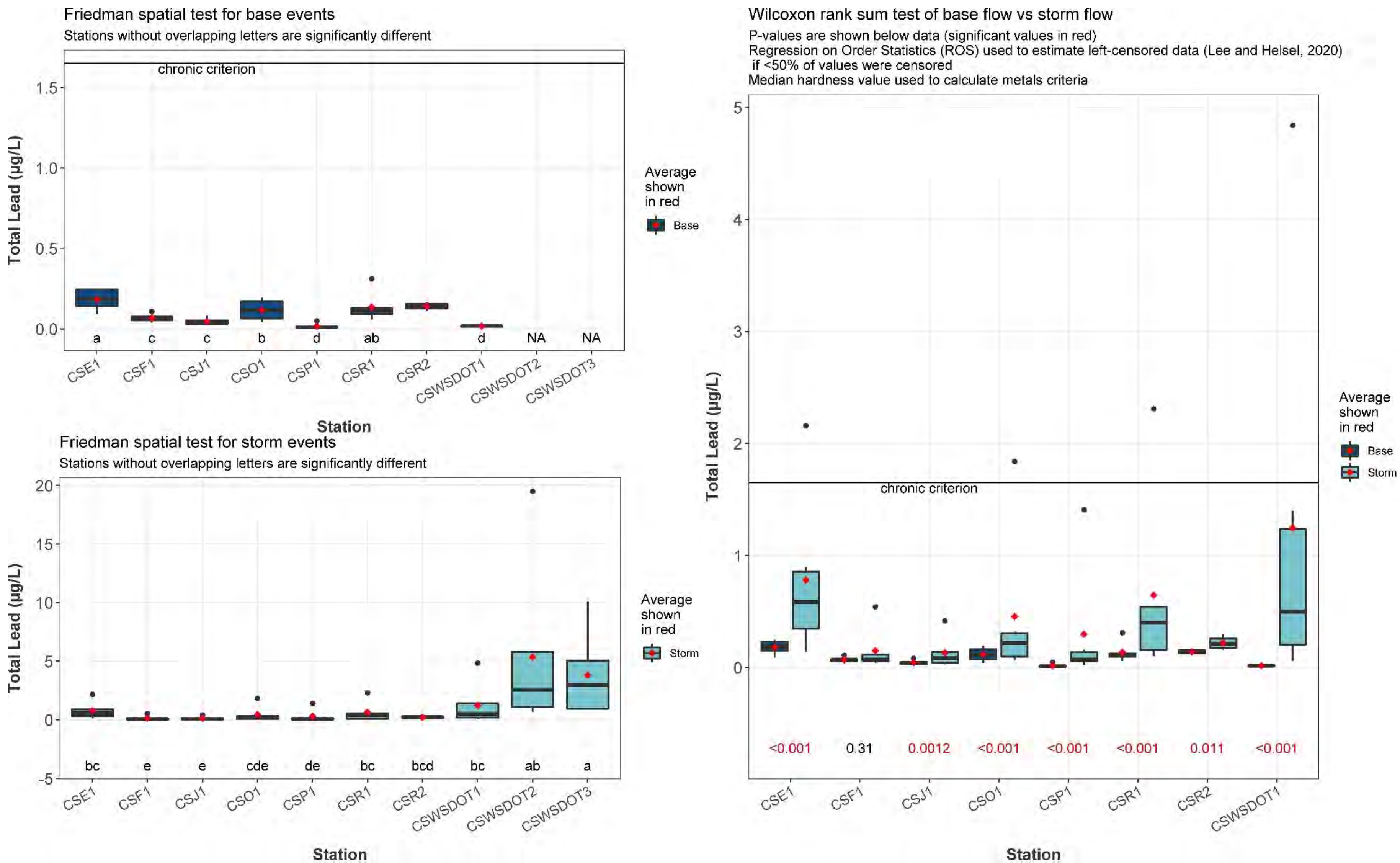

Figure 30. Total Lead Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope.

Total Zinc

Seasonal Patterns

As shown in Figure 31, base flow total zinc concentrations were fairly consistent for most stations throughout the monitoring period, ranging from 0.6 to 19 µg/L and varying by only 1-11 µg/L per station except at CSO1 where total zinc was greater than at any other station, and ranged from 14 to 48 µg/L (Appendix C).

Total zinc concentrations for each station were more varied amongst storm events, with concentrations ranging from 1 to 374 µg/L. Under storm flow, zinc concentrations did not appear to display any temporal trends consistent amongst stations (Figure 31).

Storm and Base Flow Comparison

Total zinc concentrations ranged from 0.6 to 48 µg/L at all stations during base flow events (Appendix C) and displayed significant spatial trends. Base flow concentrations at CSO1 were significantly higher than all other stations with a median of 20 µg/L, whereas total zinc at CSF1 and CSJ1 were significantly lower than all other stations (median of 1.0 µg/L for both stations) (Figure 32).

Total zinc concentrations were higher and more variable during storm flow events, ranging from 1.2 to 100 µg/L at City stations, and from 12 to 374 µg/L at WSDOT stations (Appendix C). Storm flow zinc was substantially greater at the WSDOT2 and WSDOT3, with medians of 124 and 68 µg/L respectively. Stations CSF1 and CSJ1 had significantly lower concentrations during storm flow than most stations, with medians of 1.9 and 1.4 µg/L respectively (Figure 32).

The Wilcoxon Rank Sum test (Figure 32) showed that total zinc concentrations were significantly lower during base flow than storm flow, except at CSR2 which had similar concentrations. The contributing area to CSR2 had the lowest road density of any monitoring station, which likely contributed to the lack of significant increase in storm flow total zinc concentrations. Like the other metals, total zinc is a common urban stormwater pollutant and an increase during storm flow events is typically expected.

Water Quality Criteria Comparison

All base flow total zinc concentrations were below associated water quality standards. However, total zinc concentrations during storm flow exceeded both chronic and acute criteria at least once at CSP1, CSO1, CSR2, and all WSDOT stations (Table 8). Most exceedances occurred at CSWSDOT2 and CSWSDOT3.

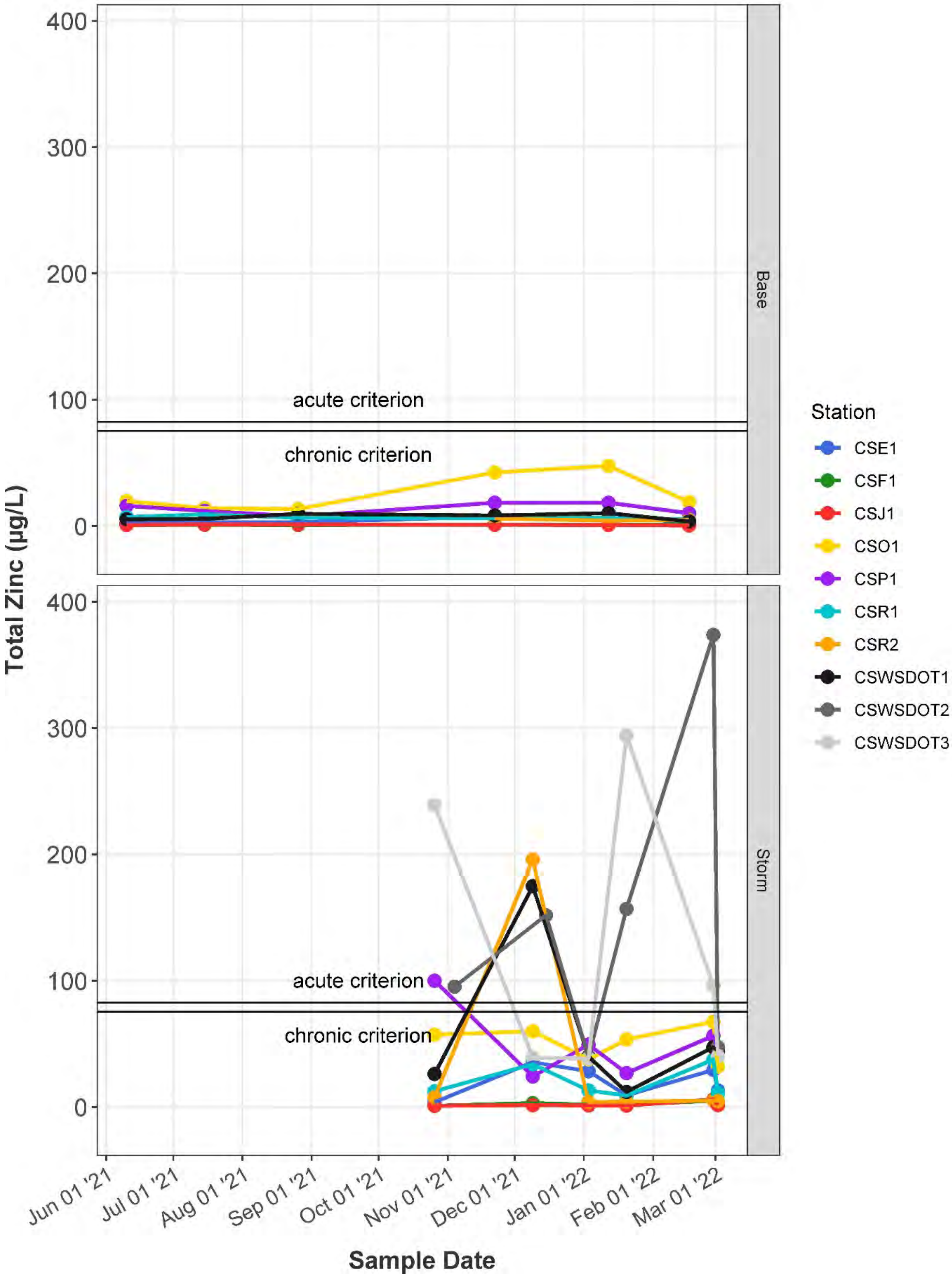

Figure 31. Total Zinc Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

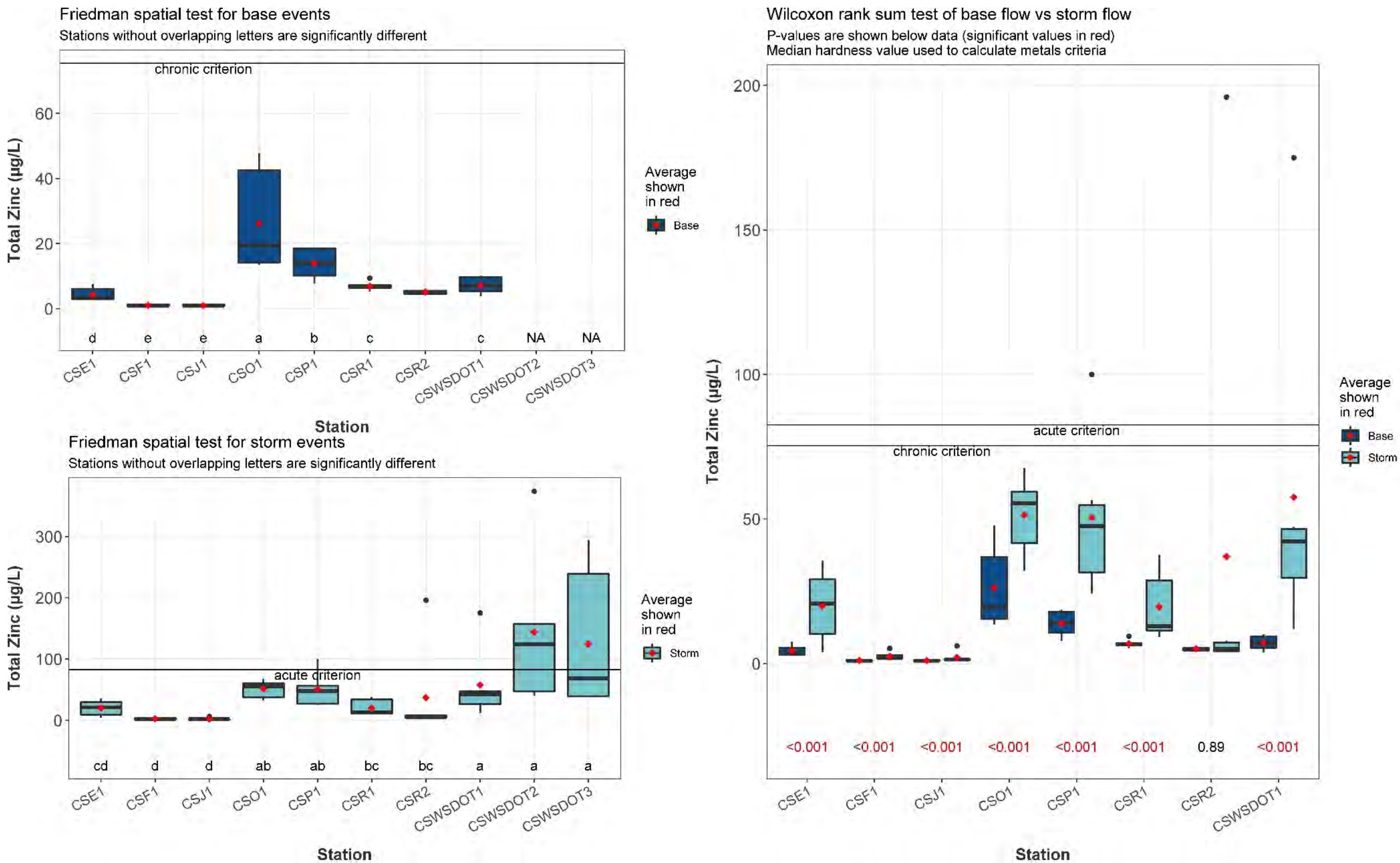

Figure 32. Total Zinc Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope.

E. coli Bacteria

In July 2018, Ecology proposed a transition from the use of fecal coliform to *E. coli* as the primary bacteria parameter for analysis of state recreational quality criteria for freshwater bodies, due to the more robust correlation of gastrointestinal illness with these bacteria parameters and conformance with EPA recommendations (Finch 2018). In January 2019, Ecology adopted the *E. coli* water quality standard that conforms to EPA's recommendation for 32 illnesses per 1,000 primary contact recreators (Recommendation 2): the geometric mean shall not exceed 100 CFU/100 mL and 90th percentile shall not exceed 320 CFU/100 mL (Finch 2018; EPA 2012; Ecology 2019). Note that *E. coli* results for this project were measured in MPN/100 mL and that these units are comparable to CFU/100 mL units used for Ecology's water quality standards.

Seasonal Patterns

As shown in Figure 33, *E. coli* during base flow varied throughout the monitoring period, with concentrations ranging from 1 to 317 MPN/100 mL across stations (Appendix C). Minimum *E. coli* concentrations during base flow were observed in January or February, while maximum concentrations were typically observed in the summer months, except at CSR1 and CSR2, where maximums were observed in February and November respectively.

For all stations except CSJ1, *E. coli* was much more variable across storm events than base flow and ranged from 4 to 3076 MPN/100 mL across stations (Appendix C). No temporal patterns in storm flow *E. coli* concentrations were observed consistently across stations, though most minimum concentrations occurred in December or January (Figure 33).

Storm and Base Flow Comparison

Few spatial differences in *E. coli* concentrations were detected by the Friedman test. Base flow concentrations at CSP1 and CSWSDOT1 (primarily commercial and highway drainage areas, respectively) were significantly lower than at stations CSE1, CSF1, CSO1, and CSR1 (Figure 34). Storm flow concentrations at CSJ1 and CSO1 were significantly lower than at CSR1, CSR2, CSWSDOT1, and CSWSDOT3.

The Wilcoxon Rank Sum test (Figure 34) showed that *E. coli* concentrations were significantly lower during base flow than storm flow at all stations except CSJ1 and CSO1 which had the lowest storm flow concentrations.

Water Quality Criteria Comparison

All stations met the state water quality criteria of a geometric mean of less than 100 CFU/100 mL and 90th percentile of less than 320 CFU/100 mL during base flow monitoring events

(Appendix C). During storm flow events, however, only monitoring stations CSJ1 and CSO1 met both the geometric mean and 90th percentile criteria, with geomeans of 38 and 39 MPN/100 mL and 90th percentiles at 112 and 150 MPN/100 mL, respectively. Station CSF1 also met the geometric mean criterion with a geomean of 87 MPN/100 mL but did not meet the 90th percentile criterion (688 MPN/100 mL). The remaining seven stations which did not meet either criterion with geometric means ranging from 114 to 206 MPN/100 mL and 90th percentiles ranging from 372 to 1,693 MPN/100 mL (Appendix C).

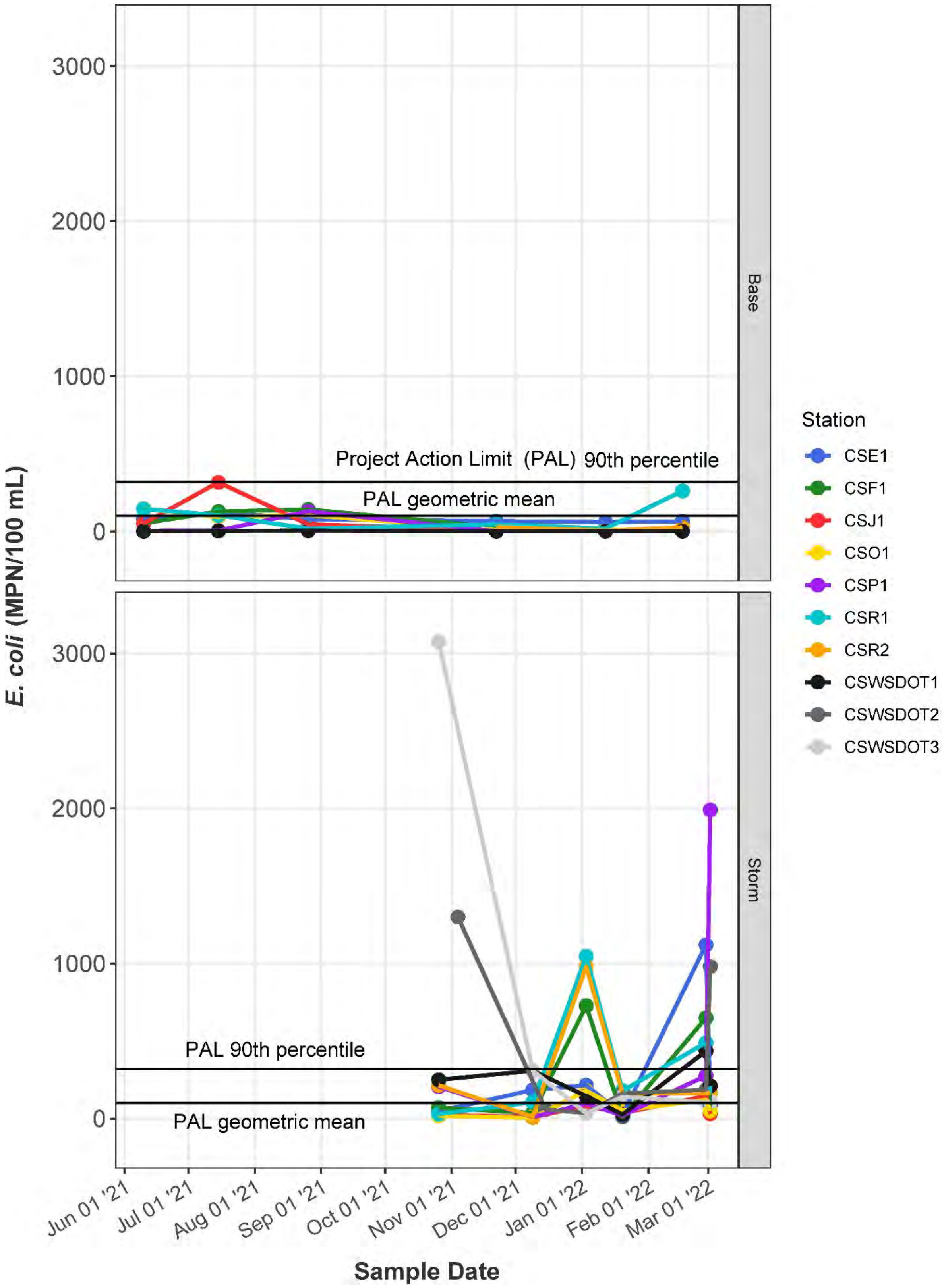

Figure 33. *E. coli* Seasonal Patterns for Base Flow (top) and Storm Flow (bottom) in the Columbia Slope.

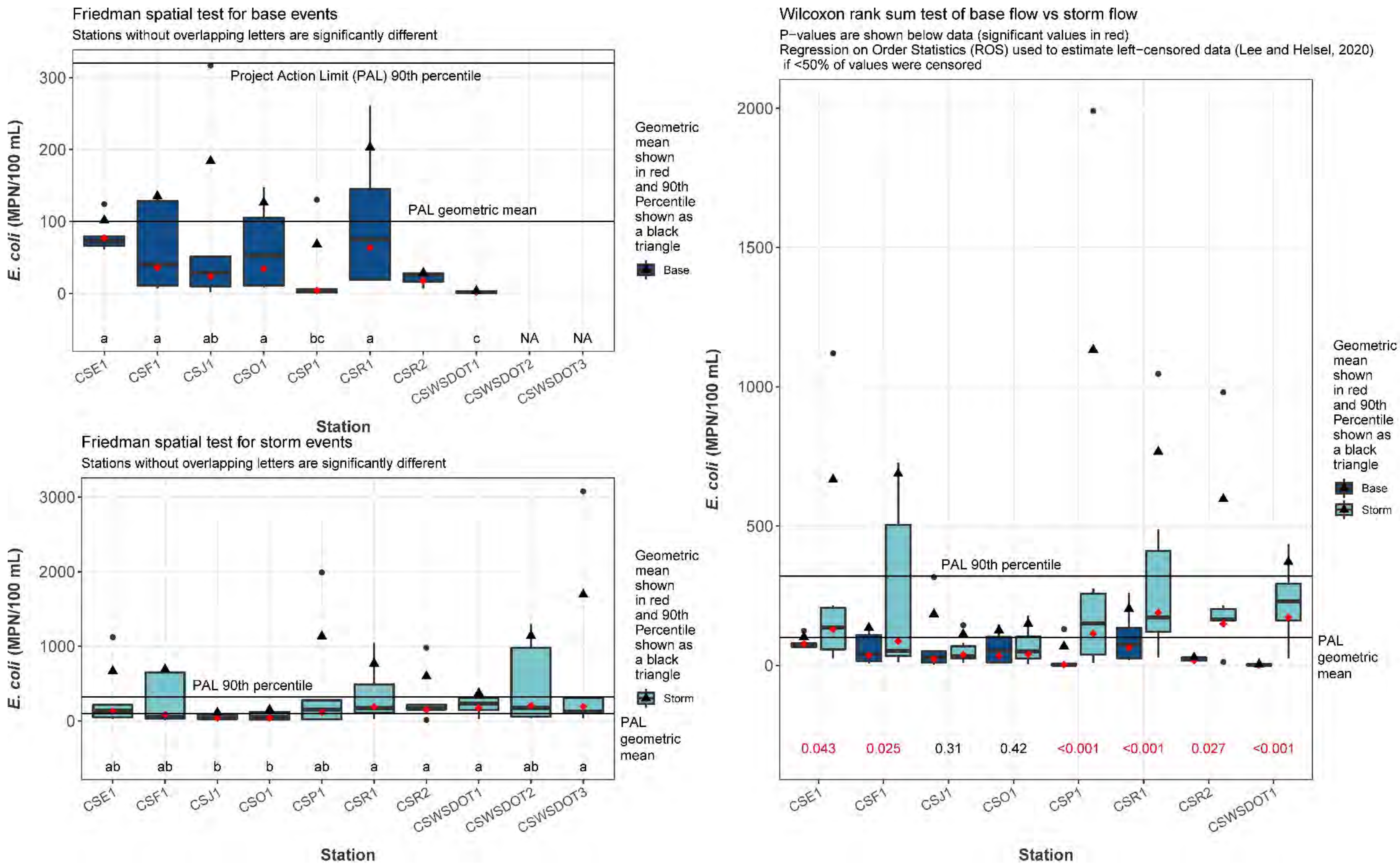

Figure 34. *E. coli* Spatial Patterns for Base Flow (top left), Storm Flow (bottom left), and Flow Comparisons (right) in the Columbia Slope.

Semi-volatile Organic Compounds

SVOCs are common pollutants in urban and highway runoff and include several subgroups including PAHs, phthalates, and chlorinated organics. These pollutants were included in the storm flow monitoring program to evaluate potential impacts to human health and freshwater aquatic life within the project area. The concentration of SVOCs in stormwater is typically related to the total suspended solids concentration, particularly silts and finer, as SVOCs can bind to this fine sediment. Potential sources of SVOCs within the Columbia Slope watershed include oil and grease, vehicle emissions, and petroleum hydrocarbons.

Washington State surface water quality standards (WAC 173 201A) lists criteria for several individual SVOCs and total PAHs (Table 4). Table 9 below provides a list of results which exceeded these criteria. Results for select individual SVOCs and total PAHs are further discussed below. Summary statistics for these data are presented in Appendix C, and all data results are presented in Appendix D.

Table 9. Storm Only Results that Exceeded Water Quality Criteria.						
Group	Parameter	Maximum Value Detected[a]	Human Health Criteria Value[b]	Human Health Criteria % Exceed	Project Action Limit Value	Project Action Limit % Exceed
CSE1						
PAHs (µg/L)	Benz(a)anthracene	0.026	0.00016	17%	0.2	0%
	Benzo(b)fluoranthene	0.06	0.00016	17%	0.2	0%
	Benzo(k)fluoranthene	0.051	0.0016	17%	0.2	0%
	Dibenz(a,h)anthracene	0.05	0.000016	17%	0.2	0%
	Indeno(1,2,3-cd)pyrene	0.062	0.00016	17%	0.2	0%
Phthalates (µg/L)	Bis(2-ethylhexyl) Phthalate	0.41	0.045	17%	1	0%
	Butyl Benzyl Phthalate	0.079	0.013	33%	0.2	0%
SVOCs (µg/L)	N-Nitrosodi-n-propylamine	0.25	0.0044	17%	0.2	17%
Organochlorine Pesticides (ng/L)	4,4'-DDE	0.76	0.00088	17%	1	0%
	Aldrin	1.2	0.000041	17%	1.9	17%
	alpha-BHC	0.86	0.048	50%	1	0%
	alpha-Chlordane	0.43	0.022	17%	43	0%
	Dieldrin	2.8	0.00007	100%	1.9	83%
	Heptachlor Epoxide	0.29	0.0024	17%	3.8	0%
CSF1						
Phthalates (µg/L)	Bis(2-ethylhexyl) Phthalate	0.37	0.045	17%	1	0%
	Butyl Benzyl Phthalate	0.081	0.013	33%	0.2	0%
Organochlorine Pesticides (ng/L)	4,4'-DDE	0.63	0.00088	17%	1	0%
	Aldrin	0.8	0.000041	17%	1.9	0%
	alpha-BHC	1.1	0.048	17%	1	17%
	alpha-Chlordane	0.4	0.022	17%	43	0%
	Dieldrin	0.8	0.00007	17%	1.9	0%
CSJ1						
Phthalates (µg/L)	Bis(2-ethylhexyl) Phthalate	0.31	0.045	17%	1	0%
	Butyl Benzyl Phthalate	0.042	0.013	17%	0.2	0%
Organochlorine Pesticides (ng/L)	2,4'-DDD	0.74	0.0079	17%	1	0%
	4,4'-DDD	0.59	0.0079	17%	1	0%
	4,4'-DDE	0.65	0.00088	17%	1	0%
	Aldrin	0.92	0.000041	17%	1.9	0%
	alpha-BHC	1.1	0.048	33%	1	17%
	alpha-Chlordane	0.41	0.022	17%	43	0%
	Dieldrin	0.74	0.00007	17%	1.9	0%
	Heptachlor Epoxide	0.31	0.0024	17%	3.8	0%
CSO1						
Phthalates (µg/L)	Bis(2-ethylhexyl) Phthalate	0.32	0.045	50%	1	0%
	Butyl Benzyl Phthalate	0.034	0.013	67%	0.2	0%
Organochlorine Pesticides (ng/L)	4,4'-DDD	0.98	0.0079	17%	1	0%
	4,4'-DDE	0.79	0.00088	17%	1	0%
	alpha-BHC	1.1	0.048	33%	1	17%
	alpha-Chlordane	0.42	0.022	17%	43	0%
	Dieldrin	0.69	0.00007	17%	1.9	0%
	Heptachlor	1.2	0.00034	17%	3.8	0%
CSP1						
Phthalates (µg/L)	Bis(2-ethylhexyl) Phthalate	0.56	0.045	33%	1	0%
	Butyl Benzyl Phthalate	0.051	0.013	33%	0.2	0%
Organochlorine Pesticides (ng/L)	2,4'-DDD	1.6	0.0079	17%	1	17%
	4,4'-DDD	0.61	0.0079	17%	1	0%
	4,4'-DDE	0.73	0.00088	17%	1	0%
	alpha-BHC	0.92	0.048	17%	1	0%
	Dieldrin	0.64	0.00007	17%	1.9	0%
CSR1						
Phthalates (µg/L)	Bis(2-ethylhexyl) Phthalate	0.3	0.045	50%	1	0%
	Butyl Benzyl Phthalate	0.038	0.013	17%	0.2	0%
Organochlorine Pesticides (ng/L)	4,4'-DDE	1.7	0.00088	17%	1	17%
	Aldrin	1.3	0.000041	17%	1.9	17%
	alpha-BHC	1	0.048	33%	1	0%
	beta-BHC	1.7	1.3	17%	1.3	17%
	Heptachlor	2.7	0.00034	33%	3.8	0%
	Hexachlorobenzene	2	0.005	17%	1	17%

Table 9 (continued). Storm Only Results that Exceeded Water Quality Criteria.						
Group	Parameter	Maximum Value Detected[a]	Human Health Criteria Value[b]	Human Health Criteria % Exceed	Project Action Limit Value	Project Action Limit % Exceed
CSR2						
Phthalates (µg/L)	Bis(2-ethylhexyl) Phthalate	0.31	0.045	33%	1	0%
	Butyl Benzyl Phthalate	0.038	0.013	17%	0.2	0%
Organochlorine Pesticides (ng/L)	4,4'-DDE	1.1	0.00088	33%	1	17%
	Aldrin	0.94	0.000041	17%	1.9	0%
	alpha-BHC	0.77	0.048	33%	1	0%
	Dieldrin	1	0.00007	17%	1.9	0%
	Hexachlorobenzene	0.87	0.005	17%	1	0%
CSWSDOT1						
PAHs (µg/L)	Benz(a)anthracene	0.049	0.00016	17%	0.2	0%
	Benzo(a)pyrene	0.057	0.000016	17%	0.2	0%
	Benzo(b)fluoranthene	0.087	0.00016	17%	0.2	0%
	Benzo(k)fluoranthene	0.031	0.0016	17%	0.2	0%
	Chrysene	0.1	0.016	17%	0.2	0%
	Indeno(1,2,3-cd)pyrene	0.046	0.00016	17%	0.2	0%
Phthalates (µg/L)	Bis(2-ethylhexyl) Phthalate	4.3	0.045	100%	1	17%
	Butyl Benzyl Phthalate	0.082	0.013	50%	0.2	0%
Organochlorine Pesticides (ng/L)	2,4'-DDD	1.1	0.0079	17%	1	17%
	4,4'-DDD	1.5	0.0079	17%	1	17%
	4,4'-DDE	1.8	0.00088	33%	1	33%
	4,4'-DDT	2.5	0.0012	17%	1	17%
	Aldrin	2.4	0.000041	17%	1.9	17%
	alpha-BHC	2.2	0.048	33%	1	17%
	alpha-Chlordane	1.2	0.022	17%	43	0%
	Dieldrin	1.9	0.00007	17%	1.9	0%
	Heptachlor Epoxide	0.47	0.0024	17%	3.8	0%
	trans-Chlordane	1.7	0.022	17%	43	0%
CSWSDOT2						
PAHs (µg/L)	Chrysene	0.052	0.016	17%	0.2	0%
Phthalates (µg/L)	Bis(2-ethylhexyl) Phthalate	9.5	0.045	100%	1	83%
SVOCs (µg/L)	N-Nitrosodi-n-propylamine	19	0.0044	33%	0.2	33%
Organochlorine Pesticides (ng/L)	2,4'-DDD	0.78	0.0079	17%	1	0%
	4,4'-DDE	1.8	0.00088	17%	1	17%
	alpha-BHC	0.27	0.048	17%	1	0%
	Heptachlor	3.8	0.00034	17%	3.8	0%
CSWSDOT3						
Phthalates (µg/L)	Bis(2-ethylhexyl) Phthalate	6.2	0.045	100%	1	50%
	Butyl Benzyl Phthalate	0.054	0.013	17%	0.2	0%
Organochlorine Pesticides (ng/L)	4,4'-DDE	2	0.00088	17%	1	17%
	alpha-BHC	0.77	0.048	17%	1	0%
	beta-BHC	11	1.3	17%	1.3	17%
	Dieldrin	1.5	0.00007	17%	1.9	0%
	Heptachlor	1.1	0.00034	17%	3.8	0%
	Heptachlor Epoxide	0.67	0.0024	17%	3.8	0%
	Hexachlorobenzene	3	0.005	17%	1	17%

[a] Only detected values were evaluated.

[b] Washington State human health criteria for the consumption of water and organisms, EPA-approved human health criteria under 40 CFR 131.45; National recommended water quality criteria for the protection of aquatic organisms and protection of human health based on consumption of organisms from Section 304 of the Clean Water Act; and Water Quality Standards for Surface Waters of the State of Washington, Chapter 173-201A WAC.

µg/L = micrograms per liter

ng/L = nanograms per liter

DDD = dichlorodiphenyldichloroethane

DDE = dichlorodiphenyldichloroethylene

DDT = dichlorodiphenyltrichloroethane

BHC = benzene hexachloride

Polycyclic Aromatic Hydrocarbons

Few PAHs were detected in samples throughout the Columbia Slope watershed; only 5 percent of all samples collected were measured above respective detection limits. Of these few, detections were most frequently observed at CSWSDOT1 (28 percent of detections), followed equally by CSWSDOT2 and CSE1 (26 percent), then by CSWSDOT1 (13 percent). No PAHs were detected in any sample at stations CSF1, CSO1, or CSJ1 (Appendix C).

With the majority of PAHs undetected in storm flow from the Columbia Slope, it follows then that no exceedances of the project action limit criteria (0.2 µg/L) occurred. However, all seven individual carcinogenic PAH (cPAH) parameters (benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene) were detected and exceeded respective human health criteria at least once during storm flow (Table 9). These exceedances occurred at CSE1 (for five events), CSWSDOT1 (for six events), and CSWSDOT2 (for one event).

The Friedman tests identified very few significant differences in PAH concentrations between stations which all appeared to be impacted by high percentage of non-detects and elevated reporting limits at CSWSDOT2 and CSWSDOT3. These stations exhibited the greatest variance in PAH concentrations due to both undetected values at elevated reporting limits and higher detected values.

Phthalates

Only 36 percent of all phthalate samples were detected (Appendix C). Specific phthalates not detected in any of the samples collected at stations listed below include:

- Butyl benzyl phthalate at CSWSDOT2;
- Diethyl phthalate at CSF1, CSJ1, and CSR2;
- Dimethyl phthalate at all stations except CSWSDOT1 and CSWSDOT2; and
- Di-n-octyl phthalate at all stations except CSE1.

Phthalates detected in at least 50 percent of samples include:

- Bis(2-ethylhexyl) phthalate (BEHP) at CSO1, CSR1, CSWSDOT1, CSWSDOT2, and CSWSDOT3;
- Butyl benzyl phthalate at CSO1 and CSWSDOT1;

- Diethyl phthalate at CSP1, CSWSDOT1, CSWSDOT2, and CSWSDOT3; and
- Di-n-butyl phthalate at all stations.

BEHP exceeded project action limits in nine samples at WSDOT stations, mostly at CSWSDOT2. Additionally, human health criteria were exceeded for BEHP in 31 samples, at least once at each station. BEHP exceeded human health criteria by more than two magnitudes in three samples at CSWSDOT2 and CSWSDOT3, and by more than one magnitude in another 14 samples, all but one of which were at WSDOT stations. All BEHP samples collected on January 3, 2022 exceeded these criteria.

Although butyl benzyl phthalate did not exceed project action limits, human health criteria were exceeded in 18 samples, at least once at all stations except CSWSDOT2. Most of the butyl benzyl phthalate human health exceedances occurred in samples collected on January 3, 2022 and March 2, 2022 (Table 9).

The Friedman tests identified few significant differences in phthalate concentrations between stations including significantly greater concentrations for di-n-butyl phthalate at all WSDOT stations compared to at any other station except CSR2.

Other SVOCs

For other SVOCs not mentioned above, only 5 percent of all samples had detected values. Detections were observed for at least one parameter at all stations (between 1 and 6 parameters each) except at CSJ1 where no other SVOCs were detected. The only individual SVOC parameter which has not already been discussed and was detected in all samples was benzyl alcohol at CSO1, CSR1, and CSR2 (Appendix C).

With the majority of other SVOCs in the Columbia Slope undetected, it follows then that concentrations for all other SVOCs were below the project action limit criteria (0.2 µg/L), except for n-nitrosodi-n-propylamine which exceeded this criterion in three samples at CSE1 and CSWSDOT2 (Table 9). As such, n-nitrosodi-n-propylamine also exceeded the human health criterion (0.0044 µg/L) for the same samples.

The Friedman tests identified few significant differences in these other SVOC concentrations between stations. Concentrations for individual SVOC parameters at WSDOT stations were more varied than at City stations due to the elevated reporting limits from dilutions needed for these stations.

Organochlorine Pesticides

Organochlorine pesticides are common persistent pollutants in urban and residential runoff and include several pollutants that have been banned from use in the United States. Several of these pesticides are still in use or were used extensively prior to being banned. These pollutants were included in the storm flow monitoring program to evaluate potential impacts to human health and freshwater aquatic life within the project area. Potential sources of organochlorine pesticides within the Columbia Slope watershed include residential and agricultural pesticide use and legacy contamination from prior widespread use.

Washington State surface water quality standards (WAC 173 201A) lists criteria for several individual organochlorine pesticides (Table 4). Table 9 above provides a list of results which exceeded these criteria. Results for select individual organochlorine pesticides are further discussed below. Summary statistics for these data are presented in Appendix C, and all data results are presented in Appendix D.

DDx Isomers

At least one isomer of dichlorodiphenyldichloroethane (DDD), dichlorodiphenyldichloroethylene (DDE), or dichlorodiphenyltrichloroethane (DDT) was detected at each monitoring station during storm flow monitoring including 4,4′-DDE which was detected twice at CSR2 and CSWSDOT1 and once at all other monitoring stations (Appendix C). Isomers 2,4′-DDE and 2,4′-DDT were not detected in any samples, and no isomer was detected more than twice at each monitoring station. Monitoring station CSWSDOT1 had the highest frequency of detections with five, though stations CSWSDOT2 and CSWSDOT3 were occasionally analyzed at dilution which elevated their associated reporting and detection limits.

DDE and DDD isomers were consistently detected at concentrations exceeding respective human health criteria and, less frequently, chronic freshwater aquatic life criteria (Table 9). No concentrations were detected in exceedance of the acute freshwater aquatic life criteria, which are more applicable to storm flow parameters and concentrations. However, the relatively low concentrations (0.6 to 2.5 ng/L) that were consistently detected of the degraded DDT isomers (DDD and DDE) indicates that these legacy pollutants are present within the project area soils and sediments without an ongoing source of DDT.

The Friedman tests identified significant differences in concentrations between stations but appeared to be heavily influenced by the elevated reporting limits at CSWSDOT2 and CSWSDOT3. Excluding these stations, CSR2 and CSWSDOT1 generally had higher concentrations that stations CSE1, CSF1, and CSJ1.

Other Organochlorine Pesticides

At least half of the storm samples submitted from several monitoring stations had detectable concentrations of the following organochlorine pesticides (Appendix C): alpha-BHC at CSE1 (three of six samples); chlorpyrifos at CSE1 (three of six samples), CSP1 (five of six samples), CSWSDOT1 (four of six samples), and CSWSDOT3 (three of six samples); and dieldrin at CSE1 (six of six samples). Chlorpyrifos, while detected at least once at all monitoring stations except CSR1, never exceeded chronic or acute freshwater aquatic life criteria (Table 9). Alpha-BHC and dieldrin, however, consistently exceeded relevant water quality criteria including project action limit exceedances for alpha-BHC at CSF1, CSJ1, CSO1, and CSWSDOT1 (Table 9). The pesticides chlordane, trans-nonachlor, toxaphene, mirex, isodrin, and hexachloroethane were not detected in any samples at all stations during the monitoring period. The few detections of organochlorine pesticides are consistent with earlier monitoring efforts performed by the USGS in 2009 which rarely found pesticides detected above the reporting limits (Morace 2012).

The Friedman tests identified a few significant differences in concentrations between stations, though most were impacted due to non-detects at elevated reporting limits. One visual outlier is that concentrations of dieldrin were substantially higher at CSE1 compared to other City monitoring stations and CSWSDOT1.

Regression Analysis

The objective of the regression analysis was to understand the influence of basin characteristics on water quality; this information would guide the selection of areas to target for additional monitoring and stormwater management. The results of the multiple regression analyses, which utilized key basin characteristics (Table 1) are described below.

As discussed in the *Data Analysis Methods* section, four basin characteristics were selected as explanatory variables in the null models for both base and storm flow, to be further reduced during the regression process:

- Percent commercial and industrial land cover
- Septic system density
- Swale density
- Pond density

Table 10 provides a summary of the explanatory variables (basin characteristics) for each monitoring station.

Table 10. Selected Regression Basin Characteristics for Station Contributing Area.				
		Treatment Density		
Station	Percent Commercial/ Industrial Land Use	Septic Systems (count/10 acres)	Swales (count/1000 acres)	Ponds (count/1000 acres)
CSE1	0%	5.3	0	0
CSF1	2%	1.9	6	6
CSJ1	7%	0.3	12	4
CSO1	8%	0.2	15	3
CSP1	21%	1.8	149	0
CSR1	12%	0.2	16	11
CSR2	8%	0.1	11	3
CSWSDOT1	25%	3.2	44	0
CSWSDOT2	100%	0.0	0	0
CSWSDOT3	37%	0.0	0	78
Summary Statistics				
Minimum	0%	0.0	0	0
25th Percentile	7%	0.1	2	0
Median	22%	1.3	25	11
Mean	10%	0.3	12	3
75th Percentile	24%	1.9	16	6
Maximum	100%	5.3	149	78

The results of the stepwise selection and multiple regression analysis for each water quality parameter are shown for the following models:

- Prediction of base flow concentrations based on basin characteristics (Table 11)
- Prediction of storm flow based on basin characteristics (Table 12)

The following model outputs are presented in Tables 11 and 12:

- Beta coefficients represent the magnitude and direction of the influence of each basin characteristic on parameter concentration. Positive and negative values indicate positive and negative correlation between variables respectively.
- R-squared values are used to assess model fit or the strength of the relationship between the pollutant concentrations and the explanatory variables. The greater the value (up to 1.0) the better the fit or ability of the model to predict median values for a parameter with more certainty.
- Significant (alpha level = 0.05) correlations are shown by bolded values.

For each parameter, the model selected only those basin characteristics that likely influenced the parameter concentration more than what is expected by random chance. As a result, individual parameters have a unique selection of explanatory variables and in some cases no variables were selected.

Base Flow

Table 11 presents the results of the regression analysis for base flow. Two statistically significant (p value less than 0.05) relationships were identified by the models for base flow:

- Septic system density was positively correlated with total phosphorus (i.e., as septic system density increases so does total phosphorus). This is an expected result as septic systems are known sources of phosphorous. While not significant, the model also identified positive correlations between septic system density and total nitrogen and nitrate + nitrite.

- Industrial/commercial land was negatively correlated with total phosphorus. This result is likely related to an underlying variable that is negatively correlated with industrial area. Median total phosphorus concentrations were greatest at CSE1 and CSF1; these monitoring stations have lower industrial/commercial land use (less than 3 percent) and high residential land use (greater than 83 percent).

Few significant relationships were identified for base flow and this may be due to a small sample size (6 base flow samples collected at each of ten stations) combined with low variability in pollutant concentrations across stations as compared to storm flows.

Table 11. Final Regression Models for Water Quality Parameters during Base Flow.					
	Standardized Regression Beta Coefficient of Potential Explanatory Variables [1]				
Water Quality Parameter	**Percent Industrial Area**	**Septic System Density (count/acres)**	**Swale density (count/1000 acres)**	**Pond density (count/1000 acres)**	**Adjusted R-squared value for model [2]**
Temperature					No model selected
pH		0.49			0.11
DO Concentration					No model selected
DO % Saturation					No model selected
Conductivity		0.57			0.21
Discharge					No model selected
Turbidity					No model selected
Total Suspended Solids (TSS)	-0.63	0.52			0.57
Nitrate+Nitrite as Nitrogen	-0.35	0.68			0.43
Total Nitrogen		0.67			0.36
Total Phosphorus	**-0.63**	**0.65**			0.78
Total Hardness as CaCO3		0.55			0.18
Chloride					No model selected
Total Copper					No model selected
Total Lead	-0.71				0.41
Total Zinc			0.48		0.10
E. coli	-0.51	0.41		0.64	0.52

1 Potential explanatory variables were selected for this analysis based on a correlation analysis of all available variables. Potential explanatory variables were considered for inclusion in a multiple linear regression model where the dependent variable is the median concentration of the component in the left column. An AIC stepwise algorithm was used to select the final explanatory variables in each model. The standardized regression coefficients, or beta slopes, of the final explanatory variables are shown. These values are calculated by dividing the slope of the variable by its standard deviation to normalize the value. Higher magnitudes of beta slopes indicate greater relative influence of the explanatory variable. Positive beta slopes (green) indicate positive correlation with the parameter concentration, while negative beta slopes (red) indicate negative correlation with parameter concentration. Values in bold are significant (alpha level = 0.05).

2 The adjusted R-squared value for the multiple regression model indicates the percent of variance of the median parameter concentration explained by the explanatory variables. Higher adjusted R-squared values indicate better 'goodness of fit' of the model. 'No model selected' in this field indicates that the stepwise algorithm failed to select a model for the median parameter concentration.

Storm Flow

Table 12 presents the results of the regression analysis for storm flow. R-squared values for those models with significant correlations were usually above 0.9 and therefore show strong fits, particularly for pesticides (most R-squared values are 0.95 or greater). No variables were in models for 65 percent of PAHs, 90 percent of chlorinated organics and 75 percent of other SVOCs. This is likely due to the high frequency of non-detects for these parameter groups and/or influences not captured by the selected explanatory variables.

Significant correlations are listed below for each explanatory variable.

Industrial/commercial (includes highway) land cover:

- Positive correlation with turbidity, TSS, total phosphorus, total copper, total lead, total zinc, and BEHP. This is expected as increased concentrations of these parameters are associated with stormwater runoff in highly urban areas and highways.

- Positive correlation with all organochlorine pesticides, di-n-butyl phthalate, two chlorinated organics (hexachlorocyclopentadiene and pentachlorophenol [PCP]), and four other SVOCs (3-nitroaniline, 4-nitroaniline, benzyl alcohol, n-nitrosodi-n-propylamine).

- Negative correlation with two PAHs (fluoranthene and pyrene), diethyl phthalate, and two other SVOCs (2-methylphenol and benzoic acid)

The magnitude of the significant beta values (greater than 0.7 for most parameters) relative to other explanatory variables indicate strong influence of industrial/commercial land cover on concentrations of these parameters, particularly for pesticides, total copper and total zinc. The results indicate that legacy pollutants (i.e., organochlorine pesticides no longer in use) are mobilized during storm events in highly urban areas and highways, potentially due to the mobilization of sediments in pipes. Industrial/commercial areas are thus more associated with conveyance of pollutants to outfalls than residential areas which are associated with pollutant retention in infiltration facilities.

Septic system density:

- Positively correlated with total lead

- Negatively correlated with one naphthalene and diethyl phthalate

The absolute value of the beta value for naphthalene was relatively high suggesting that septic system density or a correlated variable (such as residential land use) has a strong negative influence on concentrations of this parameter. All other PAH models exhibited insignificant negative correlations with septic density.

Swale density:

- Negatively correlated with turbidity, total lead, diethyl phthalate, di-n-butyl phthalate, n-nitrosodi-n-propylamine and all but six pesticides (four of which were insignificant, and two no correlation was found).

- Positively correlated with fluoranthene, hexachlorocyclopentadiene and four other SVOCs.

The results indicate that swale density is associated with decreased pollutant concentrations (particularly pesticides, turbidity and total lead). However, the absolute value of the beta coefficients indicate that swale density does not predict the parameter concentrations as well as industrial/commercial land cover.

Pond density:

- Positive correlation with turbidity, TSS, total copper, total zinc, PCP, two other SVOCs and beta-BHC.

- Negative correlation with n-nitrosodi-n-propylamine, and 19 out of 35 pesticides.

The significant positive correlations are difficult to explain and are likely related to another variable not included in the model and lack of sensitivity in the model due to use of pond densities instead of percent contributing area. For those pesticides with significant negative correlations, the absolute values of the beta coefficients are usually larger than those associated with swales. While this suggests that ponds are more effective at removing pesticides than swales, the results should be interpreted cautiously because contributing areas draining to treatment were not available.

Table 12. Final Regression Models for Water Quality Parameters during Storm Flow.

Water Quality Parameter	Standardized Regression Beta Coefficient of Potential Explanatory Variables [1]				Adjusted R-squared value for model [2]
	Percent Industrial Area	Septic System Density (count/acres)	Swale Density (count/1000 acres)	Pond Density (count/1000 acres)	
Temperature			0.52		0.18
pH		0.52			0.18
Dissolved Oxygen					No model selected
DO_Sat					No model selected
Conductivity	-0.46	0.39			0.34
Discharge	-0.63	-0.46			0.26
Turbidity	**0.80**	0.09	**-0.18**	**0.47**	0.96
Solids, Total Suspended (TSS)	**0.79**	0.20	-0.23	**0.48**	0.91
Nitrate+Nitrite as Nitrogen		0.59			0.26
Nitrogen, Total as Nitrogen		0.60			0.28
Phosphorus, Total	**0.66**	0.40	-0.45	0.37	0.66
Hardness, Total as CaCO3	-0.43	0.41			0.32
Chloride		0.60			0.29
Copper, Total	**0.92**	0.07	-0.11	**0.29**	0.98
Lead, Total	**0.74**	**0.17**	**-0.17**	**0.60**	0.98
Zinc, Total	**0.90**				0.79
E. coli					No model selected
2-Methylnaphthalene					No model selected
Acenaphthene					No model selected
Acenaphthylene					No model selected
Anthracene					No model selected
Benz(a)anthracene		-0.61			0.29
Benzo(a)pyrene					No model selected
Benzo(b)fluoranthene		-0.61			0.29
Benzo(g,h,i)perylene		-0.61			0.29
Benzo(k)fluoranthene		-0.61			0.29
Chrysene					No model selected
Dibenz(a,h)anthracene		-0.61			0.29
Fluoranthene	**-0.93**		**0.22**		0.92
Fluorene					No model selected
Indeno(1,2,3-cd)pyrene		-0.61			0.29
Naphthalene		**-0.89**	0.35		0.77
Phenanthrene					No model selected
Pyrene	**-0.96**	-0.21		0.24	0.80
cPAHs					No model selected
PAHs					No model selected
Bis(2-ethylhexyl) Phthalate	**0.87**				0.72
Butyl Benzyl Phthalate					No model selected
Diethyl Phthalate	**-0.70**	**-0.28**	**-0.74**		0.95

Table 12 (continued). Final Regression Models for Water Quality Parameters during Storm Flow.					
	Standardized Regression Beta Coefficient of Potential Explanatory Variables [1]				
Water Quality Parameter	**Percent Industrial Area**	**Septic System Density (count/acres)**	**Swale Density (count/1000 acres)**	**Pond Density (count/1000 acres)**	**Adjusted R-squared value for model [2]**
Dimethyl Phthalate					No model selected
Di-n-butyl Phthalate	**0.96**		**-0.23**	-0.06	0.98
Di-n-octyl Phthalate		-0.61			0.29
1,2,4-Trichlorobenzene					No model selected
1,2-Dichlorobenzene					No model selected
1,3-Dichlorobenzene					No model selected
1,4-Dichlorobenzene					No model selected
2,4,5-Trichlorophenol					No model selected
2,4,6-Trichlorophenol					No model selected
2,4-Dichlorophenol					No model selected
2-Chloronaphthalene					No model selected
2-Chlorophenol					No model selected
3,3'-Dichlorobenzidine					No model selected
4-Chloro-3-methylphenol					No model selected
4-Chloroaniline					No model selected
4-Chlorophenyl Phenyl Ether					No model selected
Bis(1-chloroisopropyl) Ether					No model selected
Bis(2-chloroethoxy)methane					No model selected
Bis(2-chloroethyl) Ether					No model selected
Hexachlorobenzene					No model selected
Hexachlorobutadiene					No model selected
Hexachlorocyclopentadiene	**0.73**		**0.61**		0.80
Hexachloroethane					No model selected
Pentachlorophenol (PCP)	**0.80**			**0.46**	0.92
1,2-Diphenylhydrazine					No model selected
2,4-Dimethylphenol					No model selected
2,4-Dinitrophenol					No model selected
2,4-Dinitrotoluene					No model selected
2,6-Dinitrotoluene					No model selected
2-Methylphenol	**-0.91**		**0.30**	**0.36**	0.92
2-Nitroaniline					No model selected
2-Nitrophenol					No model selected
3-Nitroaniline	**0.73**		**0.61**		0.80
4,6-Dinitro-2-methylphenol					No model selected
4-Bromophenyl Phenyl Ether					No model selected
4-Methylphenol					No model selected
4-Nitroaniline	**0.73**		**0.61**		0.80
4-Nitrophenol					No model selected
Benzoic Acid	**-0.94**		**0.26**	**0.35**	0.96

Table 12 (continued). Final Regression Models for Water Quality Parameters during Storm Flow.					
	Standardized Regression Beta Coefficient of Potential Explanatory Variables [1]				
Water Quality Parameter	Percent Industrial Area	Septic System Density (count/acres)	Swale Density (count/1000 acres)	Pond Density (count/1000 acres)	Adjusted R-squared value for model [2]
Benzyl Alcohol	**0.98**				0.95
Carbazole					No model selected
Dibenzofuran					No model selected
Isophorone					No model selected
Nitrobenzene					No model selected
N-Nitrosodi-n-propylamine	**0.95**		**-0.20**	**-0.32**	0.95
N-Nitrosodiphenylamine					No model selected
Phenol					No model selected
2,4'-DDD	**0.96**		**-0.21**	**-0.28**	0.95
2,4'-DDE	**0.95**		**-0.21**	**-0.32**	0.95
2,4'-DDT	**0.95**		**-0.18**		0.95
4,4'-DDD	**0.96**		**-0.20**	-0.15	0.95
4,4'-DDE	**1.00**	0.06	**-0.18**	**-0.12**	1.00
4,4'-DDT	**0.96**		**-0.20**	**-0.24**	0.96
DDx	**0.96**		**-0.21**	**-0.28**	0.97
Aldrin	**0.95**		**-0.21**	**-0.31**	0.95
alpha-BHC	**0.95**		**-0.20**	**-0.32**	0.95
alpha-Chlordane	**0.96**		**-0.20**	-0.18	0.95
beta-BHC	**0.79**		-0.15	**0.44**	0.96
Chlordane	**0.95**		**-0.21**	**-0.32**	0.95
Chlorpyrifos	**1.01**	0.16		0.14	0.96
cis-Nonachlor	**0.96**		**-0.21**	**-0.27**	0.95
delta-BHC	**0.95**		**-0.21**	**-0.32**	0.95
Dieldrin	**0.91**	0.42	-0.31		0.77
Endosulfan I	**0.95**		**-0.18**		0.95
Endosulfan II	**0.96**	0.06	**-0.20**	0.10	0.98
Endosulfan Sulfate	**0.94**		-0.21	-0.24	0.91
Endrin	**0.96**		**-0.20**	-0.13	0.95
Endrin Aldehyde	**0.92**			-0.20	0.80
Endrin Ketone	**0.94**		-0.21	**-0.34**	0.94
gamma-BHC (Lindane)	**0.95**		**-0.21**	**-0.32**	0.95
Heptachlor	**0.96**		**-0.20**	-0.14	0.95
Heptachlor Epoxide	**0.95**		**-0.18**		0.95
Hexachlorobenzene	**0.95**		**-0.18**		0.95
Hexachlorobutadiene	**0.95**		**-0.21**	**-0.32**	0.95
Hexachloroethane	**0.95**		**-0.21**	**-0.32**	0.95
Isodrin	**0.95**		**-0.21**	**-0.32**	0.95
Methoxychlor	**0.95**		**-0.18**		0.95
Mirex	**0.95**		**-0.18**		0.95

Table 12 (continued). Final Regression Models for Water Quality Parameters during Storm Flow.					
	Standardized Regression Beta Coefficient of Potential Explanatory Variables [1]				
Water Quality Parameter	**Percent Industrial Area**	**Septic System Density (count/acres)**	**Swale Density (count/1000 acres)**	**Pond Density (count/1000 acres)**	**Adjusted R-squared value for model [2]**
Oxychlordane	**0.95**		**-0.21**	**-0.32**	0.95
Toxaphene	**0.95**		**-0.21**	**-0.32**	0.95
trans-Chlordane	**0.95**		**-0.21**	**-0.32**	0.95
trans-Nonachlor	**0.95**		**-0.21**	**-0.32**	0.95

[1] Potential explanatory variables were selected for this analysis based on a correlation analysis of all available explanatory variables. Potential explanatory variables were considered for inclusion in a multiple linear regression model where the dependent variable is the median concentration of the component in the left column. An AIC stepwise algorithm was used to select the final explanatory variables in each model. The standardized regression coefficnents, or beta slopes, of the final explanatory variables are shown in the table. These values are calculated by dividing the slope of the variable by its standard deviation to normalize the value. Higher magnitudes of beta slopes indicate greater relative influence of the explanatory variable within the model. Positive beta slopes (green) indicate positive correlation with the parameter concentration, while negative beta slopes (red) indicate negative correlation with parameter concentration. Values in bold are significant (alpha level = 0.05).

[2] The adjusted R-squared value for the multiple regression model indicates the percent of variance of the median parameter concentration explained by the explanatory variables. Higher adjusted R-squared values indicate better 'goodness of fit' of the model. 'No model selected' in this field indicates that the stepwise algorithm failed to select a model for the median parameter concentration.

CONCLUSIONS

An evaluation of priority areas for stormwater retrofit and identified uncertainty and data gaps are presented in the following sections.

EVALUATION OF PRIORITY AREAS FOR STORMWATER RETROFITS

This monitoring project has allowed the City to begin characterizing the water quality of inputs to the Columbia River and has supported its efforts to identify priority basins for stormwater management and retrofitting. The following key evidence is considered for this evaluation:

- Relative differences in storm flow pollutant concentrations and frequency of water quality criteria exceedances.
- Results of the multiple regression models to understand how basin characteristics influence water quality.

Water quality criteria exceedances:

Except where noted, water quality criteria exceedances during storm events were observed at all stations for turbidity, nutrients, BEHP, butyl benzyl phthalate, total DDT and some other pesticides. Relative ranking of water quality impairment is shown below and is based on stormwater water quality criteria exceedances:

- High: All WSDOT sites due to frequent exceedances for metals, PAHs, BEHP, and *E. coli*.
- Moderate: CSE1, CSO1, CSP1, CSR1 and CSR2 due to metals, bacteria (except CSO1), and turbidity exceedances
- Low: CSF1 and CSJ1 did not exceed turbidity, metals, *E. coli* (CSJ1 only), or PAH criterion

Contaminants of concern and associated explanatory variables:

The following stormwater contaminants of concern were identified based on water quality exceedances. They are listed below with significant explanatory variables (for storm flow models) when available.

- Turbidity and TSS: positively correlated with industrial/commercial land cover.

- Metals (copper, lead and zinc): positively correlated with industrial/commercial land cover.
- PAHs: few significant correlations with some evidence of septic system influence (multiple negative correlations that were not significant).
- *E. coli:* no regression model available.
- Phthalates: BEHP was positively correlated with industrial/commercial land cover and no model was available for butyl benzyl phthalate.
- Nutrients: total phosphorus was positively correlated with industrial/commercial land cover. There was evidence of positive correlations (not significant) with septic system density in storm flow. However, stormwater does not appear to be causing an increase in nutrients at any site and is more of a concern in base flow.
- Organochlorine pesticides: strongly and positively correlated with industrial/commercial land cover and more weakly negatively correlated with pond and swale treatment density.

Basin Prioritization

Industrial/commercial land cover was an important predictor of most of the stormwater contaminants of concern. In the correlation analysis used to select the explanatory variables, industrial/commercial land cover was significantly correlated with impervious area. Residential area was also significantly correlated to septic density and there was some evidence of septic density predicting greater nutrient concentrations.

Prioritization of basins with relatively high industrial/commercial land cover and high impervious area is recommended based on the results of this analysis. Basins with substantial highway contribution are especially of interest due to the relatively high pollutant concentrations observed at WSDOT monitoring stations.

Basins of particular interest include:

- ***Basin I-205***: This basin encompasses a large area of interstate 205 (I-205) and has relatively high impervious and industrial/commercial land cover (60 and 25 percent respectively). Monitoring at the outfall of this basin (CSWSDOT1) indicates impaired water quality that is likely driven by highway inputs.
- ***Basin P***: The basin includes Southeast 164th Avenue, a major arterial road and relatively high impervious and industrial/commercial land cover (66 and 21 percent respectively). Water quality at monitoring station is moderately impaired relative to other sampling sites due to frequent metals, turbidity and bacteria exceedances. Two potential

stormwater retrofit projects have been identified under the Columbia Slope Retrofit Evaluation project.

- ***Basin Q***: This basin is a potential candidate for additional stormwater treatment prior to discharge to an unnamed stream in the lower portion of the basin. It is located to the east of Southeast 164th Avenue. It has high impervious area (59 percent) and relatively high industrial/commercial (12 percent) land use. Poor water quality at the highway monitoring stations in this basin (CSWSDOT2 and CSWSDOT3) was observed. Stormwater is managed by drywells and other infiltration facilities in the upper basin.

- ***Basin R*****:** The ecological and recreational value of the major stream, Fisher's Creek, makes this basin a high priority. The majority of mapped stormwater treatment is relatively high up in the basin and the basin has 10 percent industrial/commercial land cover and over 30 percent impervious area. There is substantial highway area draining to this basin as well.

- ***Basin J*****:** The Columbia Springs fish hatchery and Love Creek are located in the basin. Monitoring in this basin (CSJ1) and monitoring conducted by others at the fish hatchery (Enrico and Hossler 2019; Cifuentes et al 2021) indicated relatively good water quality. While stormwater treatment may not be a priority in this basin, ongoing monitoring is recommended due to the importance of the fish hatchery.

Uncertainty and Data Gaps

Characterization of water quality and sources of pollutants within the Columbia Slope watershed is mainly limited by the scope of the monitoring efforts described herein and limited historical data. Data collected under this monitoring project began to fill these data gaps and address core questions regarding water quality within the watershed.

Of the 22 basins characterized within the watershed (Figure 2 and Table 1), seven basin outfalls (Basins E, F, J, O, P, R, and I-205 [station CSWSDOT1]) and two highway stations in Basin Q (stations CSWSDOT2 and CSWSDOT3) were sampled in this monitoring project. While sufficient data were collected to characterize water quality in these basins during the monitoring period, applying these results to other similar basins within the watershed involves a level of uncertainty due to differences in how basin characteristics are correlated. Correlations between basin characteristics and water quality identified in the regression analysis may not be present in basins with similar characteristics due to unique basin-specific variables.

It is important to note that individual models varied in overall fitness (i.e., in their ability to explain observed variation) as represented by R-squared values and that reduced fitness limits our ability to interpret model results. Our models were further limited in terms of initial explanatory variables considered due to the reduced sample sizes and the nature of how a regression can be performed. With more monitoring events resulting in a greater sample size, additional explanatory variables may be considered in future regression modeling. For example, the impacts of climate variation on water quality and long-term trends in water quality could not be modeled without additional monitoring beyond the one-year scope of this project. Finally, the limited scope of this project restricted our ability to transform the data or to choose alternate model types to evaluate assumptions of normality and/or equal variance; results and interpretations may change with development of a more robust model.

Both storm and base flow results may also have been impacted by event timing relative to significant weather events. The sampling criteria in the QAPP (Herrera 2021a) describes minimum criteria and goals for events to qualify as base or storm flow events that were met. Base flow events were sampled in the winter and summer as designed, but spring and fall months were not sampled. Storm events were sampled during the wet season (October through March) as designed, but not during dry season. The sampled storms exhibited a wide range of rain amounts with two of the six storms exceeding 2 inches of rain, and antecedent dry periods also varied among the storms but did not exceed 3.1 days. Thus, a summer storm event or "first flush" event with a long antecedent dry period was not sampled for this project.

The parameters analyzed were comparable to those monitored in other City water quality monitoring projects and cover most typical contaminants of concern in urban and highway stormwater runoff. However, several SVOCs and organochlorine pesticides are difficult to detect at low levels with laboratory reporting and detection limits up to several orders of magnitude greater than applicable water quality criteria. Additional stormwater contaminants of concern and emerging pollutants including polychlorinated biphenyls (PCBs) and 6 PPD-quinone, which is acutely toxic to coho salmon and prevalent in urban streams and stormwater (Tian et al, 2020), have not been monitored in the watershed and may represent a gap in water quality data.

RECOMMENDATIONS

MONITORING STATIONS AND FREQUENCY

To facilitate long term tracking, continued monitoring at several monitoring stations with particularly important ecological function is recommended. Good candidates for continued monitoring include CSJ1 in Basin J (Love Creek and Columbia Springs Fish Hatchery) or CSR1 in Basin R (Fisher's creek). At least one WSDOT site should remain or be relocated to gather a more robust dataset of highway inputs. Monitoring should be conducted to further characterize highway runoff at new sites if feasible.

We recommend relocating some of the monitoring stations to help identify local pollutant sources, provide baseline data for areas for potential retrofit projects and/or evaluate effectiveness of existing treatment. For example, monitoring stormwater facility influent and effluent would reduce variables that may otherwise be difficult to tease out and provide a higher level of certainty on treatment performance. New stations established upstream of stations with high pollutant concentrations could help locate pollutant sources.

No changes to frequency of sampling are recommended but expanding the project scope to provide a more comprehensive set of data would improve characterization of water quality in the watershed and inform selection of best management practices for stormwater management.

PARAMETERS

Additional stormwater contaminants of concern and emerging pollutants should be considered for the monitoring including polychlorinated biphenyls (PCBs) and 6PPD-quinone, which is acutely toxic to coho salmon and prevalent in urban streams and stormwater (Tian et al, 2020). We recommend considering analysis of these parameters for a select set of sites and number of storm events as budget allows. Continued storm event monitoring of pesticides and SVOCs should be reevaluated for parameters that were largely undetected and/or not deemed a concern along with consideration of budgetary constraints and priorities.

Targeted flow monitoring, particularly near potential retrofit sites, may be useful to help understand impact of infiltration facilities on flow. No additional changes to field and laboratory parameters are recommended.

DATA ANALYSIS

Additional data collection will not only provide for an improved understanding of water quality conditions throughout the Columbia Slope watershed but allow for a more robust statistical analysis to tease out temporal trends, spatial differences, pollutant sources, and impacts of existing stormwater management practices.

With a larger sample size and broader geographic characterization of the watershed, potential future analyses could include but are not limited to the following:

- Further evaluation of the impact of site-specific characteristics (such as stream, residential storm drain outfall, and WSDOT/transportation corridor storm drain outfalls) on water quality.
- Assessment of how additional watershed variables impact pollutant concentrations, such as riparian condition or traffic density.
- Analysis of results of pre- and post-implementation of stormwater management activities such as riparian planting or construction of stormwater regional facilities to evaluate effectiveness and inform future activities.
- Septic system source tracking in basins where high bacteria and nutrients were observed by conducting a sanitary survey of the basin and expanding upstream sampling for human biomarkers and septic indicators.

A phased approach to these recommendations would accommodate budgetary constraints and allow for collection of enough data to identify significant statistical results.

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