2017 TREND ANALYSIS REPORT

BURNT BRIDGE CREEK AMBIENT WATER QUALITY MONITORING PROGRAM

Prepared for
City of Vancouver
Surface Water Management

Prepared by
Herrera Environmental Consultants, Inc.

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Prepared for
City of Vancouver
Surface Water Management
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INTRODUCTION

Burnt Bridge Creek is a highly modified, urban stream that flows westward 12.6 miles from its agricultural origins on the east, through the heart of Vancouver, Washington, to its terminus at Vancouver Lake (Figure 1). Burnt Bridge Creek's watershed covers approximately 28 square miles; and, as with most urban watersheds, the stream has been affected by roadways, utilities, and other infrastructure.

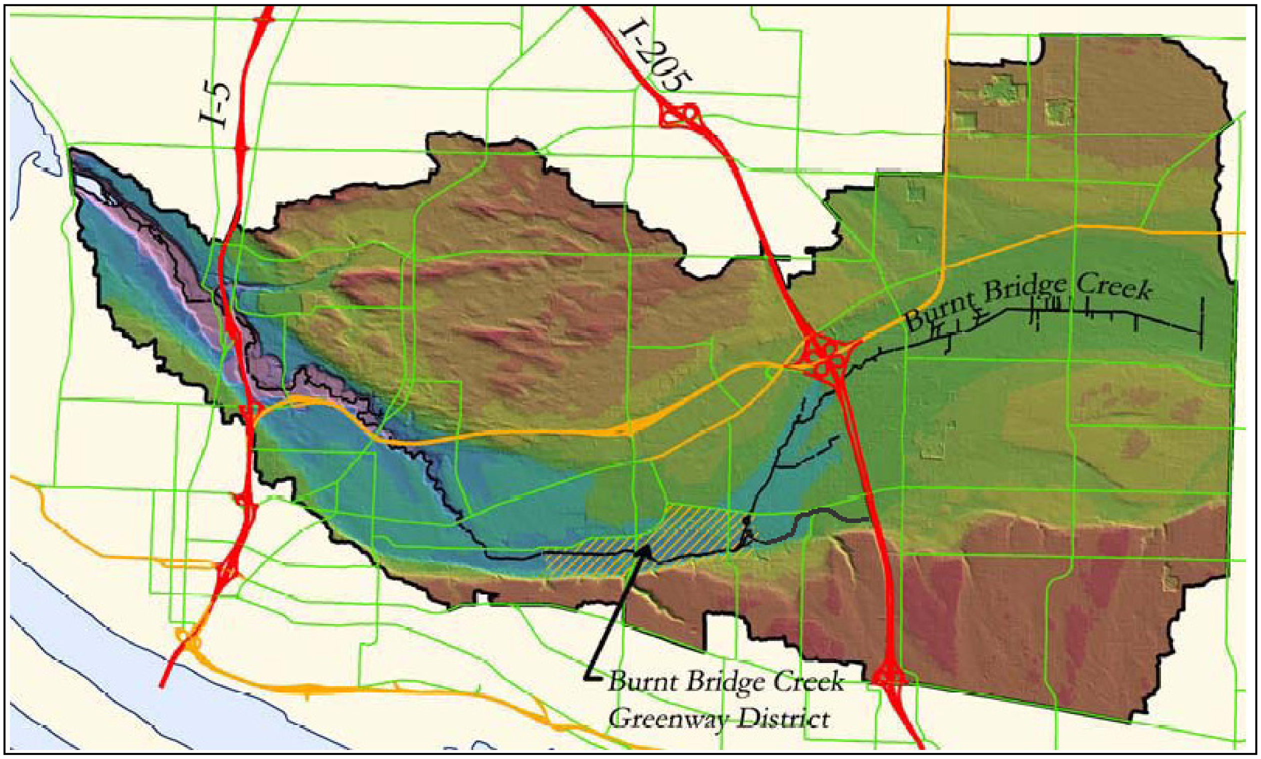


Figure 1. Burnt Bridge Creek Watershed.

Approximately 80 percent of the stream has a gradient of less than 0.1 percent (PBS 2003). Stream flow from late fall through spring is driven by precipitation, while summer flow is maintained by natural groundwater inflow coupled with industrial discharge from a manufacturing facility located east of Interstate 205 (I-205). The industrial processes at the manufacturing facility extract groundwater for cooling operations and contribute a significant amount of discharge water, which helps sustain summer base flow in the creek.

There are two minor tributaries that flow into Burnt Bridge Creek east of Northeast 86th Avenue. In addition to base flow, Peterson Channel conveys industrial discharge and urban stormwater runoff to Burnt Bridge Creek near the southern end of Royal Oaks Country Club. Burton Channel also initiates east of I-205 and joins Burnt Bridge Creek south of Burton Road, near the southern end of Meadowbrook Marsh. Another significant tributary, Cold Creek, flows west through unincorporated Clark County and joins Burnt Bridge Creek just west of Interstate 5 (I-5) approximately 2 miles upstream of Vancouver Lake (Figure 2).

State water quality standards have been established to restore and maintain the chemical, physical, and biological integrity of Washington's waters as required by the federal Clean Water Act. These standards are designed to protect public health, public recreation in the waters, and the propagation of fish, shellfish, and wildlife (WAC 173-201A). Water quality in Burnt Bridge Creek has been monitored extensively for more than 40 years, including a total maximum daily load (TMDL) study by the Department of Ecology with 14 monitoring sites in 2008–2009 (Ecology 2008, see Figure 2). Monitoring data have shown that segments of Burnt Bridge Creek do not meet state water quality standards for temperature, dissolved oxygen, pH, and/or fecal coliform bacteria at varying times of the year.

The primary goal of the Burnt Bridge Creek monitoring project described in this report is to collect credible water quality data and identify statistically significant trends in water quality. The long-term monitoring program and associated trend analyses will allow the City of Vancouver (the City) to assess the effectiveness of existing programs and to implement adaptive management strategies to protect water resources. Data collected in 2011 through 2016 were summarized in separate annual monitoring reports (Herrera 2012, 2013a, 2014a, 2015a, 2016a, 2017a). The 2013 monitoring report included evaluation of water quality trends for data collected from 2011 through 2013 (Herrera 2014a). This report describes the seventh year of monitoring in 2017, and evaluates water quality trends in the watershed from 2011 through 2017. In a separate project, Herrera is currently evaluating how watershed conditions and best management practices affect the quality of streams and shallow groundwater in the Burnt Bridge Creek watershed.

It is the City's intent to bring Burnt Bridge Creek into compliance with state water quality standards. To meet this goal, the following objectives have been defined for this project:

- Accurately characterize specific water quality parameters within the stream
- Maintain consistency with past monitoring efforts
- Monitor water temperature continuously at the selected monitoring locations
- Provide high quality data for the City and other users
- Determine whether trends are present in the water quality data

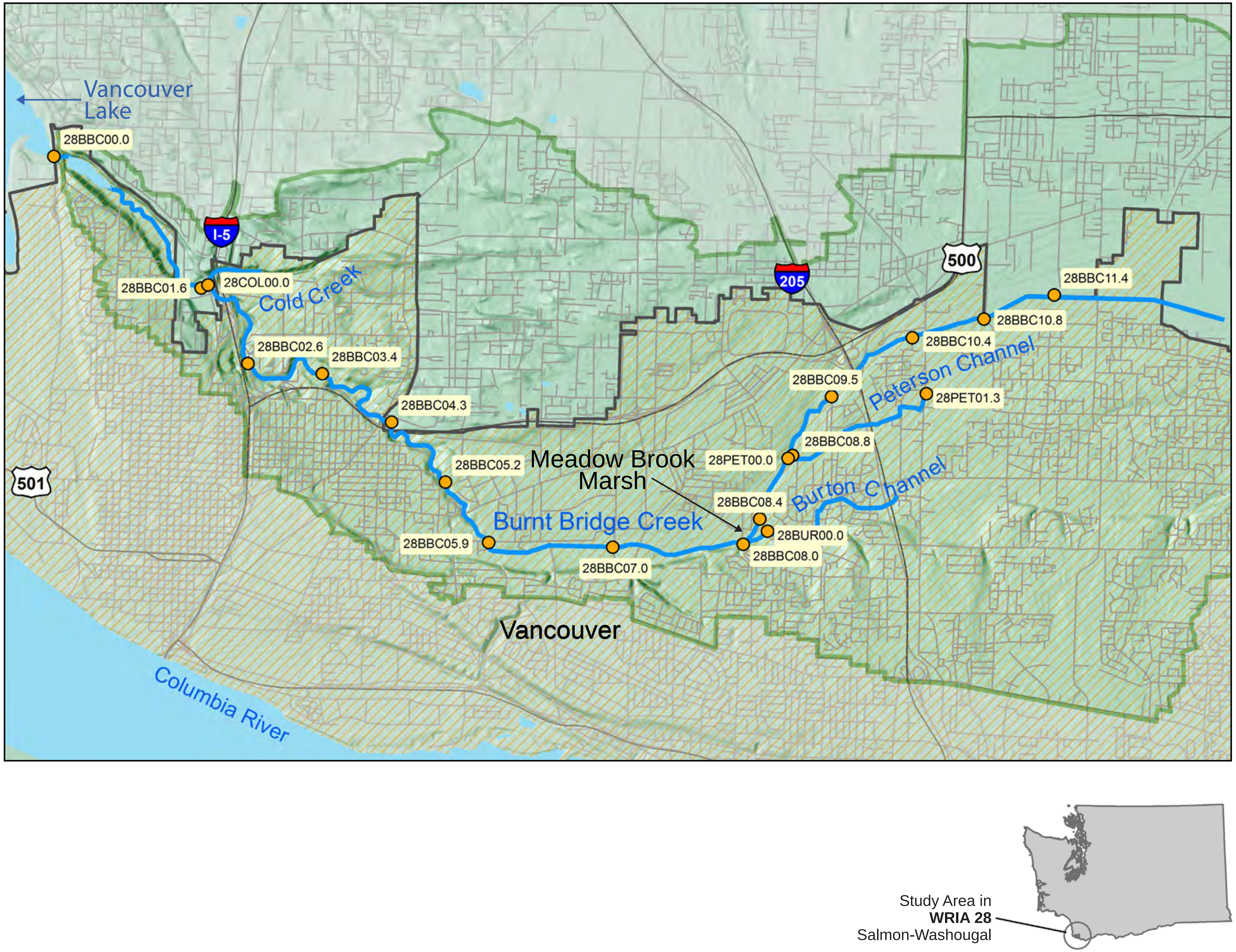


Figure 2.
Burnt Bridge Creek TMDL Study Monitoring Locations.

Legend

- Monitoring site
- Stream channel
- Watershed boundary
- Vancouver city limits

Source: Ecology 2008

N

0 0.5 1
Approximate scale in miles

HERRERA

G:\Graphics\11-05023-000\tmdl_stations

METHODS

The field monitoring, laboratory analysis, and data management and analysis methods are described below. A detailed description of these methods is provided in the 2014 quality assurance project plan (QAPP) (Herrera 2014b) prepared for the 2014 Burnt Bridge Creek ambient monitoring program, and 2015 through 2017 QAPP addendums (Herrera 2015b, 2016b, 2017b). Methods for monitoring conducted in 2011 through 2013 are described in the 2011 QAPP and subsequent QAPP addendums (Herrera 2011, 2012b, 2013b).

The following parameters were monitored in the field:

- Temperature (probe at 11 stations and continuous data logging at 8 stations)
- Dissolved oxygen (probe only)
- pH (probe only)
- Specific conductivity (probe only)

Sampling was conducted for analysis of the following parameters in the laboratory:

- Turbidity
- Total suspended solids (TSS)
- Total phosphorus
- Soluble reactive (orthophosphate) phosphorus
- Total nitrogen
- Nitrate+nitrite nitrogen
- Fecal coliform bacteria

Water quality sampling, field measurement, and continuous temperature monitoring was conducted at 11 stations along Burnt Bridge Creek and its tributaries, as shown in Figure 3. Monitoring station locations are as follows (listed below from upstream to downstream):

- **Station BBC 10.4** – Burnt Bridge Creek, located at Northeast 110th Avenue near Northeast 51st Circle
- **Station BBC 8.8** – Burnt Bridge Creek, located immediately upstream of the Peterson Channel confluence near Northeast 93rd Avenue
- **Station PET 0.0** – Peterson Channel, located near the mouth at the northern end of Northeast 93rd Avenue
- **Station BBC 8.4** – Burnt Bridge Creek, located south of Northeast Burton Road just west of Northeast 90th Avenue
- **Station BUR 0.0** – Burton Channel, located 0.3 mile upstream of the mouth at Northeast 92nd Avenue and 19th Circle (no continuous temperature monitoring)
- **Station BBC 7.0** – Burnt Bridge Creek, located at the southern end of Northeast 65th Avenue
- **Station BBC 5.9** – Burnt Bridge Creek, located at E 18th Street east of Bryant Street
- **Station BBC 5.2** – Burnt Bridge Creek, located at Algona Drive (no continuous temperature monitoring)
- **Station BBC 2.6** – Burnt Bridge Creek, located in Leverich Park near lower parking lot
- **Station COL 0.0** – Cold Creek, located near the mouth at Hazel Dell Road (no continuous temperature monitoring)
- **Station BBC 1.6** – Burnt Bridge Creek, located at Alki Road and below the Cold Creek confluence

In accordance with the recommendations in the 2011 monitoring report, the monitoring effort was streamlined from 14 sites in 2011 to 11 sites in 2012, eliminating 3 monitoring stations, monitoring continuous temperature at 8 of the remaining 11 stations, and eliminating analysis of ammonia nitrogen. Monitoring data collected for the additional stations and ammonia in 2011 are not evaluated for this trend analysis report. In addition, storm event monitoring data collected in 2012 and 2013 were discussed in the 2013 trend analysis report and are not evaluated for this report.

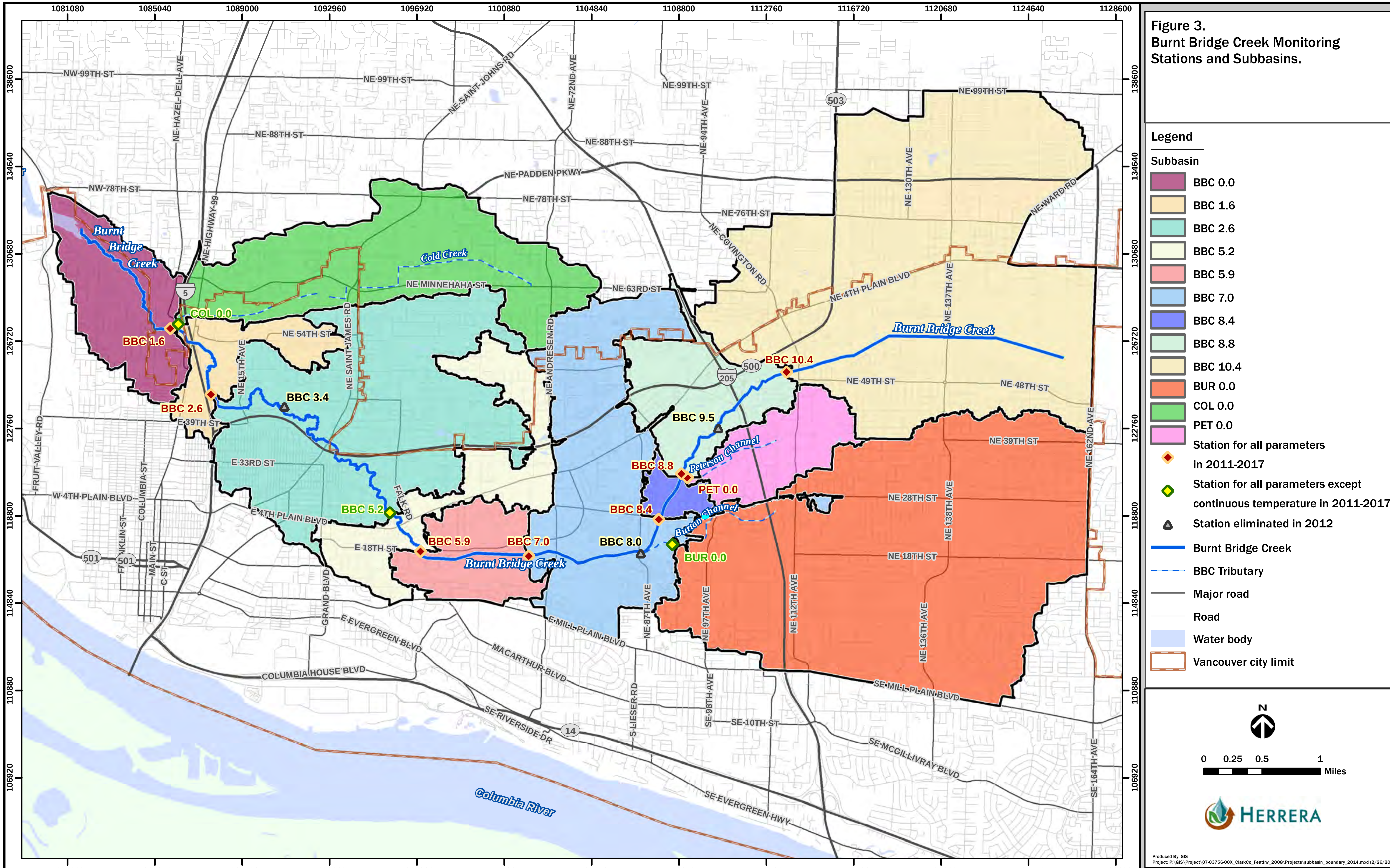


Figure 3.
Burnt Bridge Creek Monitoring Stations and Subbasins.

FIELD MONITORING METHODS

Methods for collection of continuous temperature logging data, field water quality data, and grab samples at each of the 11 stations are described in the following subsections. Table 1a presents the sampling dates for monitoring events in 2011–2017. Monitoring was scheduled for six events each year, occurring approximately once every 3 to 4 weeks over a 5-month period from June through October with the exception of one sampling event occurring in early November in 2012 and 2014. One field duplicate sample was collected during each sampling event for a total of 12 samples per event and 72 samples for all six events each year. All monitoring events in 2011–2017 occurred during dry weather and in base flow conditions where the antecedent dry period was at least 2 days. One exception was Event 6 in 2012 that had an antecedent dry period of only 1 day due to the unusually wet conditions in late October and early November.

Table 1a. Sampling Events for the Burnt Bridge Creek Ambient Water Quality Monitoring Program, 2011–2017.

Event ID	Sample Date	In Situ Sample Duplicate Station	Grab Sample Duplicate Station	Antecedent Dry Period (days)[a]
2017 Monitoring				
Event 1	6/19/2017	BBC 10.4	BBC 8.4	3
Event 2	7/11/2017	BBC 5.9	PET 0.0	25
Event 3	8/2/2017	BBC 5.2	BUR 0.0	47
Event 4	8/30/2017	BBC 7.0	COL 0.0	17
Event 5	9/26/2017	BBC 2.6	BBC 1.6	6
Event 6	10/10/2017	PET 0.0	BBC 8.8	10
2016 Monitoring				
Event 1	6/21/2016	BBC 5.9, BBC 1.6	BBC 1.6	2
Event 2	7/5/2016	BBC 8.4	BUR 0.0	10
Event 3	7/26/2016	BBC 10.4, PET 0.0	BBC 10.4	3
Event 4	8/18/2016	PET 0.0	BBC 7.0	9
Event 5	9/13/2016	BBC 7.0	COL 0.0	6
Event 6	10/12/2016	BBC 2.6	BBC 5.9	2
2015 Monitoring				
Event 1	6/16/2015	BUR 0.0	BUR 0.0	13
Event 2	7/8/2015	BBC 10.4	BBC 10.4	35
Event 3	7/28/2015	NA	BBC 7.0	2
Event 4	8/25/2015	BBC 2.6	BBC 2.6	29
Event 5	9/22/2015	BBC 5.9	BBC 5.9	4
Event 6	10/14/2015	BBC 1.6	BBC 1.6	3

Table 1a (continued). Sampling Events for the Burnt Bridge Creek Ambient Water Quality Monitoring Program, 2011–2017.				
Event ID	Sample Date	In Situ Sample Duplicate Station	Grab Sample Duplicate Station	Antecedent Dry Period (days)[a]
2014 Monitoring				
Event 1	06/19/2014	BUR 0.0	BBC 8.4	2
Event 2	07/09/2014	BBC 8.8	BBC 10.4	9
Event 3	08/05/2014	BBC 7.0	BBC 7.0	12
Event 4	08/25/2014	BBC 7.0	BUR 0.0	32
Event 5	09/23/2014	BBC 10.4	COL 0.0	4
Event 6	11/11/2014	BBC 8.8	BBC 8.8	4
2013 Monitoring				
Event 1	06/11/2013	BBC 10.4	BBC 10.4	>10
Event 2	07/09/2013	BBC 7.0	BUR 0.0	13
Event 3	07/31/2013	BBC 8.4	BBC 8.4	34
Event 4	08/20/2013	BBC 8.8	BBC 7.0	54
Event 5	09/18/2013	BBC 5.9	BBC 5.9	11
Event 6	10/15/2013	BBC 10.4, BBC 8.8	BBC 8.8	2
2012 Monitoring				
Event 1	06/11/2012	BBC 1.6	BBC 1.6	2
Event 2	07/11/2012	BUR 0.0	BUR 0.0	11
Event 3	08/08/2012	BBC 5.9	BBC 5.2	19
Event 4	08/28/2012	BBC 5.9	BBC 5.2	39
Event 5	09/25/2012	PET 0.0	BBC 7.0	14
Event 6	11/07/2012	BBC 8.4	BBC 7.0	1
2011 Monitoring				
Event 1	06/21/2011	NA	BBC 5.9	25
Event 2	07/12/2011	NA	BUR 0.0	12
Event 3	08/02/2011	NA	BBC 2.6	16
Event 4	08/30/2011	NA	BBC 10.4	44
Event 5	09/20/2011	NA	PET 0.0	2
Event 6	10/18/2011	NA	BBC 8.8	4

[a] 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. Hayden Island Rain Gage (Portland BES 2017) was used for 2014–2017. Orchards rain gage located at Whitley Pit and operated by Clark County (Clark County 2013) was used for 2011–2013.

This trend analysis report includes historical water quality data collected during six events per year from 2004–2007 at stations BBC 5.9, BBC 8.4, PET 0.0, BBC 7.0. The historical water quality data were collected as part of an ambient monitoring program that did not specifically target base flow conditions. Historical sampling dates are presented in Table 1b.

Table 1b. Historical Ambient Water Quality Monitoring Events in 2004–2007.				
	Sample Date			
Event ID	**2007**	**2006**	**2005**	**2004**
Event 1	6/27/2007	6/29/2006	6/30/2005	6/30/2004
Event 2	7/18/2007	7/20/2006	7/21/2005	7/21/2004
Event 3	8/9/2007	8/15/2006	8/11/2005	8/11/2004
Event 4	8/29/2007	8/31/2006	9/1/2005	9/1/2004
Event 5	9/19/2007	9/20/2006	9/22/2005	9/22/2004
Event 6	10/10/2007	10/12/2006	10/13/2005	10/13/2004

Continuous Temperature Logging Data

One HOBO Pro v2 water temperature data logger was installed at each of eight monitoring stations. Additional probes were installed in 2016 and 2017 at separate locations at stations BBC 2.6 and BBC 1.6 stations for backup because of previous vandalism problems (Herrera 2016a, 2017b). A backup probe was installed in 2017 at BBC 8.4 due to difficulty locating the probe in 2016. The data loggers were installed according to the Washington Department of Ecology's protocols for continuous temperature sampling (see QAPP [Herrera 2014b] for more information about those protocols). Temperature loggers were installed inside a shade device consisting of a perforated PVC pipe that was attached to rebar set in the stream bed. Due to concerns of vandalism, the PVC pipe was painted brown to camouflage the loggers. Temperature loggers were placed in well-mixed locations that were shaded from direct sunlight wherever possible to minimize influence from direct solar radiation. All temperature loggers were programmed to record temperature at an interval of 5 minutes.

Continuous temperature data were downloaded from all temperature data loggers during each 2017 monitoring event using the Onset HOBOware® software. One exception occurred at BBC 8.8 where the probe was not found during the fourth sampling event (August 30, 2017) resulting in a gap in data between the third (August 8, 2017) and fourth sampling events. A backup probe was installed at BBC 8.8 during the sampling event on August 30, 2017. In addition, data were not downloaded from temperature probes at BBC 8.4 during the fifth sampling event (September 26, 2017) due to missing backup probe and a malfunction with the original probe. The data were successfully downloaded after troubleshooting, providing a complete set of temperature data.

Field Water Quality Data

In situ water quality measurements were made at each of the 11 monitoring stations by submerging the probe of YSI Model 566 (2011 through 2016) or YSI Model ProDSS (2017) multi-probe water quality meter. Because oxygen is consumed by the sensor during measurement, 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. Stagnant water conditions were not encountered at any of the monitoring stations. Upon arrival at a monitoring station, the probe was submerged in the stream and left to stabilize during temperature data logger downloading. The probe was placed upstream of all in-stream 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 multi-probe water quality meter in the stream during the sampling event.

Grab Sample Collection

Water samples were collected by hand from each of the 11 monitoring stations using pre-cleaned bottles supplied by the laboratories (IEH Aquatic Research and PIXIS Labs). Water samples were collected from the center of the stream by wading into the channel and using 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 sample was collected from a different station during each sampling event by consecutively filling each pair of sample bottles and labeling the field duplicate sample 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). Samples were shipped overnight to the laboratory (IEH Aquatic Research) via Federal Express the same day. Fecal coliform samples were hand delivered to a different laboratory (PIXIS Labs) in 2017. A chain-of-custody form was completed and included with each batch of samples sent to the laboratory.

Laboratory Analysis Methods

All Burnt Bridge Creek water quality monitoring grab samples collected in 2017 were sent to IEH Aquatic Research in Seattle, Washington, for analysis with the exception that fecal coliform samples were delivered to PIXIS labs for analysis in 2017. Table 2 presents the required analytical methods and the total number of samples analyzed in 2017; these are consistent with the methods used during the 2011–2016 monitoring.

Table 2. Methods and Number of Samples for Water Quality Analyses in 2017.			
Parameter	**Analytical Method**	**Method Number[a]**	**Number of Samples[c]**
Turbidity	Nephelometric	SM 2130-B, EPA 180.1[b]	72
Total suspended solids	Weighed filter	EPA 160.2, SM 18 2540D[b]	72
Total phosphorus	Persulfate digestion, automated ascorbic acid	EPA 365.1	72
Soluble reactive (orthophosphate) phosphorus	Automated ascorbic acid	EPA 365.1	72
Total nitrogen	Persulfate digestion, automated Koroleff	SM 4500N-C	72
Nitrate+nitrite nitrogen	Automated cadmium reduction	EPA 353.2, SM 18 45000N03 F[b]	72
Fecal coliform bacteria	Membrane filtration	SM 9222-D	72

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

[b] This method is equivalent to that specified in the QAPP (Herrera 2014b).

[c] Number of samples based on 6 samples for each of the 11 locations plus 6 field duplicates for quality control.

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) with the following two exceptions specified in the QAPP:

- Fecal coliform bacteria samples were analyzed within 24 hours of sample collection, exceeding the recommended maximum holding time of 8 hours. Due to the number of sampling stations and proximity to the lab, it was not always feasible to deliver all the samples within 8 hours. Consequently, a holding time of 24 hours was used for this study, which was also used for the Total Maximum Daily Load (TMDL) study (Ecology 2008).

- Soluble reactive (orthophosphate) phosphorus samples were filtered at the laboratory within 24 hours of sample collection, exceeding the recommended maximum filtration time of 15 minutes. Field filtration is recommended primarily for groundwater and wastewater samples with a low dissolved oxygen concentration to prevent oxidation and precipitation of orthophosphate. However, the collected surface water samples were not expected to be in a reduced (low oxygen) state or contain high biochemical oxygen demand, and field filtration increases the potential for sample contamination. Consequently, the maximum filtration time of 24 hours was used for this project.

Data Management and Analysis Methods

This section includes a subsection for each of the following procedures: data management, computation of summary statistics, and comparison of results to the applicable water quality criteria. These analyses were performed on data collected from June through October 2017. In addition, the 2017 data were compared to 2011–2016 monitoring results and to 2004–2007 monitoring results where available. The results from these analyses are summarized in the *Results* section.

Data Management

Field measurements were entered into a Microsoft Excel spreadsheet along with the laboratory analytical results. Data flags representing estimated values were also entered in the spreadsheet database based on results of the data quality review. Database input was checked after entry to ensure that any transcription errors were corrected.

Continuous temperature data were transferred from the manufacturer's software system (HOBOware) to a Microsoft Excel spreadsheet. The data were visually reviewed and spikes and drops were removed. The one 22-day data gap for station BBC 8.8 in August 2017 was not filled because data for nearby stations clearly indicated that the water quality standard had been exceeded, and filling the gap was not required for calculating the 7-day average of the daily maximum temperature (7-DADMax). In previous years, large data gaps were filled with modeled results based on a linear regression of data from nearby stations without data gaps. The raw data were preserved for each station, while the corrected data were used for further analysis and graphical presentations. A log of all the data corrections is presented in Appendix C. All continuous temperature data and corrections previously made for 2011–2016 were reviewed for quality assurance purposes.

Computation of Summary Statistics

In order to assess water quality conditions at each of the sample locations, Microsoft Excel and R software packages were used to calculate the following summary statistics from the compiled data:

- Mean
- Median
- Geometric mean (fecal coliform only)
- Minimum
- 25th percentile

- 75th percentile
- Maximum

When undetected values were present in the data, the reporting limit was used in all calculations. Use of the reporting limit for undetected values is consistent with historical data management practices, but may result in a slightly higher bias than other estimating methods, such as using one-half of the reporting limit or zero for undetected values. The summary statistics were then compiled in individual summary tables for each of the monitoring parameters.

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 an overall range and temporal trend of data collected. The box and whisker plots were generated to present the following information: the minimum and maximum values as the lower and upper whiskers, respectively; the median and mean as the line and point in the box, respectively; and the 25th and 75th percentiles of the data as the lower and upper boundaries of the box, respectively. For fecal coliform bacteria, the 90th percentile of the data is also shown on the plot as a black triangle and the geometric mean is presented rather than the arithmetic mean for comparison to water quality criteria.

Temporal and Spatial Pattern Analysis

Statistical analyses of temporal and spatial patterns were performed in order to meet the following study objectives:

1. Detect significant temporal trends in water quality from 2011 to 2017.
2. Detect significant changes in water quality occurring between 2004–2007 and 2011–2017.
3. Determine whether there are significant differences in water quality among the stations monitored in 2011–2017 to identify spatial patterns.

In order to meet the first study objective, Kendall’s tau correlation analyses were performed on the 2011–2017 data to evaluate significant continuous increasing or decreasing trends in water quality parameters at each station. Statistical significance in these analyses was assessed at an alpha level of 0.05. The analysis was applied to all 11 parameters described above. For the continuous temperature data, Kendall’s Tau was applied to the percentage of the annual record (112 days) that temperature criterion (DADMax greater than 17.5°C) was exceeded. Kendall’s tau correlation was also used to identify temporal trends in annual Water Quality Index scores.

In order to meet the second study objective, the 2004–2007 and 2011–2017 water quality data were compared using a Mann-Whitney test, which is a nonparametric analog to the Student’s t-test that does not assume a normal distribution of data (Helsel and Hirsch 2002). For each of the four stations monitored in both study periods, significant increases and decreases in concentrations were identified. This indicates where water quality conditions improved or degraded at the monitoring station in recent years. Statistical significance for these tests was assessed at an alpha level of 0.05.

Spatial patterns were evaluated using the Friedman Test along with pairwise comparison using R for the 2011–2017 data. 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 controlled for in the analysis. 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 above each station boxplot, where stations without common letters are significantly different and stations with common letters are not significantly different. Statistical significance for this test was assessed at an alpha level of 0.05.

Comparison to Water Quality Criteria

In order to identify water quality impairment at the Burnt Bridge Creek sampling stations, 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, effective August 1, 2016)
- Ambient Water Quality Criteria Recommendations: Rivers and Streams in Nutrient Ecoregion I (EPA 2001)

Water quality standards for surface waters in the state of Washington are based on specific designated uses that have been identified for the particular water body (WAC 173-201A-602). Water quality criteria associated with designated uses for Burnt Bridge Creek are summarized in Table 3. Burnt Bridge Creek is designated for salmonid spawning, rearing, and migration that include aquatic life criteria for temperature, dissolved oxygen, pH, and turbidity. Burnt Bridge Creek is also designated for primary contact recreation that includes recreational use criteria for fecal coliform bacteria. Because the state surface water standards do not include nutrient criteria for streams, criteria recommended by the US Environmental Protection Agency (EPA 2001) for total phosphorus, total nitrogen, and nitrate+nitrite nitrogen in streams located in the Willamette Valley Ecoregion are also presented in Table 3 for comparison to monitoring data.

Table 3. Water Quality Criteria Used for Comparison to Data Collected for the Burnt Bridge Creek Ambient Water Quality Monitoring Project.	
Aquatic Life Use Criteria for Salmonid Spawning, Rearing, and Migration[a]	
Temperature	The 7-day average of the daily maximum temperature (7-DADMax) shall not exceed **17.5°C**. When a water body's temperature is warmer or within 0.3°C of 17.5°C and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C.
Dissolved oxygen	The lowest 1-day minimum shall exceed **8.0 mg/L**. When a waterbody's dissolved oxygen concentration is lower than or within 0.2 mg/L of 8.0 mg/L and that condition is due to natural conditions, then human actions considered cumulatively may not cause the dissolved oxygen concentration of that water body to decrease more than 0.2 mg/L
pH	Shall be within the range of **6.5 to 8.5**, with a human-caused variation within this range of less than 0.5 unit.
Turbidity	Shall not exceed 5 NTU over background when the background turbidity is 50 NTU or less; or a 10 percent increase in turbidity when the background turbidity exceeds 50 NTU.
Nutrient Criteria from Reference Conditions for the Willamette Valley Ecoregion[b]	
Total phosphorus	Shall not exceed **0.040 mg/L**
Total nitrogen	Shall not exceed **0.36 mg/L**
Nitrate+nitrite nitrogen	Shall not exceed **0.15 mg/L**
Recreational Use Criteria for Primary Contact Recreation[a]	
Fecal coliform bacteria	Geometric mean shall not exceed **100 colonies/100 mL**, with not more than 10 percent of all samples (or any single sample when less than 10 sample points exist) obtained for calculating the geometric mean values exceeding **200 colonies/100 mL**.

[a] Source: Ecology (2016); Washington State Surface Water Quality Standards for Surface Waters of the State of Washington (WAC 173-201A).

[b] Source: EPA (2001); 25th percentile of medians for 171 streams for all seasons from 1990–1999 in the Willamette Valley Ecoregion (Table 3a).

C = Celsius

mg/L = milligram/liter

NTU = nephelometric turbidity units

ml = milliliter

Water Quality Index

In order to summarize water quality patterns in Burnt Bridge Creek and to facilitate comparisons between the sampling sites, the water quality index (WQI) was calculated for each station and year using protocols developed by Ecology (2002). The WQI is a unitless number ranging from 1 to 100, with higher numbers indicating better water quality. The WQI is calculated using data from the following suite of parameters: temperature, pH, fecal coliform bacteria, dissolved oxygen, total suspended solids, total phosphorus, total nitrogen, and turbidity. Constituent scores from each parameter are combined and aggregated over time to produce an overall annual score for each station. Median constituent scores and overall scores for the 2011–2017 period are reported and discussed in this report.

In general, the WQI provides an indication of the adequacy of water quality for supporting the beneficial uses of a given water body as defined in the Washington State Surface Water Quality Standards (WAC 173-201A). Thus, for temperature, pH, fecal coliform bacteria, and dissolved oxygen, the WQI expresses results relative to applicable water quality standards for these parameters (see Table 3) that have been promulgated to maintain beneficial uses. For nutrients for which criteria have not been established by Ecology, the results are expressed relative to the distribution of data from Ecology's long-term monitoring stations located in that ecoregion. Sites scoring 80 and above likely meet the expectations for water quality and are of "lowest concern." Scores ranging from 40 to 80 indicate a "marginal concern," and water quality at sites with scores less than 40 likely are not meeting the expectations and are of "highest concern" (Ecology 2002).

It should be noted that the WQI conveys less information by design than the raw data summarized by the WQI. Thus, it is most useful for making broad comparisons between sites and answering general questions about the water quality in each stream (Ecology 2002). The WQI is less suited to answering site-specific questions regarding water quality because this typically requires detailed analyses of the water quality data. There are at least two reasons that the WQI may fail to accurately communicate water quality information. First, the index, like most indices, is based on a pre-identified suite of water quality parameters. Therefore, a particular site may receive a good WQI score and yet have water quality that is impaired in terms of parameters that are not included in the index. Second, aggregation of data may mask short term water quality problems. It follows that a satisfactory WQI at a particular site does not necessarily mean that water quality was always satisfactory. A good score indicates only that poor water quality was not a chronic problem. Due to these considerations, the WQI was used in this analysis only to summarize broad patterns in the data.

The Ecology WQI scores were calculated using Ecology's spreadsheet (Ecology 2018) for each site and year. The following inputs were selected:

- Recreation use: Primary
- Aquatic Life (Temperature): Spawn (17.5)
- Aquatic Life (Oxygen): Spawning
- Supplemental Spawning: None
- Ecoregion: 3 (Willamette Valley)
- Small Puget Sound Stream: Yes

The small Puget Sound stream was selected as recommended by Ecology (2002) because the nutrient scores are unreasonably low without that selection due to naturally high nutrient concentrations in the stream (Herrera 2016).

RESULTS

DATA QUALITY REVIEW

A quality assurance review was performed for all field and laboratory data collected in 2017, as specified in the QAPP (Herrera 2014b). 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 to be 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 are presented in Table 4. Data quality review findings are summarized below for field and laboratory data collected in 2017. Data quality are then summarized for 2017 and previous monitoring years.

Table 4. Summary of Measurement Quality Objectives and Required Reporting Limits of Field and Laboratory Parameters.

Parameter	Matrix Spike (percent recovery)	Lab Duplicates (RPD)	Field Duplicates (RPD)	Control Sample (percent recovery)	Reporting Limits/Unit
Field Measurements					
Temperature	NA	NA	<20	NA	+0.2°C
Dissolved oxygen	NA	NA	<20	NA	+0.2 mg/L
pH	NA	NA	<20	NA	+0.1 std. units
Conductivity	NA	NA	<20	NA	+2 µS/cm
Laboratory Analyses					
Turbidity	NA	<20	<20	90–110	0.1 NTU
Total suspended solids	NA	<20	<20	90–110	0.5 mg/L
Nitrate+nitrite nitrogen	90–110	<20	<20	90–110	0.010 mg/L
Total nitrogen	90–110	<20	<20	90–110	0.050 mg/L
Soluble reactive (orthophosphate) phosphorus	90–110	<20	<20	90–110	0.001 mg/L
Total phosphorus	90–110	<20	<20	90–110	0.002 mg/L
Fecal coliform bacteria	NA	<35	<35	NA	5 CFU/100 mL

CFU/100 mL = colony forming units per 100 milliliters

µS/cm = microsiemens per centimeter

mg/L = milligrams per liter

NA = not applicable

NTU = nephelometric turbidity unit

RPD = relative percent difference

Field Data

ProDSS Meter

The ProDSS multi-probe water quality meter was calibrated before each event, and a calibration check was conducted at the end of the event. All meter calibration checks in 2017 were within 5 percent of the calibration standard, with the exception that dissolved oxygen during Event 2 (July 11, 2017) was approximately 7 percent higher than the standard. No values were flagged due to the minor exceedance.

Continuous Temperature Loggers

An accuracy check of the temperature loggers was conducted in May 2017 prior their installation using a NIST-certified[1] thermometer. Temperatures from the NIST-certified thermometer and the temperature loggers were recorded 20 times after a 20-minute equilibration period in both ice water and ambient water. The average difference between each measurement was within 0.2°C of the NIST-certified thermometer for all probes, as specified in the QAPP. One exception is that the Backup 1 probe exhibited an average difference of –0.4°C at room temperature. Backup 1 was used at station BBC 8.8 between Events 4 and 6. Data collected by the probe were corrected using a linear regression equation. Results from the final accuracy check are presented in Appendix B.

Continuous temperature data were complete for 2017. One exception is that data were not collected between August 2, 2017, and August 30, 2017, for BBC 8.8 due to the loss of the original probe.

Laboratory Data

Completeness

All scheduled samples were collected, and the laboratory reported all parameters for all samples.

Methodology

The laboratory met all analytical method requirements.

Raw data for all fecal coliform bacteria analyses were reviewed to evaluate whether the plate counts used to calculate the results met quality control objectives established by the method. The quality control objectives established for the fecal coliform membrane filter procedure (Standard Methods method 9222D, in APHA et al. 1998) are to filter a sample volume that yields

[1] Certified by the National Institute of Standards and Technology.

an ideal range of 20 to 60 fecal coliform positive colonies on a culture plate to obtain statistically reliable results, and for not more than 200 colonies of all bacteria types to be present on a culture plate to ensure that the results are not underestimated due to crowding (e.g., merged colonies or false negatives). The analysis method also provides guidance for calculation of fecal coliform density as follows:

- If one of the plate counts is between 20 and 60, then calculate the density for the sample volume yielding a plate count in this ideal range.
- If duplicate sample volumes were analyzed, then calculate the average density for both analyses.
- If all counts are outside the ideal range, then calculate the average density for all sample volumes analyzed, excluding counts greater than 200, by dividing the sum of the plate counts by the sum of the sample volumes.
- If no plate counts less than 200 were obtained, but a plate had a total bacterial colony count greater than 200, then report the density as greater than the value associated with this plate count.
- If all plate counts were too numerous to count then report the density as greater than the value associated with a count of 200 for the smallest sample volume.

Fecal coliform bacteria results for the Burnt Bridge Creek project were qualified as estimates (J) if the plate count was outside the ideal range of 20 to 60 colonies, and were qualified as greater than (>) if the plate count exceeded 200 colonies or was too numerous to count. Forty-five of the 66 fecal coliform bacteria results (68 percent) were qualified as estimated (J) based on plate counts being outside of the ideal range (i.e., 20 to 60 colonies).

On two occasions, laboratory oversights caused incorrect dilution amounts to be used. For Event 1 samples (June 19, 2017), the laboratory used a dilution volume of 100 milliliters (mL) for three samples (BBC5.2, BBC7.0, and BBC8.8), instead of the 2 mL and 20 mL requested on the chain of custody (COC). The larger dilution volume resulted in three samples being too numerous to count. Corrective actions included review of dilution volume and laboratory duplicate requirements with laboratory personnel, highlighting of procedures on the COC, and attachment of the bench sheet to the COC.

For Event 5 samples (September 26, 2017), PIXIS laboratory subcontracted the fecal coliform analysis to another laboratory, BSK Associates, located in Vancouver, Washington. The subcontracted laboratory did not follow procedures on the COC submitted to PIXIS that requested a laboratory duplicate and two dilution volumes (5 and 50 mL) per sample, because PIXIS did not convey those requests on a separate COC submitted to the subcontracted laboratory. The laboratory did not analyze a laboratory duplicate and used either a 5 or 50 mL dilution volume for each sample. PIXIS laboratory was reminded of project specific procedures (i.e., laboratory duplicate and two dilution volumes per sample) for future fecal coliform analysis.

Holding Times

All holding times specified in the QAPP were met.

Blanks

No blanks analyzed contained levels of target parameters above the reporting limit.

Control Standards

All control standard samples met the established control limits (see Table 4).

Matrix Spikes

All matrix spike samples met the established control limits (see Table 4) with the following exceptions:

- The matrix spike recovery for total nitrogen for the sample collected on July 11, 2017 (113 percent) slightly exceeded the 90 to 110 percent range established by the QAPP. Values were not flagged because the exceedance was minor and all other quality assurance checks met criteria.

- The matrix spike recovery for total nitrogen for the sample collected on August 2, 2017 (114 percent) slightly exceeded the 90 to 110 percent range established by the QAPP. Values were not flagged because the exceedance was minor and all other quality assurance checks met criteria.

Laboratory Duplicates

All laboratory duplicate samples met the established control limits (see Table 4) with the following exception:

- The RPD values for fecal coliform for the laboratory duplicate collected on July 11, 2017 (39 percent) slightly exceeded the 35 percent criterion established in the QAPP.

Field Duplicates

One field duplicate sample was collected during each sampling event, as specified in the QAPP. Field duplicate samples met the established control limits (see Table 4) with the following exceptions:

- The RPD values for fecal coliform for the field duplicate collected on June 19, 2017 (87 percent) exceeded the 35 percent criterion established in the QAPP.

- The RPD values for fecal coliform for the field duplicate collected on July 11, 2017 (101 percent) exceeded the 35 percent criterion established in the QAPP.
- The RPD values for nitrate+nitrite for the field duplicate collected on August 2, 2017 (22 percent) slightly exceeded the 20 percent criterion established in the QAPP. Values were not flagged because the exceedance was minor and all other quality assurance checks met criteria.
- The difference value for fecal coliform for the field duplicate collected on August 2, 2017 (difference of 77 CFU/100 mL) exceeded the 10 CFU/100 mL difference criterion established in the QAPP. The difference criteria was used because the duplicate value was less than five times the reporting limit.
- The RPD values for TSS for the field duplicate collected on September 26, 2017 (59 percent) exceeded the 20 percent criterion established in the QAPP.
- The RPD values for turbidity for the field duplicate collected on September 26, 2017 (29 percent) exceeded the 20 percent criterion established in the QAPP.
- The RPD values for nitrate+nitrite for the field duplicate collected on October 10, 2017 (38 percent) exceeded the 20 percent criterion established in the QAPP.
- The RPD values for turbidity for the field duplicate collected on October 10, 2017 (38 percent) exceeded the 20 percent criterion established in the QAPP.
- The RPD values for fecal coliform for the field duplicate collected on October 10, 2017 (63 percent) exceeded the 35 percent criterion established in the QAPP.

The field duplicate values were qualified as estimated (J) and the primary sample values were used in the data analysis.

Data Quality Summary

2017 Monitoring

In general, procedures described and quality control criteria defined in the QAPP were met, resulting in no data qualification or corrective action with the following exceptions:

- Forty-five of the 66 fecal coliform bacteria results (68 percent) were qualified as estimated (J) based on plate counts being outside the ideal range (i.e., 20 to 60 colonies).
- One fecal coliform result qualified as estimated (J) based on the laboratory duplicate RPD above the objective of 35 percent.

- Three fecal coliform results were flagged as greater than (>) the reported maximum possible count of 300 because they were reported as too numerous to count at >300.
- Four fecal coliform bacteria results were qualified as estimated (J) due to the field duplicate result (RPD greater than 35 or difference of 10 CFU/mL).
- One result for TSS was qualified as estimated (J) due to field duplicate results (RPD greater than 20 percent).
- Two results for turbidity were qualified as estimated (J) due to field duplicate results (RPD greater than 20 percent).
- One result for nitrate+nitrite were qualified as estimated (J) due to field duplicate results (RPD greater than 20 percent).

Quality assurance worksheets initially provided in Interim Reports 2 and 3 have been updated in Appendix A to reflect the following data quality review findings that were observed after the interim reports were originally prepared:

- The Event 2 (July 11, 2017) post calibration check for dissolved oxygen (7 percent greater than the standard) slightly exceeded criteria (less than 5 percent of the standard). No values were flagged due to the minor exceedance.
- The matrix spike recovery for total nitrogen for the sample collected on July 11, 2017 (113 percent) slightly exceeded the 90 to 110 percent range established by the QAPP. Values were not flagged because the exceedance was minor and all other quality assurance checks met criteria.
- The matrix spike recovery for total nitrogen for the sample collected on August 2, 2017 (114 percent) slightly exceeded the 90 to 110 percent range established by the QAPP. Values were not flagged because the exceedance was minor and all other quality assurance checks met criteria.
- The difference value for fecal coliform for the field duplicate collected on August 2, 2017 (77 CFU/100 mL) exceeded the 10 CFU/100 mL difference criterion. The value was incorrectly reported as 78 CFU/100 mL in Interim Report 3.

Table 5 presents data qualified for this monitoring conducted in 2017.

Table 5. Summary of Data Qualified as Estimated Values.

Sample ID	Parameter	Reason for Qualification	Qualifier
BBC1.6-20170619	Fecal coliform	Plate count outside ideal range of 20 to 60	J
COL0.0-20170619	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC2.6-20170619	Fecal coliform	Plate count outside ideal range of 20 to 60	J

Table 5 (continued). Summary of Data Qualified as Estimated Values.			
Sample ID	**Parameter**	**Reason for Qualification**	**Qualifier**
BBC5.2-20170619	Fecal coliform	Plate count too numerous to count due to lab oversight regarding dilution volumes.	>J
BBC5.9-20170619	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC7.0-20170619	Fecal coliform	Plate count too numerous to count due to lab oversight regarding dilution volumes.	>J
BBC8.4-20170619	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BUR0.0-20170619	Fecal coliform	Plate count outside ideal range of 20 to 60	J
PET0.0-20170619	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC8.8-20170619	Fecal coliform	Plate count too numerous to count due to lab oversight regarding dilution volumes.	>J
DUPE-20170619	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC5.2-20170711	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC7.0-20170711	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC8.4-20170711	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC8.8- 20170711	Fecal coliform	Plate count outside ideal range of 20 to 60	J
PET0.0-20170711	Fecal coliform	Field duplicate RPD and plate count outside ideal range of 20 to 60	J
BBC10.4-20170711	Fecal coliform	Laboratory duplicate RPD and plate count outside ideal range of 20 to 60	J
DUPE-20170711	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC10.4-20170802	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC8.8-20170802	Fecal coliform	Plate count outside ideal range of 20 to 60	J
PET0.0-20170802	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC8.4-20170802	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BUR0.0-20170802	Fecal coliform	Field duplicate RPD and plate count outside ideal range of 20 to 60	J
BBC5.9-20170802	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC5.2-20170802	Fecal coliform	Plate count outside ideal range of 20 to 60	J
COL0.0-20170802	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC1.6-20170802	Fecal coliform	Plate count outside ideal range of 20 to 60	J
DUPE-20170802	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BUR0.0-20170830	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC7.0-20170830	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC75.2-20170830	Fecal coliform	Plate count outside ideal range of 20 to 60	J
COL0.0-20170830	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC1.6-20170830	Fecal coliform	Plate count outside ideal range of 20 to 60	J
DUPE-20170830	Fecal coliform	Plate count outside ideal range of 20 to 60	J
PET0.0-20170926	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC8.4-20170926	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BUR0.0-20170926	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC7.0-20170926	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC5.9-20170926	Fecal coliform	Plate count outside ideal range of 20 to 60	J

Table 5 (continued). Summary of Data Qualified as Estimated Values.			
Sample ID	**Parameter**	**Reason for Qualification**	**Qualifier**
BBC5.2-20170926	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC2.6-20170926	Fecal coliform	Plate count outside ideal range of 20 to 60	J
COL0.0-20170926	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC1.6-20170926	Turbidity	Field duplicate RPD	J
BBC1.6-20170926	TSS	Field duplicate RPD	J
BBC10.4-20171010	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC8.8-20171010	Fecal coliform	Field duplicate RPD	J
BBC8.8-20171010	Nitrate+Nitrite	Field duplicate RPD	J
BBC8.8-20171010	Turbidity	Field duplicate RPD	J
PET0.0-20171010	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC8.4-20171010	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BUR0.0-20171010	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC7.0-20171010	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC2.6-20171010	Fecal coliform	Plate count outside ideal range of 20 to 60	J
BBC1.6-20171010	Fecal coliform	Plate count outside ideal range of 20 to 60	J
DUPE-20171010	Fecal coliform	Plate count outside ideal range of 20 to 60	J

TSS = total suspended solids, RPD = relative percent difference

Project Summary

Table 6 presents all summer base flow data qualified as estimated values for this monitoring project. All estimated data were used in the results calculations and no data were rejected. Data quality review findings are described in previous monitoring reports for 2011 through 2016 (Herrera 2012, 2013a, 2014a, 2015a, 2016a, 2017a).

Table 6. Percentage of Project Data Qualified as Estimated Values.							
Parameter	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Temperature	0	0	0	0	0	0	0
Dissolved Oxygen	0	0	3	0	0	0	0
pH	0	0	0	0	0	0	0
Conductivity	0	0	2	0	100	0	0
Turbidity	1	2	0	0	5	5	3
Total Suspended Solids	1	3	0	2	21	3	2
Total Phosphorus	0	0	0	0	0	17	0
Soluble Reactive Phosphorus	0	0	0	0	0	0	0
Total Nitrogen	0	0	0	0	2	17	0
Nitrate+Nitrite	0	0	0	0	0	2	2
Fecal Coliform Bacteria	55	34	52	47	64	47	70

Note: Percentages are based on 66 samples collected each year and do not include duplicate samples.

HYDROLOGY

Precipitation data collected by others during the monitoring period are presented in Figure 4. Rainfall data were collected in 1-hour intervals by Portland BES (2017) at Hayden Island Rain Gage, which is located 7.5 miles southwest of station BBC 2.6. There are no stream gages currently in operation on Burnt Bridge Creek, therefore no stream discharge data are available. Base flow conditions are assumed based on the antecedent dry period meeting or exceeding the 2-day criterion for all sampling events (See Field Monitoring Methods Section).

Monthly precipitation amounts from April through October are presented for each monitoring year in Figure 5. These results indicated that 2017 was drier than normal during the summer months, and was wetter than average in September. There was almost no precipitation between Event 1 in mid-June and Event 4 in late August, with the fall precipitation arriving in mid-September prior to Event 5 (see Figure 4).

WATER QUALITY RESULTS

Water quality results are presented and described separately for each parameter in the sections below. Each parameter section presents results and summarizes implications of:

1. Seasonal patterns among the sampling stations during the 2017 summer base flow sampling period
2. Spatial patterns among the sampling stations during the 2011–2017 summer base flow sampling period
3. Temporal trends within 2011–2017 sampling period, and between the 2004–2007 and 2011–2017 sampling periods
4. Water quality criteria comparison
5. Water quality index

Summary statistics are presented for each parameter and station in Appendix D. Statistical test results of spatial and temporal trend analyses are presented in Appendix E. Table 7 summarizes the statistically significant temporal patterns in base flow water quality from 2011 to 2017 and differences between the 2004–2007 and 2011–2017 monitoring periods. Water quality index results for the 2011–2017 monitoring period are presented in Table 8.

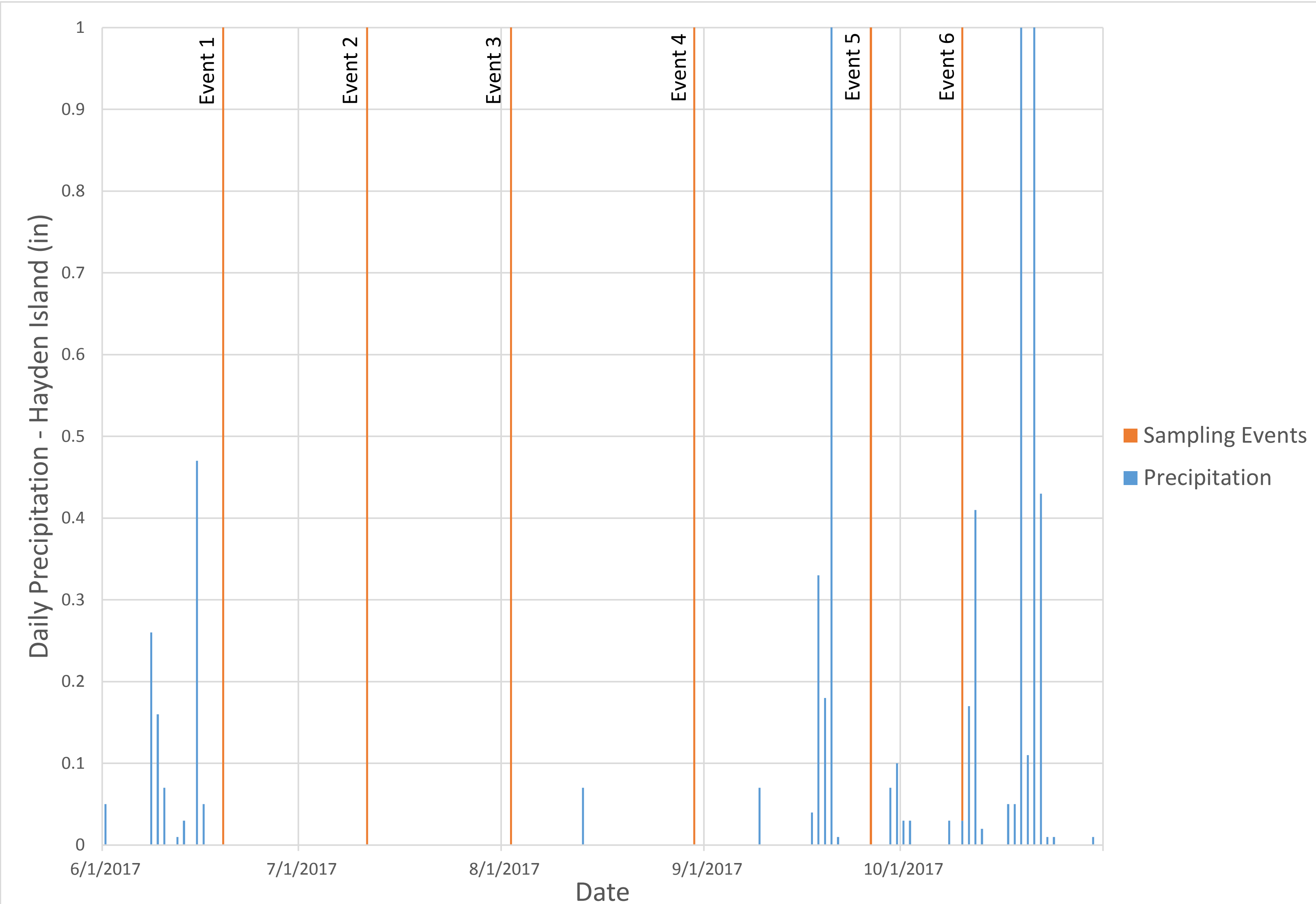


Figure 4. Burnt Bridge Creek Precipitation 7.5 Miles Southwest of BBC 2.6 During the Summer of 2017 (Portland BES 2017).

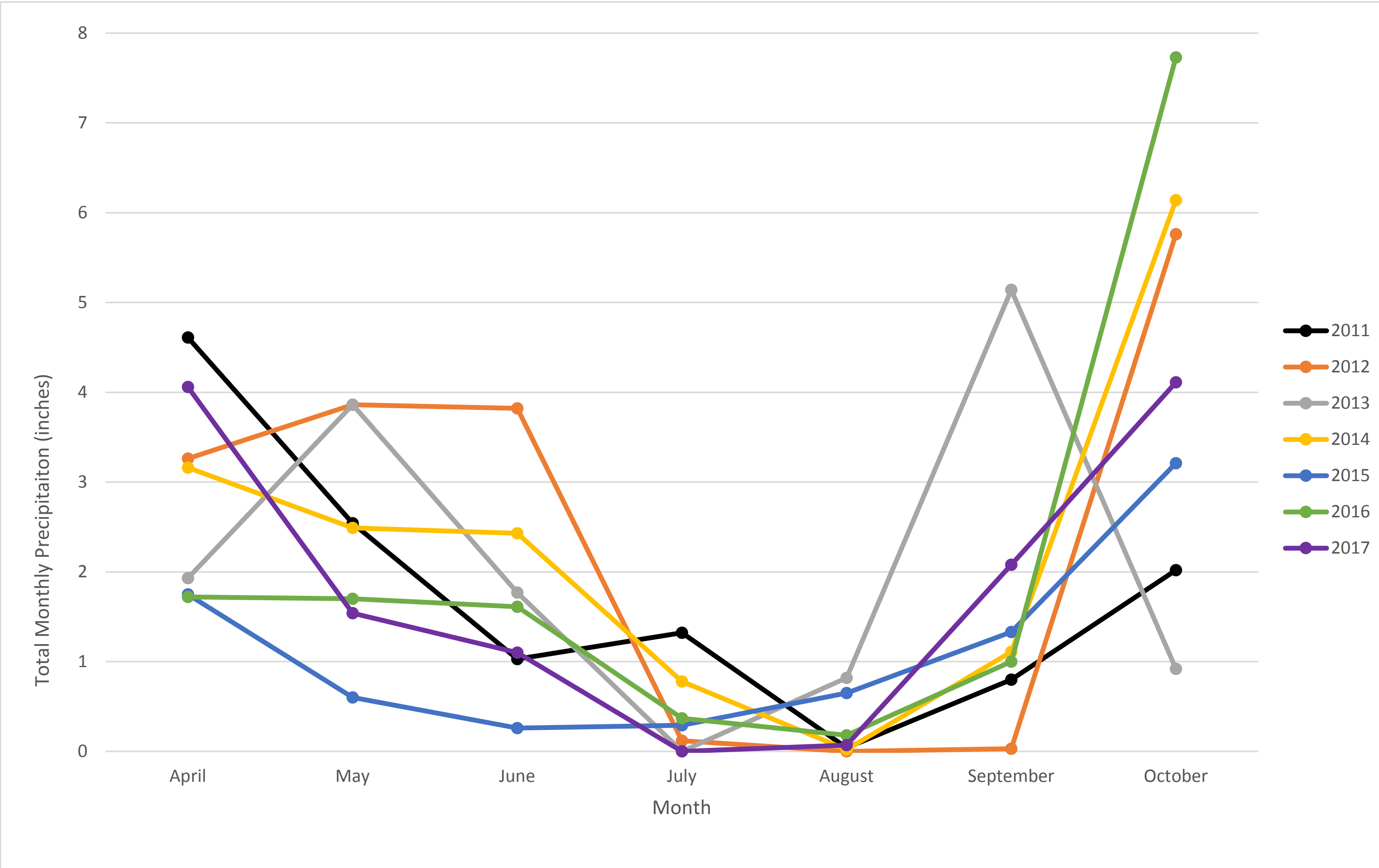


Figure 5. Total Monthly Precipitation at Burnt Bridge Creek for April through October, 2011 to 2017 (Portland BES 2017).

Table 7. Temporal Trend Analysis Summary for Burnt Bridge Creek.

	BBC10.4	BBC8.8	PET0.0	BBC8.4	BUR0.0	BBC7.0	BBC5.9	BBC5.2	BBC2.6	COL0.0	BBC1.6
Temporal Trend for 2011–2017[a]											
Temperature	–	–	–	–	–	–	–	–	–	–	–
Dissolved Oxygen	–	–	–	–	–	↘	–	–	–	–	–
pH	–	–	–	–	–	↘	–	–	–	–	–
Conductivity	–	–	↗	↗	–	↗	↗	↗	↗	↗	↗
Turbidity	↗	–	↗	–	–	–	–	–	–	–	–
Total Suspended Solids	↗	–	↘	–	–	–	↘	↘	↘	–	↘
Total Phosphorus	–	–	–	–	–	–	–	–	–	–	–
Soluble Reactive Phosphorus	–	–	↗	–	–	–	–	–	–	–	–
Total Nitrogen	↘	↘	↗	–	–	↘	↘	↘	↘	↗	–
Nitrate+Nitrite	↘	↘	↗	↘	↘	–	–	–	–	–	–
Fecal Coliform	–	–	–	–	↘	–	↘	↘	–	↘	–
Percent Change from 2004–2007 to 2011–2017[b]											
Temperature	na	na	1%	-3%	na	1%	-2%	na	na	na	na
Dissolved Oxygen	na	na	-1%	-10%	na	-15%	42%	na	na	na	na
pH	na	na	1%	0%	na	4%	8%	na	na	na	na
Conductivity	na	na	9%	-4%	na	-5%	-2%	na	na	na	na
Turbidity	na	na	46%	155%	na	127%	98%	na	na	na	na
Total Suspended Solids	na	na	34%	117%	na	73%	90%	na	na	na	na
Total Phosphorus	na	na	110%	104%	na	33%	42%	na	na	na	na
Soluble Reactive Phosphorus	na	na	108%	74%	na	42%	51%	na	na	na	na
Total Nitrogen	na	na	19%	83%	na	141%	123%	na	na	na	na
Nitrate+Nitrite	na	na	29%	81%	na	291%	277%	na	na	na	na
Fecal Coliform	na	na	-48%	-46%	na	39%	-5%	na	na	na	na

[a] Temporal trend evaluated using Kendall's Tau correlation test (a = 0.05). Empty cells are not significant.

[b] Percent change in median values from 2004–2007 and 2011–2017. Significant difference between periods tested using Mann-Whitney U test (a = 0.05).

↗ = increasing trend
↘ = decreasing trend
– = no significant trend
na = not analyzed

significant water quality improvement
significant water quality decline
significant change in pH or conductivity

Table 8. Median Annual Water Quality Index Scores for Burnt Bridge Creek.

Station	Years	FC	DO	pH	TP	TSS	Temp	TN	Turbidity	Overall WQI Score
BBC 10.4	7	73	53	74	78	95	87	1	95	60
BBC 8.8	7	74	86	94	62	79	78	1	92	69
PET 0.0	7	70	78	96	21	90	78	67	97	58[a]
BBC 8.4	7	74	74	97	45	83	80	7	93	53
BUR 0.0	7	60	83	96	81	91	86	1	98	70
BBC 7.0	7	72	71	96	41	77	65	34	87	43
BBC 5.9	7	71	57	96	49	89	74	43	92	43
BBC 5.2	7	69	83	95	49	86	74	40	93	49
BBC 2.6	7	69	84	91	49	84	73	40	93	48
COL 0.0	7	56	90	88	53	88	90	43	91	47
BBC 1.6	7	63	82	91	43	81	72	43	90	45

[a] Annual WQI Score shows significant decreasing trend over time using Kendall's Tau Correlation with an alpha of 0.05.

Low Concern WQI = 80–100

Moderate Concern WQI = 40–79

High Concern WQI = 1–39

FC = fecal coliform

DO = dissolved oxygen

TP = total phosphorus

TSS = total suspended solids

Temp = temperature

TN = total nitrogen

WQI = water quality index

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 3) 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.

Instream water temperature data were collected at all 11 stations during sampling events and also continuously over the summer at 8 stations. Instream water temperature data are presented graphically in Figures 6 and 7, and summary statistics are presented in Appendix D. The 2017 continuous temperature data are graphically presented in Appendix C.

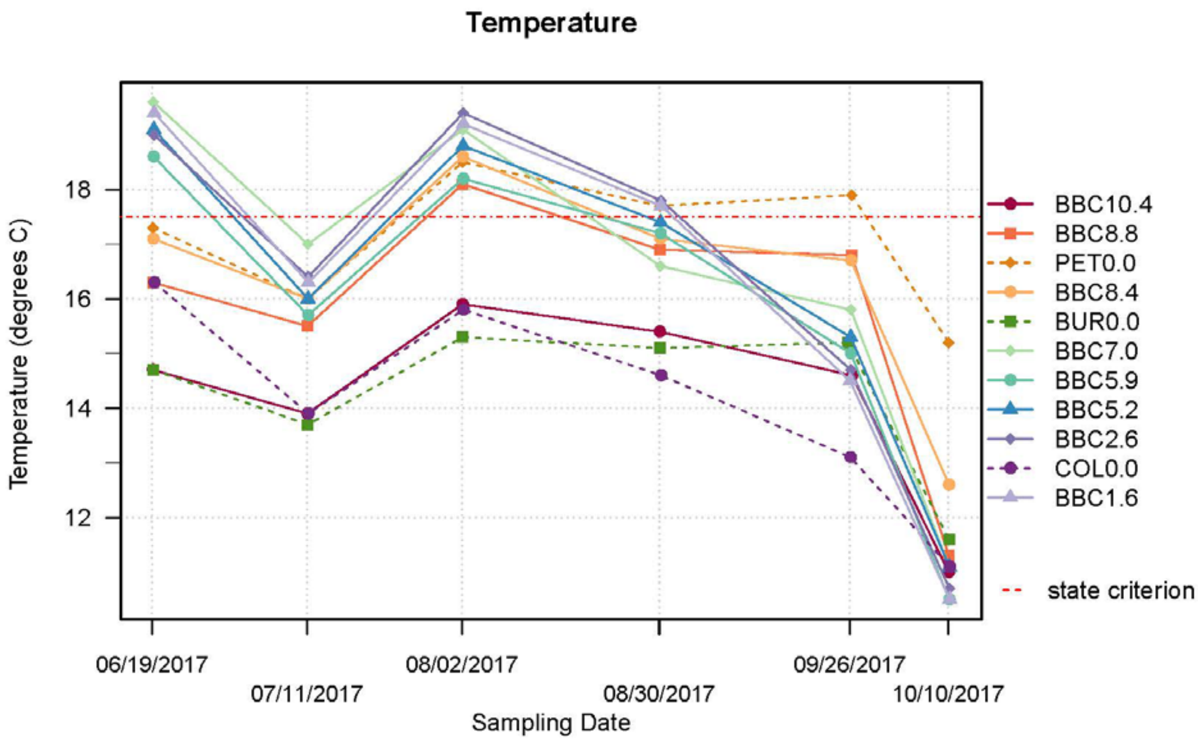
Seasonal Patterns

Figure 6 (top) shows water temperature data for each station by sampling date in 2017. Temperatures ranged from 10.5°C to 19.6°C in 2017. The seasonal pattern plot shows that water temperatures typically decreased from June to July, increased from July to early August, and decreased to minimum values (all stations) in October. Temperatures reached a maximum in June (five stations) and early August (six stations). The 2017 seasonal pattern differed from 2016 in that maximum values were observed in June and early August as opposed to late August in 2016.

Spatial Patterns

In order to assess how each monitoring basin was contributing to temperature in the main stem of Burnt Bridge Creek, the 2011–2017 temperature data are presented as box plots in Figure 7. Along the main stem, the median temperature increased downstream from BBC 10.4 (13.9°C) to BBC 7.0 (17.1°C), decreased at station BBC 5.9 (16.3°C), and remained relatively constant from stations BBC 5.2 to BBC 1.6. Peterson Channel was warmer and Burton Channel and Cold Creek were cooler than the main stem stations located upstream.

Spatial pattern analysis shows significant differences in temperature between stations (see letters on Figure 7). Temperatures were significantly higher at station BBC 7.0 than all other stations, and temperatures were significantly lower at the upstream station BBC 10.4 and tributary stations BUR 0.0, and COL 0.0 than the other stations.



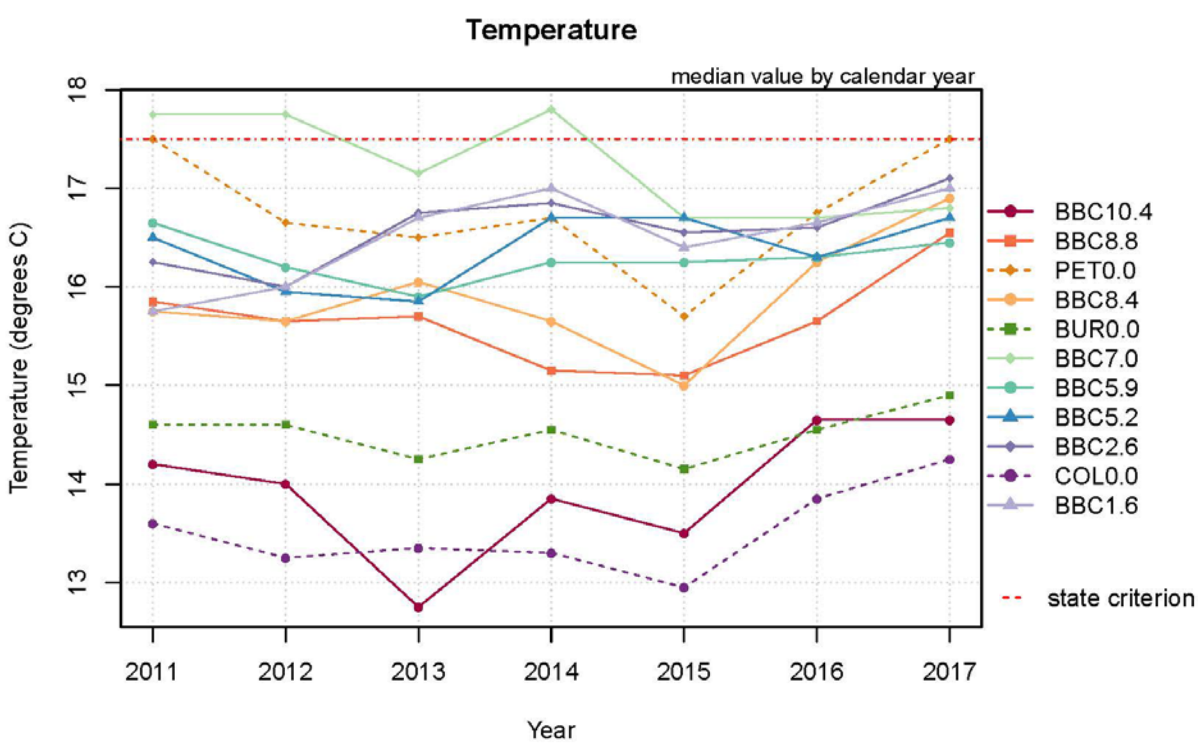


Figure 6. Temperature Seasonal Patterns in 2017 and Annual Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

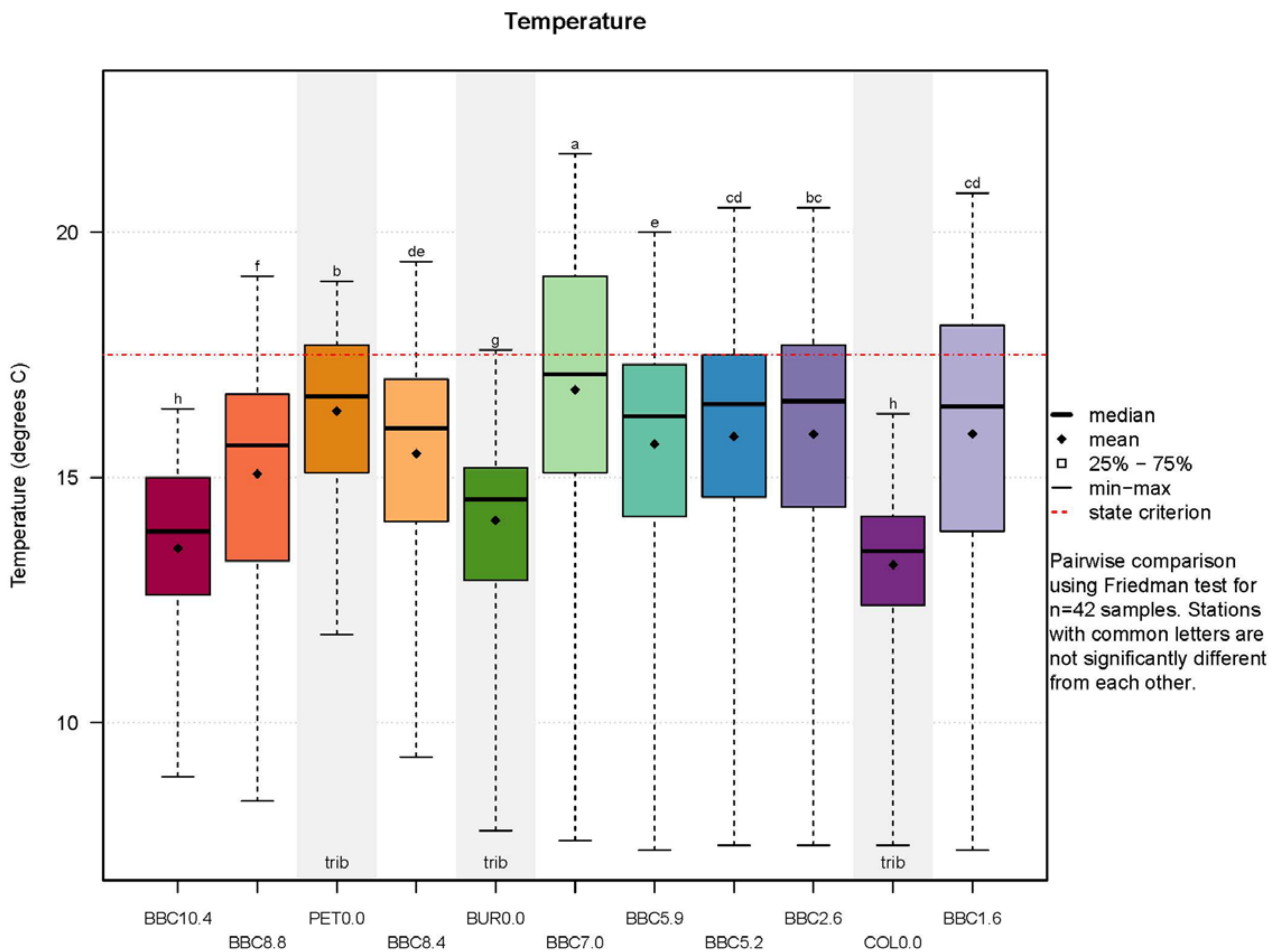


Figure 7. Temperature Spatial Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

Temporal Trends

Figure 6 (bottom) presents annual median values of temperature at each station in 2011–2017, and temporal trend analysis results are presented in Table 7. No significant recent temporal trends in instantaneous temperature data were observed in 2011–2017. Median temperature values ranged from 12.75°C to 17.8°C during 2011–2017. The 2011–2017 plot shows median temperature values reached maximum values in 2017 at all stations except BBC 7.0 and BBC 5.9. Minimum values were observed in 2015 at six stations. Median temperature tended to decrease from 2011 to 2013, increase in 2014, decrease in 2015, and increase from 2015 to 2017.

No significant historical trend between 2004–2007 and 2011–2017 was observed for instantaneous temperature data at any of the four stations with data in both periods (PET 0.0, BBC 8.4, BBC 7.0 or BBC 5.9). Percent change in median values ranged from -3 to 1 percent.

Water Quality Criteria Comparison

Temperature criteria are based on the 7-day average of the daily maximum temperature (7-DADMax). The temperature criterion for salmonid spawning, rearing, and migration is for the 7-DADMax not to exceed 17.5°C. The 7-DADMax was calculated from the continuous temperature data and is presented graphically in Appendix C. The total number of days that the 7-DADMax temperature exceeded the temperature criterion of 17.5°C in 2011–2017 is presented for each year and station in Table 9. For objective comparison between years, only days from June 25 through October 15 are included for each year because monitoring began on different dates for each year and was often exceeded at the beginning of each monitoring year.

The temperature criterion was exceeded at all continuous monitoring stations from 2011–2017 with the exception of BBC 10.4 in 2011, indicating an impairment to salmonid habitat along the entire stream during the summer. As shown in Table 9, the total percent of days exceeding criteria from June 25 through October 15 ranged from 44 percent (BBC 10.4) to 80 percent (PET 0.0). A significant increasing trend was observed at station BBC 8.8 indicating a decline in water quality conditions, whereas a significant decreasing trend was observed at BBC 7.0 indicating water quality improvement at this station.

Water Quality Index Results

Water quality index (WQI) results for instantaneous temperature data are presented in Table 8 as median values for 2011–2017. Temperature WQI scores ranged between 65 and 90. Most stations were of moderate concern (WQI 40–79) except that the three coolest stations (BBC 10.4, BUR 0.0, and COL 0.0) were of low concern (WQI 80–100) with regard to water temperatures for salmonid habitat.

Table 9. Exceedance of 7-DADMax Temperature Criterion of 17.5°C in Burnt Bridge Creek.

Stations	Total Days Between June 25 and October 15							Percent of Days Exceeding Criterion[a]							
	2011	2012	2013	2014	2015	2016	2017	2011	2012	2013	2014	2015	2016	2017	Mean
BBC 10.4	0	46	79	45	58	38	80	0%	41%	71%	40%	52%	34%	71%	44%
BBC 8.8	33	47	78	78	78	78	82 E	29%	42%	70%	70%	70%	70%	73%	61%[b]
PET 0.0	93	78	89	100	92	86	93	83%	70%	79%	89%	82%	77%	83%	80%
BBC 8.4	56	63	86	93	80	88	86	50%	56%	77%	83%	71%	79%	77%	70%
BBC 7.0	95	87	86	95	83	70 E	81	85%	78%	77%	85%	74%	63%	72%	76%[b]
BBC 5.9	95	87	86	94	76	69 E	81	85%	78%	77%	84%	68%	62%	72%	75%
BBC 2.6	69	77	84 E	91	76 E	73 E	81	62%	69%	75%	81%	68%	65%	72%	70%
BBC 1.6	73	68	84	86 E	72 E	68	80	65%	61%	75%	77%	64%	61%	71%	68%

[a] Percent of 112-day period between June 25 and October 15 when criterion is exceeded.

[b] Significant decreasing (green) or increasing (red) trend (a = 0.05) in the percentage of days exceeding the criterion from 2011 to 2017.

E = Estimated value based on data for adjacent stream stations due to a missing temperature probe for a portion of the monitoring period.

Dissolved Oxygen

Dissolved oxygen 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; therefore, it directly affects 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).

Dissolved oxygen (DO) data are presented graphically in Figures 8 and 9, and summary statistics are presented in Appendix D.

Seasonal Patterns

Figure 8 (top) presents the dissolved oxygen data for each station by sampling date in 2017. DO concentrations ranged from 6.3 mg/L to 11.2 mg/L in 2017. Seasonal patterns for dissolved oxygen generally were opposite of temperature because oxygen solubility is inversely related to temperature (e.g., more oxygen dissolves in colder water). DO concentrations increased from June to July (due to unusual cooling) and then decreased to minimum values in early or late August (10 of 11 stations). DO generally increased from August to maximum concentrations in October at five stations, with the notable exception of BBC 8.8 that peaked for a second time at the end of September, and decreased in October. Maximum DO concentrations were observed in July (6 of 11 stations) and October (5 of 11 stations).

Spatial Patterns

In order to assess how each monitoring basin was contributing to dissolved oxygen concentrations in the main stem of Burnt Bridge Creek, the 2011–2017 dissolved oxygen data are presented as box plots in Figure 9. Dissolved oxygen significantly increased from BBC 10.4 (median of 6.9 mg/L) to BBC 8.8 (median of 9.9 mg/L), significantly decreased at BBC 8.4 (median of 8.4 mg/L) and at BBC 5.9 (median of 7.5 mg/L), and then significantly increased at BBC 5.2 (median 9.2 mg/L).

Spatial pattern analysis of DO concentrations shows that stations BBC 10.4 and BBC 5.9 are significantly lower than the other stations, Cold Creek (COL 0.0) is significantly higher than all other stations, and station BBC 8.8 is significantly higher than all other main stem stations.

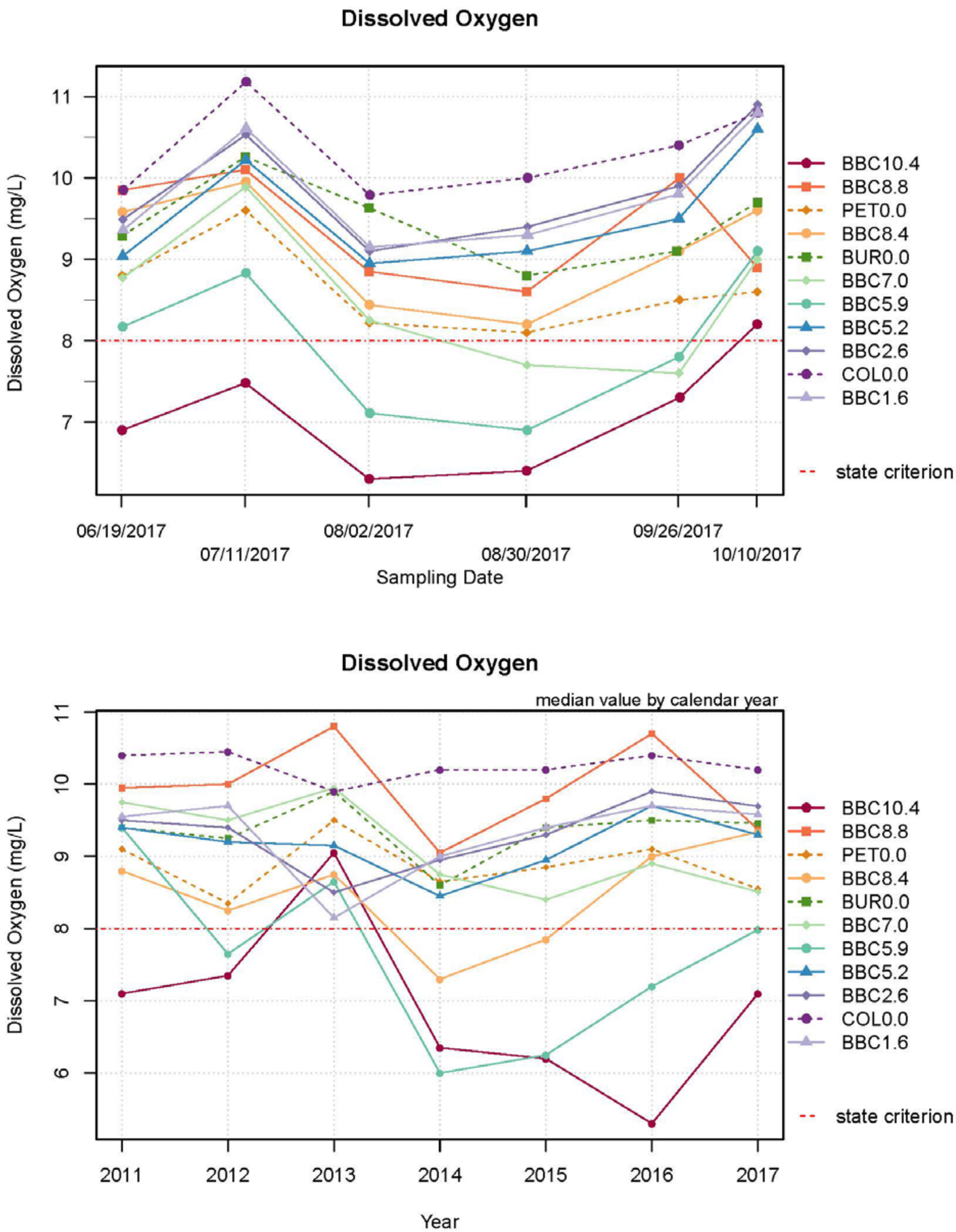


Figure 8. Dissolved Oxygen Seasonal Patterns in 2017 and Annual Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

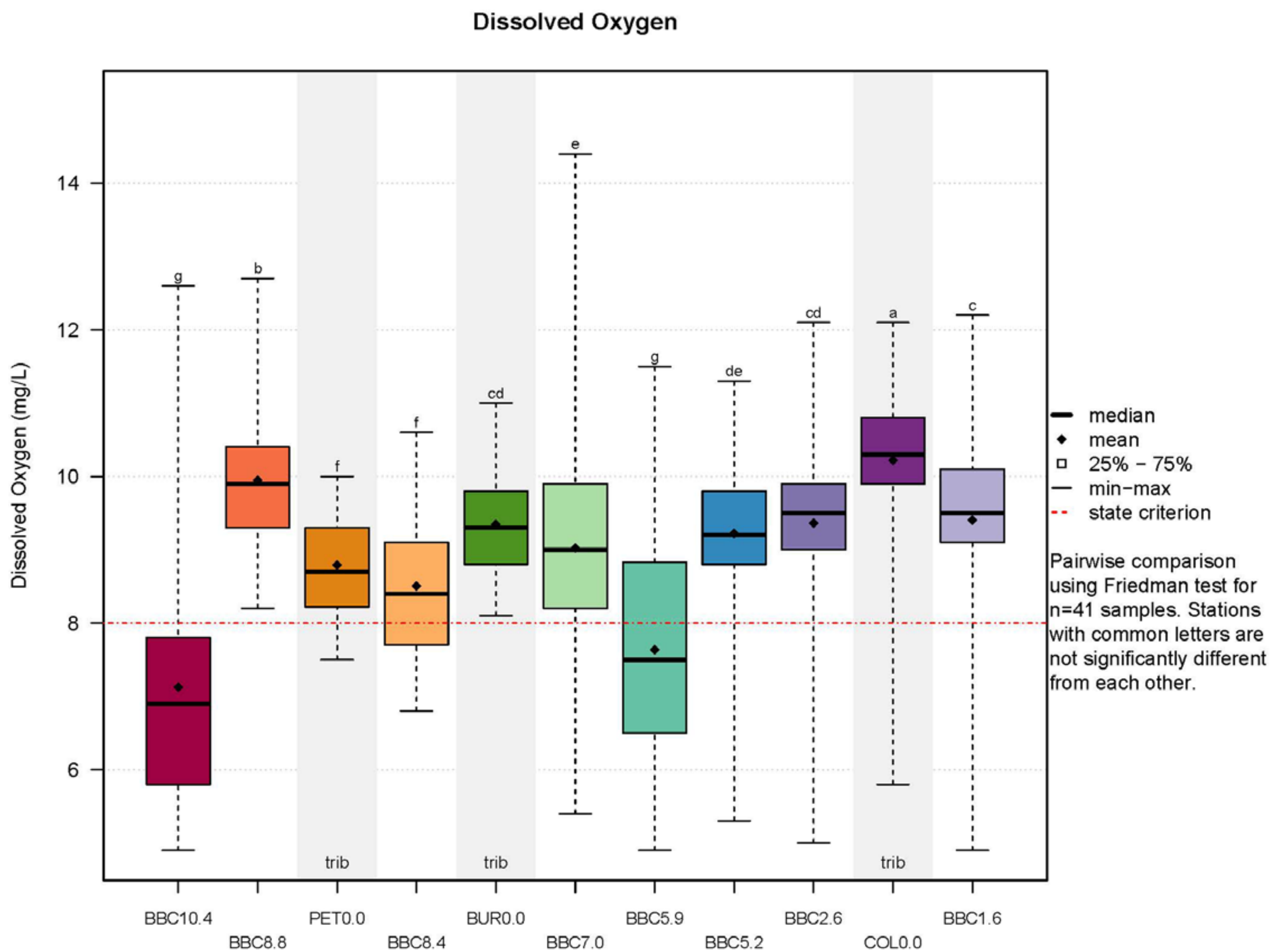


Figure 9. Dissolved Oxygen Spatial Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

Temporal Trends

Figure 8 (bottom) presents annual median values of dissolved oxygen at each station in 2011–2017 and temporal trend analysis results are presented in Table 7. A significant decreasing temporal trend in dissolved oxygen was observed only at station BBC 7.0 in 2011–2017. The 2011–2017 line plot shows that median dissolved oxygen concentrations along the main stem fluctuated between years are were typically lowest in 2014.

A significant historical trend of increased dissolved oxygen concentrations since 2004–2007 was observed at station BBC 5.9 with a 42 percent change in median values, indicating significant water quality improvement at a station that is currently the most impaired (along with BBC 10.4).

Water Quality Criteria Comparison

In 2017, three stations (BBC 10.4, BBC 7.0, and BBC 5.9) did not meet the state water quality standard for DO (i.e., the lowest 1-day minimum shall exceed 8.0 mg/L) on at least one occasion (see Figure 8), indicating potential impairment to salmonid habitat in those reaches of Burnt Bridge Creek during the summer. Minimum DO concentrations in 2017 were substantially below the 8.0 mg/L standard at the uppermost station BBC 10.4 (6.3 mg/L) and at station BBC 5.9 (6.9 mg/L). Station BBC 8.8 was the only station that always met the DO standard in 2011 through 2017.

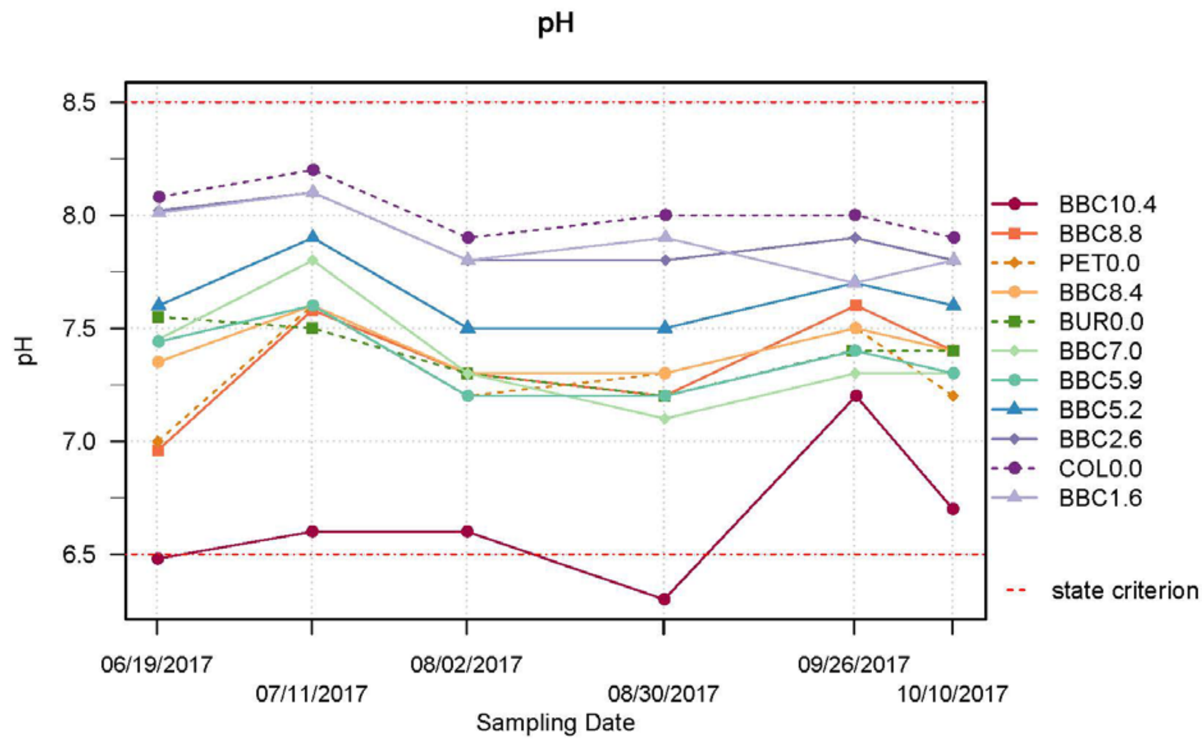
Water Quality Index Results

Water quality index (WQI) results are presented in Table 8 as median values for 2011–2017. The dissolved oxygen WQI scores ranged between 53 and 90. Stations BBC 10.4, PET 0.0, BBC 8.4, BBC 7.0, and BBC 5.9 were of moderate concern (WQI 40–79), and all other stations were of low concern (WQI 80–100) with regard to dissolved oxygen concentrations.

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).

The pH data are presented graphically in Figures 10 and 11 and summary statistics are presented in Appendix D.



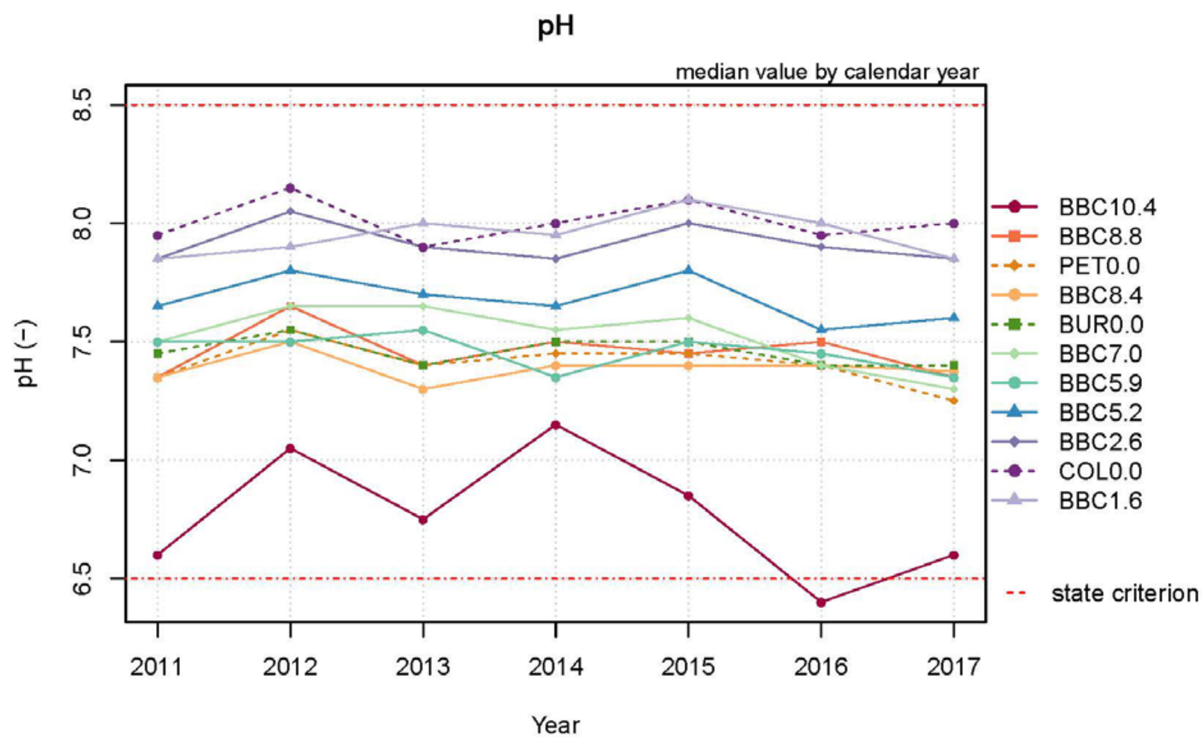


Figure 10. pH Seasonal Patterns in 2017 and Annual Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

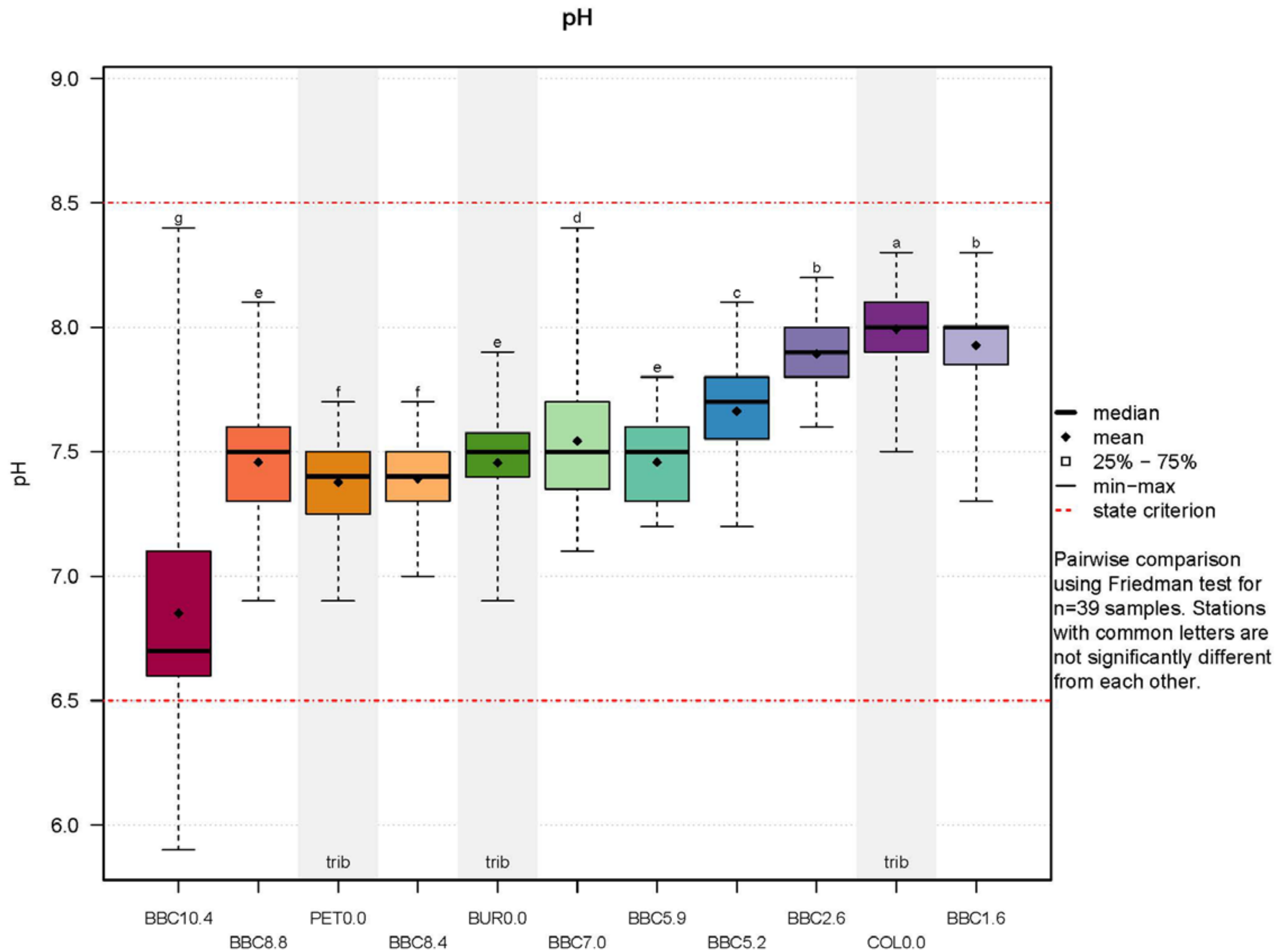


Figure 11. pH Spatial Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

Seasonal Patterns

Figure 10 (top) presents the pH data for each station by sampling date in 2017. The pH values ranged from 6.3 to 8.2 in 2017. Values generally increased from June to July, decreased in early August, and remained fairly constant to October. Maximum pH values were observed at 8 of 11 stations in July. Minimum concentrations were observed primarily in August (three and five stations in early and late August, respectively). A notably large increase of pH (from 6.3 to 7.2) was observed at station BBC 10.4 in October.

Spatial Patterns

In order to assess how each monitoring basin was contributing to pH levels in the main stem of Burnt Bridge Creek, the 2011–2017 pH data are presented as box plots in Figure 11. The plot shows a general increase in pH moving downstream in Burnt Bridge Creek with pH increasing significantly from BBC 10.4 to BBC 8.8 (median of 6.7 at BBC 10.4 to 7.5 at BBC 8.8) and remaining relatively constant until increasing at BBC 5.2 and BBC 2.6.

Spatial analysis showed significant differences between stations. Station BBC 10.4 was significantly lower than all other stations, and was substantially lower than all other stations (no overlapping interquartile range with other stations). Along the main stem, significant differences between stations BBC 8.8 and BBC 5.9 were less pronounced, with more significant increases between stations at BBC 5.9, BBC 5.2, and BBC 2.6. Cold Creek (COL 0.0) was significantly higher than all other stations.

Temporal Trends

Figure 10 (bottom) presents annual median values of pH at each station in 2011–2017, and temporal trend analysis results are presented in Table 7. A significant decreasing temporal trend in pH was observed at station BBC 7.0 in 2011–2017. The 2011–2017 plot shows that along the main stem median pH tended to peak in 2012 (maximum median values at 8 of 11 stations) and decrease in 2016 and 2017. A significant historical trend of increased pH concentrations since 2004–2007 was observed at stations BBC 7.0 and BBC 5.9 with 4 and 8 percent increase in median values, respectively.

Water Quality Criteria Comparison

All stations met the state water quality standard for pH (6.5 to 8.5) in 2017 with the exception of BBC 10.4 in late August events (see Figure 10). Annual median pH values met the water quality standard at all stations except BBC 10.4 in 2016.

Water Quality Index Results

Water quality index (WQI) results are presented in Table 8 as median values for 2011–2017. The pH WQI scores ranged between 74 and 97. Station BBC 10.4 was moderate concern (WQI 40–79), and all other stations were of low concern (WQI 80–100) with regard to pH levels.

Conductivity

Specific conductance or 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. Although there is no state surface water quality standard established for conductivity, this measurement is useful for identifying sources of dissolved pollutants and for determining the relative flow contributions attributed to groundwater, since conductivity is typically higher in groundwater than in surface water.

Conductivity data are presented graphically in Figures 12 and 13 and summary statistics are presented in Appendix D.

Seasonal Patterns

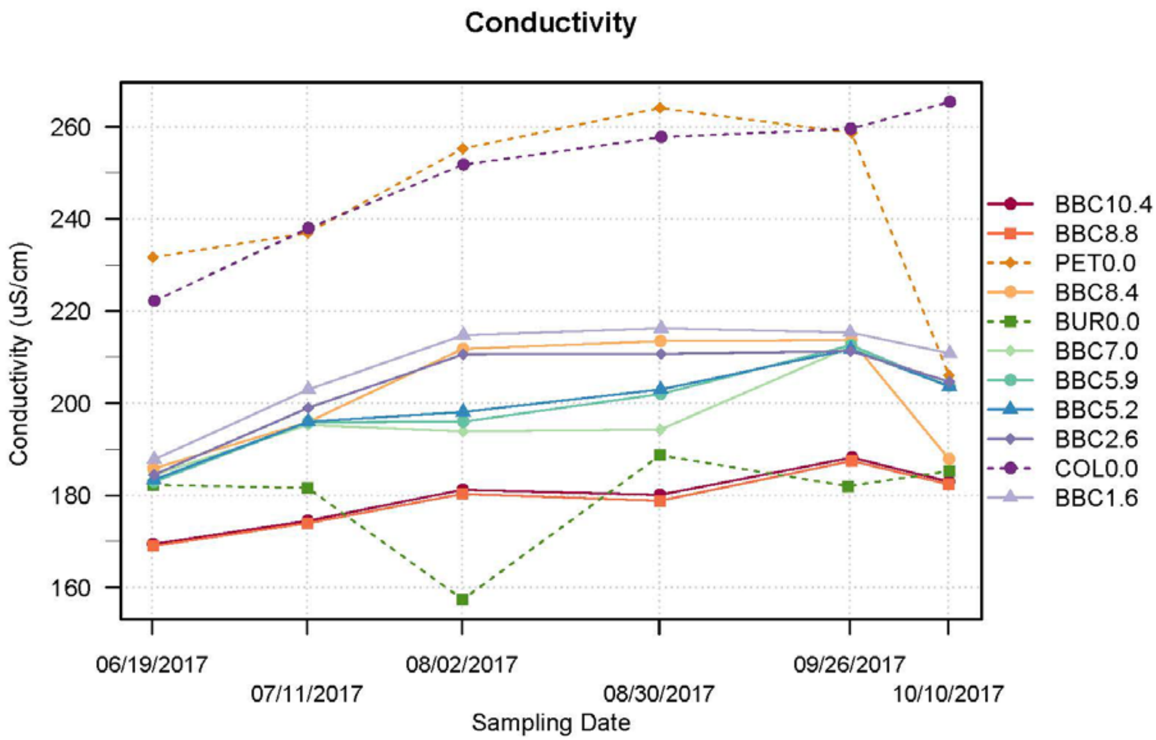
Figure 12 (top) presents the conductivity data for each station by sampling date in 2017. Conductivity values ranged from 157 to 265 μS/cm^2. In general, conductivity values increased from minimum values in June (9 of 11 stations) to maximum values in late August or September. Two notable exceptions to this trend were tributaries BUR 0.0 and PET 0.0, where minimum conductivity values were observed in August and October, respectively.

Spatial Analysis

In order to assess how each monitoring basin was contributing to conductivity levels in the main stem of Burnt Bridge Creek, the 2011–2017 conductivity data are presented as box plots in Figure 13. The plot shows that along the main stem, median conductivity significantly increased from station BBC 8.8 (179 μS/cm^2) to BBC 8.4 (195 μS/cm^2) and then remained relatively constant. Median conductivity was significantly highest in Peterson Channel (230 μS/cm^2 at PET 0.0) and Cold Creek (248 μS/cm^2 at COL 0.0), and inflow from these tributaries was likely responsible for the observed significant increases in the main stem of Burnt Bridge Creek.

Temporal Trends

Figure 12 (bottom) presents annual median values of conductivity at each station in 2011–2017 and temporal trend analysis results are presented in Table 7. A significant increasing temporal trend in conductivity was observed all stations except the two most upstream stations and Burton Channel. The 2011–2017 plot generally shows this increasing trend with the exception of unusually high conductivity values in 2015. All of the 2015 conductivity values were qualified as estimates because the meter was calibrated with an expired standard, and the reported values are likely higher than true values. A significant historical trend of increased conductivity since 2004–2007 was observed at station PET 0.0 with a 9 percent increase in median values.



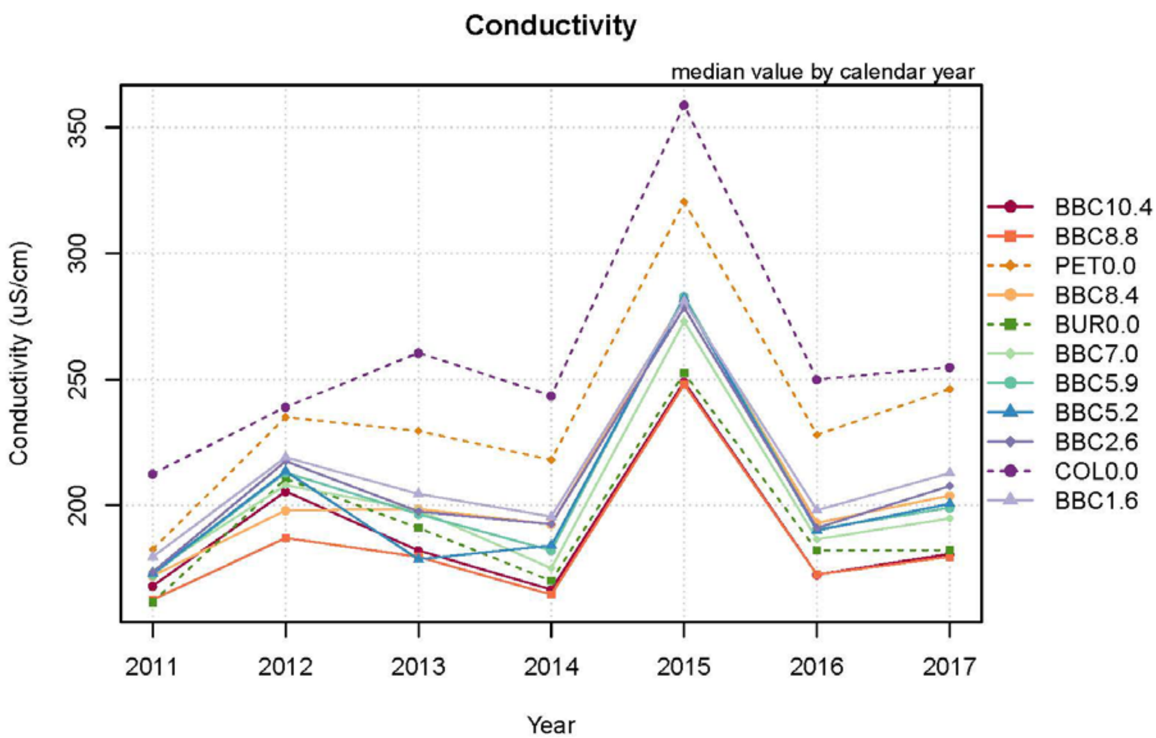


Figure 12. Conductivity Seasonal Patterns in 2017 and Annual Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

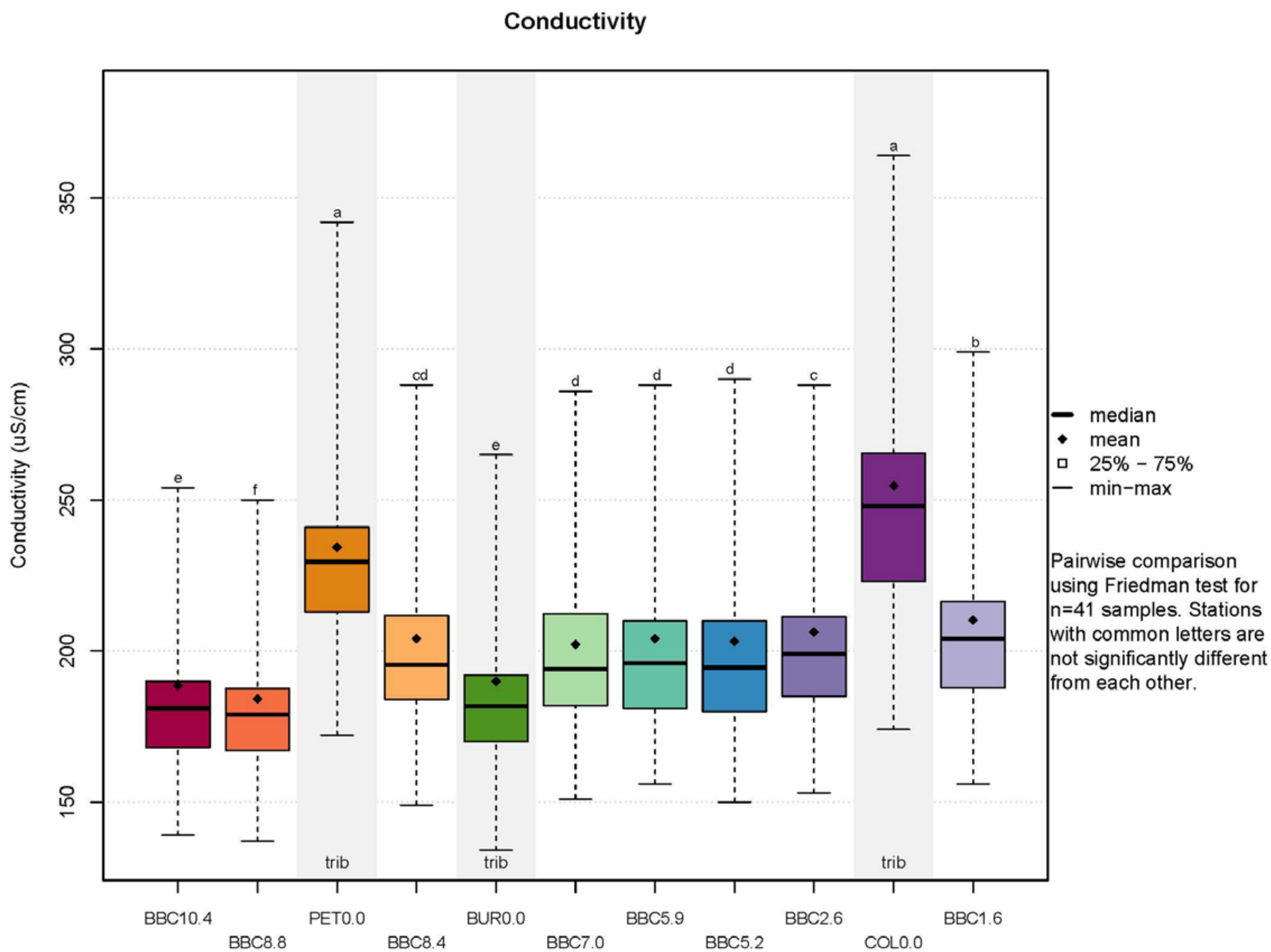


Figure 13. Conductivity Spatial Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

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).

Turbidity data are presented graphically in Figures 14 and 15 and summary statistics are presented in Appendix D.

Seasonal Patterns

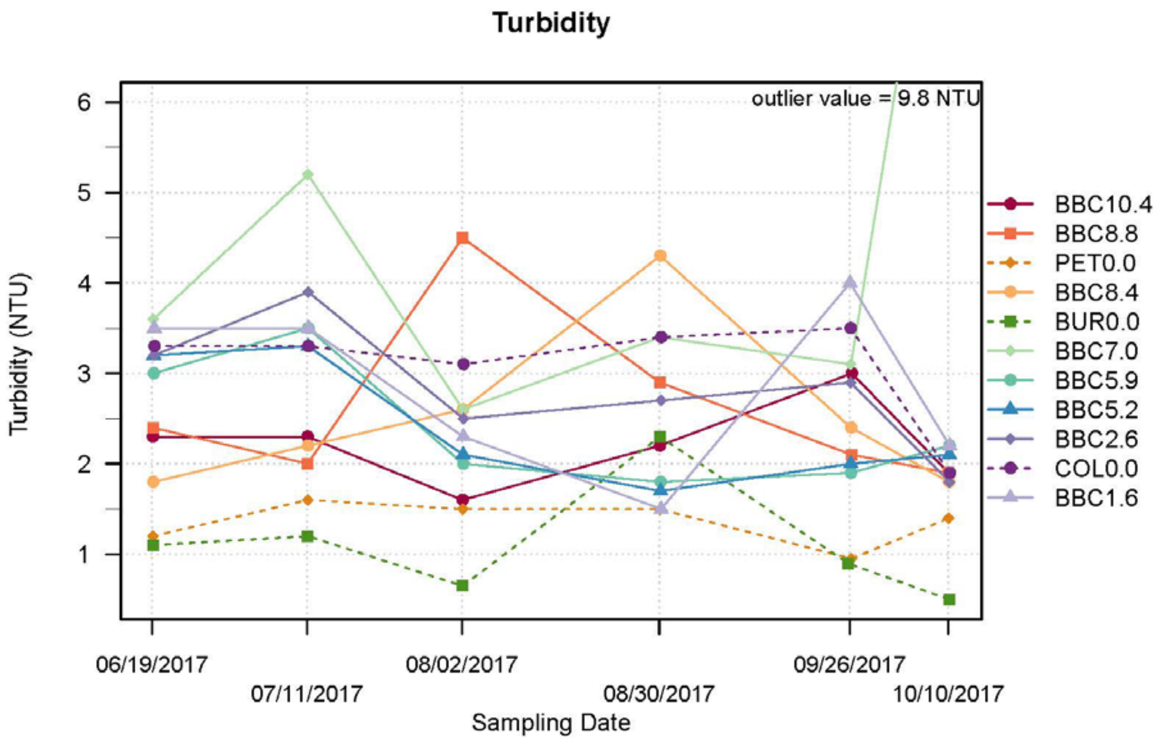
Figure 14 (top) presents the turbidity data for each station by sampling date in 2017. Turbidity values ranged from 0.5 to 5.2 NTU in 2017, excluding the 9.8 NTU outlier value in October at BBC 7.0. The maximum total suspended solids concentration (54.0 mg/L) was also observed in October at BBC 7.0. Turbidity values reached a minimum in October at five other stations, but generally did not follow a discernable seasonal pattern at any station.

Spatial Patterns

In order to assess how each monitoring basin was contributing to turbidity levels in the main stem of Burnt Bridge Creek, the 2011–2017 turbidity data are presented as box plots in Figure 15. The plot shows that turbidity was relative constant along the main stem with median values ranging between 1.4 and 3.0 NTU. The boxplots for Peterson Channel (PET 0.0) and Burton Cannel (BUR 0.0) show that turbidity was significantly lower in these tributaries than adjacent main stem stations. Spatial analysis showed significant differences between stations. Most notable was that turbidity at stations BBC 7.0 (median of 3.0 NTU) was significantly higher than all other stations.

Temporal Trends

Figure 14 (bottom) presents annual median values of turbidity at each station in 2011–2017 and temporal trend analysis results are presented in Table 7. A significant increasing temporal trend in turbidity was observed at stations BBC 10.4 and PET 0.0. The 2011–2017 plot shows that median turbidity tended to increase from 2011 to 2012, 2013 to 2014 (all stations), and from 2015 to 2017. A significant trend of increased turbidity since 2004–2007 was observed all four stations (PET 0.0, BBC 8.4, BBC 7.0, and BBC 5.9), with percent increases ranging between 46 and 155 percent.



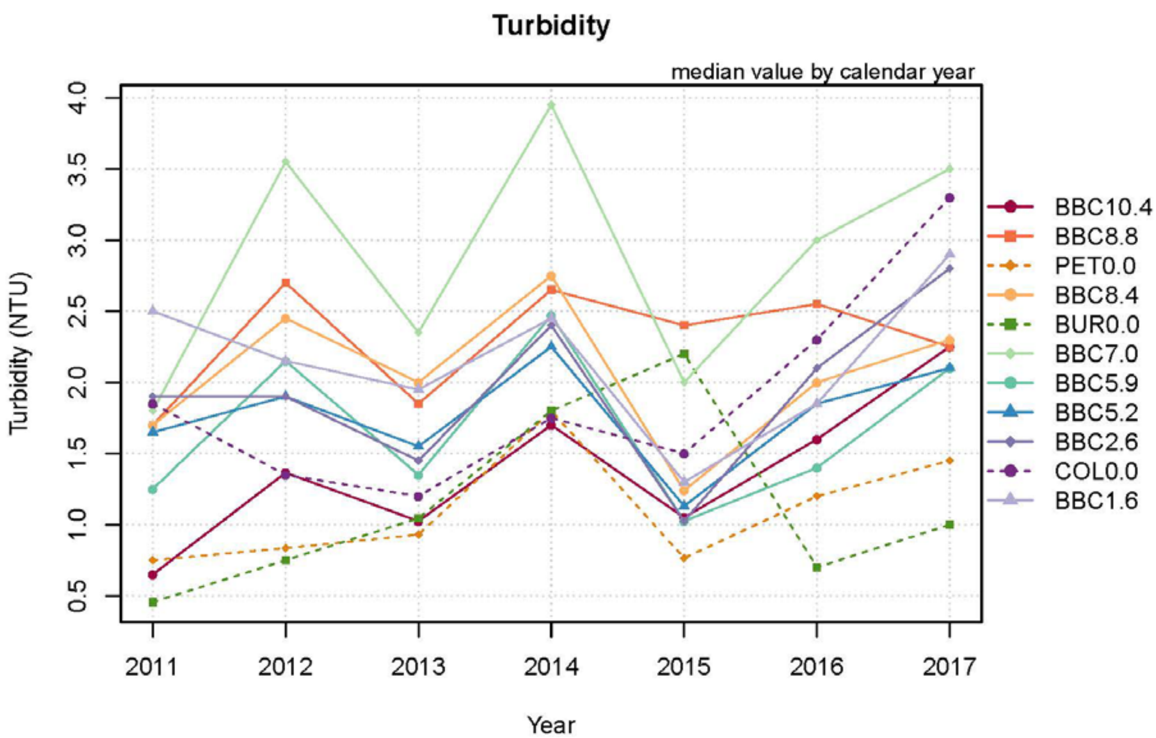


Figure 14. Turbidity Seasonal Patterns in 2017 and Annual Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

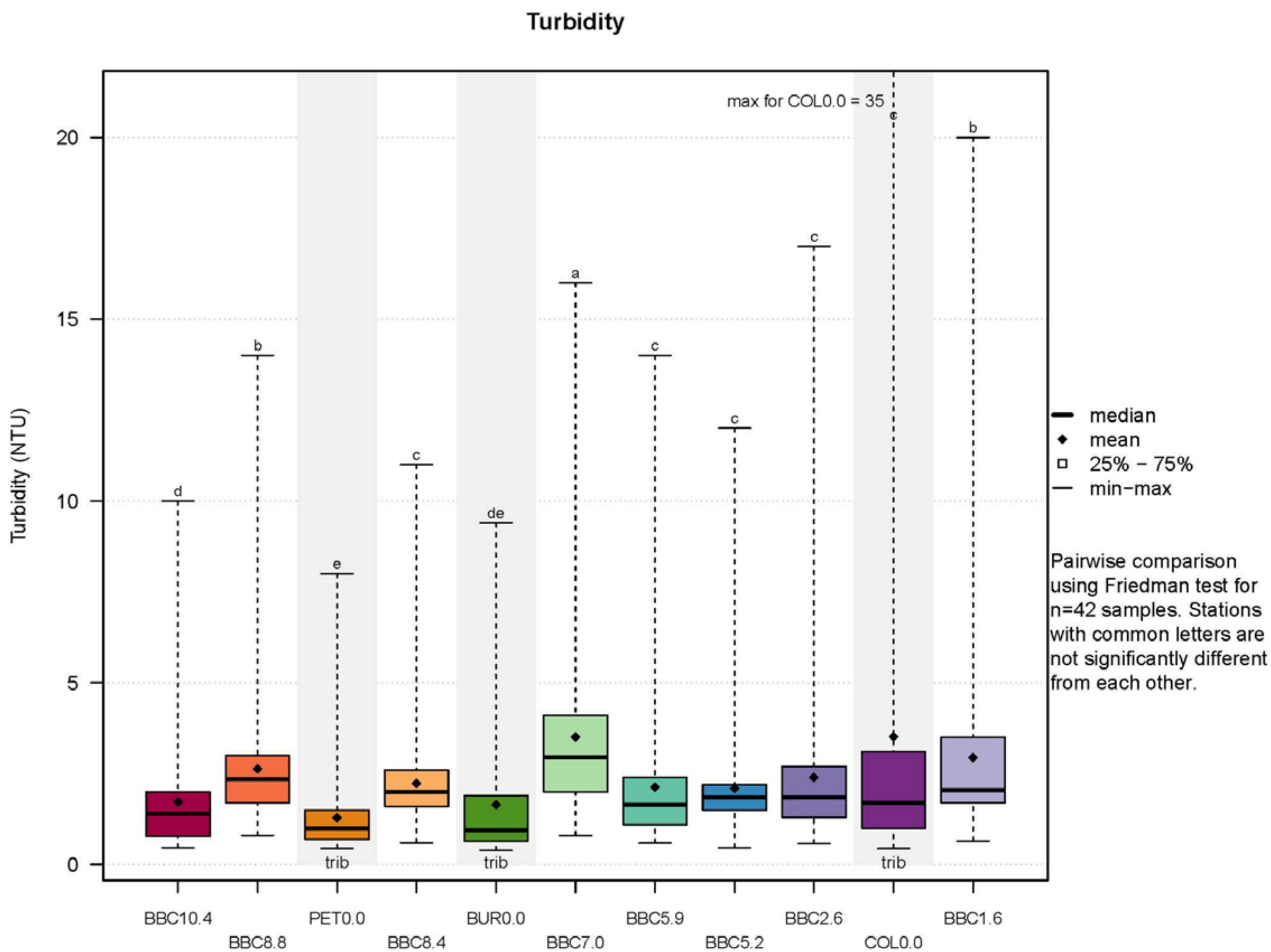


Figure 15. Turbidity Spatial Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

Water Quality Criteria Comparison

In 2017, the median turbidity did not increase more than 5 NTU downstream in Burnt Bridge Creek, indicating that the state water quality standard for turbidity (i.e., less than 5 NTU increase over background) was met at all stations. The maximum turbidity of 9.8 NTU observed in October at station BBC 7.0 represents an increase greater than 5 NTU from the upstream station BBC 8.4.

Water Quality Index Results

Water quality index (WQI) results are presented in Table 8 as median values for 2011–2017. The turbidity WQI scores ranged between 87 and 98. All stations were of low concern (WQI 80–100) with regard to turbidity.

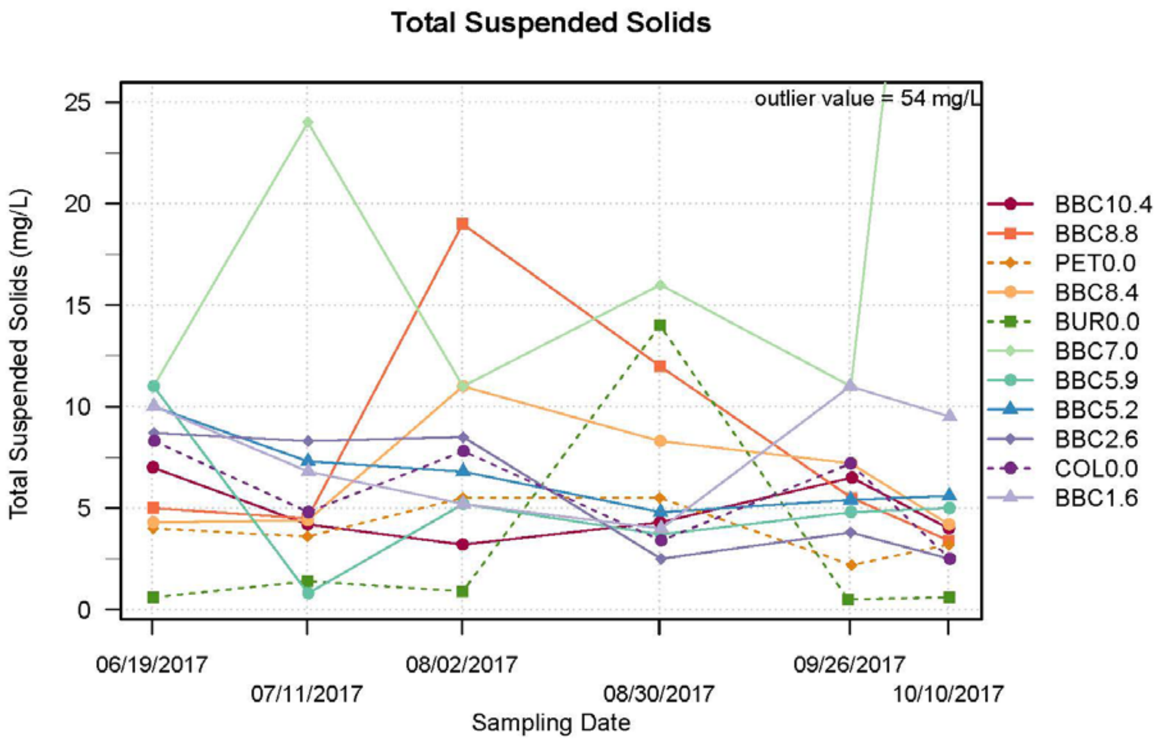
Total Suspended Solids

Total suspended solids 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 consequently 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.

Total suspended solids (TSS) data are presented graphically in Figures 16 and 17 and summary statistics are presented in Appendix D.

Seasonal Patterns

Figure 16 (top) presents the total suspended solids data for each station by sampling date in 2017. Total suspended solids concentrations ranged from 0.5 mg/L to 24.0 mg/L in 2017, excluding the outlier value of 54 mg/L observed at BBC 7.0 in October that coincided with the maximum value for turbidity (9.8 NTU). TSS concentrations generally decreased from June (maximum values at 5 of 11 stations) to July. TSS values were lower in October than in June for all other stations, but generally did not follow a discernable seasonal pattern at any station.



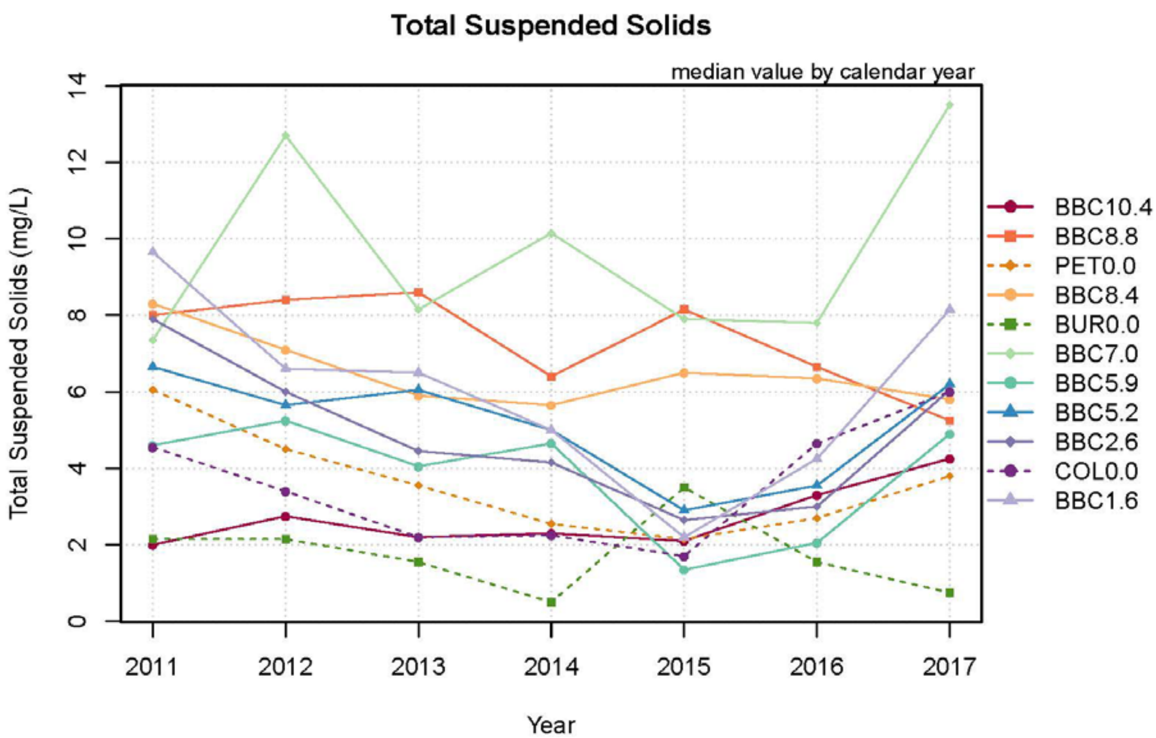


Figure 16. Total Suspended Solids Seasonal Patterns in 2017 and Annual Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

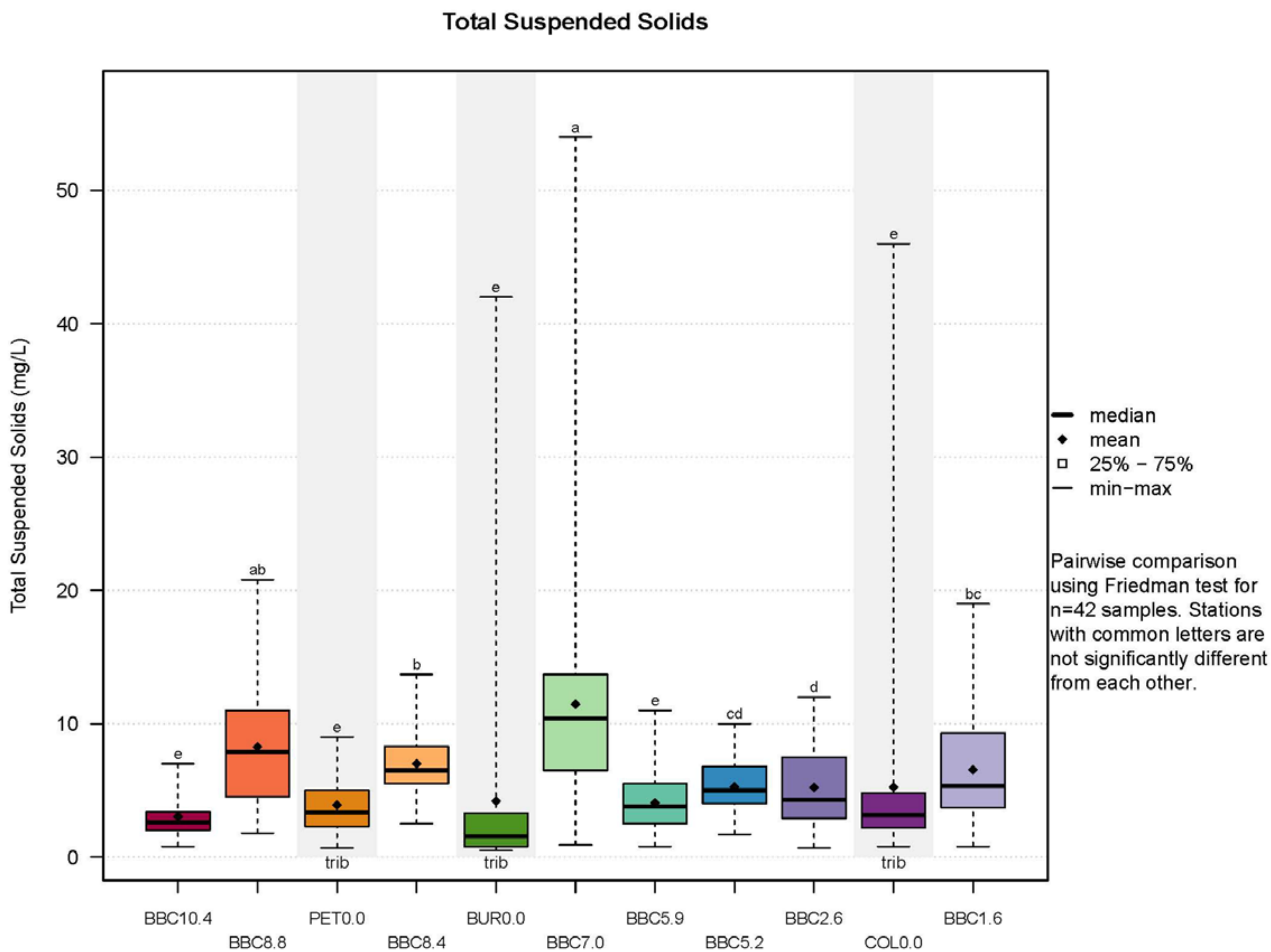


Figure 17. Total Suspended Solids Spatial Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

Spatial Patterns

In order to assess how each monitoring basin was contributing total suspended solids concentrations in the main stem of Burnt Bridge Creek, the 2011–2017 TSS data are presented as box plots in Figure 17. The plot shows that median TSS concentrations were greatest at BBC 8.8 (7.9 mg/L) and BBC 7.0 (10.4 mg/L), and relatively constant (ranging from 2.6 to 6.5 mg/L) at all other main stem stations. Spatial analyses showed that BBC 7.0 was significantly higher than all other stations except BBC 8.8. The boxplots for Peterson Channel (PET 0.0) and Burton Cannel (BUR 0.0) show that turbidity was significantly lower in these tributaries than adjacent main stem stations.

Temporal Trends

Figure 16 (bottom) presents annual median values of TSS at each station in 2011–2017 and temporal trend analysis results are presented in Table 7. For 2011–2017, a significant increasing temporal trend in TSS was observed in BBC 10.4. Significant decreasing temporal trends were observed at Peterson Channel and the four most downstream main stem stations (BBC 5.9 to BBC 1.6). The 2011–2017 plot shows that TSS tended to decrease from 2011 to 2015 and increase from 2015 to 2017. A significant trend of increased TSS since 2004–2007 was observed at stations BBC 8.4 and BBC 7.0, with percent change in medians at 73 and 117 percent, respectively.

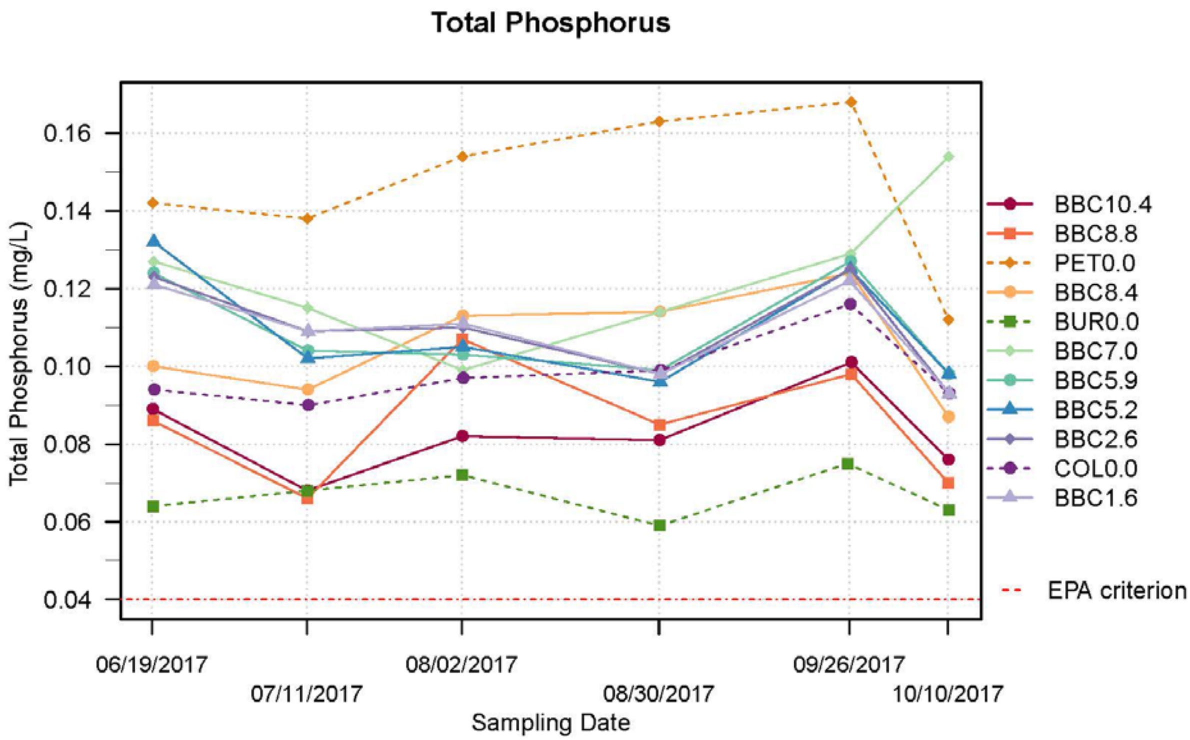
Water Quality Index Results

Water quality index (WQI) results are presented in Table 8 as median values for 2011–2017. The TSS WQI scores ranged between 77 and 95. Stations BBC 8.8 and BBC 7.0 were of moderate concern (WQI 40–79), while all other stations were of low concern (WQI 80–100) with regard to TSS concentrations.

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).

Total phosphorus (TP) data are presented graphically in Figures 18 and 19 and summary statistics are presented in Appendix D.



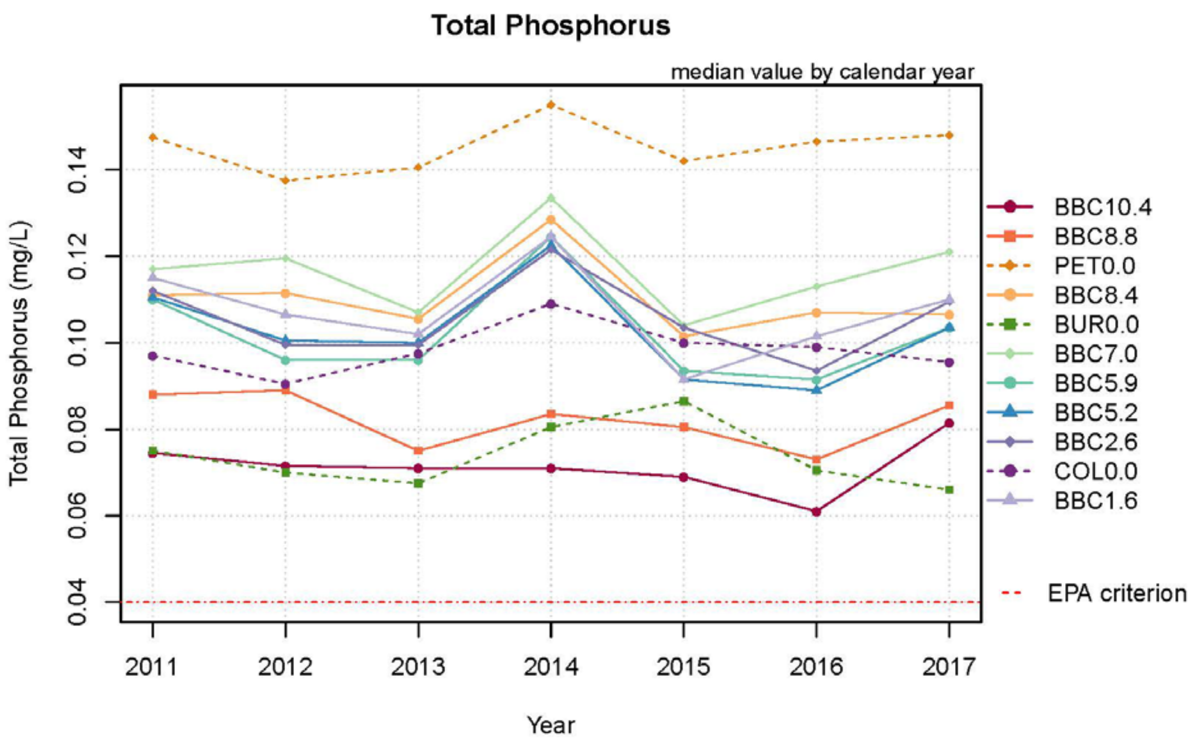


Figure 18. Total Phosphorus Seasonal Patterns in 2017 and Annual Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

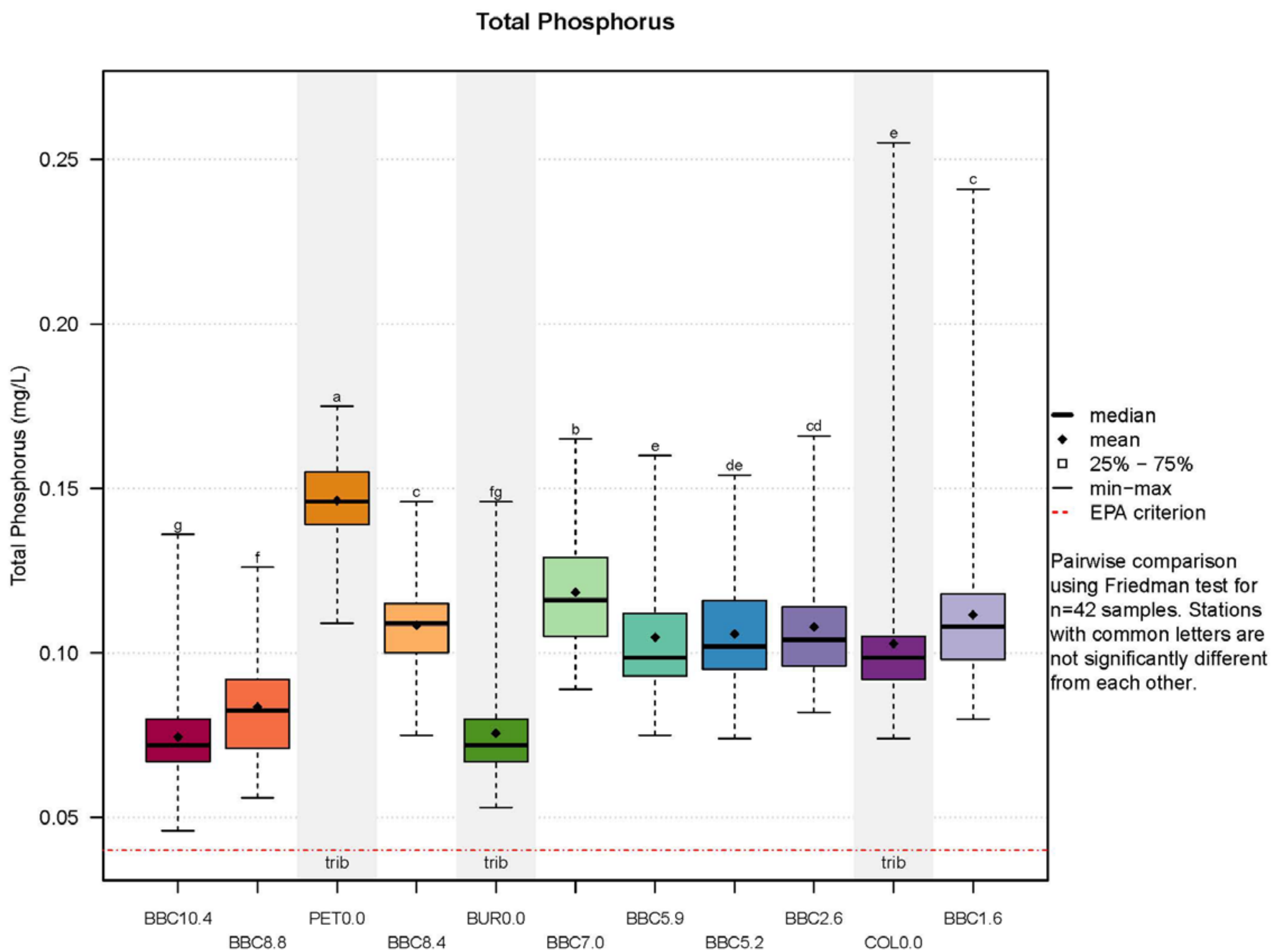


Figure 19. Total Phosphorus Spatial Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

Seasonal Patterns

Figure 18 (top) presents the total phosphorus data for each station by sampling date in 2017. Total phosphorus concentrations ranged from 0.07 mg/L to 0.17 mg/L in 2017. Total phosphorus concentrations typically reached a maximum in late September (8 of 11 stations) and then decreased to a minimum in October (5 stations). One notable exception is that station BBC 7.0 exhibited an unusually high maximum value in October 2017, which coincided with the maximum TSS concentration. Total phosphorus concentrations were typically highest at Peterson Channel (PET 0.0) and lowest at Burton Channel (BUR 0.0) compared to all main stem stations.

Spatial Patterns

In order to assess how each monitoring basin was contributing to total phosphorus concentrations in the main stem of Burnt Bridge Creek, the 2011–2017 total phosphorus data are presented as box plots in Figure 19. Median total phosphorus concentrations were lowest at the two upper main stem stations (0.07 mg/L at BBC 10.4 and 0.08 mg/L at BBC 8.8) and in Burton Channel (0.07 mg/L at BUR 0.0). The spatial pattern analysis shows that these total phosphorus concentrations were significantly lower at these stations than the other stations. Along the main stem, median total phosphorus concentrations significantly increased at each station from BBC 10.4 (0.07 mg/L) to BBC 7.0 (0.12 mg/L), significantly decreased at BBC 5.9 (0.10 mg/L), and remained fairly constant downstream to BBC 1.6 (0.11 mg/L). The high median total phosphorus concentration of 0.15 mg/L at Peterson Channel (PET 0.0) clearly contributed to the increased downstream concentration at BBC 8.4 (0.11 mg/L). Spatial pattern analysis shows that PET 0.0 and BBC 7.0 are significantly higher than all other stations. Total phosphorus concentrations were similar at Cold Creek compared to upstream stations in Burnt Bridge Creek.

Temporal Trends

Figure 18 (bottom) presents annual median values of total phosphorus at each station in 2011–2017, and temporal trend analysis results are presented in Table 7. No significant recent temporal trends in total phosphorus were observed in 2011–2017. The 2011–2017 plot shows that median total phosphorus was highest in 2014 at all main stem stations downstream of Peterson Channel (PET 0.0), and including tributary stations PET 0.0 and COL 0.0. The two upper main stem stations (BBC 10.4 and 8.8) generally exhibited decreasing median total phosphorus concentrations until 2017.

A significant historical trend of increased total phosphorus concentrations since 2004–2007 was observed at all four stations. The percent change in median values was highest at PET 0.0 and BBC 8.4 (110 and 104 percent, respectively).

Water Quality Criteria Comparison

All total phosphorus concentrations at all stations in 2011–2017 exceeded the EPA-recommended criteria for total phosphorus (i.e., shall not exceed 0.040 mg/L) (see Figure 18).

Water Quality Index Results

Water quality index (WQI) results are presented in Table 8 as average values for 2011–2017. The total phosphorus WQI scores ranged between 21 and 81. Station PET 0.0 was of high concern (WQI 1–39) and station BUR 0.0 was of low concern. All other stations were of moderate concern (WQI 40–79) with regard to total phosphorus concentrations.

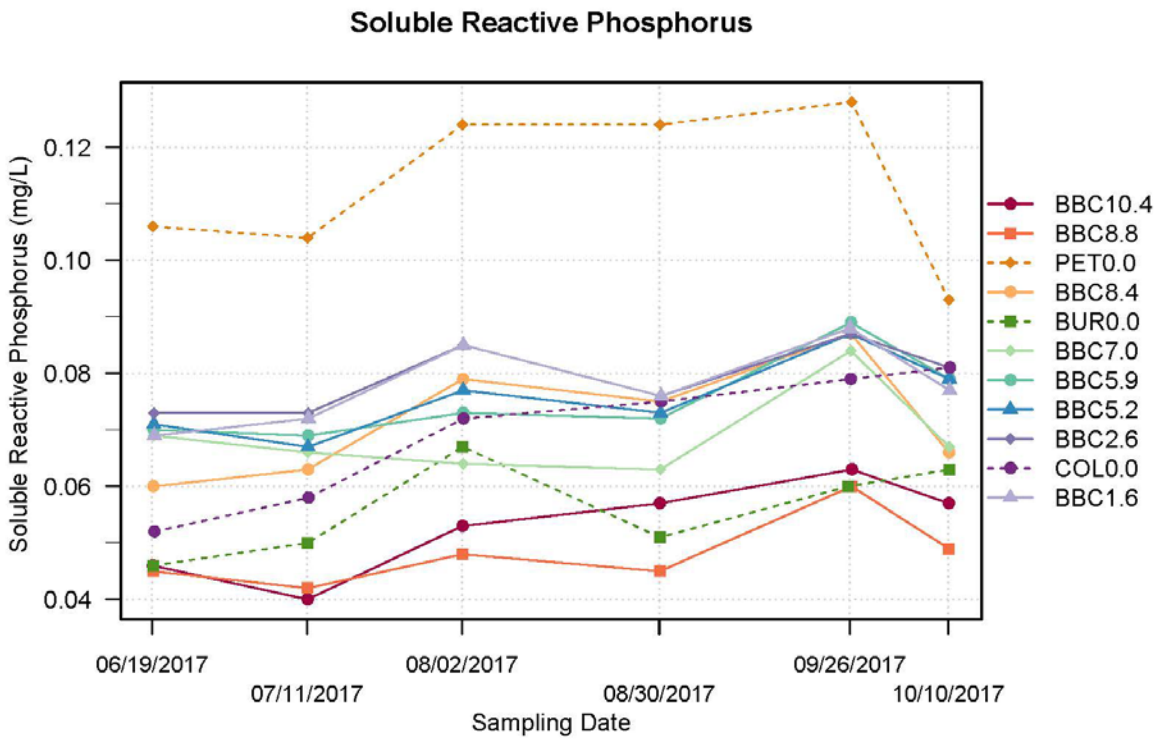
Soluble Reactive Phosphorus

Soluble reactive phosphorus, also known as orthophosphate, is an inorganic fraction of phosphorus that is produced by natural processes, but also can be measured in municipal sewage. Additional sources of soluble reactive phosphorus are similar to those for total phosphorus such as septic system failure, animal waste, decaying vegetation and animals, resuspension from the bottom of a lake, and fertilizer runoff. It is a very unstable form of phosphate that is directly absorbed by aquatic vegetation and microbes such as algae. Neither Washington State nor the EPA have established surface water quality criteria for soluble reactive phosphorus.

Soluble reactive phosphorus (orthophosphate) data are presented graphically in Figures 20 and 21 and summary statistics are presented in Appendix D.

Seasonal Patterns

Figure 20 (top) presents the soluble reactive phosphorus data for each station by sampling date in 2017. Concentrations ranged from 0.04 mg/L to 0.13 mg/L in 2017. Minimum soluble reactive phosphorus concentrations were observed in June or July for all but two stations. Concentrations generally increased from July to early August, decreased slightly from early August to late August, increased to maximum values in September (9 of 11 stations), and decreased in October.



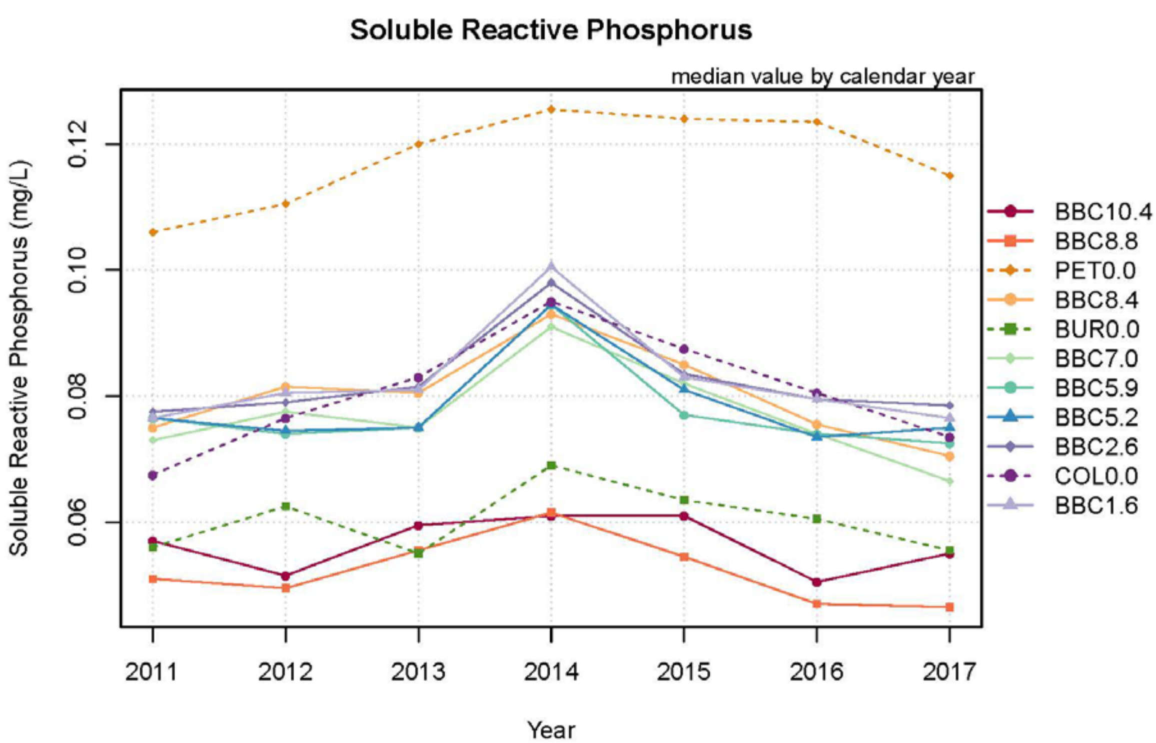


Figure 20. Soluble Reactive Phosphorus Seasonal Patterns in 2017 and Annual Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

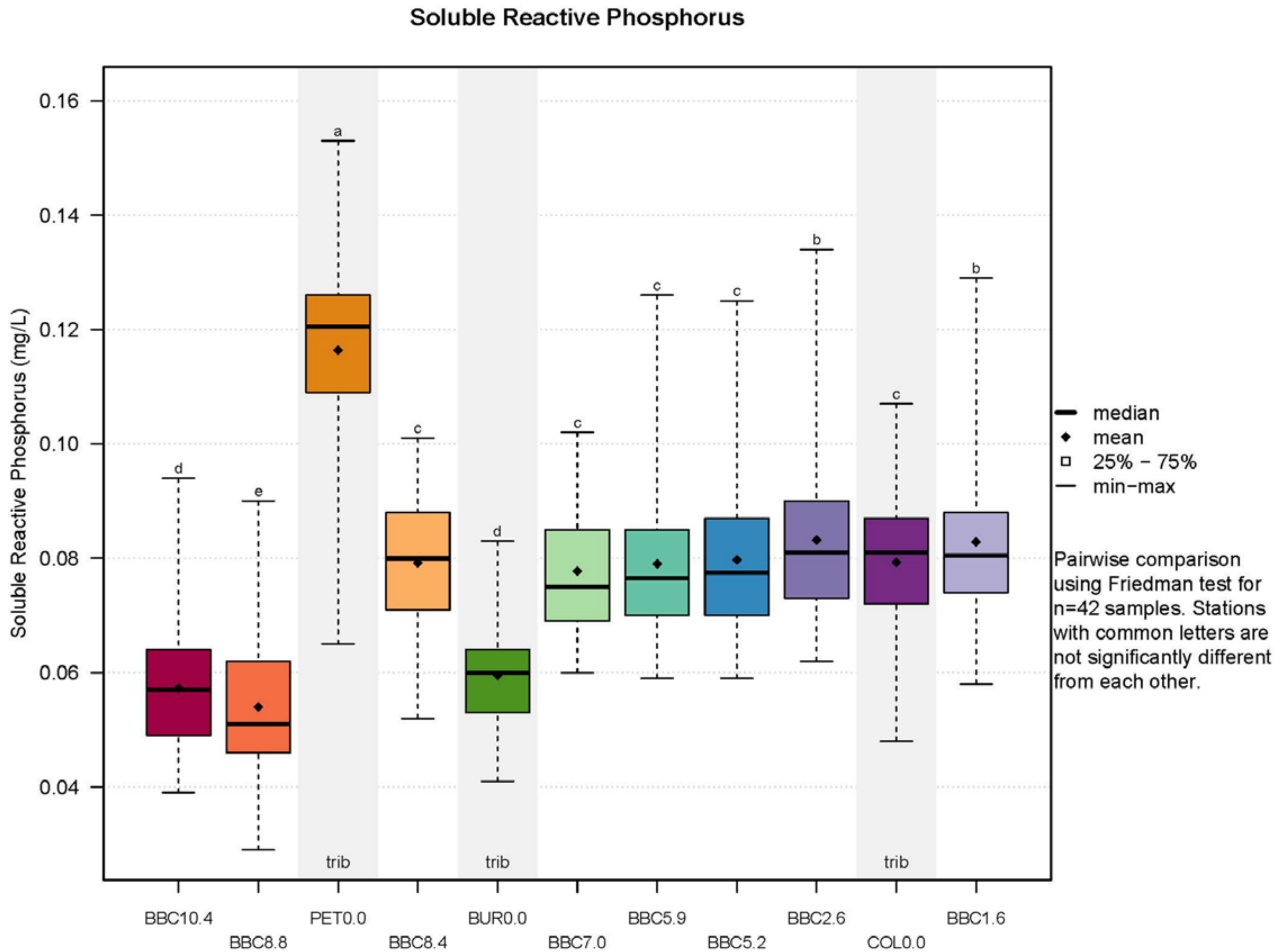


Figure 21. Soluble Reactive Phosphorus Spatial Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

Spatial Patterns

In order to assess how each monitoring basin was contributing to soluble reactive phosphorus concentrations in the main stem of Burnt Bridge Creek, the 2011–2017 soluble reactive phosphorus data are presented as box plots in Figure 21. Soluble reactive phosphorus followed a similar pattern as total phosphorus. Median soluble reactive phosphorus concentrations were lowest at the two most upstream stations (0.057 mg/L at BBC 10.4 and 0.051 mg/L at BBC 8.8). The median soluble reactive phosphorus concentration increased to 0.080 mg/L at BBC 8.4 and remained relatively stable moving downstream to BBC 1.6 (0.081 mg/L). Spatial analyses showed that Peterson Channel (PET 0.0) was significantly higher than all other stations; inflow from PET 0.0 (median of 0.121 mg/L) likely contributed to the significant increase in median concentrations from BBC 8.8 to BBC 8.4. Burton Channel (BUR 0.0) was significantly lower than adjacent upstream and downstream stations.

Temporal Trends

Figure 20 (bottom) presents annual median values of soluble reactive phosphorus at each station in 2011–2017 and temporal trend analysis results are presented in Table 7. For 2011–2017, a significant increasing temporal trend in soluble reactive phosphorus was observed in PET 0.0. The 2011–2017 plot shows that median soluble reactive phosphorus concentrations tended to increase from 2011 to 2014 and then decrease from 2014 to 2017. A significant trend of increased soluble reactive phosphorus since 2004–2007 was observed at all four stations (PET 0.0, BBC 8.4, BBC 7.0, and BBC 5.9), with percent changes ranging between 42 and 108 percent.

Water Quality Criteria Comparison

Comparing median concentrations of soluble reactive phosphorus to total phosphorus in 2011–2017 shows that between 62 to 83 percent of total phosphorus was in the dissolved state, which is readily available for uptake by algae in Burnt Bridge Creek and Vancouver Lake. The high concentrations of dissolved phosphorus and nitrogen (see below) present at all stations clearly indicate that the growth of algae is not limited by either nutrient in Burnt Bridge Creek or its tributaries.

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 0.36 mg/L for total nitrogen in streams located in the Willamette Valley Ecoregion. This criterion was used for comparison to these sampling results.

Total nitrogen data are presented graphically in Figures 22 and 23 and summary statistics are presented in Appendix D.

Seasonal Patterns

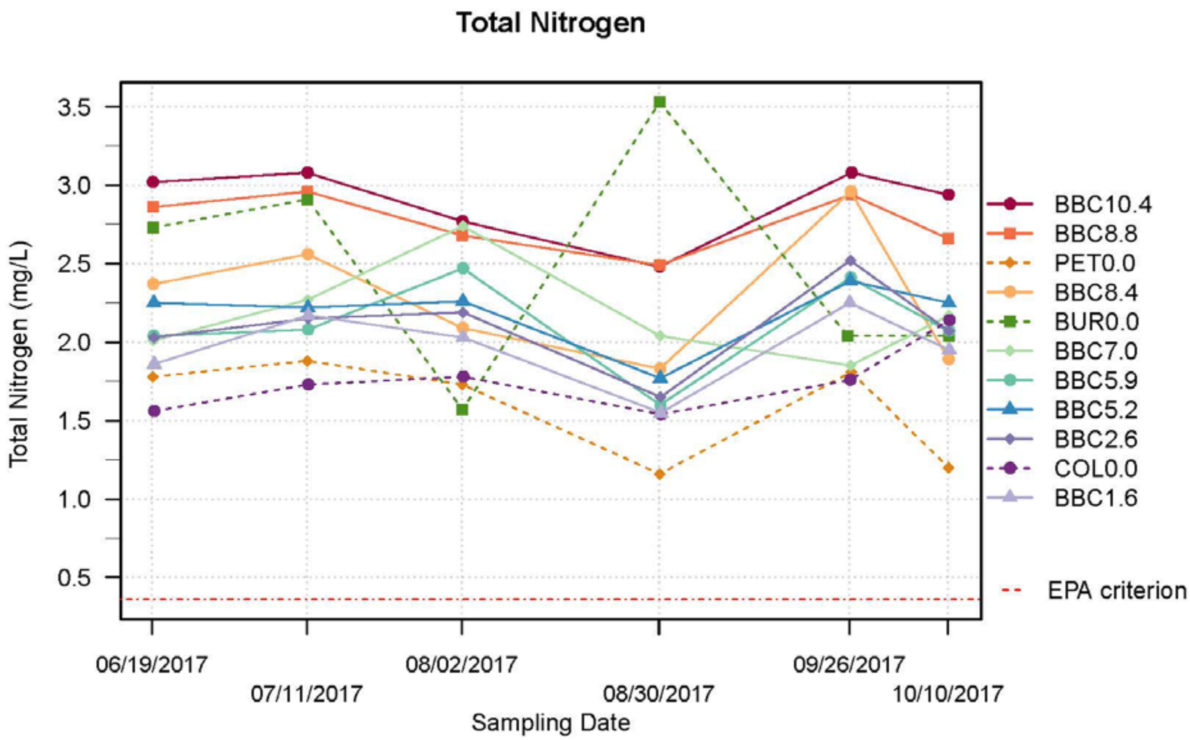
Figure 22 (top) presents the total nitrogen data for each station by sampling date in 2017. Concentrations ranged from 1.16 mg/L to 3.53 mg/L in 2017. For most stations, total nitrogen concentrations increased slightly from June to July, decreased to minimum concentrations from July to late August (9 of 11 stations), increased in September, and decreased in October. Maximum total nitrogen concentrations occurred in late September (5 of 11 stations) and July (3 stations). One notable exception was a substantial increase in concentration at BUR 0.0 from 1.57 mg/L in early August to a maximum value of 3.53 mg/L in late August.

Spatial Patterns

In order to assess how each monitoring basin was contributing to total nitrogen concentrations in the main stem of Burnt Bridge Creek, the 2011–2017 total nitrogen data are presented as box plots in Figure 23. Along the main stem, median total nitrogen concentrations were highest at the most upstream stations (3.08 mg/L at BBC 10.4 and 2.85 mg/L at BBC 8.8) and were significantly higher than all downstream stations. Median concentrations significantly decreased downstream to a minimum of 1.63 mg/L at BBC 5.9 and gradually increased to 1.78 mg/L at BBC 2.6. Lower median nitrogen concentrations in Peterson Channel (1.47 mg/L) may have contributed to the decreased downstream concentrations measured at BBC 8.4 (2.20 mg/L). Inflow from Burton Channel and Cold Creek do not appear to have influenced downstream concentrations. Burton Channel had a relatively high median total nitrogen concentration (2.79 mg/L), but channel flow is too low to affect total nitrogen concentrations in the main stem.

Temporal Trends

Figure 22 (bottom) presents annual median values of total nitrogen at each station in 2011–2017, and temporal trend analysis results are presented in Table 7. For 2011–2017, a significant increasing temporal trend in total nitrogen was observed at tributary stations PET 0.0 and COL 0.0. Significant decreasing trends were observed at the two uppermost stations BBC 10.4 and BBC 8.8, as well four downstream stations (BBC 7.0, BBC 5.9, BBC 5.2, and BBC 2.6). The 2011–2017 plot shows that total nitrogen tended to decrease from 2011 to 2014, and then increase from 2014 to 2017 at the downstream main stem stations. A significant trend of increased total nitrogen since 2004–2007 was observed at three of four stations (BBC 8.4, BBC 7.0, and BBC 5.9), with percent changes for those stations ranging between 83 and 141 percent.



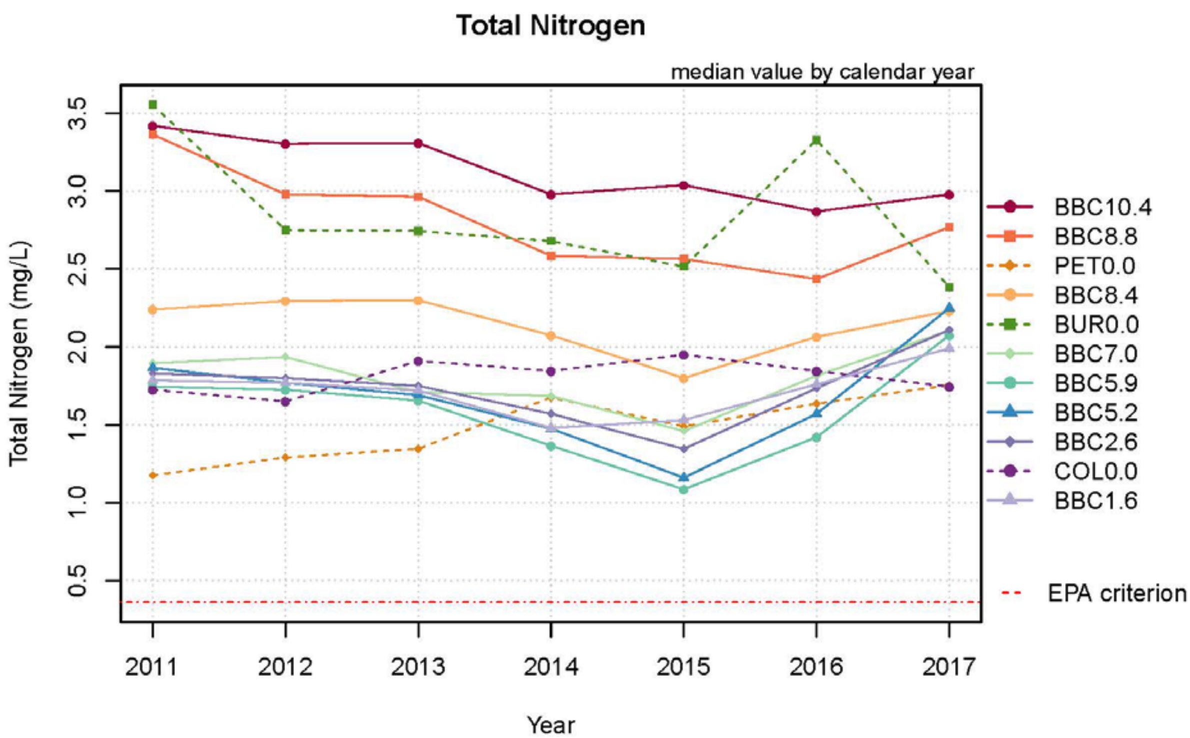


Figure 22. Total Nitrogen Seasonal Patterns in 2017 and Annual Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

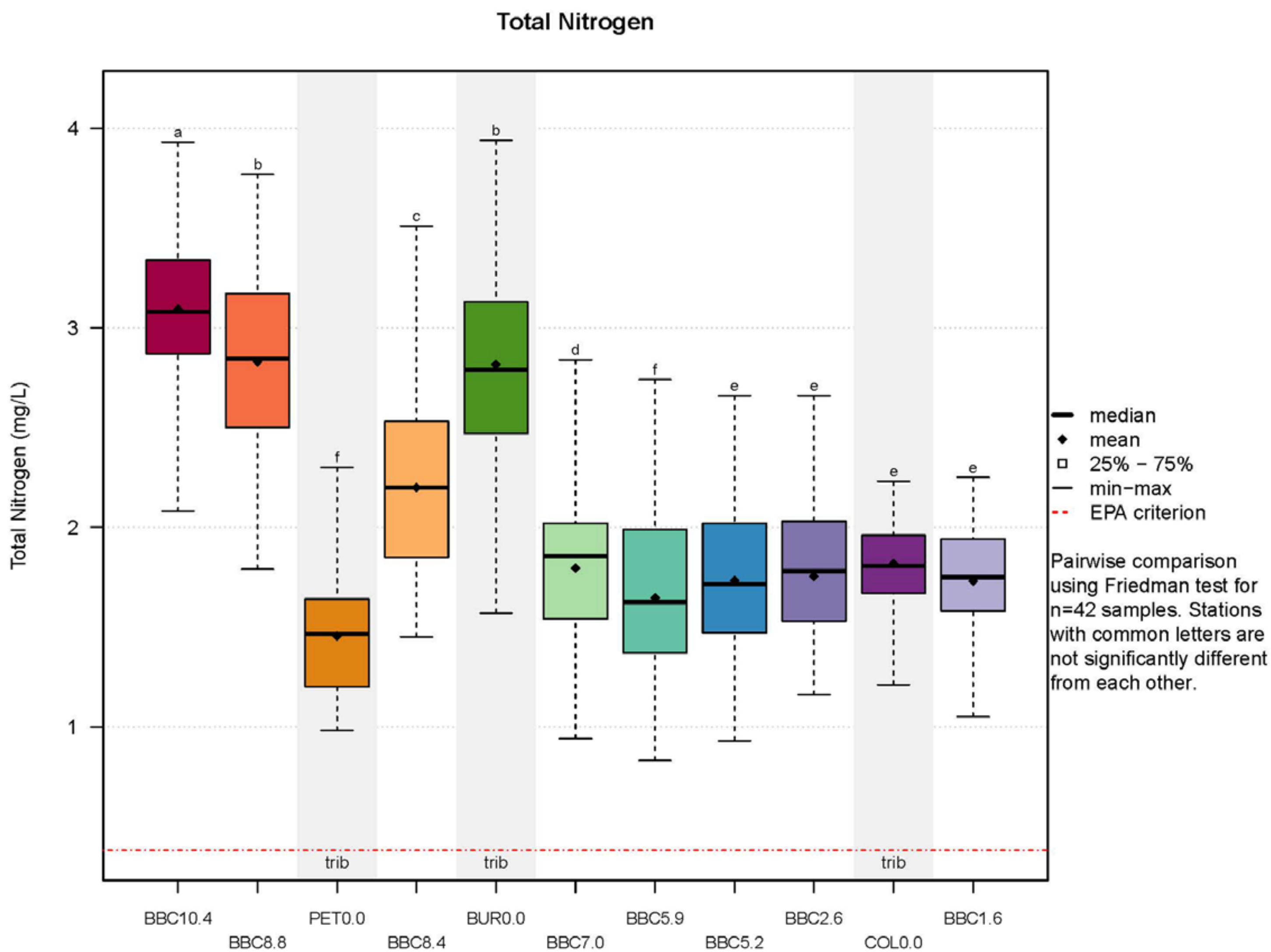


Figure 23. Total Nitrogen Spatial Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

Water Quality Criteria Comparison

All total nitrogen concentrations at all stations exceeded the EPA-recommended criterion (0.36 mg/L) in 2011 through 2017.

Water Quality Index Results

Water quality index (WQI) results are presented in Table 8 as median values for 2011–2017. The total nitrogen WQI scores ranged between 1 and 67. The four most upstream stations on the main stem of Burnt Bridge Creek as well as BUR 0.0 and COL 0.0 were of high concern (WQI 1–39); all other stations were of moderate concern (WQI 40–79) with regard to total nitrogen concentrations.

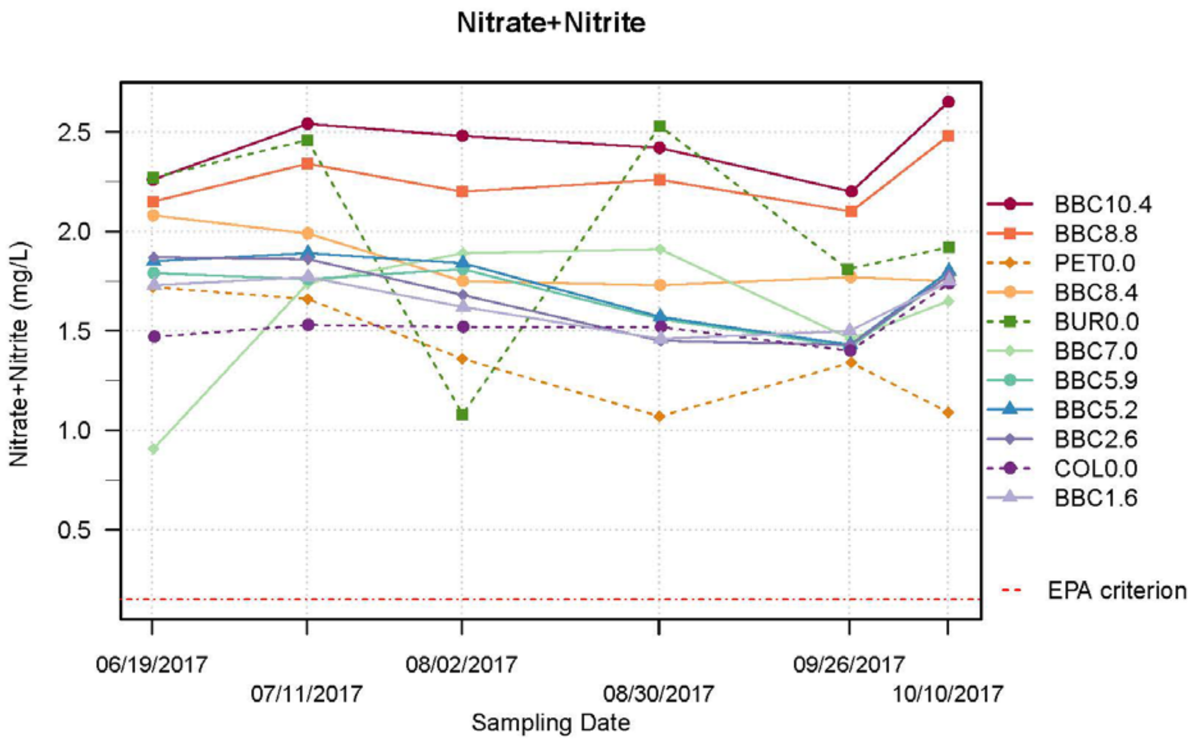
Nitrate+Nitrite Nitrogen

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 fresh water because it may contribute to an overabundant growth of 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.

Nitrate+nitrite nitrogen data are presented graphically in Figures 24 and 25 and summary statistics are presented in Appendix D.

Seasonal Patterns

Figure 24 (top) presents the nitrate+nitrite nitrogen data for each station by sampling date in 2017. Concentrations ranged from 0.91 mg/L to 2.65 mg/L in 2017. The seasonal pattern plot shows that nitrate+nitrite nitrogen concentrations typically decreased from July to late September, and increased in October. Maximum concentrations varied, while minimum concentrations were observed primarily in late August (3 of 11 stations) or late September (6 of 11 stations). Peterson Channel (PET 0.0), Burton Channel (BUR 0.0) and station BBC 7.0 exhibited notably more variation (18 to 24 percent coefficient of variation) in comparison to other stations (6 to 11 percent coefficient of variation).



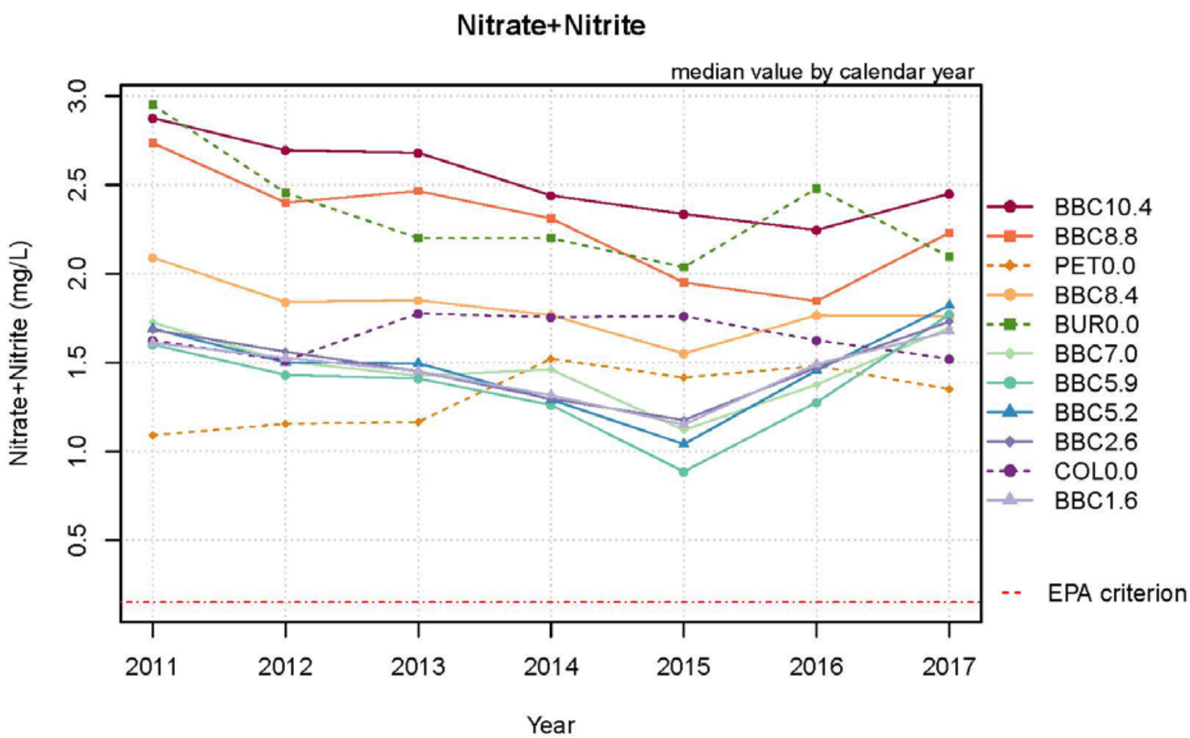


Figure 24. Nitrate+Nitrite Nitrogen Seasonal Patterns in 2017 and Annual Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

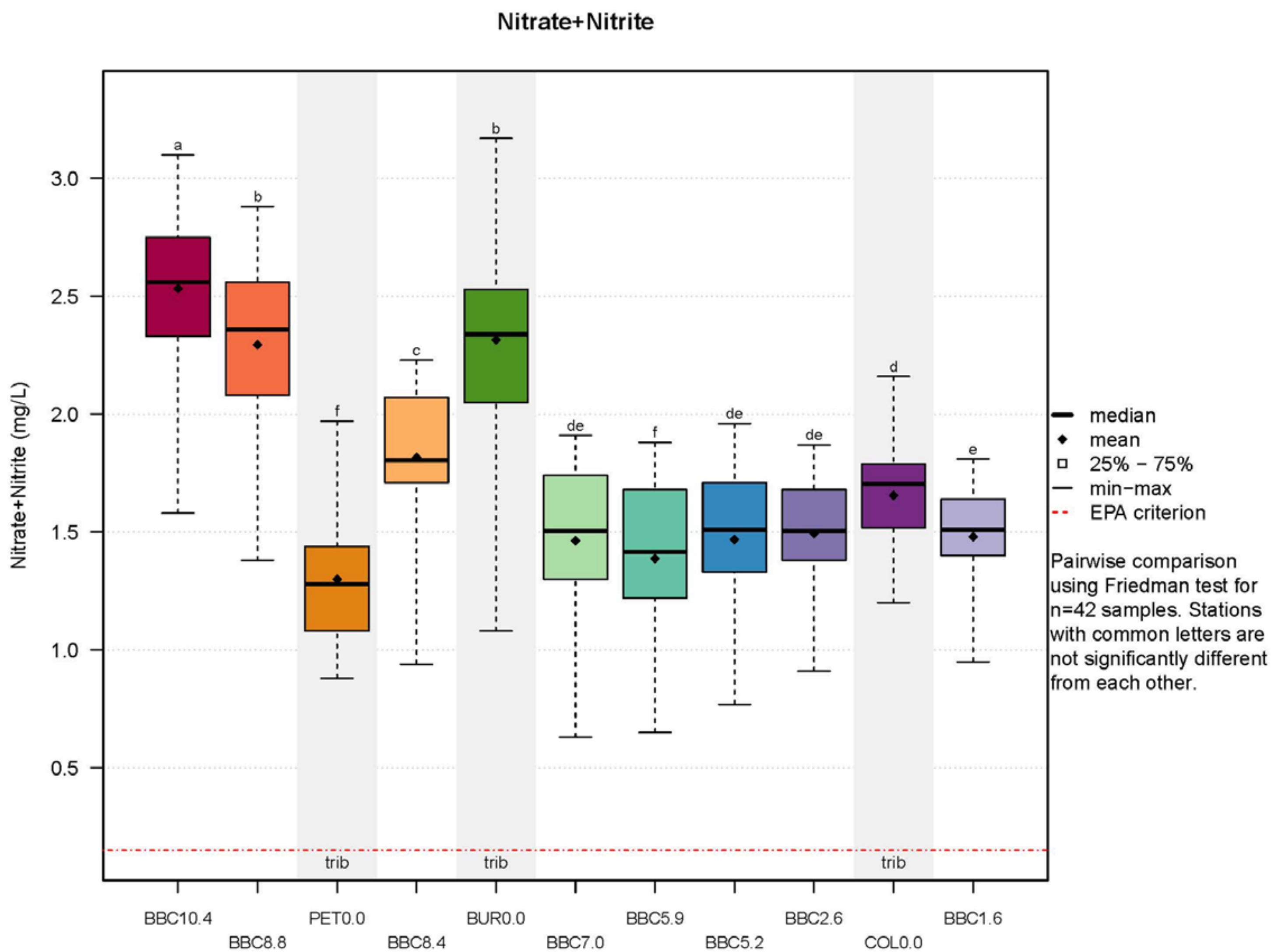


Figure 25. Nitrate+Nitrite Nitrogen Spatial Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

Spatial Patterns

In order to assess how each monitoring basin was contributing to nitrate+nitrite nitrogen concentrations in the main stem of Burnt Bridge Creek, the 2011–2017 nitrate+nitrite nitrogen data are presented as box plots in Figure 25. Nitrate+nitrite nitrogen concentrations followed a similar pattern as total nitrogen. Along the main stem, median concentrations were highest at the two most upstream stations (2.56 mg/L at BBC 10.4 and 2.36 mg/L at BBC 8.8) that were significantly higher than all downstream stations. Median concentrations significantly decreased downstream to a minimum of 1.42 mg/L at BBC 5.9, increased at BBC 5.2, and remained constant at 1.51 mg/L until BBC 1.6. Inflow from Peterson Channel (1.28 mg/L) may have contributed to the decrease in nitrate+nitrite nitrogen at BBC 8.4 (1.81 mg/L); Burton Channel and Cold Creek did not appear to impact downstream concentrations.

Temporal Trends

Figure 24 (bottom) presents annual median values of nitrate+nitrite nitrogen at each station in 2011–2017, and temporal trend analysis results are presented in Table 7. For 2011–2017, a significant increasing temporal trend in nitrate+nitrite nitrogen was observed at station PET 0.0. Significant decreasing trends were observed at the three most upstream stations (BBC 10.4 to BBC 8.4), as well as Burton Channel. The 2011–2017 plot shows that nitrate+nitrite nitrogen tended to decrease from 2011 to 2015, and then increase from 2015 to 2017 at the downstream main stem stations. A significant trend of increased nitrate+nitrite nitrogen since 2004–2007 was observed at three of four stations (BBC 8.4, BBC 7.0, and BBC 5.9), with percent changes for those stations ranging between 81 and 291 percent.

Comparing median concentrations of nitrate+nitrite to total nitrogen in 2011 through 2017 shows that between 74 and 95 percent (median 85 percent) of the total nitrogen was in the dissolved state, which is considered to be readily available for uptake by algae in Burnt Bridge Creek and Vancouver Lake.

Water Quality Criteria Comparison

All nitrate+nitrite nitrogen concentrations at all stations exceeded the EPA-recommended criterion (0.15 mg/L) (see Figure 24).

Fecal Coliform Bacteria

Urban and agricultural runoff characteristically contains elevated levels of fecal coliform bacteria. These organisms are used as indicators of fecal contamination from humans and other warm-blooded animals. Human sources include failing septic systems, municipal wastewater discharges, leaking wastewater conveyance systems or side sewers, and cross-connections with municipal wastewater systems. Animal sources include pets, livestock, and wildlife (e.g., birds and mammals). The simple presence of these bacteria does not necessarily indicate a threat to public health because only a small portion is likely to be pathogenic to humans. However, their use as an indicator of potential fecal contamination is considered important in the early detection of problems that could lead to public health concerns. Washington state surface water quality standards (WAC 173-201A) for fecal coliform bacteria are presented in Table 3.

Fecal coliform data are presented graphically in Figures 26 and 27 and summary statistics are presented in Appendix D.

Seasonal Patterns

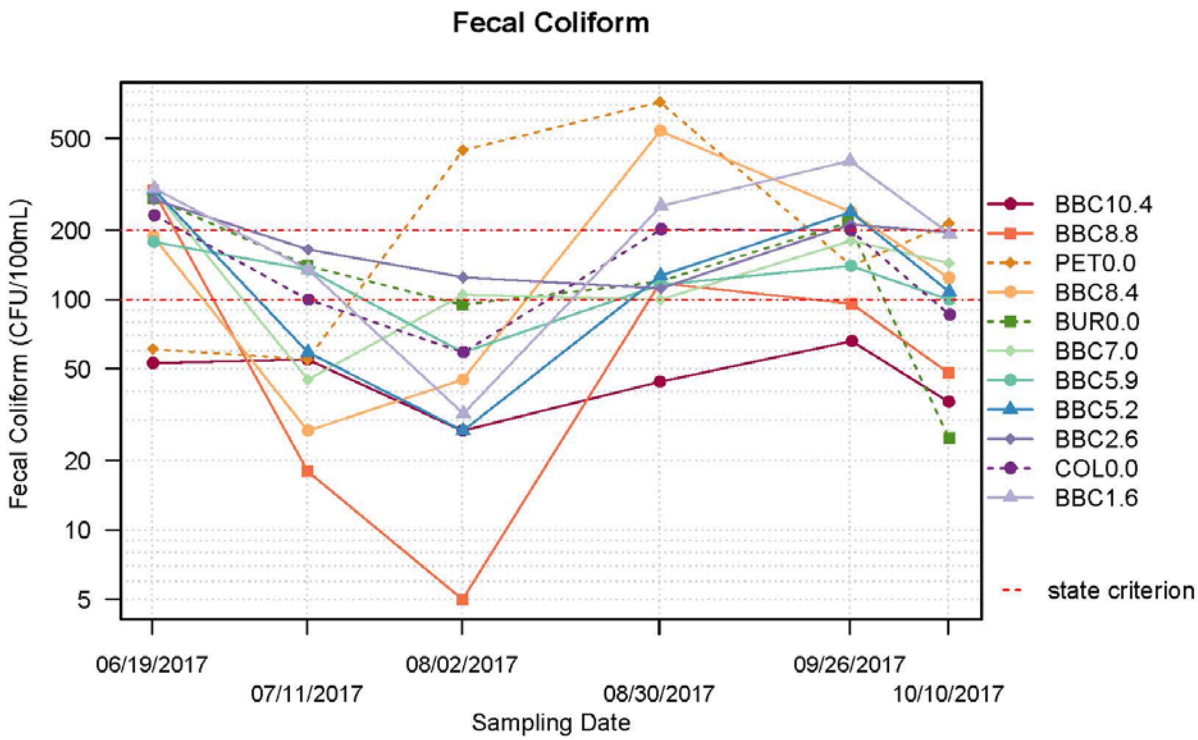
Figure 26 (top) presents the fecal coliform data for each station by sampling date in 2017. Concentrations ranged from 5 to 720 CFU/100 mL in 2017. Fecal coliform bacteria concentrations were highly variable within stations (27 to 101 percent coefficient of variation) throughout the 2017 monitoring period. They typically decreased from June to early August, then increased to late August or September before decreasing again in October. Maximum concentrations were typically observed in June (7 of 11 stations), with minimum concentrations observed in early August (6 of 11 stations).

Spatial Patterns

In order to assess how each monitoring basin was contributing to fecal coliform concentrations in the main stem of Burnt Bridge Creek, the 2011–2017 fecal coliform data are presented as box plots in Figure 27. Median fecal coliform bacteria concentrations were similar among the three most upstream main stem stations (ranging from 91 to 96 CFU/100 mL) and gradually increased from stations BBC 8.4 to BBC 1.6 (255 CFU/100 mL). High median concentrations were observed at Burton Channel and Cold Creek (275 CFU/100 mL at both stations) that may have contributed to the significantly increased concentrations observed at BBC 7.0 and BBC 1.6, respectively. Those stations with the highest concentrations (BUR 0.0, COL 0.0, and BBC 1.6) were found to be significantly different than all other stations, with the exception that BUR 0.0 was not found to be significantly different than BBC 2.6.

Temporal Trends

Figure 26 (bottom) presents annual median values of fecal coliform at each station in 2011–2017, and temporal trend analysis results are presented in Table 7. For 2011–2017, a significant decreasing temporal trend in fecal coliform was observed at stations BUR 0.0, BBC 5.9, BBC 5.2, and COL 0.0. The 2011–2017 plot shows that median fecal coliform was highest in 2013 at the downstream stations (BBC 7.0 to BBC 1.6). A significant trend of increased fecal coliform since 2004–2007 was observed at BBC 7.0, which had a 39 percent increase from historical to recent data. Significant trends of decreased fecal coliform since 2004–2007 were observed at PET 0.0 and BBC 8.4, with 48 and 46 percent decrease, respectively.



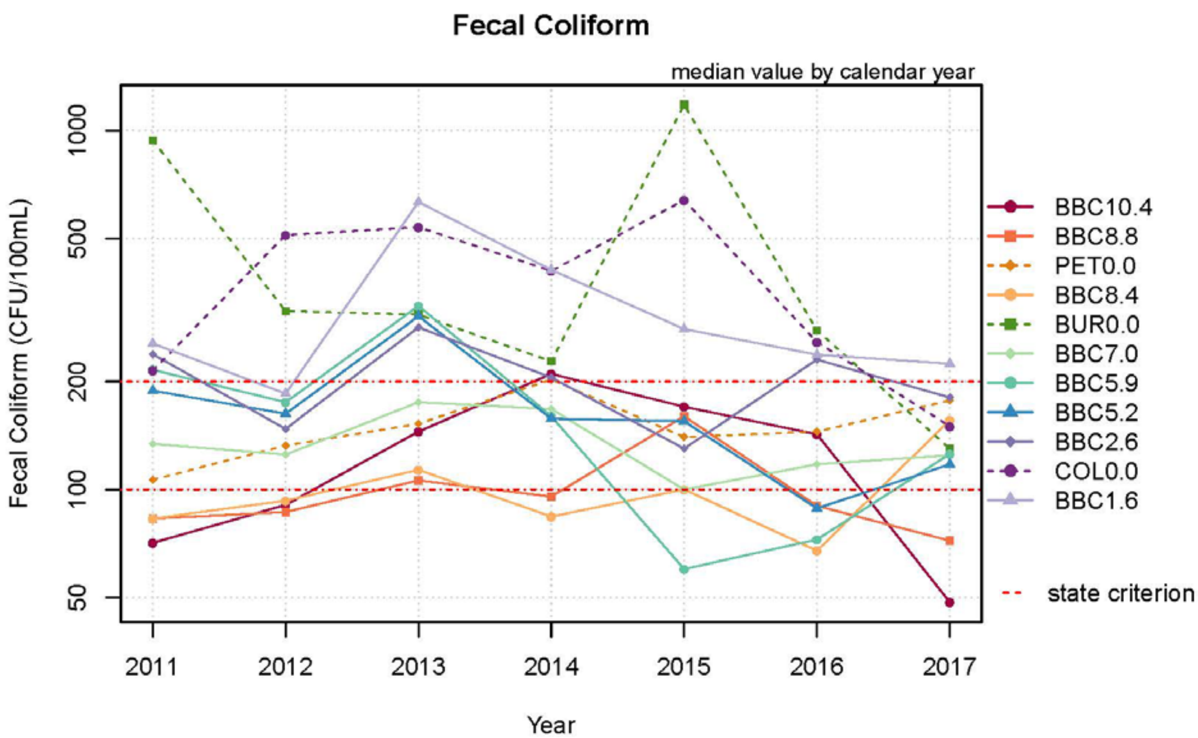


Figure 26. Fecal Coliform Seasonal Patterns in 2017 and Annual Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

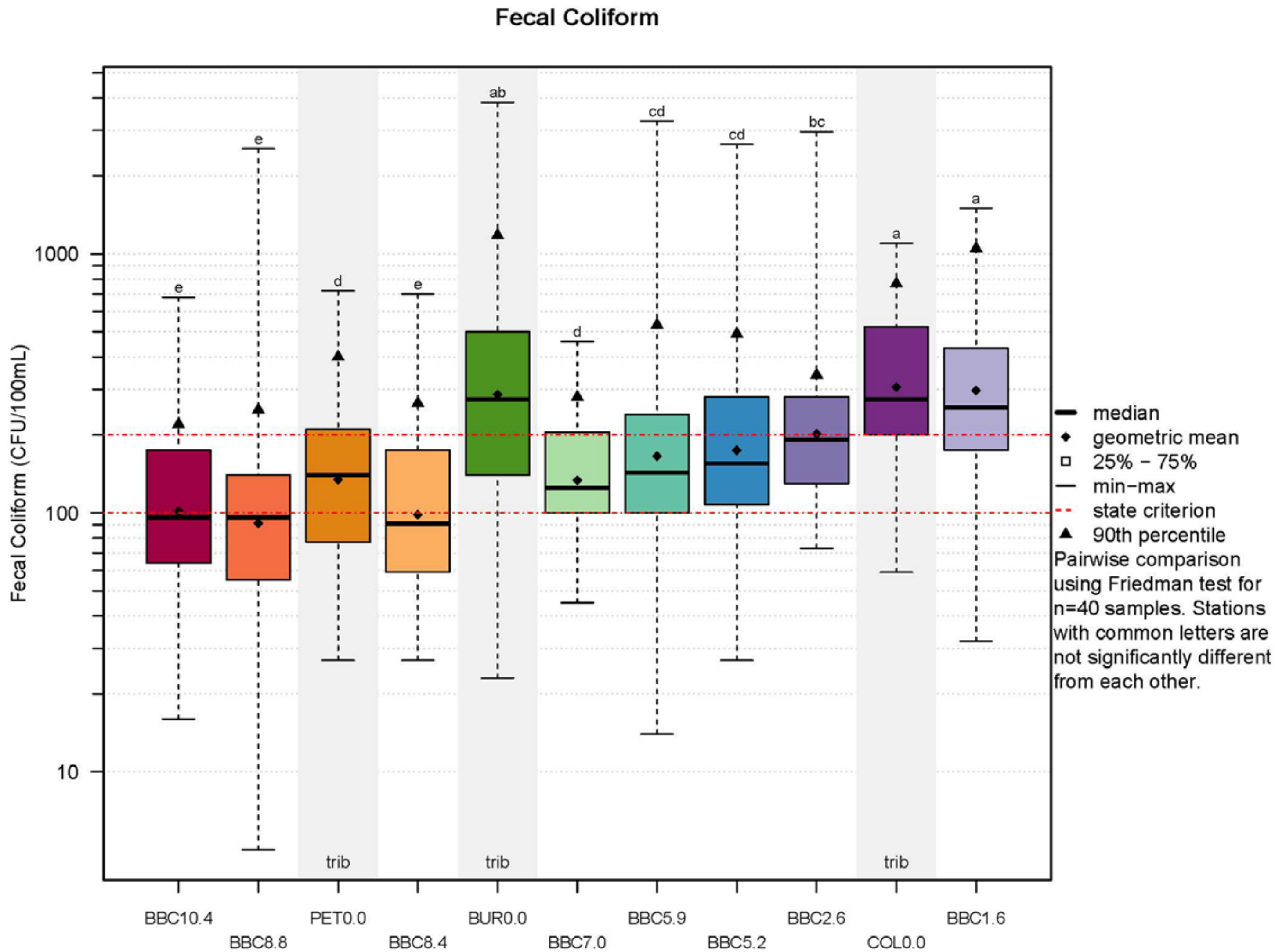


Figure 27. Fecal Coliform Spatial Patterns in 2011–2017 for Summer Base Flow in Burnt Bridge Creek.

Water Quality Criteria Comparison

Fecal coliform bacteria results exceeded the state water quality standard for the geometric mean (shall not exceed 100 CFU/100 mL) or the 90th percentile (shall not exceed 200 CFU/100 mL) at all stations in 2017. For all stations in 2011–2017, the geometric mean ranged from 91 to 306 CFU/100 mL, and the 90th percentile ranged from 220 to 1,180 CFU/100 mL.

Water Quality Index Results

Water quality index (WQI) results are presented in Table 8 as median values for 2011–2017. The fecal coliform WQI scores ranged between 56 and 74. All stations were of moderate concern (WQI 40–79) with regard to fecal coliform.

Overall Water Quality Index Scores

Overall median WQI scores ranged between 44 and 72, falling within the moderate concern range at all stations (see Table 8). A significant decreasing trend in overall WQI score was observed at Peterson Channel from 2011 to 2017.

SUMMARY OF FINDINGS

DATA QUALITY

Water quality monitoring of Burnt Bridge Creek in the summer of 2017 met the project objectives by using methods and locations that are consistent with past monitoring efforts and in accordance with the QAPP (Herrera 2017b), and by providing accurate and high quality data for use by the City of Vancouver and others. All samples were collected as planned, and the data quality objectives were met with the following exceptions:

- Forty-six of the sixty-six fecal coliform bacteria results (68 percent) were qualified as estimated (J) based on plate counts being out of range, or due to the laboratory or field duplicate results (RPD greater than 30 percent).
- Three fecal coliform results were flagged as greater than (>) the reported maximum possible count of 300 because they were reported as too numerous to count at >300 due to laboratory oversight regarding dilution volumes.
- Two results for turbidity were qualified as estimated (J) due to field duplicate results (RPD greater than 20 percent).
- One result for nitrate+nitrite were qualified as estimated (J) due to field duplicate results (RPD greater than 20 percent).
- One result for TSS was qualified as estimated (J) due to field duplicate results (RPD greater than 20 percent).
- Data from the continuous temperature probe used between Events 4 and 6 at BBC 8.8 were corrected using linear regression because the temperature accuracy check slightly exceeded the standard.

Seasonal Patterns

Seasonal patterns in parameter values were similar in 2017 to those observed in previous years. Maximum temperatures and minimum dissolved oxygen concentrations typically occurred in August, and temperatures were unusually high when monitoring started in June 2017. Conductivity, soluble reactive phosphorus, and total phosphorus typically reached maximum values in September, while nitrate+nitrite reached minimum values in September.

Spatial Patterns

The 2011–2017 data showed statistically significant spatial patterns in the water quality of Burnt Bridge Creek as base flow waters flowed downstream:

- Increasing values to mid-stream maximums at station BBC 7.0 for temperature, turbidity, total suspended solids, and total phosphorus.
- Decreasing values to mid-stream minimums at station BBC 5.9 for dissolved oxygen.
- Increasing values to downstream maximums at station BBC 2.6 or BBC 1.6 for pH and fecal coliform bacteria.
- Decreasing values to downstream maximums at station BBC 2.6 or BBC 1.6 for nitrate+nitrite and total nitrogen.

Tributaries with parameter values that were significantly different than upstream stations and significantly changed downstream values include:

- Peterson Channel with high temperature, conductivity, soluble reactive phosphorus, and total phosphorus values, and low dissolved oxygen, turbidity, nitrate+nitrite, and total nitrogen values.
- Burton Channel with high fecal coliform bacteria values.
- Cold Creek with high conductivity and fecal coliform bacteria values.

Temporal Trends

Recent Trends

All 11 stations monitored in 2011–2017 were evaluated for statistically significant temporal trends. Water quality significantly improved for the following parameters and stations:

- TSS decreased at PET 0.0, BBC 5.9, BBC 5.2, BBC 2.6, and BBC 1.6.
- Fecal coliform decreased at BUR 0.0, BBC5.9, BBC 5.2, and COL 0.0.
- Nitrate+nitrite decreased at BBC 10.4, BBC 8.8, BBC 8.4, and BUR 0.0.
- Total nitrogen decreased at BBC 10.4, BBC 8.8, BBC 7.0, BBC 5.9, BBC 5.2, and BBC 2.6.

Water quality significantly declined for the following parameters and stations:

- Dissolved oxygen decreased at station BBC 7.0.
- Turbidity increased at BBC 10.4 and PET 0.0.

- TSS increased at BBC 10.4.
- Soluble reactive phosphorus increased at PET 0.0.
- Nitrate+nitrite increased at PET 0.0.
- Total nitrogen increased at PET 0.0 and COL 0.0.

In addition, pH significantly decreased at BBC 7.0 but continued to meet state standards. Conductivity increased at stations PET 0.0, BBC 8.4, BBC 7.0, BBC 5.9, BBC 5.2, BBC 2.6, COL 0.0, and BBC 1.6.

Historical Trends

The four stations monitored in the 2004–2007 and 2011–2017 studies were also evaluated for a significant (alpha = 0.5) and substantial (at least 50 percent change) improvement or degradation in summer base flow conditions. Significant water quality degradation was observed all four stations (PET 0.0, BBC 8.4, BBC 7.0, and BBC 5.9) that outweighed the few observed improvements.

Degraded water quality conditions were observed for the following parameters and stations (significant trend):

- Turbidity increased at all stations (substantial at all stations except PET 0.0).
- TSS increased at BBC 8.4 (substantial) and at BBC 7.0 (not substantial).
- Nitrate+nitrite and total nitrogen increased at BBC 8.4, BBC 7.0, and BBC 5.9 (substantial).
- Total and soluble reactive phosphorus increased at all four stations (substantial at PET 0.0 and BBC 8.4 for total phosphorus, and substantial for soluble reactive phosphorus at all four stations except BBC 7.0).
- Fecal coliform increased at BBC 7.0 (not substantial).

Significantly improved water quality conditions were observed for the following parameters and stations:

- Dissolved oxygen increased at BBC 5.9 (not substantial).
- Fecal coliform decreased at PET 0.0 and BBC 8.4 (not substantial).

In addition, pH significantly increased at BBC 7.0 and BBC 5.9 (not substantial) but continued to meet state standards. Conductivity increased at PET 0.0 (not substantial).

Water Quality Criteria

The 11 base flow monitoring stations were evaluated for compliance with applicable state and federal water quality standards using the 2011–2017 summer base flow results. Water quality criteria were not met for the following parameters and stations:

- High water temperature at all eight stations that were monitored continuously.
- Low dissolved oxygen at all stations except BBC 8.8 and BUR 0.0.
- Low pH at BBC 10.4.
- High total phosphorus, total nitrogen, nitrate+nitrite, and fecal coliform at all 11 stations.

Water Quality Index

The overall WQI was in the moderate concern range for all 11 stations based on median scores for 2011–2017, with higher scores (53 to 70) at the upstream stations from BBC 10.4 to BUR 0.0 and lower scores (43 to 49) at the downstream stations from BBC 7.0 to BBC 1.6. A significant decreasing trend from 2011 to 2017 in the overall WQI was identified only at Peterson Channel (PET 0.0) (see Table 8 on page 31). The relative concern for WQI parameters include:

- Low concern for pH (10 stations), turbidity (11 stations), and TSS (9 stations).
- Low to moderate concern for dissolved oxygen (six and five stations, respectively).
- Moderate concern for temperature (eight stations) and total phosphorus (nine stations).
- Moderate to high concern for total nitrogen (six and five stations, respectively).

RECOMMENDATIONS

MONITORING STATIONS AND FREQUENCY

The number of monitoring locations should remain at 11 to adequately characterize the stream and to facilitate completion of sample collection and shipment in 1 day. The station locations should also remain consistent with the 2017 monitoring year. Continuous temperature monitoring should also remain consistent at the eight current continuous monitoring stations.

Ambient monitoring should continue to include six sampling events from June through October of each year. The total number of samples collected during the summer of each year would remain at 72 (including 6 duplicate samples).

If funding allows, winter storm event monitoring should occur at nine stations (excluding stations BBC 8.4 and BBC 7.0) for up to six events in the 2018–2019 wet season (October through May) to build on the storm event data collected at those same stations during the 2012–2013 wet season. The total number of storm event samples collected should be up to 60 (six events at nine stations and one field duplicate per event). Storm event monitoring should occur following at least 0.10 inches of rain in the previous 24 hours, and should be initiated when at least 0.30 inches of rain is predicted to occur in daylight hours of the sampling date.

MONITORING PARAMETERS

It is recommended that the monitoring parameters and analytical methods used in 2017 be continued in the future. Monitoring parameters for storm event monitoring should include those used for summer base flow monitoring with the exclusion of field parameters and the addition of hardness, dissolved copper, and dissolved zinc (as per storm event monitoring in the 2012–2013 wet season). Exclusion of field parameters will facilitate timely sample collection during storm events and these parameters are generally not a concern during winter storm flow.

SAMPLE ANALYSIS

Due to quality control concerns encountered in 2017, it is recommended that fecal coliform bacteria be analyzed at a different laboratory: BSK Associates, which is accredited by Ecology for fecal coliform bacteria and located in Vancouver, Washington. It is recommended that all other parameters continue to be analyzed by (IEH Aquatic Research) for consistency with 2011–2017 data.

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APPENDIX A

Interim Data Reports

The contents of this appendix will be provided separately.

APPENDIX B

Temperature Accuracy Check Data

The contents of this appendix will be provided separately.

APPENDIX C

Continuous Temperature Data

The contents of this appendix will be provided separately.

APPENDIX D

Summary of Water Quality Data for Current and Historical Studies of Burnt Bridge Creek

The contents of this appendix will be provided separately.

APPENDIX E

Statistical Test Results

The contents of this appendix will be provided separately.