Analysis of Long-term Trends in Bear Creek Water Quality

April 2017

King County

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EXECUTIVE SUMMARY

This report assesses historic water quality conditions in the Bear Creek watershed which includes areas outside of the Bear Creek Watershed-Scale Stormwater Management Plan. This report is one of many created to support the watershed-scale stormwater planning process for Bear Creek.

King County has routinely monitored water and sediment quality in Bear Creek watershed since the 1970s as part of the Routine Stream and River Monitoring Program. This analysis examined long-term trends in water quality at routine monitoring sites operated by King County, and when possible, compared to relevant Washington State water quality standards. Five long-term monitoring sites were evaluated. Three (0484, C484, J484) are located along mainstem Bear Creek, one (B484) on Evans Creek, and one (N484) on Cottage Lake Creek. Additionally, water temperature data from five continuous probes collecting data since the mid-1990s were used to compare to temperature standards.

Long-term Trends

Fecal coliform bacteria and nutrient concentrations have significantly decreased over the past 4 decades. Temperature was found to be significantly increasing at all sites at a rate between 0.3 and 0.6 °C per decade. Increasing temperature may have contributed to the significantly decreasing dissolved oxygen concentrations found at all sites but 0484. However, the rate of dissolved oxygen decrease in Evans Creek (B484) (1 mg/L per decade) was almost 10-times greater than at the other sites (~0.1 mg/L per decade). This suggests additional contributing factors exist in the Evans Creek watershed. Despite the decreasing trends observed upstream, no significant trend was observed at downstream Bear Creek (0484).

Increasing conductance was found at all sites. Increased urbanization and land development is likely a major driver of increased conductance. pH has increased (become less acidic) at C484 and decreased (more acidic) at B484. Data needed to analyze long-terms for levels of metals and organics chemicals do not exist.

Comparison to Water Quality Standards

As has been previously established, fecal coliform bacteria, temperature, and dissolved oxygen are of concern in the Bear Creek watershed. Fecal coliform bacteria levels frequently exceed the numeric water quality criteria in Washington State's water quality standards, indicating a potential for human health risk. Temperatures are too high and dissolved oxygen concentrations are too low to meet the criteria set for the protection of salmonids and other aquatic life. A multi-parameter TMDL is in place that sets forth a collaborative effort between state and local jurisdictions to combat these issues.

While no metals were found to exceed water quality criteria in routine monitoring data, recent targeted stormflow sampling detected copper concentrations above the state

standards. Those exceedances were detected in Cold Creek (a tributary to Cottage Lake Creek) and Mackey Creek (a tributary to lower Bear Creek).

Limited data on organic chemicals in Bear Creek were available, and most organic chemical samples were collected from the mouth (site 0484). In many cases, the method detection limits for chemicals were above the state aquatic life and/or human health standards. One chemical, bis(2-ethylhexyl)phthalate, was detected above the human health standard in multiple samples. Bis(2-ethylhexyl)phthalate is a plasticizer used in a wide variety of consumer products, including tablecloths, toys, furniture, and garden hoses. Whether this chemical is present at levels of concern in fish tissue is not known, and analysis of organic chemicals in fish tissue in the Bear Creek watershed would be necessary to determine if human health is at risk through the consumption of fish caught in Bear Creek.

Sediment Quality

Generally, the stream sediments within Bear Creek watershed are not greatly contaminated. Four sites were found to have potential or probable effect on benthic organisms due to high levels of pentachlorophenol (a pesticide and disinfectant), dibenzofuran (a byproduct of combustion), polycyclic aromatic hydrocarbons (PAHs), total sulfides, or bioavailable nickel. Between 1987 and 2006, concentrations of metals in sediments at the mouth of Bear Creek decreased slightly or remained level.

Conclusions

With the exception of temperature and dissolved oxygen, overall water quality in the Bear Creek watershed appears to be improving. Current fecal coliform concentrations indicate a potential risk to human health, but the concentrations have decreased over the past three decades. Temperature and dissolved oxygen levels are not conducive for salmonids (as represented by violations of the state water quality standards), and long-term trends have indicated that conditions have worsened over the past four decades.

1.0 INTRODUCTION

This report assesses historic water quality conditions in the Bear Creek watershed. King County has routinely monitored water quality in Bear Creek since the 1970s as part of the Routine Stream and River Monitoring Program. Sediment quality was monitored almost annually between 1987 and 2005, and again in 2010. This report is one of many created to support the watershed-scale stormwater planning process for Bear Creek.

King County is required to develop a watershed-scale stormwater management plan (plan) effort to satisfy permit obligations under section S5.C.5.c of the National Pollutant Discharge Elimination System Phase I Municipal Stormwater Permit (permit) issued by the Washington State Department of Ecology (Ecology), effective August 1, 2013 through July 31, 2018, and modified January 16, 2015.

King County's long-term goal of this plan is to restore Bear Creek so that it provides healthy aquatic habitat for Chinook salmon and other species now and into the future. The objective for this watershed-scale planning effort that will support reaching this goal is to identify a suite of management strategies that would result in hydrologic, water quality, and habitat conditions that fully support existing and designated uses, as defined in the Washington Administrative Code (WAC 173-201A-020).

Bear Creek contains many miles of high-quality aquatic resources, and is known to support a wide range of salmonids, including Chinook—an ESA listed "threatened" species. Recently, the Bear Creek watershed was identified by Ecology as a target watershed for stormwater retrofit planning because of its high integrity (as defined by Ecology) (King County, 2015). For this reason, King County selected the Bear Creek watershed for the watershed-scale stormwater planning effort as specified in the permit (S5.C.5.c.i). Ecology approved King County's request to select a sub-area of the Bear Creek basin to meet permit requirements S5.C.5.c.i.(1) through S5.C.5.c.i.(4). This sub-area is defined as Bear Creek drainage areas above the confluence of Evans Creek tributary and excludes Cottage Lake and its drainage basin (Figure 1). This planning area approximately totals 26 square miles and includes area within four other jurisdictions in addition to unincorporated King County (18.9 square miles):

- City of Redmond (2.4 square miles);
- City of Woodinville (1.1 square miles);
- Washington State Department of Transportation (0.003 square miles); and
- Snohomish County (3.7 square miles).

King County is lead in the planning process (S5.C.5.c.ii) and coordinate (S5.C.5.c.iii) with the participating Permittees (King County, Snohomish County, City of Redmond, City of Woodinville, and Washington State Department of Transportation) as described in the coordination document, Coordination Plan for NPDES Phase I & II Bear Creek Watershed-Scale Stormwater Plan (July 29, 2015), for permit compliance.

The watershed-scale plan will include assessments of the landscape based on historic, existing, and projected future conditions. Stormwater management strategies will be evaluated, using these landscape baselines, for stream health based on stream hydrology, water quality, and aquatic biota (life forms). The evaluations will be derived from previous study results; interpretation of existing and new data; and development of hydrologic models that will project historic and future conditions and characterize what is needed to restore Bear Creek.

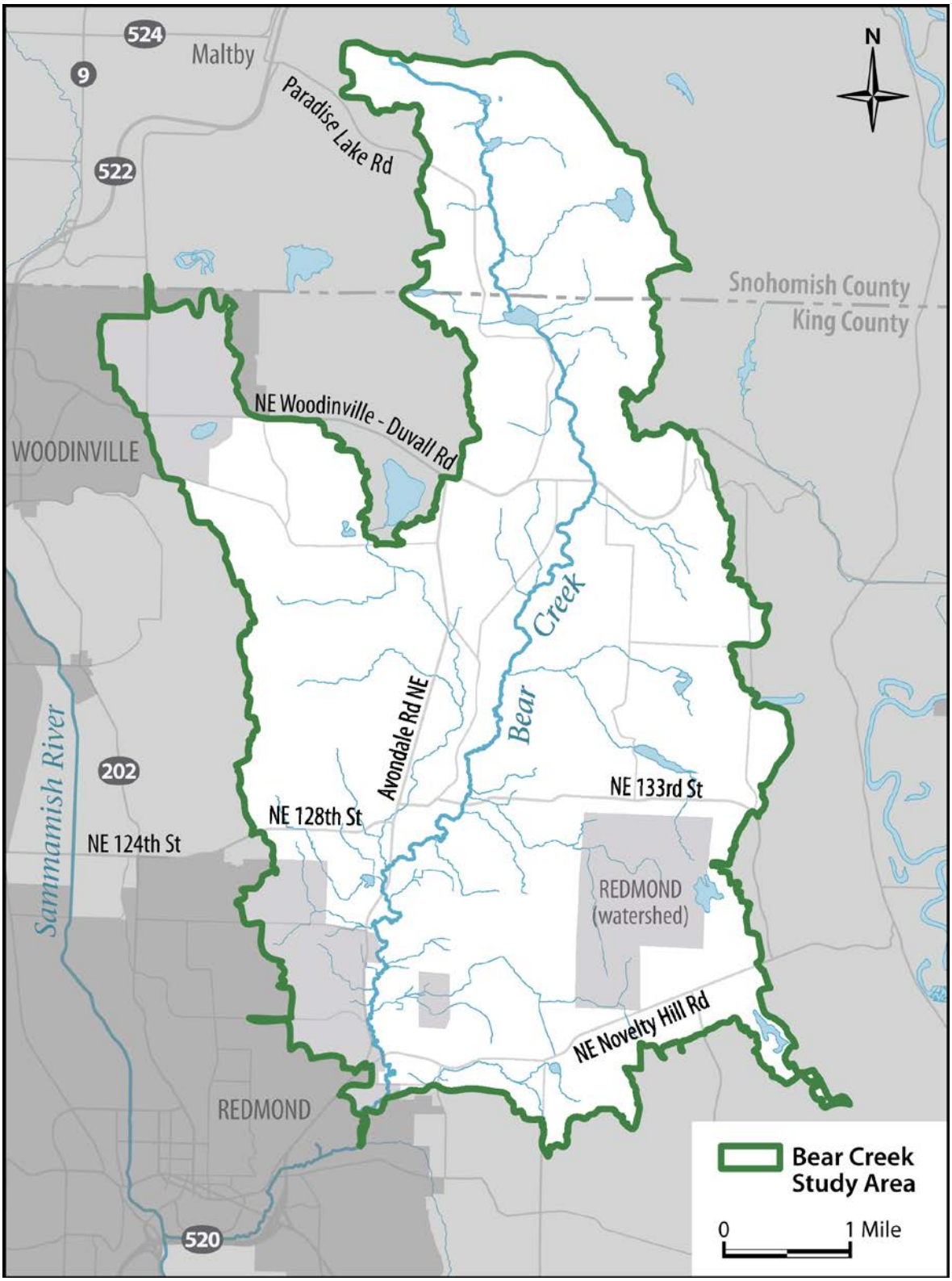

Figure 1. Bear Creek study area for watershed-level stormwater planning.

2.0 METHODS

2.1 Data Sources

This section includes a discussion of the sources of historic water quality and sediment quality for the streams in the study area. Additionally, the sources of county parcel data used to evaluate watershed development are described.

2.1.1 Water Quality Data

Surface water quality data from the King County Stream and River Monitoring Program were used to assess long-term trends in the Bear Creek basin (Figure 2). Five monitoring stations in the Bear Creek basin have been monitored for a variety of parameters since the 1970s. The targeted sampling as part of the Bear Creek stormwater planning effort was not included in this analysis. For those data and analyses, see *Bear Creek Watershed-Scale Stormwater Management Plan: Existing Water Quality Conditions* (King County, 2017).

Water quality has been monitored at approximately monthly intervals since 1979, in addition to occasional samples taken between 1971 and 1978 (Tables 1 and 2). Parameters include:

- **Conventional parameters.** Temperature, dissolved oxygen, conductance, pH, turbidity, and total suspended solids
- **Nutrients**. Total phosphorus, orthophosphate phosphorus, ammonia nitrogen, nitrite + nitrate nitrogen, and total nitrogen [beginning in 1993 at all sites]
- **Fecal coliform bacteria.**

Between 1987 and 2010, conventional parameters, nutrients, and fecal coliform bacteria were measured during up to 6 targeted storm events per year at site 0484. Additionally, *E. coli* was routinely monitored from 1999 to 2008 at the four stations.

Total metals were monitored monthly between 1979 and 1983 at all sites, bimonthly in 1984, and quarterly in 1985 and 1986. From 1987 to 2010, total metals were sampled during up to 6 targeted wet-weather events at site 0484 only. From 1998 to 2010, dissolved metals were added to the targeted wet-weather event parameter list. Additionally, dissolved and total metals were sampled quarterly at sites site 0484 in 2001, 2002, and again from 2006-2008. Site C484 was sampled for dissolved and total metals in 2001 and 2002 (0484 only), and quarterly at 0484 from 2006 to 2008. In addition, from March 2007 to December 2007, sites J484 and N484 were sampled monthly for total metals.

Organic chemicals (PAHs, pesticides, PCB Aroclors, and other semi-volatile organic compounds [SVOCs]) have not been routinely monitored and have been measured as part of specific projects. These include a single grab sample at B484 in October, 1991 tested for pesticides and PCB Aroclors, quarterly samples collected at 0484 from May 2001 to February 2003 tested for PAHs, PCB Aroclors, pesticides, and other SVOCs, quarterly

samples collected at 0484 in 2009 and 2010 during storm events and analyzed for the same suite, and a single sample at C484 in July 2003 analyzed for the same suite. Finally, four samples from C484 in 2002 and 2003 and one sample from 0484 in February 2003 were collected and analyzed for endocrine disrupting compounds (EDCs).

King County maintains several continuous flow and temperature gages on Bear Creek, Evans Creek, and Cottage Lake Creek (Table 3; Figure 2). The Bear Creek gages (02a, 02e, 02f) and Evans Creek gage (18a) have been monitored since the mid-1990s. Gages on lower Cottage Lake Creek was installed in 2000 and upper Cottage Lake Creek in 2005.

Water quality data collected by the City of Redmond could not be used for long-term trend analysis. This is because the City of Redmond's water quality monitoring stations within the Bear Creek basin do not have routine dataset with an adequate temporal extent to assess long-term trends (e.g., quarterly samples collected between 2001 and 2009). A summary of water quality data collected by the City of Redmond was published in 2009 (City of Redmond, 2009).

Water quality data collected by the Department of Ecology to support the temperature and dissolved oxygen Total Maximum Daily Load (TMDL) was not included in long-term trend analysis. These data were collected with purpose of calibrating the QUAL2Kw stream water quality model. These data only represent conditions between June 16 and October 4, 2006 and are not useful for long-term trend analysis.

Water quality data are summarized in this report using Tukey boxplots. In Tukey boxplots, the thick black line represents the median, the rectangle displays the interquartile range (IQR), the whiskers represent the minimum/maximum value within 1.5*IQR of the first and third quartiles, and the points are outliers.

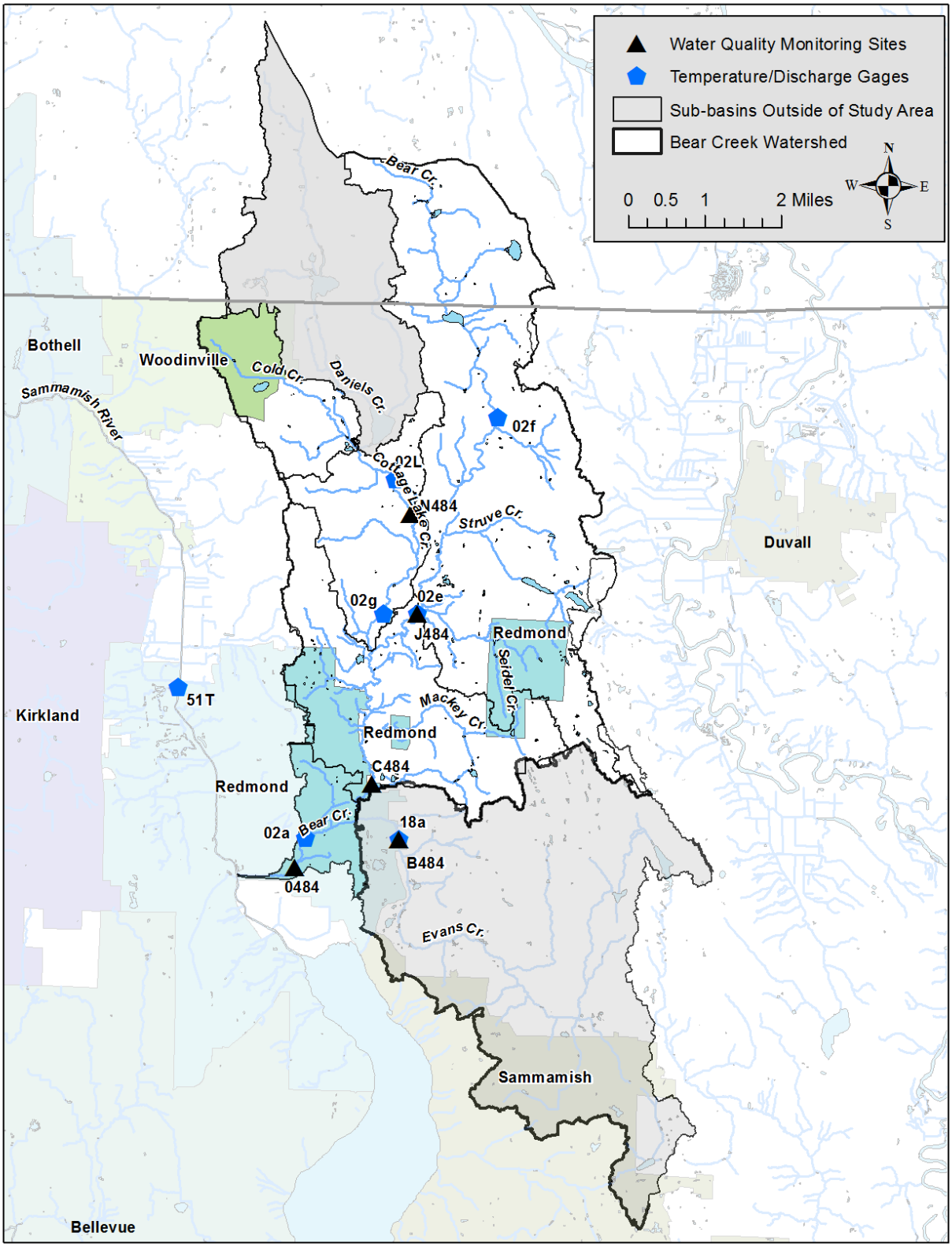

Figure 2. **Long-term water quality monitoring stations (black triangles) and continuous temperature probes (blue pentagons) in Bear Creek basin. Sub-basins not included in study area shown in grey.**

Table 1. Long-term water quality data in Bear Creek basin 1971-2015.

Site	Site Description	River Mile[a]	Parameters Monitored	Years Monitored	Number of Samples
0484	Bear Creek Mouth – downstream of Redmond Way Bridge	0.8	Conventionals, Nutrients, Fecal Coliform	1971-2015	539
			Total Metals	1979-2010	174
			Dissolved Metals	1998-2010	56
			Organic Chemicals	2001-2003, 2009, 2010	16
B484	Evans Creek – Union Hill Rd Bridge – Upstream of Bear Creek Confluence	2.8 (0.7 miles upstream of confluence with Bear Creek)	Conventionals, Nutrients, Fecal Coliform	1971-2008, 2013-2015	421
			Total Metals	1979-1986	75
			Dissolved Metals	Not measured	0
			Organic Chemicals	1991	1
C484	Bear Creek – NE 95th Ave Bridge – Upstream of Stensland Creek and Evans Creek Confluences	2.8	Conventionals, Nutrients, Fecal Coliform	1974,1976, 1977, 1979-2008, 2013-2015	408
			Total Metals	1979-1986, 2001	77
			Dissolved Metals	2001	4
			Organic Chemicals	2003	1
J484	Bear Creek – NE 133rd Ave Bridge – Downstream of Seidel Creek Confluence	5.9	Conventionals, Nutrients, Fecal Coliform	1974,1976, 1977, 1979-2008	363
			Total Metals	1979-1986, 2007	84
			Dissolved Metals	Not measured	0
			Organic Chemicals	Not measured	0
N484	Cottage Lake Creek – Tolt Pipeline Trail Bridge	7.1 (2.2 miles upstream of confluence with Bear Creek)	Conventionals, Nutrients, Fecal Coliform	1974,1976, 1977, 1979-2008, 2013-2015	407
			Total Metals	1979-1986, 2007	84
			Dissolved Metals	Not measured	0
			Organic Chemicals	Not measured	0

a. Datum for river mile set at confluence of Bear Creek with Sammamish River

Table 2. Sampling dates per year for long-term monitoring station in Bear Creek basin by parameter group.

Site	Parameter Group	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
0484	Conv., Nut., FC	1	2		13		1	2		14	12	12	11	12	11	11	12	13
	Tot. Metals									14	12	12	11	12	5	4	4	1
	Diss. Metals																	
	Org. Chem.																	
B484	Conv., Nut., FC	1	13	14			1	2		14	12	12	11	12	12	11	12	12
	Tot. Metals									14	12	12	11	12	6	4	4	
	Diss. Metals																	
	Org. Chem.																	
C484	Conv., Nut., FC				13		1	2		14	12	12	11	12	12	11	12	12
	Tot. Metals									14	10	12	11	12	6	4	4	
	Diss. Metals																	
	Org. Chem.																	
J484	Conv., Nut., FC				12		1	2		14	12	12	11	12	12	11	12	12
	Tot. Metals									14	11	12	11	12	6	4	4	
	Diss. Metals																	
	Org. Chem.																	
N484	Conv., Nut., FC				13		1	2		14	12	12	11	12	12	11	12	12
	Tot. Metals									14	12	12	10	12	6	4	4	
	Diss. Metals																	
	Org. Chem.																	

Table 2. Sampling dates per year for long-term monitoring station in Bear Creek basin by parameter group. (cont.)

Site	Parameter Group	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
0484	Conv., Nut., FC	15	16	16	18	15	15	16	18	14	16	17	16	15	13	12	13	13
	Tot. Metals	3	4	6	6	3	3	4	6	2	4	6	4	4	6	6	2	2
	Diss. Metals											4	4	4	6	6	2	2
	Org. Chem.														3	4	1	
B484	Conv., Nut., FC	12	12	10	12	12	12	12	12	12	11	11	12	11	10	10	12	11
	Tot. Metals																	
	Diss. Metals																	
	Org. Chem.				1													
C484	Conv., Nut., FC	12	12	10	12	12	12	12	12	12	11	11	12	11	12	10	12	11
	Tot. Metals														4			
	Diss. Metals														4			
	Org. Chem.																1	
J484	Conv., Nut., FC	12	12	10	11	12	12	12	12	12	12	11	12	11	10	10	12	11
	Tot. Metals																	
	Diss. Metals																	
	Org. Chem.																	
N484	Conv., Nut., FC	12	12	10	12	12	12	12	12	12	12	11	12	11	10	10	12	11
	Tot. Metals																	
	Diss. Metals																	
	Org. Chem.																	

Table 2. Sampling dates per year for long-term monitoring station in Bear Creek basin by parameter group. (cont.)

Site	Parameter Group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
0484	Conv., Nut., FC	**14**	**14**	**14**	**14**	**16**	**16**	**12**	**12**	**12**	**12**	**12**
	Tot. Metals	**2**	**6**	**6**	**6**	**4**	**4**					
	Diss. Metals	**2**	**6**	**6**	**6**	**4**	**4**					
	Org. Chem.					**4**	**4**					
B484	Conv., Nut., FC	**12**	**11**	**12**	**12**					**11**	**12**	**12**
	Tot. Metals											
	Diss. Metals											
	Org. Chem.											
C484	Conv., Nut., FC	**12**	**11**	**12**	**12**					**11**	**12**	**12**
	Tot. Metals											
	Diss. Metals											
	Org. Chem.											
J484	Conv., Nut., FC	**12**	**10**	**12**	**12**							
	Tot. Metals			**10**								
	Diss. Metals											
	Org. Chem.											
N484	Conv., Nut., FC	**12**	**11**	**12**	**12**					**11**	**12**	**12**
	Tot. Metals			**10**								
	Diss. Metals											
	Org. Chem.											

Table 3. Continuous temperature monitoring stations with over 10 years of data in Bear Creek basin.

Site	Site Description	River Mile[a]	Years Monitored
02a	Bear Creek Mouth – upstream of Union Hill Rd	0.9	1995-2015
18a	Same location at B484	2.8 (0.7 miles upstream of confluence with Bear Creek)	1995-2015
02e	Same location at J484	5.9	1994-2015
02f	Bear Creek - Woodinville-Duvall Rd	9.5	1994-2015
02g	Cottage Lake Creek – Avondale Rd NE	5.4 (0.5 miles upstream of confluence with Bear Creek)	2000-2015
02L	Cottage Lake Creek – NE 159th St	7.5 (2.6 miles upstream of confluence with Bear Creek)	2005-2015

a. Datum for river mile set at confluence of Bear Creek with Sammamish River

2.1.2 Sediment Quality Data

Sediment data were collected approximately annually from 1987 to 2006 from the mouth of Bear Creek as part of the Stream Monitoring Program. A basin-wide sediment sampling effort took place in 2006, including 22 collections with Bear Creek, Evans Creek, and Cottage Lake Creek (King County, 2004). In 2010, sediments were sampled at site 0484.

The parameters analyzed include:

- **Conventional parameters.** Ammonia nitrogen, particle size distribution, total solids, total organic carbon, orthophosphate phosphorous, total phosphorous, pH, and total sulfide.
- **Metals.** Total cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc. Acid volatile sulfides with simultaneously extractable metals (AVS/SEM for cadmium, copper, lead, mercury, nickel, and zinc).
- **Organic chemicals.** Base/neutrals and acids, nonylphenol, bisphenol A, bis(2-ethylhexyl)adipate, chlorinated pesticides, chlorobenzenes, PCBs, and petroleum hydrocarbons.

Samples were collected from beneath a shallow aqueous layer (<2 ft) using a pre-cleaned PVC core tube to penetrate the bottom sediment of the stream to a depth of five to ten centimeters. A stainless steel spatula or gloved hand was inserted under the core tube mouth to trap the sediment inside, and the tube is removed from the stream. The sediment in the tube was then transferred into the stainless steel compositing container. This process was repeated a minimum of five times to acquire an appropriate amount of material to fill all sample containers after compositing. If core tube penetration was poor, or streambed was rocky or gravelly, additional core tubes were collected.

2.2 Long-term Trend Analysis

Trend analysis for nutrients, conventional parameters, and bacteria in water was completed using the non-parametric Seasonal Mann-Kendall test. This test accounts for seasonality by computing the Mann-Kendall test by seasonal blocks and then combining the results. For this analysis, months were used as the seasonal blocks. To accommodate the effects of flow on the measured water quality parameters, the daily mean discharge rate measured in the Sammamish River (King County site 51T; gage managed by USGS prior to 2005 [12125200]) was used as a covariate. Bear Creek flow data were not used as a covariate because water quality monitoring data predates the installation of the 02a gage on Bear Creek in 1994. Flows at 51T are highly correlated with Bear Creek flows from 1995-2015 (Spearman's rho: 0.937; $p<0.001$).

The "rkt" function in the "rkt" R package was used for long-term trend analysis (Marchetto, 2015). Sediment quality trends were analyzed using the Mann-Kendall test with no covariates or seasonality incorporated. An alpha value of 0.05 was selected to determine statistical significance. The Sen slope was generated to estimate the annual change in the median values. The Sen slope for nutrients and total suspended solids are presented as parts per billion (ppb [µg/L]) per year.

Values below the analytical detection limit were rare for all parameters except ammonia. For the non-parametric Mann-Kendall test, it is necessary to set all non-detects (i.e., samples with values below the detection limit) to the maximum among all method detection limits reported. This prevents biasing the test results due to shifting detection limits over time. The purpose of the analysis is to detect trends in environmental values, not laboratory methods.

In 1998 and 2007, the King County Environmental Lab (KCEL) made two important improvements to their methods and instrumentation for examining total and dissolved nutrients in the freshwater matrix. On July 1, 1998, KCEL began using a new sample preparation technique for total phosphorus and total nitrogen analysis. On January 1, 2007, the King County Environmental Lab switched the instrument used for the automated analysis of dissolved nutrients in addition to improving the sample preparation method for total nutrients. These laboratory method changes significantly altered the results for nutrients, impacting long-term data comparability. The correction factors published by King County (2016) were used to allow long-term trend analysis.

Due to inadequate long-term datasets, trend analysis for organic chemicals and total and dissolved metals could not be completed. Total metals data collected prior to August 1987 were analyzed using flame atomic absorption spectrometry, which, due to high detection limits, cannot be compared to the values measured using the inductively coupled plasma (ICP) atomic emission spectrometry (AES) and, later, the ICP mass spectrometry (ICP-MS). Dissolved metals were not analyzed until 1998.

For total metals, a step-trend test was used where the estimated metal concentrations measured using the ICP or ICP-MS from 1988 to 1992 were compared to concentrations

measured between 2006 and 2010. This analysis was only possible at site 0484 due to a lack of metals data collected at the other sites. A Peto & Peto modification of the Gehan-Wilcoxon test (Harrington and Fleming, 1982) was used to compare the total metal concentration between the two five-year periods.

Trend analysis could not be completed for organic chemicals because water quality samples were only collected from 2001 to 2004, 2009, and 2010 at site 0484.

2.3 Comparison to Water Quality Standards

Fecal coliform, temperature, dissolved oxygen (DO), pH, ammonia, metals, and organic chemicals were compared to respective Washington State numeric water quality criteria as outlined in WAC 173-201A-200 and 240. Bear Creek and its tributaries are designated for extraordinary primary contact recreation and have designated aquatic life uses for core summer salmonid habitat and salmonid spawning, rearing, and migration.

2.3.1 Fecal coliform bacteria

Bear Creek and its tributaries are designated for extraordinary primary contact recreation. The criteria for Bear Creek are:

> Fecal coliform organism levels must not exceed a geometric mean value of 50 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100 colonies/100 mL.

2.3.2 Temperature and Dissolved Oxygen

Temperature and DO levels fluctuate over the day and night in response to changes in climatic conditions and river flows. DO is additionally impacted by the respiratory requirements of aquatic plants and algae. Since the health of aquatic species is tied predominantly to the pattern of maximum temperatures and of daily minimum oxygen concentrations, the criteria are expressed as the highest 7-day average of the daily maximum temperatures (7-DADMax) and 1-day minimum oxygen concentrations occurring in a water body. The designated uses to be protected within the Bear-Evans watershed include (1) Core Summer Salmonid Habitat and (2) Salmonid Spawning, Rearing, and Migration. The applicable temperature criteria for these designated uses are contained in 173-201A-200(c) as:

- To protect the designated aquatic life uses of "Core Summer Salmonid Habitat," the highest summer 7-DADMax temperature must not exceed 16°C (60.8°F) and 1-day minimum summer DO must not fall below 9.5 mg/L at a probability frequency of more than once every ten years on average. Summer is defined as June 15 to September 15.
- To protect the designated aquatic life uses of "Salmonid Spawning, Rearing, and Migration, and Salmonid Rearing and Migration Only," the highest 7-DADMax temperature must not exceed 17.5°C (63.5°F) and 1-day minimum DO must not fall

below 8.0 mg/L at a probability frequency of more than once every ten years on average.

In addition, all portions of the Bear and Cottage Lake Creeks, as well as Evans Creek downstream of river mile 0.8, have Supplemental Temperature Criteria and must not exceed 13°C between September 15 and May 15 (Ecology, 2011a).

Therefore at all monitoring stations (0484, B484, C484, J484, and N484) must adhere to the following water quality standards in regards to temperature and DO:

- **May 16 – September 14**: highest 7-DADMax temperature must not exceed **16 °C** more than once every ten years on average and 1-day minimum DO must not fall below **9.5 mg/L**.
- **September 15 – May 15**: highest 7-DADMax temperature must not exceed **13 °C** more than once every ten years on average and 1-day minimum DO must not fall below **9.5 mg/L**.

With a chosen threshold, an Index of Thermal Stress (ITS) can be calculated, which produces degree-day values above that threshold. A threshold of 16 °C was set because this is the "Most Recommended Value" to support the summer migrations of Chinook and sockeye (Ecology, 2002). As an example, a two-day exceedance at 18 °C [2 day x (18-16) = 4 degree-days] would count as four times as much thermal stress as a one-day exceedance at 17 °C (1 day x (17-16) = 1 degree-day]. The number of degree days between June 15 and September 15 were evaluated.

2.3.3 pH

The Washington state water quality standards state that pH shall be within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.2 units.

2.3.4 Toxic Substances (Un-ionized Ammonia, Metals, and Organic Chemicals)

Washington state has promulgated numeric water quality criteria for toxic substances "which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic toxicity to the most sensitive biota dependent upon those waters, or adversely affect public health" (WAC 173-201A-240). There are two categories of criteria: aquatic life protection and human health protection. The standards for metals and organic chemicals are presented in in Tables 4 and 5, respectively.

The Washington State aquatic life criteria contain both acute and chronic criteria. Acute criteria may represent either an instantaneous concentration not to be exceeded at any time or a 1-hour average concentration not to be exceeded more than once every three years. Chronic criteria may represent either a 24-hour average not to be exceeded or a 4-day average not to be exceeded more than once every three years. The criteria for cadmium, chromium-III, copper, lead, nickel, silver, and zinc are calculated based on water

hardness. To compare metals concentrations to the criteria, standard values were calculated using the hardness value for the corresponding metal sample.
The criteria for un-ionized ammonia are based on pH and temperature, and the level of un-ionized ammonia in the sample is estimated based on the total ammonia nitrogen concentration, pH, and temperature. For example, the un-ionized ammonia chronic criterion at 16 °C and a pH of 7 is 7.0 µg/L, and at 15.4 °C and a pH of 7.42, the criterion is 18.5 µg/L.

The human health criteria established by Washington State were calculated using a fish consumption rate of 175 g/day. Criteria for carcinogenic substances were calculated using a cancer risk level equal to one-in-one-million. The human health criteria calculations and variables include chronic durations of exposure up to seventy years.

Table 4. Washington State human health and freshwater aquatic life criteria for metals. All values in µg/L.

Analyte	Human Health Criteria	Freshwater Aquatic Life Criteria	
	Consumption of Organism	Acute	Chronic
Antimony, Total	180.	—	—
Arsenic, Dissolved	—	360[e]	190[f]
Arsenic, Total	10.	—	—
Cadmium, Dissolved	—	1.8[a,e]	0.64[a,f]
Chromium (III)[b]	—	320[a,e]	100[a,f]
Chromium (VI)	—	15[e]	10[f]
Copper, Dissolved	—	9.3[a,e]	6.5[a,f]
Lead, Dissolved	—	32[a,e]	1.24[a,f]
Mercury, Dissolved	—	2.1[e]	—
Mercury, Total	0.15	—	0.012[f]
Nickel, Dissolved	—	820[a,e]	91[a,f]
Nickel, Total	190	—	—
Selenium, Dissolved	480.	20[e]	5[f]
Silver, Dissolved	—	1.1[c]	—
Thallium, Total	0.27	—	—
Zinc, Dissolved	—	66[e]	61[f]
Zinc, Total	2,900.	—	—

a. Calculated based on median stream hardness (52.5 mg $CaCO_3$/L). However, individual samples were compared based on their associated hardness.
b. Represented by total chromium (WAC 173-201A-240; Table 24; Note 'gg': "Where methods to measure trivalent chromium are unavailable, these criteria are to be represented by total-recoverable chromium").
c. An instantaneous concentration not to be exceeded at any time.
d. A 24-hour average not to be exceeded.
e. A 1-hour average concentration not to be exceeded more than once every three years on the average.
f. A 4-day average concentration not to be exceeded more than once every three years on the average.

Table 5. Washington State human health and freshwater aquatic life criteria for organic chemicals.

Analyte	Human Health Criteria	Freshwater Aquatic Life Criteria	
	Consumption of Organism	Acute	Chronic
Chlorinated Herbicides and Pesticides			
4,4'-DDD	0.00036[a]	1.1[b]	0.001[c]
4,4'-DDE	0.00051[a]	1.1[b]	0.001[c]
4,4'-DDT	0.00025[a]	1.1[b]	0.001[c]
Aldrin	0.0000058[a]	2.5[b]	0.0019[c]
Alpha-BHC	0.00056[a]		
Beta-BHC	0.002[a]		
Chlordane	0.000093[a]	2.4[b]	0.0043[c]
Dieldrin	0.0000061[a]	2.5[b]	0.0019[c]
Endosulfan I	—	0.22[b]	0.056[c]
Endosulfan II	—	0.22[b]	0.056[c]
Endosulfan Sulfate	9.7	—	—
Endrin Aldehyde	0.035	—	—
Endrin	0.035	0.18[b]	0.0023[c]
Gamma-BHC (Lindane)	17.[a]	2[b]	0.08[c]
Heptachlor Epoxide	0.0000074[a]		
Heptachlor	0.00001[a]	0.52[b]	0.0038[c]
Hexachlorocyclopentadiene	630.[a]		
Toxaphene	0.000032[a]	0.73[d]	0.0002[e]
Organophosphate Pesticides			
Chlorpyrifos	—	0.083[d]	0.041[e]
Parathion-Ethyl	—	0.065[d]	0.013[e]
Parathion-Methyl	—	0.065[d]	0.013[e]
LPAHs			
2-Chloronaphthalene	180	—	—
Acenaphthene	110.	—	—
Anthracene	4,600.	—	—
Fluorene	610.	—	—
HPAHs			
Benzo(a)anthracene	0.021[a]	—	—
Benzo(a)pyrene	0.021[a]	—	—
Benzo(b)fluoranthene	0.021[a]	—	—

Analyte	Human Health Criteria	Freshwater Aquatic Life Criteria	
	Consumption of Organism	Acute	Chronic
Benzo(k)fluoranthene	0.021[a]	—	—
Dibenzo(a,h)anthracene	0.0021[a]	—	—
Chrysene	2.1[a]	—	—
Fluoranthene	16.	—	—
Indeno(1,2,3-Cd)Pyrene	0.021[a]	—	—
Pyrene	460.	—	—
PCBs			
Aroclor 1016	—	—	—
Aroclor 1221	—	—	—
Aroclor 1232	—	—	—
Aroclor 1242	—	—	—
Aroclor 1248	—	—	—
Aroclor 1254	—	—	—
Aroclor 1260	—	—	—
Total PCBs (Sum Aroclors)	0.00017[a]	2[d]	0.014[e]
Semi-Volatiles Organic Compounds (SVOCs)			
1,2-Dichlorobenzene	2,500.	—	—
1,2,4-Trichlorobenzene	0.14	—	—
1,3-Dichlorobenzene	16.	—	—
1,4-Dichlorobenzene	580.	—	—
2-Chlorophenol	17.	—	—
2,4-Dichlorophenol	34.[a]	—	—
2,4-Dimethylphenol	97.	—	—
2,4-Dinitrophenol	610.	—	—
2,4-Dinitrotoluene	0.18[a]	—	—
2,4,6-Trichlorophenol	0.28[a]	—	—
3,3'-Dichlorobenzidine	0.033[a]	—	—
4,6-Dinitro-O-Cresol	25.	—	—
Aniline	—	—	—
Butyl Benzyl Phthalate	0.58[a]	—	—
Bis(2-Chloroethyl)Ether	0.06[a]	—	—
Bis(2-Ethylhexyl)Phthalate	0.25[a]	—	—
Di-N-Butyl Phthalate	450.	—	—
Diethyl Phthalate	5,000.	—	—

Analyte	Human Health Criteria	Freshwater Aquatic Life Criteria	
	Consumption of Organism	Acute	Chronic
Dimethyl Phthalate	130,000.	—	—
Hexachlorobenzene	0.000052[a]	—	—
Hexachlorobutadiene	4.1[a]	—	—
Hexachloroethane	0.13[a]	—	—
Isophorone	110.[a]	—	—
N-Nitrosodi-N-Propylamine	0.058[a]	—	—
N-Nitrosodimethylamine	0.34[a]	—	—
N-Nitrosodiphenylamine	0.69[a]	—	—
Nitrobenzene	310.	—	—
Pentachlorophenol	0.1[a]	3.32[d,f]	2.1[e,f]
Phenol	200,000.	—	—

a. This criterion is based on carcinogenicity of 10-6 risk. Alternate risk levels may be obtained by moving the decimal point (e.g., for a risk level of 10-5, move the decimal point in the recommended criterion one place to the right).
b. An instantaneous concentration not to be exceeded at any time.
c. A 24-hour average not to be exceeded.
d. A 1-hour average concentration not to be exceeded more than once every three years on the average.
e. A 4-day average concentration not to be exceeded more than once every three years on the average.
f. Calculated based on pH

2.3.5 Sediment Cleanup Standards

Sediment chemistry and toxicity data were compared to Sediment Cleanup Standards established under Washington State's freshwater Sediment Management Standards (SMS) (Ecology, 2013) to identify sites of potential concern because of contaminated sediments. The freshwater SMS Sediment Cleanup Standards were developed to be protective of benthic organisms. The standards include both chemical and biological criteria.

Unlike for marine sediments, no numeric chemical and biological criteria have been established for freshwater sediments as Sediment Quality Standards (SQS) or Sediment Impact Zone maximum criteria (SIZMAX) (WAC 173-204-340). The SQS are used for addressing the release of hazardous substances from discharges permitted under NPDES that have the potential to contaminate sediment. The SIZMAX is used as an upper limit for chemical concentrations or biological effects within the immediate vicinity of a permitted discharge if a sediment impact zone has been authorized. A narrative benthic standard for freshwater sediment states that Ecology will address the sediment impacts resulting from the release of hazardous substances on a case-by-case basis using best professional judgment (WAC 173-204-340).

The freshwater SMS Sediment Cleanup Standards include two levels of chemical criteria (WAC 173-204-563):

- The Sediment Cleanup Objective (SCO) is a "no adverse effects" level, meaning concentrations of chemicals in sediment below this level are expected to have no adverse effects on the benthic community. It is the level of biological effects permissible after completion of a cleanup action.
- The Cleanup Screening Level (CSL) is the "minor adverse effects" level, which is used as an upper regulatory level for source control and cleanup decision making.

Concentrations that fall between the SCO and CSL have an unknown effect on the benthic community. The chemical SCOs and CSLs are presented in Table 6.

Table 6. Freshwater Chemical Sediment Cleanup Objectives (SCOs) and Cleanup Screening Levels (CSLs) (dry-weight basis).

Chemical Parameter	SCO	CSL
Conventional chemicals (mg/kg)		
Ammonia	230	300
Total sulfides	39	61
Metals (mg/kg)		
Arsenic	14	120
Cadmium	2.1	5.4
Chromium	72	88
Copper	400	1,200
Lead	360	> 1,300
Mercury	0.66	0.8
Nickel	26	110
Selenium	11	> 20
Silver	0.57	1.7
Zinc	3,200	> 4,200
Organic Chemicals (µg/kg)		
4-Methylphenol	260	2,000
Benzoic acid	2,900	3,800
Beta-Hexachlorocyclohexane	7.2	11
Bis(2-ethylhexyl) phthalate	500	22,000
Carbazole	900	1100
Dibenzofuran	200	680
Dibutyltin	910	130,000
Dieldrin	4.9	9.3
Di-n-butyl phthalate	380	1,000
Di-n-octyl phthalate	39	> 1,100
Endrin ketone	8.5	> 8.5
Monobutyltin	540	> 4,800
Pentachlorophenol	1,200	> 1,200
Phenol	120	210

Chemical Parameter	SCO	CSL
Tetrabutyltin	97	> 97
Total PCB Aroclors	110	2,500
Total DDDs	310	860
Total DDEs	21	33
Total DDTs	100	8100
Total PAHs	17,000	30,000
Tributyltin	47	320
Bulk Petroleum Hydrocarbons (mg/kg)		
Total petroleum hydrocarbon (TPH) - diesel	340	510
Total petroleum hydrocarbon (TPH) - residual	3,600	4,400

A ">" (greater than) before a CSL that the level is unknown but is above the concentration shown. If test results show concentrations above this CSL, bioassays should be conducted to evaluate potential benthic community toxicity. In this Lake Union/Ship Canal report, the minimum value provided in this table is treated as the CSL.

3.0 RESULTS

This section provides the results of the long-term trend analysis. Data limitations are acknowledged within the individual sections split up by parameter. Appendix A presents an analysis of the correlation between flow and the measured water quality parameters. Long-term trend results broken out by individual season are presented in Appendix E.

3.1 Fecal Coliform Bacteria

The surface Water Quality Standards for the State of Washington (WAC 173-201A) contain bacteria criteria designed to reduce the risk of people becoming ill from eating shellfish, swimming, or wading in the waters of the state. The current criterion for bacterial pollution is based on using fecal coliform as an indicator of public health risk to persons coming in contact with these surface waters.

3.1.1 Summary Statistics

Fecal coliform concentrations are highly variable at all sites, with concentrations ranging from less than 10 to 10,000 CFU/100 mL (Table 7; Figure 3). Generally, concentrations are greater during wet-weather and in downstream Bear Creek (site 0484 and C484). Fecal coliform concentrations were highly variable throughout the year, but values were typically greater between the months of May and October at all sites (Figure 4).

Table 7. Summary statistics for fecal coliform bacteria in Bear Creek basin (CFU/100 mL).

Site	Event	Years	FOD	Mean	Median	Min	Max
0484	Routine	2001-2015	178/178	150	70	5	1,900
	Wet-weather	2001-2010	25/25	1,090	500	39	3,900
B484	Routine	2001-2008, 2013-2015	129/129	118	51	4	2,900
C484	Routine	2001-2008, 2013-2015	135/135	284	120	10	10,000
J484	Routine	2001-2008	93/93	88.8	62	7	560
N484	Routine	2001-2008, 2013-2015	134/134	129	63	5	1,500

FOD: Frequency of detection

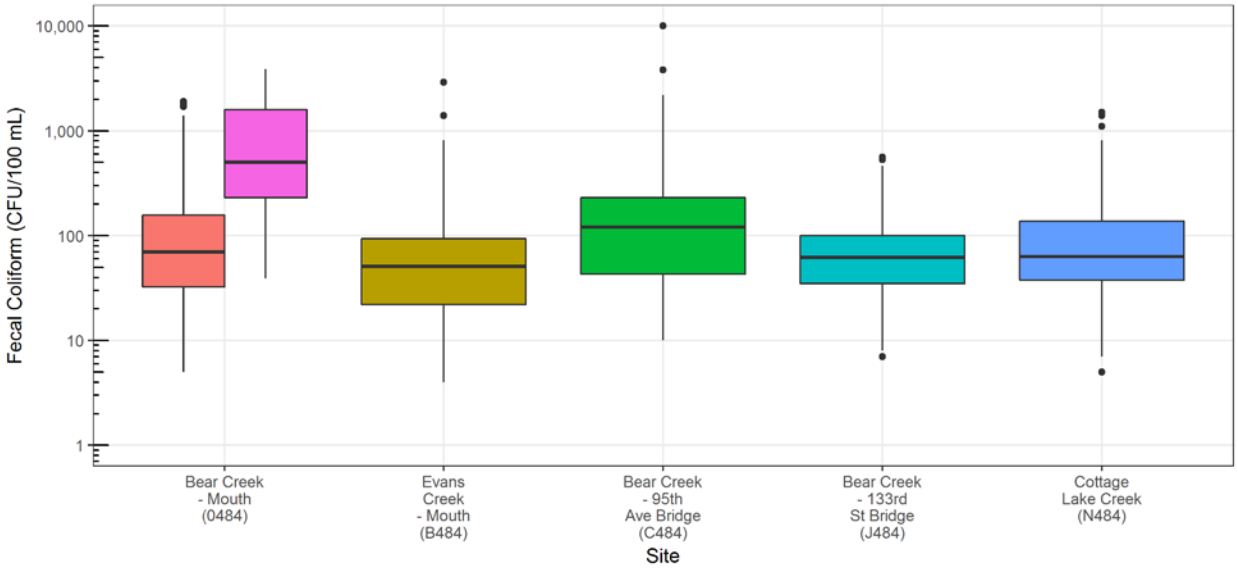

Figure 3. Fecal coliform concentrations at Bear Creek basin sites. Years included in statistics varied by site (Table 7). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

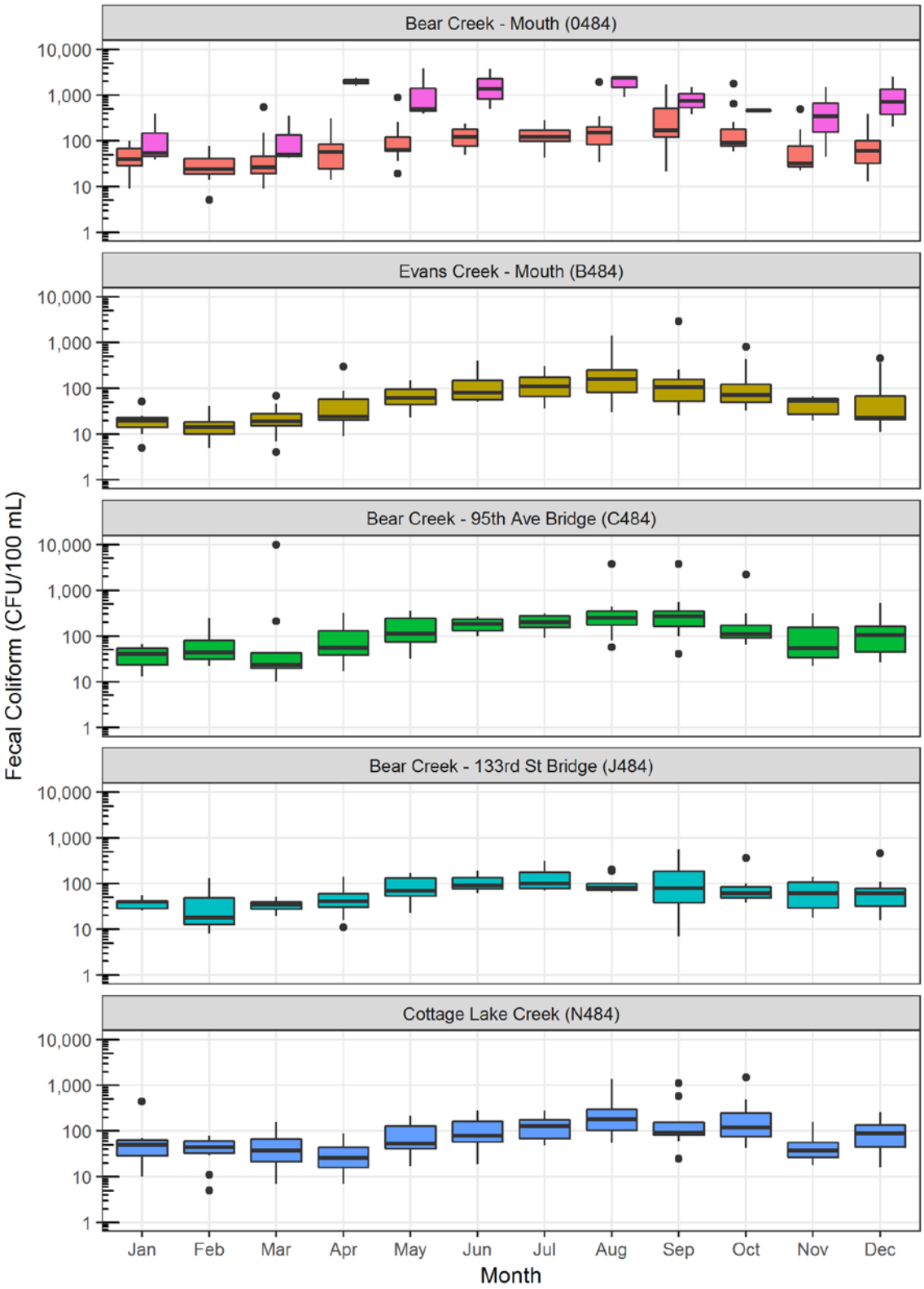

Figure 4. Monthly fecal coliform concentrations in the Bear Creek basin. Years included in statistics varied by site (Table 8). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

3.1.2 Long-term Trends

At all monitored sites, fecal coliform concentrations have significantly decreased since the 1970s (Table 8; Figure 5). The greatest decrease occurred at the furthest downstream station (0484) with a downward trend of 14.3 CFU/100 mL per year. The rate of decrease appears to be consistent across the years monitored. At all sites, the greatest magnitude of decline was seen during the summer season (Appendix E).

Table 8. Annual fecal coliform trend results from Seasonal Mann-Kendall test.

Site	Years Evaluated	p-value	Sen Slope (CFU/100mL/year)	Tau	Change 1975 to 2015[a]
0484	1971 – 2015	**<0.0001**	**-14.3**	**-0.43**	**-91%**
B484	1971 – 2015	**<0.0001**	**-2.69**	**-0.39**	**-82%**
C484	1974 – 2015	**<0.0001**	**-4.80**	**-0.33**	**-72%**
J484	1974 – 2008	**0.0011**	**-1.00**	**-0.16**	**-43%**
N484	1974 – 2015	**<0.0001**	**-2.67**	**-0.30**	**-69%**

a. Assuming constant slope.

3.1.3 Comparison to Water Quality Standards

Most fecal coliform bacteria do not cause disease, but co-exist in the intestines with disease-carrying pathogens that pose a public health risk. The higher the fecal bacteria counts, the higher the probability of pathogenic bacteria pollution. The efficacy of fecal coliforms as a fecal contamination indicator may be examined through its relationship with *E. coli*. The level of *E. coli* in surface waters is not a perfect indicator of disease-carrying pathogens, but *E. coli* has been found to have stronger relationships with human health outcomes than fecal coliform in epidemiological studies (Wade et al., 2003).

From 1999 to 2008, *E. coli* was monitored at the Bear Creek watershed long-term monitoring stations along with fecal coliform (n=629). A generalized linear mixed-effects model was completed to examine the relationship between the two fecal indicators. Values were log-transformed prior to the analysis. The model showed strong correlation between the two bacteria:

$$\log(EC) = 0.464 + 0.903 * \log(FC)$$
$$p<0.0001$$

This indicates that a 1 percent increase in fecal coliform (FC) results in a 0.9 percent increase in *E. coli* (EC). This shows that in the Bear Creek watershed fecal coliform bacteria are typically a strong indicator of *E. coli* and are not strongly impacted by non-fecal bacteria sources. However, several cases exist where fecal coliform levels are much higher than *E. coli*. For example, a sample from site 0484 on Feb. 1, 2000 following a 1-inch storm found fecal coliform bacteria levels of 1,000 CFU/100 mL, whereas the *E. coli* level was 9 CFU/100 mL. Fecal coliform bacteria may be used in Bear Creek as a strong, albeit imperfect, indicator of fecal contamination and therefore, human-health risk.

The routine sampling data indicate that Bear Creek and its tributaries often exceed the 90th percentile numeric criterion (100 CFU/100 mL) and geometric mean numeric criterion (Figures 6 and 7). Few years exist where monitoring data indicate the geometric mean or 90th percentile criteria were not exceeded. The frequency and magnitude of exceedances appear to be decreasing.

The data confirm that elevated fecal coliform concentrations in Bear Creek basin are an ongoing water quality impairment, but conditions are improving. A fecal coliform TMDL is currently in place to address this impairment (Ecology, 2011b).

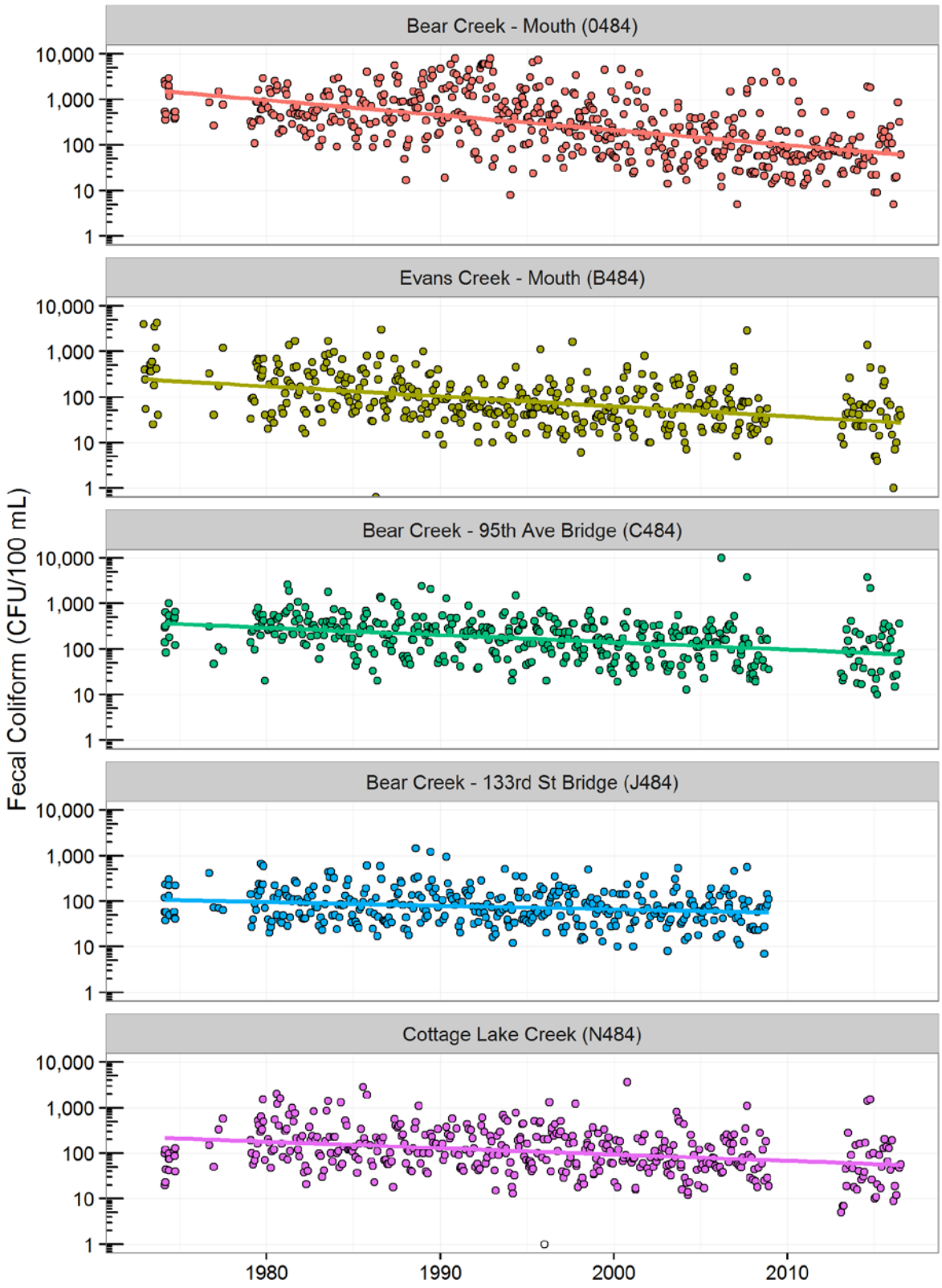

Figure 5. Long-term fecal coliform concentrations in the Bear Creek basin. Note log-scale.

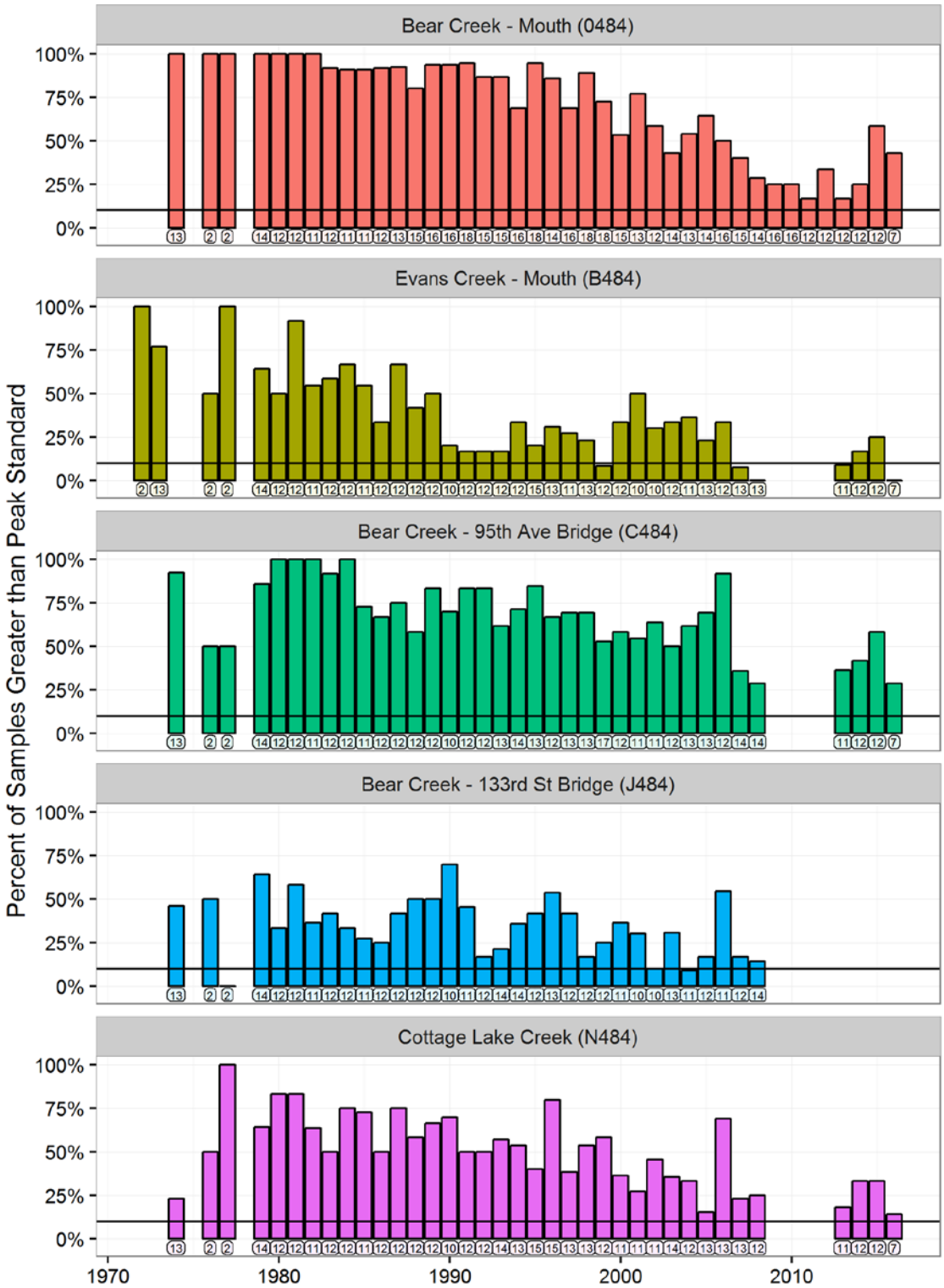

Figure 6. Frequency of exceedance of peak fecal coliform standard. Total number of samples provided. Black line shows standard of no more than 10 percent of samples exceeding 100 CFU/100 mL

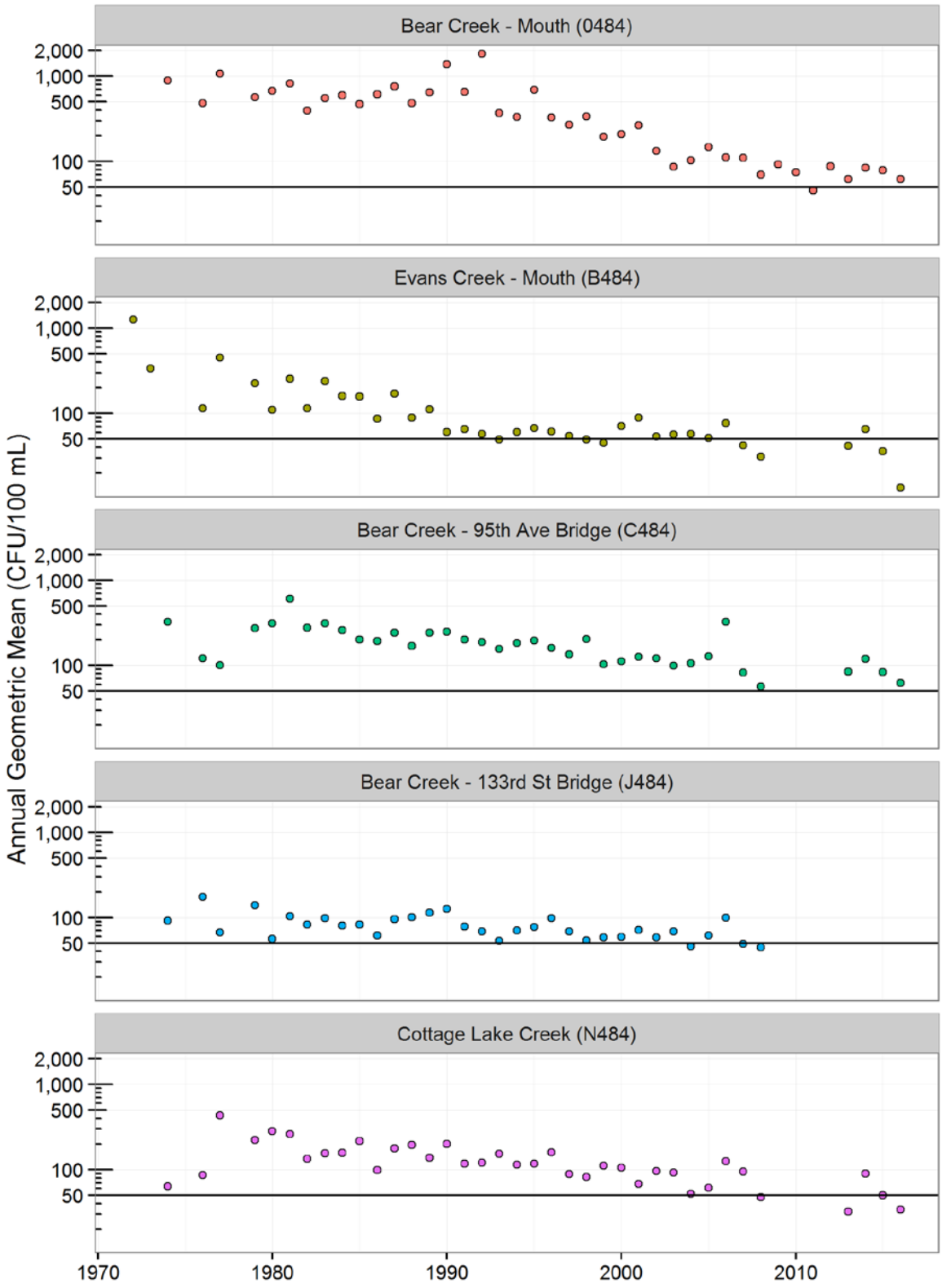

Figure 7. Annual geometric mean of fecal coliform bacteria. Black line shows standard of 50 CFU/100 mL

3.2 Temperature

Temperature is an important physical parameter for aquatic systems as it influences many of the chemical processes in water (e.g., dissolved oxygen concentration). Temperature also exerts a major influence on biological activity, growth, and therefore ultimately the survival of aquatic organisms.

3.2.1 Summary Statistics

Temperatures at the five routine monitoring stations are similar (Table 9; Figure 8). The annual average temperature in the Bear Creek basin is between 10 and 11 °C, and ranged from less than 1 °C to 21 °C in the routine samples. Strong seasonal differences were apparent for temperature in the Bear Creek basin with the warmest temperatures in July and August and coolest in January (Figure 9).

Table 9. Summary statistics for temperature in Bear Creek basin (°C).

Site	Event	Years	FOD	Mean	Median	Min	Max
0484	Routine	2001-2015	180/180	10.9	10.8	0.85	20.9
	Wet-weather	2001-2010	25/25	10.4	10.7	1.83	17.4
B484	Routine	2001-2008, 2013-2015	128/128	10.7	11.0	1.39	19.7
C484	Routine	2001-2008, 2013-2015	134/134	10.7	10.7	1.89	19.8
J484	Routine	2001-2008	93/93	10.5	10.6	2.23	18.4
N484	Routine	2001-2008, 2013-2015	134/134	10.3	10.3	2.32	21.0

FOD: Frequency of detection

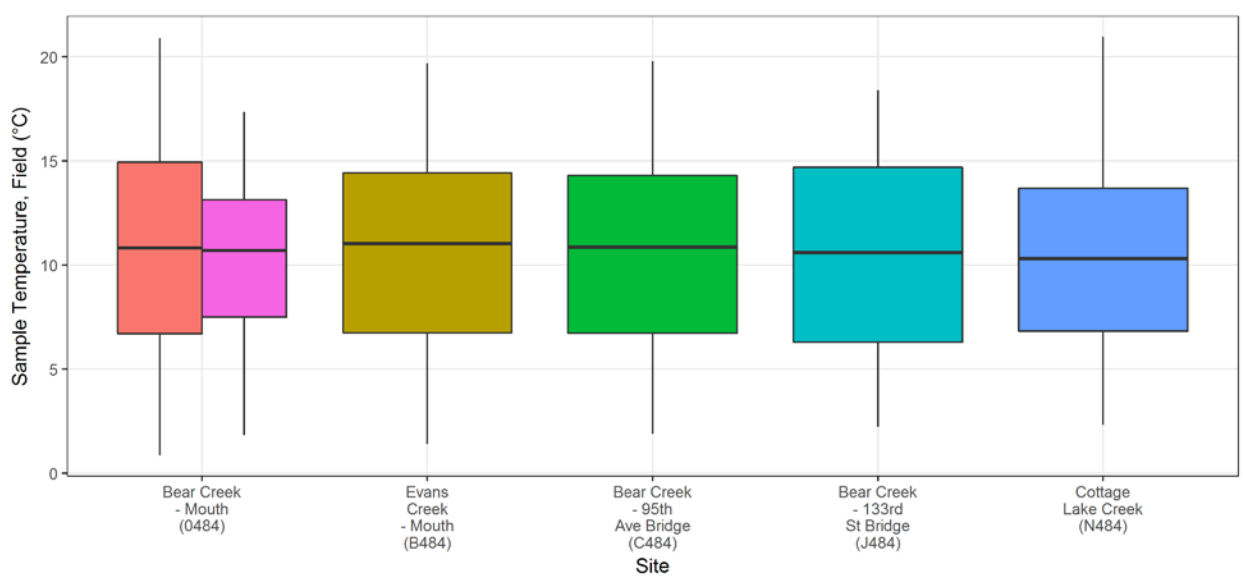

Figure 8. Water temperature at Bear Creek basin sites. Years included in statistics varied by site (Table 9). Mouth site (0484) broken up into routine (red) and wet-weather (pink).

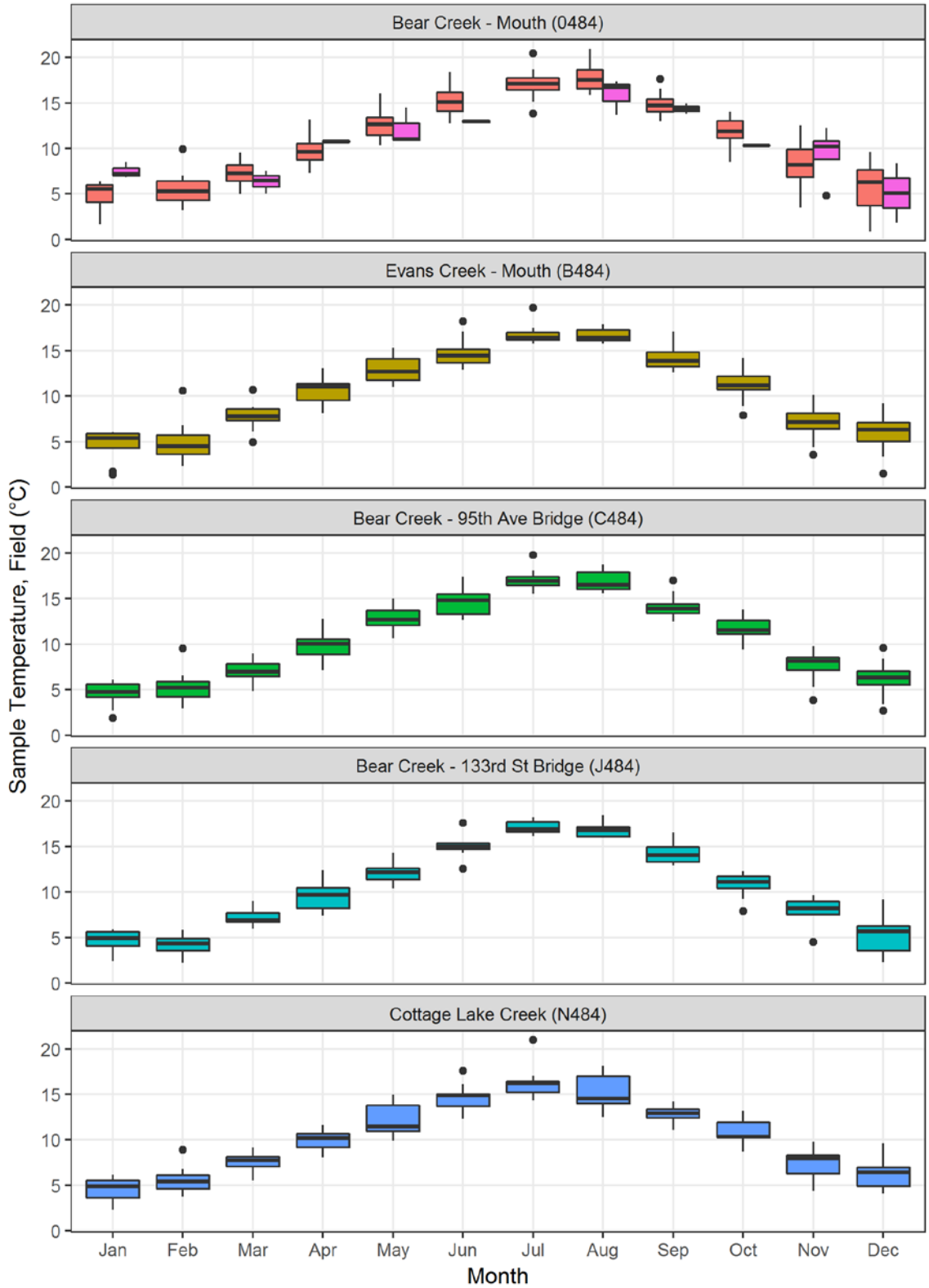

Figure 9. Monthly temperature data in the Bear Creek basin. Years included in statistics varied by site (Table 10). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

3.2.2 Long-term Trends

At all monitored sites, temperatures have significantly increased since the 1970s (Table 10; Figure 10). The greatest increase was seen at downstream Evans Creek (B484) at 0.056 °C per year. Warming in Cottage Lake Creek (N484) and in downstream Bear Creek (0484) were similar at 0.033 and 0.029 °C per year, respectively. Warming was greater at Bear Creek upstream of its confluence with Evans Creek (C484) and at the site 3.1 miles further upstream (J484) at 0.046 and 0.041 °C per year. Temperature during the winter months did not significantly change at any site, and summer temperatures increased at the greatest rate between 0.06 and 0.09 °C per year at each site (Appendix E).

Table 10. Annual temperature trend results from Seasonal Mann-Kendall test.

Site	Years Evaluated	p-value	Sen Slope (°C/year)	Tau	Change 1975 to 2015[a]
0484	1971 – 2015	**0.0013**	**0.033**	**0.14**	**13%**
B484	1971 – 2015	**<0.0001**	**0.056**	**0.22**	**24%**
C484	1974 – 2015	**0.0002**	**0.046**	**0.18**	**20%**
J484	1974 – 2008	**0.0048**	**0.041**	**0.14**	**18%**
N484	1974 – 2015	**0.0040**	**0.029**	**0.13**	**12%**
a. Assuming constant slope.					

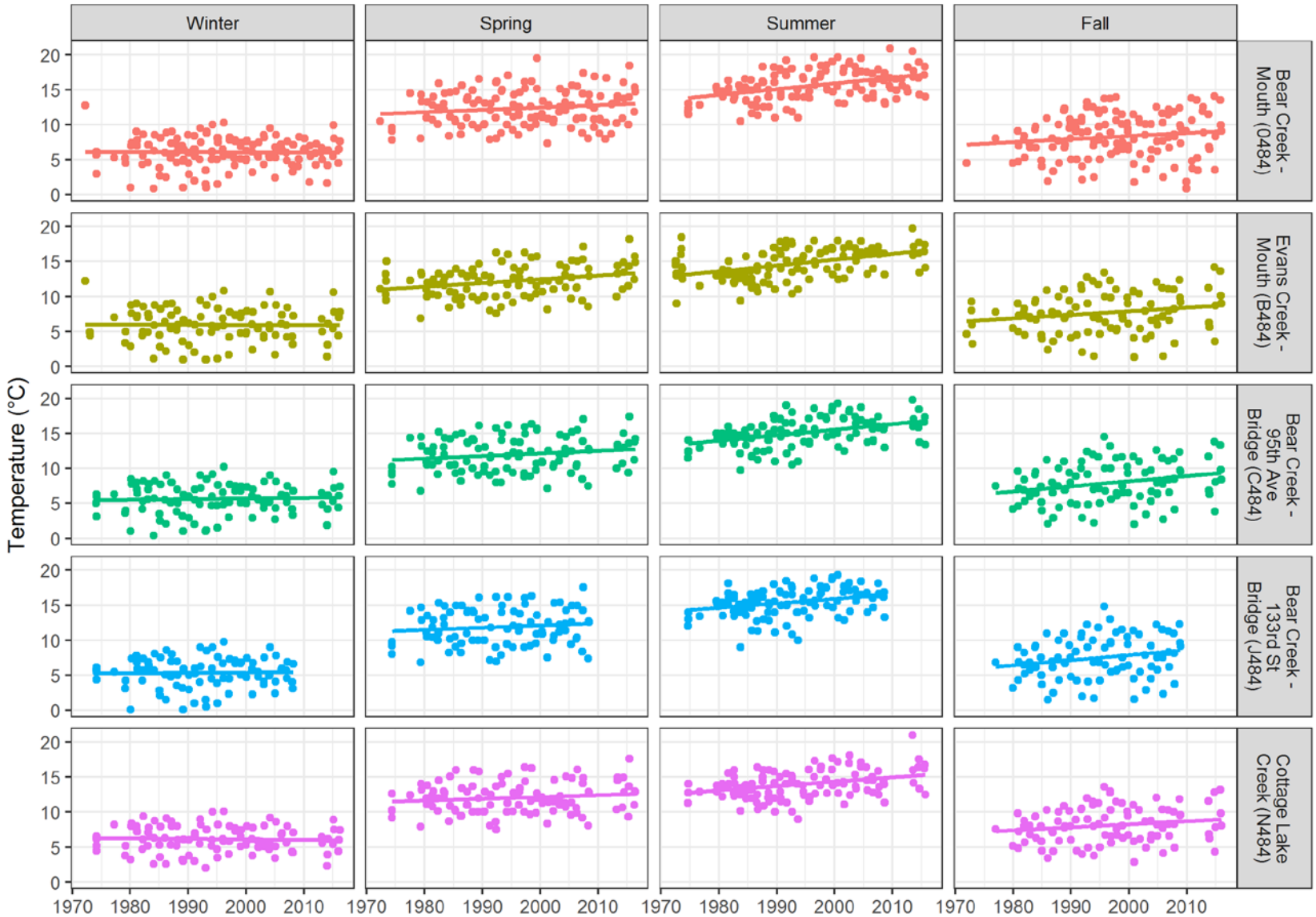

Figure 10. Long-term seasonal temperature trends in the Bear Creek basin.

3.2.3 Comparison to Water Quality Standards

Continuous temperature data from six King County stations were used to compare to the numeric temperature criteria in the state's water quality standards. The gages were located in lower Bear Creek (02a) near the 0484 sampling site, lower Evans Creek (18a) near the B484 sampling site, upper Bear Creek (02e) near the J484 sampling site, far-upper Bear Creek (02f) at Woodinville Duvall Rd., Cottage Lake Creek (02L) at NE 159th St (see Figure 2).

The data confirm that elevated temperatures in Bear Creek basin are an ongoing water quality impairment. A temperature TMDL is currently in place to address this impairment (Ecology, 2011b).

For nearly every summer on record (1995-2015), temperatures at the monitored stations have exceeded the 16 °C water quality criterion spanning the entire period (Figure 11). The single exception was in 2002 at the 02e gage – all other station monitored in 2002 (02a, 02f, and 18a) exceeded the water quality criterion. Exceedances of the supplemental 13 °C criterion occur nearly every year in late September and early May.

Since 1995, the number of summer degree days at sites 18a, 02e, and 02f has increased significantly in Evans Creek (18a), Bear Creek at 133rd Ave Bridge (downstream of Seidel Creek) and at the Woodinville-Duvall Rd crossing (Table 11; Figure 12).

Table 11. Mann-Kendall trend results for summer degree-days.

Site	Years Evaluated	p-value	Sen Slope (degree-days/ year)	Tau
02a	1995-2015	0.3811	3.14	0.14
18a	1995-2015	**0.0001**	**10.4**	**0.61**
02e	1995-2015	**0.0275**	**6.3**	**0.35**
02f	1995-2015	**0.0060**	**13.4**	**0.52**
02L	2006-2015	--	--	--

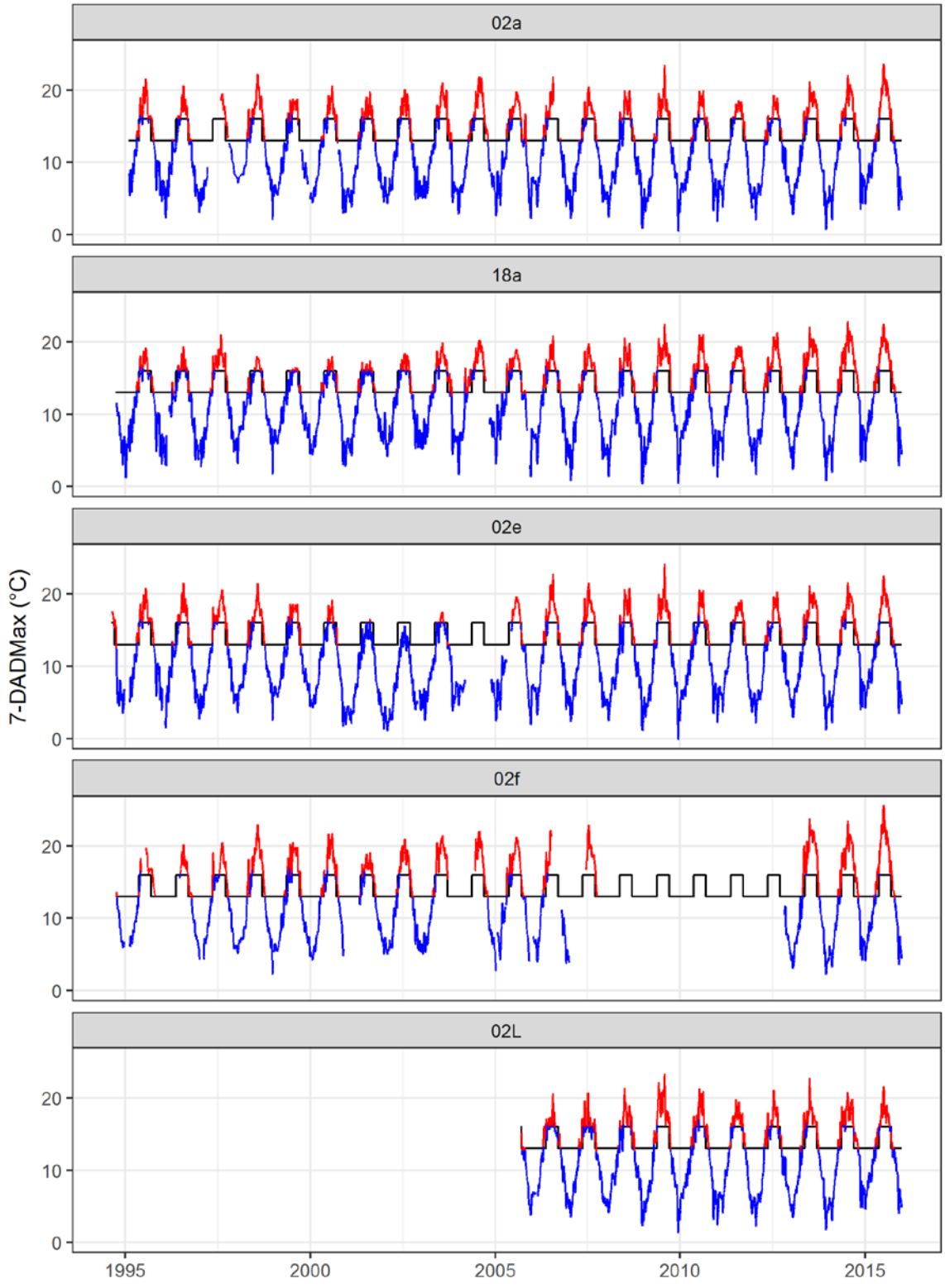

Figure 11. 7-DADMax at continuous water temperature stations in Bear Creek basin. Water quality criteria shown as black lines, values above standard in red, and values bellow in blue.

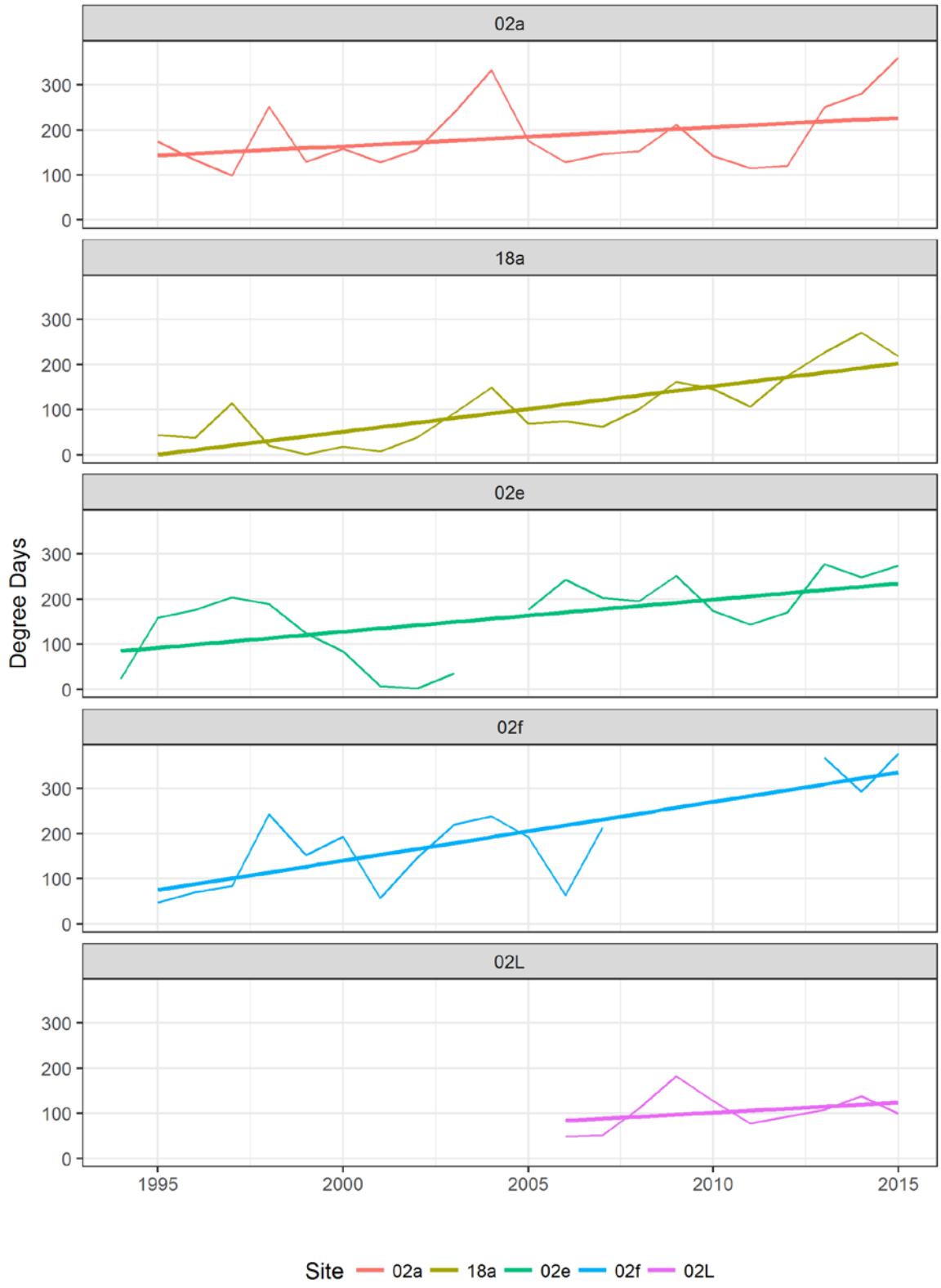

Figure 12. Summer (June 15 – Sept. 15) degree days based on 16 °C threshold. Thicker line indicates long-term trend.

3.3 Dissolved Oxygen

Dissolved oxygen is important to many of the chemical processes that are important in the aquatic environment. The concentration of dissolved oxygen is also important in determining the amount of habitat available for different types of aquatic organisms.

3.3.1 Summary Statistics

Dissolved oxygen concentrations are substantially lower in Evans Creek (B484) than in Bear and Cottage Lake creeks (Table 12; Figure 13). The average dissolved oxygen in the Bear and Cottage creeks is about 10.5 mg/L, while the average in Evans Creek is about 7.8 mg/L. The lower dissolved oxygen concentration in Evans Creek appears to occur year-round (Figure 14). Strong seasonal differences were apparent for dissolved oxygen in the Bear Creek basin mainstem corresponding to water temperature (Figure 14).

Table 12. Summary statistics for dissolved oxygen in Bear Creek basin (mg/L).

Site	Event	Years	FOD	Mean	Median	Min	Max
0484	Routine	2001-2015	177/177	10.4	10.4	6.5	13.5
	Wet-weather	2001-2010	25/25	10.2	9.8	8.2	12.8
B484	Routine	2001-2008, 2013-2015	128/128	7.81	7.8	3.8	12.3
C484	Routine	2001-2008, 2013-2015	134/134	10.4	10.2	6.8	14.1
J484	Routine	2001-2008	93/93	10.4	10.0	7.5	14.3
N484	Routine	2001-2008, 2013-2015	134/134	10.5	10.5	7.9	14.5

FOD: Frequency of detection

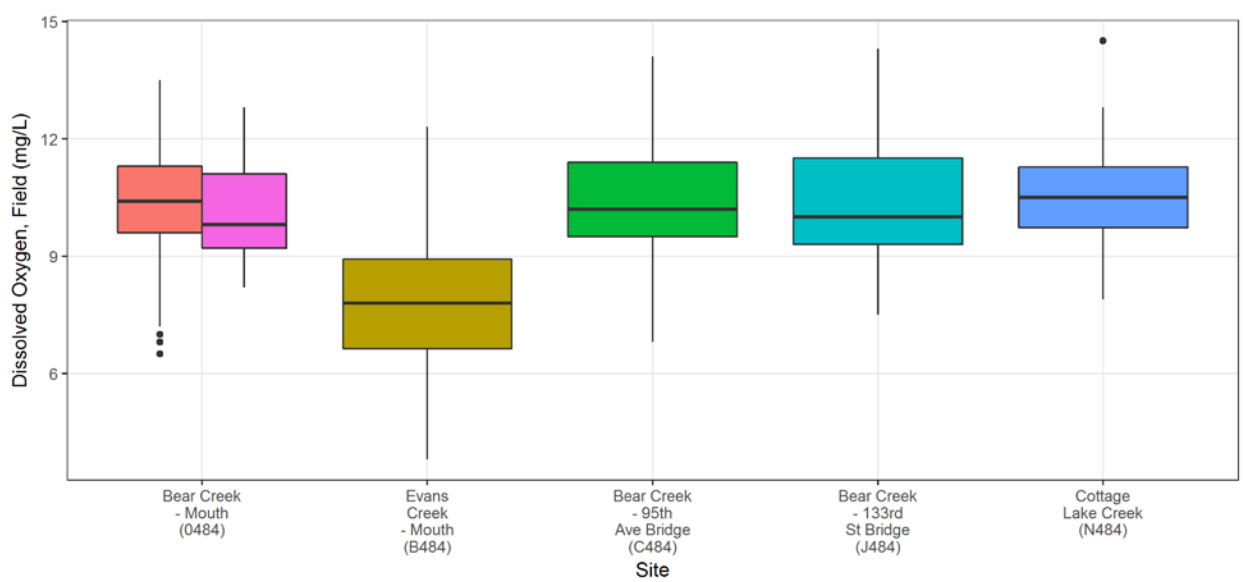

Figure 13. Dissolved oxygen concentrations at Bear Creek basin sites.Years included in the statistics vary by site (Table 12). Mouth site (0484) broken up into routine (red) and wet-weather (pink).

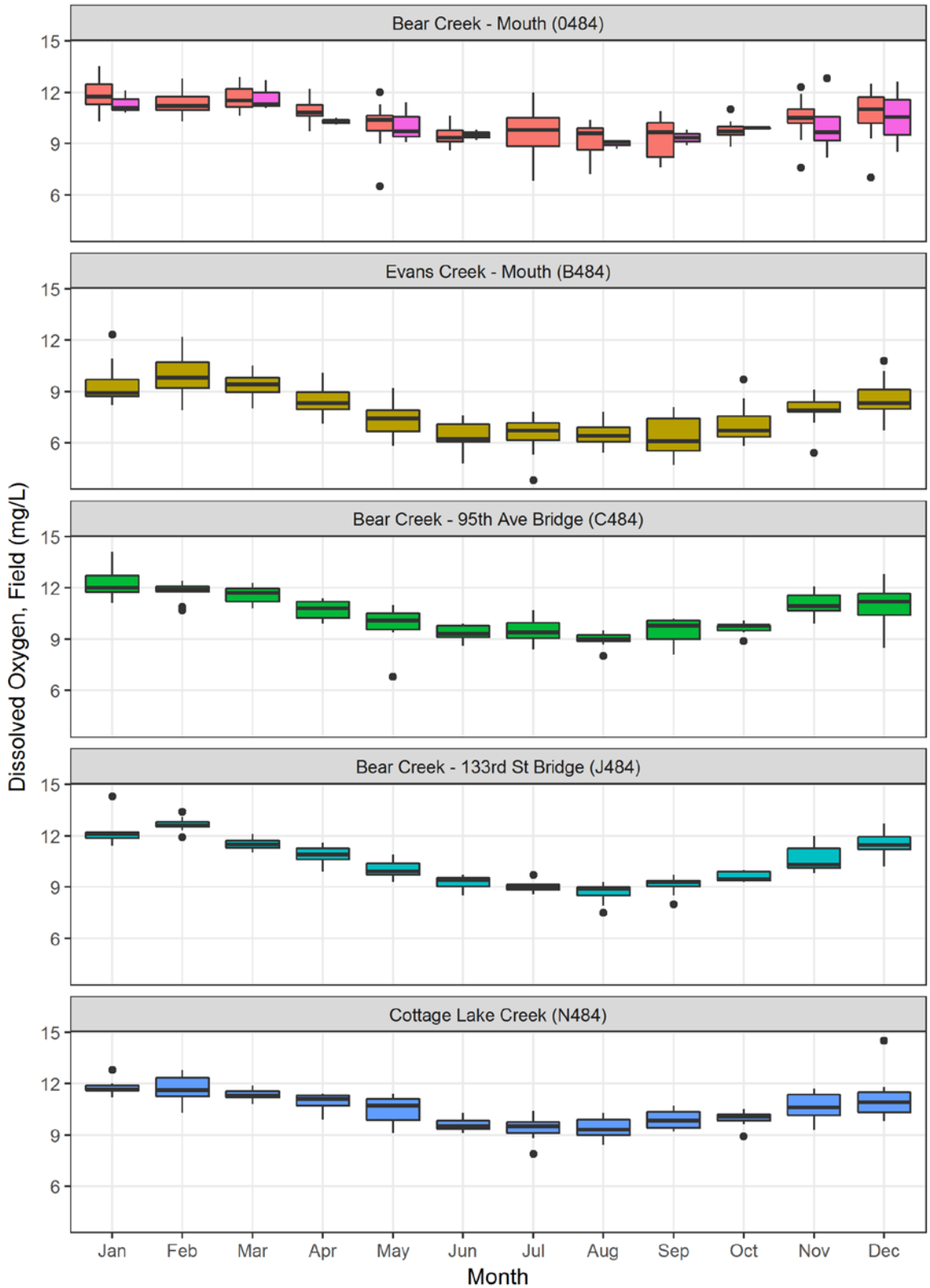

Figure 14. Monthly dissolved oxygen concentrations in the Bear Creek basin. Years included in the statistics vary by site (Table 13). Mouth site (0484) broken up into routine (red) and wet-weather (pink).

3.3.2 Long-term Trends

Since the 1970s, dissolved oxygen has decreased significantly at all Bear Creek sites except at the furthest downstream site (0484) (Table 13; Figure 15). Dissolved oxygen decreased at the greatest rate during the summer months (Appendix E). The rate of dissolved oxygen decrease was substantially greater in Evans Creek (B484) than at the other sites, approximately an order of magnitude.

In the late 1970s, the dissolved oxygen in Evans Creek was similar to that of the other sites in Bear Creek basin. In the following 40 years, Evans Creek dissolved oxygen levels have dropped relatively sharply (a 37 percent between 1975 and 2015) compared to the other sites (less than 6 percent).

Table 13. Annual dissolved oxygen trend results from Seasonal Mann-Kendall test.

Site	Years Evaluated	p-value	Sen Slope (ppm/year)	Tau	Change 1975 to 2015[a]
0484	1971 – 2015	0.2204	-0.005	-0.05	--
B484	1971 – 2015	**<0.0001**	**-0.10**	**-0.55**	**-37%**
C484	1974 – 2015	**0.0188**	**-0.010**	**-0.11**	**-3.7%**
J484	1974 – 2008	**0.0229**	**-0.010**	**-0.10**	**-3.8%**
N484	1974 – 2015	**0.0023**	**-0.014**	**-0.16**	**-5.2%**
a. Assuming constant slope.					

3.3.3 Comparison to Water Quality Standards

The water quality standard numeric criterion for dissolved oxygen states in for the Bear Creek basin states that the daily minimum DO must not fall below 9.5 mg/L.

In-situ samples are not ideal for estimating daily minimum DO concentrations. DO minima typically occur at night or in the early morning due to a lack of photosynthesis and the respiration of available DO. The King County monitoring stations on Bear Creek are typically sampled in the early afternoon, which corresponds with elevated rates of photosynthesis. The data indicate that DO often drops below the 9.5 mg/L criterion at all of the monitoring sites. During the rest of the year, DO levels not meeting the criterion appear to happen less frequently. Evans Creek (B484) often has DO values below 9.5 mg/L throughout most of the year. These data support identified DO impairment and the established TMDL for dissolved oxygen in the Bear-Evans watershed (Ecology, 2011b).

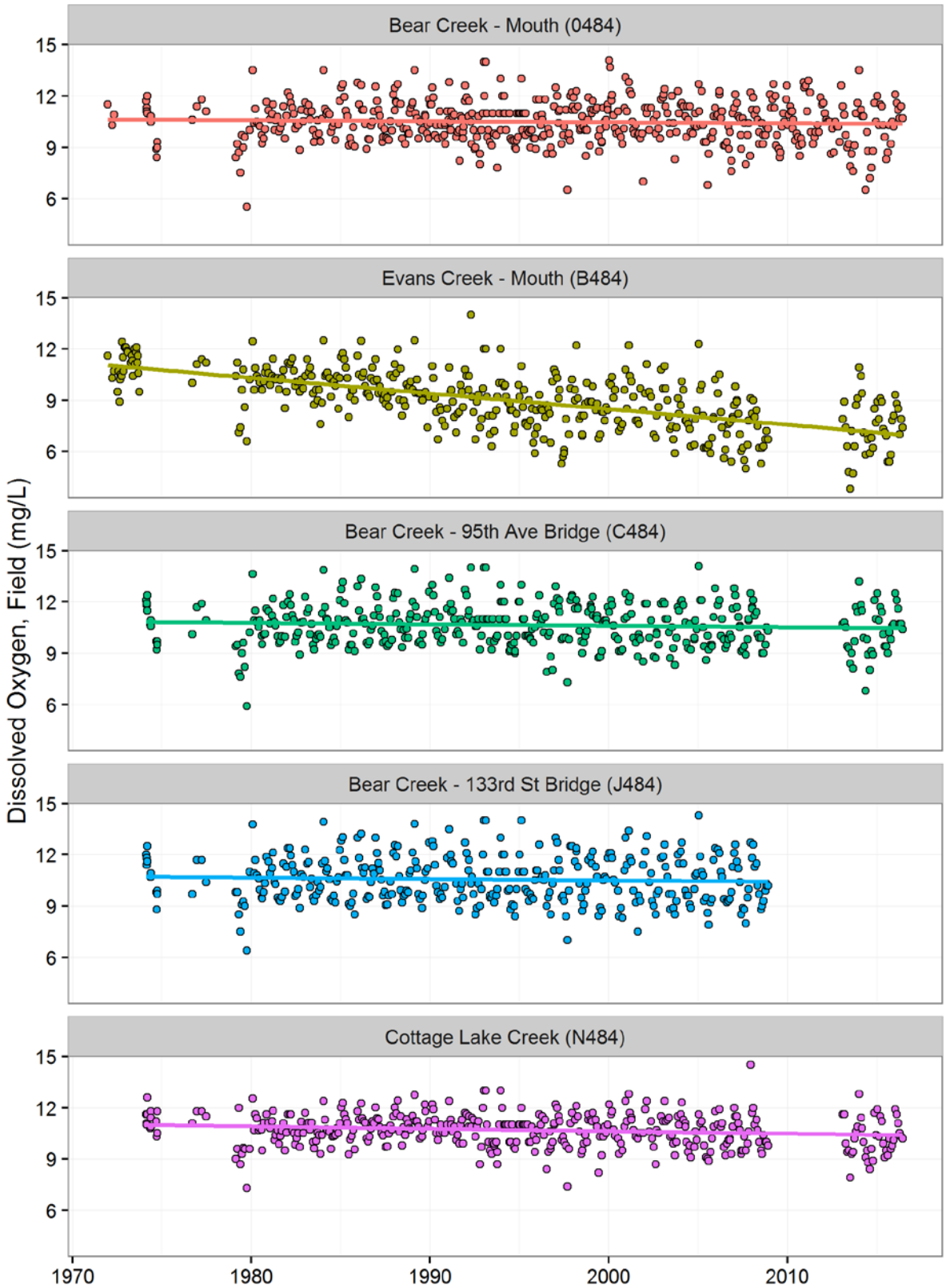

Figure 15. Long-term dissolved oxygen concentrations in the Bear Creek basin.

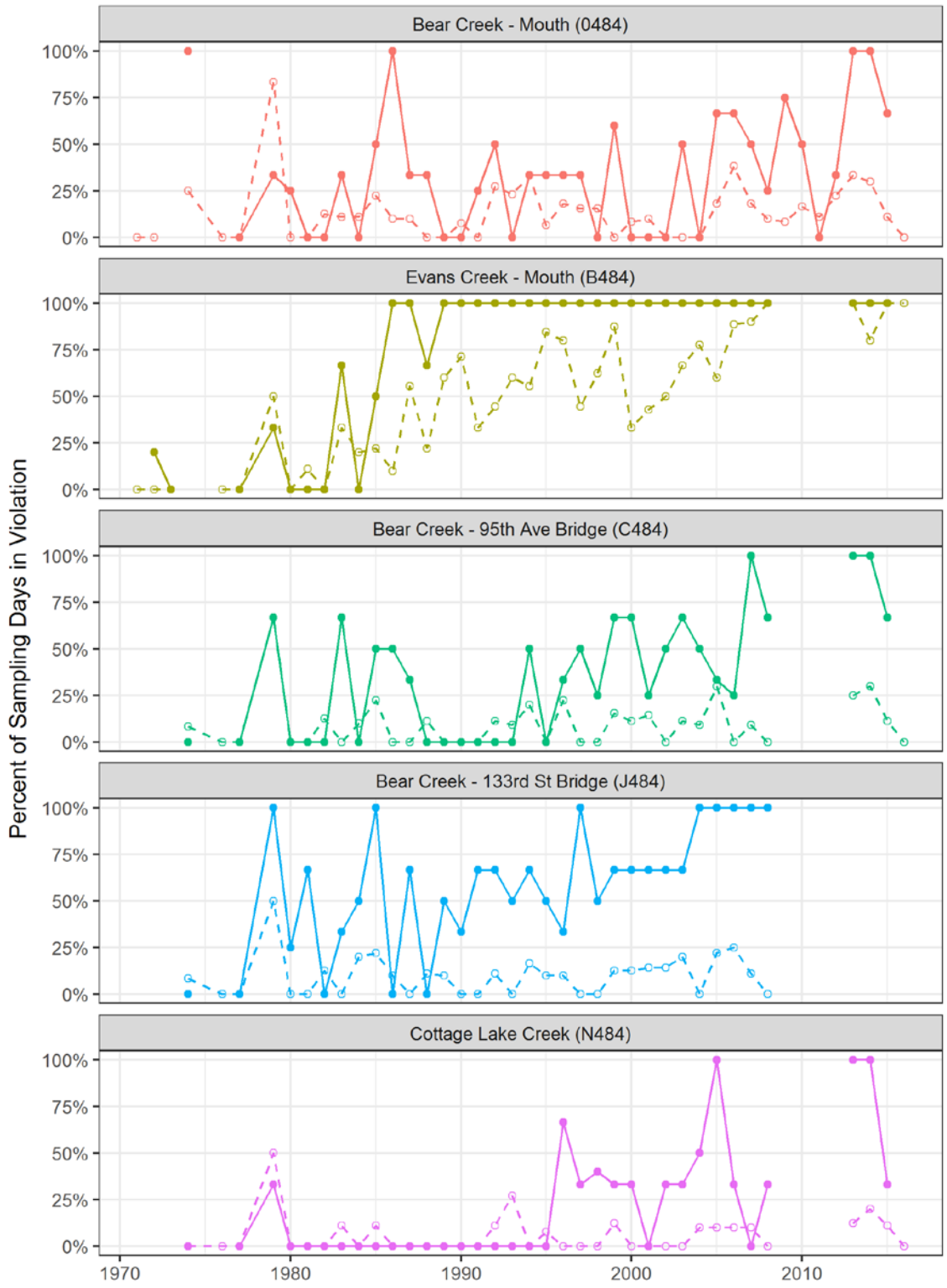

Figure 16. Percent of sampling days with values not meeting standard. Closed circles indicate percent of samples taken during summer (June 15 to Sept. 15), and open circles indicate samples taken outside summer.

3.4 pH

The pH of water is a measure of the concentration of hydrogen ions (H^+). A value higher than seven is considered basic, pH of seven is considered neutral, and a pH less than seven is considered acidic. The pH of water determines the solubility and biological availability of chemical constituents such as heavy metals and nutrients.

3.4.1 Summary Statistics

The pH in the Bear Creek basin ranges from slightly acidic to slightly basic (Table 14; Figure 17). Evans Creek is generally more acidic than Bear and Cottage creeks. Bear Creek (0484) was generally more acidic during wet-weather. Strong seasonal differences were apparent for pH in the Bear Creek basin with the highest values in June through October, corresponding with lower groundwater-driven flow (Figure 18).

Table 14. Summary statistics for pH in Bear Creek basin (unitless).

Site	Event	Years	FOD	Mean	Median	Min	Max
0484	Routine	2001-2015	181/181	7.39	7.34	6.5	8.22
	Wet-weather	2001-2010	25/25	7.19	7.20	6.7	7.5
B484	Routine	2001-2008, 2013-2015	129/129	6.99	7.00	6.4	7.5
C484	Routine	2001-2008, 2013-2015	135/135	7.39	7.40	6.7	8.0
J484	Routine	2001-2008	93/93	7.28	7.30	6.0	7.78
N484	Routine	2001-2008, 2013-2015	134/134	7.34	7.37	6.5	7.8

FOD: Frequency of detection

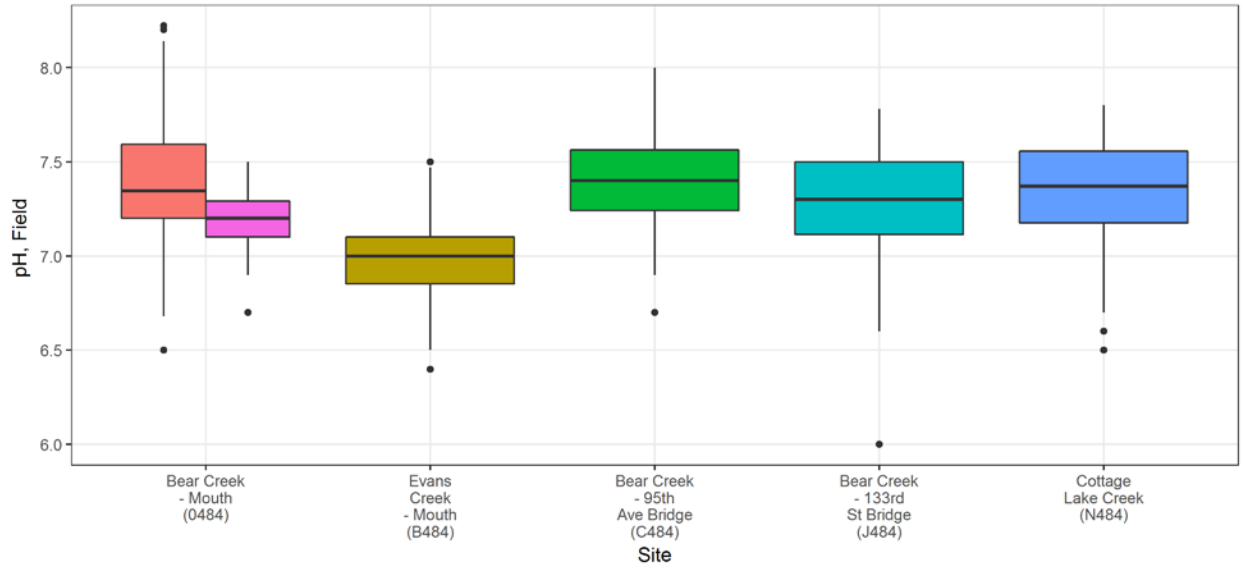

Figure 17. pH at Bear Creek basin sites. Years included in the statistics vary by site (Table 14). Mouth site (0484) broken up into routine (red) and wet-weather (pink).

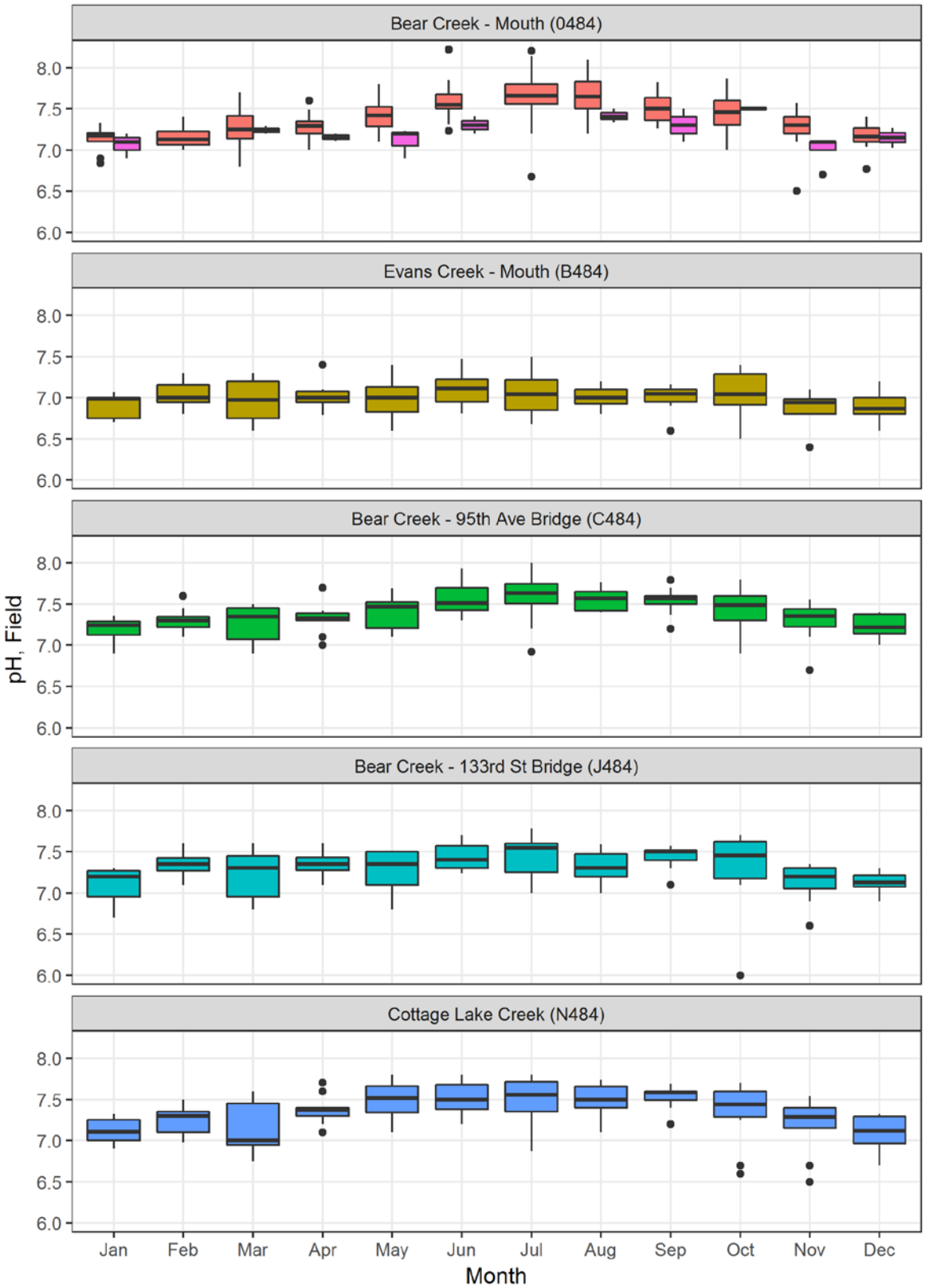

Figure 18. Monthly pH in the Bear Creek basin. Years included in the statistics vary by site (Table 15). Mouth site (0484) broken up into routine (red) and wet-weather (pink).

3.4.2 Long-term Trends

A significant decreasing trend in pH was found at Evans Creek (B484), while an increasing trend was found in Bear Creek upstream of the confluence of Bear and Evans creeks (C484) (Table 15; Figure 19). No significant trends were found at the other sites.

Table 15. Annual pH trend results from Seasonal Mann-Kendall test.

Site	Years Evaluated	p-value	Sen Slope (units/year)	Tau	Change 1975 to 2015[a]
0484	1971 – 2015	0.2617	--	0.05	--
B484	1971 – 2015	**<0.0001**	**-0.0084**	**-0.26**	**-4.6%**
C484	1974 – 2015	**0.0380**	**0.0037**	**0.13**	**2.0%**
J484	1974 – 2008	0.8267	--	0.027	--
N484	1974 – 2015	0.6002	--	-0.015	--

a. Assuming constant slope.

3.4.3 Comparison to Water Quality Criteria

The Washington State water quality standards state that pH shall be within the range of 6.5 to 8.5.

The pH values at the monitoring stations were very infrequently detected beyond the criterion range (Table 16). The samples in violation below 6.5, were collected in fall or spring, and were collected during stormflow events, except a single sample collected in July 2000 with a pH of 9.91 at site 0484 during low flow. The value of 9.91 is a singular outlier with the next highest pH measured at 8.4.

Table 16. Frequency of pH values outside water quality standards (1971-2015).

Site	Violation Frequency
0484	2/547
B484	4/430
C484	2/426
J484	5/373
N484	4/426

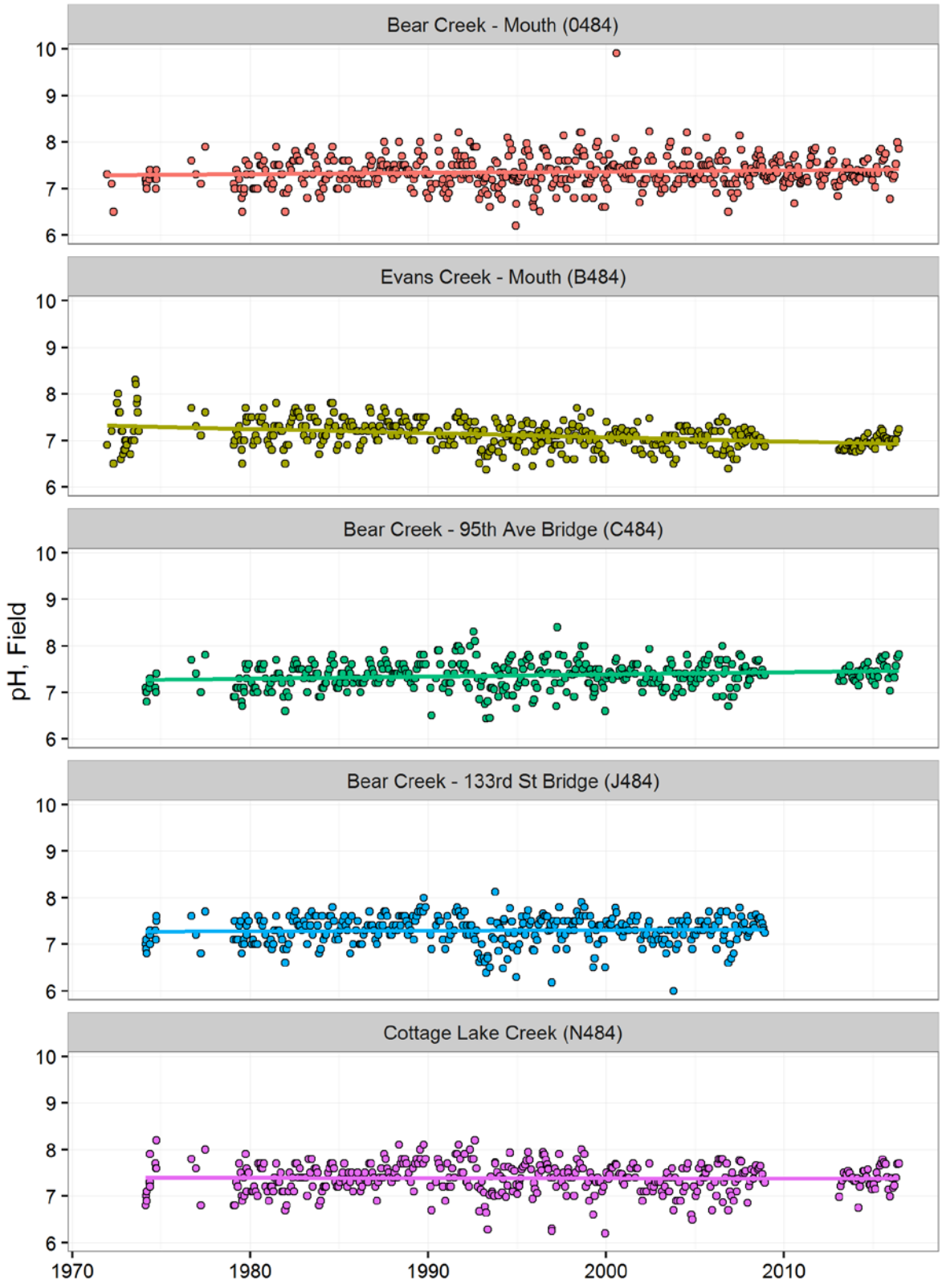

Figure 19. Long-term pH data in the Bear Creek basin.

3.5 Conductance

Conductance is a measure of the passage of electric current through water. The concentration of dissolved ions in water largely determines its conductance. Water in the Puget Sound region generally has low levels of dissolved minerals and relatively low conductance compared to regions with higher concentrations of dissolved minerals in the water. Conductance is typically greatest during the summer, when stream flows are not diluted with rain water. Increases in conductance can indicate the presence of dissolved ions potentially from a pollutant source. Increased conductance is often associated with increased land development. Much of the impervious surfaces are concrete, a large component of which is calcium, and concrete is known to weather (Davis et al., 2010, Kaushal and Belt 2012; King County, 2014).

3.5.1 Summary Statistics

Conductance is variable throughout the Bear Creek basin. Cottage Lake Creek (N484) and Evans Creek (B484) typically have greater conductance than mainstem Bear Creek, and upper Bear Creek (J484) has the lowest conductance (Table 17; Figure 20). Conductance was generally lower during wet-weather. Strong seasonal differences were apparent for conductance in the Bear Creek basin with the greatest values in June through October, corresponding with less dilution from precipitation and subsequently low, groundwater-driven flow (Figure 21).

Table 17. Summary statistics for conductance in Bear Creek basin (µS/cm).

Site	Event	Years	FOD	Mean	Median	Min	Max
0484	Routine	2001-2015	191/191	127	127	75.8	171
	Wet-weather	2001-2010	25/25	115	116	55.0	150
B484	Routine	2001-2008, 2013-2015	142/142	135	134	83.9	200
C484	Routine	2001-2008, 2013-2015	149/149	124	126	80.2	153
J484	Routine	2001-2008	106/106	101	99.5	69.6	166
N484	Routine	2001-2008, 2013-2015	148/148	140	142	55.3	172

FOD: Frequency of detection

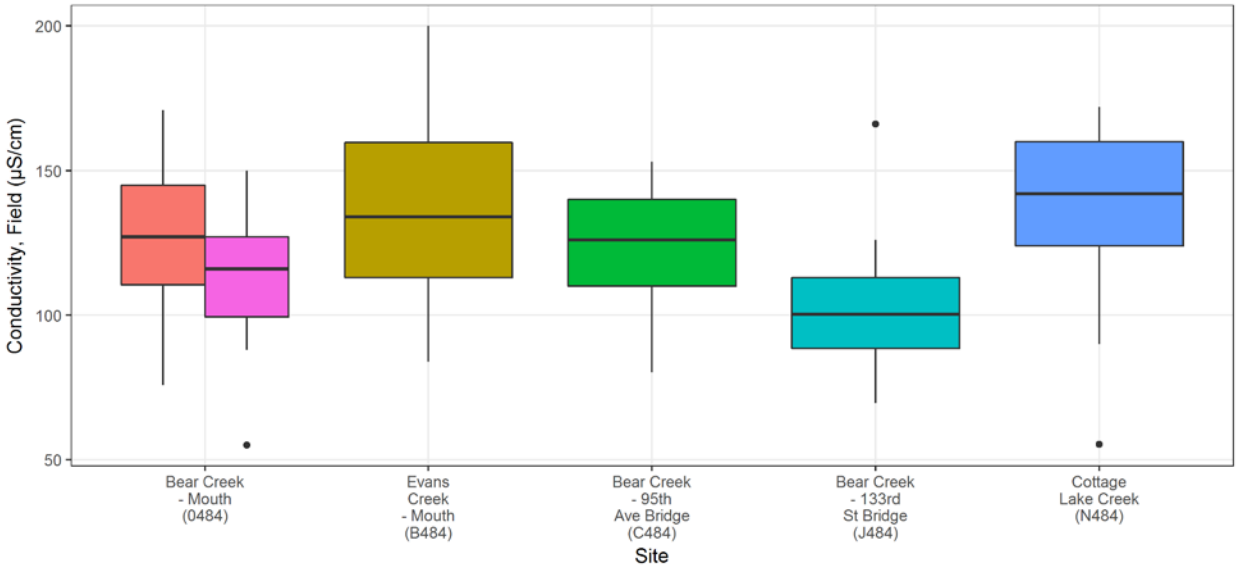

Figure 20. Conductance at Bear Creek basin sites. Years included in statistical analysis varied by site (Table 17). Mouth site (0484) broken up into routine (red) and wet-weather (pink).

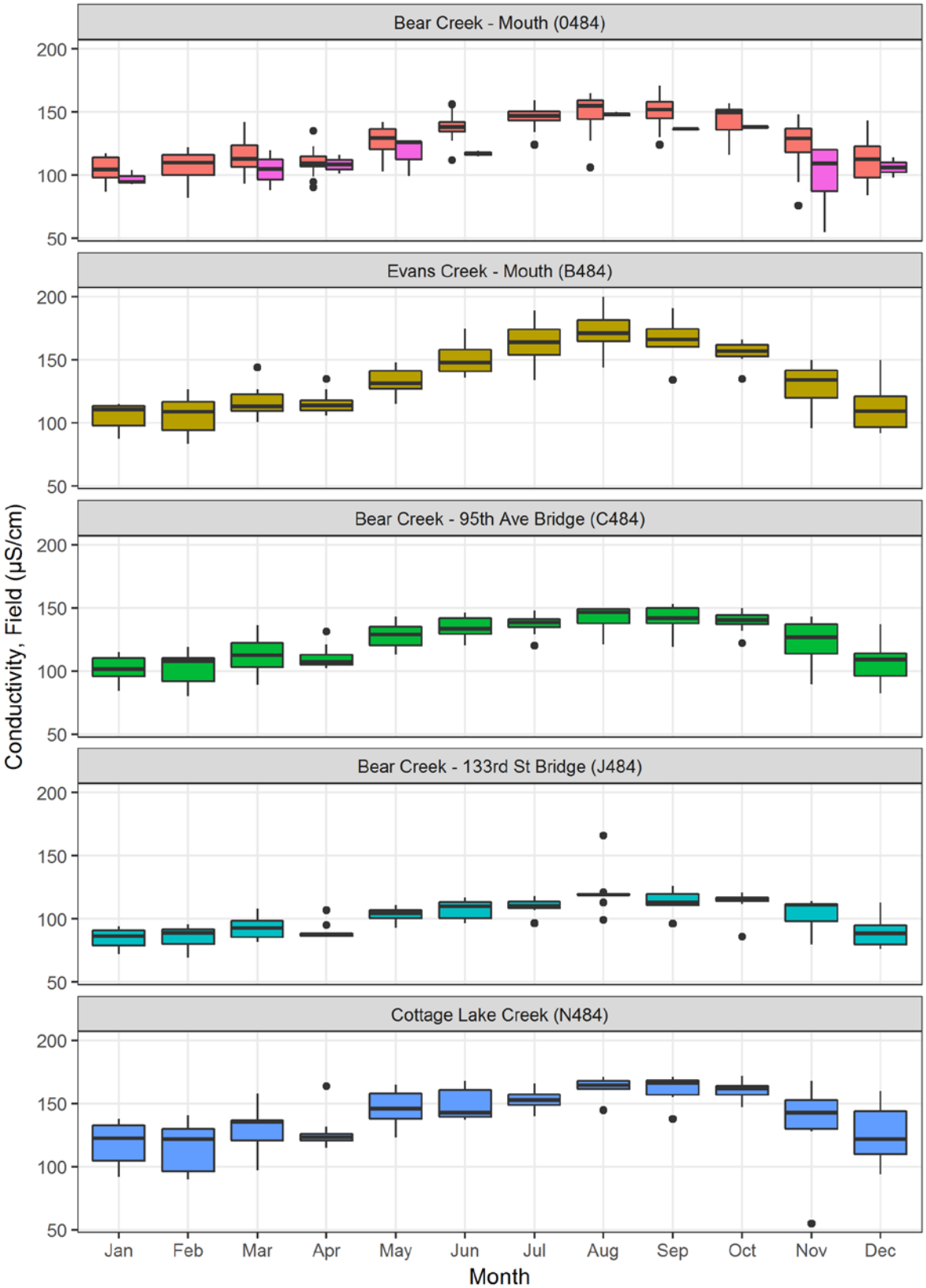

Figure 21. Monthly conductance values in the Bear Creek basin. Years included vary by site (Table 18). Mouth site (0484) broken up into routine (red) and wet-weather (pink).

3.5.2 Long-term Trends

At all monitored sites, conductance has significantly increased since the 1970s at rate of approximately 1 µS/cm per year, which has resulted in an about 50 percent greater conductance in 2015 relative to 1975 (Table 18; Figure 22). The increase appears to have occurred up until the mid-2000s, and conductance has remained more consistent over the past decade. The rate of conductance increase was generally similar among the four seasons (Appendix E).

Table 18. Annual conductance trend results from Seasonal Mann-Kendall test.

Site	Years Evaluated	p-value	Sen Slope (µS/cm/year)	Tau	Change 1975 to 2015[a]
0484	1971 – 2015	**<0.0001**	**1.0**	**0.46**	**41%**
B484	1971 – 2015	**<0.0001**	**1.2**	**0.44**	**47%**
C484	1974 – 2015	**<0.0001**	**1.2**	**0.55**	**56%**
J484	1974 – 2008	**<0.0001**	**1.0**	**0.50**	**54%**
N484	1974 – 2015	**<0.0001**	**1.3**	**0.50**	**53%**

a. Assuming constant slope.

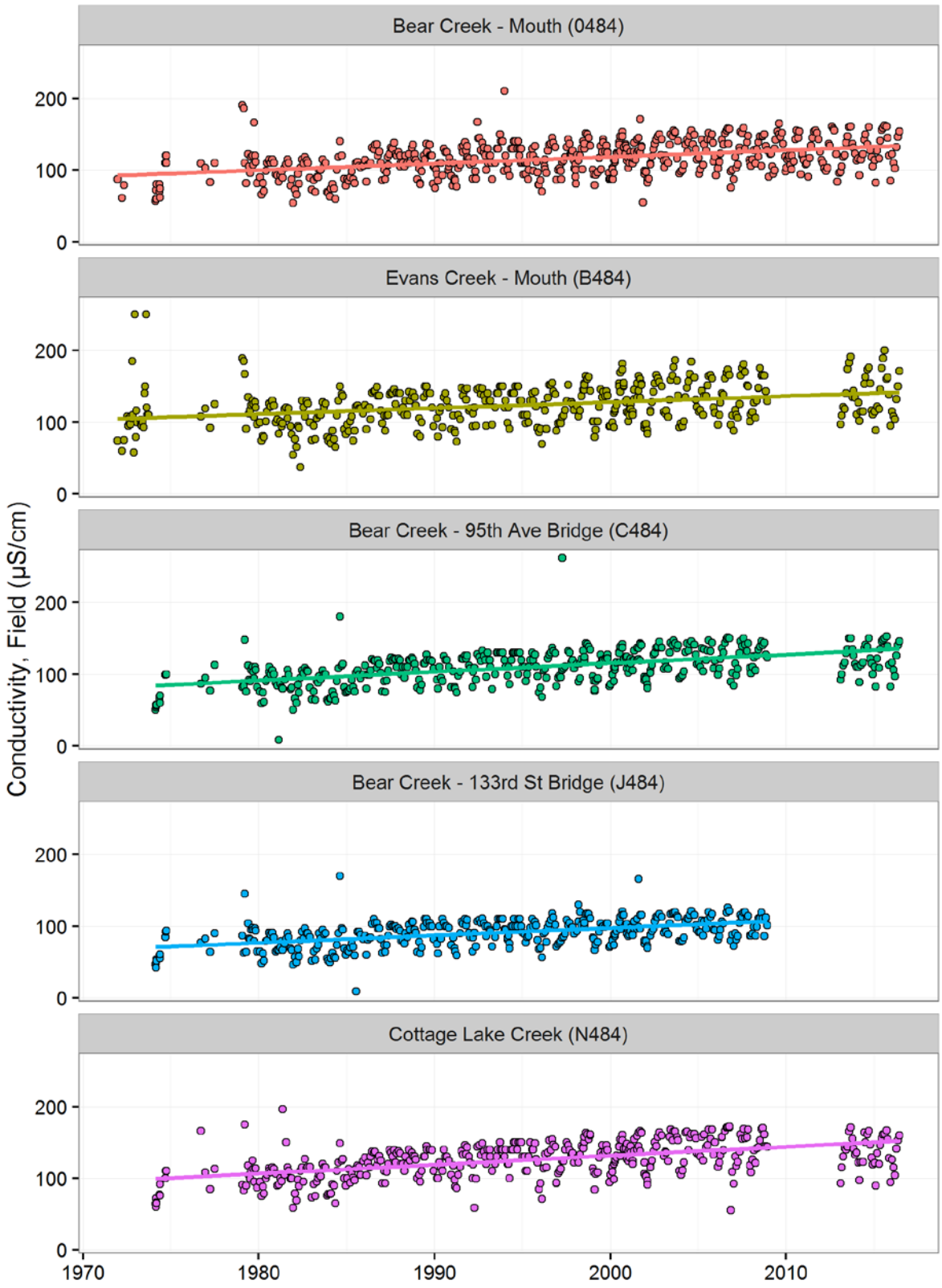

Figure 22. Long-term conductance in the Bear Creek basin.

3.6 Total Suspended Solids

Turbidity and total suspended solids (TSS) are two indicators used to estimate the amount of suspended material in the water, whether it is mineral (e.g., soil particles) or organic (e.g., plant material). Particulate matter provides attachment places for pollutants such as metals or bacteria to enter the receiving water. High concentrations of particulate matter can result in increased sedimentation that can impair important habitat for fish and invertebrates. In general, it is human activities within the watershed that usually results in higher turbidity and TSS measurements (e.g., development results in loss of vegetation, increased erosion, and runoff).

TSS is a measure of the actual weight of material per volume of water and is reported in milligrams per liter. This measurement becomes important when trying to calculate total quantities of material in a stream, or when trying to determine the loading of particulate matter into receiving waters.

3.6.1 Summary Statistics

Generally, total suspended solids concentrations are greatest at the Bear Creek mainstem sites. Evans, upper Bear, and Cottage Lake creeks have similar concentrations (Table 19; Figure 23). Concentration can vary greatly, ranging from less than 1 mg/L to over 100 mg/L, but typical values are between 3 and 9 mg/L with higher values associated with storm events and/or bank erosion. Strong seasonal differences were apparent for total suspended solids in the Bear Creek basin with the lowest concentrations late summer and the greatest in winter (Figure 24).

Table 19. Summary statistics for total suspended solids in Bear Creek basin (mg/L).

Site	Event	Years	FOD	Mean	Median	Min	Max
0484	Routine	2001-2015	178/178	6.7	5.1	0.6	48.4
	Wet-weather	2001-2010	25/25	25	14	3.6	127
B484	Routine	2001-2008, 2013-2015	129/129	4.8	4.1	0.8	23.9
C484	Routine	2001-2008, 2013-2015	139/139	7.2	5.8	1.5	42.0
J484	Routine	2001-2008	93/93	4.8	3.4	1.2	26.4
N484	Routine	2001-2008, 2013-2015	134/134	4.0	3.2	1.5	18.0

FOD: Frequency of detection

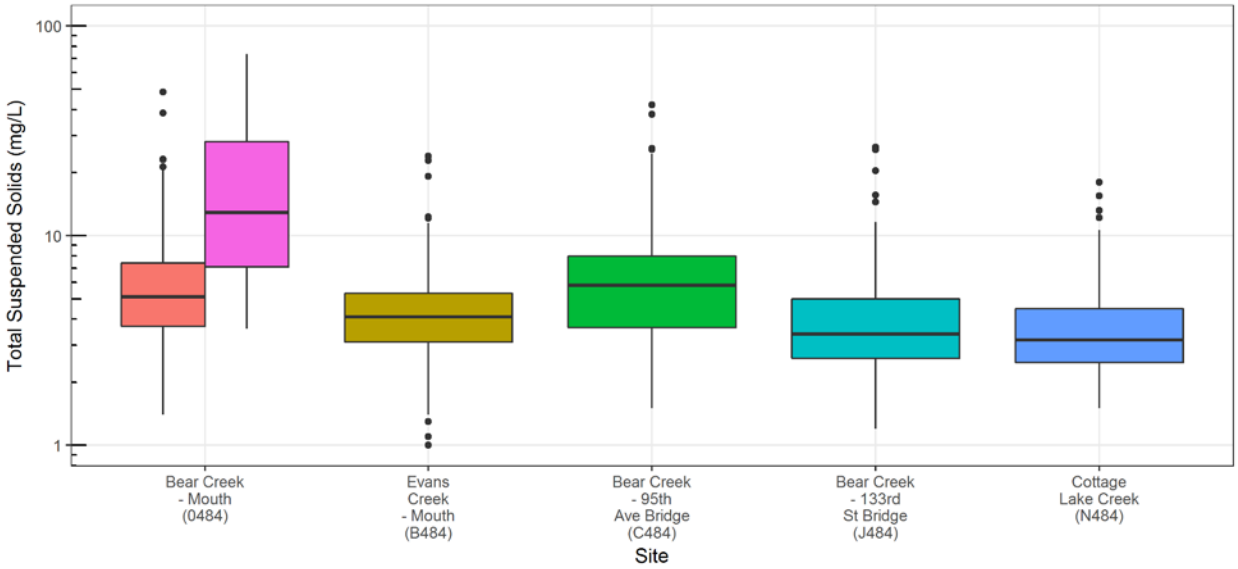

Figure 23. Total suspended solids concentrations at Bear Creek basin sites (2001-2015). Note log-scale. Years included in statistical analysis varied by site (Table 19). Mouth site (0484) broken up into routine (red) and wet-weather (pink).

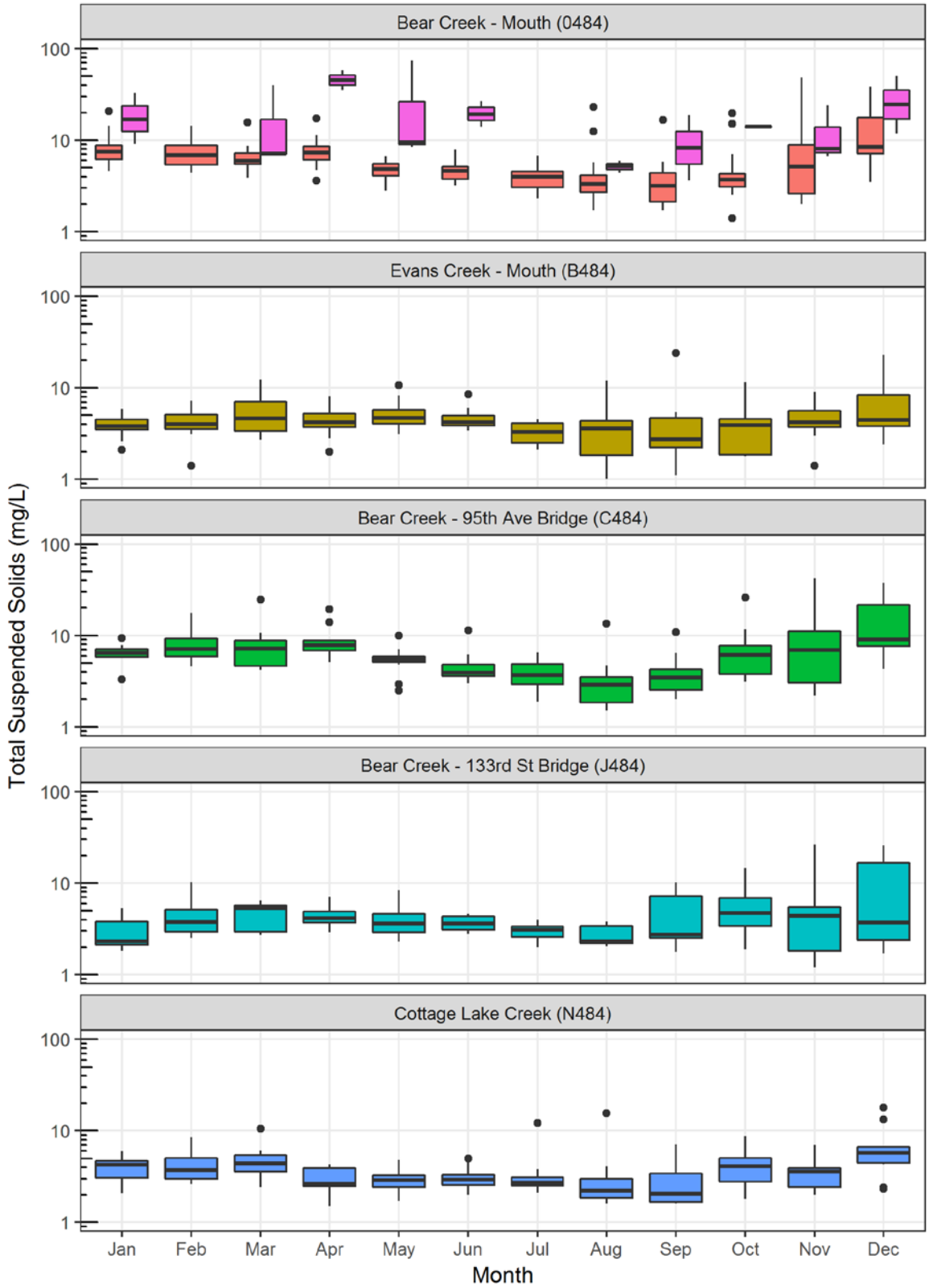

Figure 24. Monthly total suspended solids concentrations in the Bear Creek basin. Note log-scale. Years included in statistical analysis varied by site (Table 20). Mouth site (0484) broken up into routine (red) and wet-weather (pink).

3.6.2 Long-term Trends

At all monitored sites, total suspended solid concentrations have significantly decreased since the 1970s (Table 20; Figure 25). The greatest rates were seen at the downstream stations: 0484, B484, and C484, and generally, suspended solids levels have about halved between 1975 and 2015. The decrease in total suspended solids was greatest during the winter season (Appendix E).

Table 20. Annual total suspended solids trend results from Seasonal Mann-Kendall test.

Site	Years Evaluated	p-value	Sen Slope (ppb/year)	Tau	Change 1975 to 2015[a]
0484	1971 – 2015	**<0.0001**	**-110**	**-0.25**	**-44%**
B484	1971 – 2015	**<0.0001**	**-93**	**-0.27**	**-56%**
C484	1974 – 2015	**<0.0001**	**-97**	**-0.24**	**-44%**
J484	1974 – 2008	**0.0028**	**-50**	**-0.17**	**-40%**
N484	1974 – 2015	**<0.0001**	**-57**	**-0.23**	**-46%**
a. Assuming constant slope.					

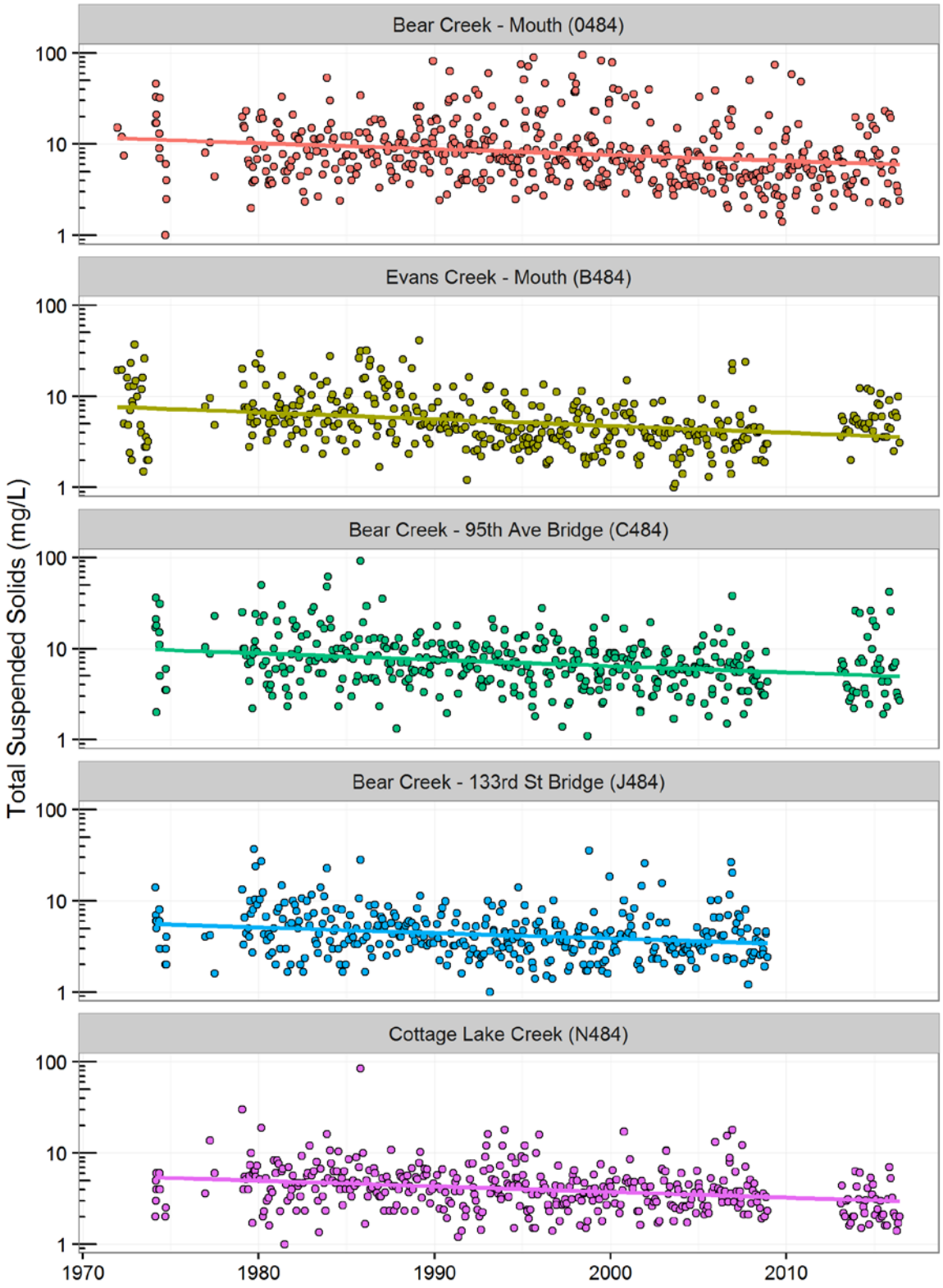

Figure 25. Long-term total suspended solids concentrations in the Bear Creek basin. Note log-scale.

3.7 Turbidity

Turbidity is measured as the amount of light scattered in a water sample and is reported as nephelometric turbidity units (NTU). The more material (e.g., erosion sediment, detritus, road grit) in the water, the greater the light scattering and higher NTU reading.

3.7.1 Summary Statistics

Similar to total suspended solids, turbidity is generally greatest at the mainstem Bear Creek sites. Evans, upper Bear, and Cottage Lake creeks have similar levels (Table 21; Figure 26). Turbidity can vary greatly, ranging from less than 1 NTU to over 50 NTU, but typical values are less than 5 NTU with higher values associated with storm events and/or bank erosion. Strong seasonal differences were apparent for turbidity in the Bear Creek basin with the lowest concentrations late summer and the greatest in winter (Figure 27).

Table 21. Summary statistics for turbidity in Bear Creek basin (NTU).

Site	Event	Years	FOD	Mean	Median	Min	Max
0484	Routine	2001-2015	143/143	4.17	3.59	0.79	14.3
	Wet-weather	2001-2008	17/17	13.7	8.09	2.86	55.4
B484	Routine	2001-2008, 2013-2015	129/129	3.9	3.27	1.30	34.5
C484	Routine	2001-2008, 2013-2015	135/135	4.03	3.47	1.19	16.6
J484	Routine	2001-2008	93/93	2.25	2.00	0.75	7.14
N484	Routine	2001-2008, 2013-2015	134/134	2.31	2.00	0.69	9.73

FOD: Frequency of detection

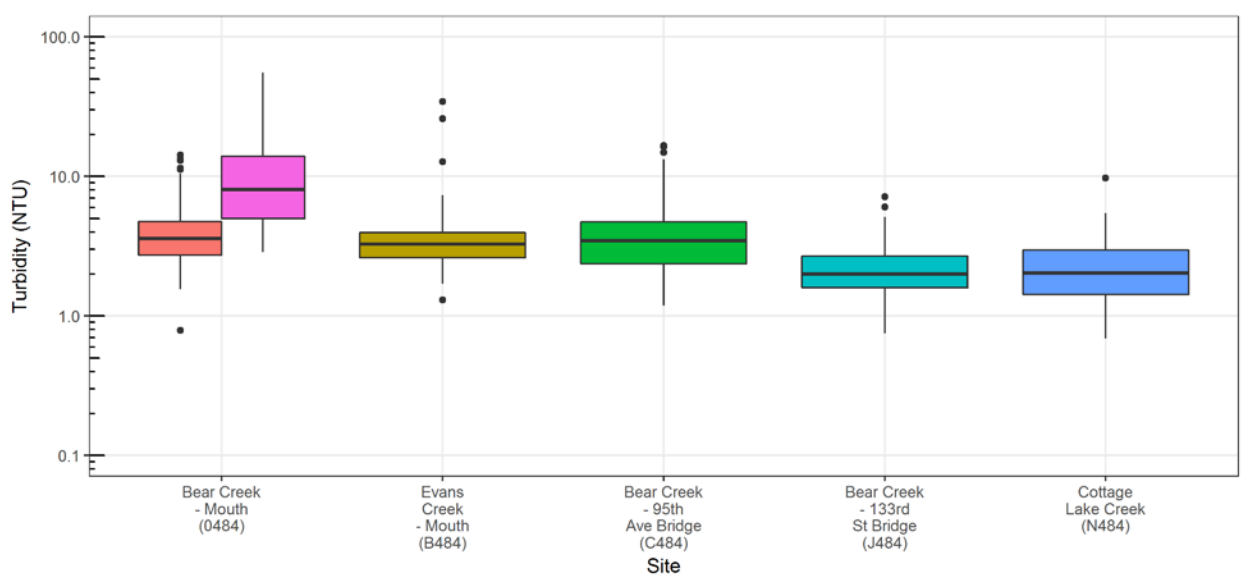

Figure 26. Turbidity at Bear Creek basin sites. Years included in statistical analysis varied by site (Table 21). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

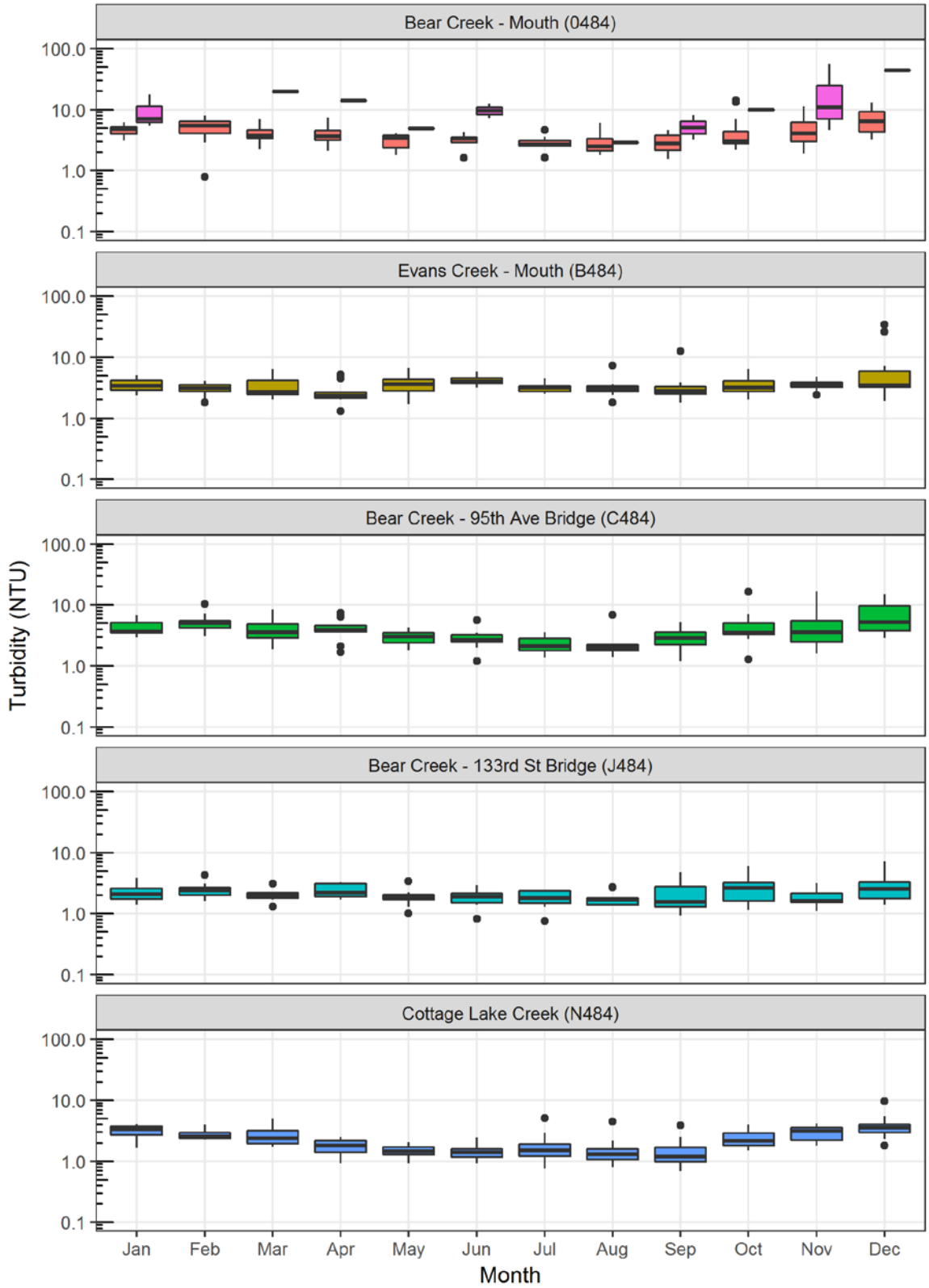

Figure 27. Monthly turbidity in the Bear Creek basin. Years included in statistical analysis varied by site (Table 22). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

3.7.2 Long-term Trends

Turbidity was found to be significantly increasing at C484 at rate of 0.014 NTU per year (Table 22; Figure 28). The 21 percent increase in turbidity at C484 between 1975 and 2015 accounts for an increase from about 2.8 NTU to 3.4 NTU, which is relatively minor because 3.4 NTU still represents clear water with little light-scattering material.

Table 22. Annual turbidity trend results from Seasonal Mann-Kendall test.

Site	Years Evaluated	p-value	Sen Slope (NTU/year)	Tau	Change 1975 to 2015[a]
0484	1971 – 2015	0.0707	0.013	0.08	--
B484	1971 – 2015	0.2626	0.009	0.06	--
C484	1974 – 2015	**0.0499**	**0.014**	**0.09**	**21%**
J484	1974 – 2008	0.1811	0.007	0.07	--
N484	1974 – 2015	0.2575	0.005	0.06	--

a. Assuming constant slope.

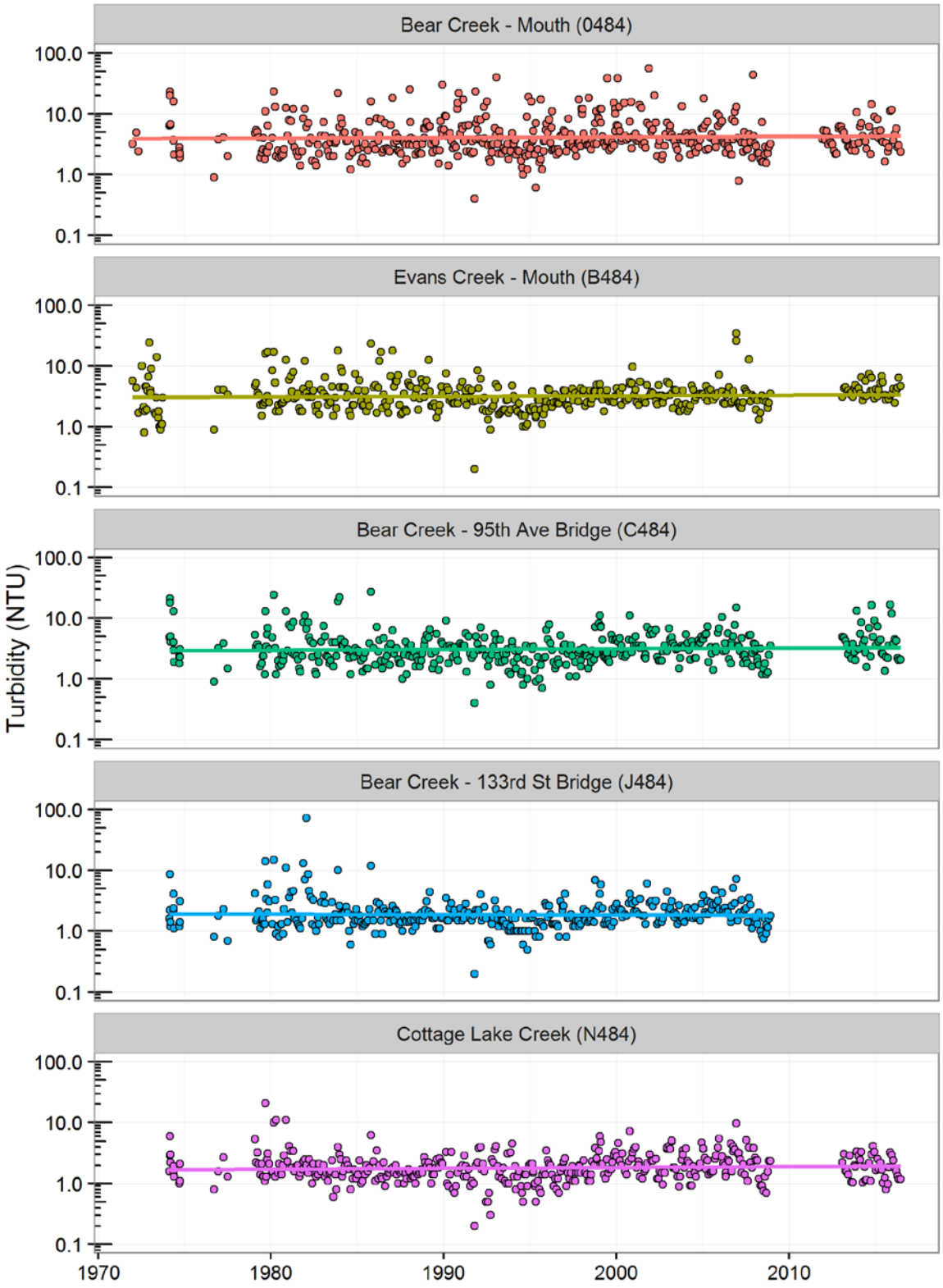

Figure 28. Long-term turbidity in the Bear Creek basin. Note log-scale.

3.7.3 Relationship Between TSS and Turbidity

Turbidity and TSS are strongly positively correlated (Figure 29; Table 23). TSS explains 30 to 70 percent of the variability in turbidity, depending on the site. On average, a one percent increase in TSS results in a 0.44 to 0.70 percent increase in turbidity, depending on the site.

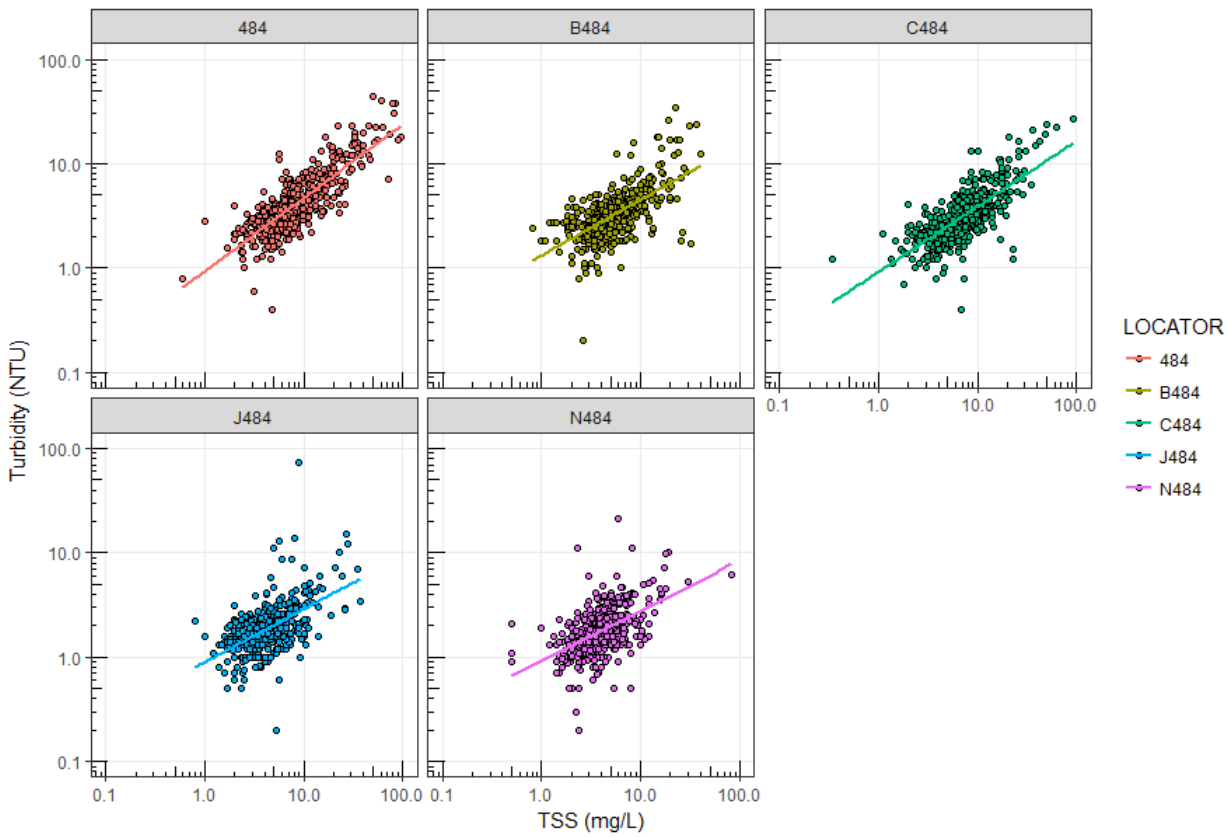

Figure 29. Total suspended solids and turbidity for historic Bear Creek watershed data.

Table 23. Regression results for relationship between TSS and turbidity.

Locator	Regression Equation	R^2	p-value
0484	log(TURB) = -0.071+**0.703***log(TSS)	0.70	<0.0001
B484	log(TURB) = 0.353+**0.491***log(TSS)	0.40	<0.0001
C484	log(TURB) = -0.101+**0.641***log(TSS)	0.56	<0.0001
J484	log(TURB) = -0.037+**0.437***log(TSS)	0.33	<0.0001
N484	log(TURB) = -0.065+**0.471***log(TSS)	0.31	<0.0001

3.8 Phosphorus

Phosphorus is found naturally in soil, plants, and animal tissue. However, the bedrock in this region is relatively low in phosphorus compared to many other regions of the country. Elevated amounts of this nutrient are usually linked to human activities such as poor gardening and animal management practices, failing septic systems, soil erosion, wastewater discharges, or stormwater runoff. Phosphorus in animal feces is also a problem when waterfowl populations become large or when large animals such as horses and cattle have free range near a stream or lake. Unlike nitrogen, most of the phosphorus reaches the receiving waters during storm events and much of it seems to be associated with particulate material.

3.8.1 Total Phosphorus

Total phosphorus includes all forms of the nutrient, including the phosphorus bound in plant and animal tissue, attached to soil particles, and dissolved.

3.8.1.1 Summary Statistics

Total phosphorus concentrations in the Bear Creek basin were similar at all sites, with concentrations at the upstream site J484 being slightly lower (Table 24; Figure 30). During wet-weather events, total phosphorus levels can reach over 0.1 mg/L (100 µg/L). No strong seasonal differences for total phosphorus are apparent in the Bear Creek basin (Figure 31). Concentrations in October appear to be slightly greater at all stations, and November and December concentrations in Cottage Lake Creek (N484) are elevated relative to the other sites.

Table 24. Summary statistics for total phosphorus in Bear Creek basin (mg/L).

Site	Event	Years	FOD	Mean	Median	Min	Max
0484	Routine	2001-2015	180/181	0.0505	0.0474	0.0251	0.126
	Wet-weather	2001-2010	25/25	0.0890	0.0743	0.0344	0.217
B484	Routine	2001-2008, 2013-2015	128/129	0.0565	0.0534	0.0280	0.137
C484	Routine	2001-2008, 2013-2015	134/135	0.0483	0.0456	0.0276	0.145
J484	Routine	2001-2008	95/96	0.0378	0.0365	0.0207	0.0946
N484	Routine	2001-2008, 2013-2015	133/134	0.0538	0.0511	0.0289	0.0979

FOD: Frequency of detection

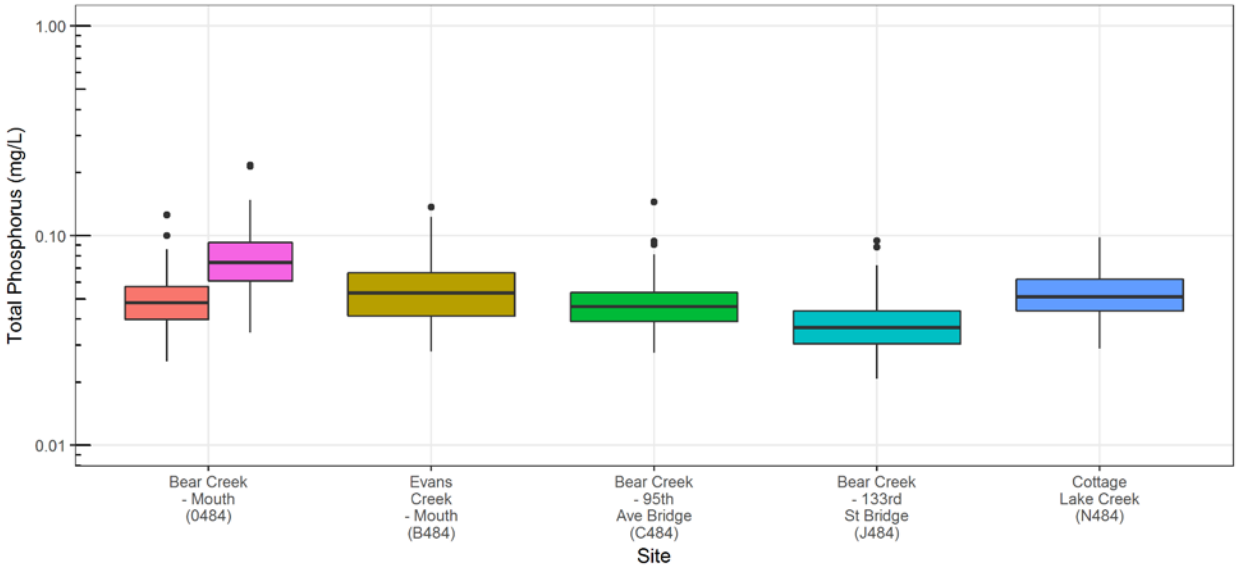

Figure 30. Total phosphorus concentrations at Bear Creek basin sites. Years included in statistical analysis varied by site (Table 24). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

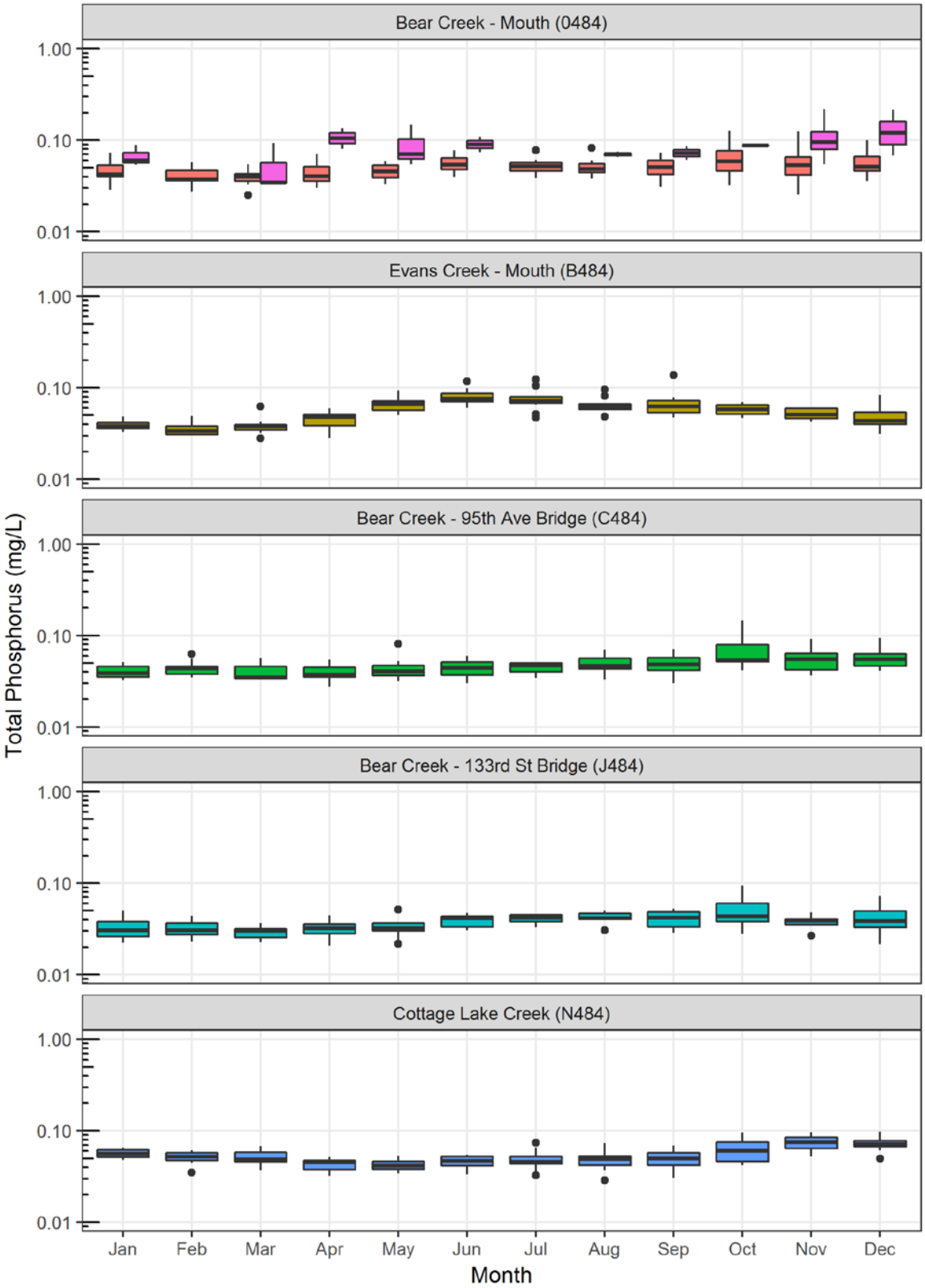

Figure 31. Monthly total phosphorus concentrations in the Bear Creek basin. Years included in statistical analysis varied by site (Table 25). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

3.8.1.2 Long-term Trends

At all monitored sites, total phosphorus concentrations have significantly decreased since the 1970s (Table 25; Figure 32). The greatest decrease occurred at the furthest downstream station (0484) with a downward trend of 1.31 ppb/year (a 56 percent decrease between 1975 and 2015). Decreased total phosphorus concentrations in both Bear Creek further upstream (C484; -0.81 ppb/year) and Evans Creek (B484; -0.69 ppb/year) contributed to the decreased concentrations observed at site 0484. Significant, but less steep, decreases were observed further upstream at sites J484 on Bear Creek and site N484 on Cottage Lake Creek.

Table 25. Annual total phosphorus trend results from Seasonal Mann-Kendall test.

Site	Years Evaluated	p-value	Sen Slope (ppb/year)	Tau	Change 1975 to 2015[a]
0484	1974 – 2015	**<0.0001**	**-1.31**	**-0.41**	**-56%**
B484	1974 – 2015	**<0.0001**	**-0.69**	**-0.26**	**-35%**
C484	1974 – 2015	**<0.0001**	**-0.81**	**-0.37**	**-46%**
J484	1974 – 2008	**0.0003**	**-0.48**	**-0.24**	**-38%**
N484	1974 – 2015	**<0.0001**	**-0.51**	**-0.28**	**-31%**

a. Assuming constant slope.

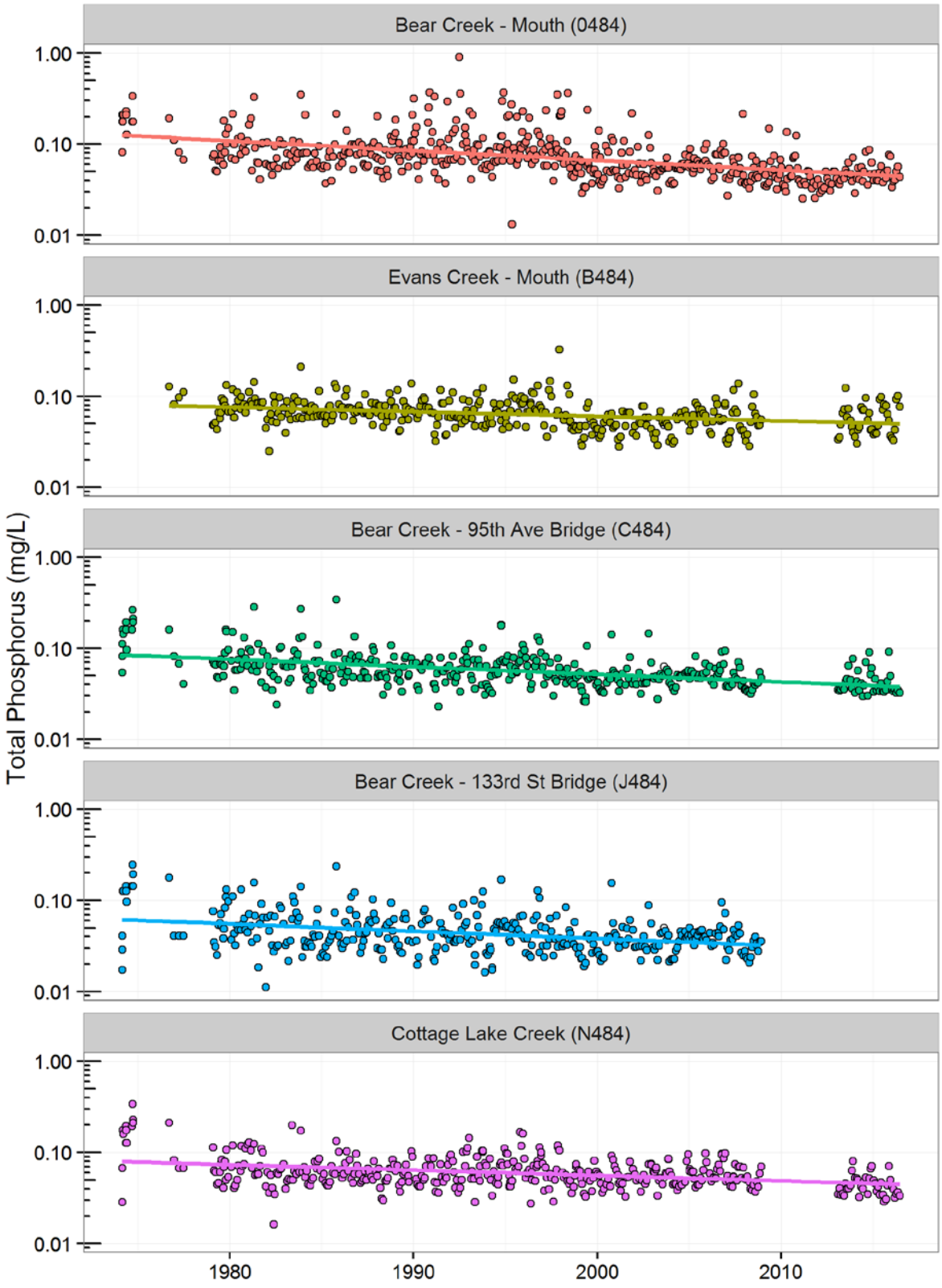

Figure 32. Long-term total phosphorus concentrations in the Bear Creek basin. Note log-scale.

3.8.2 Orthophosphate Phosphorus

Orthophosphate is a dissolved form of phosphorus, which is readily available for utilization by plants. Orthophosphate binds readily with iron in soil particles and sediments.

3.8.2.1 Summary Statistics

Generally, orthophosphate concentrations are similar across the monitoring stations with lower levels found in upper Bear Creek (site J484) (Table 26; Figure 33). No strong seasonal differences for orthophosphate are apparent in the Bear Creek basin (Figure 34). Concentrations in October appear to be slightly greater at all stations, and November and December concentrations in Cottage Lake Creek (N484) are elevated relative to the other sites.

Table 26. Summary statistics for orthophosphate phosphorus in Bear Creek basin (mg/L).

Site	Event	Years	FOD	Mean	Median	Min	Max
0484	Routine	2001-2015	177/178	0.0223	0.0209	0.00920	0.0592
	Wet-weather	2001-2010	25/25	0.0285	0.0279	0.01200	0.0703
B484	Routine	2001-2008, 2013-2015	129/129	0.0249	0.0228	0.00900	0.0708
C484	Routine	2001-2008, 2013-2015	135/135	0.0215	0.0204	0.00992	0.0848
J484	Routine	2001-2008	93/93	0.0166	0.0159	0.00668	0.0507
N484	Routine	2001-2008, 2013-2015	134/134	0.0266	0.0263	0.00619	0.0504

FOD: Frequency of detection

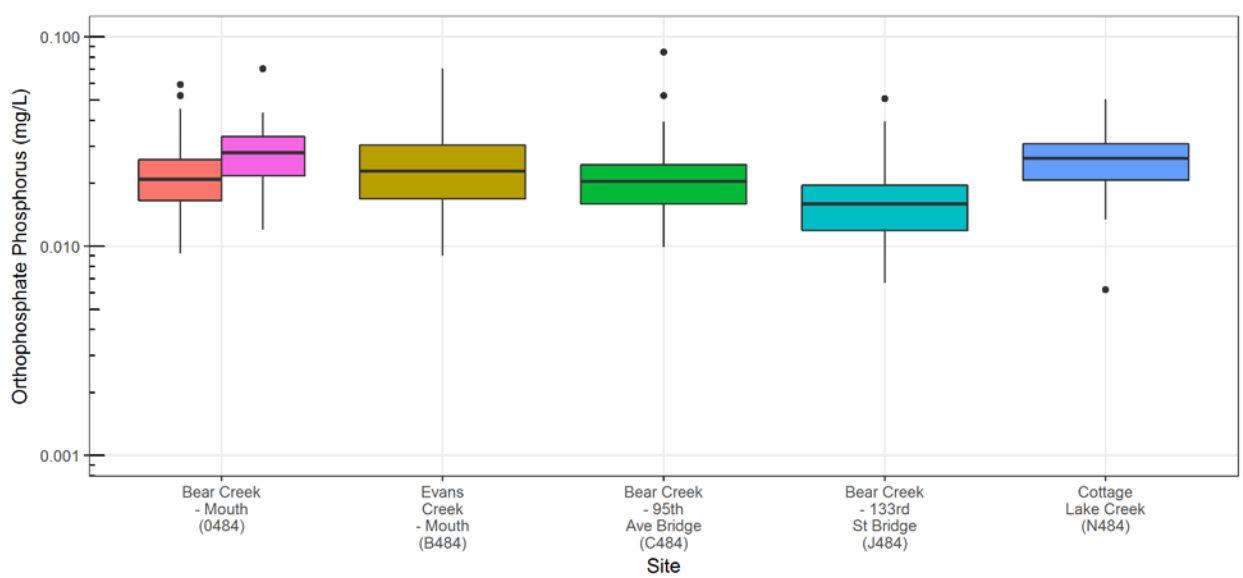

Figure 33. Orthophosphate concentrations at Bear Creek basin sites. Years included in statistical analysis varied by site (Table 26). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

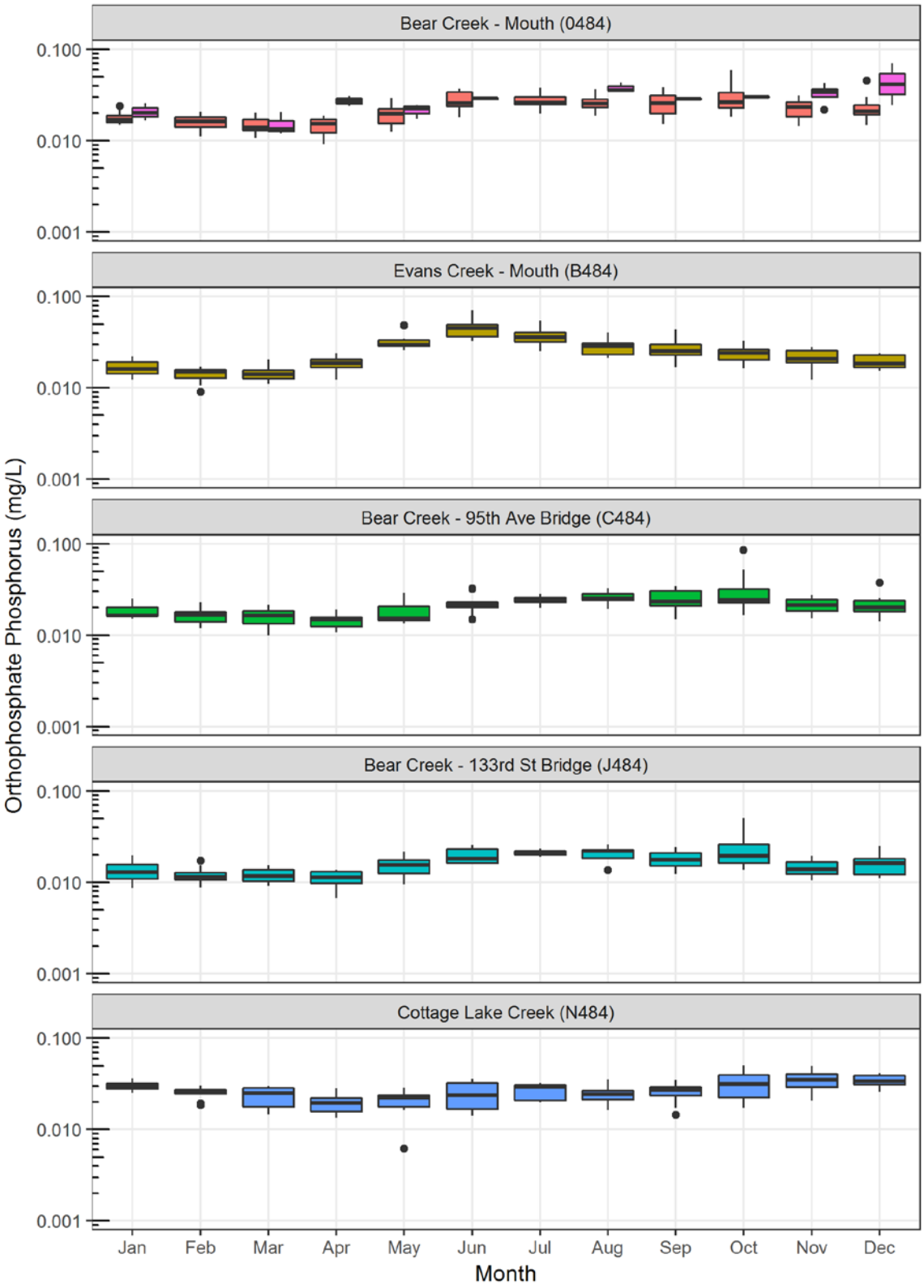

Figure 34. Monthly orthophosphate phosphorus concentrations in the Bear Creek basin. Years included in statistical analysis varied by site (Table 27). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

3.8.2.2 Long-term Trends

Orthophosphate phosphorus concentrations have significantly decreased since the 1970s at all monitored sites (Table 27; Figure 35). The greatest decrease occurred at the furthest downstream station (0484) with a downward trend of 0.55 ppb/year. Decreased orthophosphate levels in both Bear Creek further upstream (C484; -0.31 ppb/year) and Evans Creek (B484; -0.50 ppb/year) contributed to the decreased concentrations observed at site 0484.

Table 27. Annual orthophosphate phosphorus trend results from Seasonal Mann-Kendall test.

Site	Years Evaluated	p-value	Sen Slope (ppb/year)	Tau	Change 1975 to 2015[a]
0484	1974 – 2015	**<0.0001**	**-0.55**	**-0.45**	**-54%**
B484	1974 – 2015	**<0.0001**	**-0.50**	**-0.37**	**-51%**
C484	1974 – 2015	**<0.0001**	**-0.31**	**-0.35**	**-42%**
J484	1974 – 2008	**0.0004**	**-0.25**	**-0.27**	**-41%**
N484	1974 – 2015	**<0.0001**	**-0.26**	**-0.25**	**-31%**

a. Assuming constant slope.

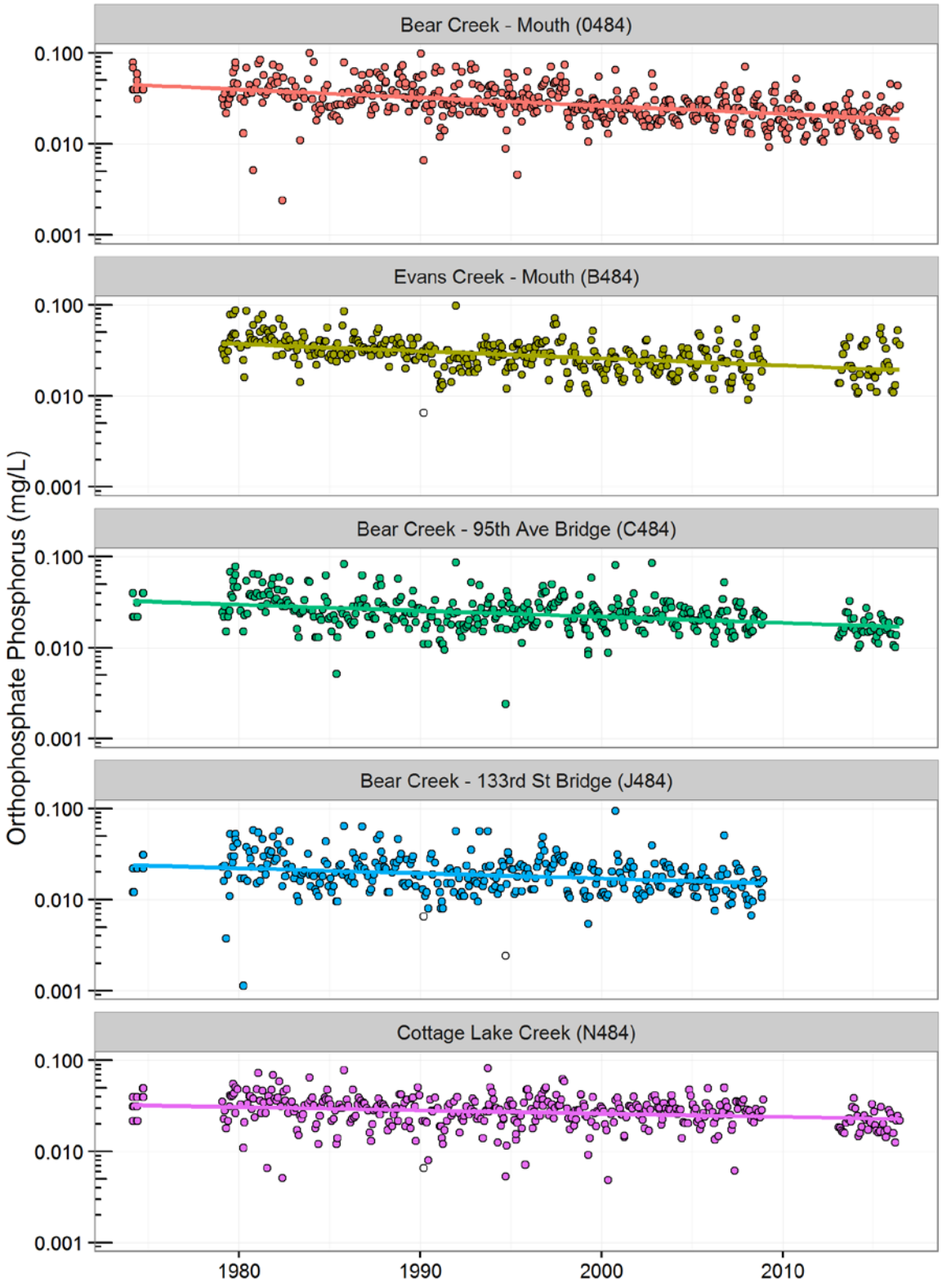

Figure 35. Long-term orthophosphate phosphorus concentrations in the Bear Creek basin. Note log-scale.

3.9 Nitrogen

Total nitrogen includes inorganic and organic nitrogen. The two forms of inorganic nitrogen (ammonia-nitrogen and nitrate+nitrite-nitrogen) are highly soluble in water and are components of fertilizers, sewage effluents, and manure. Alder trees are an important source of nitrogen in the Pacific Northwest. Alder has a symbiotic relationship with a nitrogen-fixing bacterium living in its root nodules. This increases nitrogen abundance in soils and thereby the watershed.

3.9.1 Total Nitrogen

3.9.1.1 Summary Statistics

Total nitrogen levels varied across the study area, with concentration in Evans Creek (B484 and upper Bear Creek (J484) somewhat lower than the three other sites (Table 28; Figure 36). Strong seasonal differences were apparent in total nitrogen concentration with annual minima in summer (July through September) followed by an increase to a winter maximum in December and January (Figure 37). From mid-winter to late spring, total nitrogen concentrations gradually decline.

Table 28. Summary statistics for total nitrogen in Bear Creek basin (mg/L).

Site	Event	Years	FOD	Mean	Median	Min	Max
0484	Routine	2001-2015	177/178	0.873	0.833	0.443	1.56
	Wet-weather	2001-2010	25/25	1.10	1.05	0.665	1.93
B484	Routine	2001-2008, 2013-2015	128/129	0.661	0.653	0.385	1.24
C484	Routine	2001-2008, 2013-2015	134/135	1.02	0.945	0.460	1.79
J484	Routine	2001-2008	92/93	0.743	0.647	0.254	1.49
N484	Routine	2001-2008, 2013-2015	132/134	1.19	1.20	0.398	1.95

FOD: Frequency of detection

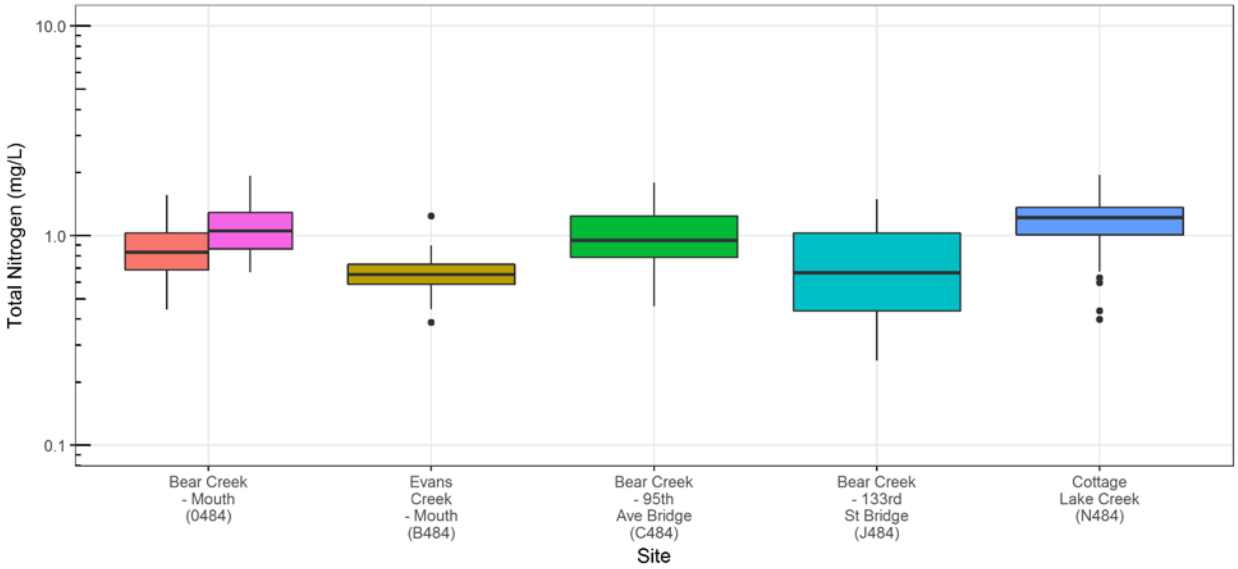

Figure 36. Total nitrogen concentrations at Bear Creek basin sites. Years included in statistical analysis varied by site (Table 28). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

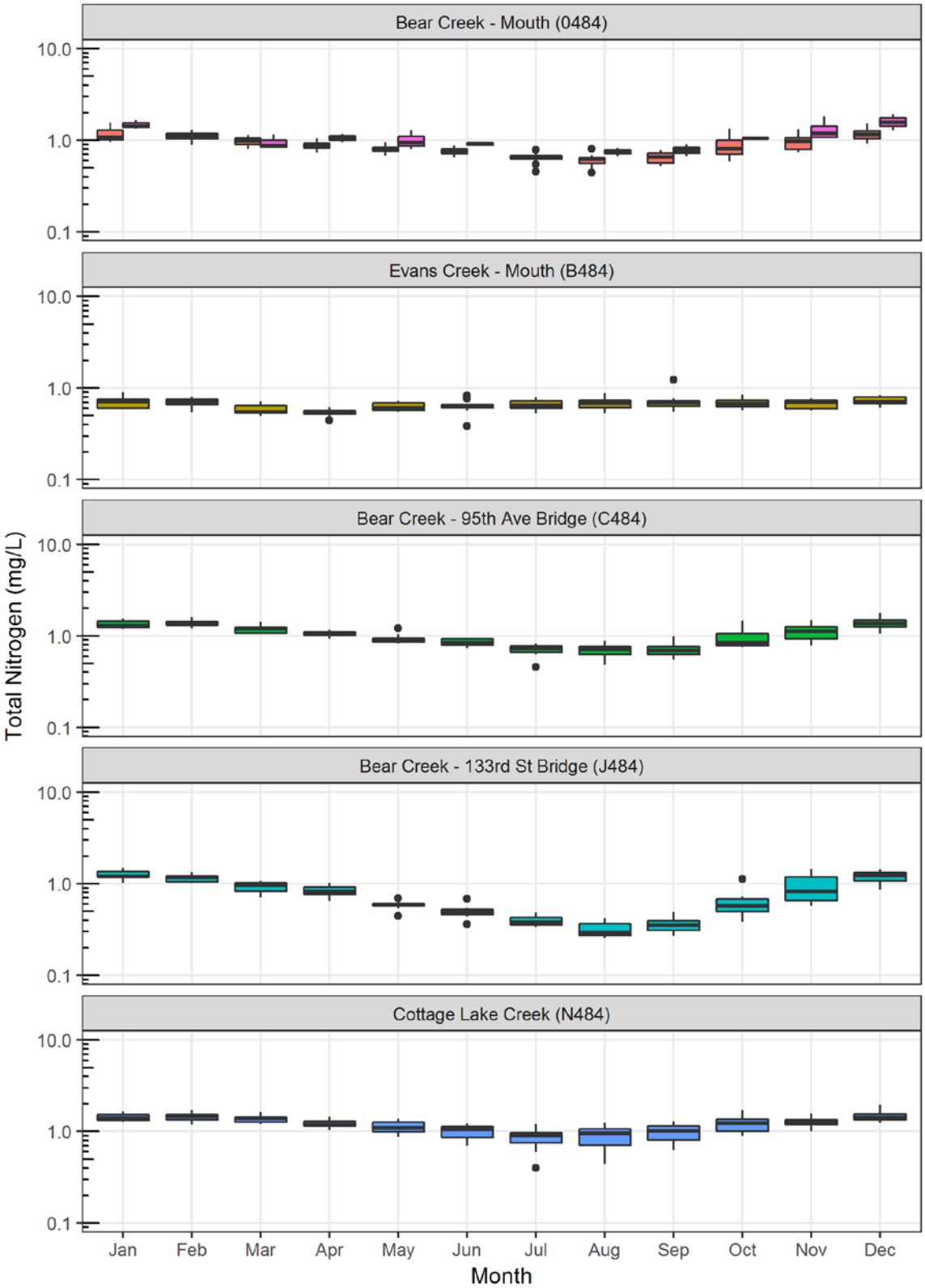

Figure 37. Monthly total nitrogen concentrations in the Bear Creek basin. Years included in statistical analysis varied by site (Table 29). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

3.9.1.2 Long-term Trends

Unlike the other nutrients, total nitrogen monitoring did not begin until 1993. Significant decreasing trends were observed at sites 0484, C484, and J484 (Table 29; Figure 38). Since 1995, total nitrogen levels have decreased by 10 to 30 percent at these sites.

Table 29. Annual total nitrogen trend results from Seasonal Mann-Kendall test.

Site	Years Evaluated	p-value	Sen Slope (ppb/year)	Tau	Change 1995 to 2015[a]
0484	1993 – 2015	**0.0001**	**-10.1**	**-0.34**	**-20%**
B484	1993 – 2015	0.0838	-3.22	-0.11	--
C484	1993 – 2015	**0.0197**	**-6.36**	**-0.21**	**-13%**
J484	1993 – 2008	**0.0085**	**-12.3**	**-0.27**	**-31%**
N484	1993 – 2015	0.2898	-5.96	-0.13	--

a. Assuming constant slope.

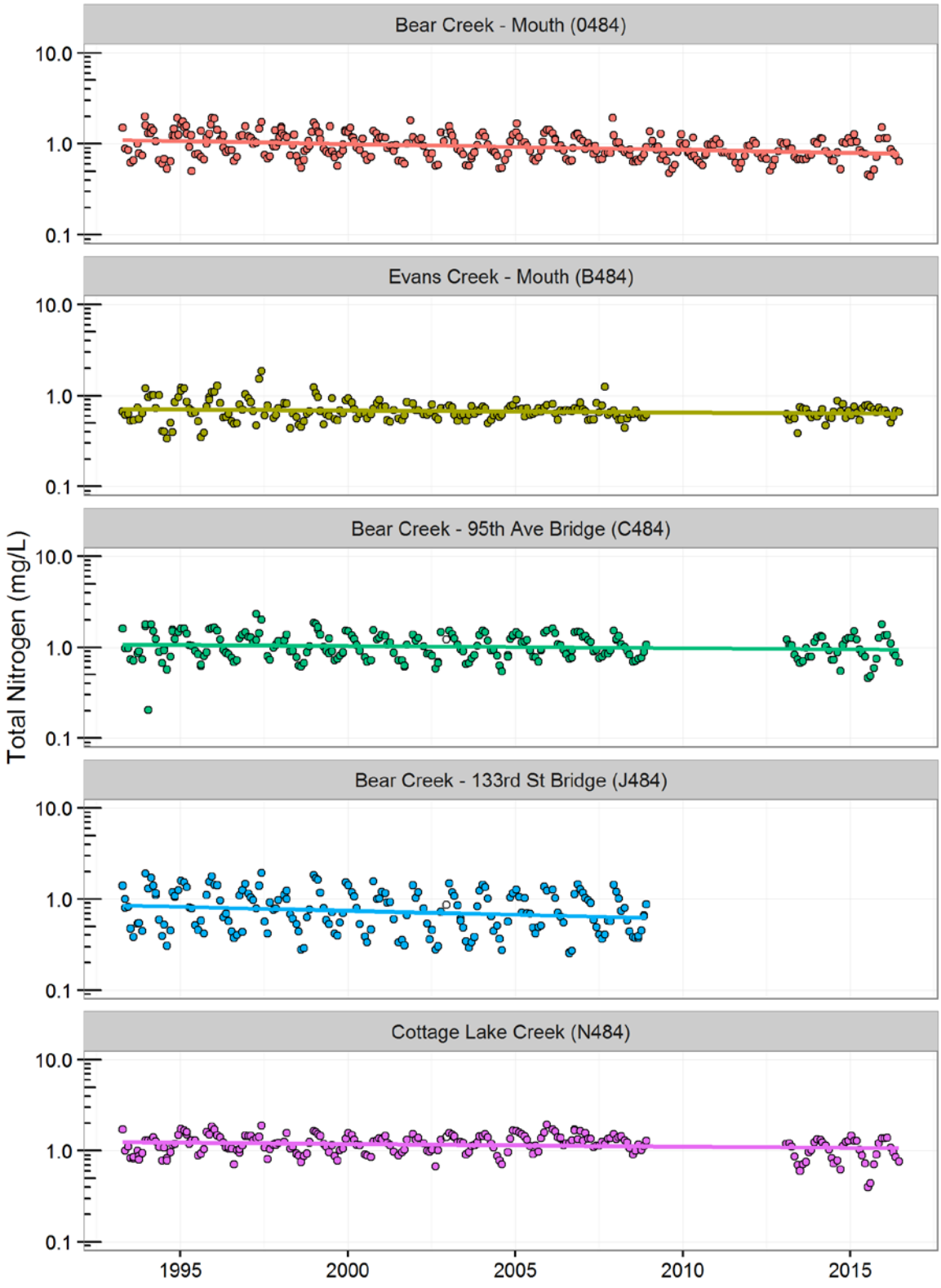

Figure 38. Long-term total nitrogen concentrations in the Bear Creek basin. Note log-scale.

3.9.2 Ammonia Nitrogen

Ammonia-nitrogen is generated by heterotrophic bacteria as the primary end product of decomposition of organic matter. Although intermediate nitrogen compounds are formed in the progressive degradation of organic material, these rarely accumulate and are deaminated rapidly by bacterial utilization. Although ammonia is a major excretory product of aquatic and terrestrial animals, in the normal aquatic environment the majority of ammonia-nitrogen is formed through decomposition.

Ammonia in water is present primarily as NH_4^+ and as un-ionized NH_4OH, the latter being highly toxic to many organisms, especially fish. The proportions of NH_4^+ to NH_4OH are dependent on pH and, to a lesser extent temperature.

3.9.2.1 Summary Statistics

Ammonia levels are similar across the study area in terms of median concentrations, but maximum levels in Evans Creek (B484) are substantially lower than maximum levels at the other sites (Table 30; Figure 39). Strong seasonal differences were apparent in ammonia nitrogen concentration with annual minima in summer (July through September) followed by an increase to winter maxima (Figure 40). At sites 0484, C484, and J484, October ammonia levels can much higher than those in September or November, likely due to plant and leaf senescence. Winter ammonia levels in Cottage Lake Creek (N484) are typically greater than the other sites, probably due to inputs from Cottage Lake as the lake mixes and primary productivity lessens.

Table 30. Summary statistics for ammonia nitrogen in Bear Creek basin (mg/L).

Site	Event	Years	FOD	Mean	Median	Min	Max
0484	Routine	2001-2015	155/178	0.0187	0.0137	0.0043	0.277
	Wet-weather	2001-2010	25/25	0.0310	0.0239	0.0099	0.163
B484	Routine	2001-2008, 2013-2015	110/129	0.0154	0.0140	0.0061	0.040
C484	Routine	2001-2008, 2013-2015	114/135	0.0215	0.0140	0.0040	0.357
J484	Routine	2001-2008	70/93	0.0194	0.0120	0.0100	0.310
N484	Routine	2001-2008, 2013-2015	115/134	0.0283	0.0150	0.0042	0.141

FOD: Frequency of detection

a. Kaplan-Meier estimate of mean in presence of non-detects.

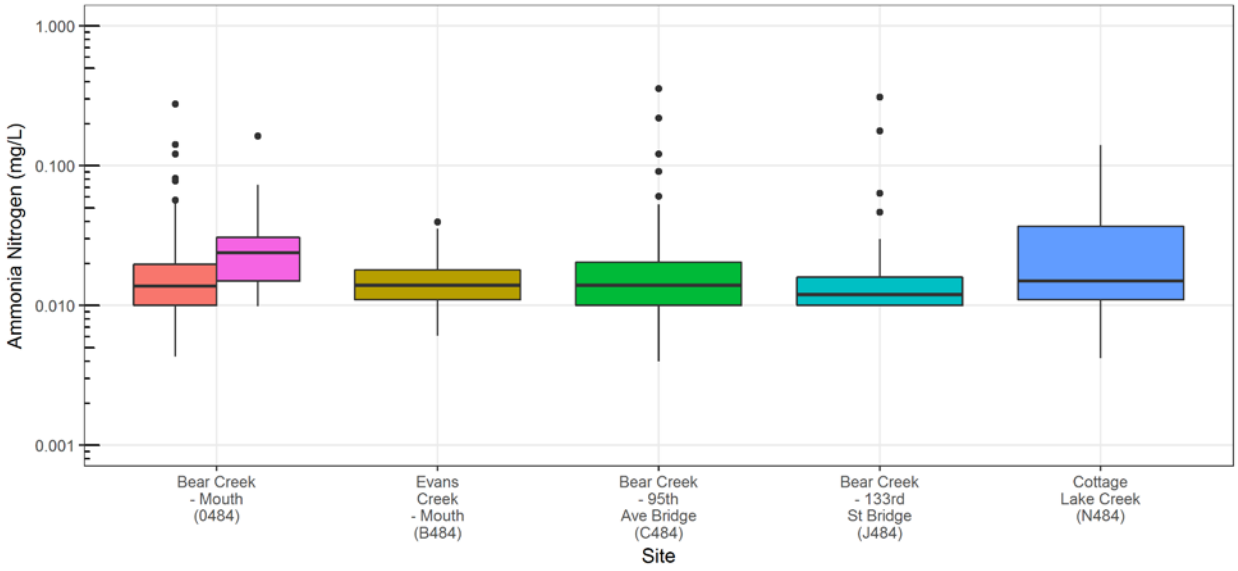

Figure 39. Ammonia concentrations at Bear Creek basin sites. Years included in statistical analysis varied by site (Table 30). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

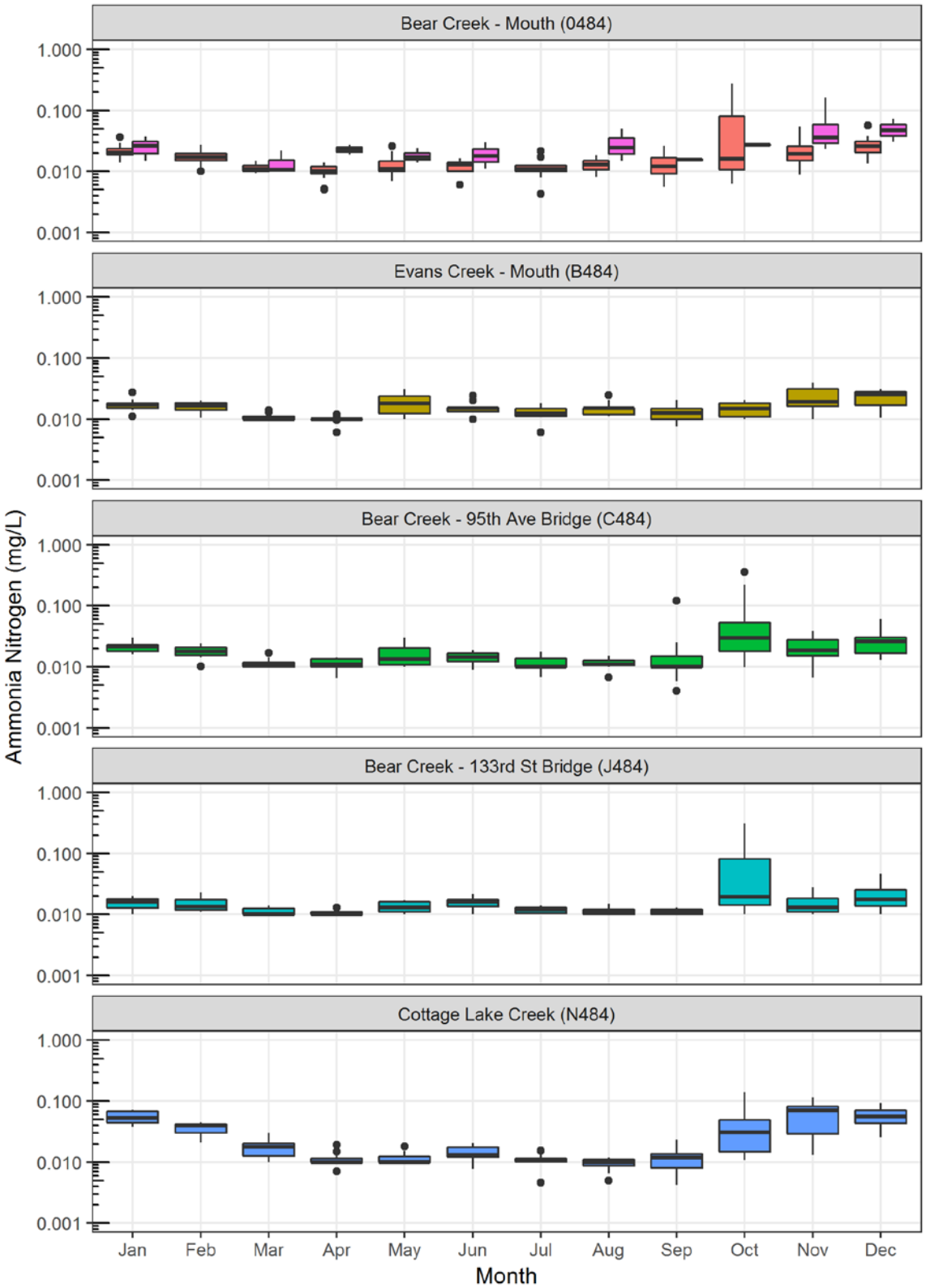

Figure 40. Monthly ammonia nitrogen concentrations in the Bear Creek basin. Years included in statistical analysis varied by site (Table 31). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

3.9.2.2 Long-term Trends

Ammonia concentrations have significantly decreased at site 0484, B484, and C484 since the 1970s, however, the rate of decrease at B484 was insubstantial (Table 31; Figure 41). Since 1975, the median ammonia concentration in lower Bear Creek (0484) has decreased by 61%, and in Bear Creek just upstream of the Evans Creek confluence (C484), ammonia levels have decreased by 32%. It appears that further actions affecting Bear Creek ammonia levels have occurred between Evans Creek and the 0484 sampling site during the monitoring period.

Table 31. Annual ammonia nitrogen trend results from Seasonal Mann-Kendall test.

Site	Years Evaluated	p-value	Sen Slope (ppb/year)	Tau	Change 1975 to 2015[a]
0484	1971 – 2015	**<0.0001**	**-0.46**	**-0.33**	**-61%**
B484	1971 – 2015	**0.0318**	**<0.01**	**-0.10**	--
C484	1974 – 2015	**0.0013**	**-0.13**	**-0.19**	**-32%**
J484	1974 – 2008	0.0604	<0.01	-0.11	--
N484	1974 – 2015	0.4199	<0.01	0.03	--

a. Assuming constant slope.

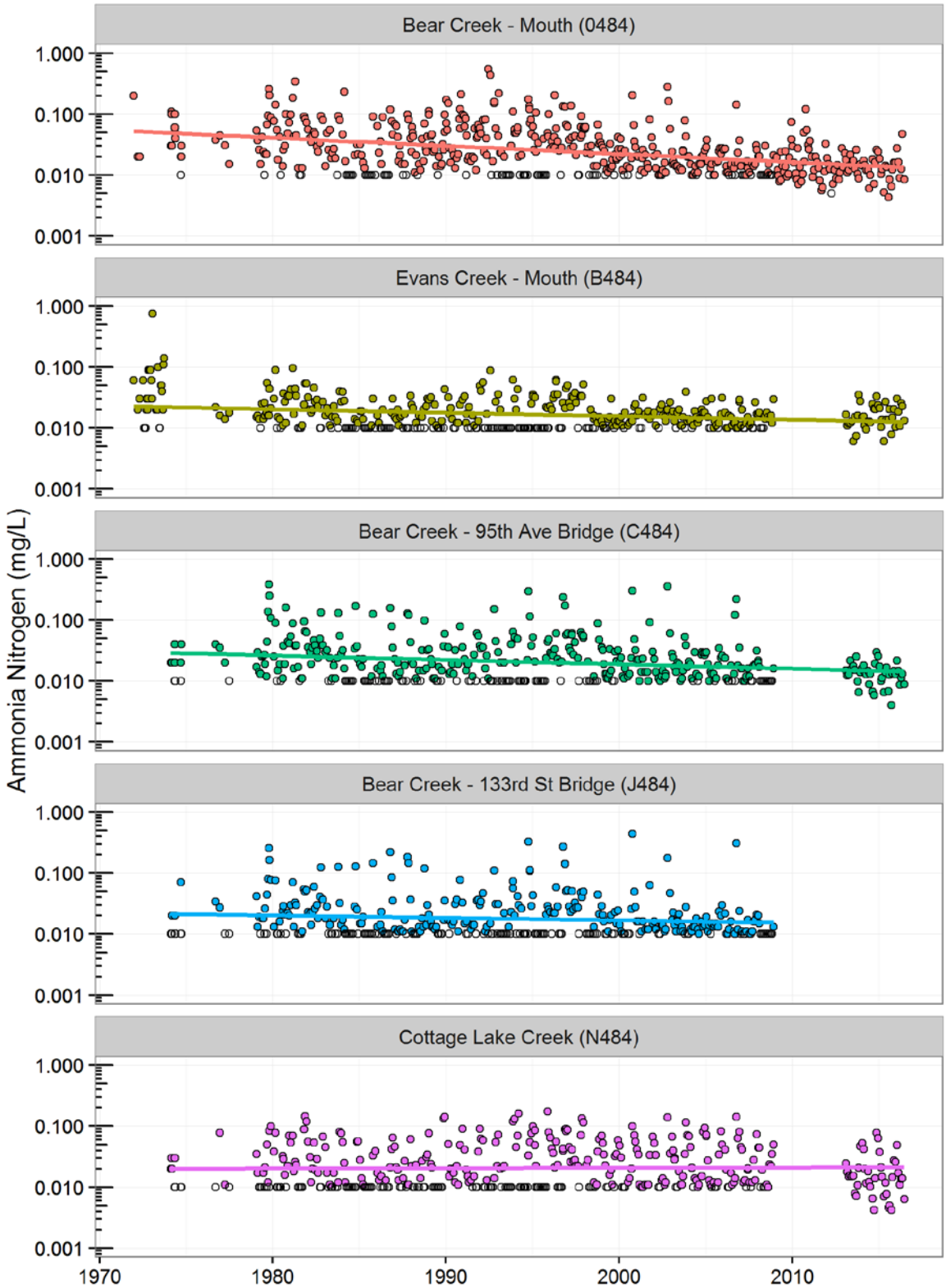

Figure 41. Long-term ammonia nitrogen concentrations in the Bear Creek basin. Note log-scale.

3.9.2.3 Comparison to Water Quality Standards

The water quality criteria for un-ionized ammonia are based on pH and temperature. The criteria were calculated based on the equations provided in WAC 173-201A-240 Table 240 Notes f and g. The amount of un-ionized ammonia was estimated based the ammonia concentration and on the sample pH and temperature.[1] The water quality criteria were not exceeded in any sample at any monitoring site (Figure 42).

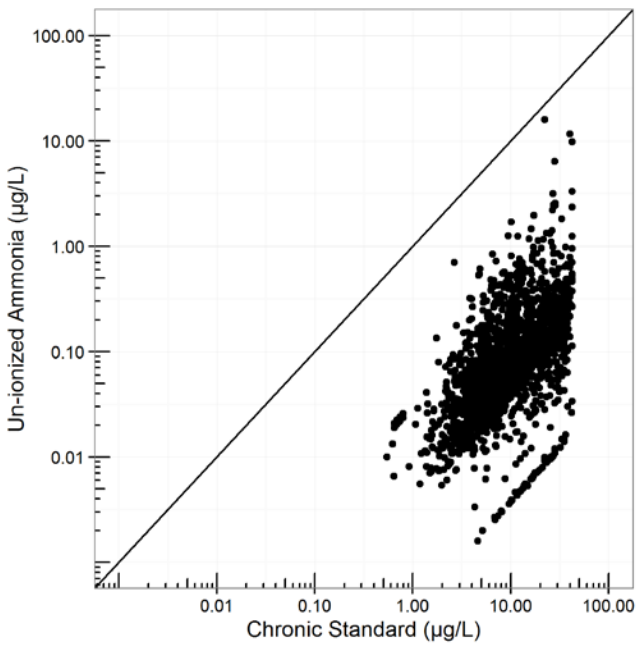

Figure 42. Estimated un-ionized ammonia versus chronic criterion. Values below diagonal lines are below the water quality standard.

3.9.3 Nitrate + Nitrite Nitrogen

Under natural conditions, the primary source of nitrate (NO_3-) in streams is terrestrial decomposition of organic materials. In soils, the regeneration of NO_3- from organic nitrogen occurs through the activities of bacteria and fungi. These organisms convert organic nitrogen forms to ammonia, and then nitrite bacteria partially oxidize ammonia (NH_4+) to nitrite (NO_2-). Under aerobic conditions, another group of bacteria converts nitrite to nitrate. In addition, some plants fix atmospheric nitrogen. Bacteria on the roots fix the nitrogen in the soil by combining it with oxygen to form NO_3-. Alder trees (Alnus sp.), which are prevalent along many of the streams, are the primary source of the nitrogen-fixing bacteria in forested areas and wetlands. Nitrogen fixation by dense stands of alder can be as high as 22,500 mg/m2 /year, most of which enters the stream as leachate from direct leaf-fall or release during decomposition of foliage (Wetzel, 1975).

[1] Fraction un-ionized = $\frac{1}{1+10^{pka-pH}}$ $where\ pka = 0.0901821 + \frac{2729.92}{T}\ where\ T = temperature\ in\ Kelvin.$

3.9.3.1 Summary Statistics

Nitrate + nitrite concentrations in the Bear Creek basin are typically about 0.25 to 0.90 mg/L (Table 32; Figure 43). Levels at B484 are lower than at sites 0484, C484, and N484, and the nitrate+nitrite concentration at J484 has the greatest variability.

Table 32. Summary statistics for nitrate + nitrite nitrogen in Bear Creek basin (mg/L).

Site	Event	Years	FOD	Mean	Median	Min	Max
0484	Routine	2001-2015	178/178	0.529	0.489	0.178	1.09
	Wet-weather	2001-2010	25/25	0.580	0.550	0.256	1.02
B484	Routine	2001-2008, 2013-2015	129/129	0.272	0.270	0.017	0.51
C484	Routine	2001-2008, 2013-2015	135/135	0.677	0.627	0.275	1.36
J484	Routine	2001-2008	93/93	0.436	0.318	0.057	1.14
N484	Routine	2001-2008, 2013-2015	134/134	0.805	0.820	0.227	1.43

FOD: Frequency of detection

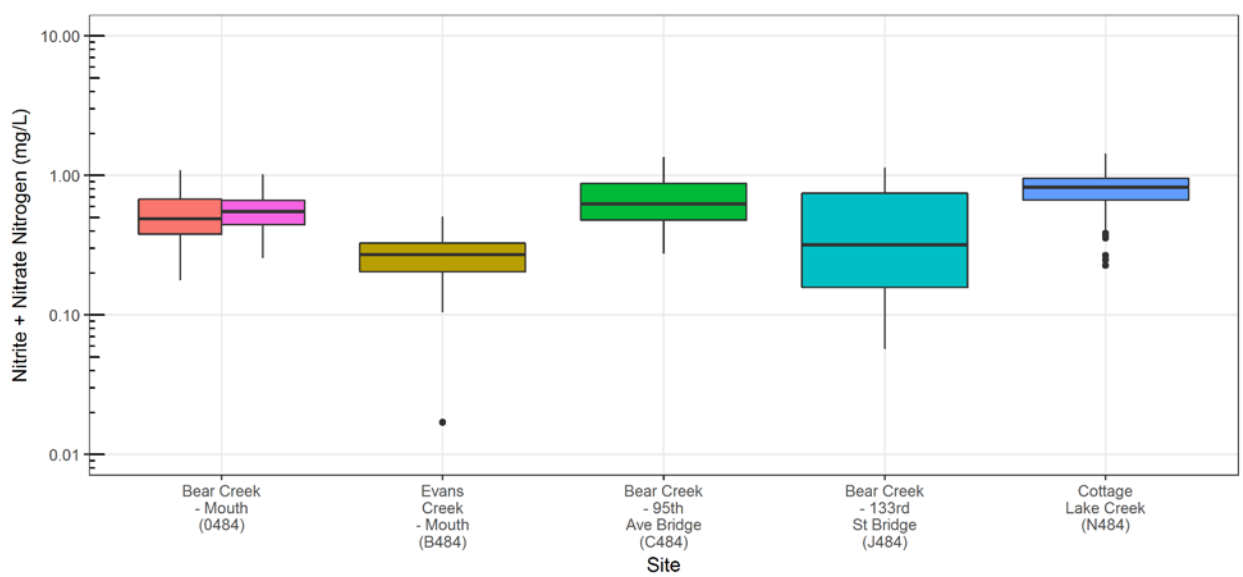

Figure 43. Nitrite + nitrate concentrations at Bear Creek basin sites. Years included in statistical analysis varied by site (Table 32). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

Strong seasonal differences are apparent in nitrate + nitrite concentrations with annual minima in summer (July through September) followed by an increase to a winter maximum in December and January (Figure 44). From mid-winter to late spring, nitrate concentrations gradually decline. This seasonal trend is most notable in the furthest upstream site (J484).

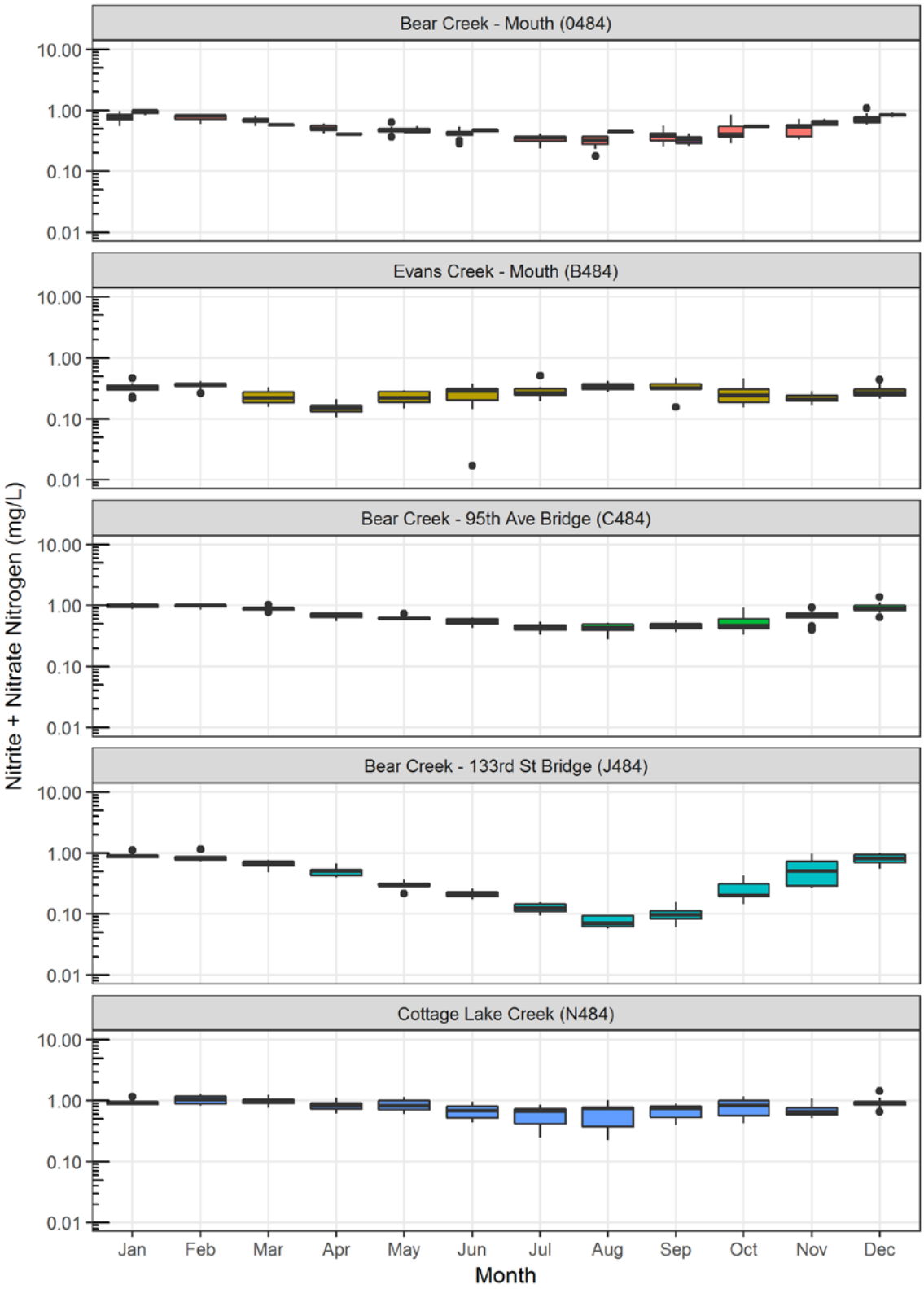

Figure 44. Monthly nitrate + nitrite concentrations in the Bear Creek basin. Years included in statistical analysis varied by site (Table 33). Mouth site (0484) broken up into routine (red) and wet-weather (pink). Note log-scale.

3.9.3.2 Long-term Trends

Since the 1970s, nitrate+nitrite concentrations at 0484, B484, and J484 have decreased significantly (Table 33; Figure 45). The greatest absolute and relative decrease occurred in Evans Creek (B484) at -7.36 ppb per year, a 67 percent decrease between 1975 and 2015. Trends varied greatly within individual seasons (Appendix E). Cottage Lake Creek (N484) had significant increases in nitrate+nitrite in winter and spring (6 ppb/yr), and middle Bear Creek (C484) had significantly increasing levels in spring (4.0 ppb/yr) and decreasing in fall (-5.5 ppb/yr) (Appendix E). The greatest decreases at Evans Creek (B484) was during the winter season (-17 ppb/yr).

Table 33. Annual nitrate + nitrite nitrogen trend results from Seasonal Mann-Kendall test.

Site	Years Evaluated	p-value	Sen Slope (ppb/year)	Tau	Change 1975 to 2015[a]
0484	1971 – 2015	**0.0003**	**-2.56**	**-0.19**	**-18%**
B484	1971 – 2015	**<0.0001**	**-7.36**	**-0.36**	**-67%**
C484	1974 – 2015	0.1811	0.854	0.06	--
J484	1974 – 2008	**0.0023**	**-2.92**	**-0.19**	**-24%**
N484	1974 – 2015	0.0907	2.91	0.12	--

a. Assuming constant slope.

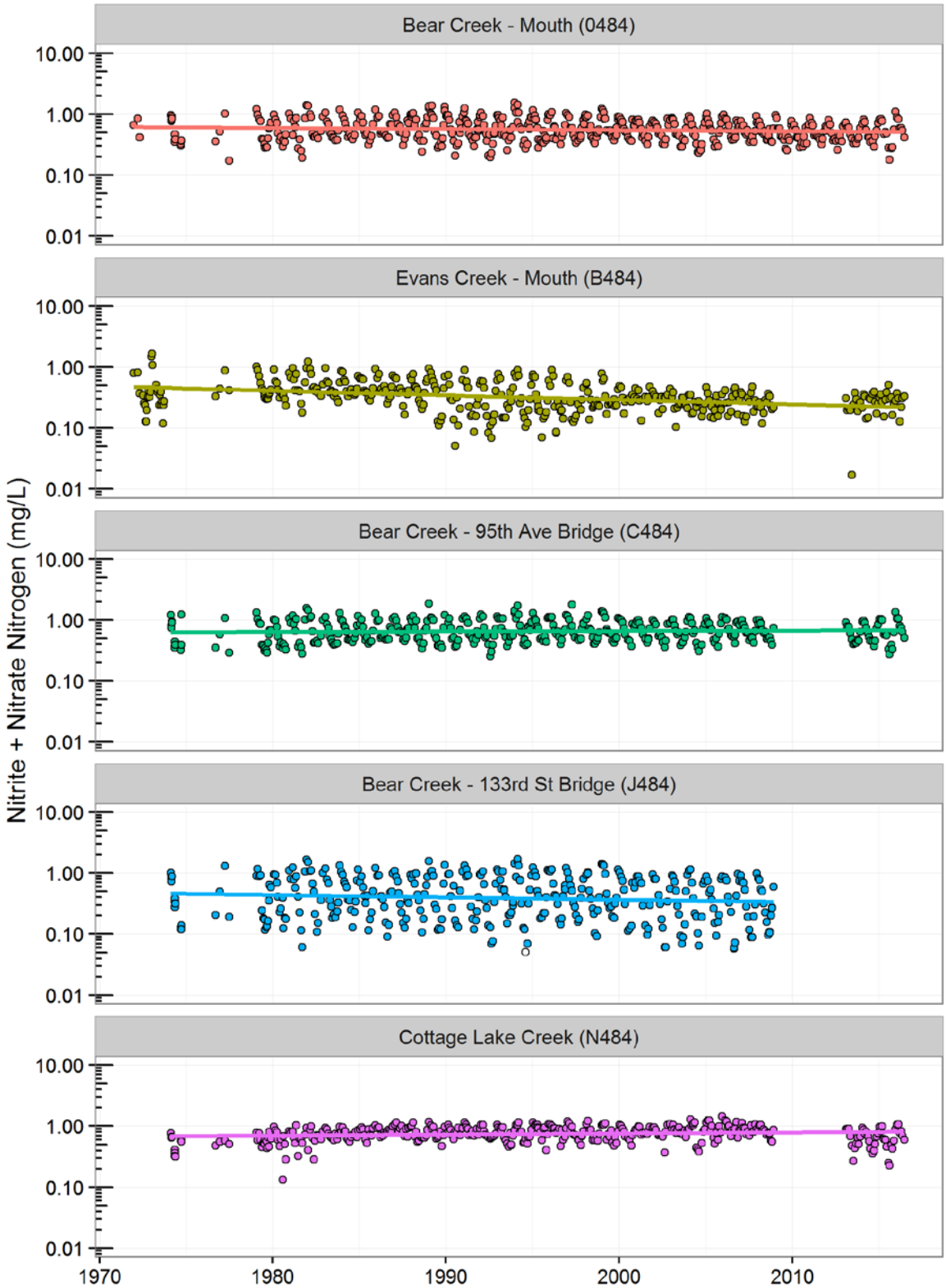

Figure 45. Long-term nitrate + nitritie nitrogen concentrations in the Bear Creek basin. Note log-scale.

3.10 Dissolved and Total Organic Carbon

The organic carbon found in surface waters consists primarily of dissolved organic carbon and particulate detritus (particulate organic carbon) (Wetzel, 2001). Organic carbon concentrations were only measured routinely at site 0484 in lower Bear Creek from 2002 to 2010 for total and in 2002-2005, 2009, and 2010 for dissolved. The monitoring period for organic carbon is too short to investigate long-term trends.

At lower Bear Creek (0484), dissolved organic carbon (particle size less than 0.45 µm) typically makes up the majority of organic carbon in the stream (70 to 100 percent) (Table 34). Dissolved and total carbon was also measured quarterly in 2001 at site C484.

Table 34. Summary statistics for dissolved and total carbon in Bear Creek basin (mg/L).

Parameter	Site	Event	Years	FOD	Mean	Median	Min	Max
Dissolved Organic Carbon	0484	Routine	2002-2005	44/44	6.59	6.06	4.61	10.7
		Wet-weather	2002-2006, 2009,2010	16/16	7.18	7.16	6.62	13.9
	C484	Routine	2001	4/4	6.49	4.56	4.39	11.7
Total Organic Carbon	0484	Routine	2002-2008	85/85	7.13	6.52	4.07	13.1
		Wet-weather	2002-2008	14/14	9.27	8.00	6.62	13.9
	C484	Routine	2001	4/4	7.57	5.97	4.63	12.3

FOD: Frequency of detection

Levels of organic carbon are greatest in fall during senescence (November through January), with elevated concentration in early spring likely associated with autochthonous generation by stream periphyton and macrophytes (Figure 46).

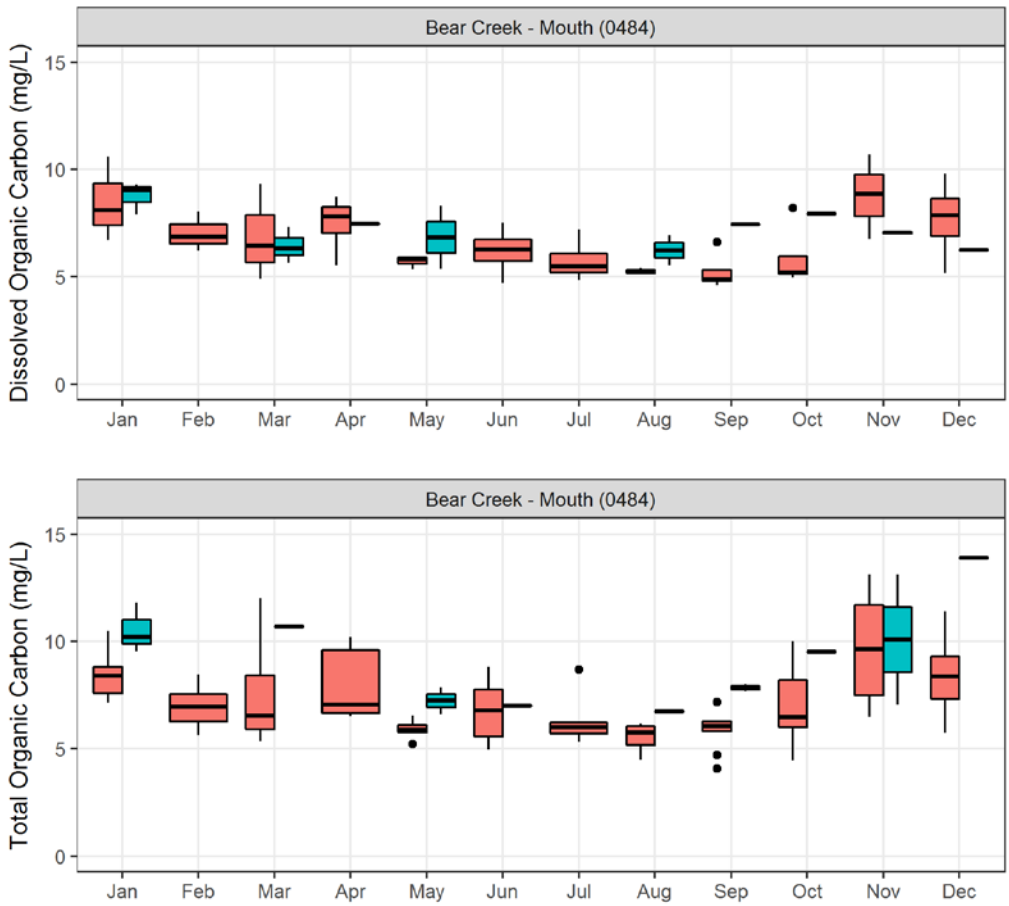

Figure 46. Dissolved (a) and total organic carbon (b) measured from 2002 to 2010 at the mouth of Bear Creek (site 0484). Mouth site (0484) broken up into routine (red) and wet-weather (pink).

3.11 DIN:DIP Ratio

The ratio of nitrogen to phosphorus is often used to assess nutrient limitation in lakes, streams, and seas. Under phosphorus-rich conditions, periphyton communities may be limited by the availability of nitrogen, and vice versa. Generally, it is accepted that molar ratios of dissolved inorganic nitrogen (DIN; ammonia and nitrite + nitrate nitrogen) to dissolved inorganic phosphorus (DIP; orthophosphate phosphorus) above 17 indicate phosphorus limitation and ratios below 10 indicate nitrogen limitation. At ratios between 10 and 16, both nutrients are likely to be limiting (Carroll and Pelletier, 1991; Welch et al., 1998).

3.11.1 Summary Statistics

Table 35 and Figure 47 the most recent DIN:DIP ratios in the Bear Creek basin. In Bear Creek (0484, C484, and J484), phosphorus appears to be the limiting nutrient in the winter and spring and nitrogen is likely limiting in the summer and fall (Figure 48). In Evans Creek

(B484), either nitrogen is limiting or both are co-limiting. In Cottage Lake Creek (N484), both appear to be co-limiting, with a tendency toward phosphorus limitation in the spring.

Table 35. Summary statistics for DIN:DIP in Bear Creek basin.

Site	Event	Years	FOD	Mean	Median	Min	Max
0484	Routine	2001-2015	277/178	12.8	10.6	3.41	32.8
	Wet-weather	2001-2010	25/25	11.1	8.78	4.17	22.8
B484	Routine	2001-2008, 2013-2015	129/129	6.16	5.35	0.37	16.1
C484	Routine	2001-2008, 2013-2015	135/135	16.7	14.0	5.22	44.0
J484	Routine	2001-2008	93/93	15.3	10.9	1.47	48.8
N484	Routine	2001-2008, 2013-2015	134/134	15.1	13.9	5.65	54.0

FOD: Frequency of detection

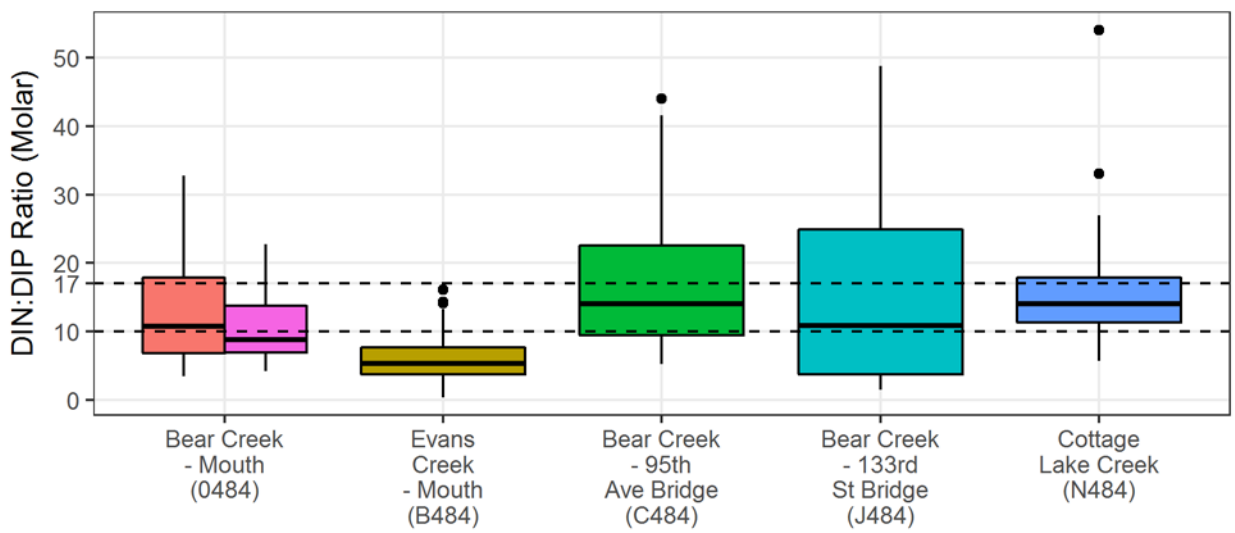

Figure 47. DIN:DIP ratios at Bear Creek basin sites. Years included in statistical analysis varied by site (Table 35). Nitrogen-limitation breakpoint (<10) and phosphorus-limitation breakpoint (>17) shown as dashed lined. Mouth site (0484) broken up into routine (red) and wet-weather (pink).

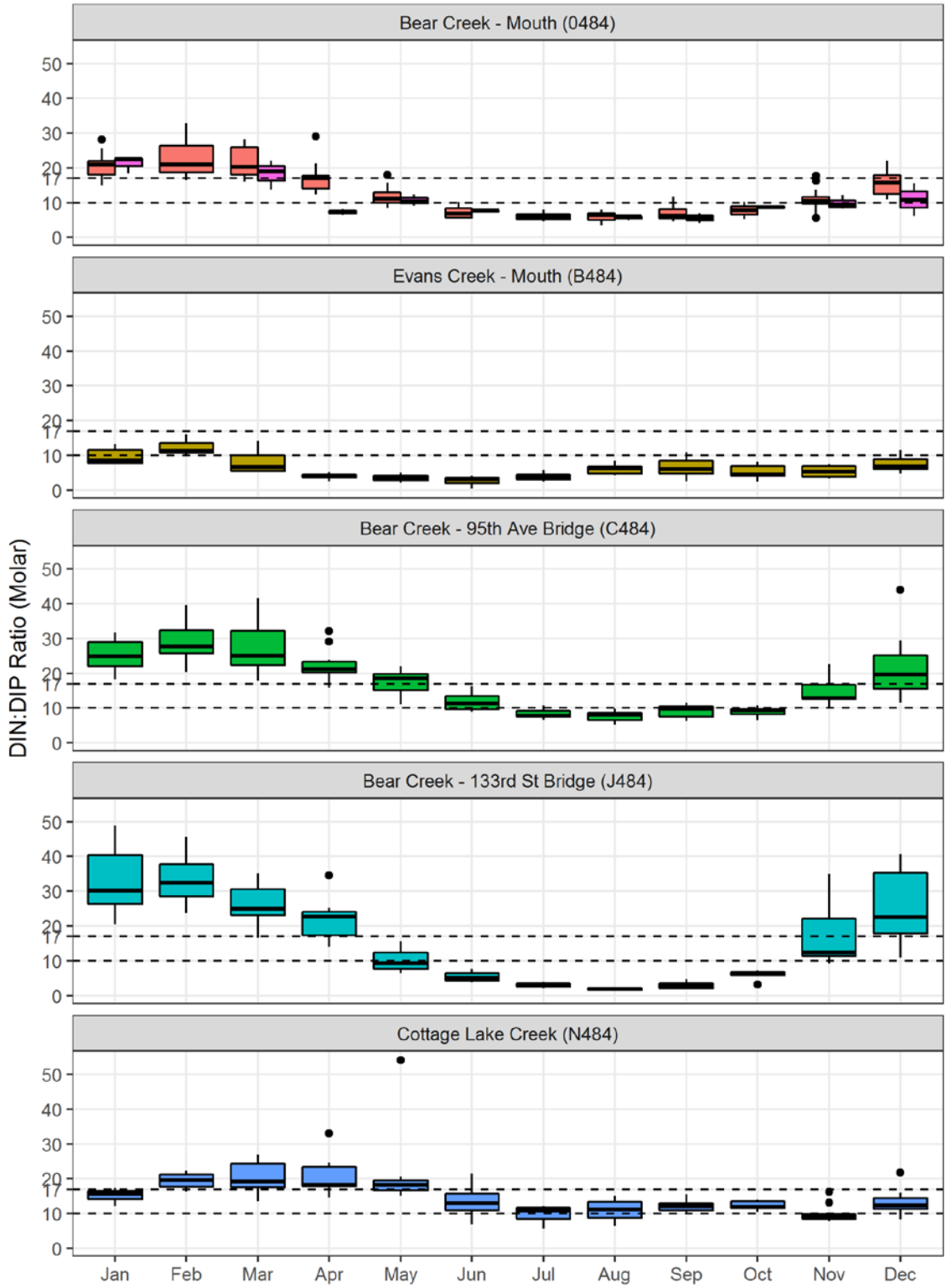

Figure 48. Monthly DIN:DIP ratios in the Bear Creek basin. Years included in statistical analysis varied by site (Table 37). Nitrogen-limitation breakpoint (<10) and phosphorus-limitation breakpoint (>17) shown as dashed lined. Mouth site (0484) broken up into routine (red) and wet-weather (pink).

3.11.2 Long-term Trends

The DIN:DIP ratio has increased significantly at sites 0484, C484, and N484 (Table 36; Figure 49). This is because the relative decrease in DIP (orthophosphate) at these sites is greater than the relative decrease in DIN (nitrate and ammonia). That is, the denominator is decreasing, resulting in an increased ratio. At these sites, phosphorus is becoming more limiting.

Table 36. Annual DIN:DIP (molar) trend results from Seasonal Mann-Kendall test.

Site	Years Evaluated	p-value	Sen Slope (units/year)	Tau	Change 1975 to 2015[a]
0484	1974 – 2015	**<0.0001**	**0.124**	**0.31**	**77%**
B484	1979 – 2015	0.4537	-0.008	-0.03	--
C484	1974 – 2015	**<0.0001**	**0.155**	**0.32**	**64%**
J484	1974 – 2008	0.1165	0.028	0.07	--
N484	1974 – 2015	**<0.0001**	**0.119**	**0.22**	**45%**

a. Assuming constant slope.

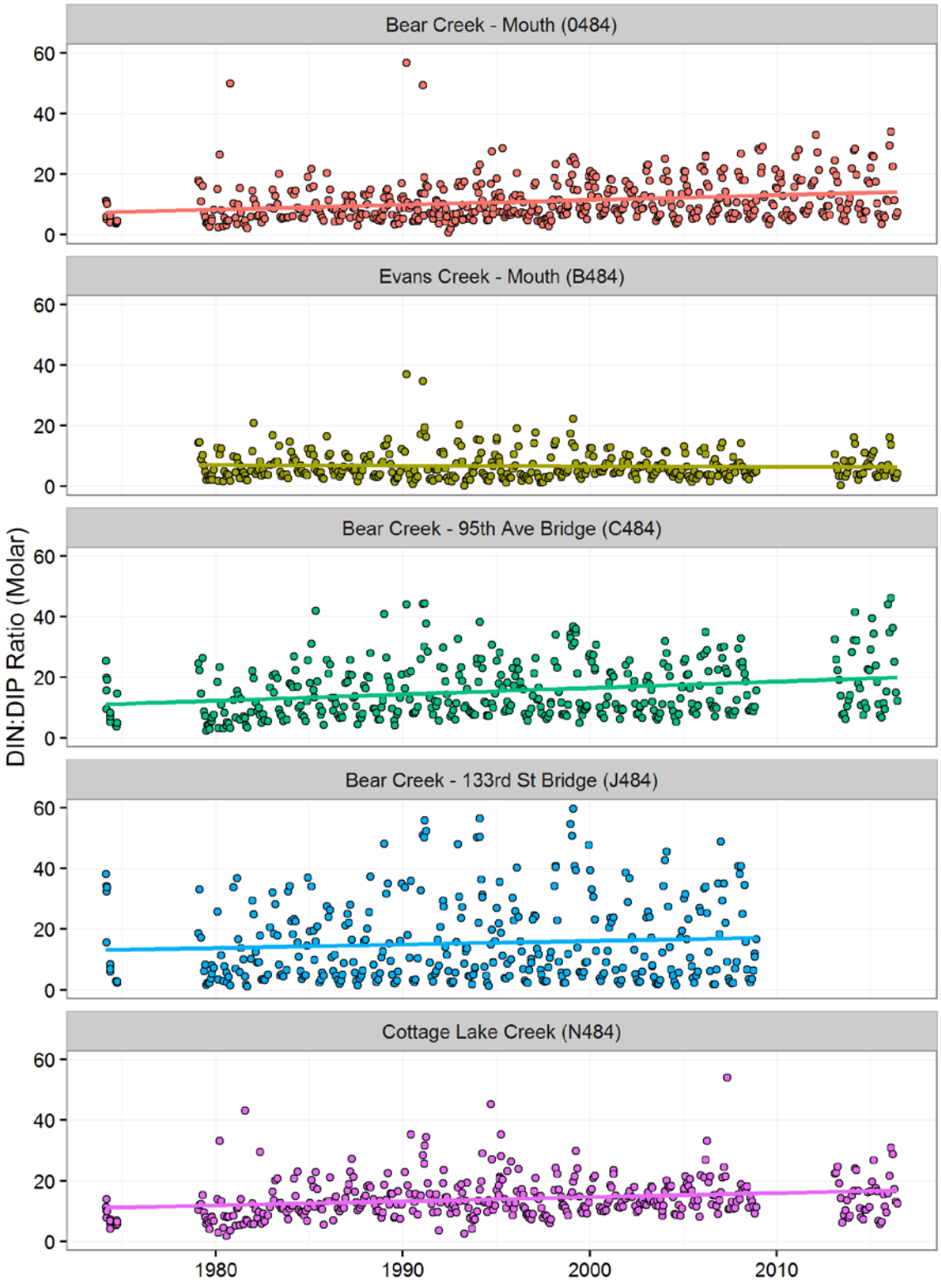

Figure 49. Long-term dissolved inorganic nitrogen (DIN) to dissolved inorganic phosphorus (DIP) ratios in the Bear Creek basin.

3.12 Metals

This section presents a summary of total and dissolved metals collected from 2001 to 2010 in the study area during routine and wet-weather samples, a step- trend analysis of total metal concentrations during storm events, and a comparison to water quality standards.

3.12.1 Most Recent Conditions

Table 37 present summary statistics for dissolved and total metal concentrations at each site. Data for 0484 are separated by whether the sample was collected as part of wet-weather or routine monitoring. Wet-weather events were targeted for sampling when antecedent precipitation conditions caused high levels of stormwater runoff to enter the stream system.

Wet-weather samples typically had greater metal concentrations than routine samples. Statistically significantly higher concentrations were found for total arsenic, dissolved and total chromium, dissolved and total copper, total iron, total lead, total mercury, dissolved and total nickel, and dissolved and total zinc.

No metals except total iron were detected at sites J484 and N484 in 2007 and 2008. This is likely due to the high detection limits associated with the analytical methods employed at that time (EPA 2007; inductively coupled plasma emission spectrometry).

Table 37. Summary statistics for dissolved and total metals in Bear Creek basin (2001-2010). All values in µg/L.

Parameter	Site	Event	FOD	Median	Mean[a]	95% LCL[a]	95% UCL[a]	Min MDL	Max MDL
Arsenic, Dissolved	0484	Wet-weather	25/25	1.33	1.35	1.21	1.48	0.1	0.5
		Routine	20/20	1.24	1.26	1.15	1.38	0.01	0.1
	C484	Routine	4/4	1.5	1.52	1.22	1.83	0.5	0.5
Arsenic, Total	0484	Wet-weather	25/25	1.9	2.02	1.68	2.36	0.1	0.5
		Routine	20/20	1.42	1.53	1.31	1.74	0.01	0.5
	C484	Routine	4/4	1.8	1.9	1.76	2.04	0.5	0.5
	J484	Routine	0/10	NA	NA	NA	NA	25	50
	N484	Routine	0/10	NA	NA	NA	NA	25	50
Cadmium, Dissolved	0484	Wet-weather	0/25	NA	NA	NA	NA	0.05	0.1
		Routine	0/20	NA	NA	NA	NA	0.01	0.01
	C484	Routine	0/4	NA	NA	NA	NA	0.1	0.1
Cadmium, Total	0484	Wet-weather	2/25	NA	NA	NA	NA	0.05	0.1
		Routine	2/20	NA	NA	NA	NA	0.01	0.01
	C484	Routine	0/4	NA	NA	NA	NA	0.1	0.1
	J484	Routine	0/10	NA	NA	NA	NA	2	3

Parameter	Site	Event	FOD	Median	Mean[a]	95% LCL[a]	95% UCL[a]	Min MDL	Max MDL
	N484	Routine	0/10	NA	NA	NA	NA	2	3
Chromium, Dissolved	0484	Wet-weather	25/25	0.52	0.513	0.469	0.558	0.2	0.4
		Routine	20/20	0.383	0.401	0.363	0.439	0.05	0.05
	C484	Routine	2/2	NA	1.4	0.141	2.67	0.4	0.4
Chromium, Total	0484	Wet-weather	25/25	1.3	2.04	1.35	2.72	0.2	0.4
		Routine	20/20	0.573	0.953	0.368	1.54	0.05	0.4
	C484	Routine	4/4	0.62	0.778	0.533	1.02	0.4	0.4
	J484	Routine	0/10	NA	NA	NA	NA	3	5
	N484	Routine	0/10	NA	NA	NA	NA	3	5
Copper, Dissolved	0484	Wet-weather	25/25	1.2	1.26	1.11	1.41	0.4	0.4
		Routine	20/20	0.523	0.641	0.495	0.786	0.1	0.1
	C484	Routine	3/4	0.41	0.558	0.326	0.789	0.4	0.4
Copper, Total	0484	Wet-weather	25/25	2.21	2.65	1.94	3.35	0.4	0.4
		Routine	20/20	0.685	1.02	0.503	1.55	0.1	0.4
	C484	Routine	3/4	0.71	0.965	0.578	1.35	0.4	0.4
	J484	Routine	0/10	NA	NA	NA	NA	4	4
	N484	Routine	0/10	NA	NA	NA	NA	4	4
Iron, Dissolved	0484	Wet-weather	12/12	200	202	169	236	50	50
		Routine	9/9	190	208	162	254	50	50
Iron, Total	0484	Wet-weather	17/17	846	1340	707	1980	10	50
		Routine	20/20	466	611	304	918	10	50
	J484	Routine	10/10	394	400	342	457	50	50
	N484	Routine	10/10	180	243	187	300	50	50
Lead, Dissolved	0484	Wet-weather	4/25	NA	0.12	0.107	0.133	0.1	0.2
		Routine	20/20	0.078	0.0846	0.0687	0.10	0.025	0.025
	C484	Routine	0/4	NA	NA	NA	NA	0.2	0.2
Lead, Total	0484	Wet-weather	25/25	0.55	1.04	0.477	1.61	0.1	0.2
		Routine	20/20	0.19	0.334	0.115	0.553	0.025	0.2
	C484	Routine	3/4	0.2	0.285	0.18	0.39	0.2	0.2
	J484	Routine	0/10	NA	NA	NA	NA	20	30
	N484	Routine	0/10	NA	NA	NA	NA	20	30
Mercury, Dissolved	0484	Wet-weather	0/13	NA	NA	NA	NA	0.005	0.2
		Routine	9/9	0.00158	0.00178	0.00116	0.0024	0.0001	0.0001
	C484	Routine	0/3	NA	NA	NA	NA	0.2	0.2

Parameter	Site	Event	FOD	Median	Mean[a]	95% LCL[a]	95% UCL[a]	Min MDL	Max MDL
Mercury, Total	0484	Wet-weather	11/25	0.00302	0.00484	0.00272	0.00695	0.0002	0.2
		Routine	20/20	0.00204	0.0028	0.0017	0.0039	0.0001	0.0002
	C484	Routine	0/3	NA	NA	NA	NA	0.2	0.2
Nickel, Dissolved	0484	Wet-weather	25/25	0.721	0.694	0.631	0.757	0.1	0.3
		Routine	20/20	0.58	0.582	0.524	0.639	0.05	0.05
	C484	Routine	4/4	0.64	0.692	0.526	0.859	0.3	0.3
Nickel, Total	0484	Wet-weather	25/25	1.24	2.01	1.36	2.66	0.1	0.3
		Routine	20/20	0.788	1.06	0.544	1.57	0.05	0.3
	C484	Routine	4/4	0.89	0.938	0.717	1.16	0.3	0.3
	J484	Routine	0/9	NA	NA	NA	NA	5	20
	N484	Routine	0/9	NA	NA	NA	NA	5	20
Selenium, Dissolved	0484	Wet-weather	0/11	NA	NA	NA	NA	1.5	1.5
		Routine	0/20	NA	NA	NA	NA	0.5	0.5
	C484	Routine	0/4	NA	NA	NA	NA	1.5	1.5
Selenium, Total	0484	Wet-weather	0/11	NA	NA	NA	NA	1.5	1.5
		Routine	0/20	NA	NA	NA	NA	0.5	0.5
	C484	Routine	0/4	NA	NA	NA	NA	1.5	1.5
	J484	Routine	0/10	NA	NA	NA	NA	25	50
	N484	Routine	0/10	NA	NA	NA	NA	25	50
Silver, Dissolved	0484	Wet-weather	0/25	NA	NA	NA	NA	0.05	0.2
		Routine	0/20	NA	NA	NA	NA	0.01	0.025
	C484	Routine	0/4	NA	NA	NA	NA	0.2	0.2
Silver, Total	0484	Wet-weather	0/25	NA	NA	NA	NA	0.05	0.2
		Routine	0/20	NA	NA	NA	NA	0.01	0.025
	C484	Routine	0/4	NA	NA	NA	NA	0.2	0.2
	J484	Routine	0/10	NA	NA	NA	NA	4	4
	N484	Routine	0/10	NA	NA	NA	NA	4	4
Zinc, Dissolved	0484	Wet-weather	25/25	2.1	2.39	1.94	2.85	0.5	0.5
		Routine	19/20	1.0	1.24	0.977	1.51	0.15	0.5
	C484	Routine	3/4	0.7	2.24	0.0387	4.51	0.5	0.5
Zinc, Total	0484	Wet-weather	25/25	5.4	7.63	4.82	10.4	0.5	0.5
		Routine	20/20	1.1	2.45	0.984	3.91	0.15	0.5
	C484	Routine	4/4	1.6	3.8	0.566	7.03	0.5	0.5
	J484	Routine	0/10	NA	NA	NA	NA	5	5
	N484	Routine	0/10	NA	NA	NA	NA	5	5

Parameter	Site	Event	FOD	Median	Mean[a]	95% LCL[a]	95% UCL[a]	Min MDL	Max MDL

FOD: Frequency of detection

a. Kaplan-Meier estimate of mean in presence of non-detects. Parameters with less than 3 detections not estimated, and parameters with more than 70 percent non-detects are italicized due to high uncertainty in estimate.

3.12.2 Step-trend Analysis of Metals (1988-1992 vs. 2006-2010)

The concentrations of total metals measured in wet-weather samples at site 0484 between 1988 and 1992 and between 2006 and 2010 were compared using the Peto & Peto modification of the Gehan-Wilcoxon test. Significant differences were not found in any of the metals measured during the two time periods (Table 37). Arsenic and selenium were not measured between 1988 and 1992. High detection limits between 1988 and 1992 resulted in few to no detections of chromium, lead, mercury, and nickel, precluding comparison to more recent conditions. Total silver was not detected during either five-year period.

The boxplots presented in this section are based on the estimated distribution of the data, where non-detects are replaced with most likely values and detected values remain unchanged (Figure 50).

Table 38. Comparison of total metal concentrations at site 0484. All values in µg/L.

Parameter	Year Range	FOD	Median	Mean[a]	95% LCL[a]	95% UCL[a]	Min MDL	Max MDL
Arsenic, Total	1988-1992	0/0	NA	NA	NA	NA	NA	NA
	2006-2010	15/15	1.7	2.01	1.47	2.55	0.1	0.5
Cadmium, Total	1988-1992	1/22	NA	2	NA	NA	2	3
	2006-2010	1/15	NA	0.1	NA	NA	0.05	0.1
Chromium, Total	1988-1992	3/22	NA	6.23	5.79	6.66	5	5
	2006-2010	15/15	1.2	1.81	1.11	2.51	0.2	0.4
Copper, Total	1988-1992	15/22	3	3.18	2.62	3.74	2	3
	2006-2010	15/15	2.27	2.68	1.73	3.63	0.4	0.4
Iron, Total	1988-1992	22/22	880	1280	851	1700		
	2006-2010	7/7	846	1350	255	2450	10	50
Lead, Total	1988-1992	0/22	NA	NA	NA	NA	30	40
	2006-2010	15/15	0.55	1.12	0.227	2.01	0.1	0.2
Mercury, Total	1988-1992	2/19	NA	NA	NA	NA	0.2	0.4
	2006-2010	11/15	0.00302	0.00484	0.00272	0.00696	0.0002	0.05
Nickel, Total	1988-1992	1/22	NA	NA	NA	NA	10	10
	2006-2010	15/15	1.21	1.80	1.10	2.51	0.1	0.3
Selenium, Total	1988-1992	0/0	NA	NA	NA	NA	NA	NA
	2006-2010	0/1	NA	NA	NA	NA	1.5	1.5
Silver,	1988-1992	0/17	NA	NA	NA	NA	3	4

Total	2006-2010	0/15	NA	NA	NA	NA	0.05	0.2
Zinc, Total	1988-1992	20/22	7	13.5	6.36	20.7	4	4
	2006-2010	15/15	5.4	8.10	3.92	12.3	0.5	0.5

a. In presence of non-detects, mean and 95% confidence intervals calculated using Kaplan-Meier method.

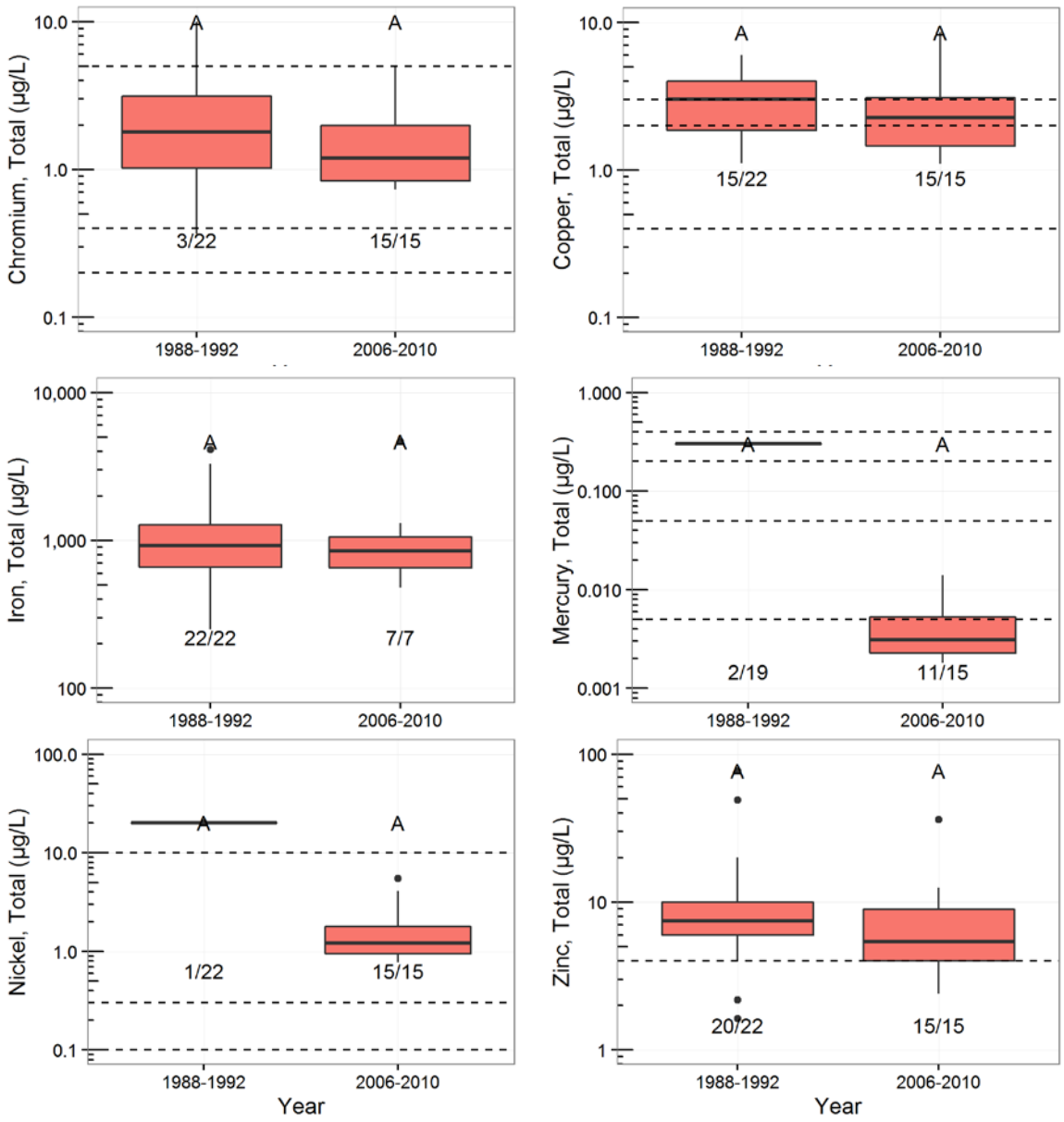

Figure 50. Total chromium, copper, iron, mercuy, nickel, and zinc concentrations in 1988-1992 and 2006-2010 wet-weather samples. Method detection limts shown as dashed lines.

3.12.3 Comparison to Water Quality Standards

No metals except for total mercury were detected at concentrations greater than the numeric criteria in the State Surface Water Quality Standards for the protection of aquatic

life or of human health between 2001 and 2010 (WAC 173-201A-240). On two occasions, total mercury concentrations were above the chronic criterion (0.012 µg/L) in November 2006 (0.012 µg/L) and December 2007 (0.014 µg/L) at site 0484, both of which during storm events (Table 39). The criterion refers to a 4-day average concentration not to be exceeded more than once every three years on average. Based on the relation of the concentrations to wet-weather events, it is not likely that the chronic criterion for total mercury was exceeded.

Table 39. Metals compared to water quality standards (2001-2010). All values in µg/L.

Analyte	FOD	Max Detect	Mean[a]	Min MDL for Non-Detect	Max MDL for Non-Detect	Human Health Criteria	Freshwater Aquatic Life Criteria	
						No. Samples Above	No. Samples Above Acute	No. Samples Above Chronic
Antimony, Total	20/32	0.298	0.0997	0.01	0.5	0/32	—	—
Arsenic, Dissolved	45/45	2.1	1.31	NA	NA	—	0/45	0/45
Arsenic, Total	45/46	5.15	1.78	0.1	0.1	0/46	—	—
Cadmium, Dissolved	0/45	NA	NA	0.01	0.1	—	0/45	0/45
Chromium (III)[b]	46/46	8.41	1.52	NA	NA	—	0/46	0/46
Chromium (VI)	0/0	NA	NA	NA	NA	—	0/0	0/0
Copper, Dissolved	45/45	1.9	0.984	NA	NA	—	0/45	0/45
Lead, Dissolved	24/45	0.22	0.0886	0.1	0.2	—	0/45	0/45
Mercury, Dissolved	9/22	0.00372	0.00178	0.005	0.2	—	0/22	—
Mercury, Total	31/46	0.014	0.00351	0.0001	0.2	0/45	—	2/46
Nickel, Dissolved	45/45	1.2	0.644	NA	NA	—	0/45	0/45
Nickel, Total	45/46	7.84	1.56	0.05	0.05	0/46		
Selenium, Dissolved	0/31	NA	NA	0.5	1.5	0/31	0/31	0/31
Silver, Dissolved	0/45	NA	NA	0.01	0.2	—	0/45	—
Thallium, Total	2/30	0.013	NA	0.01	0.2	0/30	—	—
Zinc, Dissolved	44/45	6.05	1.88	0.5	0.5	—	0/45	0/45
Zinc, Total	45/46	36	5.22	0.15	0.15	0/46	—	—

a. Kaplan-Meier estimate of mean in presence of non-detects. Parameters with less than 3 detections not estimated, and parameters with more than 70 percent non-detects are italicized due to high uncertainty in estimate.
b. Represented by total chromium (WAC 173-201A-240; Table 24; Note ‘gg’: “Where methods to measure trivalent chromium are unavailable, these criteria are to be represented by total-recoverable chromium”).

3.13 Organic Chemicals

The absence of historical water quality data and the low number of detects for organic chemicals precludes long-term trend analysis.

3.13.1 Summary Statistics

The data for the detected organic chemicals collected in 2001-2003 and in 2009-2010 are summarized below (Table 40). Appendix B provides a summary of all organic chemicals analyzed..

Table 40. Summary statistics for detected organic chemicals. All values in µg/L.

Parameter	Site	FOD	Mean[a]	Median	Min Detect	Max Detect	Min MDL	Max MDL
2,4-D	0484	1/16	NA	NA	0.74	0.74	0.016	0.5
2-Methylphenol	0484	1/16	NA	NA	0.29	0.29	0.024	0.25
Benzoic Acid	0484	6/8	0.832	0.735	0.614	1.53	0.24	0.24
Benzyl Butyl Phthalate	0484	3/16	*0.0961*	NA	0.085	0.173	0.0094	0.048
	C484	0/1	NA	NA	NA	NA	0.0095	0.0095
Bis(2-ethylhexyl) adipate	0484	0/1	NA	NA	NA	NA	0.19	0.19
	C484	1/4	NA	NA	0.269	0.269	0.0094	0.0095
Bis(2-Ethylhexyl) Phthalate	0484	5/16	1.17	NA	0.534	5.07	0.0094	0.024
	C484	0/1	NA	NA	NA	NA	0.0095	0.0095
Bisphenol A	0484	0/1	NA	NA	NA	NA	0.19	0.19
	C484	2/4	NA	NA	0.012	0.014	0.0094	0.0095
Caffeine	0484	10/16	0.0477	0.018	0.014	0.133	0.0094	0.024
	C484	0/1	NA	NA	NA	NA	0.024	0.024
Diethyl Phthalate	0484	2/16	NA	NA	0.056	0.14	0.0094	0.024
	C484	0/1	NA	NA	NA	NA	0.0095	0.0095
Dimethyl Phthalate	0484	1/16	NA	NA	0.015	0.015	0.0094	0.024
Di-N-Butyl Phthalate	0484	5/16	0.0483	0.035	0.035	0.0842	0.0094	0.024
	C484	0/1	NA	NA	NA	NA	0.0095	0.0095
Estradiol	0484	0/9	NA	NA	NA	NA	0.00048	0.019
	C484	1/4	NA	NA	0.013	0.013	0.0094	0.0095
Estrone	0484	3/9	0.000355	NA	0.00031	0.00058	0.00029	0.019
	C484	0/4	NA	NA	NA	NA	0.0094	0.0095
Fluoranthene	0484	1/16	NA	NA	0.011	0.011	0.0094	0.01
	C484	0/1	NA	NA	NA	NA	0.0095	0.0095
Hexadecanoic acid	0484	3/3	1.44	1.32	1.102	1.896	NA	NA

Parameter	Site	FOD	Mean[a]	Median	Min Detect	Max Detect	Min MDL	Max MDL
Naphthalene	0484	2/16	NA	NA	0.011	0.013	0.0094	0.025
	C484	0/1	NA	NA	NA	NA	0.024	0.024
Octadecanoic acid	0484	3/3	1.37	1.32	1.041	1.752	NA	NA
Phenanthrene	0484	2/16	NA	NA	0.011	0.012	0.0094	0.01
	C484	0/1	NA	NA	NA	NA	0.0095	0.0095
Phenol	0484	1/16	NA	NA	0.096	0.096	0.024	0.1
	C484	0/1	NA	NA	NA	NA	0.48	0.48
Pyrene	0484	5/16	0.0192	NA	0.011	0.132	0.0094	0.01
	C484	0/1	NA	NA	NA	NA	0.0095	0.0095

FOD: Frequency of detection

a. Kaplan-Meier estimate of mean in presence of non-detects. Parameters with less than 3 detections not estimated, and parameters with more than 70 percent non-detects are italicized due to high uncertainty in estimate.

3.13.2 Comparison to Water Quality Standards

One of the analyzed organic chemicals was detected at concentrations greater than the numeric criterion in the State Surface Water Quality Standards for the protection of human health. No analyzed organic chemicals were detected above the aquatic life criteria (WAC 173-201A-240). Several chemicals had method detection limits greater than the criteria. These are highlighted in yellow in Table 41. Values above the criteria are highlighted in red in Table 41.

Bis(2-ethylhexyl)phthalate was detected at levels above the human health criterion (0.25 µg/L). Of the 8 samples taken during routine monitoring between 2001 and 2003, two samples were above the criterion, five samples were contaminated in the laboratory and had detection limits set to above the criterion, and one sample was contaminated but had detection limits beneath the criterion. Of the 8 targeted wet-weather samples taken in 2009 and 2010, three were above the criterion and five were contaminated in the laboratory and had detection limits set to above the criterion. In all, 5 of 16 samples were detected above the criterion, 10 of 16 were contaminated with detection limits above the criterion, and 1 of 16 was contaminated with a detection limit below the criterion.

Table 41. Organic chemicals compared to WA State water quality standards. All values in µg/L. Detection limits above the criteria highlighted in yellow, and detects above the criteria highlighted in red.

Analyte	FOD	Max Detect	Mean[a]	Min MDL for Non-Detect	Max MDL for Non-Detect	Human Health Criteria	Freshwater Aquatic Life Criteria	
						Samples Above	Samples Above Acute	Samples Above Chronic
Chlorinated Herbicides and Pesticides								
4,4'-DDD	0/8	NA	NA	0.0047	0.0051	0/8	0/8	0/8
4,4'-DDE	0/8	NA	NA	0.0047	0.0051	0/8	0/8	0/8
4,4'-DDT	0/8	NA	NA	0.0047	0.0051	0/8	0/8	0/8
Aldrin	0/8	NA	NA	0.0047	0.0051	0/8	0/8	0/8
Alpha-BHC	0/8	NA	NA	0.0047	0.0051	0/8	—	—
Beta-BHC	0/8	NA	NA	0.0047	0.0051	0/8	—	—
Chlordane	0/8	NA	NA	0.024	0.026	0/8	0/8	0/8
Dieldrin	0/8	NA	NA	0.0047	0.0051	0/8	0/8	0/8
Endosulfan I	0/8	NA	NA	0.0047	0.0051	—	0/8	0/8
Endosulfan II	0/8	NA	NA	0.0047	0.0051	—	0/8	0/8
Endosulfan Sulfate	0/8	NA	NA	0.0047	0.0051	0/8	—	—
Endrin Aldehyde	0/8	NA	NA	0.0047	0.0051	0/8	—	—
Endrin	0/8	NA	NA	0.0047	0.0051	0/8	0/8	0/8
Gamma-BHC (Lindane)	0/8	NA	NA	0.0047	0.0051	0/8	0/8	0/8
Heptachlor Epoxide	0/8	NA	NA	0.0047	0.0051	0/8	—	—
Heptachlor	0/8	NA	NA	0.0047	0.0051	0/8	0/8	0/8
Hexachlorocyclopentadiene	0/8	NA	NA	0.24	0.24	0/8	—	—
Toxaphene	0/8	NA	NA	0.047	0.051	0/8	0/8	0/8
Organophosphate Pesticides								
Chlorpyrifos	0/8	NA	NA	0.032	0.034	—	0/8	0/8
Parathion-Ethyl	0/8	NA	NA	0.042	0.045	—	0/8	0/8

Analyte	FOD	Max Detect	Mean[a]	Min MDL for Non-Detect	Max MDL for Non-Detect	Human Health Criteria	Freshwater Aquatic Life Criteria	
						Samples Above	Samples Above Acute	Samples Above Chronic
Parathion-Methyl	0/8	NA	NA	0.034	0.036	—	0/8	0/8
LPAHs								
2-Chloronaphthalene	0/16	NA	NA	0.0094	0.024	0/16	—	—
Acenaphthene	0/16	NA	NA	0.0094	0.01	0/16	—	—
Anthracene	0/16	NA	NA	0.0094	0.01	0/16	—	—
Fluorene	0/16	NA	NA	0.0094	0.01	0/16	—	—
HPAHs								
Benzo(a)anthracene	0/16	NA	NA	0.0094	0.025	0/16	—	—
Benzo(a)pyrene	0/16	NA	NA	0.0094	0.01	0/16	—	—
Benzo(b)fluoranthene	0/16	NA	NA	0.0094	0.01	0/16	—	—
Benzo(k)fluoranthene	0/16	NA	NA	0.0094	0.01	0/16	—	—
Dibenzo(a,h)anthracene	0/16	NA	NA	0.0094	0.095	0/16	—	—
Chrysene	0/16	NA	NA	0.0094	0.025	0/16	—	—
Fluoranthene	1/16	0.011	NA	0.0094	0.01	0/16	—	—
Indeno(1,2,3-Cd)Pyrene	0/16	NA	NA	0.0094	0.051	0/16	—	—
Pyrene	5/16	0.132	0.0192	0.0094	0.01	0/16	—	—
PCBs								
Aroclor 1016	0/8	NA	NA	0.047	0.051	—	—	—
Aroclor 1221	0/8	NA	NA	0.047	0.051	—	—	—
Aroclor 1232	0/8	NA	NA	0.047	0.051	—	—	—
Aroclor 1242	0/8	NA	NA	0.047	0.051	—	—	—
Aroclor 1248	0/8	NA	NA	0.047	0.051	—	—	—
Aroclor 1254	0/8	NA	NA	0.047	0.051	—	—	—

Analyte	FOD	Max Detect	Mean[a]	Min MDL for Non-Detect	Max MDL for Non-Detect	Human Health Criteria	Freshwater Aquatic Life Criteria	
						Samples Above	Samples Above Acute	Samples Above Chronic
Aroclor 1260	0/8	NA	NA	0.047	0.051	—	—	—
Total PCBs (Sum Aroclors)	0/8	NA	NA	0.047	0.051	0/8	0/8	0/8
Semi-Volatiles Organic Compounds (SVOCs)								
1,2-Dichlorobenzene	0/16	NA	NA	0.024	0.051	0/16	—	—
1,2,4-Trichlorobenzene	0/16	NA	NA	0.0094	0.024	0/16	—	—
1,3-Dichlorobenzene	0/16	NA	NA	0.024	0.051	0/16	—	—
1,4-Dichlorobenzene	0/16	NA	NA	0.024	0.051	0/16	—	—
2-Chlorophenol	0/16	NA	NA	0.024	0.1	0/16	—	—
2,4-Dichlorophenol	0/16	NA	NA	0.047	0.1	0/16	—	—
2,4-Dimethylphenol	0/16	NA	NA	0.024	1.5	0/16	—	—
2,4-Dinitrophenol	0/16	NA	NA	0.24	1	0/16	—	—
2,4-Dinitrotoluene	0/16	NA	NA	0.047	0.24	0/16	—	—
2,4,6-Trichlorophenol	0/16	NA	NA	0.047	0.24	0/16	—	—
3,3'-Dichlorobenzidine	0/16	NA	NA	0.094	0.76	0/16	—	—
4,6-Dinitro-O-Cresol	0/16	NA	NA	0.24	1	0/16	—	—
Aniline	0/8	NA	NA	0.024	0.024	—	—	—
Butyl Benzyl Phthalate	3/16[b]	0.173	*0.0961*	0.014	0.298	0/16	—	—
Bis(2-Chloroethyl)Ether	0/16	NA	NA	0.0094	0.024	0/16	—	—
Bis(2-Ethylhexyl)Phthalate	5/16[b]	5.07	1.17	0.221	1.61	**5/16**	—	—
Di-N-Butyl Phthalate	5/16[b]	0.0842	0.0483	0.015	0.489	0/16	—	—
Diethyl Phthalate	2/16[b]	0.14	NA	0.013	0.307	0/16	—	—
Dimethyl Phthalate	1/16[b]	0.015	NA	0.0094	0.0565	0/16	—	—
Hexachlorobenzene	0/16	NA	NA	0.024	0.025	0/16	—	—

Analyte	FOD	Max Detect	Mean[a]	Min MDL for Non-Detect	Max MDL for Non-Detect	Human Health Criteria	Freshwater Aquatic Life Criteria	
						Samples Above	Samples Above Acute	Samples Above Chronic
Hexachlorobutadiene	0/16	NA	NA	0.047	0.051	0/16	—	—
Hexachloroethane	0/16	NA	NA	0.024	0.048	0/16	—	—
Isophorone	0/16	NA	NA	0.0094	0.048	0/16	—	—
N-Nitrosodi-N-Propylamine	0/16	NA	NA	0.047	0.1	0/16	—	—
N-Nitrosodimethylamine	0/15	NA	NA	0.024	0.025	0/16	—	—
N-Nitrosodiphenylamine	0/16	NA	NA	0.024	0.25	0/16	—	—
Nitrobenzene	0/16	NA	NA	0.0094	0.024	0/16	—	—
Pentachlorophenol	0/16	NA	NA	0.12	0.24	0/16	0/16	0/16
Phenol	1/16[b]	0.096	NA	0.024	3.53	0/16	—	—

a. Kaplan-Meier estimate of mean in presence of non-detects. Parameters with less than 3 detections not estimated, and parameters with more than 70 percent non-detects are italicized due to high uncertainty in estimate.
b. Blank contamination present in a least one sample. EPA National Functional Guidelines Followed.

3.14 Sediment Quality

Sediment chemistry data were collected approximately annually between 1987 and 2006 at the mouth of Bear Creek as part of the Stream Monitoring Program. A basin-wide sediment chemistry sampling effort took place in 2006, including 22 collections with Bear Creek, Evans Creek, and Cottage Lake Creek. In 2010, site 0484 was sampled.

3.14.1 Summary Statistics

Table 42 presents the summary statistics for the 2006 basin-wide sampling, lumping all sites together. Sediments in Bear Creek are typically sandy. Substantial levels of gravel (>30 percent) were found below the confluence of Cottage and Bear Creeks (HH484), at upper Cottage Lake Creek (N484), at Bear Creek near the Tolt Pipeline bridge (P484), and at upper Evans Creek (TT484). Substantial levels of fines (>20 percent) were found at Bear Creek below Paradise Lake (Q484) and at Cottage Lake Creek below the Cold Creek confluence (VV484).

Table 42. Sediment chemistry summary statistics for 2006 Bear Creek basin-wide sampling.

Parameter	FOD	Mean[a]	Median	Min	Max	Min MDL	Max MDL
Conventionals							
Ammonia Nitrogen (mg/Kg-DW)	22/22	16.4	5.35	1.9	85	0.12	5.3
Orthophosphate Phosphorus (mg/Kg-DW)	22/22	29.3	9.42	4.5	260	0.25	2.6
Total Phosphorus (mg/Kg-DW)	22/22	492	342	212	2080	3.2	27
Clay (%)	6/21	1.18	NA	0.7	7.5	0.62	5.3
Fines (%)	20/21	6.37	4.8	0.6	23	0.62	5.3
Gravel (%)	21/21	14.8	10.2	0.5	54	0.12	1.1
Sand (%)	21/21	72.9	75.5	43	93	0.12	1.1
Silt (%)	20/21	5.69	4.5	0.6	23	0.62	5.3
Total Organic Carbon (%)	22/22	1.8	0.90	0.16	8.6	0.01	0.90
Total Solids (%)	22/22	58.2	70.9	9.4	81	0.0062	0.053
Total Sulfide (mg/Kg-DW)	14/21	70.5	2.26	0.85	397	0.62	27
Sulfide, Acid Volatile (mg/Kg-DW)	14/21	40.5	6.19	1.8	217	0.31	14
Metals (mg/Kg-DW)							
Arsenic, Extractable,	1/21	NA	NA	3.2	3.2	1.2	11
Arsenic, Total	22/22	7.17	3.63	2.8	40	0.15	1.3
Cadmium, Extractable	1/21	NA	NA	0.85	0.85	0.075	0.65
Cadmium, Total	22/22	0.193	0.0639	0.044	1.2	0.031	0.27

Parameter	FOD	Mean[a]	Median	Min	Max	Min MDL	Max MDL
Chromium, Extractable	20/21	0.941	0.81	0.35	2	0.12	1.1
Chromium, Total	22/22	26.5	19.9	11	90	0.32	2.7
Copper, Extractable	21/21	2.01	1.29	0.77	9	0.1	0.87
Copper, Total, ICP	22/22	10.4	6.25	2.7	40	0.26	2.1
Lead, Extractable, SEM	21/21	4.88	2.12	1	30	0.75	6.5
Lead, Total, ICP	20/22	36.5	3.27	2.4	667	1.9	16
Mercury, Extractable,	4/21	NA	NA	0.0014	0.0021	0.0012	0.011
Mercury, Total,	10/22	0.0434	0.021	0.013	0.16	0.011	0.048
Monomethyl Mercury, Total	4/4	0.002	0.00107	0.0009	0.0047	0.000037	0.00039
Nickel, Extractable	16/21	1.4	0.91	0.54	8.2	0.51	4.4
Nickel, Total	22/22	23.8	20.3	9	65	1.2	11
Silver, Total	1/22	NA	NA	0.12	0.12	0.062	0.53
Zinc, Extractable	14/21	12	6.44	4.6	76	0.12	1.1
Zinc, Total	22/22	46.1	32.7	26	148	0.32	2.7
Organic Chemicals (µg/kg-DW)							
PAHS							
2-Methylnaphthalene	1/22	NA	NA	171	171	3.3	29
Acenaphthene	2/22	NA	NA	22	5,570	3.3	29
Acenaphthylene	1/22	NA	NA	17	17	3.3	29
Anthracene	3/22	NA	NA	4.5	1,180	3.3	29
Benzo(a)anthracene	7/22	53.7	3.46	3.5	885	3.3	29
Benzo(a)pyrene	4/22	NA	NA	20	321	3.3	29
Benzo(b)fluoranthene	11/22	64.5	3.76	3.8	928	3.3	29
Benzo(g,h,i)perylene	7/22	18.1	NA	3.6	194	3.3	29
Benzo(k)fluoranthene	10/22	49.4	NA	4.3	700	3.3	29
Chrysene	12/22	97.7	5.46	4	1,580	3.3	29
Dibenzo(a,h)anthracene	4/22	NA	NA	6.5	77	3.3	29
Fluoranthene	14/22	396	7.24	3.6	7,640	3.3	29
Fluorene	2/22	NA	NA	24	3,630	3.3	29
Indeno(1,2,3-Cd)Pyrene	5/22	NA	NA	18	191	3.3	29
Naphthalene	2/22	NA	NA	6.5	583	3.3	29
Phenanthrene	8/22	255	NA	3.8	5,380	3.3	29
Pyrene	13/22	274	6.45	4.8	5,150	3.3	29
Total HPAHS	18/22	987	32.8	7.3	17,700	3.3	29
Total LPAHs	11/22	769	3.78	3.7	16,500	3.3	29
Total PAHs	15/22	1,700	16	3.6	34,000	3.3	29
Total PCB Aroclors	2/22	NA	NA	24	25	1.6	14
SVOCs							
4-Methylphenol	0/22	NA	NA	NA	NA	6.5	56

Parameter	FOD	Mean[a]	Median	Min	Max	Min MDL	Max MDL
4,4'-DDD	0/22	NA	NA	NA	NA	1.2	11
4,4'-DDE	0/22	NA	NA	NA	NA	1.2	11
4,4'-DDT	0/22	NA	NA	NA	NA	1.2	11
Benzoic Acid	22/22	306	107	74	1,360	16	138
Benzyl Butyl Phthalate	3/22	NA	NA	11	32	6.5	56
Beta-BHC	0/22	NA	NA	NA	NA	0.62	5.3
Bis(2-ethylhexyl)adipate	1/22	NA	NA	23	23	16	138
Bis(2-Ethylhexyl)Phthalate	2/22	NA	NA	49	350	6.5	56
Carbazole	2/22	NA	NA	38	754	3.3	29
Coprostanol	4/22	NA	NA	100	1,190	65	564
Di-N-Butyl Phthalate	11/22	16	7.46	7.3	92	6.5	56
Dibenzofuran	2/22	NA	NA	11	985	3.3	29
Dieldrin	0/22	NA	NA	NA	NA	1.2	11
Diethyl Phthalate	1/22	NA	NA	7.8	7.8	6.5	56
Endrin	0/22	NA	NA	NA	NA	1.2	11
Pentachlorophenol	2/22	NA	NA	32	2,130	16	138
Phenol	14/22	25.7	9.38	7.5	167	6.5	56
Bulk Petroleum Hydrocarbons							
TPH - Diesel	0/22	NA	NA	NA	NA	62	530
TPH – Residuals	3/22	NA	NA	52	220	40	1,100

FOD: Frequency of detection
a. Kaplan-Meier estimate of mean in presence of non-detects. Parameters with less than 3 detections not estimated, and parameters with more than 70 percent non-detects are italicized due to high uncertainty in estimate.

3.14.2 Long-term Trends

Long-term sediment monitoring at site 00484 (Bear Creek mouth) allows analysis for trends. Concentrations of cadmium, chromium, copper, lead, nickel, and zinc were monitored almost annually from 1987 to 2006 (except 2003). Mercury was analyzed starting in 1989. Arsenic and silver were measured infrequently. Due to historic, higher detection limits, it is not possible to examine trends for cadmium or mercury. Organic chemicals were not measured for a period of time sufficient to evaluate trends.

Data from 1987 to 2006 indicate concentrations of chromium, copper, lead, and zinc did not change significantly over time (Table 43). Nickel levels have decreased significantly by 0.40 mg/kg per year (Table 43).

Table 43. Annual sediment metal trend results from Mann-Kendall test.

Metal	p-value	Slope (mg/Kg/year)	Tau	Change 1990 to 2005[a]
Chromium	0.1417	--	-0.25	--
Copper	0.7264	--	0.06	--

Lead	0.5577	--	-0.10	--
Nickel	**0.0252**	**-0.40**	**-0.38**	**-23%**
Zinc	0.2079	--	-0.22	--

a. Assuming constant slope.

3.14.3 Comparison to State Cleanup Criteria

Maps presenting a comparison to state sediment cleanup criteria are presented in Appendix D. All but four metals and organic chemicals were below the state standards for freshwater cleanup at all sampling sites (Table 44). Eight sites were found to have chemical concentrations above the state standards for freshwater cleanup. Of those eight sites, four are not likely to have bioavailable metals, one (0484) has potential impacts on aquatic life due to nickel, one (Q484) has potential on aquatic life due to pentachlorophenol (a pesticide and disinfectant), one (VV484) has probable effects on aquatic life due to levels of dibenzofuran (a byproduct of combustion, including tobacco) and PAHs, and four (WW484, Q484, B484, and VV484) have probable effects on aquatic life due to levels of total sulfides.

Table 44. Sediment sites, exceedances of sediment cleanup criteria, and metal bioavailability.

Sediment Site	Location	Chemicals Detected above SCO	Chemicals Detected above CSL	Metals Bioavailable (AVS/SEM >1)
00484	Bear Creek – Redmond – just upstream of Sammamish River confluence			Likely
0484	Bear Creek – Redmond - same location as water quality site 0484	Nickel		Likely
AA484	Bear Creek – Redmond – near 178th Place NE and NE Union Hill Rd			Likely
C484	Bear Creek – Redmond - same location as water quality site C484			Unlikely
M484	Bear Creek– Redmond – at NE 106th St			Likely
II484	Bear Creek – Juel Community Garden			Likely
HH484	Bear Creek– Avondale Place NE			Likely
J484	Bear Creek - same location as water quality site J484			Likely
L484	Bear Creek – Middle Bear Creek Natural Area – East of NE 143rd St			Unlikely
P484	Bear Creek – Tolt Pipeline Trail bridge			Unlikely
U484	Bear Creek – Above Paradise Lake at 232nd St SE			Likely
WW484	Bear Creek – East of NE 181st Pl		Total sulfide	Unlikely
Q484	Bear Creek – Paradise Lake Natural Area – East of NE 190th Pl	Nickel, penta-chlorophenol	Potentially penta-chlorophenol, total sulfide	Unlikely
B484	Evans Creek – Redmond - same location as water quality site B484		Total sulfide	Unlikely
BB484	Evans Creek – Evans Creek Natural Area	Arsenic, nickel	Chromium	Unlikely
SS484	Evans Creek – SR202 west of 196th	Nickel		Unlikely

Sediment Site	Location	Chemicals Detected above SCO	Chemicals Detected above CSL	Metals Bioavailable (AVS/SEM >1)
	Ave NE			
S484	Evans Creek – NE 50th St and 216th Ave NE			Unlikely
ST484	Evans Creek – NE 44th St			Unlikely
TT484	Evans Creek – SR202 west of Albertsons			Likely
X484	Cottage Lake Creek – NE 128th Way			Likely
MUSCOT01	Cottage Lake Creek – Footbridge east of NE 142nd Ct	Nickel		Unlikely
N484	Cottage Lake Creek - same location as water quality site N484			Unlikely
VV484	Cottage Lake Creek – NE 165th St – below Cold Creek confluence	Arsenic, lead, nickel	Dibenzofuran, total sulfide, total PAHs	Unlikely

4.0 SUMMARY AND CONCLUSIONS

This analysis examined long-term trends in water quality at routine monitoring sites sampled by the King County Routine Stream and River Monitoring Program, and, when possible, compared to relevant Washington State water quality standards. Five long-term monitoring sites were evaluated. Three are located along mainstem Bear Creek, one on Evans Creek, and one on Cottage Lake Creek (see Figure 2). Additionally, water temperature data from five continuous probes collecting data since the mid-1990s were used to compare to temperature standards.

4.1 Long-term Trends in Water Quality

Fecal coliform bacteria and most nutrient concentrations have significantly decreased over the past four decades at all sampling stations (Table 45). Ammonia concentrations at sites the upper Bear Creek site (J484) and Cottage Lake Creek (N484) were not found to be significantly decreasing or increasing, as with nitrate + nitrite at the middle Bear Creek site (site C484) and Cottage Lake Creek (N484). Data needed to analyze long-terms for metals and organics chemicals do not exist.

Temperature was found to be significantly increasing at all sites at a rate between 0.3 and 0.6 °C per decade. Increasing temperature may have contributed to the significantly decreasing dissolved oxygen concentrations found at all sites except the mouth (0484). The rate of dissolved oxygen decrease in Evans Creek (B484) (1 mg/L per decade) was almost 10-times greater than at the other sites (~0.1 mg/L per decade). This suggests additional contributing factors influencing dissolved oxygen exist in the Evans Creek watershed. Despite the decreasing trends observed upstream, no significant trend was observed at downstream the mouth of Bear Creek (0484).

Increasing conductance was found at all sites, which is likely directly related to increased development and, thereby, surface runoff in the basin. pH has increased (becoming more basic) at the middle Bear Creek site (C484) and decreased (more acidic) at in Evans Creek (B484).

The conversion of historic dairy farms, horse ranches, cultivated land, and pastureland to suburban development was likely a driving factor in the decreased levels of fecal coliform bacteria, nutrients, and total suspended solids observed throughout the basin since the 1970s. Many farms did not restrict livestock access to streams, resulting in erosion and manure contamination. The large amount of waste generated by livestock contaminated runoff entering streams. Furthermore, as development increased, many homes previously using septic systems in urban areas have been sewered, decreasing the risk of contamination from failing septic systems.

Table 45. Summary of significant long-term trends in Bear Creek basin since the 1970s (total nitrogen from 1993 forward). Red indicates a decline in water quality.

Parameter	Bear Creek @ Redmond (0484)	Evans Creek @ Union Hill Rd (B484)	Bear Creek @ 95th Ave Bridge (C484)	Bear Creek @ 133rd Ave Bridge (J484)	Cottage Lake Creek @ Tolt Pipeline (N484)
Fecal Coliform	↘	↘	↘	↘	↘
Temperature	↗	↗	↗	↗	↗
Dissolved Oxygen	-	↘	↘	↘	↘
pH	-	↘	↗	-	-
Conductance	↗	↗	↗	↗	↗
Total Suspended Solids	↘	↘	↘	↘	↘
Turbidity	-	-	↗	-	-
Total Phosphorus	↘	↘	↘	↘	↘
Ortho-phosphorus	↘	↘	↘	↘	↘
Total Nitrogen (*1993 forward*)	↘	-	↘	↘	-
Ammonia	↘	↘	↘	-	-
Nitrate + Nitrite	↘	↘	-	↘	-

4.2 Comparison to Water Quality Standards

As has been previously established, fecal coliform bacteria, temperature, and dissolved oxygen are of concern in the Bear Creek watershed. Fecal coliform bacteria levels frequently exceed the water quality criteria, indicating a potential for human health risk. Temperatures are too high and dissolved oxygen concentrations are too low to meet the numeric criteria set for the protection of salmonids and other aquatic life. A multi-parameter TMDL is in place that sets forth a collaborative effort between state and local jurisdictions to combat these issues.

While no metals were found to exceed water quality criteria in routine monitoring data, recent targeted stormflow sampling detected copper concentrations above the state standards (King County, 2017). The exceedances were detected in Cold Creek (a tributary to Cottage Lake Creek) and Mackey Creek (a tributary to lower Bear Creek).

Limited data on organic chemicals in Bear Creek were available, and most organic chemical samples were collected from the mouth (site 0484). In many cases, the method detection limits for chemicals were above the state aquatic life and/or human health numeric

criteria. One chemical, bis(2-ethylhexyl)phthalate, was detected above the human health numeric criterion in multiple samples. Bis(2-ethylhexyl)phthalate is a plasticizer used in a wide variety of consumer products, including tablecloths, toys, furniture, and garden hoses. Whether this chemical is present at levels of concern in fish tissue is not known, and analysis of the organic chemicals in fish tissue in the Bear Creek watershed would be necessary to determine if human health is at risk through the consumption of fish caught in Bear Creek.

4.3 Sediment Quality

Generally, the stream sediments within Bear Creek watershed are not greatly contaminated. Four sites were found to have potential or probable effect on benthic organisms due to high levels of pentachlorophenol (a pesticide and disinfectant), dibenzofuran (a byproduct of combustion), PAHs, total sulfides, or bioavailable nickel. Between 1987 and 2006, concentrations of metals in sediments at the mouth of Bear Creek (site 00484) decreased slightly or remained level.

4.4 Conclusion

With the exception of temperature and dissolved oxygen, overall water quality in the Bear Creek watershed appears to be improving. Fecal coliform levels indicate a potential risk to human health, but the levels have decreased over the past three decades. Temperature and dissolved oxygen levels increase stress on salmonids (as represented by violations of the state water quality standards), and long-term trends have indicated that conditions have worsened over the past four decades.

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Appendix A: Water Quality Correlation with Flow

Water Quality Correlations with Flow

The relationship between discharge volume and water quality was investigated by examining the correlation between water quality measurements collected between 1971 and 2015 and the daily mean flow measured at the Sammamish River 51T gage (formerly USGS 12125200). To handle non-detects, values below maximum detection limit were set to the maximum detection limit (Helsel and Hirsch, 2002). Because both analyte levels and flow exhibit seasonal patterns, correlations were analyzed within individual seasons[2] to control for seasonality. The "cor.test" function in the "base" R package was used for this analysis.

Water quality and flow correlations varied by parameter, site, and season. The results of the analysis indicate that

- Fecal coliform generally has a negative relationship with flow in the spring, a weak relationship with flow in the summer and fall, and a slightly positive relationship in the winter.
- Temperature has a negative relationship with flow in spring and fall and a weak relationship with flow in the winter and summer.
- Dissolved oxygen has a strong positive relationship with flow in the spring and fall C484 and J484, and a generally negative relationship in the winter.
- pH has a strong negative relationship with flow. The relationship is weaker in the summer.
- Conductance has a strong negative relationship with flow.
- Total suspended solids and turbidity have a strong positive relationship with flow.
- Total phosphorus has weak positive relationship with flow.
- Orthophosphate has weak positive relationship with flow.
- Total nitrogen has a positive relationship with flow.
- Ammonia has a weak relationship with flow, except at N484 which has a positive relationship with flow in spring through fall.
- Nitrate + nitrite has a positive relationship with flow.

The results of this analysis support the use of flow as a covariate in the Seasonal Mann-Kendall test for long-term trends discussed in section 2.2.

Table A-1 Correlation between water quality measurements and Sammamish River discharge by season. Significant correlations (p<0.05) in bold.

Parameter	Site	Spring	Summer	Fall	Winter
Ammonia Nitrogen	0484	0.00	0.01	-0.09	**0.13**
	B484	-0.12	0.06	**0.28**	0.08

[2] Winter = January – March, Spring = April – June, Summer = July – September, Fall = October - December

Parameter	Site	Spring	Summer	Fall	Winter
	C484	0.08	0.06	**-0.26**	**0.15**
	J484	-0.07	0.10	**-0.26**	0.09
	N484	**0.15**	**0.21**	**0.30**	0.10
Conductivity, Field	0484	**-0.44**	**-0.14**	**-0.57**	**-0.51**
	B484	**-0.47**	**-0.17**	**-0.58**	**-0.53**
	C484	**-0.41**	**-0.13**	**-0.52**	**-0.51**
	J484	**-0.43**	**-0.13**	**-0.58**	**-0.48**
	N484	**-0.35**	-0.05	**-0.50**	**-0.54**
Dissolved Oxygen, Field	0484	0.06	0.06	**0.15**	**-0.21**
	B484	0.01	0.01	0.01	**-0.17**
	C484	**0.26**	-0.07	**0.35**	-0.07
	J484	**0.34**	-0.07	**0.39**	-0.03
	N484	**0.14**	**-0.14**	0.12	-0.13
Fecal Coliform	0484	**-0.16**	-0.07	-0.04	**0.19**
	B484	**-0.26**	0.03	**-0.18**	-0.02
	C484	**-0.20**	-0.11	-0.01	**0.15**
	J484	**-0.18**	0.05	-0.09	**0.15**
	N484	**-0.18**	0.03	-0.10	-0.01
Nitrite + Nitrate Nitrogen	0484	**0.13**	**0.12**	**0.39**	**0.14**
	B484	**-0.18**	0.00	**0.24**	0.11
	C484	**0.27**	0.11	**0.47**	**0.16**
	J484	**0.59**	**0.35**	**0.65**	**0.27**
	N484	0.04	-0.03	**0.21**	-0.08
Orthophosphate Phosphorus	0484	**-0.15**	0.04	-0.02	0.10
	B484	**-0.17**	**0.29**	-0.02	-0.05
	C484	-0.10	0.00	**-0.26**	-0.04
	J484	-0.08	0.04	**-0.25**	-0.07
	N484	**-0.14**	0.08	**0.16**	-0.06
pH, Field	0484	**-0.43**	-0.06	**-0.45**	**-0.30**
	B484	**-0.21**	-0.05	**-0.34**	**-0.18**
	C484	**-0.22**	-0.10	**-0.37**	**-0.25**
	J484	**-0.20**	0.01	**-0.37**	-0.13
	N484	**-0.25**	**-0.16**	**-0.44**	**-0.20**
Sample Temperature, Field	0484	**-0.41**	0.08	**-0.31**	0.03
	B484	**-0.34**	0.00	**-0.36**	0.03
	C484	**-0.40**	0.07	**-0.36**	0.05
	J484	**-0.37**	0.02	**-0.39**	0.03
	N484	**-0.27**	0.07	**-0.37**	0.02
Total Nitrogen	0484	**0.28**	**0.29**	**0.49**	**0.18**
	B484	**-0.18**	0.08	**0.37**	0.14

Parameter	Site	Spring	Summer	Fall	Winter
	C484	**0.46**	0.13	**0.38**	**0.22**
	J484	**0.61**	**0.37**	**0.48**	0.19
	N484	**0.32**	0.10	**0.35**	-0.06
Total Phosphorus	0484	-0.01	0.02	0.02	**0.20**
	B484	**-0.17**	**0.16**	0.06	-0.12
	C484	0.01	-0.05	-0.13	**0.14**
	J484	-0.13	-0.13	**-0.23**	0.01
	N484	-0.02	-0.02	**0.14**	**-0.13**
Total Suspended Solids	0484	**0.25**	**0.20**	**0.39**	**0.27**
	B484	-0.04	0.06	**0.21**	**-0.14**
	C484	**0.29**	0.08	**0.32**	**0.32**
	J484	**0.19**	0.03	0.00	**0.26**
	N484	0.08	**0.17**	0.11	-0.11
Turbidity	0484	**0.21**	**0.17**	**0.37**	**0.36**
	B484	-0.09	**0.14**	**0.25**	0.01
	C484	**0.27**	0.10	**0.28**	**0.35**
	J484	**0.16**	0.07	**0.22**	**0.26**
	N484	**0.18**	**0.16**	**0.16**	0.06

Appendix B: Temperature Water Quality Standard Exceedance Frequency

Table B-1. Frequency of days above 7-DADMax standards out of days with adequate continuous data.

Site	Standard	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
02a	Supplemental	40/206	17/244	25/175	45/243	0/198	26/236	31/243	17/243	35/243	69/230	49/243	23/223	24/243
	Core Summer	99/122	75/122	42/42	100/122	72/121	75/122	86/122	86/122	94/122	97/122	92/122	68/79	93/122
18a	Supplemental	40/243	22/197	42/238	33/243	13/243	29/244	37/243	22/243	61/243	67/204	43/216	44/243	38/224
	Core Summer	61/122	60/122	112/122	50/112	36/122	41/122	49/122	70/122	103/122	101/122	88/122	88/122	97/122
02e	Supplemental	45/198	24/218	32/243	46/243	15/243	10/237	0/236	0/214	7/243	0/109	12/218	43/243	28/243
	Core Summer	103/122	87/122	110/122	93/122	71/122	50/122	6/122	0/122	36/122	n.d	83/95	108/122	100/122
02f	Supplemental	43/132	32/108	36/203	54/242	33/234	53/213	26/123	30/243	19/138	35/108	48/198	23/194	18/20
	Core Summer	64/77	72/88	68/122	104/122	93/122	87/122	88/122	102/122	112/122	92/92	102/122	45/52	93/93
02g	Supplemental	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
	Core Summer	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
02L	Supplemental	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	16/108	46/222	41/243
	Core Summer	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d.	69/122	62/122

Supplemental Standard: 13 °C standard from September 15 to May 15
Core Summer Standard: 16 °C standard from May 16 to September 14
n.d. = no data

Table B-1 (cont.)

Site	Standard	2008	2009	2010	2011	2012	2013	2014	2015
02a	Supplemental	24/244	34/243	40/243	23/236	37/244	30/243	58/243	54/243
	Core Summer	74/122	111/122	64/122	85/122	71/122	102/122	111/122	117/122
18a	Supplemental	29/224	49/243	54/243	38/243	56/244	51/243	73/243	84/243
	Core Summer	86/122	117/122	94/122	101/122	106/122	110/122	122/122	119/122
02e	Supplemental	24/244	29/243	39/243	25/243	32/244	28/243	57/243	45/243
	Core Summer	83/122	111/122	63/122	84/122	76/122	103/122	108/122	111/122
02f	Supplemental	n.d.	n.d.	n.d.	n.d.	0/62	38/243	66/243	68/243
	Core Summer	n.d.	n.d.	n.d.	n.d.	n.d.	119/122	122/122	121/122
02g	Supplemental	19/108	31/243	32/243	23/243	35/244	30/243	56/243	37/243
	Core Summer	31/60	95/122	59/122	70/122	57/122	101/122	85/122	97/122
02L	Supplemental	32/244	40/243	44/243	36/243	48/244	40/243	71/243	44/243
	Core Summer	84/122	120/122	85/122	96/122	75/122	105/122	111/122	102/122

Appendix C: Detection Frequency of Organic Chemicals

Table C-1 Frequency of detection and range of detection limits for organic chemicals.

Site	Parameter	Detections	Min MDL	Max MDL
484	1,2,4-Trichlorobenzene	0/16	0.0094	0.024
484	1,2-Dichlorobenzene	0/16	0.024	0.051
C484	1,2-Dichlorobenzene	0/1	0.048	0.048
484	1,2-Diphenylhydrazine	0/8	0.024	0.024
484	1,3-Dichlorobenzene	0/16	0.024	0.051
C484	1,3-Dichlorobenzene	0/1	0.048	0.048
484	1,4-Dichlorobenzene	0/16	0.024	0.051
C484	1,4-Dichlorobenzene	0/1	0.048	0.048
484	2,4,5-T	0/16	0.043	0.5
484	2,4,5-TP (Silvex)	0/16	0.016	0.5
484	2,4,5-Trichlorophenol	0/16	0.12	0.24
484	2,4,6-Trichlorophenol	0/16	0.047	0.24
C484	2,4,6-Trichlorophenol	0/1	0.48	0.48
484	2,4-D	1/16	0.016	0.5
484	2,4-DB	0/16	0.022	0.5
484	2,4-Dichlorophenol	0/16	0.047	0.1
C484	2,4-Dichlorophenol	0/1	0.48	0.48
484	2,4-Dimethylphenol	0/16	0.024	1.5
484	2,4-Dinitrophenol	0/16	0.24	1
484	2,4-Dinitrotoluene	0/16	0.047	0.24
484	2,6-Dinitrotoluene	0/16	0.047	0.24
484	2-Chloronaphthalene	0/16	0.0094	0.024
C484	2-Chloronaphthalene	0/1	0.0095	0.0095
484	2-Chlorophenol	0/16	0.024	0.1
484	2-Methylnaphthalene	0/16	0.024	0.1
C484	2-Methylnaphthalene	0/1	0.095	0.095
484	2-Methylphenol	1/16	0.024	0.25
484	2-Nitroaniline	0/16	0.094	0.24
484	2-Nitrophenol	0/16	0.047	0.096
484	3,3'-Dichlorobenzidine	0/16	0.094	0.76
484	3-Methylphenol	0/8	0.047	0.048
484	3-Nitroaniline	0/16	0.24	0.51
484	4,4'-DDD	0/8	0.0047	0.0051

Site	Parameter	Detections	Min MDL	Max MDL
B484	4,4'-DDD	0/1	0.5	0.5
C484	4,4'-DDD	0/1	0.0047	0.0047
484	4,4'-DDE	0/8	0.0047	0.0051
B484	4,4'-DDE	0/1	0.5	0.5
C484	4,4'-DDE	0/1	0.0047	0.0047
484	4,4'-DDT	0/8	0.0047	0.0051
B484	4,4'-DDT	0/1	0.5	0.5
C484	4,4'-DDT	0/1	0.0047	0.0047
484	4,6-Dinitro-O-Cresol	0/16	0.24	1
484	4-Bromophenyl Phenyl Ether	0/16	0.024	0.048
484	4-Chloro-3-Methylphenol	0/16	0.094	0.25
484	4-Chloroaniline	0/16	0.047	0.25
484	4-Chlorophenyl Phenyl Ether	0/16	0.024	0.048
484	4-Methylphenol	0/16	0.047	0.25
484	4-Nitroaniline	0/16	0.24	0.51
484	4-Nitrophenol	0/16	0.24	0.51
484	Acenaphthene	0/16	0.0094	0.01
C484	Acenaphthene	0/1	0.0095	0.0095
484	Acenaphthylene	0/16	0.0094	0.01
C484	Acenaphthylene	0/1	0.0095	0.0095
484	Aldrin	0/8	0.0047	0.0051
B484	Aldrin	0/1	0.5	0.5
C484	Aldrin	0/1	0.0047	0.0047
484	Alpha-BHC	0/8	0.0047	0.0051
B484	Alpha-BHC	0/1	0.5	0.5
C484	Alpha-BHC	0/1	0.0047	0.0047
C484	Alpha-Chlordane	0/1	0.0047	0.0047
484	Aniline	0/8	0.024	0.024
484	Anthracene	0/16	0.0094	0.01
C484	Anthracene	0/1	0.0095	0.0095
484	Aroclor 1016	0/8	0.047	0.051
B484	Aroclor 1016	0/1	5	5
C484	Aroclor 1016	0/1	0.047	0.047
484	Aroclor 1221	0/8	0.047	0.051
B484	Aroclor 1221	0/1	5	5
C484	Aroclor 1221	0/1	0.047	0.047
484	Aroclor 1232	0/8	0.047	0.051
B484	Aroclor 1232	0/1	5	5
C484	Aroclor 1232	0/1	0.047	0.047
484	Aroclor 1242	0/8	0.047	0.051

Site	Parameter	Detections	Min MDL	Max MDL
B484	Aroclor 1242	0/1	5	5
C484	Aroclor 1242	0/1	0.047	0.047
484	Aroclor 1248	0/8	0.047	0.051
B484	Aroclor 1248	0/1	5	5
C484	Aroclor 1248	0/1	0.047	0.047
484	Aroclor 1254	0/8	0.047	0.051
B484	Aroclor 1254	0/1	5	5
C484	Aroclor 1254	0/1	0.047	0.047
484	Aroclor 1260	0/8	0.047	0.051
B484	Aroclor 1260	0/1	5	5
C484	Aroclor 1260	0/1	0.047	0.047
C484	Atrazine	0/1	0.048	0.048
484	Benzo(a)anthracene	0/16	0.0094	0.025
C484	Benzo(a)anthracene	0/1	0.024	0.024
484	Benzo(a)pyrene	0/16	0.0094	0.01
C484	Benzo(a)pyrene	0/1	0.0095	0.0095
484	Benzo(b)fluoranthene	0/16	0.0094	0.01
C484	Benzo(b)fluoranthene	0/1	0.0095	0.0095
484	Benzo(g,h,i)perylene	1/16	0.0094	0.1
C484	Benzo(g,h,i)perylene	0/1	0.095	0.095
484	Benzo(k)fluoranthene	0/16	0.0094	0.01
C484	Benzo(k)fluoranthene	0/1	0.0095	0.0095
484	Benzoic Acid	6/8	0.24	0.24
484	Benzyl Alcohol	0/8	0.094	0.096
484	Benzyl Butyl Phthalate	3/16	0.0094	0.048
C484	Benzyl Butyl Phthalate	0/1	0.0095	0.0095
484	Beta-BHC	0/8	0.0047	0.0051
B484	Beta-BHC	0/1	0.5	0.5
C484	Beta-BHC	0/1	0.0047	0.0047
484	Bis(2-Chloroethoxy)Methane	0/16	0.0094	0.024
484	Bis(2-Chloroethyl)Ether	0/16	0.0094	0.024
484	Bis(2-Chloroisopropyl)Ether	0/16	0.0094	0.024
484	Bis(2-ethylhexyl)adipate	0/1	0.19	0.19
C484	Bis(2-ethylhexyl)adipate	1/4	0.0094	0.0095
484	Bis(2-Ethylhexyl)Phthalate	5/16	0.0094	0.024
C484	Bis(2-Ethylhexyl)Phthalate	0/1	0.0095	0.0095
484	Bisphenol A	0/1	0.19	0.19
C484	Bisphenol A	2/4	0.0094	0.0095
484	Caffeine	10/16	0.0094	0.024
C484	Caffeine	0/1	0.024	0.024

Site	Parameter	Detections	Min MDL	Max MDL
484	Carbazole	0/16	0.024	0.025
C484	Carbazole	0/1	0.024	0.024
484	Chlordane	0/8	0.024	0.026
B484	Chlordane	0/1	2.5	2.5
484	Chlorpyrifos	0/8	0.032	0.034
484	Chrysene	0/16	0.0094	0.025
C484	Chrysene	0/1	0.024	0.024
484	Coprostanol	0/8	0.47	0.48
484	Dalapon	0/8	0.012	0.047
484	Delta-BHC	0/8	0.0047	0.0051
B484	Delta-BHC	0/1	0.5	0.5
C484	Delta-BHC	0/1	0.0047	0.0047
484	Diazinon	0/8	0.041	0.043
484	Dibenzo(a,h)anthracene	0/16	0.0094	0.095
C484	Dibenzo(a,h)anthracene	0/1	0.095	0.095
484	Dibenzofuran	0/16	0.0094	0.024
C484	Dibenzofuran	0/1	0.0095	0.0095
484	Dicamba	0/8	0.022	0.039
484	Dichlobenil	0/2	0.49	0.49
484	Dichloroprop	0/16	0.011	0.5
484	Dieldrin	0/8	0.0047	0.0051
B484	Dieldrin	0/1	0.5	0.5
C484	Dieldrin	0/1	0.0047	0.0047
484	Diethyl Phthalate	2/16	0.0094	0.024
C484	Diethyl Phthalate	0/1	0.0095	0.0095
484	Dimethyl Phthalate	1/16	0.0094	0.024
484	Di-N-Butyl Phthalate	5/16	0.0094	0.024
C484	Di-N-Butyl Phthalate	0/1	0.0095	0.0095
484	Di-N-Octyl Phthalate	0/16	0.0094	0.024
484	Dinoseb	0/16	0.029	0.5
484	Disulfoton	0/8	0.025	0.027
484	Endosulfan I	0/8	0.0047	0.0051
B484	Endosulfan I	0/1	0.5	0.5
C484	Endosulfan I	0/1	0.0047	0.0047
484	Endosulfan II	0/8	0.0047	0.0051
B484	Endosulfan II	0/1	0.5	0.5
C484	Endosulfan II	0/1	0.0047	0.0047
484	Endosulfan Sulfate	0/8	0.0047	0.0051
B484	Endosulfan Sulfate	0/1	0.5	0.5
C484	Endosulfan Sulfate	0/1	0.0047	0.0047

Site	Parameter	Detections	Min MDL	Max MDL
484	Endrin	0/8	0.0047	0.0051
B484	Endrin	0/1	0.5	0.5
C484	Endrin	0/1	0.0047	0.0047
484	Endrin Aldehyde	0/8	0.0047	0.0051
B484	Endrin Aldehyde	0/1	0.5	0.5
C484	Endrin Aldehyde	0/1	0.0047	0.0047
484	Estradiol	0/9	0.00048	0.019
C484	Estradiol	1/4	0.0094	0.0095
484	Estrone	3/9	0.00029	0.019
C484	Estrone	0/4	0.0094	0.0095
484	Ethynyl estradiol	0/9	0.00048	0.019
C484	Ethynyl estradiol	0/4	0.0094	0.0095
484	Fluoranthene	1/16	0.0094	0.01
C484	Fluoranthene	0/1	0.0095	0.0095
484	Fluorene	0/16	0.0094	0.01
C484	Fluorene	0/1	0.0095	0.0095
484	Gamma-BHC (Lindane)	0/8	0.0047	0.0051
B484	Gamma-BHC (Lindane)	0/1	Inf	#NAME?
C484	Gamma-BHC (Lindane)	0/1	0.0047	0.0047
484	Heptachlor	0/8	0.0047	0.0051
B484	Heptachlor	0/1	0.5	0.5
C484	Heptachlor	0/1	0.0047	0.0047
484	Heptachlor Epoxide	0/8	0.0047	0.0051
B484	Heptachlor Epoxide	0/1	0.5	0.5
C484	Heptachlor Epoxide	0/1	0.0047	0.0047
484	Hexachlorobenzene	0/16	0.024	0.025
C484	Hexachlorobenzene	0/1	0.024	0.024
484	Hexachlorobutadiene	0/16	0.047	0.051
484	Hexachlorocyclopentadiene	0/8	0.24	0.24
484	Hexachloroethane	0/16	0.024	0.048
484	Hexadecanoic acid	3/3	Inf	#NAME?
484	Indeno(1,2,3-Cd)Pyrene	0/16	0.0094	0.051
C484	Indeno(1,2,3-Cd)Pyrene	0/1	0.095	0.095
484	Isophorone	0/16	0.0094	0.048
484	Malathion	0/8	0.045	0.048
484	MCPA	0/16	0.011	0.5
484	MCPP	0/16	0.013	0.5
484	Methoxychlor	0/8	0.024	0.026
B484	Methoxychlor	0/1	2.5	2.5
C484	Methoxychlor	0/1	0.024	0.024

Site	Parameter	Detections	Min MDL	Max MDL
484	Methyltestosterone	0/1	0.019	0.019
C484	Methyltestosterone	0/4	0.0094	0.0095
484	Naphthalene	2/16	0.0094	0.025
C484	Naphthalene	0/1	0.024	0.024
484	Nitrobenzene	0/16	0.0094	0.024
484	N-Nitrosodimethylamine	0/15	0.024	0.025
484	N-Nitrosodi-N-Propylamine	0/16	0.047	0.1
484	N-Nitrosodiphenylamine	0/16	0.024	0.25
484	Octadecanoic acid	3/3	Inf	#NAME?
484	Parathion-Ethyl	0/8	0.042	0.045
484	Parathion-Methyl	0/8	0.034	0.036
484	Pentachlorophenol	0/16	0.12	0.24
C484	Pentachlorophenol	0/1	0.95	0.95
484	Phenanthrene	2/16	0.0094	0.01
C484	Phenanthrene	0/1	0.0095	0.0095
484	Phenol	1/16	0.024	0.1
C484	Phenol	0/1	0.48	0.48
484	Phorate	0/8	0.031	0.033
484	Progesterone	0/1	0.019	0.019
C484	Progesterone	0/4	0.0094	0.0095
484	Prometon	0/2	2.5	2.5
484	Pyrene	5/16	0.0094	0.01
C484	Pyrene	0/1	0.0095	0.0095
484	Pyridine	0/8	0.047	0.048
484	Testosterone	0/1	0.019	0.019
C484	Testosterone	0/4	0.0094	0.0095
484	Total 4-Nonylphenol	0/1	0.19	0.19
C484	Total 4-Nonylphenol	0/4	0.019	0.048
484	Toxaphene	0/8	0.047	0.051
B484	Toxaphene	0/1	5	5
C484	Toxaphene	0/1	0.047	0.047
C484	trans-Chlordane	0/1	0.0047	0.0047
484	Triclopyr	0/2	0.49	0.49
484	Vinclozolin	0/1	0.019	0.019
C484	Vinclozolin	0/4	0.0094	0.0095

Appendix D: Sediment Quality Maps

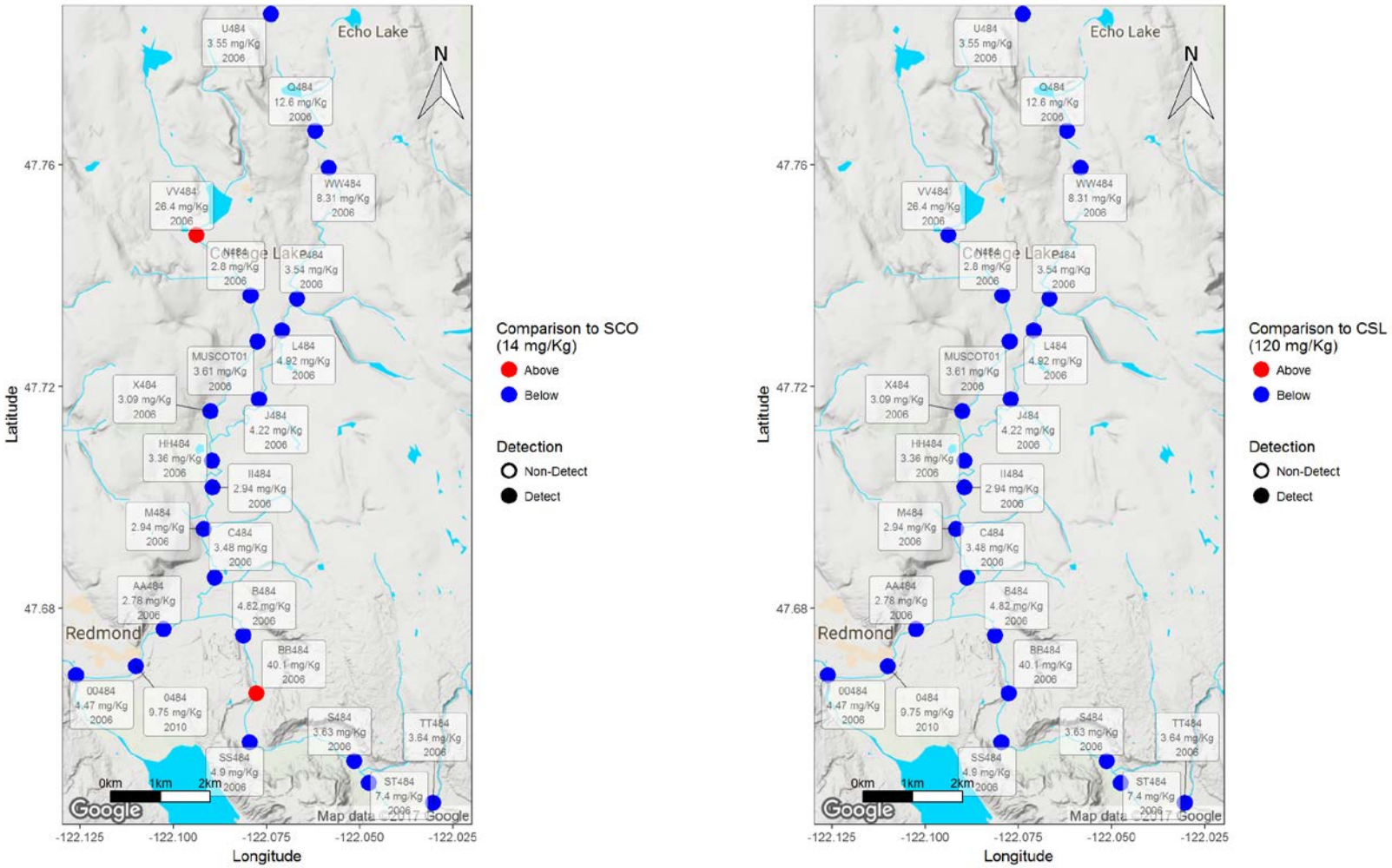

Figure D-1. Arsenic sediment concentrations compared to sediment cleanup criteria.

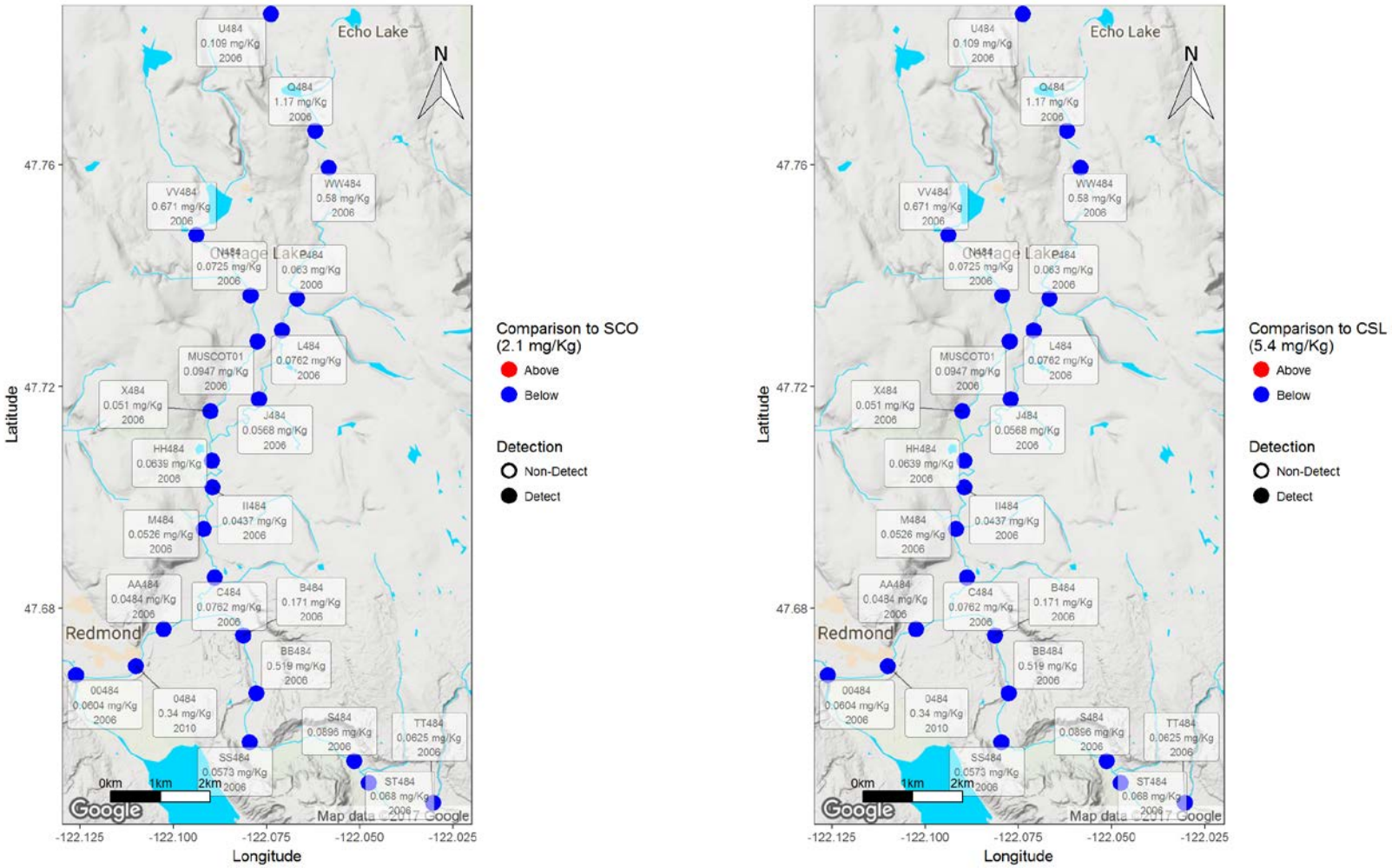

Figure D-2. Cadmium sediment concentrations compared to sediment cleanup criteria.

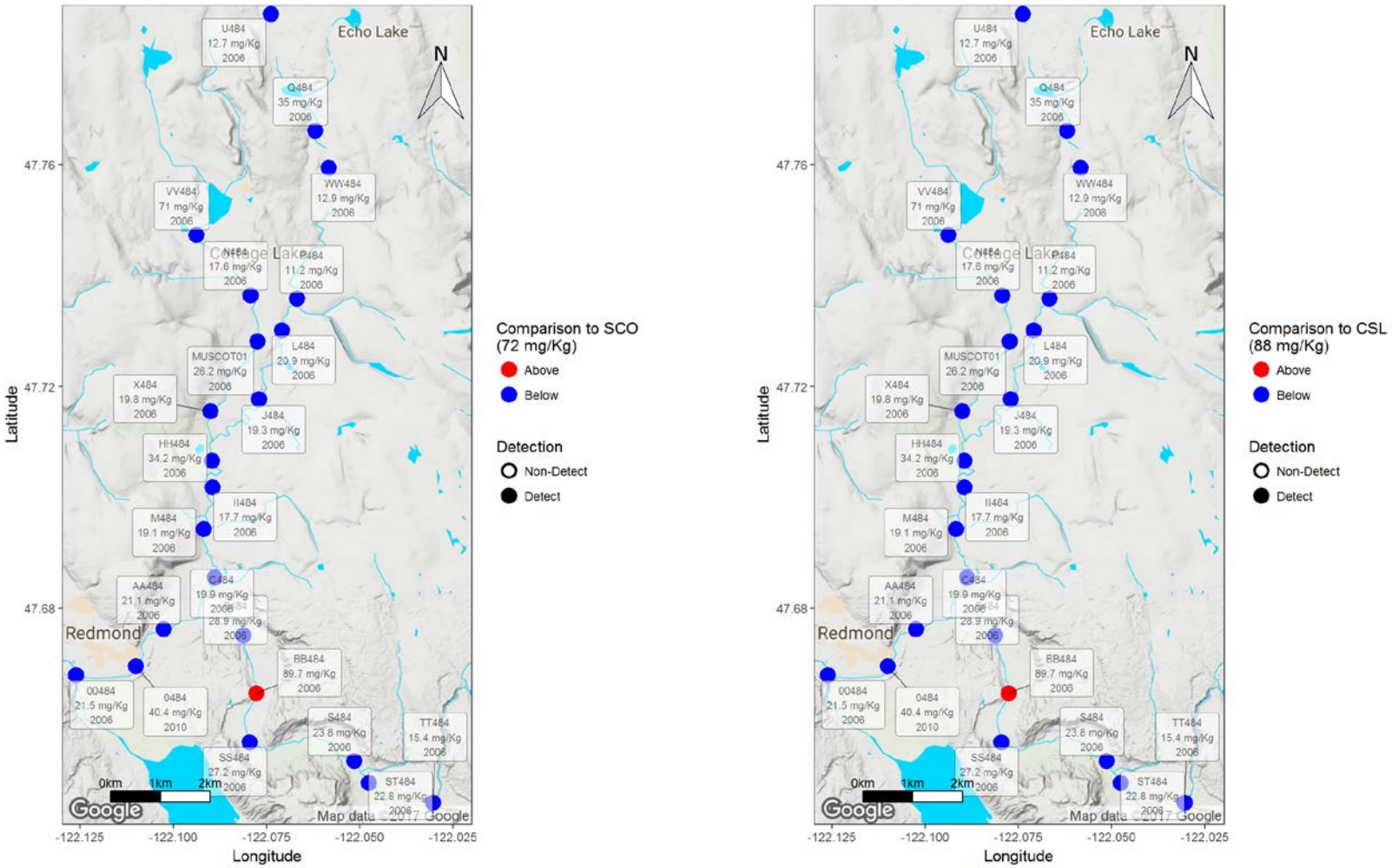

Figure D-3. Chromium sediment concentrations compared to sediment cleanup criteria.

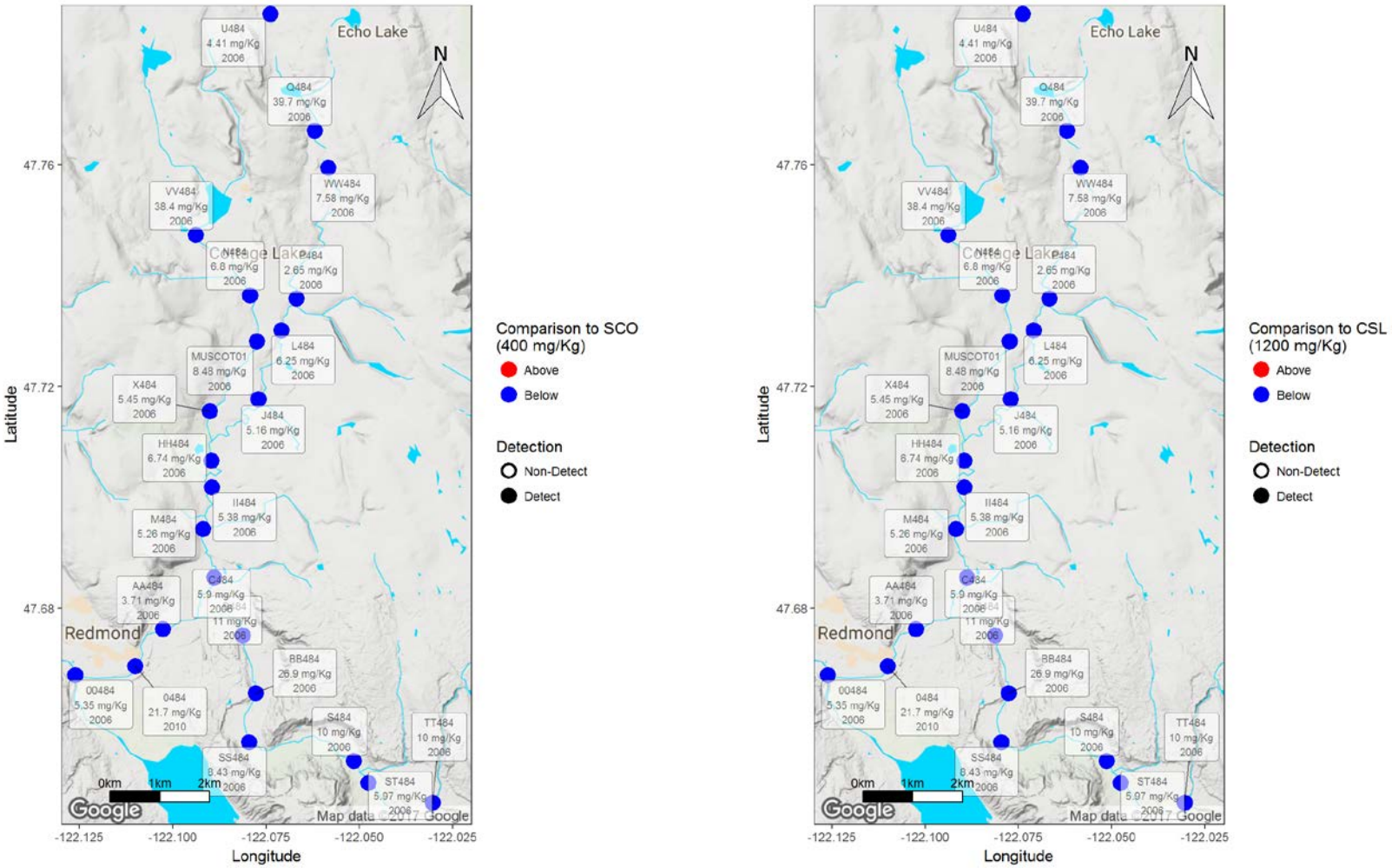

Figure D-4. Copper sediment concentrations compared to sediment cleanup criteria.

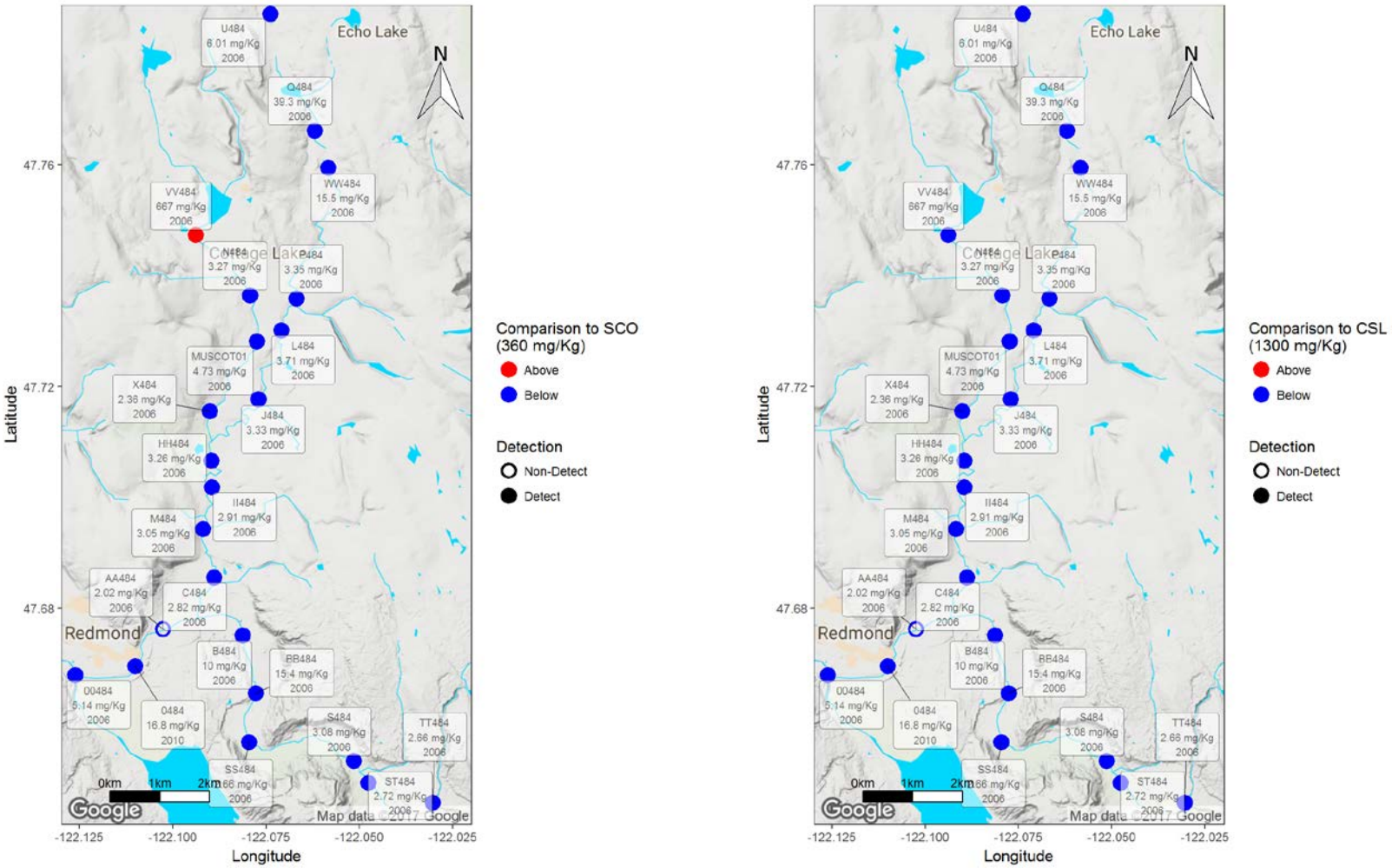

Figure D-5. Lead sediment concentrations compared to sediment cleanup criteria. For lead, the cleanup screening level (CSL) is unknown but is greater than 1300 mg/Kg).

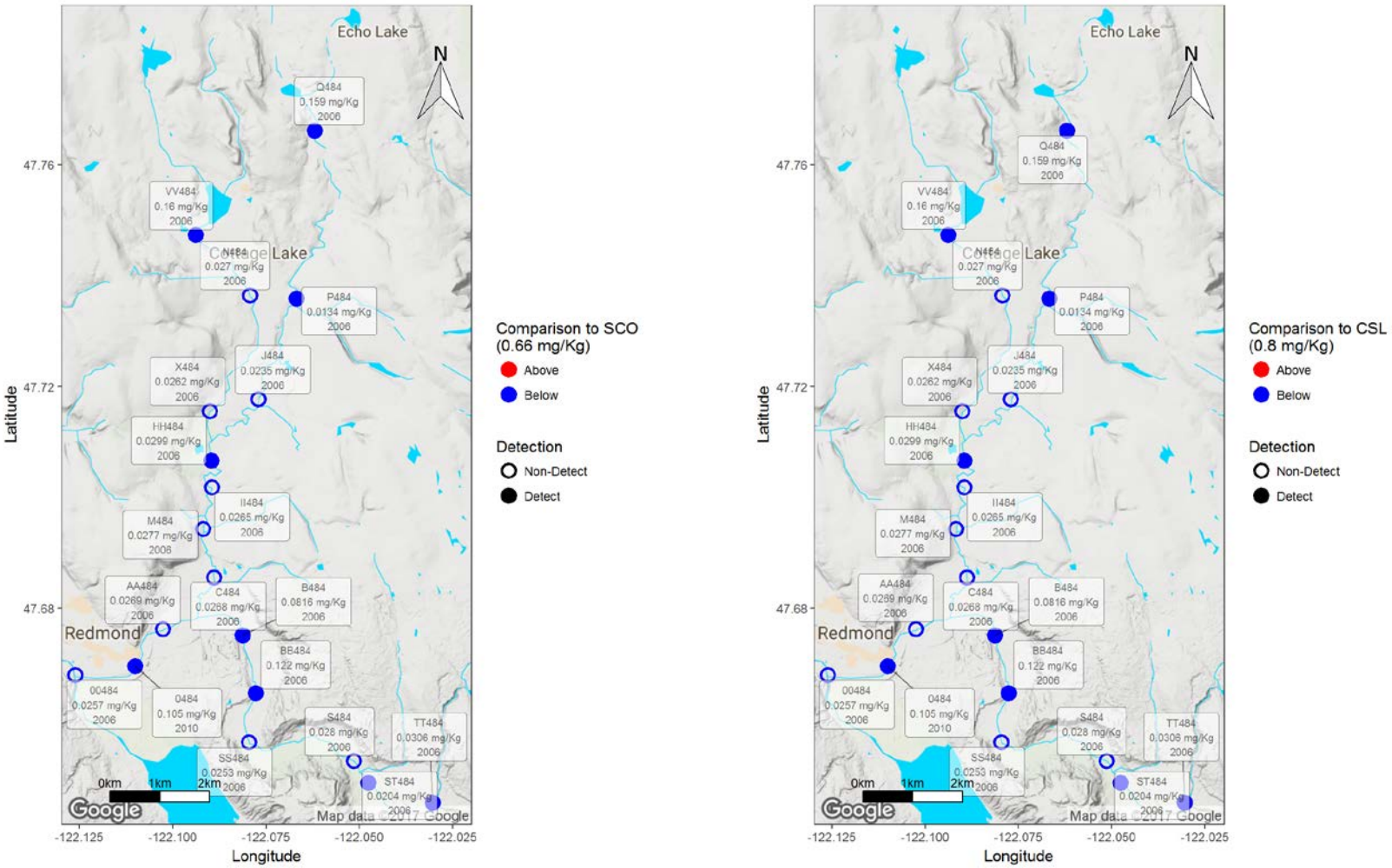

Figure D-6. Mercury sediment concentrations compared to sediment cleanup criteria.

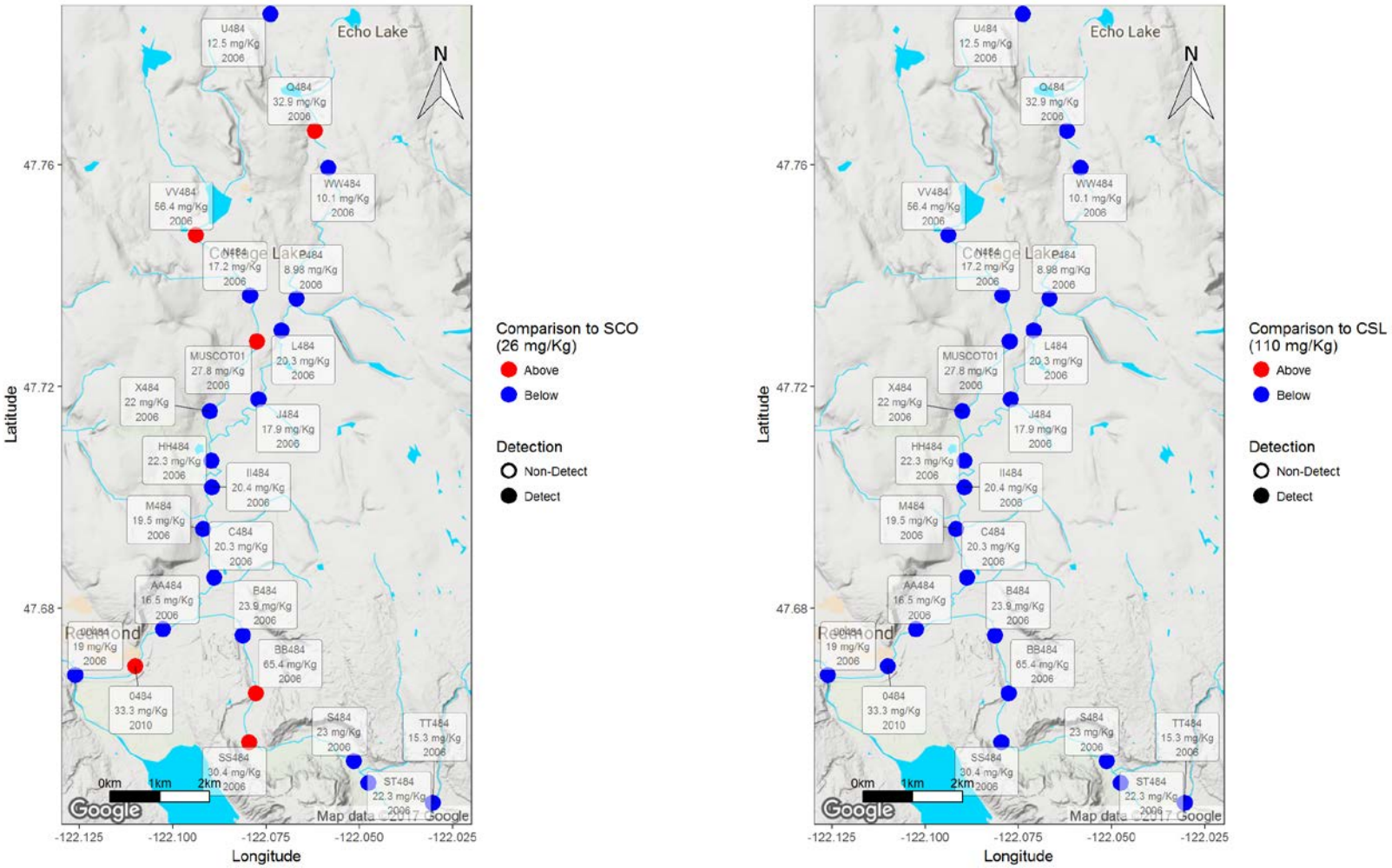

Figure D-7. Nickel sediment concentrations compared to sediment cleanup criteria.

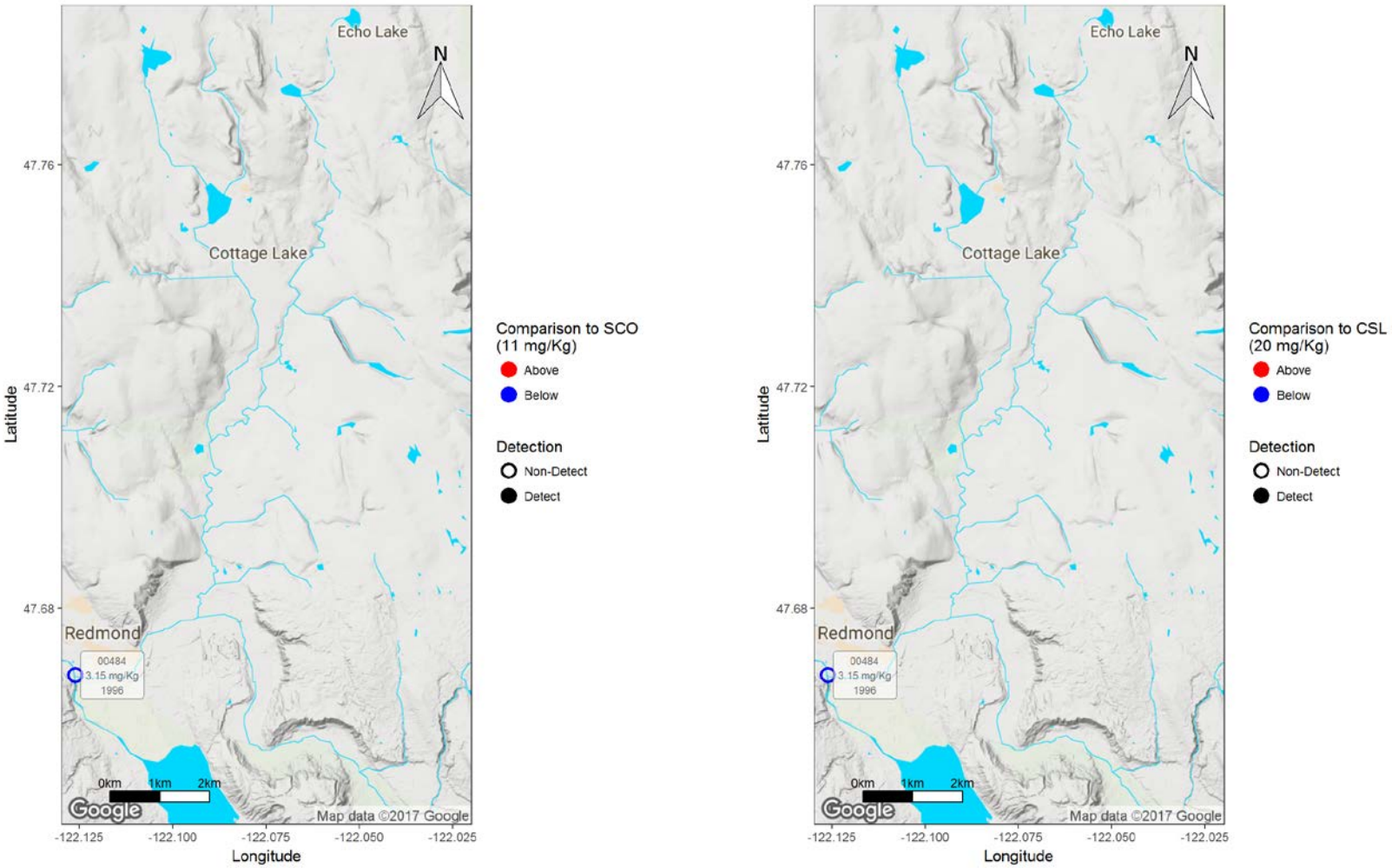

Figure D-8. Selenium sediment concentrations compared to sediment cleanup criteria. For selenium, the cleanup screening level (CSL) is unknown but is greater than 20 mg/Kg.

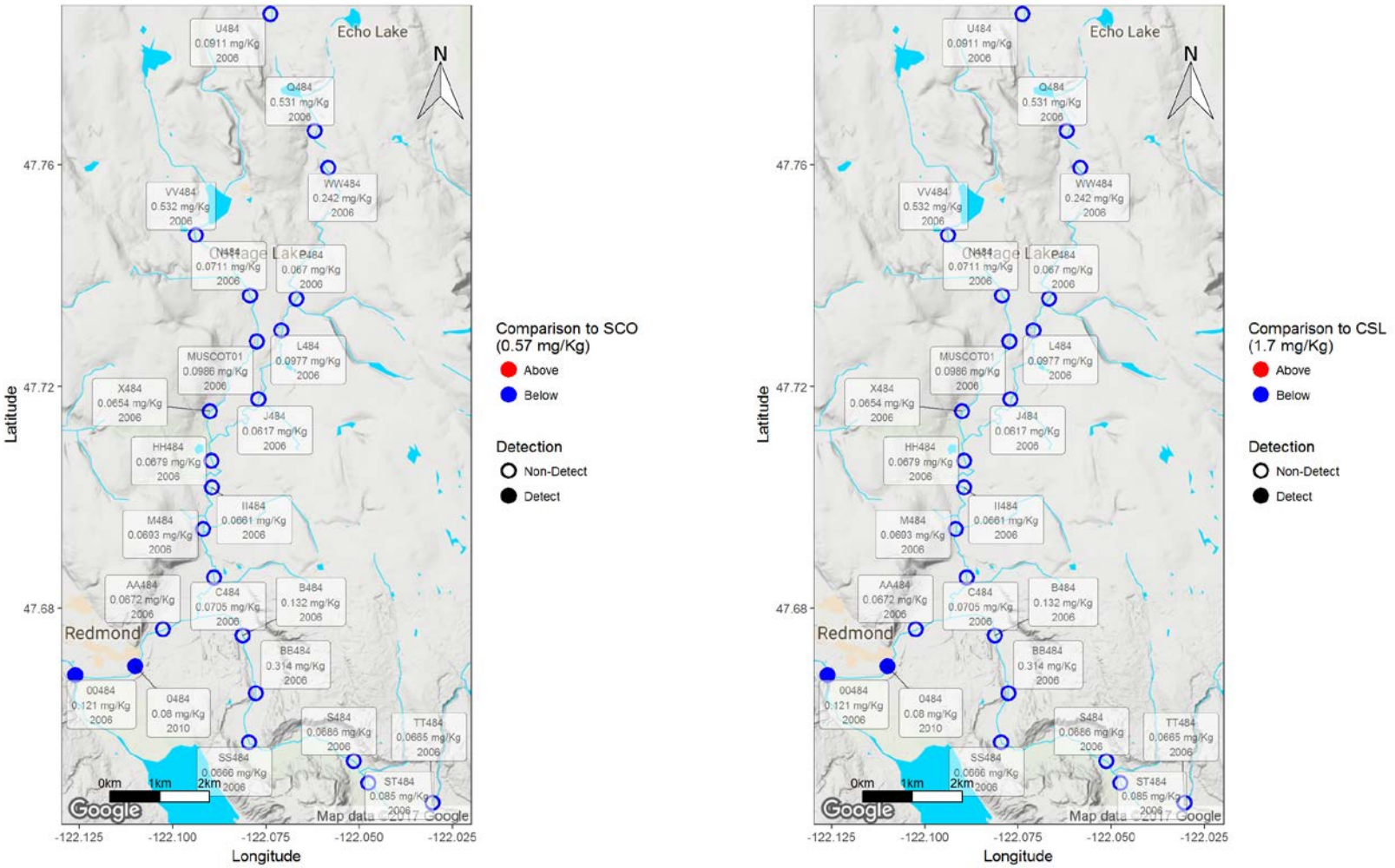

Figure D-9. Silver sediment concentrations compared to sediment cleanup criteria.

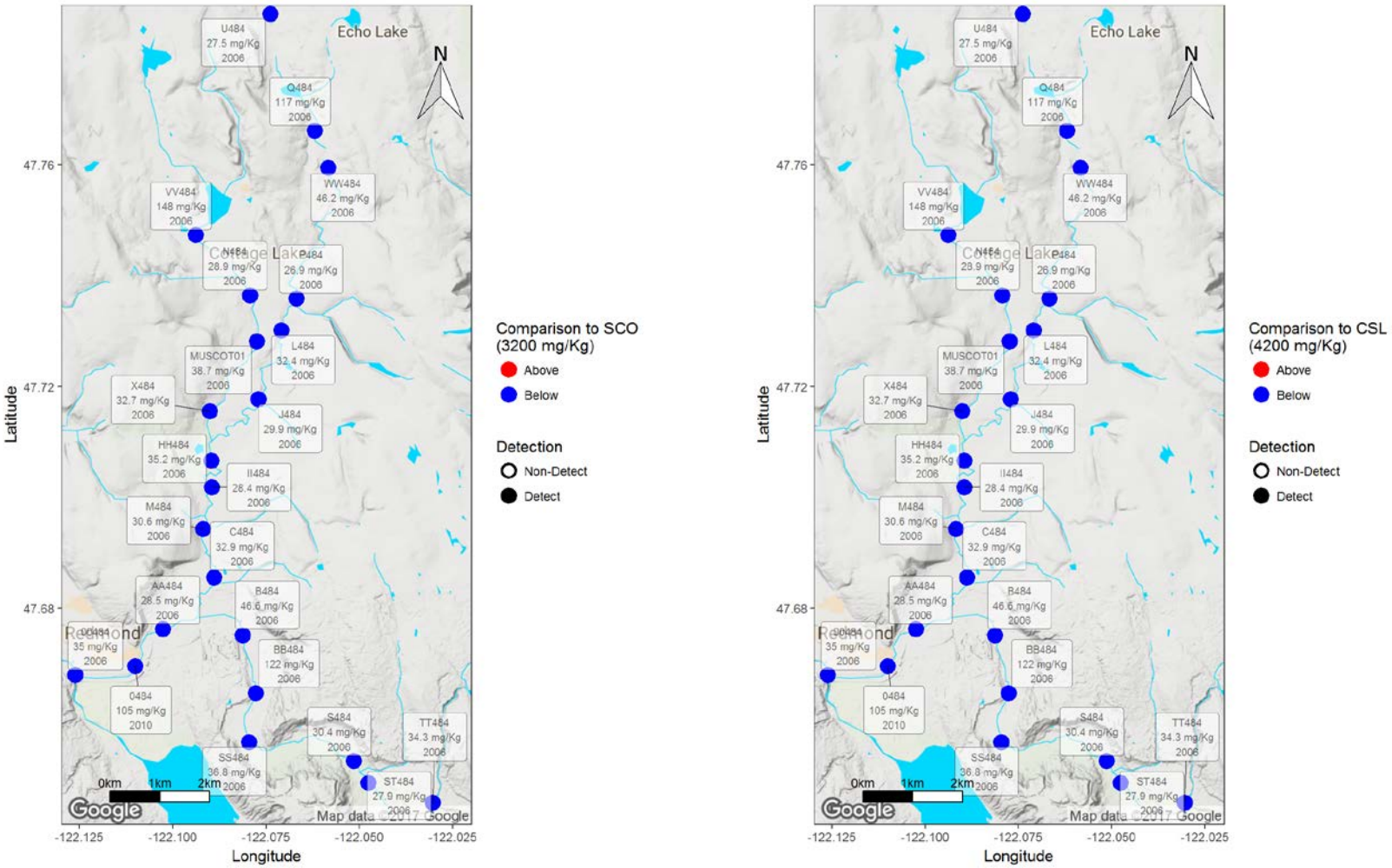

Figure D-10. Zinc sediment concentrations compared to sediment cleanup criteria. For zinc, the cleanup screening level (CSL) is unknown but is greater than 4200 mg/Kg.

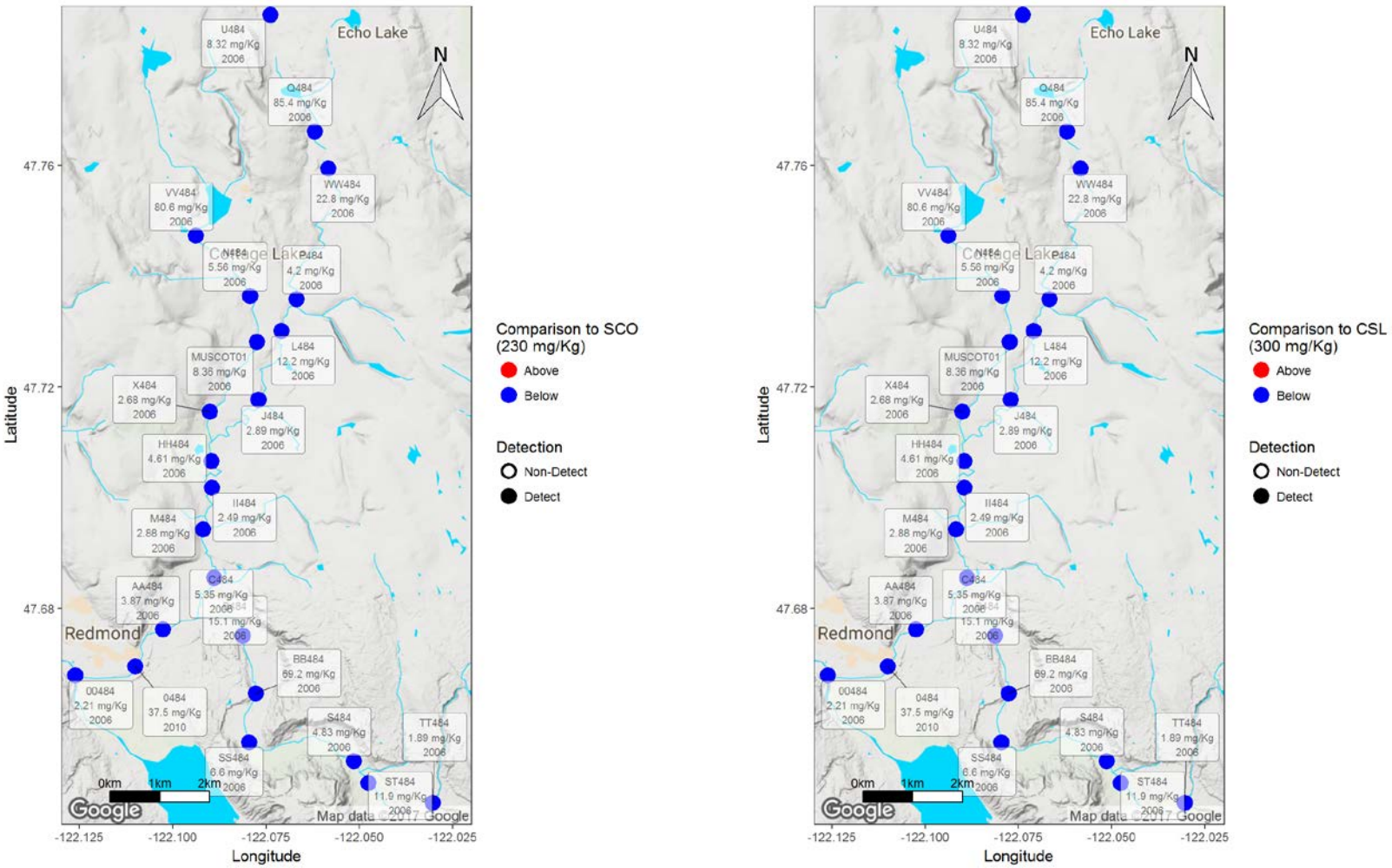

Figure D-11. Ammonia sediment concentrations compared to sediment cleanup criteria.

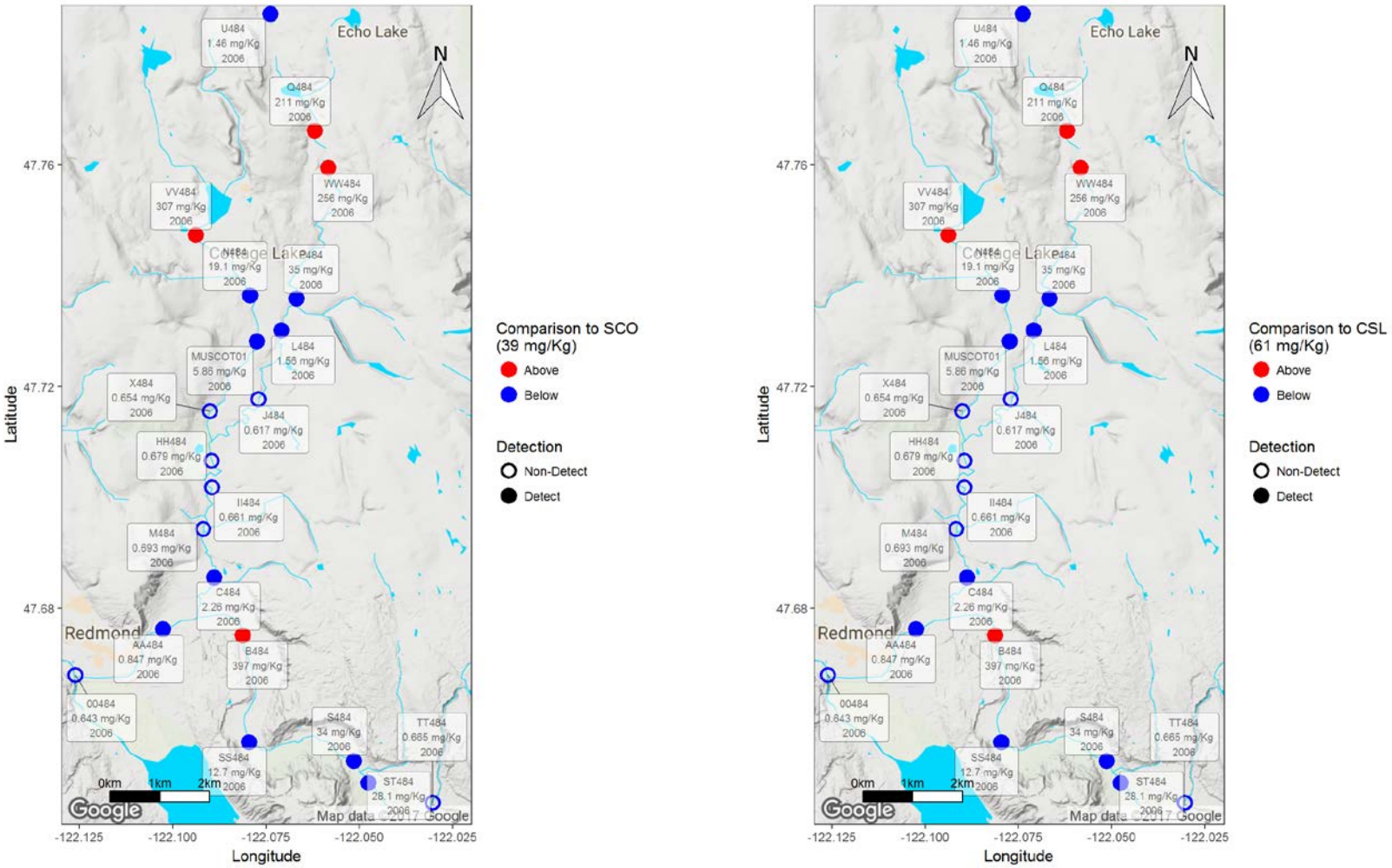

Figure D-11. Total sulfide sediment concentrations compared to sediment cleanup criteria.

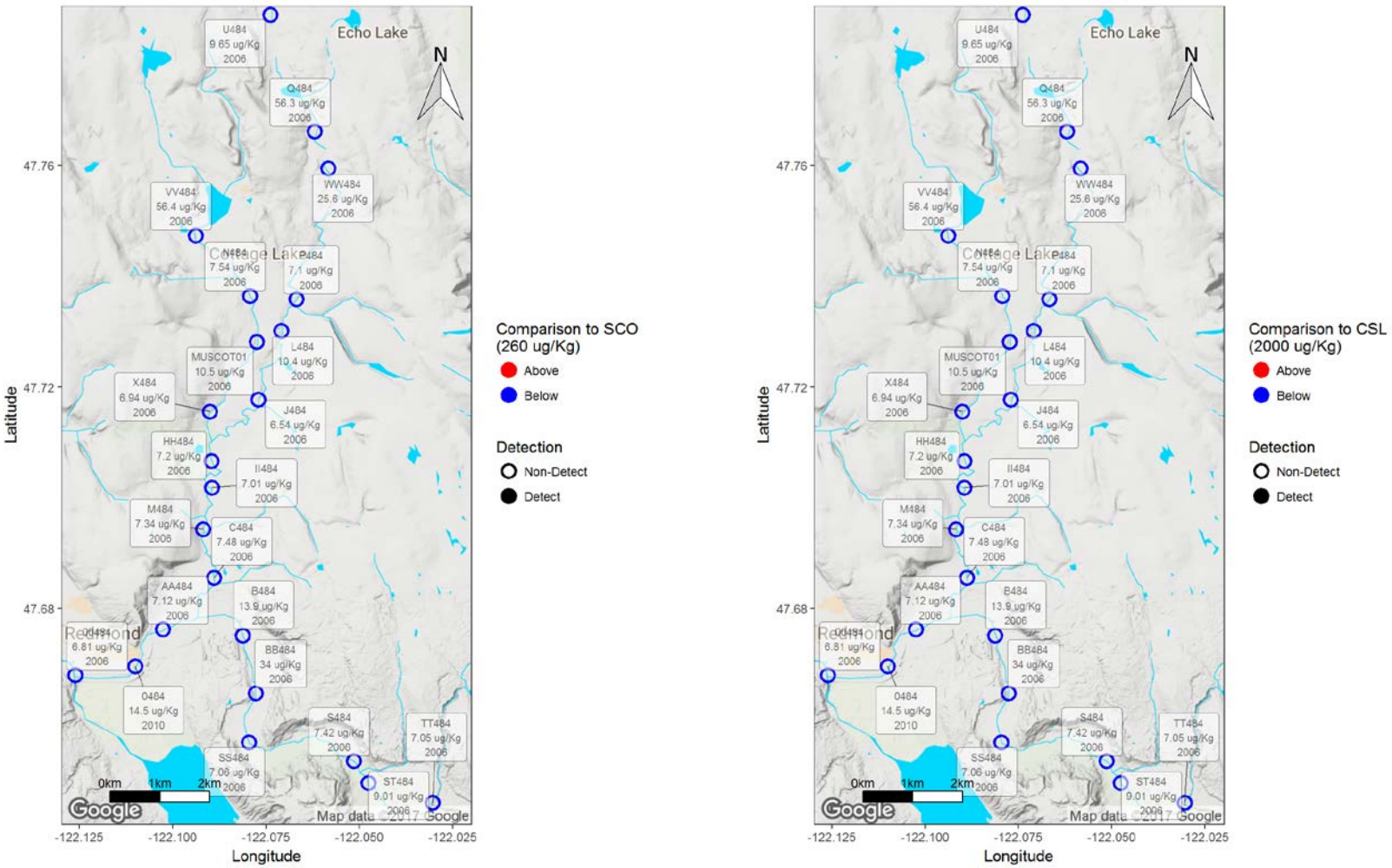

Figure D-12. 4-Methylphenol sediment concentrations compared to sediment cleanup criteria.

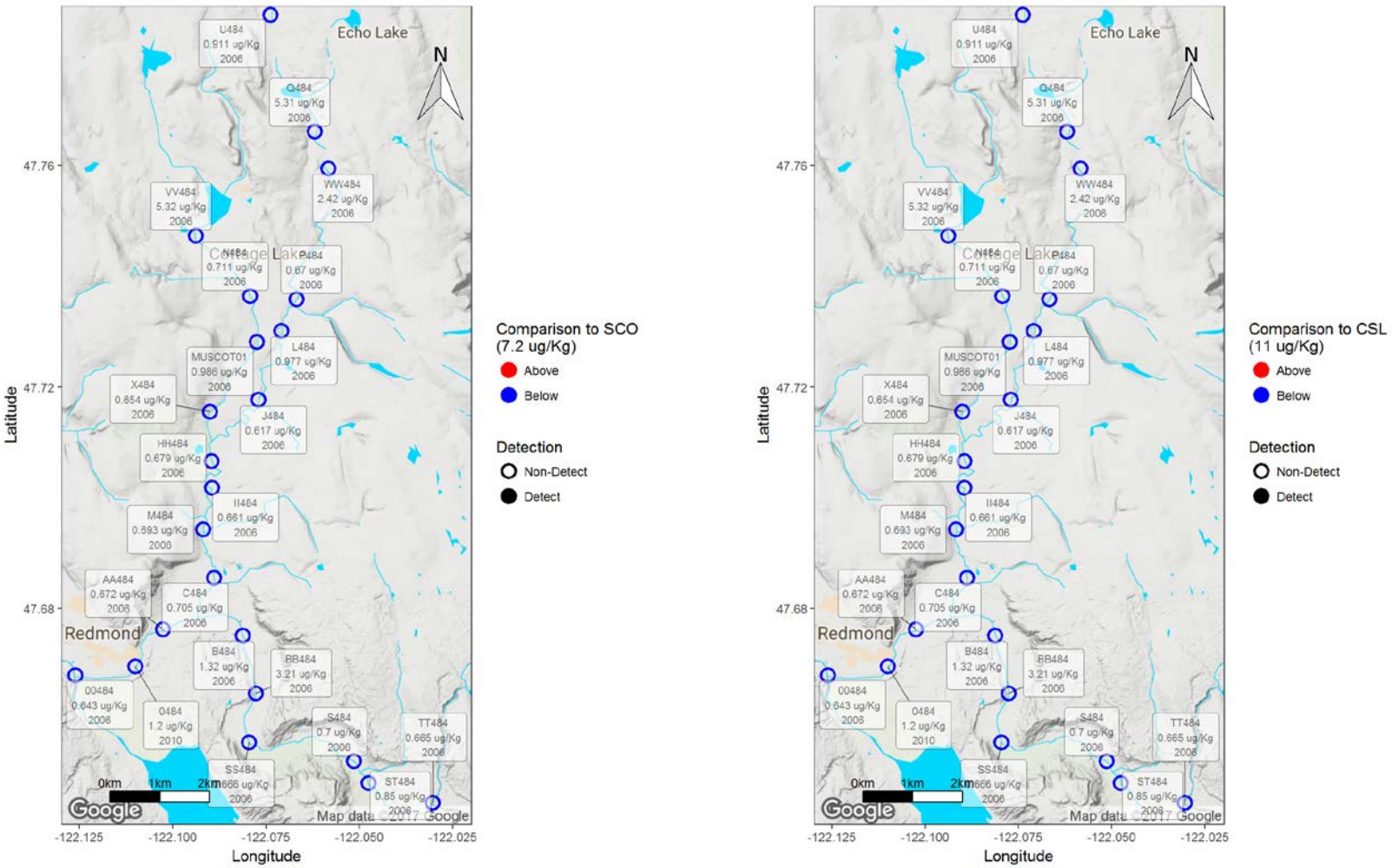

Figure D-13. Beta-BHC sediment concentrations compared to sediment cleanup criteria.

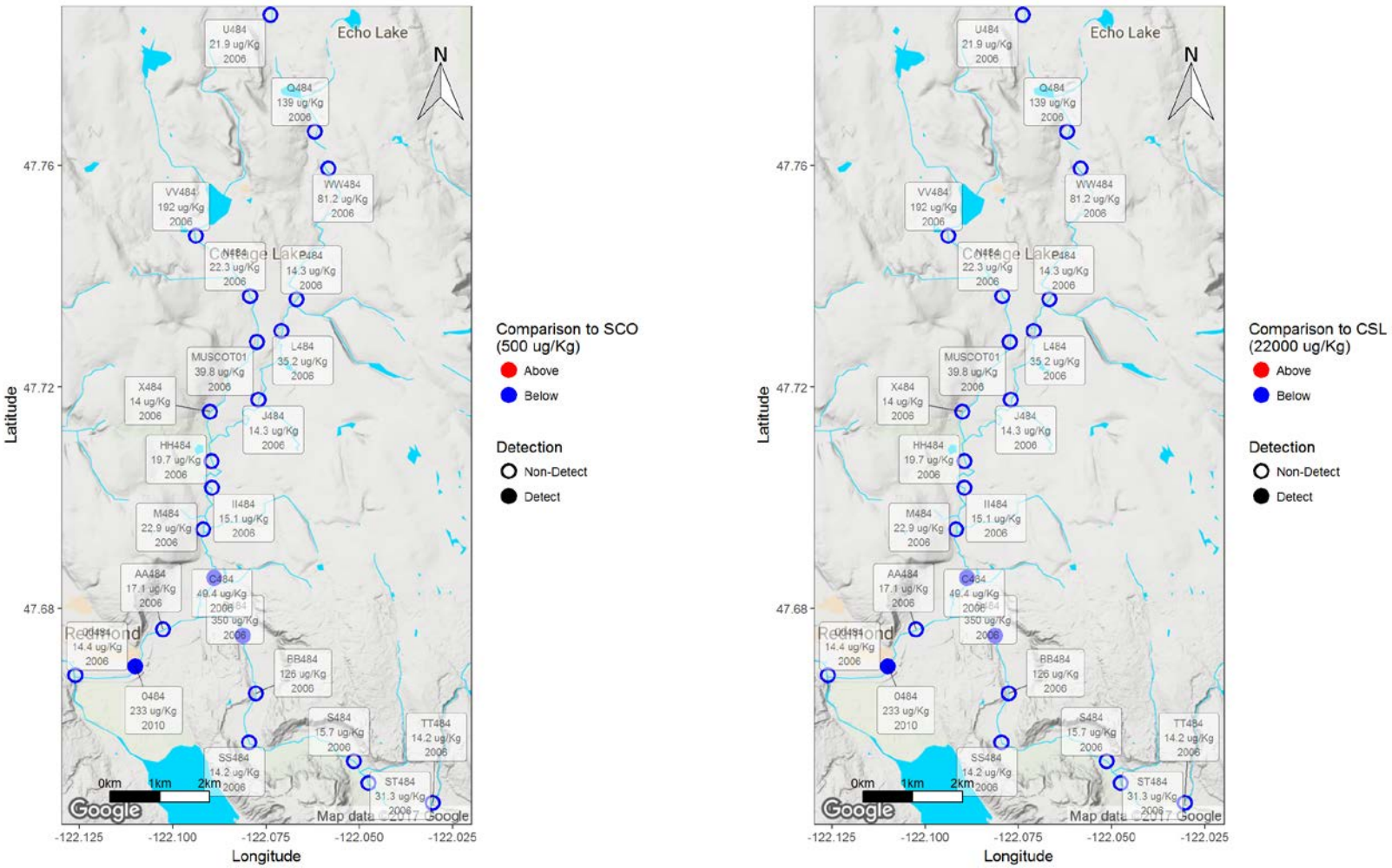

Figure D-14. Bis(2-ethylhexyl)phthalate sediment concentrations compared to sediment cleanup criteria.

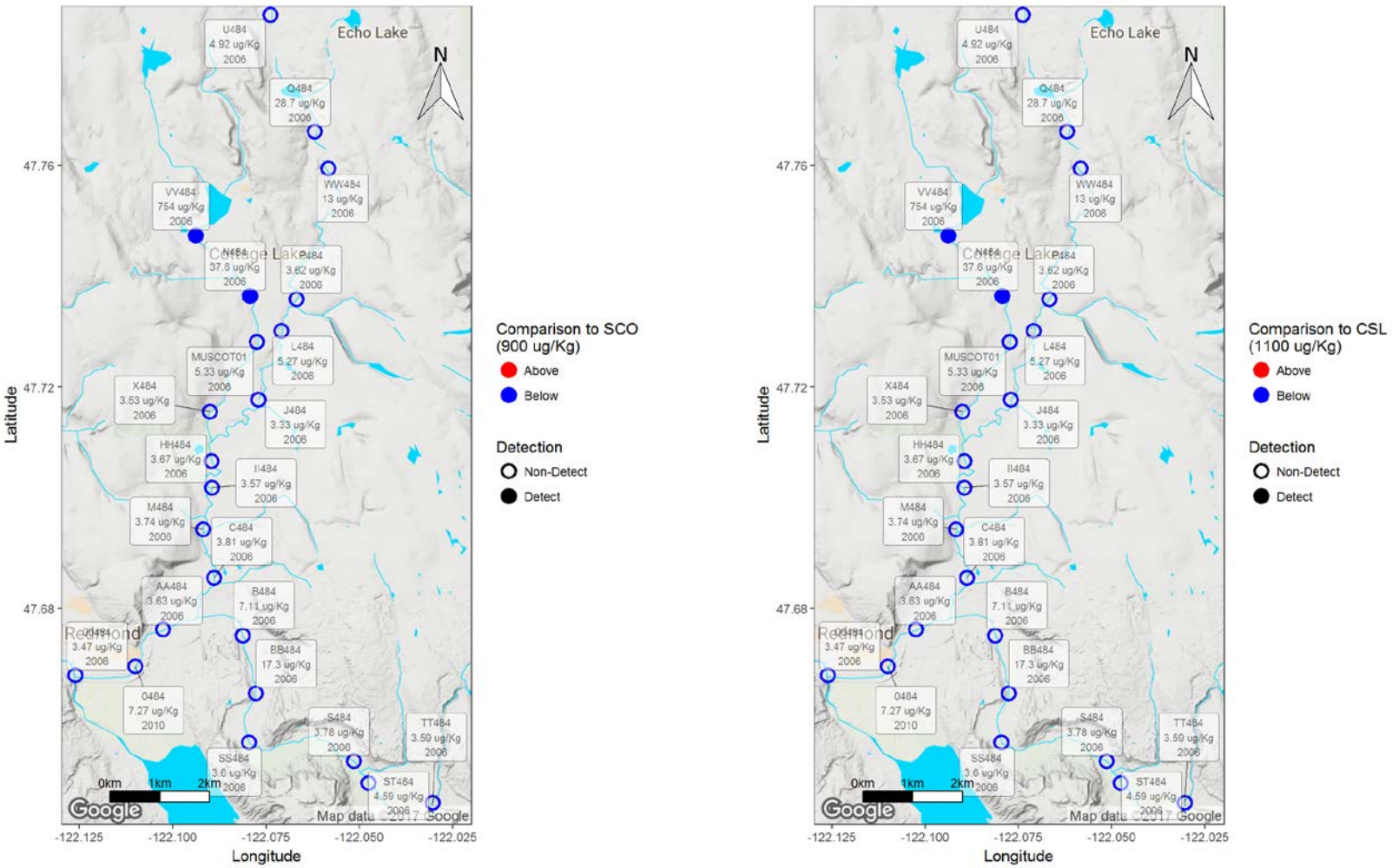

Figure D-15. Carbazole sediment concentrations compared to sediment cleanup criteria.

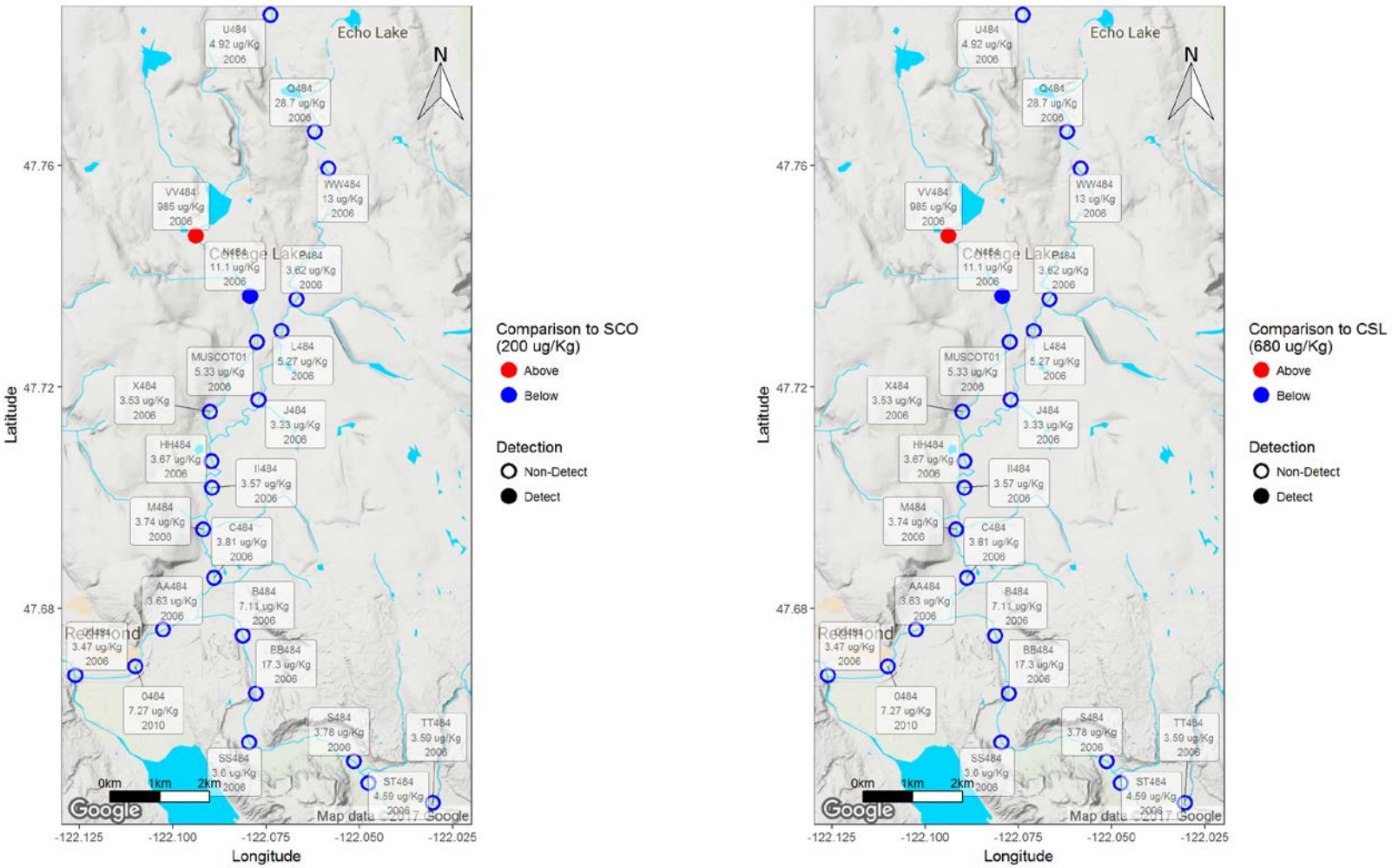

Figure D-16. Dibenzofuran sediment concentrations compared to sediment cleanup criteria.

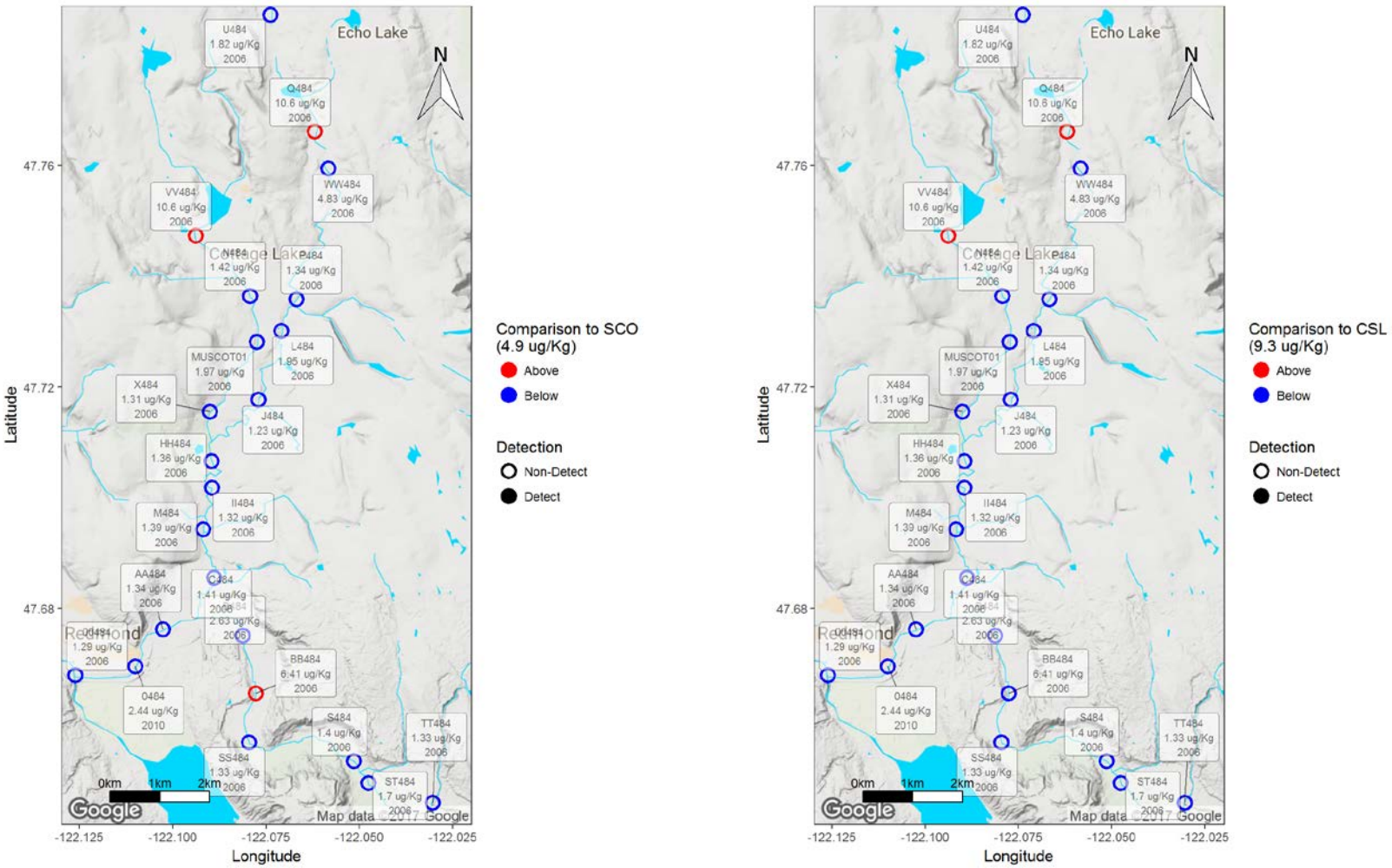

Figure D-17. Dieldrin sediment concentrations compared to sediment cleanup criteria.

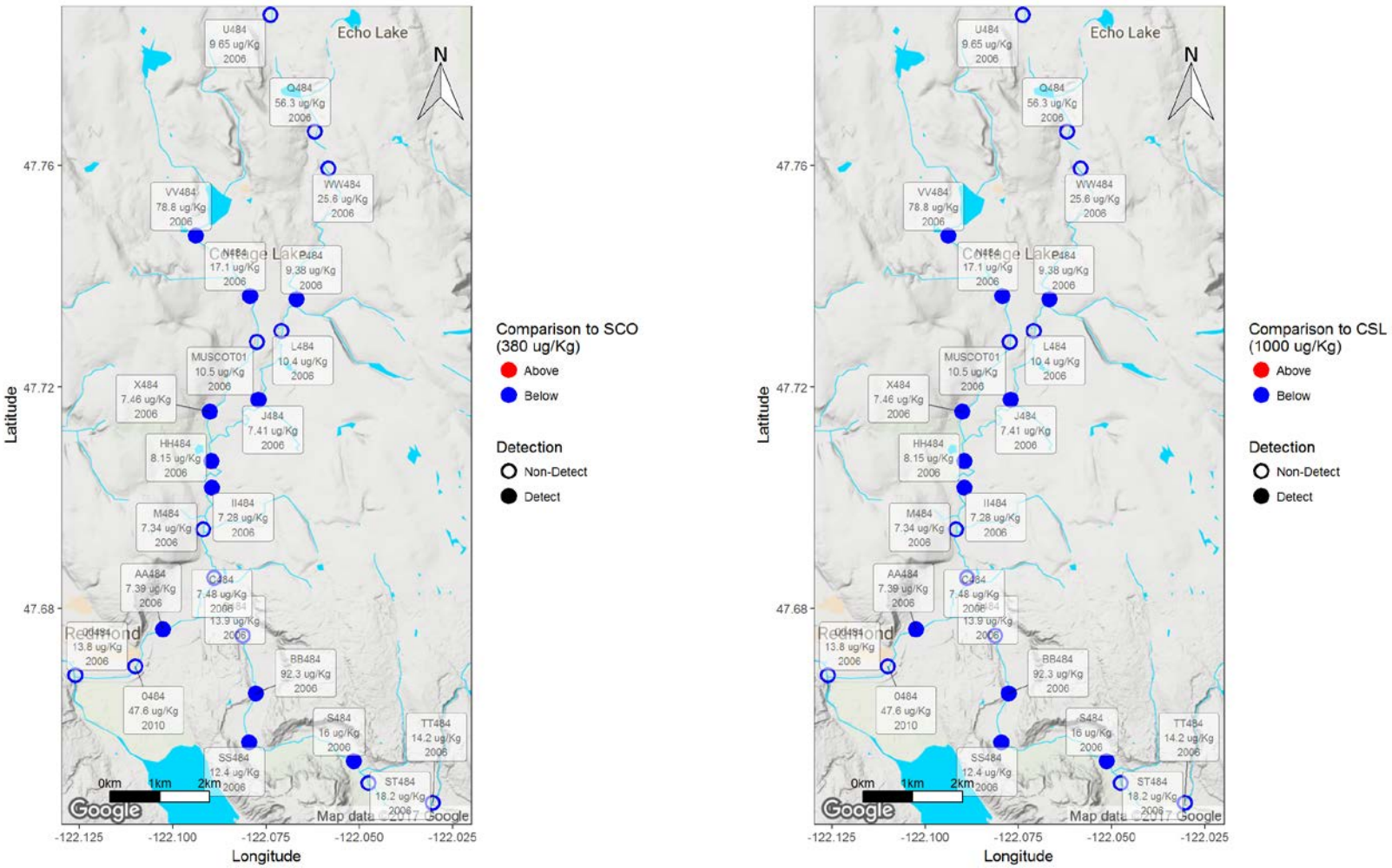

Figure D-18. Di-n-butyl phthalate sediment concentrations compared to sediment cleanup criteria.

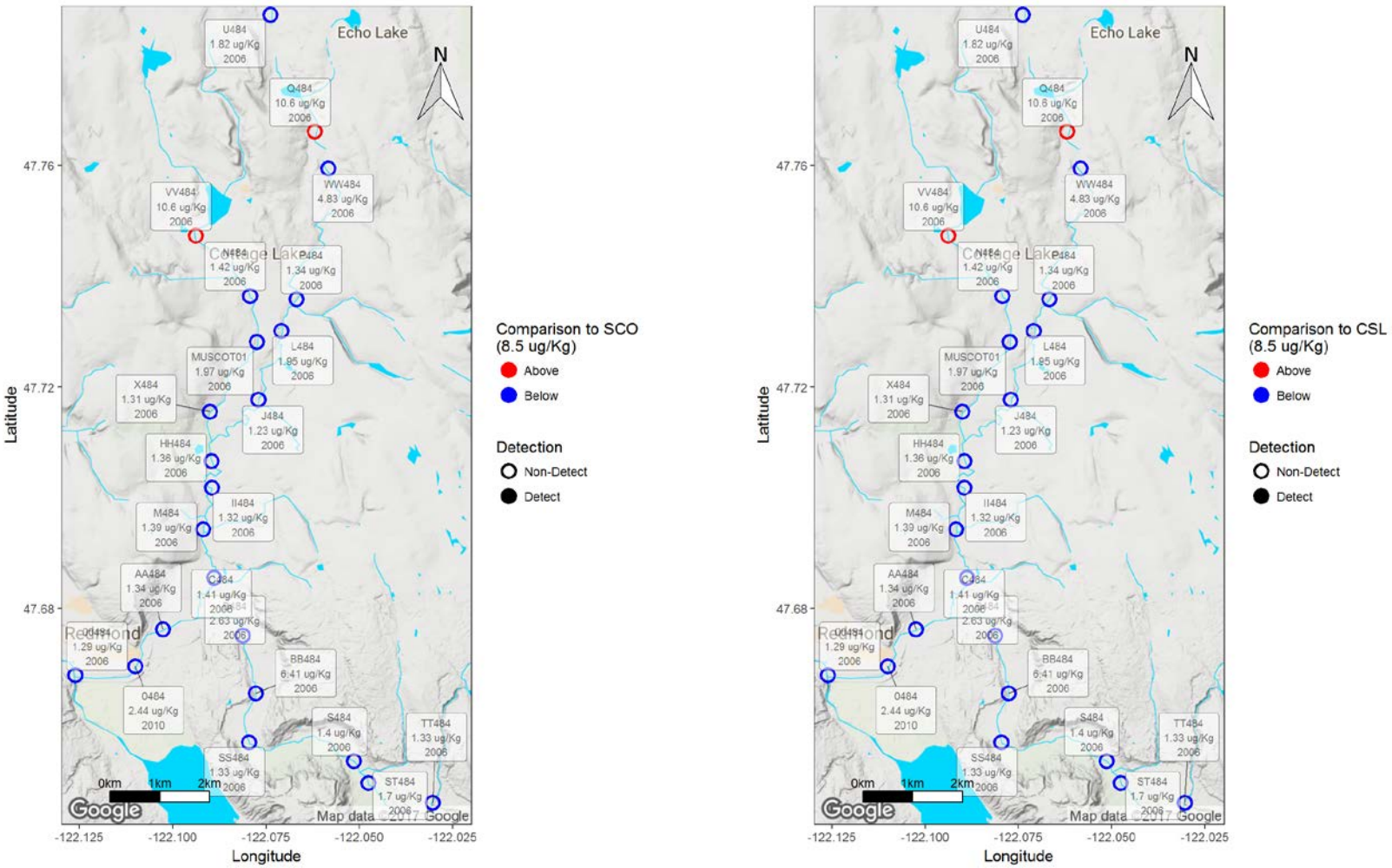

Figure D-19. Endrin ketone sediment concentrations compared to sediment cleanup criteria.

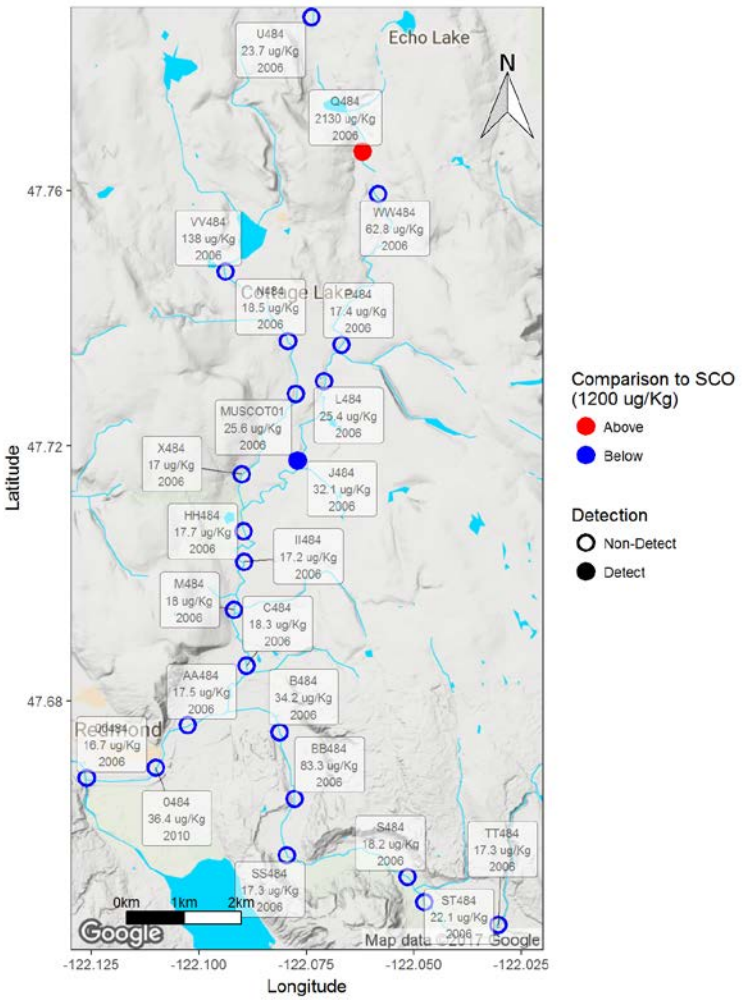

Figure D-20. Pentachlorophenol sediment concentrations compared to sediment cleanup criteria. For pentachlorophenol, the cleanup screening level (CSL) is unknown but is greater than 1200 µg/Kg.

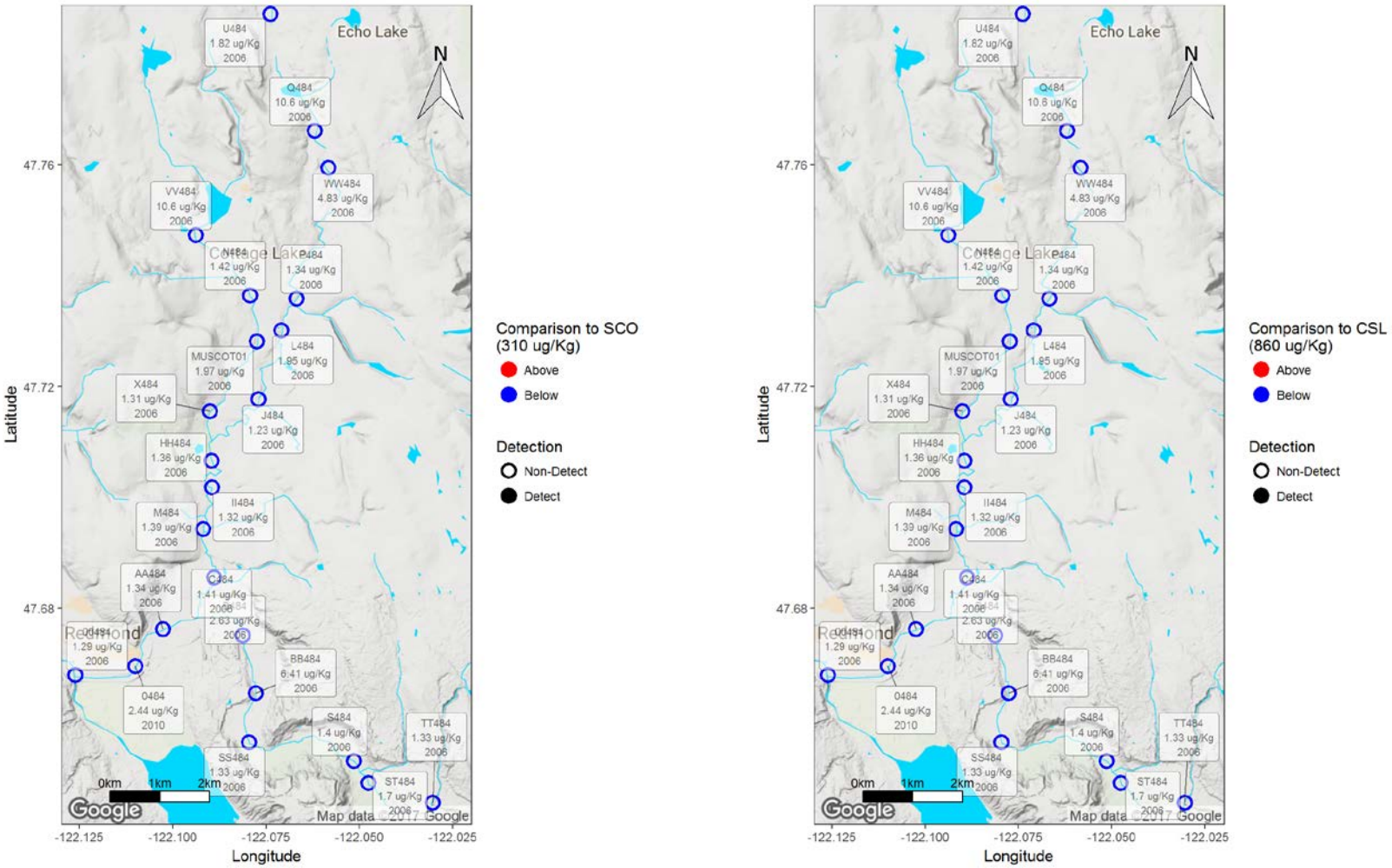

Figure D-21. Total DDDs sediment concentrations compared to sediment cleanup criteria.

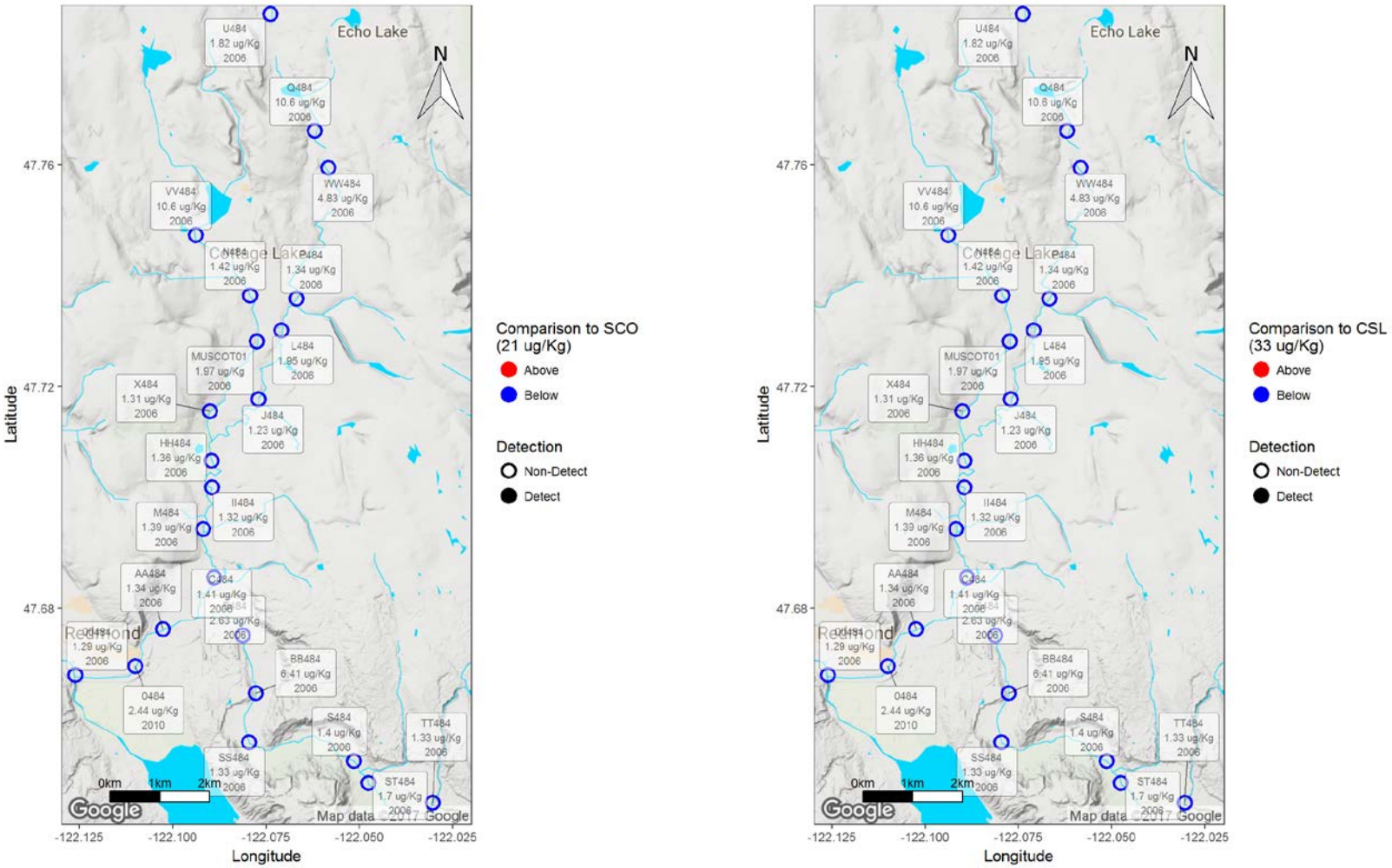

Figure D-22. Total DDEs sediment concentrations compared to sediment cleanup criteria.

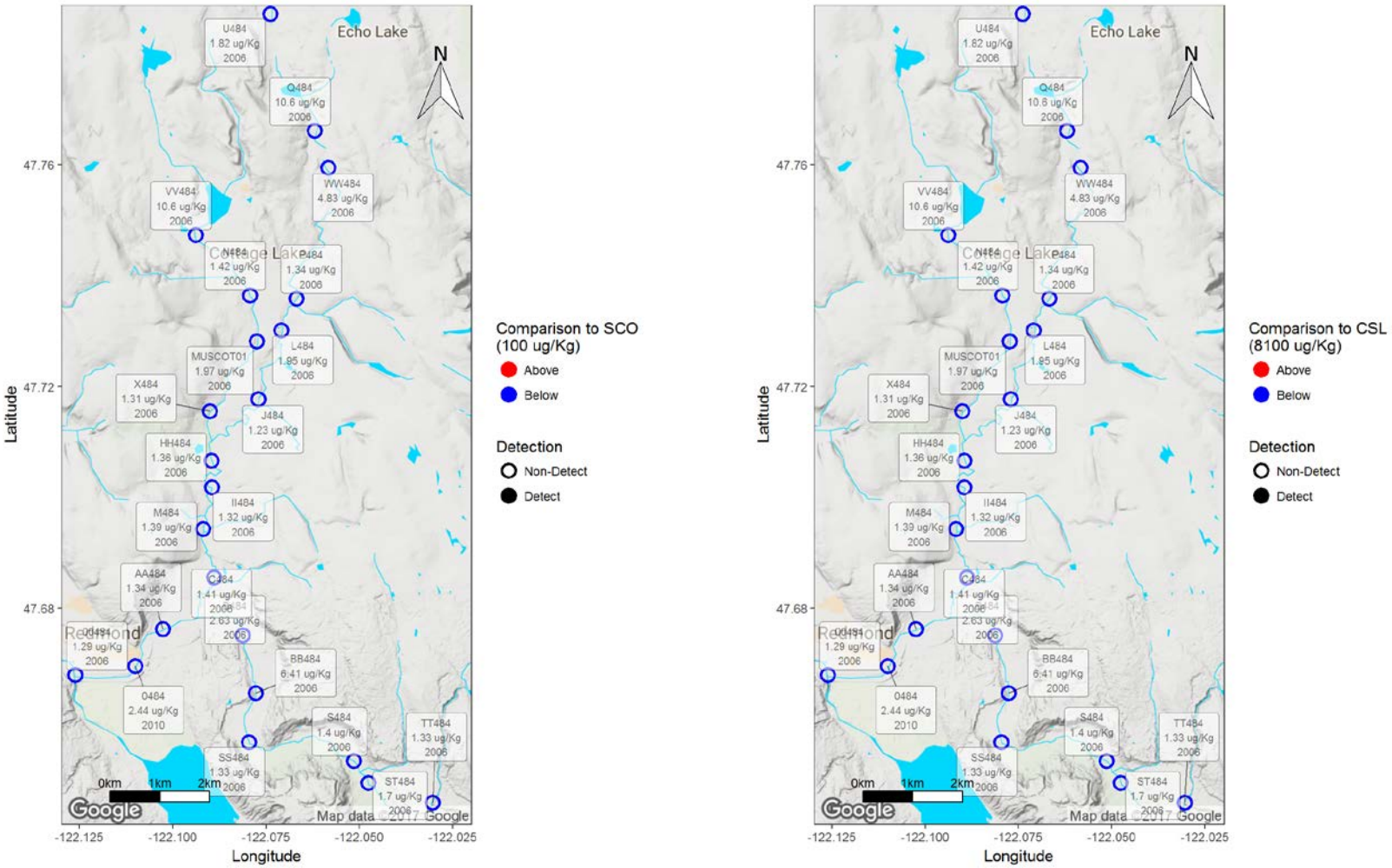

Figure D-23. Total DDTs sediment concentrations compared to sediment cleanup criteria.

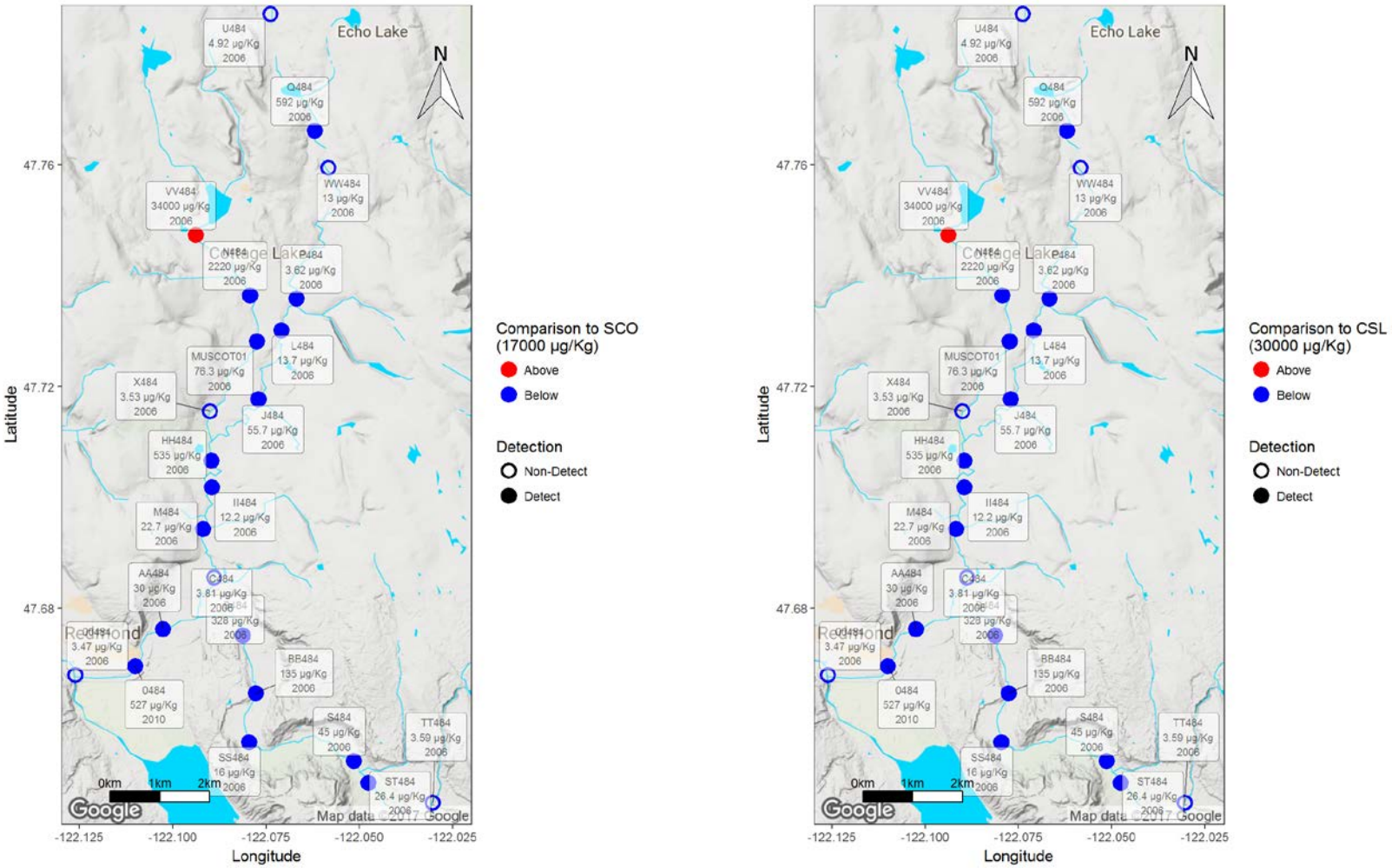

Figure D-24. Total PAHs sediment concentrations compared to sediment cleanup criteria.

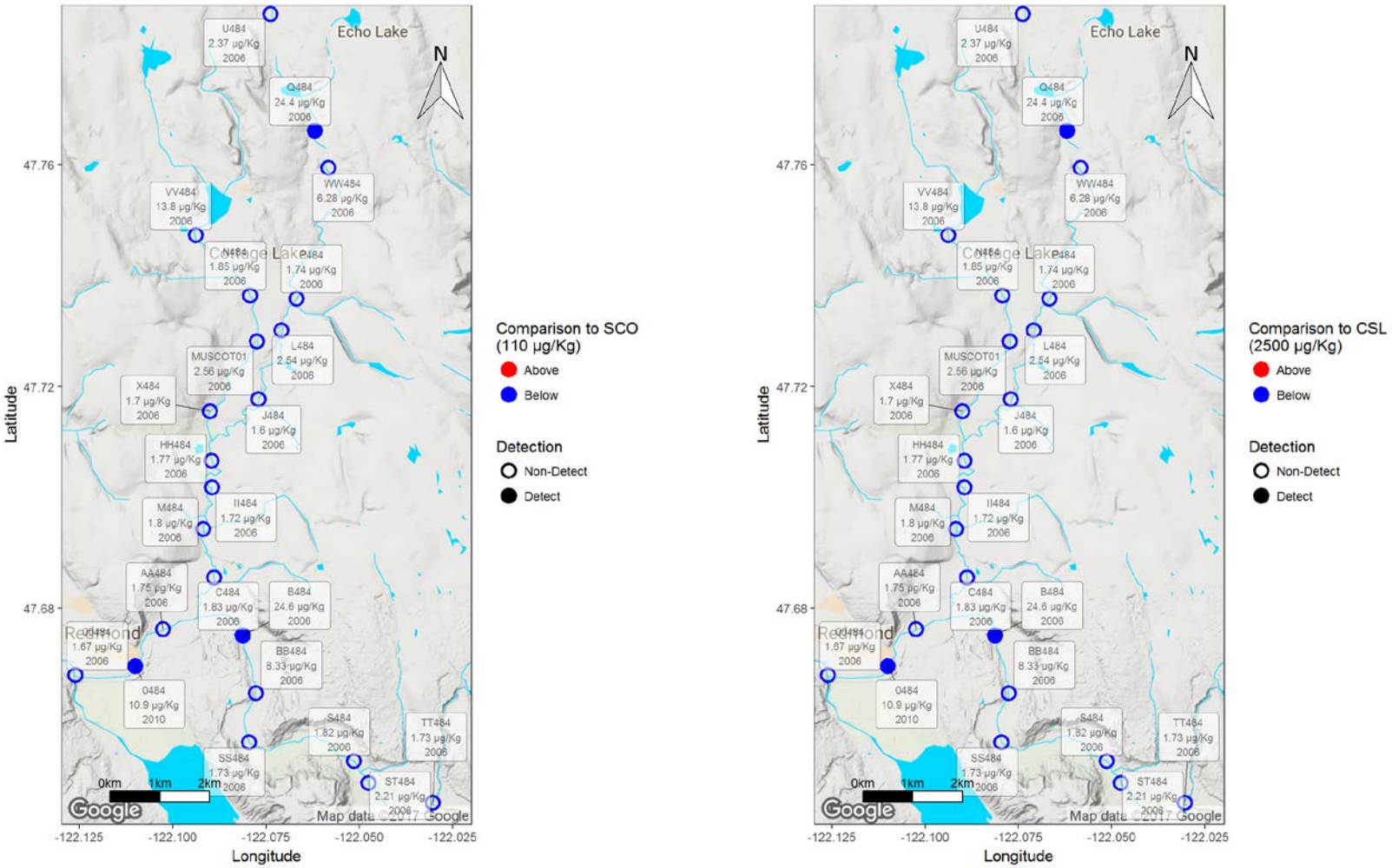

Figure D-25. Total PCBs sediment concentrations compared to sediment cleanup criteria.

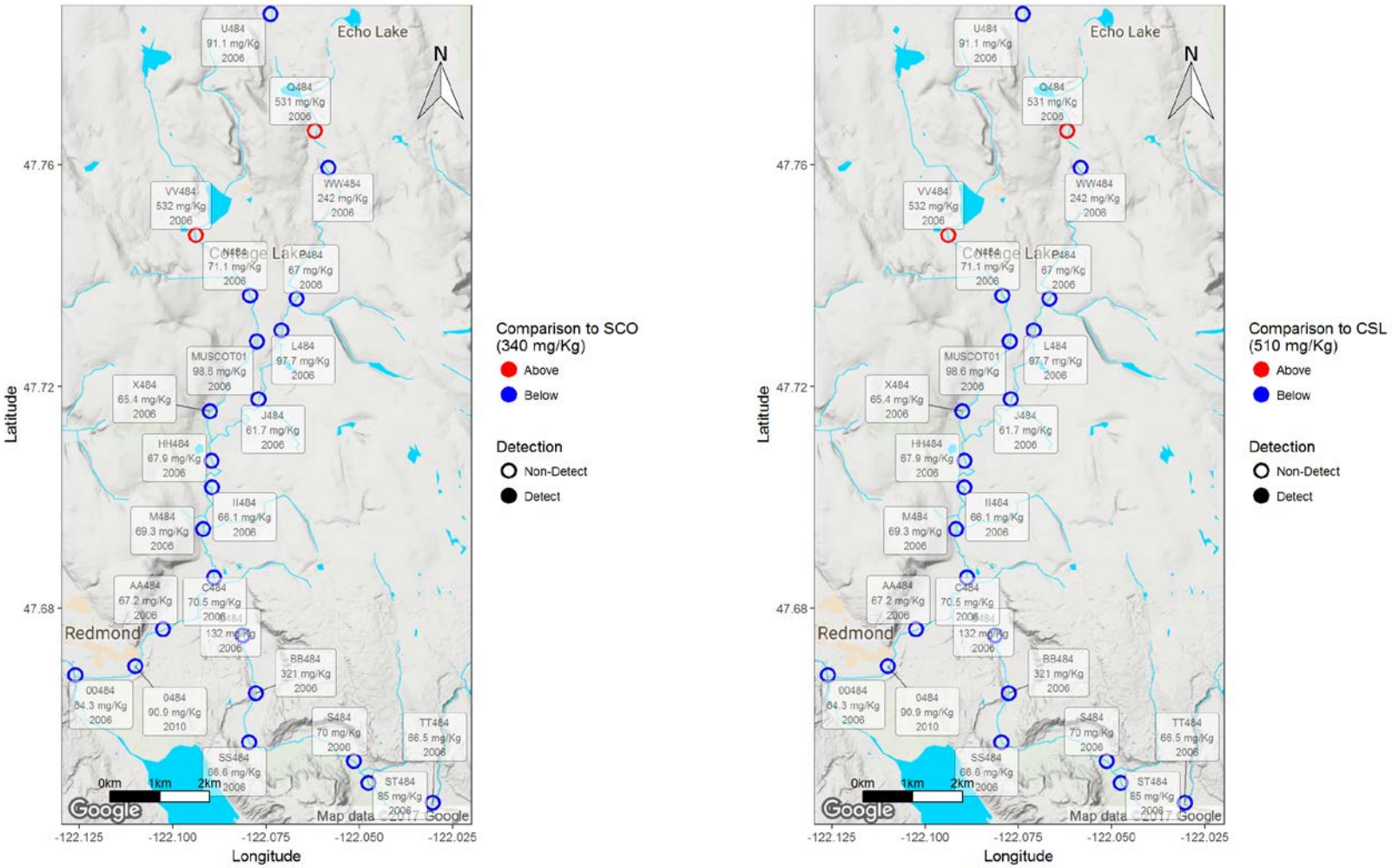

Figure D-26. Total petroleum hydrocarbons (diesel range) sediment concentrations compared to sediment cleanup criteria.

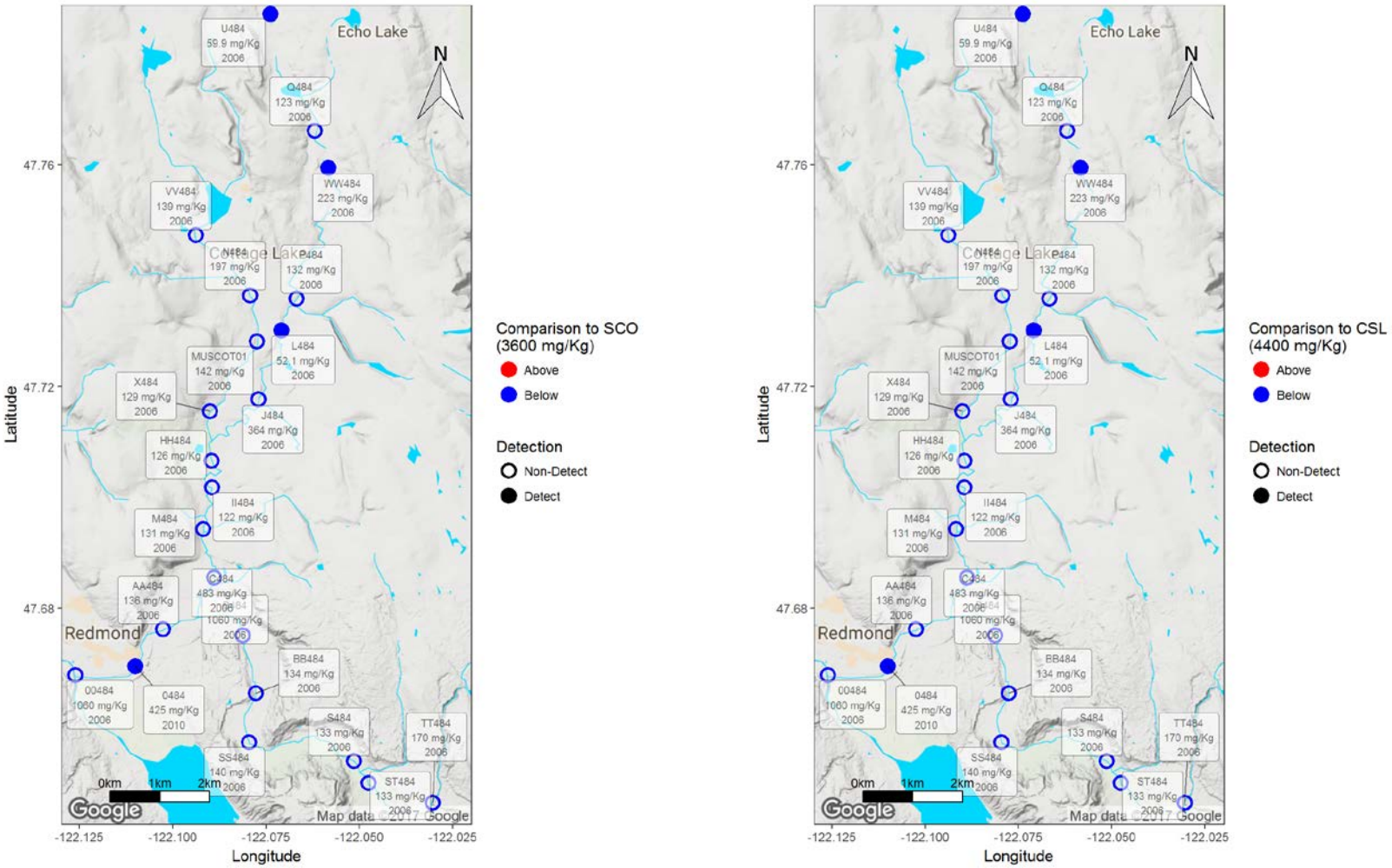

Figure D-27. Total petroleum hydrocarbons (residual range) sediment concentrations compared to sediment cleanup criteria.

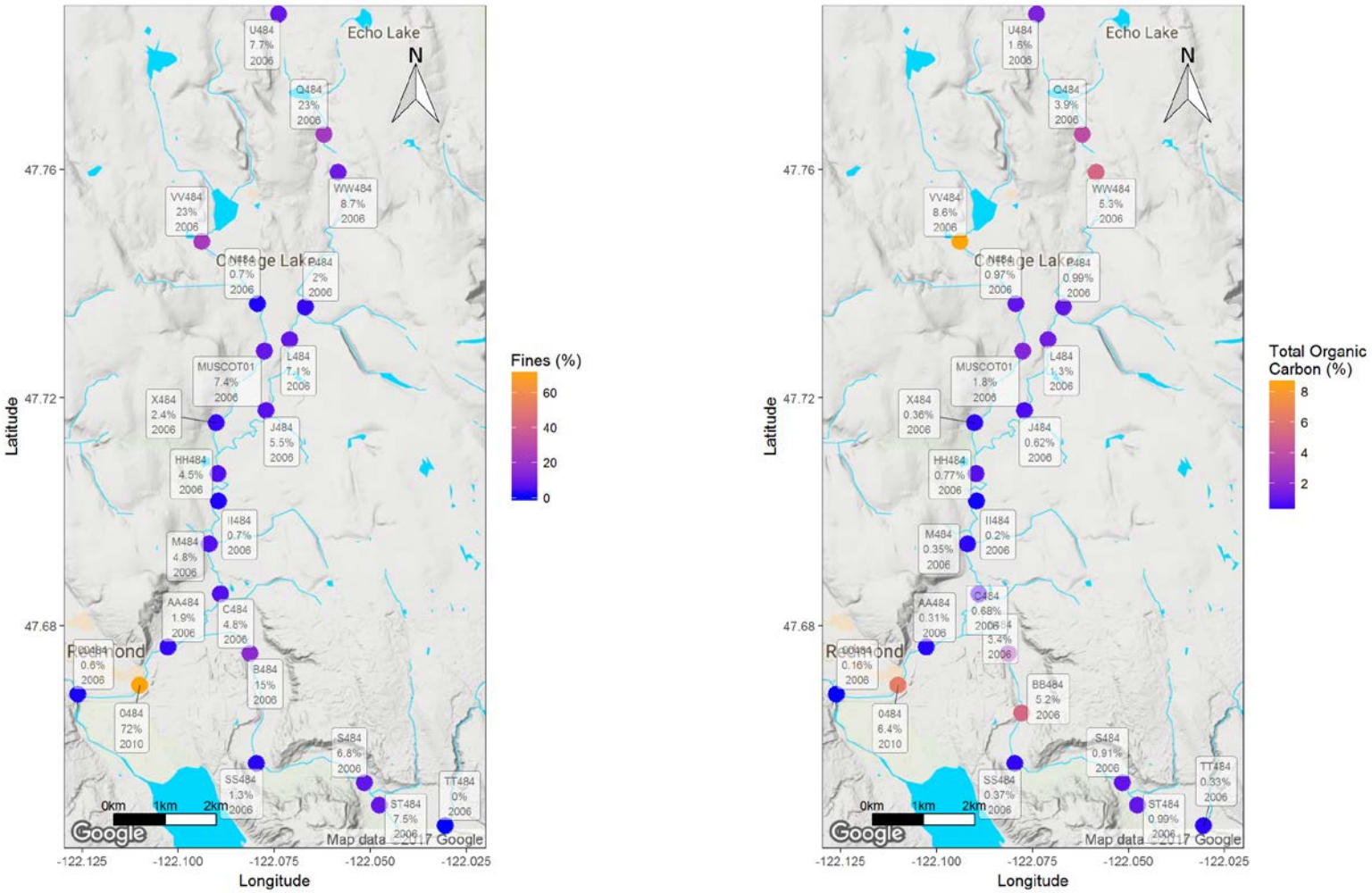

Figure D-28. Percent fine sediments (left) and percent organic carbon (right).

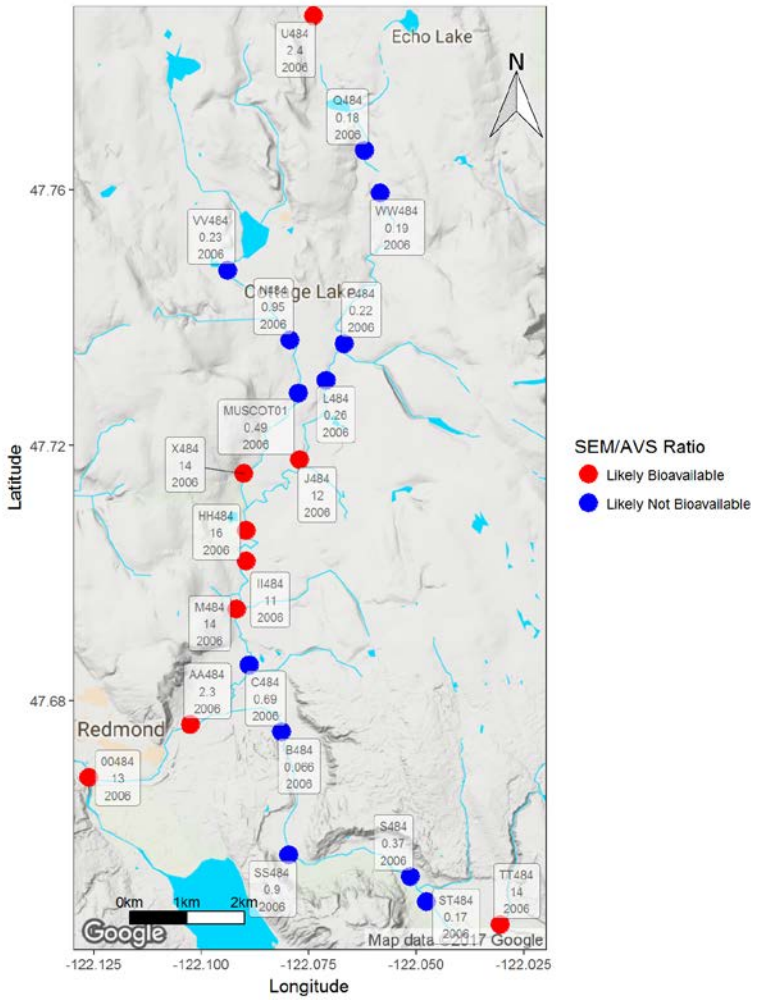

Figure D-29. SEM:AVS ratio.

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Appendix E: Water Quality Trends by Individual Season for Select Parameters

Table E-1. Mann-Kendall test results by season. Sen slope units shown with parameter name.

Parameter	Site	Season	p-value	Tau	Sen Slope
Conductance (µS/cm/yr)	Bear Creek - Mouth (0484)	**Winter**	**<0.0001**	**0.34**	**0.75**
		Spring	**<0.0001**	**0.49**	**1.0**
		Summer	**<0.0001**	**0.64**	**1.2**
		Fall	**<0.0001**	**0.37**	**0.90**
	Evans Creek - Mouth (B484)	**Winter**	**0.0041**	**0.24**	**0.55**
		Spring	**<0.0001**	**0.47**	**1.1**
		Summer	**<0.0001**	**0.69**	**1.8**
		Fall	**<0.0001**	**0.33**	**0.86**
	Bear Creek - 95th Ave Bridge (C484)	**Winter**	**<0.0001**	**0.43**	**1.1**
		Spring	**<0.0001**	**0.61**	**1.2**
		Summer	**<0.0001**	**0.73**	**1.4**
		Fall	**<0.0001**	**0.42**	**1.1**
	Bear Creek - 133rd St Bridge (J484)	**Winter**	**<0.0001**	**0.44**	**1.0**
		Spring	**<0.0001**	**0.50**	**1.1**
		Summer	**<0.0001**	**0.58**	**1.0**
		Fall	**<0.0001**	**0.46**	**0.96**
	Cottage Lake Creek (N484)	**Winter**	**<0.0001**	**0.36**	**1.0**
		Spring	**<0.0001**	**0.55**	**1.3**
		Summer	**<0.0001**	**0.67**	**1.6**
		Fall	**<0.0001**	**0.42**	**1.3**
Dissolved Oxygen, Field (ppm/yr)	Bear Creek - Mouth (0484)	Winter	0.8886	<0.01	<0.001
		Spring	0.3949	-0.06	-0.005
		Summer	0.1921	-0.09	-0.013
		Fall	0.3077	-0.05	-0.005
	Evans Creek - Mouth (B484)	**Winter**	**<0.0001**	**-0.41**	**-0.062**
		Spring	**<0.0001**	**-0.57**	**-0.100**
		Summer	**<0.0001**	**-0.72**	**-0.125**
		Fall	**<0.0001**	**-0.50**	**-0.092**
	Bear Creek - 95th Ave Bridge (C484)	Winter	0.7922	-0.01	<0.001
		Spring	0.2670	-0.10	-0.008
		Summer	**0.0077**	**-0.22**	**-0.020**
		Fall	0.0603	-0.14	-0.014
	Bear Creek - 133rd St Bridge (J484)	Winter	0.8426	0.03	0.001
		Spring	0.6642	-0.04	-0.002
		Summer	**0.0014**	**-0.27**	**-0.021**
		Fall	0.1347	-0.13	-0.017
	Cottage Lake Creek (N484)	Winter	0.9059	0.02	<0.001
		Spring	**0.0380**	**-0.16**	**-0.013**
		Summer	**0.0002**	**-0.35**	**-0.031**
		Fall	**0.0487**	**-0.13**	**-0.014**

Parameter	Site	Season	p-value	Tau	Sen Slope
Fecal Coliform (CFU/ 100 mL/yr)	Bear Creek - Mouth (0484)	**Winter**	**<0.0001**	**-0.51**	**-8.6**
		Spring	**<0.0001**	**-0.45**	**-18.6**
		Summer	**<0.0001**	**-0.38**	**-22.7**
		Fall	**<0.0001**	**-0.39**	**-12.8**
	Evans Creek - Mouth (B484)	**Winter**	**<0.0001**	**-0.47**	**-1.7**
		Spring	**<0.0001**	**-0.43**	**-4.0**
		Summer	**<0.0001**	**-0.41**	**-8.8**
		Fall	**0.0015**	**-0.24**	**-1.2**
	Bear Creek - 95th Ave Bridge (C484)	**Winter**	**<0.0001**	**-0.45**	**-4.3**
		Spring	**<0.0001**	**-0.34**	**-5.7**
		Summer	**0.0003**	**-0.29**	**-5.9**
		Fall	**0.0023**	**-0.24**	**-4.1**
	Bear Creek - 133rd St Bridge (J484)	**Winter**	**0.0137**	**-0.21**	**-0.7**
		Spring	0.0702	-0.13	-0.9
		Summer	**0.0246**	**-0.21**	**-3.5**
		Fall	0.3466	-0.09	-0.5
	Cottage Lake Creek (N484)	**Winter**	**<0.0001**	**-0.33**	**-1.7**
		Spring	**0.0002**	**-0.32**	**-2.7**
		Summer	**0.0001**	**-0.32**	**-6.7**
		Fall	**0.0026**	**-0.23**	**-2.5**
Nitrite + Nitrate Nitrogen (ppb/yr)	Bear Creek - Mouth (0484)	**Winter**	**0.0003**	**-0.32**	**-5.4**
		Spring	0.9795	<0.01	<0.1
		Summer	0.4832	-0.05	-0.5
		Fall	**<0.0001**	**-0.39**	**-8.6**
	Evans Creek - Mouth (B484)	**Winter**	**<0.0001**	**-0.65**	**-16.9**
		Spring	**<0.0001**	**-0.43**	**-7.0**
		Summer	0.3019	0.10	1.5
		Fall	**<0.0001**	**-0.46**	**-8.8**
	Bear Creek - 95th Ave Bridge (C484)	Winter	0.7883	-0.03	-0.4
		Spring	**0.0001**	**0.30**	**4.0**
		Summer	0.1577	0.13	1.5
		Fall	**0.0050**	**-0.21**	**-5.5**
	Bear Creek - 133rd St Bridge (J484)	Winter	0.1837	-0.16	-4.2
		Spring	0.1595	-0.10	-1.4
		Summer	**0.0040**	**-0.27**	**-2.2**
		Fall	**0.0023**	**-0.24**	**-7.7**
	Cottage Lake Creek (N484)	**Winter**	**0.0042**	**0.27**	**6.0**
		Spring	**0.0043**	**0.26**	**5.9**
		Summer	0.5780	-0.05	-1.7
		Fall	0.7056	-0.03	-0.9

Parameter	Site	Season	p-value	Tau	Sen Slope
Sample Temperature, Field (°C/yr)	Bear Creek - Mouth (0484)	Winter	0.8376	-0.02	-0.002
		Spring	**0.0207**	**0.12**	**0.023**
		Summer	**0.0006**	**0.30**	**0.068**
		Fall	**0.0061**	**0.18**	**0.055**
	Evans Creek - Mouth (B484)	Winter	0.9891	-0.01	<0.001
		Spring	**0.0001**	**0.28**	**0.060**
		Summer	**0.0001**	**0.39**	**0.093**
		Fall	**0.0119**	**0.20**	**0.063**
	Bear Creek - 95th Ave Bridge (C484)	Winter	0.9144	<0.01	<0.001
		Spring	**0.0054**	**0.17**	**0.037**
		Summer	**0.0010**	**0.31**	**0.065**
		Fall	**0.0018**	**0.25**	**0.081**
	Bear Creek - 133rd St Bridge (J484)	Winter	0.3740	0.05	0.015
		Spring	0.1778	0.10	0.021
		Summer	**0.0098**	**0.23**	**0.060**
		Fall	**0.0208**	**0.19**	**0.070**
	Cottage Lake Creek (N484)	Winter	0.5049	-0.05	-0.009
		Spring	0.1394	0.09	0.017
		Summer	**0.0006**	**0.28**	**0.065**
		Fall	**0.0154**	**0.20**	**0.050**
Total Phosphorus (ppb/yr)	Bear Creek - Mouth (0484)	**Winter**	**<0.0001**	**-0.47**	**-1.6**
		Spring	**<0.0001**	**-0.37**	**-1.0**
		Summer	**<0.0001**	**-0.42**	**-131**
		Fall	**<0.0001**	**-0.40**	**-138**
	Evans Creek - Mouth (B484)	**Winter**	**<0.0001**	**-0.49**	**-1.2**
		Spring	0.1324	-0.13	-0.3
		Summer	0.2200	-0.10	-0.3
		Fall	**0.0002**	**-0.35**	**-0.9**
	Bear Creek - 95th Ave Bridge (C484)	**Winter**	**<0.0001**	**-0.45**	**-0.8**
		Spring	**0.0001**	**-0.32**	**-0.6**
		Summer	**<0.0001**	**-0.36**	**-0.9**
		Fall	**0.0007**	**-0.33**	**-1.1**
	Bear Creek - 133rd St Bridge (J484)	**Winter**	**0.0148**	**-0.26**	**-0.4**
		Spring	**0.0395**	**-0.19**	**-0.4**
		Summer	**0.0005**	**-0.30**	**-0.8**
		Fall	**0.0454**	**-0.20**	**-0.6**
	Cottage Lake Creek (N484)	**Winter**	**0.0012**	**-0.26**	**-0.5**
		Spring	**0.0030**	**-0.25**	**-0.4**
		Summer	**<0.0001**	**-0.41**	**-0.8**
		Fall	**0.0344**	**-0.19**	**-0.5**

Parameter	Site	Season	p-value	Tau	Sen Slope
Total Suspended Solids (ppb/yr)	Bear Creek - Mouth (0484)	**Winter**	**<0.0001**	**-0.39**	**-240**
		Spring	**<0.0001**	**-0.25**	**-100**
		Summer	**0.0031**	**-0.21**	**-56**
		Fall	0.0662	-0.13	-73
	Evans Creek - Mouth (B484)	**Winter**	**<0.0001**	**-0.44**	**-240**
		Spring	**0.0352**	**-0.16**	**-50**
		Summer	**0.0011**	**-0.27**	**-76**
		Fall	**0.0075**	**-0.21**	**-73**
	Bear Creek - 95th Ave Bridge (C484)	**Winter**	**<0.0001**	**-0.36**	**-170**
		Spring	**0.0003**	**-0.28**	**-95**
		Summer	**0.0042**	**-0.23**	**-74**
		Fall	0.6090	-0.04	-34
	Bear Creek - 133rd St Bridge (J484)	**Winter**	**0.0035**	**-0.28**	**-94**
		Spring	0.0804	-0.13	-35
		Summer	**0.0451**	**-0.19**	**-50**
		Fall	0.7946	-0.04	-19
	Cottage Lake Creek (N484)	**Winter**	**0.0007**	**-0.25**	**-61**
		Spring	**<0.0001**	**-0.35**	**-74**
		Summer	**0.0139**	**-0.23**	**-57**
		Fall	0.2964	-0.08	-25