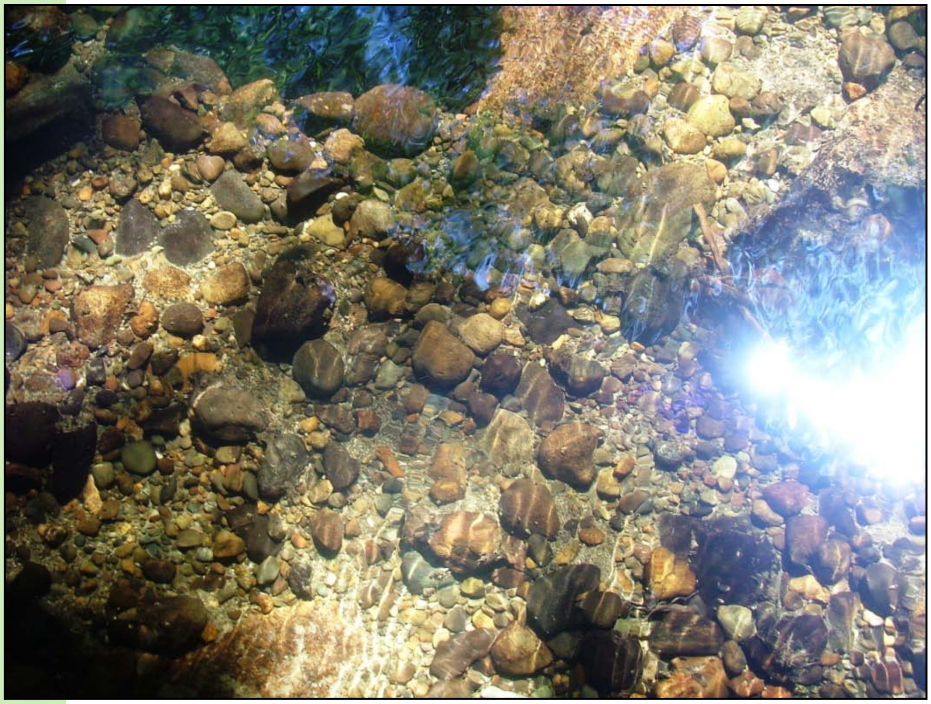

Phase 2: High Summer Bacteria Concentrations in South Puget Sound Streams

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Cover photo: Deer Creek bed sediments

Phase 2: High Summer Bacteria Concentrations in South Puget Sound Streams

by

Nuri Mathieu

Directed Studies Unit
Western Operations Section
Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington 98504-7710

Waterbody Numbers

WA-13-1100	McLane Creek
WA-14-1300	Kennedy Creek
WA-14-1750	Deer Creek
WA-15-1400	Burley Creek

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Abstract

The Washington State Department of Ecology (Ecology) conducted a study in 2008 to identify and analyze environmental conditions in streams with high bacteria levels during the summer months. The study was entitled High Summer Bacteria Concentrations in Streams. The study recommended a second monitoring phase (Phase 2) be conducted to provide additional needed information.

During 2010 Ecology conducted this study to complete the Phase 2 recommendations and research the role that streambed sediments play in contributing to high summer bacteria concentrations in South Puget Sound streams.

High bacteria concentrations in rivers and streams indicate the potential presence of harmful pathogens that pose a public health risk to the people that recreate in rivers and streams. In addition, these high bacteria streams often drain to marine waterbodies with public swimming beaches or shellfish harvesting areas. Elevated pathogen levels in the water can accumulate in shellfish tissue, making them unsafe to eat.

The study found some evidence of an indirect relationship between fecal coliform in stream bottom sediments and water. Fecal coliform concentrations in the sediment did not appear to be higher in warmer summer months; nor did they increase as the summer progressed.

The study found that sediment-bound fecal coliform accounted for 17-34%, on average, of the total fecal coliform in each stream. These results indicate that sediment- bound bacteria are likely not the primary source of fecal coliform in South Puget Sound streams during summer baseflow conditions; however, the results do suggest they are a significant secondary source.

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Background

Introduction

Water quality specialists in Southwest Washington have recently identified a number of South Puget Sound streams which, in the summer, have high fecal indicator bacteria concentrations exceeding (not meeting) Washington State Water Quality Standards (www.ecy.wa.gov/programs/wq/swqs/criteria-freshwater/wac173201a_200-bacteria.html). Washington State uses the fecal indicator bacteria of fecal coliform (FC) to assess microbiological pollution in the water quality standards.

Local governments have requested more information about the cause of high summer FC levels to address the source of the problem. In 2008, the Washington State Department of Ecology (Ecology) Environmental Assessment Program (EAP) undertook a project to study a population of stream bacteria data. Thurston County Environmental Health, the Squaxin Island Tribe, and Ecology's Water Quality Program, Southwest Regional Office requested the project. The project goal was to identify and analyze streams with high FC levels during the summer (Bell-McKinnon, 2008).

The report for this project, *High Summer Bacteria Concentrations in Streams*, compiled FC data and produced maps of locations with high FC concentrations in the summer. The report recommended that:

- A Phase 2 portion of this project should be proposed and implemented. Before analyzing any of the FC datasets compiled for this study, additional stream environmental parameters, including streamflow, total suspended solids (TSS), and substrate type need to be measured.
- As part of the Phase 2 project, the annotated bibliography should be reviewed and results from bacterial studies conducted in the Pacific Northwest and other regions of the United States should be compared and analyzed.

Study Purpose

Ecology conducted this 2010 study to complete the recommendations from the initial study (Bell-McKinnon, 2008) and research the role that streambed sediments and other factors play in contributing to high summer FC concentrations in South Puget Sound streams.

High concentrations of FC and other fecal indicator bacteria in rivers and streams indicate the potential presence of harmful pathogens that pose a public health risk to the people that recreate in rivers and streams. In addition, these high FC streams often drain to marine waterbodies with public swimming beaches or shellfish harvesting areas. Elevated pathogen levels in the water can accumulate in shellfish tissue, making them unsafe to eat.

Under certain conditions, FC deposited in stream sediments can:

- Survive longer than those suspended in the water column.

- Re-suspend in the water column when disturbed.
- In some cases even multiply in the sediment.

Currently, little information is available as to how sediment FC affect FC levels in Washington streams. This study provides information to better characterize that relationship.

The study also served as a framework for future Ecology sampling of sediment FC. Part of the project was the development of an EAP standard operating procedure (SOP) for collecting sediment bacteria samples.

Additionally, most of the study locations are waterbodies in a Water Quality Assessment (WQA) category that classifies them as having violated Washington State surface water quality standards for FC (Categories 4a, 4b, and 5). The study data provides useful information about the current status of these waterbodies and the likelihood of sediment FC as a potential source of impairment.

Literature Review: Bacteria Fate and Transport in Suspended and Bed Sediments

Acknowledgements

Much of the substance and source material of this review originated from past literature reviews of the subject matter. The author thanks the authors for providing the following summarized material and sources:

- Dynamic Existence of Waterborne Pathogens within River Sediment Compartments: Implications for Water Quality Regulatory Affairs (Droppo et al., 2009).
- Relationships between Land Uses and Indicator Bacteria in a Riverine Environment (Jolley et al., 2008).
- Partitioning Between the Soil-Adsorbed and Planktonic Phases of *Escherichia Coli* (Henry, 2004).
- High Summer Bacteria Concentrations in Streams – Appendix D: Annotated Bibliography (Bell-McKinnon, 2008).
- Annotated Bibliography and Abstracts: Survival, regrowth, and resuspension of indicator bacteria and pathogens in sediments (Keesecker, 2007).

Literature Review

What are suspended solids?

Suspended 'solids' typically consist of flocculated particles, or flocs, made up of biological organisms (for example, bacteria or alga), small sediment particles (for example, clay or silt), detritus, water, and pores (Droppo, 2001).

Indicator bacteria and pathogens often attach to sediment.

The organisms in bed sediments and flocs secrete extracellular polymeric substances (EPS) during the production of biofilm (LeChavallier et al., 1984; Schillinger and Gannon, 1985; Droppo, 2001). Microscopic images indicate that EPS is the primary mechanism for bacteria attachment to sediment particles due to the sticky nature and large surface area of the EPS fibrils (Liss et al., 1996; Higgins and Novak, 1997; Droppo, 2001; Droppo et al., 2009).

Other studies have shown that sediment-attached bacteria are more commonly associated with fine (<10 µm) particles (Albinger, 1993; Auer and Niehaus, 1993). Additionally, hydrophobic (negatively-charged cell surface) bacteria, such as *E. coli,* are more likely to attach to soil particles and wastewater treatment sludge flocs (Huysman and Verstrate, 1993; Zita and Hermansson, 1997).

Bacteria survive longer when attached to suspended solids or settled into bed sediments.

Numerous studies have observed increased bacteria survival in both fresh and marine suspended and bed sediments (Gerba and McLeod, 1976; Desmarais et al., 2002; Sherer et al., 1992; Howell et al., 1996; LaJeune et al., 2001; Davies et al., 1995; Ghoul et al., 1990; Anderson et al., 2005; Craig et al., 2001a).

Research shows observed bacteria die-off rates are lower for both suspended sediments (Sherer et al., 1992) and bed sediments (Craig et al., 2001) consisting of mostly fine particles. Davies et al. (1995) showed that sediments provide a more nutrient rich environment to support growth of bacteria.

Ghoul et al. (1990) found that *E. coli* accumulated glycine betaine (GB) from marine sediments, which increased survivability overall. GB, a substance produced by marine aquatic organisms, helps protect cell walls from the effects of osmotic pressure caused by the high salt concentrations in marine water.

Several of these studies also attribute increased bacteria survival rates to other factors including sediment composition, temperature, organic content, and protection from predators (Sherer et al., 1992; Howell et al., 1996; Craig et al., 2001b).

Attached bacteria settle to sediment bed at a faster rate compared to unattached bacteria.

Unattached bacteria are small and have very slow settling rates; while sediment-attached bacteria settle at a faster rate (Gannon et al., 1983; An et al., 2002). Flocculation increases settling rate of sediments and, by association, bacteria (Battin et al., 2008; Searcy et al., 2005; Wotton, 2007). Bacteria are more likely to accumulate in areas with significant sediment deposition (for example, pools, glides, or eddies).

Storm events and other disturbance mechanisms can resuspend bacteria accumulated in the sediment bed into the water column.

Resuspended sediment provides a transport mechanism for bacteria (Brettar and Hoffe, 1992; Kistemann et al., 2002) and often results in degraded water quality in the affected areas (An et al., 2002; Nagels et al., 2002; Muirhead et al., 2003; Jolley, 2008).

Craig et al. (2001b) found that sediment consisting mostly of sand resulted in the most resuspension of *E. coli* when compared to sediments with a variety of sand, silt, and clay fractions. One Canadian study found that most bacterial resuspension occurred during the period water levels were rising (and flow increasing), implying that a finite supply of sediment-associated bacteria are available for resuspension during individual storm events (Jamieson et al., 2005).

Some studies have shown that large amounts (and high concentrations) of *E. Coli* resulted from both a natural and an artificial flood of a stream where the catchment was used for grazing dairy and beef cattle (Nagels et al., 2002; Muirhead et al., 2003).

Indicator bacteria and pathogens can also persist in the stream margin soils and forest soils, providing a non-point source to streams during periods of runoff or elevated water levels.

Several studies have demonstrated that *E. coli* in stream margin soils can be elevated within the first 0.5 to 2 meters of shoreline and significantly correlated to percent (%) soil moisture (Byappanahalli et al., 2003; Desmarais et al., 2002).

Once established in forest soils, *E. coli* can persist throughout the year, potentially acting as a continuous non-point source of *E. coli* to nearby streams (Whitman et al., 2006).

Studies in the Pacific Northwest

Fecal coliform in freshwater sediments

In 1983-84 Ecology conducted a comprehensive FC sanitary survey of the Burley Lagoon and Minter Bay watersheds (Determan et al., 1985a). As part of the study, Ecology collected sediment FC samples and conducted artificial sediment resuspension experiments. Concentrations of FC in sediment ranged from 260 to >240,000 MPN/100 g of sediment. Burley Creek at RM 0.6 had a sediment FC concentration of 9,200 MPN/100 g of sediment (Determan et al., 1985b).

Bear Creek (a tributary to Burley Creek) had the highest sediment FC concentration (>240,000 MPN/100 g of sediment), which was over 14 times greater than the next highest site (Minter Creek at RM 4.2; 17,000 MPN/100 g of sediment) and 1,000 times the control site (located in undeveloped upland forest). The 1983-84 Ecology study attributed the abnormally high sediment FC levels in Bear Creek to nearly stagnant water and deep deposits of silt at the site, as well as the impact from heavily grazed pastures upstream (Determan et al., 1985b).

A subsequent study conducted by the Bremerton-Kitsap County Health Department (Struck, 1988) found very high sediment FC levels in both Minter and Burley Creek. The study found geometric mean sediment FC concentrations of 127,935 MPN/100 mL in Burley Creek and 5,801 MPN/100 mL in Minter Creek. Both sediment sampling locations were located in backwater eddies (depositional areas) and the sediments consisted primarily of fine silt, organic matter, and sand.

Sediment-bound fecal indicator bacteria in stormwater

A recently completed study of sediment-bound FC in Oakland Bay tributaries (Konovsky, 2010) showed a large fraction of FC in the water column were bound to suspended solids during storm events. The study:

- Measured sediment-bound FC at the mouths of Deer and Cranberry Creek during three storm events from October to December 2010.
- Found sediment-bound FC averaged 68% (of the total FC in the water column) for Deer Creek and 76% for Cranberry Creek during storm conditions.
- Was comparable to a North Carolina study (Characklis et al., 2005) that found similar results. The percent of sediment-bound FC increased during storm events, with three sites averaging 38%, 61%, and 68%, respectively, of FC bound to suspended sediment.

A 1998-99 United States Geological Survey (USGS) study (Anderson and Rounds, 2003) of *E. coli*, suspended sediment, and phosphorus in stormwater from a small urban creek in Portland, Oregon found that:

- "Rising limbs of discharge hydrographs had higher concentrations of sediment and TP, possibly indicating that sources were nearby (resuspension of streambed, bank erosion, close upland sources) and that available supplies limited downstream transport."
- *"E. coli* were correlated with suspended sediment (TSS and turbidity), indicating that they were either transported to streams attached to particles bound to resuspended streambed particles, or they had an affinity for particulate material in water."

Based on results from these studies it is likely that:

- Storm events provide both a transport and disturbance mechanism for sediment-bound FC.
- During storm events, there are more indicator bacteria attached to suspended sediment than free floating in the water column.

Summer-Specific Sources of Indicator Bacteria

Increased Human Activity During Summer

In the Puget Sound region, the summer months represent the peak time of year for travel, tourism, and recreation in general. Areas such as public parks, waterfront communities, and vacation communities see a large increase in human activity. This increase leads to a larger amount of wastewater being generated in these areas, which ultimately could result in treatment issues and seasonal contamination of surface and groundwater.

Mason County Public Health Department collected FC data in 2004 and 2005 on streams draining to Hood Canal. Three of the streams (Twanoh, Happy Hollow, and Big Bend Creeks) displayed a pattern of higher FC loads and concentrations in the summer months (Mathieu, 2010b). These three streams are unique in that there is little development in each drainage area, so there are only a few potential anthropogenic sources.

At Twanoh and Happy Hollow Creeks, the county has attributed the high FC levels to failing large on-site septic systems (OSS) discovered in each sub-basin. Mason County has not yet identified the cause of high FC loads at Big Bend Creek; however, a mobile home/trailer park with a large OSS is located at the mouth of the creek and is currently of interest as a potential source (Mason County, 2008).

A 2005 investigation of potential Twanoh Creek sources found that the large OSS at Twanoh State Park, located at the mouth of the creek, was failing and likely leaching FC to the creek (Mason County, 2008). The system was repaired in 2006. Mason County collected three samples in the summer of 2010 and preliminary results show reduced summer FC levels. The county observed FC levels between 11 and 50 cfu/100 mL (Mason County, 2011); in comparison, in the summer of 2004 the county observed FC levels between 62 and 124 cfu/100 mL. Given the park is visited more frequently in the summer months, the increased FC load in the summer may have stemmed from the combination of the failing septic system and the increased use of the restrooms at the state park during the summer.

Similarly, in the Happy Hollow Creek sub-basin, a failing OSS was identified at a store located adjacent to the creek in 2007. The system was repaired later that year. Mason County collected two FC samples in the summer 2010 and found very low FC levels of 4 and 13 cfu/100 mL (Mason County, 2011); in comparison, in the summer of 2004 the county observed FC levels between 46 and 160 cfu/100 mL. The store may have seen increased use during the summer months when recreation and tourism in the Hood Canal area increase.

Vacation homes located in areas with aesthetic and recreational value may also be visited more frequently, or exclusively, during the summer when the weather is milder, family vacations occur, or seasonal recreational opportunities occur (for example, waterskiing). Typically, vacation homes are unsewered and the increase in summer visitation leads to increased use of the OSS.

In addition, Thurston County's septic maintenance guidance cautions that systems with "infrequent use (such as vacation homes) may not keep enough waste in the system to give the [beneficial] bacteria enough food to sustain themselves" (Thurston County, 2011). Thurston County recommends that vacation home occupants use the toilet several times, before using any other water, when reoccupying the house and avoid high water use activities (for example laundry or baths) for as long as possible in order to allow the microbes enough time to re-establish.

A study of three OSS on seasonally-used vacation properties in Rhode Island found that each OSS was contaminating groundwater with nutrients and bacteria (Postma et al., 1992). The cause of OSS failure was attributed to incomplete formation of biological clogging mats in the soil absorption system of these vacation homes, which was discovered upon excavation at the end of the study. These clogging mats increase a system's ability to filter pollutants and require continuous wastewater input for 8 to 15 months to form. Therefore the OSS of vacation homes may be more prone to failure.

Increased Wildlife, Livestock, and Pet Activity During Summer

In the summer months, when food is more abundant, wildlife may show an increase in food intake and defecation. Foraging wildlife may spend more time in riparian areas and near wetlands during late summer months when the soil moisture continues to provide reliable forage at a time when upland soils become increasingly dry (Bigley, 1993).

While wildlife activity and defecation rates may increase in summer, the number of animals in the Puget Sound lowlands may actually decrease for some species. Many ruminant wildlife species are more concentrated at low elevation areas during winter months and then migrate to higher elevations in the Cascades and Olympics during summer months (WDFW, 2011).

A recent microbial source tracking (MST) study of three forested streams in northern Idaho found that wildlife was the most frequently identified source of *E. coli* in summer months (Idaho DEQ, 2010); however, the study also concluded that "… individual animal *E. coli* sources detected on days that exceeded water quality standards were not consistent and, for the most part, were not in quantities that are statistically reproducible." The study area was also located in high elevation forest land and is likely not comparable to the Puget lowlands in wildlife presence and activity.

During the summer, domestic cats may spend a greater amount of time outdoors and defecate more frequently outside (as opposed to using an indoor litter box). Similarly, dog owners may be more likely to take dogs for walks and to play near or in public waterbodies during warm weather months.

Regional research is needed to investigate and quantify seasonal variations in pet and wildlife activity in the Pacific Northwest on the watershed scale.

Some studies have shown that livestock with access to a stream consume more water in warm weather conditions and spend more time near the water during the hottest hours of the day (Bicudo et al., 2003). A temperature increase from 50 to 90 degrees Fahrenheit can more than double livestock's daily water intake (Parish and Reinhart, 2008). This research suggests livestock may defecate in and near streams more frequently during summer months.

Study Area

Four South Puget Sound streams were selected for monitoring: McLane, Kennedy, Deer, and Burley Creek. All four of these steams:

- Drain directly to a marine or brackish waterbody of South Puget Sound with either a current or historical shellfish harvest area.
- Have a drainage area of between 4,000 and 13,000 acres.
- Have watersheds dominated by non-point pollution sources. The study area does not contain any wastewater treatment plants or point source discharges. All wastewater is treated by OSS.

McLane Creek, upstream of the monitoring site (Table 1), is located in west Thurston County and drains 4,821 acres into the southernmost tip of Eld Inlet and Puget Sound. The land is predominantly forestland, with approximately 60% comprising Capitol Forest, a public multi-use area managed by the Washington State Department of Natural Resources. The remaining 40% are small commercial forests managed by private owners. Approximately 350 residential properties are located in the watershed, with approximately 200 "medium-sized," rural residential parcels between 0.5 and 5 acres. McLane Creek originates from numerous first-order, steep-gradient streams in Capitol Forest.

Deer Creek, located in Mason County, empties into the far north end of Oakland Bay. It contains the second largest drainage area of all the study sites (9,352 acres) with the smallest residential land area (665 acres; 7.1%). Deer Creek's primary land use is commercial timber with 7,400 acres of forestland, 90% of which is owned by three operations: Green Diamond Resource Company (5,742 acres), Manke Timber Company Inc. (445 acres), and Douglas Fir Christmas Tree LLC (350 acres). Of the 407 residential properties, approximately 55% are classified as "all other residential not elsewhere coded," 19% are medium residential parcels, and 15% are large parcels (greater than 5 acres). With 56 properties, Deer Creek has the most vacation home parcels of any of the four streams. The majority of these vacation homes are located around Benson Lake, where most of the creek's flow originates.

Kennedy Creek is located primarily in Thurston County (>90%) with a small portion of the drainage area in southeast Mason County (903 acres) and drains to the southern tip of Totten Inlet. Kennedy Creek is similar to Deer Creek in that it has a relatively large (compared to the other study sites) drainage area (12,253 acres), has a relatively small residential land area (7%), is dominated by forestland (84%), and originates from a lake surrounded by residences (Summit Lake). Kennedy Creek is unique in that there is virtually no commercial agriculture upstream of the study site (less than 5 acres). Of the 495 residential properties, 326 are small parcels (less than 0.5 acres). Unlike Deer Creek, there is only one parcel listed as a vacation home.

The Burley Creek site drains an area of approximately 6,403 acres in Kitsap County. Burley Creek has the largest residential land use of all four streams with over 3,800 acres and 2,400 residential parcels. The majority of these parcels are medium-sized with an average lot size of 1.73 acres. Burley Creek originates as a complex of wetlands north of Mullenix Road and flows approximately 5 miles to Burley Lagoon at the northern tip of Carr Inlet and Henderson Bay.

Methods

Study Design

EAP staff collected sediment and water quality data from four streams in Thurston, Mason, and Kitsap counties. EAP conducted ten sampling events from June to September 2010. Field data collection parameters included:

- In the water column
  - *In situ* streamflow, temperature, and conductivity measurements.
  - Continuous temperature measurements.
  - FC, TSS, turbidity, and dissolved oxygen (DO) samples.
  - Samples to determine the percentage of FC bound to suspended solids.

- In the streambed sediments
  - FC samples.
  - Total organic carbon (TOC) samples.
  - Continuous temperature measurements.

More detailed information on study design is available in the Quality Assurance (QA) Project Plan (Mathieu, 2010b).

Sampling Locations and Dates

Table 1 lists the four sampling locations chosen for the 2010 study. Figure 1 depicts the sampling locations and associated drainage basins.

Table 1. Sampling locations, including primary sampling sites and sites of interest.

Creek Name	EIM User Location ID	Study Location Name	Site Description	Latitude °N	Longitude °W
Primary Sampling Sites					
McLane	13-MCL-0.4	MCL	At Delphi Rd.; just upstream of Swift Ck.	47.03121	122.99112
Kennedy	14-KENN-0.4	KENN	~500 ft upstream of Old Olympic Hwy.	47.09449	123.09245
Deer	OAK DEE 0	DEER	Near mouth off E Gosser Rd.	47.26076	123.00902
Burley	15-BURL-0.5	BURL	~200 ft upstream of Spruce Rd. bridge	47.41492	122.63161
Additional Sites of Interest					
McLane	13-MCL-3.0	MCL2	At northernmost crossing of nature trail	47.00172	123.00915
McLane	SPS MCLA CK	MCL-flow	At Delphi Rd.; downstream of Swift Ck.	47.03175	122.99058
Swift	SCR	SWIFT	Swift Creek at mouth	47.03150	122.98980

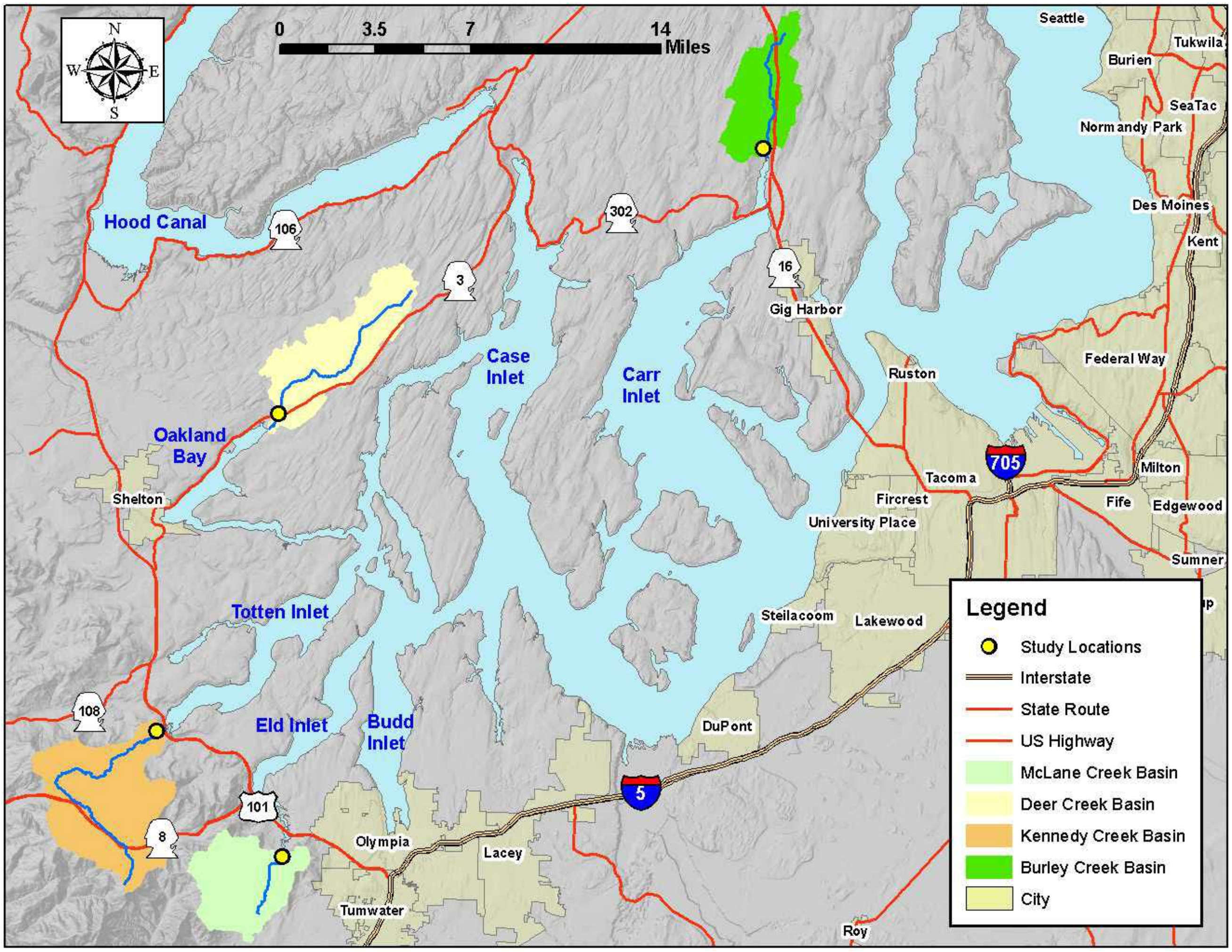

Figure 1. Study locations and associated drainage basins for the 2010 study.

Ecology field staff conducted 10 sampling events from June to September of 2010 (Table 2).

Table 2. Sampling dates.

Day of Week	Date (in 2010)
Monday	June 14
	June 28
Tuesday	July 6
Monday	July 19
	August 2
	August 16
	August 23
	August 30
	September 20
	September 27

Sampling and Measurement Procedures

Field sampling and measurement protocols followed Standard Operating Procedures (SOP) developed by EAP for Total Maximum Daily Load (TMDL) development (Table 3). Staff collected measurements for conductivity and temperature using a calibrated YSI® probe. Dissolved oxygen samples were collected by hand using a displacement sampler and analyzed using the Winkler titration method (APHA, 1998; Ward, 2007). Staff measured instantaneous flows with a Marsh McBirney® Flow-mate meter and used Hobo® Water Temp Pro V2 (Version 2) thermistors to record continuous temperature measurements.

Ecology analyzed the majority of FC samples using the membrane filtration (MF) method (Table 3); however, Ecology also analyzed a sub-set of duplicate FC samples using both the MF and a most-probable number (MPN) method (Table 3) for comparison with FC data from marine or estuarine waters, which are usually analyzed using an MPN method. Ecology typically uses the MF method for freshwater samples because the method is more precise and cost efficient.

Table 3. Sampling and measurement methods and protocols.

Parameter	Measurement/ Sample Type	Laboratory Method	SOP Number
FC - MF	Grab sample	SM 9222 D	EAP012 (Mathieu, 2006a); EAP015 (Joy, 2006)
FC - MPN	Grab sample	SM 9221 E2	EAP012 (Mathieu, 2006a); EAP015 (Joy, 2006)
FC - MF - centrifuge	Grab sample	Characklis et al., 2005	EAP012 (Mathieu, 2006a); EAP015 (Joy, 2006)
FC - MPN - sediment	Composite sample	SM 9221 E	EAP069 (Mathieu, 2010a – draft)
TOC - sediment	Composite sample	(PSEP, 1986) (PSEP, 1997)	EAP069 (Mathieu, 2010a – draft)
TSS	Grab sample	SM 2540 D	EAP015 (Joy, 2006)
Turbidity	Grab sample	SM 2130	EAP015 (Joy, 2006)
TSS - centrifuge	Grab sample	Characklis et al., 2005	EAP015 (Joy, 2006)
Dissolved oxygen	Displacement sample	SM 4500 OC	EAP035 (Mathieu, 2006b)
Continuous temperature	Hobo® Water Temp Pro V2	n/a	EAP044 (Bilhimer and Stohr, 2009)
Temperature and conductivity	YSI® probe	n/a	EAP010 (Ahmed, 2006)
Flow	Instantaneous	n/a	EAP024 (Sullivan, 2007)

Ecology's Manchester Environmental Laboratory followed standard analytical methods in their *Lab Users Manual* (MEL, 2008). The laboratory performed centrifuge analysis for FC and TSS following a method adapted from Characklis et al. (2005).

The QA Project Plan (Mathieu, 2010b) and Appendix B provide a more detailed description of QA and quality control (QC) methods.

Centrifuge Analysis

Ecology based the method for removing suspended matter from water samples on a similar method described in *Microbial Partitioning to Settleable Particles in Stormwater* prepared by Characklis et al. (2005).

Field staff collected duplicate FC water samples from each stream. After receiving the duplicate pair of samples, the laboratory:

- Centrifuged one sample (from each duplicate pair) to separate settleable solids according to methods described by Characklis et al. (2005).
- Analyzed the water from the centrifuged sample (with settleable solids removed) for FC using MF.
- Analyzed the other sample (of the duplicate pair) as a normal water sample for FC using MF without centrifuging.

Ecology then calculated the fraction of FC attached to settleable solids as the difference between the centrifuged and un-centrifuged samples. Ecology used the same method to analyze duplicate pairs of TSS samples as a QC measure. A low or non-detect TSS result in the centrifuged sample was considered indicative of effective removal of suspended solids from the water sample.

Quality Assurance Results

Overall, Ecology found the study data to be of acceptable quality and useable based on the study objectives. Some results were qualified based on failure to meet data quality objectives or other issues. A summary of data quality is provided below. Appendix B provides more detailed data quality results. In summary:

- The YSI 30 temperature and conductivity meter met all data quality criteria for end of the day checks against National Institute of Standards and Technology (NIST) thermometer and NIST-certified conductivity standards.
- All Hobo Water Temp Pro V2 thermistors readings fell within instrument specifications (±0.2 °C) when compared to a NIST-certified thermometer in both a room temperature and ice bath, post-deployment.
- The meter and probe (in situ) and deployed thermistor (continuous) water temperature results were within the instrument specifications (±0.2 °C) during all sample events for all sites. Sediment temperatures were within specifications for only 67% of measurements; however, the YSI 30 probe was not designed for use in sediment and may have needed a longer period of time to fully equilibrate. The sediment temperature results for the YSI probe were qualified as estimates.
- Field replicate samples for all parameters met their respective measurement quality objectives for precision. Field blanks for TSS, turbidity, FC, and TOC fell below the detection limit, with the exception of three TOC blanks where a very small amount of contamination was observed. The potential contamination was less than 0.001% of the sample dry weight, which was not large enough to affect the reported result values.
- The centrifuged TSS sample results fell below the detection limit on all samples processed by Ecology's Manchester Laboratory; these results indicate the method effectively removed suspended material from the FC samples.
- The project met the completeness goal of collecting and analyzing at least 95% of the data outlined in the QA Project Plan.
- Results of comparison of side-by-side water samples analyzed using the MF and MPN samples showed that the MF results were significantly correlated to the MPN results (r^2=0.87; $p<0.05$)(Figure B-1). MPN sample results displayed a positive bias when compared to the MF results.

Study Results

Ecology loaded all project data to its online Environmental Information Management (EIM) database. EIM also contains information about the study and sampling stations (including links to an online interactive map).

To access the data:

- Go to: www.ecy.wa.gov/eim/
- Click 'Search for data' link.
- Click 'Search by user study ID' link.
- Enter 'NMat0003' into the 'User Study ID' field.
- Click 'Results' link to view results online or 'Download' link to download a spreadsheet.

Data tables for the project are located in Appendix C.

For both sediment and water, McLane Creek (MCL) and Burley Creek (BURL) contained the highest geometric mean (GM) FC values, with lower GM values at Deer Creek (DEER) and Kennedy Creek (KENN) (Table 4). All four sites had GM sediment FC values approximately one order of magnitude greater than the corresponding GM water FC values (Figure 6). Figures 2-5 depict FC concentrations in the water and sediment for each sampling event at each site.

In a similar pattern to GM values for FC, MCL and BURL exhibited the highest mean total TSS and turbidity, with lower means for DEER and KENN (Table 4; Figure 6). Mean specific conductance was lowest at MCL (85.6 µmhos/cm) and highest at BURL (130.7 µmhos/cm).

Mean streamflow ranged from 8.1 cfs (MCL) to 29 cfs (DEER). Streamflow started relatively high at all sites in mid-June, steadily dropped through July and August, bottomed out in late August, and returned to near mid-June levels by late September. KENN displayed the largest range of flows during sampling (6 to 42 cfs), while BURL had the smallest range (14 to 23 cfs).

Table 4. Mean result values for water and sediment parameters.

Site	Sediment				Water									
	Solids[a]	Total Organic Carbon[b]	Temperature (°Celsius)	Fecal Coliform (FC) (MPN/100g dry weight)[c]	FC (cfu/100mL)[c]	FC-centrifuged (cfu/100mL)[c]	Total Suspended Solids (mg/L)	TSS-centrifuged (mg/L)	Turbidity (NTU)	Average Velocity (ft/sec)[d]	Flow (ft^3/sec)[d]	Temperature (°Celsius)	Specific Conductance (micromhos/cm)	Dissolved Oxygen (mg/L)
MCL	76.2%	2.72%	12.99	3536	221	177	8.0	0.8	7.4	0.91	8.1	13.09	85.6	8.89
KENN	87.1%	0.14%	13.17	324	38	24	1.4	0.1	1.1	0.94	18	13.15	86.1	9.57
DEER	86.3%	0.40%	12.91	298	33	29	2.5	0.2	1.7	1.61	29	12.88	92.2	9.79
BURL	88.1%	0.18%	11.89	1508	198	145	5.6	0.2	2.6	1.42	18	11.87	130.7	10.18

[a] percentage of sample wet weight.
[b] percentage of sample dry weight.
[c] geometric mean.

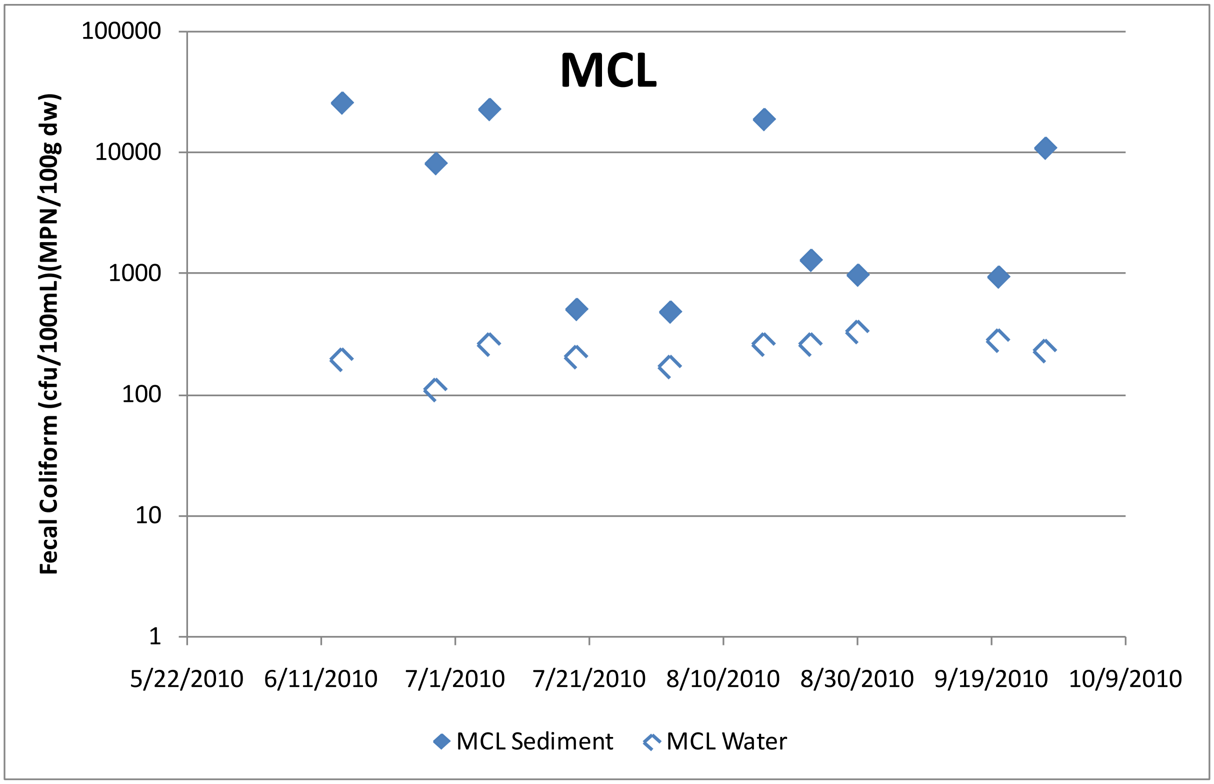

Figure 2. FC concentrations in the water and sediment at McLane Creek during the 2010 study.

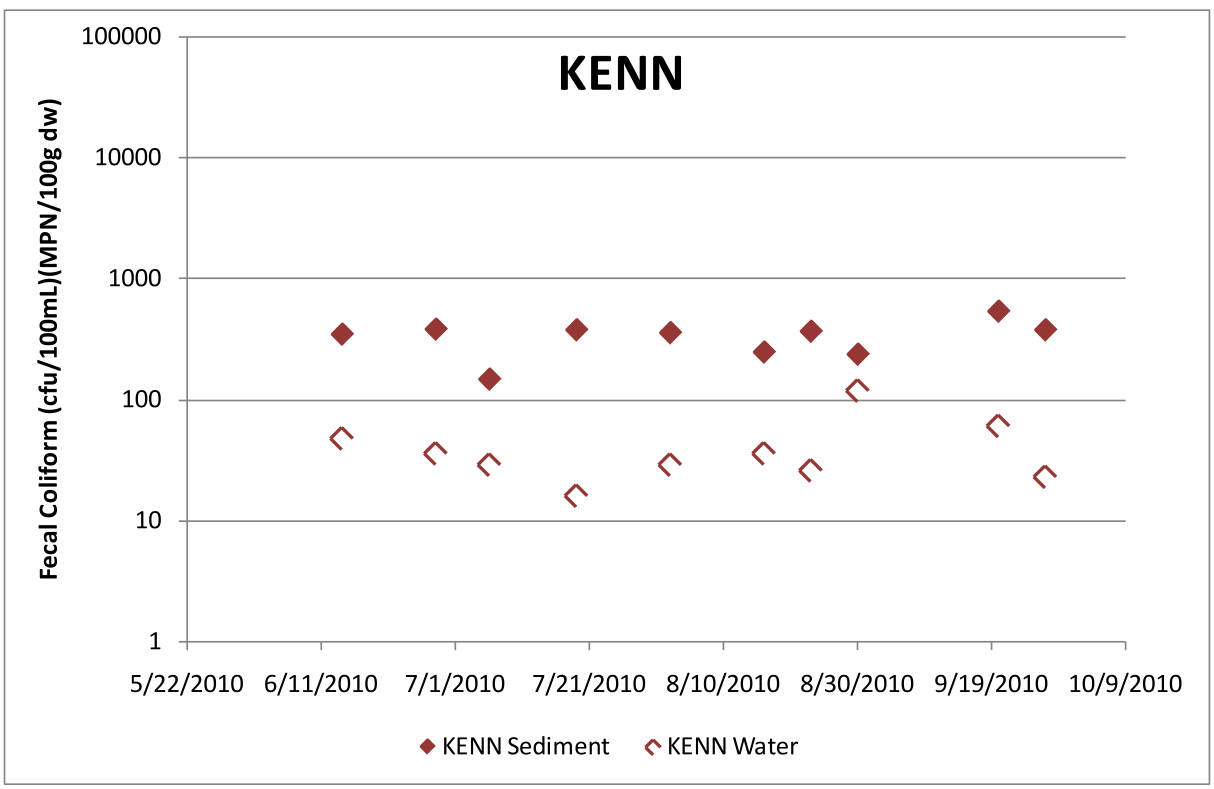

Figure 3. FC concentrations in the water and sediment at Kennedy Creek during the 2010 study.

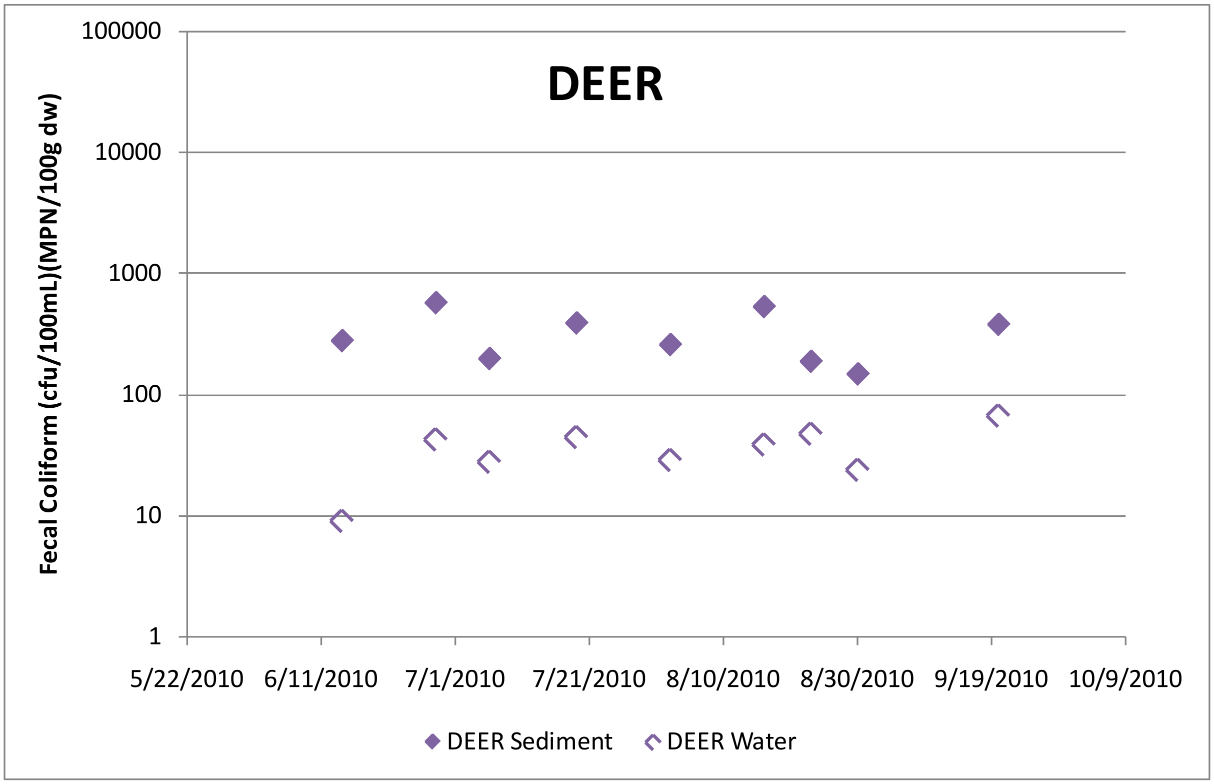

Figure 4. FC concentrations in the water and sediment at Deer Creek during the 2010 study.

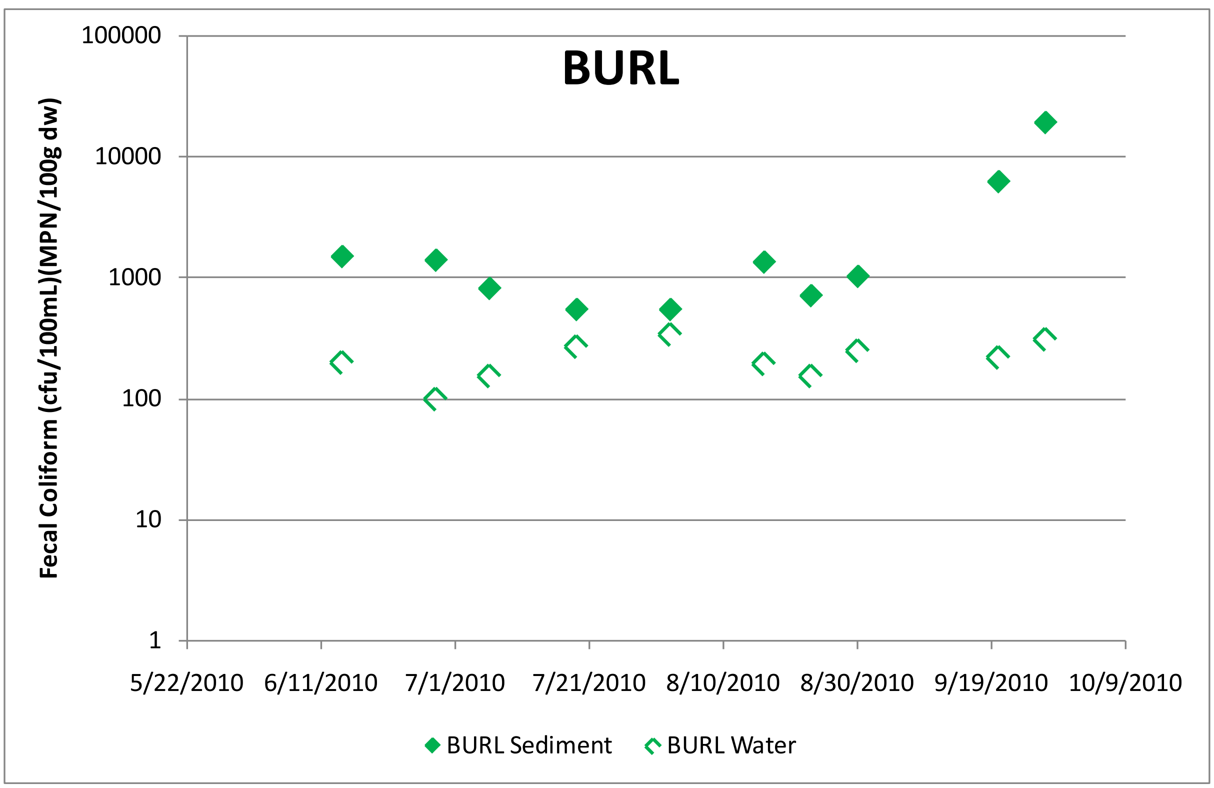

Figure 5. FC concentrations in the water and sediment at Burley Creek during the 2010 study.

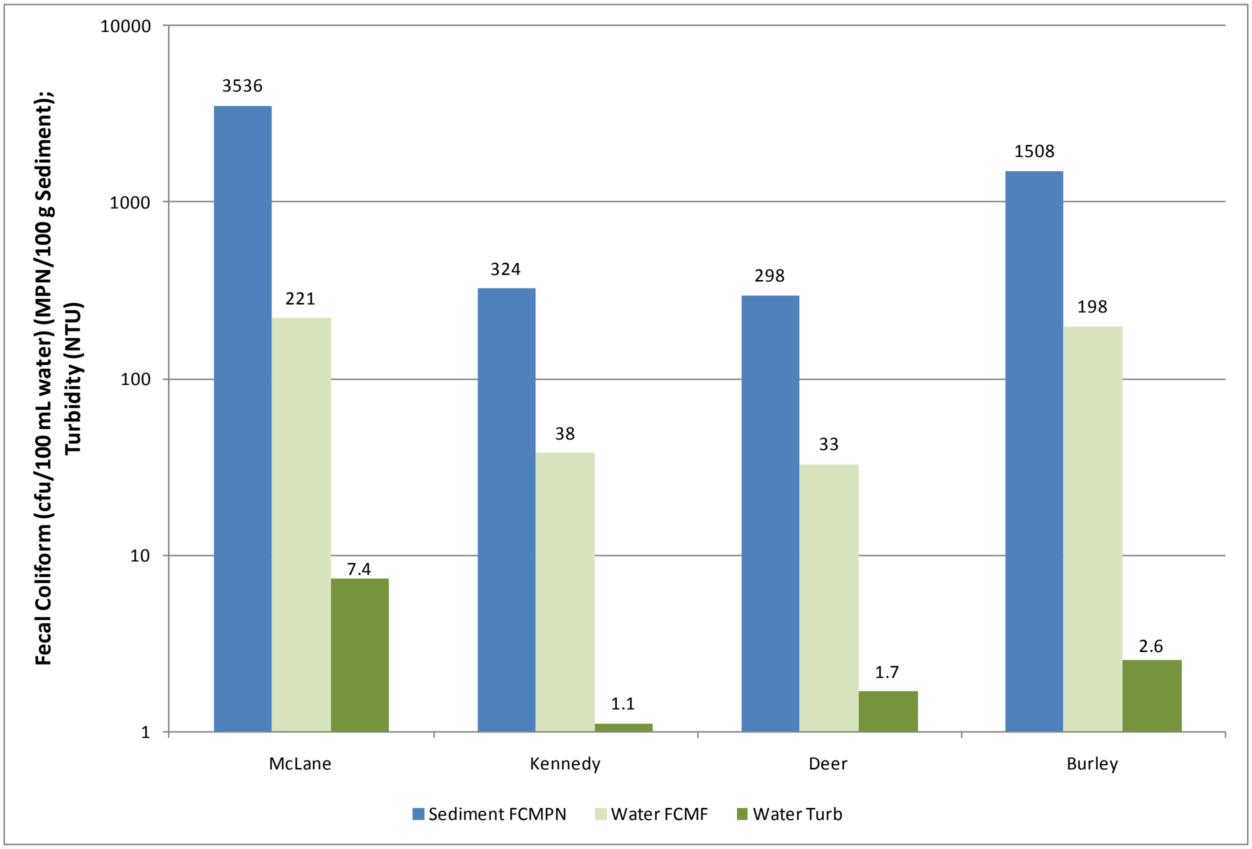

Figure 6. Mean (turbidity) and geometric mean (sediment and water FC) concentrations.

Figure 7 depicts the results of a sediment composition analysis for samples collected during the first sample event on June 14, 2010. The results show similar sediment composition at KENN, DEER, and BURL, while MCL sediments contained less gravel and more silt, clay, and water than the other three sites.

Figure 8 illustrates box plots of the fraction of FC bound to settleable solids for each site (total FC sample minus centrifuge FC sample divided by the total FC sample). Each box plot depicts the minimum, 25th percentile, median, 75th percentile, and maximum values.

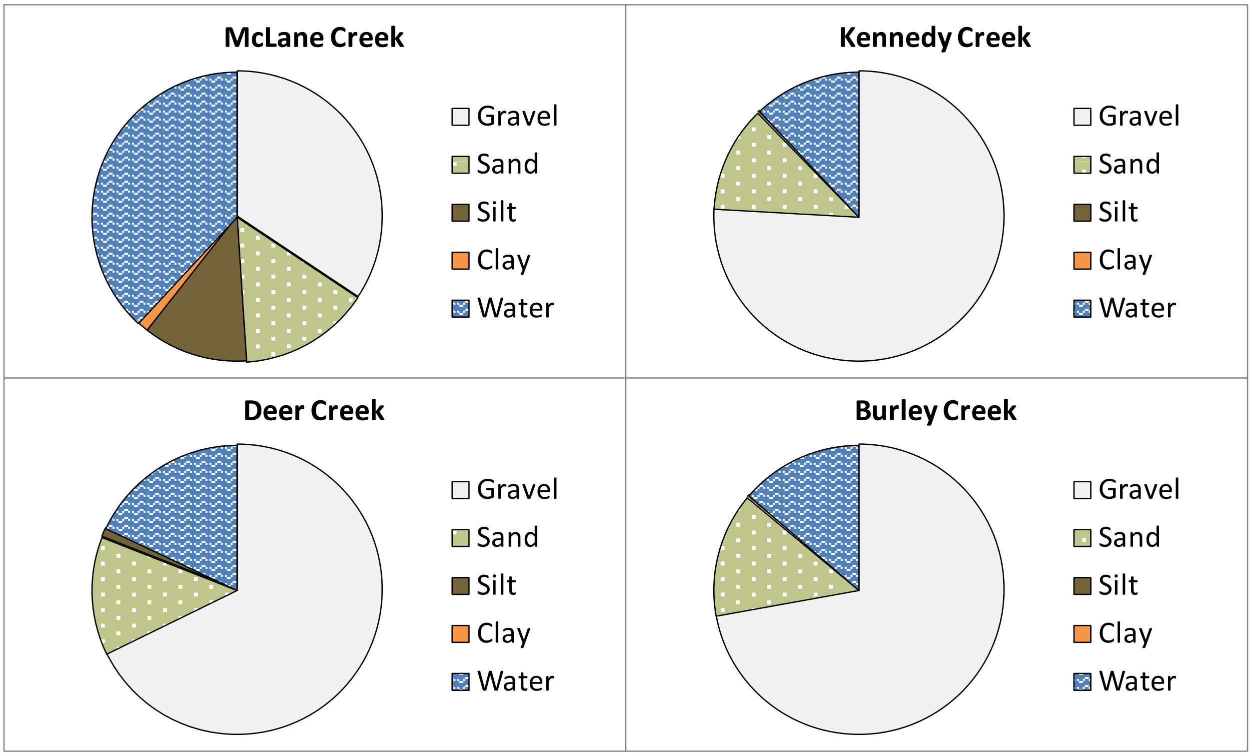

Figure 7. Sediment composition results (in percent of total weight) from grain size analysis of samples collected on June 14, 2010.

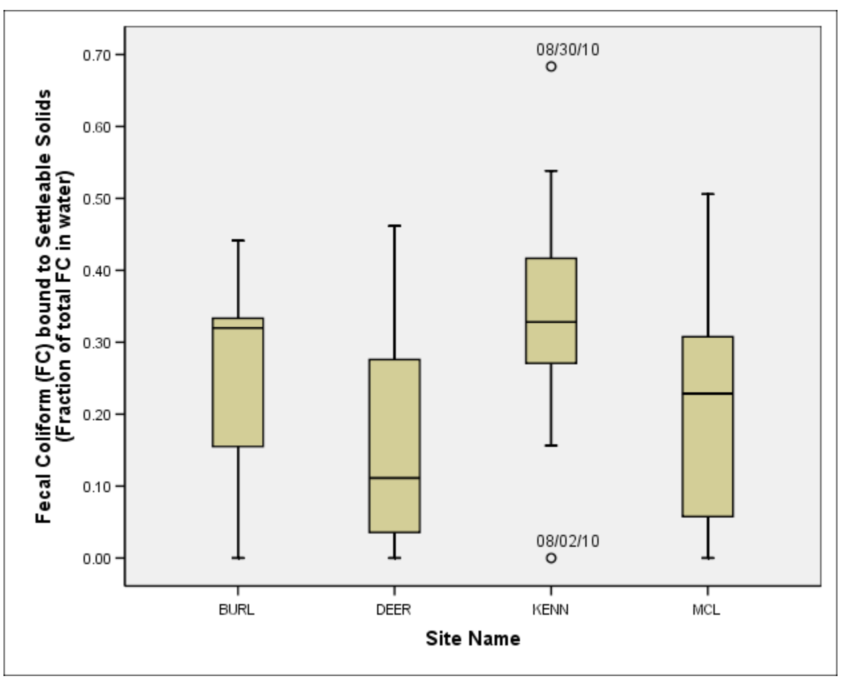

Figure 8. Box plots of the fraction of FC bound to settleable solids.

Discussion

FC in Bottom Sediments

None of the sites showed a significant correlation coefficient between sediment and water column FC concentrations (all p-values >0.05). However, the two sites with consistently high FC concentrations in the water, BURL and MCL, also had the highest geometric mean sediment concentrations and highest mean suspended sediment concentrations.

Of the four sites, MCL exhibited the highest sediment FC levels. The MCL sediment sampling reach was located in a silty, low velocity pool on McLane Creek. Deposition is likely responsible for the higher proportion of fine-grained sediment at this site and, likewise, the elevated sediment FC levels. Several factors likely increased FC survival at MCL (relative to the other three study sites) including finer sediment size, higher organic content, and higher clay content.

On September 27, 2010 Ecology collected samples at an additional site on McLane Creek in the McLane Creek nature preserve (MCL2). Results showed a noticeable increase in sediment FC, water FC, TSS, turbidity, conductivity, and temperature (as well as a decrease in DO) between the upstream (MCL2) and downstream (MCL) sites. These results indicate water quality may be heavily impacted within this stretch of the creek and warrant further investigation. Based on aerial photography and field observations, a large portion of this segment (and a drainage ditch that joins McLane Creek within it) contains very little riparian vegetation and livestock in close proximity to the stream.

BURL exhibited the second highest FC levels. On the first eight sample dates sediment FC levels held fairly constant, ranging from 550 to 1500 MPN/100 g sediment, whereas sediment FC was elevated on the last two sample dates in late September, possibly in response to recent rainfall. Sediment FC levels were 6200 MPN/100 g of sediment on 9/20/10 (0.77 inches rainfall in previous 24 hours) and 19000 MPN/100 g of sediment on 9/27/10 (0.61 in 24 hr). No significant rainfall fell prior to (preceding 24 hours) the first eight sample events.

Field staff observed that the fraction of sand in the bed sediments at BURL increased as the sampling transect moved upstream during the course of the study. In addition, the lab observed "fast settling sand" during the TSS analysis on multiple occasions for water samples collected at BURL.

As noted in the literature review, one study found that sand-dominated sediments resulted in the most resuspension of *E. coli* compared to other sediment compositions (Craig et al., 2001b). Determan et al. (1985b) characterized Burley Creek sediments at RM 0.6 as 'sand' and found that FC coliform increased 20% after artificial resuspension, although the experiment was only conducted once. Given these observations, Burley Creek sediments pose a significant risk of resuspending FC during a disturbance event.

FC in Settleable Solids

A paired Wilcoxon signed-rank test was performed for each site to test whether or not total and centrifuged FC concentrations were statistically different. At three of the four sites, FC concentrations were significantly lower after centrifuging (MCL p=0.04; KENN p=0.01; BURL p=0.01). Deer Creek was the only site without a significant decrease (p=0.19). This was likely due to samples from June 14 and September 20 where the result was slightly greater after centrifuging. When the test was re-run for July and August results only, a significant decrease was detected (p=0.03).

The average percent of FC attached to sediment for each site ranged from 17-34% (DEER=17%; MCL=21%; BURL=26%; KENN=34%). If mid-June and late-September are again removed from the Deer Creek results the average increases from 17 to 21%. These results were comparable to those of a North Carolina study, where the average percent of indicator organisms (FC, *E. coli*, and *Enterococci*) attached to sediment ranged from 20-35% during baseflow conditions (Characklis et al., 2005). Sediment-attached FC averaged 24%, 27%, and 33%, respectively, for the three sites monitored in the North Carolina study.

FC Fate and Transport During Summer Baseflow

The study results indicate that South Puget Sound lowland streams may contain more free-floating FC than sediment-attached FC in the water column during summer baseflow conditions; however, the study did find a significant number of sediment-bound FC in the water column. In addition, sediment-attached FC persists longer in the environment than unattached FC, particularly in the salt water environment. Increased survival, combined with faster settling rates, could lead to accumulation of sediment-attached FC at intertidal swimming beaches and shellfish harvesting areas. Theoretically, attached pathogens may pose a greater health risk (than unattached organisms) in these areas even though they make up a smaller fraction. Free-floating organisms typically have a very slow settling rate and a rapid die-off rate in saltwater.

The results did not suggest that FC in the sediment were more prevalent in warmer summer months than during the late spring or early fall; although without samples taken throughout the year, seasonal differences could not be tested. Sediment FC concentrations did not correlate directly to stream temperatures or flows and did not show a pattern of net increase (growth plus accumulation, minus die-off and resuspension) as the summer progressed.

The study did not segment or investigate specific sources in each watershed and thus could not attribute attached or unattached FC in each stream to specific land uses, failing septic systems, areas of livestock access, increased wildlife activity, or other sources. However, this study highlights additional tools and information for site specific investigation of high FC levels in regional streams with high summer bacteria concentrations.

For example, future investigations could collect bed sediment and suspended sediment FC samples upstream and downstream of areas with livestock access or observed wildlife activity. Ideally, the investigator would record observations about the number of animals and level of activity in the area over the course of the study. Field staff could collect samples after observed disturbance events or during specific times of day (for example, a fixed time after the hottest part of the day, depending on travel time).

Future studies might also use bed sediment samples from depositional areas to segment source of FC stormwater contamination. Given the ability of bed sediments to entrain FC and prolong their survival, samples could potentially be collected several days after a storm event.

Additionally, investigators could collect water samples to segment areas with vacation homes, parks, tourism-dependent businesses, and other areas where septic systems are used more frequently or exclusively in the summer.

Conclusions

Results of this 2010 study support the following conclusions:

- Results do not suggest a direct relationship between fecal coliform bacteria (FC) in the bottom sediments and the water column; however, an indirect relationship likely exists based on the observed relationship between average levels of FC in the water and sediment.
- Results do not suggest that FC concentrations in the sediment are higher in warmer summer months than during the late spring or early fall; nor did they show a pattern of increasing sediment bacteria concentrations as the summer progressed.
- The study found that a significant portion of FC in all four streams was attached to suspended sediment. Sediment-bound FC accounted for 17-34%, on average, of the total FC in each stream.
- Results indicate that South Puget Sound lowland streams may contain more free-floating FC than sediment-attached FC in the water column during summer baseflow conditions; however, sediment-bound FC may pose an equal or greater health risk to shellfish harvesting areas and recreational beaches.

Recommendations

- Given that significant portions of FC were attached to suspended solids, sediment transport and disturbance mechanisms within each watershed likely affect FC water concentrations downstream. A reduction of in-stream FC would be expected from implementing best management practices (BMPs) that:
  - Prevent turbid runoff from reaching waterbodies.
  - Remove suspended sediments from runoff in drainage ditches and stormwater outfalls.
  - Eliminate disturbance mechanisms (exclude livestock and vehicles from water).
  - Reduce streambank erosion (increase stability).
- Water quality researchers and managers should account for sediment-bound bacteria in future study design, computer modeling, and data analysis of regional streams. Particular attention should be given to streams with highly fluctuating water levels and streams with high turbidity.
- Future regional bacteria studies could include a sub-set of centrifuged samples to investigate if significant sediment-bound bacteria exist in other areas of the region and during different seasons. Some regional laboratories are capable of performing the centrifuge analysis.
- Public health officials should consider monitoring sediment FC levels in recreational waters where a potential for sediment disturbance exists including:
  - Shallow swimming holes and beaches.
  - Recreational shellfish harvesting areas.
  - Recreational areas with frequently windy conditions.

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Appendices

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Appendix A. Glossary, Acronyms, and Abbreviations

Glossary

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Geometric mean (GM): A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from 10 to 10,000 fold over a given period. The calculation is performed by either: (1) taking the nth root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Pathogen: Disease-causing microorganisms such as bacteria, protozoa, viruses.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Riparian: Relating to the banks along a natural course of water.

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Total suspended solids (TSS): The suspended particulate matter in a water sample as retained by a filter.

Turbidity: A measure of the amount of suspended silt or organic matter in water. High levels of turbidity can have a negative impact on aquatic life.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

BMP	Best management practice
BURL	Burley Creek
DEER	Deer Creek
DO	(See Glossary above)
EAP	Environmental Assessment Program
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
FC	Fecal coliform bacteria
GM	(See Glossary above)
KENN	Kennedy Creek
MCL	McLane Creek
MF	Membrane filtration
MPN	Most-probable number
NIST	National Institute of Standards Technology
QA	Quality assurance
QC	Quality control
SOP	Standard operating procedures
TMDL	(See Glossary above)
TOC	Total organic carbon
TSS	(See Glossary above)

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
ft	feet
g	gram, a unit of mass
mL	milliliters
NTU	nephelometric turbidity units
µg/L	micrograms per liter (parts per billion)

Appendix B. Detailed Quality Assurance Results

Overall data collected for the project was found to be of acceptable quality and useable based on the study objectives. Some results were qualified based on failure to meet data quality objectives or other issues. In summary:

- The YSI 30 temperature and conductivity meter met all data quality criteria for end-of-the-day checks against the NIST thermometer and certified conductivity standards (Table B-1).
- All Hobo Water Temp Pro V2 thermistors readings fell within instrument specifications (±0.2 °C) when compared to an NIST-certified thermometer in both a room temperature and ice bath, post-deployment.
- The meter and probe (in situ) and deployed thermistor (continuous) water temperature results were within the instrument specifications (±0.2 °C) during all sample events for all sites (Table B-2). Sediment temperatures were within specifications for only 67% of measurements; however, the YSI 30 probe was not designed for use in sediment and may have needed a longer period of time to fully equilibrate. The probe sediment temperature results were qualified in EIM.
- Field replicate samples for all parameters met their respective measurement quality objectives for precision (Table B-3). Field blanks for TSS, turbidity, FC, and TOC fell below the detection limit, with the exception of three TOC blanks where a very small amount of contamination was observed (Table B-4). The potential contamination was less than 0.001% of the sample dry weight, which was not large enough to affect the reported result values.
- The centrifuged TSS sample results fell below the detection limit on all samples processed by Ecology's Manchester Environmental Laboratory; these results indicate the method effectively removed suspended material from the FC samples.
- The project met the completeness goal of collecting and analyzing at least 95% of the data outlined in the QA Project Plan (Table B-5).
- Results of comparison of side-by-side water samples analyzed using the MF and MPN samples showed that the MF results were significantly correlated to the MPN results (r^2=0.87; $p<0.05$)(Figure B-1). MPN sample results displayed a positive bias when compared to the MF results.

Table B-1. End-of-the-day check results for the field meter compared to the NIST-certified thermometer and conductivity standards.

Temperature (degrees)					Specific Conductance (micromhos/cm)						
Date	YSI	NIST	ABS Diff	Result	YSI	Zero	ABS Diff	YSI	NIST	ABS Diff %	Result
6/15/2008	22.2	22.3	0.1	Pass				102.9	100	2.9%	Pass
6/28/2010	22.7	22.6	0.1	Pass	1.2	0	1.2	101.7	100	1.7%	Pass
7/6/2010	22.7	22.6	0.1	Pass	0.8	0	0.8	99.3	100	0.7%	Pass
7/19/2010	22.1	22.1	0	Pass	0.8	0	0.8	100.7	100	0.7%	Pass
8/2/2010	22.0	22.0	0	Pass	0.8	0	0.8	99.3	100	0.7%	Pass
8/16/2010	22.0	22.0	0	Pass	0.7	0	0.7	99.7	100	0.3%	Pass
8/23/2010	23.2	23.2	0	Pass	0.7	0	0.7	99.5	100	0.5%	Pass
8/30/2010	22.0	22.0	0	Pass	0.8	0	0.8	100.6	100	0.6%	Pass
9/20/2010	22.1	22.1	0	Pass	0.7	0	0.7	100.4	100	0.4%	Pass
9/27/2010	22.0	22.0	0	Pass	0.6	0	0.6	99.5	100	0.5%	Pass

YSI: YSI 30 Conductivity Temperature Meter/Probe.
NIST: National Institute of Standards Technology thermometer or standard.
ABS Diff: Absolute value of the difference.

Table B-2. Field temperature result comparison between deployed loggers and field meter.

Site ID	Date, Time	Matrix	Hobo Temp	YSI Temp	Abs Diff	Matrix	Hobo Temp	YSI Temp	Abs Diff
MCL	6/14/10, 10:00	Water	11.01	11.00	0.01	Sediment	10.64	10.80	0.16
MCL	6/28/10, 9:00	Water	13.06	13.10	0.04	Sediment	11.98	12.40	0.42
MCL	7/6/10, 9:00	Water	11.27	11.30	0.03	Sediment	11.35	11.40	0.05
MCL	7/19/10, 8:30	Water	12.44	12.50	0.06	Sediment	12.44	12.40	0.04
MCL	8/2/10, 9:00	Water	13.91	14.00	0.09	Sediment	13.57	13.90	0.33
MCL	8/16/10, 9:00	Water	15.75	15.80	0.05	Sediment	14.86	15.10	0.24
MCL	8/23/10, 9:00	Water	12.85	12.90	0.05	Sediment	13.47	13.40	0.07
MCL	8/30/10, 8:30	Water	12.58	12.60	0.02	Sediment	12.99	13.00	0.01
MCL	9/20/10, 8:30	Water	14.00	14.00	0.00	Sediment	13.76	13.90	0.14
MCL	9/27/10, 8:30	Water	13.69	13.70	0.01	Sediment	13.57	13.60	0.03
				median =	**0.03**			**median =**	**0.14**
Kenn	6/14/10, 10:30	Water	11.30	11.50	0.20	Sediment	11.30	11.50	0.20
Kenn	6/28/10, 10:30	Water	13.06	13.00	0.06	Sediment	13.06	13.10	0.04
Kenn	7/6/10, 10:00	Water	12.27	12.20	0.07	Sediment	12.27	12.30	0.03
Kenn	7/19/10, 10:00	Water	12.73	12.70	0.03	Sediment	12.75	12.70	0.05
Kenn	8/2/10, 10:00	Water	13.76	13.70	0.06	Sediment	13.74	13.70	0.04
Kenn	8/16/10, 10:30	Water	15.01	15.00	0.01	Sediment	14.96	15.00	0.04
Kenn	8/23/10, 10:00	Water	13.11	13.10	0.01	Sediment	13.09	13.10	0.01
Kenn	8/30/10, 10:00	Water	12.92	12.80	0.12	Sediment	12.87	12.80	0.07
Kenn	9/20/10, 10:00	Water	13.76	13.80	0.04	Sediment	13.79	13.80	0.01
				median =	**0.06**			**median =**	**0.04**
Deer	6/14/10, 12:30	Water	12.80	12.70	0.10	Sediment	12.65	12.70	0.05
Deer	6/28/10, 12:00	Water	13.76	13.70	0.06	Sediment	13.62	13.60	0.02
Deer	7/6/10, 11:00	Water	11.98	11.90	0.08	Sediment	11.81	11.90	0.09
Deer	7/19/10, 11:00	Water	12.36	12.30	0.06	Sediment	12.27	12.40	0.13
Deer	8/2/10, 11:30	Water	13.31	13.10	0.20	Sediment	13.06	13.20	0.14
Deer	8/16/10, 11:30	Water	14.55	14.60	0.05	Sediment	14.19	14.70	0.51
Deer	8/23/10, 11:00	Water	12.22	12.20	0.02	Sediment	11.98	12.20	0.22
Deer	8/30/10, 11:00	Water	11.88	11.80	0.08	Sediment	11.69	11.90	0.21
Deer	9/20/10, 11:00	Water	13.67	13.60	0.07	Sediment	13.38	13.60	0.22
				median =	**0.07**			**median =**	**0.14**
BURL	6/14/10, 14:00	Water	11.69	11.70	0.01	Sediment	11.30	11.60	0.30
BURL	6/28/10, 13:30	Water	12.29	12.20	0.09	Sediment	11.76	12.20	0.44
BURL	7/6/10, 12:30	Water	11.37	11.20	0.17	Sediment	10.81	11.00	0.19
BURL	7/19/10, 12:30	Water	11.44	11.50	0.06	Sediment	11.35	11.40	0.05
BURL	8/2/10, 13:00	Water	11.86	11.80	0.06	Sediment	11.69	11.80	0.11
BURL	8/23/10, 13:00	Water	11.61	11.60	0.01	Sediment	11.25	11.60	0.35
BURL	8/30/10, 12:30	Water	11.08	11.10	0.02	Sediment	10.83	11.80	0.97
BURL	9/20/10, 12:30	Water	12.99	12.90	0.09	Sediment	12.80	12.90	0.10
				median =	**0.06**			**median =**	**0.25**

YSI: YSI 30 Conductivity Temperature Meter/Probe.
Hobo: Hobo Water Temp Pro V2 temperature logger.
ABS Diff: Absolute value of the difference.

Table B-3. Field replicate results for all sample parameters compared to study measurement quality objectives (MQO).

Analysis	Method/ equipment	Field replicate MQO (median)	Field replicate (median RSD)	Outcome
FC-MPN-sediment	MPN 9221 E2	50% of replicate pairs < **50%** RSD 90% of replicate pairs <**100%** RSD	50th= **29.1%** 90th= **64.9%**	Pass
FC-MF	SM 9222D	50% of replicate pairs < **20%** RSD 90% of replicate pairs <**50%** RSD[1]	50th= **10.9%** 90th= **39.7%**	Pass
FC-MF-centrifuged	SM 9222D + Characklis	50% of replicate pairs < **50%** RSD 90% of replicate pairs < **90%** RSD[1]	50th= **11.3%** 90th= **26.1%**	Pass
Turbidity	SM 2130	**15%** RSD[2]	**5.4%**	Pass
TSS	SM 2540D	**15%** RSD[2]	**4.4%**	Pass
TSS-centrifuged	SM 9222D + Characklis	**15%** RSD	n/a	Pass[3]
Percent Solids-Sediment	SM 2130	none set	**1.2%**	Pass
Percent TOC-Sediment	SM 2540D	none set	**31.7%**	Pass
Dissolved Oxygen	SM 4500OC	**2.5%** RSD	**0.4%**	Pass

[1] Replicate pairs with a mean of less than or equal to 20 cfu/100 mL were evaluated separately.
[2] Replicate results with a mean of less than or equal to 5X the reporting limit were evaluated separately; the median. RSD was the same with or without these results included.
[3] All replicate pairs were below the reporting limit.
RSD: Relative standard deviation

Table B-4. Field blank results for the 2010 study.

Collection Date	Time	Parameter	Result	UOM	Below detection limit?	Method
6/14/2010	12:30	Fecal Coliform	1	#/100mL	Yes	SM9222D
6/14/2010	12:30	Fecal Coliform	1	#/100mL	Yes	SM9222D
6/28/2010	10:00	Fecal Coliform	1	#/100mL	Yes	SM9222D
6/28/2010	10:00	Fecal Coliform	1	#/100mL	Yes	SM9222D
7/6/2010	8:30	Fecal Coliform	1	#/100mL	Yes	SM9222D
7/6/2010	8:30	Fecal Coliform	3	#/100mL	Yes	SM9222D
7/19/2010	10:00	Fecal Coliform	3	#/100mL	Yes	SM9222D
7/19/2010	10:00	Fecal Coliform	3	#/100mL	Yes	SM9222D
8/2/2010	8:30	Fecal Coliform	3	#/100mL	Yes	SM9222D
8/16/2010	8:45	Fecal Coliform	3	#/100mL	Yes	SM9222D
8/16/2010	8:45	Fecal Coliform	3	#/100mL	Yes	SM9222D
8/23/2010	8:13	Fecal Coliform	1	#/100mL	Yes	SM9222D
8/30/2010	8:15	Fecal Coliform	1	#/100mL	Yes	SM9222D
9/20/2010	9:55	Fecal Coliform	1	#/100mL	Yes	SM9222D
9/27/2010	11:00	Fecal Coliform	3	#/100mL	Yes	SM9222D
6/14/2010	12:30	Total Organic Carbon	1	mg/L	Yes	SM5310B
6/28/2010	10:00	Total Organic Carbon	1	mg/L	Yes	SM5310B
7/6/2010	8:30	Total Organic Carbon	1	mg/L	Yes	SM5310B
7/19/2010	10:00	Total Organic Carbon	1.1	mg/L	**No**	SM5310B
8/2/2010	8:30	Total Organic Carbon	1	mg/L	Yes	SM5310B
8/16/2010	8:45	Total Organic Carbon	1	mg/L	Yes	SM5310B
8/23/2010	8:13	Total Organic Carbon	1.1	mg/L	**No**	SM5310B
8/30/2010	8:15	Total Organic Carbon	1.4	mg/L	**No**	SM5310B
9/20/2010	9:55	Total Organic Carbon	1	mg/L	Yes	SM5310B
6/14/2010	12:30	Total Suspended Solids	1	mg/L	Yes	SM2540D
6/28/2010	10:00	Total Suspended Solids	1	mg/L	Yes	SM2540D
7/6/2010	8:30	Total Suspended Solids	1	mg/L	Yes	SM2540D
7/19/2010	10:00	Total Suspended Solids	1	mg/L	Yes	SM2540D
8/2/2010	8:30	Total Suspended Solids	1	mg/L	Yes	SM2540D
8/16/2010	8:45	Total Suspended Solids	1	mg/L	Yes	SM2540D
8/23/2010	8:13	Total Suspended Solids	1	mg/L	Yes	SM2540D
8/30/2010	8:15	Total Suspended Solids	1	mg/L	Yes	SM2540D
9/20/2010	9:55	Total Suspended Solids	1	mg/L	Yes	SM2540D
9/27/2010	11:00	Total Suspended Solids	1	mg/L	Yes	SM2540D
6/14/2010	12:30	Turbidity	0.5	NTU	Yes	SM2130
6/28/2010	10:00	Turbidity	0.5	NTU	Yes	SM2130
7/6/2010	8:30	Turbidity	0.5	NTU	Yes	SM2130
7/19/2010	10:00	Turbidity	0.5	NTU	Yes	SM2130
8/2/2010	8:30	Turbidity	0.5	NTU	Yes	SM2130

Shaded rows indicate field blanks with values above the reporting limit.

Table B-5 contains completeness results for all sample and measurement parameters. Field staff did not collect samples or measurements at Deer Creek on the final survey date (September 27, 2010) due to adverse tidal conditions during the sampling window. Manchester Laboratory did not analyze percent TOC from the sediment samples collected on June 28, 2010 due to an omission on the analysis requested paperwork. Field staff did not collect six DO samples over the course of project due to time constraints. This data loss was deemed acceptable as DO was not a parameter of concern. The project had a 98% completion rate for all bacteria and suspended sediment parameters.

Table B-5. Completeness results for all sample and measurement parameters.

	% Solids	% TOC	Grain Size	FCMPN	FCMF	FCMF-cent	TSS	TSS-cent	Turb
Sample Count =	39	34	4	39	39	39	39	39	39
Completeness =	98%	85%	100%	98%	98%	98%	98%	98%	98%
	Flow	Temp	SpCond	DO	Temp				All
Measure Count =	38	38	38	33	38	Total Count =			496
Completeness =	95%	95%	95%	83%	95%	Completeness=			95%

Figure B-1 displays the results of the MF vs. MPN comparison between FC water samples.

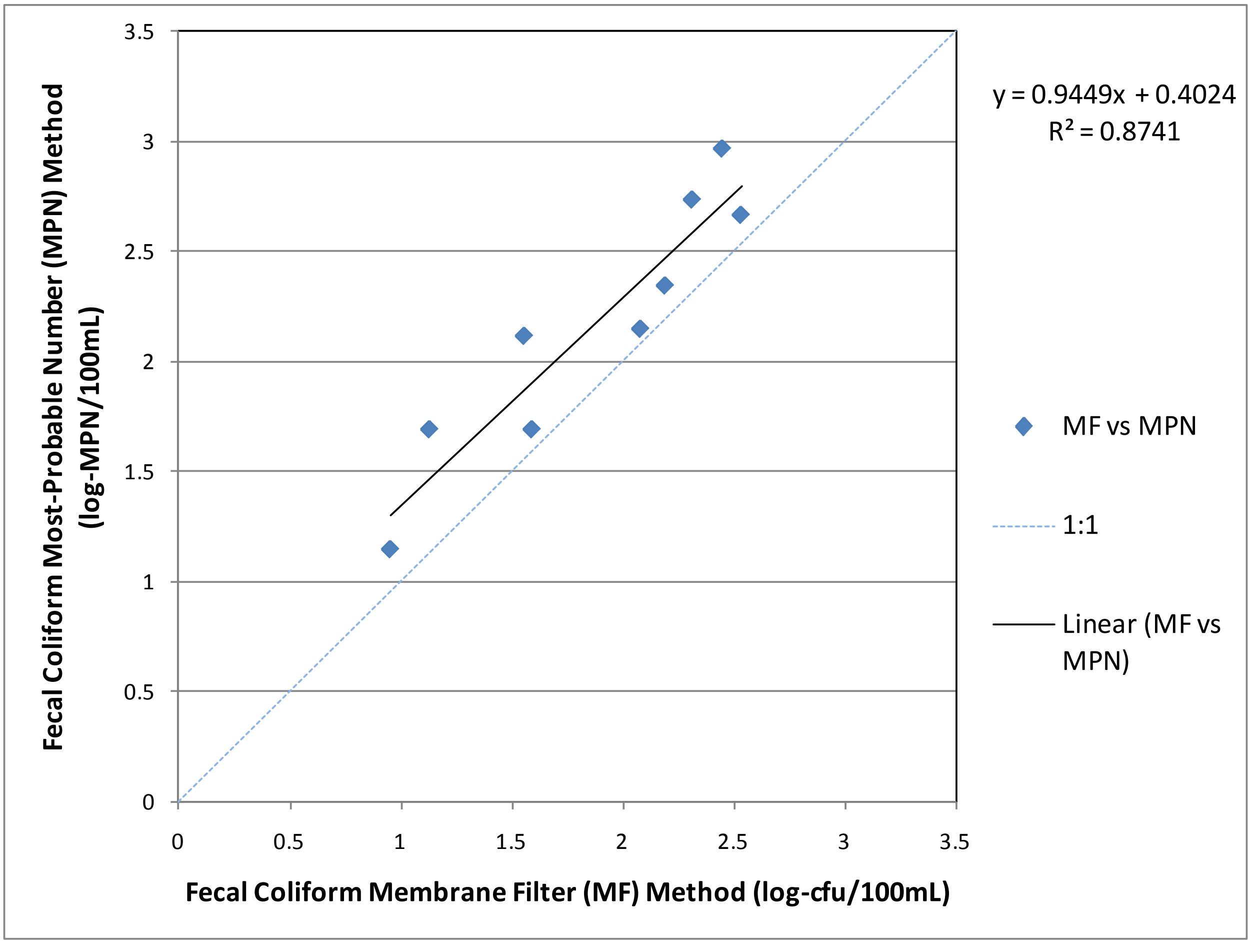

Figure B-1. MF vs. MPN water samples results for method comparison.

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Appendix C. Sample and Field Measurement Result Tables

Table C-1 contains results for samples collected during the 2010 study, including field replicate results in the QA column.

Table C-1. Results for samples collected during the 2010 study.

			Sediment						Water													
Site	Date	Time	% Solids	QA	% TOC	QA	FC-MPN	QA	FCMF	QA	FCMF-cent	QA	TSS		QA		TSS-cent		QA		Turb	QA
MCL	6/14/2010	9:45:00	61.9		2.79		26000		240	150	150	100	4		3		1	U	1	U	4.1	3.8
MCL	6/28/2010	9:00:00	65.8				8200		110		99		3				2	U			3.5	
MCL	7/6/2010	9:00:00	68.7		2.68		23000		260		150	210	3				2	U	2	U	3.6	
MCL	7/19/2010	8:30:00	82.6	79.4	1.70	3.09	400	620	230	180	150	150	3		3		1	UJ	2	UJ	3.5	3.6
MCL	8/2/2010	8:45:00	84.1	85.3	3.51	1.16	580	390	170		84		12				1	U			11	
MCL	8/16/2010	9:15:00	82.1		3.54		19000		260		230	260	11				2	U	2	U	9.3	
MCL	8/23/2010	8:53:00	84.7		3.99		1300		260		310		30				7				25	
MCL	8/30/2010	9:00:00	80.2		2.18		980		330		290	210	4				1	U	1	U	4.9	
MCL	9/20/2010	8:40:00	67.2	78.4	2.20	2.24	490	1400	280		220	220	4		3		1	U	2	U	4	3.7
MCL	9/27/2010	8:35:00	80.2		2.39		11000		230		220	300	5				1	U	1	U	5.1	
MCL2	9/27/2010	9:50:00	85.9	87.7	0.12	0.19	1300	730	17	10	10	17	1		1	U	1	U	1	U	0.5	0.5
KENN	6/14/2010	10:35:00	88.0		0.37		350		48		35		2				1	U			1.2	
KENN	6/28/2010	10:30:00	85.8	85.1			380	390	35	37	22	26	1	U	1	U	2	U	2	U	0.9	1.1
KENN	7/6/2010	10:00:00	88.2		0.10		150		29		20		2				2	U			1.2	
KENN	7/19/2010	10:15:00	87.3		0.10		380		16		15	12	2				2	UJ	2	UJ	0.6	
KENN	8/2/2010	10:05:00	85.4		0.14		360		29		30		1	U			1	U			1	
KENN	8/16/2010	10:20:00	87.8		0.13		250		36		21		1	U			2	U			0.5	
KENN	8/23/2010	10:00:00	88.8		0.11		370		26		12		1	U			1	U			0.6	
KENN	8/30/2010	10:00:00	87.9		0.11		240		120		38		2				1	U			1.5	
KENN	9/20/2010	9:55:00	85.2		0.14		540		61		41		3				1	U			2.8	
KENN	9/27/2010	11:20:00	87.2		0.10		380		23		340		1				1	U			0.8	
DEER	6/14/2010	12:30:00	82.0	83	0.49		280	280	7	11	15		2				2	U			1.3	
DEER	6/28/2010	12:00:00	86.5				570		43		27		2				2	U			1.5	
DEER	7/6/2010	11:00:00	86.7		0.19		200		28		27		1	U			1	U			1.4	
DEER	7/19/2010	11:10:00	85.0		0.76		390		45		40		2				2	UJ			1.4	
DEER	8/2/2010	11:30:00	87.0		0.24		260		29		21		2				1	U			2.1	
DEER	8/16/2010	11:35:00	86.8		0.27		530		39		21		2				2	U			1.8	

			Sediment						Water											
Site	Date	Time	% Solids	QA	% TOC	QA	FC-MPN	QA	FCMF	QA	FCMF-cent	QA	TSS	QA		TSS-cent	QA		Turb	QA
DEER	8/23/2010	11:20:00	88.0		0.24		190		48		40	40	2			1 U	1	U	1.3	
DEER	8/30/2010	11:20:00	88.1		0.48		150		24		22		2			1 U			1.6	
DEER	9/20/2010	11:20:00	86.1		0.50		380		68		84		5			1 U			2.8	
BURL	6/14/2010	14:15:00	86.4				1500		200		120		5 J			1 U			2.8	
BURL	6/28/2010	13:20:00	88.3				1400		100		92	77	5 J			2 U	2	U	2.9	
BURL	7/6/2010	12:25:00	87.0	87.3	0.11	0.10	910	730	150	160	130	88	5	5		2 U	2	U	2.2	2.2
BURL	7/19/2010	12:40:00	88.8		0.13		550		270		180		5			2 UJ			2.2	
BURL	8/2/2010	13:00:00	88.7		0.11		550		340		200	180	5			2 U	1	U	2.3	
BURL	8/16/2010	13:25:00	86.5	89.2	0.18	0.18	1500	1200	180	210	140	120	8	8		2 U	2	U	3.6	3.3
BURL	8/23/2010	13:15:00	90.1	88.3	0.14	0.22	540	890	210	100	160	160	4	4		1 U	1	U	1.4	1.6
BURL	8/30/2010	12:48:00	86.2	87.5	0.37	0.11	1500	560	240	260	200	140	4	4		2 U	2	U	1.8	1.7
BURL	9/20/2010	12:40:00	86.7		0.21		6200		220		220	210	8 J			1 U	2	U	3.5	
BURL	9/27/2010	13:10:00	91.3		0.25		19000		310		23		6 J			1 U			3.0	

Table C-2 contains results for all field measurements taken during the 2010 study.

Table C-2. Results for all field measurements taken during the 2010 study.

			Water					Sediment	Rainfall	
Site	Date	Time	Avg Vel.	Flow(cfs)	Temp	SpCond	DO	Temp	7 day	24 hr
MCL	6/14/2010	9:45:00	1.6	20	11.0	75.5		10.8	0.68	0
MCL	6/28/2010	9:00:00	1.3	13.5	13.1	80	8.95	12.4	0	0
MCL	7/6/2010	9:00:00	1.2	11	11.3	81	10.6	11.4	0.16	0
MCL	7/19/2010	8:30:00	0.85	6.2	12.5	85	9.9	12.4	0	0
MCL	8/2/2010	8:45:00	0.78	5.5	14.0	86.9	8.9	13.9	0	0
MCL	8/16/2010	9:15:00	0.56	3.7	15.8	90.5	8.2	15.1	0.01	0.01
MCL	8/23/2010	8:53:00	0.46	3	12.9	90.1	8.9	13.4	0	0
MCL	8/30/2010	9:00:00	0.48	3	12.6	90.4	7.3	13	0	0
MCL	9/20/2010	8:40:00	0.92	8	14.0	87.1	8.57	13.9	4.19	0.1
MCL	9/27/2010	8:35:00	0.91	7.5	13.7	89.1	8.65	13.6	0.82	0.31
MCL2	9/27/2010	9:50:00	0.41	2.7	12.8	72.9	9.7	12.8	0.82	0.31
KENN	6/14/2010	10:35:00	1.3	42	11.5	72.3		11.5	0.55	0
KENN	6/28/2010	10:30:00	1.2	29	13.0	77.4	8.75	13.1	0.01	0

			Water					Sediment	Rainfall	
Site	Date	Time	Avg Vel.	Flow(cfs)	Temp	SpCond	DO	Temp	7 day	24 hr
KENN	7/6/2010	10:00:00	1.2	29	12.2	74.4	10.25	12.3	0.29	0
KENN	7/19/2010	10:15:00	0.72	12	12.7	86.8	9.9	12.7	0	0
KENN	8/2/2010	10:05:00	0.71	11	13.7	90.4	9.75	13.7	0	0
KENN	8/16/2010	10:20:00	0.77	6.3	15.0	93.1	9.85	15	0.01	0.01
KENN	8/23/2010	10:00:00	0.66	5.3	13.1	95		13.1	0	0
KENN	8/30/2010	10:00:00	0.78	5.9	12.8	95.8	9.25	12.8	0	0
KENN	9/20/2010	9:55:00	1.1	27	13.8	84.3	9.5	13.8	3.33	0.17
KENN	9/27/2010	11:20:00	0.95	14	13.7	91.2	9.3	13.7	1.08	0.58
DEER	6/14/2010	12:30:00	1.7	32	12.7	85.6		12.7	0.42	0
DEER	6/28/2010	12:00:00	1.7	36	13.7	89.5	8	13.6	0.01	0
DEER	7/6/2010	11:00:00	1.8	31	11.9	88	10.85	11.9	0.42	0
DEER	7/19/2010	11:10:00	1.7	27	12.3	93.6	10.2	12.4	0	0
DEER	8/2/2010	11:30:00	1.5	25	13.1	92.5	10	13.2	0	0
DEER	8/16/2010	11:35:00	1.4	22	14.6	105	9.95	14.7	0.01	0
DEER	8/23/2010	11:20:00	1.3	19	12.2	95.9	10.22	12.2	0	0
DEER	8/30/2010	11:20:00			11.8	94.9	10.03	11.9	0	0
DEER	9/20/2010	11:20:00	1.8	42	13.6	85	9.05	13.6	2.46	0.24
BURL	6/14/2010	14:15:00	1.6	21	11.7	131.2		11.6	0.4	0
BURL	6/28/2010	13:20:00	1.6	20	12.2	132.2	9.85	12.2	0.03	0
BURL	7/6/2010	12:25:00	1.6	20	11.2	130	9.9	11	0.29	0.01
BURL	7/19/2010	12:40:00	1.4	18	11.5	131.2	10.7	11.4	0.01	0
BURL	8/2/2010	13:00:00	1.3	16	11.8	130.8	10.35	11.8	0	0
BURL	8/16/2010	13:25:00	1.2	13					0.04	0
BURL	8/23/2010	13:15:00	1.1	14	11.6	134.5	10.5	11.6	0	0
BURL	8/30/2010	12:48:00	1.2	14	11.1	130.6	10.5	11.8	0	0
BURL	9/20/2010	12:40:00	1.6	22	12.9	126.5	9.8	12.9	2.73	0.77
BURL	9/27/2010	13:10:00	1.6	23	12.8	129.3	9.8	12.7	1.06	0.61

Table C-3 contains the weight for each particle size class and water for sediment samples collected on June 14, 2010.

Table C-3. Weight for each particle size class and water for sediment samples collected on June 14, 2010.
Unit of measurement = grams.

Site	Gravel	Sand	Silt	Clay	Water	Total
MCL	20.503	8.734	6.960	0.760	22.746	59.703
KENN	58.188	9.070	0.135	0.085	9.202	76.680
DEER	56.600	10.998	0.775	0.110	15.033	83.516
BURL	66.346	12.741	0.210	0.045	12.594	91.935

Figures C1 through C9 contain continuous water and sediment temperatures for all sites in the 2010 study.

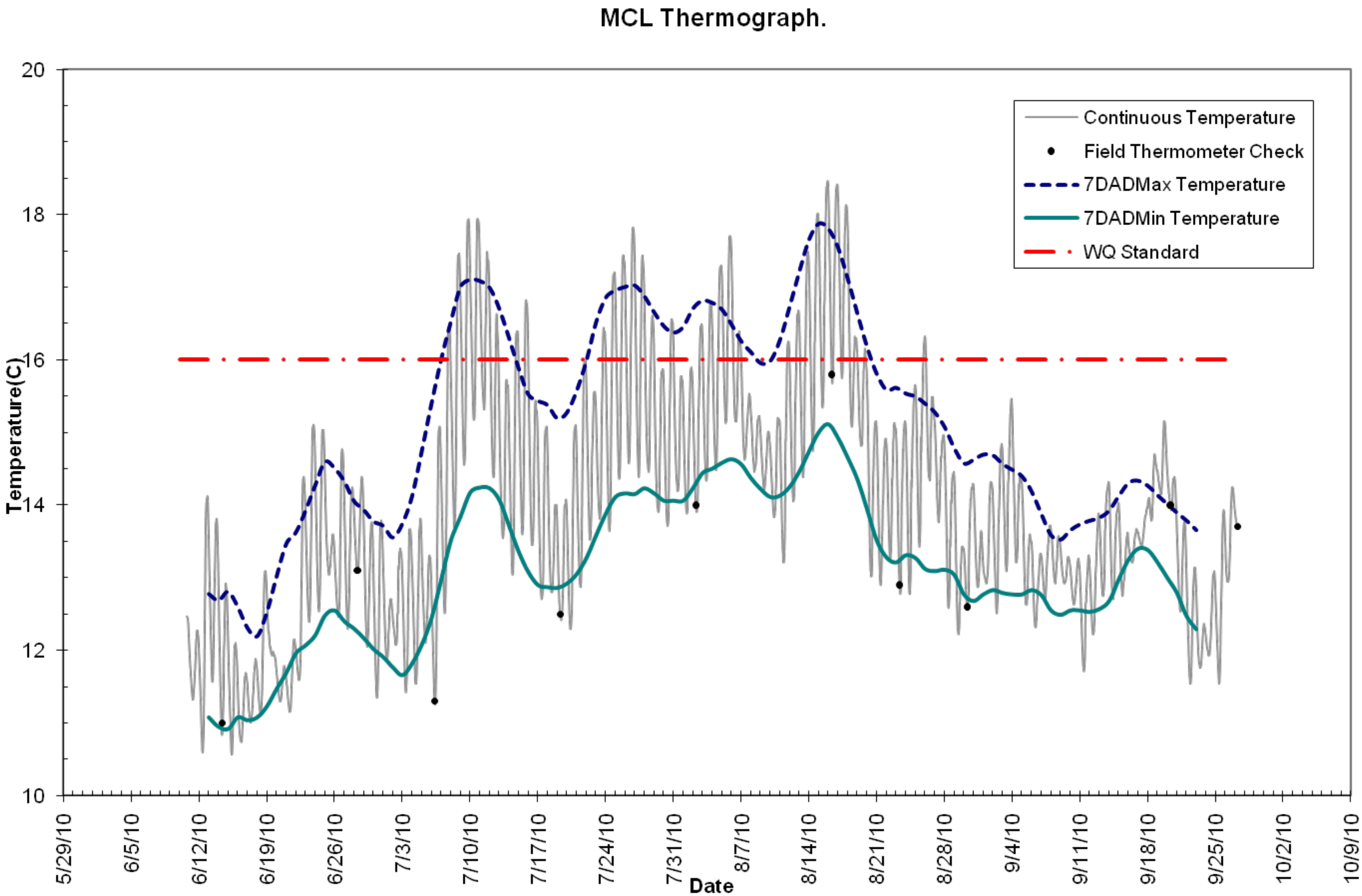

Figure C-1. Continuous water temperatures at McLane Creek during the 2010 study.

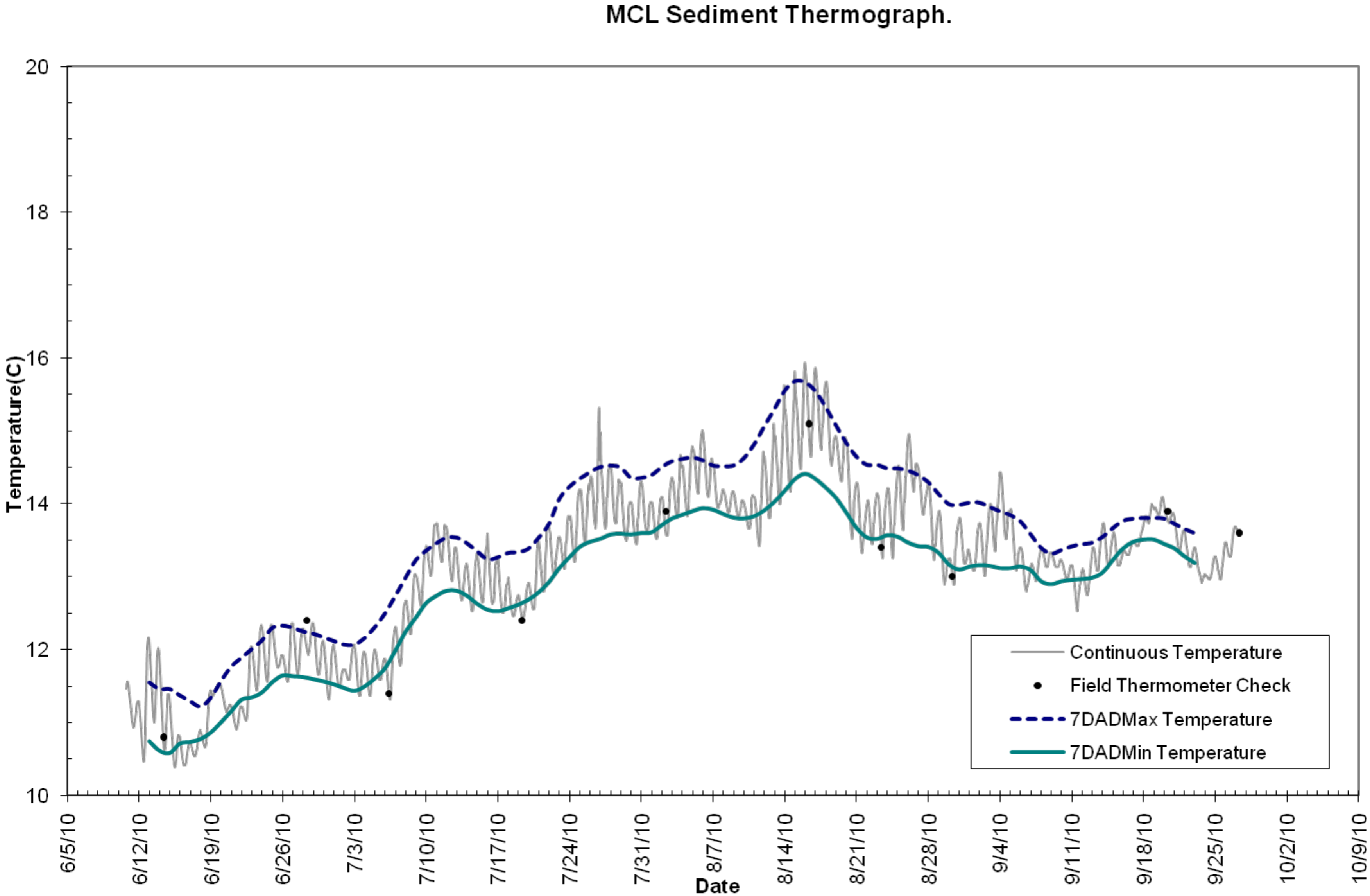

Figure C-2. Continuous sediment temperatures at McLane Creek during the 2010 study.

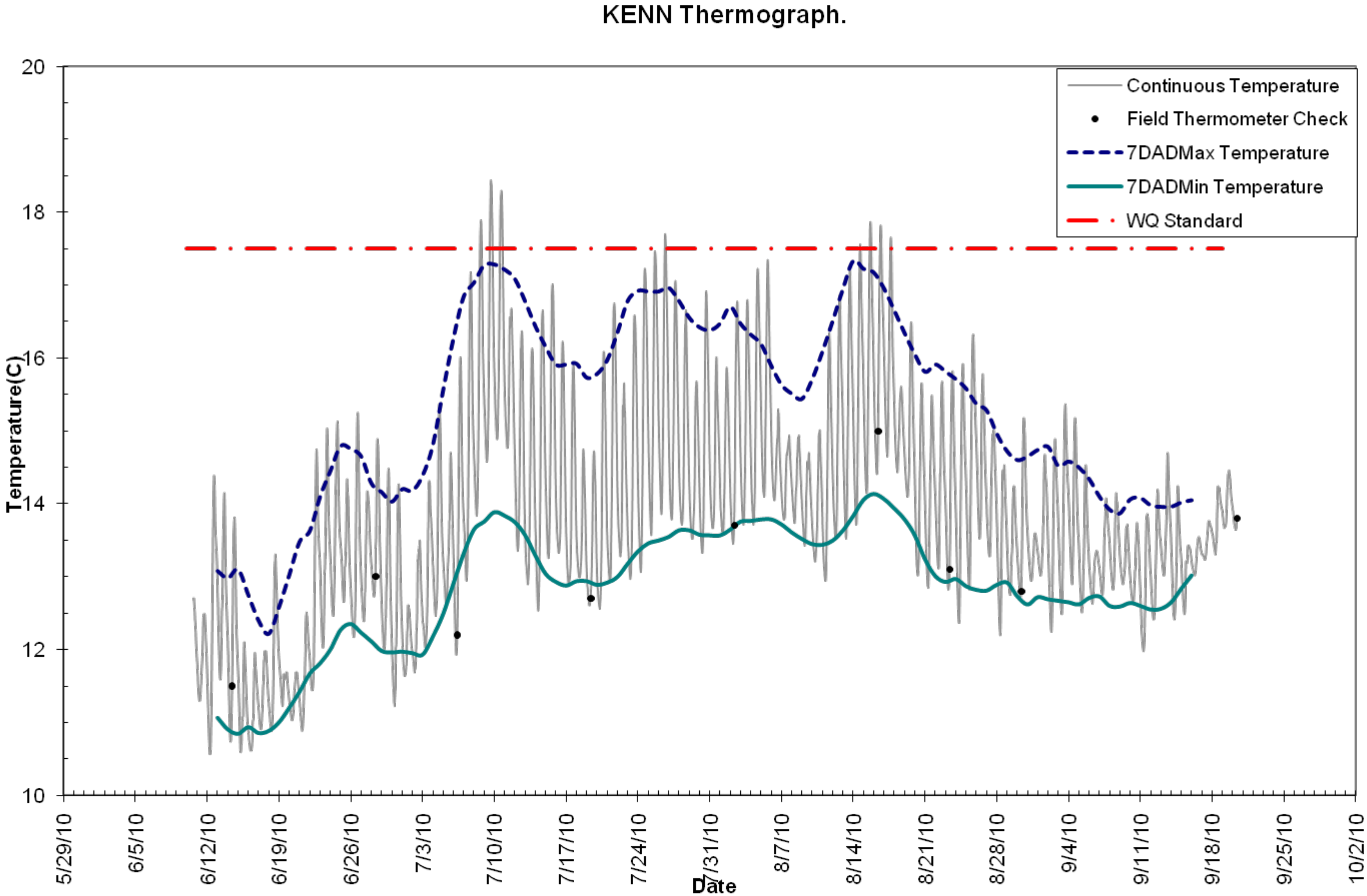

Figure C-3. Continuous water temperatures at Kennedy Creek during the 2010 study.

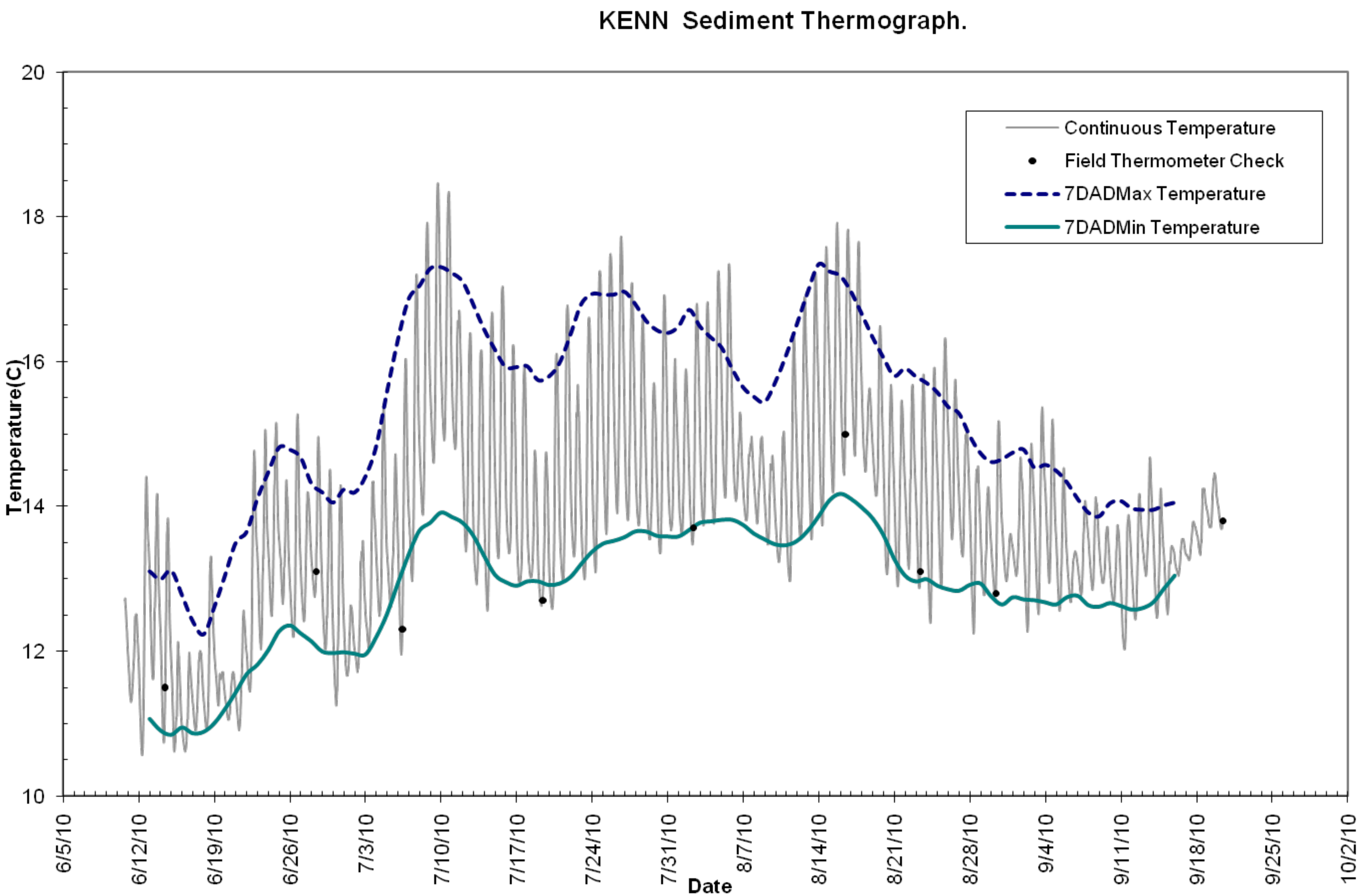

Figure C-4. Continuous sediment temperatures at Kennedy Creek during the 2010 study.

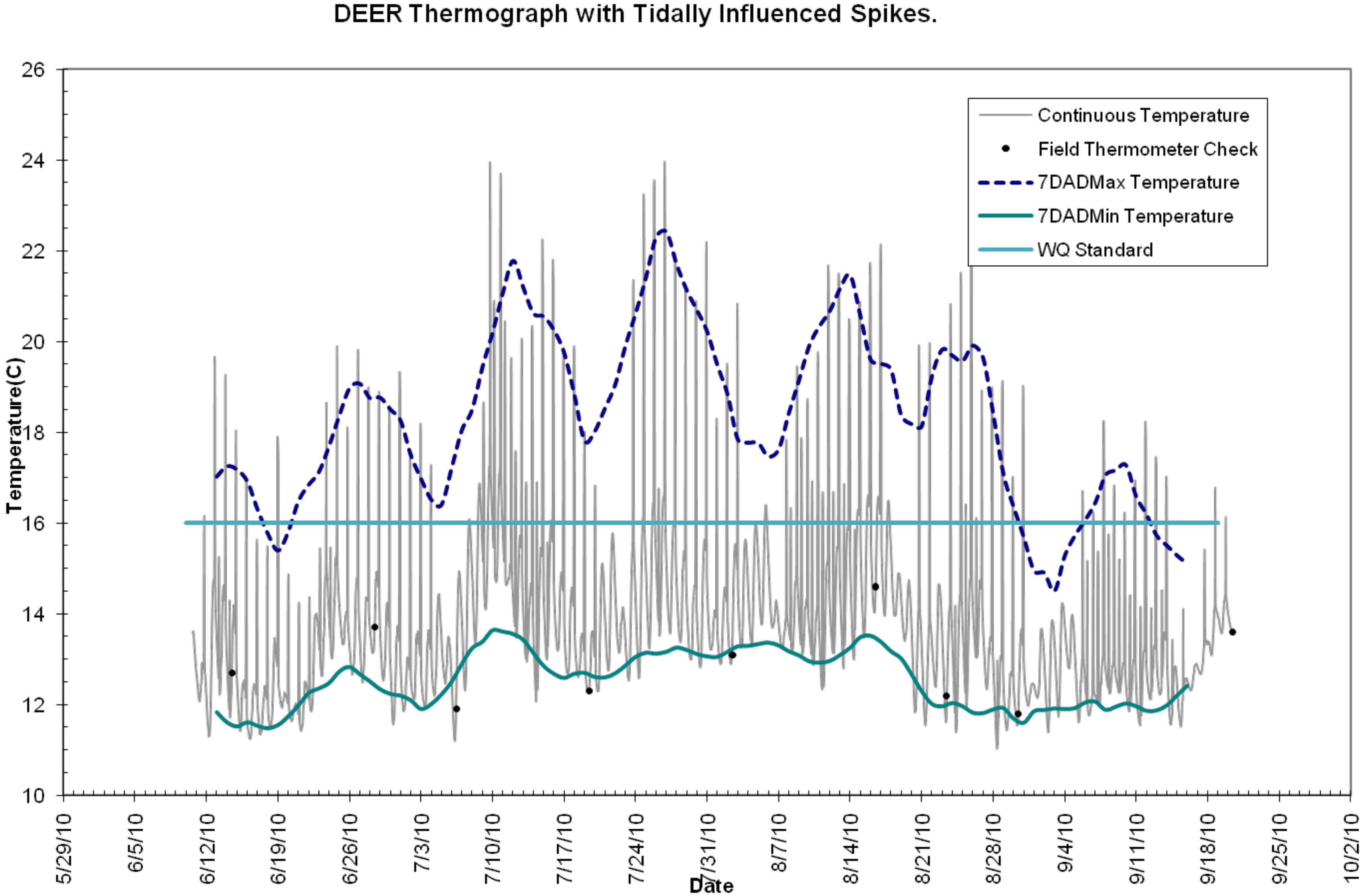

Figure C-5. Continuous water temperatures at Deer Creek during the 2010 study. Brief, dramatic spikes indicate tidal influence from Oakland Bay.

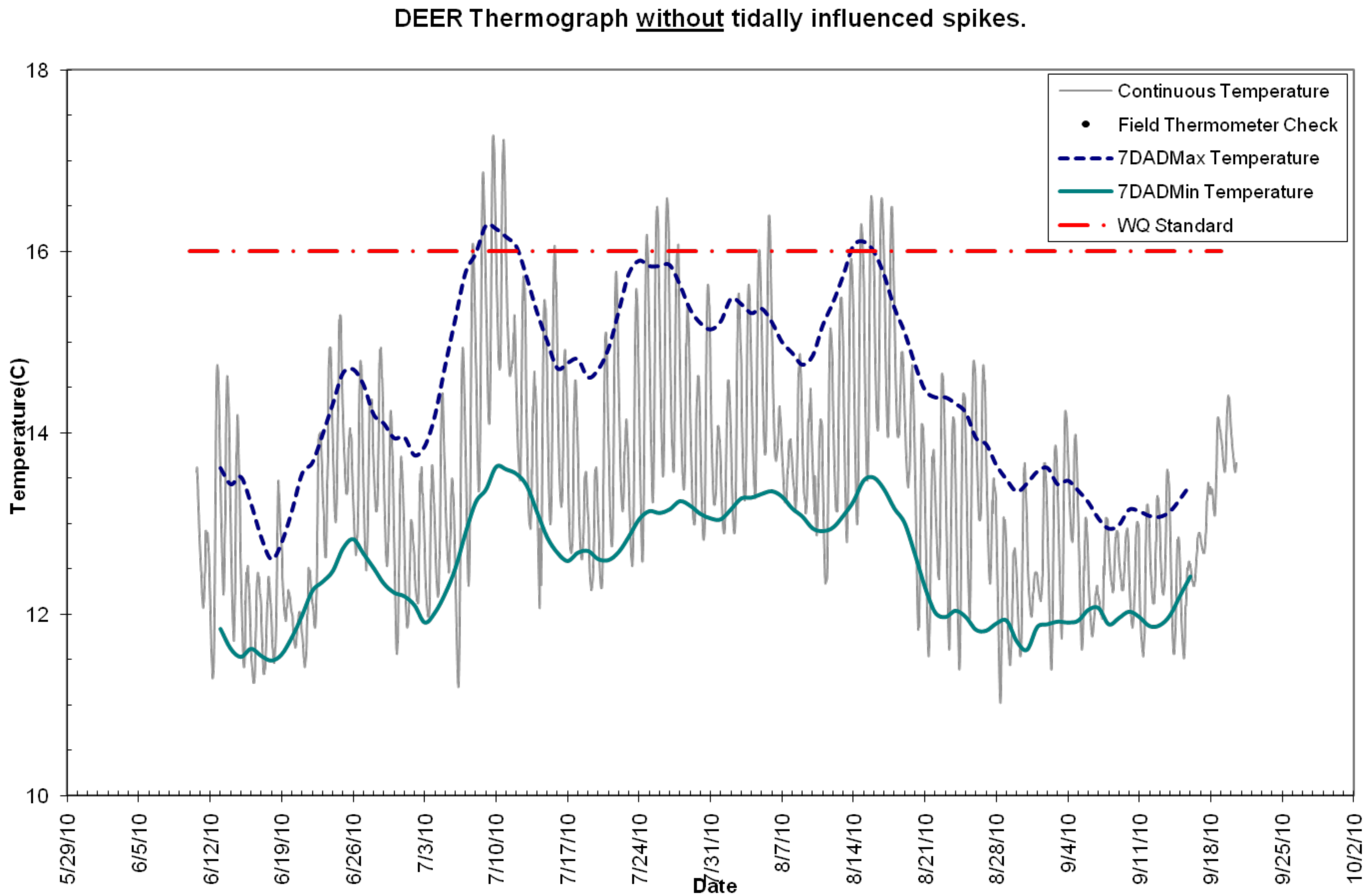

Figure C- 6. Continuous water temperatures at Deer Creek during the 2010 study. Tidally influence spikes have been removed.

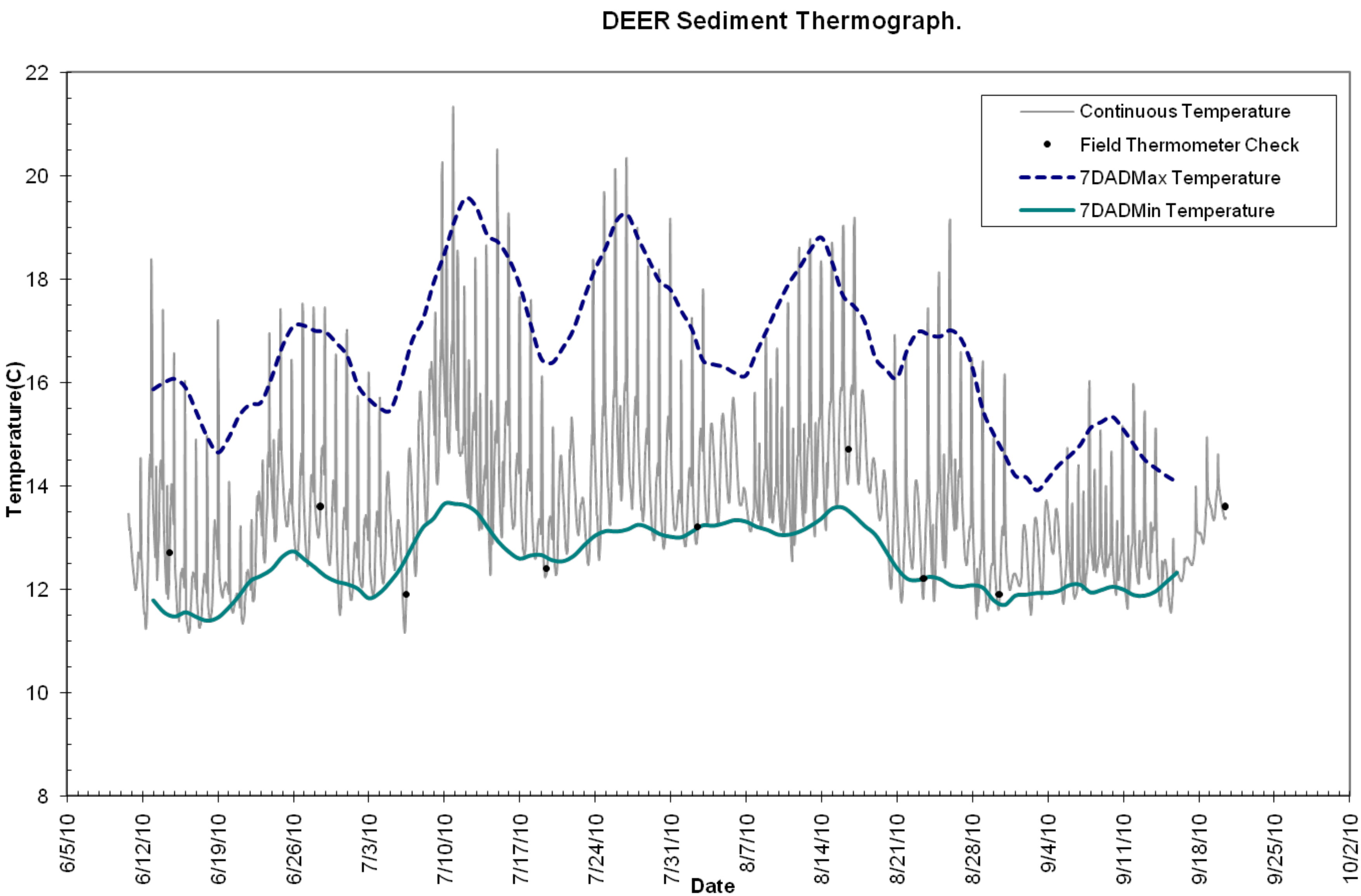

Figure C- 7. Continuous sediment temperatures at Deer Creek during the 2010 study. Brief, dramatic spikes indicate tidal influence from Oakland Bay.

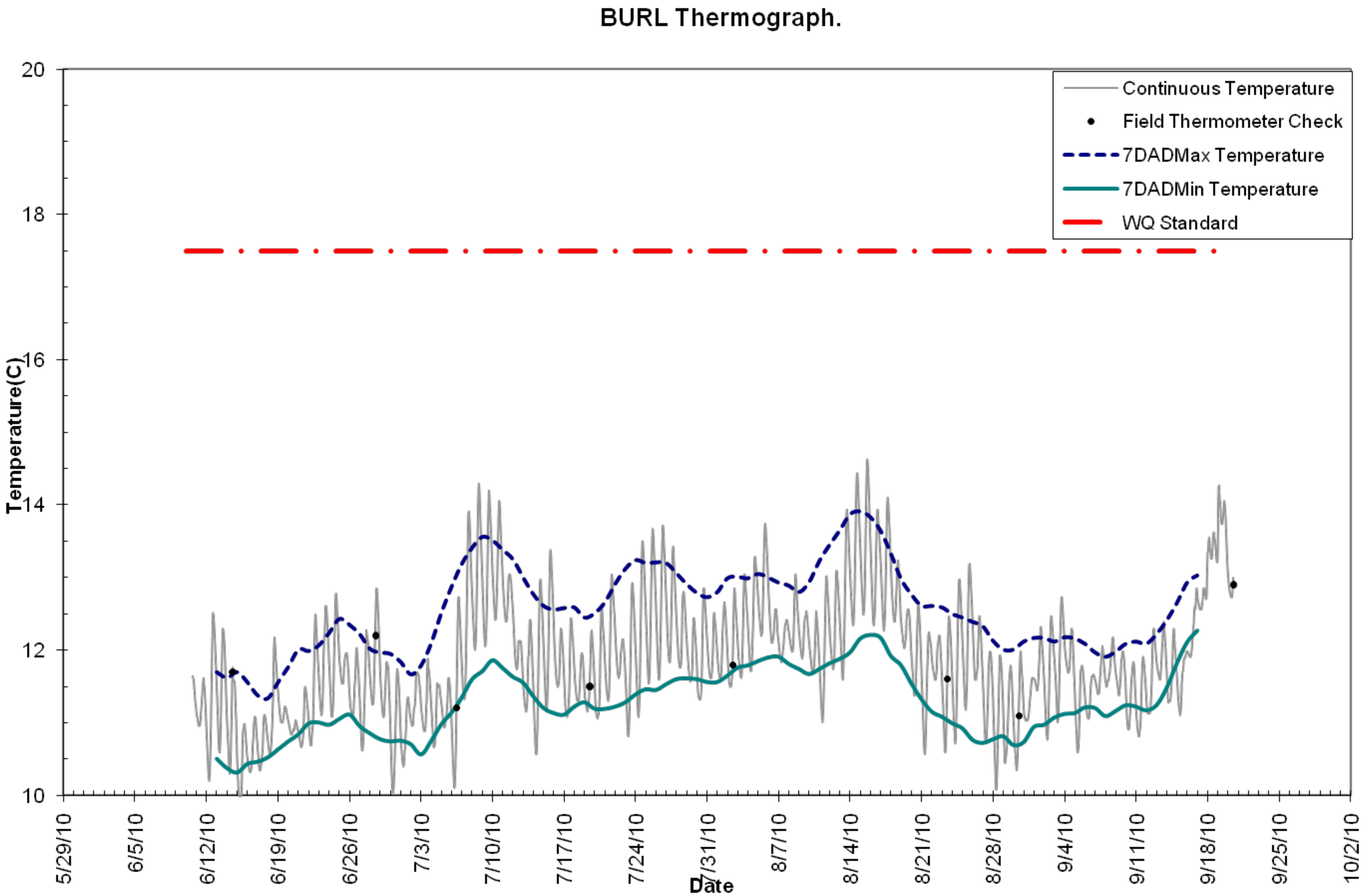

Figure C- 8. Continuous water temperatures at Burley Creek during the 2010 study.

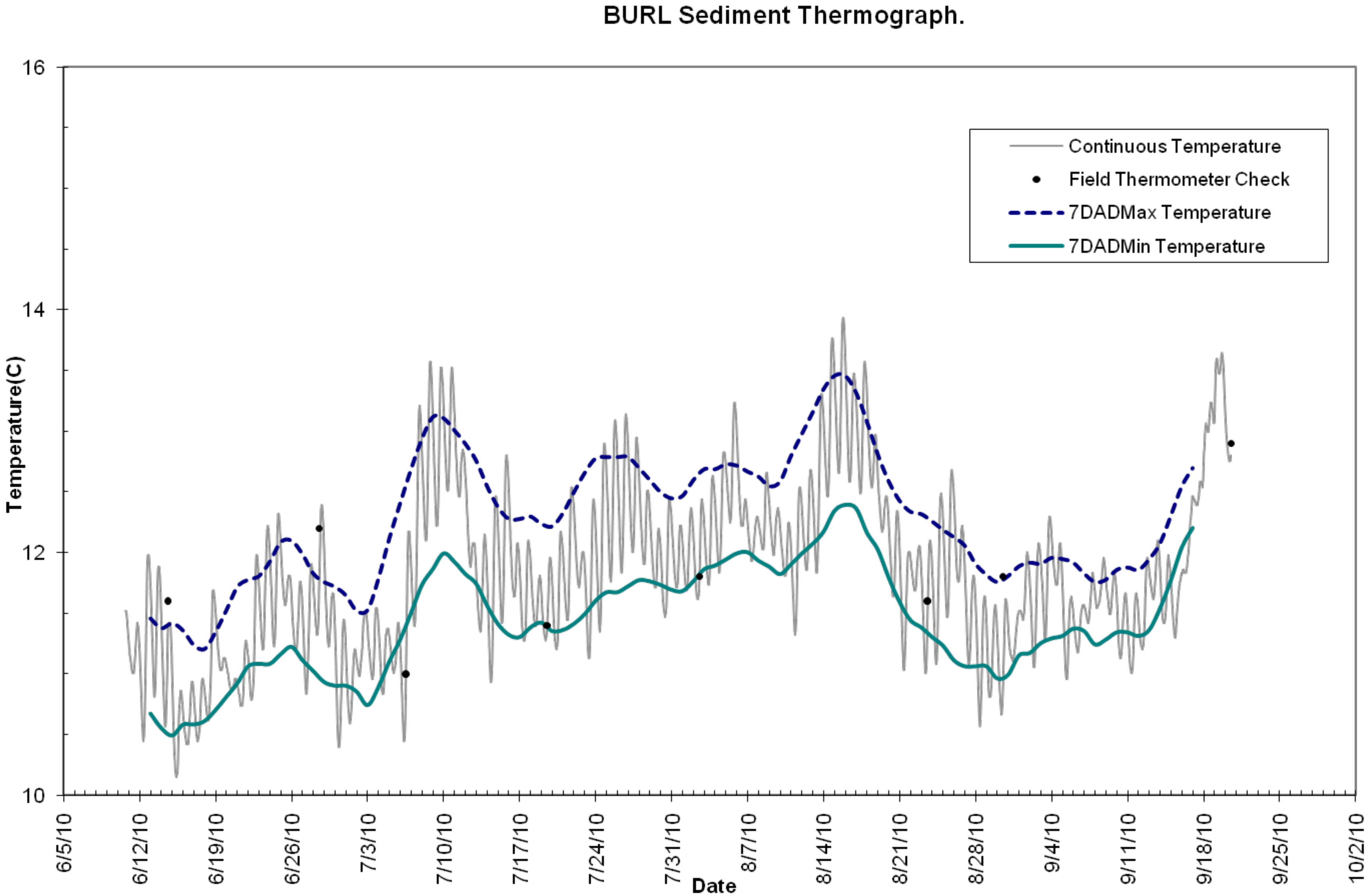

Figure C- 9. Continuous sediment temperatures at Burley Creek during the 2010 study.