Chimacum Watershed
Water Quality and Fishes
A Comprehensive Review

For

Washington State Conservation Commission

Olympia, Washington

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May 1, 2015

Prepared by

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205 W. Patison St.
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For

Washington State Conservation Commission
Olympia, Washington

TABLE OF CONTENTS

APPENDIX A - Station Locations

APPENDIX B - Quality Control

APPENDIX C - Temperature Profiles

ACKNOWLEGEMENTS

Many people and organizations have played a role in the Chimacum watershed to maintain and improve its natural environment and quality of life.

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We thank all the landowners who have implemented BMP's on their land and who have granted the District access to their land for water quality monitoring.

Finally, we want to thank Al Latham, Lige Christian, Roger Short, and Ron Shultz for reviewing this report.

PURPOSE

From a water quality perspective, the Chimacum watershed is undoubtedly the most studied watershed in Jefferson County. The Jefferson County Conservation District (JCCD) began monitoring water quality in the Chimacum watershed in 1996. Prior to 1996, the Jefferson County Planning Department conducted monitoring in 1988-89 and Washington Department of Ecology (Ecology) conducted monitoring in 1972-73 (without fecal coliform) and in 1993-94 (with fecal coliform). In the 1980's, the District began implementing Best Management Practices (BMPs) in agricultural areas of the watershed to improve water quality and salmonid habitat.

The purpose of this report is to:

1. establish a baseline for future studies to refer to;
2. report the District's most recent water quality findings;
3. report water quality trends over time;
4. consolidate the water quality data and other related information about the watershed including salmon runs, juvenile salmon abundance, stream flows, rainfall, beaver activity, restoration projects, etc.;
5. based on the data in this report, to draw preliminary conclusions and, where appropriate, to make recommendations.

ABSTRACT

Best Management Practices have resulted in decreasing trends in fecal coliform concentrations in the Chimacum watershed since monitoring began in the 1980's. Of 28 stations monitored in the 2011-12 water-year, 3 stations passed the "extraordinary contact" standard. Microbial Source Tracking results showed human *Bacteroides* present at 19 of the 20 stations monitored and ruminant *Bacteroides* at 10 stations. Human *Bacteroides* was detected five times more frequently than ruminant *Bacteroides* in all 237 samples. It is likely that fecal coliform bacteria are reproducing and multiplying in the stream environment. Of 29 stations monitored with temperature data loggers in 2013, 13 stations passed the 7-DADMax-16^{o}C standard. The temperature trend from 1998 to 2013 showed a decrease of 1^{o}C (1.8 ^{o}F) on Chimacum Creek's main stem and a decrease of 2^{o}C (3.6^{o}F) on the east fork. Fourteen of 25 stations passed the 1-day minimum 9.5 mg/L dissolved oxygen standard. Interactions of decomposition and photosynthesis on prolific in-channel vegetation have been shown to cause differences up to 5.5 mg/L from morning to afternoon. Most pH measurements ranged from 7.0 to 7.5 and passed the standard. In 1999, Chum Salmon came back from extinction with 38 adults returning; in 2013, a recent record of 3,066 fish returned to Chimacum Creek. Coho returns ranged from 333 adults to 3,539 adults from 1998 to 2013 and exhibited a very slight decreasing trend. Juvenile Coho exhibited increasing trends at habitat restoration sites.

BACKGROUND

The Chimacum Creek watershed is located in the northeastern corner of the Olympic Peninsula in Eastern Jefferson County, Washington and comprises 37 square miles (Figure 1). The climate is marine with cool, dry summers and mild, wet winters. Rainfall, measured in Center, averages 29 inches of rain per year (Figure 2). Average monthly rainfall from 1949 to 2013 ranged from 0.9 inches in July to 4.5 inches in December (Figure 2). Monthly rainfall in the 2011-12 water-year ranged from 0.13 inches in August and September to 6.33 inches in March (Figure 3). Stream flow in recent years has ranged from 2 cubic feet per second (cfs) to 270 cfs (Figure 4). Vegetation ranges from coniferous forest in the uplands to agricultural pasture in the lowlands.

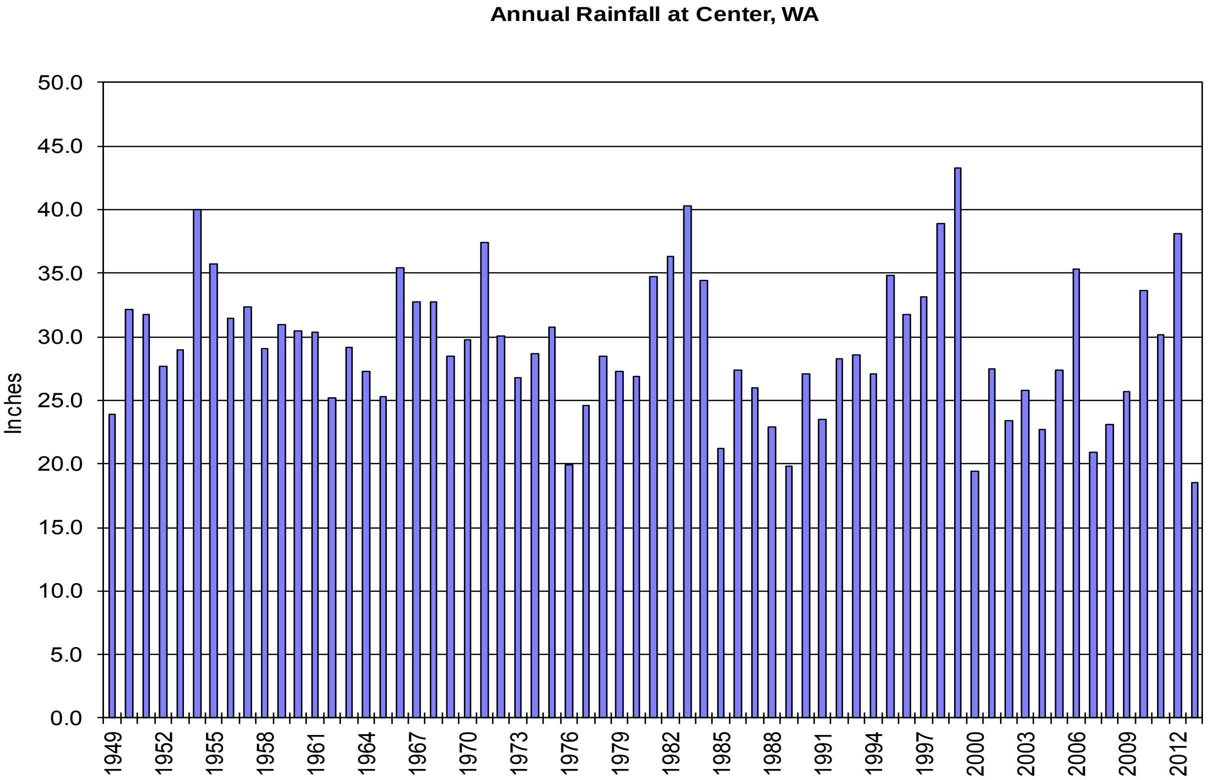
At about the turn of the 20th century most of the lowlands in the Chimacum watershed was cleared of existing spruce/cedar/fir/hemlock forest and converted to pasture (Bahls and Rubin 1996). To facilitate farming, much of Chimacum Creek and its tributaries were channelized, tile drains were installed, and ditches were excavated to improve drainage. Numerous dairy farms were operated in the Chimacum watershed at one time. Although only one dairy remains active today, most of the original dairy farms are still active in some form of agriculture. Today, the most common agricultural activities are pasturing beef cattle, horses and sheep, and growing hay and vegetable crops.

Chimacum Creek's main stem originates from Delanty Lake at River Mile (RM) 13.1. From Delanty Lake to RM 11.8 at Old Eaglemount Road the stream passes through agricultural land with peat soil and very low gradient. This section of stream is dry from about June to October. Juvenile Largemouth Bass (*Micropterus salmoides*), which drop down from Delanty Lake, and juvenile Coho Salmon (*Oncorhyncus kitsutch*) have been trapped in this reach in April and May (Renee 2002). Unless fish in this reach move downstream past Old Eaglemount Road, where there is continual stream flow, they would not survive. Upstream movement into Delanty Lake is blocked by a drop at the box culvert at Eaglemount Road. Replacing this culvert with a fish-passable one would allow fish to move upstream into the lake. However, there is no guarantee that the juvenile Coho would do that before the reach dries up. It is not uncommon for fish in the upper part of a watershed to become trapped and die in pools as the stream dries up.

From RM 11.8 to RM 9.3 Chimacum Creek passes through predominantly commercial forest land. The stream in this forested reach has good gradient and stream complexity. Extensive Coho and trout spawning occurs within this reach. From RM 9.3 to RM 3.4 at Highway 19 in Chimacum, the stream passes through agricultural land with peat soil.

From about RM 6.0 to RM 3.4 the gradient is extremely flat (0.0005). Throughout the agricultural areas, residences are fairly scattered, but from RM 2.7 downstream to RM 1.1 at Irondale Road, houses become more concentrated as Chimacum Creek passes

Figure 1. Map of the Chimacum watershed showing Chimacum Creek and its tributary streams.



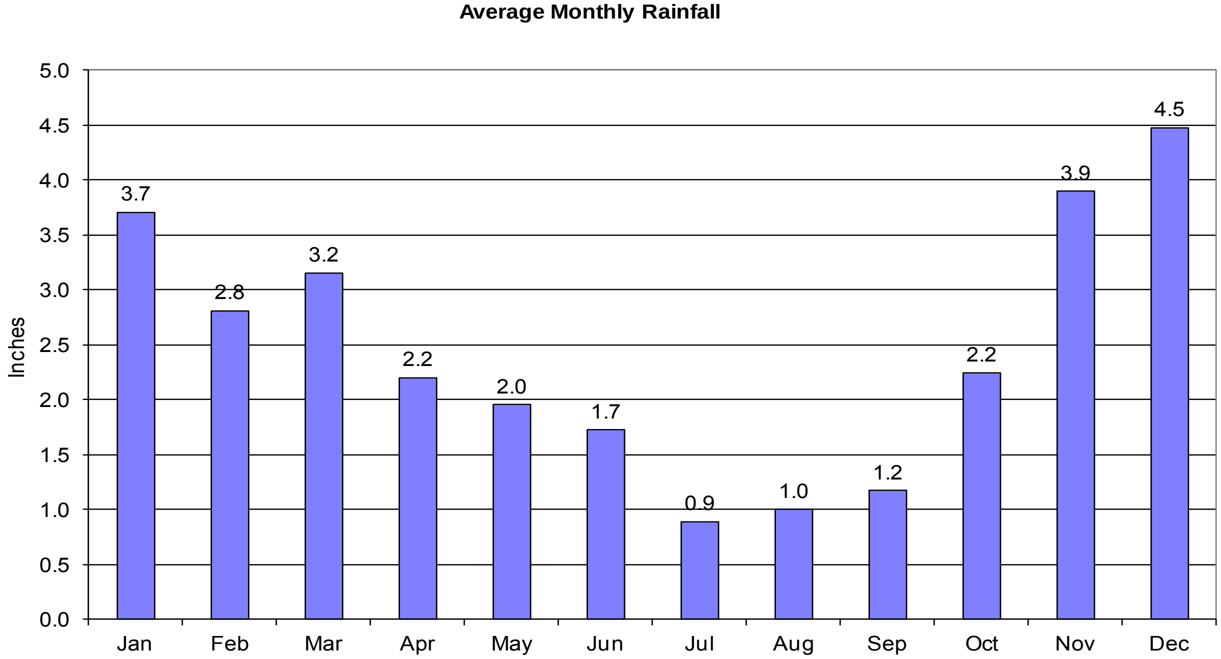


Figure 2. Annual Rainfall (top) and average monthly rainfall (bottom) measured at Center, Washington (Station CHIMACUM 4S, Washington 451414). Data provided by George Huntingford and the Western Regional Climate Center, Reno, Nevada.

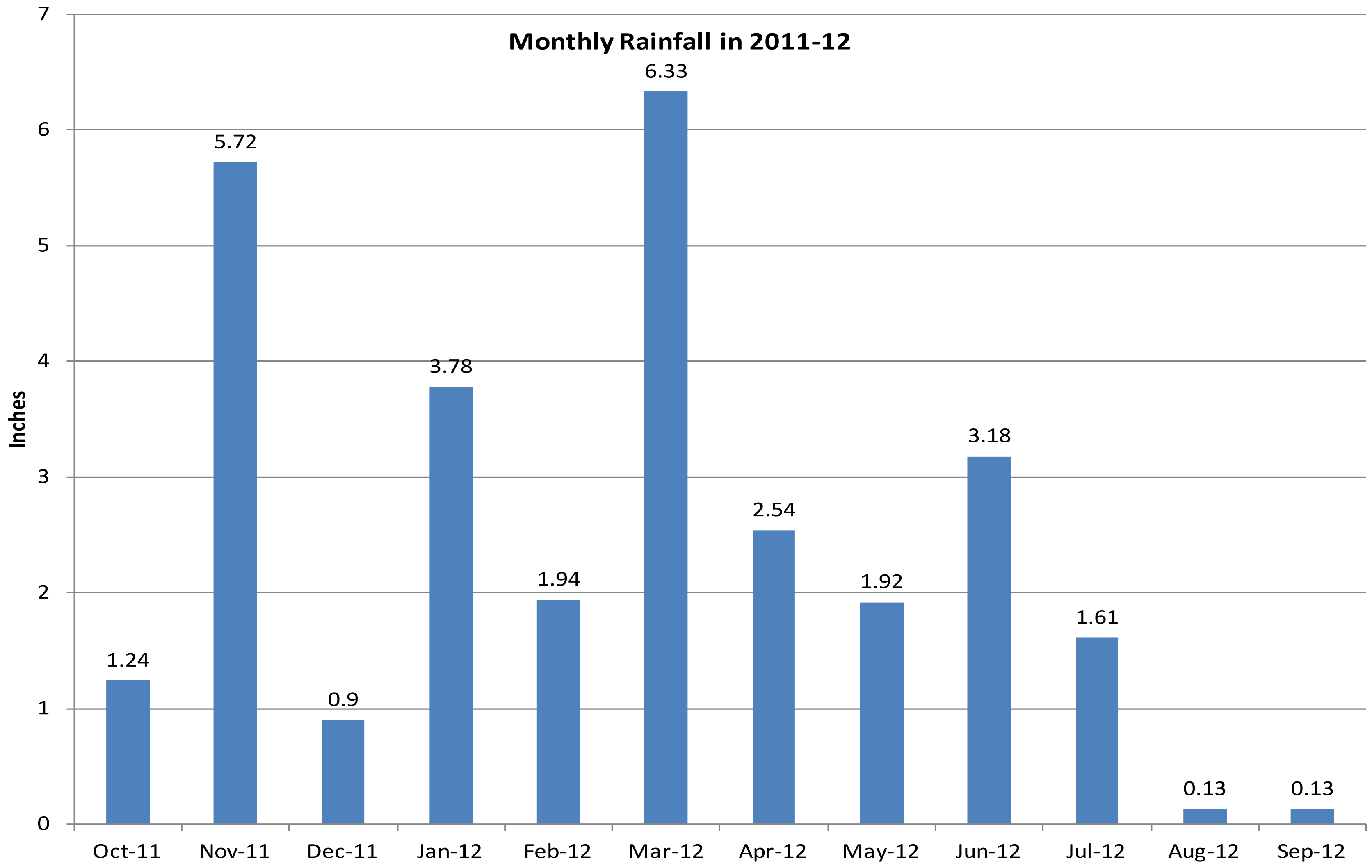


Figure 3. Monthly rainfall in the 2011-12 water-year measured at Center, Washington (Station CHIMACUM 4S, Washington 451414). Data provided by George Huntingford.

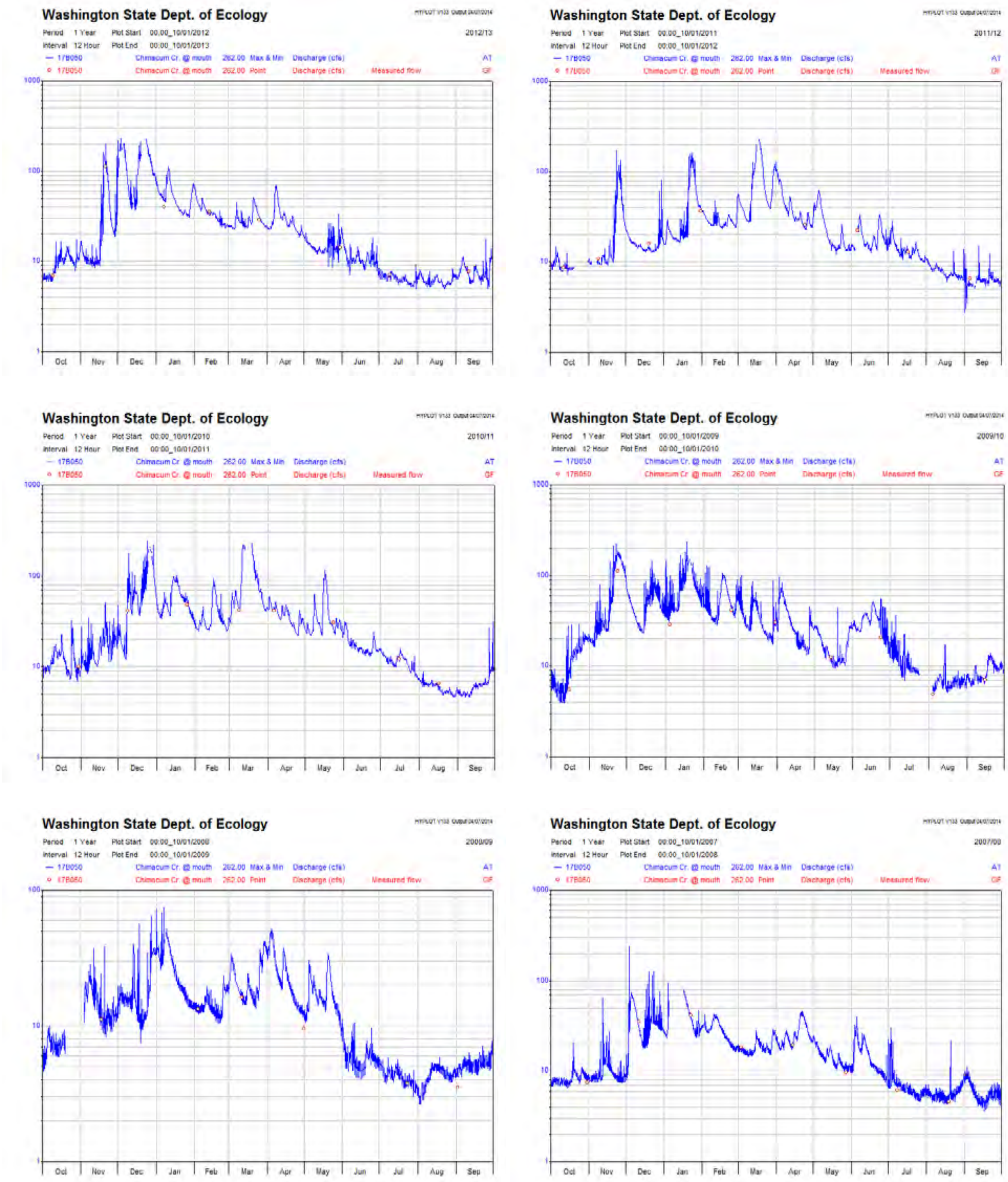


Figure 4. Chimacum Creek flow for water-years 2007-08 to 2012-13 measured at CH/0.1 by Washington Department of Ecology. Graphs were taken from Ecology's website https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=17B050&historical=true#block2

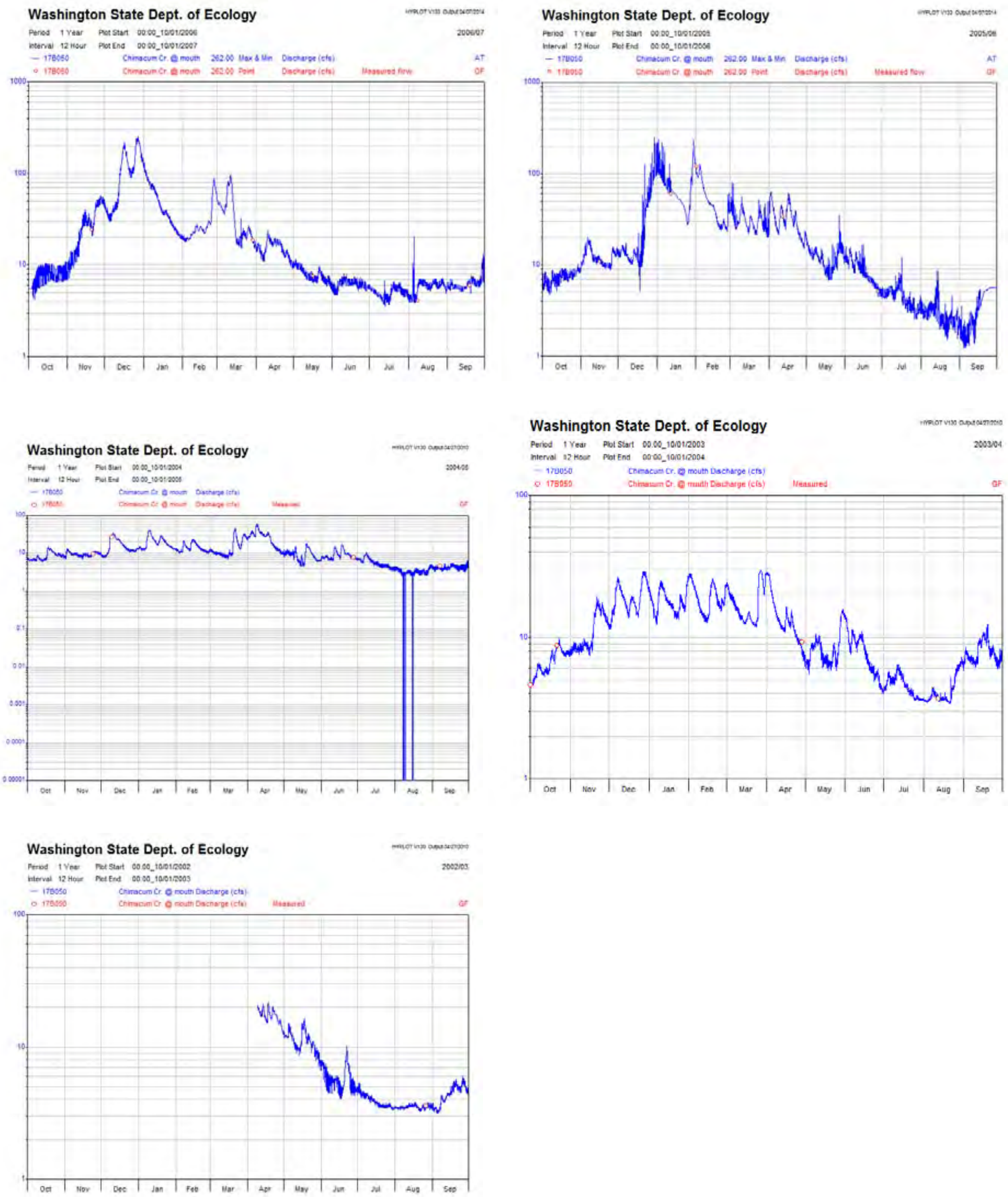


Figure 4 cont'd. Chimacum Creek flow for water-years 2002-03 to 2006-07 measured at station CH/0.1 by Washington Department of Ecology. Graphs were taken from Ecology's website https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=17B050&historical=true#block2.

through the towns of Chimacum, Port Hadlock, and Irondale. Downstream from RM 1.1 to its mouth in Port Townsend Bay, the gradient increases and the stream passes through a forested ravine, offering a natural setback from houses. Prior to their extinction in the 1980's Chum Salmon (*Oncorhynchus keta*) spawned in this stream reach, and after being re-established in 1999, continue to use it to this day (see Chum Salmon section for more information). East Chimacum Creek originates in forested wetlands south of Egg and I Road. It leaves the forest at RM 5.4 and flows through mostly agricultural land to its confluence with Chimacum Creek at RM 2.7 near the community of Chimacum.

Putaansuu Creek joins the main stem on its west side at River Mile 2.4, Naylors Creek on the west side at River Mile 5.3, Barnhouse Creek on the south side at River Mile 9.0, and Peterson Creek on the west side at River Mile 11.1. Some portions of Naylors Creek and Peterson Creek are dry during summer. Besides Delanty Lake, other lakes in the basin are Anderson, Beausite, Gibbs, and Peterson.

Fish trapping from 1996 to 2013 by District staff and volunteers revealed the following species inhabiting the Chimacum watershed: Coho Salmon, Chum Salmon, Steelhead (*Oncorhynchus mykiss*), Cutthroat Trout (*Oncorhynchus clarki*), Sculpin (family Cottidae), Threespine Stickleback (*Gasterosteus aculeatus*), Western Brook Lamprey (*Lampetra richardsoni*), and Largemouth Bass. In February 2015, a single 2 in.-long Pumpkinseed (*Lepomis gibbosus*) was trapped in the Chimacum Creek main stem at RM 5.2. A second Pumpkinseed was trapped in March at the same location. These were the first Pumpkinseed that the District has seen in the Chimacum watershed. In April, one 2-in. long cyprinid (minnow family) was trapped at RM 5.2.

Seining in the Chimacum Creek estuary in April 2009 by North Olympic Salmon Coalition staff and volunteers showed the following species using the estuary: juvenile Chum and Pink Salmon (*Oncorhynchus gorbuscha*), Starry Flounder (*Platichthys stellatus*), English Sole (*Parophrys vetulus*), Herring (*Clupea harengus pallasi*), Surf Smelt (*Hypomesus pretiosus*), Sand Lance (*Ammodytes hexapterus*), Green Gunnel (*Apodichthys flavidus*), Pipefish (family Syngnathoidei), and Sculpin (Sarah Doyle, personal communication, 2014).

Until the 1980's when fencing began more earnestly, livestock had access to much of Chimacum Creek. Monitoring downstream of agricultural areas in the 1980's and 1990's revealed high fecal coliform concentrations which were generally attributed to manure from livestock. Recent monitoring in 2011-12, however, is indicating that human sources (i.e. septic systems) may also be contributing to fecal coliform levels (see fecal coliform bacteria section). Since the 1980's, many miles of fencing have been installed along the banks of Chimacum Creek and its tributaries. In the early days, buffers were narrow, often occurring at "top of bank." Restricting livestock access to surface water even with narrow buffers improved water quality. Since the start of the Conservation Reserve Enhancement Program (CREP) in 2002, landowners have received rent for land put into buffers varying in width from 35 ft. to180 ft. More recently, landowners may receive rent for a “hedgerow” buffer with a width of 15 ft. on streams, minor tributaries, and ditches that have ordinary high water levels less than 15 ft. wide and are hydrologically connected to a fish bearing stream. Through fencing and other Best Management Practices (BMPs), progress has been made in reducing fecal coliform levels in Chimacum Creek. In instances where well water or electrical power was not available to provide water for livestock, "water gaps" were installed in the fence lines to enable livestock to drink from the creek. These water gaps minimized livestock access to one or two locations and resulted in less fecal coliform input as well as less bank erosion. In the past several years, the District has been encouraging landowners to use solar-powered pumps to water their livestock in lieu of these “water gaps.” Conversion of forestland to pasture land has caused the water temperature in Chimacum Creek to be higher than what would be expected in pre-settlement times. Water temperature is highest downstream of agricultural areas where shade is lacking. As has been mentioned, fenced-buffers have been created on most of Chimacum Creek’s agricultural land. All of the CREP buffers as well as some of the non-CREP buffers have been planted with a variety of coniferous and deciduous trees and shrubs. Because it takes 10-15 years for these trees to shade the creek channel, many of the planted trees have not yet reached sufficient size to provide full shade. There are still long reaches remaining that lack trees or shrubs.

METHODS

Monitoring Stations

Monitoring stations were selected using two criteria: 1) sites that were used in previous studies in order that comparisons can be made, and 2) sites bracketing (i.e. upstream and downstream) BMPs. In the 2011-12 water-year, the water-year most recently monitored, monitoring was conducted at twenty-eight stations once per month from October to September (Figure 5). However, because of laboratory limitations, microbial source tracking was conducted at only 20 of the 28 stations (Figure 5).

Monitoring station numbers contain the river mile, which is the distance measured upstream from the mouth. For instance, water quality station CH/1.1 on Chimacum Creek is located 1.1 miles upstream from the mouth. Water Resource Inventory Area 17 maps (Williams et al. 1975), topographic maps, and aerial photos were used in establishing station numbers. Monitoring station coordinates are provided in Appendix Table A-1.

Fecal Coliform Concentration

Fecal coliform samples were collected in sterilized bottles and analyzed within 30 hours at the Twiss Analytical Laboratory (accredited by Ecology) in Poulsbo, Washington. All sample bottles were placed in a cooler containing ice. Twiss Analytical Laboratory carried out dilutions of 10% and 50%.

Replicate fecal coliform samples were collected at two stations on each sampling date. A different pair of stations was selected on each date. Quality control results are reported in Appendix B.

Fecal Coliform Loading

Fecal coliform loading, the number of fecal coliform bacteria flowing past a point in a given period of time, was calculated by the formula:

$$\text{FC loading (billions per day)} = \text{FC} \times Q \times 0.0246$$

where FC is the fecal coliform count per 100 mL of water; and Q is the stream flow (cfs).

Stream Flow

The stream flow at station CH/0.1 was obtained from the 15-minute interval tables on Ecology's web site (https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=17B050#block2). Flows at

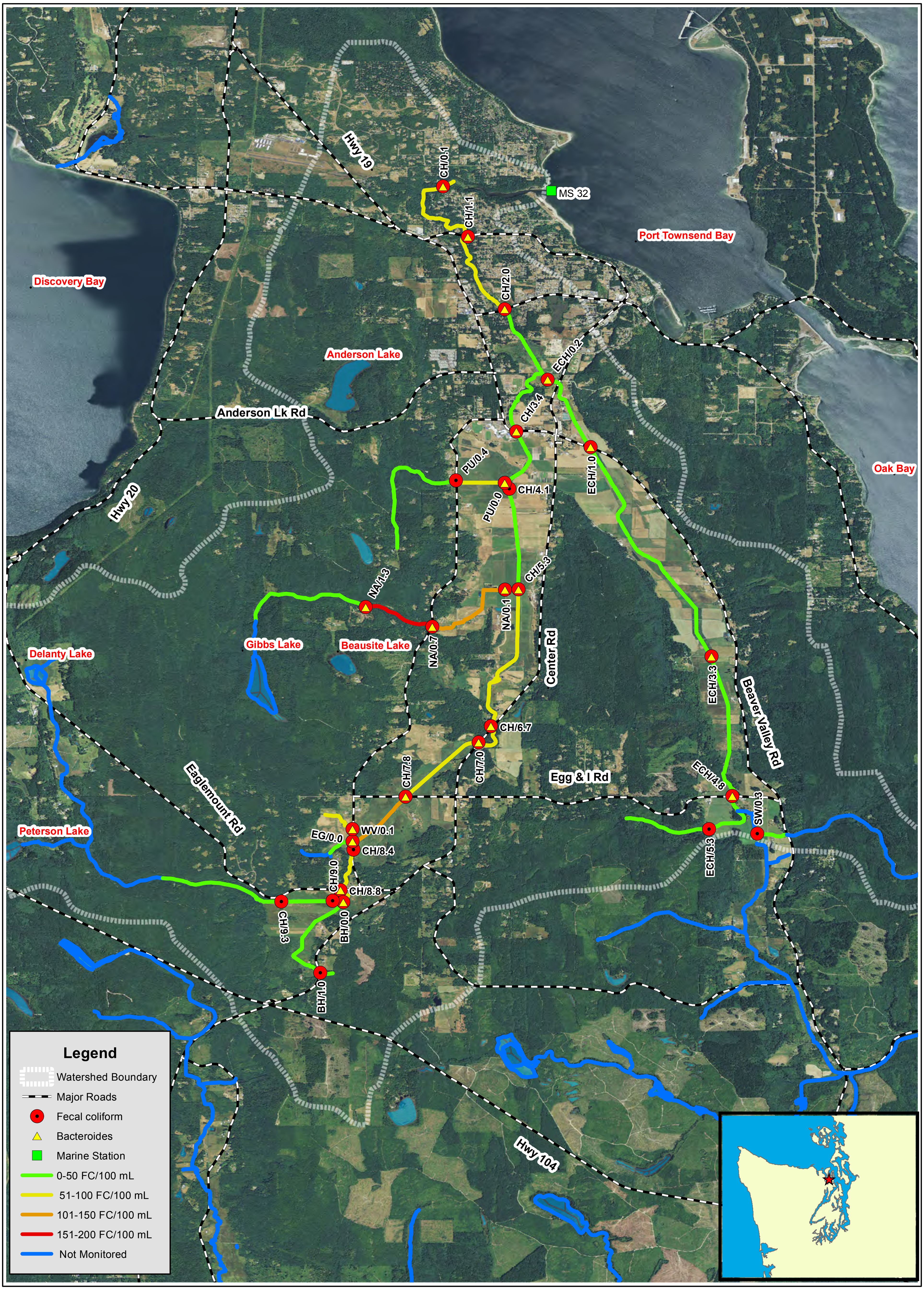


Figure 5. Map of Chimacum watershed showing fecal coliform and *Bacteroides* monitoring stations. Stream segments between stations are color-coded to ranges of fecal coliform geometric mean values (GMVs). GMVs were for the station at the downstream end of the segment and were based upon data collected monthly during the entire 2011-2012 water-year.

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0.5 0.25 0 0.5 Miles

other stations were obtained by establishing relationships (based on regressions) between flows on these streams and ditches to the flow at CH/0.1. Flows were measured at CH/0.1 and the other streams and ditches on the same day within a few hours of one another.

Flows used for the regression analysis were obtained by taking numerous velocity measurements across each stream with a Marsh-McBirney current meter (Model 201D), calculating flows for the individual subsections, and summing them.

The formula used was:

$$Q = \Sigma (A \times V)$$

where Q is the total flow (cubic feet per second or cfs);

A is the area (ft.^{2}) of an individual subsection;

and V is the corresponding mean velocity (feet per second)

of that subsection.

Regression analyses yielded the following equations:

Stream/Ditch	Station	Equation
Barnhouse Creek	BH/0.0	BH/0.0=0.0229*CH/0.1
Chimacum Creek	CH/3.4	CH/3.4=0.601*CH/0.1
East Chimacum Creek	ECH/0.2	ECH/0.2=0.186*CH/0.1
Ditch at CH/8.4	EG/0.0	EG/0.0=0.00972*CH/0.1
Naylors Creek	NA/0.2	NA/0.2=0.070*CH/0.1
Putaansuu Creek	PU/0.4	PU/0.4=0.0254*CH/0.1
Swansonville Creek	SW/0.3	SW/0.3=0.00505*CH/0.1
West Valley Ditch	WV/0.1	WV/0.1=0.00789*CH/0.1

Bacteroides **- Microbial Source Tracking**

Concurrently with collecting fecal coliform samples, samples were collected for deoxyribonucleic acid (DNA) analysis of the bacteria *Bacteroides* spp. for “microbial source tracking" or MST. Due to laboratory constraints, MST monitoring was limited to 20 stations (Figure 5). Samples were collected in 250 mL sterilized bottles, packed in a cooler with ice, and shipped to the Environmental Protection Agency (EPA) laboratory in Port Orchard, Washington where they arrived the next day. The samples were filtered and frozen within 48 hours of sample collection and analyzed by polymerase chain reaction (PCR) and electrophoresis at a later date. The samples were identified as "general" (any warm-blooded animal), "ruminant," or "human."

As part of the quality control procedure, two laboratory duplicates were analyzed for each batch of 20 samples. Additionally, several "blind" samples were submitted for analysis during the course of the study. The blind samples were made by placing about 1 gram of manure from known sources (cattle, chicken, and human) into bottles containing sterilized water. They were submitted to the laboratory for analysis without identifying the source.

In order to better assess the MST results, additional details of the methods used as well as the quality control results are provided in the Results and Discussion section.

Temperature

Hobo U22 Water Temp Pro v2 temperature data loggers (TDLs), manufactured by Onset Computer Corporation, were used in this study. The TDLs have an accuracy of plus or minus 0.2 degrees Celsius.

TDLs were programmed to record temperature every hour. They were maintained at 30 stations in the Chimacum Creek watershed from mid-May to mid-October throughout the study (Figure 6). Most of these TDL stations were monitored in previous years by the District. Coordinates of station locations are provided in Appendix Table A-2. Data loggers were placed on the stream bottom in deeper areas of the stream. They were attached to 0.5 inch rebar with #14 black, single-strand electrical wire.

Temperature profile graphs were made for each station and the number of days on which the 7-DADMax exceeded the standard was calculated. Prior to 2004 the state standard was based on a single temperature measurement that was not to exceed 16 degrees Celsius. The number of days that the 7-DADMax exceeded 16 degrees Celsius was calculated for the pre-2004 data in order to assess trends consistently.

Because the data loggers were not in the streams all year (data loggers can be easily lost during winter high flows), the number of days that the 13 degree Celsius standard was exceeded should be considered a minimum.

Single temperature measurements were also taken at the time the fecal coliform samples were collected. Temperature was measured with a Yellow Springs Instrument

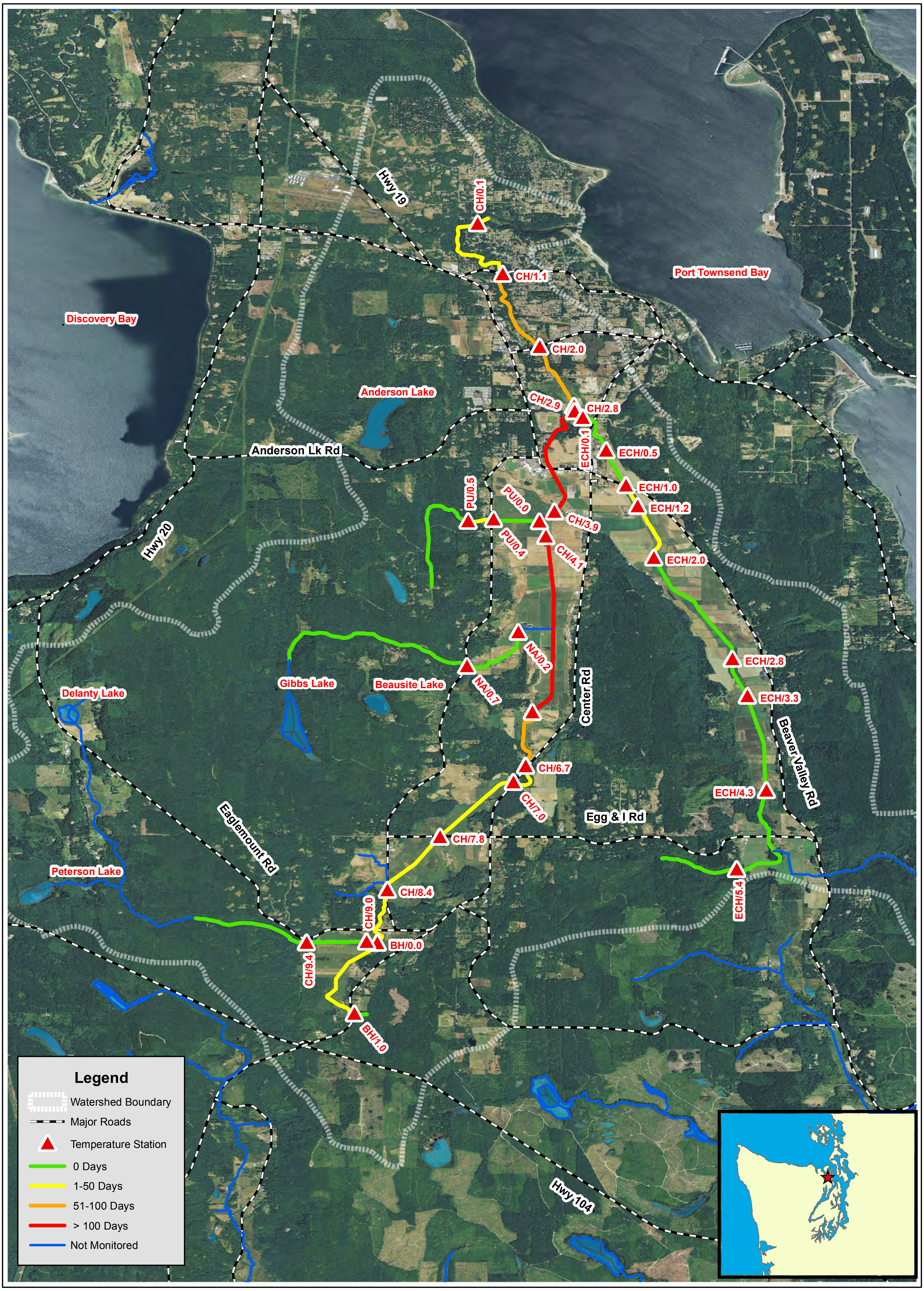

Figure 6. Map of Chimacum watershed showing temperature monitoring stations where data loggers recorded temperature every hour from mid-May to mid-October. Stream segments between stations are color-coded based on the number of days the state standard (16º Celsius 7-DADMax) was exceeded. Color codes were based on the temperature data for the station at the downstream end of the segment.

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0.5 0.25 0 0.5 Miles

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(YSI) model 556 meter with built-in barometer. The YSI is not designed to alter the factory-set temperature calibration. However, temperature measurements of the two YSIs used in this study were periodically compared to each other and a laboratory grade thermometer and were always within 0.2 degrees Celsius of one another and the laboratory grade thermometer.

Chimacum High School students measured temperature with a glass thermometer with 0.5 ^{o}C gradations. They recorded temperature to the nearest 0.1^{o}C.

Turbidity

District staff collected turbidity samples in 125 mL high density polyethylene bottles and analyzed the samples with a Hach model 2100N turbidity meter at the JCCD laboratory in Port Hadlock within the prescribed 2-day holding time. Chimacum High School students used their own Hach model 2100N turbidity meter and analyzed the samples the day they were collected at the Chimacum School. JCCD staff and Chimacum School students used turbidity procedure 214 A in Standard Methods (APHA 1981).

Dissolved Oxygen, pH, and Conductivity

Dissolved oxygen, pH, and conductivity were measured with the YSI model 556 meter. Dissolved oxygen was calibrated periodically in stream water at 100% saturation by placing the YSI probe in the stream in a water-tight cylinder vented by tube to the atmosphere. This enables calibration to be made at stream temperature and is more accurate than calibrating in the laboratory at room temperature, which is usually different from stream water temperature.

pH was calibrated in the laboratory using 4.00, 7.02, and 10.06 buffer standards.

Conductivity was calibrated in the laboratory using a 718 umho/cm standard.

Additional checks were periodically accomplished in the field by comparing measurements of the two meters.

Chimacum School students used the azide modification of the Winkler method (APHA 1981, Standard Methods 421B) to measure dissolved oxygen. Students collected samples in 300-mL BOD bottles and “fixed” them on-site with Hach manganous sulfate and alkaline-iodide azide “powder pillows.” On the same day in the school laboratory, a sulfamic acid “powder pillow” was added to each sample to dissolve the precipitate. Two 100-mL samples were then titrated using a Hach digital titrator with 0.2000 N sodium thiosulfate solution. If the results were within 0.5 mg/L of one another, the two measurements were averaged. Otherwise, a third titration was performed and the two closest measurements were averaged.

Intragravel Dissolved Oxygen

Intragravel dissolved oxygen (IGDO) monitoring was conducted in Chimacum Creek from 1999 to 2010. In late July/early August, simulated "redds" were dug to a depth of about 7 inches in several reaches of Chimacum Creek. A 4-inch aquarium air stone was placed in the "redd" with 6 feet of tubing trailing downstream in the current. Two or three 1-2 inch stones were placed over the air stone and then the "redd" was filled in with bottom material from immediately upstream. An aluminum tag, engraved with a station identification number, was secured to the tubing with aluminum wire.

Water samples were collected by means of a battery-powered drill and peristaltic pump. Samples were collected in 60-mL BOD bottles after discarding the first 60 mL to clear the tubing. Samples were analyzed using the azide modification of the Winkler method (APHA 1981 Standard Methods 421B). Samples were "fixed" on-site with 8 drops of manganous sulfate solution and 8 drops of alkaline-iodide azide solution. The samples were transported to the JCCD lab where 0.5 mL 50%-sulfuric acid was added to the sample bottles to dissolve the precipitate. When the precipitate was dissolved (10-20 minutes), the samples were titrated with a Hach digital titrator using 0.0250 N sodium thiosulfate solution. Two 20-mL titrations were made on each sample and the results averaged. A third titration was made if the results of the first two were not within 0.5 mg/L. If three measurements were made, the two closest measurements were averaged.

Relative Fish Abundance

Fish trapping was conducted to obtain an index of relative fish abundance (RFA) for a particular stream reach in order to assess BMPs in terms of salmonid habitat improvement. Landowners, students, and other volunteers were trained in fish trapping and fish identification. The traps used were standard minnow traps (Cuba Specialty Mfg. Co.) made of ¼-inch wire mesh with a $^7/_8$-inch opening in each of the funnel ends. Traps were baited with bread and set overnight for a one-day trapping period. Volunteers identified, enumerated, and then released the fish. Data were recorded on standardized forms. Usually at least two traps were set in a stream reach on each trapping day and a minimum of 9 sets were made each quarter. Traps were often moved around within the stream reach. RFAs were calculated for each species for each of the four quarters (Q) of the year, roughly corresponding to winter (Q1), spring (Q2), summer (Q3), and fall (Q4). The formula used was:

$$\text{RFA} = \sum F / \sum T$$

where F is the number of fish caught (by species) within the quarter;
and T is the number of traps set in that quarter.

Climate Data

Rainfall data for Center, Washington, located in the Chimacum Watershed, was obtained from the Western Regional Climate Center in Reno, Nevada and also from the operator of the weather station. Officially, it is station CHIMACUM 4S, WASHINGTON (451414).

Air temperature data for Bremerton, Washington was obtained from the National Climatic Data Center (NCDC) in Asheville, North Carolina from their website (http://www.ncdc.noaa.gov/).

Statistics

Box and whisker plots were used to graphically show parameter concentrations at the various monitoring stations. Interpretation of the box and whisker plot is shown in Figure 7.

Statistical tests, including regression analysis and box and whisker plots, were made with *Statistix 10* from Analytical Software, PO Box 12185, Tallahassee, Florida 32317-2185, www.statistix.com. Additionally, trends (i.e. regression lines) were obtained using Microsoft Excel 2007.

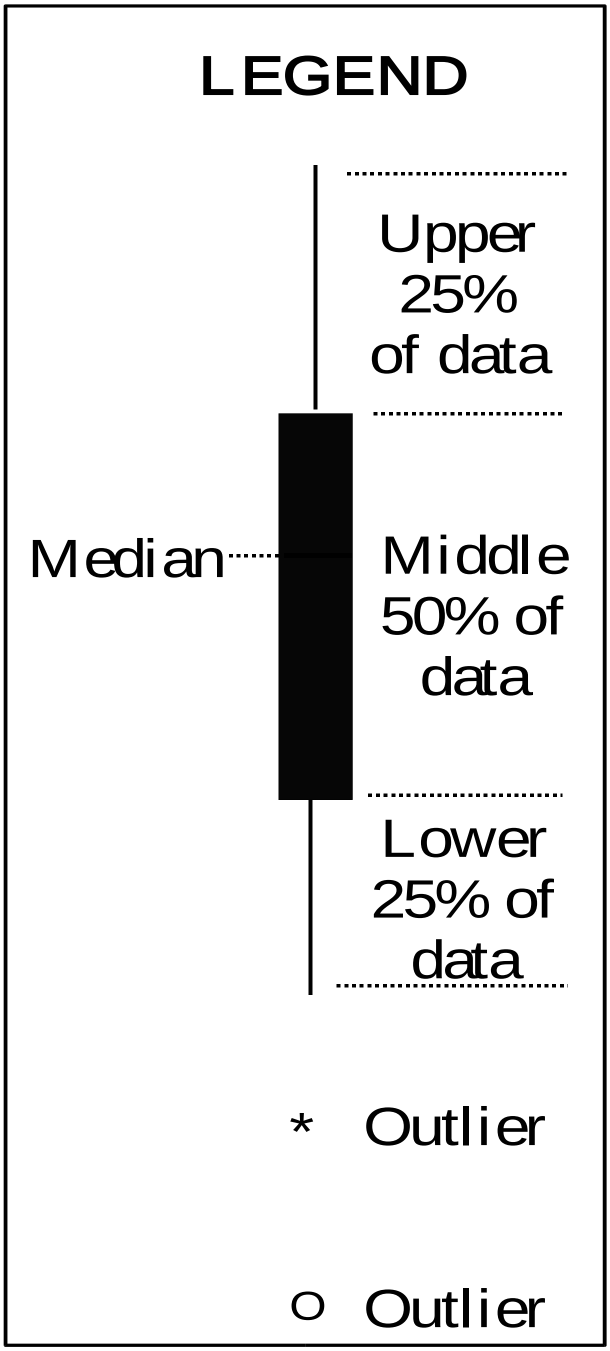


Figure 7. In the box and whisker plot shown above the shaded area within the box represents the middle 50 percent of the data and the horizontal line within the box is the median. Fifty percent of the data points are above the median and 50 percent are below it. The upper vertical line or "whisker" represents the upper 25 percent of the data, and the lower "whisker" represents the lower 25 percent. A "whisker" always ends at a data point and cannot be more than 1.5 times the length of the box. Data points which fall beyond 1.5 times the length of the box are called "outliers." An outlier 1.5-3.0 times the length of the box is represented by an asterisk (*) and a data point greater than 3 times the length of the box is represented by a circle (o).

RESULTS AND DISCUSSION

Fecal Coliform Bacteria

Fecal coliform bacteria originate in the digestive tract of warm-blooded animals and are released into the environment through excretion. They serve as an indicator of disease-causing organisms released with them. The rationale is that an increase in the bacteria's concentration indicates an increased chance that pathogens are also present. The higher the concentration of fecal coliform, the greater is the chance for disease.

The use of coliform bacteria as an indicator of potential pathogens has some limitations. The coliform indicator system was initially based on a series of assumptions about the relationships between coliform bacteria, pathogenic organisms, and human sewage. Originally intended for large, somewhat predictable discharges of human sewage, the coliform indicator system has been broadened to include nonpoint sources such as on-site septic systems, boater wastes, stormwater run-off and animal wastes (Lilja and Glasoe 1993). Some authorities believe that the coliform indicator system is poorly suited for assessing these more variable pollution sources. This is particularly true for animal wastes because research suggests that the risk of viral infection from animal wastes may be less than that associated with human sewage (Stelma and McCabe 1992; Lilja and Glasoe 1993).

However, to say that the risk is less is not to say that no risk exists. Many bacterial pathogens are known to be communicated from animals to man (Acha and Szyfres 1980) and can be transmitted via shellfish (Bidwell and Kelly 1950; Stelma and McCabe 1992; Lilja and Glasoe 1993). Bacterial pathogens of greatest concern include various species in the genera *Salmonella, Shigella, Escherichia, Listeria*, *Yersinia, Campylobacter, Vibrio*, and *Leptospira* (Lilja and Glasoe 1993). *Salmonella*, one of the more common of these pathogens, occurs in a broad range of domestic and wild animals including cattle, swine, sheep, goats, horses, dogs, cats, rodents, chickens, ducks, and geese (Acha and Szyfres 1980).

Two Protozoan parasites, *Giardia lamblia* and *Cryptosporidium spp.*, have the potential to be transmitted from animals to humans via shellfish and water (Stelma and McCabe 1992). *Giardia duodenalis* and *Cryptosporidium spp.* have been found in sheep, cattle, goats, swine, and horses (Willis et al. 2013). Cysts from these parasites can remain viable in water for up to 1 year.

Some viruses common to both humans and animals are capable of crossing species barriers and producing disease (Stelma and McCabe 1992). Therefore, it is conceivable that humans could acquire viral illness from shellfish contaminated with animal viruses, especially the rotaviruses, which are environmentally stable in freshwater and seawater (Stelma and McCabe 1992).

Until the 1980's, fecal coliform bacteria have been considered only as indicators of potential pathogens. However, it is now recognized that *Escherichia coli* 0157:H7, a fecal coliform bacterium, is itself a pathogen. *E. coli* 0157:H7 was first recognized as a pathogen in the early 1980's. In 1990, its contamination of a drinking water supply in Missouri resulted in over 200 illnesses (Swerdlow *et al*. 1992). In 1993, *E. coli* 0157:H7 received nationwide attention when it caused a serious outbreak of illnesses in Washington State (Bell *et al*. 1994). Undercooked beef hamburgers, contaminated with *E. coli* 0157:H7 proved to be the cause of the deaths and illnesses.

Studies have linked *E. coli* 0157:H7 to cattle. In culture surveys conducted at dairy farms, a stockyard, and a packinghouse, the fecal isolation rate for *E.coli* 0157:H7 was 0.15% for cows and 2.8% for heifers and calves (Wells *et al*. 1990 cited by Bell *et al.* 1994).

The possibility exists that animal feces containing *E. coli* 0157:H7 could contaminate a stream and eventually the marine water, where this bacterium could be concentrated in shellfish. This is essentially what researchers at the U.S. Food and Drug Administration (FDA) Seafood Products Research Center concluded after conducting experiments on *E. coli* 0157:H7 survival rates in waters of varying salinities and temperatures and in oysters injected with this bacterium (Kaysner *et al.* 1994). They concluded, "It appears that *E. coli* 0157:H7 can survive under aquatic (freshwater) and estuarine conditions for extended periods which may lead to possible contamination of shellfish and their growing area."

It should be understood that *E. coli* 0157:H7 is a relatively rare strain of *E. coli* and one should not equate this rare pathogenic strain with the much more prevalent non-pathogenic ones. *E. coli* 0157:H7 has not been associated with this study or any other monitoring study conducted in Jefferson County.

The state fecal coliform standard has two parts. For all of Jefferson County's streams, Part 1 requires that the geometric mean value (GMV) not exceed 50 colonies of fecal coliform bacteria in 100 milliliters of water (50 FC/100mL). Part 2 requires that not more than 10% of the samples exceed 100 FC/100 mL. Both parts need to be met to pass the standard. Additionally, wet months (October – May) and dry months (June – September) are analyzed separately and the standard must be met during both periods.

Based on these criteria, three of 28 stations passed the standard in 2011-12 (Table 1). These were the upstream control stations on Naylors Creek (NA/1.3), Barnhouse Creek (BH/1.0), and East Chimacum Creek (ECH/5.3). In 2009-10, two stations passed the standard, and in 2007-08, no stations passed. Currently, Chimacum Creek stream reaches near stations CH/0.1 and CH/3.4 are on Ecology's 303(d) list for failing the fecal coliform standard.

Table 1. Chimacum watershed monitoring stations showing status relative to the state fecal coliform standard. Part 1 of the standard requires that the geometric mean value (GMV) not exceed 50 FC/100 mL and part 2 requires that not more than 10% of the samples exceed 100 FC/100 mL. Both parts need to pass for the standard to be met. Stations were monitored once per month from October to May and twice per month from June to October in 2007-08 and 2009-10; stations were monitored once per month from October to September in 2011-12.

Station	2007-08				2009-11				2011-12			
	October to May		June to September		October to May		June to September		October to May		June to September	
	Part 1	Part 2	Part 1	Part 2	Part 1	Part 2	Part 1	Part 2	Part 1	Part 2	Part 1	Part 2
CH/0.1	Fail	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Fail
CH/1.1	Fail	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Fail	Fail	Fail	Pass
CH/2.0	Fail	Fail	Fail	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Fail	Pass
CH/3.4	Fail	Fail	Fail	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Fail	Pass
CH/4.1	Fail	Fail	Fail	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Pass
CH/5.3	Fail	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Fail
CH/6.7	Fail	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Fail
CH/7.0	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Fail
CH/7.8	Fail	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Fail	Fail	Fail	Fail
CH/8.4	Fail	Fail	Fail	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Fail	Fail
CH/8.8	Fail	Fail	Fail	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Fail	Fail
CH/9.0	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Fail	Fail
CH/9.3	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Pass
PU/0.0	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Fail
PU/0.4	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Fail	Pass	Pass	Fail	Fail
NA/0.1	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
NA/0.7	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
NA/1.3	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
WV/0.1	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Fail
EG/0.0	Fail	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Fail
BH/0.0	Fail	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Fail
BH/1.0	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Pass	Pass	Pass
ECH/0.2	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Fail	Fail
ECH/1.0	Pass	Fail	Fail	Fail	Pass	Fail	Pass	Pass	Pass	Fail	Fail	Fail
ECH/3.3	Fail	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Fail
ECH/4.8	Fail	Fail	Fail	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Fail	Fail
ECH/5.3	Pass	Fail	Pass	Pass	Pass	Fail	Pass	Fail	Pass	Pass	Pass	Pass
SW/0.3	Pass	Fail	Fail	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Fail	Fail

Figure 8 shows the GMVs for the 28 monitoring stations (see map, Figure 5) based on the entire water-year. The highest GMV (185 FC/100 mL) occurred on Naylors Creek at NA/0.7 on West Valley Road. Next highest (132 FC/100 mL) occurred on Chimacum Creek's main stem at CH/7.8 on Egg and I Road. Several stations on Chimacum Creek's main stem exceeded or approached the 50 FC/100 mL standard from station CH/8.8 on Eagle Mount Road downstream to station CH/0.1 at the upper end of the estuary in Irondale. Station PU/0.0 near the mouth of Putaansuu Creek had a GMV of 89 FC/100 mL. Although two of the five stations on East Chimacum Creek had GMVs approaching the standard, none of the stations exceeded it. Fecal coliform GMV ranges for stream reaches throughout the watershed are color-coded on the map in Figure 5.

Fecal coliform trends at downstream and other key stations are shown in Figures 9 and 10. Chimacum Creek's main stem station CH/3.4, located at the State Route 19 bridge in Chimacum, is at the downstream end of about 6 miles of agricultural land including several cattle operations. Data collected from 1988 to 2012 at this station shows a downward trend (Figure 9). Downward trends were also observed at stations ECH/0.2 on East Chimacum Creek and BH/0.0 on Barnhouse Creek (Figure 10). Upward trends were observed at stations NA/0.1 on Naylors Creek and PU/0.0 on Putaansuu Creek (Figure 10). Beginning in 2007-08, fecal coliform concentrations began increasing substantially at station NA/0.7 on West Valley Road. Since there is no agriculture upstream from this station, the source appears to be human. Whereas, the increasing trend on Putaansuu Creek appears to be agricultural. Livestock are pastured on both sides of the stream from Chimacum Creek to West Valley Road. The 2011-12 fecal coliform GMV was 89 FC/100 mL at station PU/0.0 near Chimacum Creek compared to a GMV of 19 FC/100 at station PU/0.4 at West Valley Road upstream from the pasture. This 0.4 mile reach is fenced at the top of the bank, but has two gaps for watering livestock.

At station CH/0.1, closest to the marine water and shellfish beds, the trend from 2007 to 2012 is essentially flat, showing neither increase nor decrease (Figure 10). Station CH/1.1 at Irondale Road, which has a longer monitoring period (1988-2012), shows a slightly downward trend (Figure 10).

Loading, which takes into account stream flow as well as concentration, is shown for downstream stations in Figures 11 and 12. Loading was highest in both the wet season October – May) and dry season (June – September) at Chimacum Creek's downstream station CH/0.1. Undoubtedly, the greater flow at this station, which receives water from the entire watershed, is a large contributing factor to the higher loading. The high average loading (160.1 billion FC/day) at station CH/0.1 in the 2011-12 wet season (Figure 11) was largely due to the exceptionally high flow (82.2 cfs) combined with an exceptionally high fecal coliform concentration (1,380 FC/100 mL) which occurred on March 13, 2012. Loading on this day was 2,791 billion FC/day. Rainfall for the 24-hour

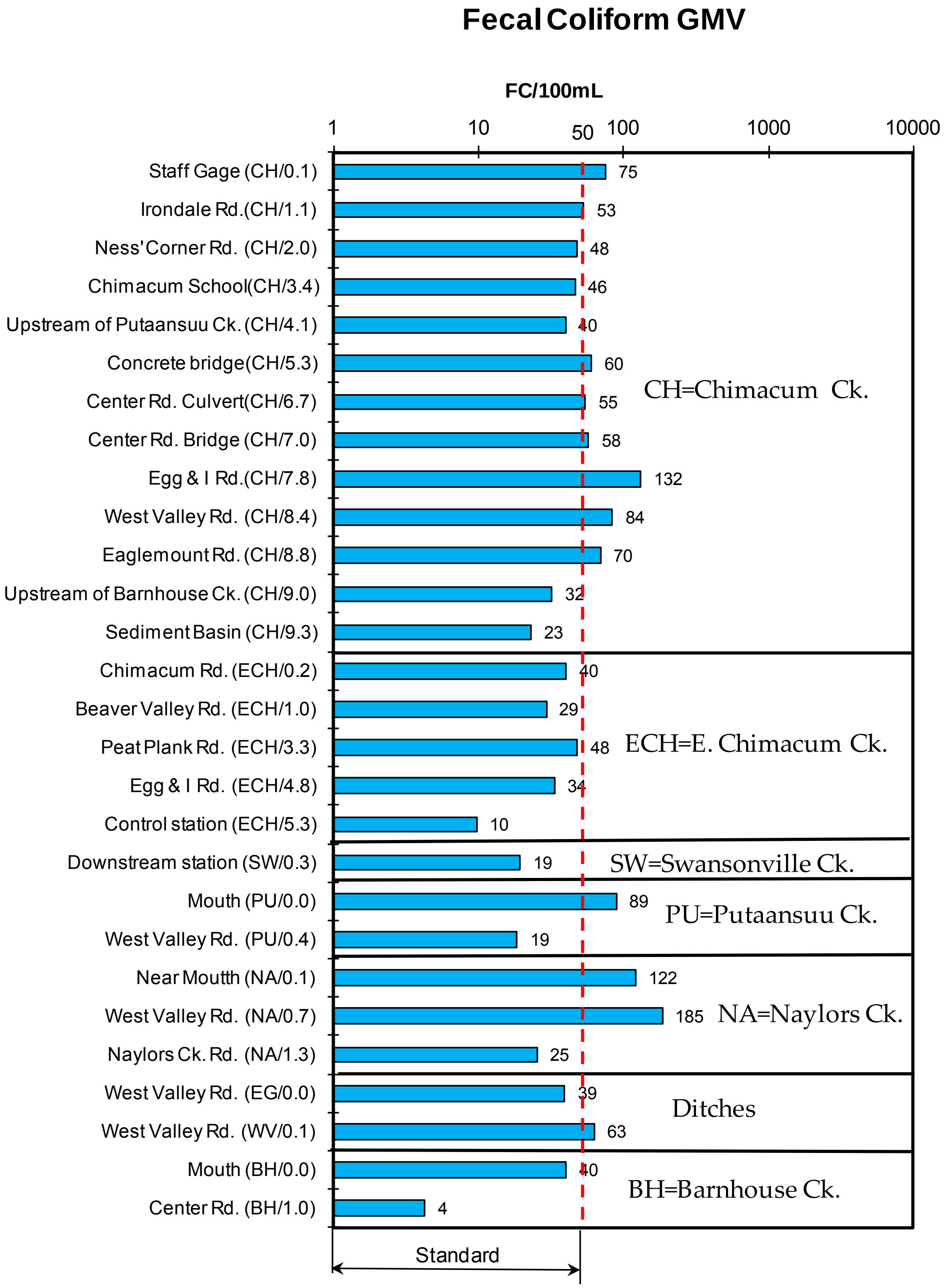


Figure 8. Fecal coliform GMVs for stations monitored monthly in the Chimacum watershed during the 2011-12 water-year. The fecal coliform standard is indicated by the dashed red line.

Fecal Coliform

Chimacum Creek at CH/3.4

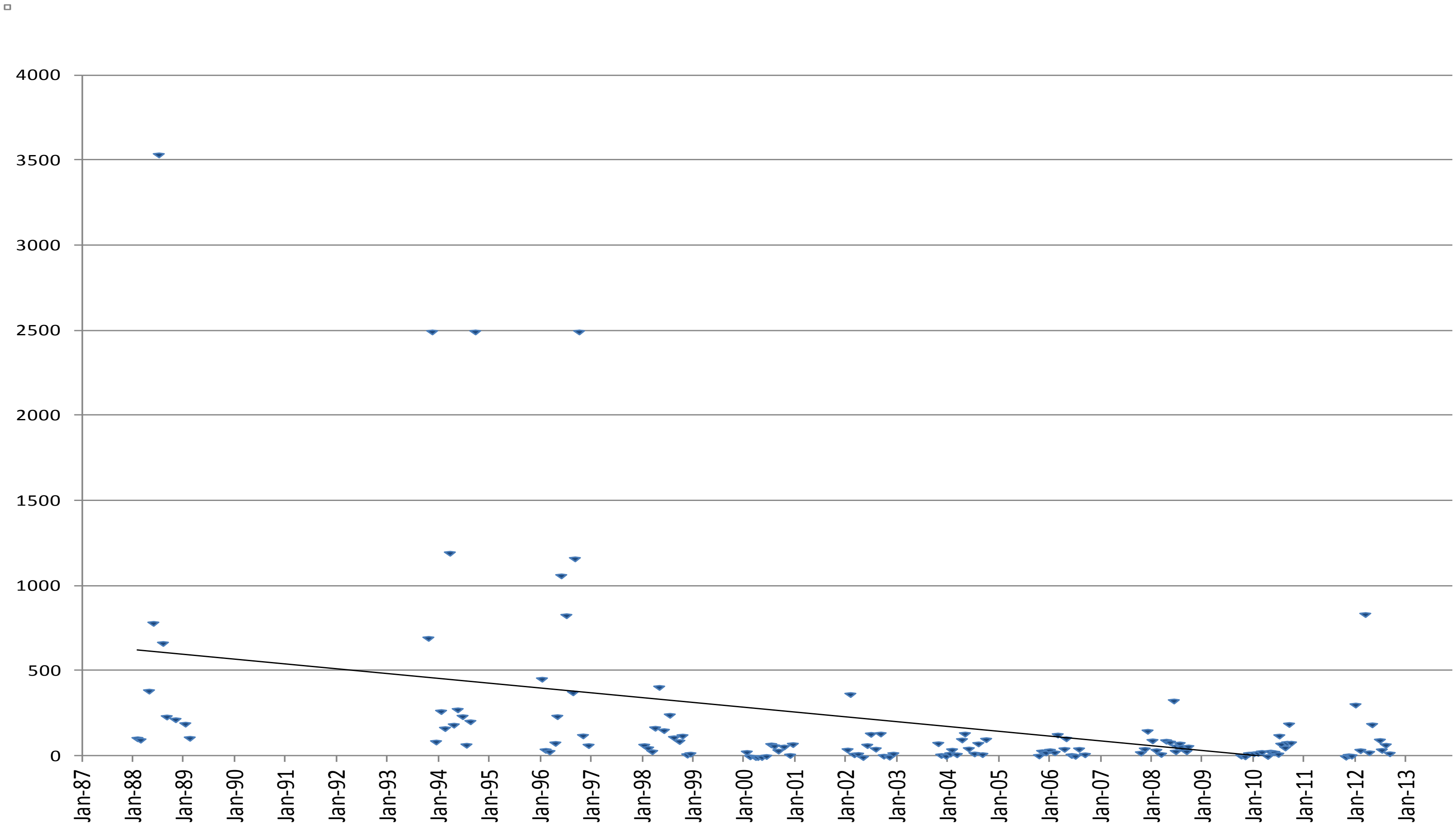


Figure 9. Time series plot of fecal coliform concentration (with regression line) at Chimacum Creek station CH/3.4, located at the SR 19 bridge. Station CH/3.4 is downstream of about 6 miles of agricultural land.

Fecal Coliform

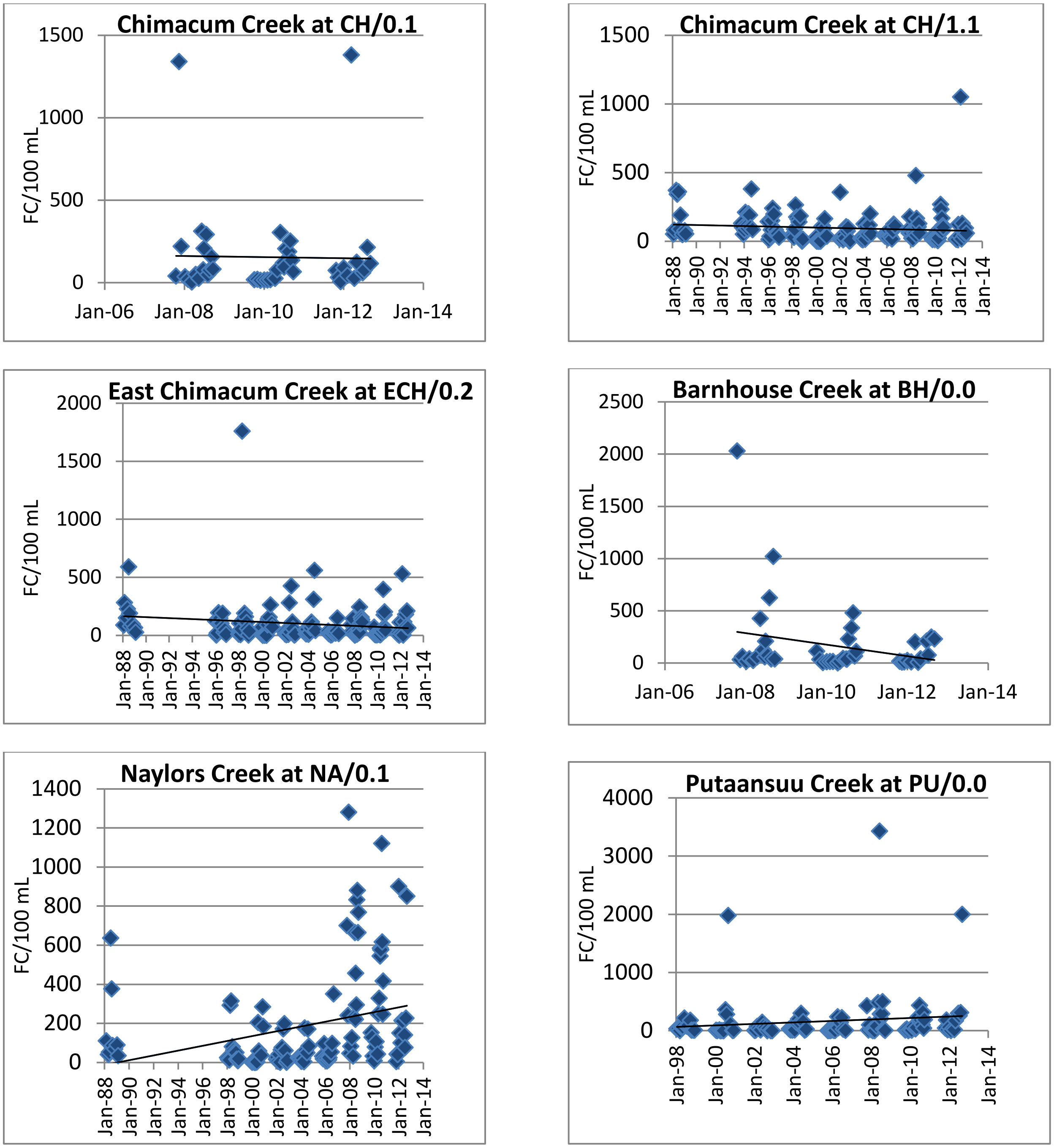


Figure 10. Time series plots of fecal coliform concentration (with regression line) at downstream stations on Chimacum Creek and tributaries. Note different scales used in different graphs.

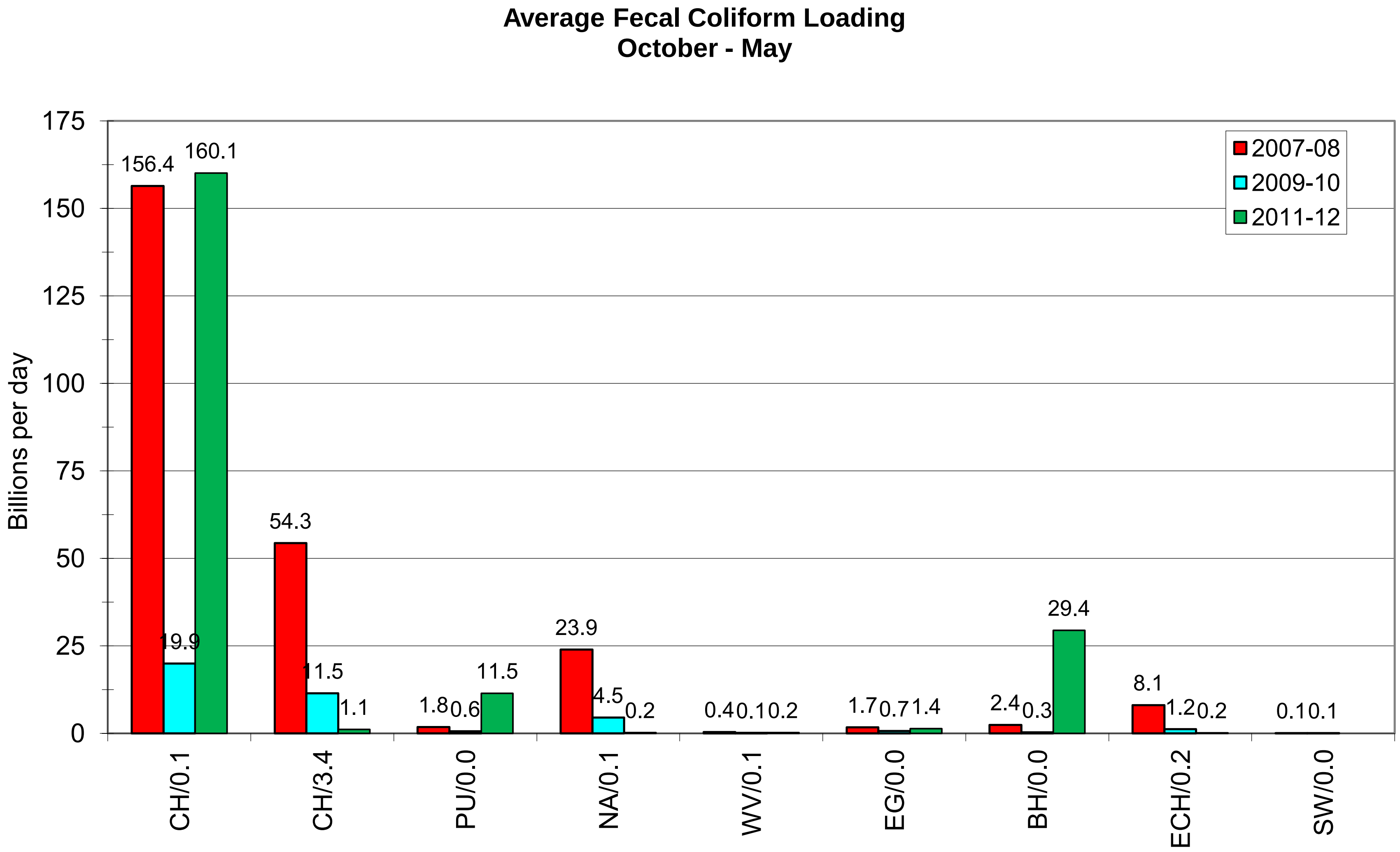


Figure 11. Average fecal coliform loading for stations in the Chimacum watershed monitored once per month from October to May in 2007-08, 2009-10, and 2011-12.

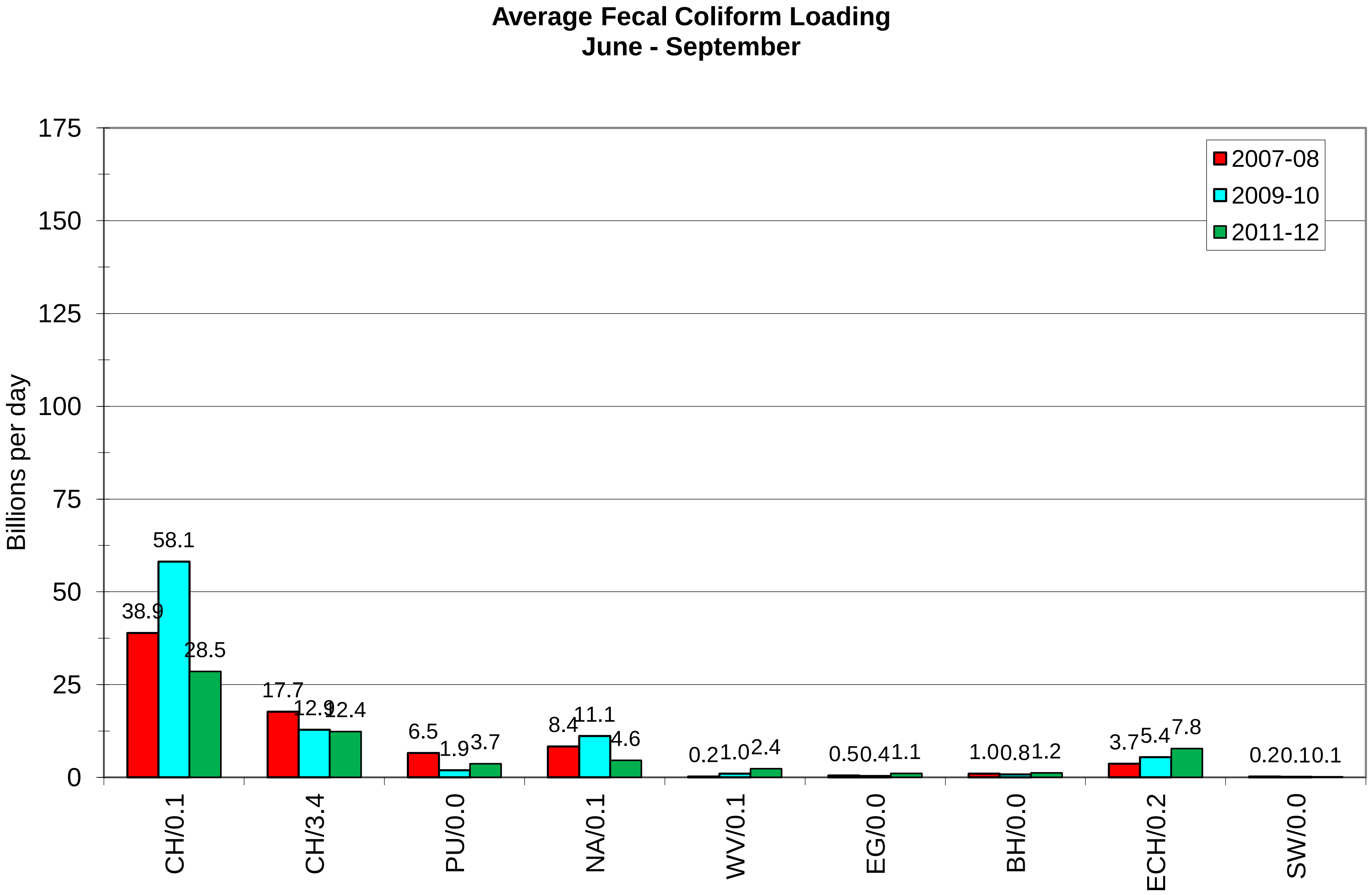


Figure 12. Average fecal coliform loading for stations in the Chimacum watershed monitored twice per month from June to September in 2007-08 and 2009-10 and once per month in 2010-11.

period measured at 9:00 AM on March 13 was 0.95 inches and 3-day rainfall preceding sampling was 1.57 inches. Eight of the 28 stations monitored, all on Chimacum Creek's main stem and East Chimacum Creek, had the highest concentration of the 2011-12 water-year on this date. Rainfall, especially heavy rainfall that results in surface runoff, can wash animal waste into the stream channel and can cause fecal coliform bacteria to enter the stream via groundwater. Fecal coliform concentration at station CH/0.1 was positively correlated with rainfall in the 2011-12 water-year (n=12; p=0.0000).

Rainfall can also increase fecal coliform concentration by re-suspending bacteria living in the bottom sediment. Of the 11 months that turbidity was measured at station CH/0.1 in the 2011-12 water-year (no measurement was made in July), turbidity was highest (16.9 NTU) on March 13.

Numerous studies have shown that fecal coliform bacteria can survive and multiply in bottom sediment and that on a volume basis are much more numerous in the bottom sediment than in the overlying water (Stephensen and Rychert 1982; Skinner et al. 1984; Marino and Gannon 1991; Sherer et al. 1992; Howell et al. 1996; Davis et al. 2005).

Davis et al. (2005) reported that *Escherichia coli (E. coli)* concentrations in Arkansas spring water increased rapidly during the rising limb of a storm hydrograph, peaked prior to or coincident with the peak of the storm pulse, and then declined rapidly, well before the recession of the storm hydrograph. They suggested that *E. coli* are associated with re-suspension of sediment during the onset of turbulent flow.

Grimes (1980) showed that dredging in the Upper Mississippi River caused bacterial levels to increase in the water column. Fecal coliform levels were 4 times greater immediately below the dredge discharge pipe than in samples upstream from the dredge and fecal streptococcus was 50 times greater downstream from the dredge. Both fecal coliform and fecal streptococcus concentrations were correlated with turbidity levels at the downstream site.

Struck (1988) reported correlations between fecal coliform levels in the water column and bottom sediment with rainfall and turbidity in Minter Creek, Washington.

In laboratory experiments, Gerba and Mcleod (1976) showed that E. coli survived longer in seawater with sediment than in seawater alone and attributed the longer survival to the greater organic content of the sediment compared to the seawater.

Goyal and Adams (1984) found *E. coli* and several other fecal bacteria in sediment and overlying water from a sewage sludge dumpsite 46 miles off the Delaware-Maryland coast 30 months after cessation of sludge dumping.

Fecal coliform concentrations in the Chimacum Creek watershed from 1993 to 2012 were correlated to turbidity (n= 2,232; p=0.0000).

Despite the positive correlation between fecal coliform concentration and rainfall and turbidity, the fecal coliform standard in the Chimacum watershed was exceeded more often during the dryer, warmer months than during the wetter, colder months (Table 1, Figure 13). Regression analysis of data collected from 1993 to 2012 in the Chimacum watershed showed a positive correlation of fecal coliform concentration with temperature (n=2,226; p=0.0000).

Higher fecal coliform concentrations during summer months have been found in other studies. Clark and Norris (2000) reported that fecal coliform concentrations in Wyoming streams were generally higher from April through September than from October through March and that fecal coliform concentrations were positively correlated to temperature.

Town (2001) reported a moderate positive correlation between temperature and fecal coliform concentration in Pennsylvania streams. Concentrations were higher when water temperatures were greater than about 15^oC (usually from June to September) than they were when water temperatures were less than about 15^oC (usually during March and April).

Hyer and Moyer (2003) reported that fecal coliform concentrations in three Virginia streams were highest in the summer and lowest in the winter.

McFeters et al. (1978) also found coliform bacteria concentration to be correlated to temperature, but they also discovered something even more interesting in their investigation of an unpolluted, pristine mountain stream in Grand Teton National Park. In this small stream, which is an outlet to a high elevation lake, total coliform counts were consistently greater than 200 colonies/100 mL in midsummer. Concurrent with the increase in bacteria was the emergence of periphyton (benthic algae) on rocks in the stream. Further investigation in the laboratory using *Escherichia coli* and *Klebsiella* led them to conclude that the bacteria were growing and multiplying on algal excretory products.

Ksoll et al. (2007) found that fecal coliform bacteria, including *E. coli*, were growing in periphyton communities on rocks along the shoreline of Lake Superior. Densities peaked (1,400,000 colonies per square centimeter) in late July. DNA analysis showed that most (68-99%) of the identifiable *E. coli* strains were from waterfowl. In accompanying laboratory experiments, *E. coli* rapidly occupied periphyton communities, persisted in them for several weeks, and released *E. coli* cells to the overlying water. At the end of the experiment, agitation of the water caused an abundance of the *E. coli* cells to be released from the periphyton into the overlying water, yielding a concentration of 500 colonies/100 mL.

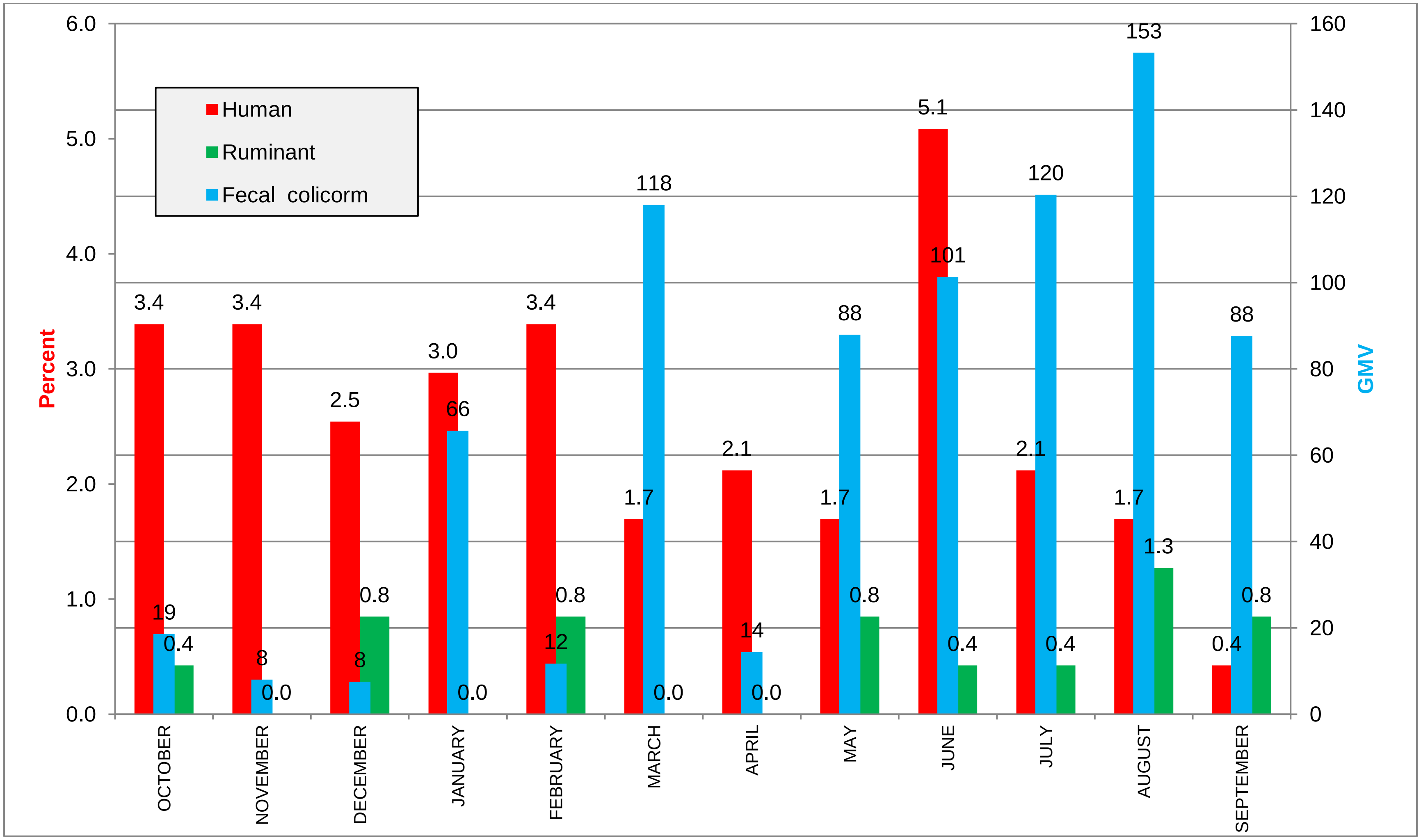


Figure 13. Percent frequency of occurrence by month of human and ruminant markers detected in samples collected at the 20 MST monitoring stations in the Chimacum watershed in the 2011-12 water-year, compared to fecal coliform monthly GMVs based on samples collected at all 28 monitoring stations.

Ksoll et al. (2007) concluded, "…although many *E. coli* strains isolated from periphyton may have originated from waterfowl and sewage effluent, other strains appeared to be unique to the periphyton that we studied and may have developed self-sustaining populations in these communities. *E. coli* cells attached to periphyton, whether they are unique to these periphyton communities or not, can detach and contribute to fecal coliform numbers measured in coastal waters. The presence, persistence, and possible naturalization of *E. coli* in periphyton communities further confound the use of fecal coliform as a reliable indicator of recent fecal contamination of recreational waters."

Whitman et al. (2003) sampled *Cladophora*, a filamentous alga, from 10 beaches in Lake Michigan. *E. coli,* as well as enterococci, was found in up to 97% of the samples. Based on these findings the investigators concluded that algae "may be an important environmental source of indicator bacteria and call into question the reliability of *E. coli* and enterococci as indicators of water quality for freshwater recreational beaches."

Taking the previous results a step further, Byappanahalli et al. (2003) determined that the *Cladophora* provides a suitable environment for indicator bacteria to persist for extended periods and to grow under natural conditions.

This relationship between algae and bacteria may help to explain the high fecal coliform concentrations that consistently occur in Chimacum Creek in the summer. Aquatic vegetation, including algae, is abundant in much of Chimacum Creek and its tributaries. Several factors account for this abundance. First of all, despite many miles of stream being planted with trees under the Conservation Reserve Enhancement Program, much of Chimacum Creek and its tributaries remain unshaded. Second, much of Chimacum Creek flows through nutrient-rich peat soils. Third, much of the watershed has an extremely low gradient. The low gradient, combined with low summer flow (Figure 4) produces pond-like characteristics, including a silt bottom and aquatic vegetation, both of which provide a substrate for algae to grow on.

In 2012, the Environmental Protection Agency recommended that states use the fecal indicator bacteria enterococci and *E. coli* as indicators of fecal contamination in fresh water and enterococci as an indicator in marine water (USEPA 2012). Washington Department of Ecology has "recreational criteria" on their 5-year review schedule and will be evaluating other potential indicators of fecal contamination. Another factor of Ecology's criteria selection relates to the criteria used by the National Shellfish Sanitary Protection (NSSP) program administered by the FDA. The NSSP's marine criteria for shellfish protection will continue to be based on fecal coliform concentration as long as the current FDA standards remain in place. Freshwater TMDLs for Washington waters must meet standards for immediate receiving waters as well as for downstream uses such as those of downstream marine waters. Therefore, many freshwater bacteria TMDLs flowing to marine waters will continue to have fecal coliform load allocations calculated to meet the most sensitive use in the watershed – shellfish harvesting. (Chad Brown, Ecology, personal communication, September 2014).

Of the 27 streams monitored in eastern Jefferson County in recent years, Chimacum Creek had the next to the highest entire-year GMV (75 FC/100 mL), only exceeded by Cemetery Drain (206 FC/100 mL; Figure 14). Tarboo Creek had the third highest GMV (67 FC/100 mL) and Donovan Creek had the fourth highest (65 FC/100 mL).

Fecal Coliform in the Marine Water

Consumption of shellfish is the most likely way for humans to be exposed to potential pathogens in water polluted by human or animal wastes. Ingestion when swimming is another possible way. Washington Department of Health (DOH) collects water samples at stations throughout Puget Sound and Hood Canal and issues annual reports on its findings. DOH maintains a monitoring station (number 32) off the mouth of Chimacum Creek (Figure 5). In DOH's latest report the GMV for 31 samples collected from December 2008 to November 2013 was 2.6 FC/100 mL with a 90th percentile of 9.0 FC/100 mL and a range of 1.7 FC/100 mL to 110.0 FC/100 mL.

The state standard for fecal coliform in salt water is different than that of fresh water. For salt water, the GMV should not exceed 14 FC/100 mL and the 90th percentile should not exceed 43 FC/100 mL. Although station 32 easily met the standard, it is noteworthy that it had the next to the highest GMV of the 17 stations monitored in Port Townsend Bay and the highest 90th percentile.

Given the location of station 32 off the mouth of Chimacum Creek, it is likely that Chimacum Creek is a contributing source of fecal coliform in samples collected at this station. Evidence of it being a source is indicated by a negative correlation (p=0.0000) between fecal coliform concentration and salinity measured at station 32 (Figure 15). In other words, the fecal coliform concentration was higher when there was more fresh water in the sample, implicating Chimacum Creek.

Also implicating Chimacum Creek was a higher average concentration in samples collected on an outgoing tide than on an incoming tide. The arithmetic mean concentration of 75 fecal coliform samples collected from 1989 to 2013 on an outgoing tide was 7.2 FC/100 mL compared to a mean of 4.2 FC/100 mL for 75 samples collected during the same period on an incoming tide (Wilcoxon rank sum test, p=0.09).

At marine station 32, regression of fecal coliform concentration on temperature showed a slight decrease in concentration with increasing temperature, but the correlation was not statistically significant (p=0.24; Figure 15,). In Discovery Bay, fecal coliform sampled at DOH marine station 48 off the mouths of Snow Creek and Salmon Creek was positively correlated to temperature (Spearman rank P=0.04 and negatively

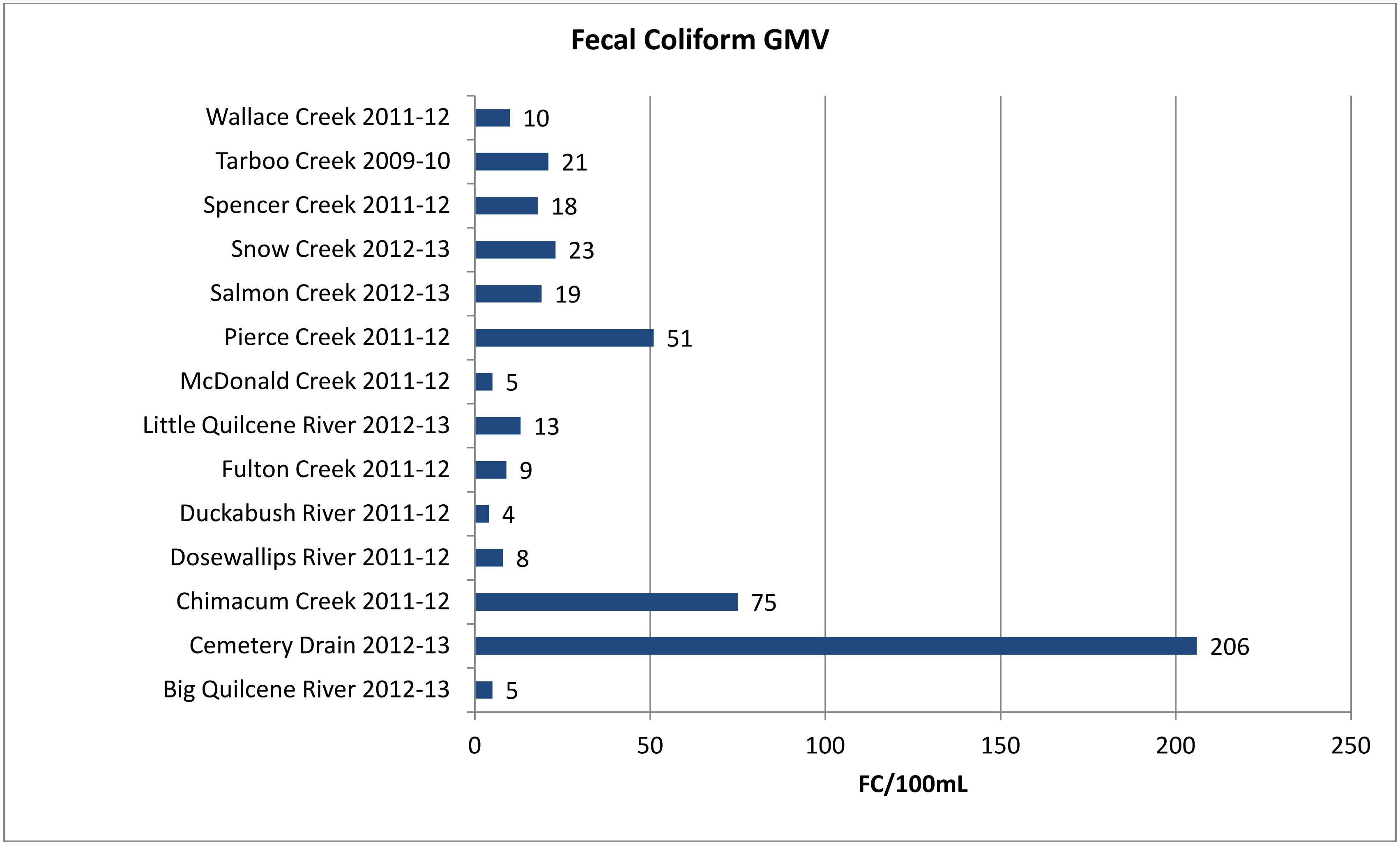
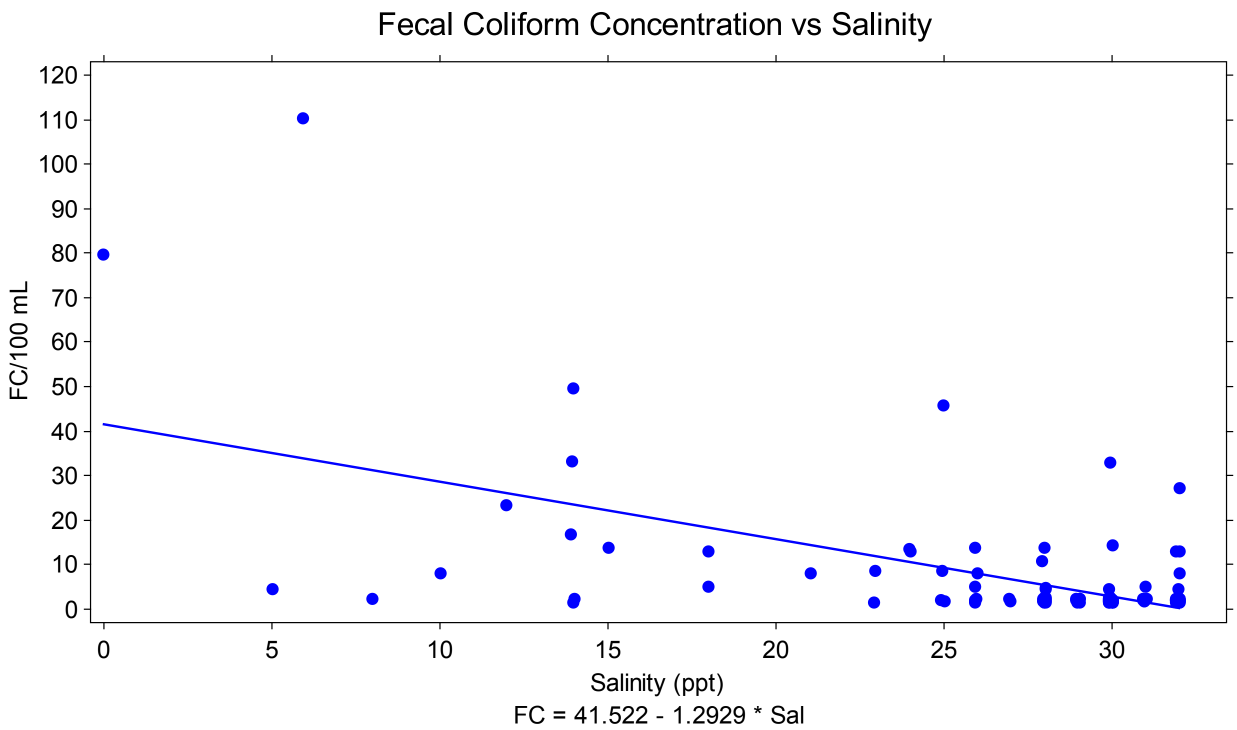
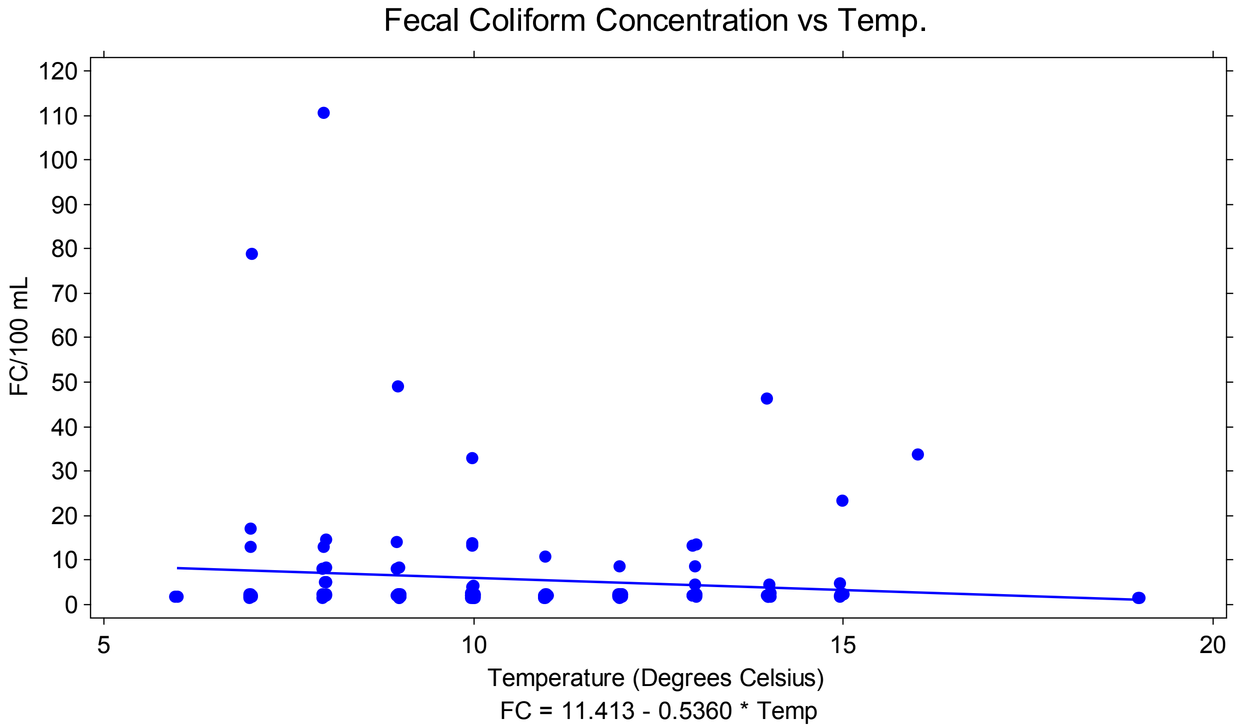


Figure 14. Fecal coliform GMV for Chimacum Creek downstream station CH/0.1 compared to GMVs for other Jefferson County streams monitored at downstream stations.


Fecal Coliform Concentration vs Salinity

FC = 41.522 - 1.2929 * Sal


Fecal Coliform Concentration vs Temp.

FC = 11.413 - 0.5360 * Temp

Figure 15. Regression of fecal coliform concentration on salinity (top; p=0.0000) and temperature (bottom; p=0.24) for samples collected at Station 32 off the mouth of Chimacum Creek every other month from 1989 to 2013. Data courtesy of Washington Department of Health Office of Shellfish and Water Protection.

correlated to salinity (P=0.08; Gately et al. 2007) In the fresh water studies, as previously mentioned, fecal coliform concentration increased with increasing temperature.

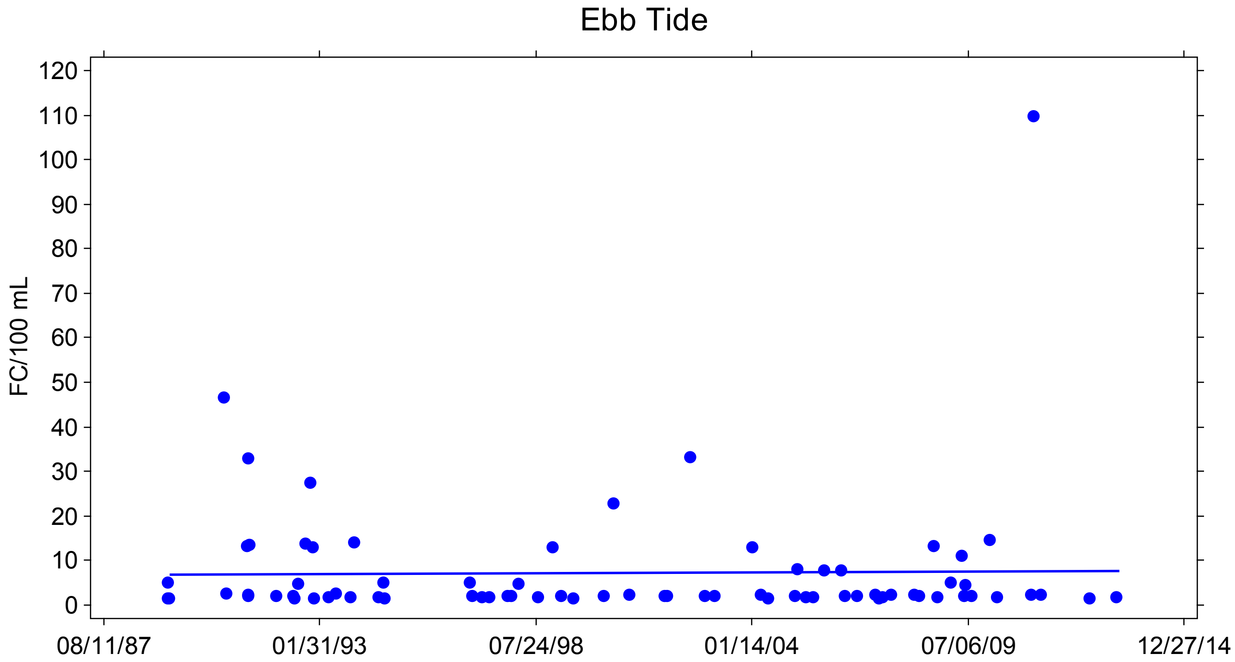
Regression of fecal coliform concentration against time showed a very slight increase for samples collected on an ebb (outgoing) tide and a slight decrease for samples collected on a flood (incoming) tide (Figure 16). However, neither correlation was statistically significant (p=0.87 and p=0.32 respectively).

Another possibility affecting the fecal coliform concentration at marine station 32 needs to be mentioned. A small rivulet enters the marine water about 2000 ft. south of the mouth of Chimacum Creek. This small rivulet was sampled 70 times by Jefferson County Environmental Health Department for *E. coli* from April 16, 2013 to August 27, 2014. Its flow was estimated by the floating stick method once on April 16, 2013 and has been considered to be fairly constant throughout the monitoring period (Michael Dawson, personal communication, September 2014). *E. coli*, which generally composes most of the fecal coliform bacteria, ranged from 126 colonies/100 mL (Most Probable Number) to 24,192 colonies/100 mL with a GMV of 3,580 colonies/100 mL. E. coli loading, based on a constant flow of 0.087 cfs ranged from 0.3 billion colonies per day to 51.8 billion colonies per day with an average loading of 11.1 billion colonies per day. Chimacum Creek's average fecal coliform loading in 2011-12 was 28.5 billion per day in the dry months and 160.1 billion per day in the wet months (Figures 11 and 12). Thus, this small rivulet with very high fecal coliform concentrations could be a contributing factor to the marine fecal coliform concentration at marine station 32 and vicinity.

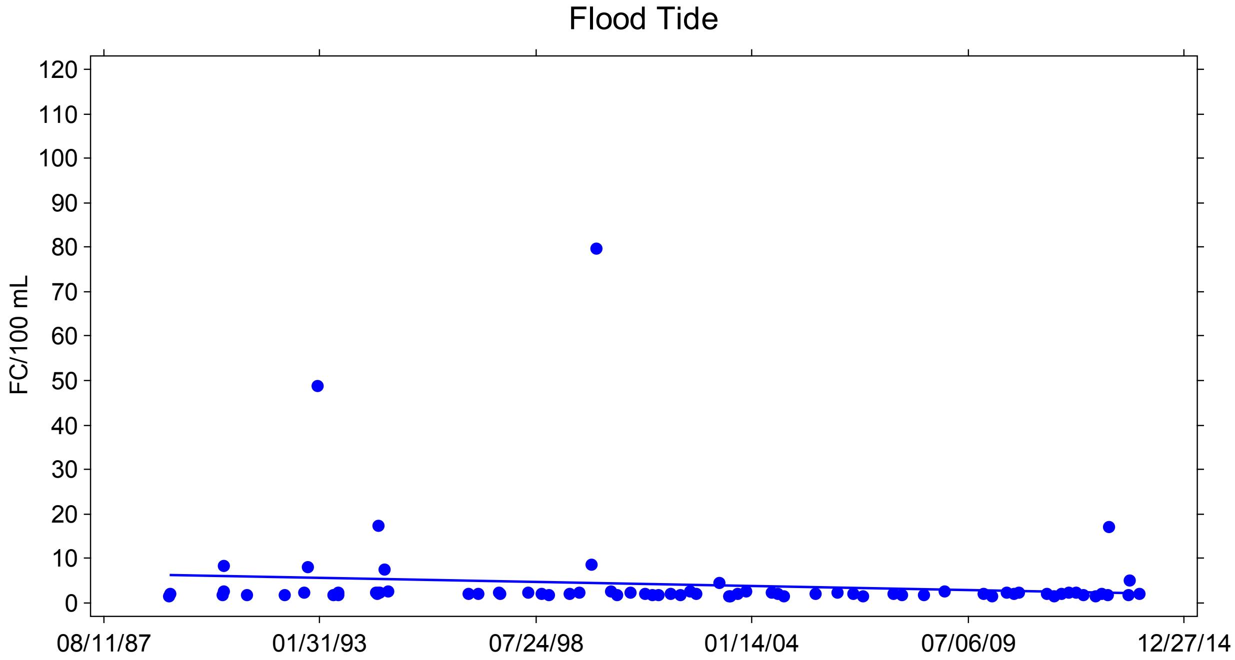
***Bacteroides* - Microbial Source Tracking**

When fecal coliform concentrations are high, the question is always asked, "What is the source"? Since fecal coliform bacteria are in the intestinal tracts of all warm-blooded organisms, sources could be humans, livestock, pets, or wildlife. Fecal coliform analysis does not differentiate between these sources. However, since the advent of DNA testing, it is possible to narrow down the contaminant source. The high cost (about $100/sample) has prevented the District from using microbial source tracking (MST) in the past. However, monitoring in this study was funded by an EPA grant and EPA has a laboratory that does microbial source tracking, which allowed the District to conduct microbial source tracking in 2011-12.

In interpreting the MST results, it is important to understand how the results are obtained. First of all, it is the bacteria *Bacteroides* spp. that is analyzed. Like fecal coliform bacteria, *Bacteroides* spp. reside in the gastro-intestinal tracts of all warm-blooded animals. The advantage of identifying these bacteria is that each host animal



FC = 3.2215 + 1.09E-04 * Date



FC = 21.442 - 4.61E-04 * Date

Figure 16. Regression of fecal coliform concentration on date for samples collected during ebb tide (top; p=0.87) and flood tide (bottom; p=0.32) at Station 32 off the mouth of Chimacum Creek every other month from 1989 to 2013. Data courtesy of Washington Department of Health Office of Shellfish and Water Protection.

carries a specific kind of *Bacteroides.* The first test is a “general” one to determine if any kind of *Bacteroides* is present. If none is found, testing ceases and the result is designated “absent.” If *Bacteroides* is present, the sample is analyzed for the presence of a “ruminant” biomarker and up to two “human” biomarkers. If the first “human” biomarker tests “negative,” a second, different biomarker is tested for. If either of the two biomarkers test positive, the result is designated “positive.” Only one biomarker is tested for “ruminant.” A ruminant is an animal with multiple stomachs which chews a cud, and includes cattle, sheep, goats, buffalo, elk, and deer.

Unlike fecal coliform analysis, there is no numerical count of *Bacteroides* bacteria, and therefore no concentration figure. MST results are based solely on presence or absence. Percent frequency of occurrence is the closest one can assign a quantitative value to *Bacteroides*. Frequency of occurrence is the number of positive outcomes divided by the total number of tests.

If DNA analysis was 100% accurate and a sample tested positive for “general” and negative for both “human” and “ruminant”, one could conclude that the *Bacteroides* bacteria came from a non-human/non-ruminant animal. Unfortunately, as the following duplicate and blind sample results show, that is not the case.

Below are the results of duplicate samples, obtained in the laboratory from the same sample bottle:

Microbial Source Testing Duplicates

Date	Station	Run #1	Run #2
10/26/2011	NA/0.1	Human	General
10/26/2011	CH/1.1	Human	Human
11/15/2011	NA/0.1	Human	General
11/15/2011	CH/7.8	General	General
12/6/2011	NA/0.1	Human	General
12/6/2011	NA/0.7	Human	Human
1/3/2012	WV/0.1	General	General
1/3/2012	EG/0.0	General	General
2/7/2012	PU/0.0	Human	Human
2/7/2012	ECH/1.0	General	General
3/13/2012	CH/8.8	General	General
3/13/2012	BH/0.0	General	Human
4/10/2012	ECH/4.8	Human	Human
4/10/2012	ECH/0.2	General	Human
5/1/2012	CH/7.0	Human	Human
5/1/2012	NA/1.3	Ruminant	Ruminant
6/26/2012	EG/0.0	General	General
6/26/2012	NA/0.1	Human	Human
7/10/2012	CH/1.1	General	General
7/10/2012	WV/0.1	Absent	General
8/7/2012	CH/7.0	General	General
8/7/2012	CH/5.3	Human	General
9/4/2012	CH/8.8	General	General
9/4/2012	CH/2.0	General	Ruminant

As these results show, out of 12 pairs of duplicates in which at least one of the pair tested “human,” six tested “human/human” and six tested “human/general.” Similarly, out of 2 pairs of duplicates in which at least one tested “ruminant,” one pair tested “ruminant/ruminant” and the other tested “ruminant/general.” These duplicate results suggest that many of the samples which tested “general” could actually be “human” or “ruminant.” Based on the frequency of mismatched pairs (50% for “human” and 50% for “ruminant”), one might expect there to be twice as many “human” results and twice as many “ruminant” results as reported. Admittedly, the sample size for “ruminant” is very small.

In one case one pair tested “absent/general.” This suggests that some “absent” results could have been “general.”

The reason for the disagreement in some of the duplicates could be due to a paucity of “ruminant” or “human” *Bacteroides* in the sample compared to a much larger number of “general” *Bacteroides*. When the 250-mL sample is shaken and divided into two 100-mL aliquots, one aliquot could receive all of the “human” or “ruminant” *Bacteroides* and the other aliquot receive none.

In addition to the analysis of duplicate samples, accuracy was also tested with “blind” samples. Samples from various sources, known to the collector but unknown to the laboratory analyst, were submitted at different times during the study. Results were as follows:

Microbial Source Testing - Blind Samples

Date	Source	Identified as
10/25/2011	Human	Human
10/25/2011	Organic Dairy Cows	General
10/27/2011	Chicken	Ruminant
1/3/2012	Human	Human
1/3/2012	Organic Dairy Cows	General
6/3/2013	Organic Dairy Cows	General
6/3/2013	Chicken	Ruminant
6/4/2013	Human	Human
9/23/2013	Beef Cattle	Ruminant
9/23/2013	Beef Cattle	Ruminant
9/23/2013	Beef Cattle	Ruminant
9/23/2013	Beef Cattle	Ruminant & Human
9/23/2013	Human	Human

As the “blind” sample results show, all three of the organic dairy cow samples tested “general,” whereas all four of the beef cattle samples tested “ruminant.” EPA researchers in Cincinnati have found that cattle fed a diet primarily of unprocessed grains have a much lower population of microorganisms harboring the target genetic marker than those cattle fed a diet primarily of processed grains and grass. It is believed the higher levels of starch in unprocessed grains are the cause (Stephanie Bailey, EPA, personal communication, October 2014).

That the two chicken samples tested positive for “ruminant” could be explained by the fact that both samples were taken from the same flock of free-ranging chickens and that they periodically had access to deer pellets (manure). *Bacteroides* are commensalist bacteria. That is, they can live side-by-side with other bacteria in the gut of their host and cause no problems to either the host or the host’s native flora. Once *Bacteroides* is introduced to the gut it will stay there indefinitely (Stephanie Bailey, EPA, personal communication, October 2014).

All four human samples (one from the Port Townsend sewage treatment plant and three from an individual) tested “human.” One false positive “human” detection occurred with one of the “beef cattle” samples.

Of the 237 MST samples collected monthly at 20 stations, 90% tested “general,” 30% tested “human,” 6% tested “ruminant,” and 10% tested “absent” (Figure 17). When duplicate samples did not agree, the more specific result was used (i.e. “human” or “ruminant” was used instead of “general”) in calculating “frequency of occurrence.”

Based on the duplicate results which indicated a 50% mismatch between “general” and “human” and a 50% mismatch between “general” and “ruminant,” true percentages of “human” and “ruminant” could be double what was detected. This would make it 60% for “human” and 12% for “ruminant” out of the 237 samples.

Over the 12-month period, “general” occurred at all 20 stations; “human” occurred at 19 stations, all except NA/1.3; and “ruminant” occurred at 10 of the 20 stations (Figure 18).

There does not appear to be any relationship between fecal coliform concentration and frequency of occurrence of any of the MST markers (human, ruminant, and general; Figure 13). Regression analysis of the three markers yielded probabilities (p) of 0.31, 0.70, and 0.84 respectively. This lack of correlation may be due to the fact that fecal coliform bacteria survive and grow in the stream environment, whereas *Bacteroides* do not survive long in oxygenated water (Fiksdal et al. 1985; Kreader 1998).

When the District began the MST testing, it was with the assumption that there would be a large number of “ruminant” occurrences, so it was surprising that “human” was detected as often as it was at the 20 monitoring stations in the Chimacum watershed. Hyer and Moyer (2003) experienced similar results regarding the high number of “human” occurrences in their study of three Virginia streams using RNA (ribonucleic acid) “fingerprinting.” The investigators stated, “In these streams, the presence of fecal coliform bacteria was not unexpected; however, the identification of humans as one of the top three contributors in each stream was unexpected.”

Unlike the Chimacum Creek MST study which differentiated between only three sources, the Virginia study targeted a large library of potential sources. Another difference between the two studies was that the Virginia study used *E. coli* instead of *Bacteroides.* The total number of different sources identified for the three streams ranged from 18 to 21. Sources identified in the Urban Watershed that were found in 5% or more of the 279 samples were, in decreasing order of occurrence: goose, human, dog, duck, cat, sea gull, and raccoon; in the Agricultural Watershed (n=285), sources

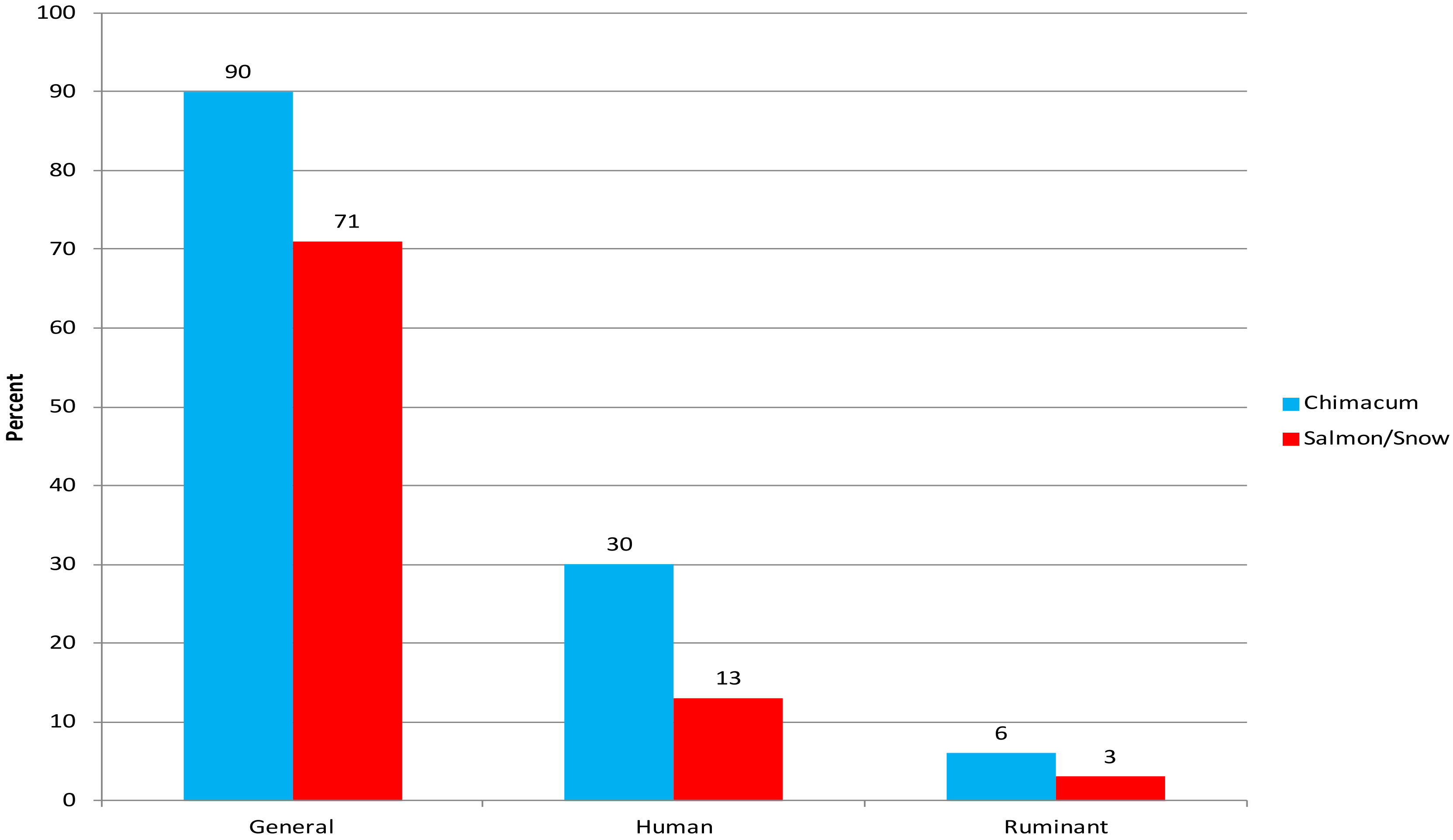


Figure 17. Frequency of occurrence of general, human, and ruminant *Bacteroides* in 237 samples collected in the Chimacum watershed in the 2011-12 water-year compared to that of 197 samples collected in the Salmon Creek and Snow Creek watersheds in the 2012-13 water-year. “General” includes all warm-blooded birds and animals including humans and ruminants. “Ruminant” represents animals that chew a cud including cattle, sheep, goats, buffalo, deer, and elk.

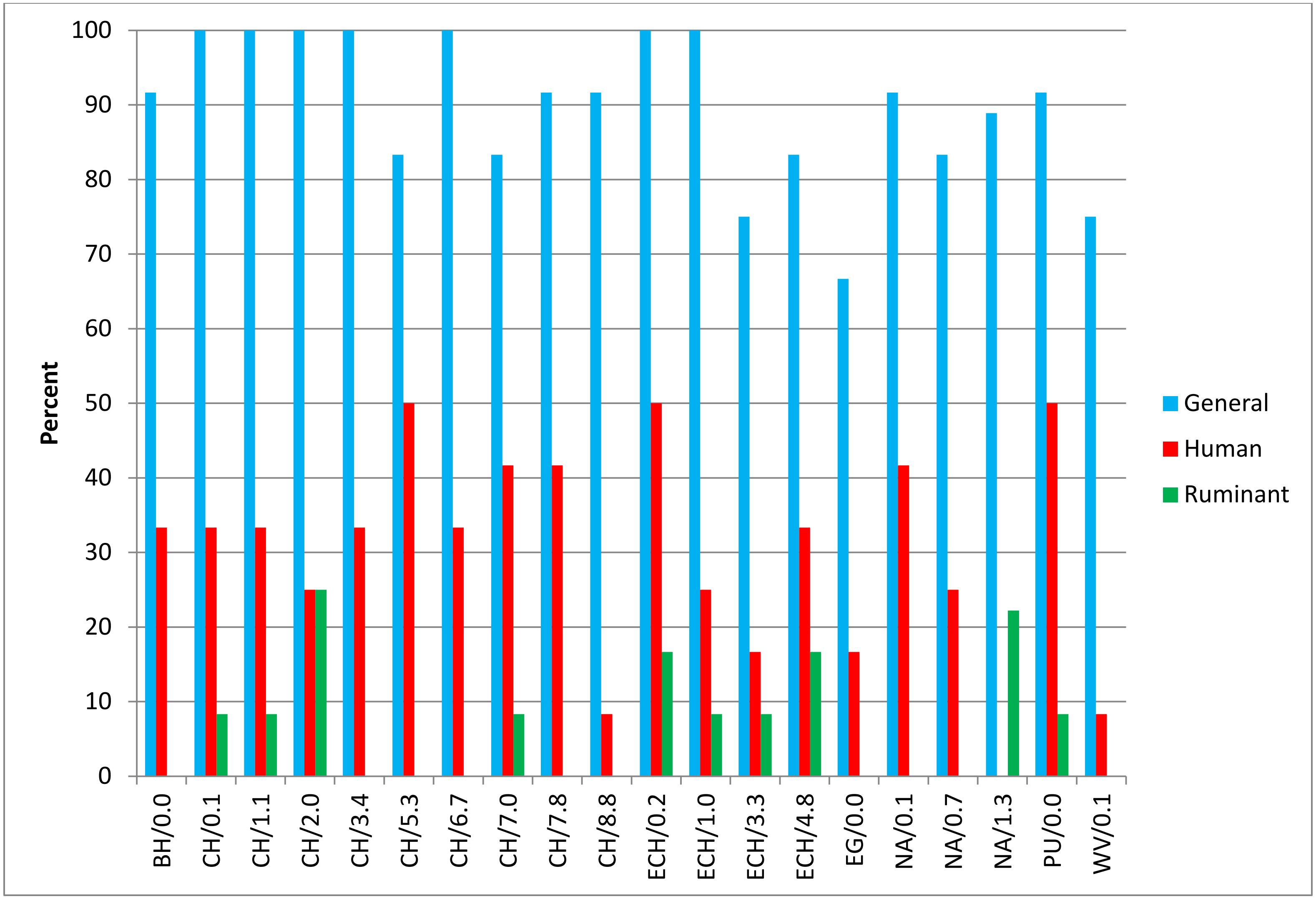


Figure 18. Frequency of occurrence of general, human, and ruminant *Bacteroides* in samples collected monthly at 20 stations in the Chimacum Watershed during the 2011-12 water-year. “General” includes all warm-blooded birds and animals including humans and ruminants. “Ruminant” represents animals that chew a cud including cattle, sheep, goats, buffalo, deer, and elk.

were: cattle, poultry, human, dog, and cat; and in the mixed Urban/Agricultural Watershed (n=274), sources were: poultry, cattle, human, dog, horse, and deer. Other animal sources that occurred in less than 5% of the samples were: opossum, sheep, rodent, coyote, pig, crow, muskrat, swan, ground hog, fox, bear, goat, skunk, and beaver.

Although the MST results are not quantitative in the way fecal coliform results are, frequency of occurrence provides some means of comparison. “Human” occurred at 95% of the Chimacum monitoring stations and “ruminant” occurred at 50% of the stations. Overall, “human” occurrences were 5 times greater than “ruminant” occurrences in the 237 samples collected.

The District, in conjunction with the EPA lab, conducted microbial source tracking in the Salmon Creek and Snow Creek watersheds in the 2012-13 water-year. All three categories (general, human, and ruminant) occurred at lower frequencies in the Salmon Creek and Snow Creek watersheds than in the Chimacum watershed (Figure 17). Seventy-one percent of the 197 (Figure 17) samples collected were positive for “general” *Bacteroide*s, compared to 90% in the Chimacum watershed; 13% were identified as “human”, compared to 30% in Chimacum watershed; and 3% were “ruminant,” compared to 6% in Chimacum watershed.

Given the unmistakable odor of surfacing septage effluent, it is unlikely that the human *Bacteroides*, detected at 95% of the monitoring stations, is entering the stream channel on the surface, but is more likely entering the stream in subsurface flow. In the 1970’s, on-site waste disposal systems (OSWDS) ranked highest in total volume of wastewater discharged directly into the groundwater and were also the most frequently reported source of groundwater contamination (Geraghty and Miller 1978).

In a properly functioning OSWDS, fecal organisms are filtered and/or adsorbed by the soil adjacent to the drainfield trenches (Viraraghavan and Warnock 1976). However, improper site selection and/or poor installation can result in surfacing of untreated effluent or subsurface escape of fecal organisms from the treatment zone (McCoy and Hagedorn 1979). A seasonally high water table can inundate the soil adjacent to the drainfield trenches and cause rapid movement of water and organisms away from the drainfield with little filtering or adsorption (Rahe et al. 1978).

In a review of subsurface drainage in agricultural soils, Jamieson et al. (2002) reported that tile drains were a major transport pathway of pathogens in agricultural land. Hunter et al. (2000 cited by Jamieson et al. 2002) monitored fecal coliform in drainage water (subsurface and surface) from an upland sheep pasture in England over a 21 month period. They observed significant fecal contamination with higher concentrations in summer than in winter. They believed that artificial land drainage represented an important transport pathway as bacteria were being transported to receiving waters during drier summer months when surface runoff was not occurring. However, as other studies cited in this report have shown, bacterial reproduction in the environment, especially in summer, is another possibility.

As previously mentioned, artificial drainage, both surface and subsurface, has been used in the Chimacum watershed to make agricultural land more productive. Various types of subsurface devices have been used over the years: “punching” drains composed of cedar shakes in the 1920’s, clay and concrete tiles in the 1950’s, and PVC/ABS pipe in the 1970’s and later (Roger Short, personal communication, February 2015). Mr. Short said that drainage in peat soil is not that effective because water does not move well in the peat, which tends to hold water.

In the absence of artificial drainage, it is believed that “preferential flow” through macropores in undisturbed soil is the primary method of transport by bacteria (Jamieson et al. 2002). Macropores result from burrowing animals, earthworms, insects, plant root holes, etc.

Stolt and Reneau (1991) reviewed over 500 publications to evaluate the cause and effect relationships between OSWDS and ground and surface water pollution. They found that Virginia OSWDS were polluting ground and surface water with bacteria, viruses, and nitrogen. OSWDS had the greatest potential to pollute if they occurred in high density areas or if they were placed in soils with high water tables and/or coarse textures. When OSWDS were located in areas with shallow aquifers, bacterial pollution was considerable.

DeWalle and Schaff (1980) examined well records and water samples covering a 30-year period for an area underlain with glacial deposits near Tacoma, Washington. The population of the area was 242,000 with 100,000 of the residents on OSWDS. As many as 35% of the wells were contaminated with coliform bacteria.

Bacteria have been shown to survive at least 70 days in groundwater (Bitton et al. 1983) and greater than 120 days in soil (Kibbey et al. 1978). Gerba et al. (1975, cited by Jamieson et al. 2002) reported survival times of enteric bacteria in soil and groundwater ranged from 2 to 4 months. Filip et al. (1988, cited by Jamieson et al. 2002) examined the survivability of several organisms in simulated conditions of saturated soil and observed that most organisms tested for, including E. coli, survived for over 100 days at 10^{o}C.

Sandhu et al. (1979) examined levels of total coliforms, fecal streptococci, and *E. coli* in water samples from 460 wells in South Carolina. Fecal streptococci and *E. coli* were found in 75% and 43% of the wells, respectively. *E. coli* levels decreased as the distance between OSWDS and the wells increased.

Lusk et al. (2011) stated that the most commonly recommended means of reducing bacterial transport from septic systems is to increase distances from the drainfield to the groundwater, thus increasing the chances for removal of pathogens and reducing the chances of pathogen transport to groundwater.

Reneau et al. (1975) examined levels of bacteria in ground and surface waters in a small (80 hectare) watershed in Virginia. Soils in the watershed were divided into three groups based on their suitability for OSWDS; 17% were suitable, 41% marginal, and 42% unsuitable. The OSWDS in marginal soil failed during periods of high precipitation. All of the OSWDS in the unsuitable soils failed. Water samples collected from ground and surface waters near failing OSWDS had high numbers of total and fecal coliform bacteria. Coliform concentrations decreased with increasing distance from the OSWDS.

Wang et al. (2004) reported that in laboratory experiments fecal coliform bacteria in dairy cow manure remained viable for over 3 months at any moisture level. Kress and Gifford (1984) found that cattle manure still produced fecal coliform counts as high as 4,200 FC/100mL after 100 days.

As with fecal bacteria from human sources, fecal bacteria from animal sources can be transported through the soil into groundwater and surface water. Howell et al. (1996) reported on the effects of cattle grazing in two Kentucky watersheds, both with deep, well-drained soils. Before grazing occurred near a spring, fecal coliform levels in the spring water exceeded the EPA standard of 200 FC/100mL in 29% of the samples. After cattle began grazing the surrounding pasture, 80% of the samples exceeded the standard.

Jawson et al. (1982) reported that fecal coliform levels exceeded the 200 FC/100 mL standard in many samples collected from a northeast Idaho stream more than a year after cattle were removed from the watershed.

The large diversity of animals that were found to be sources of *E. coli* in the previously mentioned Virginia study (Hyer and Moyer 2003) demonstrates that fecal coliform is a nonpoint source, not only in terms of location, but also in terms of sources. Besides humans and ruminants, a wide variety of wildlife contributed; geese ranked first and ducks fourth in the Urban Watershed.

Standridge et al. (1979) attributed high fecal coliform levels resulting in beach closures in a recreational lake in Madison, Wisconsin to a permanent duck population of 100-200 Mallard ducks. Valiela et al. (1991) calculated that waterfowl (ducks, geese, and swans) contributed 82% of the fecal coliform loading to Buttermilk Bay, Massachusetts from January to March, but only 7% from July to September when the birds were sparse.

Geohring et al. (1999, cited by Jamieson et al. 2002) reported that fecal coliform contamination occurred on study plots that had not received liquid dairy manure for two years and attributed it to geese, which were frequently observed on the field.

Chimacum Creek provides habitat to large numbers of geese, ducks, and trumpeter swans that undoubtedly contribute to the fecal coliform concentrations.

The survival and growth of fecal coliform bacteria in stream sediment, algae, soil, and animal manure; the capability of bacteria to infiltrate groundwater and be transported to surface water; and the variety of fecal sources, including human and wildlife, all make it a challenge to meet the “extraordinary” water quality standard set for fecal coliform bacteria in the Chimacum watershed.

These factors also make it difficult to demonstrate improvements resulting from Best Management Practices. As Wilkes and his co-authors (2013) put it, “Clearly, for systems impacted by multiple sources of fecal contamination, the mitigation benefits of a BMP could potentially be offset or clouded by other fecal pollution sources.”

Temperature

Temperature is one of the most important environmental influences on salmonid biology. The ambient water temperature determines the salmon’s internal temperature and therefore influences feeding rate, growth, metabolism, development of embryos and alevins, and timing of life history events such as upstream migration of adults, spawning, and downstream migration of smolts. Sub-lethal temperatures can effectively block migration, reduce growth, affect reproduction, inhibit smoltification, and cause stress and disease (Carter 2006).

Preferred temperatures for Coho rearing and growth have been reported as 12-14°C (Brett 1952; MacDonald et al.1991) and as 10-12°C (Konecki et al. 1995).

Washington State Department of Ecology (2002) reviewed the literature on three types of temperature studies to determine the temperature which, if exceeded, may result in adult and juvenile salmonid mortality: constant temperature studies, fluctuating temperature studies, and field studies. From this information they calculated the 7-day average of the daily maximum temperatures (7-DADMax). The 7-DADMax temperatures for these studies were as follows: constant temperature studies, 22.64°C; fluctuating temperature studies, 23.05°C and field studies, 22.18°C.

USEPA (1999) reported that temperatures in the range of 22-24°C totally eliminates salmonids from an area. USEPA (2003) Region 10 designated 16°C as the 7-DADMax temperature that should not be exceeded.

Despite the many temperature studies supporting salmonids' preference for cooler water, there exist certain conditions when warmer water (>19°C) may result in a greater condition factor (weight-length relationship), which is a measure of a fish's health. Roegner and Teal (2014) studied the condition factor of 5,536 juvenile Chinook Salmon, captured in different seasons in the lower Columbia River in relation to water temperature ranging from 4.2°C to 23.5°C. Contrary to their hypothesis that condition would decline during periods of high temperature, condition actually increased during summer when temperatures ranged from 19°C to 23.5°C. Other studies have shown that positive growth can be maintained at temperatures above 19°C if oxygen and food rations are sufficiently high (Brett et al. 1982; Clarke and Shelbourn 1986; Marine and Cech 2004). Because dissolved oxygen levels in the study area were generally above 70% saturation and an adequate food supply existed, Roegner and Teal conjectured that the high fish metabolism in summer was compensated by increased food intake, resulting in an above-average condition factor. Furthermore, they surmised that some stocks may be relatively tolerant of—or even benefit from—temperatures above 19°C due to genetic adaption.

It is possible that the high-temperature reaches of Chimacum Creek meet the oxygen and food supply conditions described in the Columbia River study. As discussed in the following section "Surface Water Dissolved Oxygen", photosynthesis results in high dissolved oxygen levels in unshaded, vegetation-rich reaches during afternoon hours, when water temperature is highest. After sundown, when dissolved oxygen declines (see Figure 29 in the Dissolved Oxygen section), temperature also declines. The nutrient-rich peat soils in these reaches may support an adequate food supply to match the salmonid's high metabolism during summer. And it is possible that Chimacum Creek's salmonids could have genetically adapted to the warmer summer temperatures in the unshaded reaches.

Higher metabolism and increased growth of salmonids in freshwater has been shown to affect their growth and survival in marine water. Ward and Slaney (1988) found that marine survival of Steelhead reared in the Keogh River, British Columbia was correlated with smolt length and weight. Thompson and Beauchamp (2014) found that the marine survival of Skagit River Steelhead appeared to be related to a higher growth rate set in an early freshwater stage which resulted in larger smolts. Holtby et al. (1990) studied the marine survival of Coho Salmon from Carnation Creek, British Columbia over a 17-year period. Although they attributed marine survival to variable ocean conditions (i.e. upwelling off the northwest coast of Vancouver Island), they noted that large smolts survived better in years when marine survival was relatively poor.

Temperature criteria for Chimacum Creek is listed in Table 200 (1) (c) of WAC 173-201A. The temperature standard is based on the 7-day average of the daily maximum temperatures (7-DADMax). Chimacum Creek and tributaries are categorized as "core summer salmonid habitat,” which calls for a 7-DADMax of 16°C. However, more restrictive criteria apply to the Chimacum Creek main stem. Ecology publication 06-10-038 titled “Waters Requiring Supplemental Spawning and Incubation Protection for Salmonid Species" requires that the 7-DADMax not exceed 13°C from September 15 to July 1 for Chimacum Creek’s main stem. Chimacum Creek and East Chimacum Creek are both on Ecology’s 303(d) list for having failed the temperature standard.

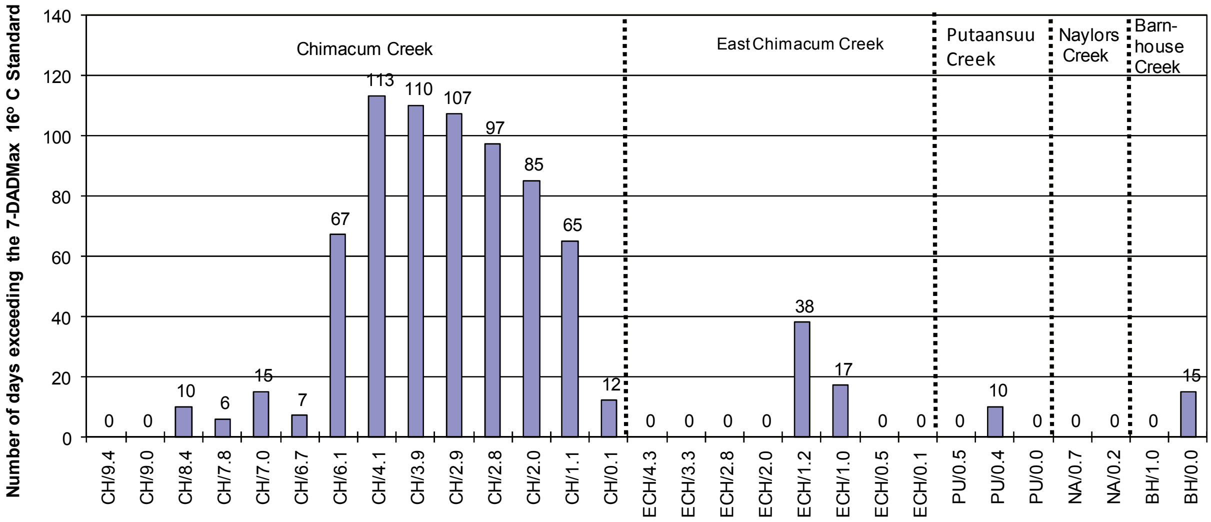
Of the 29 stations monitored with temperature data loggers (TDLs) in 2013, 16 stations (55%) failed to meet the 7-DADMax-16°C standard (Figure 19, Table 2). Most failures (12 stations) occurred on Chimacum Creek’s main stem. Station CH/4.1, immediately upstream of the confluence with Putaansuu Creek, had 113 days of temperatures exceeding the standard. This station had the highest maximum daily average temperature (20.1°C for July and August (Figure 20, Table 2). The greatest temperature increase (3.6 °C) occurred between stations CH/6.1 and CH/4.1, a predominantly unshaded reach (see Figure 43 in Farms, Buffer, and Beaver section).

The 1.5 °C increase between stations CH/6.7 and CH/6.1 was surprising because the stream channel is well shaded due to three older restoration projects (Figure 20, Table 2). Trees planted in these projects are providing good canopy cover over the stream channel. However, in one of the projects (RM 6.2-6.5) the channel was connected to a 16-acre adjacent wetland (Figure 21). Connectivity increased when beaver moved in and built dams, raising the water level and sending more water into the canary grass wetland. The slow flow of water through the unshaded wetland is probably responsible for the temperature increase.

From station CH/4.1 downstream, temperature gradually decreased to station CH/0.1 where the standard was exceeded on only 12 days. Two of 8 stations on East Chimacum Creek failed the standard, 1 station on Putaansuu Creek failed, and 1 station on Barnhouse Creek failed. Figure 6 shows a map of the Chimacum watershed with stream reaches color-coded according to temperature ranges.

On East Chimacum Creek the greatest number of 16°C exceedances (38 days) occurred at station ECH/1.2 (Figure 19). The greatest July-August temperature increase occurred between stations ECH/2.0 and ECH/1.2 (Figure 20). Two restoration projects were completed in this reach, but the trees have done poorly due to flooding caused by beaver dams (Figure 21). All 14 stations on the Chimacum Creek main stem failed the 7-DADMax of 13°C standard (Figure 19). Except for the two upstream stations, which exceeded the standard on 2 days and 8 days, exceedances for the other stations ranged from 33 days to 57 days. Most of the exceedances occurred prior to July 1 with a fewer number after September 15. Since the longest day of the year occurs in June, the extra sunlight at this time of the year helps account for the higher number of exceedances at this time.

16°C 7-DADMax Standard



13°C 7-DADMax Standard

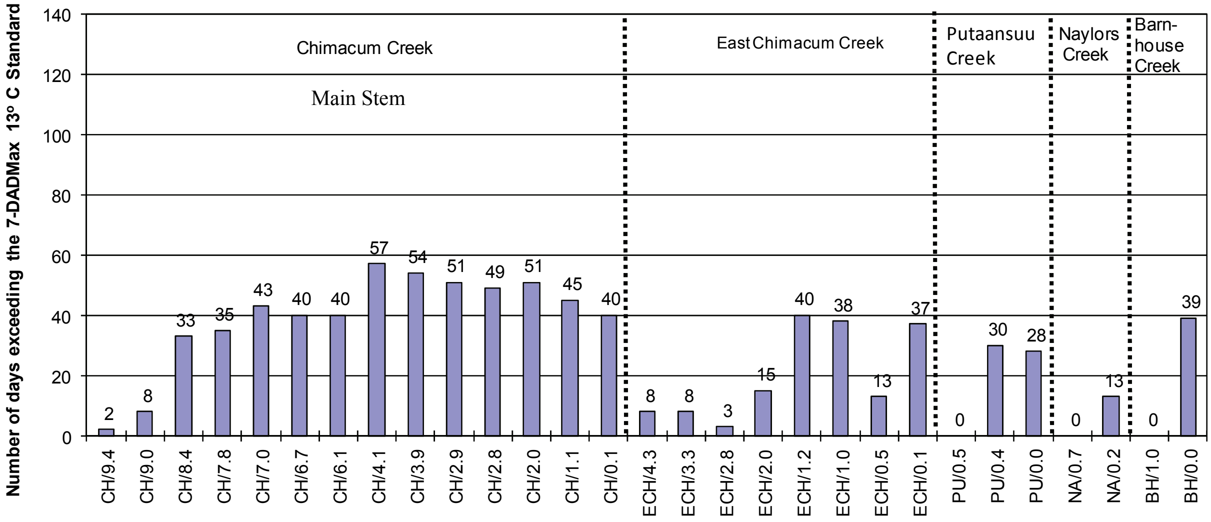


Figure 19. Number of days exceeding the 7-DADMax 16° C standard (top) and 7-DADMax 13° C standard (bottom). The 7-DADMax 13° C standard is from September 15 to July 1 and applies only to the Chimacum Creek main stem. Tributary streams are shown only for comparison.

Table 2. Temperature data obtained from temperature data loggers deployed in the Chimacum watershed in 2013. The state standard requires that the 7-DADMax not exceed 16° Celsius for all streams in the Chimacum watershed and that the 7-DADMax not exceed 13° Celsius from September 15 to July 1 on Chimacum Creek's main stem.

Station	No. of Days 7-DADMax>16° Celsius from 1/1/13 to 12/13/13	No. of Days 7-DADMax>13° Celsius from 1/1/13 to 7/1/13 and from 9/15/13 to 12/31/13[1]	Average Maximum Daily High Temperature for July and August Combined	Temperature Data Logger Started Recording	Temperature Data Logger Stopped Recording
BH/0.0	15	-	15.7	18-May-13	17-Oct-13
BH/1.0	0	-	11.3	18-May-13	28-Oct-13
CH/0.1	12	40	15.7	18-May-13	29-Oct-13
CH/1.1	65	45	16.4	18-May-13	29-Oct-13
CH/2.0	85	51	17.0	18-May-13	20-Oct-13
CH/2.8	97	49	17.5	18-May-13	20-Oct-13
CH/2.9	107	51	18.2	18-May-13	20-Oct-13
CH/3.9	110	54	19.9	18-May-13	24-Oct-13
CH/4.1	113	57	20.1	18-May-13	20-Oct-13
CH/6.1	67	40	16.5	18-May-13	28-Oct-13
CH/6.7	7	40	15.0	18-May-13	28-Oct-13
CH/7.0	15	43	15.5	18-May-13	28-Oct-13
CH/7.8	6	35	15.0	18-May-13	20-Oct-13
CH/8.4	10	33	15.4	18-May-13	20-Oct-13
CH/9.0	0	8	14.1	18-May-13	20-Oct-13
CH/9.4	0	2	12.6	18-May-13	21-Oct-13
ECH/0.1	0	-	14.9	18-May-13	23-Oct-13
ECH/0.5	0	-	14.2	18-May-13	24-Oct-13
ECH/1.0	17	-	15.6	18-May-13	30-Oct-13
ECH/1.2	38	-	16.3	18-May-13	30-Oct-13
ECH/2.0	0	-	13.8	18-May-13	30-Oct-13
ECH/2.8	0	-	13.1	18-May-13	29-Oct-13
ECH/3.3	0	-	13.7	18-May-13	30-Oct-13
ECH/4.3	0	-	13.7	18-May-13	30-Oct-13
NA/0.2	0	-	13.8	18-May-13	25-Oct-13
NA/0.7	0	-	11.8	18-May-13	17-Oct-13
PU/0.0	0	-	14.8	18-May-13	17-Oct-13
PU/0.4	10	-	15.2	18-May-13	17-Oct-13
PU/0.5	0	-	12.3	18-May-13	17-Oct-13

[1] Number of days are a minimum because the data logger was not deployed during the entire year.

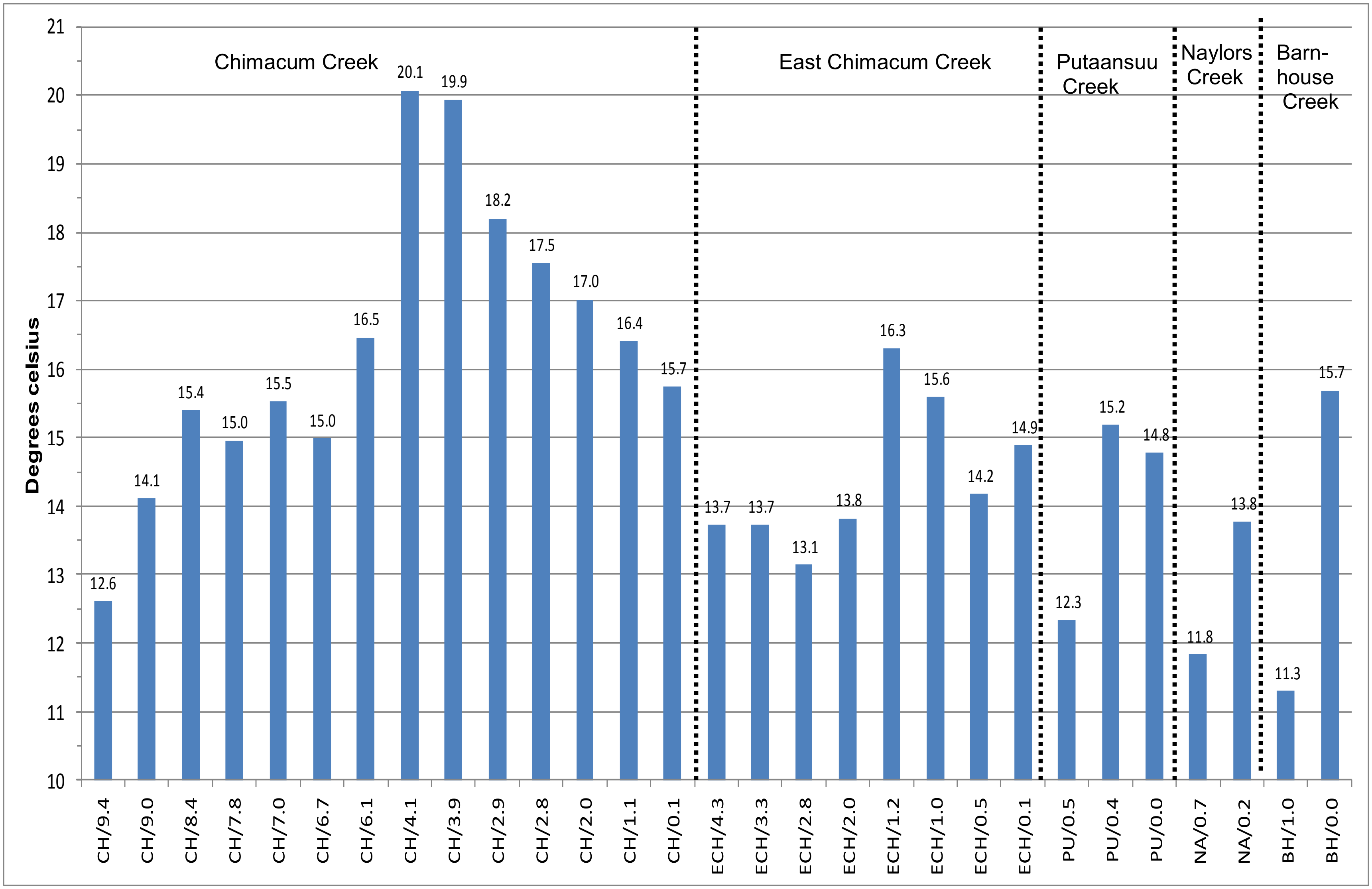


Figure 20. Average daily maximum high temperatures for July and August 2013 at temperature logger stations in the Chimacum watershed.

Figure 21. Restoration projects flooded by beaver dams on Chimacum Creek (top; RM 6.2-6.5) and East Chimacum Creek (bottom; RM 1.7-2.0). Trees with brown foliage in bottom picture are dying shore pine. Pictures were taken on October 6, 2014.

Temperature profiles for the 29 stations monitored in the 2013 water-year are shown in Appendix C.

The general north-south direction of Chimacum Creek and East Chimacum Creek make them more susceptible to solar heating. Apparently, anything that blocks direct contact with the sun’s rays helps to lower the water temperature. This was made apparent in August 2006 when a 0.5 mile reach between stations CH/7.5 and CH/8.0 was cleared of Canary Grass and European Bittersweet in August 2006. The 7-DADMax temperature increased 2.5^{o}C at station CH/7.0, downstream of the project, at the same time upstream station CH/9.0 was decreasing.

The thousands of trees that have been planted in riparian buffers over the years are making a measureable difference. Regression analysis of the average of the maximum daily highs for July and August (n=62) from 1998 to 2013 shows downward trends occurring at three key downstream stations: CH/3.9 (Figures 22), ECH/0.1(Figure 23), and CH/0.1 (Figure 24). To distinguish changes in water temperature that are due entirely to changes in air temperature, trends in water temperature are contrasted to trends in air temperature and to trends in water temperature at upstream stations on the main stem (CH/9.4) and East Chimacum Creek (ECH/5.4). Both upstream control stations are located in well-shaded, mature forests, providing complete and stable shade to the entire stream reach upstream from these stations. This is in contrast to the three key stations which are downstream from numerous restoration projects where thousands of trees have been planted in riparian buffers over the years. As these trees grew, they provided increasing amounts of shade each year.

In contrast to a constant trend in air temperature (average of the maximum daily highs for July and August) in Bremerton and very slightly decreasing trends at control stations CH/9.4 and ECH/5.4, average maximum daily high water temperature at station CH/3.9, downstream from 5.5 miles of agricultural land, decreased about 1^{o}C over the 15-year period from1998 to 2013 (Figure 22). Average maximum high temperature at station ECH/0.1 on East Chimacum Creek, downstream from 5.3 miles of mostly agricultural land, decreased about 2^{o}C (Figure 23). The downstream-most station CH/0.1, at the upper end of the estuary, decreased about 1^{o}C (Figure 24).

Surface Water Dissolved Oxygen

Water becomes aerated as it comes in contact with the atmosphere. The steeper the stream’s gradient, the greater is the aeration; more aeration occurs in riffles than in pools. Since Chimacum Creek has an extremely flat gradient (0.0005) between stations CH/3.4 and CH/6.1, this stream reach is essentially one long pool with aeration being limited to the water’s surface layer.

When water holds the maximum amount of dissolved oxygen (DO) possible under

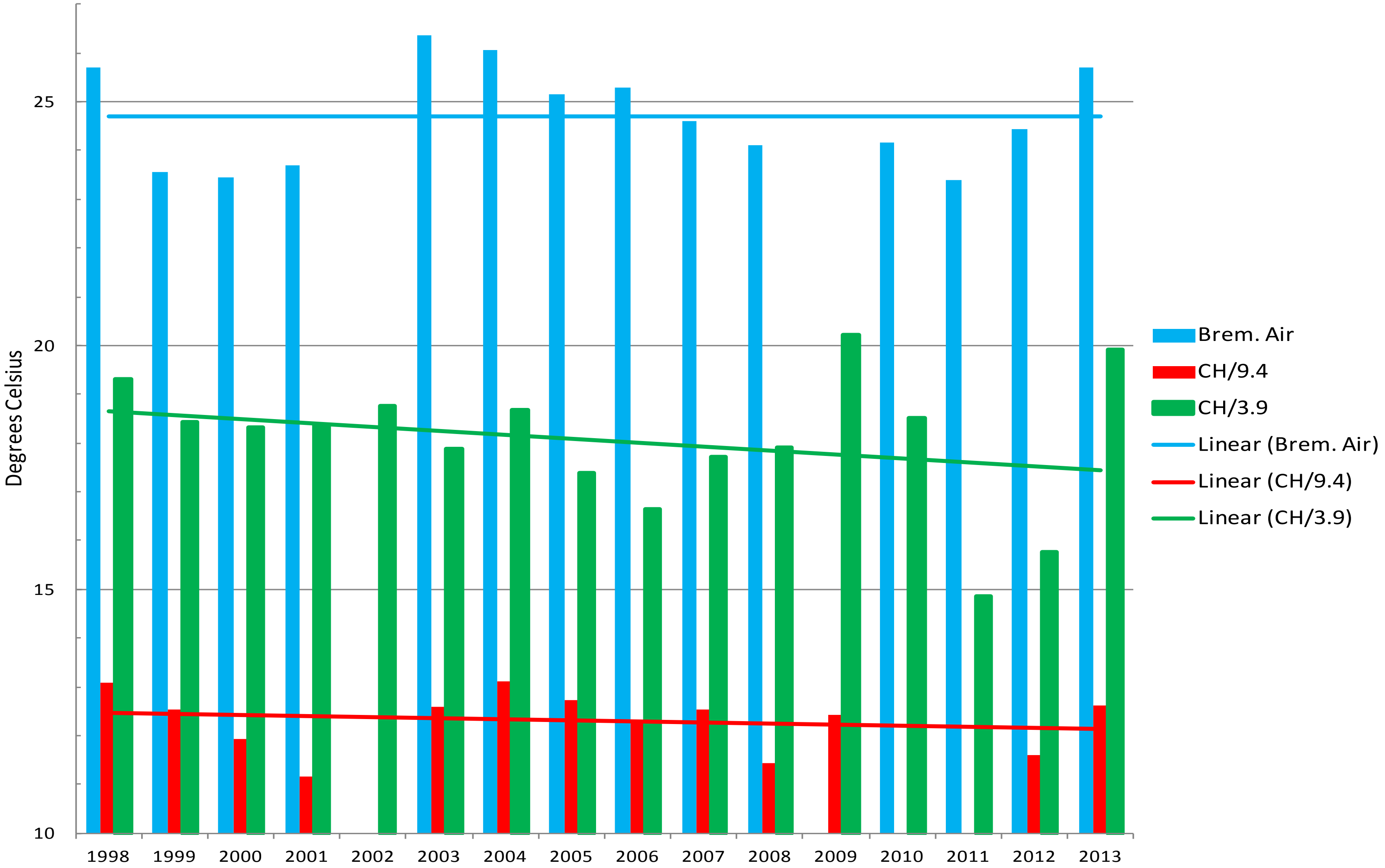


Figure 22. Comparison of the temperature trend at station CH/3.9, downstream from 5.5 miles of mostly agricultural land, to that of the forested, upstream control station CH/9.4, and to the air temperature trend in Bremerton. Temperatures shown are averages of the daily maximum high temperatures for July and August combined.

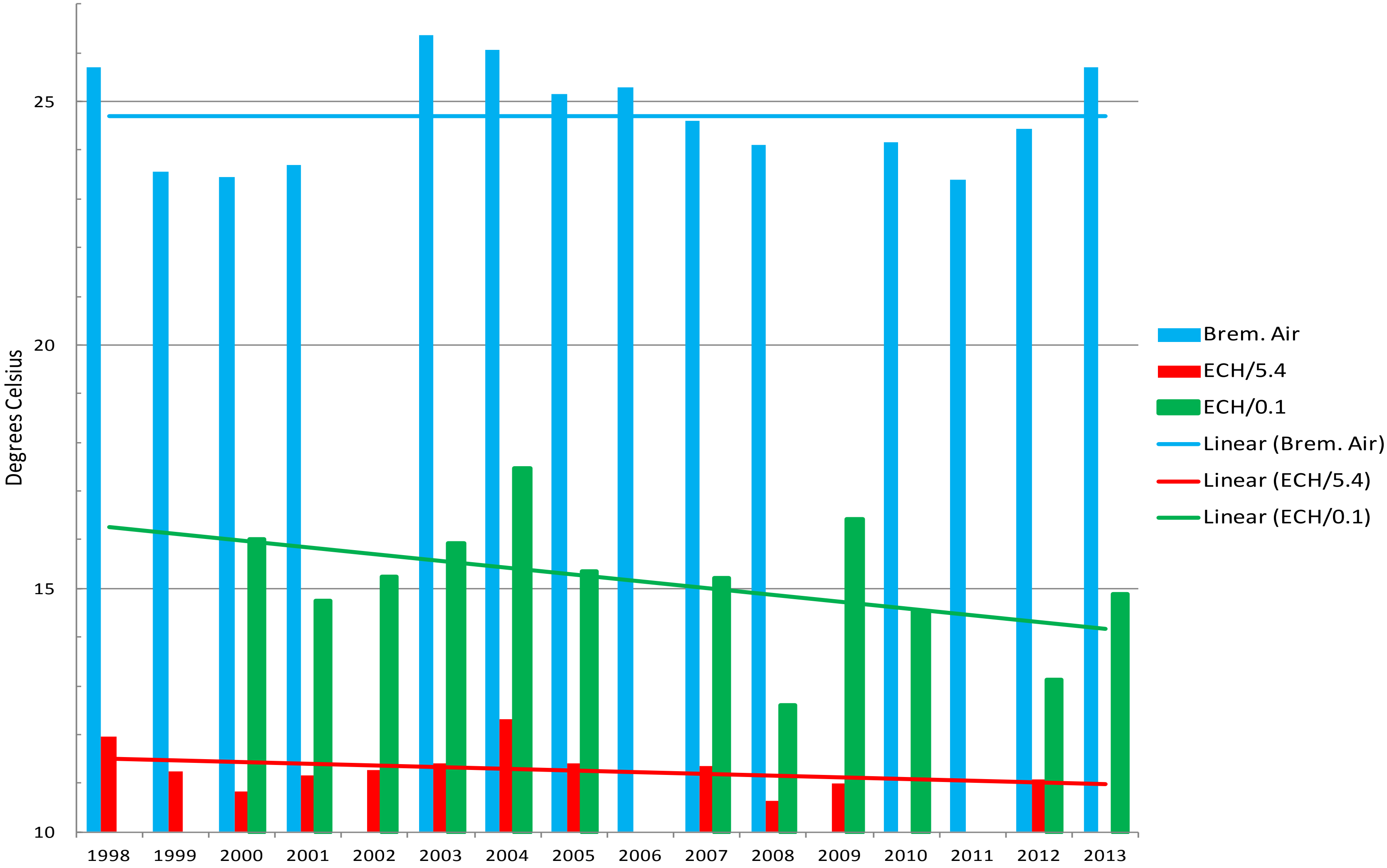


Figure 23. Comparison of the temperature trend at station ECH/0.1, downstream from 5.3 miles of mostly agricultural land, to that of the forested, upstream control station ECH/5.4, and to the <u>air</u> temperature trend in Bremerton. Temperatures shown are averages of the daily maximum high temperatures for July and August combined.

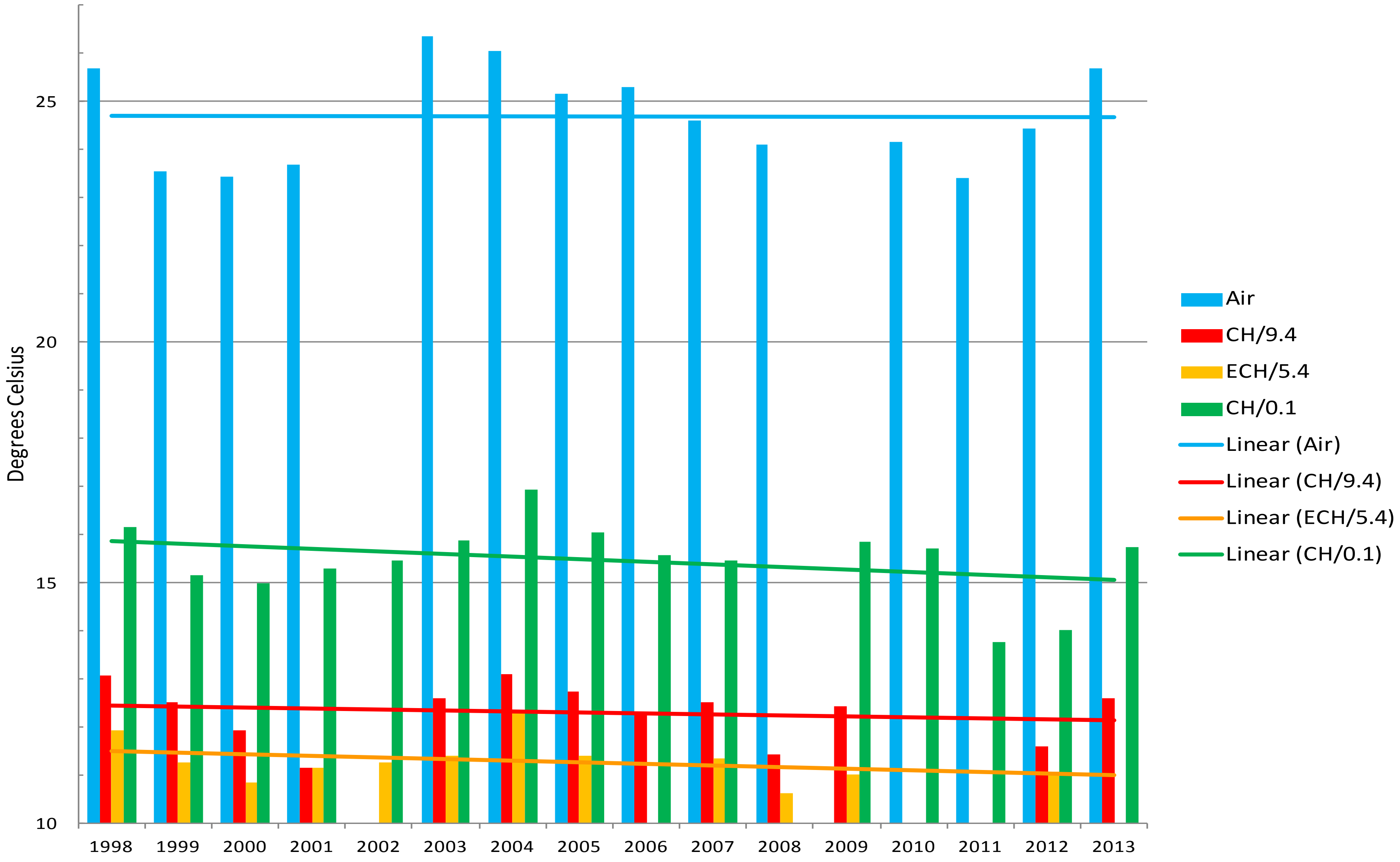


Figure 24. Comparison of the temperature trend at downstream station CH/0.1 to the trends at forested, upstream control stations CH/9.4 and ECH/5.4, and to the air temperature trend in Bremerton. Temperatures shown are averages of the daily maximum high temperatures for July and August combined.

"normal" conditions, it is said to be saturated. Warm water has a lower saturation level than cold water and therefore cannot hold as much oxygen as cold water. For instance, the saturation level of 20°C water is 9.1 mg/L, compared to 11.3 mg/L for 10°C water.

Aquatic plants release dissolved oxygen into the water by photosynthesis and on bright sunny days the water can become supersaturated (>100%) with dissolved oxygen. When plants die, their decomposition removes oxygen, causing the DO concentration to decrease.

Fish and aquatic invertebrates need oxygen, and salmonids require higher levels than most species. The following oxygen concentrations with their corresponding effects on salmon and trout were reported by the Environmental Protection Agency (USEPA 1986):

DO Concentration (mg/L)	Effect On Salmon and Trout
8	No production impairment
6	Slight production impairment
5	Moderate production impairment
4	Severe production impairment
3	Limit to avoid acute mortality

The Washington state DO standard for "core summer salmonid habitat" is a 1-day minimum of 9.5 mg/L (WAC chapter 173-201A).

In the 2011-12 water year, 14 of 25 stations met the DO standard (Figure 25); three ditches (EG/0.0, SW/0.3, and WV/0.1) were monitored primarily for fecal coliform and were excluded from this count. However, all 14 stations were above 5 mg/L on all monitoring dates and exceeded 8 mg/L most of the time. Of particular interest were sharp decreases on the main stem of Chimacum Creek from CH/7.8 at Egg and I Road to CH/7.0 at Center Road; on the East Fork from ECH/3.3 at Peat Plank Road to ECH/1.0 at Beaver Valley Road; and on Barnhouse Creek from BH/1.0 on Center Road to BH/0.0 at its confluence with Chimacum Creek. A more gradual decrease occurred on the main stem from CH/5.3 to CH/2.0 on Ness' Corner Road. These decreases from upstream to downstream are probably due to the excessive vegetation within the reaches and to decreasing gradients from upstream to downstream. DO saturation for the 25 stations of interest ranged from 55% to 108% (Figure 25). Figure 26 shows a

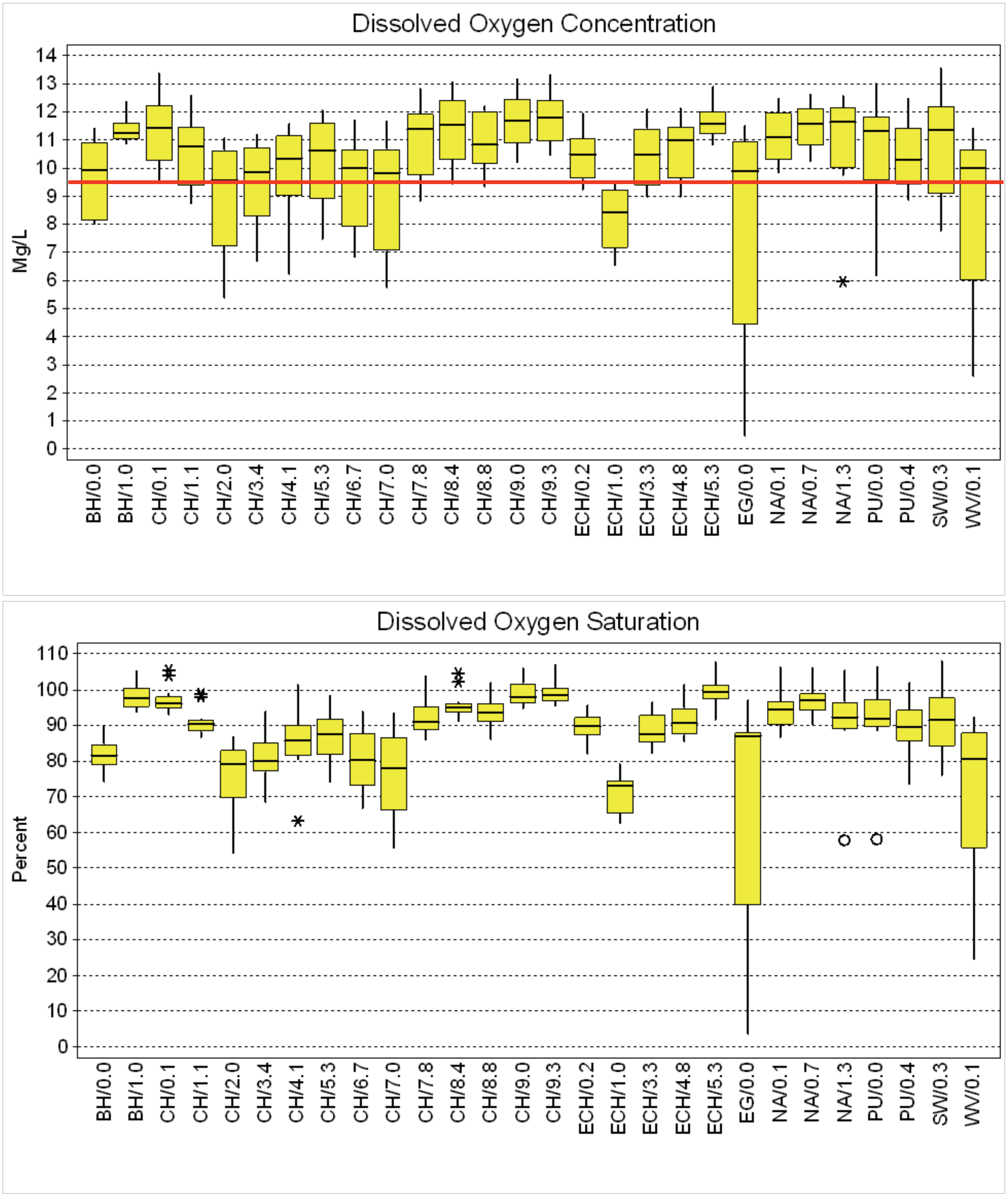


Figure 25. Dissolved oxygen concentration (top) and saturation (bottom) at stations in the Chimacum watershed monitored monthly in the 2011-12 water-year. The state standard requires that the dissolved oxygen concentration not be less than 9.5 mg/L. For an explanation of the “box and whiskers,” refer to “statistics” in the “methods” section.

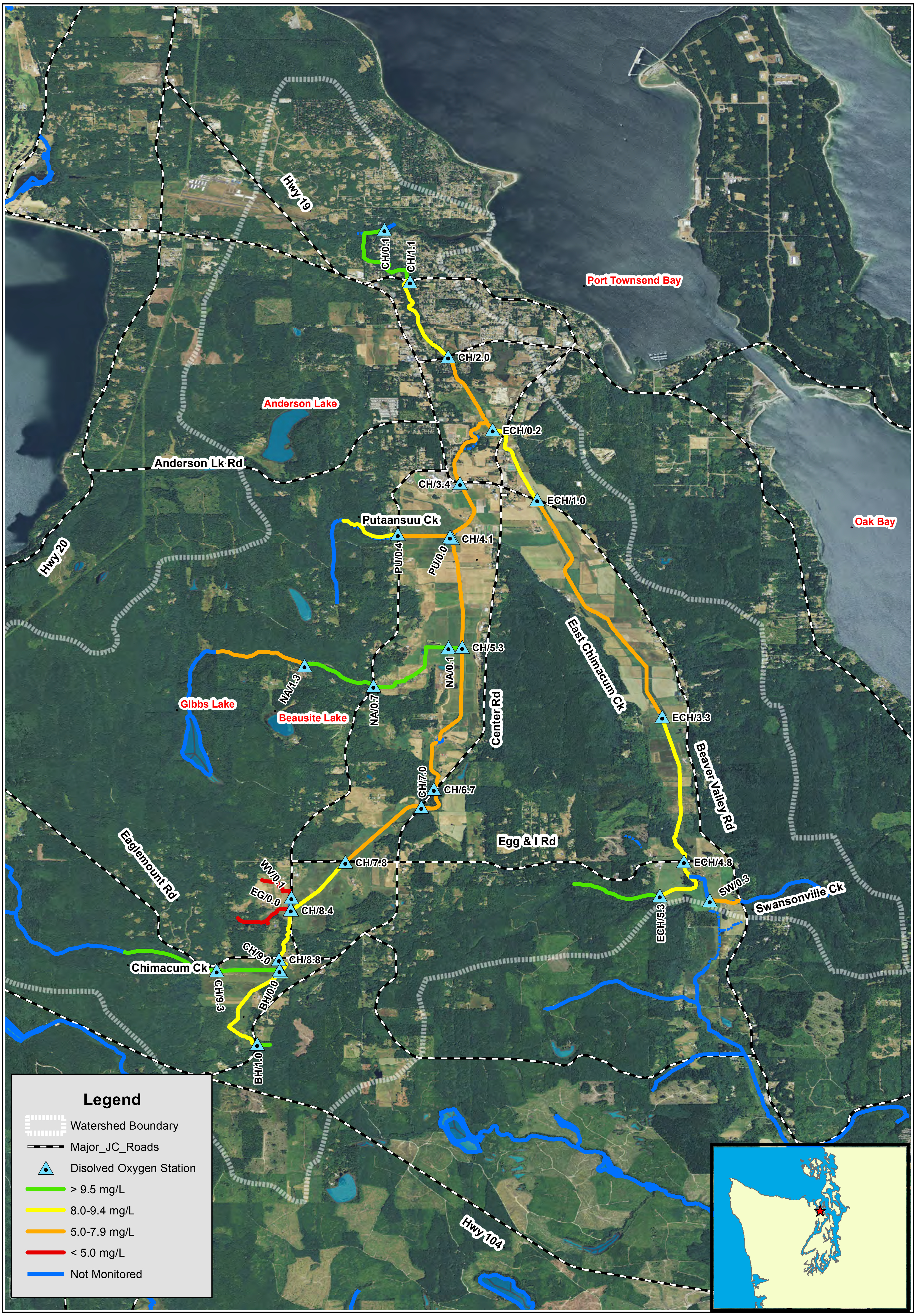


Figure 26. Map of Chimacum watershed showing stream segments color-coded based on the lowest dissolved oxygen level of 12 monthly measurements made in the 2011-12 water-year.

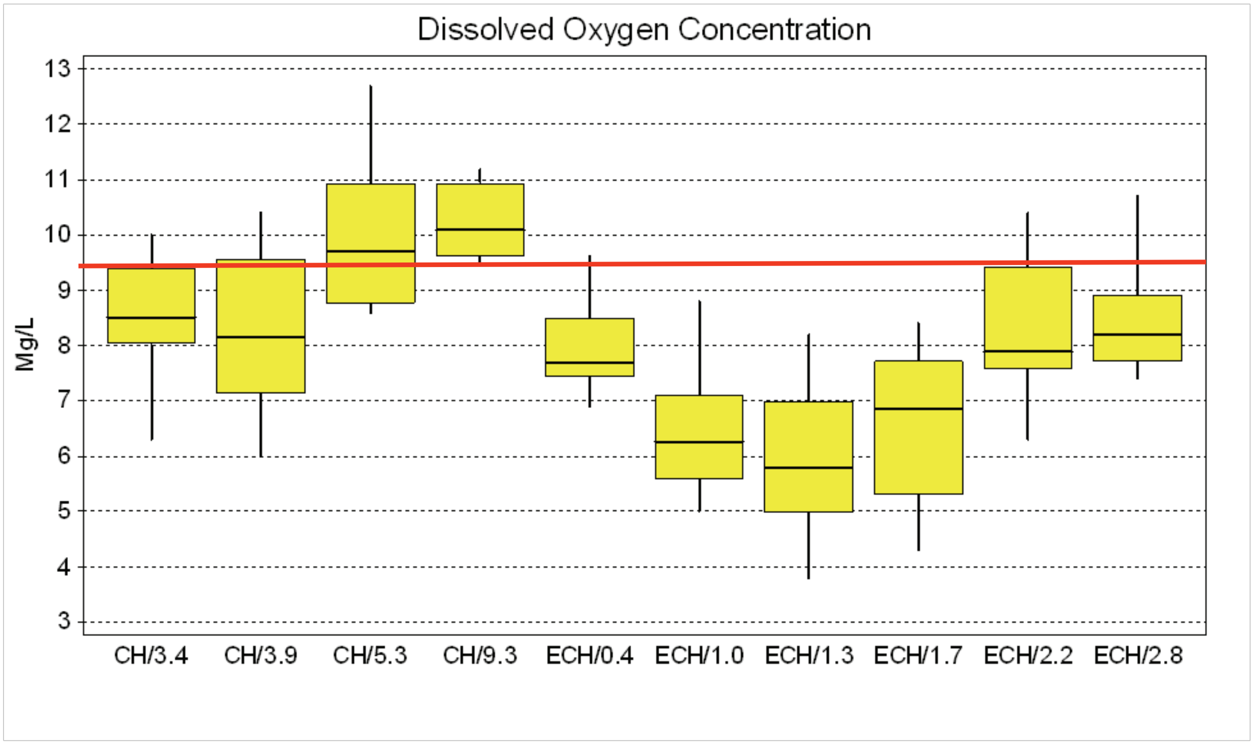
map of the Chimacum watershed with stream reaches color-coded according to dissolved oxygen ranges.

Figure 27 shows some additional DO measurements taken in the 2013-14 water-year by the Chimacum School Hydrology Class and includes several stations on East Chimacum Creek and two stations on the main stem including one (CH/3.9) not routinely monitored by the District. These data show the same decreasing trend from upstream (CH/9.3) to downstream (CH/3.4) on the main stem, probably caused by the in-channel vegetation and decreasing gradient. On East Chimacum Creek the data show a decreasing trend on East Chimacum Creek from station ECH/2.8 to station ECH/1.3 and then an increasing trend from station ECH/1.3 to station ECH/0.4. The reach from ECH/2.8 to ECH/1.3 has more in-channel vegetation than the ECH/1.3 to ECH/0.4 reach, which is well shaded due to earlier restoration projects.

Not untypical for much of Chimacum Creek and East Chimacum Creek, DO concentrations at station ECH/1.0 have shown much variation from year to year as well as within any single water-year (Figure 28). Some of this variation could be due to the time of day that the measurements were made, the weather conditions (sunny or cloudy), and/or the amount of vegetation in the channel that is subject to photosynthesis and decay. The nutrient-rich peat soils combined with direct sunlight over extensive reaches of Chimacum Creek, East Chimacum Creek, and Barnhouse Creek result in vigorous aquatic plant and algal growth. During the day, plants are both respiring (consuming oxygen) and photosynthesizing (emitting oxygen) with a net effect of increasing stream DO. Whereas, at night photosynthesis ceases while respiration continues causing stream DO to decrease.

This diurnal pattern was observed in August 2001when DO was measured at hourly intervals on Chimacum Creek (CH/3.9) and East Chimacum Creek (ECH/1.0). DO concentration followed the same pattern at both stations, increasing from about 4 mg/L at 6:00 AM to about 9.5 mg/L at 3:00 PM, a difference of 5.5 mg/L (Figure 29). DO concentration at station CH/7.0, downstream of 0.5 miles of unshaded stream channel having excessive vegetation, was directly correlated with time of day during daylight hours (data from 2002 to 2012, $n=80$, $p=0.0000$).

Decomposition of dead vegetation is a major cause of low dissolved oxygen. In low gradient, unshaded reaches of Chimacum Creek, vegetation can completely fill the stream channel, bank to bank and top to bottom (Figure 30). This often results in flooding, which renders agricultural fields unusable. To remedy the situation, vegetation historically has been periodically removed from the stream channel. The effect of excessive vegetation on dissolved oxygen was made dramatically apparent in August 2006 when a one-half mile reach of Chimacum Creek (CH/7.5-CH/8.0) was cleared of dying vegetation. DO was measured on a regular basis at about 11:00 AM each day



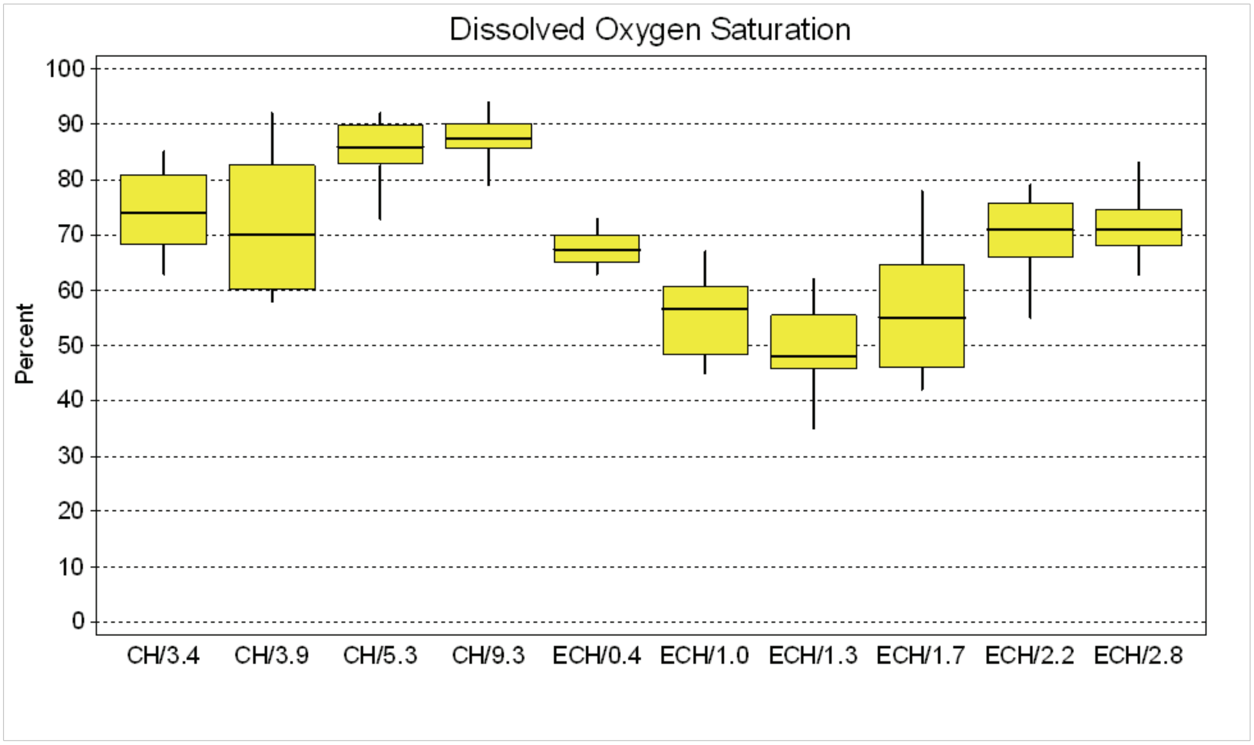


Figure 27. Dissolved oxygen concentration (top) and saturation (bottom) at stations on Chimacum Creek and East Chimacum Creek monitored monthly from September 2013 to June 2014 by the Chimacum School Hydrology Class. The state standard requires that the dissolved oxygen concentration not be less than 9.5 mg/L. For an explanation of the "box and whiskers," refer to "statistics" in the "methods" section.

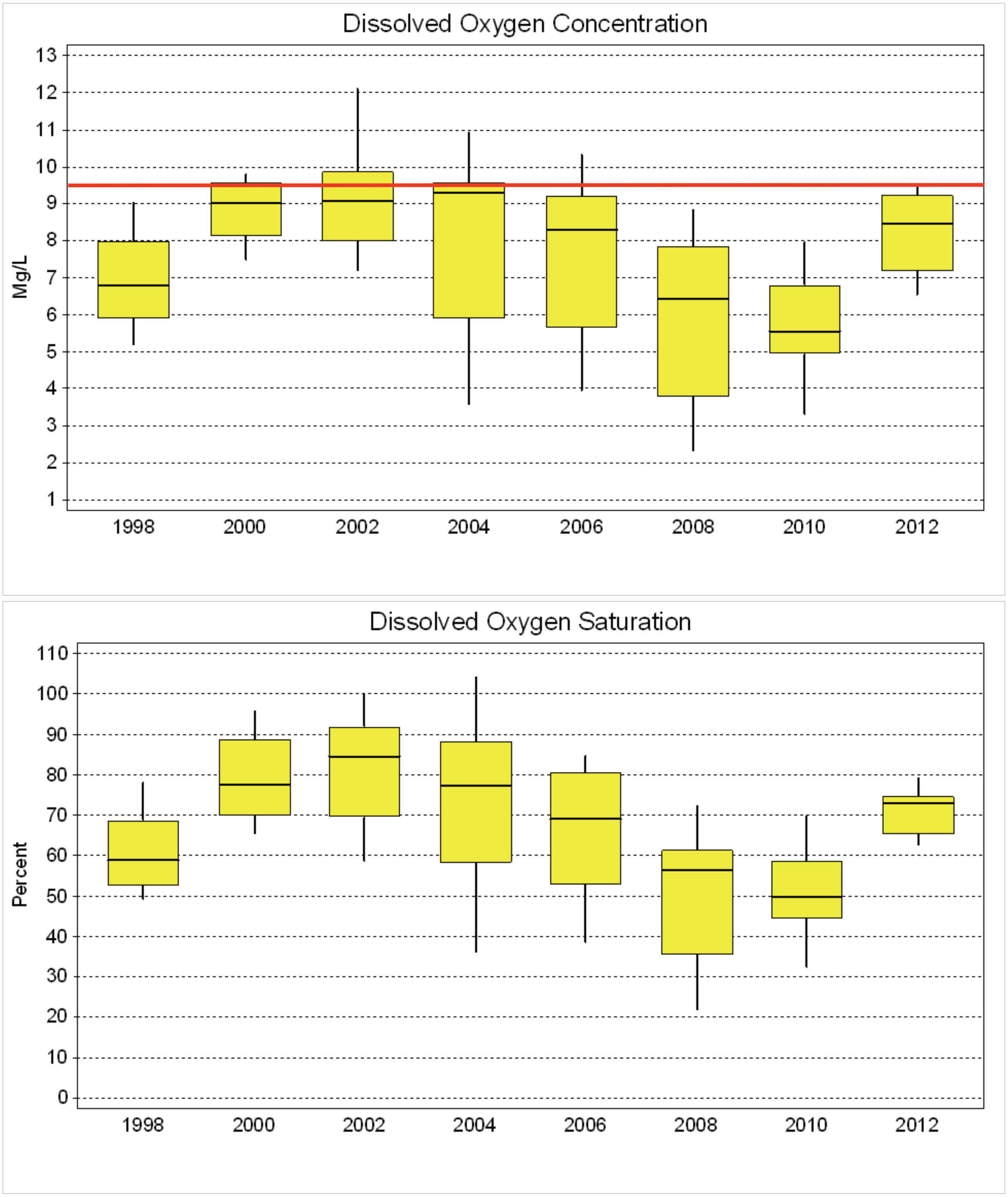


Figure 28. Dissolved oxygen concentration (top) and saturation (bottom) at station ECH/1.0 on East Chimacum Creek monitored monthly in various years from 1998 to 2012. The state standard requires that the dissolved oxygen concentration not be less than 9.5 mg/L. For an explanation of the “box and whiskers,” refer to “statistics” in the “methods” section.

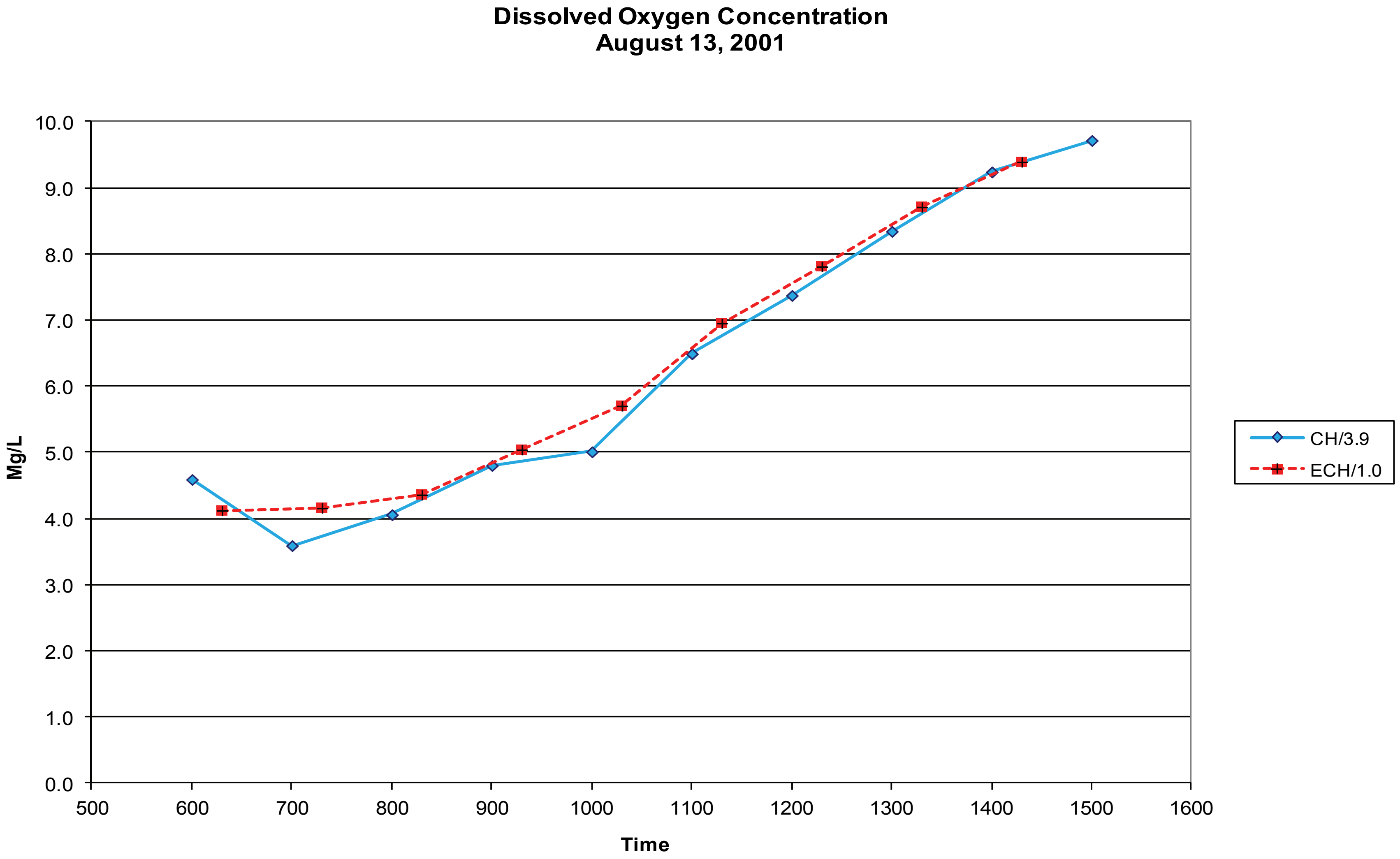


Figure 29. Dissolved oxygen concentration measured at 1-hour intervals on August 13, 2001 at station CH/3.9 on Chimacum Creek and station ECH/1.0 on East Chimacum Creek.

Figure 30. Vegetation (mostly Canary Grass) filling Chimacum Creek channel at monitoring stations CH/3.9 (bottom) and CH/7.0 (top) on September 18, 2014.

from August 10 to August 30. Vegetation consisting primarily of Canary Grass and European Bittersweet was removed from August 15 to August 24. Prior to the start of the project, DO ranged from 6.2 mg/L to 6.3 mg/L. After completion, DO ranged from 7.8 mg/L to 8.8 mg/L (Figure 31). Obtaining permitting to remove excessive vegetation can be time consuming and costly to landowners.

In some circumstances, beaver dams probably contribute to lower DO levels by causing the stream to flow out of its channel onto adjacent land, thereby increasing the amount of vegetation subject to decay as well as making the water more subject to warming.

Shade provided by riparian buffers will improve the DO levels in three ways. First of all, shade will greatly inhibit aquatic plant growth, resulting in less biomass to decompose. Although leaves and needles falling into the stream will decompose, they will probably constitute less biomass than vegetation growing in the stream. Secondly, the leaves and needles will decompose at a slower rate because the water is cooling down at the time of year when leaves and needles fall. Thirdly, shade results in cooler water and cooler water holds more oxygen.

One thing that shade will not remedy is the extremely flat gradient in the agricultural areas, which limits aeration to the surface layer.

Intragravel Dissolved Oxygen

In 1982, a rain storm washed out the Irondale Road and an estimated 10,000-20,000 cubic yards of road fill was flushed downstream onto the traditional spawning ground of the summer Chum Salmon (Michael Kennedy, Wild Olympic Salmon, personal communication, 1996). A reddish-brown plume was visible in lower Port Townsend Bay for weeks. During the spawning season, the gravel was cemented together and many Chum attempting to spawn wore their tail fins to the bone attempting to dig a redd (Ray Lowrie, Chimacum High School Biology Teacher, personal communication, 2014). No redds were observed that year. In 1991, three years after Wild Olympic Salmon monitored the creek with a weir without seeing a single Chum, the Chimacum Creek summer Chum Salmon was determined to be extinct.

Two other events, which happened at approximately the same time, could also have played a part in the demise of Chimacum Creek's Chum Salmon. In June 1979, a large chlorine spill entered the creek at RM 2.0. And in 1983, a landslide occurred at about RM 10.4 and released a load of sediment, estimated at 5,000-10,000 cubic yards, into the creek. Harvest, as well as natural ocean mortality, could also have contributed to the Chum's extinction.

In 1996, to assess the quality of the spawning gravel, Wild Olympic Salmon volunteers assisted by District staff, surveyed the spawning gravel in three segments of Chimacum

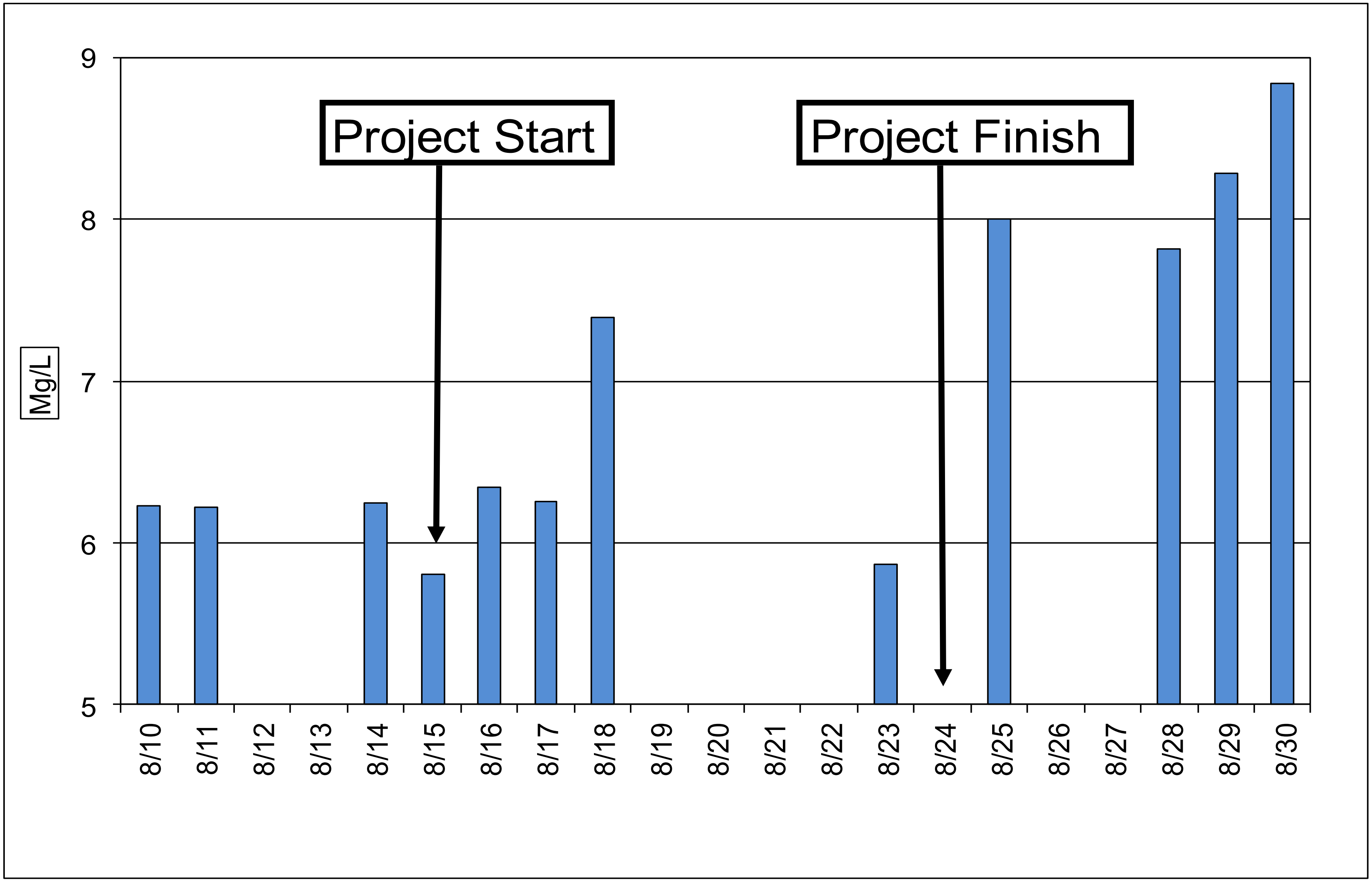


Figure 31. Dissolved oxygen levels monitored from August 10 to August 30, 2006 between 10:40 AM and 11:48 AM at station CH/7.5 on Chimacum Creek. Canary grass and bittersweet were removed from a half-mile section of channel (CH/7.5-8.0) from August 15 to August 24.

Creek: two downstream from Irondale Road and one upstream from the road. Conservative estimates of the percentage of “fines” (<0.84 mm diameter) in the spawning gravel in the three segments were 16%, 18%, and 22% respectively from downstream to upstream. Fines at all three levels are considered excessive and would be expected to cause mortality to salmon eggs and fry.

Determining the percentage of fines in the spawning gravel proved to be very labor intensive, so in 1999 the District tried another approach to assess the spawning gravel – intragravel dissolved oxygen monitoring or IGDO for short.

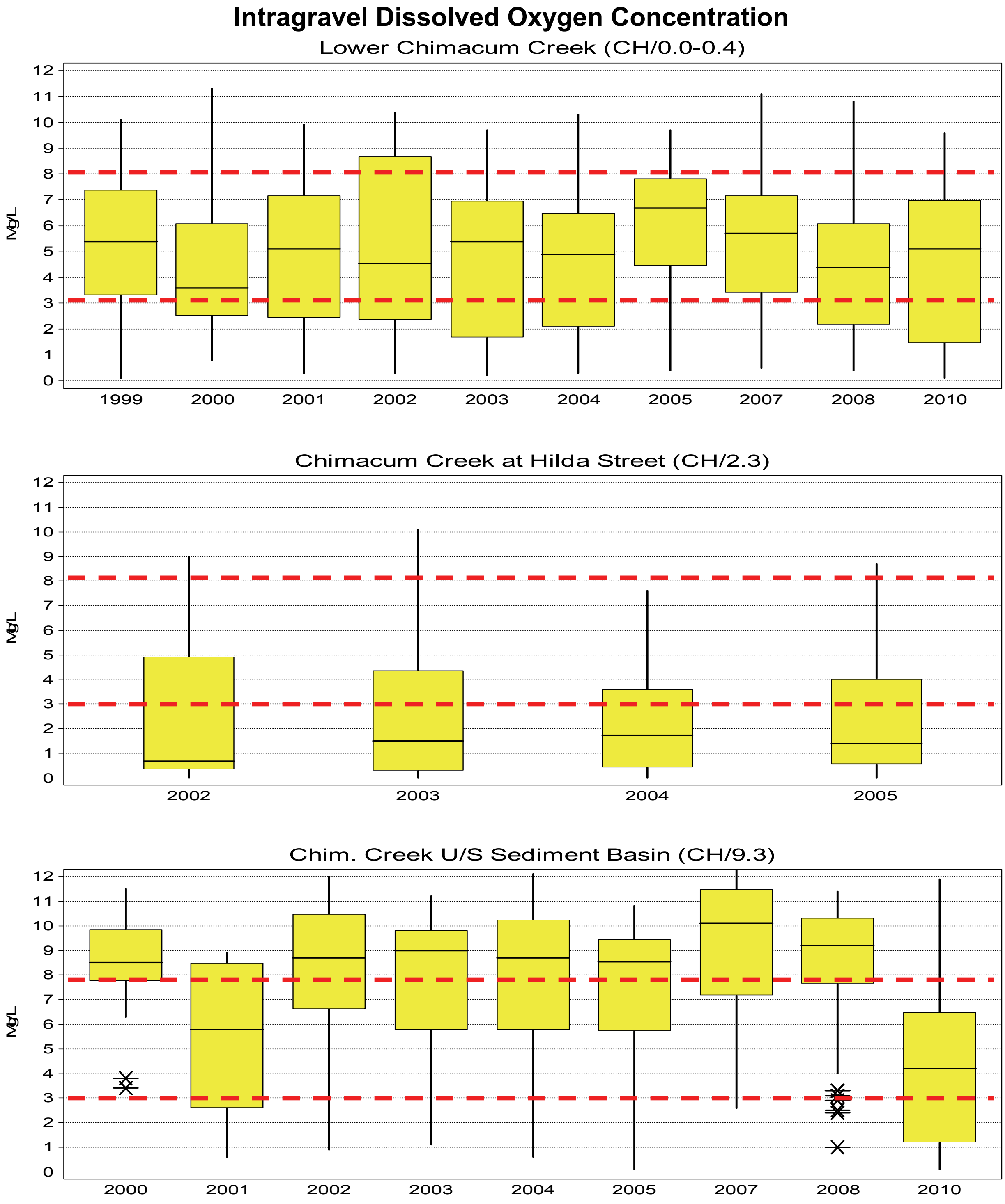
IGDO refers to the dissolved oxygen in the subsurface flow (i.e. the DO in the water flowing through the gravel). Developing salmonid eggs and alevins (sac-fry) as well as macro-invertebrates (e.g., stoneflies, mayflies, caddis flies, etc.) depend upon an adequate supply of oxygen.

DO levels required by salmonid eggs and alevins in the gravel are no less than they are for salmonids above the gravel; no impairment occurs above 8 mg/L and acute mortality occurs below 3 mg/L (see chart in Dissolved Oxygen section for intermediate levels of impairment).

IGDO monitoring was conducted in lower Chimacum Creek (CH/0.0-0.4) from 1999 to 2010. For purposes of comparison, two other sites were added: Hilda Street (CH/2.3) from 2002 to 2005 and a reach upstream from the sediment basin (CH/9.3) from 2000 to 2010.

In lower Chimacum Creek, median IGDO levels ranged from 3.6 mg/L to 6.8 mg/L; at Hilda Street, median levels ranged from 0.7 mg/L to 1.8 mg/L; and upstream from the sediment basin median levels ranged from 4.2 mg/L to 10.1 mg/L (Figure 32). The site upstream of the sediment basin, which has the highest IGDO levels of the three sites, is not used by Chum Salmon, which do not ascend that far upstream. However, it is used by Coho Salmon.

Figure 32 shows that there are differences in IGDO levels from one site to another. However, it does not convey the variability that exists at individual “redd” sites. Figure 33 shows the month-to-month variation that exists at individual redds: two redds in lower Chimacum Creek, one at Hilda Street, and one upstream from the sediment basin. One should realize that survival of the eggs and alevins requires acceptable IGDO levels throughout the entire time period that they are in the gravel from September to March. This means that, at a minimum, the IGDO level must be maintained above 3 mg/L, the acute mortality level. As Figure 33 shows, IGDO levels within individual redds were extremely dynamic with DO in some redds fluctuating from near 8 mg/L to near 0 mg/L in one season.



Intragravel Dissolved Oxygen Concentration

Lower Chimacum Creek (CH/0.0-0.4)

Chimacum Creek at Hilda Street (CH/2.3)

Chim. Creek U/S Sediment Basin (CH/9.3)

Figure 32. Intragravel dissolved oxygen levels measured monthly at simulated redd sites in three reaches of Chimacum Creek during the summer chum egg incubation period (Sept.–Mar.) over the course of several years. EPA(1986) guidelines state that acute mortality occurs below 3 mg/L, some production impairment occurs between 3 mg/l and 8 mg/L, and no impairment occurs above 8 mg/L. For an explanation of the “box and whiskers”, refer to “statistics” in the “methods” section.

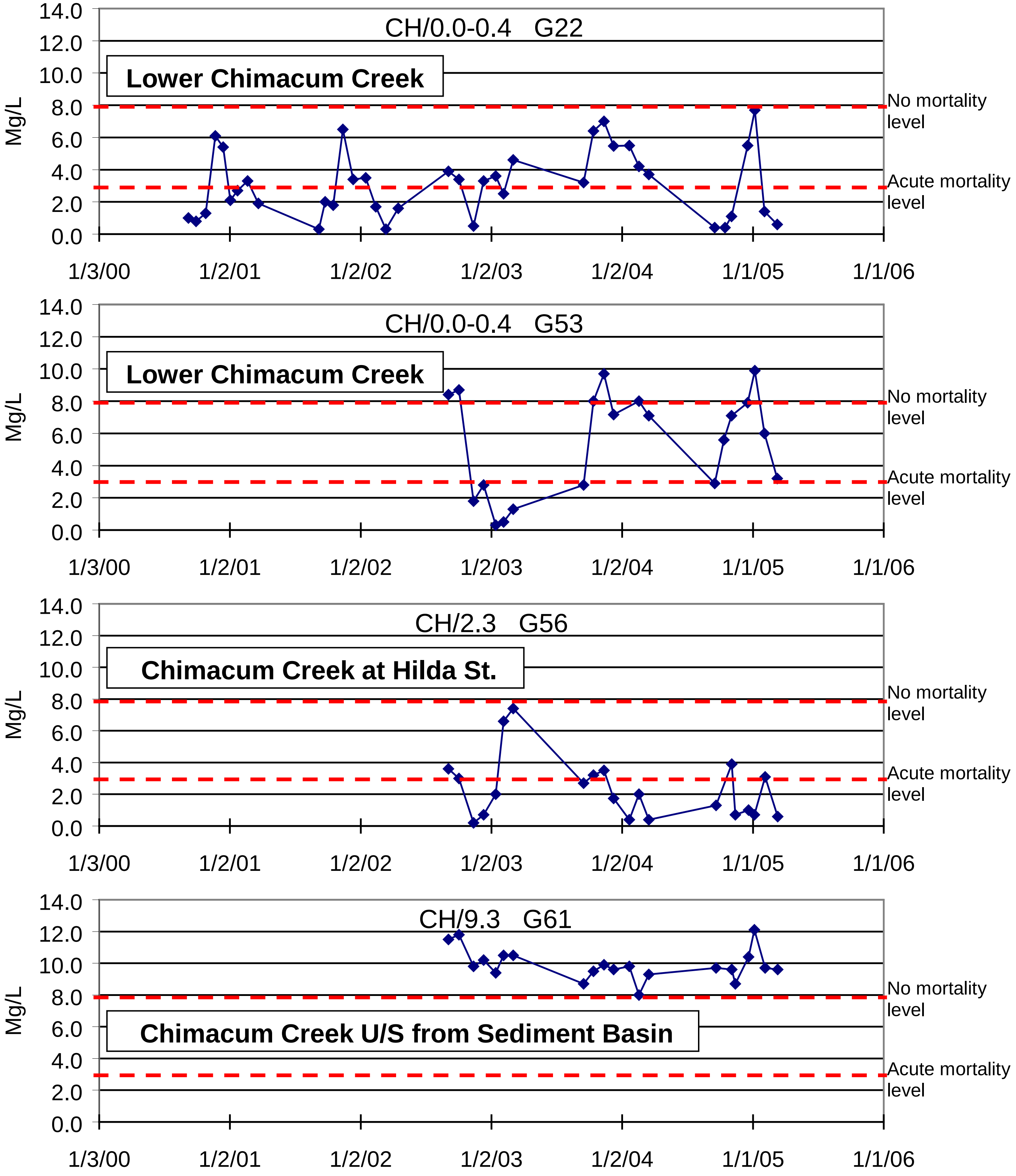


Figure 33. Intragravel dissolved oxygen levels at four simulated redd sites on Chimacum Creek where dissolved oxygen was measured monthly during the summer chum egg incubation period (Sept.–Mar.) over the course of several years. EPA(1986) guidelines state that acute mortality occurs below 3 mg/L, some production impairment occurs between 3 mg/l and 8 mg/L, and no impairment occurs above 8 mg/L.

Our IGDO monitoring has shown that the horizontal placement of the “redd” in a riffle, either from side to side or from upstream to downstream, by only a few feet can make a great difference in the IGDO level in the redd. Vertical placement of the air stone was also shown to make a difference. In one experiment in which one air-stone was placed 2 inches above the other, IGDO was greater closer to the surface.

In hundreds of IGDO measurements, we have never observed IGDO levels greater than DO levels in the surface water. For this reason it is important for egg/alevin survival that DO in the surface water be as close to saturation as possible. Various studies (Shumway et al. 1964, Bjornn and Reiser 1991, Malcolm et al. 2003) on the relationship between the IGDO concentration and egg/alevin survival show that survival is directly related to the IGDO concentration. As Chapman (1988) put it, “*Any* decremental reduction in dissolved oxygen levels from saturation probably reduces survival to emergence or post-emergent survival.”

Turbidity

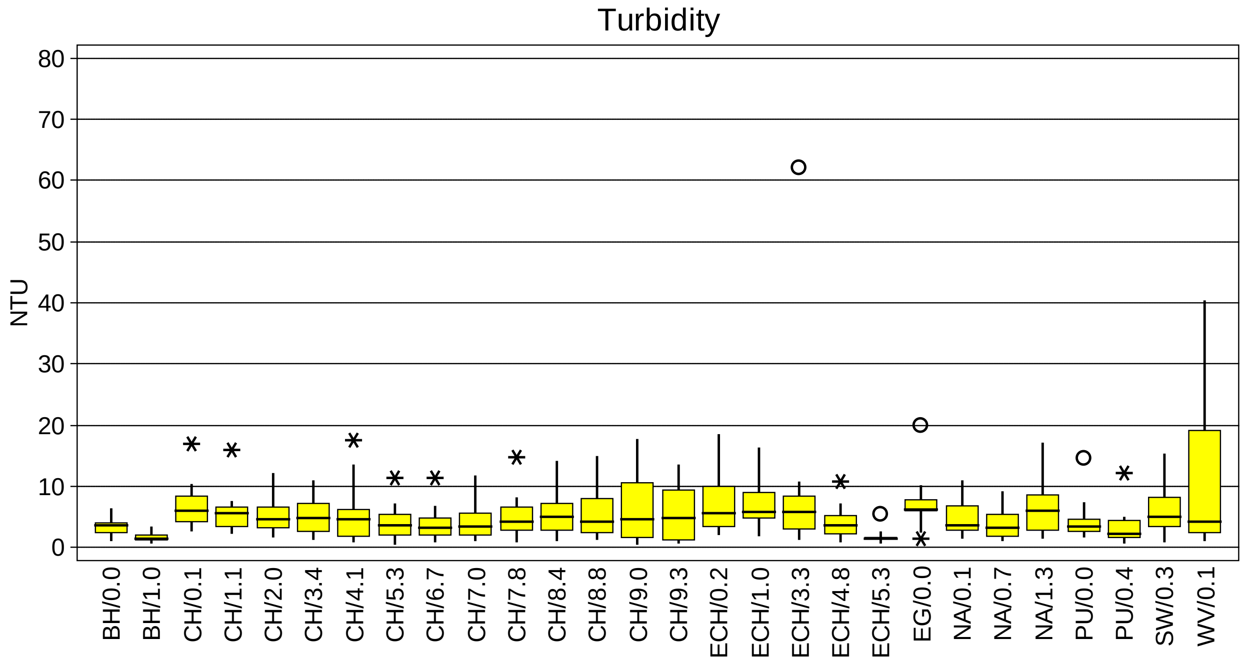
Turbidity is a measure, based on light scattering, of the suspended matter in the water column. The state standard requires that turbidity not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10% increase in turbidity when the background turbidity is greater than 50 NTU. Turbidity measurements are not as precise as other water quality measurements because the reading is constantly changing as the suspended matter settles out. Generally, several samples are analyzed before determining if the standard has been violated.

As was discussed in the IGDO section, it is important for egg/alevin survival that “fines” in the gravel are kept to a minimum to allow water to flow through the gravel. Thus continued effort needs to be made to reduce erosion in the Chimacum watershed and the amount of "fines" entering the creek.

The problem of erosion and “fines” is a common one. In a 1996 survey of 47 states managing coldwater fisheries, 34 states (72%) indicated that “erosion or sediment” was an obstacle to maintaining self-sustaining trout populations (Epifanio 2000).

Turbidity at the 28 stations monitored by the District in 2010-11 ranged from 0.6 NTU to 62 NTU (Figure 34). Turbidity at the 10 stations monitored by the Chimacum School Hydrology Class from September 2013 to June 2014 ranged from 0.8 NTU to 80 NTU (Figure 34).

Besides suspended sediment, turbidity can also be caused by particles sloughing off from decaying vegetation. High turbidity levels observed in 2010-11 and 2013-14 could have resulted from decaying vegetation. Stations CH/5.3, ECH/1.3, ECH/1.7, ECH/3.3, and WV/0.1 are downstream from reaches that were open to the sun and had excessive



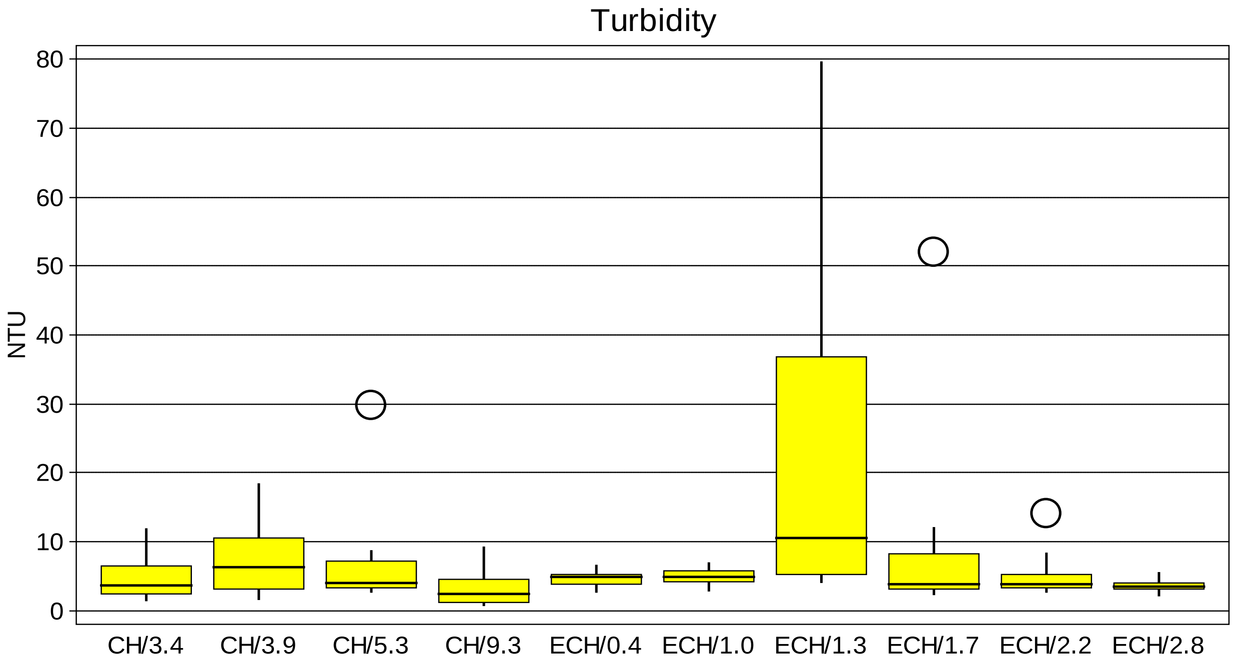


Figure 34. Turbidity measurements taken monthly in the Chimacum watershed in the 2011-12 water-year (top) and from September 2013 to June 2014 by the Chimacum School Hydrology Class (bottom). The state standard requires that turbidity not increase more than 5 NTU over the background level. For an explanation of the “box and whiskers,” refer to “statistics” in the “methods” section.

vegetation in the channel. Whether fines in the gravel are inorganic or organic (from decaying vegetation), both can plug gravel pores, limiting flow and causing egg and/or alevin mortality.

pH

pH is a measure of the water's acidity (pH < 7), neutrality (pH = 7), or basicity (pH > 7). The scale of measurement is logarithmic. Thus, a 1-unit difference represents a 10-fold change in the hydrogen ion concentration; a 2-unit difference represents a 100-fold change, etc. The state standard requires that the pH be within the range of 6.5 to 8.5.

In 2011-12, most pH measurements were slightly basic between 7.0 and 7.5 (Figure 35). Four measurements fell below the 6.5 standard. These low measurements could have been due to an aging pH sensor that had a slow response time.

Conductivity

Conductivity refers to the ability of a substance (e.g., water) to conduct an electric current. The unit of measurement for conductivity is the mho, which is the reciprocal of the ohm, the unit of measurement for resistance (i.e. mho=1/ohm). The more dissolved ions in the water, the higher the conductivity. Conductivity is affected primarily by the geology of the area through which the stream and contributing groundwater flow.

Because an increase in water temperature causes an increase in conductivity, for the purpose of comparison measurements are adjusted to a common temperature (25^{o}C). Distilled water has a conductivity in the range of 0.5 to 3 µmhos/cm. The conductivity range for potable water in the United States is 30-1500 μmho/cm (MacDonald et al. 1991). Most Pacific Northwest streams have conductivities near the low end of this range. There is no state standard for conductivity, and except for unusual circumstances, conductivity is seldom deleterious to fish. Conductivity does help characterize the water. To a limited degree, it indicates the fertility of the water with low measurements typical of nutrient-poor water. Low conductivity is characteristic of waterbodies at high elevations with shallow soil overlying bedrock. Conductivity typically increases as elevation decreases.

Conductivity ranged between 75 μmho/cm and 325 μmho/cm in the Chimacum Creek watershed (Figure 36). This range was similar to that of past years. In Chimacum Creek, East Chimacum Creek, and Naylors Creek conductivity increased from upstream to downstream, whereas in Barnhouse Creek and Putaansuu Creek measurements were similar at upstream and downstream stations.

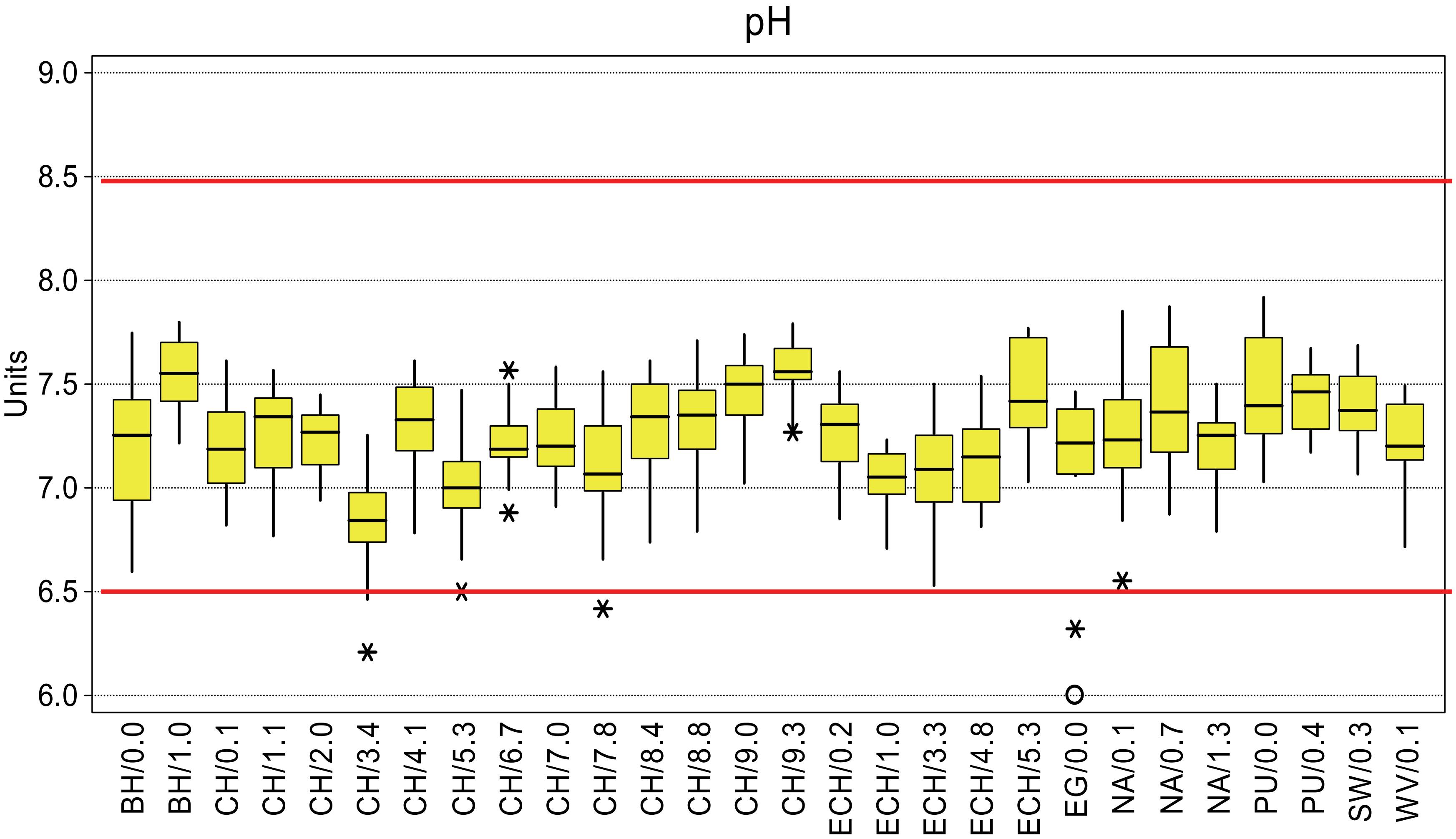


Figure 35. pH measurements taken monthly at stations in the Chimacum watershed in the 2011-12 water-year. The dashed lines represents the state standard. Measurements outside the dashed lines fail the standard. For an explanation of the "box and whiskers," refer to "statistics" in the "methods" section.

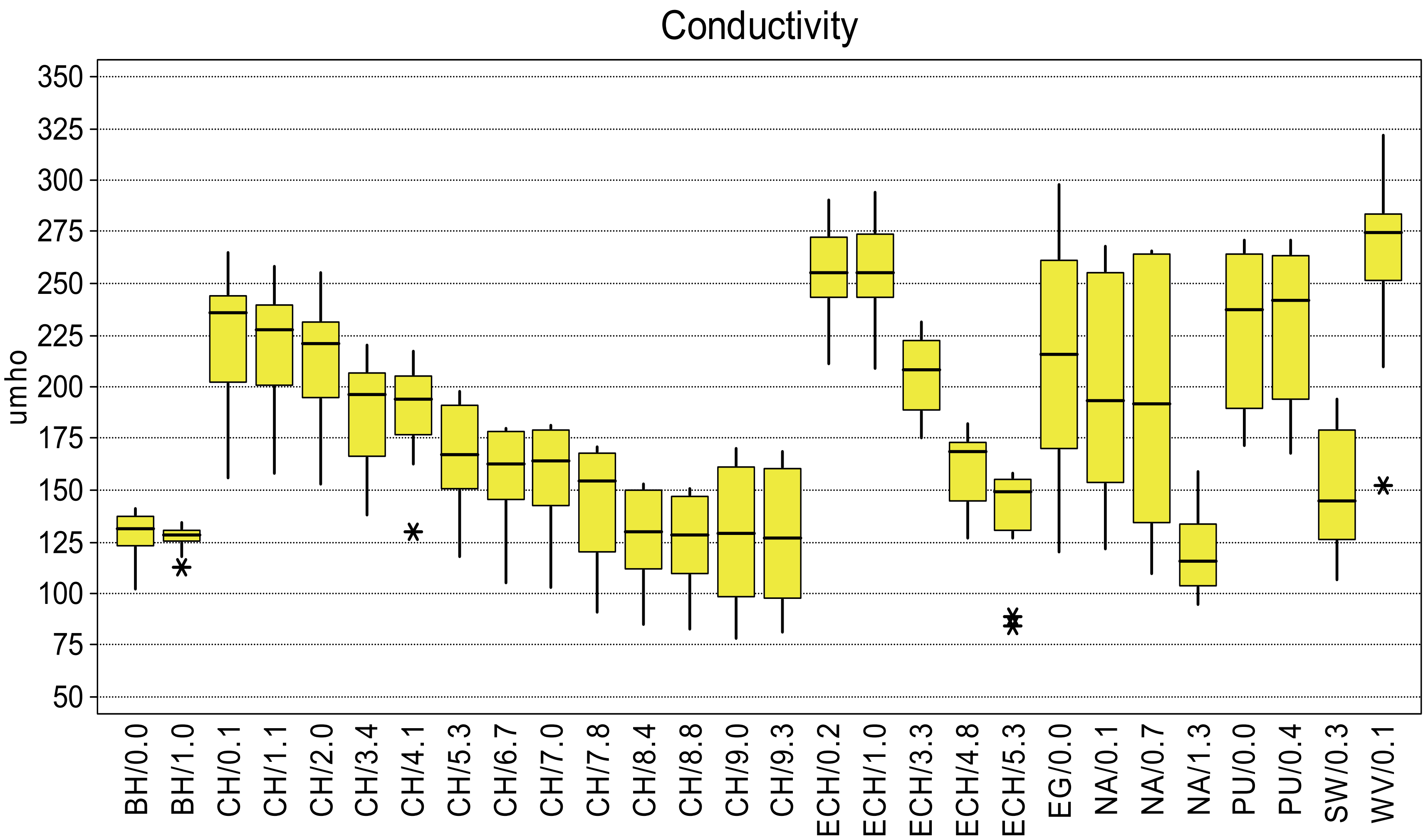


Figure 36. Conductivity measurements taken monthly at stations in the Chimacum watershed in the 2011-12 water-year. For an explanation of the “box and whiskers,” refer to “statistics” in the “methods” section.

Nitrogen

Nitrogen is an important nutrient for all plants, including phytoplankton. Most researchers believe nitrogen to be the limiting factor to plant production in salt water, although some researchers believe that phosphorus could be the limiting factor, or that it could be a combination of both, or that it changes with the season (Howarth 1988). In recent years, excessive nitrogen has been associated with fish kills in Hood Canal (Cope and Roberts 2013). It is believed that nitrogen fuels the growth of phytoplankton. This is important because the phytoplankton die and sink to the bottom where bacterial decomposition causes a reduction in dissolved oxygen. When an upwelling occurs, the oxygen-depleted bottom water is brought to the surface and fish trapped in the oxygen-deficient water die. Similar situations occur in the Gulf of Mexico (Rabalais et al. 2001) and Chesapeake Bay (Breitburg 1992).

Besides being a potential problem in marine water, nitrate-nitrogen can also be a problem in ground water. Because it readily dissolves in water, nitrate-nitrogen can percolate through the soil and contaminate well water. In excessive concentrations, it can cause methemoglobinemia (blue baby syndrome), which can be fatal. For this reason EPA standards require nitrate-nitrogen to be less than 10 mg/L NO_3-N nation-wide.

Nitrogen occurs in different forms and not all forms are immediately available to plants. Organic nitrogen must first break down to be available. Inorganic nitrate-nitrogen (NO_3-N) is the form that is readily available. The District most recently monitored nitrogen in 2007-08.

In 2007-08, nitrate-nitrogen concentrations ranged from 0.0 mg/L to 6.5 mg/L in samples collected monthly in the Chimacum watershed **(**Figure 37). Concentrations were highest in December with the highest level occurring at Peat Plank Road station ECH/3.3. This station also had the highest level in 2002 (Gately 2003) and in the 2005-06 water-year (Gately et al. 2007). Other East Chimacum Creek stations were also high in December 2007.

Monthly nitrate-nitrogen loadings for the 2007-08 water-year for station CH/0.1 are shown in Figure 38. The highest loadings at this station occurred in December 2007 (1,564 pounds N per day) and January 2008 (1,051 pounds N per day).

Sources of nitrate-nitrogen include soils, organic fertilizer (manure), inorganic fertilizer (chemicals), septic drainfields, automobile exhaust, fossil fuel combustion, and atmospheric nitrogen (through denitrification). Based on their literature review, Carpenter et al. (1998) concluded that agriculture and urban activity, including industry, were the major nonpoint sources of both nitrogen and phosphorus.

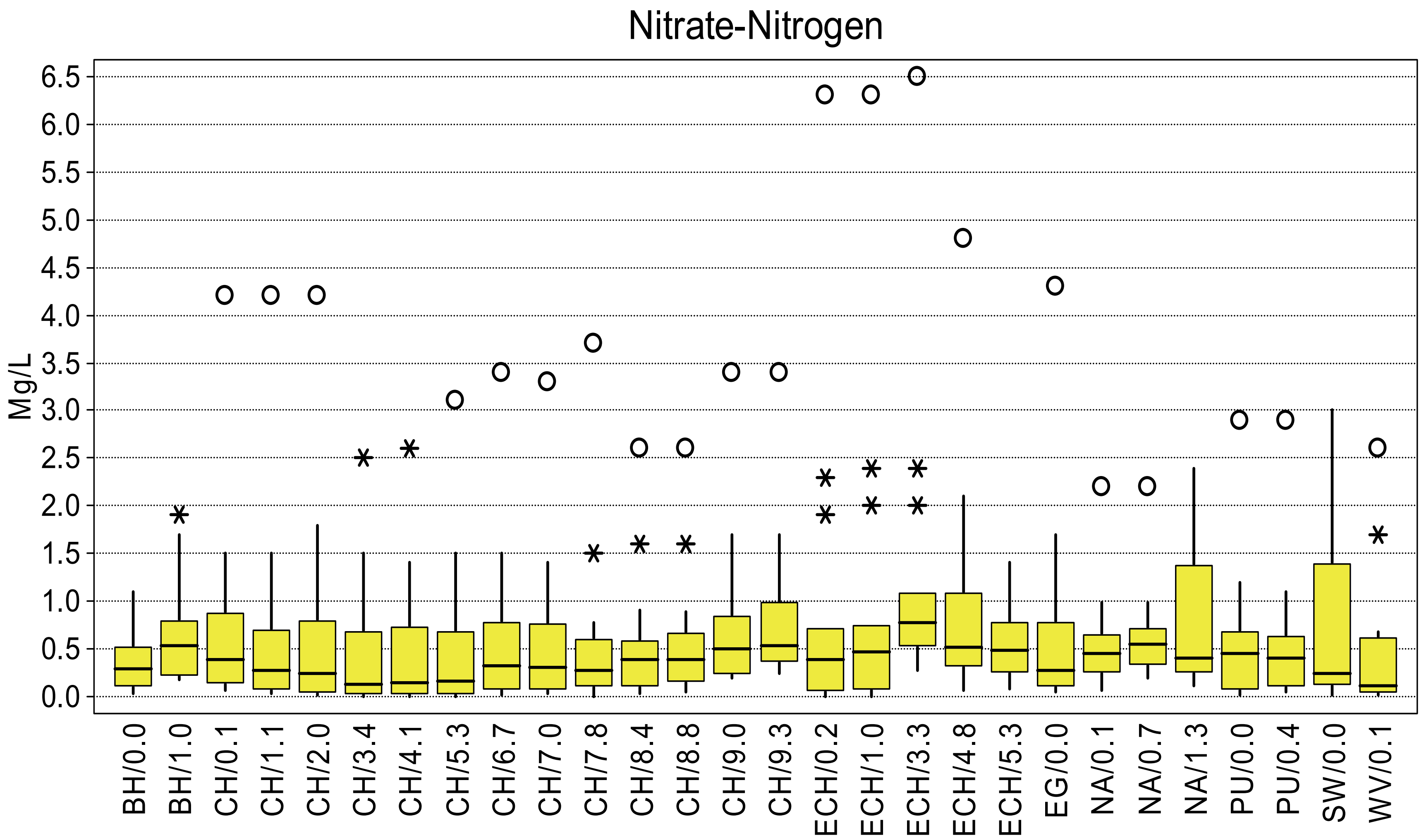


Figure 37. Nitrate-nitrogen measured monthly from October 2007 to September 2008 in the Chimacum watershed. For an explanation of the “box and whiskers,” refer to “statistics” in the “methods” section.

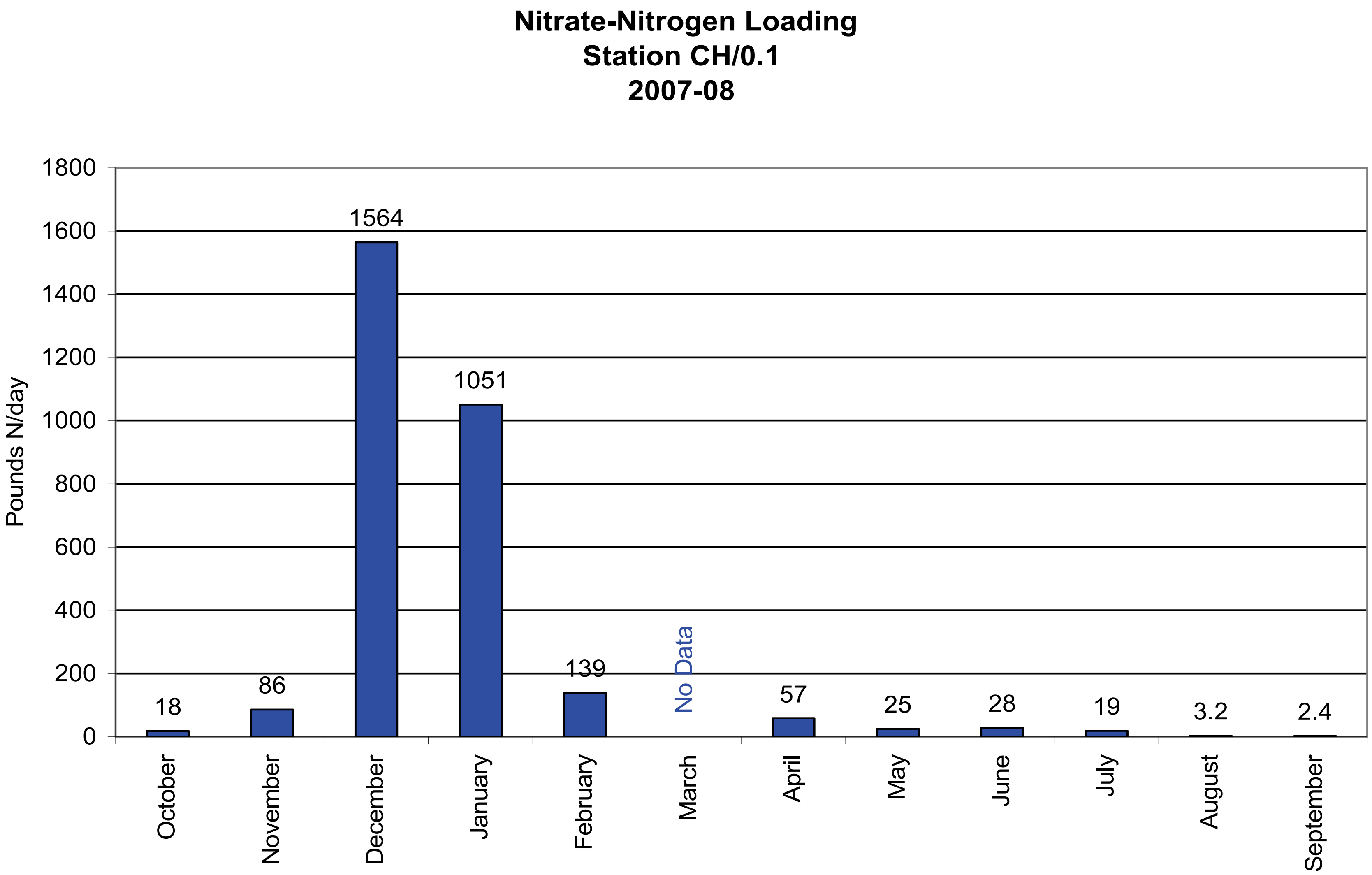


Figure 38. Nitrate-nitrogen loadings at Chimacum Creek downstream station CH/0.1 by month in the 2007-08 water-year.

Although efforts to control nutrient loadings to coastal waters have traditionally focused on agricultural land use (cropland and livestock practices), there is an increased awareness of nitrogen loadings coming from residential and urbanized lands (Reay 2004). Studies in New England indicate that effluent from residential septic tanks is a significant, and in many cases, dominant nitrogen source to coastal embayments (Valiela and Costa 1988; Giblin and Gaines 1990; Weiskel and Howes 1991; Valiela et al. 1997; all as cited by Reay, 2004).

Most of the nitrogen in septic waste passes through an on-site septic system into the groundwater. In the anaerobic septic tank, organic nitrogen is converted to soluble ammonium-nitrogen. In the aerobic drainfield, soluble ammonium nitrogen is oxidized to soluble nitrate-nitrogen (Wilhelm et al. 1994), which then enters the ground water (Reay 2004)

In soils, decaying organic matter (plants and animals) is the source of nitrogen. Thus soils rich in organic matter contain more nitrogen than sandier soils. Chimacum watershed soils have a high organic content and are therefore potentially high in nitrogen.

In order to prevent nitrogen from leaching into the ground water or surface water during the rainy season, farmers and gardeners should take care not to apply more fertilizer than plants can take up in the growing season.

Phosphorus

Like nitrogen, phosphorus is an important nutrient for plants. Phosphorus is usually the limiting factor to plants in fresh water and can cause eutrophication in lakes. Excessive phosphorus can cause fish kills in fresh water, similar to the way nitrate-nitrogen does in saltwater. Fish kills in the Great Lakes in the 1960’s were caused by phosphorus in laundry detergents making their way through treatment plants into the lakes. Laws now limit the amount of phosphorus allowed in detergents. There is no state standard for phosphorus in streams. In lakes, Ecology’s “action level” for total phosphorus (TP) is 0.02 mg/L.

Unlike nitrate-nitrogen, which readily percolates through soil into the groundwater, orthophosphate-phosphorus generally binds to soil particles and would not enter waterbodies except through soil erosion. However, in sandy soils with high water tables or in older septic drainfields where phosphate sorption capacity has become limited, phosphorus contamination of ground water from septic effluent can occur (Harman et al. 1996).

Like nitrogen, phosphorus comes in various forms, both organic and inorganic. It is inorganic orthophosphate (PO_4), also known as soluble reactive phosphorus (SRP), that is readily taken up by plants. Because of this rapid uptake, there is usually not enough phosphorus in the water to indicate a problem. For this reason, the District chose to monitor total phosphorus, which includes all forms of phosphorus.

Total phosphorus was last monitored by the District in the 2005-06 water-year. At the 5 stations monitored on the Chimacum main stem and East Chimacum Creek, TP concentrations ranged from 0.003 mg/L to 0.12 mg/L (Figure 39). Median concentrations for all 5 stations were very similar to those of 2002 (Gately 2003). As in 2002, median concentrations in 2005-06 were higher at downstream stations CH/1.1 and CH/3.4 than at upstream station CH/9.3. On East Chimacum Creek, median concentrations were identical at downstream station ECH/0.2 and upstream station ECH/5.3.

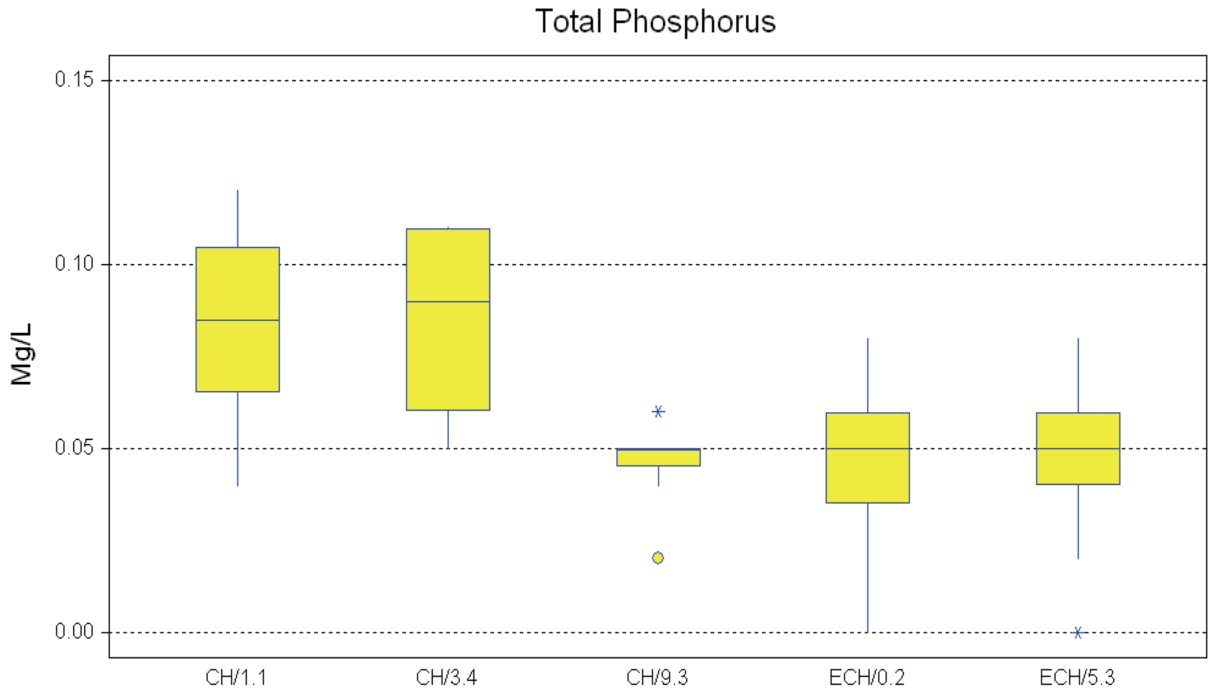
TP loading ranged from 0.03 pounds/day to 30 pounds/day for the three stations monitored (Figure 39). Median loading was highest for station CH/1.1 and lowest for station ECH/0.2. The highest loadings occurred on January 4, 2006 when stream flow was highest (no February data available). Regression analysis showed a significant positive correlation (p=0.0000) between TP loading and flow.

Water Quality Results versus Water Quality Standards

The reader should understand that although water quality parameters analyzed in this study often failed Ecology's water quality standard, water quality in the Chimacum watershed is not as bad as it may appear. Fecal coliform is required to meet the most stringent classification, termed "extraordinary primary contact recreation." This classification provides extraordinary protection against waterborne disease and includes shellfish harvesting. The next classification, termed "primary contact recreation" provides protection against complete submergence as in skin diving, swimming, and water skiing. The GMV must not exceed 100 FC/100 mL and not more than 10% of sample may exceed 200 FC/100 mL. A third classification, termed "secondary contact recreation," provides protection from activities requiring limited contact with water including wading and fishing. The GMV must not exceed 200 FC/100 mL and not more than 10% of the samples may exceed 400 FC/100 mL.

As has been previously mentioned, it is likely that the fecal coliform levels that have been consistently high in the summer, when there was no rain runoff, were due to fecal coliform reproduction in the stream.

Standards for temperature (16^{o}C) and dissolved oxygen (9.5 mg/L) were not met in some reaches at some times of the year. However, salmon do survive at temperatures greater than 16^{o}C and at dissolved oxygen levels less than 9.5 mg/L. Although salmon production (biomass/area) may not be optimum in the Chimacum watershed, this does



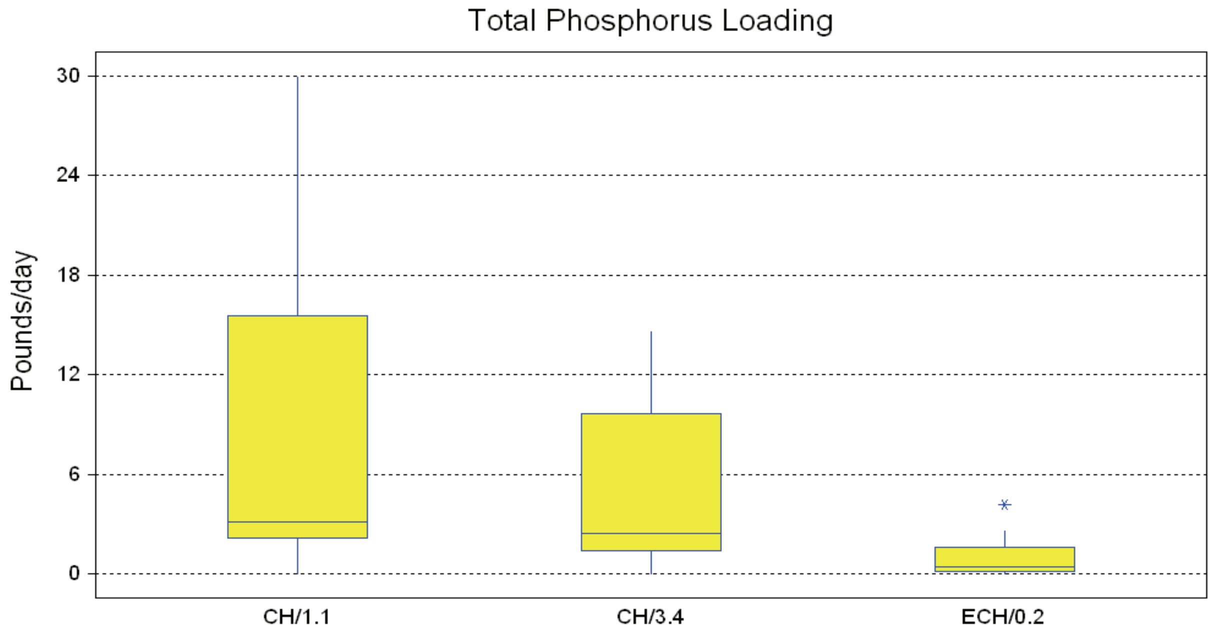


Figure 39. Total phosphorus concentration (top) measured monthly in the 2005-06 water-year and total phosphorus loading (bottom) measured monthly (except February) in the Chimacum watershed .

not negate the presence of healthy salmon populations as the Coho and Chum returns demonstrate (see the following Chimacum Watershed Fishes section).

Even in pre-settler times, this nutrient-rich watershed probably produced a lot of organic material that drew the dissolved oxygen level down when it decomposed. Also, the extremely low gradient existing in much of the Chimacum watershed limits aeration in these reaches.

Chimacum Watershed Fishes

There are nine species of fish known to inhabit the streams and lakes of the Chimacum watershed: Chum Salmon, Coho Salmon, Rainbow/Steelhead Trout, Stickleback, Sculpin, Largemouth Bass, Western Brook Lamprey, Pumpkinseed, and a minnow (currently unidentified). Additionally, the following species are known to use the Chimacum Creek estuary: juvenile Chum and Pink Salmon, Starry Flounder, English Sole, Herring, Surf Smelt, Sand Lance, Green Gunnel, Pipefish, and Sculpin.

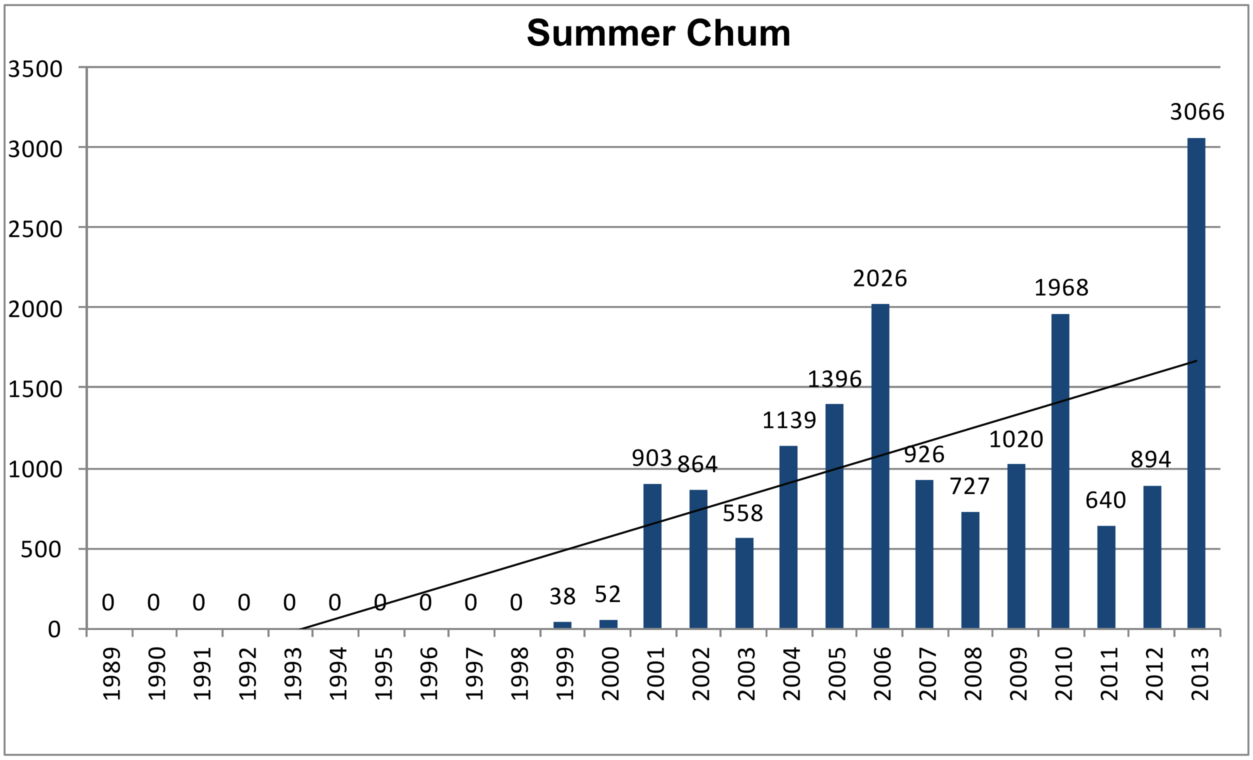
Much of the District's restoration projects and water quality monitoring are pertinent to factors affecting salmon. Although we can discern much from monitoring temperature, dissolved oxygen, and other water quality parameters, the million-dollar question is, "Have the restoration projects made a difference to the salmon"?

Chum Salmon

For the Chum Salmon, which migrates to salt water immediately upon emerging from the gravel, almost all of its juvenile freshwater life-stage is spent within the gravel. Except for its out-migration to salt water, its habitat consists of gravel with cool, well-oxygenated water flowing through it. Monitoring IGDO and stream temperature are the best parameters to assess water quality relating to Chum Salmon.

However, no water quality parameter measures success better than the number of returning adults. Coming from extinction with a return of 38 Summer Chum in 1999 to a record return of 3,066 fish in 2013 (Figure 40), the Chimacum Summer Chum is a true success story and shows what determined citizen volunteers, working with the Washington Department of Fish and Wildlife, can do.

In the 1980's, Summer Chum Salmon experienced a severe drop in abundance in Hood Canal and Strait of Juan de Fuca streams. This critical situation resulted in the National Marine Fisheries Service listing the Summer Chum of this Evolutionary Significant Unit as "threatened" under the Endangered Species Act. To counteract the decline of the Summer Chum, in 2000 the Washington Department of Fish and Wildlife developed the Summer Chum Salmon Conservation Initiative. One of the strategies of this initiative



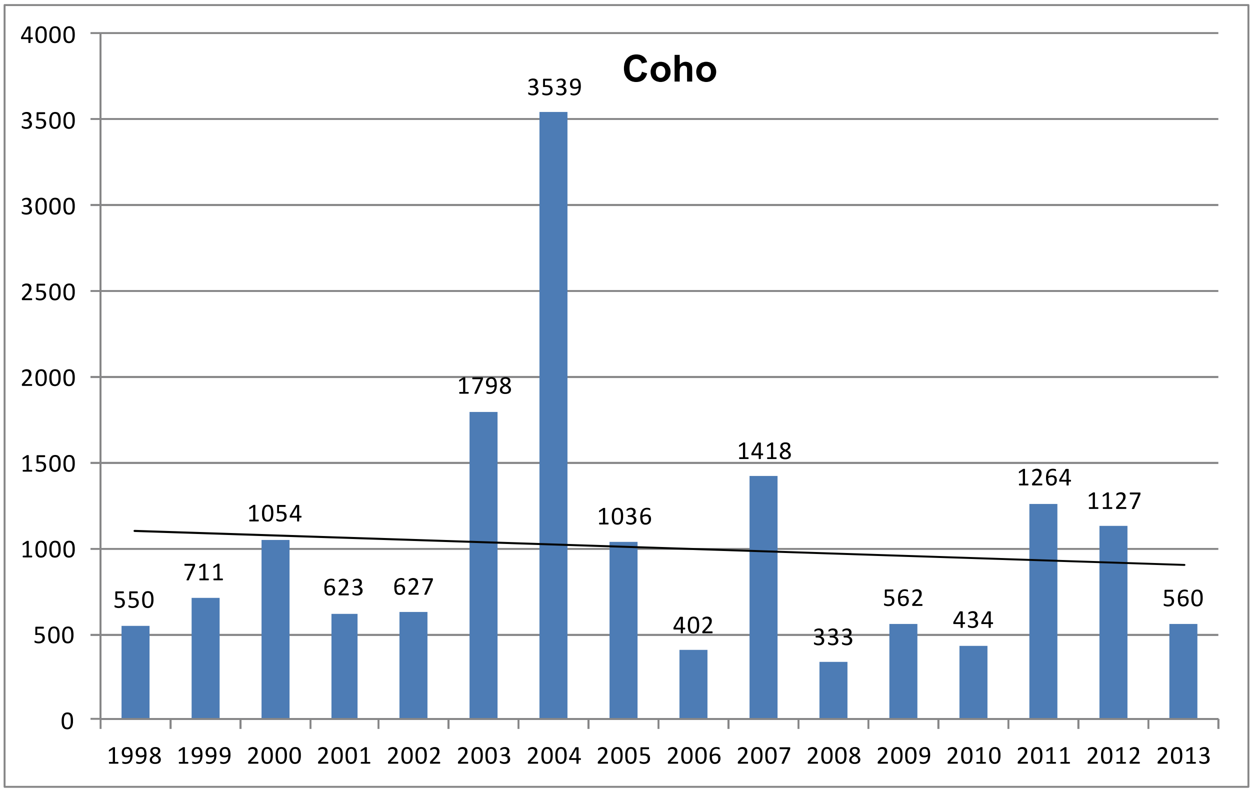


Figure 40. Estimated number of summer Chum (top) and Coho (bottom) returning to the Chimacum watershed (the 2013 Coho estimate has not been refined yet).

was to supplement natural reproduction by releasing fry reared artificially from eggs obtained from the parent stock.

About 10 years prior to the WDFW's formalizing the Summer Chum Salmon Conservation Initiative, a group of concerned citizens known as Wild Olympic Salmon (WOS) took some initiative of their own. Their concern was focused on the run of Summer Chum in Chimacum Creek, or more aptly stated, "lack of a run." By 1991, after several years of monitoring a weir on Chimacum Creek without observing a single Chum Salmon, WOS concluded that the Chimacum Creek Summer Chum was extinct. The only solution appeared to be starting a new run, but where would the fish come from? Because each river system has its own genetically distinct stock, WOS looked for the system that best matched Chimacum Creek. After considering the possibilities, they chose Salmon Creek.

There was one problem, however. Salmon Creek was, at that time, experiencing record low returns of Summer Chum. Before any eggs could be donated to Chimacum Creek, the run in Salmon Creek would have to be bolstered. WOS and WDFW got together and developed a plan to supplement natural reproduction in Salmon Creek. WOS constructed a hatchery on Houck Creek, a Salmon Creek tributary, and in 1992 the first eggs were taken to supplement natural reproduction in Salmon Creek. By 1996 Salmon Creek returns had increased to 894 fish, a sufficient enough number to allow some eggs to be transferred to a hatchery on Chimacum Creek.

From 1996 to 2003, 29,000 to 73,000 Chum fry were released each year, either directly into Chimacum Creek or into Port Townsend Bay. Fish released into the bay were reared to a larger size in net pens at Kala Point in order to increase survival, (Figure 41). Success was first evidenced in 1999 when 38 3-year-old Summer Chum returned to Chimacum Creek. In 2013, a record 3,066 Chum returned to spawn in Chimacum Creek! The good news is that all of the Summer Chum returning since 2007 were from natural reproduction because 2003 was the last year that hatchery-reared fish were released.

Coho Salmon

Unlike Chum Salmon, which migrate to sea immediately upon emerging from the gravel, Coho Salmon spend an entire year in freshwater before heading to sea. Besides needing clean gravel for spawning, juvenile Coho require suitable freshwater rearing habitat. In addition to cool, well-oxygenated water, both juvenile and adult Coho require adequate cover in which to hide from predators and to provide a refuge to avoid fast-moving water. Well-shaded pools with large woody debris (LWD) are ideal for this purpose.

Chimacum hatchery—preparing fish for transfer.

Kala Point pier net pens—getting ready for chum fingerlings in March 2003.

Here volunteers help release chum fingerlings directly into Chimacum creek.

April 2003

Figure 41. Wild Olympic Salmon volunteers releasing summer chum fingerings into Chimacum Creek and preparing net pens at Kala Point for rearing the fingerlings to a larger size before releasing them into Port Townsend Bay.

Low-gradient, channelized reaches in the Chimacum watershed lack LWD and tend to be homogenous glides lacking stream complexity (alternating pools and riffles). Numerous studies have shown that the addition of LWD increases stream complexity resulting in increased salmonid abundance (Cederholm et al. 1997; Roni and Quinn 2001; Johnson et al. 2005; Whiteway et al. 2010; Jones et al. 2014). Beaver dams also provide stream complexity (Pollock 2004).

In reaches lacking riparian buffers, planting trees will eventually provide the needed cover as they grow and fall into the stream. Installing LWD as part of a restoration project speeds up the process.

During the rainy season when stream flow is often high, off-channel habitat is especially important to juvenile Coho. Off-channel habitat includes small tributary streams, side channels, some drainage ditches, and pools created by beaver dams.

Based on spawning surveys conducted in the Chimacum watershed from 1998 to 2013, returning Coho ranged from 333 to 3539 (Figure 40). The trend over these 16 years is slightly downward. Fluctuation in the number of returning adults is normal for salmon. Survival at every stage in the salmon’s 4-year life cycle, from eggs to adults, affects the number of adults returning. Disease, predation, and harvest all play a part. Good survival in the creek could be countered by poor survival in the ocean and result in low returns.

Restoration Projects

The 1980’s marked the beginning of salmon habitat restoration projects and water quality improvement projects in the Chimacum watershed. Restoration projects to improve fish passage were completed on Barnhouse Creek and Naylors Creek. To enable salmon to reach upstream spawning habitat, the Four Creeks Association installed log weirs on Barnhouse Creek downstream from the Center Road culvert and on upper Naylors Creek downstream from the Van Trojan Road culvert.

Another early restoration project occurred on Putaansuu Creek by a team effort of several organizations. Chimacum High School Teacher Ray Lowrie and his Fisheries Class installed log weirs on the upstream side of West Valley Road to provide pool habitat and access to a rearing pond that they excavated (Figure 42). From West Valley Road downstream to Chimacum Creek, the Washington Conservation Corps installed fencing and the Boy Scouts planted trees. Two concrete “Perkin’s troughs,” funded by the U.S. Department of Agriculture and North Olympic Salmon Coalition, were installed for livestock drinking.

With the advent of CREP, restoration projects accelerated. Under CREP, a landowner is paid rent for land put into riparian buffers. Buffers can vary in width from 35 feet to

Figure 42. Coho Salmon jumps weir on Putaansuu Creek originally installed by Chimacum High School Teacher Ray Lowrie and his Fisheries Class. The weir received some maintenance in 2004 by Jefferson County Conservation District.

180 feet. Streams that have an ordinary high water level less than 15 feet wide and that flow into a fish bearing stream qualify for a 15-ft. wide hedgerow buffer. Based on soil productivity, a landowner receives about $300 per acre per year for land installed in CREP.

CREP and non-CREP projects have resulted in tens of thousands of trees and shrubs being planted in riparian buffers in the Chimacum watershed. About 32,000 trees and shrubs were planted from 2000 to 2013 under CREP alone. Counting both sides of the stream, CREP and non-CREP buffers total 9.3 miles in length and cover 82.2 acres of land (Table 3). About 71% of this total buffer length and 96% of the total buffer area have been implemented under CREP. Average buffer width for CREP buffers is 86 feet on Chimacum Creek and 112 feet on East Chimacum Creek. Buffer width for historical non-CREP projects is about 10 ft. One 15-ft. hedgerow buffer was installed under CREP on Naylors Creek. CREP buffer locations are shown on a map in Figure 43 and details (e.g., length and width) are given in Table 4.

As previously discussed, water temperature has exhibited decreasing trends for both Chimacum Creek and East Chimacum Creek (see Temperature section). It is the accumulative effect of all the restoration projects that has resulted in measurable temperature improvements.

Improvements in juvenile Coho abundance have been observed at project sites where long term fish trapping data is available. One such project (ECH/1.0-1.2) is on East Chimacum Creek just south of Beaver Valley Road (Figure 44). In 1984, seven varieties of willow were planted along the creek’s west bank (Purser 1988; Taylor 2000). Then in 1999-2000 under CREP, the reach was re-meandered, LWD was installed, and both sides were planted with trees and shrubs for an average width of 119 ft. (Figure 44). Fish trapping data from 1998 to 2013 shows increasing trends in juvenile Coho abundance during all four quarters of the year (Figure 45).

Another older project (ECH/0.9-1.0) with long-term fish trapping data is located on East Chimacum Creek just north of Beaver Valley Road (Figure 46). Increasing Coho trends were observed in this stream reach for all quarters except October-December (Figure 47).

Farms, Buffers, and Beaver

Since the 1800’s when settlers moved into eastern Jefferson County, farming has been a way of life in the Chimacum watershed. At one time there were more than a hundred dairy farms in eastern Jefferson County (Roger Short, personal communication, April 2015). Some of the best farmland, with rich peat soils, is located in the Chimacum watershed in Beaver, Center, and West valleys where settlers cleared the land to make it suitable for growing crops and pasturing livestock.

Table 3. Buffer data for CREP and non-CREP projects completed in the Chimacum Creek watershed since 1980. Buffer length includes buffers on both sides of the stream.

Stream	**Project Type**	**Buffer Area**	**Buffer Length**	**Stream Length**	**Average Buffer Width**
		(Acres)	**(Miles)**	**(Miles)**	**(Feet)**
Chimacum Creek	CREP	25.3	2.4	1.3	86
Chimacum Creek	Non-CREP	2.2	1.9	1.2	11
Totals		**27.5**	4.3	2.5	
East Chimacum Creek	CREP	53.1	3.9	2.0	112
East Chimacum Creek	Non-CREP	0.4	0.3	0.2	10
Totals		**53.5**	4.2	2.2	
Naylors Creek	CREP	0.6	0.3	0.1	15
Naylors Creek	Non-CREP	0.3	0.2	0.2	10
Totals		**0.9**	0.5	0.3	
Putaansuu Creek	CREP	0.0	0.0	0.0	0
Putaansuu Creek	Non-CREP	0.3	0.3	0.2	10
Totals		**0.3**	0.3	0.2	
All streams	CREP	79.0	6.6	3.4	
All streams	Non-CREP	3.2	2.7	1.8	
Grand Total	CREP & Non-CREP	**82.2**	**9.3**	**5.2**	

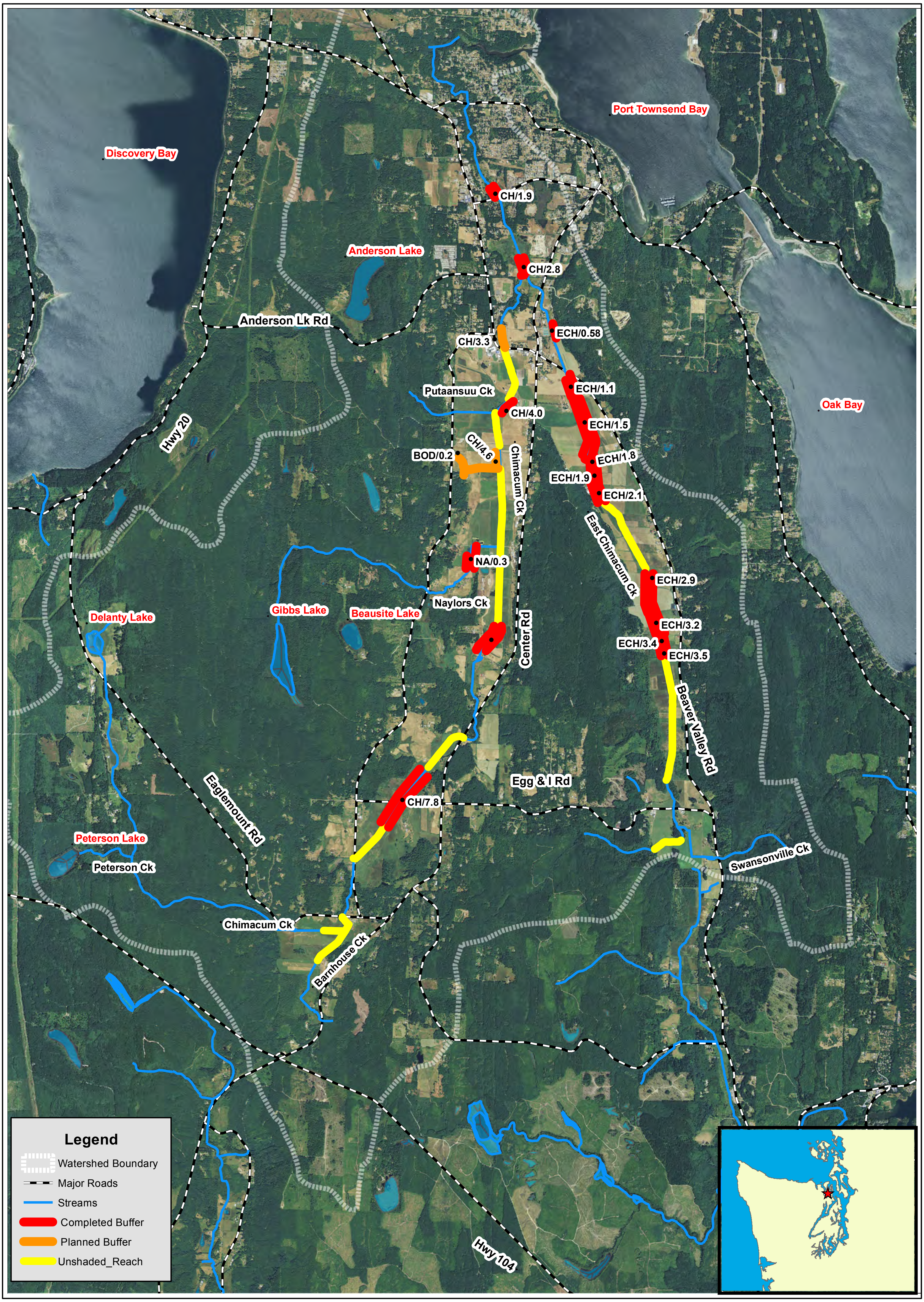


Figure 43. Map of Chimacum watershed showing CREP buffers and unshaded reaches on Chimacum Creek and its tributaries. For buffer details (length, width, etc.), see Table 3.

N

Jefferson County Conservation District
PORT HADLOCK, WASHINGTON, U.S.A.

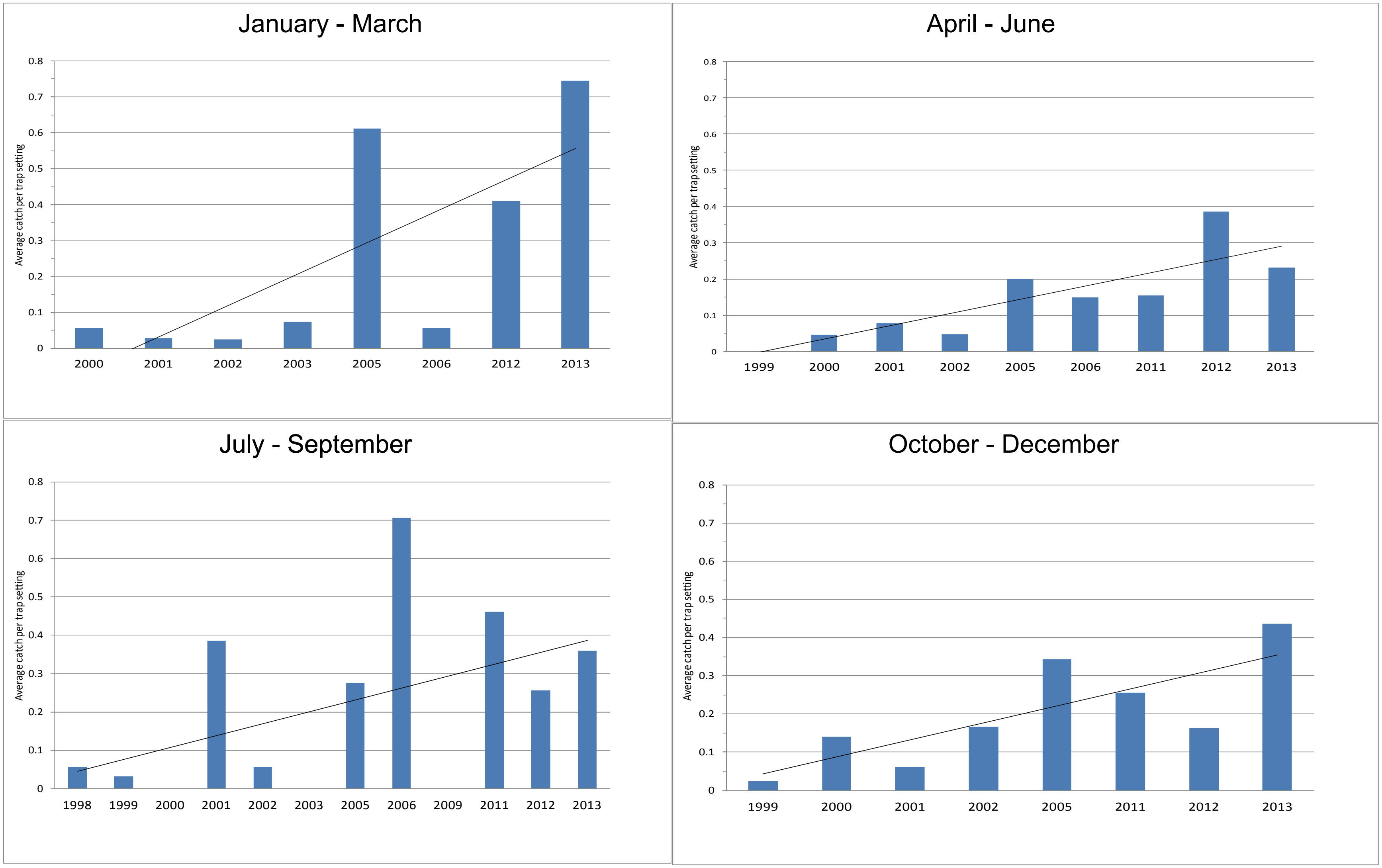
0.5 0.25 0 0.5 Miles

Table 4. Buffer data for completed and planned CREP projects in the Chimacum Creek watershed. Buffer length includes buffers on both sides of the stream.

Buffer ID	Stream	Status	Planted	Buffer Area	Buffer Length	Stream Length	Buffer Width
			(Year)	(Acres)	(Feet)	(Feet)	(Feet)
BOD/0.2	Ditch	Planned	Future	1.0	3900	2290	15
CH/1.9	Chimacum Creek	Completed	2007	3.2	1006	503	50
CH/2.8	Chimacum Creek	Completed	2010	3.6	2180	1090	72
CH/3.3	Chimacum Creek	Planned	Future	0.8	600	600	58
CH/4.0	Chimacum Creek	Completed	2011	1.0	918	918	50
CH/4.6	Chimacum Creek	Planned	Future	0.6	800	800	35
CH/6.1	Chimacum Creek	Completed	2005	7.4	1840	920	165
CH/6.1	Chimacum Creek	Completed	2003	3.3	987	494	165
CH/7.8	Chimacum Creek	Completed	2007	3.9	3340	1670	50
CH/7.8	Chimacum Creek	Completed	2007	2.9	2550	1275	50
ECH/0.58	East Chimacum Creek	Completed	2003	2.4	597	597	175
ECH/1.1	East Chimacum Creek	Completed	2002	6.6	2408	1204	119
ECH/1.5	East Chimacum Creek	Completed	2003	10.1	5535	2768	79
ECH/1.8	East Chimacum Creek	Completed	2005	5.1	1456	728	153
ECH/1.9	East Chimacum Creek	Completed	2005	3.8	1740	870	95
ECH/2.1	East Chimacum Creek	Completed	2005	1.9	1590	795	52
ECH/2.9	East Chimacum Creek	Completed	2003	14.1	3445	1723	178
ECH/3.2	East Chimacum Creek	Completed	2003	5.9	2008	1004	128
ECH/3.4	East Chimacum Creek	Completed	2010	1.2	1326	663	35
ECH/3.5	East Chimacum Creek	Completed	2008	2.0	586	293	150
NA/0.3	Naylors Creek	Completed	2011	0.6	1440	700	15

Figure 44. Restoration project on East Chimacum Creek. In 1984 seven varieties of willow were planted along part of the west bank. In 1999 under CREP, the 1200-ft. channelized reach was remeandered, LWD was placed in the channel, and both sides were planted with a variety of trees and shrubs.

ECH/1.0-1.2


January - March

April - June

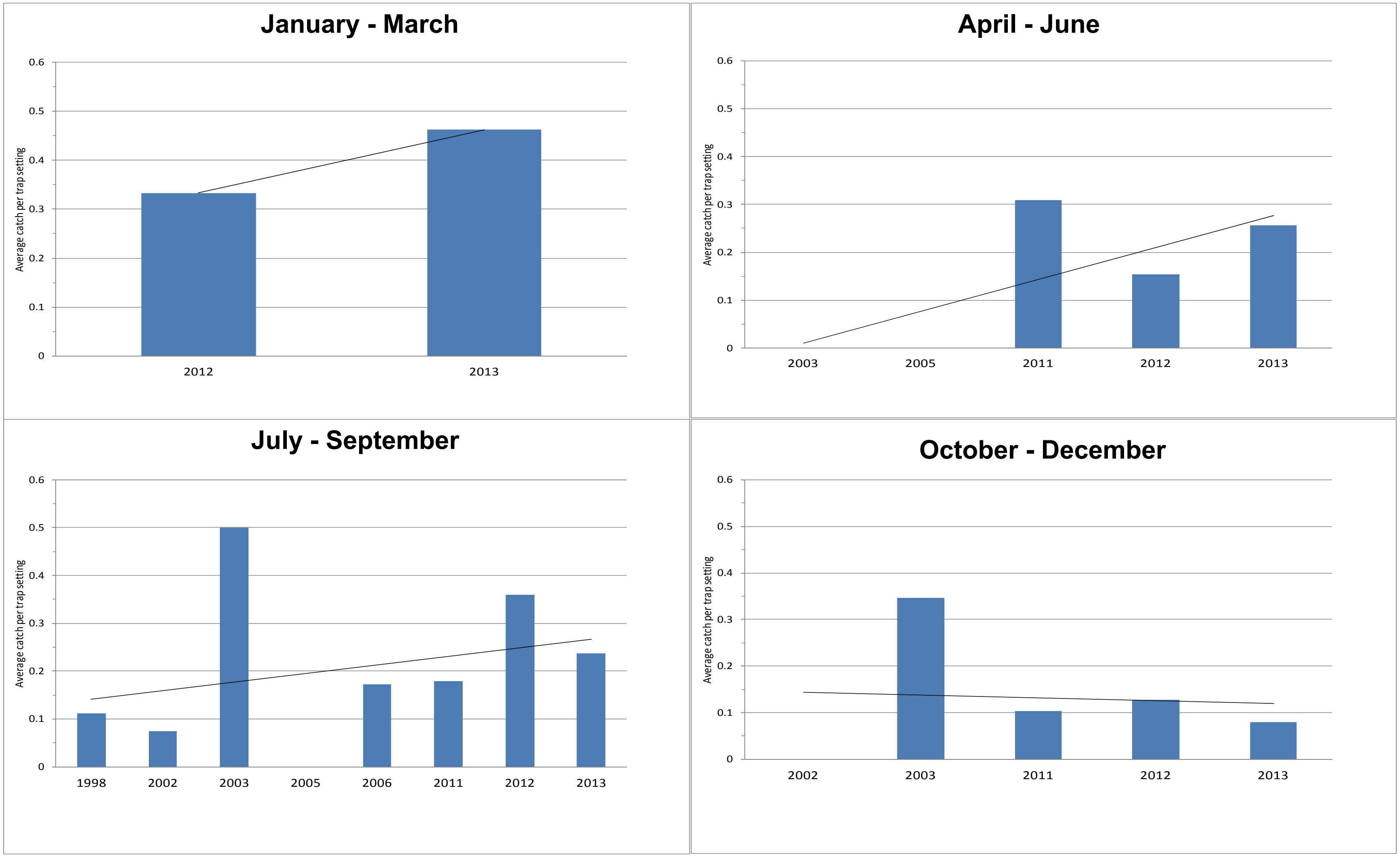
July - September

October - December

Figure 45. Average number (with trendline) of juvenile coho salmon caught in fish traps in various years in East Chimacum Creek reach ECH/1.0-1.2, a JCCD Riparian Buffer CREP Project located upstream of Beaver Valley Road.

Figure 46. Restoration project sponsored by the North Olympic Salmon Coalition. In 2003, a 1500-ft. channelized reach on the north side of Beaver Valley Road was fitted with alternating alcove pools, LWD, and deflector logs, and was planted with a variety of trees and shrubs.

ECH/0.9-1.0



January - March

April - June

July - September

October - December

Figure 47. Average number (with trendline) of juvenile coho salmon caught in fish traps in various years in reach ECH/0.9-1.0 within a stream restoration reach in East Chimacum Creek on the downstream side of Beaver Valley Road.

In the 1900's the U.S. Soil Conservation Service (now the Natural Resource Conservation Service), together with the Jefferson County Conservation District, assisted farmers in making the land more productive. Because land in the valleys was low gradient, had a high water table, and was prone to flooding, these agencies assisted farmers with the installation of tile drains and drainage ditches. To make the land more productive, the stream was channelized and trees were removed all the way to the water's edge. Because the newly channelized reach was not always located in the lowest part of the terrain, the land became more prone to flooding and requiring more time to dry out.

Removal of the tree canopy opened the stream up to unmitigated sunlight, allowing vegetation in the channel to flourish. Around the 1950's, Canary Grass was introduced into the area as a wet-tolerant forage species for cattle. Canary Grass proved to be extremely wet-tolerant, and left unchecked, can completely fill the stream channel. When this happens, stream velocity decreases, suspended matter settles out, which improves conditions for more Canary Grass. The build-up of Canary Grass can result in pastures being flooded and water coming in contact with manure. Flooded pastures can result in a temperature increase and dissolved oxygen decrease. A forested buffer would in time effectively shade out the Canary Grass, but in the meantime, the trees would prevent access to the channel for mechanically removing the Canary Grass. Furthermore, the forested buffer could be used by beaver to build dams, resulting in pasture flooding.

To keep the stream flowing and the water table down, Chimacum Creek and associated drainage ditches were cleaned periodically. The Chimacum Drainage District was formed in the early 1950's for this purpose. The District has continued to assist farmers with vegetation removal where it causes flooding on agricultural land. However, permitting for this type of maintenance work has become increasingly time consuming and costly. When permitting becomes too cumbersome and expensive, this important maintenance work is often postponed or delayed, leading to a proliferation of vegetation, silt, and lowered water quality.

In more recent years, government agencies, including those that assisted with channelizing streams, are now involved with re-meandering them, installing LWD, and establishing riparian buffers. In other words, best management practices are now attempting to restore the channelized streams to their pre-settler state.

It is the planting of riparian buffers that has exacerbated an existing problem to emerge in stream restoration work – beaver. Beaver are indigenous to Jefferson County and the Chimacum watershed. Beaver Valley got its name from these industrious creatures! Beaver have had their ups and downs over the years. Prior to Euro-American settlement in the 1850's, Chimacum Creek and East Chimacum Creek had meandering channels interlaced with beaver ponds and large seasonally flooded wetlands (Bahls and Rubin 1996). Riparian areas were forested with spruce, cedar, hemlock, and fir. At the turn of the 20th century, beaver were still common. However, by about 1950, beaver were mostly trapped out except for Peterson Lake where they were introduced and protected. In the 1960's beaver were reintroduced to eastern Jefferson County. Until recent years, their climb from near extinction to viable populations, combined with the lack of suitable habitat, has limited their distribution. However, with the increasing number of restoration projects which are creating more suitable habitat (i.e. forested buffers), beaver numbers are rising steadily. In the past few years there have been beaver dams at a minimum of 16 locations in the Chimacum watershed (Figure 48).

Beaver have been building dams within the newly created buffers, sometimes causing flooding in adjacent farmland. Dam removal and beaver removal by trapping has proven to give only temporary respite as new beaver move into the vacated areas. It is also expensive. From January 2010 to July 2014, it cost $15,300 or $3,400 per year to remove beaver and beaver dams from CREP Projects ECH/2.9 and ECH/3.2 where adjacent farmland was being flooded (Figures 43 and 49). Beaver dams at CREP Project ECH/2.9 have caused flooding outside the 180-ft. buffer onto about 10 acres of land used for hay. And they have caused flooding outside the 128-ft. buffer at CREP Project ECH/3.2, causing the loss of about 3 acres of pasture.

Beaver dams have also created problems for home owners both upstream and downstream from SR 116 at RM 2.0. Two dams on the downstream side of the road have caused water to back up through the culvert and into the backyards of several homes. The higher water level could also undermine the road by softening the roadbed. In October 2014 a beaver deceiver was installed in each of the two dams downstream from SR 116, lowering the water level at the SR 116 culvert by about 2.5 ft. (Figure 50). Also, a trapezoidal fence was installed near the upstream end of the SR 116 culvert to prevent beaver from building a dam in it (Figure 50). This was a cooperative effort involving the Jefferson County Conservation District, Washington Department of Transportation, Jefferson County Public Works, Snohomish Conservation District, and University of Washington Ph. D candidate Benjamin Dittbrenner, who led the hands-on training exercise. A December 2014 storm event, resulting in a flow of about 200 cfs, caused some damage to the trapezoidal fence and the two beaver deceivers and prevented them from functioning properly. All were repaired in January 2015 by the Washington Conservation Corps crew and are now functioning again.

In addition to the cost to humans created by the flooding, we also face challenges in getting the planted tree buffers established in the waterlogged soil. Beaver often cut down trees in the buffers, sometimes reducing tree numbers by as much as 40%. Falling trees can damage livestock fences, bridges, and other infrastructure. Repair and replacement of these integral pieces of the buffers is costly and time consuming. Given

Figure 48. Map of Chimacum watershed showing beaver dams.

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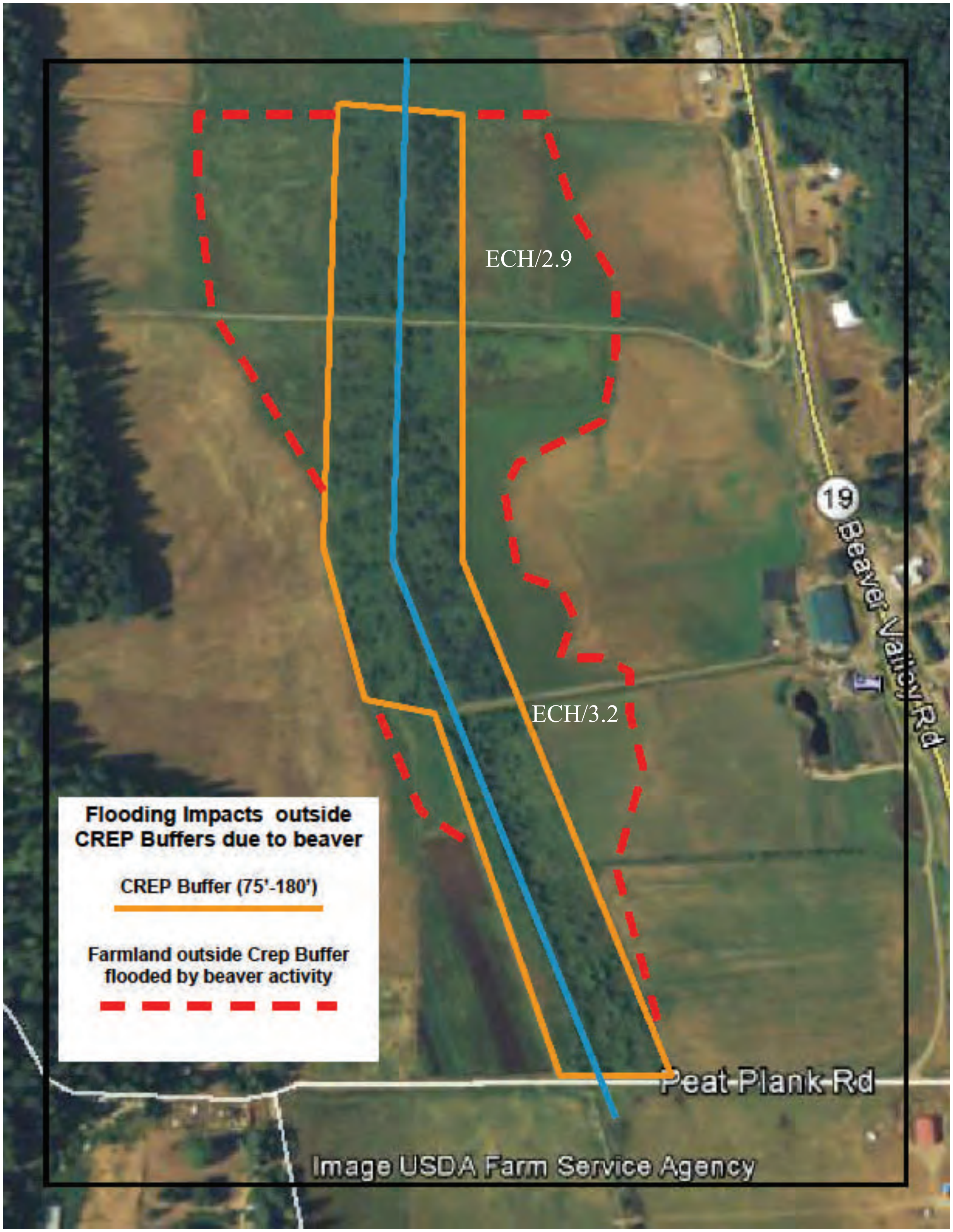

Figure 49. Map showing flooded farmland (area between the orange and red lines) caused by beaver dams in CREP buffers ECH/2.9 and ECH/3.2 (see map, Figure 43).

Figure 50. Installing a “beaver deceiver” pipe through a beaver dam downstream of the SR 116 culvert to control the water level at the culvert (top) and a trapezoidal fence upstream of the culvert to prevent beaver from plugging it (bottom).

the flooding and other problems caused by beaver, and the trend in their rising population numbers, we need to carefully evaluate each individual site before establishing a forested buffer. The lower the slope is toward the stream channel, the more likely the adjacent land will be impacted by flooding. In reaches prone to flooding, a grass buffer may be a better choice than a forested one.

Buffer Functions, Buffer Widths, and Balance

As this report is being written, the Jefferson County Planning Department is holding meetings to gather public input for the Critical Area Ordinance. The focus is on determining buffer widths adequate to protect streams and wetlands.

Riparian buffers serve several valuable functions:

1. Forested buffers provide shade, keeping the water temperature cool for salmon and trout.
2. Forested buffers reduce the amount of in-channel vegetation, which can impede salmon migration and lower dissolved oxygen through decomposition.
3. Forested buffers provide LWD which creates stream complexity (pools and riffles) and provides salmon a refuge from predators.
4. Forested and grass buffers stabilize stream banks.
5. Forested and grass buffers provide habitat for fish and wildlife.
6. Forested and grass buffers help prevent soil particles from entering the stream and suffocating eggs, alevins, and macro-invertebrates.
7. Forested and grass buffers help reduce the amount of pollutants, including bacteria, nitrogen, and phosphorus, from entering the stream.

The question is, how wide does a buffer need to be to achieve these functions? In answering this question, we need to consider that the wider the buffer, the more farmland is taken out of production. Jefferson County residents, and visitors, place a high value on our unique rural atmosphere, including the pastoral feel of working fields with grazing cattle, sheep, and buffalo. With a growing movement in buying local food, consumers are increasingly aware of the need to preserve working farmland. Jefferson County farms tend to be small holdings with a limited amount of acreage in production. This generally means small profit margins. Taking productive farmland out of production could mean the difference between a viable farm and a bankrupt one. If we truly value local food and sustainability, then when determining buffer widths, we need to consider the viability of our farms as well as the benefits to fish and wildlife.

"Fish and wildlife" are often lumped together when we speak about benefiting them, but this is an over-simplification. Different species have different habitat requirements. Waterfowl, including Chimacum's trumpeter swans, would be better served by the more open habitat that a grass buffer provides. Even Chimacum Creek’s two salmon species may be affected differently by forested buffers. Forested buffers provide beaver with dam-building material. The ponds created by their dams provide useful habitat, especially in winter, for juvenile Coho Salmon, but the dams could prevent adult Chum Salmon from reaching their spawning ground.

Land use should also be considered when determining buffer width. Some land uses may not require as wide a buffer as others. The ideal buffer would strike a balance between maximizing benefits to certain species of fish and wildlife and minimizing loss of production on farmlands.

In areas that are prone to flooding, we need to proceed with caution when considering planting trees that could attract beaver. It may not be necessary to have trees everywhere on Chimacum Creek. Some low gradient reaches, naturally prone to flooding, may be better buffered with grass and left as waterfowl habitat. An ideal ordinance would maintain flexibility and not prescribe a "one size fits all."

SUMMARY

Much has changed in the Chimacum watershed since pioneers settled in the 1800's, when salmon were abundant and the emphasis was on farming. The rich peaty land in the valleys was cleared of trees, streams were straightened, and tile drains and ditches were installed. Dairy cows and other livestock had access to the creek, as this was considered natural and best for the animals.

In the late 1900's, government agencies began shifting their emphasis from maximizing farm production to a more environmental focus, in particular the protection of salmon and shellfish. Although some stream improvements started earlier, momentum began picking up in the 1980's with livestock exclusion fences and some tree planting along stream banks on the lands of willing landowners. The 1990's saw more fencing, tree planting, and some channel re-meandering.

To date, 9.3 miles of stream bank, covering 82 acres in the Chimacum watershed, have been planted with trees and shrubs under CREP and other voluntary restoration projects. About 32,000 trees and shrubs have been planted under CREP alone.

Fecal Coliform and *Bacteroides* Bacteria

Livestock manure entering the stream channel has been the greatest factor of concern, as far as detrimental effects of farming on water quality. Manure can harbor pathogenic bacteria and viruses that are harmful to people. These pathogens may enter humans through ingestion of contaminated water when swimming or through consumption of contaminated shellfish. Clams, oysters and mussels are filter-feeders and can concentrate pathogens in their organs.

Fecal coliform bacteria, which occur in the gut of all warm-blooded animals, are used as an indicator of the potential presence of other pathogenic bacteria and viruses. Fecal coliform monitoring in the Chimacum watershed began in 1988-89 and was last monitored in 2011-12.

In the 2011-12 water-year, fecal coliform concentrations failed Ecology's "extraordinary contact" standard at 25 of the 28 monitoring stations. Concentrations at stations downstream of agricultural areas on the main stem and east fork have declined over time, but similar to stations in non-agricultural areas, are still not meeting the "extraordinary contact" standard.

Fecal coliform in Naylors Creek at the West Valley Road station shows an increasing trend. Since there are no livestock upstream from this station, livestock do not appear to be the source. Microbial Source Tracking data for this station showed the presence of "human" *Bacteroides* on 3 of the 12 dates monitored; "ruminant" *Bacteroides* was not present on any of the dates monitored.

Out of 20 stations monitored for *Bacteroides*, "human" *Bacteroides* was detected at 19 stations and “ruminant” *Bacteroides* was detected at 10 stations. Ninety percent of the 237 samples tested positive for "general" *Bacteroides*, which includes all warm-blooded animals including "human" and "ruminant"; 30% tested positive for "human", 6% were positive for "ruminant", and *Bacteroides* were absent at 10% of the stations. Based on laboratory duplicate results, the presence of "human" and "ruminant" *Bacteroides* is thought to be closer to double the percentages reported. Either way, “human” *Bacteroides* were present five times more often than “ruminant” *Bacteroides*.

As in other monitoring years, fecal coliform concentrations in the 2011-12 water-year were higher in the warmer, dryer months than in the colder, wetter months. Based on a review of other studies, it is likely that, during the warmer months, bacteria are reproducing in the stream in the bottom sediment and in association with periphyton algae.

Although almost all of Chimacum Creek and tributaries are now fenced, livestock still have limited access, in some locations, to the creek for drinking. The District continues to work with willing landowners to develop farm plans that include best management practices such as fencing, complete exclusion of livestock, off-channel watering facilities, and forested buffers.

Temperature

Sixteen of 29 stations monitored with temperature data loggers failed the 7-DADMax-16ºC standard in 2013. However, based on decreasing temperatures shown through trend analysis, the trees growing in the District's numerous CREP projects, North Olympic Salmon Coalition projects, and other voluntary buffer projects have made a measurable difference. Temperature is showing an improvement with decreasing trends on both the main stem and the east fork. Over the 15-year monitoring period from 1998 to 2013, temperature has dropped 1 degree Celsius (1.8 degrees Fahrenheit) on the main stem and 2 degrees Celsius (3.6 degrees Fahrenheit) on the east fork. Additional decreases are expected to occur as trees continue to grow and new CREP projects, now in the planning stage, are implemented.

It is possible that temperatures above 16ºCelsius may actually benefit Chimacum Creek's salmonids. Studies have shown that salmonids can achieve a greater condition factor in water with temperatures exceeding 19ºCelsius when there is an abundant food supply and adequate dissolved oxygen. Other studies have shown that survival increases as the condition factor increases. In one study, researchers surmised that, due to genetic adaption, some stocks may be relatively tolerant of--or even benefit from--temperatures above 19^{o}Celsius.

Dissolved Oxygen

Of 25 stations monitored by the District for dissolved oxygen, 11 stations failed the 1-day minimum 9.5 mg/L standard. However, all stations were above the 5 mg/L-EPA "moderate production impairment" level on all monitoring dates and exceeded the 8 mg/L-EPA “no production impairment” level most of the time.

Nine of the 10 stations monitored by the Chimacum School students failed the standard on some or all of the dates sampled. Eight of the stations had DO levels below the 8 mg/L-EPA “no production impairment” level and 2 stations on East Chimacum Creek had levels below the 5 mg/L-EPA "moderate production impairment" level on some monitoring dates. All of the school's stations, except upstream station CH/9.4, are in low gradient reaches, which have a scarcity of aerating riffles and an abundance of in-channel vegetation, which reduces the DO level when it decays.

Decomposition of vegetation in the stream channel is a major cause of low DO levels, especially in the early morning hours. Dissolved oxygen increases of 5.5 mg/L have been observed from early morning to mid-afternoon on both the main stem and east fork. Oxygen consumption due to decomposition is countered by the photosynthetic production of oxygen during daylight hours. In unshaded reaches with excessive vegetation, DO concentration is directly correlated with time of day during the daylight hours.

Salmon

Coming back from extinction in the 1990's, summer Chum Salmon experienced returns ranging from 558 to 3,066 adults for the years 2001 to 2013. Coho returns ranged from 333 to 3,539 adults from 1998 to 2013. Juvenile Coho have exhibited increasing trends in abundance at salmon habitat restoration sites.

Beaver

The establishment of forested buffers has coincided with an increase in beaver numbers resulting from a ban on leg-hold traps in 2000; the greater expense of live-traps, combined with low returns for beaver pelts, has resulted in a decline in recreational beaver trapping. Over the past 10 years, the District has witnessed a significant increase in beaver damming and tree damage in forested buffers.

Removal of beaver and their dams is time-consuming and expensive and is, ultimately, only a temporary solution as new beaver move in to recolonize the vacated areas. Our limited experience with “beaver deceivers” and “flow-thru-devices” shows that they can control the water level under low flow conditions, but not under high flow conditions. They require periodic maintenance and are susceptible to damage under excessively high flow conditions.

In the past several years, beaver dams have caused flooding outside of CREP buffers and have rendered farmland unusable, as well as causing mortality to trees within the buffers. In other areas, they have caused problems to homeowners by flooding yards and by threatening septic drain fields and compromising home integrity. Public roadways have been endangered by rising water that can erode road beds and overtop roads. All of these factors need to be evaluated when considering forested buffers.

Buffer Functions, Buffer Widths, and Balance

Buffers provide a number of valuable functions, some of which are provided only by forested buffers. It is widely accepted that trees benefit salmon and trout by cooling the water, providing large woody debris, and reducing excessive vegetation, which lowers dissolved oxygen when it decays. Other benefits may be provided by both grass buffers and forested buffers. Both kinds will stabilize stream banks, provide habitat for fish and wildlife, and help prevent soil, nutrients, and pollutants from entering the stream.

What is the best size buffer to achieve these functions? Although there has been a fair amount of research and discussion concerning buffers, there is no real consensus on the best buffer width. Part of the reason for this is due to the variable conditions (e.g., soil type, land slope, amount of precipitation, etc.) under which the studies have been conducted. Our observations lead us to conclude that establishing an appropriate buffer width is best done on a site-specific basis both due to the unique characteristics of each site (e.g., soil type and land slope) and in consideration of what we are buffering for and what we are buffering from. Are we trying to improve the habitat for salmon or trumpeter swans? There is no “one size fits all” solution when it comes to "fish and wildlife." Different species have different habitat requirements. It is also important to consider what we are buffering from (e.g., bacteria, nutrients, sunlight, etc.). Forested buffers, designed to prevent direct sunlight from hitting the stream, may not need to be as wide as buffers designed to prevent manure and associated bacteria from entering the stream. If shade is the objective, our data shows that narrow forested buffers, 10 to 20 feet wide, provide adequate shade to lower water temperature. However, if the objective is to exclude bacteria from the stream, a wider buffer may be required.

CONCLUSIONS

Salmon, shellfish, trumpeter swans, beef cattle, dairy cows, row crops, people, clean water - can the Chimacum watershed support them all? The answer is yes, but not to the extent that it would if we managed each one by itself. To have them all is going to require some compromise. Will Chimacum Creek ever meet the "extraordinary contact" standard for fecal coliform bacteria? Probably not. The Chimacum watershed is the most populated watershed in Jefferson County in terms of both people and livestock. It is probably unrealistic to expect it to meet an "extraordinary" standard when it is no longer a pristine watershed.

The implementation of Best Management Practices, primarily fencing, has resulted in substantial fecal coliform reductions from livestock. Is there still room for improvement? Yes, and off-channel watering facilities and other BMPs should help.

What about humans? Our MST data show that the frequency of occurrence of human *Bacteroides* was six times greater than that of ruminant *Bacteroides*. Can we keep fecal bacteria from humans from entering Chimacum Creek? That is certainly possible, but it is not going to be easy; septic systems which are not obviously "failing" are hard to identify and are most likely the contributing source of human bacteria to Chimacum Creek via groundwater.

Can we keep the hundreds of waterfowl, including trumpeter swans, from contributing their fecal bacteria to the creek? If we could, would we really want to? Or is it more realistic to accept their contribution as part of the natural fecal coliform "background”?

What about the likelihood of bacteria reproducing and multiplying in the creek? The consistently higher fecal coliform concentrations occurring in summer, together with what researchers have found regarding bacteria reproduction in the stream environment, is another reason why the "extraordinary" standard is not likely to be met.

Should we give up trying to keep fecal bacteria out of the creek? No, we should do what we reasonably can to make improvements. BMPs and CREP buffers have been proven successful in improving water quality. Conservation District and Natural Resource Conservation Service staff are trained to write farm plans that prescribe site-specific BMPs for individual farms. A well-researched farm plan will knowledgeably identify resource concerns and prescribe best management practices that will most efficiently correct water quality issues. Incentives such as cost sharing for BMPs and rent for CREP buffers definitely help in encouraging landowners to participate in actions to correct resource concerns on their land.

While it is easy to point fingers at resource concerns, what is lacking is the funding to help landowners correct those issues. Even with cost sharing, many landowners cannot afford the prescribed best management practices. The Conservation District could get more work done on the ground with a reliable funding source and adequate staff. Programs like CREP pay for fencing and plantings, but do not cover the often significant cost of in-stream work that is of great benefit to salmon and that can help minimize flooding. In-stream work needs to be done before the buffer goes in to be most effective and cost-efficient. After a CREP buffer is in place is not the time to be re-meandering it and adding LWD.

Funding for habitat and restoration projects tends to be a highly competitive process with preference given to endangered species and large-scale projects. Chimacum Creek projects tend to be smaller in scale and somewhat piecemeal as landowners come around to a willingness to participate at different times. Our projects do not compete well statewide, or even regionally. Therefore, we are often stopped from moving forward on good projects by a lack of funding. Even though we may have willing landowners today, circumstances may change and landowners may change their minds tomorrow. We should be ready to move when the landowner is ready to move. A more reliable funding source for these sorts of projects would ensure our ability to make positive changes with willing landowners as opportunities arise.

As we look to the future of water quality improvements in the Chimacum Creek watershed, it is critical that we consider the costs associated with the projects and the available sources of funding. Our landowners are generally not able to bear the cost of restoration, even if they are willing to give up part of their land to make improvements. The District and other agencies have the technical capacity to assist landowners in being part of moving the dial on water quality, but there has to be a commitment on the part of funders to help us make those changes possible. We see the measureable difference voluntary stewardship can make in the trends outlined in this report. The next steps should build upon the work that has already been done, and work to make future work even better based on what we have learned from past efforts. This will take time, thoughtfulness and money. We know it works. That is the good news.

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APPENDIX A

Station Locations

Table A-1. Water quality monitoring station locations.

Station	Stream	Description	Latitude	Longitude
BH/0.0	Barnhouse Creek	At mouth	47.93876	-122.80160
BH/1.0	Barnhouse Creek	Center Road	47.92777	-122.80512
CH/0.1	Chimacum Creek	Upstream end of estuary at gaging station	48.04975	-122.78608
CH/1.1	Chimacum Creek	Irondale Road	48.04197	-122.78223
CH/2.0	Chimacum Creek	Ness Corner Road	48.03075	-122.77652
CH/3.4	Chimacum Creek	State Route 19 - Chimacum School	48.01177	-122.77473
CH/4.1	Chimacum Creek	Upstream of Putaansuu Creek confluence	48.00353	-122.77595
CH/5.3	Chimacum Creek	Concrete Bridge	47.98725	-122.77440
CH/6.7	Chimacum Creek	Center Road double culvert	47.96600	-122.77866
CH/7.0	Chimacum Creek	Center Road bridge	47.96329	-122.78055
CH/7.8	Chimacum Creek	Egg and I Road	47.95507	-122.79190
CH/8.4	Chimacum Creek	West Valley Road	47.94789	-122.79999
CH/8.8	Chimacum Creek	Eagle Mount Road	47.94051	-122.80187
CH/9.0	Chimacum Creek	Upstream of Barnhouse Creek confluence	47.93884	-122.80161
CH/9.3	Chimacum Creek	Upstream of sediment basin	47.93878	-122.81119
ECH/0.2	East Chimacum Creek	Near Chimacum Road - Lutheran Church	48.01981	-122.76984
ECH/1.0	East Chimacum Creek	State Route 19	48.00933	-122.76318
ECH/3.3	East Chimacum Creek	Peat Plank Road	47.97681	-122.74445
ECH/4.8	East Chimacum Creek	Egg and I road	47.95516	-122.74119
ECH/5.3	East Chimacum Creek	Forest/Pasture interface	47.95003	-122.74483
EG/0.0	Ditch	West Valley Road	47.94793	-122.80011
NA/0.1	Naylors Creek	500 ft. upstream from mouth	47.98718	-122.77648
NA/0.7	Naylors Creek	West Valley Road	47.98142	-122.78774
NA/1.3	Naylors Creek	Naylors Creek Road	47.98450	-122.79806
PU/0.0	Putaansuu Creek	Near mouth	48.00378	-122.77626
PU/0.4	Putaansuu Creek	West Valley Road	48.00413	-122.78408
SW/0.3	Swansonville Creek	1500 ft. upstream from East Chimacum Creek	47.94929	-122.73735
WV/0.1	Ditch	West Valley Road	47.94978	-122.80002

Table A-2. Temperature data logger locations.

Station	Stream	Description	Latitude	Longitude
BH/0.0	Barnhouse Creek	At mouth	47.93859	-122.80180
BH/1.0	Barnhouse Creek	Center Road	47.92777	-122.80512
CH/0.1	Chimacum Creek	Estuary	48.04933	-122.78716
CH/1.1	Chimacum Creek	Irondale Road	48.04197	-122.78223
CH/2.0	Chimacum Creek	Ness Corner Road	48.03180	-122.77776
CH/2.8	Chimacum Creek	Downstream of East Chimacum Creek	48.02140	-122.77098
CH/2.9	Chimacum Creek	Upstream of East Chimacum Creek	48.02093	-122.77101
CH/3.9	Chimacum Creek	Near Red Dog Farm	48.00527	-122.77425
CH/4.1	Chimacum Creek	Upstream of Putaansuu Creek	48.00353	-122.77595
CH/6.1	Chimacum Creek	Finn River Farm	47.97433	-122.77762
CH/6.7	Chimacum Creek	Center Road Double Culvert	47.96547	-122.77808
CH/7.0	Chimacum Creek	Center Road Bridge	47.96329	-122.78055
CH/7.8	Chimacum Creek	Egg and I Road	47.95485	-122.79214
CH/8.4	Chimacum Creek	West Valley Road	47.94691	-122.80014
CH/9.0	Chimacum Creek	Upstream of Barnhouse Creek	47.93879	-122.80169
CH/9.4 Air	Chimacum Creek	Upstream of Sediment Basin	47.93870	-122.81198
CH/9.4	Chimacum Creek	Upstream of Sediment Basin	47.93871	-122.81245
ECH/0.1	East Chimacum Creek	Near Lutheran Church, Chimacum Road	48.01972	-122.76986
ECH/0.5	East Chimacum Creek	Near Gladys Nursery, Chimacum Road	48.01471	-122.76626
ECH/1.0	East Chimacum Creek	State Route 19	48.00851	-122.76254
ECH/1.2	East Chimacum Creek	1000 ft. upstream from State Route 19	48.00617	-122.76126
ECH/2.0	East Chimacum Creek	Crep Buffer	47.99803	-122.75780
ECH/2.8	East Chimacum Creek	CREP Buffer, Farm road across valley	47.98253	-122.74676
ECH/3.3	East Chimacum Creek	Peat Plank Road	47.97681	-122.74445
ECH/4.3	East Chimacum Creek	Private Road	47.95003	-122.74608
NA/0.2	Naylors Creek	1000 ft. upstream from mouth	47.98667	-122.77982
NA/0.7	Naylors Creek	West Valley Road	47.98142	-122.78774
PU/0.0	Putaansuu Creek	At mouth	48.00372	-122.77744
PU/0.4	Putaansuu Creek	West Valley Road, downstream from pond	48.00413	-122.78408
PU/0.5	Putaansuu Creek	Upstream from pond	48.00380	-122.78529

APPENDIX B

Quality Control Results

Appendix B -- QUALITY CONTROL

Field replicates of those parameters measured with the YSI Model 556 water analyzer (temperature, conductivity, pH, and dissolved oxygen) were taken at the sampling sites. Two sets of measurements were taken within a few minutes of one another. Replicate water samples, collected in separate bottles within a few minutes of one another, were taken for fecal coliform and turbidity.

Replicate measurements provide an estimate of the random variability (precision) in the results due to the instrument and its operator. The analysis of replicate samples provides an estimate of the variability due to sampling and analysis. The results for different parameters will exhibit different levels of variability due to the nature of the measurement, sampling and/or analytical process. The variability in the fecal coliform counts exhibits a log normal distribution.

The standard deviation is an estimate of the absolute variability of the results and usually increases with the magnitude of the results. Precision is reported as the *relative standard deviation* (RSD). The RSD is usually inversely proportional to the magnitude of the results. Because the RSD is often small, it is multiplied by 100 to express it as a percent.

The **RSD** (in percent) is given by:

$$\mathbf{RSD\ (\%) = (s\ /\ x) \times 100}$$

where **s** is the estimate of the standard deviation of the individual results; and **x** is the mean of the replicate results (Zar 1984[1]).

Replicate measurements generally showed acceptable precision, especially concerning absolute differences between the two replicates (Table B-1). As is usual, RSDs were highest when values were lowest and near detectable limits. One large discrepancy occurred with the conductivity replicate measurements taken on July 10, 2012 (172 umho vs. 239 umho).

As is typical, fecal coliform replicates showed the greatest variation. Although much of this variation could simply be due to the uneven distribution of the bacteria in the stream channel, some is probably due to the method because of an uneven distribution in the sample bottle.

[1] Zar, J. H 1984. Biostatistical Analysis. 2nd ed. Prentice-Hall, Englewood Cliffs, New Jersey. 718 pp.

Table B-1. Quality control results of stations monitored in the Chimacum watershed watershed showing the absolute difference (AD) and relative standard deviation (RSD) for field replicates (R1 and R2) sampled for fecal coliform, temperature, dissolved oxygen, pH, conductivity, and turbidity. Minimum, maximum, and mean ADs and RSDs are also shown.

Station	Date	Fecal Coliform				Temperature				Dissolved Oxygen				pH				Conductivity				Turbidity			
		R1	R2	AD	RSD	R1	R2	AD	RSD	R1	R2	AD	RSD	R1	R2	AD	RSD	R1	R2	AD	RSD	R1	R2	AD	RSD
		FC/100 mL			%	°C	°C	°C	%	mg/L	mg/L	mg/L	%	units	units	units	%	umho	umho	umho	%	NTU	NTU	NTU	%
CH/0.1	10/26/11	74	108	34	26	7.06	7.06	0.00	0.0	11.18	11.20	0.02	0.1	7.45	7.45	0.00	0.0	244	244	0	0.0	4.2	4.2	0.0	0.0
CH/1.1	10/26/11	14	16	2	9	7.25	7.25	0.00	0.0	10.48	10.51	0.03	0.2	7.46	7.40	0.06	0.6	236	236	0	0.0	2.3	1.8	0.5	18.8
CH/2.0	11/15/11	12	14	2	11	4.33	4.35	0.02	0.3	9.82	9.72	0.10	0.7	6.94	6.85	0.09	0.9	227	227	0	0.0	3.1	4.9	1.8	32.8
PU/0.4	11/15/11	1	2	1	47	5.20	5.20	0.00	0.0	9.25	9.30	0.05	0.4	7.19	7.14	0.05	0.5	271	271	0	0.0	0.9	1.0	0.1	9.2
EG/0.0	12/6/11	1	4	3	85	5.75	5.72	0.03	0.4	0.49	0.48	0.01	1.5	6.00	5.95	0.05	0.6	298	294	4	1.0	6.5	6.6	0.1	1.2
WV/0.1	12/6/11	12	10	2	13	5.56	5.57	0.01	0.1	11.38	11.29	0.09	0.6	7.15	7.14	0.01	0.1	280	282	2	0.5	2.2	2.7	0.4	12.4
CH/8.4	1/3/12	40	56	16	24	5.77	5.76	0.01	0.1	11.46	11.45	0.01	0.1	7.35	7.34	0.01	0.1	128	130	2	1.1	7.8	7.6	0.2	1.6
CH/9.0	1/3/12	52	70	18	21	5.99	5.99	0.00	0.0	11.74	11.71	0.03	0.2	7.48	7.46	0.02	0.2	130	130	0	0.0	11.5	12.7	1.2	7.0
BH/0.0	2/7/12	10	4	6	61	2.34	2.39	0.05	1.5	11.40	11.20	0.20	1.3	7.30	7.27	0.03	0.3	124	125	1	0.6	4.2	4.3	0.1	1.0
CH/9.3	2/7/12	12	6	6	47	3.81	3.81	0.00	0.0	12.78	12.78	0.00	0.0	7.67	7.64	0.03	0.3	103	110	7	4.6	6.4	5.0	1.4	17.2
CH/6.7	3/13/12	150	156	6	3	4.77	4.81	0.04	0.6	10.03	9.99	0.04	0.3	6.99	6.96	0.03	0.3	105	104	1	0.7	11.3	10.3	1.0	6.5
BH/1.0	4/10/12	1	1	0	0	9.03	9.04	0.01	0.1	11.20	11.15	0.05	0.3	7.56	7.60	0.04	0.4	118	118	0	0.0	1.1	1.1	0.0	0.6
CH/8.8	4/10/12	10	4	6	61	9.56	9.60	0.04	0.3	10.84	10.80	0.04	0.3	7.34	7.34	0.00	0.0	100	100	0	0.0	5.9	5.3	0.5	6.6
CH/3.4	5/1/12	192	152	40	16	9.73	9.76	0.03	0.2	10.60	10.61	0.01	0.1	6.83	6.88	0.05	0.5	165	165	0	0.0	8.5	9.1	0.6	4.6
CH/5.3	5/1/12	260	234	26	7	9.73	9.76	0.03	0.2	11.11	11.06	0.05	0.3	7.09	7.09	0.00	0.0	149	150	1	0.5	6.9	9.7	2.8	23.6
CH/7.8	6/26/12	290	240	50	13	11.75	11.75	0.00	0.0	9.57	9.67	0.10	0.7	7.05	6.94	0.11	1.1	125	126	1	0.6	6.8	6.6	0.2	2.1
NA/0.1	6/26/12	140	90	50	31	11.75	11.76	0.01	0.1	10.10	10.16	0.06	0.4	7.07	7.20	0.13	1.3	170	169	1	0.4	6.9	6.5	0.4	4.2
CH/4.1	7/10/12	20	16	4	16	15.18	15.23	0.05	0.2	10.21	10.31	0.10	0.7	7.52	7.50	0.02	0.2	193	195	2	0.7				
PU/0.0	7/10/12	258	230	28	8	13.51	13.56	0.05	0.3	9.57	9.61	0.04	0.3	7.41	7.53	0.12	1.1	172	239	67	23.1				
ECH/0.2	8/7/12	210	160	50	19	14.32	14.32	0.00	0.0	9.22	9.14	0.08	0.6	7.32	7.39	0.07	0.7	290	290	0	0.0	6.7	6.5	0.2	2.1
ECH/1.0	8/7/12	48	50	2	3	13.74	13.74	0.00	0.0	6.55	6.47	0.08	0.9	7.13	7.13	0.00	0.0	294	294	0	0.0	7.3	7.2	0.1	1.0
ECH/4.8	9/4/12	70	98	28	24	11.27	11.32	0.05	0.3	9.76	9.60	0.16	1.2	7.18	7.22	0.04	0.4	176	180	4	1.6	2.0	1.4	0.6	25.0
ECH/5.3	9/4/12	6	12	6	47	10.72	10.73	0.01	0.1	11.28	11.17	0.11	0.7	7.42	7.54	0.12	1.1	157	158	1	0.4	1.3	1.0	0.3	18.4
Minimum				0	0			0	0.0			0.00	0.00			0.00	0.0			0	0.0			0.0	0.0
Maximum				50	85			0	1.5			0.20	1.46			0.13	1.3			67	23.1			2.8	32.8
Mean				17	26			0	0.2			0.06	0.51			0.05	0.5			4	1.6			0.6	9.3

APPENDIX C

TEMPERATURE PROFILES

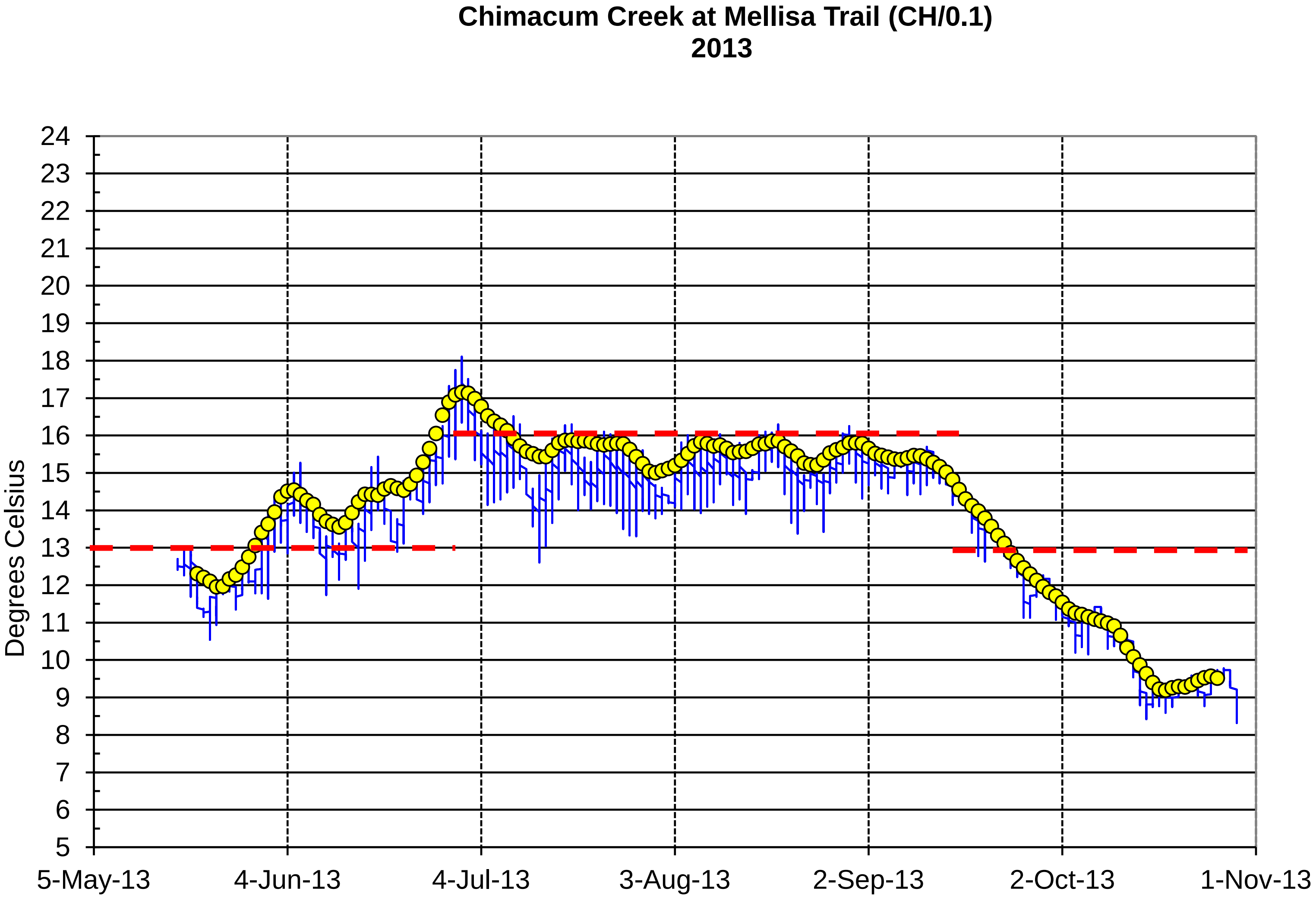


Figure C-1. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Chimacum Creek at Irondale Road (CH/1.1)
2013

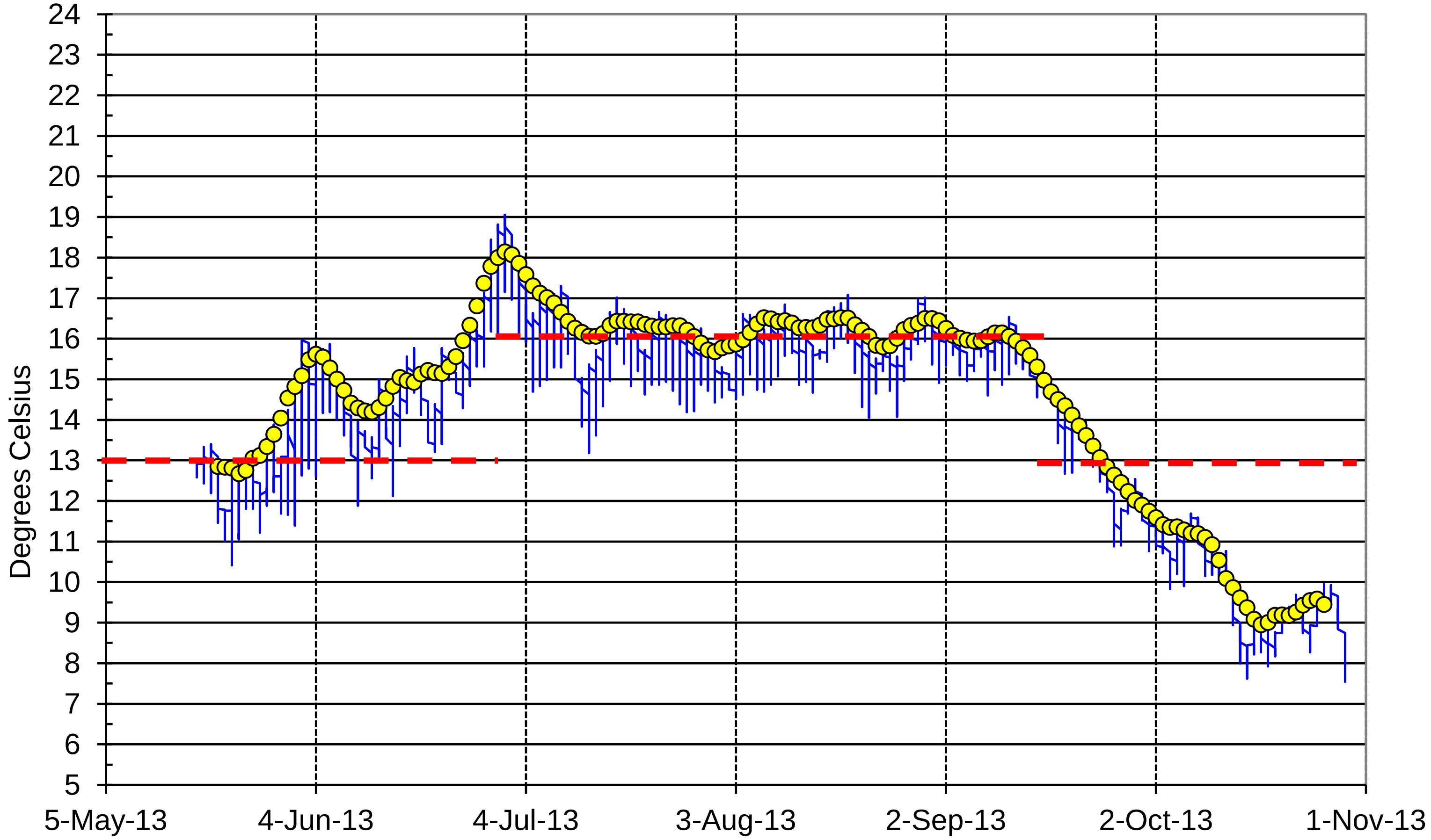


Figure C-2. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Chimacum Creek at Ness' Corner Rd. (CH/2.0)
2013

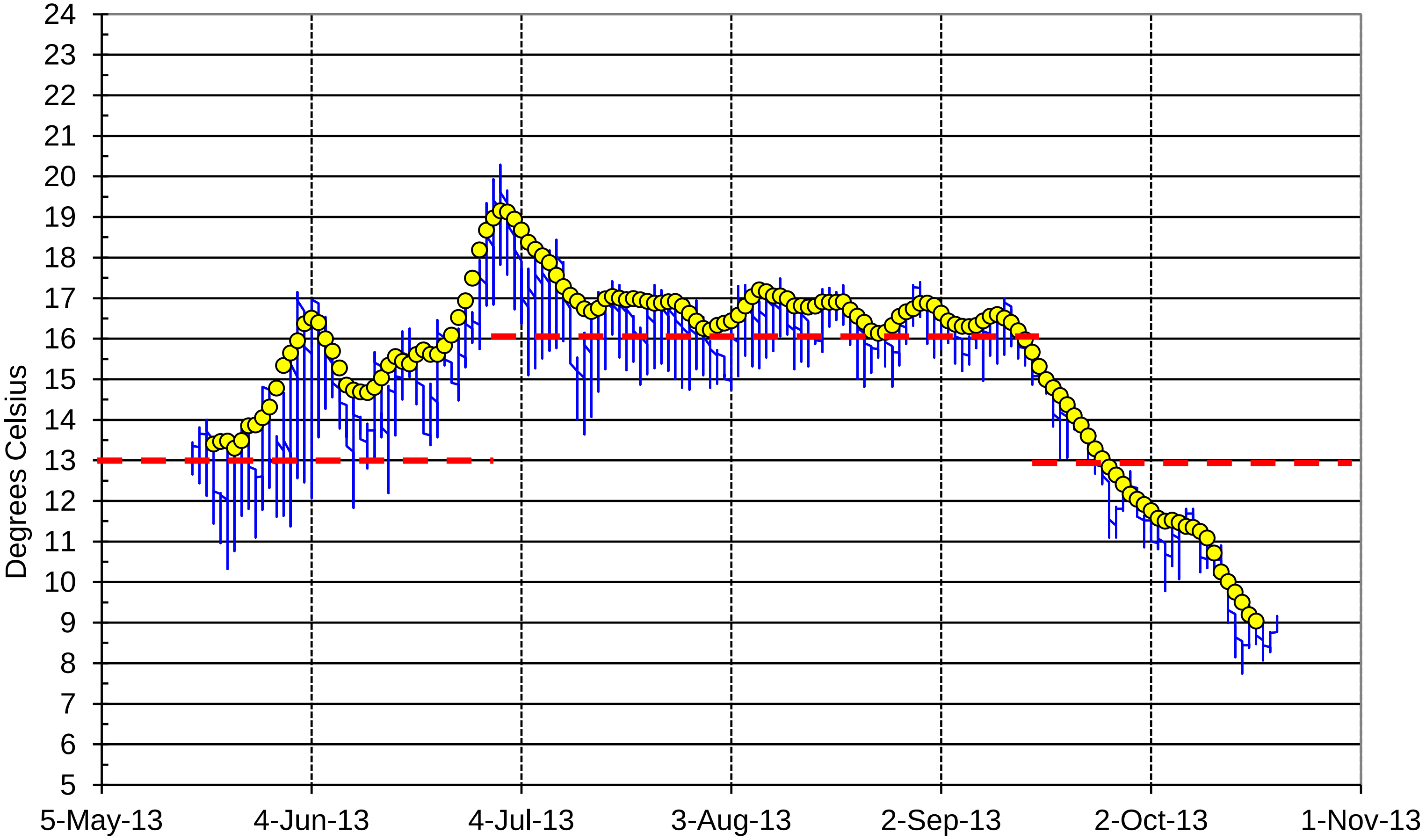
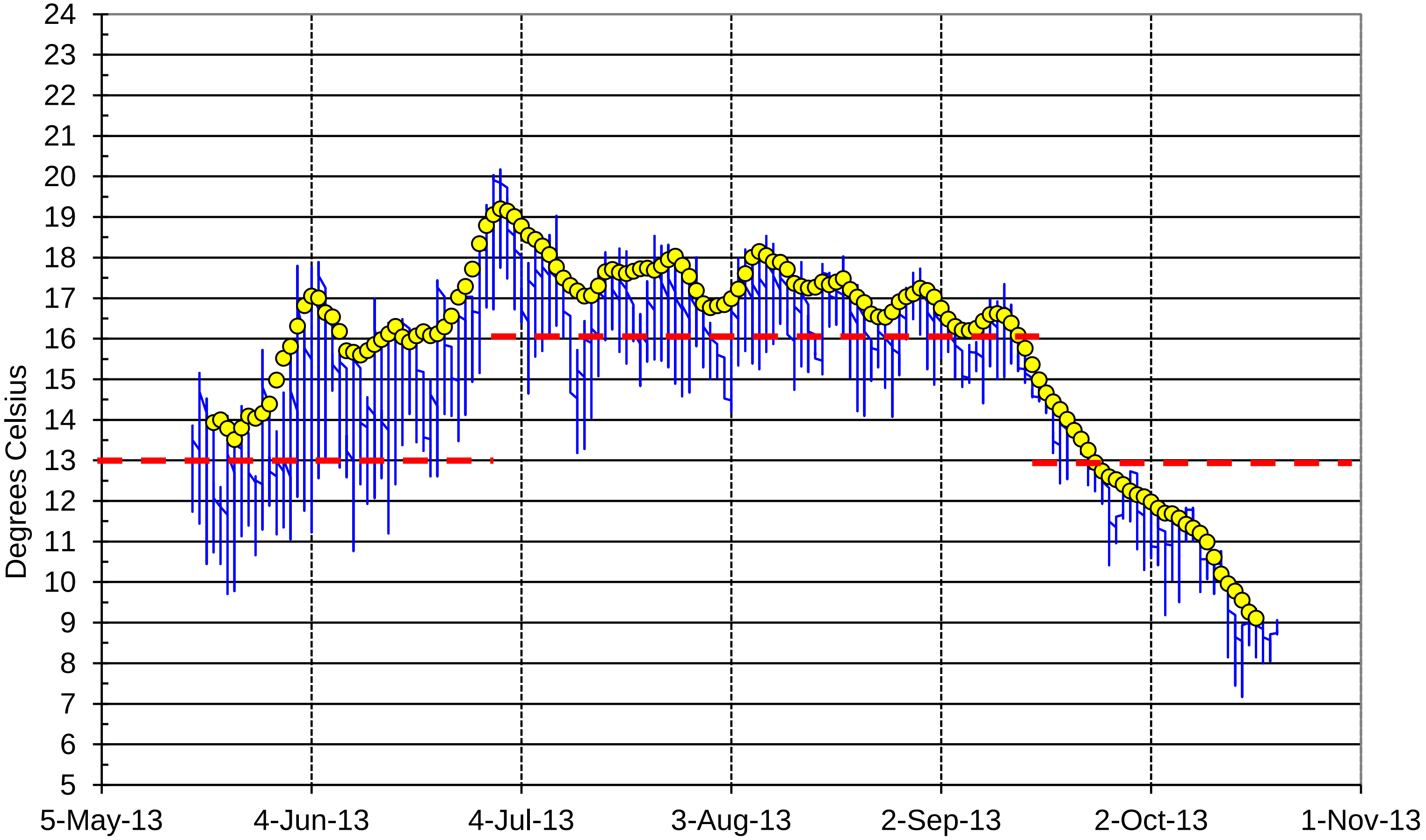


Figure C-3. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid



Chimacum Creek about 100 ft. downstream from East Chimacum Creek (CH/2.8)
2013

Figure C-4. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Chimacum Creek about 50 ft. upstream from East Chimacum Creek (CH/2.9)
2013

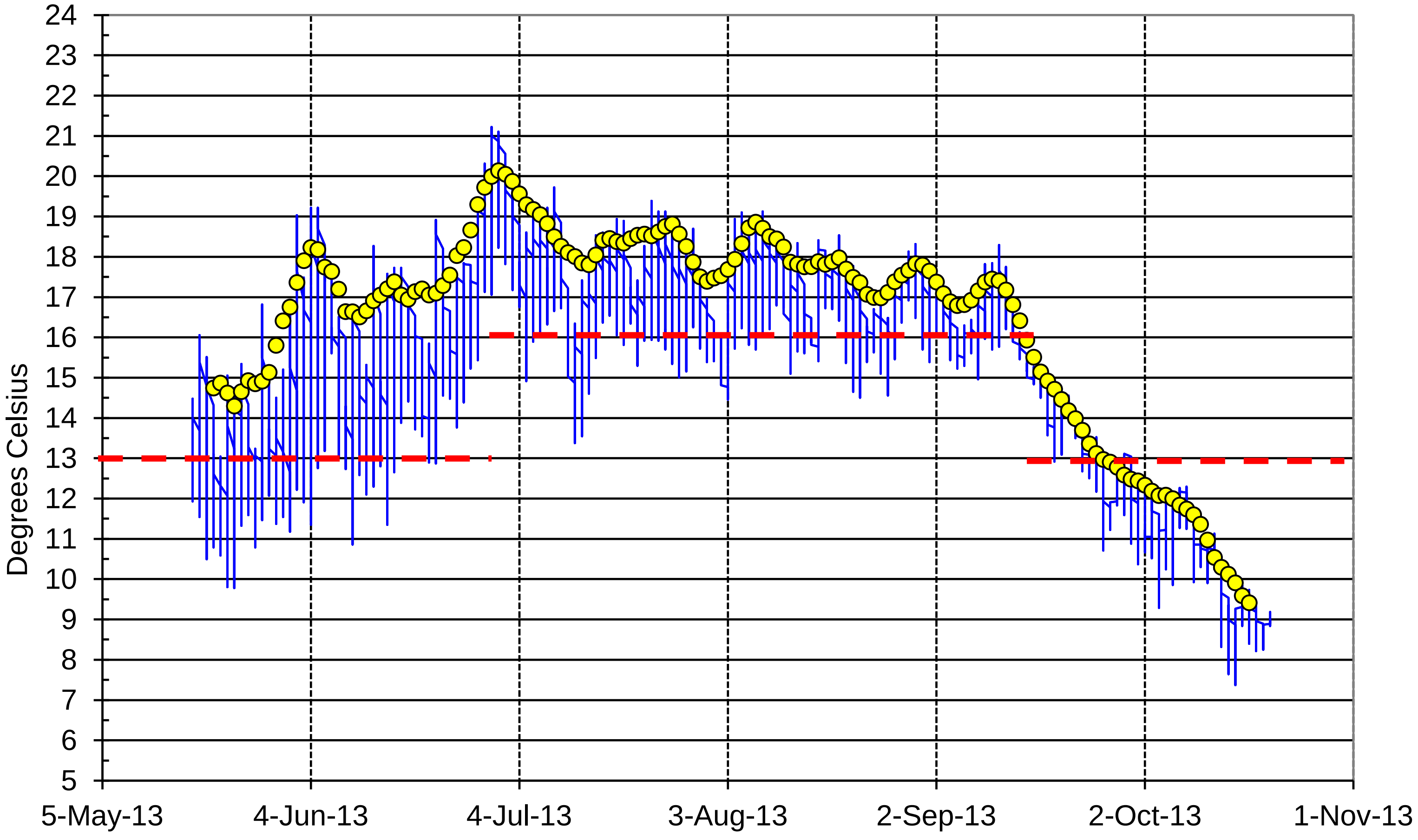
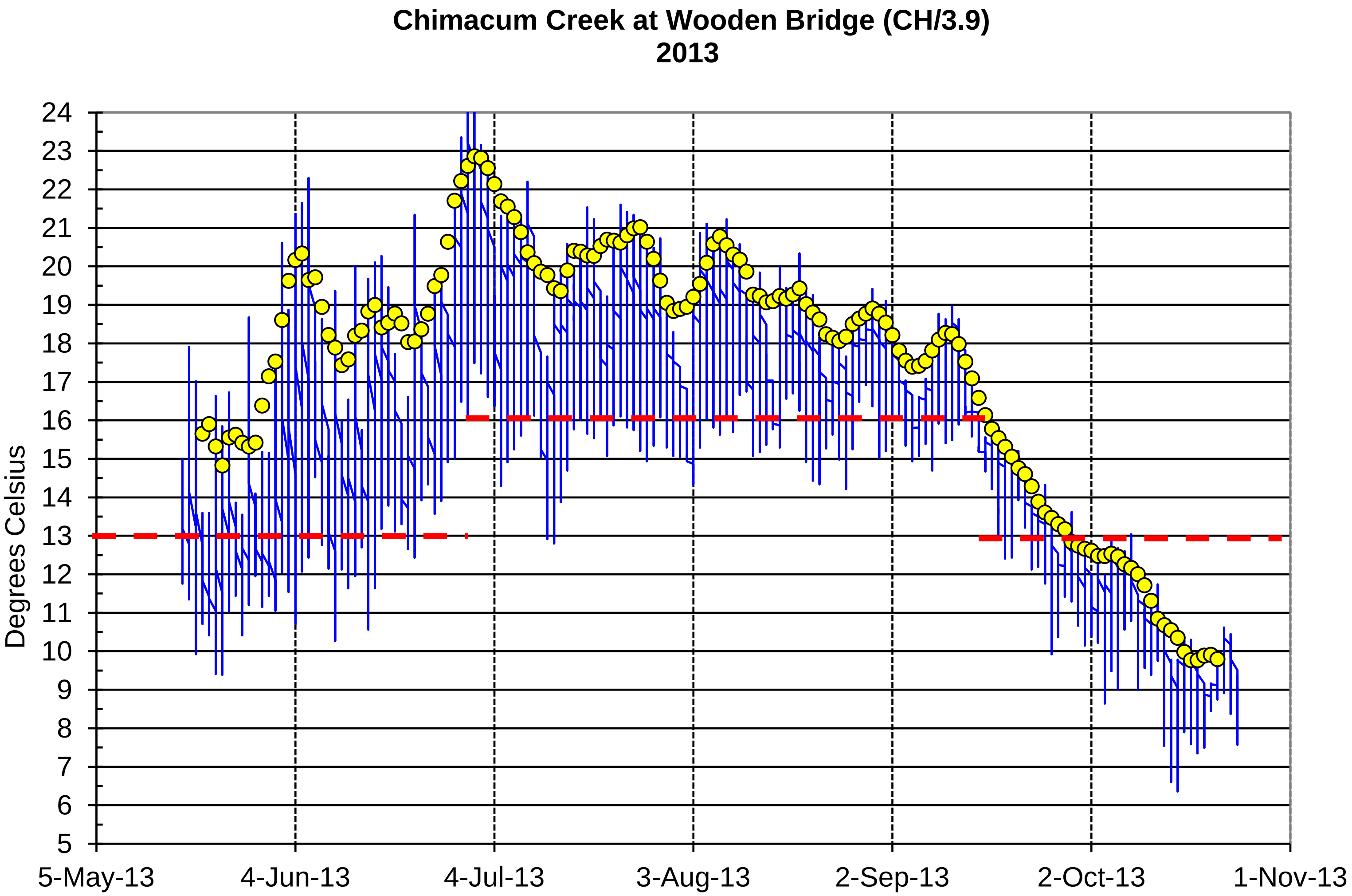


Figure C-5. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.



Chimacum Creek at Wooden Bridge (CH/3.9)
2013

Figure C-6. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

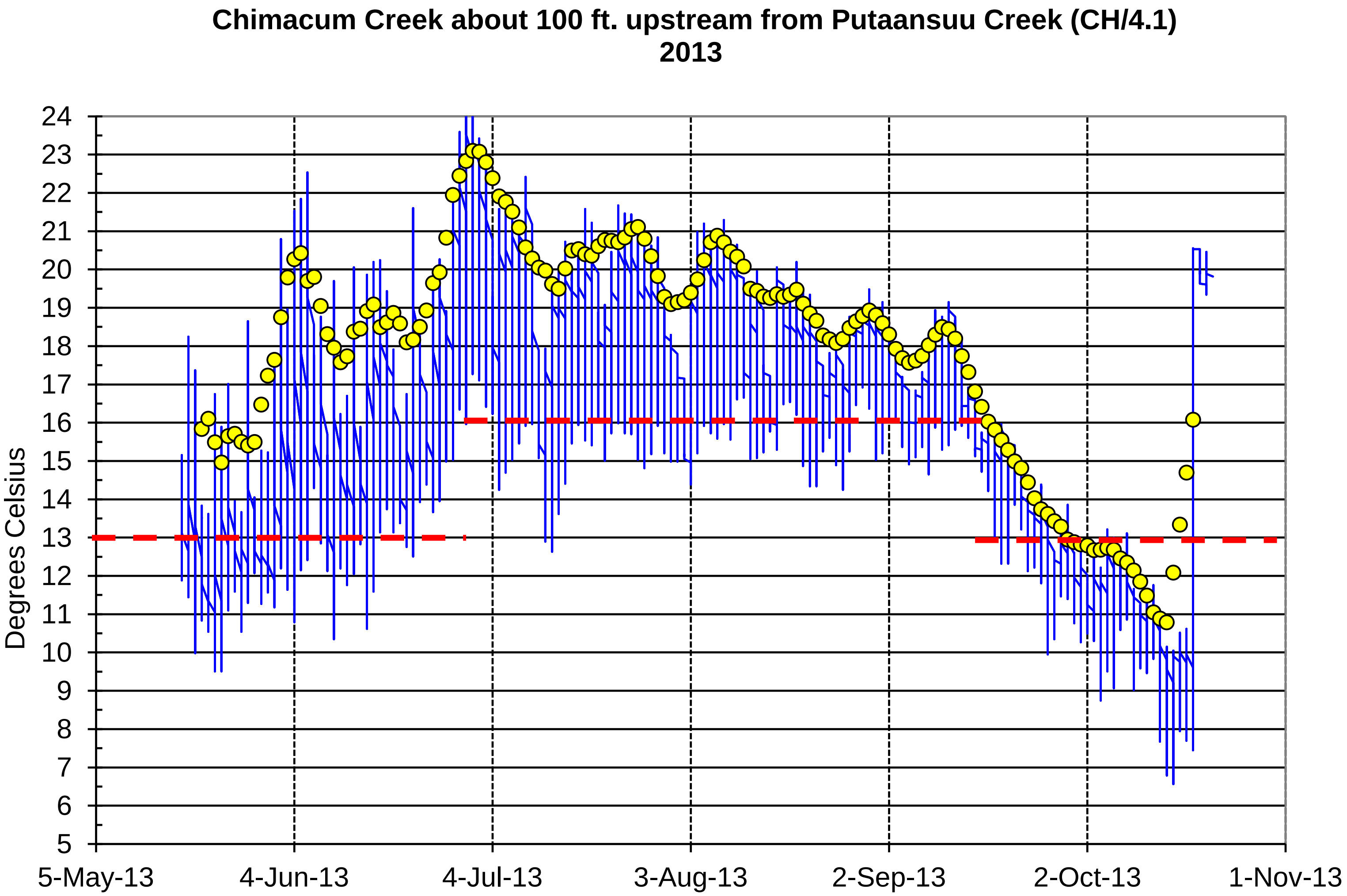


Figure C-7. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Chimacum Creek at Upstream End of Christian Project (1998) LWD Section (CH/6.1)
2013

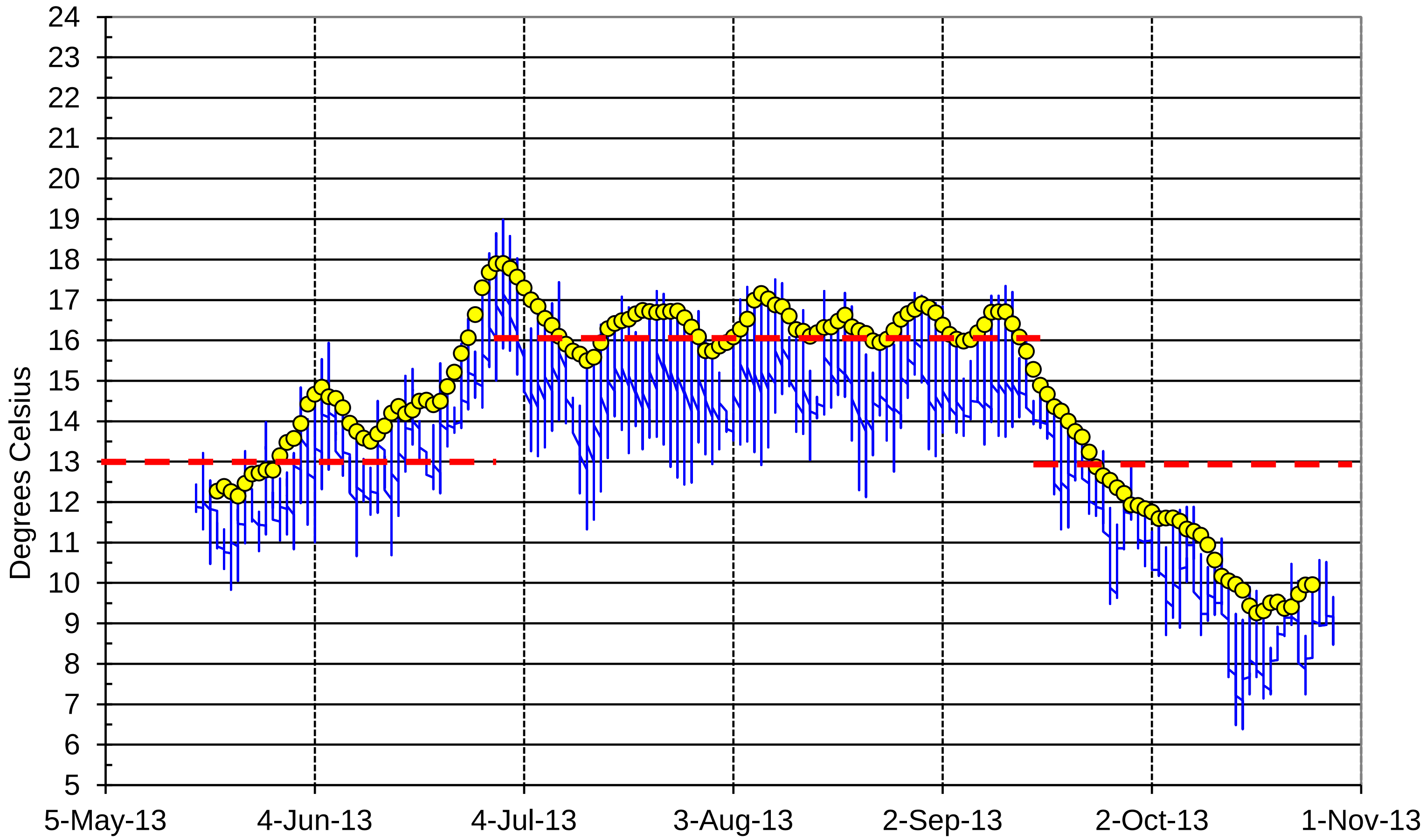


Figure C-8. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Chimacum Creek at Center Valley Road Double Culvert (CH/6.7)
2013

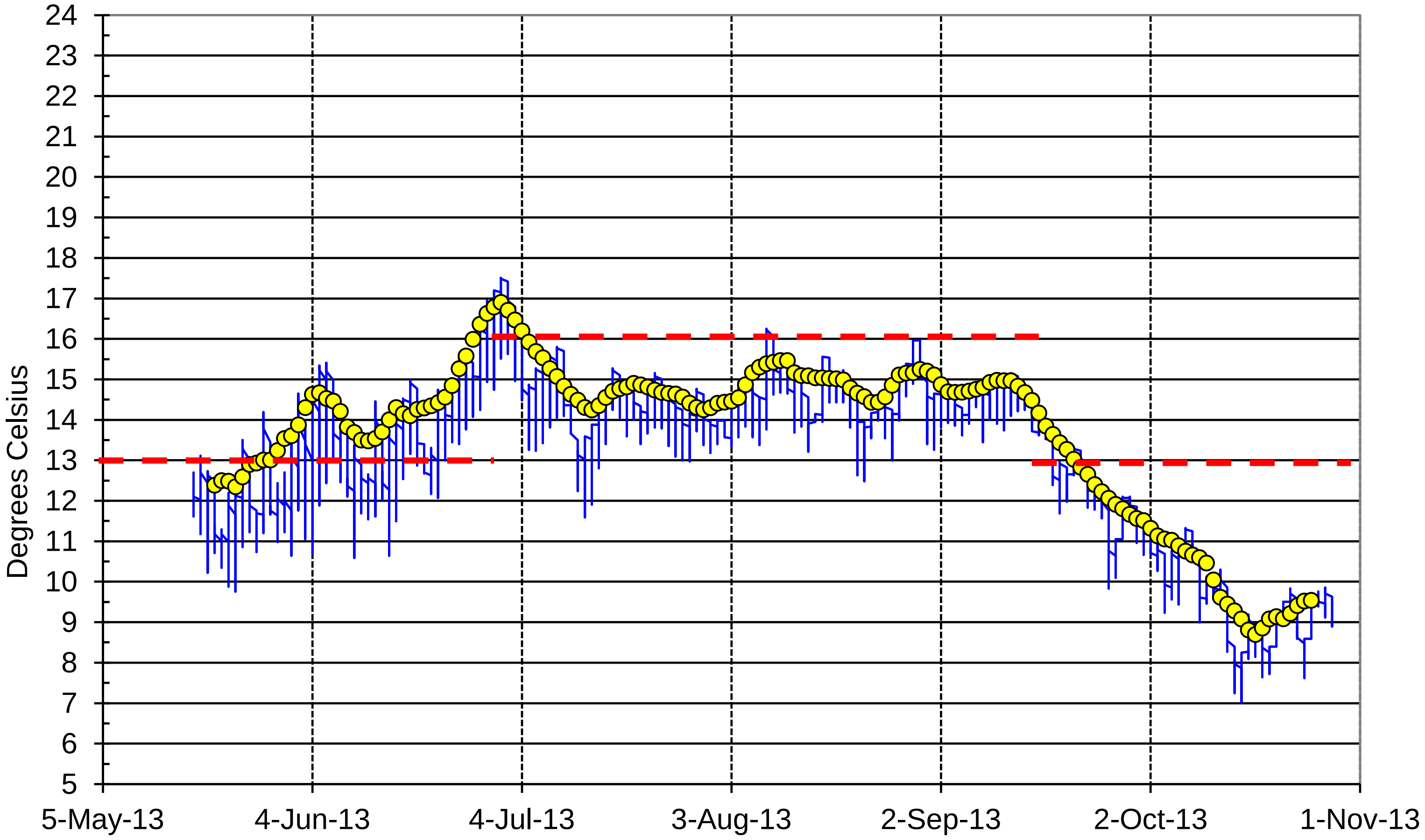


Figure C-9. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Chimacum Creek at Center Valley Road Bridge (CH/7.0)
2013

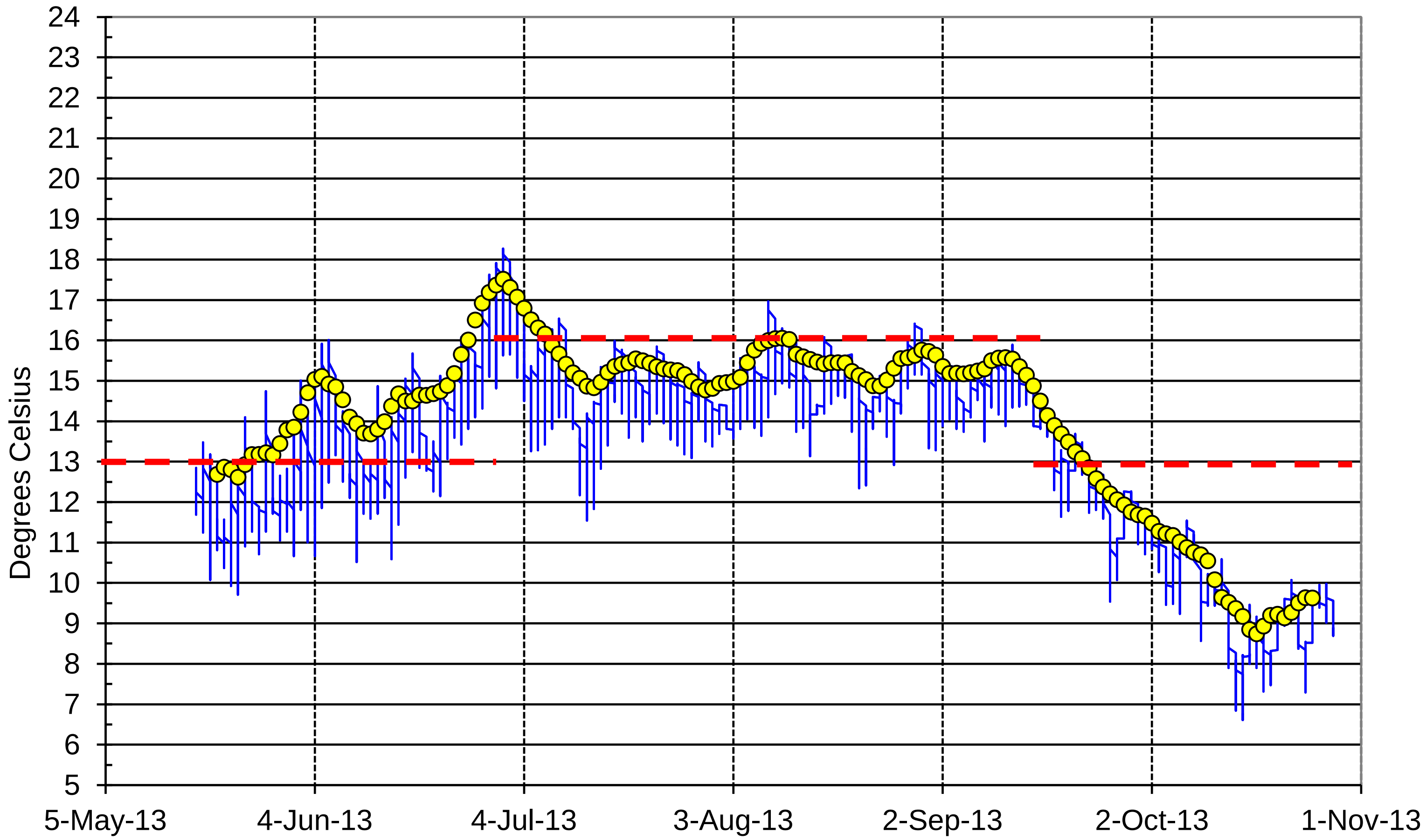


Figure C-10. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Chimacum Creek at Egg and I Road (CH7.8)
2013

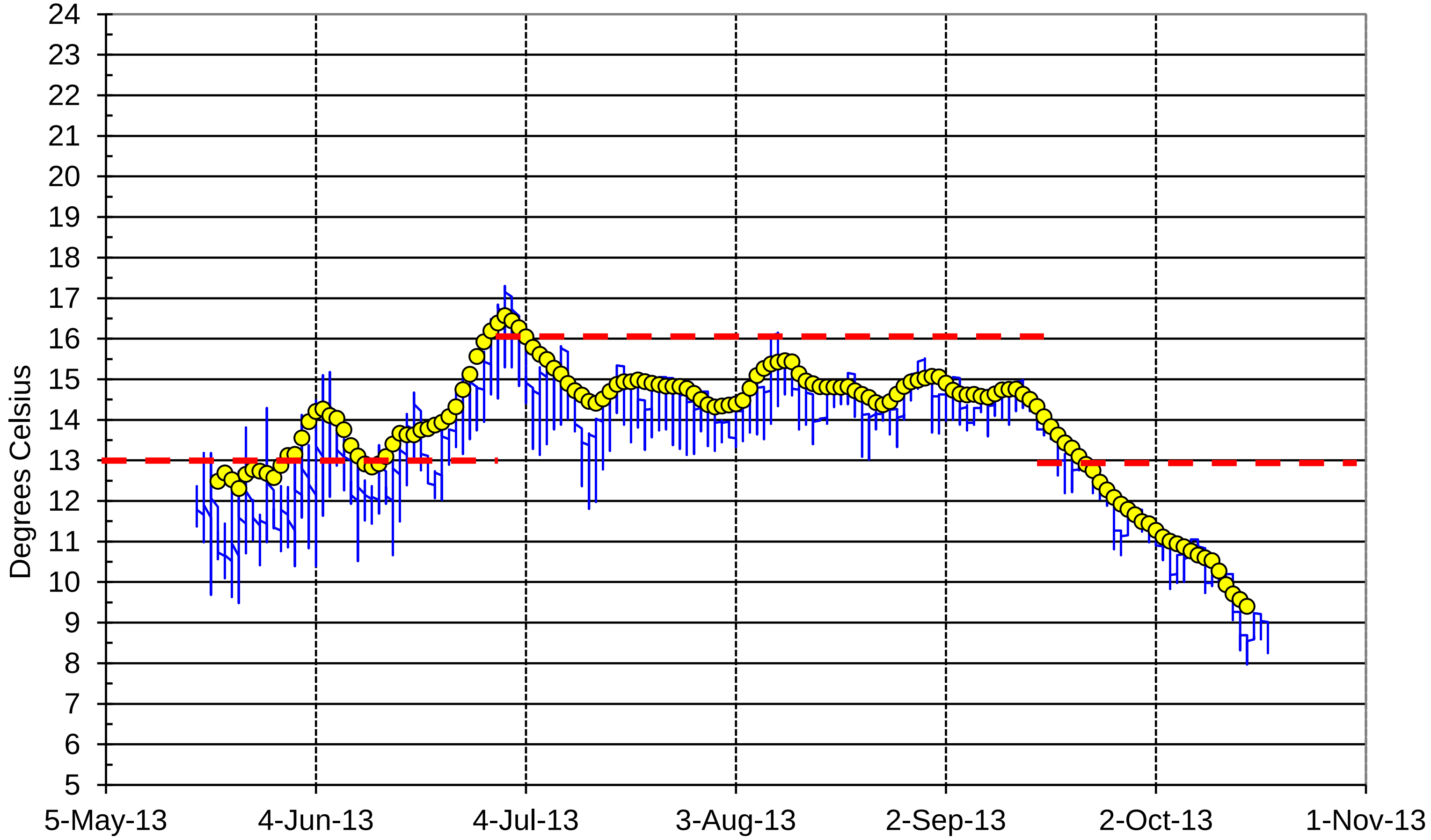


Figure C-11. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Chimacum Creek at West Valley Road (CH/8.4)
2013

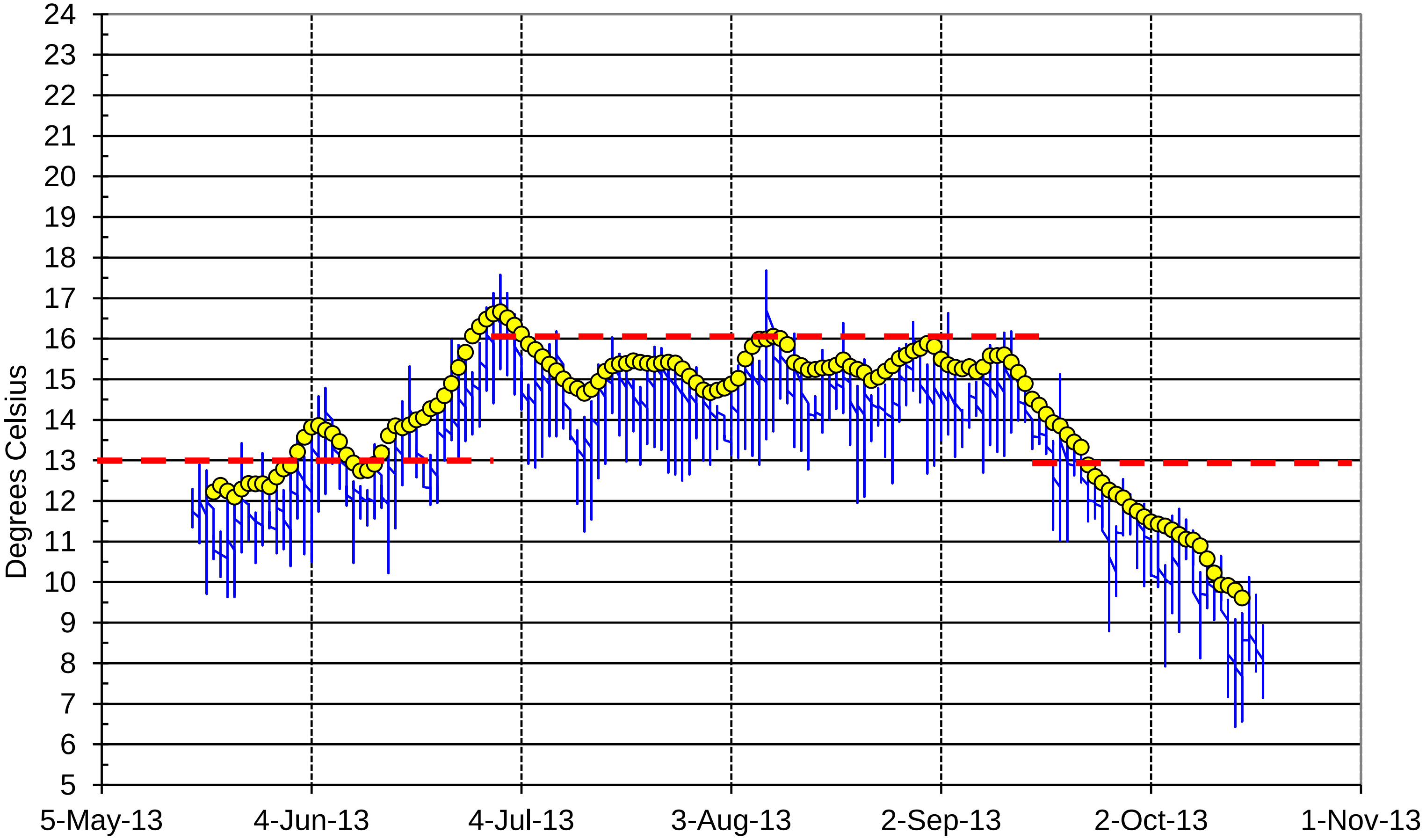


Figure C-12. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Chimacum Creek about 200 ft. Upstream from Barnhouse Creek (CH/9.0)
2013

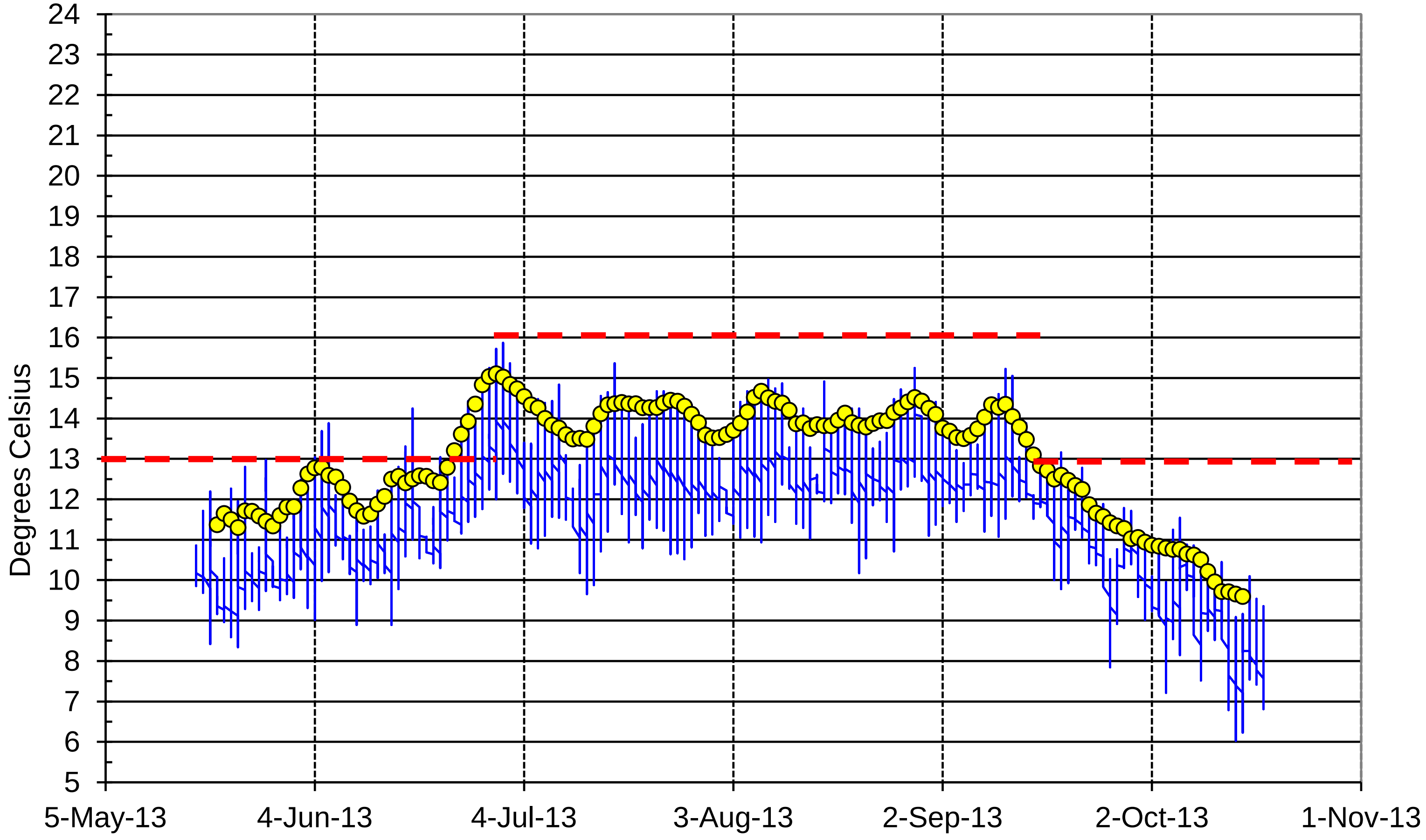


Figure C-13. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Chimacum Creek about 500 ft. Upstream from Sediment Basin (CH/9.4)
2013

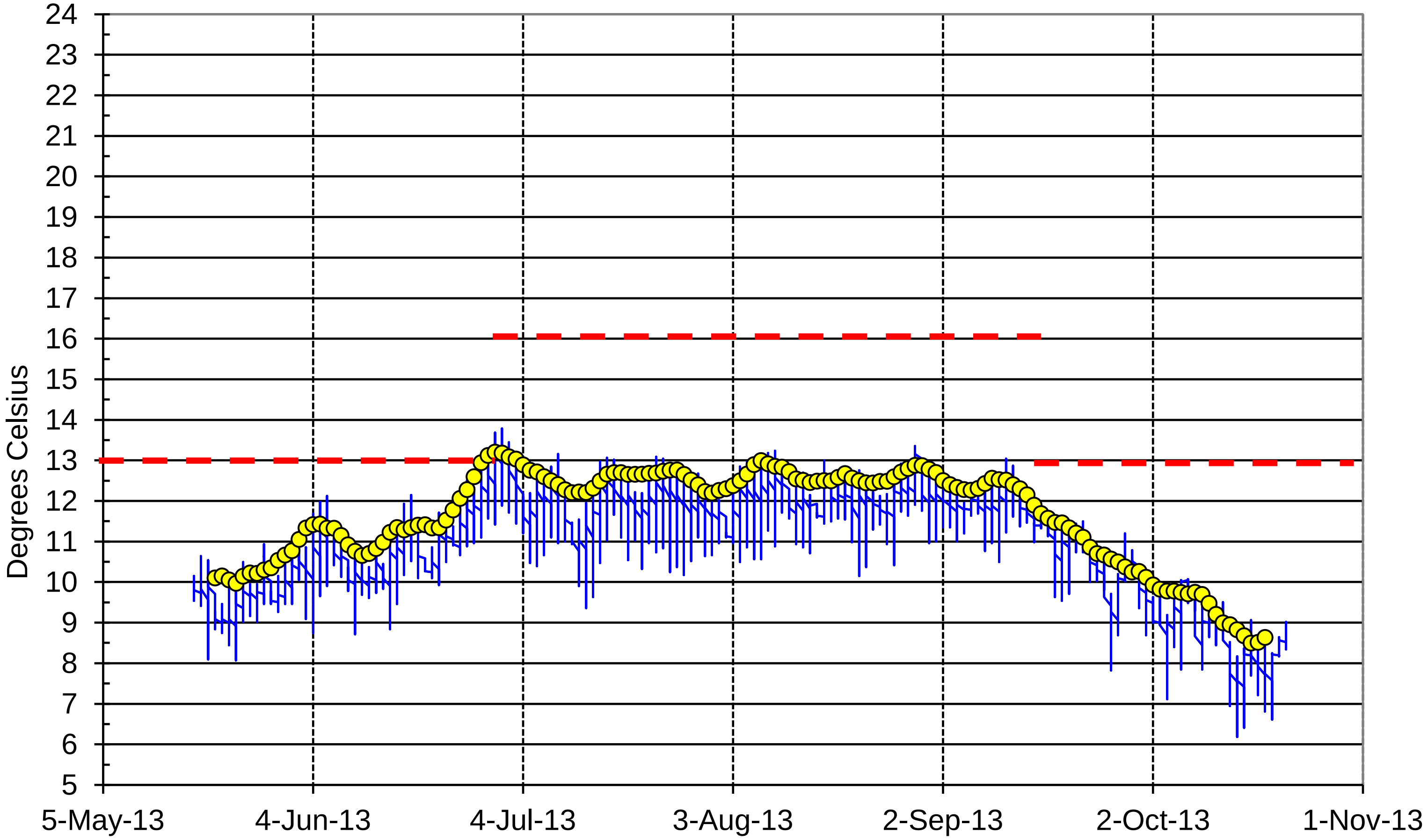


Figure C-14. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Chimacum Creek about 500 ft. Upstream from Sediment Basin (CH/9.4)
Air Temperature
2013

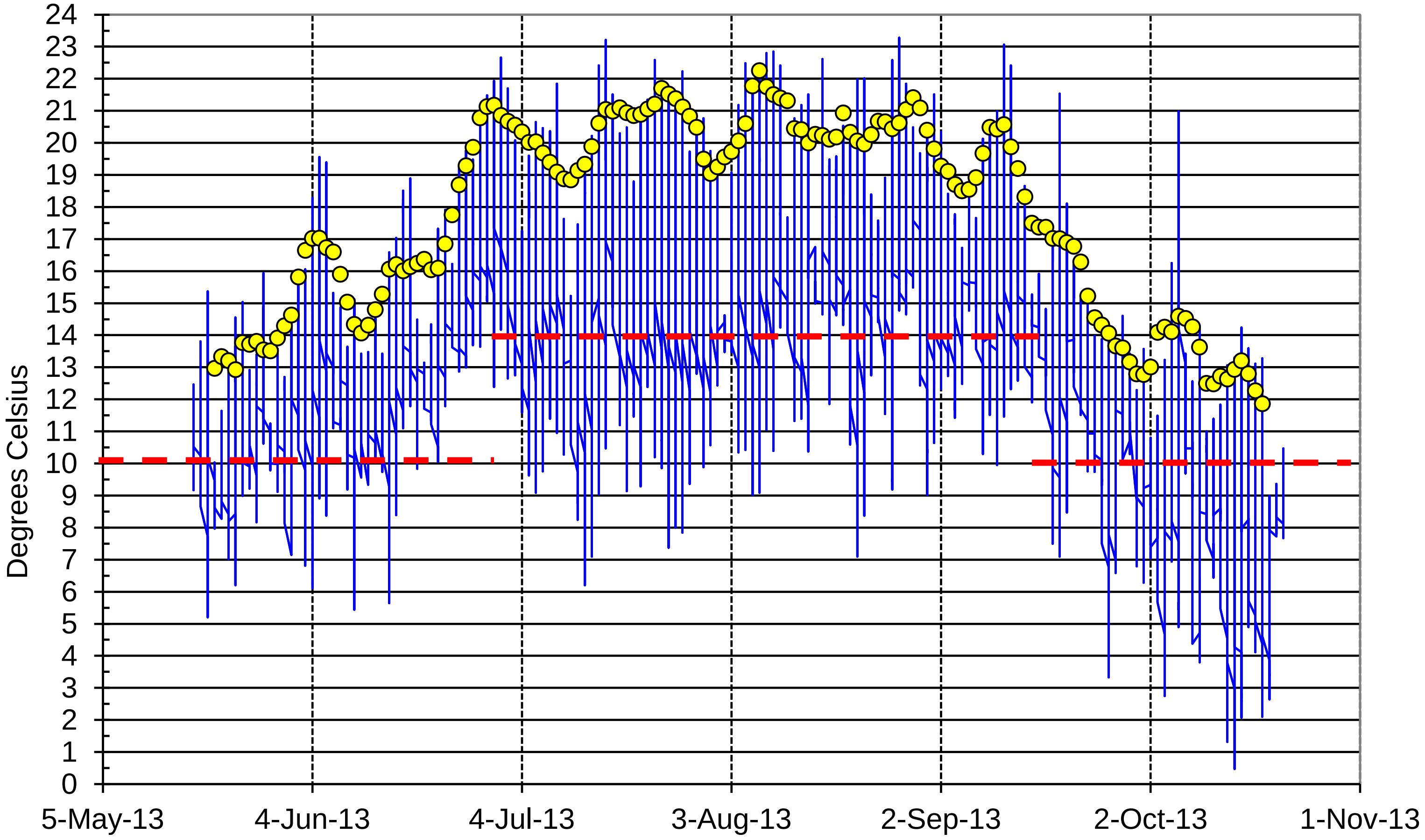


Figure C-15. Hourly <u>air</u> temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

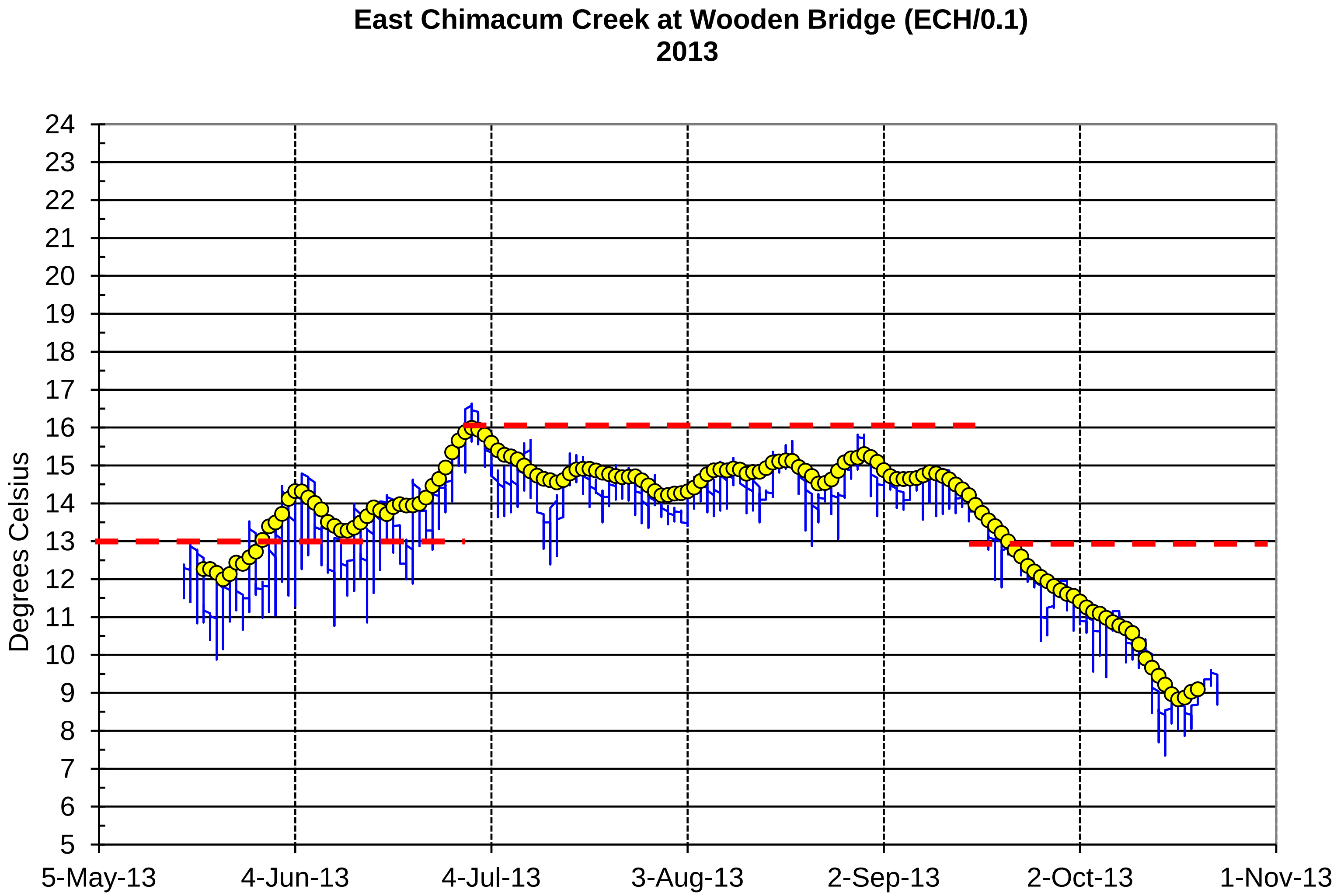


Figure C-16. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

East Chimacum Creek at Gladys' Nursery (ECH/0.5)
2013

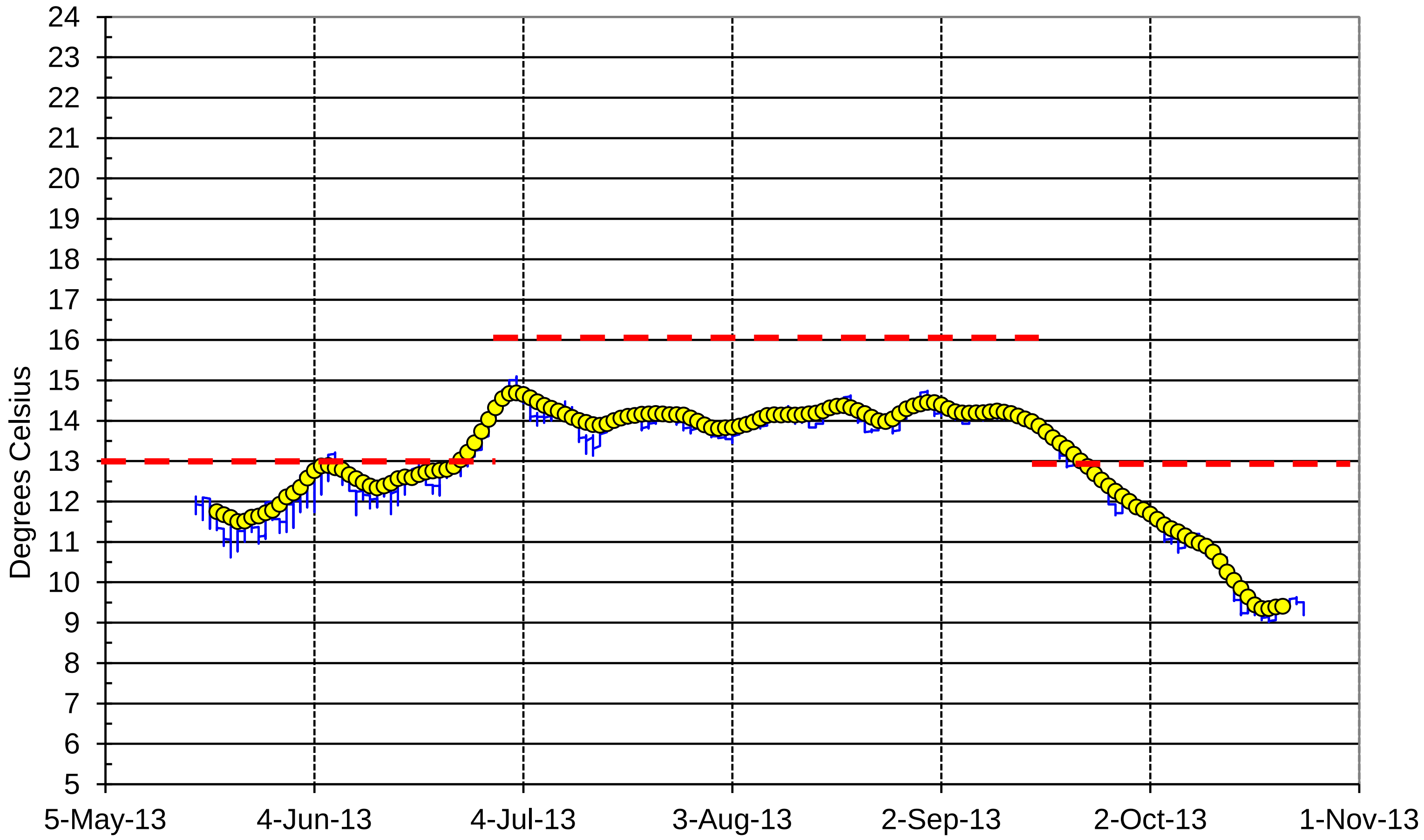


Figure C-17. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

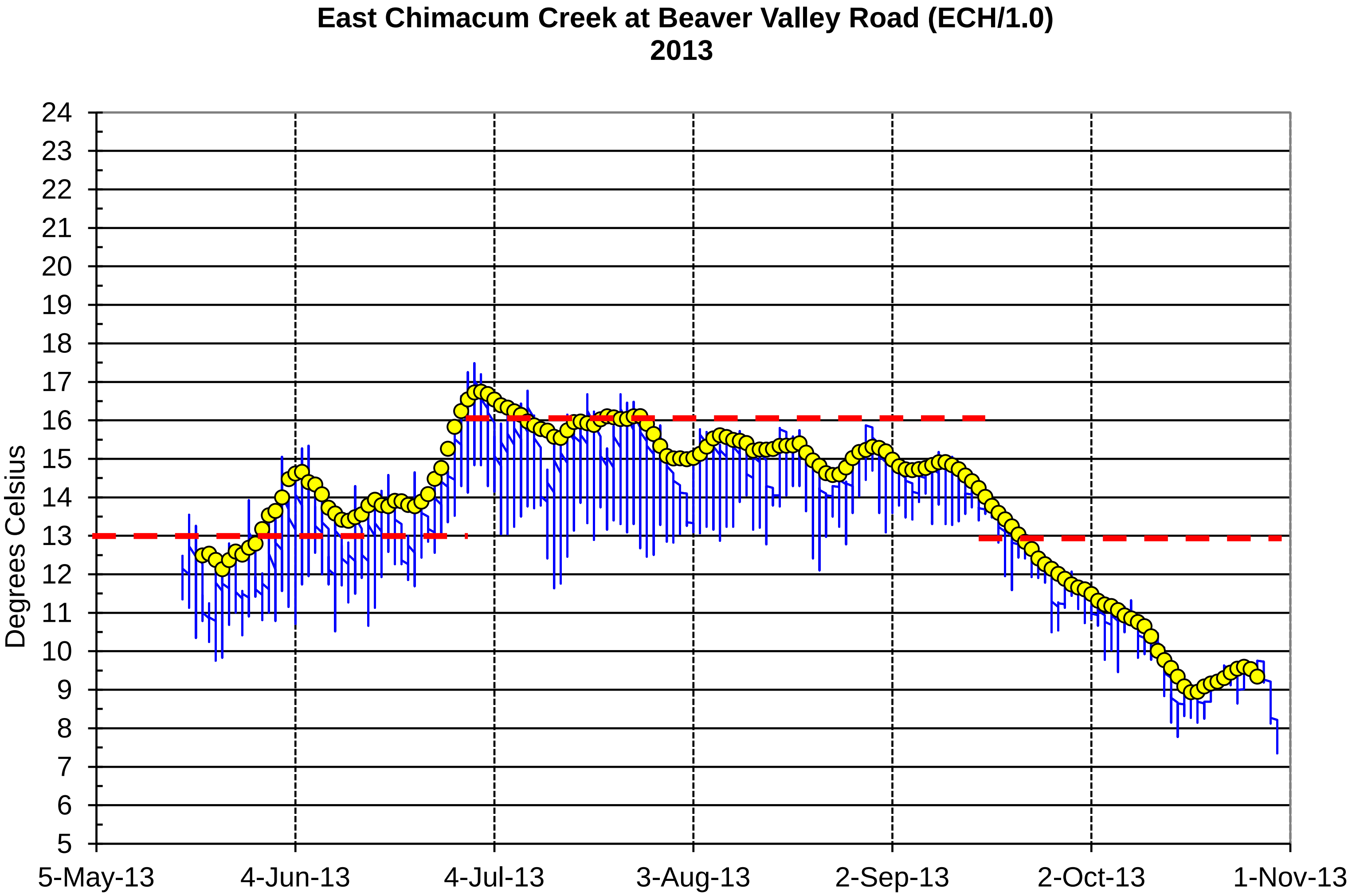


Figure C-18. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

East Chimacum Creek (ECH/1.2)
2013

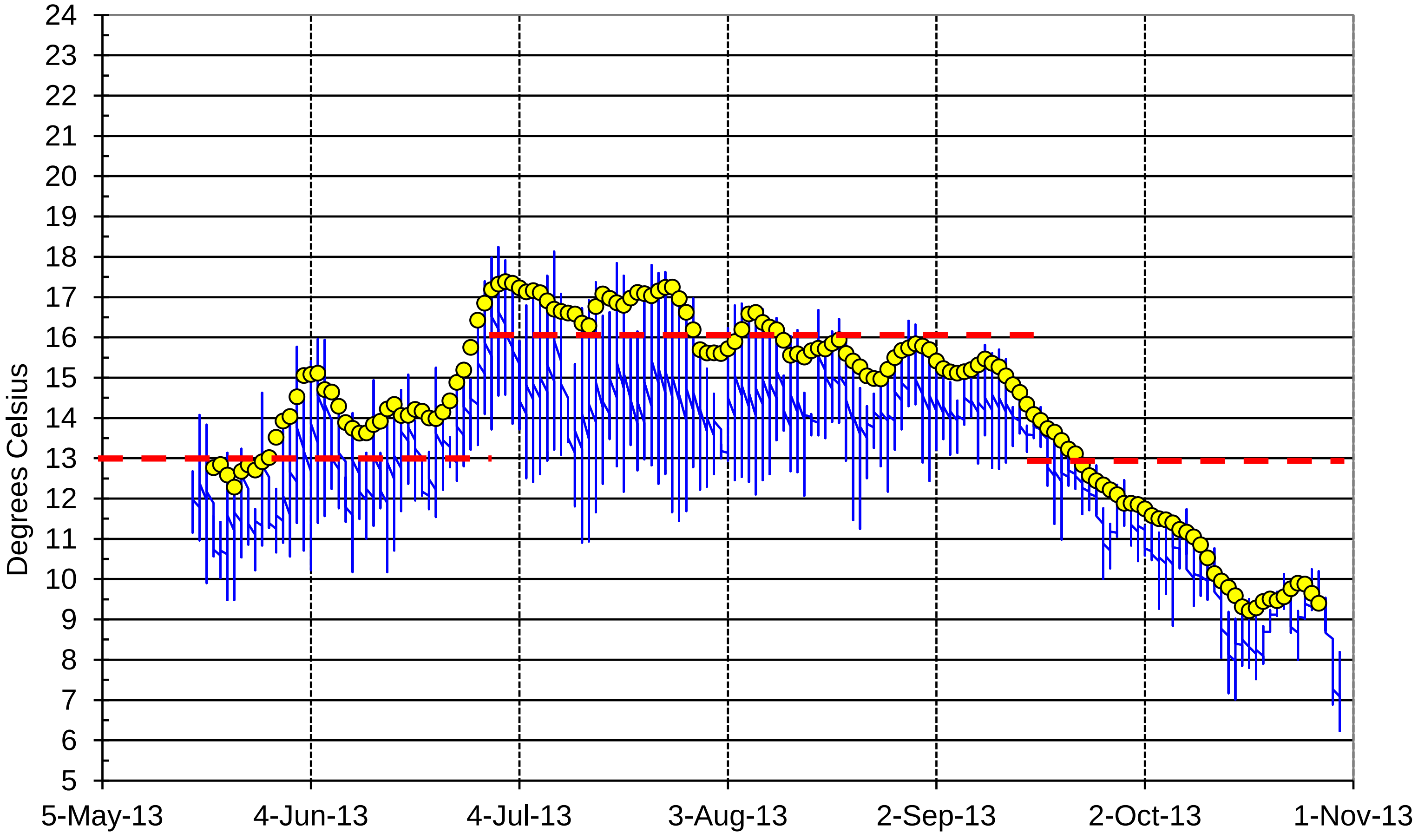


Figure C-19. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

East Chimacum Creek (ECH/2.0)
2013

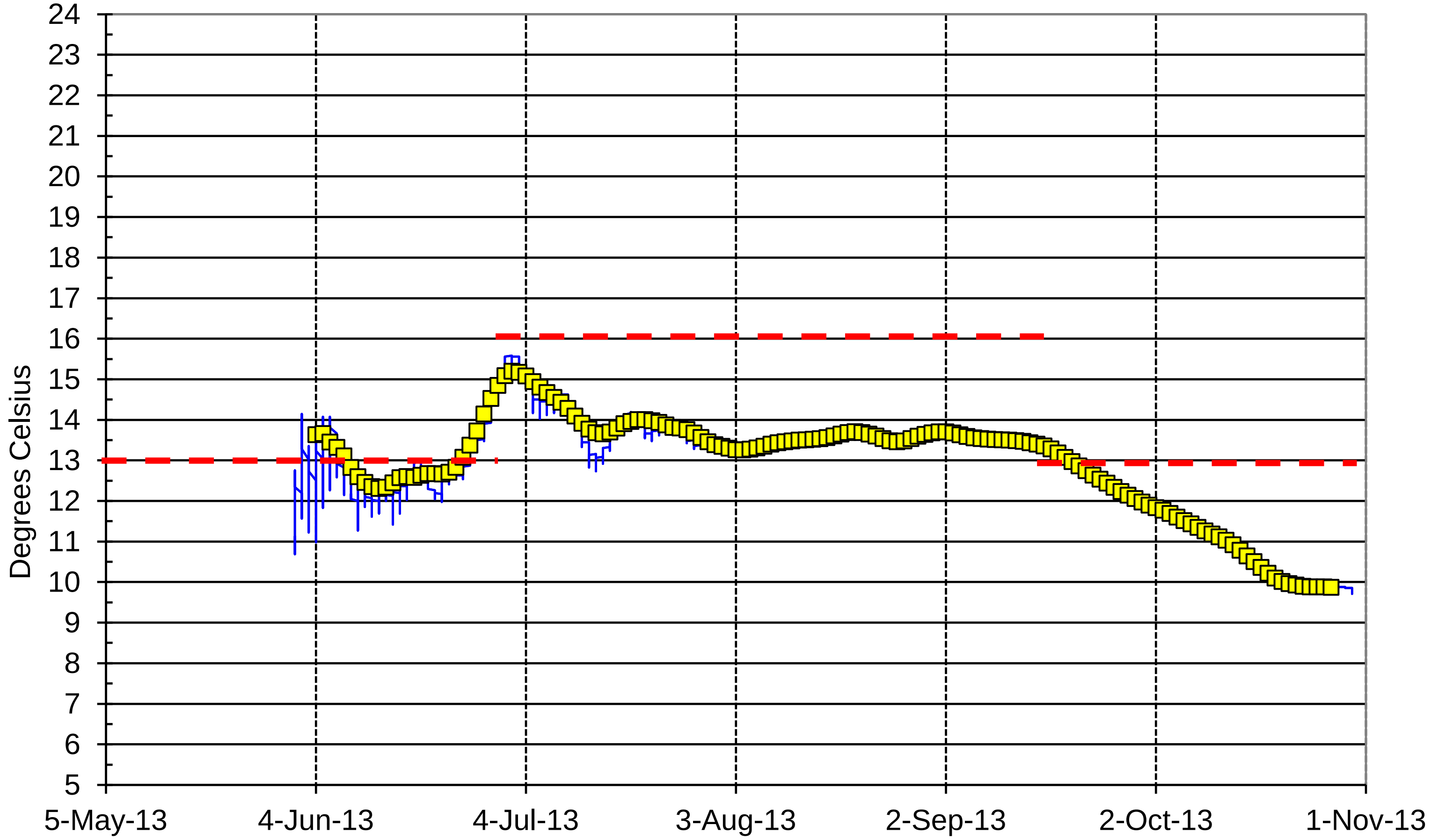


Figure C-20. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

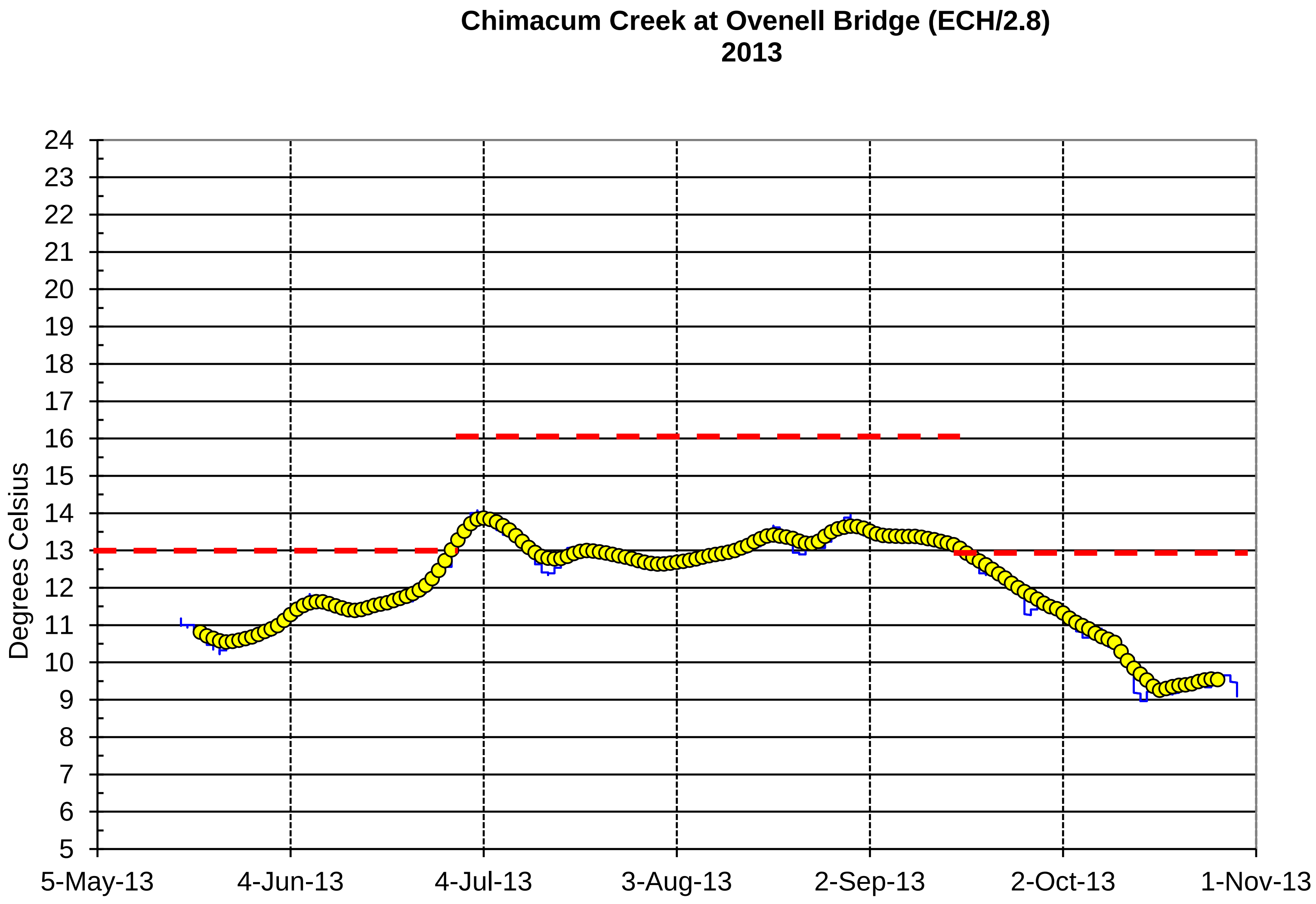


Figure C-21. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

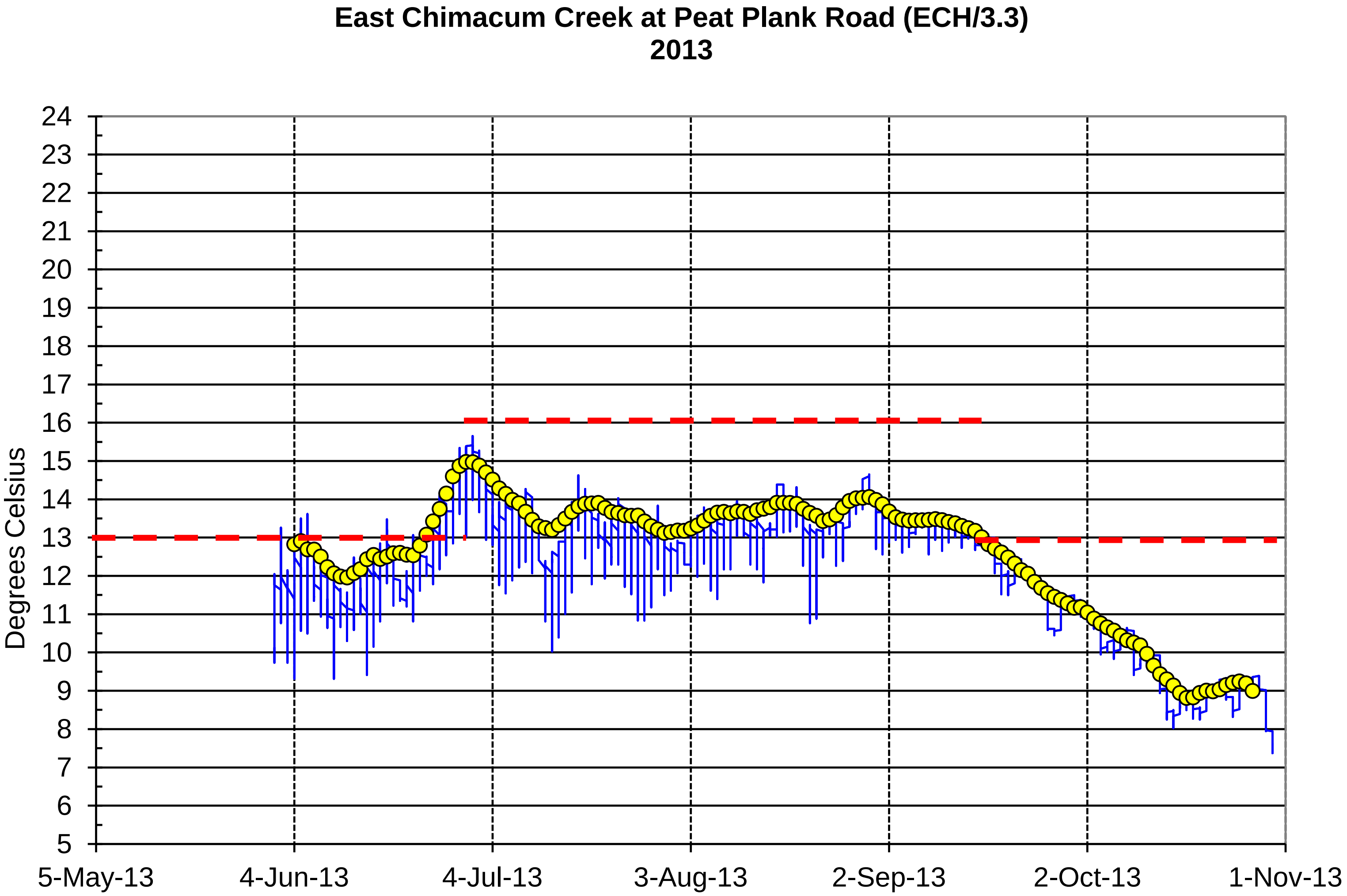


Figure C-22. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

East Chimacum Creek at Private Road (ECH/4.3)
2013

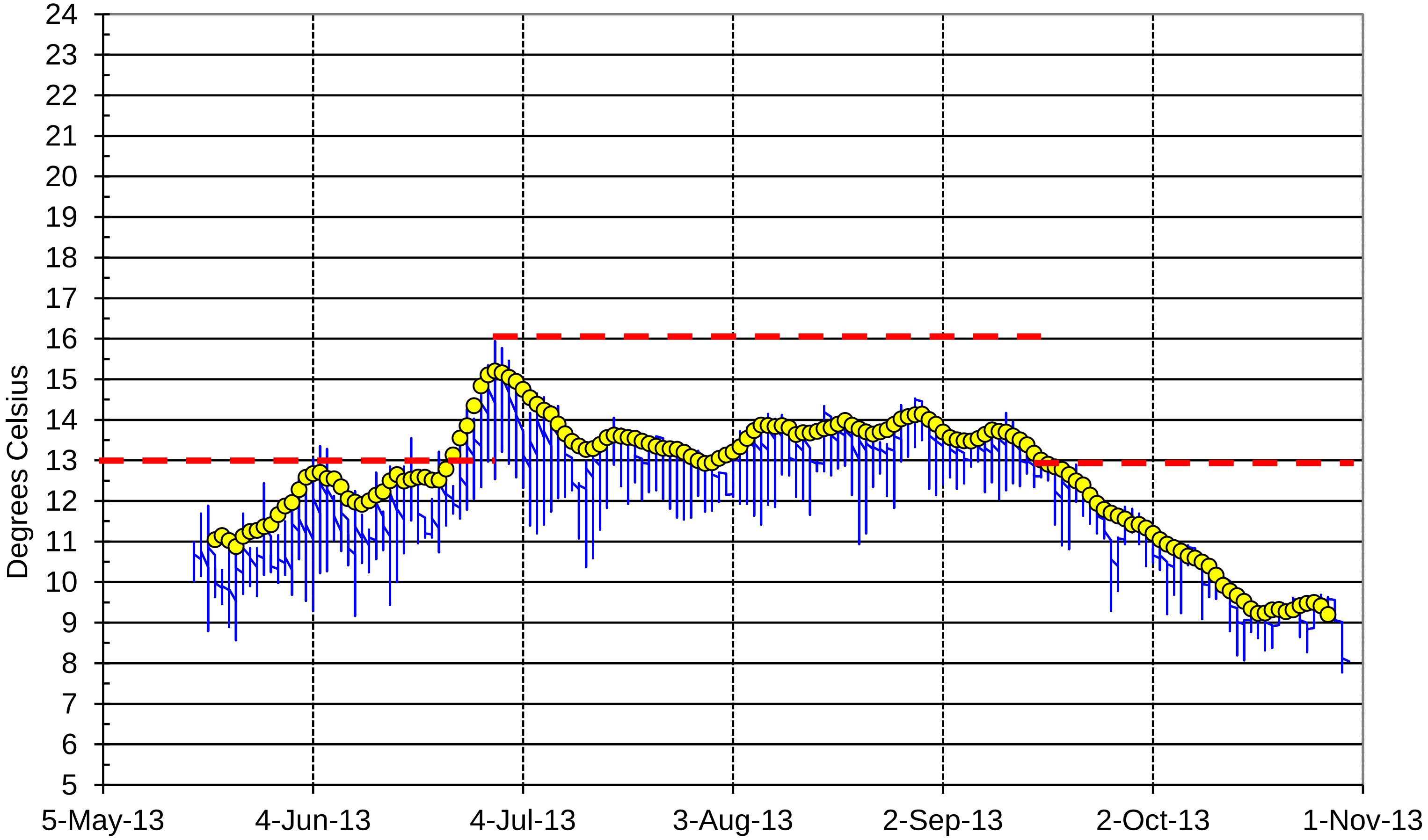


Figure C-23. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Barnhouse Creek at Mouth (BH/0.0)
2013

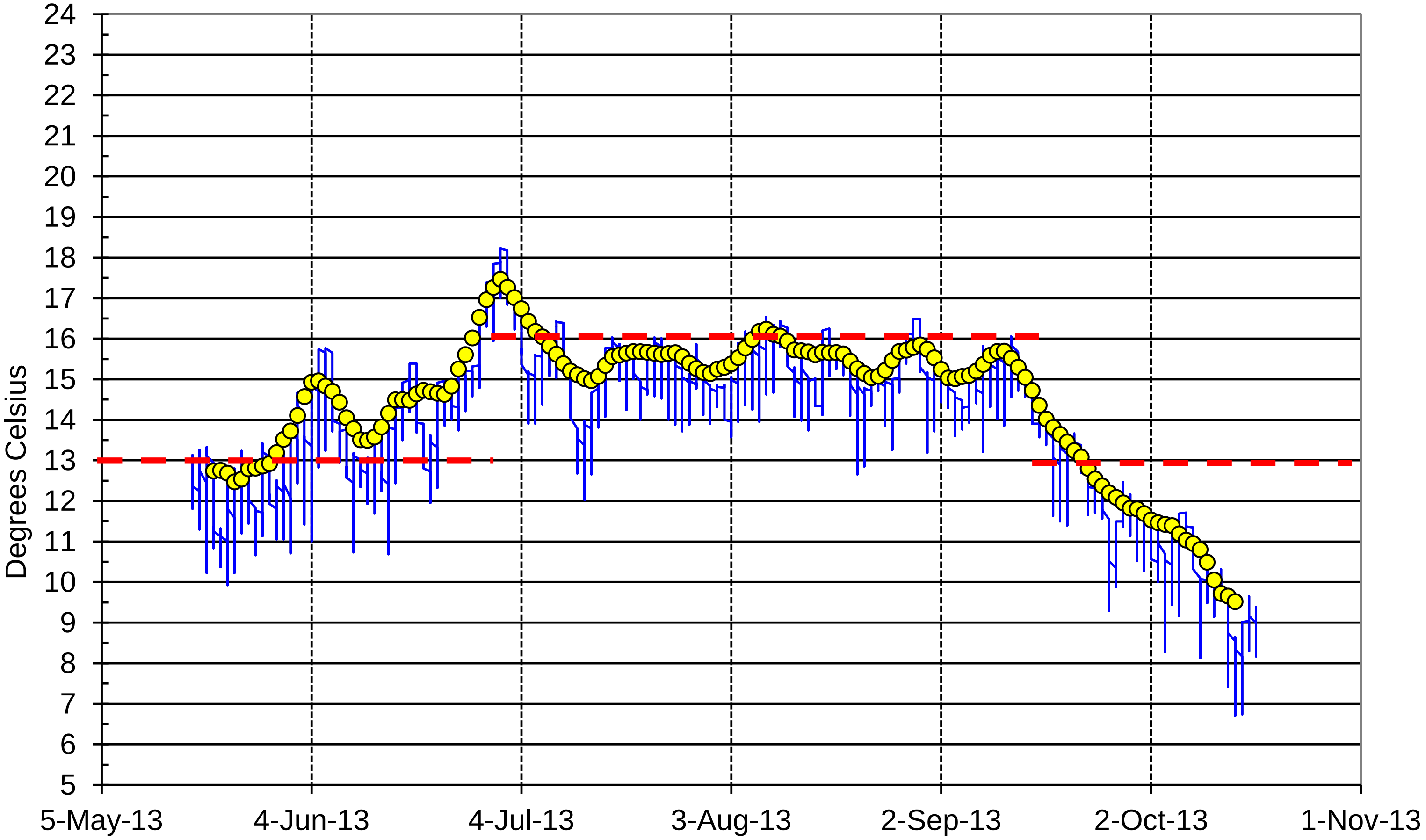


Figure C-24. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Barnhouse Creek at Center Valley Road (BH/1.0)
2013

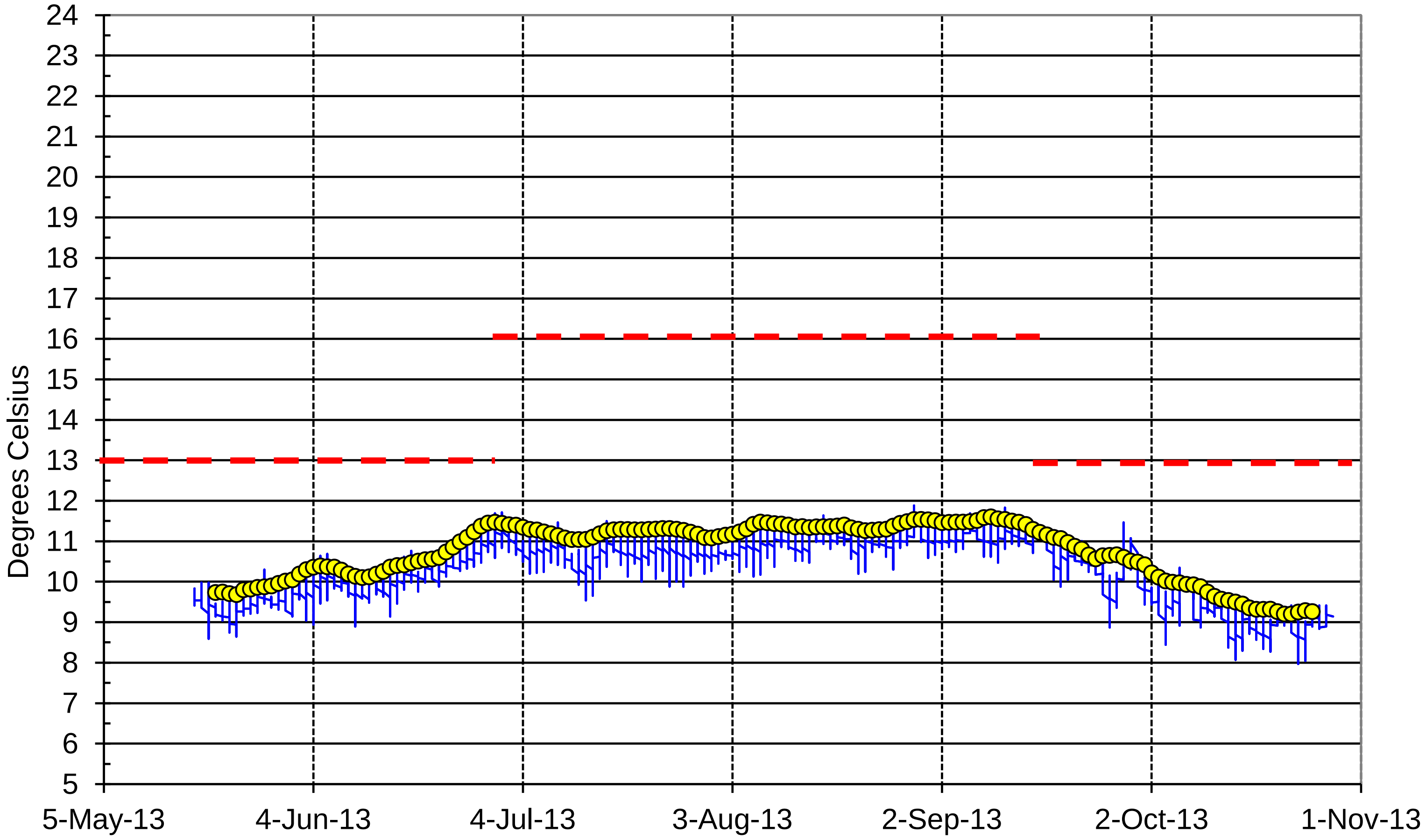


Figure C-25. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Naylors Creek (NA/0.2)
2013

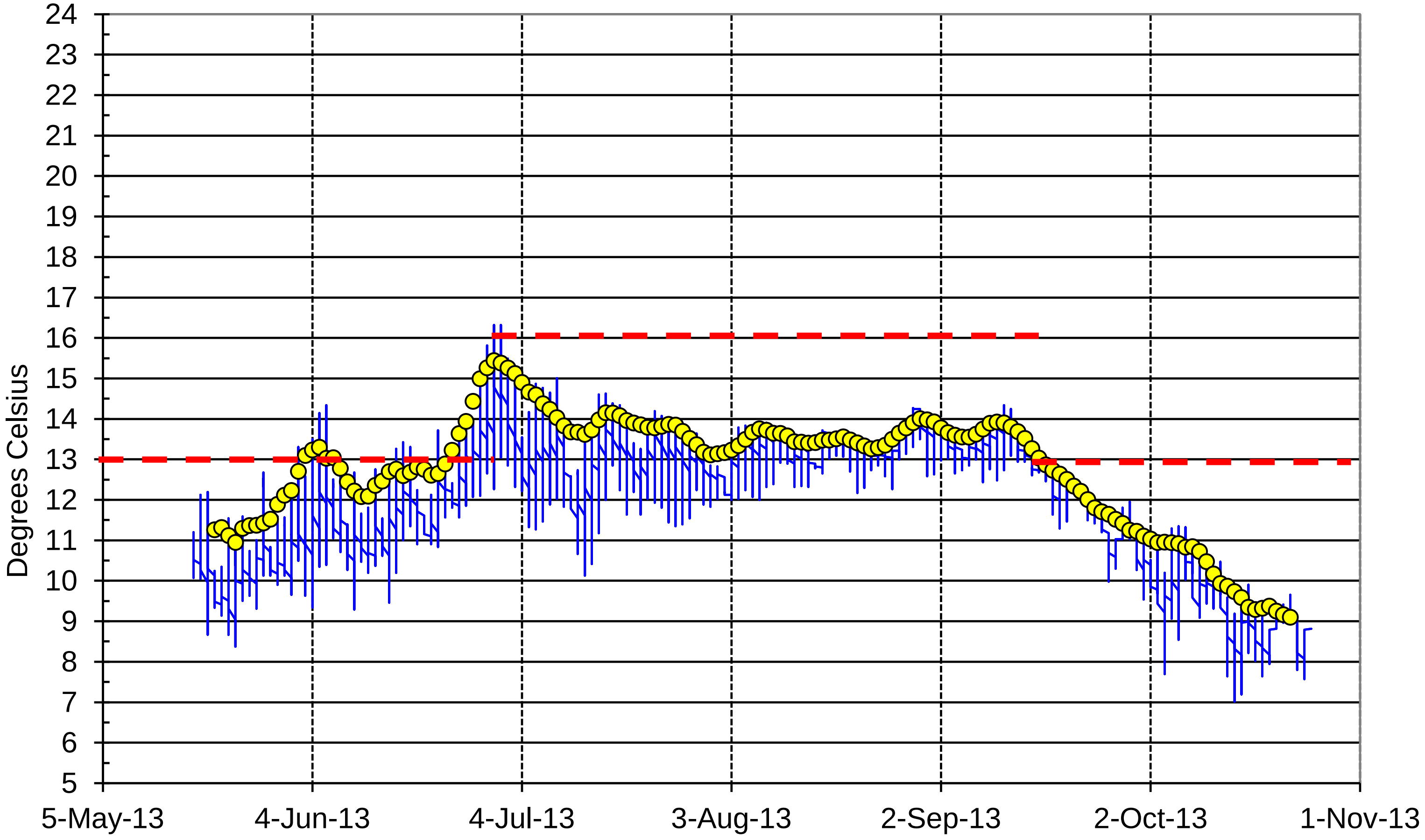


Figure C-26. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Naylors Creek at West Valley Road (NA/0.7)
2013

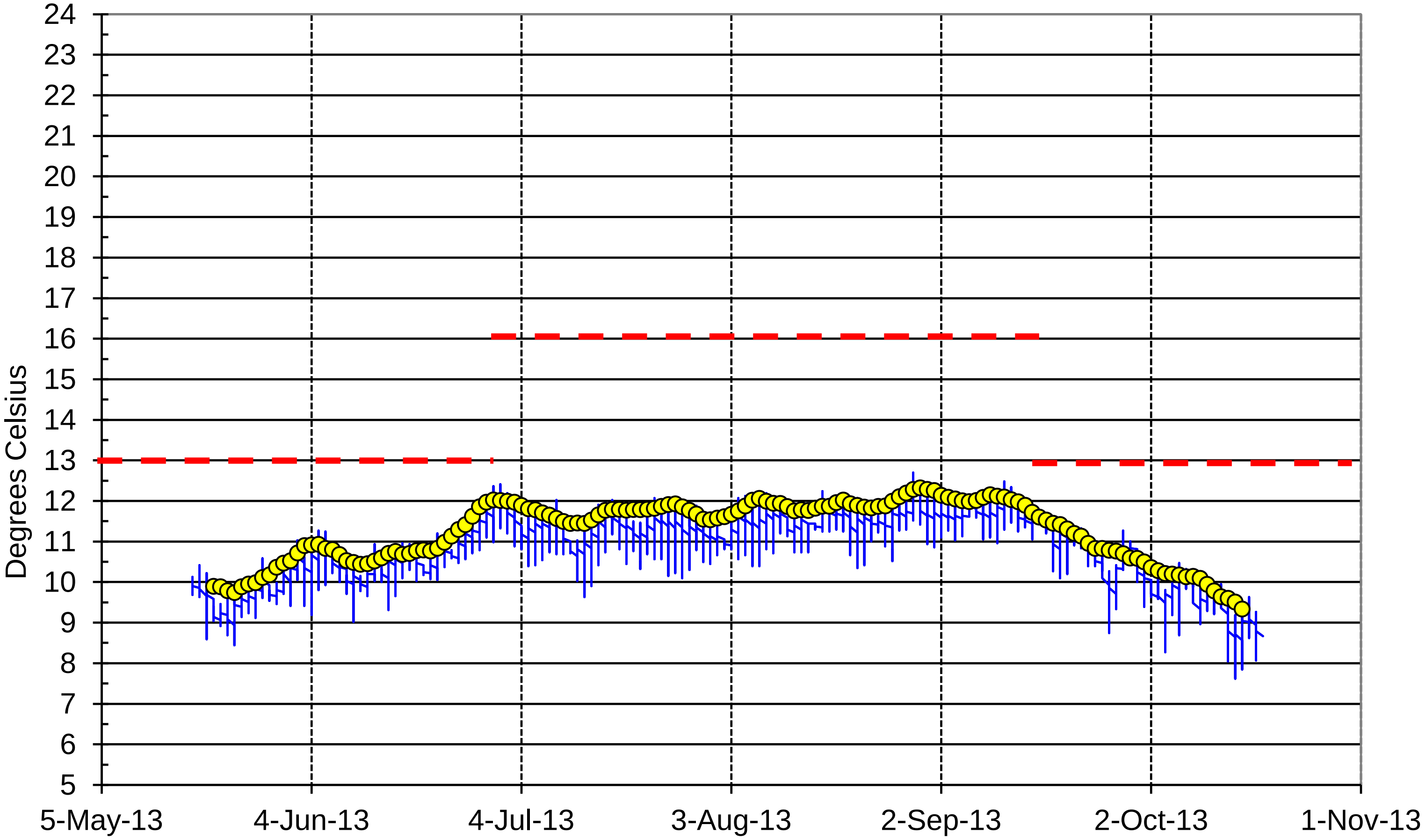


Figure C-27. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Putaamsuu Creek at Mouth (PU/0.0)
2013

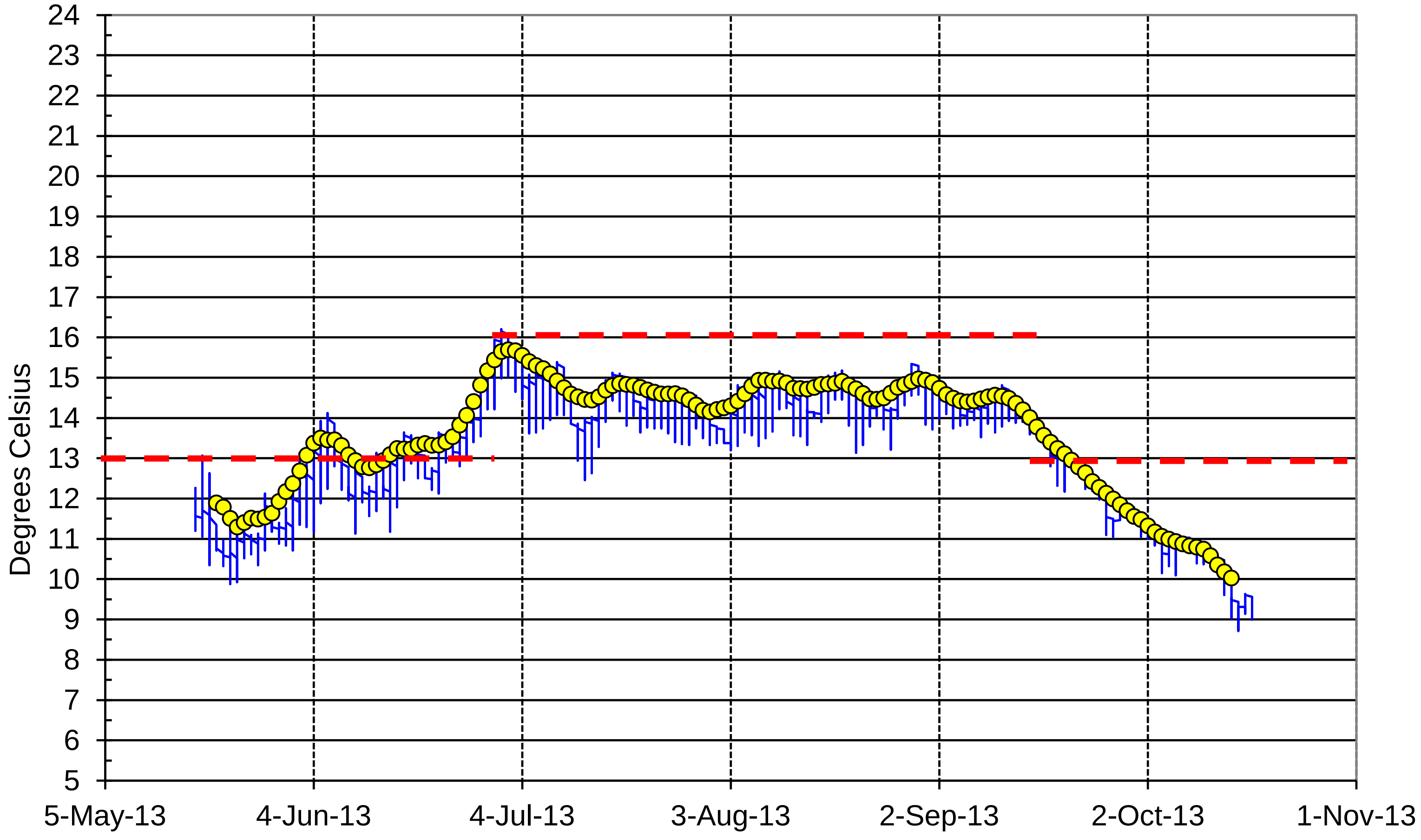


Figure C-28. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Putaansuu Creek at West Valley Road (PU/0.4)
2013

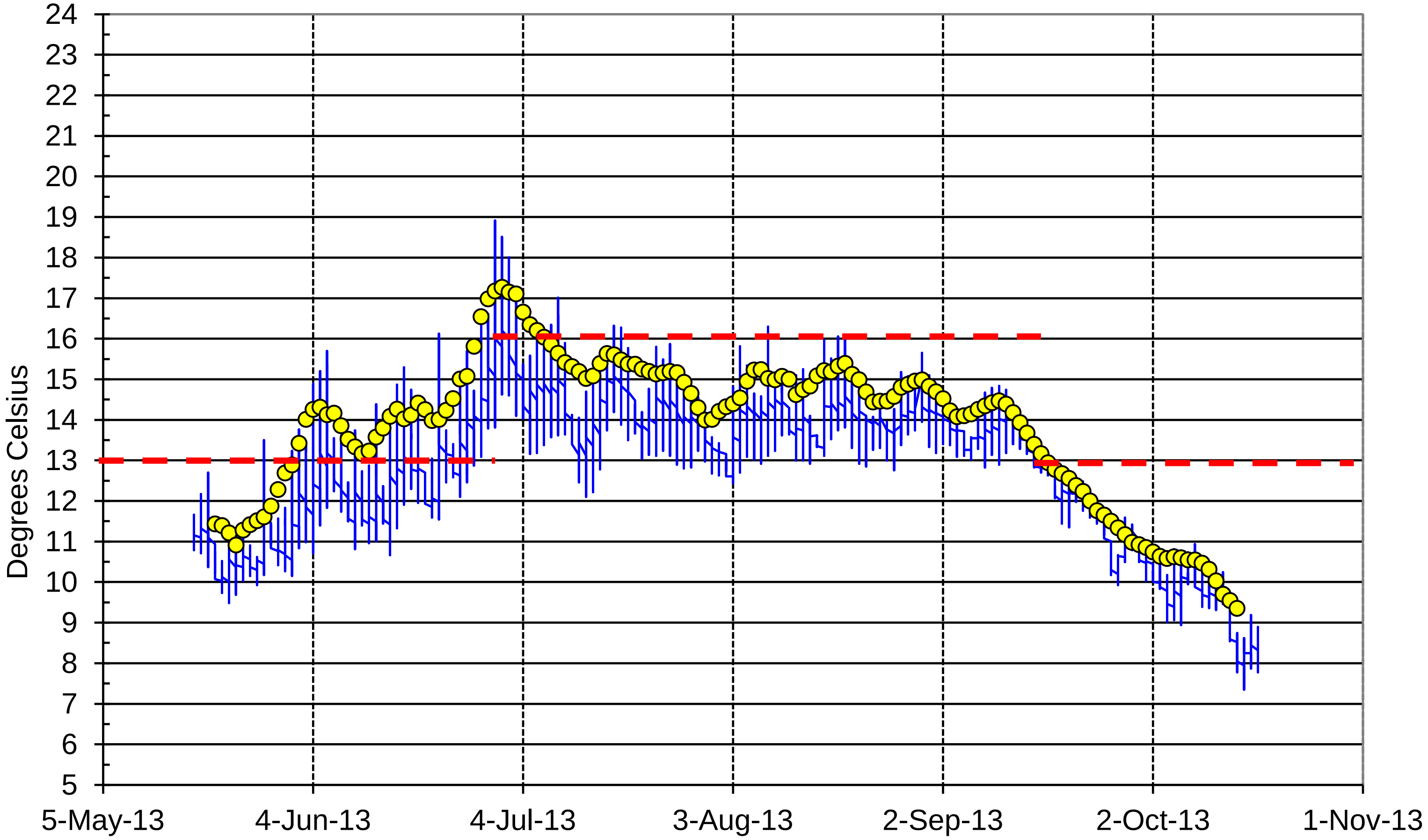


Figure C-29. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

Putaansuu Creek About 200 Feet Upstream From Pond (PU/0.5)
2013

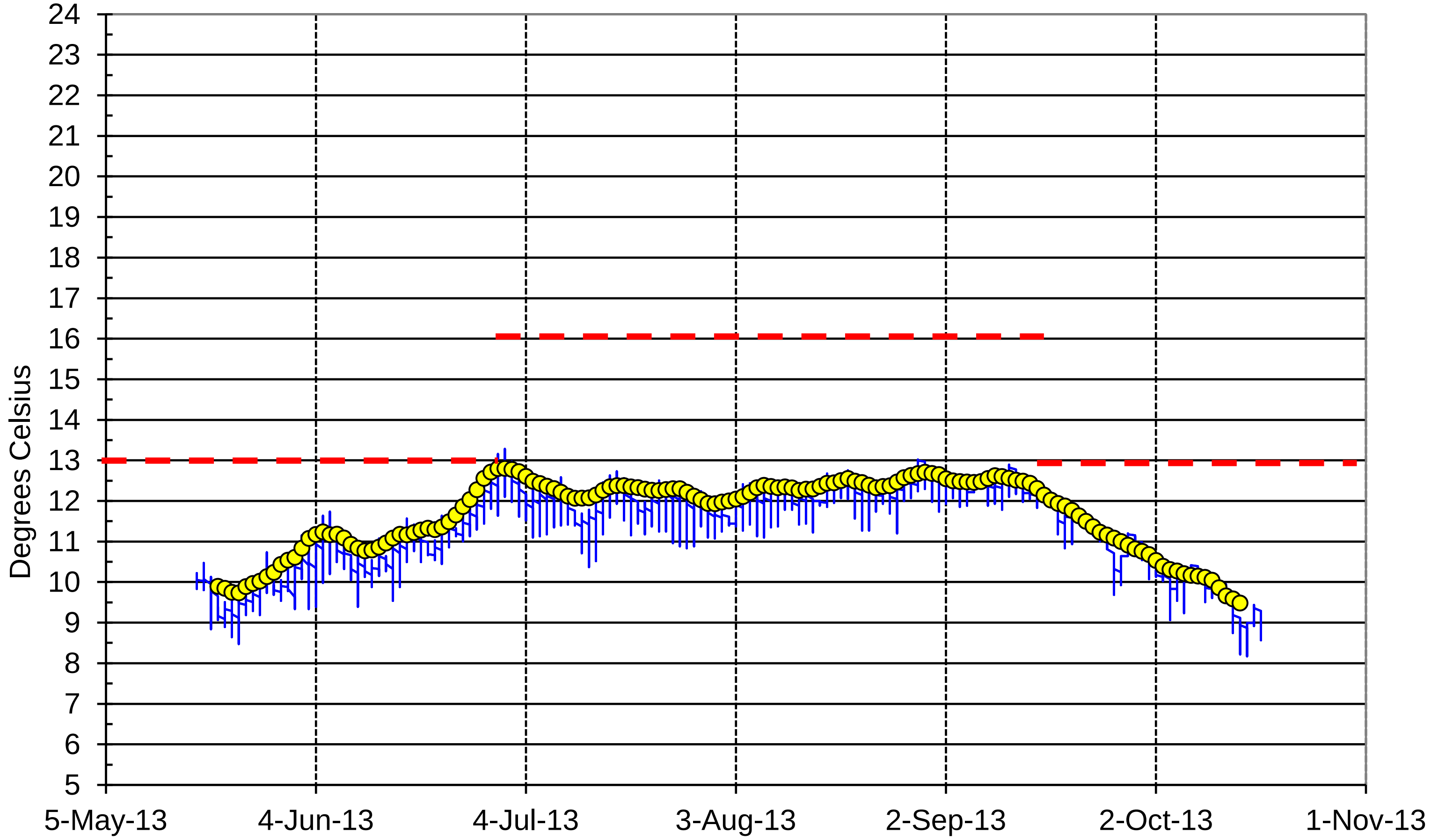


Figure C-30. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.