



Lower Columbia River Study

2006

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Background

The Lower Columbia River is a huge, diverse system that faces many anthropogenic impacts that hinder salmonid recovery. The Native Fish Society has worked since 1995 to protect, conserve and restore wild fish populations in the Pacific Northwest. Under contract with the Native Fish Society, Willamette Riverkeeper was hired to complete a yearlong monitoring project in the Lower Columbia River and several tributaries. The monitoring plan focused on collecting tributary temperature data for 15 tributaries to the Lower and Middle Columbia River, collecting samples for heavy metal analysis and examining cold-water refugia and methods for locating coldwater refugia.

Tributary Temperature

The temperature of salmon bearing streams is one of the most important factors in their inhabitability. Temperature directly impacts dissolved oxygen, a physical property that effects salmonid survival and development. High temperatures decrease available oxygen, resulting in stream temperatures that decrease egg success. Temperature also dictates salmonid metabolism. At high temperatures, metabolism increases and salmonids rapidly use stored energy. This is especially problematic during migration.

In the Pacific Northwest unnaturally high temperatures create suitable conditions for invasive organisms such as large and smallmouth bass, Asian clam and carp (among others). The presence of some invasive organisms enhanced by high stream temperatures can be detrimental to salmonids due to predation, competition and habitat alterations.

High stream temperature may make metals and other potentially toxic constituents more bio-available to aquatic organisms. As contaminants build up in fatty tissue, salmonids may die, experience developmental problems or become unfit for human consumption. Pollutants that become more bio-available at higher temperatures include ammonia, cadmium and copper (Van Hattum et al 1993, Heath 1987).

Human impacts such as deforestation, urbanization, thermal pollution and erosion all contribute to unnaturally high stream temperatures. So that restoration and regulation efforts can be justified and prioritized it is necessary to provide temperature data for salmon bearing streams.

In this study, 15 tributaries with little or insufficient temperature data were monitored with temperature dataloggers through the summer of 2006. Sites were located in close proximity to stream confluence with the mainstem Columbia River in order to document potential refugia that these tributaries may create. In some cases, temperature probes were used to examine the effects of tide gates and culverts.

Metal Sampling

Certain metals, even at low concentrations, have been shown to have a negative effect upon salmonid survival and development. While background levels of many metals exist depending upon the geology and nature of a watershed, anthropogenic sources have greatly increased metal concentrations in some locations. Air pollution, industrial and municipal discharge, stormwater, agriculture and erosion all contribute to metal pollution.

Metals may be present in the water column dissolved and bonded to particulate. Through changes in water chemistry and the settling of particulate, metals accumulate in the benthic sediment of water bodies. Metal levels in the water column give a more instantaneous measure of pollutant load when compared to sediment samples which may tell a long term story. Water quality characteristics including hardness, temperature, pH, redox and organic carbon may determine the bio-availability and toxicity of water and sediment borne metals.

Metals sampled for this work include Arsenic, Cadmium, Copper, Mercury, Silver and Zinc. Samples were taken from the water surface and from sediment at depth, depending upon the site. Oregon DEQ, Clark County Public Works and Columbia River Estuary Study Taskforce assisted in site selection.

Arsenic (As) is a highly toxic metal that is used in herbicides, pesticides, lumber treatment (pressure treated wood), bronzing, pyrotechnics and the manufacturing of certain electronic items. Arsenic is also emitted into the atmosphere by coal-fired power plants and lead smelters. Arsenic has a high toxicity to aquatic life, is capable of long-term persistence at chronic levels and bio-accumulates in organic forms (not as toxic as inorganic).

Cadmium (Cd) is a rare metal that is used primarily in batteries. Additional uses include televisions, paints, PVC, solder and electroplating. Since Cadmium can be found in tires, oil and fuel it is often associated with high traffic areas. Cadmium may bio-accumulate and has high short term and long term toxicity to aquatic life.

Copper (Cu) is an essential element for all animals yet elevated levels can be toxic. It is the third most widely used metal due to its malleability and conductivity. Because of its widespread use and production, copper is readily found in the environment. Many factors including pH, dissolved oxygen, alkalinity, and organic compounds effect the toxicity of copper in water. Anywhere there is industry, urban areas and roads, elevated levels of copper should be expected.

Mercury (Hg) has recently been recognized as a pollutant of importance. Released into the atmosphere from coal fuelled power plants, vehicular exhaust, volcanic activity and evaporation, mercury settles on the landscape and is carried into rivers. Additional sources include batteries, thermometers, light switches and industrial processes. Once methylated, mercury can be absorbed by animal tissue and biomagnified through the food chain. Toxicity to fish is not well documented but human exposure through fish consumption is known to cause developmental and neurological disorders. Due to atmospheric deposition baseline levels can be expected in most places while elevated levels may be found near industrial and municipal areas.

Although less common than most other metals in this study, silver (Ag) is a toxic metal that may harm fish species. Silver compounds and salts are used in some pesticides, fungicides and herbicides and may be bio-accumulated by aquatic organisms. Elevated levels of silver may be present in streams that drain agricultural and industrial areas.

Found in many proteins we eat and even secreted by some human cells, Zinc (Zn) is an abundant element. Zinc is an essential element and like copper, also toxic in high dosages. Most dangerous is the free zinc ion which has been shown to kill fish and invertebrates. Being the fourth most used metal, zinc will appear in the environment wherever human population centers exist. Zinc is used in batteries, currency,

galvanization, many applications in the automobile industry and sunblock among thousands of other uses. Zinc's omnipresence results in difficulties with contamination in field sampling procedures.

Coldwater Refugia

Coldwater (or thermal) refugia are areas of water that is cooler (at least 3° C cooler – Torgersen et al 1995) than surrounding water. These areas may be used as rest areas during migration (Torgersen et al 1995), spawning areas for chum and Chinook salmon (Geist 2000) or refuge from extremely high temperatures. Thermal refugia may be caused by the confluence of a cooler tributary, the hyporheic activity of gravel bars or the entrance of cooler, subsurface water to another body of water (Geist 2000).

Clearly it is in the interest of those who are concerned with preserving salmonid populations to know the location of thermal refugia. Once located, these areas can be protected from over-fishing, pollution and development. An idea of the number, size and distribution of such resources will aid salmonid recovery efforts.

Site Selection

Tributary Temperature

Streams and rivers for temperature monitoring were selected based on review of available data and conversations with Oregon Department of Environmental Quality (ODEQ), Scappoose Bay Watershed Council (SBWC), United States Geological Survey (USGS), Clark County Public Works (CCPW), Columbia River Estuary Study Taskforce (CREST), Washington Department of Ecology (WADOE), Lower Columbia River Estuary Partnership (LCREP) and Cowlitz County Soil and Water Conservation District (CCSWCD). Since there are many sub-projects within several of these organizations that may collect continuous temperature data at their project sites, avoiding replication was difficult.

In most cases, sites were chosen close to the mouth of the stream so that the potential for the stream to act as coldwater refugia could be ascertained. Temperature dataloggers were placed to ensure that they would not become exposed during periods of low flows. In some cases, accessibility and characteristics (such as objects available for anchorage) had a great influence on the exact location of the datalogger. Dataloggers were placed to ensure adequate mixing for representative data.

Metal Sampling

In order to maximize efficiency, provide a meaningful use of the data and fill data gaps metal monitoring sites were focused on three study areas; Scappoose Bay, OR, the Lake River Watershed, WA and the Columbia River Estuary (Table 1).

ODEQ was interested in metal samples from Scappoose Bay (Figure 2) to gather supplementary data for potential site cleanup work. Fiberboard production began at this facility in the 1930s and wastewater was discharged directly to the bay. A large amount of sludge resulting from production was buried on-site and may now leak into Scappoose Bay through a shallow aquifer. High concentrations of arsenic, lead, zinc and copper have been found in stormwater and on-site soils. Two sites were chosen close to the Armstrong facility, one at the mouth of Milton Creek (marks northeast property boundary) and the other just outside the navigation channel south of the complex. Another site closer to the Scappoose Bay marina was chosen to repeat a site from the 1993 Bi-state Back Channel Survey. Another site was Scappoose Creek at West Lane road, one of the major tributaries to Scappoose Bay.

CCPW was interested in gathering metals data for several sites within the Lake River watershed (Figure 2). Little freshwater sediment metals data exists for Clark County and data collected for this project would provide a small amount of baseline information. The Lake River Watershed is facing rapid urbanization, making assessment of baseline conditions important. Gee creek in Ridgefield and Whipple Creek at 91st Avenue were selected since they are both long-term CCPW monitoring sites. Salmon Creek is a highly impacted urban stream that also has received the most intensive monitoring in the Lake River Watershed. The site chosen in Lake River was a replicate of a sediment sampling site used by WADOE.

In the Columbia Estuary sites were selected by CREST (Figure 3). CREST is interested in understanding the level and distribution of contaminants throughout the estuary. Previous sampling has suggested that contaminants from upriver are accumulating in low velocity areas of the estuary. All sampling sites were selected to replicate study sites from the 1991 and 1993 Bi-State reports. Since CREST is interested in the fate and transport of PCBs and DDT, sediment samples for these contaminants were also taken at all sampling sites.

Coldwater Refugia

To test methodology, a well known example of coldwater refugia, Wood's Landing, was selected. At this site ½ mile north of the I-205 bridge, nearly 1,000 chum salmon (a threatened species under the Endangered Species Act) spawn every autumn. Adequate spawning habitat is created by coldwater springs bubbling up through the riverbed. For the study sites, stretches along the Columbia River near Rooster Rock which demonstrated the topography suggestive of subterranean tributaries were selected.



Figure 1: Astoria area study sites. Continuous temperature monitoring sites are circled with blue font, sediment sample sites are rectangular with red font.

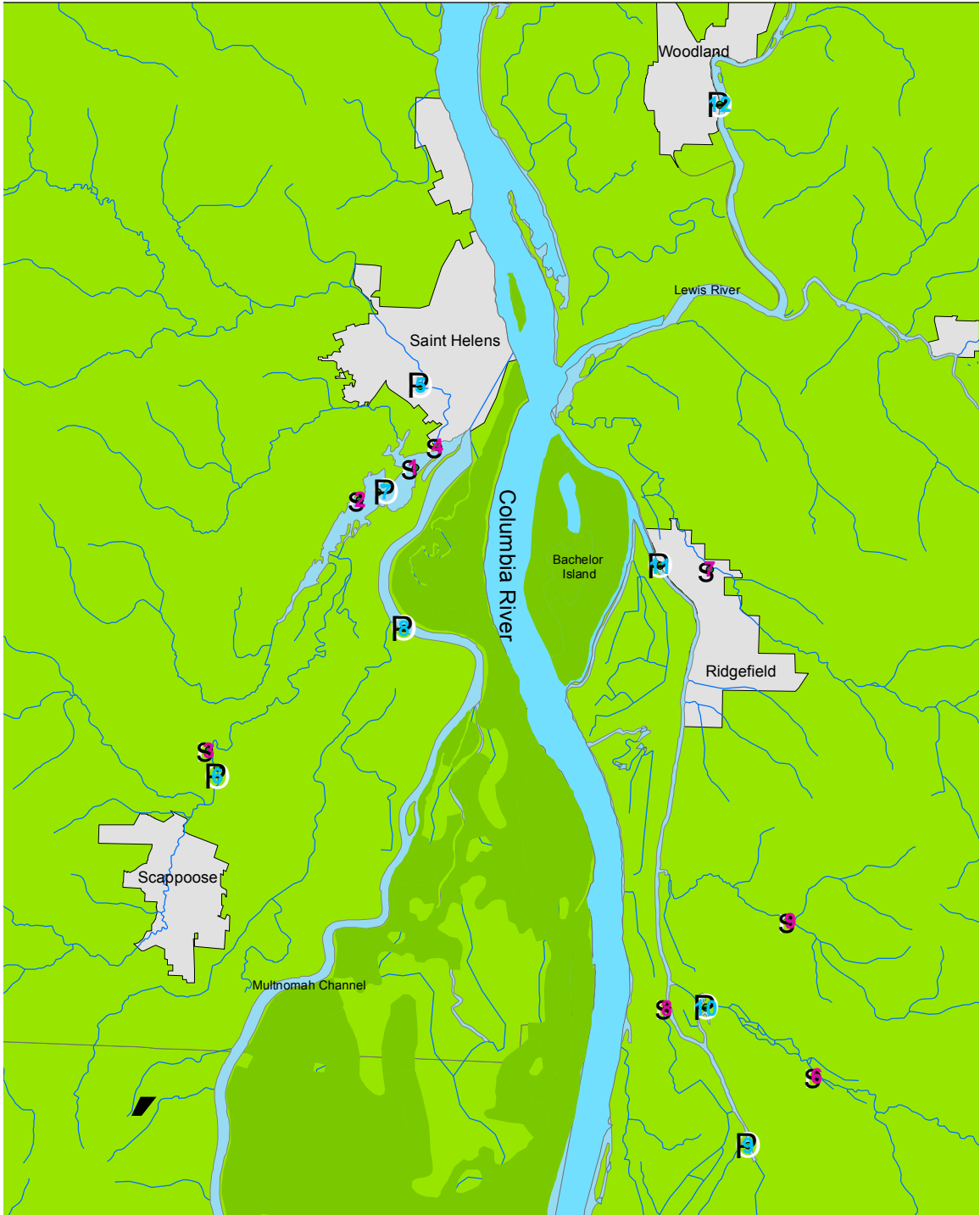


Figure 2: Scappoose and Clark County study sites. Continuous temperature monitoring sites are circular with blue font, water and sediment sample sites are square with magenta font.

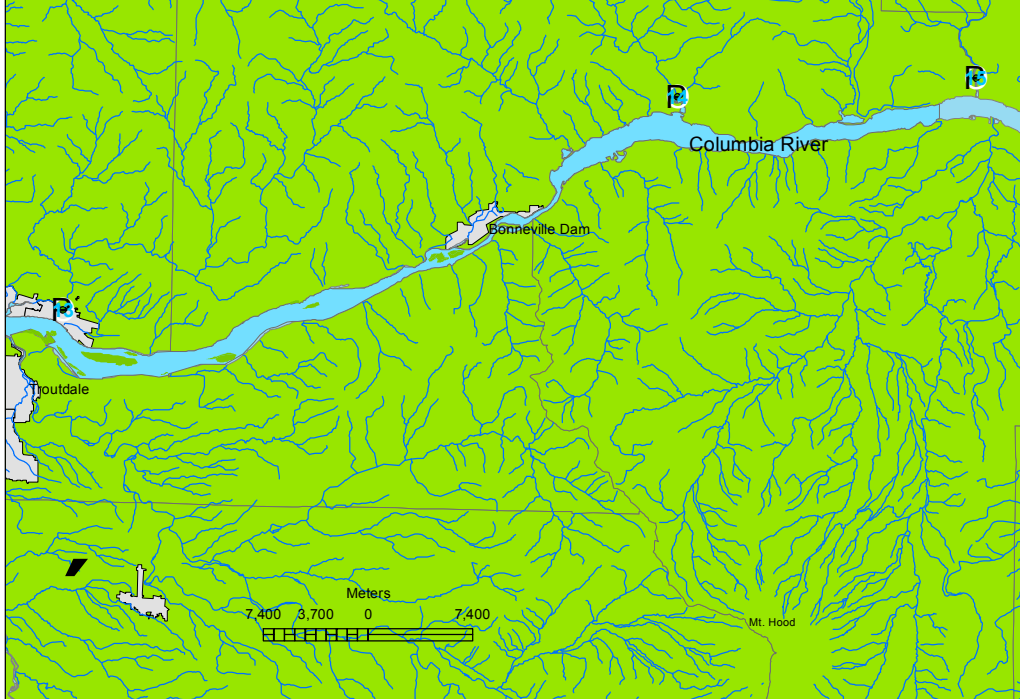


Figure 3: Columbia River Gorge study sites. Continuous temperature monitoring sites are circular with blue font.

Table 1: Sample sites for Tributary Temperatures and Metal Sampling. These sites are displayed in Figures 1-3.

Site Name	Latitude	Longitude	Cont. Temp #	Sediment #	Water and Sed #	Figure #
Alder Creek	46.18322	-123.92381	1			1
Skipanon Waterway	46.16775	-123.91432	2			1
John Day River	46.15706	-123.73155	3			1
Ferris Creek	46.16384	-123.64684	4			1
Cathlamet Bay	46.19038	-123.74195		1		1
Cathlamet Bay, South Channel	46.17577	-123.69508		2		1
Svenson Island	46.17672	-123.67620		3		1
Knappa Slough	46.20202	-123.58825		4		1
Prairie Channel	46.22325	-123.55293		5		1
Green Island	46.21490	-123.70015		6		1
Youngs Bay	46.16970	-123.82480		7		1
Grays Bay	56.29683	-123.70068		8		1
Milton Creek	45.85061	-122.81837	5			2
Scappoose Creek	45.77608	-122.87127	6			2
Scappoose Creek	45.77947	-122.87368			3	2
Scappoose Bay @ marker # 3	45.82992	-122.82930	7			2
Scappoose Bay @ marker # 9	45.82837	-122.83412			2	2
Scappoose Bay @ Armstrong Industries	45.83487	-122.81900			1	2
Scappoose Bay @ Milton Ck.	45.83906	-122.81307			4	2
Multnomah Channel	45.80388	-122.82102	8			2
Lewis River	45.90624	-122.73812	12			2
Lake River @ Ridgefield	45.81734	-122.75101	11			2
Lake River @ Felida	45.70626	-122.72251	9			2
Lake River 1 mi. D/S of Felida	45.73235	-122.74579			8	2
Gee Creek	45.81689	-122.73738			7	2
Whipple Creek	45.74972	-122.71253			9	2
Salmon Creek	45.72006	-122.70428			6	2
Salmon Creek	45.73260	-122.73513	10			2
Willamette River @ Holgate Channel	45.49430	-122.66060			5	NA
Washougal River	45.58291	-122.34808	13			3
Wind River	45.72584	-121.79422	14			3
White Salmon River	45.74038	-121.52299	15			3

Methods

Tributary Temperature

Onset Tidbit temperature dataloggers were used to measure continuous temperature. These devices were set to record temperature once every hour. Dataloggers were placed inside camouflage housing and attached to the stream bottom with rebar or tied to pilings. Care was taken to ensure that loggers remain at least .5 m below the water surface (where possible) and off of the stream bottom. Areas of little sun exposure were selected for placement.

Pre, post and field audits were performed with a NIST certified thermometer to ensure datalogger accuracy. Several sites were outfitted with duplicate dataloggers to ensure precision. Dataloggers were deployed to monitor summer time stream temperatures for 2006 with the earliest being placed in November 2005 and the latest being placed in early April 2006. Dataloggers were removed as early as late September 2006 and as late as December 2006.

In several sites, dataloggers were lost to high flow events or vandalism. Sites with lost data include Washougal River and Salmon Creek. Some data was retrieved at field audits for Washougal River while none exists for Salmon Creek.

At two sites in the Columbia River Estuary, dataloggers were used to test the effects of tide gates. Tide gates are used to prevent the incoming tide from flooding historical tidal floodplain so that these areas may be used for agriculture and development. While these devices may allow easier management of flooding waters, they separate salmonids from important habitat where a wealth of aquatic and terrestrial macro-invertebrates as well as refuge from predators exists. At Alder Creek, dataloggers were placed on either side of a tide gate to determine any impacts the tide gate may have on temperature. On the John Day River, a similar installation was created on either side of a culvert where tide gates have been present in the past and may be reinstalled in the future. The culvert separates the John Day from a large wetland area.

Analysis

Temperature data was analyzed using Hydrostat Simple 7 (2002), an excel macros created by the ODEQ for continuous temperature data analysis. Data was first edited to remove any partial days and periods of datalogger exposure evidenced by extremely high temperatures and bizarre graphs (experienced in some tidal areas).

In order to determine each monitored tributary's potential to function as a coldwater refugia, temperature datalogger data was compared to USGS gage data. The comparison was limited to June 26th- October 2nd, dates when the mainstem Columbia exceeded criteria (18°C). Only sites in close proximity to the mainstem Columbia or of a large volume were included in this assessment. The Washougal River was not included due to insufficient data. Tributaries consistently 3°C cooler than the mainstem Columbia were considered potential sources of coldwater refugia. Since salmonids have been shown to favor water as little as 1°C cooler than ambient temperature (Torgersen et al. 1995), sites with this characteristic were also noted.

Metal Sampling

Metal concentrations were tested in water and sediment. All samples were taken and handled using “clean hands, dirty hands” technique according to EPA method 1669. For water, samples were taken from the surface by submerging a clean 500 mL polyethylene bottle containing a powdered acid preservative provided by Columbia Analytical Services (Kelso, WA). One sample was collected for As, Cd, Cu, Ag and Zn. Due to different methods of analysis, a separate fluoropoly sampling bottle was used for Hg. Initially, a Van Dorn sampling bottle was used for acquiring water column samples. However, after sampling at Ross Island it was demonstrated that contamination levels associated with this bottle were too high for continued use.

Samples were chilled until delivery. Field blanks were created by pouring 500 mL of clean reagent water into additional sample bottles (both supplied by CAS) to determine contamination as a result of sampling technique or transport.

For Clark County water samples, hardness was also tested at the request of CCPW. Hardness tests were performed on the sample for trace metals.

Sediment samples were acquired by using a Teflon coated Petit Ponar and sterile poly-ethylene scoops. For samples from boat in water of a depth greater than 1m, the Petit Ponar was utilized. For sites in the Scappoose and Clark County sample areas, all sediment samples were composites of 5 grabs. Due to time constraints, samples in the Columbia Estuary study area were from single grabs or several composites when grab volume was not sufficient. For each sediment grab with the Petit Ponar, water lying on top of the sample was drawn off with a clean, large syringe. Using sterile polyethylene scoops, the top 2 cm of material from the Ponar was removed and placed in a clean glass container with a Teflon-lined lid (provided by CAS). Samples were chilled until delivery. Rinsate blanks were created by pouring reagent water over the Petit Ponar and analyzing the rinsate identically to water samples.

For sediment samples in shallow water, sterile polyethylene scoops were used to remove the top 2 cm of substrate in areas with adequate sediment. Composites of 5 scoops were used for each sample. Rinsate blanks were created by pouring reagent water over the sterile polyethylene scoops and analyzing the rinsate identically to water samples.

For Clark County sediment, a sample was also taken to determine grain size and Total Organic Carbon (TOC) at the request of CCPW. For Columbia River Estuary sediment, samples were also taken for organochlorine pesticides and PCBs at the request of CREST (Appendix C).

Analysis

All analyses were performed by Columbia Analytical Services in Kelso, WA. All samples were analyzed for Total metals. As, Cd, Cu, Ag and Zn concentrations were determined using EPA method 200.8, Inductively Coupled Plasma- Mass Spectrometry (ICP-MS). This allowed for sufficiently low detection levels. Hg concentration in sediments was analyzed by EPA method 7471A, Cold Vapor Atomic Absorption Spectrometry (CVAAS). Hg concentration in water was analyzed by EPA method 1631, Cold Vapor Atomic Fluorescence Spectrometry (CVAFS). In Clark County, TOC and grain size were determined by ASTM D4129-98M and D422 respectively. In the

Columbia River Estuary, organochlorine pesticides were tested by EPA method 8081A. PCB aroclors were tested with EPA method 608/8082. Both pesticides and PCBs were extracted by EPA method 3540C.

Water and sediment metal sample results were compared to state standards or guidelines when applicable. A lack of hardness data for Scappoose area water column samples rendered comparisons to standards for all Hardness dependent metals (Cd, Cu, Ag, Zn) impossible. Grain size determination for sediment samples in Clark County enabled a comparison between sites and to state recommended guidelines. Grain size normalized data for sediment metal concentrations were determined by the following modified formula (Horowitz 1985):

$$\frac{100}{(100-P)} \times Y = \text{normalized metal concentration}$$

Where P= percent of sediment > 70 μm
And Y= measured metal concentration

Sediment standards do not exist in Oregon and are designated on a case by case basis for freshwater sediments in Washington. Due to a lack of officially recognized standards, comparisons in this study were made with NOAA ERL and ERM sediment values and Washington Department of Ecology recommended sediment standards (Table 3). NOAA effects range-low (ERL) values were created as unofficial guidelines for the National Status and Trends Program. Generated from a number of toxicity studies, these data represent values below which negative effects rarely occur to aquatic life. Sediments with values above the effects range-median (ERM) will probably have negative effects on any organisms present. Washington Ecology recommended sediment guidelines (referred to as WADOE SQS in this document) were generated in a similar (if not more complicated) fashion and are intended as general guidelines although no set sediment standards for freshwater exist in Washington (Michelsen 2003). These values are also defined as levels of contaminants below which negative effects are not observed.

Table 2: Parameters tested with method, Method Detection Limit and Method Reporting Limit. All laboratory analyses performed by Columbia Analytical Services (Kelso, WA).

Parameter	Matrix	Method	Detection Limit	Reporting Limit
Hg	Water	EPA 1631E	0.06 ng/L	1 ng/L
Hg	Sediment	EPA 7471A	0.008 mg/Kg	0.02 mg/Kg
As	Water	EPA 200.8/6020	0.09 µg/L	.02 µg/L
Ag	Water	EPA 200.8/6020	0.002 µg/L	0.02 µg/L
Cu	Water	EPA 200.8/6020	0.02 µg/L	0.1 µg/L
Cd	Water	EPA 200.8/6020	0.007 µg/L	0.02 µg/L
Zn	Water	EPA 200.8/6020	0.3 µg/L	0.5 µg/L
As	Sediment	EPA 200.8/6020	0.07 mg/Kg	0.5 mg/Kg
Ag	Sediment	EPA 200.8/6020	0.003 mg/Kg	0.02 mg/Kg
Cu	Sediment	EPA 200.8/6020	0.01 mg/Kg	0.1 mg/Kg
Cd	Sediment	EPA 200.8/6020	0.005 mg/Kg	0.05 mg/Kg
Zn	Sediment	EPA 200.8/6020	0.2 mg/Kg	0.5 mg/Kg
Hardness	Water	EPA 130.2	-----	2 mg/L
Organo. Pest.	Sediment	EPA 8081A	Varies µg/Kg	Varies µg/Kg
PCBs	sediment	EPA 8082	Varies µg/Kg	Varies µg/Kg
TOC	Sediment	ASTM D4129-98M	0.02 %	0.05 %
Redox	Sediment	Beckman Omega Series Meter	1 mV	10 mV
Temp	Water	Hydrolab Quanta	0.01 °C	0.2 °C
pH	Water	Hydrolab Quanta	0.01 SU	0.2 SU
pH	Sediment	Hydrolab Quanta	0.01 SU	0.2 SU
Redox	Water	Hydrolab Quanta	1mV	10 mV
DO	Water	Hydrolab Quanta	0.01 mg/L	.2 mg/L
Turbidity	Water	Hach 2100P	0.01 NTU	0.1 NTU
Conductivity	Water	Hydrolab Quanta	.1 µS/cm	1 µS/cm
Cont.Temp.	Water	Stowaway Tidbit	-20 °C	-5 °C

Table 3: Comparison of recommended sediment quality guidelines from NOAA and WADOE. All values are in mg/Kg dry weight (ppm).

Analyte	NOAA ERL	NOAA ERM	WADOE 2003
Arsenic	8.2	70	20
Cadmium	1.2	9.6	0.6
Copper	34	270	80
Mercury	0.15	0.71	0.5
Silver	1	3.7	2
Zinc	150	410	140

Coldwater Refugia

Coldwater refugia was surveyed for using a Hydrolab Quanta (multi-parameter probe) attached to a boat moving along the shoreline. The boat moved at an average speed of 4 kmph (as determined by onboard GPS unit). Every 15 seconds, a data point including depth, temperature, dissolved oxygen, pH and conductivity was recorded by the probe. This resulted in a transect of data points with a 15-20 m gap between each point. A researcher logging points also recorded the GPS coordinates for each logged point using a handheld GPS unit.

Analysis

Data recovered from coldwater refugia was not statistically analyzed. Data points were visualized on graphs in order to elucidate departures from the mean (which may represent groundwater input). Points were plotted using GIS to visualize proximity to landmarks and potential ground water sources. Using ArcHydro, flow lines were generated from a Digital Elevation Map to represent potential subterranean flow.

Results

Tributary Temperature

Of 21 dataloggers deployed, 18 were recovered. Dataloggers lost to vandalism or flooding include Salmon Creek, Multnomah Channel and Washougal River. The Washougal datalogger was visited twice before vandalism so data exists until mid June. The Multnomah Channel datalogger was a duplicate so data for this site exists. No data exists for the Salmon Creek datalogger.

A large percentage of temperature results demonstrate standard exceedances (Tables 5 & 6). Only two sites did not exceed standards, Lewis River and White Salmon River. Since temperatures were recorded close to the mouths of many of the surveyed water bodies, it is not surprising that temperatures were exceeded in many instances. However, many of these streams face temperature challenges that can be addressed. A large number of the streams shown to exceed limits in Oregon are not 303(d) listed (Table 6).

In the Columbia Gorge study region, temperatures mostly met state standards. The Washougal temperature logger was lost early in the summer (data extends to 6/29/06). Since temperatures from last available data demonstrated exceedances and other gorge sites showed maximum temperatures in late July, it is likely that a large number of temperature exceedances would have occurred at this site. More data needs to be collected for the Washougal River in consideration for 303(d) listing.

In the Scappoose study area all tested water bodies experienced temperature standard exceedances. Exceedances varied from 29% of days tested (Multnomah Channel) to 50% (Milton Creek). None of the water bodies tested were 303(d) listed for temperature.

In the Columbia River Estuary study area, all tested water bodies experienced temperature standard exceedances. Results from Alder Creek and the John Day are further discussed below. The temperature standard for the Skipanon River was exceeded 62% of measured days. Ferris Creek demonstrated a low exceedance percentage (37%) relative to other Oregon streams in this study with similar standards. Further investigation of this stream's habitat potential may be warranted.

Table 4: Temperature statistics for all tested tributaries in Oregon and Washington. All data is in °C.

Stream	Start date	End date	Max temp	Max T change	7 Day Max	Avg Temp
White salmon	3/25/06	9/18/06	13.23 - 7/24/06	1.87 - 7/24/06	12.70 - 7/26/06	9.72
Wind river	2/21/06	9/18/06	18.94 - 7/24/06	3.99 - 7/23/06	18.16 - 7/24/06	10.84
Washougal River	2/21/06	6/29/06*	22.82 - 6/27/06	4.35 - 6/24/06	20.39 - 6/25/06	10.57
Lewis River	11/1/05	9/14/06	17.23 - 8/8/06	3.58 - 5/19/06	16.57 - 8/5/06	9.70
Lake River @ Felida	3/23/06	9/14/06	27.55 - 9/2/06	7.78 - 5/20/06	25.93 - 7/24/06	18.69
Lake River @ Ridgefield	3/15/06	9/14/06	25.58 - 7/24/06	5.48 - 6/5/06	24.81 - 7/24/06	17.12
Scappoose Creek	4/10/06	10/31/06	26.11 - 7/24/06	5.13 - 7/21/06	24.43 - 7/24/06	15.01
Scappoose Bay	11/1/05	10/31/06	26.61 - 7/24/06	5.94 - 5/16/06	25.61 - 7/24/06	13.27
Milton Creek	3/15/06	9/15/06	27.14 - 7/23/06	7.47 - 6/24/06	25.21 - 7/23/06	14.56
Multnomah Channel	11/1/05	10/20/06	24.12 - 8/6/06	2.04 - 12/24/05	23.80 - 7/26/06	13.37
Alder Creek (U/S of floodgate)	5/10/06	10/26/06	23.26 - 7/20/06	6.48 - 8/13/06	22.61 - 7/21/06	17.29
Alder Creek (D/S of floodgate)	5/7/06	10/26/06	23.75 - 7/20/06	6.84 - 8/13/06	22.6 - 7/23/06	16.99
Ferris Creek	4/6/06	12/8/06	24.03 - 7/22/06	8.55 - 7/16/06	23.18 - 7/23/06	12.84
John Day trib (U/S culvert)	4/6/06	12/8/06	26.89 - 7/23/06	8.65 - 6/24/06	25.36 - 7/23/06	15.41
John Day trib (D/S culvert)	4/6/06	12/8/06	26.82 - 7/23/06	8.52 - 6/24/06	25.19 - 7/23/06	15.30
Skipanon	4/6/06	10/26/06	22.77 - 7/21/06	3.5 - 5/20/06	22.36 - 7/22/06	16.59

*Washougal River datalogger lost to vandalism. 6/29 represents date of last audit.

Table 5: Table of temperature criteria for tributary temperatures in Washington. All streams are designated as Class A. Stream designation is from WAC 173-201A-600/602 and temperature criteria is from WAC 173-201A-200.

Stream	Designation	Temp Criteria	Standard Exceeded?	# exceeded of total days	303(d) listed?
White Salmon River	Core summer salmonid habitat	7 day max avg. not to exceed 16.0 °C	No	-----	No
Wind River	Core summer salmonid habitat	7 day max avg. not to exceed 16.0 °C	Yes	39 of 201 (19%)	No*
Washougal River	Core summer salmonid habitat	7 day max avg. not to exceed 16.0 °C	Yes	14 of 120 (12%)	No
Lewis River	Salmonid spawning, rearing and migration	7 day max avg. not to exceed 17.5 °C	No	-----	No
Lake River at Felida	Salmonid spawning, rearing and migration	7 day max avg. not to exceed 17.5 °C	Yes	121 of 167 (72%)	No
Lake River at Ridgefield	Salmonid spawning, rearing and migration	7 day max avg. not to exceed 17.5 °C	Yes	103 of 174 (59%)	Yes

*= Wind River at the site monitored was considered by WADOE to meet standards after testing (most recent data reported data from 2001).

Table 6: Table of temp criteria for tributary temperatures in Oregon. Temperature criteria are from OAR 340-041-0028

Stream	Temp criteria dates	Designation	Temp criteria	Designation from OAR 340-041 Figure:	Standard Exceeded?	7 Day Max Exceeded of Total	303(d) listed?
Scappoose Creek	1/1 to 5/15	Salmon and steelhead spawning	7 day max avg. not to exceed 13.0 C	340B	Yes	85 of 196 (43 %)	No
	5/16 to 12/31	Salmon and trout rearing and migration	7 day max avg. not to exceed 18.0 C	340A			
Scappoose Bay	Year-round	Salmon and trout rearing and migration	7 day max avg. not to exceed 18 C	340A	Yes	135 of 356 (38%)	No
Milton Creek	5/16 to 10/14	Salmon and trout rearing and migration	7 day max avg. not to exceed 18 C	340A	Yes	112 of 222 (50%)	No
	10/15 to 5/15	Salmon and steelhead spawning	7 day max avg. not to exceed 13.0 C	340B			
Multnomah Channel	Year-round	Salmon and trout rearing and migration	7 day max avg. not to exceed 18 C	340A	Yes	100 of 344 (29%)	No
Alder Creek (U/S of culvert)	5/16 to 10/14	Salmon and trout rearing and migration	7 day max avg. not to exceed 18 C	230A	Yes	124 of 166 (75%)	No
	10/15 to 5/15	Salmon and steelhead spawning	7 day max avg. not to exceed 13.0 C	230B			
Alder Creek (D/S of culvert)	5/16 to 10/14	Salmon and trout rearing and migration	7 day max avg. not to exceed 18 C	230A	Yes	119 of 166 (72%)	No
	10/15 to 5/15	Salmon and steelhead spawning	7 day max avg. not to exceed 13.0 C	230B			

Table 6 continued: Table of temp criteria for tributary temperatures in Oregon. Temperature criteria are from OAR 340-041-0028

Stream	Temp criteria dates	Designation	Temp criteria value	Designation from OAR 340-041 Figure:	Standard Exceeded?	7 Day Max Exceeded of Total	303(d) listed?
Ferris Creek	5/16 to 10/14	Salmon and trout rearing and migration	7 day max avg. not to exceed 18 C	230A	Yes	88 of 239 (37%)	No
	10/15 to 5/15	Salmon and steelhead spawning	7 day max avg. not to exceed 13.0 C	230B			
John Day (U/S of culvert)	5/16 to 10/14	Salmon and trout rearing and migration	7 day max avg. not to exceed 18 C	230A	Yes	167 of 239 (70%)	No
	10/15 to 5/15	Salmon and steelhead spawning	7 day max avg. not to exceed 13.0 C	230B			
John Day (D/S of culvert)	5/16 to 10/14	Salmon and trout rearing and migration	7 day max avg. not to exceed 18 C	230A	Yes	164 of 239 (69%)	No
	10/15 to 5/15	Salmon and steelhead spawning	7 day max avg. not to exceed 13.0 C	230B			
Skipanon	5/16 to 10/14	Salmon and trout rearing and migration	7 day max avg. not to exceed 18 C	230A	Yes	121 of 195 (62%)	Yes, delisted*
	10/15 to 5/15	Salmon and steelhead spawning	7 day max avg. not to exceed 13.0 C	230B			

* the Skipanon River was delisted from 303(d) status in 2002 due to its classification as “estuarine”.

Tide gate effects at Alder Creek

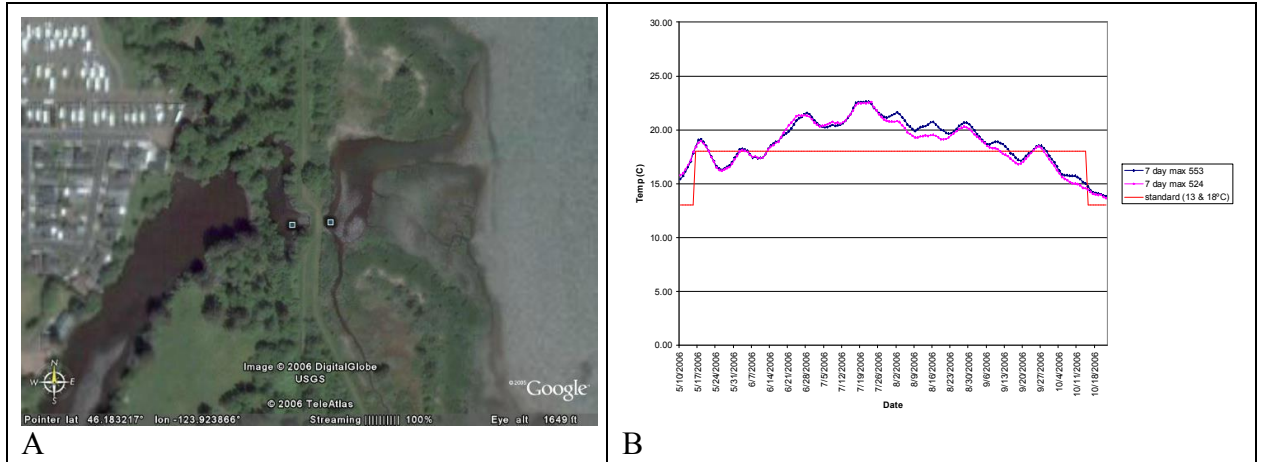


Figure 4: Layout of dataloggers at mouth of Alder Creek (A) and temperature charts for corresponding dataloggers (B). Point at left in A is upstream of the tidegate on Alder Creek (553 in B), point at right in A is downstream of the tidegate, connecting to the Columbia River (524 in B).

Dataloggers were placed on either side of the tidegate located at the mouth of Alder Creek. The average temperature was 0.30°C greater on the upstream side of the tidegate (Table 4). The upstream and downstream temperatures exceeded the state standard on 124 and 119 of 166 days, respectively.

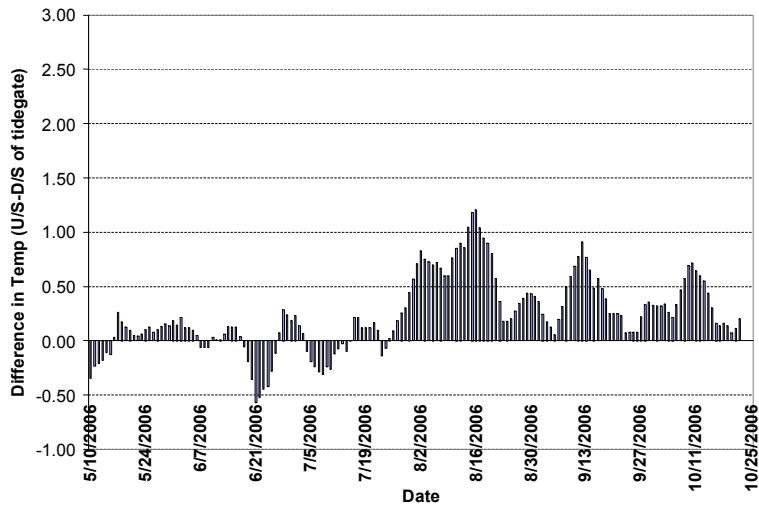


Figure 5: Difference in 7 day maximum average temperature between the datalogger upstream of the tide gate and the datalogger downstream of the tide gate at Alder Creek (U/S – D/S = difference). Negative values indicate that the downstream datalogger recorded higher temperatures.

While this data suggests that temperatures upstream of the tidegate are, on average, slightly higher than those downstream of the tidegate, there was not a statistically significant effect of the tidegate.

Although temperatures seem to correspond on either side of the tide gate during periods of high temperature (peaks on Figure 4B), there seems to be some latency in the rate of the upstream water's cooling as temperatures decline. It is possible that the exclusion of tidal flows prevents more rapid cooling. Further investigation is needed to support this hypothesis and completely understand tide gate impacts upon temperature.

Potential tide gate site at John Day

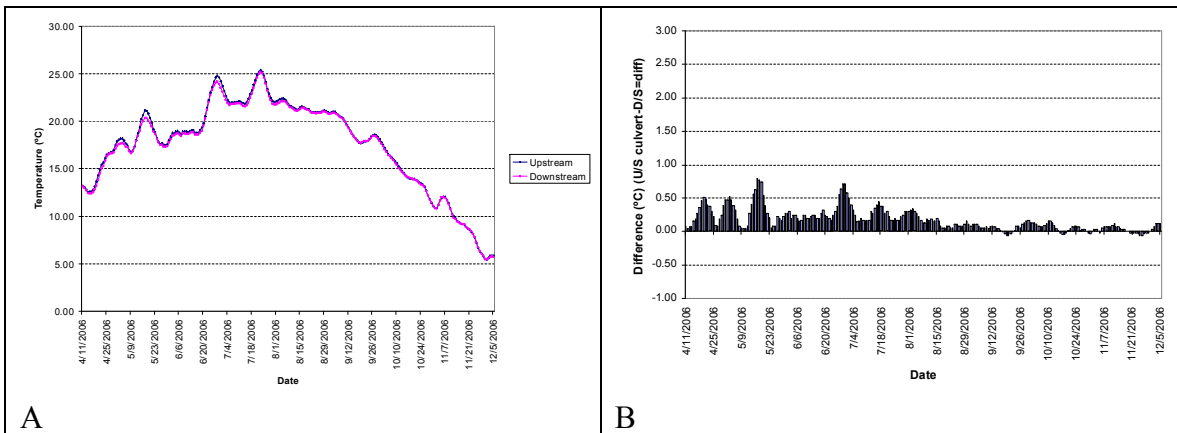


Figure 6: Comparison of seven day maximum averages (A) and display of difference in seven day maximum averages (upstream culvert-downstream culvert= difference, B) for dataloggers positioned on either side of a culvert connecting a wetland tributary to the John Day River.

This site was outfitted with temperature loggers similarly to the positioning at Alder Creek. At this site, a tide gate had been temporarily removed and was absent from the study site for the duration of temperature datalogger deployment. Currently in the place of the tide gate is a simple culvert. Water moves in both directions through the culvert according to tide although the constriction created by the culvert effects the rate at which water moves from one side to the other.

At several temperature spikes during the recording period, temperatures on the upstream side of the culvert rose higher than the downstream side. However, the temperatures rapidly reconvened and the upstream side showed little latency in cooling off when compared to the downstream side. On average, the daily temperature was 0.11°C greater upstream of the culvert compared to downstream (Table 4).

Although the respective presence and absence of tide gates at Alder Creek and the John Day tributary creates a tempting comparison between the two streams, the physical differences between the two create many confounding factors. A more appropriate comparison between tide gates and culverts effects on temperature would be a repetition of the above trial once the tide gate is reinstalled on the tributary to the John Day.

Lake River at Felida and Ridgefield

Lake River was historically a slough fed by the Columbia River. The inflow channel at the south end of Lake River was blocked for agriculture thus creating Vancouver Lake. This shallow lake receives water from Burnt Bridge Creek and several small, unnamed creeks. Lake River drains Vancouver Lake and flows past several

tributaries including Salmon Creek, Whipple Creek and Flume Creek before entering Bachelor Slough (approx 15.5 km from Vancouver Lake to Bachelor Slough).

Temperature loggers were placed at Felida Moorage and Ridgefield, the South and North ends of Lake River, respectively. Results showed a daily temperature discretion between the two sites at times over 4°C. Slow moving, shallow, exposed streams are generally expected to increase in temperature downstream. These results were contrary to this expectation (Figure 7).

Due to its tidal nature, the hydrology of Lake River is very complex. A likely explanation of these unexpected results is the tidal activity of the Columbia River. Vancouver Lake is wide and shallow, resulting in rapid heating and high temperatures. Cooler water flowing upstream during flooding tides from the Columbia probably created the lower temperature values at Ridgefield. The flow contribution from the shaded and assumed comparatively cool tributaries along Lake River may also have played a part in cooling Lake River as it approaches Ridgefield.

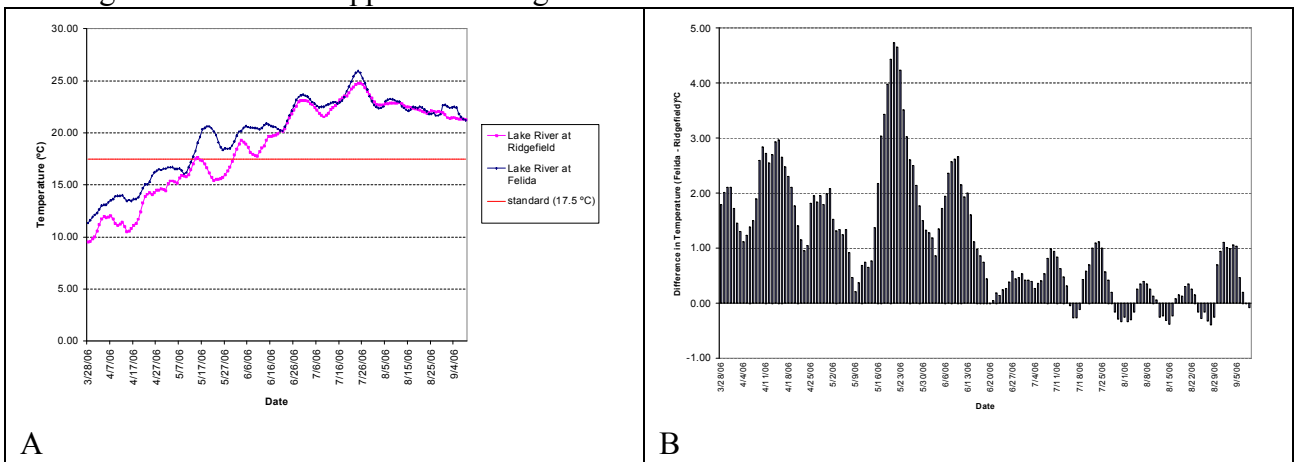


Figure 7: Seven day maximum average temperature at Felida and Ridgefield on Lake River (A) and difference between seven day maximum average temperatures (Felida-Ridgefield=difference, B).

Tributaries as coldwater refugia

In order to determine each monitored tributary’s potential to function as a coldwater refugia, temperature datalogger data was compared to data from USGS gages downstream of the Dalles Dam and near Quincy, OR (Figure 8).

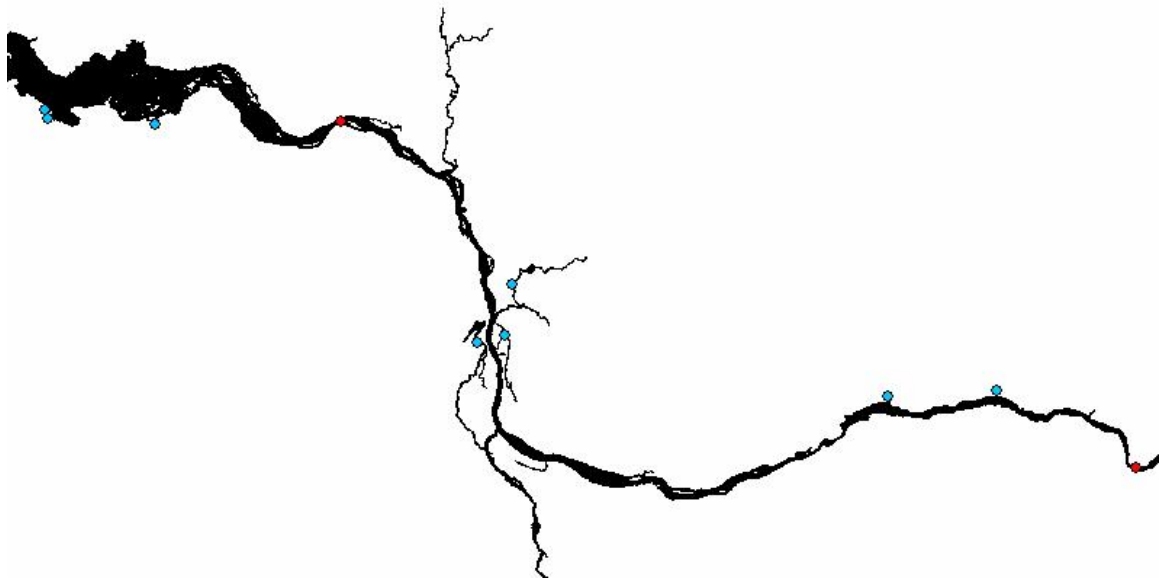


Figure 8: Map of monitored sites located close enough to the mainstem Columbia to have coldwater refugia potential. Blue points are temperature gages from this study. Red sites are USGS temperature gages on the mainstem Columbia.

Table 7: Percentage of days between 6/26/06 and 10/2/06 when tributary temperatures were lower than mainstem temperature reported by USGS gages at Quincy, OR and The Dalles, OR.

Site	% days 3°C cooler than mainstem	% days 1°C cooler than mainstem
Alder creek	0	41
Skipanon	0	41
Ferris Creek	18	59
Lewis River	100	100
Scappoose Bay	0	4
Lake River	0	0
Multnomah Channel	0	0
Wind River	89	96
White Salmon River	100	100

The White Salmon River and Lewis River were always more than 3 °C cooler than the mainstem Columbia. This is likely due to the dams upstream (White salmon = 5 km upstream and Lewis = 19 km upstream) of these monitoring sites. The Wind River was frequently cooler than the mainstem Columbia (Table 7). Ferris Creek was sometimes 3 °C cooler than the mainstem Columbia (18 %) and more than half the time over 1 °C cooler (59%).

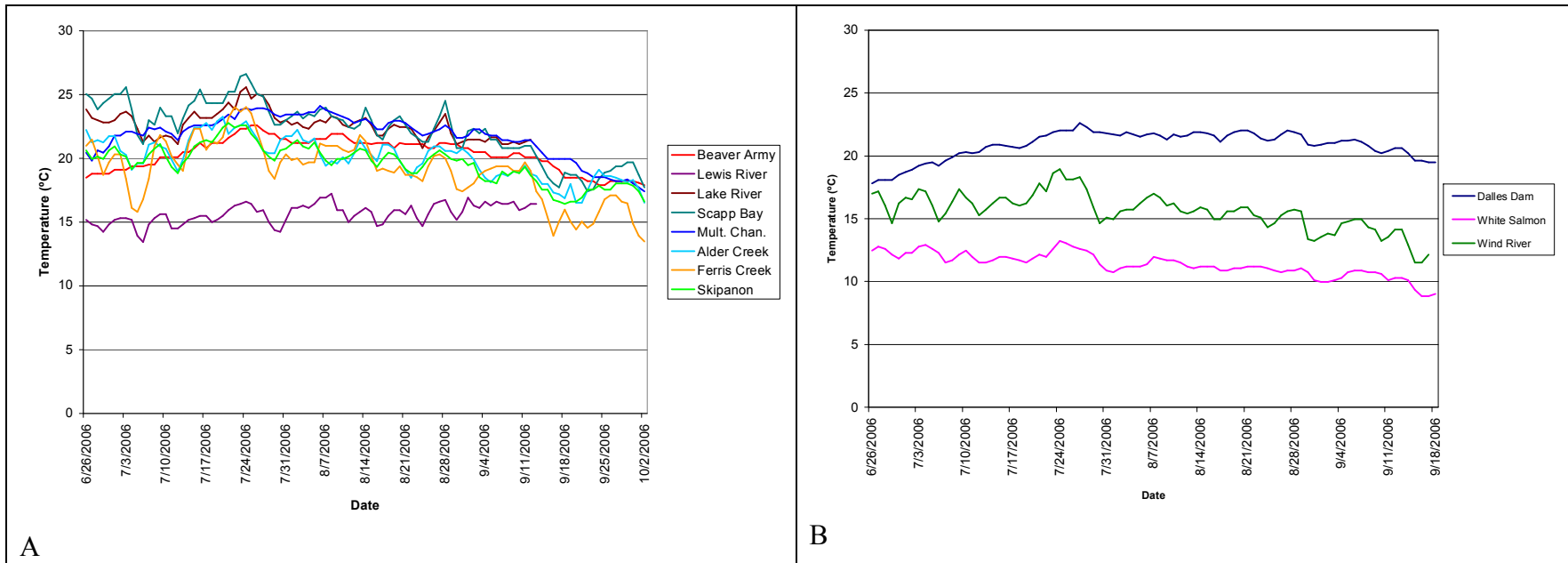


Figure 9: Thermographs for sites considered in the tributary as refugia analysis. Sites in A are compared to the USGS gage at Quincy (displayed as Beaver Army with a red line). Sites in B are compared to the USGS gage D/S from the Dalles Dam (blue line).

Metal Sampling

Data Quality

Most data quality objectives were accomplished for metal samples. The most significant instance of poor data quality occurred with ultra-low (EPA 1631E) Mercury samples from water. The eight samples taken in the Scappoose and Clark County areas must be regarded as unusable data due to high contamination values in the field blanks. This is likely due to a failure to fill bottles so that no air bubbles existed. Air bubbles were present in all 1631 samples and most likely the vector for contamination.

Zinc contamination was found in water samples for Clark County and the Scappoose area. The discrepancy between the field blank and all of the samples except two in the Scappoose area was not great enough to consider the contamination negligible. This data is considered unusable. Zinc contamination is incredibly difficult to control (Ed Wallace, CAS labs, pers. comm.). Samplers wore gloves and tyvek suits. The Zinc contamination could have been atmospheric or shed from the samplers' bodies.

Copper contamination was found for a water column sample taken at Ross Island. It is likely that the sampling device (a Van Dorn Beta bottle) was the source of contamination. Its use was discontinued after these results. The water column copper results for Ross Island were considered unusable.

No field duplicates were measured for water samples. Although a duplicate sample for metals in water at Lake River was delivered to CAS in an additional bottle, the laboratory failed to analyze the duplicate sample. WRK did not notice this omission until after the data report was returned.

All sediment data was considered usable.

Table 8: Metal concentrations in water samples. Metal concentrations are in µg/L. ND= not detected, below MRL. C!= contamination, data rejected. Hardness was only tested for Clark County sites. CCC and CMC (there is no CCC for Silver) values correspond to state standard and Hardness for each site.

Site	As		Cd		Cu		Ag		Zn		Hardness (mg/L)
	Obs.	CCC	Obs.	CCC	Obs.	CCC	Obs.	CMC	Obs.	CCC	
Willamette River @ Ross Island	ND	190	ND	NA	C!	NA	ND	NA	10.3	NA	NA
Scappoose Bay @ Channel Marker #9	1.3	190	ND	NA	1.6	NA	ND	NA	6.4	NA	NA
Scappoose Bay @ Armstrong Industries	2.1	190	ND	NA	1.6	NA	ND	NA	6.5	NA	NA
Scappoose Bay @ mouth of Milton Ck	0.7	190	ND	NA	1.2	NA	ND	NA	C!	NA	NA
Scappoose Creek @ West Lane Rd	ND	190	ND	NA	0.4	NA	ND	NA	C!	NA	NA
Gee Creek @ Abrams Park	1.4	190	ND	0.81	1.3	8.57	ND	1.96	C!	79.12	72
Lake River 1 mi. D/S of Felida Moorage	2.2	190	0.03	0.78	2.1	8.16	ND	1.78	C!	75.38	68
Whipple Creek @ 91st Ave	2.2	190	ND	1.06	0.7	11.74	ND	3.69	C!	108.04	104
Salmon Creek U/S of Seward Highway	0.8	190	ND	0.81	0.9	8.57	ND	1.96	C!	79.12	72

Comparison to Standards

No water column metal concentrations exceeded Oregon or Washington standards. Hardness data for Clark County allowed calculation of Criteria Maximum Concentration (CMC) and Criteria Chronic Concentration (CCC) calculation for hardness dependent metals including Cd, Cu, Ag and Zn. At CMC levels, acute toxic effects may occur. At CCC levels, long-term chronic health impacts may occur.

Since metals in sediment primarily adhere to fine particles and silt, larger grains are considered to have a diluting effect. Therefore, metal concentrations are normalized to reflect the amount of contaminant that would be present in the sediment if it was completely fine grain material (a more accurate portrayal of how much of a particular pollutant is moving through the site).

The finest sieve used in the grain size analysis for this study had a 70 µm screen. Particles greater than 70 µm were assumed to have a diluting effect on the metal concentration. The more conventional formula (Horowitz 1985) uses a threshold of 20 µm. Therefore, grain size normalized values presented in this study are conservative. A similar formula exists for total organic carbon but it was omitted from these results since the concentrations of TOC were tested were very low and had little effect on the results.

It is important to recognize that not all sediment samples have been normalized based on grain size. Grain size data was collected only for Clark County sites. This was due to an unfortunate oversight on the part of the investigators. It is important to recognize that normalizations based on grain size can amplify but not decrease laboratory reported values. Therefore, reported exceedances of recommended sediment quality values are valid and possibly quite higher. Qualitative assessments of grain size are reported in Table 9 in order to give some idea of how normalization would effect results. Small size grains and silts would amplify concentrations less than larger grains and sand. Unfortunately, a lack of quantitative grain size data limits comparability between sites and against historical data.

Although specified sediment standards do not exist for Oregon or Washington, NOAA and WADOE recommended guidelines were used for comparison. Two sites in Scappoose Bay exceeded recommended guidelines for Arsenic in sediment (NOAA ERL = 8.2 ppm, WADOE SQS = 20 ppm). A sample from nearby Armstrong Industries demonstrated the highest Arsenic levels reported in this study. This is likely due to this facility's history (see site selection). WADOE's recommended guideline for Cadmium (0.6 ppm) was exceeded at Prairie Channel. NOAA's ERL for Copper (34 ppm) was exceeded at Gray's Bay.

Table 9: Non-normalized metal concentrations in sediments. Bolded values represent recommended guideline exceedances (NOAA ERL and WADOE SQS). Duplicate samples are in parentheses.

Site	Date	As	Cd	Cu	Hg	Ag	Zn	Qualitative Sediment Grain Size
Willamette River @ Ross Island	6/9/06	2.7	0.08	20.1	0.04	0.1	59.1	Coarse sand
Scappoose Bay @ Channel Marker #9	7/7/06	11.5	0.54	24.2	0.14	0.18	95.9	Silt, organic
Scappoose Bay @ Armstrong Industries	7/7/06	26.7 (29.8)	0.26 (0.27)	16.5 (17.7)	0.12 (0.11)	0.11 (0.15)	83 (84.5)	Silt, organic
Scappoose Bay @ mouth of Milton Ck	7/7/06	3.9	0.27	18.5	0.05	0.11	91	Silt, organic
Scappoose Creek @ West Lane Rd	7/7/06	2.5	0.12	11	ND	0.09	66.4	Silt to sand
Gee Creek @ Abrams Park	7/20/06	2.7	0.11	9.7	ND	0.08	40.1	Silt to sand*
Lake River 1 mi. D/S of Felida Moorage	7/20/06	6.3	0.12	6.8	0.02	0.05	32.8	Sand*
Whipple Creek @ 91 st Ave	7/20/06	2.2	0.08	6.4	0.02	0.05	34.2	Silt to sand*
Salmon Creek U/S of Seward Highway	7/20/06	2.6	0.12	14.6	0.02	0.07	56.4	Coarse Sand*
Cathlamet Bay	8/3/06	3.9	0.2	14.8	0.04	0.04	64.7	Sand
Cathlamet Bay, South Channel	8/3/06	5.0 (4.8)	0.31 (0.32)	13 (13.1)	0.03 (0.03)	0.08 (0.07)	77.1 (78.1)	Silt, organic
Svenson Island	8/3/06	4.8	0.28	10.4	0.02	0.06	65	Coarse sand
Knappa Slough	8/3/06	2.4	0.1	4.9	ND	0.02	32.2	Coarse sand
Prairie Channel @ Bug Hole	8/3/06	4.8	0.62	29.8	0.1	0.15	104	Silt, organic
Green Island	8/3/06	2.3	0.18	8	ND	0.04	44.7	Sand
Youngs Bay	8/3/06	5.9	0.28	14	0.04	0.04	72.8	Silt to sand
Grays Bay	8/3/06	4.6	0.31	41.3	0.03	0.03	105	Sand

*= grain size also quantified using ASTM D4129-98M.

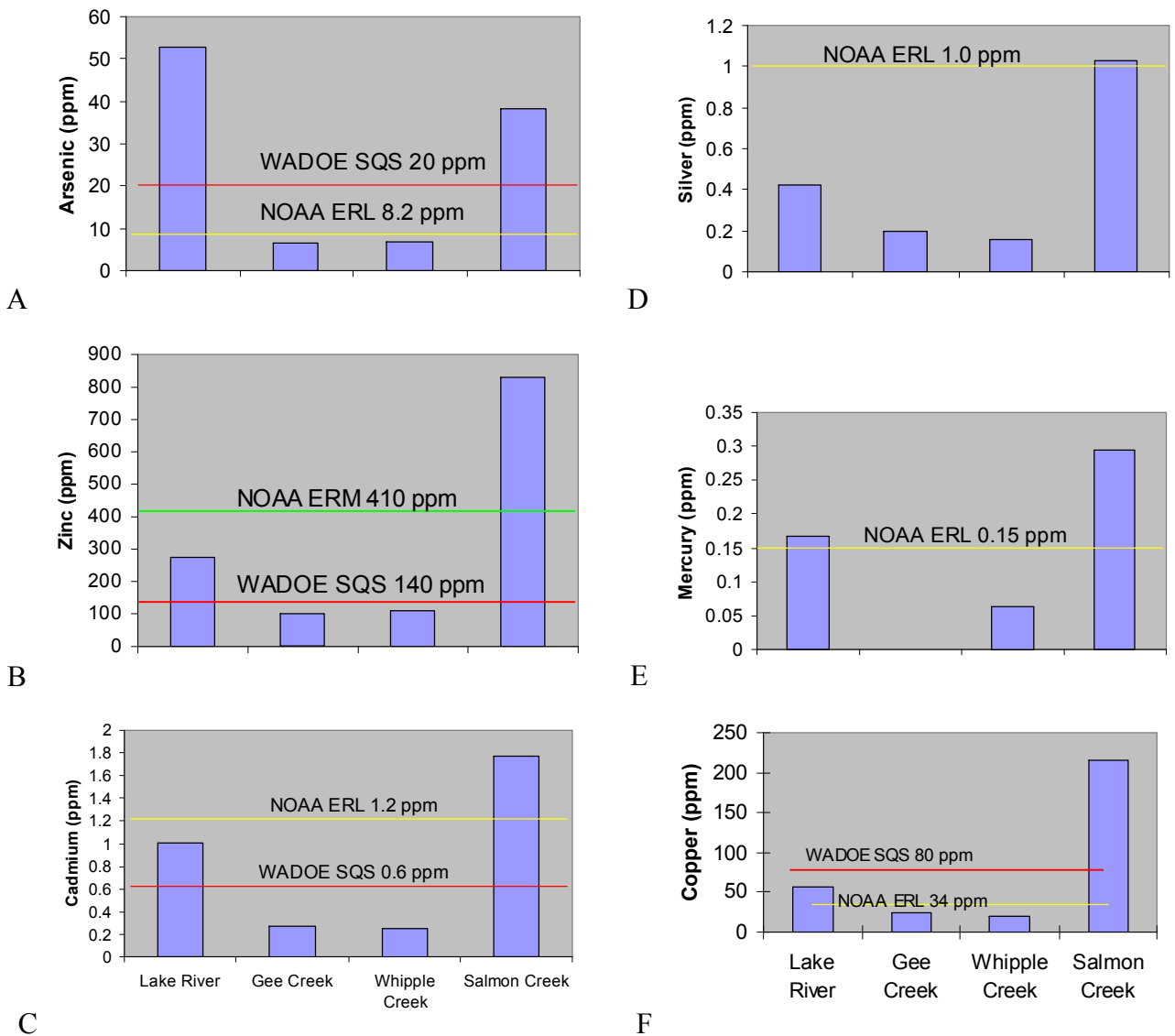


Figure 10: Grain size normalized metal concentrations in sediment at Clark County sites in comparison to NOAA ERL and ERM and WADOE SQS recommended guidelines.

Table 10: Grain size normalized values for sediment metal concentrations from sites in Clark County, WA. All values are expressed in mg/Kg dry weight (ppm).

Site	As	Cd	Cu	Hg	Ag	Zn
Lake River	52.9	1.0	57.1	0.2	0.4	275.4
Gee Creek	6.6	0.3	23.8	ND	0.2	98.5
Whipple Creek	7.0	0.3	20.3	0.1	0.2	108.5
Salmon Creek	38.3	1.8	215.0	0.3	1.0	830.6

Coldwater refugia

An attempt to develop a methodology for locating coldwater refugia using a multi-parameter probe was inconclusive. A well known coldwater refuge and documented chum salmon spawning area, Wood's Landing (RM 113.5), was used as a site for method development. A nearby shoreline on government island where no source of cool groundwater was expected was used for comparison. Results for temperature and conductivity demonstrated a clear deviation from the mean at the coldwater source (Figure 11).

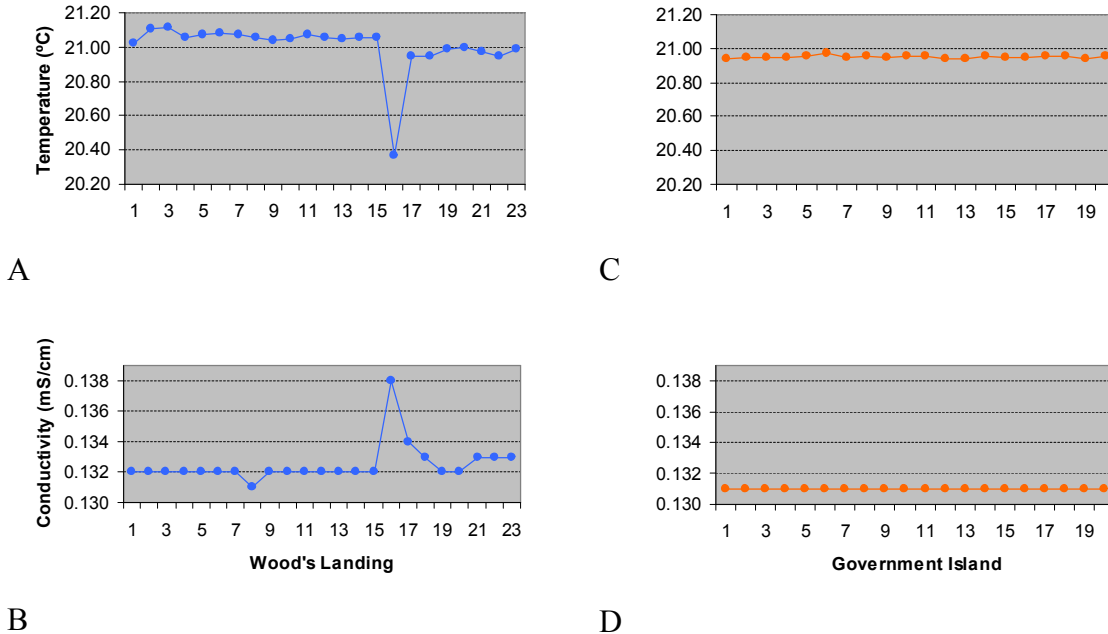


Figure 11: Comparison of temperature and conductivity between Wood's Landing (known coldwater refuge) and Government Island.

The method was used at two sites near Rooster Rock (RM 129). One site was on the Oregon side from Rooster Rock to 3 km downstream (Figure 12). The other site was on the Washington side at Mt. Pleasant (RM 130) and reached 3.3 km (Figure 14). Sites were selected based upon intact shoreline and the potential of upland topography for subterranean flow and intact shoreline.

Temperature varied little on the Oregon side (.42°C) and more on the Washington side (1.41°C). Using a Digital Elevation Map of the upland topography, predicted stream lines for the Washington side were generated using ArcHydro. Temperature data was then compared to the positioning of these predicted flowlines (Figure 14). A small but inconclusive amount of correspondence is evident between flow lines and cooler water in the East side of Figure 14. Visible surface flow was noted at this location. Due to the conductivity measurements lower than the mainstem Columbia (Table 11), it is likely that this coldwater pocket is from surface flow and not groundwater (groundwater generally displays elevated conductivity).

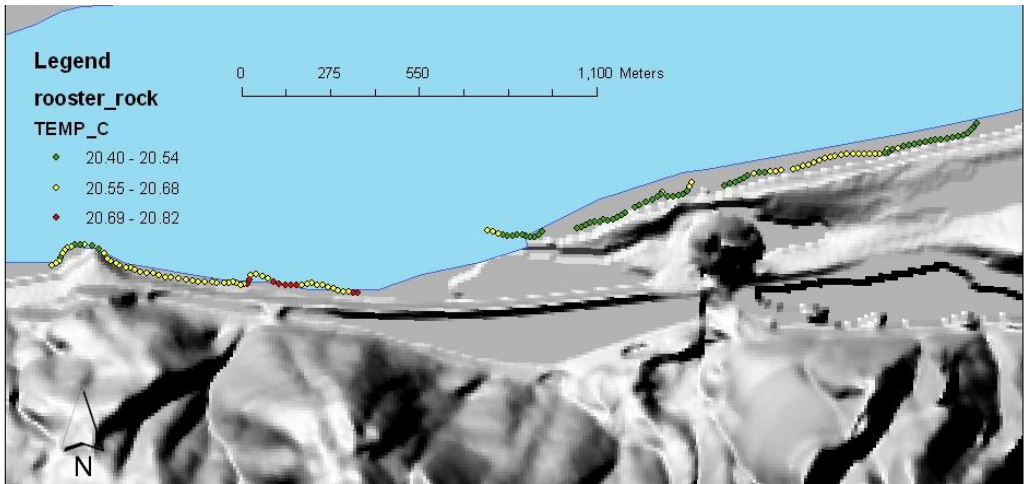


Figure 12: Temperature data from coldwater search at Rooster Rock.

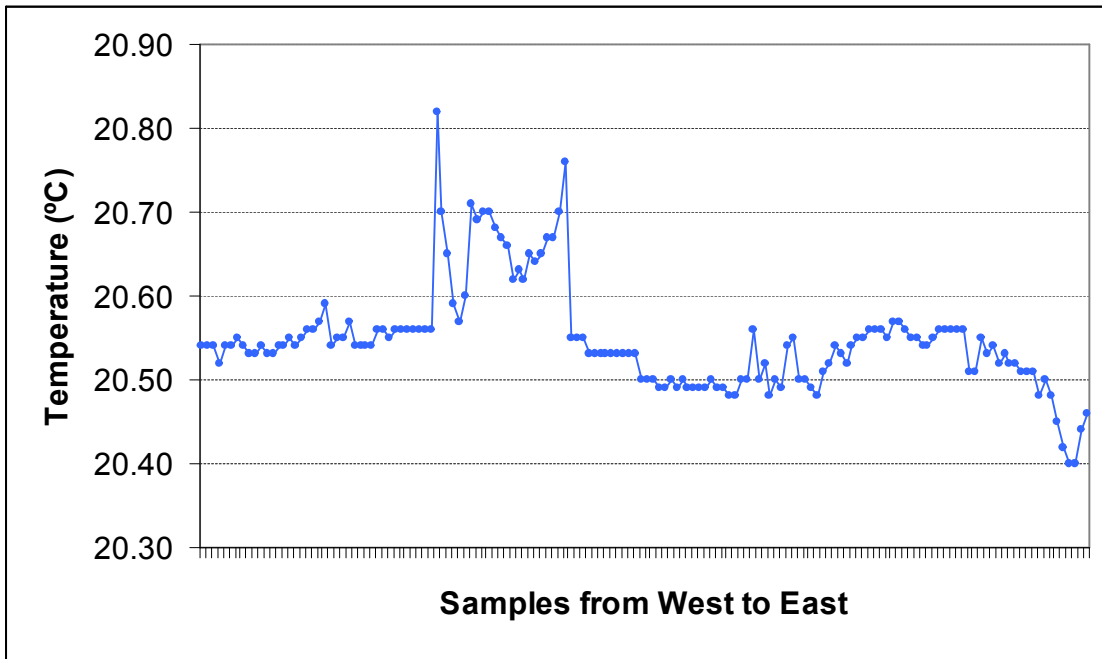


Figure 13: Temperature chart corresponding to points in Figure 12. For reference, peaks left of center in graph correspond to red points in Figure 12.

Table 11: Temperature and conductivity at coldwater sources and average temperature and conductivity at corresponding transects.

Site	Transect temp average °C	Coldwater source temp °C	Transect cdt. average mS/cm	Coldwater source cdt mS/cm
Wood's Landing	21.01	12.33	.130	.228
Mt. Pleasant	21.21	16.84	.133	.072

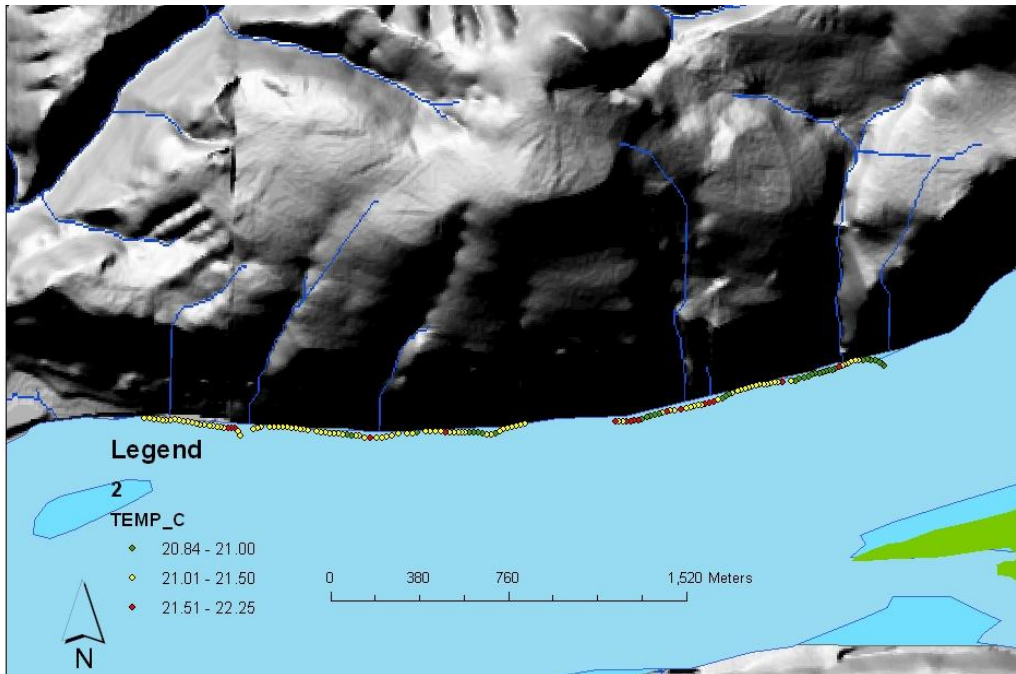


Figure 14: Temperature data from coldwater search at Mt. Pleasant (north of Rooster Rock). Flow lines are blue. Cooler pockets of water are represented by green points.

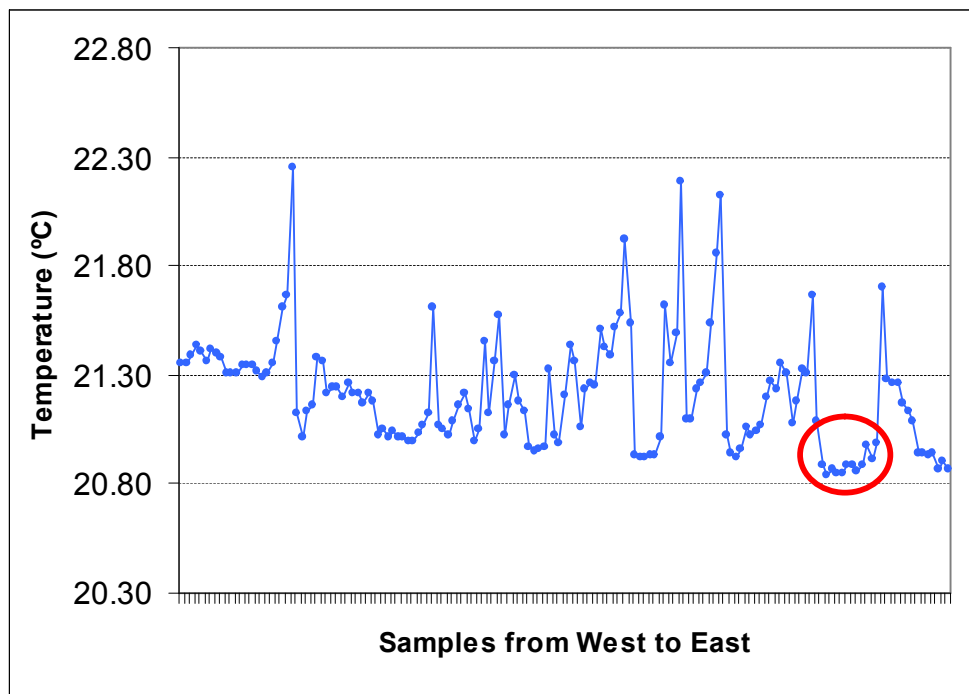


Figure 15: Temperature chart corresponding to points in Figure 12. Circled series of low points in this figure correspond to concentration of green points in Figure 12 near the end of an ArcHydro generated flow-line.

Conclusion

Tributary Temperatures

Tributary temperatures for tested Oregon streams exceeded state standards frequently. Although many tested sites may not represent optimal spawning salmonid habitat due to their proximity to each stream's mouth, they do represent important habitat for rearing and migration. The standard for rearing and migration was frequently exceeded. The majority of the tested waters are not 303(d) listed for temperature.

The Lewis River and White Salmon River in Washington were within temperature criteria during the time monitored. Of interest is temperature data collected for the Washougal River. Few temperature exceedances are evident in the data collected for this project due to the fact that the temperature logger was vandalized and lost in mid-June. Prior to 6/29/06, 10 temperature exceedances had already occurred at this site. Since most temperature loggers experienced highest temperatures in late July, it is likely that temperatures exceeded state standards for extended periods during the summer. Due to the Washougal River's importance as a home for coho, steelhead and chinook salmon, additional temperature monitoring along this river is recommended. The Washougal is not 303(d) listed for temperature.

Temperature data collected at the Alder Creek tide gates suggests that tide gates may restrict tidally flooding water's ability to cool Alder Creek after periods of high temperature. For organisms upstream of the tide gates, this may hinder water quality. Further investigation at multiple sites is necessary to draw conclusions about the impacts of tide gates on upstream temperature. Giannico and Souder (2004) state that tide gates create elevated temperatures due to stagnation and hypothesize that side-hinged tide gates may allow better temperature mixing than top-hinged tide gates.

Temperature data for a tributary temporarily connected to the John Day River by culvert was collected on both sides of the culvert. In the event that the tide gate that once resided in this location is replaced, it would be worthwhile to replicate the temperature logger sites reported in this study. The unique opportunity to make a comparison between culvert and tide gate at one site may further elucidate the role of tide gates in stream temperature.

The analysis of tributary potential for coldwater refugia functions upon a number of assumptions. First, we assume that USGS gage maximum temperatures are an acceptable approximation of river temperature local to each monitored tributary. The large size of the Columbia River makes water temperature slow to change. Unless large sources of coldwater are present, the temperature is unlikely to decrease as we move away from USGS gages. In the slow-moving, side channel environments where some of the measured tributaries (including Ferris Creek, Scappoose Bay and Lake River) meet the mainstem Columbia temperatures may be higher than reported by the gages used for this comparison. Therefore, predictions of potential coldwater refugia from Table 7 may be conservative estimates. The second assumption is that stream temperature does not change much between the monitoring site and the stream's mouth. In large volume streams this is generally a safe assumption to make unless another fair size tributary enters downstream of the monitoring site (as in the case of the Lewis River). Finally, we assume that tidal activity does not confound mainstem temperatures. Indeed, tides may complicate the function of coldwater at all sites below the Bonneville Dam, especially

those closer to the mouth of the Columbia. These assumptions aside, it is likely that the Lewis, Wind and White Salmon Rivers function as coldwater refugia at their confluence with the mainstem Columbia due to their consistently low temperatures.

Due to relatively low temperatures observed at Ferris Creek, this stream should be investigated for restoration potential. A number of similar creeks exist nearby Ferris Creek (such as Bear, Big and Gnat Creeks) and may provide important coldwater habitat for migrating salmonids.

Metal sampling

A total of twenty-eight metal samples were taken and reported for this study. Nine samples were from water. Water concentrations were relatively low and many constituents were below method detection limits. For those samples where Hardness data was available, sample concentrations were well below state standards.

Seventeen samples (including duplicates) were collected from sediments. Concentration normalization was only performed for four sites where sediment grain size data existed. These sites were in the Lake River Watershed of Clark County, WA. After normalization a clear pattern exists in the data (Figure 8). Whipple Creek and Gee Creek show much lower levels of all metals than Lake River and Salmon Creek. Normalized metal concentrations for Salmon Creek and Lake River exceeded (sometimes greatly) sediment quality guidelines from Washington and NOAA Fisheries. This is likely due to urban effects from Vancouver and the I-5 corridor upstream on Salmon Creek. While the elevated metal levels in Lake River may come from Burnt Bridge Creek (an urban tributary to Vancouver Lake) and Salmon Creek, the complex hydrology of this waterway and the Columbia River may also be involved. Another possible metal source is Felida Moorage, a boat house community 1.5 km upstream from the sampling site.

Due to a lack of sediment grain size and total organic carbon data for the remaining thirteen sediment samples, data can not be soundly compared to previous data from 1991 and 1993 Bi-state reports. However, due to the amplifying effect of grain size and TOC normalization, it can be concluded that sediment metal concentrations are at least conservative estimates of current conditions. Under this context, sites that demonstrate exceedances of recommended sediment quality guidelines may actually exceed this guidance by a much greater degree. Two sites in Scappoose Bay demonstrated elevated Arsenic levels. These sites also displayed elevated levels of other sampled metals. A site located adjacent to Armstrong Industries demonstrated elevated levels of Arsenic, likely due to historical fiberboard manufacturing and irresponsible waste disposal. Further sampling is recommended for this area. Additional recommended guideline exceedances were found at Prairie Channel for Cadmium (0.62 ppm, WADOE SQS= 0.6 ppm) and Gray's Bay (41.3 ppm, NOAA ERL= 34 ppm).

Lacking quantitative data for grain size normalization, field recorded qualitative data was used to characterize each sediment sample. Four classifications including silt (1), silt to sand (2), sand (3) and coarse sand (4) compose a rough scale for sediment grain size. Comparing this qualitative data to non-normalized results demonstrates each metal's positive association with finer grains (Figure 16). As grain size increases, metal concentration decreases. Due to a small sample size and the use of an ordinal variable (qualitative sediment rank), R^2 values are not very high. However, a similar trend for all metals is visible. Recommended guideline exceedances mentioned in the paragraph

above are displayed as outliers (Figure 16 b,d,e). Furthermore, by comparing Figure 16 to Table 9, potential problem sites can be visualized. For instance, in Figure 16 f, a high outlier is seen with a grain size rank of 3 (sand). This point represents Gray's Bay where a Zinc concentration of 105 ppm was recorded. Given that the sediment grain was mostly sand, it is likely that grain size normalization would place the Zinc concentration at Gray's Bay well over the recommended guidelines (WADOE SQS= 140 ppm). Since grain size classification is qualitative the data should be conservatively used to make predictions about conditions in a given area. This information could be used to guide further sampling efforts that can make more concrete conclusions about metal concentrations in these sites.

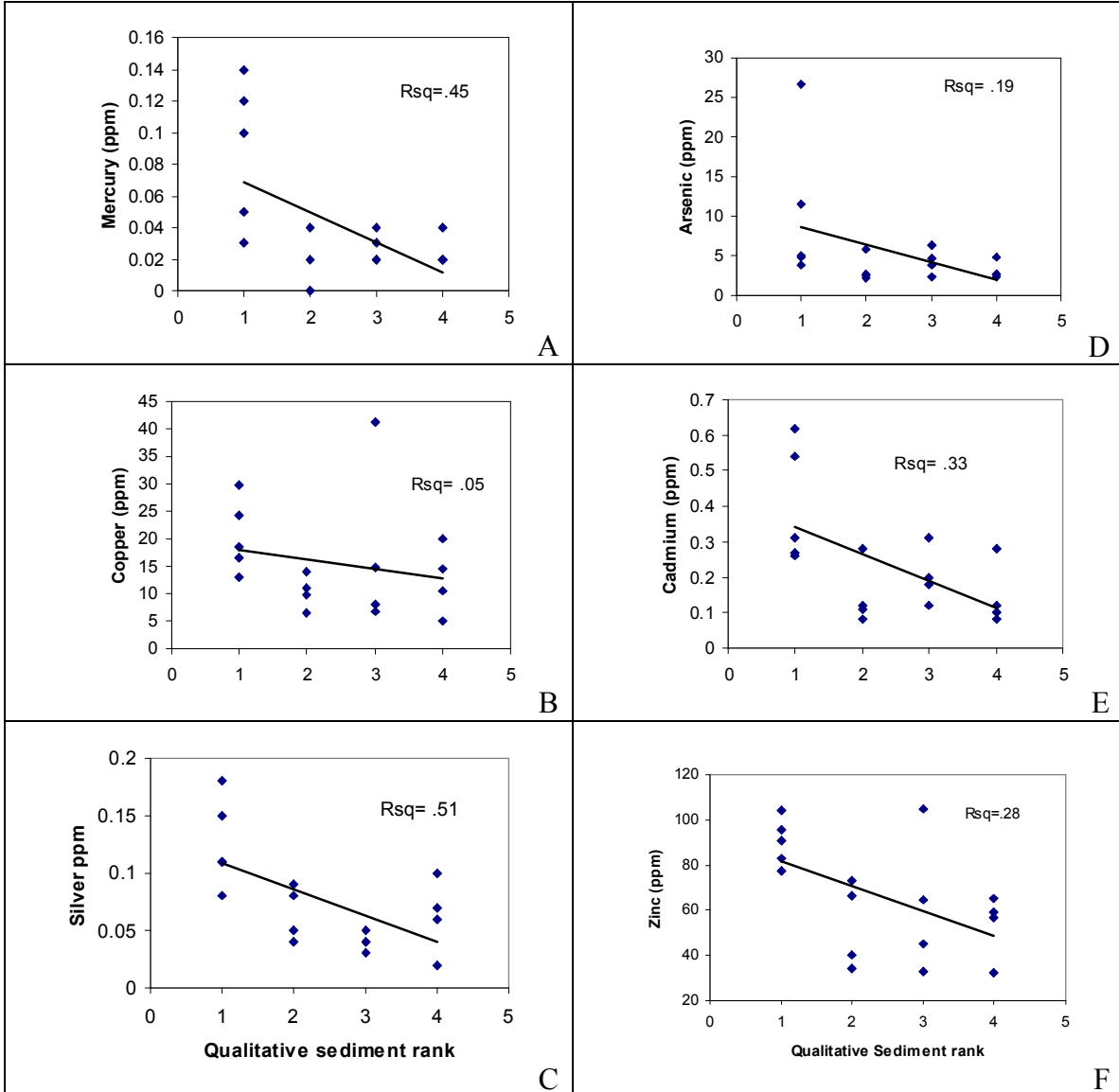


Figure 16: Comparison of qualitative sediment rank (1=silt and organics, 2= silt to sand, 3= sand, 4= coarse sand) and non-normalized sediment metal concentrations.

Coldwater refugia survey

While the methodology employed to search for coldwater refugia did detect a known coldwater refugia site (Wood's Landing) it is not recommended for locating coldwater refugia. This stems from several factors including complexity of the Columbia due to its size, many sources of potential interference and an incomplete understanding of what conditions may provide coldwater refugia.

Since the Columbia is so large, contributions from groundwater sources are instantly diluted and difficult to detect. Wood's Landing for instance, is an important site for Chum Salmon spawning due to its groundwater input. However, at a distance of over several meters, the impact of this groundwater input is negligible. Ideal conditions may persist at a greater depth but it is impractical to survey large stretches of shoreline while trying to maintain a monitoring instrument just above the substrate.

Potential interferences that may provide misleading results using the above methodology include plants, thermal sinks, surface warming, pollution and complex hydrology. Daily surface temperature changes might prevent comparison between transects over the course of a day as warming occurs. Incomplete warming might create cooler pockets that could be mistaken for a coldwater source. For this reason research is best completed on overcast days, a rarity in PNW summers. Thermal absorbers such as rock outcroppings and bridges might artificially elevate water temperatures making unheated areas appear as coldwater refugia. Plant photosynthesis effects dissolved oxygen and pH, requiring investigators using this method to document plant presence in order to ameliorate confounding effects. Below surface outfalls could create confusing temperature, conductivity, pH and dissolved oxygen variation. The complicated hydrology of a large river such as the Columbia might result in eddies and upwellings capable of causing misleading temperature shifts.

Although a coldwater source may be discovered it may not be suitable for fish utilization. Ground water dissolved oxygen can be lower than mainstem and inadequate for fish respiration. Substrate conditions may be less than desirable for chum spawning. The area may not provide sufficient refuge from predators. Although temperature is an important factor, it may not be the sole determinant of useful coldwater refugia.

Alternatives to this methodology include utilizing GIS, FLIR and telemetry. GIS can be used to predict subterranean flow and potential groundwater sites. Geology, elevation, bathymetry and groundwater hydrology may all be analyzed by GIS. Once likely areas for cold refugia have been identified, utilizing the above methodology may prove useful. FLIR (forward looking infrared) technology, a helicopter based imaging system, can be used to map temperature differences in a river. However, a daily high expense prohibits much repetition on a temporal scale. Utilizing telemetry would be the ideal method for determining sites of coldwater refugia. Tagged fish can reveal the positioning of important coldwater sites and will disregard misleading areas with coldwater but other inadequate characteristics.

A combination of these approaches (GIS, telemetry and FLIR) was used by Torgerson et al. (1995) in the John Day basin. FLIR imagery visualized with GIS was compared to data from snorkel surveys and telemetry. In high temperature stream reaches, researchers found that spring Chinook resided primarily in coldwater habitat. If the goal is to locate coldwater refugia for protection, a combination of the methods above would be the best approach.

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Appendix A: Tributary Temperature charts Washington

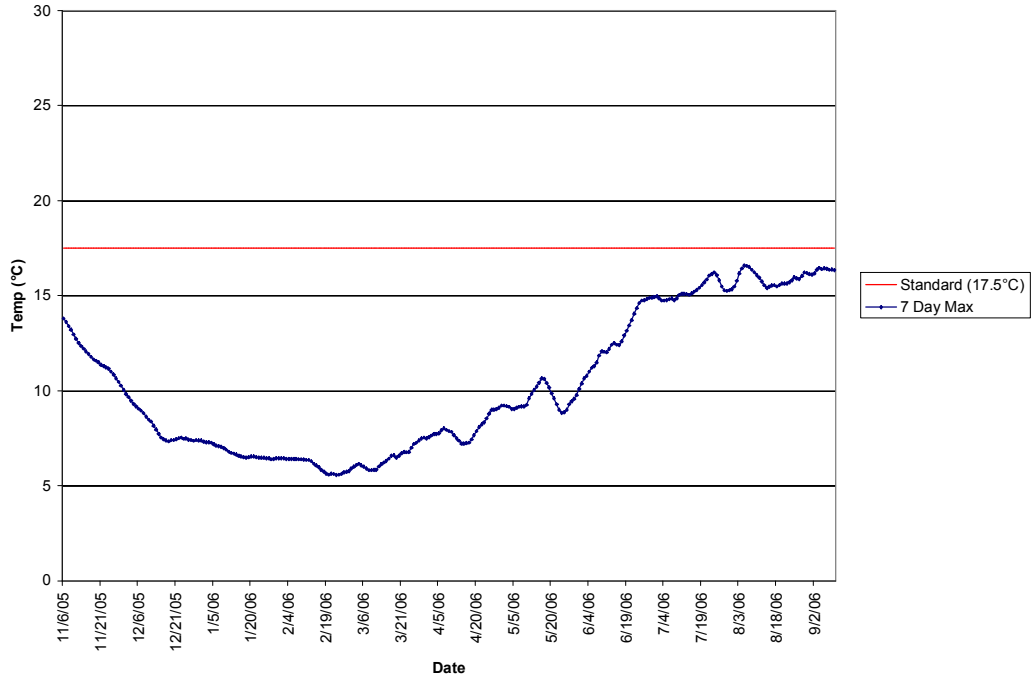


Figure 17: Seven day maximum average temperature on the Lewis River at Hayes Rd Bridge from 11/3/05 to 9/13/06.

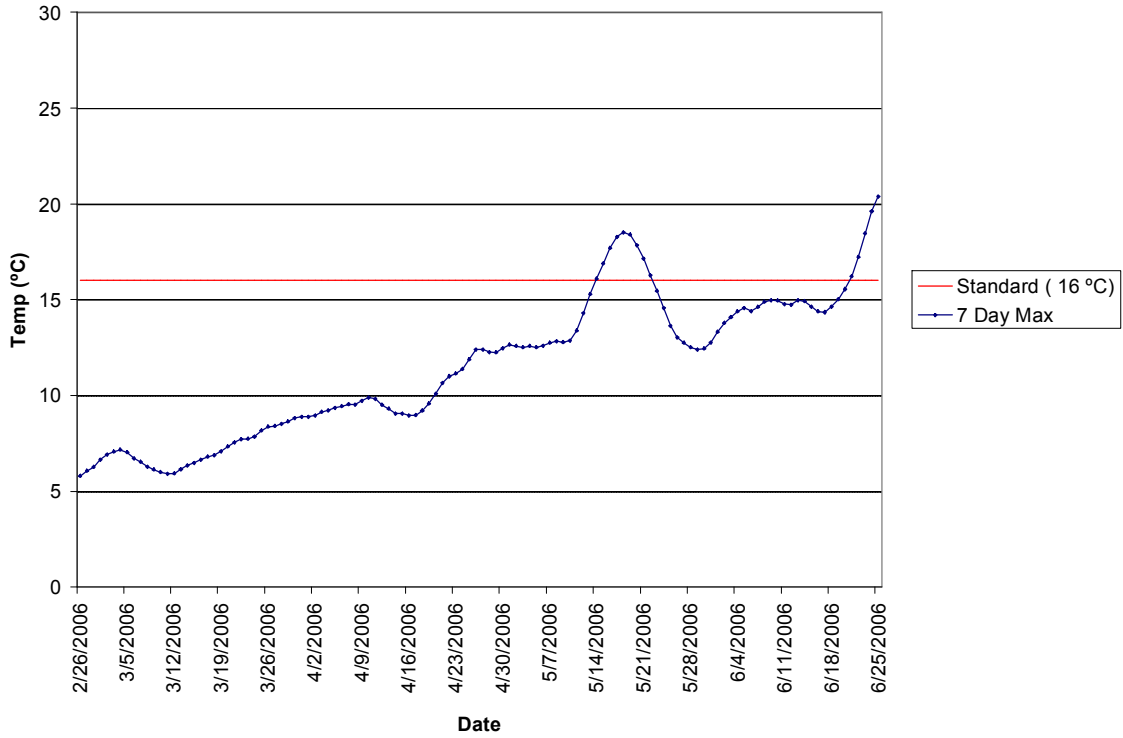


Figure 18: Seven day maximum average temperature on the Washougal River at Hathaway Park from 2/26/06 to 6/29/06.

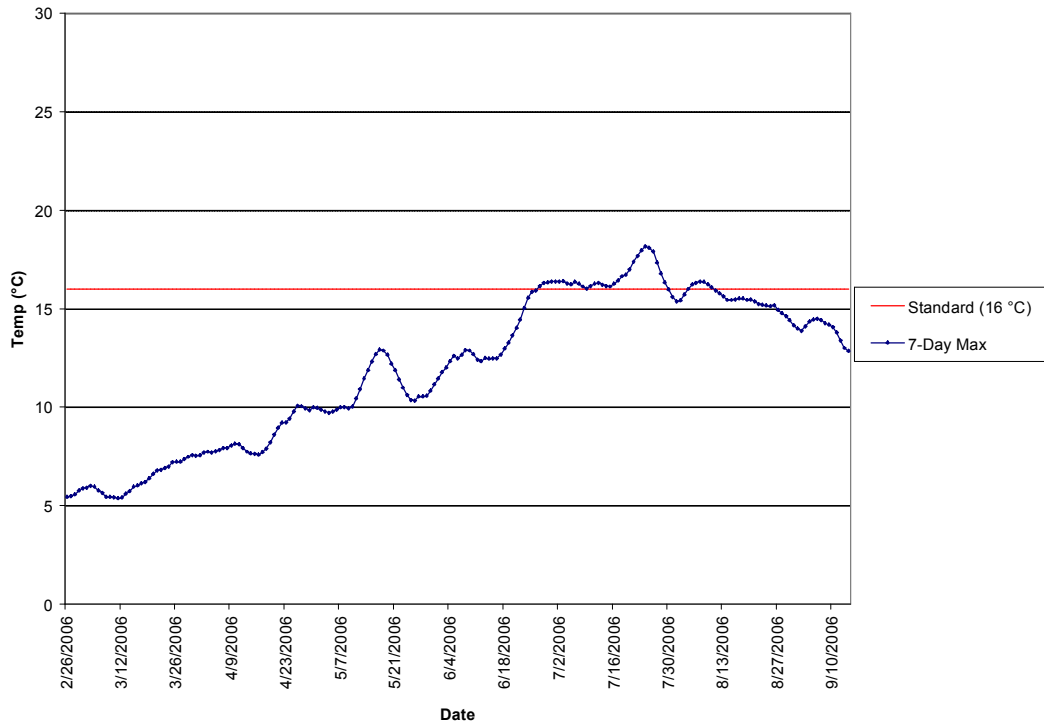


Figure 19: Seven day maximum average temperature of the Wind River at Indian Cabin Rd from 2/23/06 to 9/17/06.

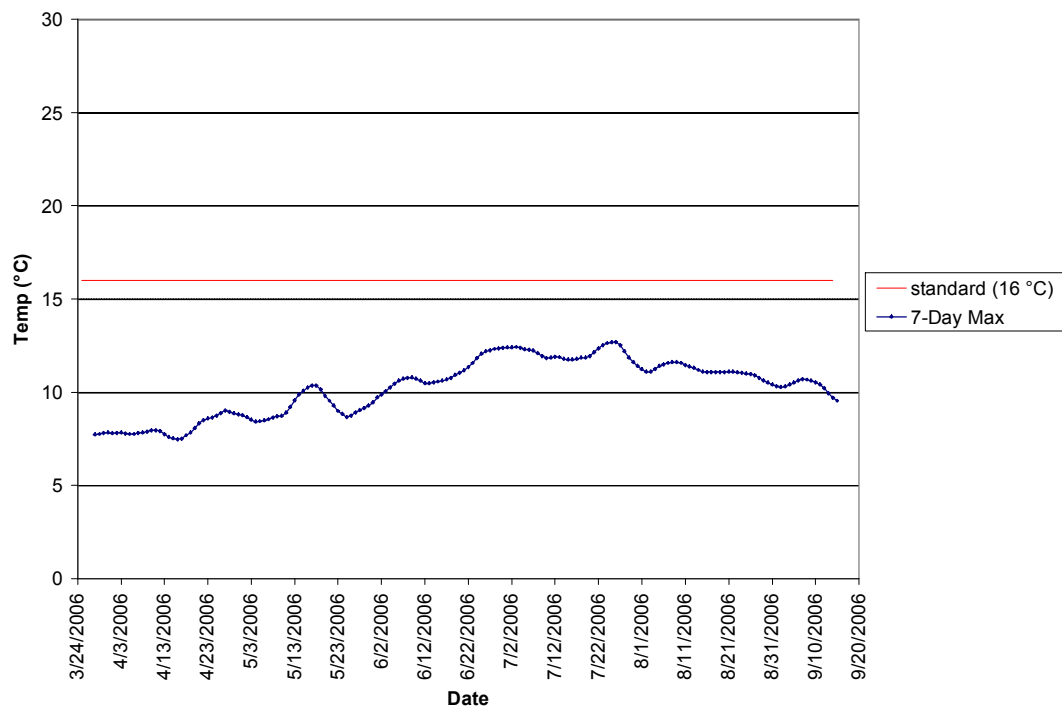


Figure 20: Seven day maximum average temperature of the White Salmon River near mouth from 3/25/06 to 9/17/06.

Oregon

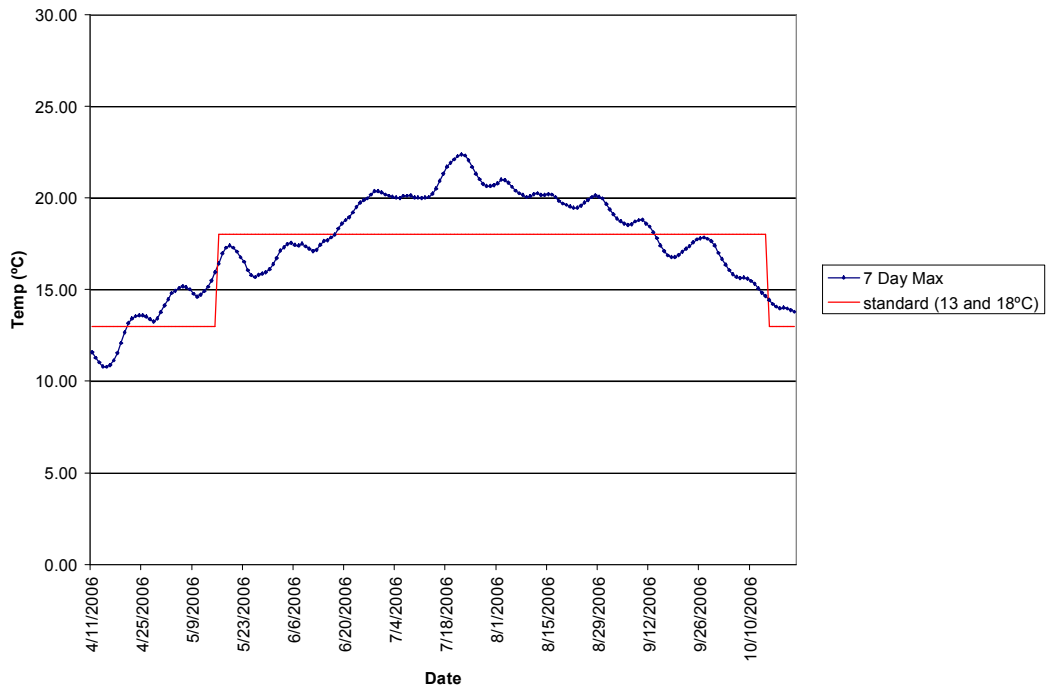


Figure 21: Seven day maximum average temperature of the Skipanon River near mouth from 4/6/06 to 10/26/06.

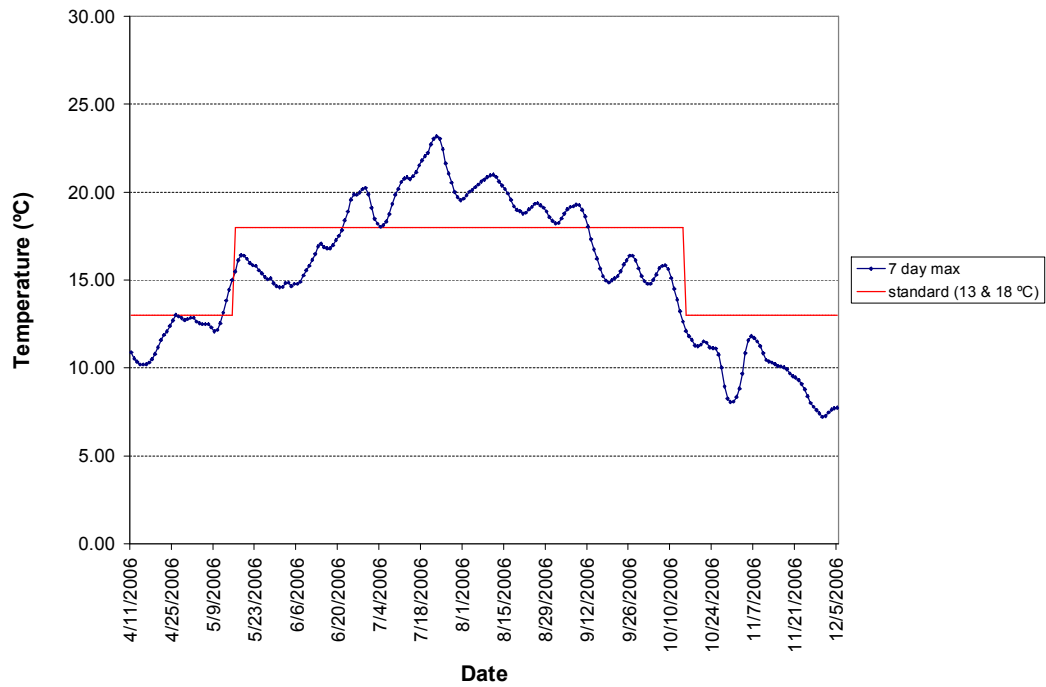


Figure 22: Seven day maximum average temperature of Ferris Creek at Rte. 30 from 4/6/06 to 12/8/06.

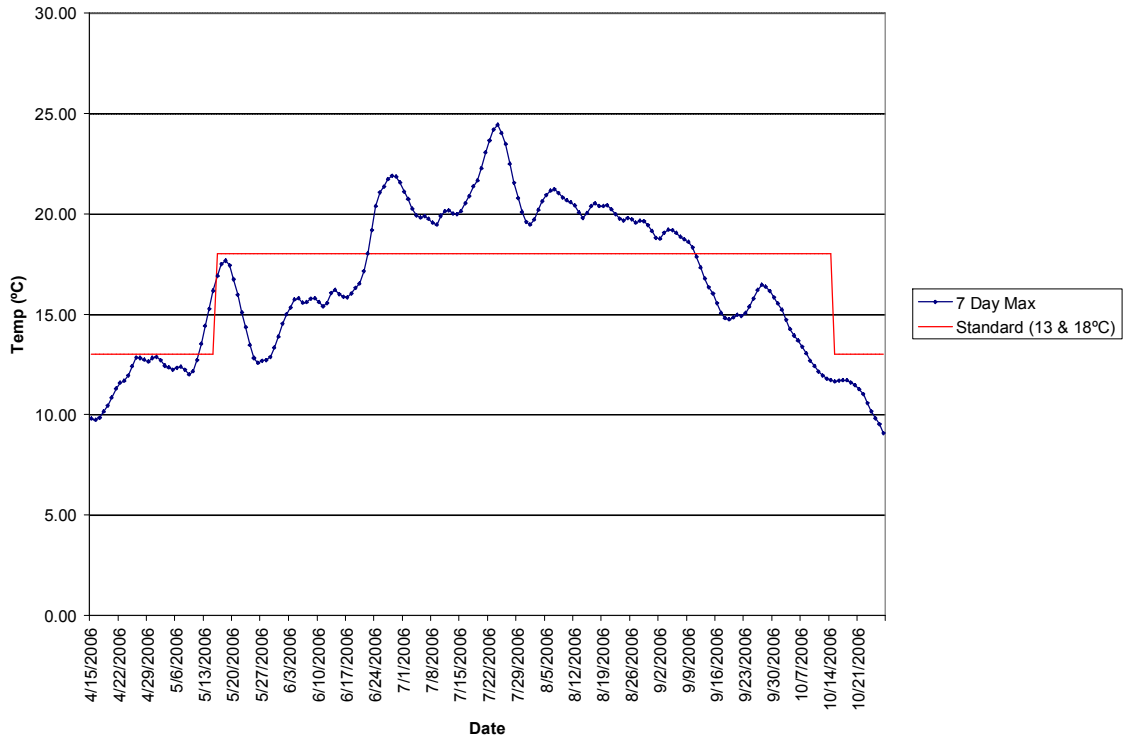


Figure 23: Seven day maximum average temperature of Scappoose Creek near West Lane Rd from 4/10/06 to 10/31/06.

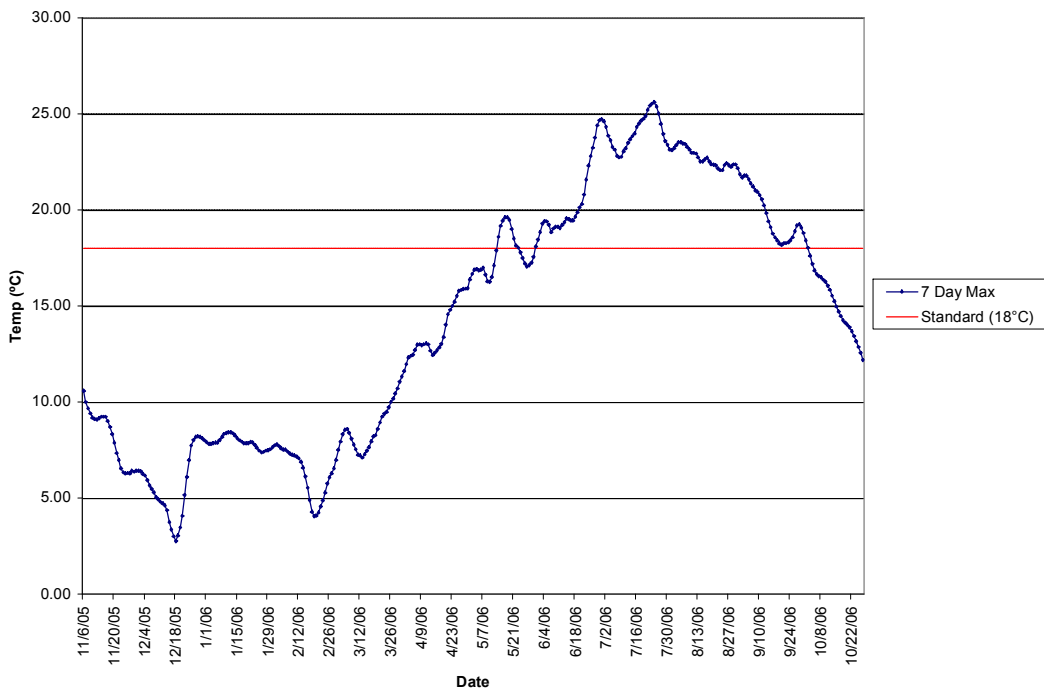


Figure 24: Seven day maximum average temperature of Scappoose Bay from 11/1/05 to 10/31/06.

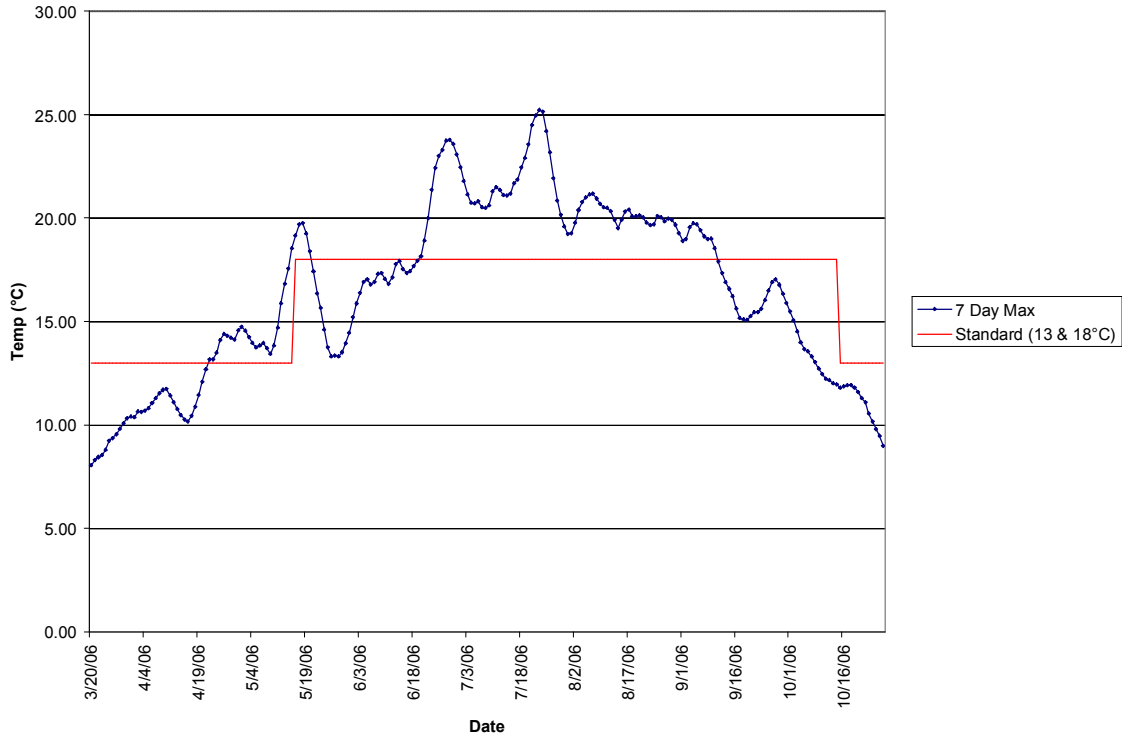


Figure 25: Seven day maximum average temperature of Milton Creek at St. Helens from 3/15/06 to 9/15/06.

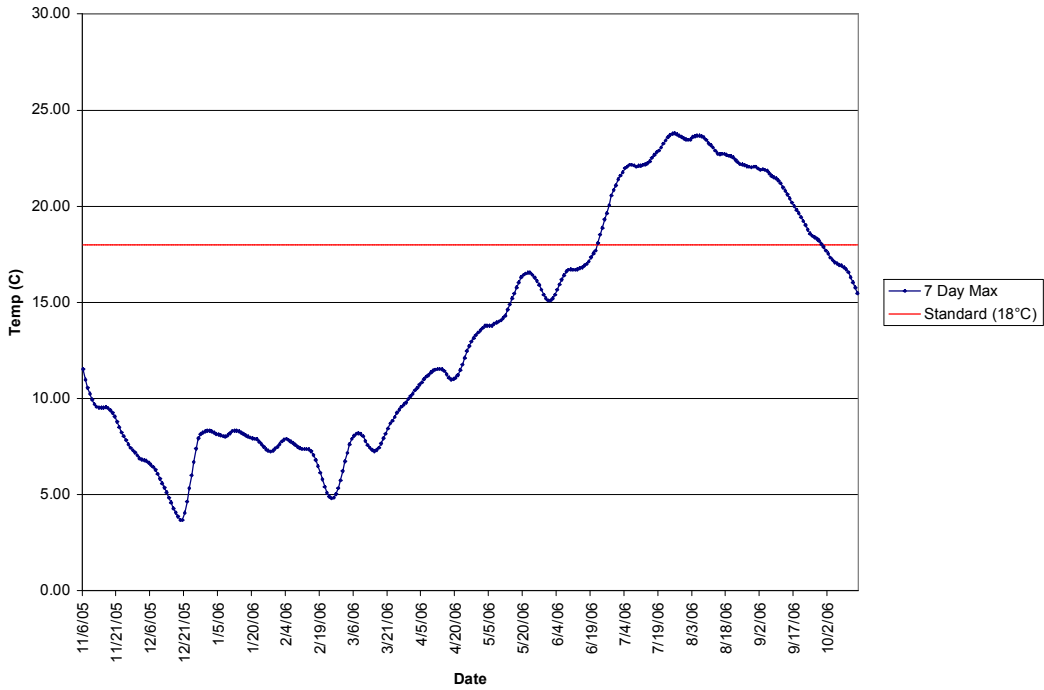


Figure 26: Seven day maximum average temperature of Multnomah Channel D/S of Gilbert River from 11/1/05 to 10/20/06.

Appendix B: Conventional Parameters from Metal Sampling

Table 12: Conventional parameters measured in the field during metal sample collection.

Site name	Date	Time Start	Time End	Metals in Wat	Metals in Sed	temp °C	pH (su)	turbidity (ntu)	redox (mV)	dissolved oxygen (mg/L)	EC25 (µS/cm)	soil redox (mV)
Armstrong Industry, Scappoose Bay	7/7/06	10:43	11:25	x	x	23.15	7.24	22.4	43 !	5.25	107	-122.3
Scappoose Bay at Marker #9	7/7/06	9:10	10:10	x	x	19.62	7.27	20.3	56 !	5.03	114	-161.3
Scappoose Creek	7/7/06	14:04	14:30	x	x	17.9	7.6	1.94	19 !	7.12	96	NA
Scappoose Bay at Milton Creek	7/7/06	12:04	12:30	x	x	20.9	7.24	18.1	45 !	5.81	99	-140.1
Willamette River @ Ross Island	6/9/06	10:37	12:17	x	x	16.07	7.46	6.98	57 !	9.61	67	135
Salmon Creek U/S of 36th Ave	7/20/06	15:30	15:50	x	x	22.42	8.31	7.62	298	11.45	164	120.6
Gee Creek @ Abrams Park	7/20/06	9:15	10:10	x	x	17.29	7.58	7.08	238	7.95	183	132.6
Lake River D/S Felida	7/20/06	11:40	12:50	x	x	22.34	8.67	43.2	214	8.17	151	69.1
Whipple Creek @ 91st and 179th	7/20/06	14:25	14:50	x	x	18.68	7.78	8.09	242	8.52	234	129.5
Cathlamet Bay	8/3/06	7:52	8:30		x	20.54	7.71	4.38	248	6.67	1350	223.6
Cathlamet Bay, South Channel	8/3/06	8:59	9:29		x	20.5	7.67	4.83	253	6.52	176	242.6
Svenson Island	8/3/06	10:02	10:35		x	21	7.78	4.25	250	6.92	122	301.9
Knappa Slough	8/3/06	11:00	11:27		x	21.07	7.77	5.84	244	6.75	124	262.5
Prairie Channel @ Bug Hole	8/3/06	11:40	12:20		x	21.09	8.24	6.68	247	7.74	124	-168
Green Island	8/3/06	12:55	13:15		x	20.41	7.85	5.21	271	7.25	135	167.9
Young's Bay	8/3/06	15:00	16:00		x	20.1	7.93	5.1	239	7.14	7840	-54.6
Gray's Bay	8/3/06	17:40	18:30		x	21.6	8.4	5	216	8.14	2.29	11.6

Appendix C: Pesticide and PCB data for Columbia River Estuary Sediment Sites

Table 13: Pesticides including DDT analyzed using EPA method 8081. All values in $\mu\text{g}/\text{Kg}$ dry weight (ppb).

Analyte Name	MRL ($\mu\text{g}/\text{Kg}$)	CABA	CBSC	SVIS	KNSL	PCBH	GRIS	YOBA	GRBA
Alpha-BHC	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Beta-BHC	1.0	ND	ND	ND	ND	ND	ND	ND	ND*
Gamma-BHC (lindane)	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Delta-BHC	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Heptachlor	1.0	ND	ND	ND	ND	1.5	ND	ND	ND
Aldrin	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Heptachlor Epoxide	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Gamma-Chlordane	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Endosulfan I	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Alpha-Chlordane	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Dieldrin	1.0	ND	ND	ND	ND	ND	ND	ND	ND
4,4'- DDE	1.0	ND	ND	ND	ND	3.2	ND	ND	1.3
Endrin	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Endosulfan II	1.0	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDD	1.0	ND*	ND*	ND*	ND	1.8	ND*	1.7	ND
Endrin Aldehyde	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Endosulfan Sulfate	1.0	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDT	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Endrin Ketone	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Methoxychlor	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Toxaphene	50	ND	ND	ND	ND	ND	ND	ND	ND

*= MRL/MDL elevated due to a chromatographic interference. For 4,4'-DDD elevated MRLs are anywhere from 1.1 to 1.9 $\mu\text{g}/\text{Kg}$. For Beta-BHC at Gray's Bay, the elevated MRL was 1.2 $\mu\text{g}/\text{Kg}$.

Table 14: PCBs analyzed using EPA method 608/8082. All values in $\mu\text{g}/\text{Kg}$ dry weight (ppb).

Analyte Name	MRL	CABA	CBSC	SVIS	KNSL	PCBH	GRIS	YOBA	GRBA
Aroclor 1016	10	ND	ND	ND	ND	ND	ND	ND	ND
Aroclor 1221	20	ND	ND	ND	ND	ND	ND	ND	ND
Aroclor 1232	10	ND	ND	ND	ND	ND	ND	ND	ND
Aroclor 1242	10	ND	ND	ND	ND	ND	ND	ND	ND
Aroclor 1248	10	ND	ND	ND	ND	ND	ND	ND	ND
Aroclor 1254	10	ND	ND	ND	ND	ND	ND	ND	ND
Aroclor 1260	10	ND	ND	ND	ND	ND	ND	ND	ND

Table 15: Site codes for Tables 13 & 14.

Site Name	Code
Cathlamet Bay	CABA
Cathlamet Bay, South Channel	CBSC
Svenson Island	SVIS
Knappa Slough	KNSL
Prairie Channel @ Bug Hole	PCBH
Green Island	GRIS
Young's Bay	YOBA
Gray's Bay	GRBA