Quality Assurance Project Plan

Tributaries to Totten, Eld, and Little Skookum Inlets Temperature and Fecal Coliform Bacteria Total Maximum Daily Load Study

by
Anise Ahmed

Washington State Department of Ecology
Environmental Assessment Program
Olympia, Washington 98504-7710

May 2004

Publication No. 04-03-106

This plan is available on the Department of Ecology home page on the World Wide Web at http://www.ecy.wa.gov/biblio/0403106html.

Quality Assurance Project Plan

Tributaries to Totten, Eld, and Little Skookum Inlets Temperature and Fecal Coliform Bacteria Total Maximum Daily Load Study

May 2004

303(d) Listings Addressed in this Study:

Inlet	Stream	Waterbody ID		Parameter
		Old	New	
Totten	Pierre Creek	WA-14-1190		fecal coliform bacteria
	Burns Creek	WA-14-1195		fecal coliform bacteria
	Kennedy Creek		AO33HF	fecal coliform bacteria, temperature
	Schneider Creek	WA-14-1200	ER21HD	fecal coliform bacteria
Eld	McLane Creek		SD15AI	fecal coliform bacteria
	Perry		FE29VY	fecal coliform bacteria
Little Skookum	Skookum Creek	WA-14-1400	B164LF	fecal coliform bacteria, temperature

Ecology EIM Number: DBAT0002 (bacteria) and AAHm001 (temperature)

Approvals

Approved by:	April 29, 2004
Christine Hempleman, Southwest Regional Office	Date
Approved by:	May 3, 2004
Kim McKee, Unit Supervisor, Southwest Regional Office	Date
Approved by:	April 29, 2004
Kelly Susewind, Section Manager, Southwest Regional Office	Date
Approved by:	April 29, 2004
Anise Ahmed, Project Manager, Watershed Ecology Section	Date
Approved by:	April 29, 2004
Karol Erickson, Unit Supervisor, Water Quality Studies Unit Studies Unit	Date
Approved by:	April 29, 2004
Will Kendra, Section Manager, Watershed Ecology Section	Date
Approved by:	April 29, 2004
Cliff Kirchmer, Ecology Quality Assurance Officer	Date
Approved by:	April 30, 2004
John Konovsky, Squaxin Island Tribe	Date

Table of Contents

Abstract

Tributaries to the Totten, Eld, and Little Skookum Inlets are on Washington State's 1998 303(d) list for fecal coliform bacteria. Segments of Kennedy and Skookum Creeks are proposed to be included in the 2002 303(d) list for temperature. Therefore, in accordance with the Federal Clean Water Act, Total Maximum Daily Loads (TMDLs) for fecal coliform bacteria and temperature must be established to bring these tributaries into compliance with water quality standards. The inlets themselves are not on the 303(d) list. This plan describes the approach to be used to develop TMDLs for the listed tributaries.

For compliance with fecal coliform bacteria standards, a simple roll-back method will be used to establish target reductions for each tributary. Available fecal coliform data from the National Monitoring Program (NMP), Thurston and Mason Counties, and the Squaxin Island Tribe are deemed sufficient for using the roll-back method; therefore, no new data will be collected.

Temperature listings for Skookum and Kennedy Creeks are based on data collected by the Squaxin Island Tribe. Further data collection for Skookum Creek will consist of continuous temperature monitoring, streamflow monitoring, riparian surveys, and an extensive groundwater study in the summer of 2004. The Washington State Department of Ecology (Ecology) will work cooperatively with the Squaxin Island Tribe to coordinate field work. Water temperature in Skookum Creek will be characterized and load allocations established for heat sources to meet water quality standards. A QUAL2Kw model will be used for this purpose.

Most of Kennedy Creek is already covered by an existing TMDL. For the remaining segment, approximately the lower one mile, no TMDL is deemed necessary at this time.

A final report will be available in June 2005.

Introduction

Tributaries to the Totten, Eld, and Little Skookum Inlets in South Puget Sound have been placed on Washington State's 303(d) list (1996, 1998, and proposed 2002/2004) of waterbodies not meeting water quality standards for fecal coliform (FC) bacteria and temperature (Table 1). Thus, under the Federal Clean Water Act of 1972, a cleanup plan called a TMDL must be developed and implemented to address this impairment and bring the waterbody segments into compliance with the standard. This report is a project plan for proceeding with the TMDL analysis. Available data for the tributaries are reported and the procedure for completion of the TMDL analysis is explained. No additional data collection is planned for the fecal coliform TMDL portion of this project. However, data for the temperature TMDLs will need to be gathered in summer 2004. The report is, therefore, divided into two sections: 1) fecal coliform bacteria and 2) temperature TMDL.

Table 1. Tributaries to Totten, Eld, and Little Skookum Inlets on the 303(d) List.

Stream	New Waterbody ID	Old Waterbody ID	Listings	Segment	Proposed 2002/2004	1998	1996
Totten Inlet							
Pierre Creek	----	WA-14-1190	FC	Near Mouth	Yes	Yes	----
Pierre Creek	----	WA-14-1190	FC	Near Mouth	Yes	Yes	Yes
Burns Creek	----	WA-14-1195	FC	Near mouth	Yes	Yes	----
Burns Creek	----	WA-14-1195	FC	Near mouth	Yes	Yes	Yes
Kennedy Creek	AO33HF	----	FC	125m above old pacific hwy bridge	Yes	-----	-----
Kennedy Creek	AO33HF	----	Temperature	125m above old pacific hwy bridge	Yes	-----	-----
Schneider Creek	ER21HD	WA-14-1200	FC	Near mouth, RM0.3	Yes	Delisted	Yes
Eld Inlet							
McLane	SD15AI	----	FC	100 m below bridge at Delphi Rd	Yes	----	----
Perry	FE29VY	----	FC	400 m above Perry Creek Road	Yes	----	----
Little Skookum Inlet							
Skookum Creek	BI64LF	WA-14-1400	FC	Station at Hwy 101	Yes	Yes	----
Skookum Creek	BI64LF	WA-14-1400	Temperature	Station at Hwy 108, RM2.2	Yes	----	----
				Total listings	11	5	3

Background

Eld Inlet (Figure 1) is located within Thurston County between Totten and Budd Inlets. It falls within Water Resource Inventory Areas (WRIA) 13 and 14. The boundary between WRIA 13 (Deschutes Watershed to the south) and WRIA 14 (Kennedy-Goldsborough Watershed to the north) cuts through the middle of Eld Inlet. Two major tributaries to Eld Inlet are McLane and Perry Creeks, both draining into Mud Bay at the southern end of Eld Inlet. Both McLane and Perry Creeks were included in the proposed 2002/2004 303(d) list for fecal coliform bacteria. Both of these tributaries are designated as Class A waterbodies in Washington Administrative Code (WAC) Chapter 173-201A. The fecal coliform standard for this designation is a geometric mean of 100 colony forming units (cfu, i.e. bacteria)/100 mL with no more than 10% of samples exceeding 200 cfu/100 mL. The 1996 list included Eld Inlet on the 303(d) list but has since been dropped based on data from the Washington State Department of Health (DOH). There are no temperature listings for tributaries to Eld Inlet.

Totten Inlet (Figure 1) is in WRIA 14 (Kennedy-Goldsborough Watershed). Thurston County is to the south and Mason County to the north of Totten Inlet. The county boundary cuts through the middle of Totten Inlet. Tributaries on the 303(d) list are: Kennedy, Schneider, Burns, and Pierre Creeks, all of which are Class AA waterbodies. The fecal coliform standard for this designation is a geometric mean of 50 cfu/100 mL with no more than 10% of samples exceeding 100 cfu/100 mL. Kennedy Creek is included in the proposed 2002/2004 303(d) list for temperature. The temperature standard for Class AA freshwater is 16 ˚C, with a 0.3˚C degradation allowed if natural conditions are in excess of 16˚C. If natural conditions are below the temperature criterion, incremental temperature increases, resulting from nonpoint source activities, shall not exceed 2.8°C or bring the stream temperature above 16 ˚C (WAC173-201A-030 (1)).

Little Skookum Inlet (Figure 1) is in WRIA 14 and is located within Mason County. Skookum Creek is a tributary to Little Skookum Inlet and is on the 303(d) list for fecal coliform bacteria. The Squaxin Island Tribal land is located near the mouth of Skookum Creek. Skookum Creek is a Class AA waterbody. The fecal coliform standard for this designation is a geometric mean of 50 cfu/100 mL with no more than 10% of samples exceeding 100 cfu/100 mL. Skookum Creek is included in the proposed 2002/2004 303(d) list for temperature. The temperature standard for Class AA freshwater is 16 ˚C, with a 0.3 ˚C degradation allowed if natural conditions are in excess of 16 ˚C. If natural conditions are below the temperature criterion, incremental temperature increases, resulting from nonpoint source activities, shall not exceed 2.8°C or bring the stream temperature above 16 ˚C (WAC173-201A-030 (1)).

Totten, Eld, and Little Skookum Inlets produced 7% of the state's shellfish in 1990, 9% in 1995, and 11% in 2000 (Batts and Seiders, 2003). Nonpoint source bacterial contamination is a significant pollution threat to these inlets (Seiders, 1999). Anthropogenic sources of bacterial pollution include failing on-site sewage systems (i.e. septic systems) and small livestock farming practices (typically less than 20 acres with horses, cows, llamas, chickens, ducks and turkeys). Although these inlets are not on the 303(d) list for fecal coliform bacteria and are currently approved for shellfish harvesting by the DOH, these waterbodies are considered to be "threatened" by bacterial nonpoint source pollution (Batts and Seiders, 2003). Eld Inlet has been specifically listed as threatened by the Washington State Department of Health (DOH, 2003).

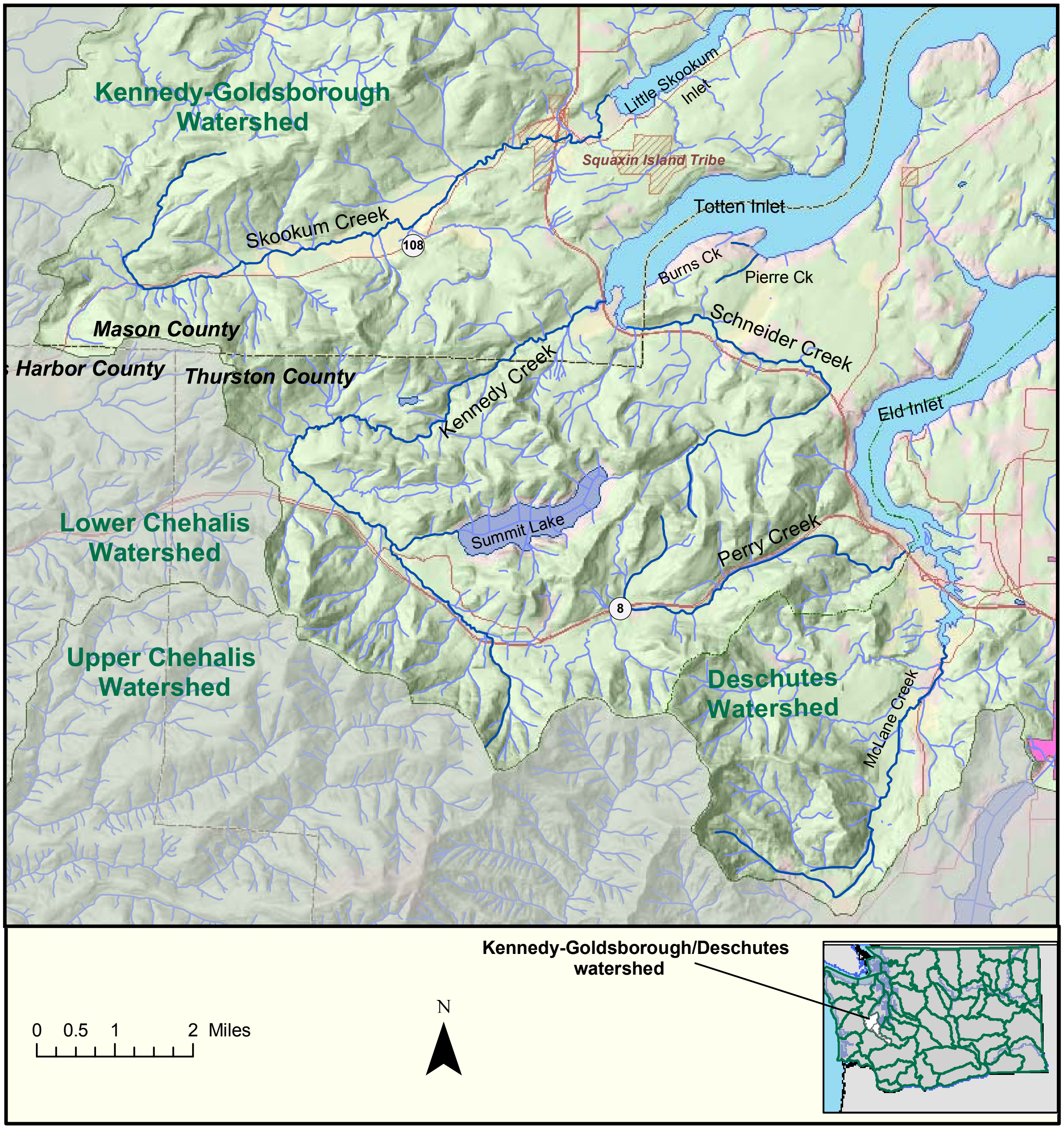

Figure 1. Totten, Eld, Little Skookum Inlets and Tributaries.

Water Quality Standards

Washington State has adopted a new rule on Water Quality Standards (WAC 173-201A) as of July 2003. The rule has not yet been approved by the Environmental Protection Agency (EPA) and, therefore, has not yet gone into effect. The new fecal coliform standards for waters with "extraordinary primary contact" and "primary contact" recreation designations are identical to the existing Class AA and Class A waters, respectively.

The temperature standard in the new rule is a 7-Day Average of Daily Maximum (DADM) temperatures not to exceed a use-based criterion. Table 602 of the new rule (WAC-173-201A) includes a list of specific uses for many waterbodies in Washington State. However, since Kennedy and Skookum Creeks are not listed in Table 602, Section WAC-173-201A-600 applies. Based on relevant designated uses in WAC-173-201A-600 (i.e. salmon and trout spawning, core rearing, and migration; and extraordinary primary contact recreation) and the aquatic life temperature criterion in Table 200(1)(c) (Section WAC-173-201A-200), the temperature standard is a 7-DADM temperatures of 16 ˚C. In contrast, the existing standard for a Class AA waterbody is a one-day maximum of 16 ˚C.

Fecal Coliform Bacteria TMDL

In general, reductions in fecal coliform bacteria in the watersheds can be achieved through employment of Best Management Practices (BMPs) at small livestock farms and addressing failing septic systems. However, target bacteria reduction goals must be established through a TMDL analysis to direct these efforts towards meeting water quality standards. TMDLs for fecal coliform bacteria will be calculated for the following tributaries: Pierre Creek, Burns Creek, Kennedy Creek, Schneider Creek, McLane Creek, Perry Creek, and Skookum Creek.

Data Needs

The Totten, Eld, and Little Skookum Inlets are not included in the 303(d) list for fecal coliform bacteria. Thus, no modeling of the inlets is needed. Bacterial target reductions for the tributaries will be established through the use of the *roll-back* method (Ott, 1995). The roll-back method assumes that the distribution of fecal coliform bacteria concentrations follows a log-normal distribution. The cumulative probability plot of the observed data gives an estimate of the geometric mean and 90th percentile which then can be compared to the fecal coliform bacteria standards. The roll-back procedure is as follows:

a) The data are plotted on a log-scale against a linear cumulative probability function; a straight line signifies a log-normal distribution of the data.

b) The geometric mean of the data has a cumulative probability of 0.5.

c) The 90th percentile of the data has a cumulative probability of 0.9. This is equivalent to the "no more than 10% samples exceeding …." criterion in the fecal coliform standard (WAC 173-201A).

d) Alternately, the 90th percentile can also be estimated by using the following statistical equation:

$$90^{th}\text{ percentile} = 10^{(\mu_{log} + 1.28 * \sigma_{log})}$$

where: μ_{log} = mean of the log transformed data; σ_{log} = standard deviation of the log transformed data

e) The target percent reduction required is the highest of the following two comparisons. either:

$$\left[\frac{\text{90th percentile} - \text{200 cfu/100mL}}{\text{90th percentile}}\right]\text{x100} \quad \text{or:} \quad \left[\frac{\text{geometric mean} - \text{100 cfu/100mL}}{\text{geometric mean}}\right]\text{x100}$$

f) As BMPs for nonpoint sources are implemented and the target reductions are achieved, a new but similar distribution (same coefficient of variation) of the data is assumed to be realized with the previous mean and standard deviation reduced by the target percent reductions.

g) If the data do not meet the 90th percentile criteria, then the goal would be to meet a 90th percentile FC of 200 cfu/100 mL, and no goals would be set for the geometric mean since, with the implementation of the target reductions, the already low geometric mean (<100 cfu/100mL) would only get better. Similarly, if the data do not meet geometric mean criteria, the goal would be to achieve a geometric mean of 100 cfu/100mL with no goal for the already low (<200 cfu/100mL) 90th percentile.

For this approach to work, sufficient data must be available to establish a log-normal distribution of fecal coliform bacteria. Target reductions based on data from the critical season will be more realistic in driving an implementation plan towards meeting water quality standards. Flow data may be used to establish loads which could be used as a management tool to prioritize areas where BMPs are needed.

Available Data

Data on fecal coliform and flow in tributaries to Totten and Eld Inlets were collected on a weekly basis over a ten-year period (1992-2002) by Ecology under the NMP funded by EPA (Batts and Seiders, 2003). In addition, bacterial data for these tributaries are also available on a weekly basis from Thurston County for the period between 1988 and 2002. Some tributary data are also available from the Squaxin Indian Tribe (Taylor et al., 1999). Monthly data on Skookum Creek were gathered at 14 stations by the Squaxin Indian Tribe (1995-1998, 2000-present), and 8 stations by Mason County (1991-1992). Although data for Skookum Creek are not as extensive as the other tributaries, there are sufficient data available for the roll-back method and establishment of reduction targets. Ecology has only flow data for Little Skookum Creek.

Table 2. Available Fecal Coliform Data for Tributaries (Number of Stations in Parentheses).

Inlet	Creek	Thurston	Mason	Ecology	Squaxin Tribe
Eld	Perry	1988-2002 (1)		1992-2002 (1)	
	McLane	1988-2002 (1)		1992-2002 (1)	8/02-5/03 (1)
Totten	Kennedy	1988-2002 (1)		1992-2002 (1)	
	Schneider	1988-2002 (1)		1992-2002 (1)	
	Pierre	1988-2001 (1)		1992-2002 (1)	
	Burns	1988-2000 (1)		1992-2002 (1)	
Little Skookum	Skookum		1989-91(8)	1986-91,99 (1)	1995-98, 2000-03 (14)

Data Analysis and Results

Where long term data are available, the roll-back method will be used to estimate long term monthly geometric mean and 90th percentile concentrations and then compared with water quality standards. The most restrictive of the differences between each of these two concentrations (observed and standard) will be the target reduction in fecal coliform concentrations for that month. These target bacterial reductions will be included in a follow-up TMDL report. Priority segments requiring the highest bacterial reductions would be identified for further monitoring as BMPs are implemented. A detailed implementation plan will be developed in conjunction with the local stakeholders to address how target reductions will be achieved. The following illustrative example explains the procedure for establishing targets for bacteria reductions.

1. Figure 2 shows the average monthly flows, geometric mean, and 90th percentile fecal coliform concentrations over a ten-year period at the Ecology/Thurston County station (125 meters above Old Olympic highway) in Kennedy Creek. Exceedences of the fecal coliform bacteria standards were observed during low summer flows with the maximum concentrations during the month of September.

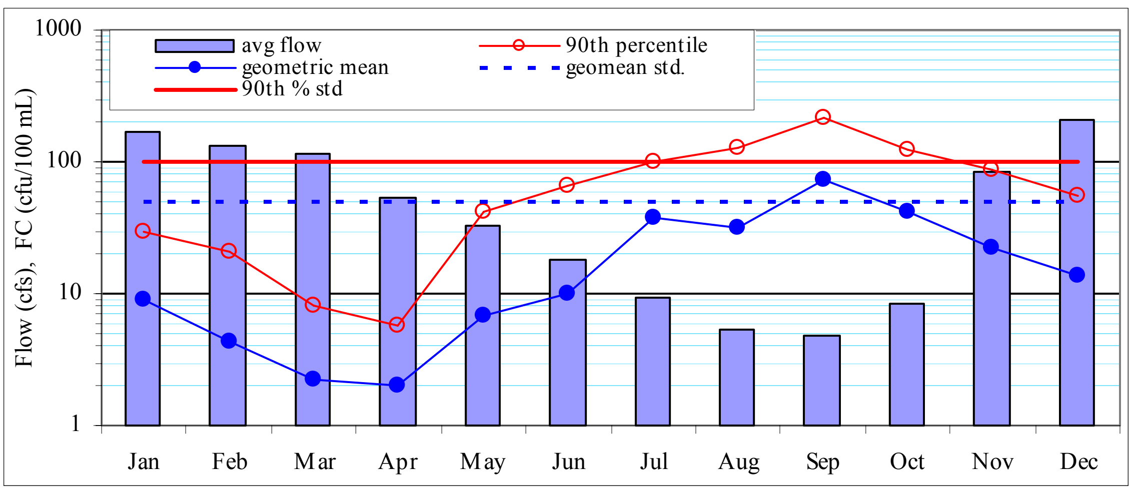

Figure 2. Distribution of Monthly Flow and Fecal Coliform Concentrations in Kennedy Creek, 1992-2002.

2. The target reduction in fecal coliform concentrations is based upon the critical month of September and the most restrictive of Class AA standard of 50 cfu/100 mL and 100 cfu/100 mL, geometric mean and 90th percentile, respectively. This is shown in Table 3.

Table 3. Fecal Coliform Concentrations and Target Reductions in Mainstem Kennedy Creek, 125m Above the Old Olympic Highway, 1992-2002.

Month	Number of samples	Geometric Mean (cfu/100 mL)	90th Percentile (cfu/100 mL)	Limiting basis for reduction	Target Reductions (%)
September	10	74	218	90th percentile	54

All creeks except Skookum Creek have long-term data over a ten-year period (1992-2002) so data can be evaluated to establish target reduction goals on a monthly basis. Skookum Creek has approximately four years of monthly data. Therefore, only seasonal evaluation will be done on a running three-month and four-month geometric mean and 90th percentile concentrations. This will increase the number of data points relative to a monthly evaluation. However, if five years of monthly data becomes available at the time of data analysis, the procedure outlined above will be followed.

Temperature TMDL

Two tributaries in the study area have been included in the proposed 2000 303(d) list—Kennedy Creek and Skookum Creek—and are discussed below.

Kennedy Creek

Kennedy Creek is a ten-mile long stream draining about 19 square miles. The land use is primarily rural residential, forestry, and some farming. The creek originates in the Black Hills and falls gradually to lowlands except for a series of falls, cascades, and log jams 2.5 miles from the mouth. It discharges to the head of Totten Inlet.

Available Data

Continuous temperature monitoring data were gathered by the Squaxin Island Tribe in June through September, 2003, at a location less than a mile upstream of the Old Olympic Highway Bridge at the public fish viewing area (Figure 3). This location also represents the lower boundary of Simpson timberland (Phil Peterson, Simpson Resource Company, Personal Communication, January 2004). Figures 4 and 5 show the daily maximum and the seven-day average of the daily maximum (7-DADMax) temperatures, respectively, in Kennedy Creek. The temperature criterion for Kennedy Creek is 16˚C daily maximum in the existing rule (WAC 173-201A) or 16 ˚C 7-DADMax in the new proposed rule. Clearly, this segment of the creek is not meeting the water quality standard.

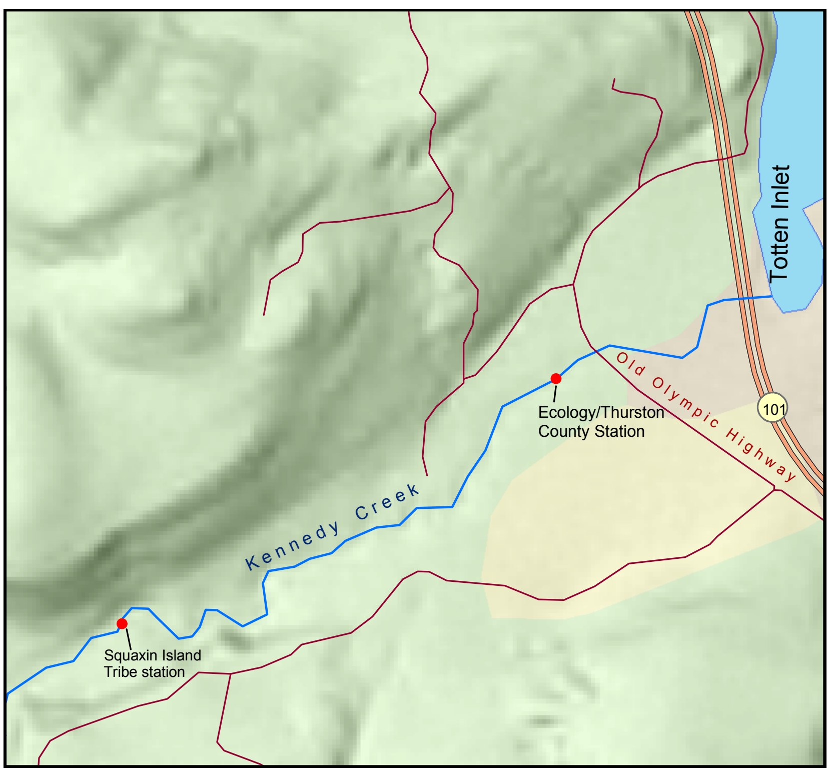

Figure 3. Historical Monitoring Stations in the Lower Reach of Kennedy Creek.

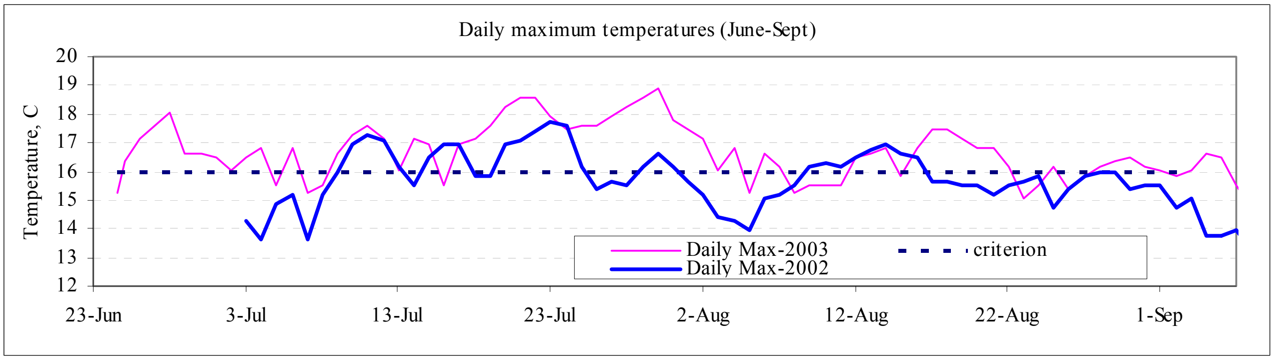

Figure 4. Daily Maximum Temperatures in Kennedy Creek (Approximately 1 Mile Upstream of Old Olympic Highway Bridge).

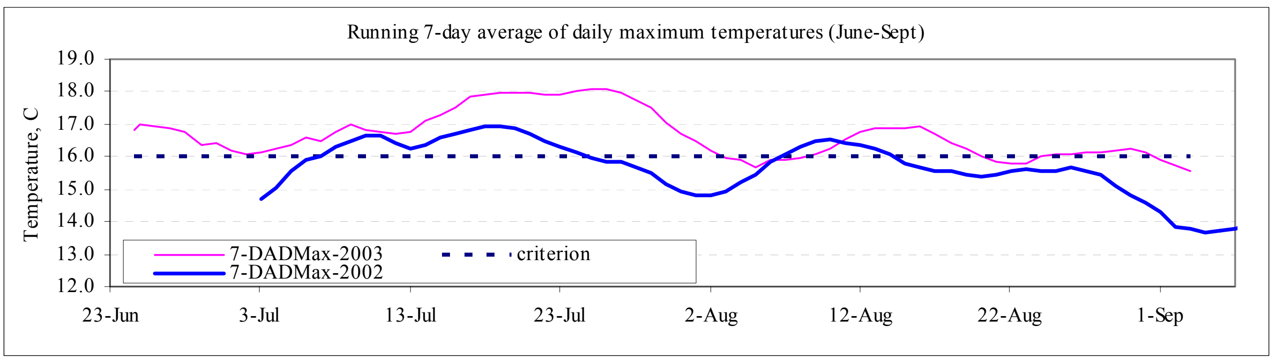

Figure 5. Seven-day Average of Daily Maximum Temperatures in Kennedy Creek (Approximately 1 Mile Upstream of Old Olympic Highway Bridge).

TMDL Approach

Most of Kennedy Creek is in Simpson timberland and is covered under a temperature TMDL which is based upon a Habitat Conservation Plan (HCP) (Cleland et al., 2000). The segment of Kennedy Creek proposed to be included in the 2002 303(d) list is an approximately one-mile segment at the mouth of the creek, which is not covered by the HCP. A temperature TMDL will not be conducted for this segment at this time pending implementation of the Simpson HCP. It is assumed that as the Simpson HCP is implemented, temperatures in the lower segment will improve. Follow-up temperature monitoring will be conducted to confirm compliance with the water quality standards. If the temperature standard is met at the Simpson boundary and the temperature within the listed segment exceeds the standard, a TMDL will then be developed for this segment.

The Simpson timberland on Kennedy Creek extends from the public fish viewing area (about a mile upstream of the mouth of Kennedy Creek) to below the mouth of the tributary that drains Summit Lake into Kennedy Creek. A majority of the land above this location is owned by the Department of Natural Resources or the Forest Board. Fish and Forest regulations give most forest lands until 2009 to come into compliance (or show that they can) with water quality standards. It is recommended that any TMDL related monitoring for those lands be deferred until that evaluation is made. Data collected prior to that evaluation may not be useful since any BMPs implemented, as per the Fish and Forest regulations, may change water quality over this period.

Skookum Creek

Skookum Creek is the largest and the most significant freshwater input to Little Skookum Inlet. Skookum Creek originates from perennial springs near Stimson Station on the Burlington Northern Railroad close to the Mason County line. Although the headwaters and tributaries drain the steep ridges of the Black Hills, most of the Mainstem Skookum Creek meanders in a northeasterly direction through a wide, alluvial valley. In several places, the channel appears to be incised within the sediments of the valley floor. A well-developed estuary has formed at the mouth of the creek and is dominated by estuarine emergent wetlands with deep pools that offer good transitional habitat for juvenile salmon (Schuett-Hames and Flores, 1993). Skookum Creek is a nine-mile long stream that drains an area of 23.6 square miles. The Mainstem Skookum Creek and its tributaries are shown in Figure 6 along with monitoring stations set up by the Squaxin Island Tribe. Continuous temperature monitoring data in the months of June through September (2000-2003) have been gathered at two locations along the mainstem, three locations along Little Creek, and one location at the mouth of Reitdorf Creek. The mainstem segment on the proposed 2002 303(d) list is between stations SKOK3 and SKOK1. However, daily maximum temperatures in excess of the criterion were also observed at station SKOK5. Station SKOK3 is at RM2.2 upstream of the Squaxin Island Tribal boundary, while station SKOK1 is within the tribal trust land.

The temperature TMDL will be limited to the reach upstream of the tribal land. The segment near the mouth of the creek, below the tribal boundary, is tidally influenced, consists of mudflats, and will not be included in the TMDL.

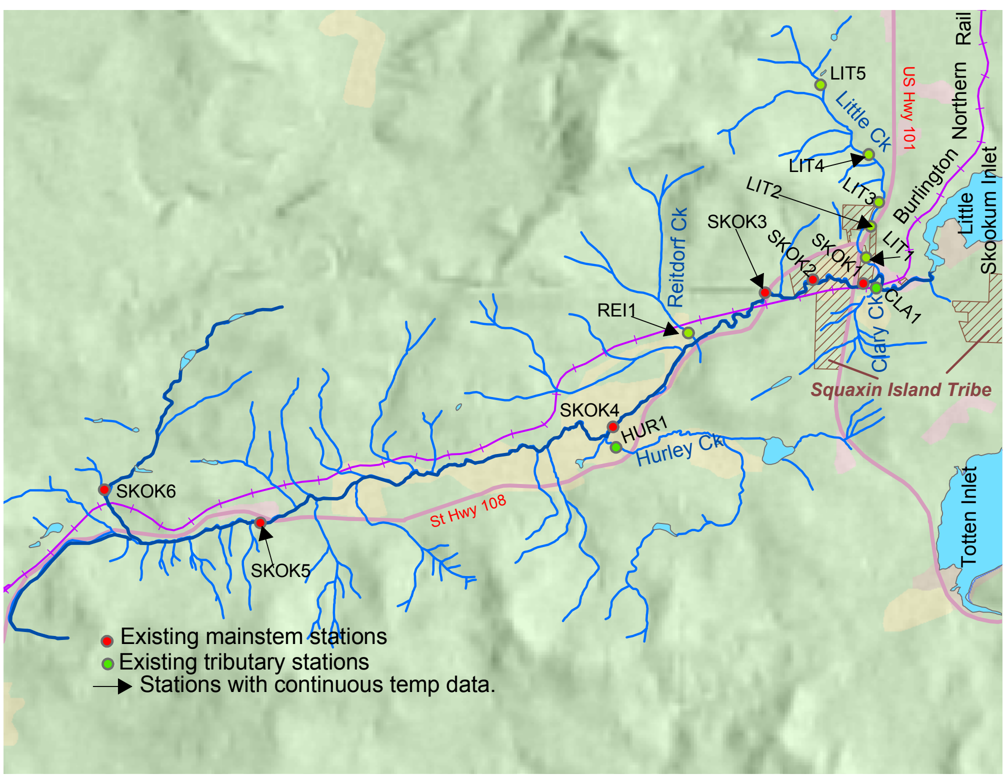

Figure 6. Mainstem Skookum Creek and its Tributaries.

Available Data

Continuous temperature monitoring data (2002-2003) are available at the Mainstem Skookum Creek stations at river miles (RM) 2.2 (SKOK3) and RM 6 (SKOK 5) and several tributary stations (Reitdorf and Little Creeks). Some limited flow data are available for the mainstem near Highway 101.

The daily maximum and the 7-DADMax temperatures in the mainstem locations are shown in Figure 7. Temperature excursions of the daily maximum criterion of 16 C were observed at both the locations (stations SKOK3 and SKOK5). However, excursion of the 7-DADMax criterion was observed only at the downstream station (SKOK3).

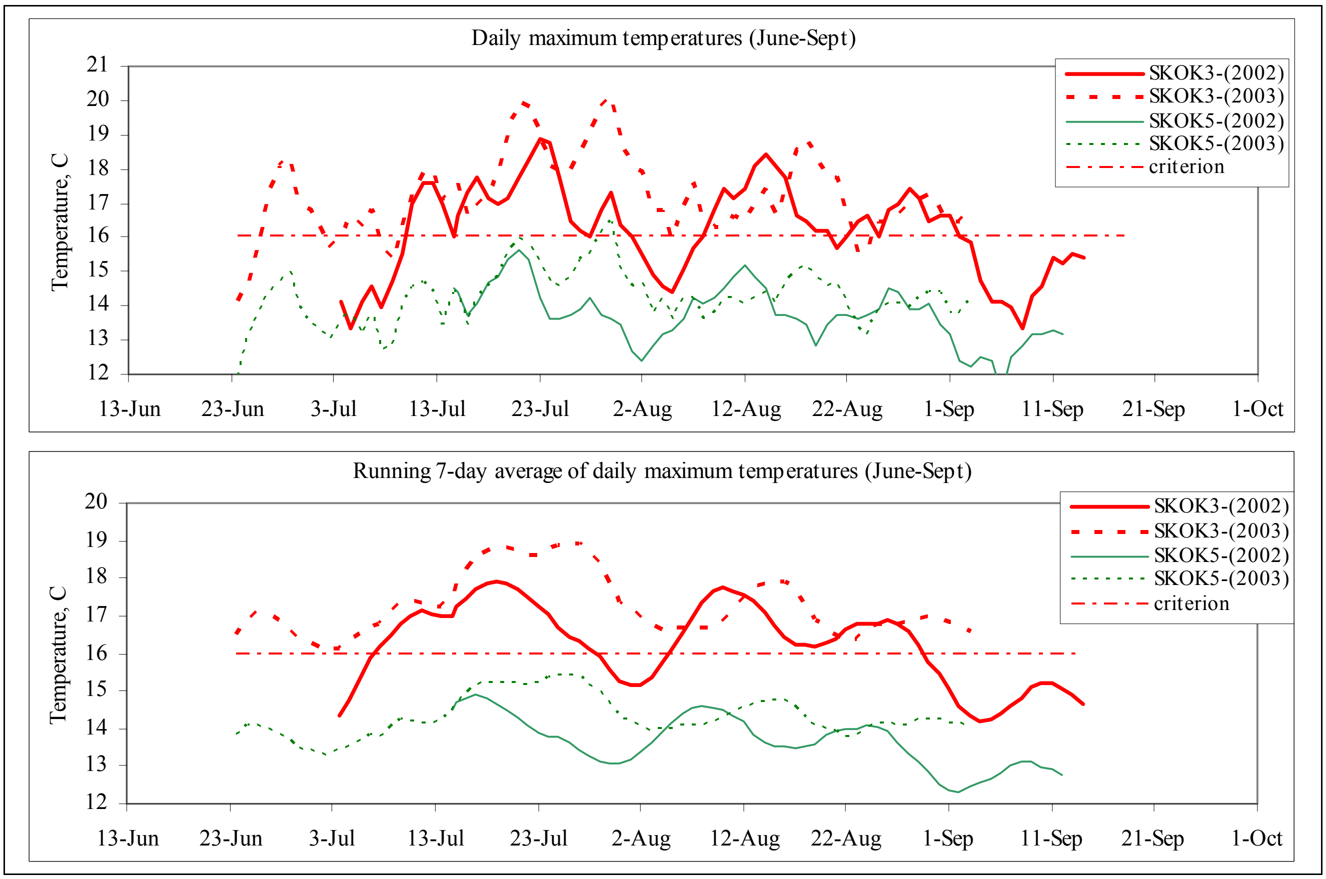

Figure 7. Daily Maximum and Running 7-DADMax Temperatures in Skookum Creek at Two Stations (SKOK3 and SKOK5).

Temperatures in Little Creek were monitored at three locations along the Highway 101 corridor: LIT1, LIT2, and LIT4. Station LIT1 is within the tribal boundary. In addition, temperature was also monitored near the mouth of Reitdorf Creek (station REI1). No excursions of the temperature standard were observed at any of these stations (Figure 8).

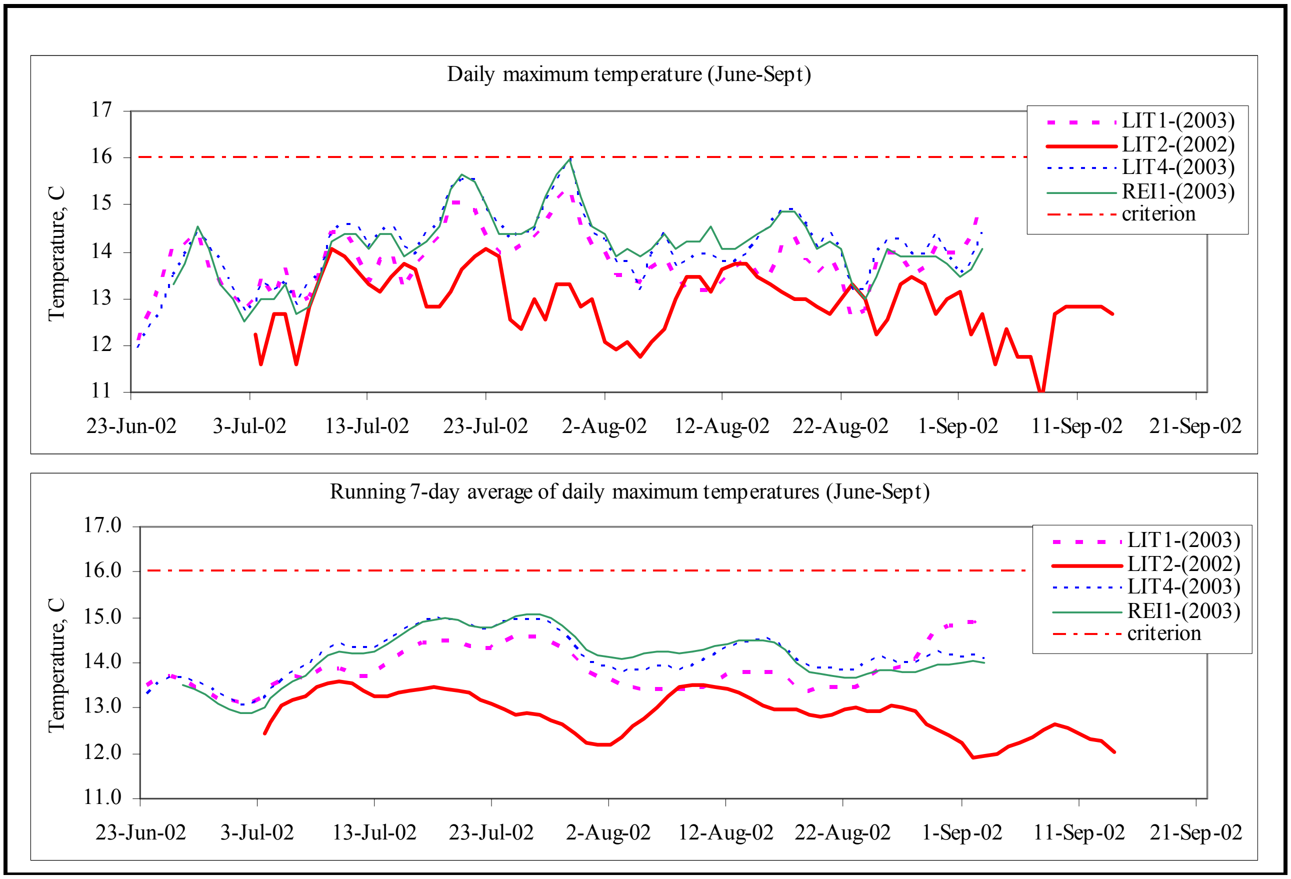

Figure 8. Daily Maximum and Running 7-DADMax Temperatures in Little (Stations LIT1, LIT2, LIT4) and Reitdorf (Station REI1) Creeks.

Data Needs

Since temperature is a measure of heat content, the TMDL will be developed for heat. Processes that impact heat content of water column are (Chapra, 1997):

- Heat input from point and non-point sources.
- Solar radiation: (i) shortwave solar radiation.

  (ii) longwave radiation exchange between air and water.
- Convection: exchange between air and water due to temperature differential.
- Conduction: exchange between water and sediment due to temperature differential.
- Evaporation: when vapor pressure is less than the dew point.

- Wind: impacts both convection and evaporation.

- Groundwater: (i) inflow groundwater will cool stream temperatures and increase flow.

  (ii) outflow of warmer stream water will increase temperatures due to reduced depth of flow.

The heat content per unit volume is defined as temperature. So, if heat accumulates in the waterbody due to the processes discussed above, there will be a net increase in temperature of the water column and vice versa.

In addition to point and non-point sources of thermal pollution, other causes of increased stream temperature are:

- Channel widening increases surface area exposed to solar radiation.

- Reduced riparian vegetation reduces surface shading and increases exposure to solar radiation.

- Reduced summer base flows resulting from increased water rights, land development, and timber harvesting (less groundwater recharge from rain and therefore less late-summer groundwater contributions to streamflow) reduces heat holding capacity of the stream.

- Presence of stratified lakes in upstream locations may increase stream temperatures if lake outlet is from the upper layers of the lake.

Stream temperatures will be modeled using QUAL2Kw, a stream water quality model based on the QUAL2E model (Brown and Barnwell, 1987) and developed by Dr. Steven Chapra (Chapra, 2001). QUAL2Kw is a one dimensional (completely-mixed vertically and laterally) model with steady state hydraulics and diurnal water quality simulation capabilities.

Effective shade produced by current riparian vegetation will be estimated using Ecology’s Shade model (Ecology, 2003). Shade is a spreadsheet model that calculates effective shade either by using the HeatSource model developed by Oregon Department of Environmental Quality (ODEQ, 2000) or the HSPF SHADE model developed by Chen (1996).

Data needs for temperature modeling are listed in Table 4 below.

Table 4. Data Needs for Modeling Stream Temperatures.

	Parameter	Model: Shade	Model: QUAL2Kw	Data collected by Squaxin Island tribe	Data estimated/ selected by Ecology	Comment
Flow	discharge - tributary		x	x		
	discharge (upstream & downstream)		x	x		
	flow regression constants		x		x	Calculated from field data
	flow velocity		x	x		
	groundwater inflow rate/discharge		x	x		
	travel time		x		x	
General	calendar day/date	x	x		x	
	duration of simulation	x	x		x	
	elevation - downstream	x	x		x	USGS or GIS Maps
	elevation - upstream	x	x		x	USGS or GIS Maps
	elevation/altitude	x	x		x	USGS or GIS Maps
	latitude	x	x		x	USGS or GIS Maps
	longitude	x	x		x	USGS or GIS Maps
	time zone	x			x	
Physical	channel azimuth/stream aspect	x			x	
	cross-sectional area	x	x	x		
	Manning's n value	x	x		x	Calculated from flow data
	Pebble count	x	x	x		
	reach length	x	x	x		
	stream bank slope	x		x		
	stream bed gradient	x	x		x	USGS or GIS Maps
	width - bankfull	x		x		
	width - stream	x	x	x		
	Width – flood prone			x		For information only
Temperature	temperature - ground	x	x	x		
	temperature - groundwater		x	x		
	temperature – water downstream		x	x		
	temperatures - water upstream		x	x		
	temperature - air		x	x		
Vegetation	vegetation overhang	x		x		Hemispherical photography o densiometer at representative sites and Orthophotos for remaining reaches
	canopy density	x		x	x	
	distance to shading vegetation	x		x	x	
	topographic shade angle	x			x	
	vegetation height	x		x		
	vegetation shade angle	x			x	
	vegetation width	x		x		
Weather	relative humidity		x	RH meters	x	weather station*
	% possible sun/cloud cover		x		x	weather station*
	solar radiation		x		x	weather station*
	temperature - air		x		x	weather station*
	wind speed/velocity		x		x	weather station*

*** Squaxin Island Tribe has a weather station at the tribal office off Old Olympic Highway**

Temperature Monitoring Locations

The temperature plots of the mainstem and some tributaries suggest that Reitdorf and Little Creeks meet the water quality standard for temperature while the mainstem below station SKOK3 (near Highway 108, RM 2.2, Figure 6) does not meet the standard. However, continuous temperature data is lacking for most of the Skookum Creek reach. According to the Squaxin Island Tribe (SIT) most of the tributaries, except Little, Reitdorf, Hurley, and Clary Creeks, do not have any flow during the summer dry season (John Konovsky, Squaxin Island Tribe, Personal Communication, December, 2003). Thus, a simplified map (using a GIS layer for major tributaries to Skookum Creek) was used to establish proposed locations for water/air temperature, relative humidity, and flow measurements (Figure 8).

The Squaxin Island Tribe will lead the field study for the Skookum temperature TMDL. The segment of the creek that will be addressed in this TMDL would be the reach upstream of the tribal boundary (Figure 9). This will include monitoring station SKOK3 (RM2.2, Figure 6). A monitoring station will also be set up downstream of the tribal land as shown in Figure 9.

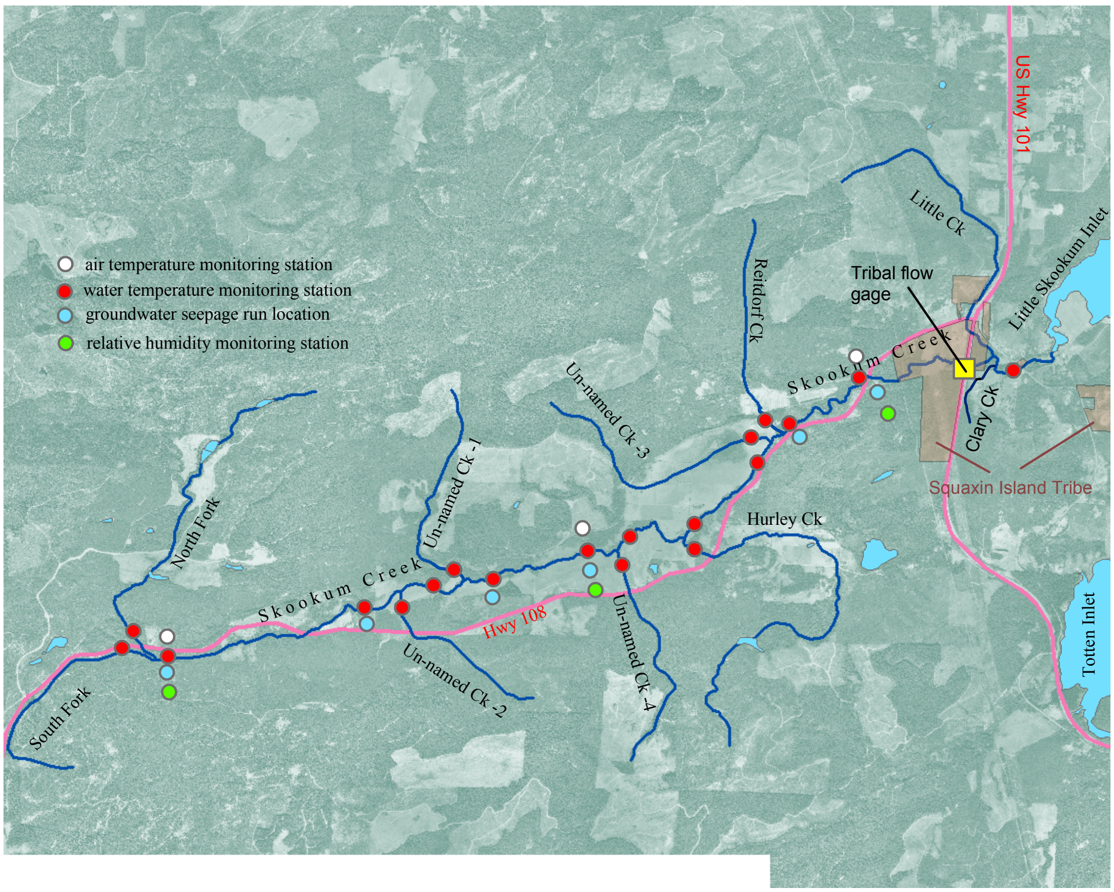

Figure 9. Skookum Creek and Tributaries with Proposed Monitoring Stations.

Continuous water temperature monitoring sites will be established at 19 locations (red dots in Figure 9) in the mainstem and tributaries to Skookum Creek. Air temperature and relative humidity will be monitored at three mainstem sites (white and green dots, respectively, in Figure 9. Water and air temperature will be measured with Onset StowAway temperature data loggers. Relative humidity will be measured with an Onset H8 Pro RH/temperature data logger. The air temperature data loggers will be installed in a location in the stream or riparian forest which is shaded from direct sunlight. They will be placed in an area representative of the surrounding environment. The water temperature logger will be installed at approximately one-half of the water depth and as close to the center of the thalweg as possible. The installation site will be located where there is obvious water mixing and at a depth that will not become exposed if the water level drops but will not be affected by groundwater inflow or stratification. The air temperature data loggers will be installed adjacent to the water temperature probe about one to three meters into the riparian zone from the edge of the bankfull channel and about one meter off the ground.

Riparian Stream and Habitat Surveys

Timber-Fish-Wildlife Stream Temperature Survey methods will be followed for the collection of data during thermal reach surveys (Schuett-Hames et al., 1999). The surveys will be conducted from July to August 2004 at the mainstem temperature sites established in the previous section. Field measurements will be taken at six to ten locations over a 300-meter thermal reach and will consist of bankfull width and depth, wetted width and depth, effective shade, and channel type. Riparian Management Zone (RMZ) characteristics, such as active channel width, cover, size, density, and bank erosion, will also be recorded during the surveys. Hemispherical photography or densiometer will be used to measure effective shade and canopy density at all water temperature stations, and at additional selected locations as necessary, to ground-truth the range of vegetation classes digitized from inspection of digital orthophotos.

Groundwater Survey

Mini in-stream piezometers will be installed along the seepage run locations (blue dots in Figure 9) to define the vertical hydraulic gradient between area streams and the water-table aquifer. The piezometers consist of a seven-foot length of ½ inch diameter galvanized pipe, one end of which is crimped and slotted. The piezometers will be hand driven into the stream bed to a depth of approximately five feet. If in any stream reach (area between blue dots in Figure 9) hard pan is encountered, piezometers will not be installed and the groundwater-stream interaction will be assumed to be negligible.

Water levels in the piezometers will be measured monthly between June and September, 2004, using a calibrated electric well probe or steel tape in accordance with standard USGS methodology (Stallman, 1983). The head difference between the internal piezometer water level and the external creek stage provides an indication of the vertical hydraulic gradient and the direction of flow between the creek and groundwater. When the piezometer head exceeds the creek stage, groundwater discharge into the creek can be inferred. Similarly, when creek stage exceeds the head in the piezometer, loss of water from the creek to groundwater storage can be inferred. Surface water temperature, groundwater temperature, and conductivity will be measured during each of the monthly piezometer surveys. Stream reaches with significant groundwater input (especially during low flow periods) should have similar water chemistry to area groundwater. Measurements will be made with properly maintained and calibrated field meters in accordance with standard USGS methodology.

Thermal Infrared (TIR) Surveys

Approximately nine miles of the creek in the study area will be flown to provide simultaneous thermal infrared (TIR) and visible video coverage that are geographically linked through a Global Positioning System (GPS) and geo-referenced through a Geographic Information System (ArcView GIS). This area includes the mouth of the Skookum Creek to the headwaters. Each thermal image will cover a ground area of approximately 100 x 150 meters and have a spatial resolution of less than 0.5 meters per pixel. The thermal imagery will be calibrated to measured water temperatures and will have an accuracy of approximately +/- 0.4 degrees C. The TIR survey will occur sometime between July 20 and August 20. Data collection will be timed to capture the maximum daily stream temperatures, which typically occur between 14:00 and 17:00 hours.

Synoptic Surveys

Four field synoptic surveys will be conducted during summer 2004 low flow season, one each in June, July, August, and September. Each survey will be completed in one day. The following measurements will be made during each survey (see Table 4 for a complete list):

- Stream cross-sectional dimensions: width (bankfull and wetted), depth, and stream bank slope.
- Velocity (*in situ*) and estimated flow.
- Temperature (*in situ*).
- Piezometer water level.
- Associated creek stage.

The monitoring locations are shown in Figure 8.

Data Collection Timeline

The schedule for field work is as follows.

May 3-7	Reconnaissance survey of the creek to locate areas of least riparian vegetation and inputs from lakes and ponds.
May 24-28	Temperature, humidity data logger and peizometers installed at critical locations.
June 1-15	First synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
June 15-30	Download temperature and humidity data from data loggers.
July1-15	Second synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
July 30-August 30	Stream and habitat surveys.
August 1-15	Third synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
August 15-30	Download temperature and humidity data from data loggers.
September 1-15	Fourth synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
September 30-October15	Download final temperature data, remove tidbits.

*Timeline may change due to irregularities in stream discharge and/or weather to ensure data quality.

Data Quality Objectives

Accuracy objectives for field measurements are presented in Table 5. Experience at Ecology has shown that duplicate field thermometer readings consistently show a high level of precision, rarely varying by more than 0.2°C. Therefore, replicate field thermometer readings were not deemed to be necessary and will not be taken. Accuracy of the thermograph data loggers and the field thermometers will be maintained through pre- and post-calibration in accordance with Timber-Fish-Wildlife (TFW) Stream Temperature Survey Manual (Schuett-Hames et al., 1999) to document instrument bias and performance at representative temperatures. A certified reference thermometer will be used for the calibration. The certified reference thermometer, manufactured by HB Instrument Co. (part number 61099-035, serial number 2L2087) is certified to meet ISO9000 standards and calibrated against National Institute of Standards and Technology (NIST) traceable equipment. The field thermometer is a Brooklyn Alcohol Thermometer (model number 67857). If there is a temperature difference of greater than 0.2°C, the field thermometer's temperature readings will be adjusted by the mean difference.

Table 5. Summary of Field Measurement Parameters, Targets for Accuracy of Reported Values, and Methods.

Parameter	Accuracy or Reporting Values	Method
Air Temperature Water Temperature	± 0.4°C ± 0.2°C	Onset Stowaway Onset Stowaway
Relative Humidity	± 3 %	Onset RH
Velocity	± 2 % of reading	AquaCalc Pro with Pigmy meter

Manufacturer specifications report an accuracy of ±0.2°C for the Onset StowAway (-5°C to +37°C) and ±0.4°C for the Onset StowAway (-20°C to +50°C). If the mean difference between the NIST thermometer and the thermal data loggers differs by more than the manufacturer's reported specifications, the thermal data logger will not be used during field work.

Accuracy of the Onset Stowaway will be evaluated by comparing the downloaded data to reference temperature readings taken with a calibrated field thermometer during site visits throughout the sampling season. The mean difference between the downloaded data and the reference thermometer readings will be calculated. Data are only acceptable if they do not exceed a maximum mean difference of 0.2 °C.

Representativeness of the data is achieved by a sampling scheme that accounts for land practices, flow contribution of tributaries, and seasonal variation of in-stream flow and temperatures in the basin. Extra calibrated field thermometers and thermograph data loggers will be taken in the field during site visits and surveys to minimize data loss due to damaged or lost equipment.

Measurement and Sampling Procedures

Field sampling and measurement protocols will follow those described in the TFW Stream Temperature Survey Manual (Schuett-Hames et al., 1999) and the Watershed Assessment Section (WAS) protocol manual (WAS, 1993). Temperature recorders will be installed in the water and air in areas which are representative of the surrounding environment and are shaded from direct sunlight. To safeguard against data loss, data from the loggers will be downloaded midway through the sampling season. The stream surveys will collect data according to TFW protocols for bankfull width and depth, wetted width and depth, canopy closure, and channel type. The RMZ characteristics, such as width, cover, size, density, and windthrow, will also be recorded during the surveys (Schuett-Hames et al., 1999).

Quality Control Procedures

Variation for field sampling will be addressed with a field check of the instruments with a handheld thermometer at all thermograph sites upon deployment, retrieval, and also once during the sampling season (mid-August). Field sampling and measurements will follow quality control protocols described in the WAS protocol manual (WAS, 1993) and the TFW stream temperature manual (Schuett-Hames et al., 1999). The Onset Stowaway Tidbits will be pre- and post-calibrated in accordance with TFW stream temperature survey protocol to document instrument bias and performance at representative temperatures. A certified reference thermometer will be used for the calibration.

Data Analysis, Modeling Procedures, and Results

From the raw data collected at each monitoring location for temperature, the maximum, minimum, and daily average will be determined. The data will be used to characterize the water temperature regime of the basin and to determine periods when the water temperatures are above state numeric water quality standards. Estimates of groundwater inflow will be calculated by constructing a water mass balance from continuous and instantaneous streamflow data and piezometer studies.

A model will be developed for observed and critical conditions. Critical conditions for temperature are characterized by a period of low-flow and high-water temperatures. The model will be used to develop load allocations for heat energy to the stream. Sensitivity analysis will be run to assess the reliability of the model results.

GIS coverages of riparian vegetation in the study area will be created from information collected during the 2004 temperature field study and analysis of the most current digital orthophotos. Riparian forest coverages will be created by qualifying four attributes: tree height, species and/or combinations of species, percent vegetation overhang, and the average canopy density of the riparian forest. All four attributes of vegetation in the riparian zone on the right and left bank will be sampled from GIS coverages of the riparian vegetation along the stream at 30-meter to 100-meter intervals using the Ttools extension for Arcview that was developed by the Oregon Department of Environmental Quality (ODEQ, 2001). Other spatial data that will be estimated at each transect location include stream aspect, elevation within the riparian area, and topographic shade angles to the west, south, and east.

Data collected during this TMDL effort will allow the development of a temperature simulation methodology that is both spatially continuous and which spans full-day lengths. The GIS and modeling analysis will be conducted using three specialized software tools:

- ODEQ's Ttools extension for Arcview (ODEQ, 2001) will be used to sample and process GIS data for input to the HeatSource/Shadealator and QUAL2Kw models.

- Ecology's shade calculator (Ecology, 2003) will be used to estimate effective shade along the Mainstem Skookum Creek. Effective shade will be calculated at 50 to 100-meter intervals along the streams and then averaged over 500 to 1000-meter intervals for input to the QUAL2Kw model.

- The QUAL2Kw model (Pelletier and Chapra, 2004)) will be used to calculate the components of the heat budget and simulate water temperatures. QUAL2Kw simulates diurnal variations in stream temperature for a steady flow condition. QUAL2Kw will be applied by assuming that flow remains constant for a given condition such as a seven-day or one-day period but key variables are allowed to vary with time over the course of a day. For temperature simulation, the solar radiation, air temperature, relative humidity, headwater temperature, and tributary water temperatures are specified or simulated as diurnally varying functions. QUAL2Kw uses the kinetic formulations for the components of the surface water heat budget that are described in Chapra (1997). Diurnally varying water temperatures at 500 to 1000-meter intervals along the Mainstem Skookum Creek will be simulated using a finite difference numerical method.

- The thermal infrared surveys would help locate stream segments where temperatures are warmer and where riparian vegetation is absent. The survey also shows cooler stream segments resulting from either riparian shade or groundwater. The longitudinal temperature profile developed from thermal infrared survey will provide a basis for comparison and calibration of model predicted longitudinal temperature profiles.

- Groundwater surveys will be used to provide a mass balance on flows and stream temperatures. The cooling effect of groundwater inflow on stream temperature will also be evaluated and modeled.

- The natural conditions provision of the water quality standard will be the basis of the load allocations in the temperature TMDL (WAC 173-201A-070(2)): "Whenever the natural conditions of said waters are of a lower quality than the criteria assigned, the natural conditions shall constitute the water quality criteria."

- The natural condition of temperature will be approximated by the system potential temperature, which is an evaluation of the combined effect of hypothetical conditions with mature riparian vegetation, reduction of channel width, and increases in groundwater inflows.

- The load allocations are expected to result in water temperatures that are equivalent to the temperatures that would occur under natural conditions. Therefore, the load allocations are expected to result in water temperatures that meet the water quality standard.

- The load allocation for effective shade is the maximum potential effective shade that would occur from mature riparian vegetation. This will be predicted using the QUAL2Kw model.

Reporting Schedule

The reporting schedule for this project is as follows:

January 2005	Draft Report Due to Unit Supervisor.
February 2005	Draft Report Due to Ecology's Southwest Regional Office and the Squaxin Island Tribe.
April 2005	Draft Report Sent for External Review.
June 2005	Final Report to Printer.
July 2005	EIM Data Entered into Ecology's Database System.

Project Organization

The roles and responsibilities of Ecology staff involved in this project are provided below:

Anise Ahmed, Project Manager, Watershed Ecology Section, Environmental Assessment Program.
Responsible for overall project management. Defines project objectives, scope, and study design. Responsible for writing the project QA Project Plan and final technical report. Manages the data collection program. Oversees and coordinates field sampling by the Squaxin Island Tribe. Writes the TMDL technical study report.

John Konovsky, Temperature Study Lead Field Investigator, Squaxin Island Tribe.
Responsible for review and approval of the QA Project Plan. Coordinates and conducts all field investigations.

Christine Hempleman, TMDL Lead, Water Quality Program, Southwest Regional Office (SWRO).
Reviews and comments on QA Project Plans and reports. Coordinates local outreach and information exchange about the technical study and local development of implementation and monitoring plans between Ecology and local planning groups. Supports data collection as part of the TMDL implementation monitoring.

Kim McKee, Unit Supervisor, Water Quality Program, Southwest Regional Office (SWRO).
Responsible for review and approval of the QA Project Plan and final report

Kelly Susewind, Section Manager, Water Quality Program, SWRO.
Responsible for approval of TMDL submittal to EPA.

Will Kendra, Section Manager, Watershed Ecology Section, Environmental Assessment Program.
Responsible for approval of the QA Project Plan and final report.

Karol Erickson, Unit Supervisor, Water Quality Studies Unit, Environmental Assessment Program.
Responsible for review and approval of the QA Project Plan and final report

Cliff Kirchmer, Quality Assurance Officer, Environmental Assessment Program.
Responsible for review and approval of the QA Project Plan. Available for technical assistance on quality assurance issues and problems during the implementation and assessment phases of the project.

References

Batts, D. and K. Seiders. 2003. Totten and Eld Inlets Clean Water Projects, Final Report. Washington State Department of Ecology. Publication Number 03-03-010.

Brown, L. C. and Barnwell, T. O. 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS, EPA/600/3-87-007, USEPA, Athens, Georgia, 189 pp.

Chapra, S. C. 1997. Surface Water Quality Modeling. McGraw-Hill Publishing Company.

Chapra, S. C. 2001. Water Quality Modeling Workshop for TMDLs, Washington State Department of Ecology, Olympia, Washington, June 25-28, 2001.

Chen, Y. D. 1996. Hydrologic and Water Quality Modeling for Aquatic Ecosystem Protection and Restoration in Forest Watersheds: A Case Study of Stream Temperature in the Upper Grande Ronde River, Oregon. Ph.D. Dissertation. University of Georgia. Athens, Georgia.

Cleland, B., N. Jewett, S. Ralph, and S. Butkus. 2000. Simpson Northwest Timberlands Temperature Total Maximum Daily Load. Washington State Department of Ecology. Publication Number 00-10-047.

DOH. 2003. Threatened Shellfish Growing Areas. April 2003. Washington State Department of Health, Shellfish Protection Program. http://www.doh.wa.gov/ehp/sf/Pubs/Threatareas02.pdf Olympia, Washington.

Ecology. 2000. DRAFT - Instantaneous Flow Measurements: Determination of Instantaneous Flow Measurements of Rivers and Streams. Stream Hydrology Unit, Environmental Assessment Program, Washington State Department of Ecology, Olympia, Washington.

Ecology. 2003. Shade.xls - A Tool for Estimating Shade from Riparian Vegetation. Washington State Department of Ecology, Olympia, Washington. http://www.ecy.wa.gov/programs/eap/models/.

ODEQ. 2001. Ttools 3.0 User Manual. Oregon Department of Environmental Quality. Portland, Oregon. http://www.deq.state.or.us/wq/TMDLs/WQAnalTools.htm.

ODEQ Website. 2000. Heat Source Methodology Review. http://waterquality.deq.state.or.us/wq/HeatSource/HeatSource.htm. Oregon Department of Environmental Quality.

Ott, W. R. 1995. Environmental Statistics and Data Analysis. CRC Press LLC. Boca Raton, Florida, 313 Pages.

Pelletier, G. and S. Chapra. 2004. QUAL2Kw. Documentation and User Manual for a Modeling Framework to Simulate River and Stream Water Quality. Draft Publication. Washington State Department of Ecology, Olympia, Washington. http://www.ecy.wa./programs/eap/models/.

Schuett-Hames, D., A. Pleus, E. Rashin, and J. Matthews. 1999. TFW Monitoring Program Method Manual for the Stream Temperature Survey. Prepared for the Washington State Department of Natural Resources Under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-005. DNR # 107. June.

Schuett-Hames and H. R. Flores. 1993. Environmentally Sensitive Areas: Selected Sites of Mason County. Squaxin Island Tribe, Shelton, Washington. 23 Maps.

Seiders, K. R. 1999. Totten and Eld Inlet Clean Water Projects: Annual Report. Washington State Department of Ecology. Environmental Assessment Program. Publication Number 99-316.

Stallman, R. W. 1983. Aquifer-Test Design, Observation and Data Analysis: Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter B1, 26 p.

Taylor, K., T. Moreland, and M. Stevie. 1999. Little Skookum Inlet Watershed Assessment. Squaxin Island Tribe, Shelton.

WAS. 1993. Field Sampling and Measurement Protocols for the Watershed Assessments Section. Publication Number 93-e04. Washington State Department of Ecology, Olympia, Washington.