Stillaguamish River Temperature Total Maximum Daily Load

Quality Assurance Project Plan

by
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Introduction

The Stillaguamish River Basin includes portions of Snohomish and Skagit Counties in Washington. The study area also includes three tributaries to the Skagit River. Ecology's assessment of the Stillaguamish Watershed identified the system as a high priority for development of a Total Maximum Daily Load (TMDL) for temperature. The purpose of the Stillaguamish River Temperature TMDL is to characterize the water temperature in the basin and establish load and wasteload allocations for the heat sources to meet water quality standards for surface water temperature. This study was initiated because of the 303(d) listings of river segments which are water quality limited for temperature.

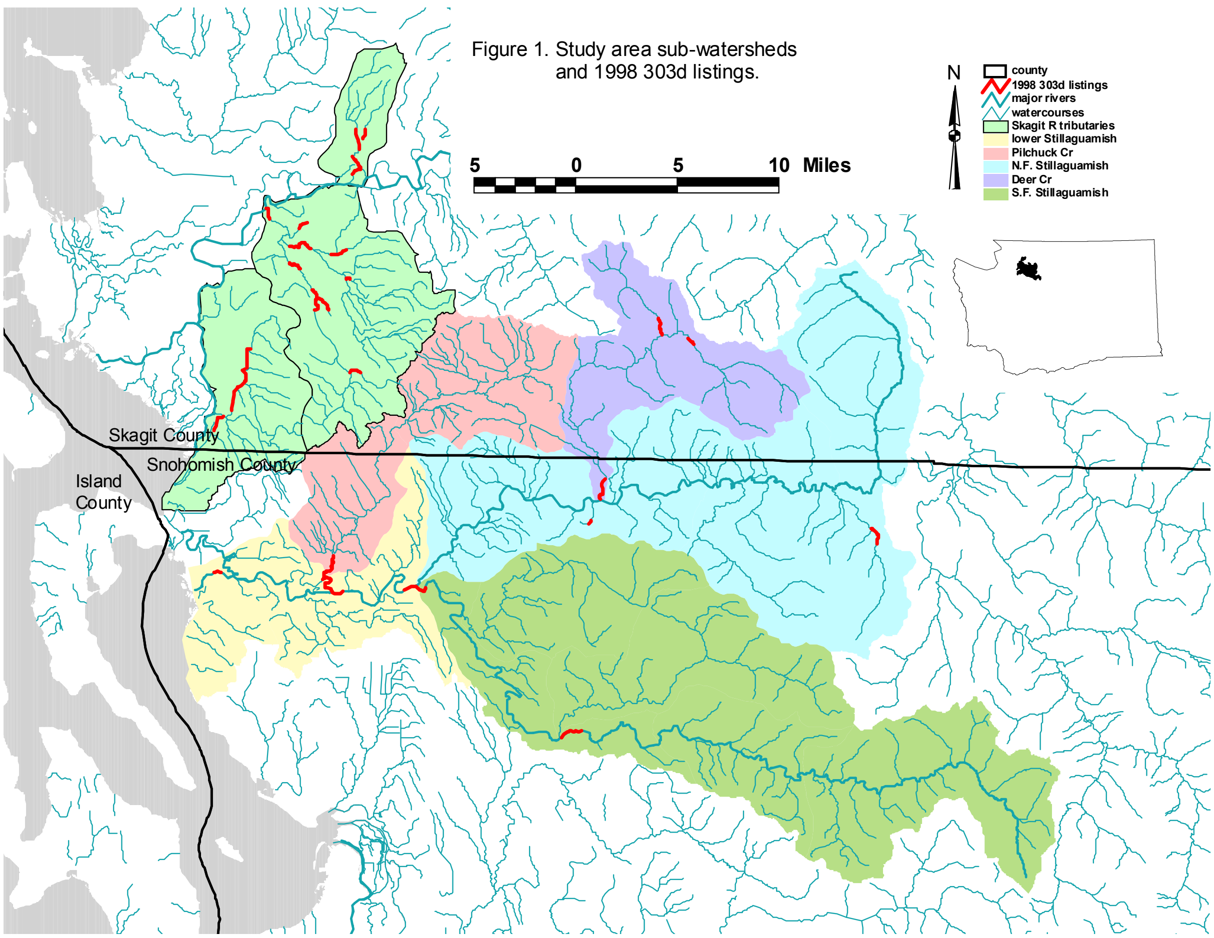


Figure 1. Study area sub-watersheds and 1998 303d listings.

In total the study area has 29 segments that are listed for not meeting water quality criteria for temperature. Table 1 provides a list of all river and stream segments identified as limited according to the Water Quality Standards for Surface Waters of the State of Washington. Temperature problems in the basin may or may not be limited to the segments reported on the 303(d) list. Therefore, this study will address the 303(d) listed segments and those in other regions of the study area as well.

Table 1. 1998 303d listings for temperature in the study area.

Watercourse Name	WRIA	Township	Range	Section	WBID	IIP303D_ID
CARPENTER CREEK	3	33N	04E	20	WA-03-1011	YA61IC1.949
CARPENTER CREEK	3	33N	04E	17	WA-03-1011	YA61IC3.631
CARPENTER CREEK	3	33N	04E	09	WA-03-1011	YA61IC6.016
DEER CREEK	5	32N	07E	08	WA-05-1021	PA13UD0.049
DEER CREEK	5	34N	07E	36	WA-05-1021	PA13UD25.160
FISHER CREEK	3	33N	04E	30	WA-03-1012	JK73SN5.516
HANSEN CREEK	3	35N	05E	29	WA-03-1019	PU87PF0.989
HANSEN CREEK	3	35N	05E	20	WA-03-1019	PU87PF1.507
HANSEN CREEK	3	35N	05E	17	WA-03-1019	PU87PF3.966
HIGGINS CREEK	5	32N	07E	20	WA-05-1025	BH79GG1.583
LITTLE DEER CREEK	5	34N	07E	35	WA-05-1023	EX67XM0.000
MUD LAKE CREEK	3	34N	04E	11	None10	IL21OS1.366
NOOKACHAMPS CREEK	3	34N	04E	04	WA-03-1017	LZ60MT0.000
NOOKACHAMPS CREEK	3	34N	04E	14	WA-03-1017	LZ60MT6.701
NOOKACHAMPS CREEK	3	34N	04E	25	WA-03-1017	LZ60MT10.063
NOOKACHAMPS CREEK	3	33N	05E	08	WA-03-1017	ZZ50GP0.000
NOOKACHAMPS CREEK, E.F.	3	34N	04E	11	WA-03-4200	DV97DN0.895
NOOKACHAMPS CREEK, E.F.	3	34N	05E	19	WA-03-4200	FE06WU0.000
OTTER POND CREEK	3	34N	04E	25	None5	GK78TY0.000
PILCHUCK CREEK	5	31N	05E	06	WA-05-1018	VJ74AO0.000
PILCHUCK CREEK	5	32N	05E	31	WA-05-1018	VJ74AO0.155
RED CREEK	3	35N	05E	17	None6	TL30EW0.000
STILLAGUAMISH RIVER	5	32N	04E	31	WA-05-1010	ZO73WL2.236
STILLAGUAMISH RIVER	5	31N	05E	06	WA-05-1010	QE93BW23.077
STILLAGUAMISH RIVER	5	31N	05E	02	WA-05-1010	QE93BW35.996
STILLAGUAMISH RIVER, N.F.	5	33N	09E	22	WA-05-1020	XN66YN5.302
STILLAGUAMISH RIVER, S.F.	5	31N	05E	02	WA-05-1040	SN06ZT0.000
STILLAGUAMISH RIVER, S.F.	5	30N	07E	07	WA-05-1040	SN06ZT26.213
TURNER CREEK	3	34N	05E	18	None12	EI77IQ1.402

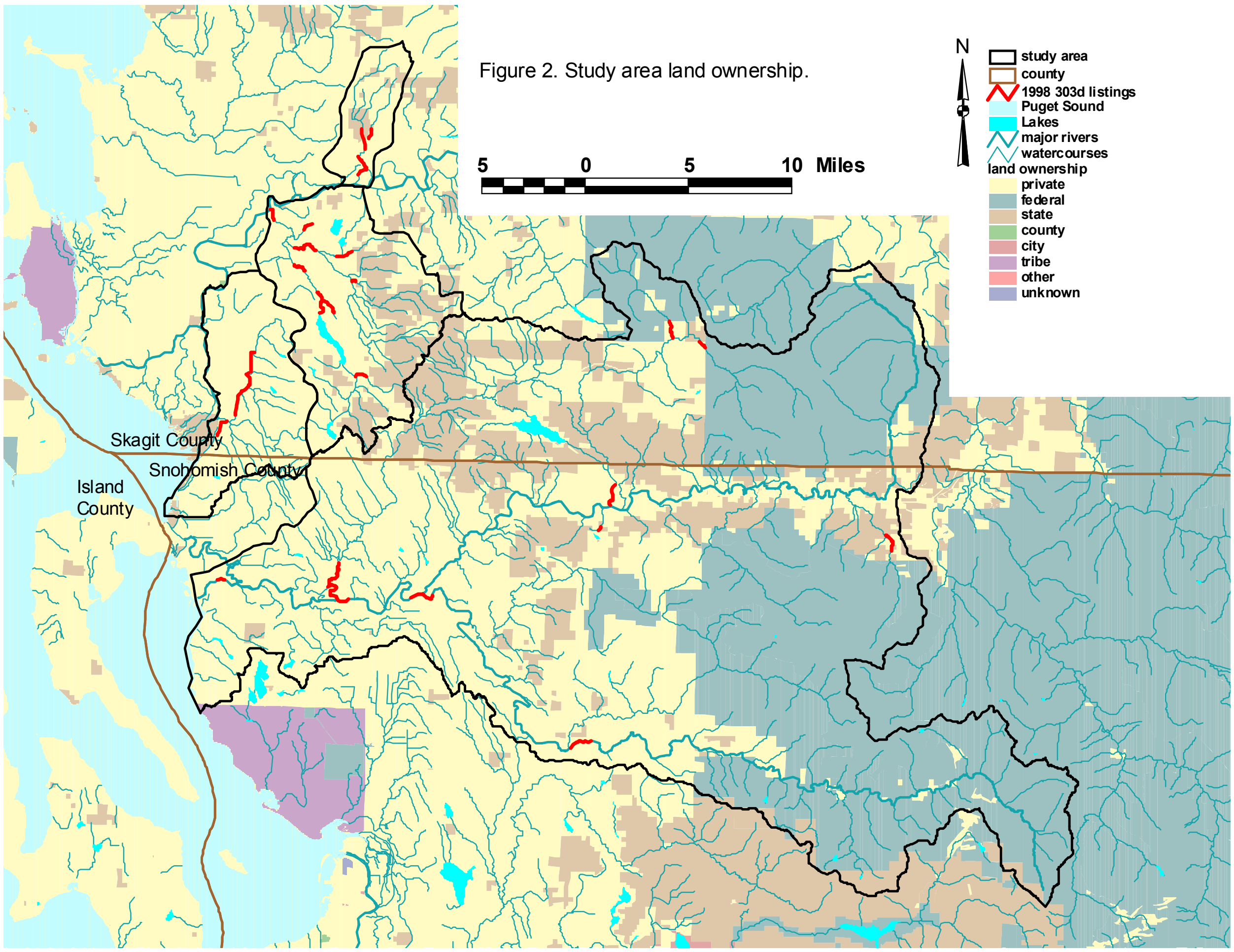
Project Description

Study Area

The Stillaguamish River drains an area of approximately 680 square miles (1,770 square kilometers) and includes more than 4,618 miles (7,432 Km) of streams and rivers. The river enters Puget Sound at Stanwood, 16 miles (25 Km) north of Everett in northwest Snohomish County. Elevations in the watershed range from sea level to about 6,844 ft (2,086 m) on Whitehorse Mountain.

The study area also includes three sub-watersheds of the Skagit River watershed: Carpenter/Fisher Creek, Nookachamps Creek, and Hansen Creek (Figure 1).

The watershed includes a mix of public and private land in portions of Snohomish and Skagit counties (Figure 2). The upper watershed is part of the Mount Baker Snoqualmie National Forest and is managed by the U.S. Forest Service. The State of Washington DNR owns portions of the middle watershed areas. The remainder of the watershed is mostly privately owned.



The climate is typically maritime with cool, wet winters and mild summers. Precipitation and streamflows are highest in late autumn and winter as a result of rainstorms and rain-on-snow events. During the summer dry period, the lowest flows occur usually from July through September.

Project Objectives

1. Characterize summer (June – October) water temperature in the Stillaguamish River Watershed.
   - Compile existing data, including:
     - Data collected during an ongoing study performed by the Stillaguamish Tribe.
     - Data collected by Snohomish County.
   - Collect additional data at selected sites throughout the basin.

2. Develop a predictive computer temperature model of the Stillaguamish River stream network.
   - Model the basin temperature regime at critical conditions.
   - Evaluate the ability of various watershed Best Management Practices (BMPs) to reduce water temperatures to meet water quality standards.

3. Establish a Total Maximum Daily Load for temperature in the Stillaguamish River Watershed.
   - Develop TMDL for thermal load to the stream.
   - For ease of implementation, load allocations will be reported in terms of a surrogate for solar radiation such as shade, size of tree necessary in the riparian zone to produce adequate shade, channel width, channel width-to-depth ratio, or miles of active eroding stream banks.

Sources of Thermal Pollution

Many environmental variables affect water temperature, including (Brown, 1969):

- Solar radiation.
- Air temperature.
- Stream width, depth, and velocity.
- Stream flow.
- Tributary and ground water influence.

Sources of nonpoint thermal pollution are:

- Riparian vegetation disturbance and loss of shade due to:
  - Removal of trees and shrubs for pasture, crops, or timber harvest.
  - Heavy grazing by livestock.
  - Conversion from forest to pasture land.
- Channel morphology impacts resulting from:
  - Removal of large woody debris by commercial harvest and agriculture.
  - Increased sediment loading from agriculture, timber harvest, and roads.
  - Channel constraint/diking for agriculture and flood control.
  - Bank instability/erosion and sedimentation from removal of root structure and increased land use practices in the watershed.

- Hydrologic changes from:
  - Extraction of water for irrigation or other purposes.
  - Altered stream flow patterns from urbanized and timber harvest areas resulting in increased spring runoff and decreased summertime base flows.

These activities potentially raise the water temperature of rivers due to increased solar input resulting from lack of shade along streams, reduction of river water volume from withdrawals, and increased water surface area from sedimentation, making the channel wider and shallower.

Beneficial Uses

Rivers and streams in the study area are a mix of Class A (excellent) and AA (extraordinary) as defined by the Water Quality Standards for Surface Waters of the State of Washington (Hicks, 2000; Chapter 173-201A-030 WAC):

Stillaguamish River from mouth to north and south forks (river mile 17.8)	Class A
Stillaguamish River, north fork, from mouth to Squire Creek (river mile 31.2)	Class A
Stillaguamish River, north fork, from Squire Creek (river mile 31.2) to headwaters	Class AA
Stillaguamish River, south fork, from mouth to Canyon Creek (river mile 33.7)	Class A
Stillaguamish River, south fork, from Canyon Creek (river mile 33.7) to headwaters	Class AA
Carpenter, Fisher, Nookachamps, and Hansen Creeks	Class A

The water quality standards establish beneficial uses of waters and incorporate specific numeric and narrative criteria for parameters such as water temperature. The criteria are intended to define the level of protection necessary to support the beneficial uses (Rashin and Graber, 1992). The beneficial uses of the waters in this specific area are:

- *Recreation:* fishing and swimming.
- *Fish and Shellfish:* Anadromous salmonid species in the basin generally use streams at elevations below 750 meters depending on preference for low gradients and natural barriers to upstream migration such as bedrock falls. Anadromous species include chinook salmon, pink salmon, chum salmon, coho salmon, steelhead trout, cutthroat trout, and dolly varden char.
- *Water Supply & Stock Watering:* agriculture extracts water for irrigation and stock watering.
- *Wildlife habitat:* Riparian areas are used by a variety of wildlife species which are dependent on the habitat.

Numeric freshwater quality criteria for Class A streams state that temperature shall not exceed 18.0°C due to human activities. When natural conditions exceed 18.0°C, no temperature increases will be allowed which will raise the receiving water temperature greater than 0.3°C. If natural conditions are below 18.0°C, incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C or bring the stream temperature above 18.0°C at any time (Chapter 173-201A-030 WAC).

Numeric freshwater quality criteria for Class AA streams state that temperature shall not exceed 16.0°C due to human activities. When natural conditions exceed 16.0°C, no temperature increases will be allowed which will raise the receiving water temperature greater than 0.3°C. If natural conditions are below 16.0°C, incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C or bring the stream temperature above 16.0°C at any time (Chapter 173-201A-030 WAC).

Temperature is a water quality concern because most aquatic organisms, including salmonids, are "cold-blooded," and are strongly influenced by water temperature (Schuett-Hames et al., 1999). Temperature is a major concern in the Stillaguamish River and its tributaries because of the use of its waters by chinook salmon, a species listed in 1999 as threatened under the Endangered Species Act, as a migration corridor and as spawning and rearing habitat. Elevated temperature and altered channel morphology resulting from various land use activities, such as timber harvest and agriculture in the area, limit available spawning and rearing habitat for chinook salmon and other anadromous salmonids.

Historical Data Review

Snohomish County's Surface Water Management (SWM) section summarized the available data in the Stillaguamish River (Thornburgh and Williams, 2000). The Stillaguamish Tribe, the Tulalip Tribes, Ecology, and SWM have coordinated monitoring to provide coverage of the North and South Forks of the Stillaguamish River and some of the major tributaries since 1990.

North and South Forks of the Stillaguamish River

SWM found the best water quality in the Stillaguamish watershed in the North and South Forks, except for high sediment levels. The Tulalip Tribes concluded that the North Fork (1400 tons per day from a watershed area of 285 mi^2) delivered over nine times the load of suspended sediment compared with the South Fork (130 tons per day from a watershed area of 255 mi^2) even though the watersheds have similar area.

The major sources of fine sediments in the North Fork were identified in Deer Creek, Boulder River, the Hazel Slide on the North Fork above Oso, and the agricultural reach between Oso and Arlington. The Stillaguamish Tribe also measured high sediment levels in Montague Creek. The major sources of sediment in the South Fork were identified as above Redbridge, the Goldbasin Slide, and Mallardy and Boardman Creeks. Low levels of sediment were observed in Jim and Canyon Creeks. The Tribes found highest sediment loads where susceptible soils coincided with forest harvesting practices.

Violations of the temperature standard were measured in the North Fork at Highway 9, South Fork at Arlington, Deer Creek, Boardman Creek, Jordan Creek, and Slurry Creek.

Stillaguamish Lower Mainstem

The Tulalip and Stillaguamish Tribes and Snohomish County SWM have monitored the lower mainstem continuously since 1988. Temperatures above 20 degrees C have been recorded at Arlington, Silvana, and Marine Drive. Temperatures at the lower part of the mainstem near Marine Drive during the hottest periods are approximately 2 degrees C warmer than upper parts of the lower mainstem at Arlington. During 1996 a temperature logger at the Interstate 5 crossing recorded temperatures over 22 degrees C on 12 days, and 16 percent of the time temperatures were over 20 degrees C.

Pilchuck Creek

Snohomish County SWM found Pilchuck Creek to be among the best for water quality compared with other tributaries to the lower Stillaguamish. A temperature logger near the mouth of Pilchuck Creek in 1996 recorded temperatures over 22 degrees on ten days, and 10 percent of the time temperatures were greater than 20 degrees C.

Church Creek

Church Creek is a major tributary to the Stillaguamish that enters from the north and lies to the west of Pilchuck Creek. Temperatures measured by the Snohomish County SWM were found to meet water quality standards on all sampling occasions, although a temperature logger in 1996 observed three days when temperatures reached 18 degrees C.

Portage Creek

Portage Creek is a tributary to the lower Stillaguamish River that enters from the south, draining the city of Arlington and the area west of the city. Temperature loggers placed in the creek in 1996 recorded temperatures below 16 degrees C in the upper reaches, and below 17 degrees C in the lower reaches. Groundwater inflows were credited by SWM with keeping temperatures cool even though much of the riparian area has little vegetative shade.

Glade Bekken (Tributary 30)

Glade Bekken, formerly know as Tributary 30 to the Stillaguamish, was named by watershed residents in 1998. Glade Bekken drains about 3 square miles and flows into the Stillaguamish from the south and to the west of Portage Creek. Temperatures in Glade Bekken are generally low due to largely intact riparian vegetated areas and ground water inflows.

Tributaries to the Lower Skagit River

Three tributaries to the lower Skagit River are included in the study area: Carpenter/Fisher Creek, Nookachamps Creek, and Hansen Creek. Each of these tributaries is on the 1998 303(d) list for temperature. The Skagit System Cooperative submitted data from the summer of 1997 to Ecology to document exceedence of the temperature standard for the following segments (Figure 1):

- three excursions beyond the criterion on Fisher Creek above Hwy 530 Bridge,
- three excursions beyond the criterion on Carpenter Creek at Hill Ditch/Carpenter Creek below Hwy 534 Bridge,
- four excursions beyond the criterion on Carpenter Creek on Hill Ditch /Carpenter Creek below Cedardale Road Bridge,
- three excursions beyond the criterion on Carpenter Creek on Hill Ditch/ Carpenter Creek above the Johnson Creek confluence,
- five excursions on Nookachamps Creek beyond the criterion above Francis Road,
- five excursions beyond the criterion on Nookachamps Creek under Knapp Road Bridge,
- three excursions on Nookachamps Creek beyond the criterion under Hwy 9 bridge,
- seven excursions on Nookachamps Creek beyond the criterion below Highway 9 bridge below Big Lake,
- three excursions beyond the criterion on Nookachamps Creek above McMurray Shores Drive,
- two excursions beyond the criterion on the East Fork of Nookachamps Creek below Beaver Lake Road Bridge,
- two excursions beyond the criterion on Nookachamps Creek above Highway 9 (at RM 13.2),
- two excursions beyond the criterion on Hansen Creek above River Road,
- two excursions beyond the criterion on Hansen Creek above Hansen Creek Road,
- two excursions beyond the criterion on Hansen Creek below Highway 20.

Study Design

Approach

The Stillaguamish Temperature TMDL will be developed for heat, which is considered a pollutant under Section 502(6) of the Clean Water Act. Heat energy processes that control energy transfer to and from a given volume of water include:

- ♦ Shortwave solar radiation.
- ♦ Longwave radiation exchange between the stream and both the adjacent vegetation and the sky.
- ♦ Evaporative exchange between the stream and the air.
- ♦ Convective exchange between the stream and the air.
- ♦ Conduction transfer between stream and the streambed.
- ♦ Groundwater exchange with the stream (Adams and Sullivan, 1989).

If the heat energy entering the water from these sources is greater than the heat energy leaving the water, then stream water temperature will rise. Water temperature change, which is an expression of heat energy exchange per unit volume, is most strongly influenced by solar radiation input (Adams and Sullivan, 1989).

Increased solar radiation levels at the stream surface due to anthropogenic causes result from the following conditions:

- Channel widening (increased width-to-depth ratios) that increases the stream surface area exposed to energy processes.
- Riparian vegetation disturbance that reduces stream surface shading through reductions in riparian vegetation height and density (shade is commonly measured as percent effective shade).
- Reduced summertime baseflows resulting from instream withdrawals, wells in hydraulic continuity with the stream, or altered stream flow patterns due to land use practices that increase runoff instead of storage.

The sources of increased stream temperatures will be examined in the Stillaguamish Temperature TMDL to produce a loading capacity and load and wasteload allocations for the heat load sources. Loading capacity and allocations will be established via field surveys and development of a predictive computer temperature model. Field data collection and assessment will be governed by the data set requirements of the computer temperature model.

Model Data Requirements

Six water quality/temperature models gathered from EPA, Timber-Fish-Wildlife, and Oregon DEQ were evaluated to determine the most practical application to model the temperature regime in the basin (Sullivan et al., 1990; USEPA, 1997; Oregon DEQ website, 2000). Criteria for model selection were ease of use, public availability, reliability of predictions, data requirements, region for which it was developed, applicability to the Stillaguamish region, and model sensitivity to selected parameters. At this point the preferred model is the HeatSource model developed by Oregon's Department of Environmental Quality (ODEQ). Ecology will compile data to represent all of the necessary model parameters using either new data collected during this study, or existing data collected by Ecology or others.

Data Collection and Ecology Field Surveys

Data collection, compilation, and assessment will be governed by the data set requirements of the computer temperature model (Table 2). The data will be assembled from local third party studies and Ecology field surveys. Local third party studies include investigations by Snohomish County, Skagit County, the Stillaguamish Tribe, the Tulalip Tribe, the Skagit System Cooperative, the U.S. Geological Survey, and other potential data sources that are discovered during the study.

Table 2. Data collection needs.

	PARAMETER	MODEL HeatSource Required Data	Collected By: Ecology Field Sampling	GIS or Orthophoto Coverages	Other Specify
Flow	discharge - tributary	x	x		
	discharge (upstream & downstream)	x	x		USGS gage
	flow regression constants	x			calculated from field data
	flow velocity	x	x		
	Bed friction factor	x			calculated from flow data
	groundwater inflow rate/discharge	x	x		ecology hydrogeology study
General	calendar day/date	x			calendar
	elevation/altitude	x		x	
	latitude	x		x	
	longitude	x		x	
Physical	channel azimuth/stream aspect	x		x	
	percent bedrock	x	x	x	
	reach length	x		x	
	stream bank slope/incision	x	x		
	topographic shade angle	x		x	
	stream gradient	x		x	
	Width - average channel	x	x	x	
	width - wetted	x	x	x	
Temperature	temperature - groundwater	x	x		mean annual air or T of ground
	temperature - water downstream	x	x		
	temperatures - water upstream	x	x		
	temperature/rel. humidity - air	x	x		airport as check
Vegetation	vegetation overhang	x	x		Vegetation information will be gathered at representative sites throughout the basin. Orthophotos will be used to determine vegetation characteristics for remaining stream reaches
	canopy density	x	x	x	
	distance to shading vegetation	x	x	x	
	vegetation height	x	x	x	
	vegetation width	x	x	x	
	vegetation shade angle	x		x	calc using GIS from veg ht @ width
Weather	% possible sun/cloud cover	x			weather station
	solar radiation	x			calc from day, latitude, and cloud
	wind speed/velocity	x	x		weather station and field checks

Four types of Ecology field surveys will be conducted: 1) continuous flow monitoring at selected gaging stations, 2) temperature monitoring, 3) riparian surveys of the streams and rivers in the study area, and 4) remote sensing of surface temperatures using FLIR.

1. Continuous Flow Monitoring

Six on-site continuous flow-monitoring stations (Table 3) are tentatively planned to be established in the study area during the duration of the sampling season – June through October. Periodic and synoptic flow measurements, which include data from the six continuous flow-monitoring stations and 22 additional instantaneous flows taken during stream surveys, will be used to establish flow-rating curves and estimate groundwater inflows by difference. The tidally influenced Carpenter Creek sub-basin will be monitored using synoptic flow measurements taken at low tide. The on-site data loggers for flow gaging will be installed and maintained by

Ecology's Environmental Assessment Program's Stream Hydrology Unit. The standard protocols for the on-site continuous data loggers will follow those currently established by Ecology's Hydrology Unit (Ecology, 2000).

Table 3. Tentatively planned flow measurement stations.

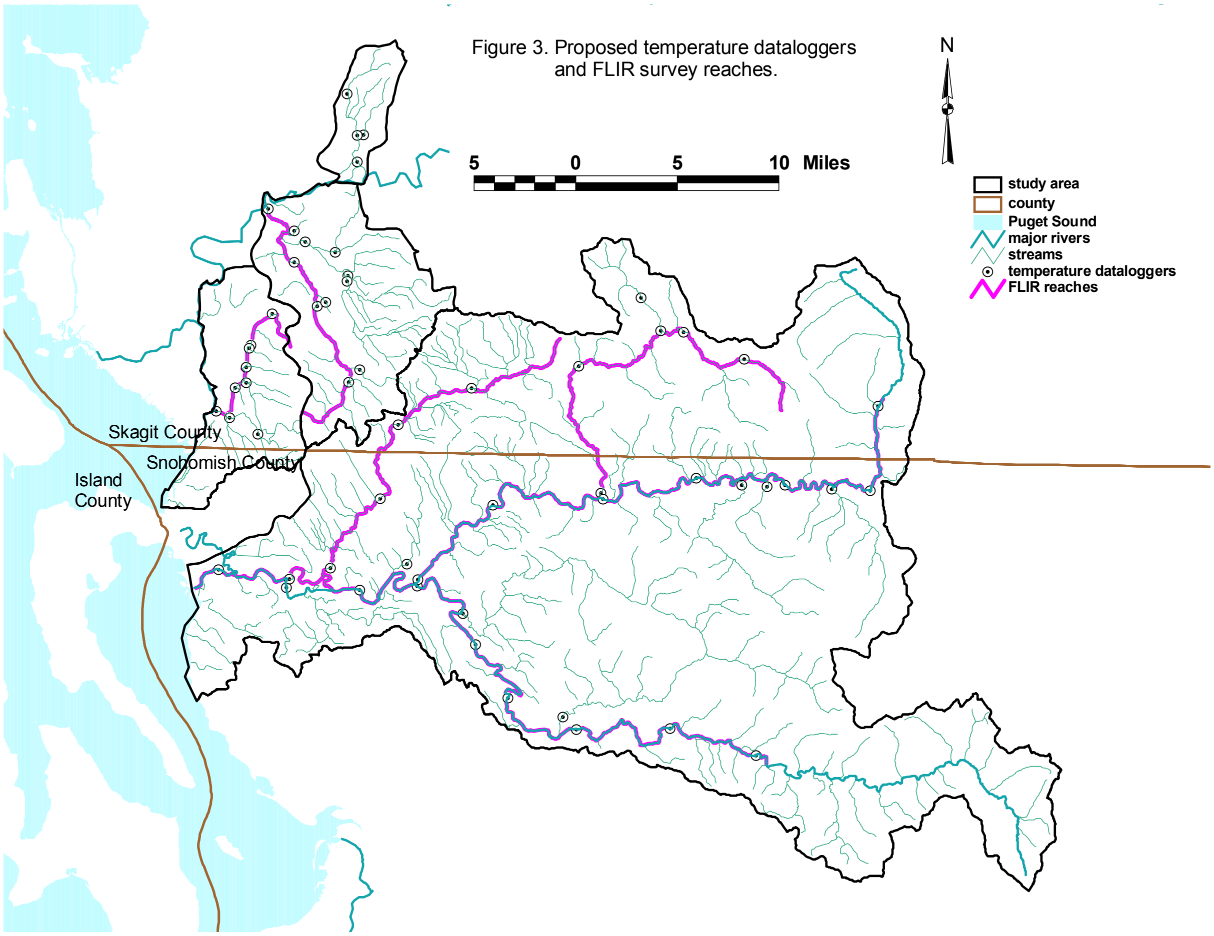
station id	station name	latitude (decimal degrees N, NAD27)	longitude (decimal degrees W, NAD27)	continuous flow gage	periodic or synoptic flow measurement
03C02	Carpenter Creek at SR534	48.341110	-122.323060		X
03C04	Carpenter Creek at Little Mtn Rd	48.395560	-122.284440		X
03EF01	East Fork at SR9	48.446390	-122.251110		X
03EF02	East Fork at Beaver Lake Rd	48.424170	-122.208610	X	
03F01	Fisher Creek at Franklin Rd	48.319720	-122.328890		X
03H01	Hansen Creek at Hoehn Rd	48.503890	-122.197500		X
03N01f	Nookachamps at Swan Lake Rd	48.453900	-122.270300		X
03N04	Nookachamps abv Big Lake	48.345560	-122.205830		X
05A01	Armstrong Creek	48.218610	-122.134170		X
05B01	Boulder R at SR530	48.278382	-121.779877		X
05C01	Canyon Creek nr mouth	48.114720	-121.958890		X
05D01	Deer Creek at Bunker house	48.277220	-121.929720	X	
05D04	Deer Creek at FR 1820	48.368060	-121.778610		(low flow only)
05F01	French Creek at SR530	48.277713	-121.753489		X
05J01	Jim Creek at mouth	48.184440	-122.075830		X
05LD01	Little Deer at mouth	48.387500	-121.868610		(measure twice)
05M04f	Mainstem Stilly ww gage at I-5	48.197000	-122.208600		X
05NF03	N.F. Stillaguamish at 221st	48.267220	-121.927220		(from bridge)
05NF07	N.F. Stillaguamish abv Crevice Cr	48.335938	-121.636011	X	X
05P01	Pilchuck Creek nr mouth	48.213890	-122.217220	X	X
05P04f	Pilchuck Creek blw Bear Cr	48.343100	-122.055300		(low flow only)
05SF02	S.F. Stillaguamish at River Meadows Park	48.162089	-122.061209	X	
05SF05	S.F. Stillaguamish at Verlot	48.089170	-121.776390	X	
05SF05f	S.F. Stillaguamish at Verlot bridge	48.086200	-121.760300		X
05SQ01	Squire Cr nr mouth	48.277003	-121.683980		X
05B110	EMTS station nr Darrington	48.279830	-121.702350		X

2. Temperature Sites

Air and water temperature sites will be established at 54 locations (Table 4 and Figure 3). Water and air temperature will be measured with Onset StowAway Tidbits. The temperature data loggers will be installed in a location in the stream or riparian forest that is shaded from direct sunlight by vegetation if possible, or placed within a shaded enclosure. They will be placed in an area which is 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, usually about one to three meters into the vegetated riparian zone from the edge of the near stream disturbance zone and about one meter off the ground. Relative humidity will also be measured at five of the stations using Onset data loggers.

Table 4. Tentatively planned stations for continuous monitoring of water temperature, air temperature, and relative humidity.

station id	station name	latitude (decimal degrees N, NAD27)	longitude (decimal degrees W, NAD27)	water temperature site	air temperature site	air temperature and relative humidity site
03B01	Bulson Creek nr mouth	48.345000	-122.311390	X	X	
03C01	Carpenter Creek nr mouth	48.323890	-122.342220	X		X
03C02	Carpenter Creek at SR534	48.341110	-122.323060	X	X	
03C03	Carpenter Creek at Stackpole Rd	48.371110	-122.307780	X	X	
03C04	Carpenter Creek at Little Mtn Rd	48.395560	-122.284440	X	X	
03CL01	Unkn Trib from Clear Lake	48.453610	-122.263610	X	X	
03EF01	East Fork at SR9	48.446390	-122.251110	X	X	
03EF02	East Fork at Beaver Lake Rd	48.424170	-122.208610	X	X	
03F01	Fisher Creek at Franklin Rd	48.319720	-122.328890	X	X	
03F02	Fisher Creek at Starbird Rd	48.309170	-122.296670	X	X	
03H01	Hansen Creek at Hoehn Rd	48.503890	-122.197500	X	X	
03H02	Hansen Creek at Hwy 20	48.521940	-122.198060	X	X	
03H03	Hansen Creek at Hansen Cr Rd	48.559170	-122.208060	X	X	
03J01	Johnson Creek at Johnson Rd	48.356110	-122.313060	X	X	
03N01	Nookachamps nr mouth	48.467500	-122.292220	X	X	
03N02	Nookachamps abv Barney Lake	48.431390	-122.263060	X	X	
03N03	Nookachamps blw Big Lake	48.400280	-122.237220	X	X	
03N04	Nookachamps abv Big Lake	48.345560	-122.205830	X	X	
03S01	Sandy Creek at Kanoko Ln	48.368330	-122.308060	X	X	
03T01	Turner Creek at Beaver Lake	48.439440	-122.219720	X	X	
03U01	Mundt Cr nr mouth	48.424170	-122.208610	X	X	
03U02	Unkn Trib at Otter Pond Rd	48.403060	-122.227500	X	X	
03U03	Unkn Trib at Lake Cavanaugh	48.356390	-122.191110	X	X	
03U04	Red Creek nr Hwy 20	48.523330	-122.191110	X	X	
05A01	Armstrong Creek	48.218610	-122.134170	X	X	
05B01	Boulder R at SR530	48.278382	-121.779877	X	X	
05C01	Canyon Creek nr mouth	48.114720	-121.958890	X	X	
05D01	Deer Creek at Bunker house	48.277220	-121.929720	X		X
05D02	Deer Creek 8km blw Little Deer	48.361181	-121.956715	X	X	
05D03	Deer Creek abv Little Deer	48.386110	-121.865830	X	X	
05D04	Deer Creek at FR 1820	48.368060	-121.778610	X	X	
05F01	French Creek at SR530	48.277713	-121.753489	X	X	
05J01	Jim Creek at mouth	48.184440	-122.075830	X	X	
05LD01	Little Deer at mouth	48.387500	-121.868610	X	X	
05M01	Mainstem Stillaguamish at Marine Drv	48.210560	-122.335280	X		X
05M02	Mainstem Stillaguamish at Larson Rd	48.200000	-122.262780	X	X	
05M03	Mainstem Stillaguamish at Norman Rd	48.205560	-122.260830	X	X	
05M04	Mainstem Stillaguamish at 27th Ave	48.198610	-122.186940	X	X	
05NF01	N.F. Stillaguamish at Twin Rivers	48.206390	-122.125280	X	X	
05NF02	N.F. Stillaguamish abv Cicero bridge	48.267780	-122.008330	X	X	
05NF03	N.F. Stillaguamish at 221st	48.267220	-121.927220	X	X	
05NF04	N.F. at Interpretive pull-out	48.278330	-121.809720	X	X	
05NF05	N.F. Stillaguamish at 311th St	48.279346	-121.733659	X	X	
05NF06	N.F. Stillaguamish nr FR28	48.275827	-121.642991	X	X	
05NF07	N.F. Stillaguamish abv Crevice Cr	48.335938	-121.636011	X	X	
05P01	Pilchuck Creek nr mouth	48.213890	-122.217220	X	X	
05P02	Pilchuck Creek at SR9	48.268060	-122.164170	X	X	
05P03	Pilchuck Creek blw Crane Cr	48.321390	-122.141110	X	X	
05P04	Pilchuck Creek blw Bear Cr	48.344440	-122.071670	X	X	
05SF02	S.F. Stillaguamish at River Meadows Park	48.162089	-122.061209	X		X
05SF03	S.F. Stillaguamish at Littlefield	48.126940	-122.024720	X	X	
05SF04	S.F. Stillaguamish at Robe	48.096670	-121.812500	X	X	
05SF05	S.F. Stillaguamish at Verlot	48.089170	-121.776390	X		X
05SQ01	Squire Cr nr mouth	48.277003	-121.683980	X	X	



The field schedule during 2001 shows approximate dates of datalogger installation and data download:

May 15 – Jun 22	-	Temperature data logger (tidbit) installation
May 15 – Jun 22	-	Continuous flow monitoring devices installed and launched
Jun 1 - Oct 30	-	Instantaneous flow measurements for rating curves (6-7 flow measurements per station)
Jul 15 – Aug 31	-	FLIR survey with synoptic flow measurements taken on tributaries and mainstem (schedule depends on FLIR contractor)
Jun 25-29	-	Download temperature data from loggers
Jul 16-20	-	Download temperature data from loggers
Jul 15 - Aug 31	-	Stream and Habitat Surveys
Sep 10-13	-	Download temperature data from loggers
Oct 22-31	-	Download final temperature data, remove tidbits

3. Riparian Stream and Habitat Surveys

TFW 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 mid-July to mid-August 2001 at the temperature sites established by Ecology (Table 3). Field measurements taken every 30-meters over a 300-meter thermal reach will consist of bankfull width and depth, wetted width and depth, canopy closure, stream gradient and channel type. Riparian Management Zone (RMZ) characteristics, such as active channel width, cover, size, density, bank erosion, and windthrow, will also be recorded during the surveys. Instream flow will be measured at the upstream and downstream boundaries of the thermal reaches. Hemispherical photography will be used to measure effective shade and canopy density at all water temperature stations, and at additional selected locations, to ground-truth the range of vegetation classes digitized from inspection of digital orthophotos.

4. Forward Looking Infrared Radiometer (FLIR) Thermal Imagery

Approximately 230 miles of streams and rivers in the study area (Figure 3) will be flown to provide simultaneous thermal (FLIR) and visible video coverage that are geographically linked through a Global Positioning System (GPS) and geo-referenced through a Geographic Information System (ArcView GIS). 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 FLIR survey will occur sometime between July 15 and August 31. Data collection will be timed to capture the maximum daily stream temperatures, which typically occur between 14:00 and 17:00 hours. The contractor for the FLIR survey will be Watershed Sciences, LLC.

Project Organization

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

Greg Pelletier: Project manager and Principal Investigator for the TMDL technical study, Environmental Assessment Program, Watershed Ecology Section. Responsible for overall project management. Defines project objectives, scope, and study design. Responsible for review of the project QAPP, data modeling, and final report. Responsible for primary contact with the client and stakeholders. Responsible for communications and reporting of the technical study.

Dustin Bilhimer: Field Lead, Environmental Assessment Program, Watershed Ecology Section. Coordinates and conducts all field sampling and data collection. Assists in defining project objectives, scope, and study design. Assists with data analysis and modeling tasks. Responsible for writing the portions of the quality assurance project plan (QAPP) and draft and final report related to data collection, field methods, data quality review and analysis.

Dave Garland and Margot Stiles: Water Quality Program TMDL Lead, Northwest Regional Office (NWRO). Reviews and comments on QAPP 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.

Brad Hopkins, Chuck Springer, and Robert Garrigues: Environmental Assessment Program, Environmental Monitoring and Trends Section, Stream Hydrology Unit. Responsible for the deployment and maintenance of continuous flow loggers and staff gages on mainstem tributaries. Responsible for producing records of hourly flow data at select sites for the study period.

Kevin Fitzpatrick: Water Quality Program, Section Supervisor, NWRO. Reviews and comments on QAPP and reports. Responsible for approval of TMDL submittal to EPA.

Will Kendra: Environmental Assessment Program. Section supervisor of the Watershed Ecology Section. Responsible for approval of the project QAPP and final report.

Karol Erickson: Environmental Assessment Program. Unit supervisor of the Watershed Studies Unit. Responsible for review of the project QAPP, final technical report, and budget of the technical study.

Cliff Kirchmer: Environmental Assessment Program, Quality Assurance Unit. Responsible for review of QAPP. Available for technical assistance on quality assurance issues and problems.

Data Quality Objectives

Accuracy objectives for field measurements are presented in Table 5. Experience at the Department of 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 will be maintained by a two-point comparison between the thermograph, a field thermometer, and a certified reference thermometer. The Certified Reference thermometer, manufactured by HB Instrument Co. (part no. 61099-035, serial no. 2L2087), is certified to meet ISO9000 standards and calibrated against National Institute of Standards and Technology traceable equipment. The field thermometer is a Brooklyn Alcohol Thermometer (model no. 67857). First, the field thermometer's accuracy will be evaluated by comparison to a certified reference thermometer. 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. Secondly, the accuracy of the thermal data loggers will be evaluated by comparison to the field thermometer. Manufacturer specifications report an accuracy of ±0.2°C for the Onset StowAway Tidbit (-5°C to +37°C) and ±0.4°C for the Onset StowAway Tidbit (-20°C to +50°C). If the mean difference between the field 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.

Representativeness of the data is achieved by a sampling scheme that accounts for land practices, flow contribution of tributaries, and seasonal variation of instream 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

Table 5. Summary of field measurements, target accuracy or reporting values, and methods.

Parameter	Accuracy or Reporting Values	Method[1]
Temperature	Air ± 0.4°C Water ± 0.2°C	Thermograph
Velocity	± 0.5 feet/second	Marsh-McBirney model 201 current meter

[1]Method references: TFW Stream Survey, 1999; WAS, 1993

Measurement and Sampling Procedures

Field sampling and measurement protocols will follow those described in the TFW Temperature Stream Survey Manual (Scheutt-Hames, 1999) and the WAS protocol manual (WAS, 1993). Temperature thermographs 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 several times 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, stream gradient, and channel type. Riparian Management Zone (RMZ) characteristics, such as width, cover, size, density, and windthrow, will also be recorded during the surveys. Instream flow will be measured at the upstream and downstream boundaries of the thermal reach (Scheutt-Hames et al., 1999).

Quality Control Procedures

Variation for field sampling will be addressed with a field check of the instruments with a hand held 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 Survey Manual (Schuett-Hames et al., 1999). The Optic 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. At the completion of the monitoring, the raw data will be adjusted for instrument bias, based on the pre- and post-calibration results, if the bias is greater than ±0.2°C (Schuett-Hames et. al, 1999).

Data Analysis and Modeling Procedures

From the raw data collected at each monitoring location 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 (18°C). Estimates of groundwater inflow will be calculated by constructing a water mass balance from continuous and instantaneous streamflow data.

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 and wasteload allocations for heat energy to the stream. Sensitivity analysis will be run to assess the reliability of the model results.

Reporting Schedule

The reporting schedule for this project is as follows:

October, 2002	Draft report
January, 2003	Final report to printer

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