Quality Assurance Project Plan

Woodland Creek Temperature Total Maximum Daily Load

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303(d) listings addressed in this study:
Woodland Creek: WA-13-1500, 18N, 01W, 16, JH31LN

Ecology EIM number: BZAL0001

Approvals

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Abstract

The purpose of the Woodland Creek temperature study is to characterize mainstem and tributary surface water temperature regimes, channel morphology, hydrology, and streamside vegetation within the watershed. Woodland Creek is a small (29.7 mi^2) watershed located in Thurston County, Washington, and is the largest tributary to the Henderson Inlet of Puget Sound.

Analysis of historical surface water temperature data in Woodland Creek show that violations of the Class AA criteria of 16°C occur only in the upper portions of the mainstem. Streamflow in this portion of the creek is derived from a series of shallow lakes which, during the summer months, frequently reach temperatures of 24°C. In addition, this same section of Woodland Creek can be characterized as influent or ‘losing’ (to the surrounding aquifer) and is frequently dry between the months of May and November. It is believed that these two conditions exert a major influence on surface water temperatures in the upper portions of Woodland Creek.

A predictive computer temperature model of the Woodland Creek stream system will be used to calculate the components of the heat budget and simulate surface water temperatures. Field data will be used to build model components and verify model output.

Results from this study will assist in determining whether surface water temperature exceedences in the upper portions of Woodland Creek are the result of natural or anthropogenic influences. A temperature TMDL will be initiated if surface water temperature violations in Woodland Creek are due to anthropogenic influences. The TMDL technical assessment will use effective shade as a surrogate measure of heat flux.

Air and water temperature sites will be established at seven mainstem and three tributary locations for a period of five months (June-October). Periodic flow measurements, channel morphology, and streamside vegetation data will be collected at all ten sites.

Introduction

The Woodland Creek watershed is located in Thurston County, Washington, and is the largest tributary to the Henderson Inlet of Puget Sound. Ecology's assessment of the Woodland Creek watershed identified the system as a high priority for development of a Total Maximum Daily Load (TMDL) for temperature. The purpose of the Woodland Creek temperature study is to characterize surface water temperatures in the mainstem and tributaries and, if necessary, develop a TMDL and establish load and wasteload allocations for all heat sources in order to meet the state's water quality standards for temperature. This study was initiated as a result of the 1996 and 1998 303(d) listing of Woodland Creek. Data supporting this listing was acquired by Ecology between 1991 and 1993 (Patterson and Dickes 1994).

The Woodland Creek Temperature study is part of a larger TMDL study that addresses water quality concerns in the Henderson Inlet and Nisqually River watersheds. The Henderson Inlet watershed (sited within Water Resource Inventory Area (WRIA) 13) is located entirely in Thurston County. The technical study to address water quality concerns in the watershed will be split into two years. The first study year will focus on temperature, pH, fecal coliform, and dissolved oxygen in Woodland Creek; pH and fecal coliform in Dobbs Creek; pH, fecal coliform, and dissolved oxygen in Sleepy (Libby) Creek; and fecal coliform, pH, and dissolved oxygen in Woodard Creek. The second study year will focus on dissolved oxygen and fecal coliform in Henderson Inlet with continuing data collection of dissolved oxygen and fecal coliform in Woodland Creek. This Quality Assurance (QA) Project Plan applies only to the Woodland Creek temperature TMDL, and an additional QA Project Plan will be developed for year two (Sargeant, in press).

The 1998 303(d) listings addressed in this study:

Waterbody	T	R	S	New ID	Old WBID	Parameter
Woodland Creek	18N	01W	16	JH31LN	WA-13-1500	Temperature

Project Description

Study Area

Woodland Creek drains an area of approximately 29.7 square miles (76.8 square kilometers) and flows through northeast Olympia and central Lacey before emptying into Henderson Inlet as a fourth-order stream (Figure 1). Four lakes connected by extensive wetlands form a horseshoe-shaped chain which makes up the headwaters of Woodland Creek. Hicks Lake flows into Pattison Lake and then Long Lake; all three lie between 152 and 157 feet above sea level (USGS 1989). Long Lake drains to Lake Lois, which lies at a slightly lower elevation of about 145 feet above sea level. The creek then flows through a narrow, steep-sided ravine through second-growth forest before continuing north through rolling hills and finally wetlands at the south end of Henderson Inlet.

The climate is typically maritime with cool dry summers and mild wet winters. Annual precipitation averages about 51 inches (Western Regional Climate Center http://www.wrcc.dri.edu/index.html).

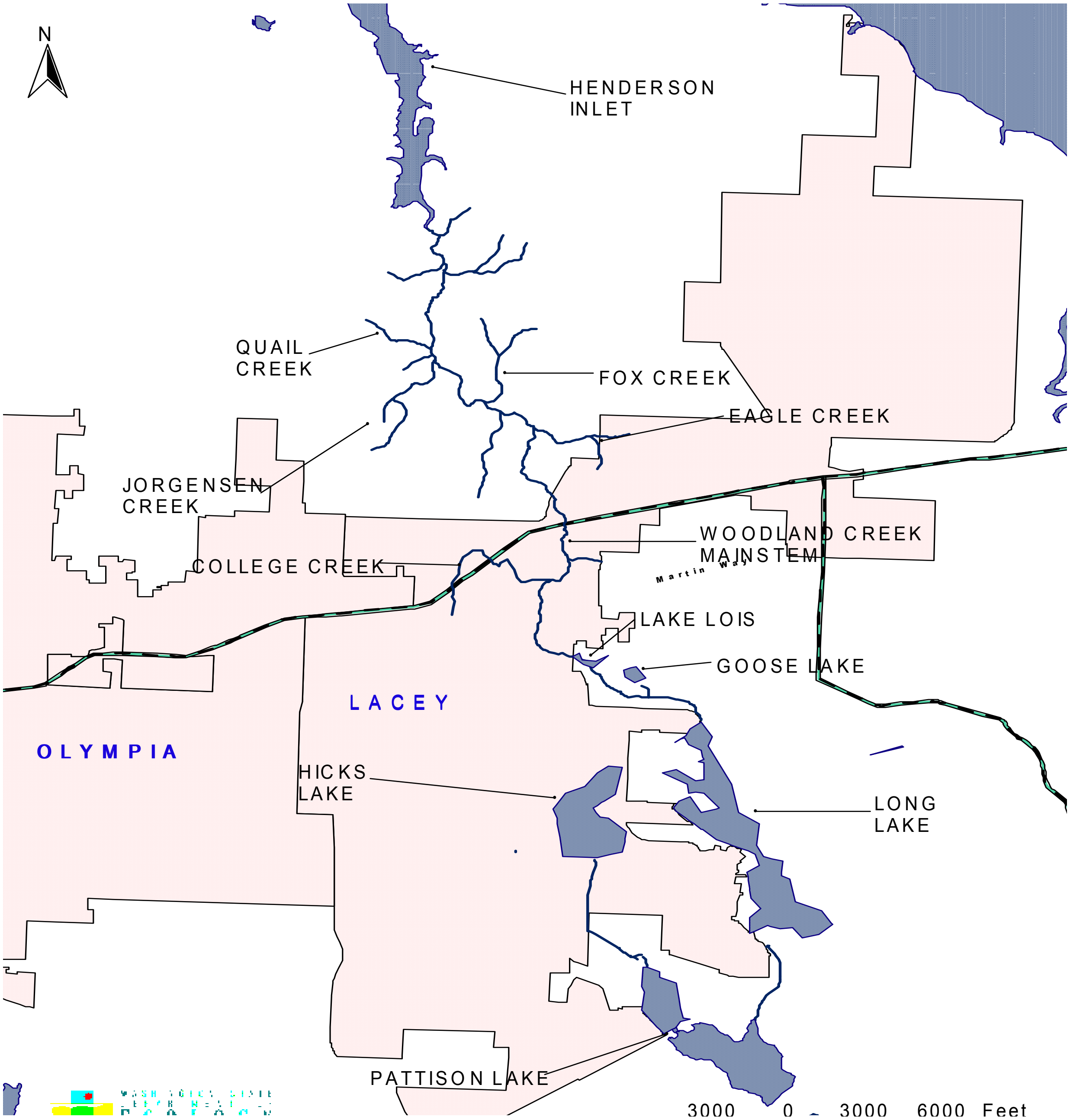

Figure 1. Woodland Creek Study Site.

Winter precipitation typically consists of frequent, light-to-moderate intensity rainfall while summer storms produce short, moderate-to-high intensity rainfall.

The hydrology of Woodland Creek is characterized by high peak flows that develop quickly during heavy rains and decline rapidly with the cessation of rainfall, and prolonged periods of low or no flow during the summer and early fall. The peak flows become more extreme near the mouth, and the dry reaches occur primarily from Lake Lois to just downstream (north) of Martin

Way. A major groundwater contribution to the creek in the form of springs occurs just north of Martin Way near the Nisqually Trout Farm. Woodland Creek originates in a large wetland and lakes complex that includes Hicks, Pattison, and Long Lakes. The soils, lakes, wetlands, and flat topography all contribute to the significant available storage capacity found in the headwaters of Woodland Creek.

The Woodland Creek basin is one of the fastest growing areas in Thurston County (Thurston County Department of Water and Waste Management 1995). The basin still contains substantial areas of undeveloped forests, and the dominant land use is suburban-density residential development. Residential subdivisions are spreading rapidly in the area around the headwater lakes and near the mouth of the basin. Residential development is most dense in the southern portion of the basin. Homes and roads in this portion of the basin lined approximately 80% of the lake shorelines and 16% of the creek shorelines in 1987 (Thurston County Department of Water and Waste Management 1995) and have likely increased since then.

Agricultural and forest lands and large lot single family homes predominate in the northern Woodland Creek basin. Tree farms, livestock pastures, and hay fields constitute typical agricultural uses. Livestock entering some parts of the creek and drainage channels in the northern basin trample the vegetation and contribute to stream bank erosion and water quality problems; however, much of the creek's shoreline is still forested. Most of the Woodland Creek corridor within the city of Lacey is zoned Open Space/Institutional, which provides a higher level of protection for riparian areas than residential zoning (Lacey Municipal Code Chapter 16.48). Approximately 55% of the Henderson Inlet watershed is located inside Thurston County's urban growth management area (GMA). The urban GMA was designed to encourage the concentration of growth in the urban areas where adequate public facilities and services exist or can be efficiently provided.

Problems associated with development (urbanization) in the basin include increased and contaminated runoff, decreased groundwater recharge, and removal of riparian vegetation. Specific land use activities of potential concern to this study include:

- Removal of riparian vegetation, leading to erosion and sedimentation and subsequent channel widening and increased width-to-depth ratios.
- Increased impervious areas resulting in decreased infiltration and groundwater recharge and reduced streamflow in dry periods.

The study area includes mainstem Woodland Creek and three major tributaries--Jorgensen Creek, Fox Creek, and Eagle Creek. Temperature recording devices will be placed along mainstem and tributary stations from approximately one mile upstream of the mouth of Woodland Creek south to the outlet of Long Lake. Sufficient temperature data exist in Hicks, Pattison, and Long Lakes to characterize their thermal regimes and examine their role as a natural and seasonal heat source to downstream Woodland Creek.

Project Objectives

1. Characterize Summer and Early Fall (June – October) Water Temperatures in Woodland Creek and Tributaries

- Compile existing data, including:
  - ♦ Data collected by Ecology during 1991 and 1993.
  - ♦ Data collected by the Stream Team.
  - ♦ Date collected by Thurston County Storm and Surface Water Program.
- Collect additional temperature and flow data at selected sites throughout the basin.
- Determine whether Woodland Creek and/or tributaries exceed the Class AA temperature water quality standard due to anthropogenic factors, as well as the extent of the impairment.

2. Develop a Predictive Computer Temperature Model of the Woodland Creek 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. If Necessary, Establish a Total Maximum Daily Load for Temperature in the Woodland Creek Watershed

- Develop TMDL for thermal load to the stream.
- For ease of implementation, load allocations will be reported in terms of a surrogate(s) 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

The Woodland Creek TMDL will be developed for heat (i.e., incoming solar radiation). Heat is considered a pollutant under Section 502(6) of the Clean Water Act. Heat generated by solar radiation reaching the stream provides energy to raise water temperatures. Heat can be defined as molecular kinetic energy, in this case the kinetic energy of water molecules. Temperature is a scale of measurement that is proportional to the average kinetic energy of the water molecules.

The principal source of heat for small streams is the solar radiation that directly strikes the surface of the stream (Brown 1971). The amount of sunlight reaching the stream depends on the surface area of the stream and the shade provided by vegetation and topography. For a given rate of solar radiation input, temperature change is directly proportional to surface area and inversely proportional to discharge (Sullivan et al. 1990).

Summer air temperature is an important factor regulating maximum stream temperature due to the magnitude of heat exchange between the stream and surrounding air. As the water moves downstream, it exchanges (gains/loses) heat with the air passing over the water surface. When the surrounding air is warmer, the stream gains heat from the air (in addition to solar radiation). Conversely, when the surrounding air is cooler, the stream loses its heat to the air and becomes cooler.

Other factors also affect the maximum temperature regime of streams. Variation in discharge over time affects water depth and volume of water to heat. Input of water from other sources may locally influence summer stream temperatures. Groundwater entering streams is typically cooler (often creating localized cool water refuges), while warmer water entering streams from shallow lakes and open wetlands may raise stream temperatures.

Elevated summertime stream temperatures may result from anthropogenic influences. The following processes potentially affect water temperatures in Woodland Creek and tributaries:

- Reduced summertime baseflows.
- Riparian vegetation disturbance that compromises stream surface shading through reductions in riparian vegetation height and density (shade is commonly measured as percent effective shade).
- Channel widening (increased width-to-depth ratios) that increases the stream surface area exposed to solar radiation.
- Natural and manmade impoundments which act as heat sources to downstream portions of Woodland Creek.

Beneficial Uses

Woodland Creek and tributaries are designated Class AA (extraordinary) as defined by the Water Quality Standards for Surface Waters of the State of Washington (Hicks, 2000; Chapters 173-201A-030 and 173-201A-120 WAC).

The water quality standards establish beneficial uses of waters and incorporate specific numeric and narrative criteria for parameters such as water temperature. These criteria are intended to define the level of protection necessary to support 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. Anadromous species include chinook salmon, chum salmon, coho salmon, and steelhead trout.
- *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 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 concern in Woodland Creek and tributaries because of its use by salmon as a migration corridor and as spawning and rearing habitat. Elevated temperature and altered channel morphology resulting from various land use activities, such as agriculture and urban development in the area, limit available spawning and rearing habitat for Chinook salmon and other anadromous salmonids.

Historical Data Review

Woodland Creek Water Quality Assessment (Patterson and Dickes 1994)

Four sites along the mainstem of Woodland Creek were monitored before and during construction of the new Ecology Headquarters Building from January 1991 through July1993 (Figure 2). The primary objective was to assess water quality impacts resulting from runoff from construction activities. Water quality monitoring included monthly temperature measurements collected in-situ at each of the four stations. The four stations encompass a reach of Woodland Creek approximately 0.9 miles in length.

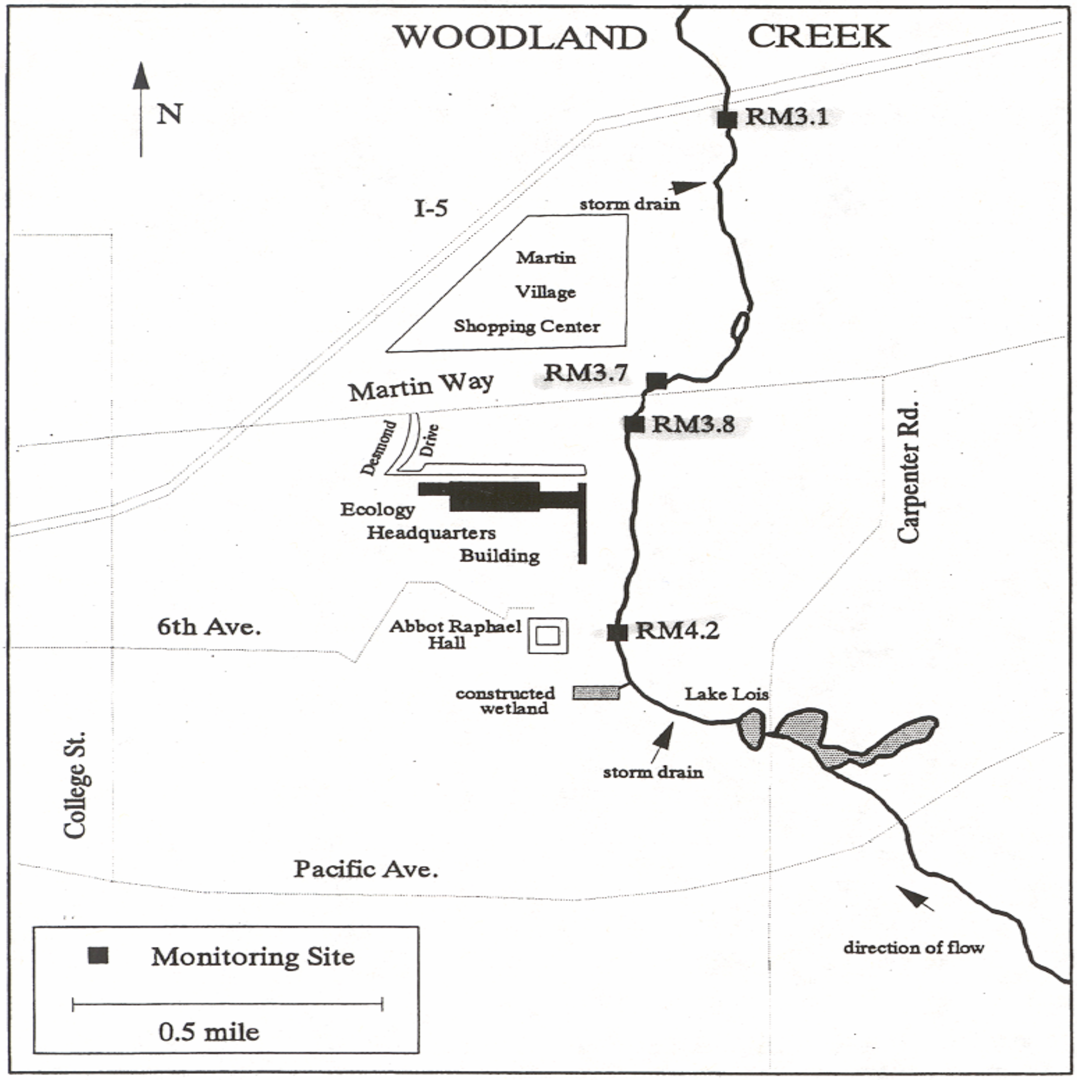

Figure 2. Monitoring Sites for Woodland Creek Water Quality Assessment, January 1991-September 1993 (Patterson and Dickes 1994).

The data show that the critical time period during which surface water temperatures approach or exceed the Class AA temperature standard of 16° C exists between the months of May and September. A second critical time period, during which low flow or no flow conditions occur, exists between river mile (RM) 4.2 and 3.7 between the months of June and the following March.

Surface water temperatures have been evaluated based on the critical time period of May to September; therefore, all percentages and average, maximum, and minimum values have been summarized from temperature data collected between this time interval. Temperature data collected outside of this time period have been excluded from analysis.

Temperature violations occurred at three of the four sites between the months of May and September with 60-80% of those measurements exceeding the Class AA standard of 16°C (n=9-10). Average surface water temperatures between RM 4.2 and RM 3.7 decreased approximately

1°C (from 17.6°C to 16.7°C). Land use in this area consists entirely of second and third growth forest, which provides ample streamside shading. Average flows between RM 4.2 and RM 3.7 during this critical time period were similar (4.2 cfs and 4.7 cfs, respectively). Average surface water temperatures between RM 3.7 and RM 3.1 decreased significantly from 16.7°C to 11.9°C. Average flows increased from 4.7 cfs to 12.5 cfs and likely reflect groundwater contributions in the area.

During portions of the study period, Woodland Creek went dry between stations RM 4.2 and RM 3.7. During this same time period, station RM 3.1 was always flowing. The average difference in discharge between station RM 3.7 and downstream station RM 3.1 during the study period was +9.6 cfs, with a minimum increase of 4.0 cfs and a maximum increase of 18.0 cfs. Groundwater inflow likely accounts for the increases in measured discharge as well as the 4.8°C average decrease in surface water temperatures (May-September) between the two stations.

Lake Lois, located approximately 0.5 miles upstream of RM 4.2, is the last in a series of lakes that make up the headwaters of Woodland Creek. Low and no flow conditions have historically occurred between Lake Lois and RM 3.7 and these natural conditions are thought to be the primary reason for water quality occasionally not meeting the Class AA criteria for temperature (Patterson and Dickes 1994).

Stream Team Program

The Stream Team Program is a program for citizens interested in protecting and enhancing water resources in north Thurston County watersheds. The program is jointly coordinated by the city of Olympia, the city of Lacey, the city of Tumwater, and Thurston County. Stream Team volunteers perform a wide array of services from planting native trees and stenciling storm drains to monitoring local streams and removing litter. Past water quality monitoring has included in-situ measurements of stream temperature at mainstem and tributary stations within the Woodland Creek watershed.

A total of nine stations, the majority of which were located in the upper portion of the watershed south of Martin Way, have in-situ stream temperature data between years 1993 and 2001 with between 1 to 27 data points. The data were collected primarily during the winter, spring, and early summer months with the majority of temperature measurements recorded every 3-6 months. Exceedences of the Class AA temperature criteria of 16°C were found at six of the nine stations with maximum temperatures ranging from 16.4°C to 24°C.

The highest mean temperatures were found at the outlets of Lake Lois (14.8°C, n=9) and Goose Pond (12.9°C, n=7), while the lowest mean temperatures were found at Woodland Creek at I-5 (10.6, n=12) and Woodland Creek at Draham Road (9.7°C, n=27). Low mean surface water temperatures were also found at the outlet of Long Lake (10.3°C, n=21).

Thurston County Water Resources Monitoring

The Thurston County Storm and Surface Water Utility and Environmental Health Division has been collecting water quality data, continuous stream flow records, lake level data, and precipitation records within waterbodies in Thurston County since 1988. The objectives of the program are to collect baseline information about the water quantity and quality of streams and lakes, identify problem areas, and track trends in stream flow and water quality over time.

Water quality and quantity data have been collected at one station along the Woodland Creek mainstem near Pleasant Glade Road. Ecology's evaluation of surface water temperatures included data from 1995 to 2001. During this time period, surface water temperatures were measured 5-6 times per year, with over two-thirds of the measurements made during the winter months. The average summer (July-Sept) surface water temperature at this station was 11.1°C (n=12) with a maximum recorded temperature of 13.8°C and a minimum recorded temperature of 11.0°C.

Study Design

Heat Energy Processes

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).

Figure 3 shows the heat energy processes or fluxes that control heat energy transfer to and from the surface of a waterbody.

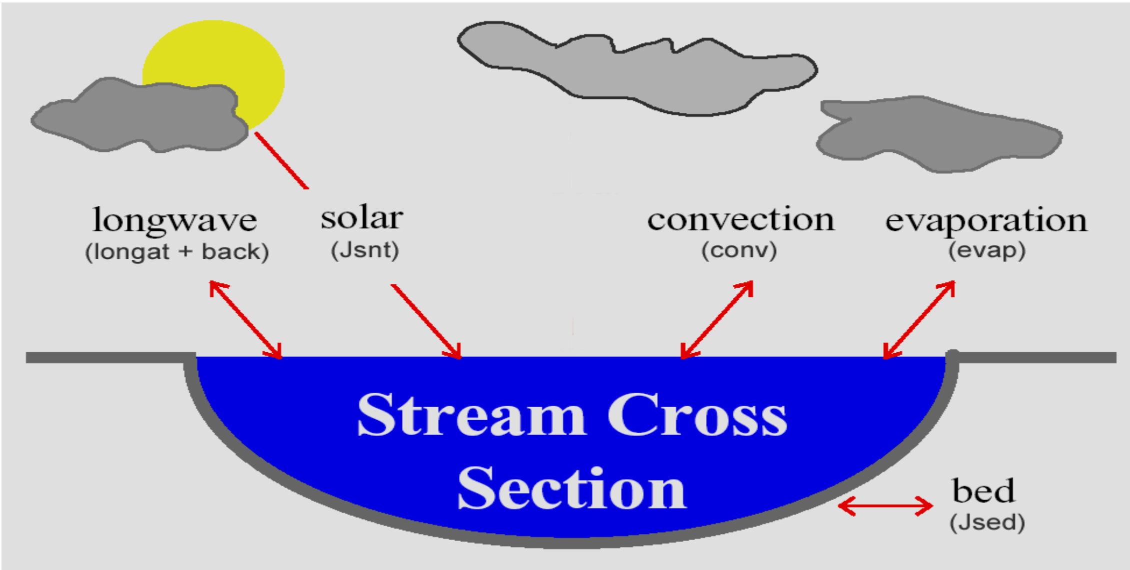

Figure 3. Surface Heat Transfer Processes that Affect Water Temperature (Net Heat Flux) = Jsnt + $long_{at}$ - $long_{back}$ ± conv - evap ± Jsed).

The solar short wave radiation flux (Jsnt) is typically the dominant component of the heat budget in unshaded streams. Other heat transfer components include: groundwater interactions with the stream, convection (heat transfer interaction between water and air) and evaporation (loss of heat and water molecules to the air). The daily changes in water temperature typically follow the same pattern as solar radiation delivered to a stream. The solar shortwave flux can be controlled by managing vegetation in the riparian areas adjacent to the stream. Shade that is produced by riparian vegetation can reduce the solar shortwave flux. The net heat flux to a stream can be reduced by increasing the shade produced by vegetation, which reduces the shortwave solar flux and causes a reduction in the water temperature of a stream during the hottest part of a day.

Other processes, such as longwave radiation and convection, also introduce energy into a stream, but usually at smaller rates when compared with solar short wave radiation in un-shaded waterbodies (Chapra, 1997; Beschta and Weatherred, 1984; Boyd, 1996). If streamflow increased the volume of water available, these same surface heat transfer processes would be in place but would usually result in a smaller temperature gain to the stream.

Mass transfer processes refer to the downstream transport and mixing of water throughout a stream system and inflows of surface water and groundwater. The downstream transport of dissolved/suspended substances and heat associated with flowing water is called advection. Dispersion results from turbulent diffusion that mixes the water column. Due to dispersion, flowing water is usually well mixed vertically. Stream water mixing with inflows from surface tributaries and subsurface groundwater sources also redistributes heat within the stream system. These processes (advection, dispersion, and mixing of surface and subsurface waters) redistribute the heat of a stream system via mass transfer. Turbulent diffusion can be calculated as a function of stream dimensions, channel roughness, and average flow velocity. Dispersion occurs in both the upstream and downstream directions. Tributaries and groundwater inflows can change the temperature of a stream segment when the inflow temperature is different from the receiving water.

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 and/or natural conditions.

The Woodland Creek temperature study will investigate current temperature conditions throughout the mainstem and tributaries and evaluate the sources of heat. If surface water temperatures exceed state standards due to anthropogenic factors, the study will produce a loading capacity for heat. Allocations will be established via field surveys and development of a predictive computer temperature model.

The installation and downloading of temperature data loggers will follow those protocols described in the Timber Fish and Wildlife (TFW) Temperature Stream Survey Manual (Schuett-Hames, 1999). Temperature dataloggers will be installed in the water and air in areas which are representative of the surrounding environment interacting with the stream, and are shaded from direct sunlight. Data from the loggers will be downloaded once in early to mid August, after peak temperatures typically occur, and again in October.

Effective shade measurements for riparian vegetation will be collected at the stream center as well as at the right and left banks using hemispherical digital photography and analyzed using the Hemi-view 2.1 software from Delta-T Devices. Sites for hemispherical photography will be selected randomly (close to a stream access point) from vegetation polygons digitized from 1:24,000 scale digital orthophotos to provide a statistically-based effective shade of each vegetation type. Vegetation types will be generally classified by species type and density as well as tree height.

Data collected during the stream surveys will follow TFW protocols for measurements of bankfull width and depth and wetted width and depth. Reaches selected for channel geometry measurements will be based on both channel gradient and land type association. All stream velocity measurements will be made following the field sampling and measurement protocols described in the Department of Ecology Watershed Assessment Section (WAS) protocol manual (WAS 1993).

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 1). The data will be assembled from Ecology field surveys.

Table 1. Dataset Requirements of Computer Temperature Model.

	PARAMETER	Effective shade	Qual2K	TIR	WDFW	Ecology
Flow	discharge - tributary		x		x	x
	discharge (upstream & downstream)		x		x	x
	flow regression constants		x			
	flow velocity		x		x	x
	groundwater inflow rate/discharge		x			x
	travel time		x			
General	calendar day/date	x	x	USGS or GIS Maps		
	duration of simulation	x	x			
	elevation - downstrean	x	x			
	elevation - upstream	x	x			
	elevation/altitude	x	x			
	latitude	x	x			
	longitude	x	x			
	time zone	x				
Physical	channel azimuth/stream aspect	x				
	cross-sectional area	x	x			x
	Manning's n value	x	x			
	percent bedrock	x	x			x
	reach length	x	x			x
	stream bank slope	x				x
	stream bed slope	x	x	Collect from USGS or GIS Maps		
	width - bankfull	x				x
	width - stream	x	x		x	x
Temperature	temperature - ground		x			x
	temperature - groundwater		x			x
	temperature - water downstream		x	x	x	x
	temperatures - water upstream		x	x	x	x
	temperature - air		x			x
	thermal gradient		x			
Vegetation	% forest cover on each side	x				x
	canopy-shading coefficient/veg density	x				x
	diameter of shade-tree crowns	x				x
	distance to shading vegetation	x				x
	topographic shade angle	x				x
	vegetation height	x				x
	vegetation shade angle	x				x
	vegetation width	x				x
Weather	relative humidity		x	Weather Staion/RH meters Weather Station Weather Station Field check/Weather Station Weather Station		
	% possible sun/cloud cover		x			
	solar radiation		x			
	temperature - air		x			
	wind speed/velocity		x			

Four types of Ecology field surveys will be conducted: 1) continuous and periodic flow monitoring at selected gaging stations, 2) temperature monitoring, 3) riparian and stream habitat surveys, and 4) time of travel study.

1. Continuous and Periodic Flow Monitoring

One continuous flow-monitoring station (Table 2) is planned to be established in the study area during the duration of the sampling season – June through October. The on-site data logger for flow gaging will be installed and maintained by Ecology's Environmental Assessment Program's Stream Hydrology Unit. The standard protocols for the setup and operation of the on-site continuous data logger will follow those currently established by Ecology's Hydrology Unit (Ecology, 2000). Periodic flow measurements will be made at nine additional stations and will be combined with information collected from the continuous monitoring station to estimate groundwater inflows in the watershed.

Table 2. 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
JC01	Mouth of Jorgensen Creek	47.0759	-122.8209		●
WC03	Woodland C. downstream of confluence with Jorgensen	47.0763	-122.8201		●
FC01	Fox Creek at Pleasant Glade Road NE	47.0743	-122.8110		●
EC01	Eagle Creek nr Mouth	47.0687	-122.8053		●
WC06	Woodland Creek at Draham Road	47.0610	-122.8032		●
WC07	Woodland Creek at I-5	47.0579	-122.8010	●	
WC08	Woodland Creek at Martin Way	47.0497	-122.8038		●
WC09	Woodland Creek at outlet of Lake Lois	47.0407	-122.7992		●
WC10	Woodland Creek at inlet of Lake Lois	47.0386	-122.7949		●
WC11	Woodland Creek at outlet of Long Lake	47.0350	-122.7811		●

2. Temperature Monitoring

Air and water temperature sites will be established at seven mainstem and three tributary locations (Table 3 and Figure 4). 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. 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 be measured at the Fox Creek site (FC01) using an Onset data logger. Both water and air temperature will be measured at 30-minute intervals with Onset StowAway Tidbits.

Table 3. Tentatively planned stations for continuous monitoring of water and air temperature.

station id	station name	latitude (decimal degrees N, NAD27)	longitude (decimal degrees W, NAD27)	water temperature site	air temperature site
JC01	Mouth of Jorgensen Creek	47.0759	-122.8209	●	●
WC03	Woodland C. downstream of confluence with Jorgenser	47.0763	-122.8201	●	●
FC01	Fox Creek at Pleasant Glade Road NE	47.0743	-122.8110	●	●
EC01	Eagle Creek nr Mouth	47.0687	-122.8053	●	●
WC06	Woodland Creek at Draham Road	47.0610	-122.8032	●	●
WC07	Woodland Creek at I-5	47.0579	-122.8010	●	●
WC08	Woodland Creek at Martin Way	47.0497	-122.8038	●	●
WC09	Woodland Creek at outlet of Lake Lois	47.0407	-122.7992	●	●
WC10	Woodland Creek at inlet of Lake Lois	47.0386	-122.7949	●	●
WC11	Woodland Creek at outlet of Long Lake	47.0350	-122.7811	●	●

3. Riparian Stream and Habitat Surveys

Stream and habitat surveys will be conducted at the temperature sites established by Ecology (Table 3). Two to three transects taken within a 100-meter thermal reach will consist of channel incision, near channel disturbance zone, bankfull width and depth, wetted width and depth, canopy closure, stream gradient, and channel type. Riparian Management Zone (RMZ) characteristics, such as active width, cover, size, density, and bank erosion, will also be recorded during the surveys. Hemispherical photography will be used to measure effective shade and canopy density at all water temperature stations, at additional selected locations, to ground-truth the range of vegetation classes digitized from inspection of digital orthophotos.

4. Time of Travel Study

Travel times will be estimated for two locations (WC08 and near WC03 at low tide) during critical flow conditions. While several methods can be used, the shallow water depths preclude the use of drogues. Thus, tracers will provide the best information on travel time and dispersion, both important parameters for modeling. Low-volume pumps will be used to inject sufficient salt solution to achieve a measurable conductivity at the downstream station without affecting aquatic species. Conductivity will be measured where fully mixed conditions occur downstream of the injection and at a point 1000 to 3000 feet downstream of the injection.

The field schedule during 2002 shows approximate dates of study-related activities:

June 17 - 19	-	Temperature data logger (tidbit) installation and staff gage and rebar installation for flow measurement stations.
June - Oct	-	Instantaneous flow measurements as needed.
August 21	-	Download temperature data from loggers.
August 22	-	Time of travel study.
Late August	-	Stream and riparian surveys.
Mid October	-	Download final temperature data, remove tidbits.

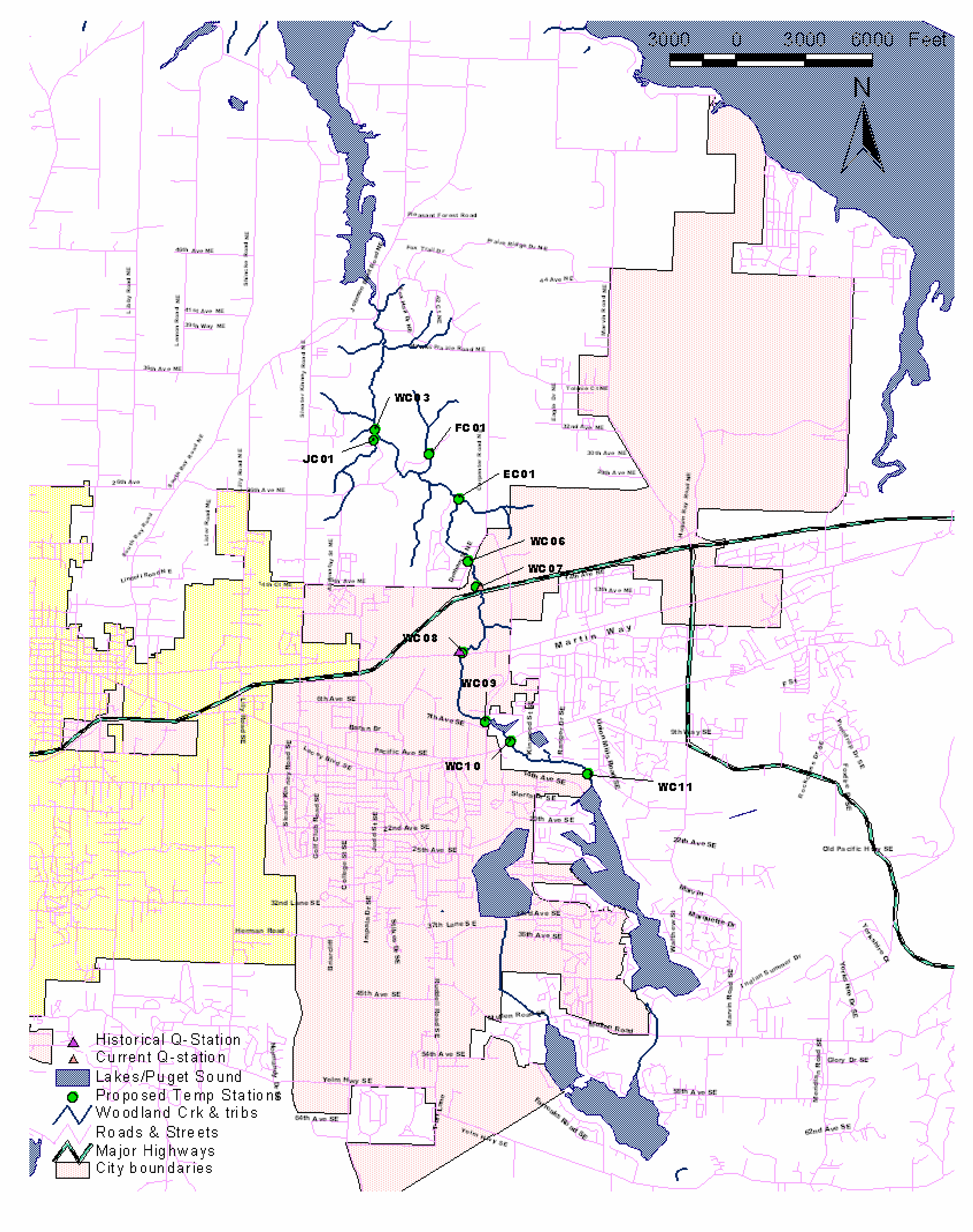

Figure 4. Woodland Creek Basin- Proposed Temperature Datalogger Station Locations.

Project Organization

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

Brian Zalewsky, Temperature Study Project Lead, Nonpoint Studies Unit, Environmental Assessment Program: Responsible for managing and implementing Temperature TMDL technical study. Defines project objectives, scope, and study design. Responsible for writing the temperature QA Project Plan. Manages data collection program and conducts data acquisition, data analysis, and data quality review. If necessary, conducts analyses, develops models, and writes TMDL technical study report subsections on temperature.

Mindy Roberts, Technical Review, Water Quality Studies Unit, Environmental Assessment Program: Provides technical review of interim data and modeling products as well as project QA Project Plan and final TMDL report.

Debby Sargeant, Conventional Parameter Project Lead, Water Quality Studies Unit, Environmental Assessment Program: Responsible for project management of the Henderson Inlet and Nisqually Reach study. Defines project objectives, scope, and study design. Manages data collection program for parameters other than temperature. Writes TMDL technical study report.

Jeannette Barreca, 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.

Brad Hopkins and Chuck Springer, Stream Hydrology Unit, Environmental Monitoring and Trends Section, Environmental Assessment Program: Responsible for the deployment and maintenance of continuous flow loggers and staff gages on I-5 Woodland Creek site. Responsible for producing records of hourly flow data at select sites for the study period.

*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.

Darrel Anderson, Unit Supervisor, Nonpoint Studies Unit, Environmental Assessment Program: Responsible for review of the QA Project Plan, final technical report, and budget of the technical study.

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

Measurement Quality Objectives

Accuracy objectives for field measurements are presented in Table 4. 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 and the field thermometers will be maintained through pre-and post-calibration 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. The certified reference thermometer, manufactured by HB Instrument Company (part No. 61099-035, serial No. 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 No. 68857). 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 (calculated from an 'n' value 10).

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

Representativeness of the data is achieved by utilizing 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 4. 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	± 2% of reading	Marsh-McBirney model 201 current meter

[1]Method references: Schuett-Hames et al., 1999; WAS, 1993

Measurement and Sampling Procedures

Field sampling and measurement protocols will follow those described in the TFW Temperature Stream Survey Manual (Schuett-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. Data from the loggers will be downloaded early-to-mid August. 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.

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 performance (absence or presence of anomalies such as drifting and spiking) and bias at representative temperatures. A certified reference thermometer will be used for the calibration. A post-survey calibration check is done to determine if the temperature instruments accurately and consistently recorded data from the installation to removal period. The raw data will be adjusted for instrument performance and 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 (16°C). Estimates of groundwater inflow will be calculated by constructing a water mass balance from continuous and instantaneous streamflow data.

Data collected during this study will allow for 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 QUAL2K models.
- A modification of ODEQ's HeatSource/Shadealator model (ODEQ 2000) will be used to estimate effective shade along the mainstem and major tributaries in the Woodland Creek watershed.

- The QUAL2K model (Chapra 2001) will be used to calculate the components of the heat budget and simulate water temperatures. QUAL2K simulates diurnal variations in stream temperature for a steady flow condition. QUAL2K will be applied by assuming that flow remains constant for a given condition such as a 7-day or 1-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. QUAL2K 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 streams in the Woodland Creek watershed will be simulated using a finite difference numerical method. The water temperature model will be calibrated to in-stream temperature data collected by Ecology along the mainstem and tributaries.

At this point, Qual2K and HeatSource are the preferred tools to model temperature. HeatSource has a proven history in calculating effective shade in both Oregon and Washington temperature TMDLs. Qual2K can model various water quality parameters, providing the opportunity to incorporate temperature modeling with other TMDL efforts.

A TMDL technical assessment for Woodland Creek will use riparian shade as a surrogate measure of heat flux to fulfill the requirements of Section 303(d). Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. Effective shade accounts for the interception of solar radiation by vegetation and topography.

Heat loads to the stream will be calculated in the TMDL in a numerical model that accounts for surface heat flux and mass transfer processes. Heat loads are of limited value in guiding management activities needed to solve identified water quality problems. Shade will be used as a surrogate to thermal load as allowed under EPA regulations (defined as "other appropriate measure" in 40 CFR §130.2(i)). A decrease in shade due to inadequate riparian vegetation causes an increase in solar radiation and thermal load upon the affected stream section. Human-caused activities that contribute to lack of shade include livestock grazing, recreation, agriculture, and logging. Other factors influencing the distribution of the solar heat load will also be assessed, including increases in the wetted width-to-depth ratios of stream channels and instream flow.

The *Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program* (EPA 1998) includes the following guidance on the use of surrogate measures for TMDL development:

"When the impairment is tied to a pollutant for which a numeric criterion is not possible, or where the impairment is identified but cannot be attributed to a single traditional "pollutant," the state should try to identify another (surrogate) environmental indicator that can be used to develop a quantified TMDL, using numeric analytical techniques where they are available, and best professional judgment (BPJ) where they are not."

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 results of the temperature study will be published in the overall Henderson Inlet/Nisqually Reach technical report. Sargeant (in press) describes the schedule. A draft technical analysis will be presented by December 2002. A final technical analysis will be presented by March 2003.

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