Chapter 6

Stream Temperature Protocol

Background

Water temperature is a key factor affecting the growth and survival of all aquatic organisms. The effect of stream temperature on fish, amphibians, macroinvertebrates, etc. varies between species and within the life cycle of a given species (Armour 1991; Beschta et al. 1987; Bjornn and Reiser 1991; Lantz 1971; DEQ 1995). Preferred temperature ranges for major fish species and their particular life stages are shown in Table 6-1.

Increases in stream temperature cause an increase in an organism's metabolic rate (Warren 1971). If enough food is available, growth rates can actually increase with some increase in temperature. For salmonids, temperature ranges of 40-66°F support healthy growth. Outside this temperature range, salmon and trout generally don't grow in size, and extreme temperatures can be lethal. Research has found that elevated stream temperatures often result in increased competition for a limited food supply, with young salmonids forced into habitat areas where they are easier prey (Reeves, Everest and Hall 1987). As food availability goes down, so does the growth rate. In addition, elevated stream temperatures increase the risk of disease-related mortality.

As stream temperatures increase, the amount of dissolved oxygen (DO)[1]available to aquatic biota decreases. As a result, even if food is abundant at higher temperatures, decreases in DO may metabolically stress salmonids, further increasing their susceptibility to disease.

When temperatures reach stressful levels, pockets of cool water provide "refugia" for fish and amphibian species that are sensitive to high stream temperature. Cool water refugia can sustain populations of sensitive species (Sedell et al. 1990). Cool water habitat can be sustained in deep pools, cold springs, areas of groundwater inflow, and at the junction of cooler tributary streams.

Stream temperature has been heavily researched and monitored (DEQ 1996; Dissmeyer 1994). Studies have investigated the effects of land management on stream temperature, developed models to predict stream temperature, and evaluated the effects of elevated temperature on aquatic biota. What follows is a detailed description of how to monitor stream temperature at multiple scales. *Please refer to previous chapters and Appendix B for information on developing a monitoring plan, selecting sites, and storing data.*

[1] The term "dissolved oxygen" (DO) refers to the amount of oxygen that is dissolved in water at a given temperature and atmospheric pressure. The amount of dissolved oxygen available in the stream is important for the respiratory and other metabolic functions of water borne organisms.

Table 6-1. Optimum and lethal limit temperature ranges for coho, chinook, and bull trout.

Fish Species	DEQ Standard	Preferred Juvenile Temperature Range	Adult migration, holding, or spawning	Lethal Limit
Coho	64°F	54-57°F	45-60°F	77°F
Chinook	64°F	50-60°F	46-55°F	77°F
Bull Trout	50 °F	39-50°F	39-59°F	---------

Mentors

As with any monitoring project, questions will come up that are not answered or covered sufficiently in this protocol. Therefore, a group of mentors that are agency experts in monitoring have been identified. These mentors may be contacted with specific questions about a particular monitoring effort.

Statewide DEQ Volunteer Monitoring Coordinator
Karen Williams: (503) 229-5983
E-mail: williams.karen@deq.state.or.us

North Coast
Larry Caton (503)229-5983;
E-mail: caton.larry@deq.state.or.us

South Coast & Willamette
Dennis Ades (503) 229-5983;
Email: ades.dennis@deq.state.or.us

Eastern Oregon
Larry Marxer (503) 229-5983;
E-mail: marxer.larry@deq.state.or.us

Equipment

Temperature Recorders

Temperature recorders include maximum/minimum thermometers, mechanical thermographs, and digital thermographs or temperature data loggers.

Max/min recording thermometers designed for total immersion may be used, but require daily site visits during the entire sampling period. Use of max/min data is also limited because it lacks information about the length of time when temperatures were at or near the maximum. They are therefore not preferred in most watershed studies.

Mechanical thermographs have been used successfully in watershed studies. Reliability can be a problem for some mechanical thermographs and the data needs to be transferred from the instrument to a database.

Temperature data loggers are the preferred temperature recorder for watershed monitoring. These data loggers have temperature recorders that can be set to record at regular intervals (usually hourly). This allows them to capture the shape of the water temperature over a day. Shorter time intervals will more closely approximate the maximum for any day. These types of instruments continuously record data for weeks or even months. This makes it more likely to detect the maximum daily temperature during the critical stream temperature season. Data loggers also significantly reduce the work load of the person or group conducting the monitoring because data can be directly downloaded to a computer database. The cost of temperature data loggers continues to decline while their reliability and ease of use continues to improve. A list of manufacturers who sell temperature recorders and their phone numbers is provided in Table 6-2.

Table 6-2. Temperature recorder manufacturers and their telephone numbers.

Company	Telephone
Vemco	(902) 852-3047
Onset	(508) 759-9500
Ryan	(206) 883-7926

Temperature recorders must have a temperature range which is appropriate for the environment that will be monitored. Water temperatures do not vary as greatly as air temperatures, but they can change 10 to 15ºC over a 24-hour period. Instruments with a measurement range of –5ºC to 35ºC are suitable for monitoring all stream systems.

Temperature recorders should have a an accuracy of approximately 0.3ºC or better for Level A quality data (See Chapter 4). This information will be available from the manufacturer.

Listed below are several useful materials and pieces of equipment that should be taken to the field to install or service temperature probes.

- Securing devices such as rebar, aircraft cables, locks, and/or diver's weights
- Surveyors marking tape
- 2-pound sledge hammer
- Wire cutters or pocket knife
- Temperature recording equipment requirements (silicone rings, submersible cases, silicone grease, silica packets)
- Portable computer and interface as needed by the temperature recorder if downloading and launching will be completed in the field
- Backup batteries and temperature recorders
- Timepiece
- Field book
- Waders
- Camera and film
- Machete or other brushing equipment
- Maps and aerial photos
- Wood or metal stakes or spikes Global Positioning System Device
- First aid kit and personal ID

Calibration Vs. Accuracy Check

Checking the temperature logger against a known temperature is often referred to as "calibrating" the instrument. This is a misnomer, however, since the temperature readings of continuous temperature loggers cannot be changed to agree with a known standard (i.e., calibrated). Their reading is simply checked against a known temperature, and any deviation from the known temperature is recorded. We refer to this procedure as an accuracy check.

Table 6-3. Estimated equipment costs.

Equipment	Required Costs *	Possible Shared Costs
NIST** thermometer		$180
Audit thermometer	$60	
Computer (laptop if field downloads are planned)		$2500
Waders	$100	
Rebar, cables, tubing, etc.	$100	
Surveyors tape	$2 / unit	
Sledge Hammer	$15	
Wire cutters	$10	
Camera and film		$100
Maps	$3 /each	
Compass	$30	
*** Global Positioning System (GPS)		$500
Field notebook	$10	
Watch	$20	
Backup batteries	$10/each	
Backup temperature recorders		$135/each
TOTAL	$360	$3415

***** Required costs are those expenses each study will incur. Actual total cost will depend on the number of study sites and temperature logging units required. Shared costs are for items used infrequently and could be shared between different groups or projects.

** National Institute of Standards and Technology

******* Accurate location of study sites on a map and latitude and longitude information is necessary. A GPS unit is one simple way of collecting this information, but it can also be obtained from good maps. A GPS unit is not required. Excellent map location information is also available on CD-ROMs for about $20.

Equipment Costs

Estimates of equipment costs are based on 1997 prices (Table 6-3). It may be possible to share some equipment with others doing similar monitoring or to receive funding from the DEQ Healthy Streams Partnership program for equipment

Equipment Set-Up

Hardware and Software Checks

Prior to going to the field, make sure the operator is familiar with the software for the computer and data logger. The clock on the computer should be synchronized with the user's watch. Knowing the quality of the data being collected is necessary for any monitoring effort. The following procedures describe methods for documenting the accuracy of the temperature recorders before and after they are

deployed in the field, and testing for proper function during the sampling period. Temperature recorders not properly tested may result in data showing streams cooler or warmer than actual temperatures.

Pre- and Post-deployment Accuracy Checks

The accuracy of temperature recorders needs to be tested before and after field deployment to insure that they are operating within their designed range of accuracy. Monitoring equipment with detachable sensors should be marked in order to match sensors with temperature recorders. This allows an instrument and sensor to be consistently tested together, and also makes malfunctions easier to diagnose and correct. A logbook is helpful to document each unit's accuracy, check dates and test results. (An example of a temperature audit form is shown in Table 6-4.)

Accuracy checks should be made at one or more temperatures, preferably two; one between 5-15ºC (42-62ºF) and one between 15-25ºC (62-82ºF). Testing is done using a stable thermal mass, such as a water-filled thermos bottle or cooler. Procedures for determining temperature recorder accuracy are as follows:

Needed Equipment

- NIST (National Institute of Standards and Technology) traceable (calibrated and maintained) thermometer accurate to ±0.2ºC or a field audit thermometer accurate to ±0.2ºC or better, that has been checked against an NIST traceable thermometer. (NIST temperatures are given in Celsius. Please refer to the table in Appendix G).
- 1 or 2 medium sized coolers
- Temperature audit forms
- Small weights (bags of sand, diver weights, lead weights, etc.)
- Temperature recorders. Note: If using HOBOs, **do not** use their sealed plastic cases.
- 2 bags of ice

Accuracy Check Procedure

1. For the 20ºC calibration test, pour room temperature water into a cooler. Adjust temperature in the ice chest with ice, cold water, or warm water to the desired temperature near 20ºC. If ice is used make sure it all melts. Close lid. Repeat procedure for the 10º calibration test but start with cold water.
2. Insert the NIST thermometer probe through a hole in the cooler lid. Pull it through enough so that when the lid is closed, the probe will be suspended midway (or slightly higher) in the waterbath.
3. Use accompanying software and a laptop computer to set the recorders to a 1-minute time interval.
4. Most temperature probes can be placed directly into the waterbath. If the temperature recorders are either internal or external sensor HOBOs, place the temperature recorders without their cases into a plastic pint-size Ziplock® bag. Place this bag inside a gallon-size plastic bag along with the small weight(s). The weight(s) should be sufficient in mass to hold down the combined lifting force of the temperature recorders and the air trapped inside the Ziplock® bags while allowing the temperature recorders to be suspended in the water column. Place the double bagged HOBOs into the waterbath.
5. Wait approximately an hour or until the waterbath temperature has stabilized before recording the NIST temperatures in a logbook. Record temperatures every minute for five minutes (a total of six readings). More readings may be necessary if there is suspicion that the waterbath temperature has not reached an equilibrium.
6. Download temperature results from temperature recorders and record logger results and audit thermometer results with time of record on an audit form. Water temperatures should not vary more than ±0.5ºC between the NIST recorded temperature and the data logger's temperature. Units not passing the accuracy test should not be used.

NIST thermometers are available at DEQ offices in Coos Bay, Astoria, and Medford, and at the Hatfield Marine Science center in Newport. DEQ has 60 NIST thermometers available for use by watershed councils. Contact the temperature mentor with additional questions about accuracy checks. Remember, accuracy checks should be made before units are deployed and after they are retrieved at the end of the sample period..

Table 6-4. Temperature logger audit form.

Project Name:

Temperature Logger ID:
Data File Name:
Date of Battery Installation:

Start Date:
Interval:
Duration:

Site Name:
Site STORET #:
USGS Quad Name & #:
Site Latitude:
Site Longitude:
Site Description:

Pre- Deployment Temperature Check
Date of Check:
Master thermometer ID: DEQ

Low Temp TIME	TEMP MASTER	TEMP UNIT	Difference	STATUS

Pre- Deployment Temperature Check
Date of Check:
Master thermometer ID: DEQ

Room Temp TIME	TEMP MASTER	TEMP UNIT	Difference	STATUS

AUDIT VALUES		Water Temperature		Air Temperature		**Audit Thermometer ID**		
Date	**Time**	**Audit**	**Logger**	**Audit**	**Logger**		**Comments**	**STATUS**

COMMENT:

Post- Deployment Temperature Check
Date of Check:
Master thermometer ID: DEQ

Low Temp TIME	TEMP MASTER	TEMP UNIT	Difference	STATUS
	-	-	-	-
			0.0	
			0.0	
			0.0	
			0.0	
			0.0	
			0.0	

Post- Deployment Temperature Check
Date of Check:
Master thermometer ID: DEQ

RoomTemp TIME	TEMP MASTER	TEMP UNIT	Difference	STATUS
	-	-	-	-
			0.0	
			0.0	
			0.0	
			0.0	
			0.0	
			0.0	

Alternative Method

To achieve Level A data quality (the highest level as described in Chapter 4, *Data Quality*) the accuracy check procedure using an NIST thermometer described above must be used. If a lower level of data quality (Level B or C—see page Chapter 4 *Data Quality)* is acceptable for a project, an alternate accuracy check procedure can be used that does not require a NIST thermometer.

For this method, create an ice-water slurry in a large insulated cooler by mixing cold water with a large amount of ice. Temperature recorders can be placed into the cooler to check that they are performing accurately. They should read 0°C (±0.5ºC). Multiple probes can be placed in the cooler at the same time to provide cross-checks. This method only assures accuracy at 0°C. If the data will be used for regulatory purposes, the described NIST method must be used instead

Field Checking Instrument Performance

In addition to pre- and post-deployment checks, check temperature recorders during the field measurement period. A field check compares the continuous temperature recorder reading with the reading on a field audit thermometer. The purpose in conducting field checks is to insure data accuracy.

Attempt to obtain at least two field temperature audits for three months of sampling—one after deployment when the instrument has reached thermal equilibrium with the stream (approximately 30 minutes to 1 hour after placement), and one just before temperature units are removed from the stream. Additional field checks, while not critical, are useful as they can minimize loss of data in case loggers malfunction during the sample period. Field audit thermometers used for field checks should have an accuracy of ±0.5ºC (±1.0ºF) and resolution of ±0.2ºC (±0.4ºF).

Check the temperature by placing the audit thermometer next to the continuous monitoring instrument's sensor. The temperature is recorded when a stable reading is obtained. A stable reading is usually achieved within 10 "thermal response times". For example, a thermometer with a 10-second response time (refer to manufacturer specifications) should give a stable reading within 100 seconds.

Most temperature recorders interrupt data collection when the unit is connected to a computer. With this type of unit, field checking data can only be applied by "post-processing" (i.e., after the units are retrieved and the stored data are offloaded). For this reason, field audit times should be scheduled close to the temperature recorder's logging time. Otherwise, rapidly changing water temperatures may cause the audit thermometer to record a different temperature than the logger.

Temperature recorders typically set date and time based on the set-up computer's clock. Field personnel should synchronize watches to this time, otherwise a poorly timed check could cause valid data to be rejected. Post-processing audit accuracy should be within ± 1.5ºC (±3ºF) as well.

Field Methods

Site Selection

Chapter 3 addresses site selection criteria. Some additional considerations unique to stream temperature (Figure 6-1) include:

> Install temperature recorders at sites with turbulence and mixing, such as riffles, runs, or cascades (high stream energy, fast moving stream reaches).
>
> Install temperature recorders toward the lowest point of the channel bed (the"thalweg") of the channel where possible.
>
> Consider that flow will decrease throughout the summer and a location that appears adequate in June may leave the temperature recorder exposed in August.
>
> Some researchers have recommended shading temperature recorders from direct sunlight. Discuss this with a temperature mentor.

Do not place monitoring equipment in pools, areas where stream temperatures can be stratified by depth or channel width, or other confounding variables (See Chapter 3), unless the specific purpose is to evaluate these areas for temperature refugia.

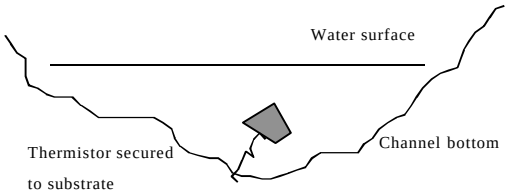

Figure 6-1. Illustration of temperature recorder installation and site locations.

Adequate Mixing

If uncertain whether a selected site has adequate mixing, a hand-held thermometer can be used to evaluate the degree of mixing. Make frequent measurements horizontally and vertically across the stream cross-section. If stream temperatures are relatively homogeneous throughout the cross-section during summer low-flow conditions, then sufficient mixing exists.

Installation

Installation of the sensor[2] or probe at the monitoring site can be an important consideration. Monitoring equipment must be installed so that the:

- temperature sensor is completely submerged
- temperature sensor is not in contact with the bottom or other mass that could serve as a heat sink/source
- where possible, the sensor is set about half-way in the water column

For non-wadeable streams, the sensor should be placed one meter below the surface, but not in contact with a large thermal mass like a bridge abutment or boulder. If volunteers are working in a large, non-wadeable stream, contact the temperature mentor for guidance. Field checks during the monitoring should confirm that the temperature sensor has remained submerged, that it is not buried in the substrate, and that it has not been damaged by changing flows, animals or vandals.

Temperature recorders frequently become coated with algae or silt and can be difficult to locate when one returns to retrieve the unit or check the temperature. A photograph of the monitoring site can be useful for locating equipment. The Governor's Watershed Enhancement Board (1993) provides guidance for photo documentation of monitoring sites.

Installing, maintaining, and retrieving the temperature recorder is fairly simple. The general procedure for field work is as follows:

1. Start the temperature recorder either prior to going to the field or in the field with a laptop computer. Follow instructions for the specific logging device. Many temperature loggers have a delayed start function which allows them to be initialized prior to going to the field. It also allows recorders to be synchronized to have the same starting time throughout the watershed.
2. Secure the temperature recorder with rebar, cable, or weights depending on the streambed characteristics, in a section of stream channel with adequate mixing and flow.
3. Record in a fieldbook the time of deployment and how long the monitor will record measurements. Check the stream temperature with an audit thermometer. Record site conditions, weather conditions, and site location using latitude and longitude.
4. Collect any additional environmental parameters of interest such as riparian shade, flow, channel width and depth, substrate composition, and riparian vegetation characteristics. For more information on these measures, check the

[2] The sensor is the thermistor or other temperature detector and is a part of the temperature recorder. The sensor or probe must be submerged in the water column, not the temperature recorder.

following references: EPA 1993; EPA 1996; Bjornn and Reiser 1991; ODF 1994; and Appendix D.

5. Photograph the site location for future reference. Write a description of the site and sketch the exact location of the temperature recorder. Record the serial number of the logger with each site description.

6. If possible, permanently mark the site location. Vandalism, theft, and landowner permission should be considered.

Attaching and Securing the Temperature Recorder

DEQ uses aircraft cable to attach temperature monitors for security purposes and stabilization in large river systems. Other securing devices such as rebar and hose clamps or diver's weights also can be used.

Retrieval and/or Mid-Season Redeployment

1. Locate the temperature recorder and check stream temperature with audit thermometer before removing it from the stream.

2. Offload the data using a laptop computer and the temperature recorder's specific software. Back up the data files on both the hard drive and a disk.

3. Record the time of downloading, site conditions (changes in streamflow, riparian vegetation, etc.), and weather conditions.

Monitoring Timing

For assessing maximum stream temperature, continuous temperature monitoring is generally conducted from June through September when solar angles are high and streamflow is low. Where this is not possible, monitoring can be conducted during a three-month period including July and August when stream temperatures are generally the highest. Depending on study objectives, temperature data may be of interest during fish spawning seasons also. This typically occurs in the fall, winter, or spring. Ideally, at least two weeks of data should be collected on either side of the period of maximum temperature.

Monitoring Frequency

The monitoring frequency should be adequate to provide a realistic estimate of the maximum temperature. If monitoring data are collected infrequently, the maximum temperature may be missed. *The Monitoring Team recommends that the monitoring frequency should be set for continuous temperature recorders at one hour intervals.* More frequent monitoring can more precisely determine the duration of daily maximum temperatures. The disadvantage to more frequent readings is fewer days of data collection are possible and more data points for the same period of time must be stored and analyzed.

Data Analysis

Data Quality

Reviewing data for errors prior to analysis is important. Viewing data graphically as soon as possible is a good way of checking for errors. Some data logging software actually graph the data while it is offloaded from the temperature recorder. Graphing the data provides a view of the entire period of record. The collected data set can then be scrutinized for illogical or incorrect segments. For example, extremely high or low blips and sustained periods of little or no change in temperature shown by flat portions on the graph are areas of concern. Often these areas exist at the beginning or end of the data file and can result from starting the temperature recorder long before it is placed in the stream. Areas of concern in the middle of the data period may have occurred when the temperature recorder was exposed to the air because of low flow or because of removal by animals, or vandals. These areas of concern must be deleted from the dataset. However, it is valuable to keep a backup file of the complete unaltered dataset in case the data quality comes into question.

DEQ will provide an electronic spreadsheet for reporting temperature data. Contact one of the mentors listed at the beginning of this chapter for a copy, or for further information on data reporting. An example of a data summary sheet is provided in Table 6-5. What follows are some examples of statistical parameters for summarizing stream temperature data.

Seven-Day Moving Mean of Daily Maximum

The "seven-day moving mean of daily maximum" smoothes out some of the daily fluctuations in the temperature profile and also provides a picture of the average temperature affecting fish over a longer period of time than daily maximum. It is also the basis of the DEQ water quality standard for stream temperature.

Before calculating the seven-day moving mean of daily maximums, the daily maximum temperatures must be determined. Using a spreadsheet, query the maximum reading for each 24-hour period of measurement. Store these temperature readings in a separate file or column accompanied by their date. The seven-day moving mean is calculated as the average of the 24-hour maximum temperature for the day and the maximum temperatures for the proceeding three days and following three days

Daily Fluctuation

Daily fluctuations are also often used in stream temperature analysis. This is the difference between the daily maximum and daily minimum temperatures at a station.

Spatial Trends & Rate of Change

With two or more temperature recorders available, changes in temperature between multiple stations on a stream can be analyzed. This is calculated by subtracting the temperature (maximum, minimum, or seven-day moving mean of maximum) at one station from the other station. The change is reported as an increase (positive value) or an decrease (negative value) in temperature.

Temperature change can also be reported in terms of rate of change. This is commonly reported as change in temperature per linear distance (i.e. 2°C/1000 feet). Two or more probes are needed, and the distance between stations must be measured.

Basin Trends

Stream temperature generally increases in a downstream direction. If stream temperatures are monitored throughout a basin (i.e. 5-20 probes) the basin trend from the divide can be analyzed by distance. Graph the highest 7-day maximum temperature for each station versus its distance from the ridge or watershed divide. Then answer the following questions: How does the rate of change (calculated above) vary from upstream locations to downstream locations? Is there a point in the basin where stream temperatures stop increasing and level off? What is the maximum stream temperature and where does it occur? How does tributary input affect the basin trend?

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Table 6-5. Examples for stream temperature data summary.

Template for stream temperature data management.

Stream Name	Station Number	GPS * Location	Calibration Method	Monitoring Period		Highest 7-day Max	Date of Occurrence	Absolute Maximum	Date of Occurrence	F
			(NIST or Alternative)	(beginning date)	(end date)	(°F)	(m/d/yr)	(°F)	(m/d/yr)	
Deer Creek	1		NIST	6/15/98	9/15/98	58.3	8/4/98	60.2	8/3/98	
Deer Creek	2		NIST	6/15/98	9/15/98	60.3	8/4/98	62.9	8/5/98	
Deer Creek	3		NIST	6/15/98	9/15/98	62.2	8/4/98	65.7	8/3/98	
Deer Creek	4		NIST	6/15/98	9/15/98	62.1	8/4/98	63.3	8/2/98	
Clear Creek	1		NIST	7/4/98	9/20/98	62.5	7/21/98	63.7	7/19/98	
Clear Creek	2		NIST	7/4/98	9/20/98	58.1	7/21/98	59.2	7/18/98	
Clear Creek	3		NIST	7/4/98	9/20/98	58.9	7/22/98	60.1	7/18/98	

* If a Global Positioning Station was not used, then latitude and longitude will suffice.

** Rate of change can only be calculated when more than one station is established.

NOTE: Other useful data that were not described in this protocol include: elevation, distance from divide, shade, channel gradient, substrate, channel width, and depth, and riparian buffer width. These could be added as columns to this template.