Monitoring for Stream Temperature Total Maximum Daily Load Development

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I. Background

A. What is a TMDL

Under the Clean Water Act (CWA) all states are required to set water quality standards that are designed to protect designated beneficial uses–for example, supporting populations of cold water fish like salmonids. The DEQ determines if waterbodies achieve beneficial uses by comparing available water quality data to water quality standards. When a waterbody does not meet a water quality standard the reach is placed on a list of waters that violate the standard (called the 303(d) list after the section of the CWA that requires it). States are then required to figure out the amount of pollutant that can be present in the stream without causing a violation of the water quality standard. The amount is referred to as the Total Maximum Daily Load (TMDL). Once established, plans are developed to reduce the amount of pollution to that level.

In the case of streams on the 303(d) list for exceeding the temperature standard, the pollutant of interest is heat. The TMDL analysis determines what the stream's temperature would be under estimated natural conditions. If the natural temperature is greater than the water quality standard temperature, then the natural condition is adopted as the new criteria for that portion of the stream.

B. Components of a Stream Temperature TMDL

In a temperature TMDL an analysis is conducted to determine how much heat can be added to a stream without raising the temperature of the water above the appropriate criteria.

A number of factors determine the amount of heat a stream will absorb and different streams are going to be governed by these factors to varying degrees. For example, some streams might be greatly impacted by a point discharge, like cooling water used by an industrial plant and released as warm water into the stream; another stream might be most impacted by a reduction in streamside shading resulting in more sunlight hitting the stream; or changes to a stream's channel characteristics may increase exposure of the stream to incoming heat and be the largest impact on temperature. For most streams it will be a combination of point sources, channel morphology, hydrology and near stream vegetation conditions that contribute to impairment.

The majority of temperature TMDL's in the state are established through mathematical models that simulate processes affecting stream temperature. The extent of modeling is determined by the size of the stream, the likely impacts on the stream and the available resources. The HEATSOURCE temperature model is a deterministic hydrodynamic model which simulates stream channel, hydrology and near stream vegetation conditions in order to compute heat flow and temperature. HEATSOURCE is used to model most main channels in a basin requiring a temperature TMDL. For smaller streams without point sources, a simpler model that simulates the relationship of stream vegetation and channel size is used to determine what impact changes in vegetation would have on heat transfer to the stream.

C. Why Collect Data

The quality of the temperature model is largely determined by the amount and quality of the data that is collected to define the parameters of the model. The better the information available to build the model, the better the model will simulate the conditions on the ground and the better the model will be able to predict what impact changes in the landscape will have on stream temperature. The EPA requires that the TMDL protect beneficial uses and therefore requires that a margin of safety be incorporated into the model to compensate for model uncertainty. The better the model is at simulating conditions in the basin, the smaller the model uncertainty is, and therefore, the smaller the imposed margin of safety will be for TMDL implementation.

Local understanding of the TMDL process and locally based monitoring efforts have increased community receptivity to restoration goals, made for stronger coordination of the process with landowners and increased the quality of the estimates of potential conditions and temperature profiles.

II. Where to Begin

Before you begin to develop a monitoring plan, you first need to establish what information already exists in your basin and determine if the information will be useful to you. Data sources should be evaluated with the goal of finding data gaps and analyzing results to find areas that need more data to be understood. Ideally you want all the different types of data in the basin represented during a single snapshot in time.

A. Data Mining

The most cost effective way of collecting environmental data is to use data that someone else has already collected! Generally, most natural resource management organizations in your basin may have historical or current data which they may want (or be required) to share with you. Always make sure that anyone sharing data with you understands how you plan on using their data.

Examples of natural resource management organizations include: USFS, USBLM, ODFW, tribes, counties, and federal or state water resource and climate programs. Support organizations such as watershed councils and conservation districts often are a data resource as well. The natural resource partner data types that are most commonly employed in TMDLs include: flow, continuous temperature, vegetation descriptions, shade and vegetation height measurements, historical photographs, habitat and channel and substrate assessments, weather, and potential vegetation types. Remote sensing tends to be shared as well, and can dramatically influence ground level data mining and planning.

It is important that you understand the limitations of any data that you retrieve from other sources and that you apply the data understanding those limitations. Any data that doesn't have explicitly defined location and time of collection will likely be of little to no value.

Stream Temperature- Most federal land management agencies, tribes, the DEQ, other state agencies, and large landowners (private timber or utility companies for example) in your basin may have continuous temperature data that could be used.

Stream Flow- The Oregon Water Resources Department is probably the best resource to find out what stream flow measurements are being made in your basin. The U.S. Geological Survey Water Resources Division is also an excellent resource for data. In addition to these agencies, county governments, irrigation districts and land management agencies may also have some information on stream discharge in your basin. A lack of sufficient stream flow data is consistently a limiting factor in the quality of models used to develop TMDL's. There are rarely enough installed stream gages (continuous data) to provide for robust modeling. During the critical temperature assessment time frame, additional measurements (instantaneous data) should be implemented at many locations. In addition to discharge, flow measurements provide important hydraulic information: width, depth and velocity. Typically this is not reported, and the sites are selected for discharge rather than representative width and velocity. If possible pre-planning could prevent this. Alternatively, data collection may be supplemented through new monitoring via inter-organizational teamwork.

Meteorological- Data on air temperature, solar radiation, relative humidity, and wind speed are used in the model. Identify where weather stations are that collect this data and if the data are relevant to near stream conditions.

Spawning Areas- Identifying when fish are using your stream is important to determine when you need to be monitoring. You can view fish use maps on the DEQ web page. Your local ODFW representative or other natural resource management organization fish biologists should be able to provide you with additional information about when cold water species use your watershed.

Vegetation- Any existing information about vegetation in your basin could be useful in determining where and how you conduct your monitoring. If a watershed assessment has been completed for your watershed, then there probably is some information about different vegetation types and where they are in the watershed.

Channel- Rosgen Level II Inventories, EMAP, Habitat surveys, historic and current channel surveys done for dams and levees, gage cross-sectional profiles, etc. all provide useful morphologic information.

B. Data Analysis

The extent of analysis required depends on the question you are trying to answer. In some cases you may not even need to look at the actual result values; instead, you may just be interested in what was monitored where (example- a colored tack in a map on the wall). For other data sets you may wish to do some summarizing to allow you to compare sites to one another (example- charts showing maximum temperatures vs. river mile). The following questions are good places to start when you begin to analyze your mined data:

- What is monitored where in the watershed?
- Are there creeks that are unusually hot or cold?
- How does the temperature of the river change as it flows downstream and are there any places where this pattern is unusual (Example, rapid heating or cooling as you move downstream)?
- What are the major sources of stream flow and how are they distributed around the watershed?
- How does stream discharge change over the course of the summer and into early fall?
- Are there any major water withdrawals or springs in the basin, where are they and what is their impact on stream discharge and temperature patterns?
- Where is groundwater input or exchange most likely?
- Where has land management caused the most alteration of vegetation and channel geometry? How?
- When are fish in your basin and how are they using it (Example, rearing, spawning, etc)?
- What are the major vegetation types in your basin near the stream and how are they distributed?

You probably will not be able to answer all of these, but the process of trying to answer these questions will likely lead you towards identifying what should be monitoring in your basin.

- Temperature- When analyzing continuous temperature data you can use tools like HYDROSTAT.xls or TEMPTURE.xls to create summary statistics. TEMPTURE will create statistics for multiple sites at a single time. Resources on how to do this are available on DEQ Laboratory's website under Volunteer Monitoring.

- Stream Flow- Continuous stream gages are great for modeling purposes, but instantaneous measurements made during the modeled periods of the summer are also needed for broad spatial coverage. Summer low flow conditions are usually the stream flow conditions of concern when developing a temperature TMDL. The timing of stream flow measurement is critical due to the variability of stream flow within and between years. Stream flow measurements from two different sites during different years (example: average 2000 July flow at river mile 5 vs. average 2002 July flow at river mile 23) should not be directly compared except to get a relative idea of scale. In the effort to get a single time period with stream discharge estimates at all your sites, you may be able to use years of overlapping record to develop a relationship between gauge stations that allows you to estimate how much a gauge might be reading during a period of missing record. However, the limitations of these guesstimates should be understood--the more you guesstimate the further you are from reality.
- Spawning- Under the new temperature standard a new emphasis is given to the spatial distribution of spawning. It is important that continuous temperature information be available throughout the entire spawning period--fall, winter and spring.
- Vegetation- Characterization of vegetation is critical for temperature modeling. During model development this information needs to be associated with an exact location so that measurements made on the ground can be compared to what the modeler is looking at on the computer monitor (usually aerial photographs). Important information includes: type, height, structure and shade of existing, historic and potential vegetation - particularly of shade-producing stands or the absence thereof.

III. Planning Your Monitoring

Based on existing data sources and gaps, you can start to develop a plan for how you can contribute to the TMDL development process. You should stay in contact with your DEQ Basin Coordinator to make sure they are aware of what you are planning to do. You may promote partnerships that save you, the DEQ and other stakeholders in your basin from duplicating efforts.

A. What to Monitor

A summary of required data is appended to this document listing what parameters are sampled.

Latitude and Longitude- Any data you collect must have a latitude longitude associated with it. TMDL development relies on spatial distribution for all of its calculations. Latitude and longitude should be reported in decimal degrees to 5 decimal places.

Stream Temperature- Continuous temperature data collected using data loggers like Vemcos, TidBits, or Hobos should be recorded throughout the summer and also whenever there is salmonid spawning.

Stream Flow- Stream flow is often a critical missing piece of data for TMDL development. Instantaneous stream flow measurements along the mainstem and at all major tributaries estimated to contribute 5% or more of the flow to the mainstem at their confluence should be measured.

Vegetation- Type of vegetation (conifer or deciduous) and height are the two most important types of vegetation information used in the model development. Additional information about species of trees, seral class, or other community information may also be useful when determining site potentials. The extent of vegetation overhanging the edge of the stream can also be useful when developing the model.

Shade- Measurement of the amount of sun hitting the stream is critical to model verification. Shade is the result of vegetation, topography and aspect at each monitoring point along the stream.

Channel Characteristics- Channel cross sections are used in the model to describe the hydrology and thermal properties of the stream at a given point. Important information includes wetted width, depth profile, near stream disturbance zone, and others. Extending cross-sections beyond bankfull using a surveyor's level provides additional channel parameters that can greatly improve the model. These more intensive surveys are strongly encouraged.

Air Temperature (Meteorological)- Riparian/near stream air temperatures are critical to heat transfer equations. Established weather stations often are of limited value due to the distance from streams. Therefore, near stream temperature or meteorological monitoring may be needed.

B. Where to Monitor

Undoubtedly you will not have the resources to monitor in all the places you would like to monitor. You should try to prioritize sites and compare your "wish list" to your resources.

Mainstem- Typical TMDL's utilize temperature loggers every 5-30 miles longitudinally on modeled streams. More is generally better, but exceeding a frequency of 2-10 miles may be overkill, at least on a large system. Units should be placed along modeled streams and at the mouths of tributary inputs. Vegetation, stream flow and channel information should be collected at temperature logger sites and at as many other locations on the mainstem as is practical.

Tributaries- Temperature and stream discharge information should be collected as close to the mouth of tributaries as possible, but upstream of any direct impacts of the mainstem on the tributary temperature or flow. If the tributary is not going to be modeled, then there is no need to collect any of the additional flow or temperature. System potential vegetation assessments are needed on most perennial streams. Check with the DEQ Basin Coordinator to find out if a tributary is going to be modeled.

Areas of interest- Examples of areas of interest include reaches with significant and unexpected gains or losses of stream flow or temperature. Any reaches of special interest you have identified should receive extra emphasis. If there are lots of springs in a reach, for example, then stream temperature and discharge measurements should be made at the top and bottom of the reach.
Landscape changes- Significant changes in terrain, geology or land use are often good locations to place a monitoring station as these will likely impact the temperature regime.
Vegetation Communities- Knowledge gathered from the data mining process and local knowledge can be used to make sure that you locate monitoring stations in enough reaches to represent all the different vegetation communities.

C. When to Monitor

Your goal is to get a snapshot of your basin so that you can develop relationships between all the measured features in the basin and stream temperature. Therefore, you will need to have temperature and stream discharge all measured within a fairly tight timeframe. If thermal infrared remote sensing for stream temperature is being conducted, flow measurements should correspond to that time frame, within a matter of days. Vegetation characteristics have a slightly wider timeframe for measurements.
Warmest time of year- It is best to determine the warmest time of the year by looking at charts of previously collected stream temperature data. Due to low flows, the accumulation of solar heat, and the continued long days, the peak in stream temperatures usually occurs around the end of July or beginning of August. This is usually the target for temperature TMDL development monitoring.
Spawning times- Under the new temperature standard it is now appropriate to keep continuous temperature loggers in the water whenever salmonids are expected to be spawning there. For the sake of successful data recovery, it is often advisable to make separate deployments of temperature recorders through the year to ensure the loss of a datalogger does not result in the loss of an entire year's data. Stream flow measurements will likely not be safe in most streams except during summer low flow conditions.
Leaf-out- Vegetation and shade monitoring can be conducted any time after the trees have completely leafed out and may continue at different sites until trees and shrubs begin to loose their leaves.
Low flow conditions- Stream flow should be measured at the targeted time of modeling. Additional flows near the beginning and end of the summer can be used to characterize the decrease of flows over the summer. This might be useful, especially if there are fall spawning runs that might be affected by late summer low flows.

D. How to Monitor

The most critical part of building partnerships to collect data for use in TMDL development is making sure all the data is collected, processed and stored using agreed upon protocols. If the data is to be used in TMDL development, then it is essential that approved methods, like those described in the OWEB Guidebook or the DEQ Laboratory's Mode of Operations Manual (MOM's) be followed. The monitoring program must also be documented in an approved QAPP, and all quality assurance and quality control measures must be followed and documented. The referenced protocols do not have protocols for complete channel surveys nor TMDL monitoring design guidance.

You should work closely with DEQ personnel or others who have been through similar processes to help you with these aspects of the monitoring.

Latitude and Longitude- Being able to identify the exact location for all data is absolutely critical to all data collected for TMDL development. If the data cannot be placed on a map, then it will most likely not be used. The most efficient way to identify locations is using latitude and longitude. In a worst case scenario, if your GPS does not work at a location you may use distance and direction (upstream/downstream or compass bearing) from a location or a specific object that could be identified from an aerial photograph, like a bridge or confluence, and for which you can determine latitude and longitude. (Large trees or rocks cannot be differentiated on an aerial photograph!) The modelers typically work on a scale of 100-meter increments. At the very least the modelers need to feel confident that a location belongs somewhere along a 100 meter increment in the stream.

Site Identification/photographs- An accurate site description is also important when working with data. It is important that the site names be consistent from year to year. The name should be descriptive of the area such that someone unfamiliar with the site could find its general location on a map. Photographs of the site assist with answering a number of questions about the data that may come up during analysis. Digital photographs are the most useful for this. Note the number and type of photos in your field notes and make sure that your date/time stamp is working properly on your camera. Photos should be taken of the site in general and specifically of things like vegetation, temperature logger location and stream flow transect.

Continuous Stream Temperature- Methods for conducting continuous temperature monitoring are defined in the OWEB Guidebook and are familiar to most Watershed Councils conducting monitoring in Oregon. It is particularly important that these methods be followed closely and be well documented if the data is to be used in TMDL development.

Stream Flow- The preferred method of stream discharge measurement is the standard USGS/ WRD protocol described in the DEQ MOM's. If you intend to conduct stream flow measurements you should receive training from a water resources professional and consult with DEQ personnel about site selection. Other less technical options for determining stream flow exist and they may be useful in determining stream discharge, especially in areas with very little flow. Because there is usually a limited amount of stream discharge data at different sites, especially small tributaries, even a well calibrated visual estimate of stream flow coming at minor tributaries can help modelers develop the flow balance. When modeling mainstem temperatures, a tributary continuous temperature record without flow information is of little value to model calibration. Cross sectional stream discharge measurements provide useful stream channel and hydraulic characteristics that can also be used in developing the model. It should be noted however, that the best flow transects are often located at anomalous cross sections and should therefore not be used as the only source for channel characterization. Channel profiles are discussed in the channel morphology section below.

Continuous Air Temperature- The DEQ Watershed Assessment Section has standard protocols defined for setting up UNIDATA data loggers to collect meteorological data but this equipment may not be available. Riparian/near stream air temperatures can be easily measured by hanging a continuous temperature logger in the riparian vegetation in an area where it is very well shaded but representative of near stream ambient conditions. To place standard continuous temperature equipment, make sure the equipment is not exposed to direct sunlight at any time of the day and that it is located near the stream.

Vegetation/Shade- The most important measurements of vegetation are type of shade causing vegetation (conifer or deciduous if trees), vegetation height and Solar Pathfinder shade readings. Solar Pathfinder shade readings are used because they measure shade based on the solar trajectory. Multiple measurements of shade may be required in the area to estimate an average value for a reach. A discussion of vegetation and shade monitoring is presented in the Temperature TMDL Habitat Methods PDF. The DEQ Temperature TMDL Habitat Field sheet is also presented as an example format. This data, along with channel information is sometimes referred to as "Habitat" data because many of the methods used are simplified versions of those used by biological monitoring crews to quantify fish and macro invertebrate habitat.

Channel – Channel dimensions and substrate type are used in the model. A presentation of basic channel morphology parameters is available in the Temperature TMDL Habitat Methods PDF. A Field Notes sheet for channel morphology, substrate and solar pathfinder is also presented as an example format. This data, along with vegetation information is sometimes referred to as "Habitat" data because many of the methods used are simplified versions of those used by biological monitoring crews to quantify fish and macro invertebrate habitat.

IV. Data Management

All of the data must be associated with a spatial descriptor--latitude and longitude in decimal degrees. Data management can be a challenge since no real infrastructure exists to handle most of this data. In addition much of the information is not in a format that can easily be entered into a spreadsheet. For example, a complete data set at a given site would have continuous temperature files, stream discharge measurements, vegetation measurements, shade measurements, channel measurements, photos and drawings. While individual measurements can and should be entered into a spreadsheet, photos channel cross sections, and drawings are not easily entered into a database. Excel spreadsheets with all the simple measurements should be created including fields for hyperlinks to photos or scanned field sheets with drawings. Keeping this master spreadsheet in a folder with all the hyperlinked images or documents is a good way to manage the data. An example dataset (minus the hyperlinked files) is available to serve as a template.

Appendix
TMDL Analytical Approach:
What is Sampled?

Site Specific

In-Stream
- Recording thermistors
- DO, pH, bacteria, nutrients, macroinvertebrates, TSS, turbidity (all other variables on this page are needed for temperature assessment; these can be linked to temperature)

Channel
- Bankfull Cross-Section: Width (also via remote sensing), Depth, Side Slope, Cross-Sectional Area
- Substrate particle size/distribution
- Sinuosity (also via remote sensing)
- Entrenchment
- Aspect (also via remote sensing)
- Stream Type

Vegetation
- Height, Map Pattern, Canopy Density, Percent Effective Shade

Hydraulics
- Gradient (also via DEM)
- Streambed Roughness, Percent Bedrock/Boulder
- Discharge and Velocity
- Wetted Width & Depth

Weather
- Wind Speed
- Humidity
- Air Temperature
- Cloud Cover

Geographic Information Systems

Remote Sensing
- Thermal Infrared Radiometry (TIR)
- Sub-meter/pixel color orthoimagery
- Satellite Land Use Assessment
- Optional enhancements: LiDAR and Near-IR

Digital Elevation Model
- Stream Elevation Profile
- Shade Angles (near and far)
- Gradient