NORTH COAST SUBBASINS TMDL

APPENDICES

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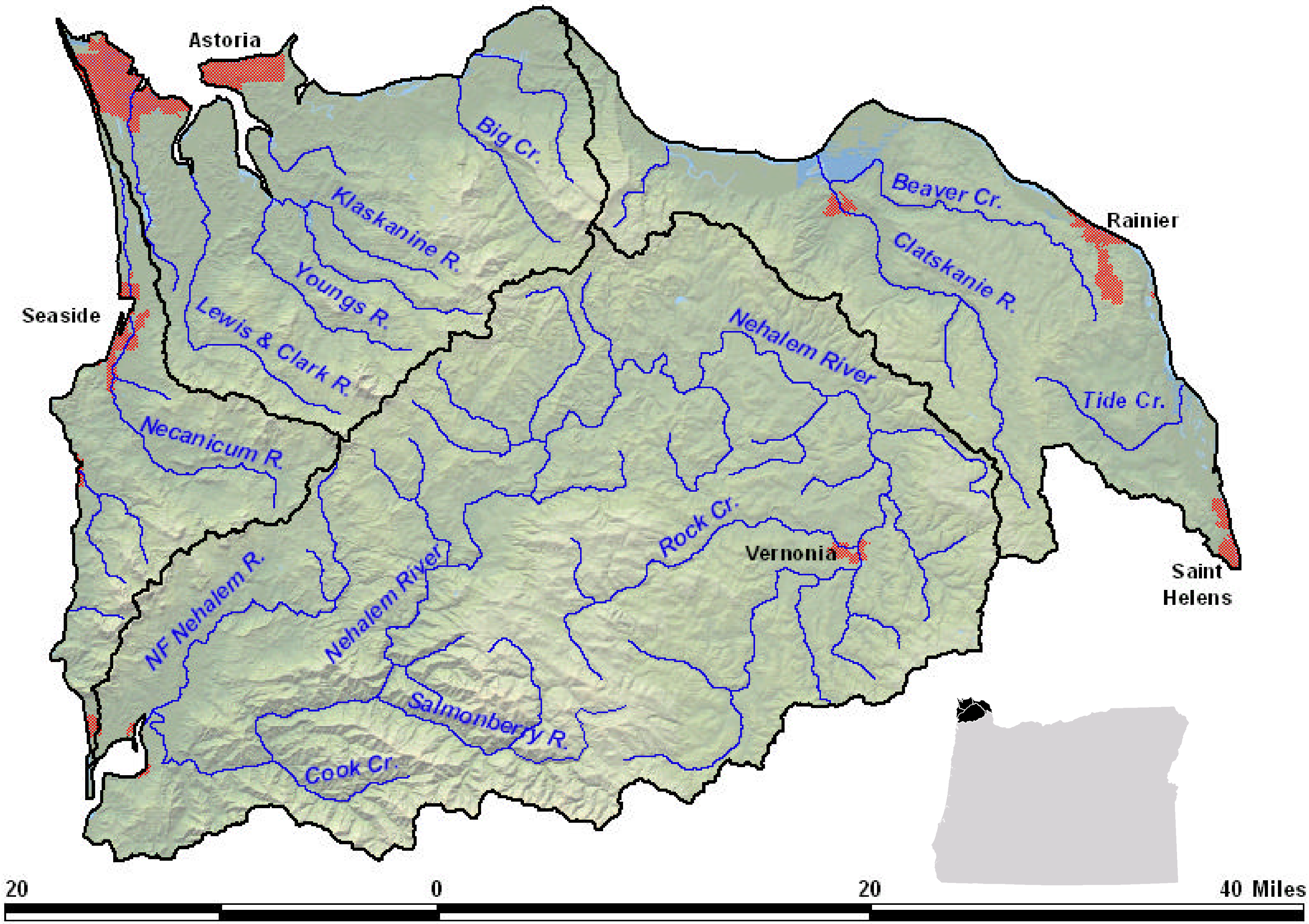
State of Oregon
Department of Environmental Quality

Appendix A: Temperature Technical Analysis

PREPARED BY OREGON DEQ
JUNE, 2003


Astoria
Big Cr.
Klaskanine R.
Youngs R.
Lewis & Clark R.
Seaside
Beaver Cr.
Rainier
Clatskanie R.
Nehalem River
Tide Cr.
Necanicum R.
Rock Cr.
Vernonia
Saint Helens
NF Nehalem R.
Nehalem River
Salmonberry R.
Cook Cr.
20
0
20
40 Miles

NORTH COAST SUBBASINS STREAM TEMPERATURE ANALYSIS

VEGETATION, HYDROLOGY AND MORPHOLOGY

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CHAPTER 1. INTRODUCTION

Figure 1-1. *The North Coast area includes four 4th field hydrologic units: Nehalem, Necanicum, Lower Columbia, and Clatskanie River Subbasins.*

Terms Used in this Chapter :

Advection - Flowing open channels transport suspended/dissolved s ubstances and heat. The rate of transportation of substances and heat in the water column is called advection. It is a function of stream gradient, channel dimensions and channel roughness.

Anthropogenic – Caused by or originating from humans

Background – All non-anthropogenic sources of pollutants. In cases DEQ is unable to distinguish background and anthropogenic sources of pollutants, the pollutants are considered as background in the analysis.

Dispersion - Diffusion in flowing open channels occurs at a high rate due to turbulent mixing. Water flows are turbulent because cross-sectional flow velocities are variable, with slower velocities near the channel boundaries caused by friction. Dispersion refers to turbulent diffusion and is often much greater than molecular diffusion.

Heat - Energy associated with the random motion of molecules.

Heat Flux – Rate of heat transfer per unit surface area.

Heat Transfer - Processes that change the heat of a body. Can occur through direct contact, radiation, evaporation and other related processes.

Hydrologic Unit - A USGS classification of drainage areas: watershed (5th Field), subbasin (4th Field) and basin (3rd Field).

Hyporheic Zone - The saturated sediments and interstitial spaces beneath streams, receiving water from both above and below ground.

Load Allocation – The portion of pollutants allowed in a total maximum daily load for anthropogenic and background nonpoint sources.

Mass Transfer - Processes that change the mass of a body. In open channel systems it can occur through advection, dispersion and mixing with surface and subsurface waters.

Nonpoint Sources – Pollutants that originates from dispersed locations such as, but not limited to, agricultural land uses, forestry and background sources.

Point Sources – Pollution that originates from a fixed location such as industrial waste.

Pollutant – Solid waste, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, and industrial, municipal, and agricultural waste discharge into water.

Pollution – Alteration of physical, chemical or biological properties of any waters of the state which tends to, either by itself or in connection with any other substance, create a public nuisance or which will or tends to render suc h waters harmful, detrimental or injurious to beneficial uses.

Solar Zenith - For any given day, the angle at which the sun is at the highest position in the sky.

Source – Any process, practice or activity that causes pollution or induces pollutants into a waterbody.

Thermodynamic - The physics that relate to the processes of heat transfer and mechanical processes associated with heat.

Total Maximum Daily Load – A plan developed under the Clean Water Act that is designed to reduce pollution to levels that meet water quality standards.

Unit Volume - A standardized volume measurement.

Waste Load Allocation - The portion of pollutants allowed in a total maximum daily load for point source

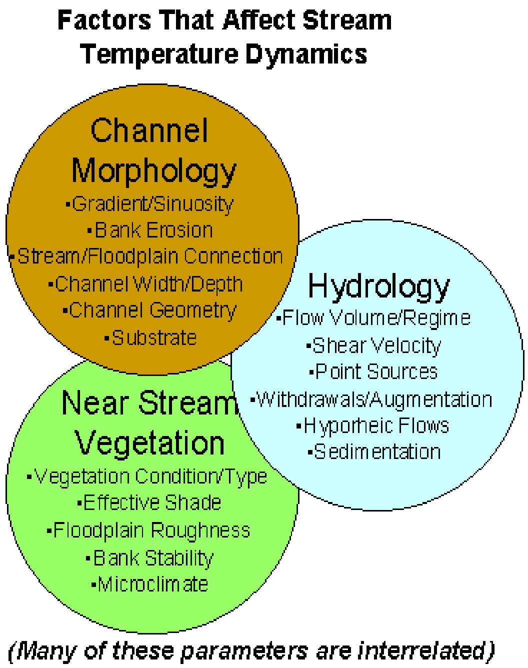
1.1 SCALE

The lands within the North Coast Subbasins occupy 1,600 square miles in northwestern Oregon. This area includes four 4th field hydrologic unit subbasins: Nehalem (17100202), Necanicum (17100201), Lower Columbia (170800006), and Clatskanie (17080003). While the stream temperature TMDL considers all surface waters within the North Coast area, this analysis largely focuses on the largest water bodies and those that are most thermally impaired, namely: the Nehalem River and some of its tributaries.

1.2 SCOPE

Parameters that affect stream temperature can be grouped as near stream vegetation and land cover, channel morphology and hydrology. Many of these stream parameters are interrelated (i.e., the condition of one may impact one or more of the other parameters). These parameters affect stream **heat transfer processes** and stream **mass transfer processes** to varying degrees. The analytical techniques employed to develop the North Coast Subbasins Temperature TMDL are designed to include all of the parameters that affect stream temperature given that available data and methodologies allow accurate quantification.

Stream temperature dynamics are further complicated when these parameters are evaluated on a watershed or subbasin scale. Many parameters exhibit considerable spatial variability. For example, channel width measurements can vary greatly over small stream lengths. Some parameters can have a diurnal and seasonal temporal component as well as spatial variability. The current analytical approaches developed for stream temperature assessment consider all of these parameters and rely on ground level and remotely sensed spatial data. To understand temperature on a landscape scale is a difficult and often resource intensive task. General analytical techniques employed in this effort are statistical and deterministic modeling of hydrologic and thermal processes.



Stated Purpose:

The overriding intent of this analytical effort is to improve the understanding of the North Coast Subbasins stream temperature dynamics in both spatial and temporal scales.

Acknowledged Limitations:

It should be acknowledged that there are limitations to this effort:

- The scale of this effort is large with obvious challenges in capturing spatial variability in stream and landscape data. Available spatial data sets for land cover and channel morphology are coarse, while derived data sets are limited to aerial photo resolution, rectification limitations and human error.

- Data are insufficient to describe high-resolution instream flow conditions making validation of derived mass balances difficult.
- The water quality issues are complex and interrelated. The state of the science is still evolving in the context of comprehensive landscape scaled water quality analysis. For example, quantification techniques for microclimates that occur in near stream areas are not developed and available to this effort. Regardless, recent studies indicate that forested microclimates play an important, yet variable, role in moderating air temperature, humidity fluctuations and wind speeds.
- Quantification techniques for estimating potential subsurface inflows/returns and behavior within substrate are not employed in this analysis. While analytical techniques exist for describing subsurface/stream interactions, it is beyond the scope of this effort with regard to data availability, technical rigor and resource allocations.
- Land use patterns vary through the drainage from heavily impacted areas to areas with little human impacts. However, it is extremely difficult to find large areas without some level of either current or past human impacts. The development of potential conditions that estimate stream conditions when human influences are minimized is statistically derived and based on stated assumptions within this document. Limitations to stated assumptions are presented where appropriate. It should be acknowledged that as better information is developed these assumptions will be refined.

While these assumptions outline potential areas of weakness in the methodology used in the stream temperature analysis, the Oregon Department of Environmental Quality has undertaken a comprehensive approach. All important stream parameters that can be accurately quantified are included in the analysis. In the context of understanding of stream temperature dynamics in the North Coast Subbasins, these areas of limitations should be the focus for future study.

1.3 Overview of Stream Heating Processes

Stream temperature dynamics are complex. Changes in rates of heat transfer can vary considerably across relatively small spatial and temporal scales. In quantifying and understanding stream heat and mass transfer processes, the challenge is not represented in theoretical conceptions of thermodynamics and relations to flowing water. Thermodynamics is a well-established academic discipline that offers a scientifically tested methodology for understanding stream temperature. In fact, the methodology used to evaluate stream temperature is quite simple when compared to other thermodynamic applications that have become common technological necessities to the American way of life (i.e. a car radiators, cooling towers, solar thermal panels, insulation, etc.). Instead, the true challenge in understanding stream temperature materializes with the recognition that thermally significant heat and mass transfer processes occur in very fine spatial and temporal scales. Tremendous spatial variability occurs across a watershed, and is compounded by adding a temporal component. At any stream reach, thermal processes constantly change throughout the day, month and year. Stream temperatures are a result of a multitude of heat transfer and mass transfer process. The conceptual and analytical challenge is to develop a framework that captures these forms of variability to the best possible extent.

Water temperature change (ΔT_w) is a function of the heat transfer in a discrete volume and may be described in terms of changes in heat per unit volume. It is then possible to discuss stream temperature change as a function of two variables: heat and mass transfer.

Water Temperature Change as a Function of Heat Exchange per Unit Volume,

$$\Delta T_w \propto \frac{\Delta \text{Heat}}{\text{Volume}}$$

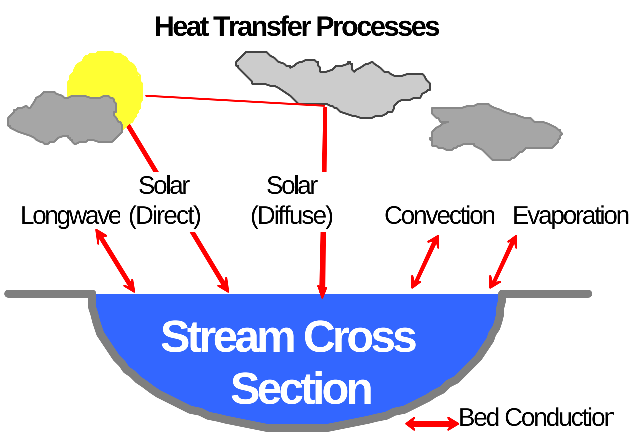
1. **Heat transfer** relates to processes that change heat in a defined water volume. There are several thermodynamic pathways that can introduce or remove heat from a stream. For any given stream reach heat exchange is closely related to the season, time of day and the surrounding environment and the stream characteristics. Heat transfer processes can be dynamic and change over relatively

small distances and time periods. Several heat transfer processes can be affected by human activities. These pathways are discussed below in **Section 1.3.1 Heat Transfer Processes**

2. **Mass transfer** relates to transport of flow volume downstream, instream mixing and the introduction or removal of water from a stream. For instance, flow from a tributary will cause a temperature change if the temperature is different from the receiving water. Mass transfer occurs commonly in stream systems as a result of advection, dispersion, groundwater exchange, hyporheic flows, surface water exchange and other human related activities that alter stream flow volume. Mass transfer processes are discussed in **Section 1.3.2 Mass Transfer Processes**

1.3.1 Heat Transfer Processes

Stream heating processes follow two cycles: a seasonal cycle and a diurnal cycle. In the Pacific Northwest, the seasonal stream heating cycle experiences a maximum positive flux during summer months (July and August) while the minimum seasonal stream heating periods occur in the winter months (December and January). The diurnal net heating cycle experiences a daily maximum at or near midday. This maximum usually corresponds to the solar zenith. The daily minimum rate of stream heating usually occurs during the late night or the early morning. It should be noted, however, that meteorological conditions are variable. Cloud cover and precipitation, humidity and wind seriously alter the heat transfer pathways between the stream and its environment.



The heat transfer processes that control stream temperature include solar radiation, longwave radiation, convection, evaporation, and bed conduction. All other processes are capable of both introducing and removing heat from a stream, with the exception of solar radiation, which only delivers heat energy. These thermal processes occur simultaneously and result in an overall rate of heat exchange with a stream.

When a stream surface is exposed to midday solar radiation, large quantities of heat will be delivered to the stream system (Brown 1969, Beschta et al. 1987). Low levels of stream shade allows solar radiation to become a dominant stream heating transfer process. This holds true even when accounting for surface reflection and the absorption properties of water outside the visible spectrum. As would be expected maximum heat transfer rates occur when a stream is exposed to midday solar radiation.

Longwave radiation, also referred to as thermal radiation, is a source of both heating and cooling. Longwave radiation heat is derived from the atmosphere and vegetation along stream banks and is a source of heat when received by the stream surface. Water readily absorbs the thermal spectral wavelength. Longwave radiation is also emitted from the stream surface, and thus, has a cooling influence. Thermal radiation emitted from the stream is called back radiation and can be accurately measured from aerial remote sensing equipment. The net transfer of heat via longwave radiation usually balances so that the amount of heat entering is similar to the rate of heat leaving the stream (Beschta and Weatherred, 1984; Boyd, 1996). The overall net heat transfer rate from longwave radiation (i.e. the sum from the atmosphere, surrounding land cover and back radiation from the stream) is small relative to other thermal processes.

Evaporation occurs in response to internal energy of the stream (molecular motion) that randomly expels water molecules into the overlying air mass. Evaporation is the most effective method of dissipating heat from water. This is the preferred cooling mechanism employed by the human body via perspiration. As stream temperatures increase, so does the rate of evaporation. Air movement (wind) and low vapor pressures and relative humidity increase the rate of evaporation and accelerate stream cooling. Evaporation is the primary mechanism for stream cooling.

Condensation is the opposite of evaporation. When the air temperature reaches the dew point, the air mass at the stream surface interface becomes saturated and triggers a phase change of water vapor into liquid. Condensation represents a heating process, but occurs during limited portions of the day if at all (usually during early morning periods when nighttime temperatures are cool). Condensation is a minor component relative to other the heat transfer processes.

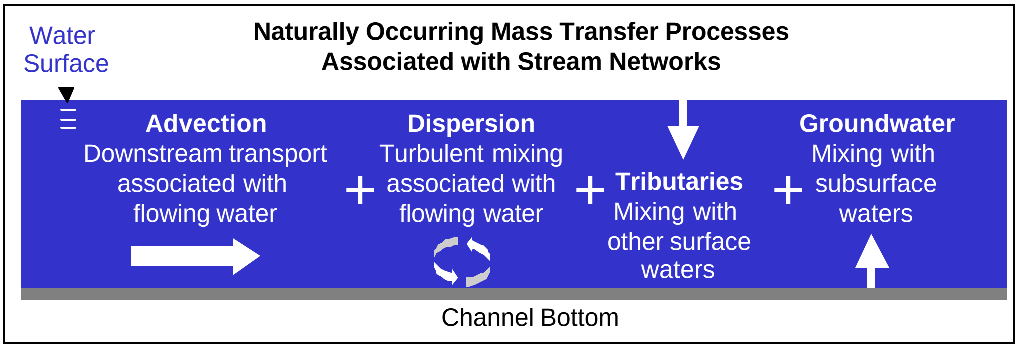
Convection transfers heat between the stream and the air via molecular and turbulent conduction. Heat is transferred in the direction of warmer to cooler. Air can have a warming influence on the stream when the stream is cooler. The opposite is also true. The amount of convective heat transfer between the stream and air is low. Air has a low conductance relative to water and simply cannot conduct heat efficiently. An easy way to conceptualize the conductance between water and air is to compare the body's perception of temperature when both water and air are at the same temperature. Human exposure to air at 60^{o}F is possible for long periods, while exposure to 60^{o}F water is fatal in a matter of two hours. Air is a poor conductor of heat. Nevertheless, this should not be interpreted to mean that air temperatures do not affect stream temperature. Air temperatures play a complex role in stream heating processes affecting vapor pressure gradients, relative humidity and atmospheric thermal radiation levels. However, air temperatures can only impart heat to a stream very slowly via conduction.

Depending on streambed composition, solar radiation may warm the streambed. Larger substrate dominated streambeds and/or shallow streams may allow the bed to differentially heat and then conduct heat to the stream as long as the bed is warmer than the stream. Bed conduction of heat to the water column may cause maximum stream temperatures to occur later in the day, possibly into the evening hours.

Heat associated with physical processes such as friction and compression is a negligible source and is not included in this analysis.

1.3.2 Mass Transfer Processes

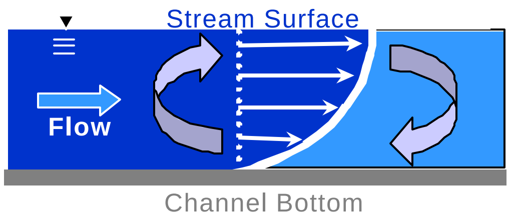
Mass transfer processes refer to the downstream transport and mixing of water throughout a stream system. The downstream transport of dissolved/suspended substances and heat associated with flowing water is called advection. Dispersion results from turbulent diffusion that mixes the water column. Due 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.



Heat that is transported by river flow is referred to as advected heat. It follows that advection can only occur in the downstream direction. No heat energy is lost or gained by the system during advection, assuming the heat from mechanical processes such as friction and compression is negligible.

Dispersion refers to mixing from turbulent flow.

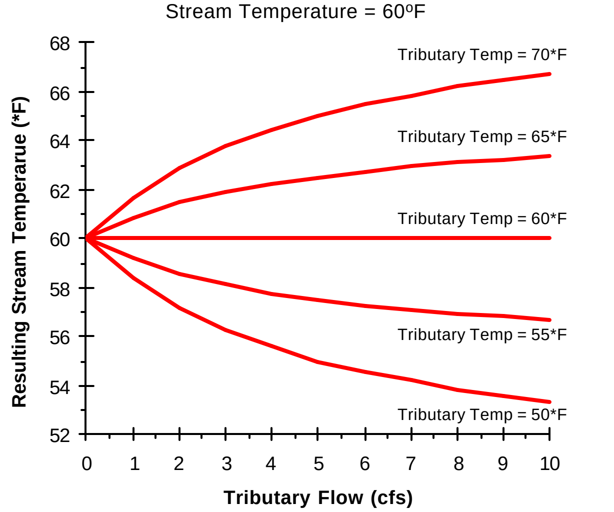
Dispersion results from a vertical velocity profile. Velocity varies as a function of channel depth. Slower velocities occur at the bottom of the water column. Faster velocities occur at the top of the water column. The vertical gradient in flow velocity causes a tumbling motion of water.



Advection is simply the rate at which water and heat is transferred downstream.

Dispersion refers to the mixing caused by turbulent diffusion. In natural stream systems flows are often vertically mixed due to turbulent diffusion of water molecules. Turbulent flows result from a variable flow velocity profile, with lower velocities occurring near the boundaries of the channel (i.e. channel bottom and stream banks). Higher velocities occur farthest away from channel boundaries, commonly at the top of the water column. The velocity profile results from the friction between the flowing water and the rough surfaces of the channel. Since water is flowing at different rates through the channel cross-section, turbulence is created, and vertical mixing results. Dispersion mixes water molecules at a much higher rate than molecular diffusion. 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.

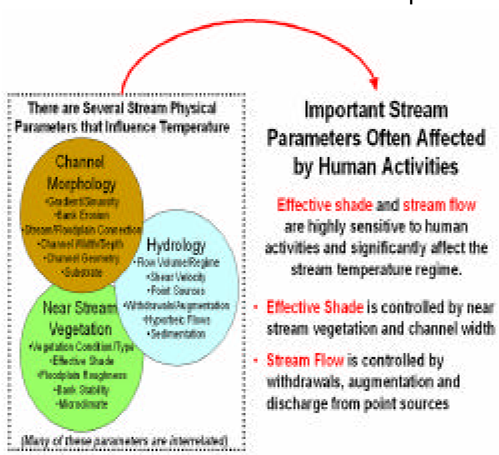
Example of Resulting Stream Temperatures After Stream Mixing With Variable Tributary Flows and Temperatures
Stream Flow = 5 cfs
Stream Temperature = 60ºF



Tributaries and groundwater mixing change the heat of a stream segment when the stream temperature is different from the receiving water. Mixing simply changes the heat as a function of stream and inflow volumes and temperatures. Remote sensing using forward looking infrared radiometry can easily identify areas where heat change occurs due to mixing with surface and subsurface waters.

1.3.3 Human Sources of Stream Warming

The overriding intent of the Oregon stream temperature standard is to minimize human related stream warming. Brown (1969) identified temperature change as a function of heat and stream volume. Using this simple relationship, it becomes apparent that stream temperature change is a function of the heat transfer processes and mass transfer processes. To isolate the human influence on this expression, it is important to associate the human influence on the heat transfer processes and/or mass transfer processes.



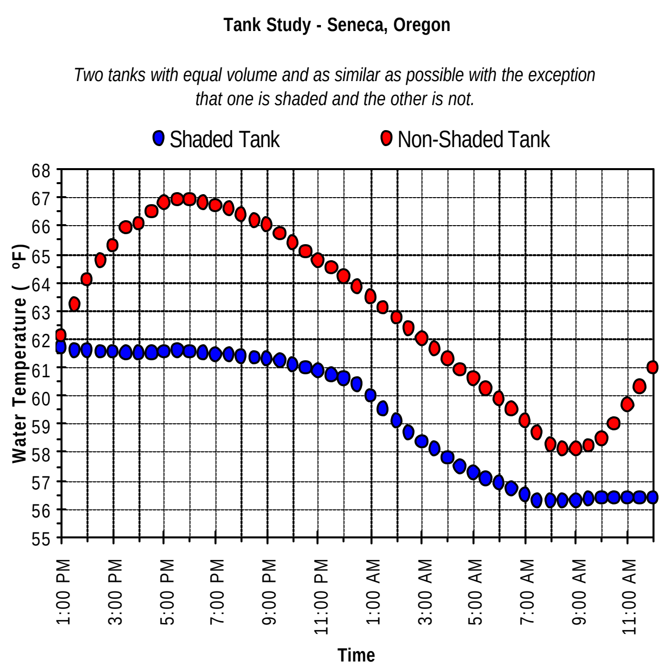
Solar Radiation and Effective Shade

The solar radiation heat process considered in the stream thermal budget is often the most significant heat transfer process and can be highly influenced by human related activity. Decreased levels of stream shade increase solar radiation loading to a stream. The primary factors that determine of stream surface shade are near stream vegetation physical characteristics and channel width. Near stream vegetation height controls the shadow length cast across the stream surface and the timing of the shadow. Channel width determines the shadow length necessary to shade the stream surface. Near stream vegetation and channel width are sometimes interrelated in that stream bank erosion rates can be a function of near stream vegetation condition. **Human activities that change the type or condition of near stream land cover and/or alter stream channels by widening beyond appropriate channel equilibrium dimensions to levels that result in decreased stream surface shading will like have a warming effect on stream temperature.**

Two Recent Studies Relating Shade and Water Temperatures

The Effect of Shade on Water: A Tub Study
J. Moore, J. Miner and R. Bower
Department of Bioresource Engineering
Oregon State University - 1999

Two tanks with equal volumes of water and similar initial temperatures were insolated on the sides and bottom. One was exposed to August solar radiation, while the other was completely shaded. Results are presented in the graph below.



The Impact of Shade on the Temperature of Running Water
B. Petersen, T. Stringham and W. Krueger
Department of Rangeland Resources
Oregon State University - 1999

Results
"Shade from tarps provided a significant amount of protection from additional heating of the water at all shade levels tested… affirms the importance of even small amounts of shade in moderating stream heating."

Conclusion
"At the scale of this study, air temperature appears to have a minor impact on the temperature of water. The dominant factor seemed to be solar radiation."

Stream Flow Modifications

Recall the simple relationship presented by Brown (1969):

$$\Delta T_w \propto \frac{\Delta \text{Heat}}{\text{Volume}}.$$

It follows that large volume streams are less responsive to temperature change, and conversely, low flow streams will exhibit greater temperature sensitivity. Specifically, stream flow volume will affect the wetted channel dimensions (width and depth), flow velocity (and travel time) and the stream assimilative capacity. **Human related reductions in flow volume can have a significant influence of stream temperature dynamics, most likely increasing diurnal variability in stream temperature.**

Beyond the simple conception of reduced flow and corresponding reduced assimilative capacity, flow modifications can be highly complex in nature. Diversions can reroute surface waters through irrigation systems of various efficiencies. Often a portion of it irrigated water returns to the stream system at some lower gradient location.

1.3.4 Natural Sources and Stream Warming

Natural sources that may elevate stream temperature include drought, fires, insect damage to near stream land cover, diseased near stream land cover and windthrow and blowdown in riparian areas. The processes in which natural sources affect stream temperatures include increased stream surface exposure to solar radiation and decreased summertime flows. Legacy conditions (increased width to depth ratios and decreased levels of stream surface shading) that currently exist are, in part, due to natural disturbances. The extent of natural disturbances on near stream vegetation, channel morphology and hydrology in not well documented.

1.3.5 Cumulative Effects

"Cumulative effects are those effects on the environment that result from the incremental effect of the action when added to past, present and reasonably foreseeable future actions... Cumulative effects can result from individually minor but collectively significant actions taking place over a period of time". (Forest Ecosystem Management: An Ecological, Economic and Social Assessment. Report of the Forest Ecosystem Management Assessment Team)

Stream temperature changes result from upstream and local conditions. Incremental increases can combine to create relatively warm stream temperatures. Water has a relatively high heat capacity ($c_p = 10^3$ cal kg^{-1} K^{-1}) (Satterlund and Adams 1992). Conceptually, water is a heat sink. Heat energy that is gained by the stream is retained and only slowly released back to the surrounding environment. Any given measurement of stream temperature is the result of a multitude of processes occurring upstream, as well as those processes acting at the site of measurement. For this reason it is important to consider stream temperature at a stream network scale.

1.4 IMPLEMENTATION OF OREGON DEQ'S STREAM TEMPERATURE STANDARD

Table 1-1. Beneficial uses occurring in the North Coast Subbasins
(OAR 340 – 41 – 202)
Temperature-Sensitive Beneficial uses are marked in Red

Beneficial Use	***Occurring***	***Beneficial Use***	***Occurring***
Public Domestic Water Supply	✓	Salmonid Fish Spawning	✓
Private Domestic Water Supply	✓	Salmonid Fish Rearing	✓
Industrial Water Supply	✓	Resident Fish and Aquatic Life	✓
Irrigation	✓	Anadromous Fish Passage	✓
Livestock Watering	✓	Wildlife and Hunting	✓
Boating	✓	Fishing	✓
Hydro Power		Water Contact Recreation	✓
Aesthetic Quality	✓	Commercial Nav./Transport.	

North Coast Subbasins Temperature Standard

OAR 340-41-0205(2)(b)(A)

No measurable surface water temperature increase resulting from anthropogenic activities is allowed:

(i) In a basin for which salmonid fish rearing is a designated beneficial use, and in which surface water temperatures exceed 64.0°F (17.8°C);

(ii) In the Columbia River or its associated sloughs and channels from the mouth to river mile 309 when surface water temperatures exceed 68.0°F (20.0°C);

(iii) In waters and periods of the year determined by the Department to support native salmonid spawning, egg incubation, and fry emergence from the egg and from the gravels in a basin which exceeds 55.0°F (12.8°C);

(iv) In waters determined by the Department to support or to be necessary to maintain the viability of native Oregon bull trout, when surface water temperatures exceed 50.0°F (10.0°C);

(v) In waters determined by the Department to be ecologically significant cold-water refugia;

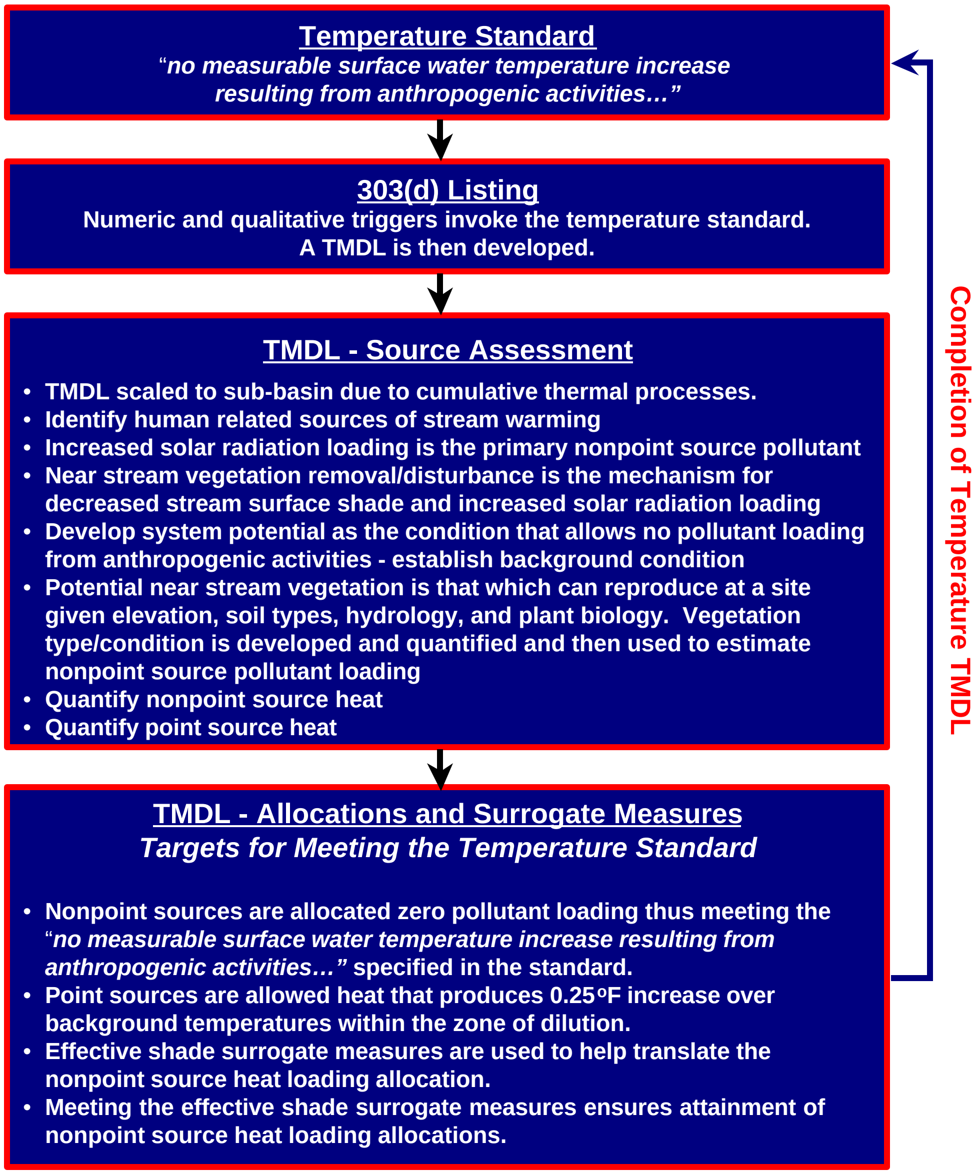
(vi) In stream segments containing federally listed Threatened and Endangered species if the increase would impair the biological integrity of the Threatened and Endangered population;

(vii) In Oregon waters when the dissolved oxygen (DO) levels are within 0.5 mg/l or 10 percent saturation of the water column or intergravel DO criterion for a given stream reach or subbasin;

(viii) In natural lakes.

Summary of Temperature TMDL Development and Approach

Oregon DEQ Temperature Standard, 303(d) Listing and TMDL Development Process



1.4.1 Summary of Stream Temperature Standard

Human activities and aquatic species that are to be protected by water quality standards are deemed beneficial uses. Water quality standards are developed to protect the most sensitive beneficial use within a water body of the State. **The stream temperature standard is designed to protect cold water fish (salmonids) rearing and spawning as the most sensitive beneficial use.**

Several numeric and qualitative trigger conditions invoke the temperature standard. Numeric triggers are based on temperatures that protect various salmonid life stages. Qualitative triggers specify conditions that deserve special attention, such as the presence of threatened and endangered cold water species, dissolved oxygen violations and/or discharge into natural lake systems. The occurrence of one or more of the stream temperature trigger will invoke the temperature standard.

Once invoked, a water body is designated water quality limited. For such water quality limited water bodies, the temperature standard specifically states that "***no measurable surface water temperature increase resulting from anthropogenic activities is allowed"*** (OAR 340-41-0205(2)(b)(A)). Thermally impaired water bodies in the North Coast Subbasins are subject to the temperature standard that mandates a condition of no allowable anthropogenic related temperature increases.

1.4.2 Summary of Stream Temperature TMDL Approach

Stream temperature TMDLs are generally scaled to a subbasin or basin and include all perennial surface waters with salmonid presence or that contribute to areas with salmonid presence. Since stream temperature results from cumulative interactions between upstream and local sources, the TMDL considers all surface waters that affect the temperatures of 303(d) listed water bodies. For example, the Nehalem River is water quality limited for temperature. To address this listing in the TMDL, the Williamson River and all major tributaries are included in the TMDL analysis and TMDL targets apply throughout the entire stream network. This broad approach is necessary to address the cumulative nature of stream temperature dynamics.

The temperature standard specifies that "***no measurable surface water temperature increase resulting from anthropogenic activities is allowed***". An important step in the TMDL is to examine the anthropogenic contributions to stream heating. The pollutant is heat. The TMDL establishes that that the anthropogenic contributions of nonpoint source solar radiation heat loading results from varying levels of decreased stream surface shade throughout the subbasin. Decreased levels of stream shade are caused by near stream land cover disturbance/removal and channel morphology changes. Other anthropogenic sources of stream warming include stream flow reductions and warm surface water return flows.

System potential, as defined in the TMDL, is the combination of potential near stream land cover condition and potential channel morphology conditions. Potential near stream land cover is that which can grow and reproduce on a site, given: climate, elevation, soil properties, plant biology and hydrologic processes. Potential channel morphology is developed using an estimate of near stream disturbance zone widths appropriate for the Rosgen channel type related to drainage area. *System potential* does not consider management or land use as limiting factors. **In essence, *System potential* is the design condition used for TMDL analysis that meets the temperature standard by minimizing human related warming.**

- *System potential* <u>is</u> an estimate of the condition where anthropogenic activities that cause stream warming are minimized.
- *System potential* <u>is not</u> an estimate of pre-settlement conditions. Although it is helpful to consider historic land cover patterns, channel conditions and hydrology, many areas have been altered to the point that the historic condition is no longer attainable given drastic changes in stream location and hydrology (channel armoring, wetland draining, urbanization, etc.).

All stream temperature TMDLs allocate heat loading. Nonpoint sources are expected to eliminate the anthropogenic portion of solar radiation heat loading. Point sources are allowed heating that results in less than 0.25^{o}F increase in a defined mixing zone. Allocated conditions are expressed as heat per unit time (kcal per day). The nonpoint source heat allocation is translated to effective shade surrogate measures that linearly translates the nonpoint source solar radiation allocation. Effective shade surrogate measures provide site-specific targets for land managers. And, attainment of the surrogate measures ensures compliance with the nonpoint source allocations.

1.4.3 Limitations of Stream Temperature TMDL Approach

It is important to acknowledge limitations to analytical outputs to indicate where future scientific advancements are needed and to provide some context for how results should be used in regulatory processes, outreach and education and academic studies. The past decade has brought remarkable progress in stream temperature monitoring and analysis. Undoubtedly there will be continued advancements in the science related to stream temperature.

While the stream temperature data and analytical methods presented in TMDLs are comprehensive, there are limitations to the applicability of the results. Like any scientific investigation, research completed in a TMDL is limited to the current scientific understanding of the water quality parameter and data availability for other parameters that affect the water quality parameter. Physical, thermodynamic and biological relationships are well understood at finite spatial and temporal scales. However, at a large scale, such as a subbasin or basin, there are limits to the current analytical capabilities.

The state of scientific understanding of stream temperature is evolving, however, there are still areas of analytical uncertainty that introduce errors into the analysis. Three major limitations should be recognized:

- Current analysis is focused on a defined critical condition. This usually occurs in late July or early August when stream flows are low, radiant heating rates are high and ambient conditions are warm. However, there are several other important time periods where data and analysis is less explicit. For example, spawning periods have not received such a robust consideration.
- Current analytical methods fail to capture some upland, atmospheric and hydrologic processes. At a landscape scale can these exclusions can lead to errors in analytical outputs. For example, methods do not currently exist to simulate riparian microclimates at a landscape scale.
- In some cases, there is not scientific consensus related to riparian, channel morphology and hydrologic potential conditions. This is especially true when confronted with highly disturbed sites, meadows and marshes, potential hyporheic/subsurface flows, and sites that have been altered to a state where potential conditions produce an environment that is not beneficial to stream thermal conditions (such as a dike).

CHAPTER 2. AVAILABLE DATA

Terms Used in this Chapter

Canopy Cover/Density – The percentage of the area vegetation canopy/cover relative to a specific area. Commonly measured on the ground with a densiometer or with aerial photos in plan view.

Channel Morphology – The structure, form and evolution of stream channels.

Continuous Data - Data that is collected at consistent intervals over a specified time period.

Emissivity –The ratio of the actual emitted radiance to that of an ideal blackbody. Emissivity ranges from 0 to 1 (where 1 would be a blackbody) and is a term in the Steffan-Boltzmann Law for black body thermal radiation.

Effective Shade – The percentage of direct beam solar radiation attenuated and scattered before reaching the ground or stream surface. Commonly measured with a Solar Pathfinder.

Forward Looking Infrared Radiometry (FLIR) – The collection of radiation data used in this analysis to quantify the temperature of streams and the surrounding environment.

Gage Data – Flow volume information collected at a fixed location over long time periods.

Geographic Information Systems (GIS) – A computer system designed to view, sample and create spatial data sets.

Ground Level Data - Data collected where staff visited a site.

Hydrology - The scientific study of the water of the earth, its occurrence, circulation and distribution, its chemical and physical properties, and its interaction with its environment, including its relationship to living things.

Longitudinal Direction – Parallel to the stream flow direction.

NPDES – National Pollutant Discharge Elimination System established by the CWA

Near Stream Land Cover – Vegetation or other physical structures occur in the near stream area.

Nonpoint Sources – Pollutants that originates from dispersed locations such as, but not limited to, agricultural land uses, forestry and background sources.

Point Sources – Pollution that originates from a fixed location such as industrial waste.

Remotely Sensed Data - Data collected from an aerial or satellite based platform.

Rosgen Stream Type – Stream groupings that are based on basic channel and valley measurements.

Transverse Direction - Perpendicular to the stream flow direction

2.1 GROUND LEVEL DATA

Several ground level data collection efforts have been completed for the North Coast Subbasins. Available ground level data sources are included and are discussed in detail in this chapter. Specifically, this stream temperature analysis relied on the following data types: continuous temperature data, flow volume - gage data and instream measurements, near stream land cover surveys, channel morphology surveys and effective shade measurements.

2.1.1 Continuous Temperature Data

Continuous temperature data are used in this analysis to:

- *Calibrate stream emissivity for forward looking infrared radiometry,*
- *Calculate temperature statistics and assess the temporal component of stream temperature,*
- *Calibrate temporal temperature simulations.*

Continuous temperature data is collected at one location for a specified period of time, usually spanning several summertime months. Measurements were collected using thermistors[1] and data from these devices are routinely checked for accuracy. Continuous temperature data were collected in 2000 and 2001 at ninety-five sites. DEQ processed all of these data sets for the seven-day moving average maximum stream temperature (i.e., seven-day statistic). **Figure 2-1** displays continuous temperature data monitoring locations and seven-day moving average maximum daily temperatures. **Figures 2-2** to **2-11** graph temporal data (i.e., seasonal and daily) for selected streams in the North Coast Subbasins. **Table 2-1** lists the seven-day moving average daily maximum stream temperatures and the monitoring location description.

Calculated seven-day moving average maximum stream temperatures indicate a large extent of the North Coast Subbasins stream systems exceed the 64^{o}F numeric trigger in Oregon's stream temperature standard. The majority of stream segments experience summertime daily stream temperatures in the low to upper-60^{o}F range for long periods of time between May and October. The Nehalem River exceeds 70^{o}F at several reaches during the summer months.

Areas where seasonal stream temperatures remain below the 64^{o}F numeric trigger are limited to upper headwater reaches and smaller forested streams. For example, the Salmonberry River and Cook Creek are mostly forested and their temperatures barely exceed 64^{o}F at their mouths.

[1] Thermistors are small electronic devices that are used to record stream temperature at one location for a specified period of time.

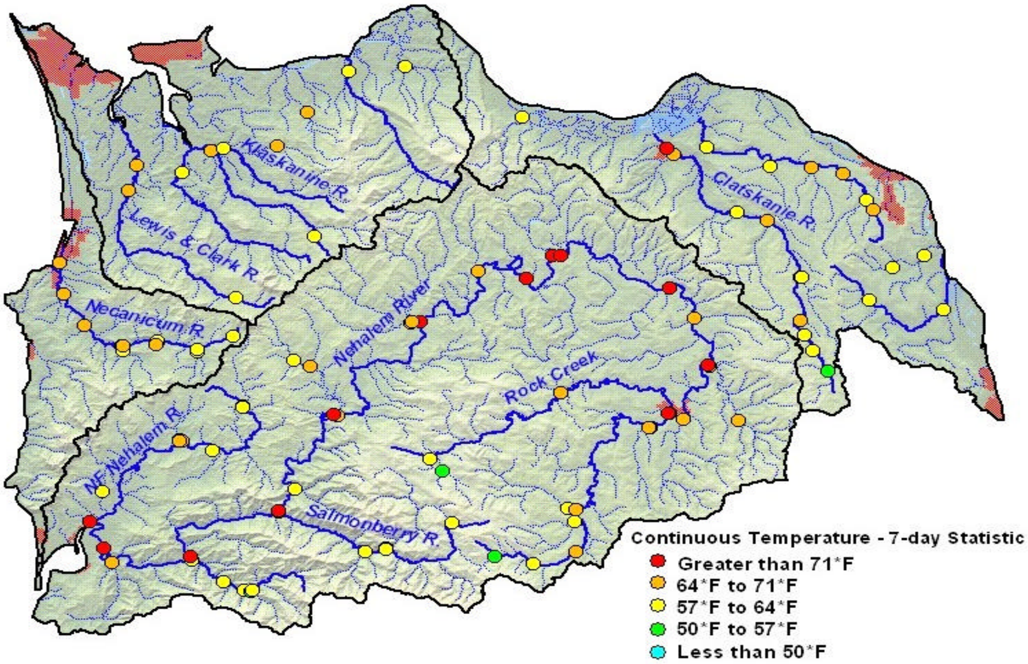


Figure 2-1*. Continuous stream temperature measurement locations – Ninety-five instream continuous temperature measurements were collected in 2000 and 2001. Maximum seven-day moving average daily maximums (7-day statistic) suggest that temperatures are highly variable throughout the North Coast Subbasins.*

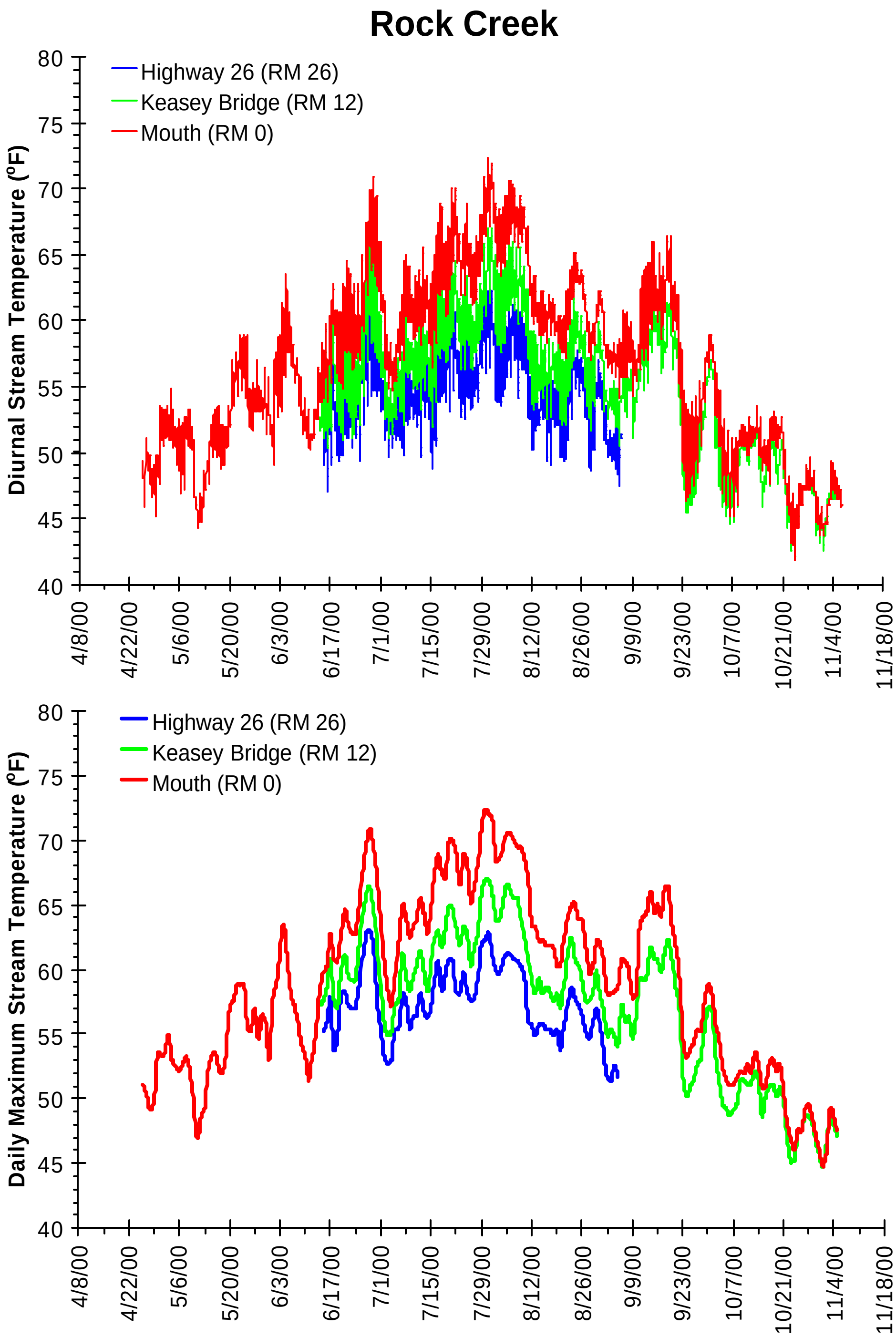


***Figure 2-2**. Rock Creek continuous temperature data.*

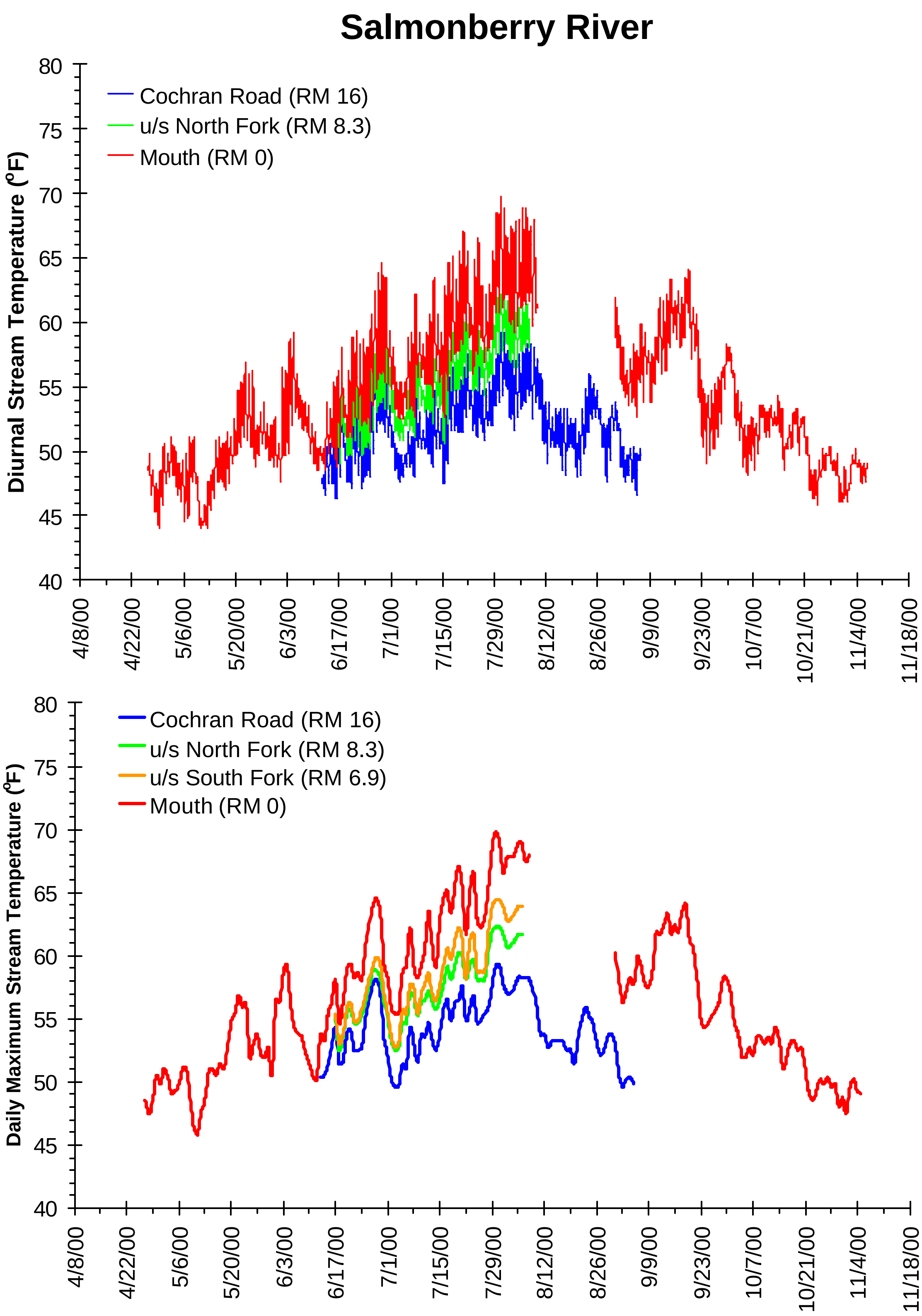


***Figure 2-3**. Salmonberry River continuous temperature data.*

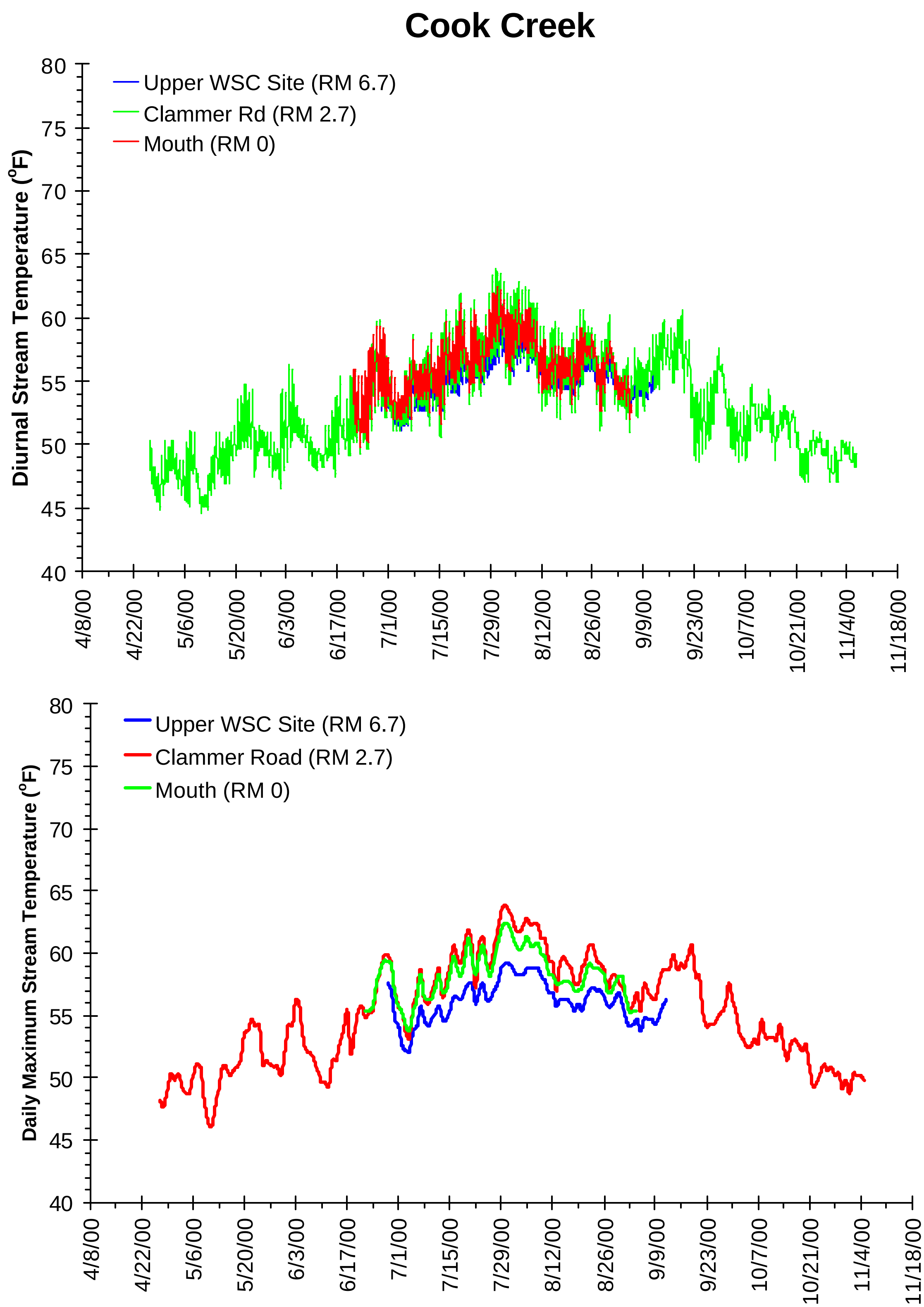


***Figure 2-4**. Cook Creek continuous temperature data.*

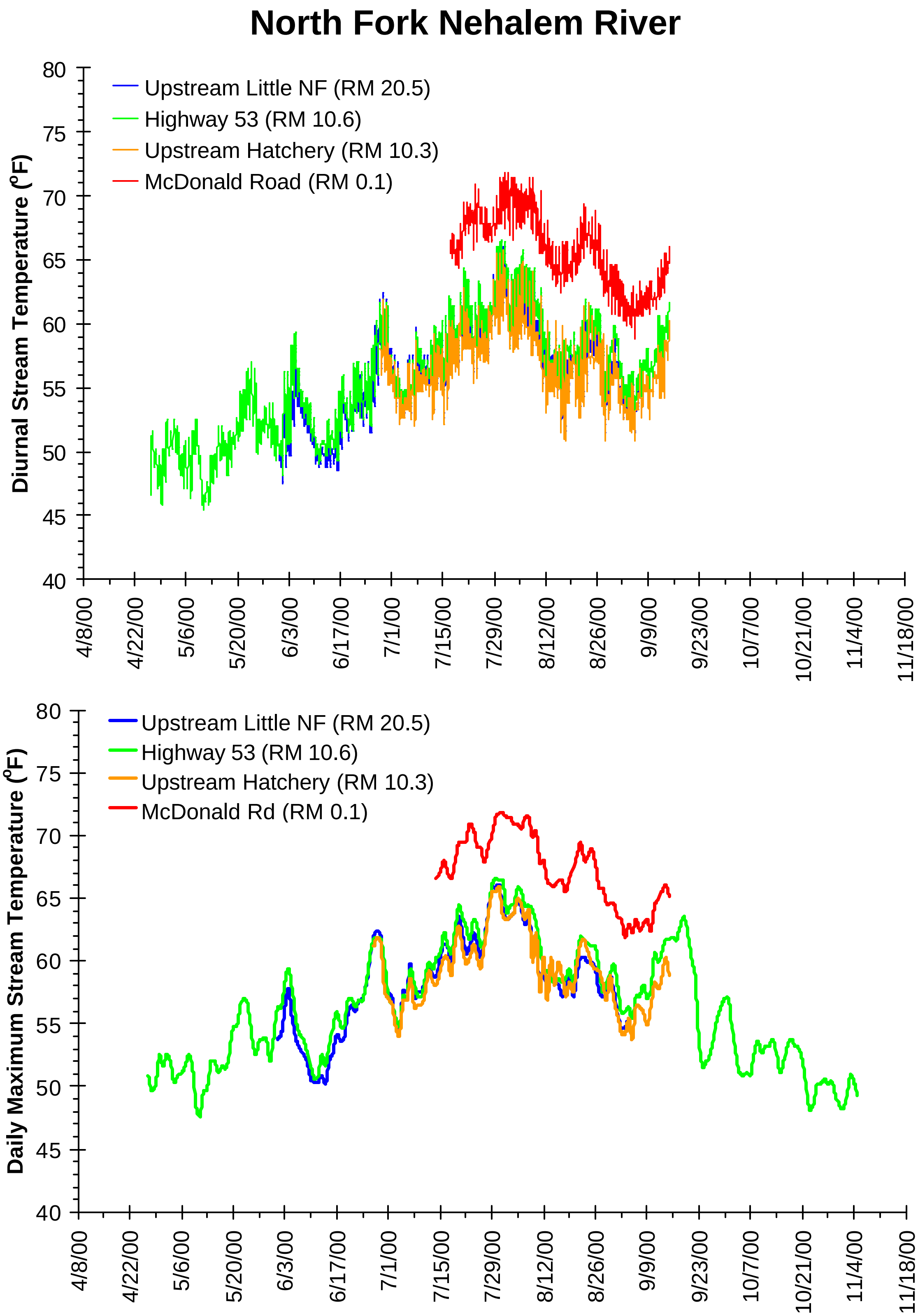
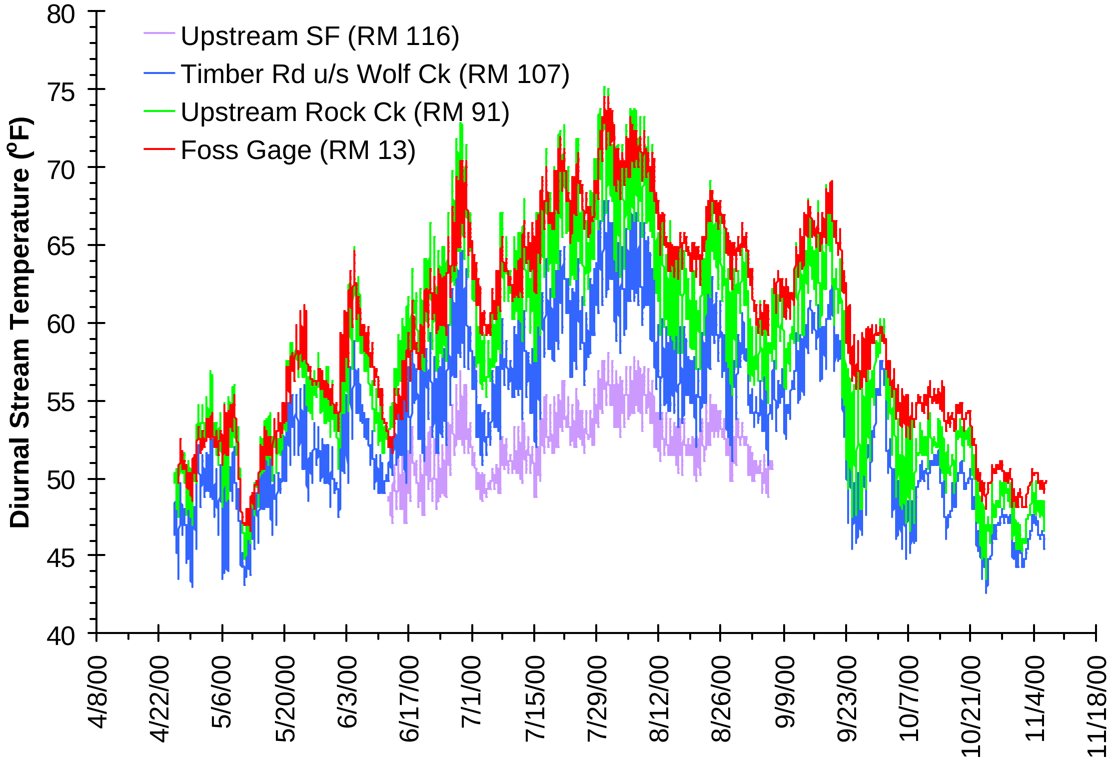


***Figure 2-5**. North Fork Nehalem River continuous temperature data.*

Nehalem River



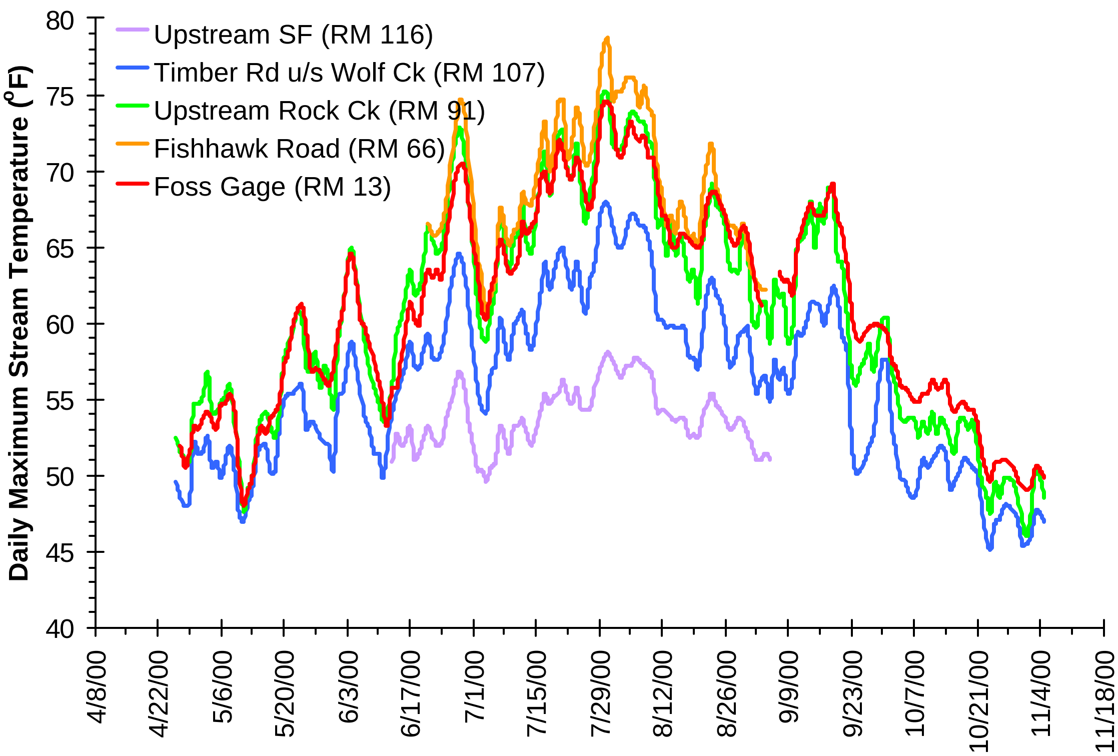


***Figure 2-6**. Nehalem River continuous temperature data.*

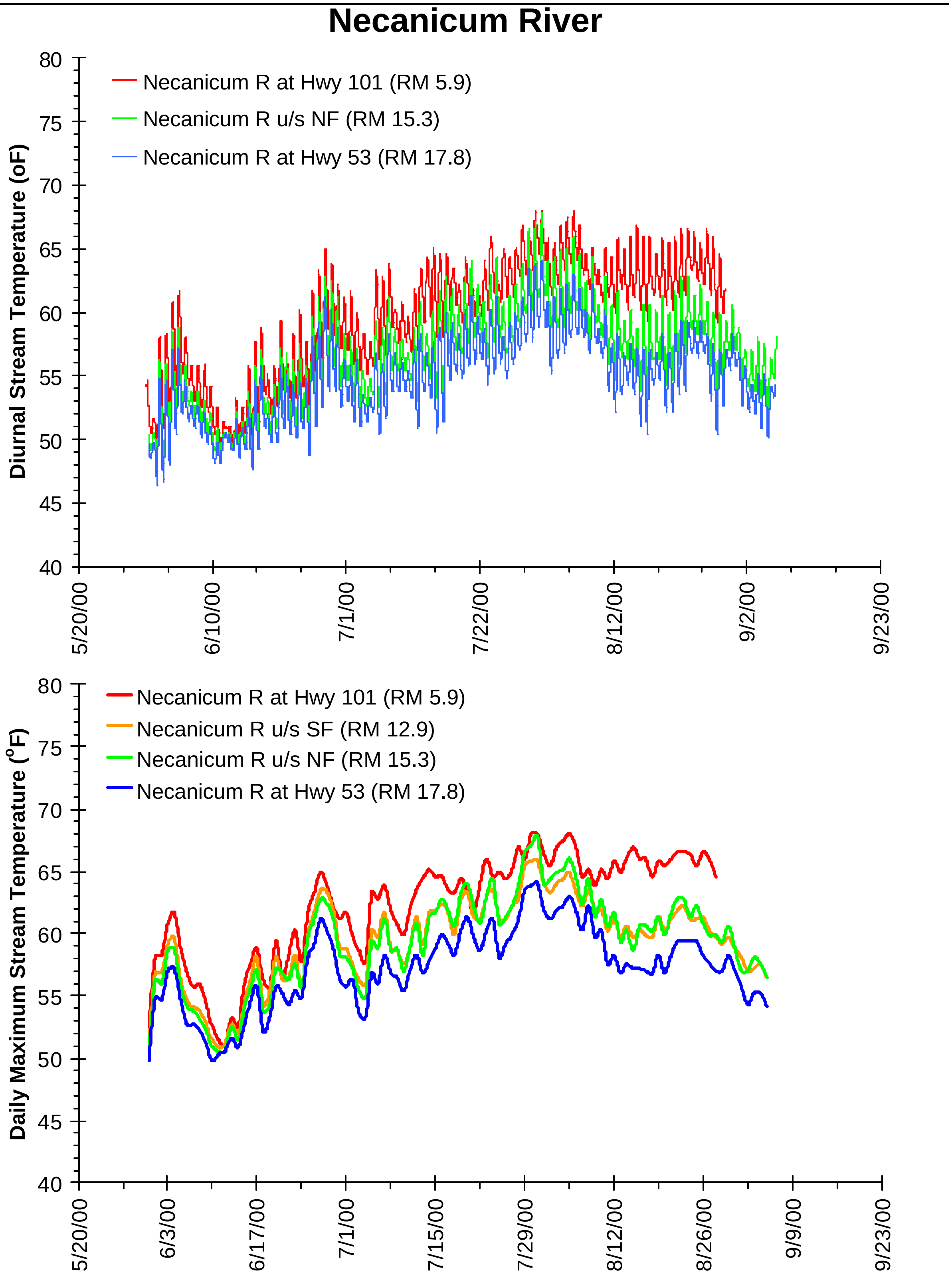


***Figure 2-7**. Necanicum River continuous temperature data.*

Lower Columbia River Subbasin Streams

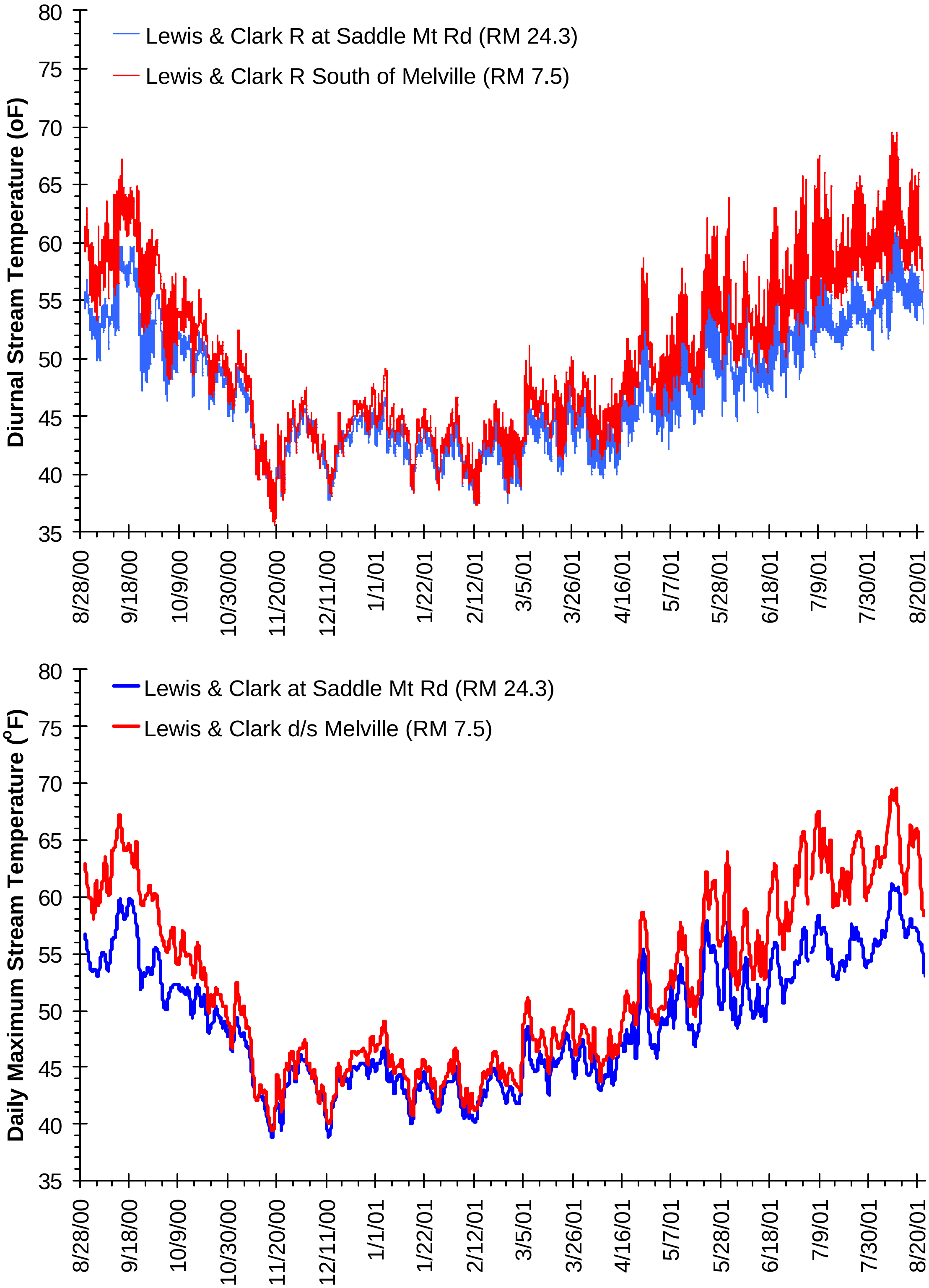


***Figure 2-8**. Lower Columbia River subbasin streams continuous temperature data (1 of 2).*

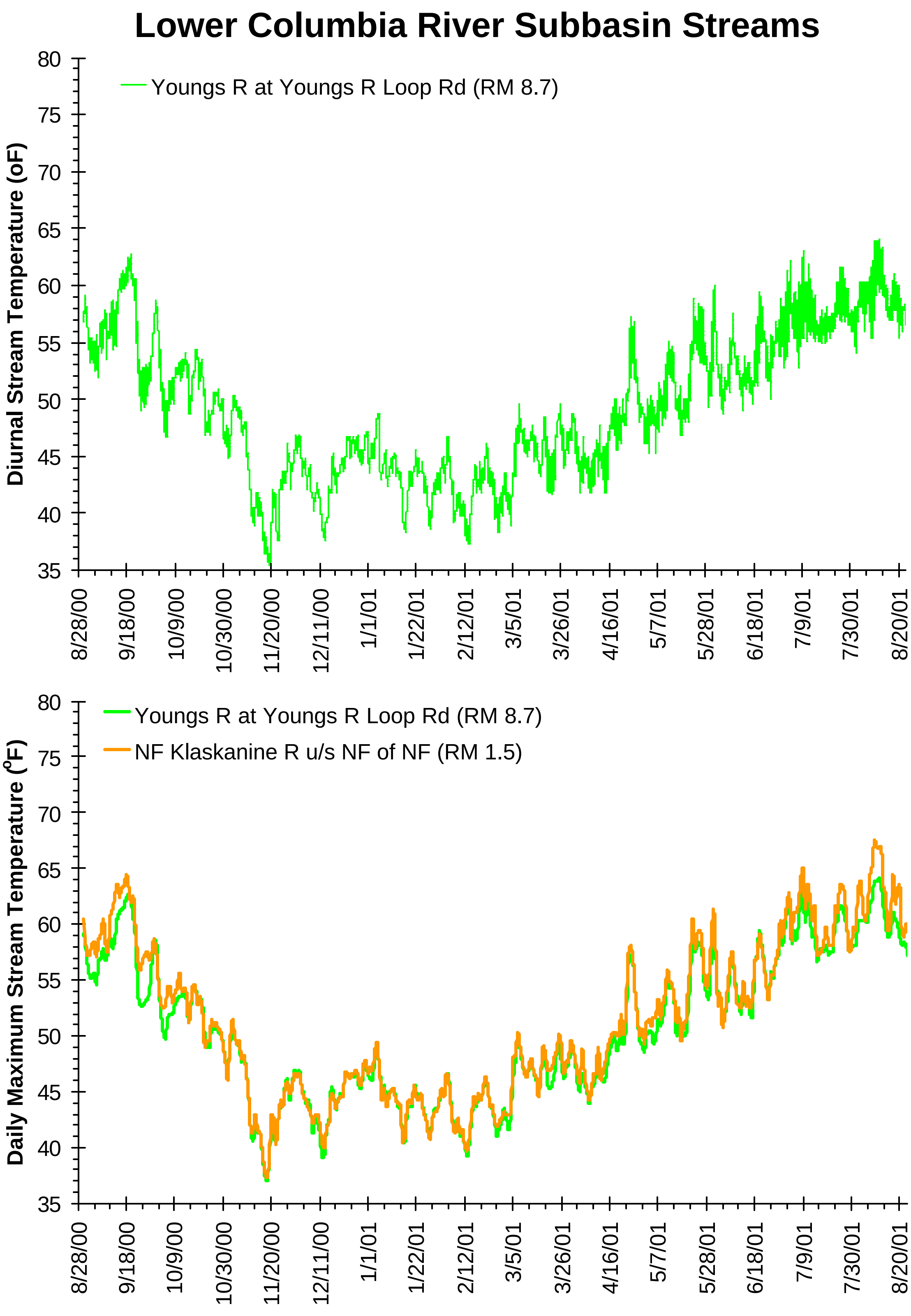
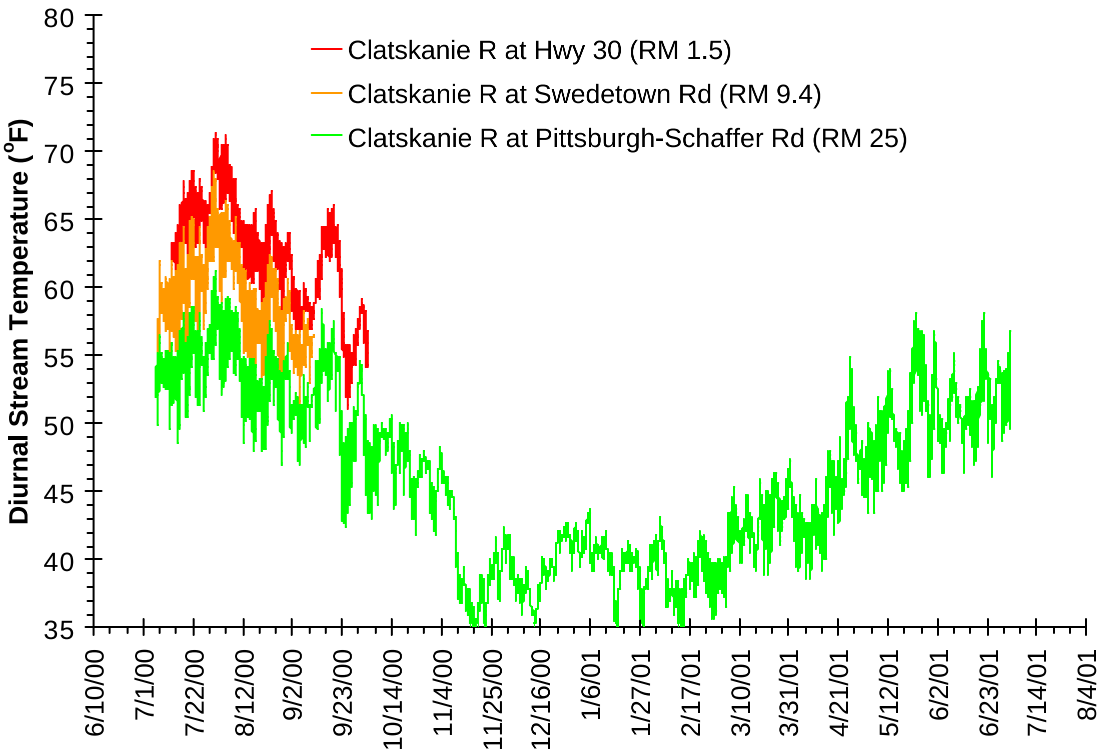


Figure 2-9. Lower Columbia River subbasin streams continuous temperature data (2 of 2).

Clatskanie River



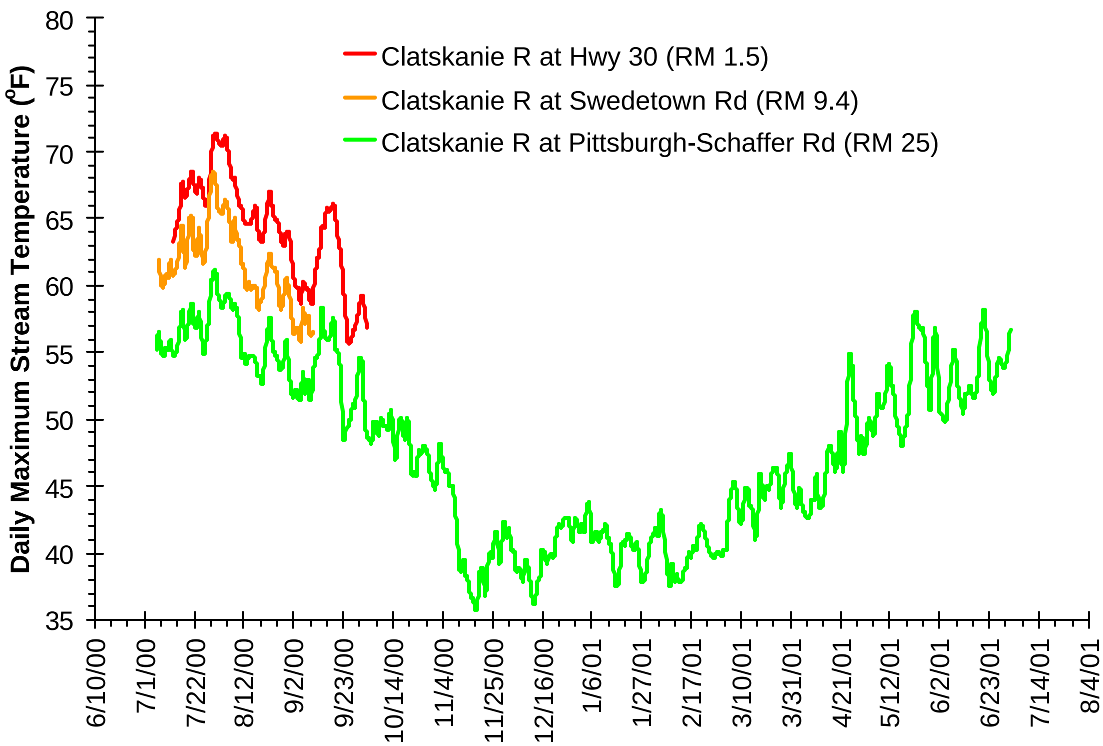


***Figure 2-10**. Clatskanie River subbasin streams continuous temperature data (1 of 2).*

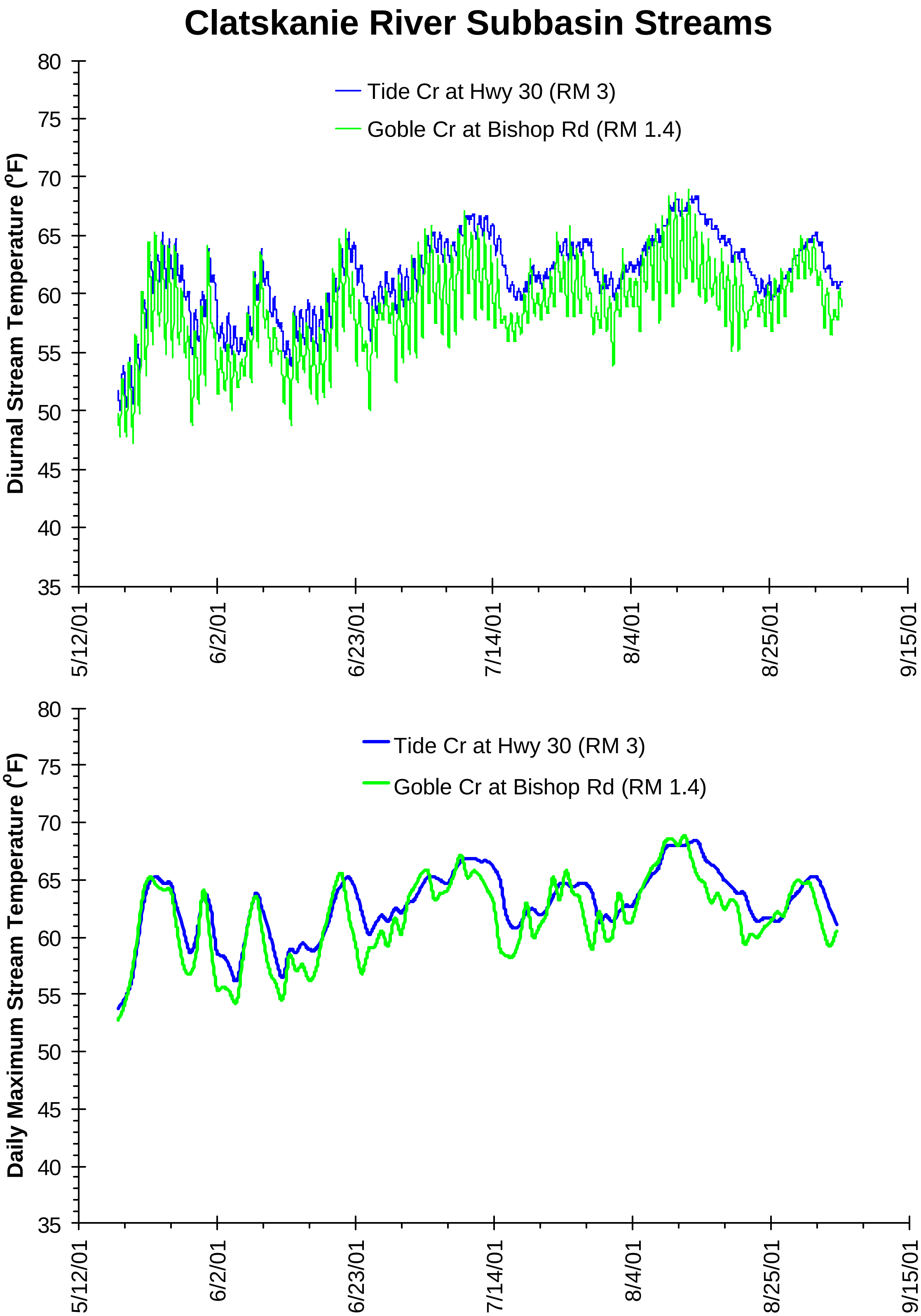


***Figure 2-11**. Clatskanie River subbasin streams continuous temperature data (2 of 2).*

Table 2-1. Continuous Temperature Data - 7-Day Statistics

	Site Name	River Mile (OWRD)	Date	7-Day Statistic (^oF)
Nehalem River Subbasin	Nehalem R. u/s SF Nehalem R.	116.7	8/3/2000	57.4
	South Fork Nehalem R. at Cochran Rd.	0.1	8/2/2000	55.2
	Nehalem R. at Cochran Rd. (Brdg. 1393)	112.7	8/1/2000	61.5
	Lousignont Cr. at Mouth	0.1	7/29/2000	62.8
	Nehalem R. u/s Wolf Cr. at Timber Rd. Br.	106.8	8/1/2000	66.4
	Wolf Cr. at Mouth	0.1	8/2/2000	63.7
	Nehalem River u/s Beaver Cr.	92.9	7/30/2000	70.5
	Beaver Cr. At Mouth	0.1	7/30/2000	63.7
	Nehalem R. u/s Rock Cr.	90.8	8/1/2000	73.0
	South Fork Rock Cr. near Mouth	0.3	8/1/2000	56.7
	Rock Cr. At Hwy 26 u/s SF Rock Cr.	25.9	8/1/2000	61.2
	Rock Cr. at Rock Cr. Rd. (Keasey)	12.1	8/2/2000	65.7
	Rock Cr. at Mouth	0.1	8/1/2000	70.5
	Pebble Cr. at Mouth	0.1	8/1/2000	68.2
	Nehalem R. u/s EF Nehalem R.	84.1	8/3/2000	73.4
	East Fork Nehalem R. at Scappoose-Vernonia Rd.	6	7/31/2000	65.3
	East Fork Nehalem R. at Hwy 47	0.1	8/1/2000	66.7
	Oak Ranch Cr. at Mouth (Hwy 47)	0.1	8/1/2000	64.2
	Nehalem R. at Burris Rd.	76.3	8/1/2000	74.7
	Nehalem R. at Fishhawk Rd.	66.5	8/1/2000	76.3
	Fishhawk Cr. at Mouth (Nehalem RM 65.7)	0.1	8/1/2000	71.4
	Nehalem R. at Hwy 202 (Vesper)	61.8	8/2/2000	73.6
	Northrup Cr. at Mouth	0.1	8/1/2000	64.6
	Nehalem R. at Hwy 202 (Jewell)	47.3	8/2/2000	72.5
	Beneke Cr. at Hwy 202 (Mouth)	0.1	8/1/2000	65.8
	Fishhawk Cr. at Mouth	0.1	8/1/2000	68.5
	West Humbug Cr. at Mouth	0.1	7/31/2000	62.8
	East Humbug Cr. at Mouth	0.1	7/31/2000	64.2
	Humbug Cr. at Mouth	0.1	8/1/2000	68.4
	Nehalem R. d/s Humbug Cr.	34.7	8/7/2000	74.1
	Cronin Cr. at Mouth	0.1	8/5/2000	62.6
	Nehalem R. u/s of Salmonberry R.	22.4	8/2/2000	74.5
	North Fork Salmonberry R. at Mouth	0.1	7/31/2000	60.8
	South Fork Salmonberry R. at Mouth	0.1	8/1/2000	56.5
	Salmonberry R. at Wheeler (Cochran) Rd.	16	8/1/2000	57.9
	Salmonberry R. u/s NF Salmonberry R.	8.2	8/1/2000	61.5
	Salmonberry R. u/s of SF Salmonberry R.	6.9	8/1/2000	63.7
	Salmonberry R. at Mouth	0.1	8/1/2000	68.2
	Nehalem R. at Foss USGS Gage	13.5	8/2/2000	72.9
	South Fork Cook Cr at EF Rd. (Mouth)	0.1	7/30/2000	55.8
	Foley Cr. at Mouth	0.3	8/1/2000	64.4
	Cook Cr. u/s SF Cook Cr.	4.6	8/1/2000	61.7
	Cook Cr. at Clammer Rd.	2.2	7/31/2000	62.8
	Cook Cr. at Cook Cr. Rd.	3.7	8/2/2000	60.1
	Cook Cr. at Mouth	0.1	7/31/2000	61.3
	Nehalem R. at Hwy 53 (Mohler)	5.7	8/2/2000	72.3

	Little NF Nehalem R. at Mouth	0.1	7/31/2000	63.9
	North Fork Nehalem R. u/s Little NF Nehalem R.	20.5	7/31/2000	64.6
	North Fork Nehalem R. at Hwy 53	10.6	8/1/2000	65.5
	North Fork Nehalem R. u/s Hatchery	10.3	8/1/2000	64.4
	Coal Cr. at Mouth	0.1	7/31/2000	60.1
	Gods Valley Cr. at Mouth	0.1	7/31/2000	63.5
	Soapstone Cr. at Mouth	0.1	8/7/2000	63.7
	North Fork Nehalem R. at Mouth	0.1	8/2/2000	71.4
Necanicum River Subbasin	Necanicum R. at Highway 26	18.6	7/29/2000	62.6
	Necanicum R. at Hwy 53	17.8	7/29/2000	62.6
	Bergsvik Cr. at Mouth	0.1	8/21/2000	59.0
	Necanicum R. u/s NF Necanicum R.	15.3	7/29/2000	65.7
	North Fork Necanicum R. at Hwy 26	0.2	7/30/2000	61.2
	Necanicum R. u/s SF Necanicum R.	12.9	7/29/2000	64.8
	South Fork Necanicum R. at MP 5	0.4	7/29/2000	61.7
	South Fork Necanicum R. Near Mouth	0.1	7/29/2000	61.9
	Necanicum R. at Klootchie Cr. Rd.	9.6	7/30/2000	67.3
	Necanicum R. at Highway 101	5.9	7/30/2000	67.1
	Necanicum R. at U Street	2.9	8/22/2000	66.2
Lower Columbia Subbasin	Lewis & Clark R. at Saddle Mt. Rd.	24.3	8/8/2001	59.7
	Lewis & Clark R. (0.8 Miles South of Melville)	7.5	8/6/2001	67.1
	Youngs R. at Youngs R. Loop Rd.	8.7	8/7/2001	63.0
	North Fork Klaskanine R. at Green Mt. Rd.	0.5	8/7/2001	63.0
	North Fork Klaskanine R. u/s NF of NF	1.5	8/7/2001	65.8
	South Fork of South Fork Klaskanine R. at Hwy 202	0.1	8/7/2001	58.6
	Bear Cr. d/s Astoria Reservoir	3.8	7/6/2001	68.2
	Gnat Cr. at Weir	2.5	8/7/2001	61.0
	Big Cr. at Old Highway 30	1.2	8/8/2001	63.5
Clatskanie River Subbasin	Clatskanie R. at Pittsburgh-Schaffer Rd.	25	7/29/2000	59.5
	Clatskanie R. at Schaffer Rd. 2 Miles d/s Pittsburgh Rd.	23	7/31/2000	61.5
	Clatskanie R. at Schaffer Rd.	21	7/30/2000	63.5
	Clatskanie R. at Private Bridge (Nichols)	20	7/30/2000	64.2
	Clatskanie R. u/s Little Clatskanie R.	16.2	7/29/2000	65.1
	Clatskanie R. u/s Carcus Ck.	11.5	7/29/2000	66.9
	Clatskanie R. at Swedetown Rd.	9.4	7/29/2000	66.7
	Clatskanie R. at Highway 30	1.5	7/30/2000	70.9
	Little Clatskanie R. at Apiary Rd.	0.1	7/29/2000	65.1
	Carcus Cr. at Mouth	0.1	7/30/2000	63.1
	Tide Creek at Highway 30	3	8/9/2001	67.8
	Tide Creek at Anliker Road	9.9	8/7/2001	66.2
	Goble Creek at Holbrook Road	2.7	7/6/2001	67.5
	Goble Creek at Bishop Road	1.4	8/7/2001	67.6
	Beaver Creek at Parkdale Road	14	8/7/2001	74.1
	Beaver Creek at Beaver Springs Road	17.5	8/25/2001	62.4
	Lost Creek at Highway 30	0.3	8/7/2001	66.4
	SF Beaver Creek at Old Rainier Road	0.1	8/7/2001	67.6
	Plympton Creek at Highway 30	0.3	8/8/2001	60.4

2.1.2 Flow Volume - Gage Data and Instream Measurements

Flow volume data was collected at seventy sites during the critical stream temperature period in late July and early August of 2000 by the Oregon DEQ and local watershed councils. These instream measurements (listed in **Table 2-2**) were used to develop flow mass balances for the Nehalem River subbasin streams that were modeled for temperature. **Figure 2-12** displays measured flow rates. Data from one USGS gage (located at Foss on the Nehalem River) was also used in the analysis.

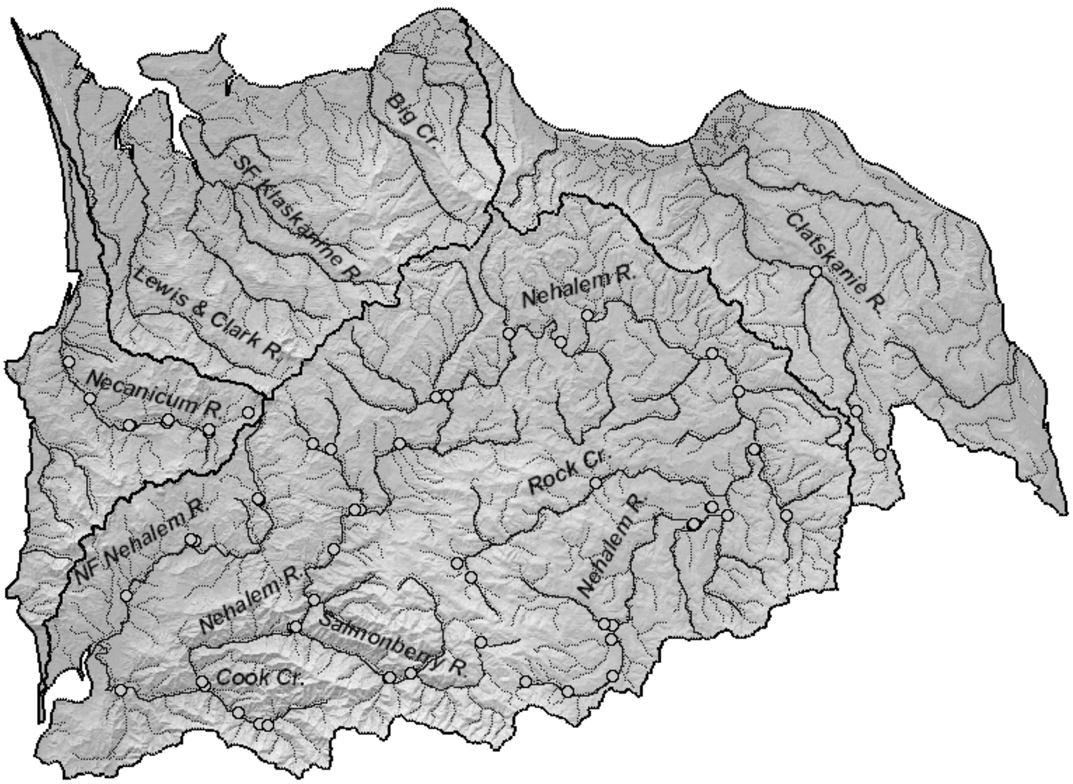


***Figure 2-12**. Flow measurement locations (July/August, 2000). DEQ collected seventy instream measurements during this period.*

Table 2-2. Flow Measurement Data			
Subbasin	**Site**	**Date**	**Flow (cfs)**
Nehalem	Beneke Creek at Highway 202	8/2/2000	6.12
	Cook Creek at Clammer Road	8/2/2000	15.52
	Cook Creek at Cook Cr Rd (1st bridge u/s TinShack Rd)	8/1/2000	2.42
	Cook Creek at Mouth	8/2/2000	22.90
	Cook Creek u/s SF Cook Creek	8/1/2000	10.41
	Cronin Creek at Mouth	8/2/2000	4.54
	East Fork Nehalem River at Mouth	8/1/2000	2.46
	East Fork Nehalem River at Scappoose-Vernonia Road (RM 6)	8/1/2000	0.20
	East Humbug Creek at Mouth (Hwy 26)	8/2/2000	2.75
	Fishhawk Creek at Highway 103	8/2/2000	5.39
	Fishhawk Creek at Northbank Road	8/2/2000	9.35
	Foley Creek at Lommen Road	8/1/2000	14.98

	Humbug Creek at Mouth	8/3/2000	7.14
	Little North Fork Nehalem at Mouth	8/1/2000	3.40
	Lousignont Creek at Timber Road	8/2/2000	1.46
	Nehalem River at Burris Road	8/2/2000	46.84
	Nehalem River at Cochran Road 1393	8/2/2000	9.25
	Nehalem River at Highway 202 Bridge in Vesper	8/3/2000	58.01
	Nehalem River at Highway 202 d/s Fishhawk Cr (Jewel)	8/2/2000	89.14
	Nehalem River at Spruce Run County Park	8/9/2000	91.15
	Nehalem River at Timber Road 1 mile ds Hwy 26	8/4/2000	11.69
	Nehalem River at Timber Road 1 mile ds Hwy 26	8/4/2000	8.71
	Nehalem River at USFS Gage	8/5/2000	142.00
	Nehalem River at Vinemaple (d/s of Fishhawk Ck)	8/9/2000	67.26
	Nehalem River at Vinemaple (d/s of Fishhawk Ck) QA	8/9/2000	65.41
	Nehalem River d/s Salmonberry (1.5 miles) LEFT CHANNEL	8/9/2000	85.99
	Nehalem River d/s Salmonberry (1.5 miles) RIGHT CHANNEL	8/9/2000	65.87
	Nehalem River downstream Beaver Creek (1st channel)	8/1/2000	13.03
	Nehalem River downstream Beaver Creek (2nd channel)	8/1/2000	2.00
	Nehalem River downstream East Fork Nehalem	8/1/2000	45.71
	Nehalem River downstream Humbug Creek	8/3/2000	96.08
	Nehalem River upstream Rock Creek	8/1/2000	14.13
	Nehalem River upstream Salmonberry	8/9/2000	123.37
	Nehalem River upstream SF Nehalem	8/2/2000	0.91
	Nehalem River upstream Wolf Creek on Timber Road	8/2/2000	6.75
	NF Nehalem @ Hwy 53	8/1/2000	28.76
	NF Nehalem u/s Little NF Nehalem	8/1/2000	0.23
	North Fork Nehalem River at Alderdale	8/2/2000	45.01
	North Fork Salmonberry at Mouth	8/7/2000	9.99
	Northrup Creek at Mouth	8/3/2000	2.50
	Oak Ranch Creek at Mouth (Hwy 47)	8/2/2000	1.77
	Pebble Creek at Pebble Creek Road	8/1/2000	2.18
	Rock Creek at Kearsey 2nd Bridge RM 11	8/1/2000	20.41
	Rock Creek at Mouth	8/1/2000	18.88
	Rock Creek upstream SF Rock Creek (Hwy 26)	8/3/2000	1.75
	Salmonberry River at Cochran Road	8/2/2000	1.94
	Salmonberry River at Mouth	8/2/2000	42.70
	Salmonberry River at Mouth (QA)	8/2/2000	39.34
Nehalem	Salmonberry River u/s NF Salmonberry	8/7/2000	12.40
	Salmonberry upstream South Fork Salmonberry	8/7/2000	24.83
	SF Cook Creek at East Fork Road	8/1/2000	5.33
	Soapstone Creek @ RM 0.5	8/1/2000	3.22
	South Fork Nehalem River at Mouth	8/2/2000	0.48
	South Fork Rock Creek at Highway 26	8/3/2000	3.18
	South Fork Salmonberry at Mouth	8/7/2000	5.88
	West Humbug Creek at Mouth	8/2/2000	4.28
	Wolf Creek at Highway 26	8/2/2000	2.90
Necanicum	Bergsvick Creek at Mouth	8/8/2000	1.40
	Necanicum River at Highway 101	8/9/2000	16.01
	Necanicum River at Highway 26	8/8/2000	2.70

	Necanicum River at Highway 53	8/8/2000	2.44
	Necanicum River at Klootchie Road	8/9/2000	14.14
	Necanicum River u/s NF Necanicum	8/8/2000	5.56
	Necanicum River upstream SF Necanicum	8/8/2000	9.19
	North Fork Necanicum at Mouth (Highway 26)	8/8/2000	2.30
	South Fork Necanicum at Mouth	8/8/2000	1.51
Clatskanie	Beaver Creek at Mouth	8/1/2000	0.34
	Carcus Creek at Mouth	7/31/2000	2.91
	Clatskanie River 0.27 miles d/s of Apiary-Shaffer Rd.	7/31/2000	2.41
	Clatskanie River at Schaffer Rd.	7/31/2000	2.3
	Clatskanie River u/s of Carcus Creek	7/31/2000	5.76

2.1.3 Stream Surveys

During the year 2000 field season, DEQ collected ground-level habitat data at several locations in the North Coast Subbasins, focusing mainly on the Nehalem River subbasin. Stream survey data focuses on near stream land cover classification and measurements, channel morphology measurements, and stream shade measurements.

2.1.3.1 Near Stream Land Cover

At each site, near stream land cover species and composition was identified, as well as, land cover height, canopy density and width estimations.

2.1.3.2 Channel Morphology and Rosgen Stream Classifications

Ground level channel assessments characterized the near stream disturbance zone (NSDZ) width, incision depths, and substrate composition. Substrate was characterized by the percentage of bedrock, boulder, cobble, gravel, sand, or silt. This information was used as temperature model input, to validate GIS measurements, and to validate Rosgen Level 1 characterizations.

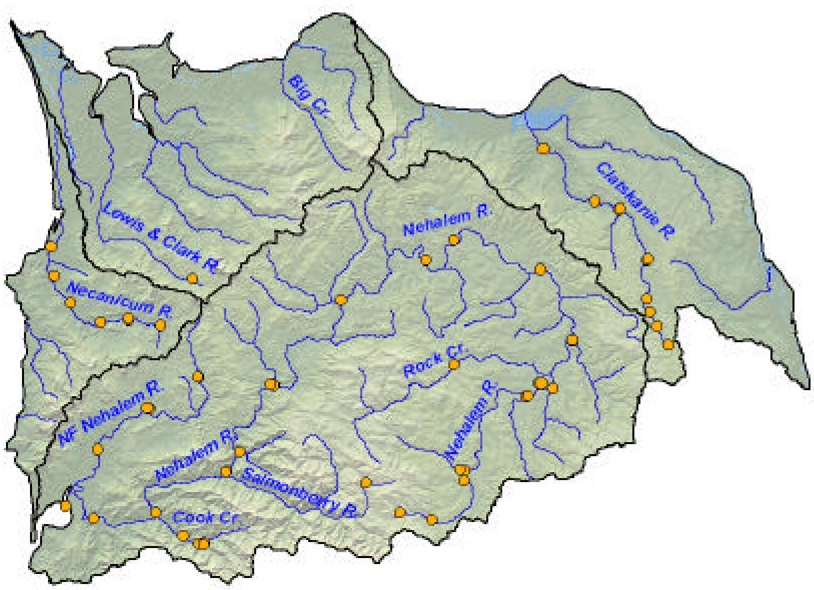


Figure 2-13. Ground Level Channel Morphology Measurement Sites

Physical processes shape stream channels within a given drainage basin. These physical processes are the natural result of interrelated landscape and instream characteristics and interactions. Key parameters that affect stream channel evolution are: near stream land cover, stream flow regimes and erosion/deposition patterns.

Employing Rosgen stream characterizations helps make estimates of the evolution of stream conditions. Rosgen offers the premise that stream channels reach equilibrium with physical parameters and processes. Human land use can alter these parameters and processes, and in turn, alter stream channel conditions. Human land use can change the near stream vegetation type and condition. Flow augmentation and withdrawal can change stream flow patterns. Erosion and depositional processes can increase from various landscape and instream human activities. By establishing the natural evolution patterns of a stream channel it may become possible to distinguish deviations caused by human land use activities.

Level I Rosgen stream classifications group streams (letters A through G) based on valley shape, channel patterns and channel slope and cross-section. GIS and remote sensing data can be used to estimate Level I Rosgen stream types at a landscape scale. Specifically, high-resolution GIS stream channel, gradient and sinuosity data can be derived at a stream network scale. By applying these GIS derived data in combination with selected ground level checkpoints, system-wide stream type estimates can be completed.

Identification of important valley morphology characteristics can also help identify stream morphology types. Rosgen states that "the interpretation of stream types as derived from an analysis of landforms and related valley types are reliable."[2] The analysis of valley type considers landform at a landscape scale. GIS analysis can be used to quantify valley slope, form/morphology, soil materials/texture and erosional process estimates. Level I stream types can be associated with specific valley types.

Rosgen Level II morphologic classifications considers all of the Level I parameters as well as substrate particle size, entrenchment ratio, width to depth ratio and sinuosity. Level II classifications can provide insight as to reach-specific sediment supply, sensitivity to disturbance and the potential for natural recovery. Generalized characteristics can be associated with each of the Level II Rosgen stream classes that relate channel morphology to sensitivity to disturbance, recovery potentials, sediment supply, streambank erosion potential and vegetation controlling influence. Rosgen (1994) presents these characteristics to provide guidance to riparian and sediment management.

In summary, level I stream types have been estimated for major streams in the Nehalem River subbasin, using ground level data and GIS data. These level I stream classifications are then used to group stream segments in the development of near stream disturbance zone width targets.

Geomorphic Characterization Parameters

Channel Patterns:	Single or Multiple Channels
Stream Slope:	Stream (Water Surface) Gradient
Valley Slope:	Longitudinal Valley Gradient
Sinuosity:	Stream Length Divided by Valley Length
Meander Width Ratio:	Belt Width Divided by Bankfull Width
Entrenchment Ratio:	Floodprone Width Divided by Bankfull Width
Width to Depth Ratio:	Bankfull Width Divided by Bankfull Depth

[2] D. Rosgen. 1996. Applied River Morphology. Wildland Hydrology. Pasoga Springs, Colorado. p. 4-11.

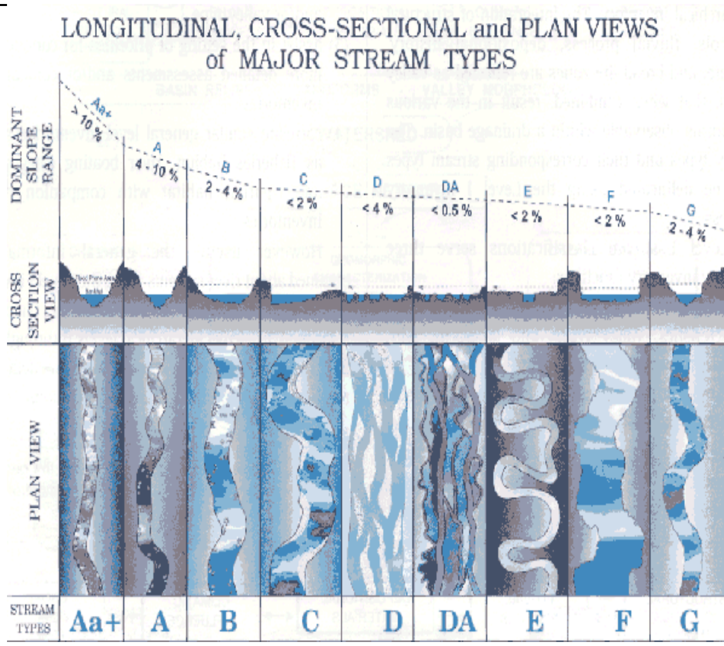


Figure 2-14. Slope Ranges, Cross-Sections and Plan Views of Level I Rosgen Stream Types
(Image from Rosgen, 1996)

Table 2-3. Rosgen Stream Types
(Data from Rosgen, 1996)

Channel	Bed Slope	Sinuosity	Entrenchment Ratio	Meander Width Ratio	W:D	Description	Rosgen Channel Type
Single	High (5% - 10%)	**Low** (1.0 - 1.2)	**Low** (< 1.4)	**Low** Ave = 1.5 (1 - 3)	**Low** (< 12)	High Relief, Erosional/Depositional and Bedrock Features, Entrenched and Confined Streams w/ Cascading Reaches	Type A
Single	Moderate (2% - 4%)	**Moderate** (> 1.2)	**Moderate** (1.4 - 2.2)	**Low** Ave = 3.7 (2 - 8)	**Moderate** (> 12)	Moderate Relief, Moderate Entrenchment and W/D Ratio, Narrow Gently Sloping Valleys, Rapids Predominate w/ Scour Pools	Type B
Single	**Low** (< 2%)	**Moderate** (> 1.2)	**Low** (< 1.4)	**Low** Ave = 3.7 (2 - 8)	**Low** (< 12)	Gullies, Moderate Slopes, Low W/D Ratio, Narrow Valleys or Deeply Incised, Unstable, High Bank Erosion	Type G
Single	**Low** (< 2%)	**High** (> 1.2)	**High** (> 2.2)	**High** Ave = 11.4 (4 - 20)	**Moderate/High** (> 12)	Broad Valleys w/ Terraces, Associated w/ Floodplains, Alluvial Soils Slightly Entrenched, Well Defined Meandering Channels	Type C
Single	**Low** (< 2%)	**Very High** (> 1.5)	**High** (> 2.2)	**Very High** Ave = 24.2 (20 - 40)	**Very Low** (< 12)	Broad Valley/Meadows, Alluvial Materials w/ Floodplains, Highly Sensuous, Stable Well Vegetated Banks, Very Low W/D	Type E
Single	**Low** (< 2%)	**Moderate** (> 1.2)	**Low** (< 1.4)	**Moderate** Ave = 5.3 (2 - 10)	**Moderate/High** (> 12)	Entrenched in Highly Weathered Material, Gentle Gradients, High W/D, Meandering Laterally, Unstable w/ High Bank Erosion Rates	Type F
Multiple	**Low** (< 4%)	n/a	n/a	**Low** Ave = 1.1 (1 - 2)	**Very High** (> 40)	Broad Valleys w/ Alluvium, Steeper Fans, Glacial Debris, Active Lateral Adjustment, Abundant Sediment Supply, Aggradational Processes, High Bedload and Bank Erosion	Type D
Multiple	**Very Low** (< 0.5%)	Variable	**High** (> 2.2)	n/a	**Low** (< 40)	Broad Low Gradient Valleys, Fine Alluvium, Multiple Channels, Laterally Stable w/ Broad Wetland Floodplains, Very Low Bedload, High Wash Load Sediment	Type DA

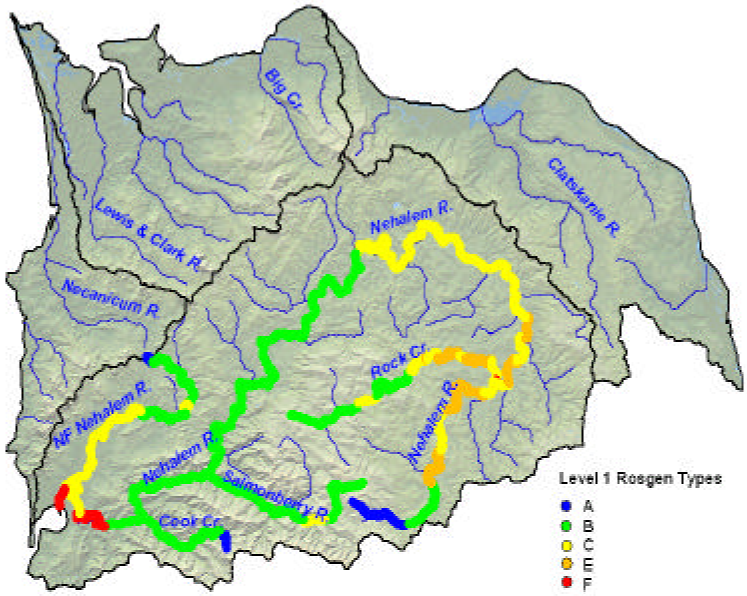


Figure 2-15. *Level I Rosgen Stream Types developed from ground level and GIS data. These classifications are later used as a guide for applying near stream disturbance zone width targets in the temperature modeling process.*

2.1.3.3 Effective Shade

Effective shade data are used in this analysis to:

- *Validate simulated effective shade data.*

Effective shade is a measurement of the portion of direct beam solar radiation that is attenuated and scattered before reaching the stream surface. Effective shade can be highly variable when vegetation and channel morphology conditions are variable. Therefore, it is preferable to collect multiple measurements along a reach and then average the values. **Figure 2-16** shows the locations and relative effective shade values collected by DEQ during the year 2000 field season. All effective shade measurements were collected using the Solar Pathfinder®.

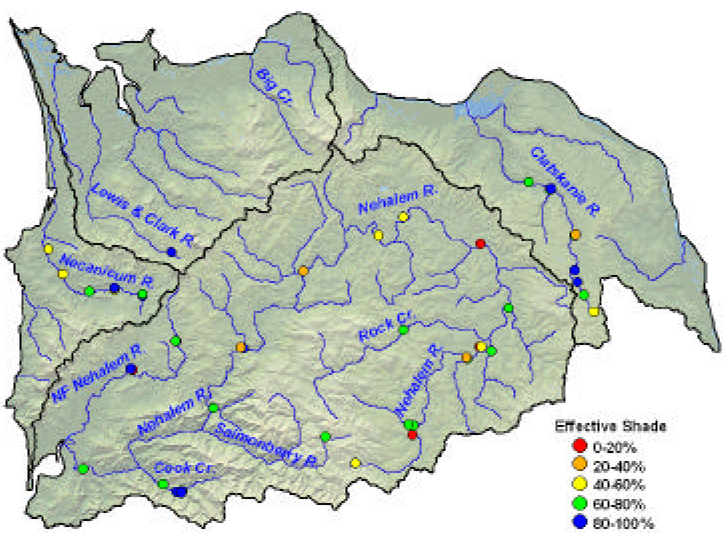


Figure 2-16. *Ground level effective shade measurements, collected using a Solar Pathfinder®.*

2.2 GIS AND REMOTELY SENSED DATA

2.2.1 Overview – GIS and Remotely Sensed Data

A wealth of spatial data has been developed for the North Coast Subbasins. This report relies extensively on GIS and remotely sensed data. Water quality issues in the North Coast Subbasins are interrelated, complex and spread over hundreds of square miles. The TMDL analysis strives to capture these complexities using the highest resolution data available. Some of the GIS data used to develop this report are listed in the table below along with the application for which it was used.

Table 2-4. Spatial Data and Application

Spatial Data	Application
10-Meter Digital Elevation Models (DEM)	• Measure Valley Morphology • Measure Topographic Shade Angles
Aerial Imagery - Digital Orthophoto Quads and Rectified Aerial Photos	• Map Near Stream Land Cover • Map Channel Morphology • Map Roads, Development, Structures
FLIR Temperature Data	• Measure Surface Temperatures • Develop Longitudinal Temperature Profiles • Identify Subsurface Hydrology, Groundwater Inflow, Springs
Water Rights Information System (WRIS) and Points of Diversion (POD) Data	• Map locations and estimate quantities of water withdrawals

2.2.2 10-Meter Digital Elevation Model (DEM)

DEM data are used in this analysis to:

- ***Delineate drainage area,***
- ***Sample stream elevation,***
- ***Sample topographic shade.***

The Digital Elevation Model (DEM) data files are representations of cartographic information in a raster form. DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. The U.S. Geological Survey, as part of the National Mapping Program, produces these digital cartographic/geographic data files. DEM grid data is rounded to the nearest meter for ten-meter pixels. DEMs are used to determine stream elevation, stream gradient, valley gradient, valley shape/landform and topographic shade angles.

2.2.3 Aerial Imagery - Digital Orthophoto Quads and Rectified Aerial Photos

Aerial imagery isused in this analysis to:

- *Map stream features such as stream position, channel edges and wetted channel edges,*
- *Map near stream vegetation,*
- *Map instream structures such as dams, weirs, unmapped diversions/withdrawals, etc.*

A digital orthophoto quad (DOQ) is a digital image of an aerial photograph in which displacements caused by the camera angle and terrain have been removed. In addition, DOQs are projected in map coordinates combining the image characteristics of a photograph with the geometric qualities of a map. The standard digital orthophoto is a black-and-white with one-meter pixels covering a USGS quarter quadrangle.

2.2.4 WRIS and POD Data - Water Withdrawal Mapping

WRIS and POD Data are used in this analysis to:

- *Map stream instream diversions/withdrawals,*
- *Associate an estimated flow rate to each diversion/withdrawal.*

The Oregon Water Resources Department (OWRD) maintains the Water Rights Information System (WRIS). WRIS is a database used to monitor information related to water rights. A separate database tracks points of diversions (POD). These two databases were linked by DEQ to map the locations of diversions, rates of water use and types of water use in the North Coast Subbasins (see **Figure 2-17**). Consumptive use was estimated using these data and incorporated in developing mass balance flow profiles in the Nehalem River Subbasin.

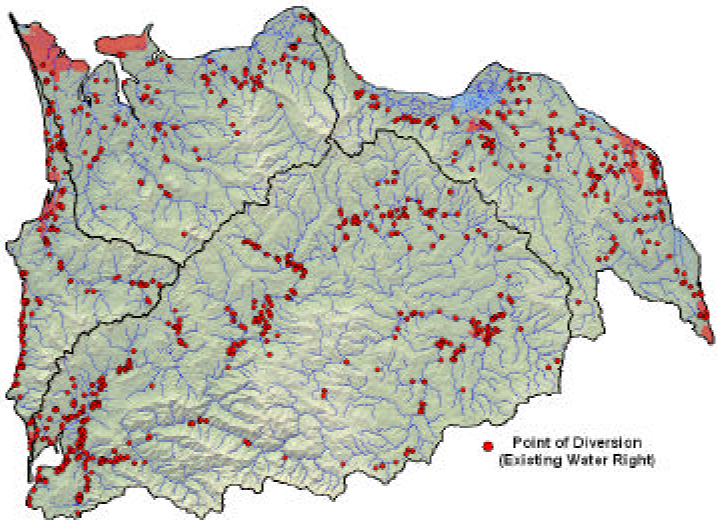


Figure 2-17. *Mapped points of diversion in North Coast Subbasins derived from the WRIS and POD databases (OWRD data, DEQ database programming and mapping).*

2.2.5 FLIR Temperature Data

FLIR temperature data are used in this analysis to:

- *Develop continuous spatial temperature data sets,*
- *Calculate longitudinal heating profile/gradients,*
- *Visually observe complex distributions of stream temperatures at a large landscape scale,*
- *Map/Identify significant thermal features,*
- *Develop mass balances,*
- *Validate simulated stream temperatures.*

FLIR thermal imagery measures the temperature of the outermost portions of the bodies/objects in the image (i.e., ground, riparian vegetation, stream). The bodies of interest are opaque to longer wavelengths and there is little, if any, penetration of the bodies.

FLIR data is remotely sensed from a sensor mounted on a helicopter that collects digital data directly from the sensor to an on-board computer at a rate that insures the imagery maintains a continuous image overlap of at least 40%. The FLIR detects emitted radiation at wavelengths from 8-12 microns (long-wave) and records the level of emitted radiation as a digital image across the full 12-bit dynamic range of the sensor. Each image pixel contains a measured value that is directly converted to a temperature. Each thermal image has a spatial resolution of less than one-half meter/pixel. Visible video sensor captures the same field-of-view as the FLIR sensor. GPS time is encoded on the recorded video as a means to correlate visible video images with the FLIR images during post-processing.

FLIR Equiped helicopter

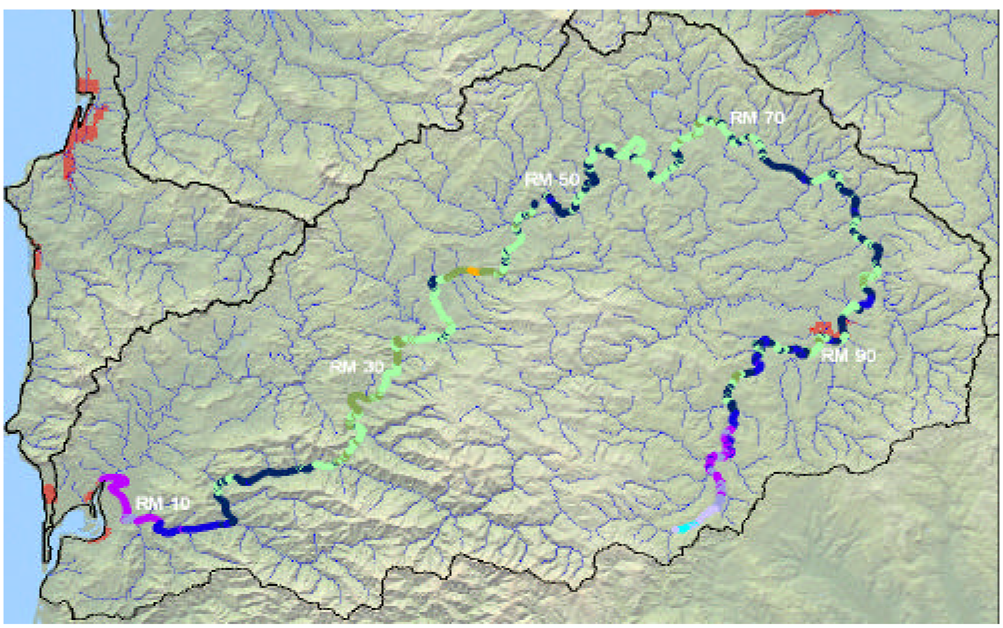
Data collection is timed to capture maximum daily stream temperatures, which typically occur between 14:00 and 18:00 hours. The helicopter is flown longitudinally over the center of the stream channel with the sensors in a vertical (or near vertical) position. In general, the flight altitude is selected so that the stream channel occupies approximately 20-40% of the image frame. A minimum altitude of approximately 300 meters is used both for maneuverability and for safety reasons. If the stream splits into two channels that cannot be covered in the sensor's field of view, the survey is conducted over the larger of the two channels.

In-stream temperature data loggers (Onset Stowaways or VEMCOs) are distributed in each subbasin prior to the survey to ground truth (i.e., verify the accuracy) the radiant temperatures measured by the FLIR. FLIR data can be viewed as GIS point coverages or FLIR imagery.

Direct observation of spatial temperature patterns and thermal gradients is a powerful application of FLIR derived stream temperature data. Thermally significant areas can be identified in a longitudinal stream temperature profile and related directly to specific sources (i.e., water withdrawal, tributary confluence, land cover patterns, etc.). Areas with stream water mixing with subsurface flows (i.e., hyporheic and inflows) are apparent, and often dramatic, in FLIR data. Thermal changes captured with FLIR data can be quantified as a specific change in stream temperature or a stream temperature gradient that results in a temperature change over a specified distance.

2.2.5.1 Nehalem River FLIR Derived Longitudinal Heating and Imagery

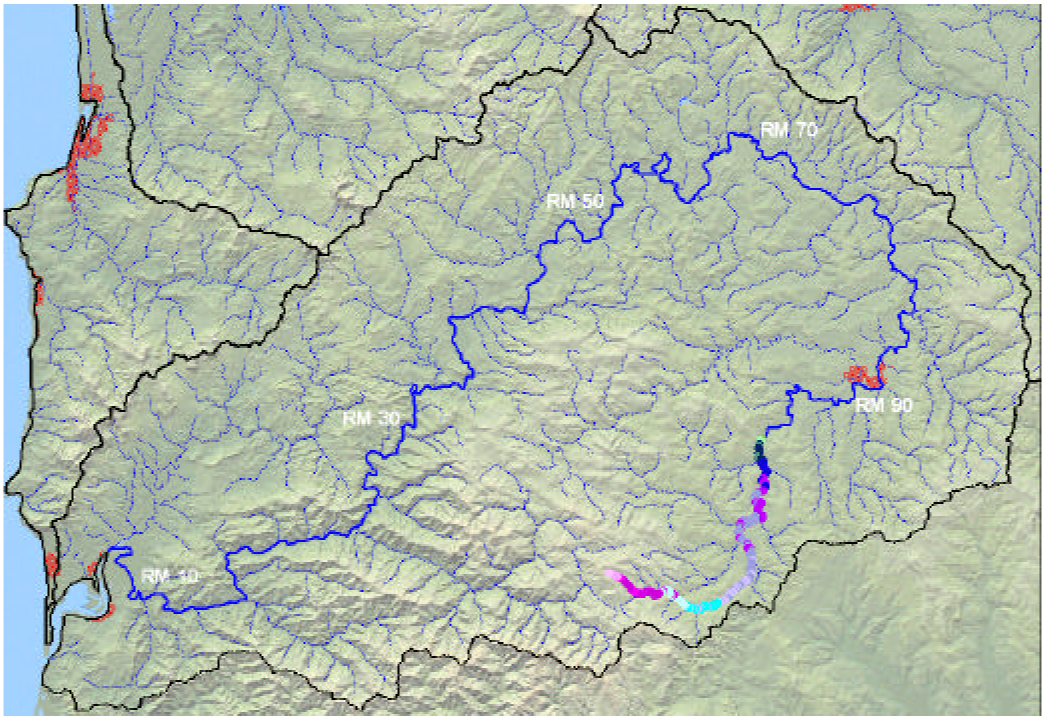
Nehalem River longitudinal temperatures were sampled using forward looking infrared radiometry (FLIR) in two separate flights. River miles 0 to 113 were sampled on August 5, 2000 between 2:26 PM and 5:29 PM. River miles 100 to the headwaters were sampled on August 6, 2000 between 4:12 PM and 4:52 PM. Temperature data sampled from the FLIR imagery reveals a spatial pattern that is variable due to localized high rates of stream heating, tributary mixing, and thermal stratification. **Figures 2-18** and **2-18b** display graphics of FLIR-sampled temperatures for the Nehalem River. The longitudinal temperature profile for the Nehalem River is presented in **Figure 2-19**. **Images Nehalem 1** through **5** depict FLIR and digital video imagery for selected areas of interest.



Temperature Scale (°F)

<50 | 50 | 52 | 54 | 55 | 57 | 59 | 61 | 63 | 64 | 66 | 68 | 70 | 72 | 73 | 75 | 81 | 83 | 85

Figure 2-18. *Nehalem River Sampled FLIR Temperatures (Flight One)*



Temperature Scale (^{o}F)

<50	50	52	54	55	57	59	61	63	64	66	68	70	72	73	75	81	83	85 →

Figure 2-18b. *Nehalem River Sampled FLIR Temperatures (Flight Two)*

Nehalem River sampled temperatures suggest variable spatial distributions (50°F to 75°F), localized areas of thermal stratification. Since the majority of the Nehalem River Subbasin is currently forested, stream heating rates are somewhat gradual. Much of the river is low gradient, resulting in slow velocities, greater depths, and thermal stratification. The lower quarter of the Nehalem River is steeper gradient, more forested, and enclosed in a deeper canyon, resulting in a gradual cooling trend. Cool tributaries, such as Cronin Creek and the Salmonberry River also play a role in cooling the Nehalem River through this reach.

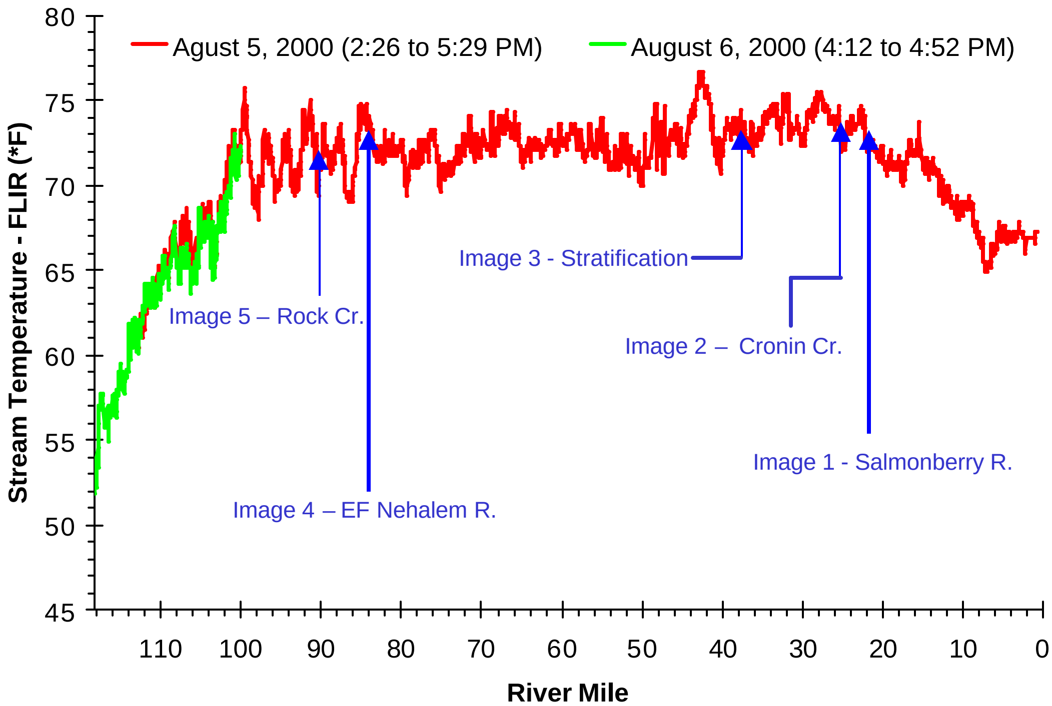
Summary of Selected FLIR Imagery - Nehalem River

- **Nehalem - Image 1**. Nehalem River – Confluence with the Salmonberry River – River Mile 22. This image depicts the Salmonberry River entering the Nehalem river, and the cooling effect that it has on the Nehalem River. The Salmonberry River is approximately 5°F cooler than the Nehalem. The temperature of the Nehalem River drops from approximately 73°F to 72°F after mixing with the Salmonberry contribution.
- **Nehalem - Image 2**. Nehalem River - Confluence with Cronin Creek - River Mile 24.5. Cronin Creek is entering the Nehalem at about 62°F. The Nehalem River is around 72-73°F. A small plume of cooler water can be seen just downstream of Cronin Creek, and it rapidly mixes with the much larger volume of water in the Nehalem River. Also note the large gravel bar below the Cronin Creek mouth, indicating some large substrate transport and deposition.
- **Nehalem - Image 3**. Nehalem River – Thermal Stratification - River Mile 38. Large sections of the Nehalem River are very low gradient and slow-moving, resulting in areas of thermal

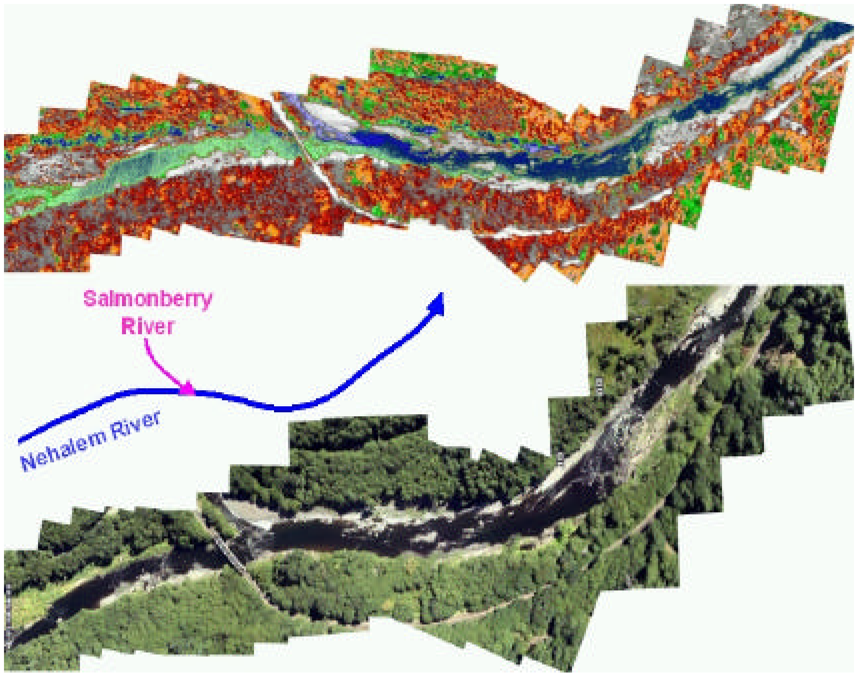
stratification. This image is an example of stratification as observed from FLIR. (Note that all thermally stratified reaches were identified and acknowledged in the temperature modeling effort.)

- **Nehalem - Image 4**. Nehalem River – East Fork Nehalem River Confluence - River Mile 84. This image shows the East Fork Nehalem River flowing beneath a road just before entering the Nehalem River. The East Fork is approximately 5°F cooler than the mainstem, and a cool plume is observed downstream. This reach of the Nehalem River is rather low gradient and thermal stratification occurs upstream and downstream of this site.
- **Nehalem - Image 5**. Nehalem River – Rock Creek Confluence - River Mile 90.7. Rock Creek contributes a large volume of cooler water to the Nehalem River, nearly doubling its flow volume. The FLIR image reveals that the Nehalem River was 72-73°F upstream of Rock Creek, and dropped to around 70°F just of the confluence.

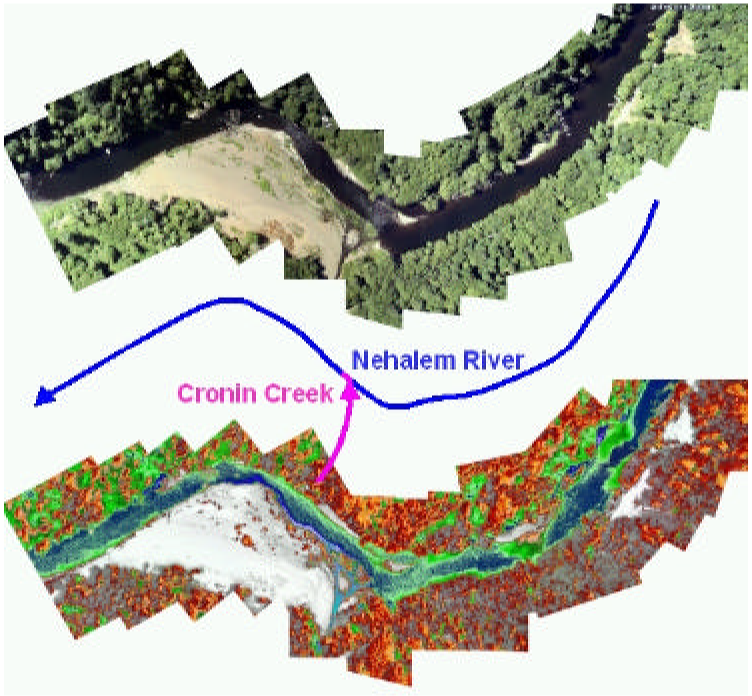
Figure 2-19. *Nehalem River FLIR Derived Temperatures*



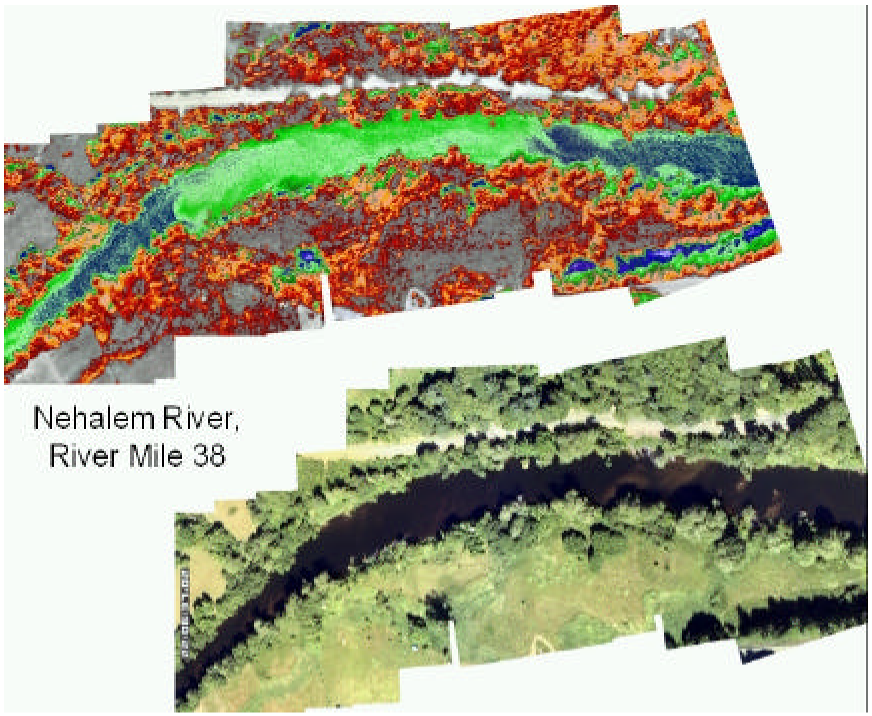
Nehalem - Image 1. *Nehalem River – Confluence with Salmonberry River.*



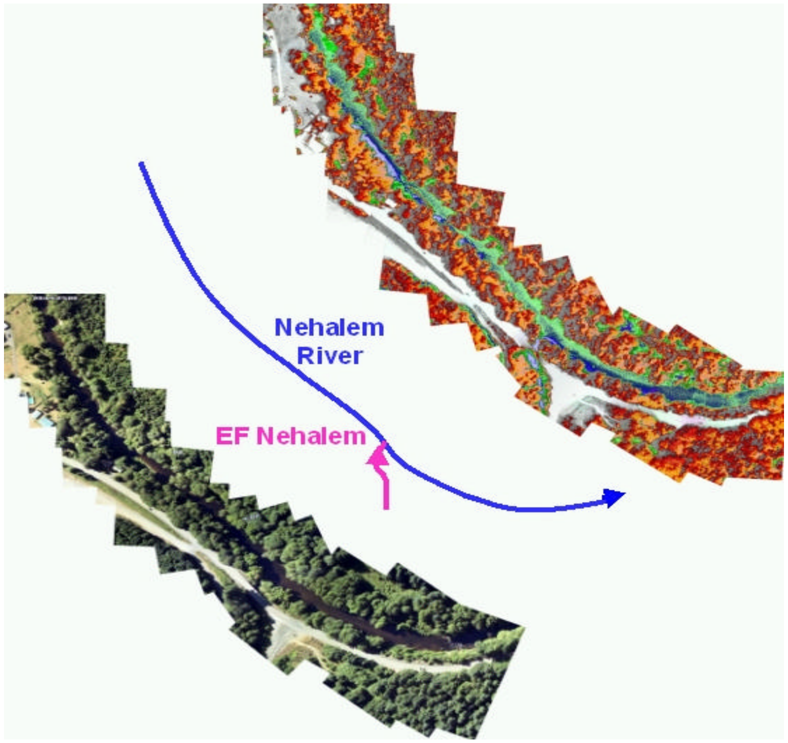
Nehalem - Image 2. *Nehalem River - Confluence of Cronin Creek*



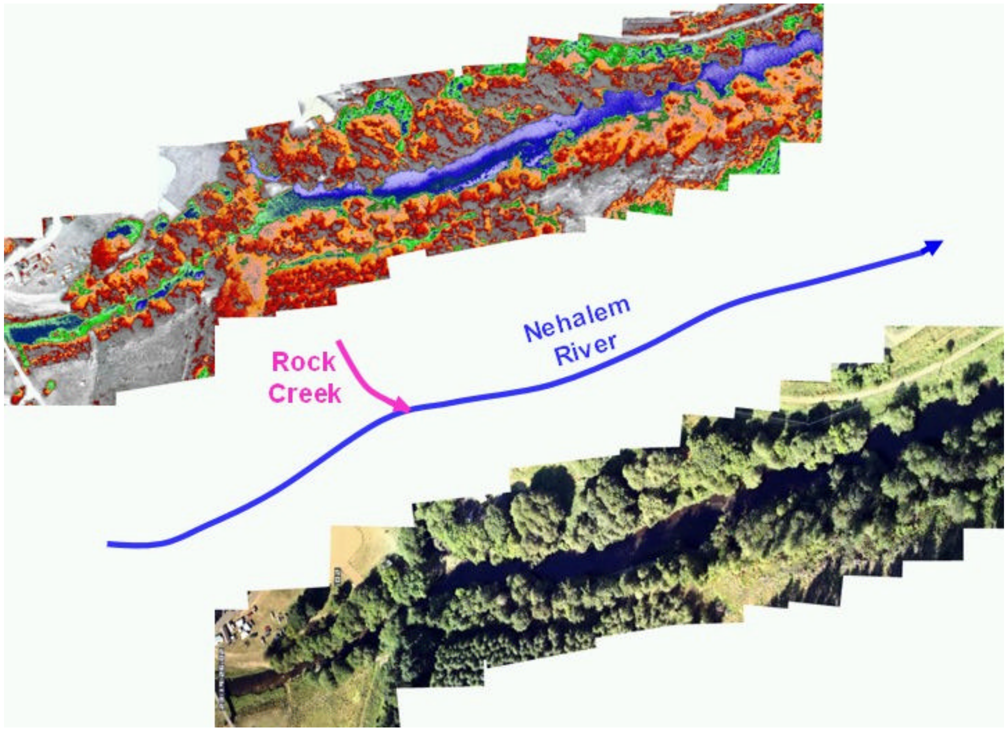
Nehalem - Image 3. *Nehalem River – Thermal Stratification - River Mile 38.*



Nehalem - Image 4. *Nehalem River - East Fork Nehalem River Confluence*



Nehalem - Image 4. *Nehalem River - Rock Creek Confluence*



2.2.5.2 Rock Creek FLIR Derived Longitudinal Heating and Imagery

Rock Creek longitudinal temperatures were sampled using FLIR on August 6, 2000 between 2:53 PM and 3:05 PM. **Figure 2-20** shows the FLIR flight path – color coded to represent the measured stream temperature.

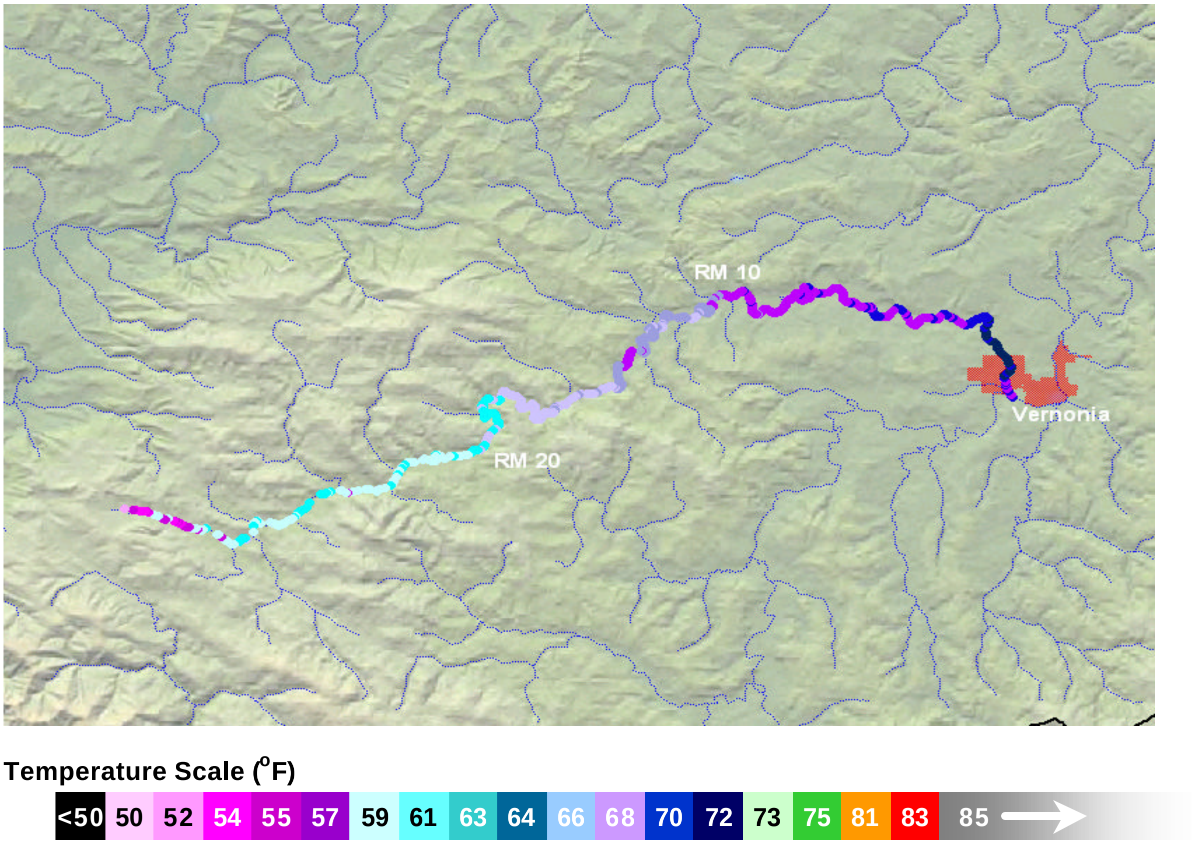


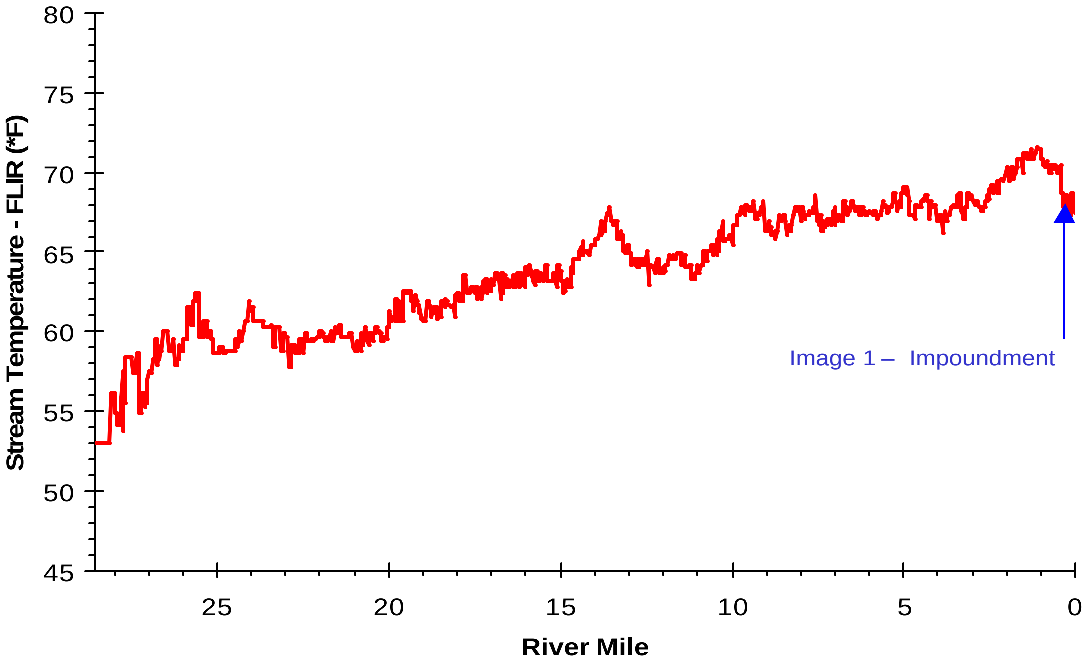
Figure 2-20. *Rock Creek Sampled FLIR Temperatures*

Headwater Rock Creek temperatures in the upper 5 river miles are more variable due to the small flow volume. Between river mile 25 and the mouth, there is a gradual 10°F temperature increase. The FLIR temperature profile (**Figure 2-21**) reveals a warm area near the impoundment by the mouth. Downstream of the impoundment are cooler (mixed water column) temperatures.

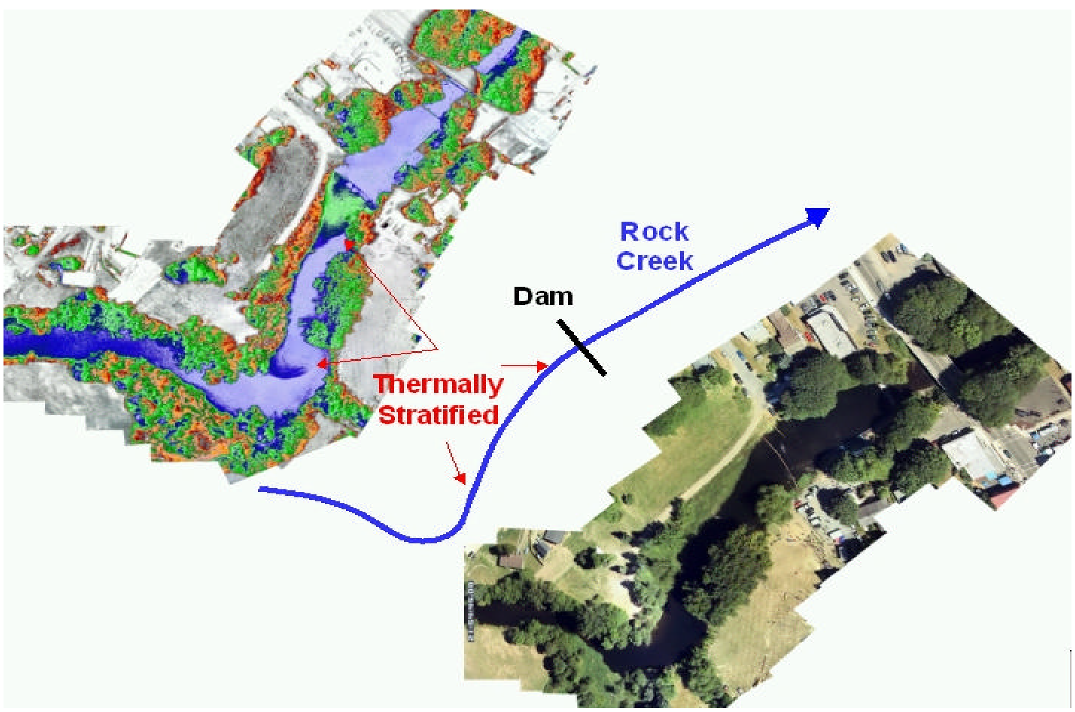
Summary of Selected FLIR Imagery – Rock Creek

- **Rock Creek - Image 1**. Rock Creek – Impoundment Near Mouth. This FLIR imagery shows an impoundment near the mouth of Rock Creek, that creates a pool behind it. The pool is thermally stratified, especially directly behind the impoundment. Below the impoundment, the mixed water column has a cooler surface temperature.

Figure 2-21. *Rock Creek FLIR Derived Temperatures - August 6, 2000 (2:53 to 3:05 PM)*



Rock Creek - Image 1. *Rock Creek – Impoundment Near Mouth*



2.5.2.3 Salmonberry River FLIR Derived Longitudinal Heating and Imagery

Salmonberry River longitudinal temperatures were sampled using FLIR on August 4, 2000 from 3:20 PM to 4:02 PM. **Figure 2-22** shows the FLIR flight path, color coded to display the measured stream temperature. At the time of FLIR sampling, the Salmonberry River temperatures were not greater than 67°F. **Figure 2-23** shows the FLIR derived stream temperature longitudinal profile.

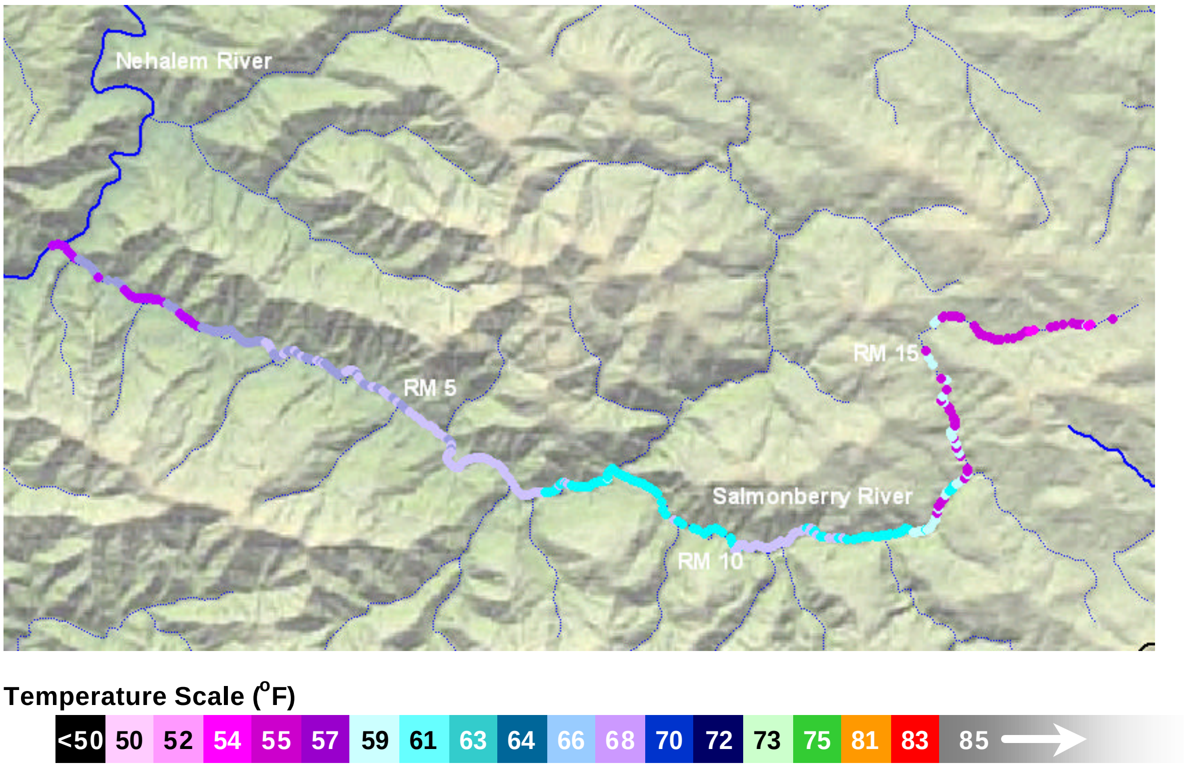
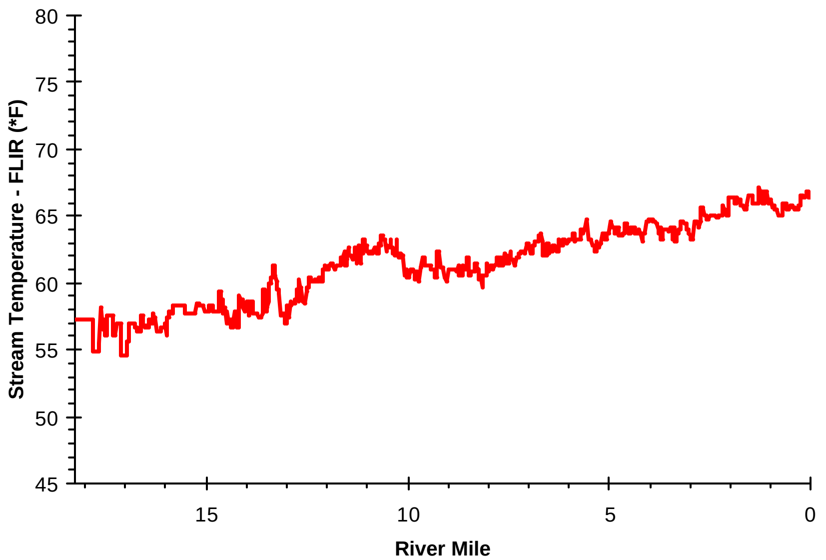


Figure 2-22. *Salmonberry River Sampled FLIR Temperatures*

The Salmonberry River is almost entirely forested and displays a gradual heating from the lower 50°F range near the headwaters to about 65°F at the mouth. The Salmonberry River displays some localized cooling effects at its tributary confluences. No mosaics of FLIR imagery were made for the Salmonberry River because there were no significant plumes from tributaries or groundwater (i.e., heating and cooling rates were gradual and/or un-pronounced in the infrared images).

Figure 2-23. *Salmonberry River FLIR Derived Temperatures - August 4, 2000 – 3:20 to 4:02 PM*



2.2.5.4 North Fork Salmonberry River FLIR Derived Longitudinal Temperature and Imagery

North Fork Salmonberry River longitudinal temperatures were sampled using FLIR on August 4, 2000 between 4:06 PM and 4:30 PM. **Figure 2-24** graphically displays FLIR-sampled temperatures for the North Fork Salmonberry River. The longitudinal temperature profile for the North Fork Salmonberry River is presented in **Figure 2-25**.

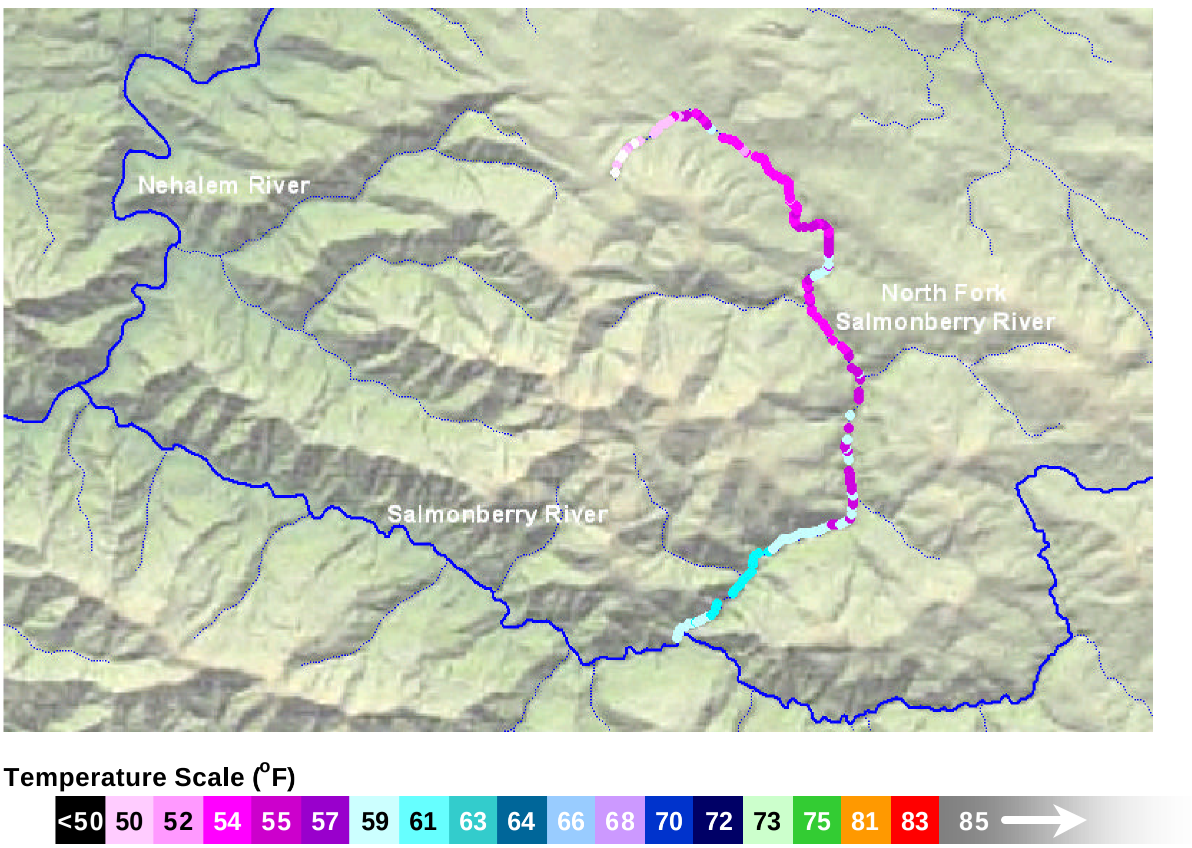


Figure 2-24. *North Fork Salmonberry River Sampled FLIR Temperatures*

North Fork Salmonberry River temperatures barely exceeded 60°F during the time of FLIR sampling. River miles 10 to 8 display more variability due to smaller flow volumes, which are more sensitive to localized effects such as shade or stream depth. The North Fork Salmonberry River is almost entirely forested, which is helping to minimize stream heating. It was not determined from FLIR how tributaries or groundwater impact the North Fork Salmonberry River; however; they cannot be ruled out as factors that could affect stream temperatures.

2.2.5.5 Cook Creek FLIR Derived Longitudinal Heating and Imagery

Cook Creek longitudinal temperatures were sampled using FLIR on August 6, 2000 from 2:08 to 2:32 PM.

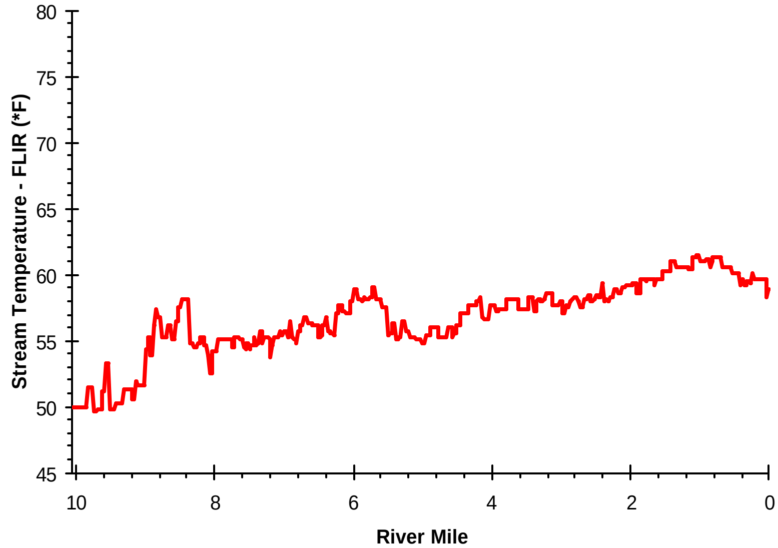


Figure 2-25. *North Fork Salmonberry River FLIR Derived Temperatures - August 4, 2000 – (4:06 PM to 4:30 PM)*

Figure 2-26 shows the FLIR flight path – color coded to represent the measured stream temperature. Stream temperatures did not exceed 61°F at the time of the FLIR survey. Examination of the longitudinal temperature profile (**Figure 2-27**) and actual infrared and day television images reveals the smaller scale variability of the Cook Creek temperatures.

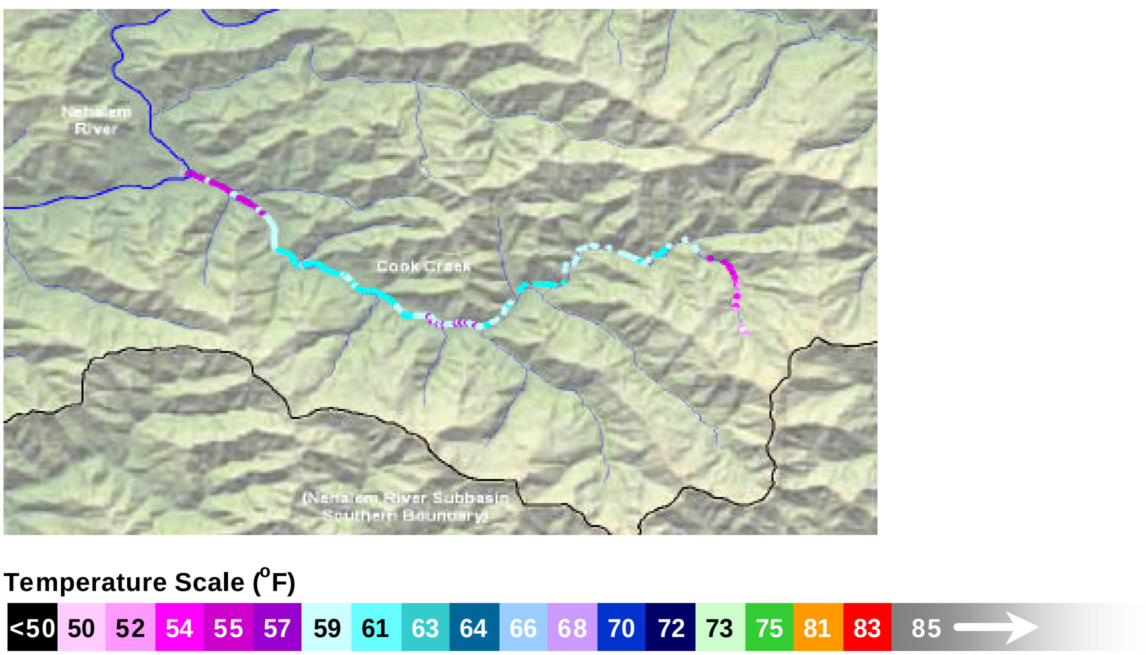


Figure 2-26. *Cook Creek Sampled FLIR Temperatures*

At the time of FLIR sampling, Cook Creek did not display much variability in its longitudinal stream temperature profile. Temperatures peaked at 61°F over about 9 river miles. Due to the fact that there were no significant tributary or groundwater plumes visible in the FLIR imagery, no mosaics are presented for Cook Creek.

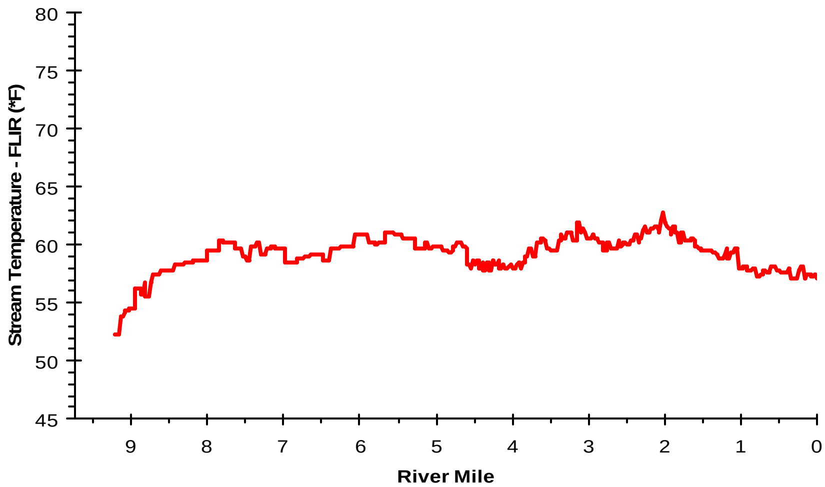


Figure 2-27. *Cook Creek FLIR Derived Temperatures - August 6, 2000 – 2:08 to 2:32 PM*

2.2.5.6 North Fork Nehalem River FLIR Derived Longitudinal Heating and Imagery

North Fork Nehalem River longitudinal temperatures were sampled using forward looking infrared radiometry (FLIR) on August 8, 2000 from 2:02 to 2:53 PM. **Figure 2-28** shows the FLIR flight path – color coded to display the measured stream temperature. **Figure 2-29** shows the longitudinal variability of the stream temperature.

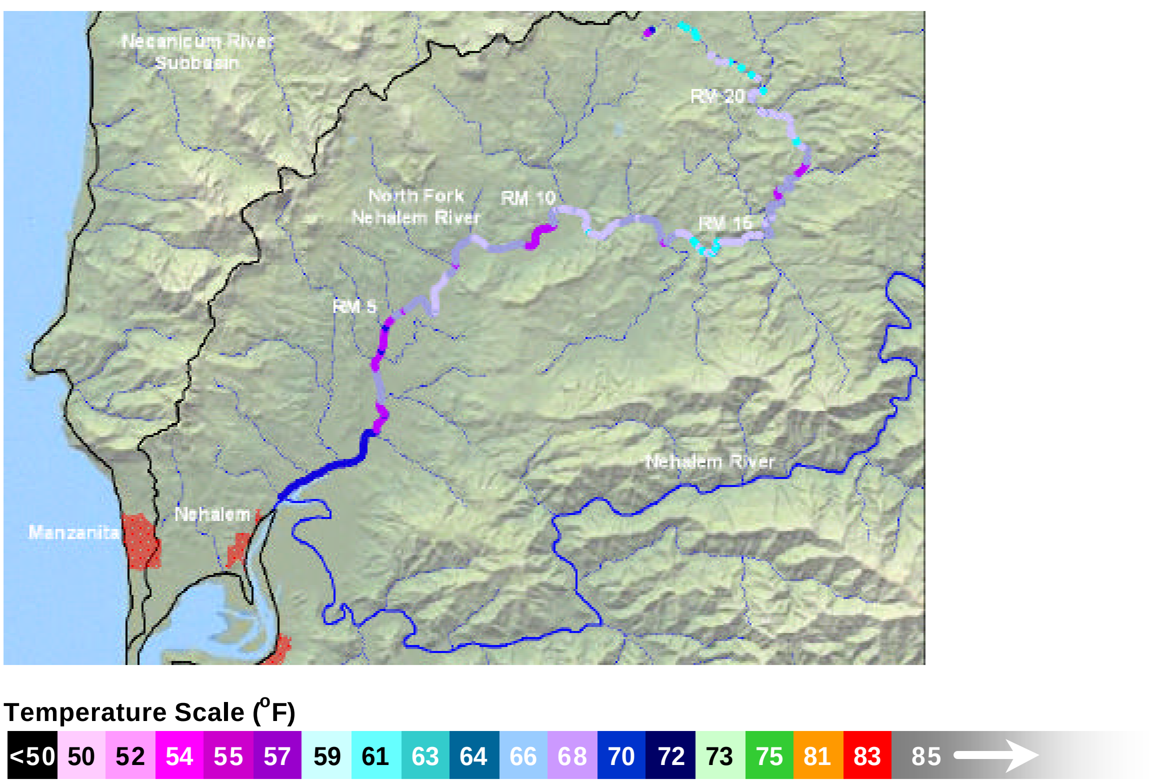
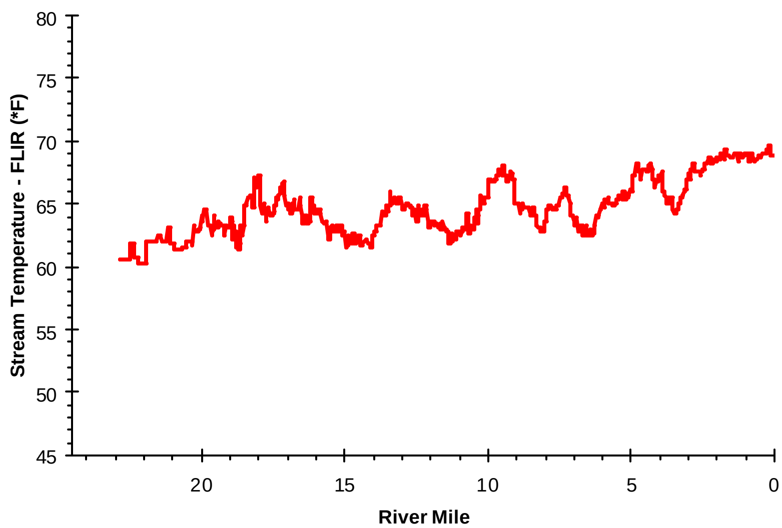


Figure 2-28. *North Fork Nehalem River Sampled FLIR Temperatures*

Figure 2-29. *North Fork Nehalem River FLIR Derived Temperatures - August 8, 2000 - 2:02 to 2:523 PM*



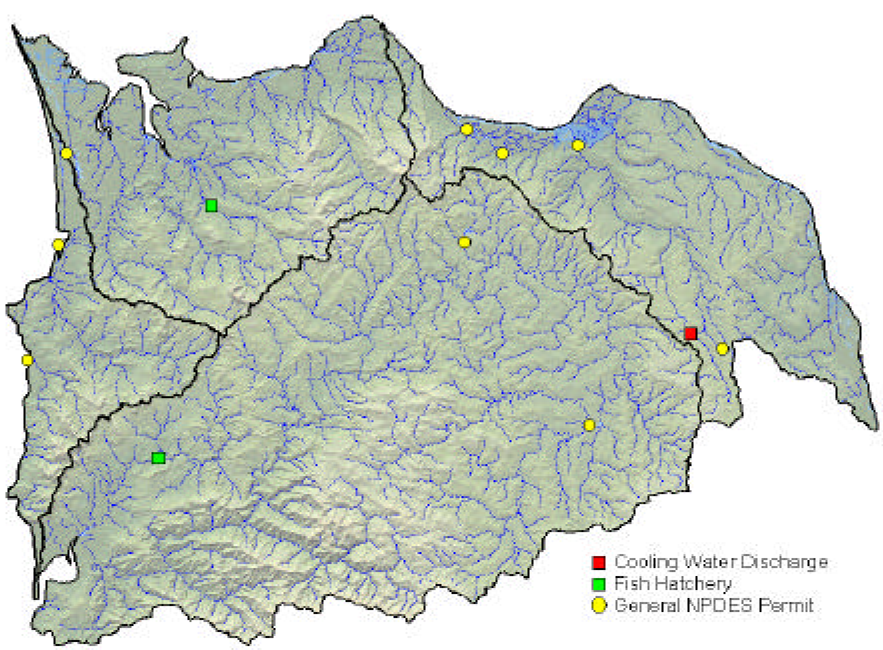
2.2.6 Point Source Type/Location Data

Point Source Type/Location Data are used in this analysis to:

- *Map stream NPDES[3] and other point sources, and develop waste load allocations.*

The Oregon Department of Environmental Quality maintains a database for point source information. This data was used to identify thermal point sources within the North Coast Subbasins (**Figure 2-30**).

Figure 2-30. *Point sources of heat*



[3] National Pollutant Discharge Elimination System established by the CWA