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Upper Humptulips River Temperature Total Maximum Daily Load

Technical Report

September 2001
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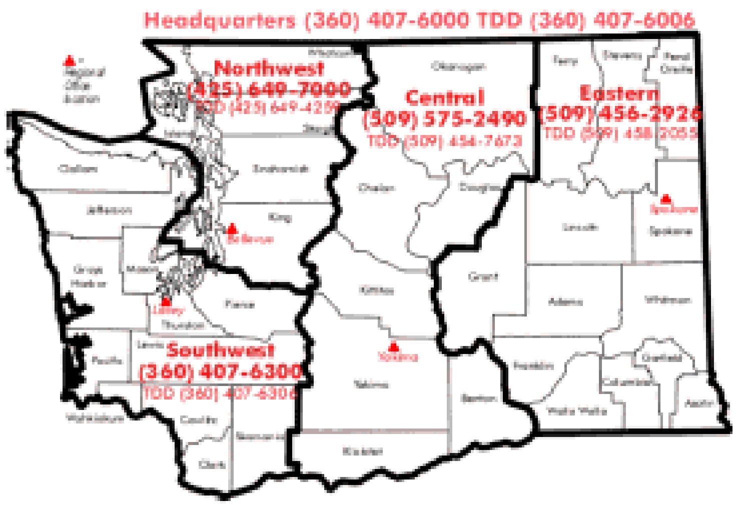

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Section A Water Quality Assessment Objectives and Approach

Introduction

Water quality is an important characteristic that affects the value of aquatic resources. These resources include rivers, streams, lakes, reservoirs, estuaries, and wetlands. The value of aquatic resources is reflected by their ability to support a variety of uses. The public is interested in quality water to supply domestic, agricultural, and industrial needs. Quality water is also important for recreational activities, such as swimming, boating, and fishing. Finally, aquatic life depends on suitable water quality for survival. Land management activities, combined with natural watershed processes, influence water quality which in turn affects these beneficial uses.

Management of water quality is carried out through of the Federal Clean Water Act (CWA). The primary objective of the CWA is to *"restore and maintain the chemical, physical, and biological integrity of the Nation's waters."* Taken together, the interaction of chemical, physical, and biological conditions define the overall ecological integrity of an aquatic system over time. Characteristics addressed include indicators such as dissolved oxygen concentrations, sediment, nutrients, temperature, and bacteria as well as habitat structure and processes, species composition, and diversity / abundance of aquatic dependent flora and fauna.

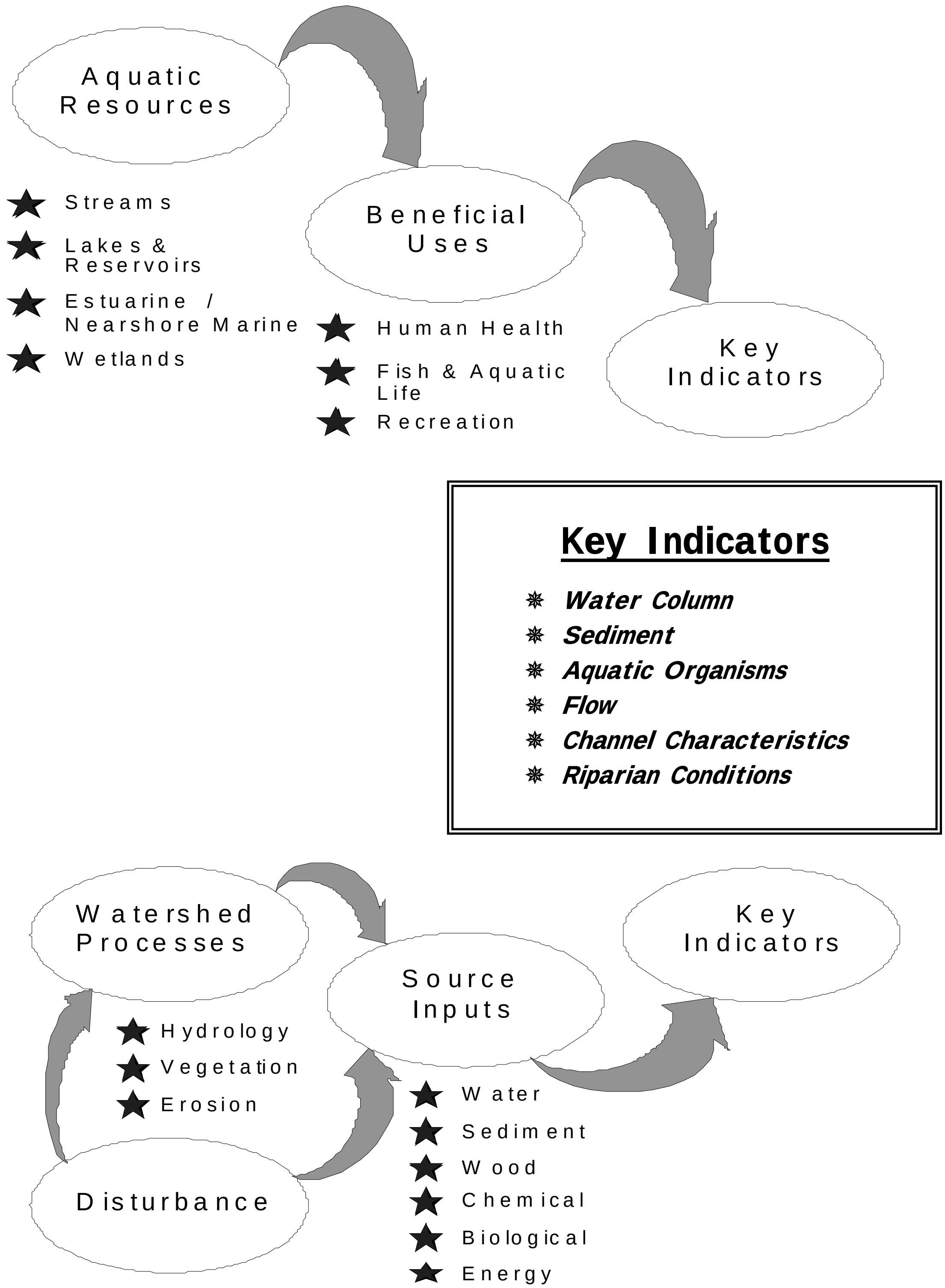
Objectives and Key Questions

The purpose of this assessment is to describe water quality in the Upper Humptulips watershed. Specifically, the water quality assessment is intended to:

- describe water quality concerns in the context of the setting, the aquatic resources, beneficial uses, applicable standards, and the condition of key indicators;
- evaluate pollution sources and disturbance activities that contribute to water quality problems; and
- outline water quality management needs including identification of those waters which still require total maximum daily loads (TMDLs).

Assessment of water quality is often viewed from two perspectives *(Figure A-1)*. The first centers on setting objectives. This involves describing the aquatic resources (i.e. streams, lakes, etc), the beneficial uses associated with these resources, and a set of indicators which reflect conditions. The objectives set are reflected in Washington's water quality standards. The second water quality assessment perspective relates to program management. Here, the focus is on how watershed processes and disturbance activities, through changes to input variables (e.g. sediment, water, wood, chemicals, etc.) affect beneficial uses as reflected through the same indicators used to assess conditions.

Figure A-1. *Water Quality Assessment -- The Context*



The following critical questions help frame the assessment of water quality in the Upper Humptulips:

- ***What beneficial uses dependent on aquatic resources occur in the watershed and which water quality parameters are critical to these uses?***
- ***What are the current conditions and trends of beneficial uses and associated water quality parameters?***
- ***What were the historic water quality characteristics of the subbasin?***
- ***What are the natural and human causes of change between historic and current water quality conditions?***
- ***What are the influences and relationships between water quality and other watershed processes in the subbasin (e.g. mass wasting, fish habitat, stream channel, etc.)?***

Subbasin Scale

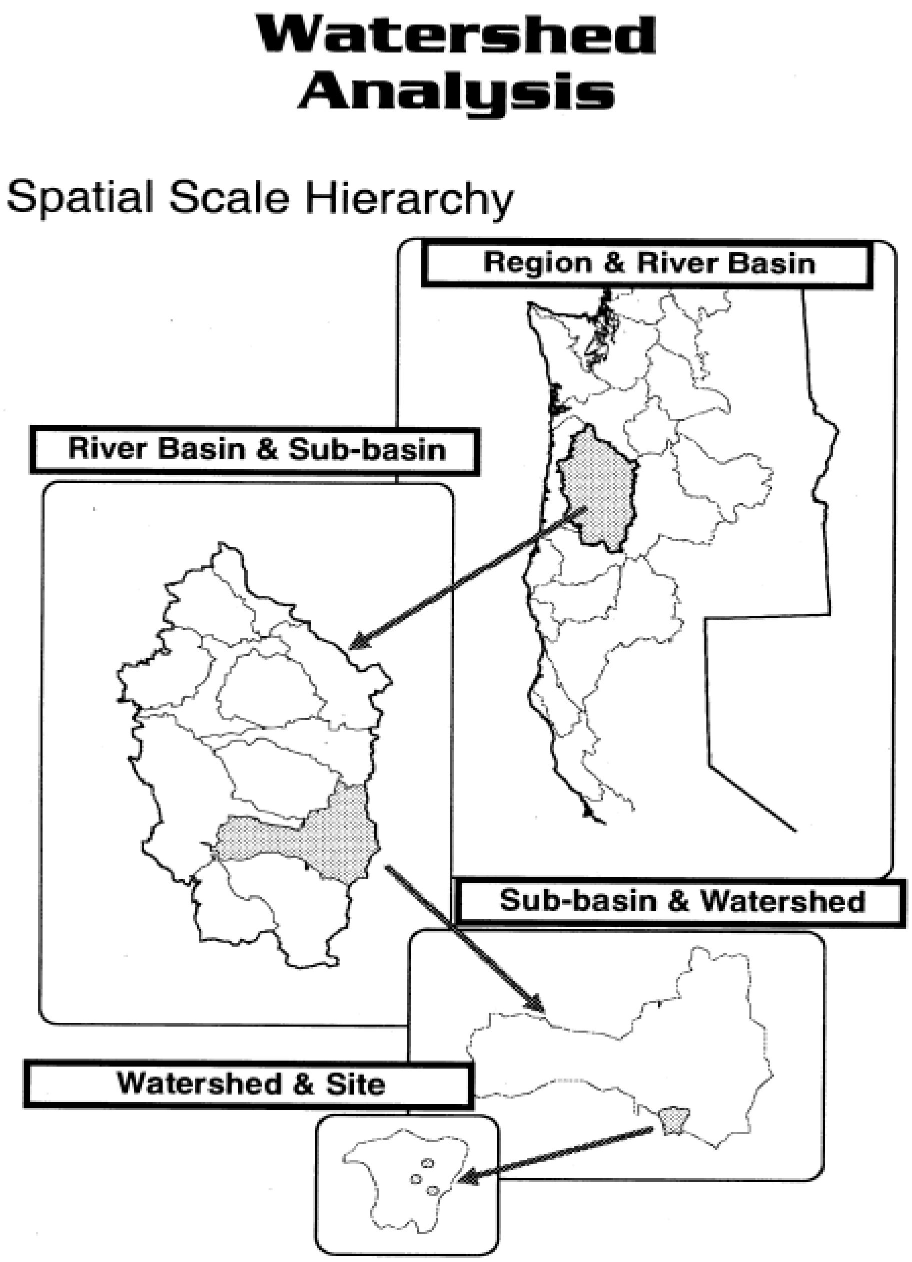
Water quality assessment is not a rigid, *"one-size-fits-all"* approach. Watershed management can be conducted at several scales (or resolutions) to meet a variety of needs. Different scales of watershed management units are utilized. The Department of Ecology, charged with managing water quality in Washington, divides the state into Water Resource Inventory Areas (WRIAs) and manages water quality basin-wide. Local governments, on the other hand, concerned about protecting source water supplies, for instance, focus on watersheds that drain to surface- or ground-water supply intakes or recreational areas.

Watershed cataloging units reflect scales of resolution, with small subwatersheds nesting within larger watersheds that nest within subbasins which nest within river basins *(Figure A-2)*. Different agencies collect and assess data for analysis efforts at all scales of resolution. Using a common set of geographic management units for assessment greatly improves opportunities for sharing data and coordinating management activities. This coordination is particularly important when using Geographic Information Systems (GIS) technology, which has the capability to scale up or down. The U.S. Geological Survey (USGS) has developed an 8-digit system of hydrologic cataloging units (HCUs or HUCs). These units, referred to from here on as subbasins, also provide a foundation for CWA assessments. The Upper Humptulips lies within the Grays Harbor USGS subbasins (17100105).

Regulatory Framework

Within the state of Washington, water quality standards are published pursuant to Chapter 90.48 of the Revised Code of Washington (RCW). Authority to adopt rules, regulations, and standards as are necessary and feasible to protect the environment and health of the citizens of the State is vested with the Department of Ecology. Through the adoption of water quality standards, Washington has identified the designated uses to be protected in each of its drainage basins and the criteria necessary to protect these uses Water quality standards are located in Chapter 173-201 of the Washington Administrative Code (WAC).

Figure A-2. *Water Quality Assessment --Scales of Resolution*



Washington also has a comprehensive framework in place for the Department of Ecology to monitor state waters and implement pollution control strategies, including development of total daily maximum loads (TMDLs). Waterbodies not fully supporting beneficial uses are prioritized depending upon the severity of pollution and the uses of the water. These waters are then subject to TMDL development or equivalent processes consistent with the Clean Water Act and Washington law. For these waters, appropriate limitations are placed on point sources. In addition, appropriate changes are made to best management practices (BMPs) for nonpoint sources.

Approach

The water quality assessment attempts to identify, for waterbodies occurring in the drainage, those situations where beneficial uses dependent on water quality are impaired, or are likely to be impaired, as a result of disturbance activities. The approach taken in preparing these assessments is to summarize information on water quality within the watershed(s). The subbasin assessment is then used to support watershed analyses and TMDL development within the subbasin. The water quality assessment consists of three components which follow as a separate section for each. These include:

- Characterization (Section B)
- Condition Assessment (Section C)
- Interpretation (Section D)

The focus of these subsequent efforts is then used to evaluate information on how water quality within the watershed is affected by the cumulative effects of disturbance activities and to develop solutions to problems and concerns. In particular, the assessment describes technical considerations for developing appropriate measures for water quality-based controls which include:

CONSIDERATIONS -- Developing Appropriate Measures	
CONDITIONS	***Normal water quality conditions***, *i.e. a condition assessment using appropriate indicators.*
FLOWS	***Flow rates*** *affect water quality. Analysis of hydrology, as appropriate to concern.*
VARIABILITY	***Seasonal variations*** *are important, both in terms of timing of beneficial uses and effects on water quality. Seasonal considerations allow the proper time frame to be applied.*
INPUTS	***Existing source inputs***, *or other appropriate source inputs should be put in perspective to develop solutions.*
WATER TYPE	***Dissipative capacity*** *is affected by the water type.*

Section B Characterization

The purpose of this characterization is to provide background information about the Upper Humptulips watershed, particularly those aspects important to development of the Total Maximum Daily Load (TMDL). The intent is to summarize basic information on physical characteristics, land use, aquatic resources, beneficial uses, land ownership, and available data. This characterization focuses on the question: ***"What beneficial uses dependent on aquatic resources occur in the watershed and which water quality parameters are critical to these uses?"*** In addressing this question, subtopics considered include:

Characterization --- *Other Considerations*
What characteristics in the watershed are important to water quality? • What waterbodies and beneficial uses occur in the watershed and where are they located? • Which water quality parameters best reflect the condition of beneficial uses in the watershed relative to development of water quality-based controls?

Setting

This Upper Humptulips water quality assessment has been developed to address fisheries concerns within the watershed. The assessment uses information from a Watershed Analysis (WA) prepared by the U.S. Department of Agriculture -- Forest Service (USFS), Rayonier, and the Washington Department of Natural Resources for the Upper Humptulips. These forested watersheds include Rayonier's commercial timberland in Grays Harbor county as well as public lands administered by the USFS -- Olympic National Forest. The plan area lies north of Hoquiam and northeast of Highway 101 *(Figure B-1)*.

The plan area includes nearly 700 miles of streams that drain lands bordering the southwestern extent of the Olympic Mountains. Salmon, steelhead, and cutthroat trout occur throughout the Upper Humptulips watershed. Significant fish-bearing streams within the watershed include the East and West Forks and key tributaries (Goforth Creek, Flatbottom Creek, Donkey Creek, Chester Creek).

<u>Figure B-1</u>. *Vicinity Map of Upper Humptulips Watershed*

Physical Characteristics

Climate

Climate in the Upper Humptulips watershed is mild and moist due to air masses that advance inland from the Pacific Ocean. The strong maritime influence includes seasonal changes that result from shifts in the pathways of the dominant westerly tradewinds. Major rain and wind storms that occur in the fall and winter most often approach the Olympic Peninsula from the Pacific Ocean following a southwest-to-northeast path. Winters (generally mid-October through mid-March) are influenced by low pressure systems and associated storms. These storms may develop into *"super storms"* that can bring occasional devastating winds. Northerly shifts in the westerly tradewinds result in relatively dry summers.

Rainfall ranges from 40 inches in the low elevations to over 160 inches in the upper areas. Seasonal and annual variations in precipitation are evident based on data collected at Wynoochee Dam from 1971 to 1998. Precipitation patterns in the Wynoochee are similar to those in much of the Upper Humptulips watershed. The weather station is located just east of the Humptulips drainage at an elevation of 820 feet. Precipitation at the station is concentrated in the winter months beginning in October with few breaks in wet weather until April or May. Monthly averages range from a low of 2.7 inches in July to 25 inches in November. Air temperatures at the station are somewhat moderate, averaging from around 38°F in December and January to about 61°F in July and August.

Landform

Landforms vary across the Upper Humptulips watershed. The headwaters originate in the steep Olympic Mountains. The streams then flow into gradually broadening glaciated river valleys. The influences of the geologic setting and associated physical processes that affect aquatic habitats have been captured in the Watershed Analysis by stratifying the landscape into *"geomorphic map units"* (GMUs). The Upper Humptulips has been divided into 17 GMUs. These GMUs have been further grouped into six categories that share similar erosional and channel forming processes. The GMU categories include:

- Glacial Erosional
- Fluvial Erosional Hillslopes
- Mass Wasting
- Glacial Depositional
- Fluvial Depositional
- Inner Gorge

GMU boundaries are determined by geology, geological history, and topographic relief. Summaries of characteristics for each GMU are found in the Watershed Analysis Report.

Geology and Soils

Geologic formations within the watershed are among the oldest peripheral rock found on the Olympic Peninsula. The basaltic volcanic rocks of the Crescent Formation, mostly of marine origin, are the predominant bedrock terrain within the watershed; thick-bedded sandstones of the Blue Mountain Unit occur in lower abundance (Taber and Cady, 1978). The steep uplands consist mostly of shallow, permeable, weakly structured soils derived from the underlying basalt bedrock. Four major alpine glaciers moved in and out of the river valleys, leaving behind moraines and stratified deposits including sand, gravel, silt, and clay (Long, 1975).

Vegetation

Potential vegetation on the south side of the Olympic Mountains falls into five zones. These include (from low to high): Sitka Spruce, Western Hemlock, Silver Fir, Mountain Hemlock, and Subalpine zones. Moist maritime plant associations are more common than dryer associations in each zone. The Sitka Spruce Zone occupies the lower valleys and foothills where maritime fog is common. The Silver Fir Zone and above are the areas of permanent winter snowpack. The Subalpine Zone is the area where snowpacks are too deep and last too long to permit all but minimal tree growth. Current plant communities are younger and more fragmented than past plant communities. Young stands lack structural and biological diversity that was present in older stands. Clearcutting, slash burning, and replanting have resulted in a greater proportion of Douglas fir and red alder on the landscape than was present historically. Major vegetation disturbance regimes in the past were fire, wind, flooding (including channel migration), snow avalanche, and mass wasting. Although these factors still exist in the Upper Humptulips, timber harvest and associated road construction have become the most important disturbance regimes.

Land Use

Land use in the Upper Humptulips is predominantly silviculture, including commercial forest owned by Rayonier Timber and Washington State Department of Natural resources. Upper portions of the watershed originate in the Olympic National Park and Olympic National Forest. Some valley bottomland in the extreme lower watershed consists of small farms.

Aquatic Resources

The headwaters of both the E.F. and W.F. Humptulips River systems initiate in the steep Olympic Mountains and flow into gradually broadening glaciated river valleys. Short, high-gradient first-, second- and third-order tributaries predominantly feed the East Fork. Drainages form a dendritic pinnate pattern. The West Fork is fed by short, high-gradient streams in addition to several major tributaries including Chester, Grouse, Newbury, Donkey, and Furlough Creeks. Most tributaries in both river systems confluence with the mainstems at 90 degree angles.

Non-forested wetlands are the predominant water body feature in the watershed, totaling approximately 512 acres. About 75 percent of the wetlands are found in the West Fork Humptulips. Highest concentrations of these water bodies occur in the lower elevation subbasins (Donkey Creek, West Fork Lower, and East Fork Lower *(see Watershed Analysis Report — Module B: Vegetation Assessment).* Wetlands exist primarily as the result of oxbow formations along the East Fork and West Fork mainstems as well as along major tributaries. These water bodies are positioned on terraces above the current flood plains. Wetlands within the Donkey Creek Subbasin have different characteristics — riverine wetlands are present; and wetlands are also formed as the result of beaver activity in the Donkey Creek flats area. Aquatic resources in the Upper Humptulips are summarized in Table B-1.

Table B-1. ***Aquatic Resources -- Upper Humptulips Watershed***

ID	Watershed Name	Area (mi^2)	Waterbody Type Drainage (mi.)	Lakes & Ponds (acres)	Wetlands (acres)
	Upper East Fork	14.9	88.1	0.0	29.0
	Middle East Fork	15.9	101.2	0.0	19.1
	Lower East Fork	15.1	98.6	3.2	80.9
	Upper West Fork	18.3	110.2	1.0	14.7
	W.F. above Chester Creek	8.3	37.8	0.0	60.5
	Chester Creek	10.6	69.3	0.0	0.0
	W.F. above Donkey Creek	14.5	81.0	1.1	64.4
	Donkey Creek	7.5	39.4	0.0	134.6
	Lower West Fork	14.3	74.4	0.0	110.7
	Brittain Creek			0.0	94.8
	Above Stevens Creek			8.7	142.4

Stream characteristics within the Upper Humptulips watershed vary across the landscape. Although there is limited streamflow data available for the drainage, methods have been developed to estimate flow from basin area for the Olympic Peninsula (Amerman and Orsborn, 1987). A channel classification system developed by Simpson Timber Company for use in their Habitat Conservation Plan (HCP) identifies streams as being small (active channel width # 4m), medium (4m < active channel width # 16m), or large (active channel width > 16m). Figure B-3 illustrates the relationship between drainage area and channel width in the Simpson HCP area. Table B-2 summarizes drainage characteristics in the WA area by *“lithotopo unit”* (LTU).

Drainage density within the highly dissected watershed averages around 6 miles per square mile. Densities equal or exceed 6 miles per square mile in the Chester Creek, West Fork Upper, East Fork Lower, and East Fork Middle subbasins. Drainage density calculations (in miles per square mile) were generated from the USDA Forest Service — Olympic National Forest (ONF) Geographic Information System (GIS) data based on stream length (linear miles) and watershed and subbasin areas (square miles). The stream layer is the result of the combined USDA Forest Service Geometronics Service Center (GRC) and the Washington Department of Natural Resources (DNR) stream data. The GRC and DNR layers were both digitized at the 1:24,000 scale from U.S. Geological Survey (USGS) 7.5-minute quadrangles, aerial photo interpretation, and field-based information from various sources. In addition, stream segments were added to the layer based on field reconnaissance by Watershed Analysis Team members.

Figure B-3. *Simpson HCP Area*

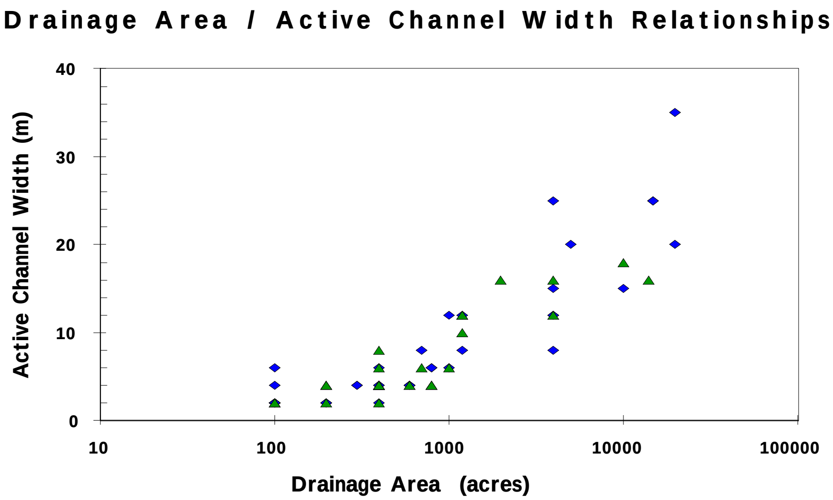


Table B-2. ***Subbasin / Drainage Characteristics***

Watershed Name	**Watershed Area** ***mi²***	**Drainage Miles**	**Drainage Density** ***(mi/mi²)***	**Yield** ***(cfs / mi²)***	**Inflow** ***(cfs / mi)***
Upper East Fork	14.9 (12.5%)	88.1	5.9	1.0	0.17
Middle East Fork	15.9 (13.3%)	101.2	6.4	1.0	0.16
Lower East Fork	15.1 (12.6%)	98.6	6.5	1.0	0.15
Upper West Fork	18.3 (15.3%)	110.2	6.0	1.0	0.17
W.F. above Chester Creek	8.3 (7.0%)	37.8	4.6	1.0	0.22
Chester Creek	10.6 (8.9%)	69.3	6.6	1.0	0.15
W.F. above Donkey Creek	14.5 (12.1%)	81.0	5.6	1.0	0.18
Donkey Creek	7.5 (6.3%)	39.4	5.3	1.0	0.19
Lower West Fork	14.3 (12.0%)	74.4	5.2	1.0	0.19
Brittain Creek					
Above Stevens Creek					

- Flow yield estimated for each LTU from Amerman and Orsborn, 1987 (Figure 10-5). Represents seven-day, two-year (7Q2) low flow based on Olympic Peninsula gage information.
- Inflow is the flow yield divided by the drainage density to provide a rough estimate of flow derived per mile of stream (rough indicator of potential groundwater contribution).

Beneficial Uses / Applicable Standards

Aquatic Life

The primary designated use requiring protection in the Upper Humptulips watershed is aquatic life. Primary native salmonid species include coho, chinook, chum, steelhead, coastal cutthroat trout, resident rainbow trout, mountain whitefish, and the non-native Eastern brook trout. Distribution of the species is very broad in the drainage. Current distribution is similar to the historical areas used by salmonids except where culverts block migration. Coho use many of the tributaries for spawning and rearing. Cutthroat trout may occur well up into high gradient tributaries. The Watershed Analysis Report provides more detail on current and historic species distribution of native salmonids.

Applicable Water Quality Standards

Within the state of Washington, water quality standards are published pursuant to Chapter 90.48 of the Revised Code of Washington (RCW) and are located in Chapter 173-201 of the Washington Administrative Code (WAC). In Washington, *"specific fresh waters of the State of Washington are classified ..." [WAC 173-201-080]*. The Upper Humptulips watershed lies within the Grays Harbor subbasin. WAC 173-201-080 identifies these watersheds as either class *"A"* or class *"AA"*. Class *"AA"* waters are those located on public lands administered by the Olympic National Forest. Waters downstream of the National Forest are designated as Class *"A"*. Water quality standards not to be exceeded are described in WAC 173-201-045. These waters have assigned temperature criteria to protect characteristic uses. The primary water quality concern in the Upper Humptulips Watershed that is reflected in Washington's 1998 §303(d) list is water temperature exceedances. For Class A waters:

> *"Temperature shall not exceed 18.0°C…due to human activities. When natural conditions exceed 18.0°C…, no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C." [WAC 173-201A-030(2)(c)(iv)]*

For class *"AA"* streams:

> *"Temperature shall not exceed 16.0°C (freshwater) or 13.0°C (marine water) due to human activities. ... When natural conditions exceed 16.0°C (freshwater) or 13.0°C (marine water), no temperature increase will be allowed which will raise the receiving water temperatures by greater than 0.3°C" [WAC 173-201A-045(1)(c)(iv)]*.

The applicable water quality standard for sediment states:

> *"deleterious material concentrations shall be below those which may adversely affect characteristic water uses ..." [WAC 173-201A-045(1)(c)(vii)]*.

Finally, during critical periods, natural conditions may exceed the numeric criteria for temperature identified in the water quality standards. In these cases, the following applies:

> *"Whenever the natural conditions of said waters are of a lower quality than the criteria assigned, the natural conditions shall constitute the water quality criteria"* *[WAC 173-201A-070(2)]*.

Land Ownership

The Watershed Analysis Report provides a general overview land ownership patterns and their percentage of total lands. These lands encompass usual and accustomed fishing areas of the Quinault tribe.

Available Data

Temperature conditions in the Upper Humptulips watershed reflect the range of watershed characteristics, interannual variation, and the effect of management activities. Table B-4 identifies monitoring sites that were used to assess water temperature conditions in the Upper Humptulips.

Table B-4a. ***Upper Humptulips Stream Temperature Monitoring Sites***

ID	Validation Site				Maximum Temperature	
	GCU	Group	Name	*(acres)*	1997	1998
USFS09	*spc*		*W.F. Humptulips (RM 56.6)*	4,897	11.6°C	12.71°C
USFS13	*spc*		*E.F. Humptulips (RM 28.0)*	1,712	N/A	12.94°C
USFS14	*fpr*		*Lost Creek*	948	N/A	13.56°C
USFS15	*fpr*		*Flatbottom Creek*	971	N/A	15.09°C
USFS12	*fpr*		*E.F. Humptulips (RM 25.5)*	4,655	N/A	15.62°C
T02	*fpr*		*Donkey Creek*	4,430	N/A	16.92°C
USFS16	*fpr*		*E.F. trib (jct. 22 & 2206)*	954	N/A	17.27°C
USFS01	*fpm*		*E.F. Humptulips (RM 15.0)*	11	15.6°C	17.93°C
T11	*rw*		*Donkey Creek trib (Rd. 3610)*	130	N/A	18.68°C
T12	*rw*		*Upper Donkey Creek wetland*	198	N/A	26.54°C
T10	*rw*		*Rd. 3610 wetland*	62	N/A	38.04°C
T09	*bb*		*Lower Donkey tr. (Nr W0710.2)*	0.0	N/A	16.26°C
T07	*bb*		*Lower E.F. trib*	203	N/A	23.17°C

T04	*tc*		*E.F. Humptulips above W.F.*	29,276	N/A	24.29°C

Table B-4b. ***Upper Humptulips Stream Temperature Monitoring Sites***

ID	**Validation Site**				**Maximum Temperature**	
	GCU	**Group**	**Name**	***(acres)***	**1997**	**1998**
T05	*lgpr*		*Goforth Creek*	2,169	N/A	16.23°C
T01	*lgpr*		*O'Brien Creek*	1,252	N/A	16.43°C
T08	*lgpr*		*Furlough Creek*	1,138	N/A	18.19°C
T03	*lgpr*		*W.F. Humptulips above E.F.*	46,975	N/A	23.19°C
T13	*fpm*		*East Fork at Flatbottom*	11,480	N/A	19.59°C
USFS06	*fpm*		*W.F. above Elk Creek (RM 45.3)*	24,217	18.3°C	20.36°C
USFS03	*fpm*		*W.F. blw Rainbow Cr. (RM 41.0)*	30,774	18.7°C	20.78°C

Table B-5 identifies sites where the U.S. Geological Survey (USGS) has collected water resource data, either in or near the Upper Humptulips watershed.

Table B-5a. ***USGS Data -- Upper Humptulips Watershed***

Gage ID	Gage Name	River Mile	Area	Elev.	Flow Period of Record	Other WQ Data
12035400	Wynoochee River near Grisdale	51.3	41.3 mi^2	630	1965 -	
12035450	Big Creek near Grisdale	0.6	9.57 mi^2	600	1972 - 96	
12036000	Wynoochee above Save Creek	40.6	74.1 mi^2	401	1925 -	
12036400	Schafer Creek near Grisdale	1.0	12.1 mi^2	280	1986 - 96	
12036650	Anderson Creek near Montesano	1.0	2.72 mi^2	150	1972 -	
12037400	Wynoochee above Black Creek	5.9	155 mi^2	40	1956 -	[WQ Records]
12039000	Humptulips River near Humptulips		130 mi^2	120	1933 - 79	[WQ Records]

Section C Condition Assessment

Overview

After characterization, the next level of water quality analysis involves assessing conditions of waterbodies using key indicators (or parameters). The focus of the condition assessment is to answer the questions: ***"What are the current conditions and trends of beneficial uses and associated water quality parameters?"*** and ***"What were historic water quality characteristics of the watershed?"***. In addressing this question, other subtopics could be considered which include:

Condition Assessment --- *Other Considerations*
Are waterbodies within the subbasin adversely affected by water quality based on information about current and past conditions? ◆How does water quality in the watershed compare to State Water Quality Standards? ◆What do current conditions or changes from past conditions indicate about the effect of input variables on the function of waterbodies?

Water quality information collected in the Upper Humptulips Watershed indicate that excessive summer water temperatures may reduce the quality of rearing habitat for coho salmon as well as for steelhead and cutthroat trout. As a result of water quality standards (WQS) exceedances for temperature, one segment (the Humptulips River at the Highway 101 bridge) is included on Washington's 1998 §303(d) list.

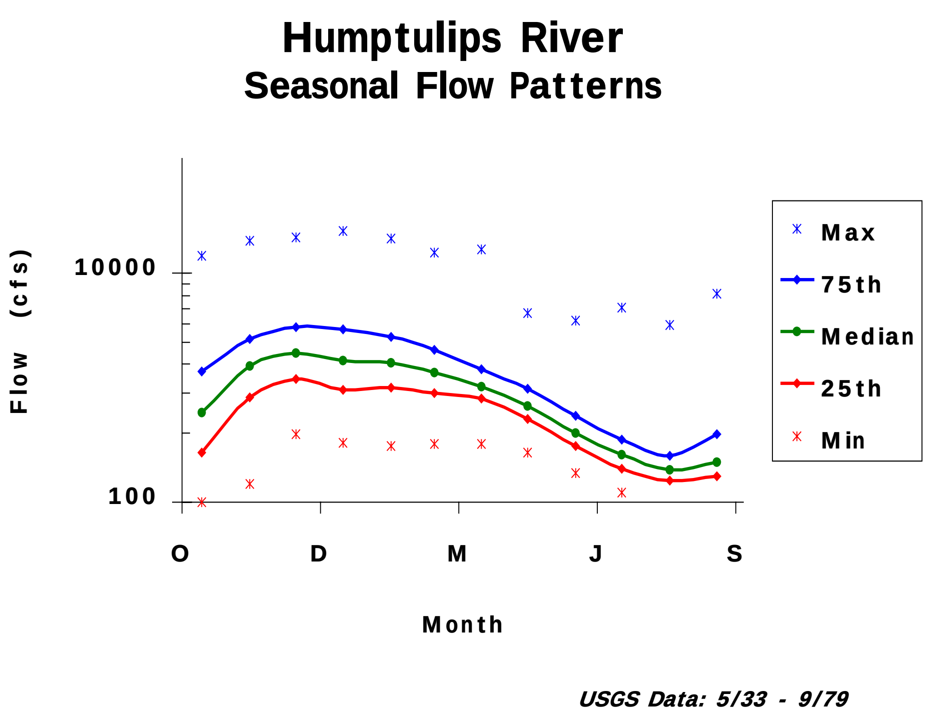
Existing Data

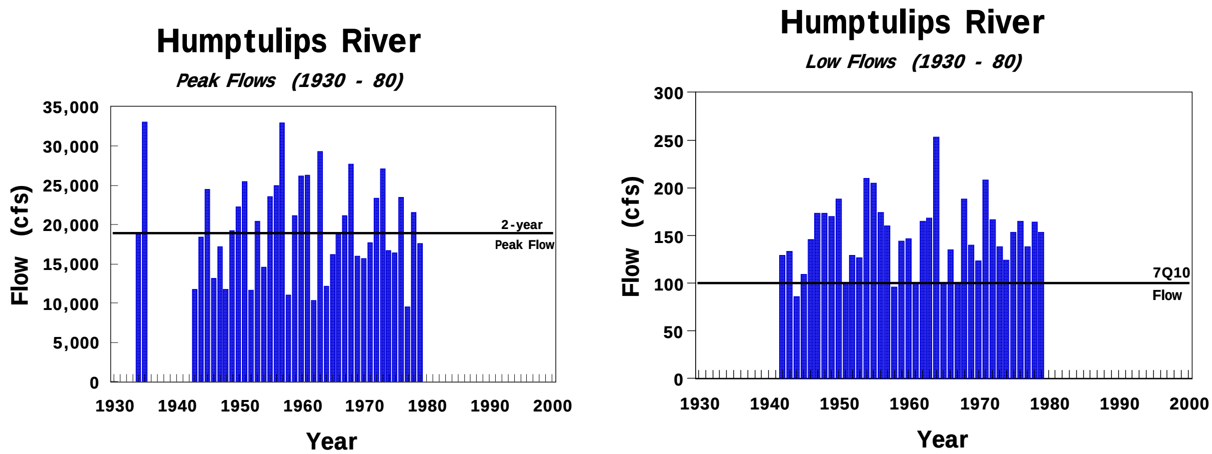
Flow

Streamflow is a major factor that affects water quality. Consequently, a starting point in the condition assessment is a brief analysis of streamflow patterns in the Upper Humptulips Watershed Analysis area. The Hydrologic Change Assessment in the Watershed Analysis Report *(Module C)* provides a good background summary. Precipitation in the Upper Humptulips is concentrated in the winter months beginning in October, with few breaks in wet weather until April or May. Streamflow patterns closely mimic seasonal precipitation patterns.

Seasonal Variation: The U.S. Geological Survey (USGS) has collected streamflow data at one gage just below the Watershed Analysis area. The longest continuous record for flow data is the USGS gage on the Humptulips River near Humptulips (12039000). Figure C-1 depicts seasonal patterns. Highest flows occur in December and January while the lowest flows are typically in August and September. Figure C-2 shows both peak and low flow history for the Humptulips gage.

Figure C-1. *Flow Patterns for Humptulips River*





<u>Figure C-2</u>. *Humptulips River Peak and Low Flow History*

Stream Temperature

Stream temperatures have been monitored by the U.S. Forest Service, Rayonier, and the Washington Department of Ecology. The Watershed Analysis describes summer stream temperature monitoring at 15 different locations conducted by the USDA Forest Service - Quinault Ranger District since 1992. Martin Environmental also monitored stream temperature at 12 sites in 1998. Information from both efforts are summarized in the Watershed Analysis Report *(<u>see</u> Module F: Fish Habitat Assessment)*.

Temperature conditions in the Watershed Analysis area are influenced by a variety of factors which include shade, groundwater flow, and channel morphology. The geomorphic channel units (GCUs), described in the Stream Channel Assessment of the Watershed Analysis Report *(Module E)*, have been used to classify segments based on channel morphology, geology, and location within the drainage system. These GCUs represent a starting point to then group stream reaches by the dominant control(s) that affect water temperature (e.g. shade, groundwater flow, and channel morphology).

<u>Source reaches</u> are defined in the Stream Channel Assessment as those channels that occur in sediment source areas or that contribute a significant source of sediment from bank erosion. These are small to medium sized, high gradient streams in the Watershed Analysis area. Table C-1 identifies those GCUs which are in this category, specifically slope deposit (sd) and step-pool / cascade (spc). Several basic characteristics associated with each GCU in this group are also summarized.

Table C-1. ***Characteristics of Source Reaches***

GCU	Size Class	mi.	Basin Area *(acres)*	Active Channel Width *(m)*	Slope	Subwatershed
sd	small	6.34	100 – 400	< 3	> 8%	East Fork --- Upper West Fork --- Upper, Lower
spc	small	115.76	100 - 1,600	< 5	4 - 20%	East Fork --- Upper, Middle, Lower West Fork --- Upper, abv Chester, abv Donkey, Lower Chester Creek, Donkey Creek
Total		122				

- ❖ Small (CMZ # 4m) channels
- ❖ Crescent basalt landscape
- ❖ Upper elevations of Watershed Analysis area
- ❖ High channel confinement (W:D # 15)
- ❖ Low flow range: 0 - 5 cfs (drainage area < 5 mi^2)

Slope Deposit: This GCU includes steep (> 8 percent) channels that occur adjacent to debris fans and deep-seated landslides. These channels function as sediment source and transport sites as a result of bank erosion and undercutting at the margin and toes of the fans and landslides. Large woody debris (LWD) helps to stabilize the channel and minimize bank erosion. Channel morphology is variable depending on the accumulation of sediment and LWD.

More than 90% of the slope deposit channels occur in the Upper West Fork and the Upper East Fork subwatersheds. No slope deposit channels were monitored for water temperature in 1998. Summer flows in these channels are likely derived from groundwater.

Step-pool / Cascade: This GCU includes moderate to high gradient channels (4 percent to 20 percent) in moderately confined to confined valleys that occur in the upper portions of the drainage network. Channel morphology is characterized by step-pools and cascades formed by boulders, rocks, and LWD. LWD may form pools, especially in the lower-gradient channels, and create sediment storage sites behind log jams. Substrate is dominated by cobble, boulder, and bedrock.

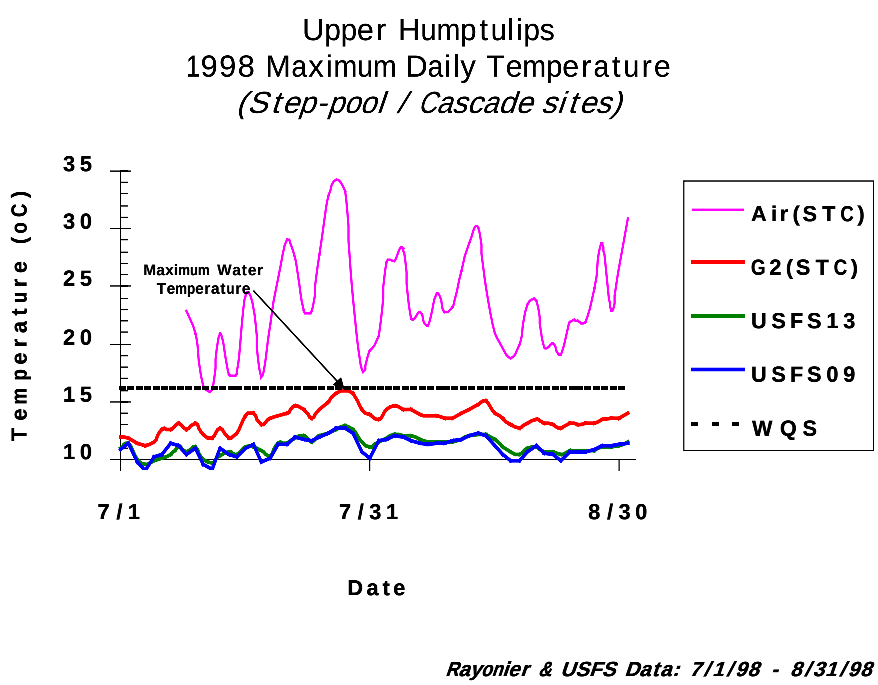
Monitoring data for water temperature has been collected in the upper W.F. Humptulips *(Site USFS09)* and the upper E.F. Humptulips *(Site USFS13)*. These sites are used to summarize water temperatures in step-pool / cascade channels *(Table C-2)*. As indicated, all daily maximum water temperatures observed in 1998 were below the 16.0°C water quality criteria.

Table C-2. ***Upper Humptulips Temperature Sites – Step-pool / Cascade Channels***

GCU	Water Temperature Monitoring Site				Maximum Temperature	
	Site ID	**Name**	*(acres)*	**Shade**	**1997**	**1998**
spc	*USFS09*	*W.F. Humptulips (RM56.6)*	4897.13	---%	11.6°C	12.71°C
spc	*USFS13*	*E.F. Humptulips (RM 28.0)*	1711.50	---%	N/A	12.94°C

Figure C-3 depicts daily maximum water temperatures observed at these sites in 1998. For comparative purposes, 1998 data for North Mountain Creek (located east of the Humptulips in the Satsop drainage) is also shown. The North Mountain site has been used to describe small to medium sized, highly confined channels for which groundwater is the dominant control of water temperature. These streams (referred to as Temperature Group G-2) are topographically shaded and are *"near"* the water source with substantial groundwater influence which shows as side seeps and springs. These systems are typically cool and are resistant to water temperature changes.

Figure C-3. Maximum Water Temperature Patterns: Step-pool / Cascade Channels



<u>Transport reaches</u> are defined in the Stream Channel Assessment as those channels that function as sediment transport zones. These range from small to large sized, mid-gradient streams in the Watershed Analysis area. Table C-3 identifies those GCUs which are in this category, specifically terrace transition (tt), forced pool / riffle (fpr) and bedrock gorge (brg). Several basic characteristics associated with each GCU in this group are also summarized.

<u>Table C-3. ***Characteristics of Transport Reaches***</u>

GCU	Size Class	mi.	Basin Area *(acres)*	Active Channel Width *(m)*	Slope	Stream(s)
tt	small - medium	59.25	100 - 6,400	2 - 7	> 4%	East Fork --- Upper, Middle, Lower West Fork --- Upper, abv Chester, abv Donkey, Lower Chester Creek, Donkey Creek
fpr	Medium	42.94	400 - 1,600	4 - 8	2 - 4%	East Fork --- Upper, Middle, Lower West Fork --- Upper, abv Chester, abv Donkey, Lower Chester Creek, Donkey Creek
brg	medium - large	6.38		10 - 20	< 2%	East Fork --- Upper, Middle, Lower West Fork --- above Chester, above Donkey
Total		108.57				

- Small (CMZ # 4m), medium (4 < CMZ # 16m), and large (16 < CMZ # 20m) channels
- Crescent basalt landscape
- Middle to upper elevations of Watershed Analysis area
- Moderately confined and confined channels (W:D # 25)
- Low flow range: 0 – 10 cfs (drainage area < 10 mi^2)

<u>Terrace Transition</u>: This GCU includes the moderate to high gradient (> 4 percent), confined channels that occur in a transition zone between the tops of glacial terraces and the valley floor. This GCU includes channels characterized by a series of steep cascades, chutes, or falls (some up to 50 feet high) that are usually formed in bedrock, but also occur on glacial outwash. The steep gradient zones may be interspersed with short, low-gradient pool / riffle zones where the channel flows across intermediate terraces. The large channels are eroded to the bedrock base level, but similar channels may continue to downcut and erode headward. The Terrace Transition classification was applied to all mixed steep and low gradient reaches that flow between the top of the highest terrace and the valley floor. This GCU was listed as a source reach in the WA. In reference to temperature these segments function in a way consistent with other Transport reaches.

Forced Pool / Riffle: This GCU includes moderate gradient (2 percent to 4 percent), moderately confined channels that occur in the middle to upper portions of most tributaries and in the upper East Fork mainstem. Small pools formed by LWD or other obstructions are the dominant channel morphology. Flood plain development is limited along most of these segments by banks formed of consolidated material. Some channels, however, may have narrow, discontinuous flood plains. The substrate is dominated by cobble and gravel.

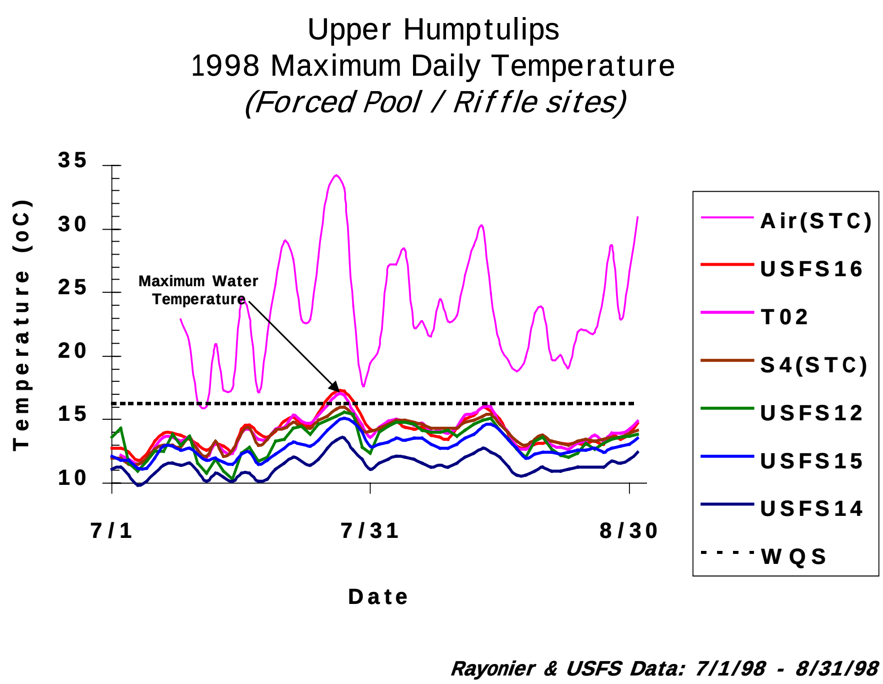
Monitoring data for water temperature has been collected in Lost Creek, Flatbottom Creek, the upper E.F. Humptulips, Donkey Creek, and an unnamed tributary to the middle E.F. Humptulips *(Table C-4)*. These sites are used to summarize water temperatures in the forced pool / riffle channels. As indicated, daily maximum water temperatures observed in 1998 for this GCU exceeded the 16.0°C water quality criteria at two sites.

Table C-4. ***Upper Humptulips Temperature Sites – Forced Pool / Riffle Channels***

GCU	Water Temperature Monitoring Site				Maximum Temperature	
	Site ID	**Name**	*(acres)*	**Shade**	**1997**	**1998**
Fpr (tt)	*USFS14*	*Lost Creek*	948.29	---%	N/A	13.56°C
Fpr (tt)	*USFS15*	*Flatbottom Creek*	971.42	---%	N/A	15.09°C
Fpr (lgpr)	*USFS12*	*E.F. Humptulips (RM 25.5)*	4654.50	---&	N/A	15.62°C
Fpr fpr)	*T02*	*Donkey Creek*	4429.54	---%	N/A	16.92°C
Fpr (tt)	*USFS16*	*E.F. trib (jct. 22 & 2206)*	953.63	---%	N/A	17.27°C

Figure C-4 depicts daily maximum water temperatures observed at these sites in 1998. For comparative purposes, data for Schafer Creek located in the Simpson HCP area is also displayed. The Schafer site has been used to describe small to medium sized channels in glacial till landscape with pool riffle and forced pool riffle / plane beds. These systems have moderate to low flows in the summer with varying amounts of groundwater influence (referred to as Temperature Group S-4). Along the continuum, those with minimal groundwater influence are susceptible to elevated water temperatures with loss of shade. Those with significant amounts of groundwater influence are resistant to temperature changes.

Figure C-4. *Maximum Water Temperature Patterns: Forced Pool / Riffle Channels*



Bedrock Gorge: This GCU only occurs in the East and West Fork mainstems. It includes low-gradient (<2 percent) segments that are confined by steep bedrock walls, which rise 100 to 200 feet above the river bed. Rapids, glides, and trench pools formed by boulders and bedrock outcrops are the dominant channel features. Pools formed by LWD are rare, and LWD recruitment processes are limited. Most LWD in these channels is derived by fluvial transport from upstream. Retention of LWD is low because of high transport capacity in the confined channels.

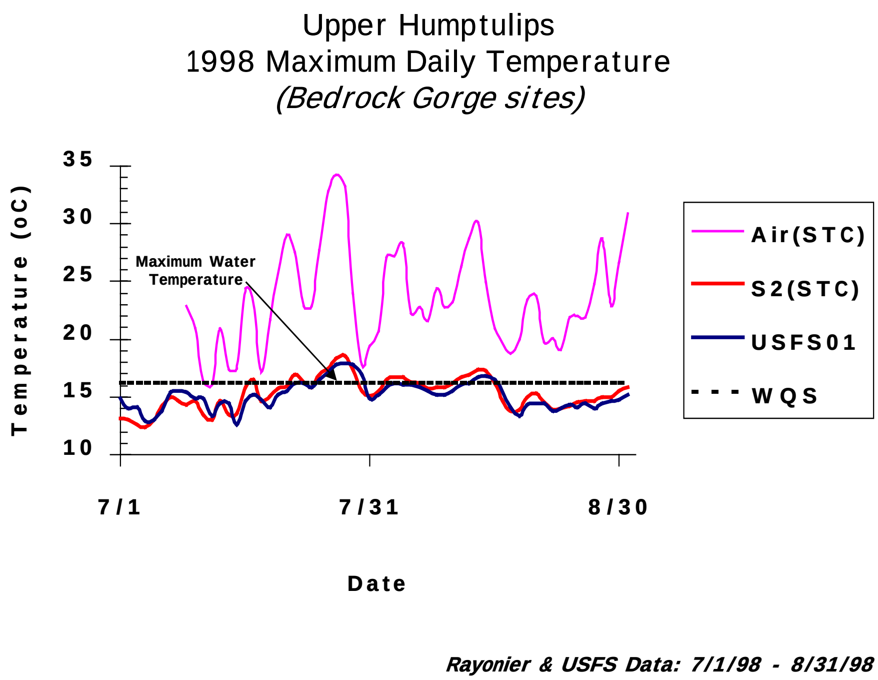
Monitoring data for water temperature has been collected in E.F. Humptulips *(Table C-5)*. Data from this site is used to summarize water temperatures in the bedrock gorge channels. As indicated, daily maximum water temperatures observed in 1998 for this GCU exceeded the 16.0°C water quality criteria.

Table C-5. ***Upper Humptulips Temperature Sites – Bedrock Gorge Channels***

GCU	Water Temperature Monitoring Site				Maximum Temperature	
	Site ID	**Name**	*(acres)*	**Shade**	**1997**	**1998**
fpm ->brg (tt)	*USFS01*	*E.F. Humptulips (RM 15.0)*	10.9	*---%*	15.6°C	17.93°C

Figure C-4 depicts daily maximum water temperatures observed at this site in 1998. For comparative purposes, data for Bell Creek is also displayed *(Temperature Group S-2)*. The *brg* segments are confined by steep bedrock walls. However, these channels are below flood plain migration channels in which water temperatures elevate as a result of the wide, shallow nature of these segments.

Figure C-5. *Maximum Water Temperature Patterns: Bedrock Gorge Channels*



Response reaches are defined in the Stream Channel Assessment as channels that are sensitive to sediment or flow changes. These range from small to large sized, low gradient streams in the Watershed Analysis area. Table C-6 identifies those GCUs which are in this category, specifically riverine wetland (rw), babbling brook (bb), hillslope confined (hsc), terrace confined (tc), low gradient pool / riffle (lgpr), and floodplain migration (fpm). Several basic characteristics associated with each GCU in this group are also summarized.

Table C-6. ***Characteristics of Response Reaches***

GCU	Size Class	mi.	Basin Area *(acres)*	Active Channel Width *(m)*	Slope	Subwatersheds
rw	small - medium	12.60		2 - 10	< 2%	East Fork --- Middle, Lower West Fork --- above Donkey Donkey Creek
bb	Small	7.01		< 2	1 - 4%	East Fork --- Upper, Middle, Lower West Fork --- Upper, abv Chester, abv Donkey, Lower Chester Creek, Donkey Creek
hsc	Large	0.97		20 - 30	< 2%	East Fork --- Middle
tc	Large	9.82		25 - 35	< 2%	East Fork --- Upper, Middle, Lower West Fork --- Lower
lgpr	Medium			8 - 15	< 2%	East Fork --- Upper, Middle, Lower West Fork --- above Donkey, Lower Chester Creek, Donkey Creek
	Large	41.24		25 - 35	< 2%	
fpm	Large	25.92		25 - 35+	< 2%	East Fork --- Upper, Middle, Lower West Fork --- Upper, abv Chester, abv Donkey, Lower
Total		97.56				

- ❖ Small (CMZ # 4m) to large (16 < CMZ # 35+m) channels
- ❖ Crescent basalt landscape
- ❖ Lower elevations of Watershed Analysis area
- ❖ Unconfined channels (W:D # 25)
- ❖ Low flow range: 0 - 4 cfs (drainage area < 10 mi^2)

Riverine Wetland: This GCU includes low gradient (< 2 percent) streams within wetland valley bottoms. Channels are typically incised in fine lacustrine deposits and bordered by wetland vegetation. Low velocity, placid flow sloughs are the dominant channel morphology, and substrate is dominated by organic and inorganic silt. Beaver dams frequently create ponds in these channels and influence riparian vegetation composition.

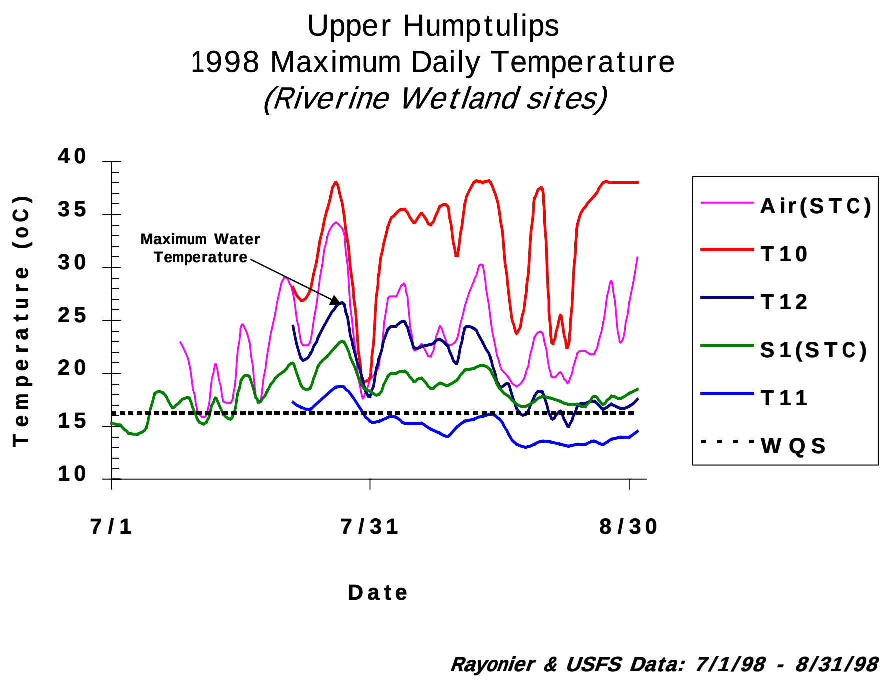
Monitoring data for water temperature has been collected in several tributaries to Donkey Creek *(Table C-7)*. These sites are used to summarize water temperatures in the riverine wetland channels. As indicated, daily maximum water temperatures observed in 1998 for this GCU exceeded the 16.0°C water quality criteria at all three sites.

Table C-7. ***Upper Humptulips Temperature Sites – Riverine Wetland Channels***

GCU	Water Temperature Monitoring Site				Maximum Temperature	
	Site ID	Name	*(acres)*	Shade	1997	1998
Rw (fpr)	*T11*	*Donkey Creek trib (Rd. 3610)*	130.45	---%	N/A	18.68°C
Rw (rw)	*T12*	*Upper Donkey Creek wetland*	197.93	---%	N/A	26.54°C
Rw (rw)	*T10*	*Rd. 3610 wetland*	62.17	---%	N/A	38.04°C

Figure C-6 depicts daily maximum water temperatures observed at these sites in 1998. For comparative purposes, data for Glenn Creek is also displayed. The Glenn site has been used to describe small to medium sized pool riffle and forced pool riffle / plane beds channels. Water temperature is driven by shade and low flows (poor water storage in these watersheds over glacial tills and shallow soils, also referred to as Temperature Group S-1). Headwaters of these systems are usually in wetlands or bogs and beavers frequently pond water within the channel.

Figure C-6. *Maximum Water Temperature Patterns: Riverine Wetland Channels*



Babbling Brook: This GCU includes small (< 2.0 m bankfull width), unconfined and moderately-confined, low and moderate gradient (1 to 4 percent) brooks. They occur in small basins with low relief, most of which are located in the lower portion of the watershed. These segments would be classified in the low gradient pool / riffle GCU if they were larger, but babbling brook channels do not have enough flow and hydraulic power to form pools and riffles. Channel morphology is characterized by shallow glides with small pools that are occasionally formed around tree roots, shrubs, and wood debris. Substrate in this GCU is dominated by sand, silt, and small gravel.

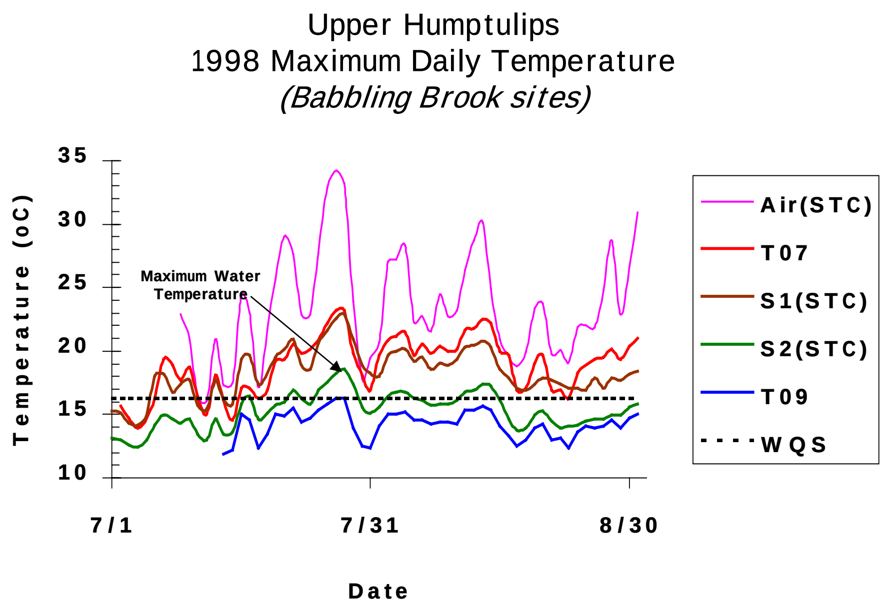
Monitoring data for water temperature has been collected in tributaries to the lower East Fork and Donkey Creek *(Table C-8)*. These sites are used to summarize water temperatures in the babbling brook channels. As indicated, daily maximum water temperatures observed in 1998 for this GCU exceeded the 16.0°C water quality criteria at both sites.

Table C-8. ***Upper Humptulips Temperature Sites – Babbling Brook Channels***

GCU	**Water Temperature Monitoring Site**				**Maximum Temperature**	
	Site ID	**Name**	*(acres)*	**Shade**	**1997**	**1998**
Bb (lgpr)	*T09*	*Lower Donkey tr. (nr W0710.2)*	?	---%	N/A	16.26°C
Bb (bb)	*T07*	*Lower E.F. trib*	203.10	---%	N/A	23.17°C

Figure C-7 depicts daily maximum water temperatures observed at these sites in 1998. For comparative purposes, data for Bell Creek is also displayed. The Bell site has been used to describe small to medium sized channels that often have hardwood dominated riparian systems and subtle groundwater influence through wet side slopes (referred to as Temperature Group S-2). This temperature group is subject to heating with the loss of riparian shade which can happen through damage to riparian leave areas by natural factors or through insufficient leave area.

Figure C-7. *Maximum Water Temperature Patterns: Babbling Brook Channels*



Rayonier & USFS Data: 7/1/98 - 8/31/98

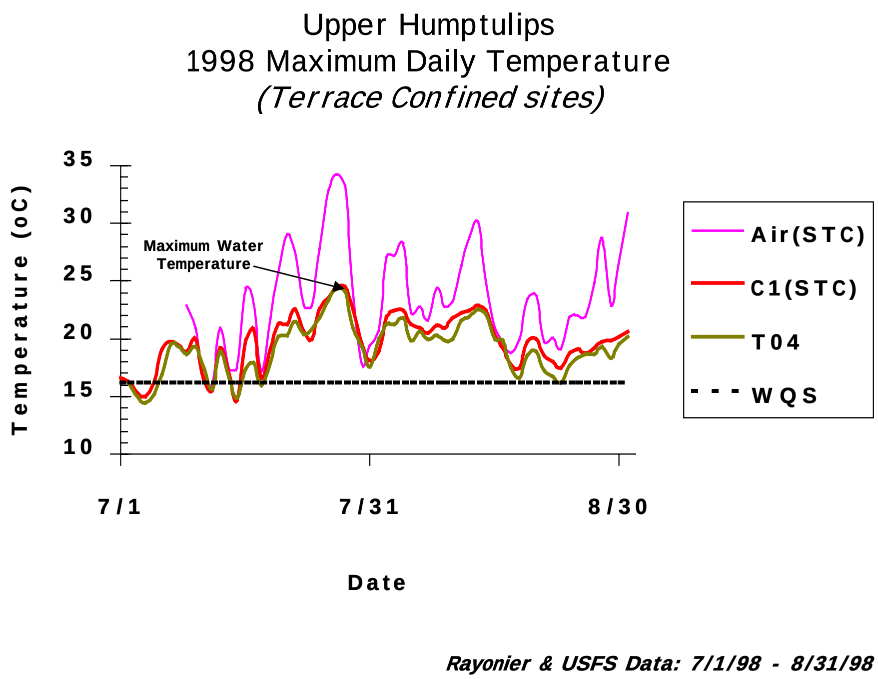
Hillslope Confined: This GCU includes low gradient (< 2 percent) mainstem channels that are mostly confined by adjacent sideslopes. Glides and pools formed by boulders and rock outcrops are the dominant channel features. Short, wide riffles are present at the transitions between units, and the substrate is dominated by cobble and gravel. Some gravel patches occur in association with retention structures formed mostly by boulders and in some cases LWD. LWD recruitment processes are limited by the confined channel morphology, and pools formed by LWD are rare.

Terrace Confined: This GCU includes the low gradient (< 2 percent) segments of the East and West Fork mainstems that are confined by glacial terraces. Steep walls composed of glacial deposits on one or both sides of the channel confine this GCU in a narrow valley. Pools and glides formed by lateral scour are the dominant channel morphology. Short riffles are present at the transitions between units, and the substrate is dominated by cobble and gravel. Undercutting of toe slopes by the river is a common source of sediment and LWD. LWD retention, however, is low because of the high transport capacity of this GCU.

Table C-9. ***Upper Humptulips Temperature Sites – Terrace Confined Channels***

GCU	Water Temperature Monitoring Site				Maximum Temperature	
	Site ID	**Name**	***(acres)***	**Shade**	**1997**	**1998**
Tc (tc)	*T04*	*E.F. Humptulips above W.F.*	29,275.98	---%	N/A	24.29°C

Figure C-8. *Maximum Water Temperature Patterns: Terraced Confined Channels*



Low-gradient Pool / Riffle: This GCU includes the moderately confined, low-gradient (<2 percent) channels in the East and West Fork mainstems and in the larger tributaries. Channel morphology typically consists of alternating pool and riffle units with occasional glides. Pools are formed by channel meandering and in-channel scour elements (i.e. LWD and bedrock outcrops). The stream bed material is predominantly gravel. The channels have narrow, often discontinuous flood plains that are punctuated by bedrock outcrops. Channel morphology in the Low-gradient Pool / Riffle GCU is similar to that of the Flood Plain Migration GCU, in the mainstem, except the frequency and extent of channel movement are reduced, resulting in fewer flood plain features (e.g. side channels, sloughs, and ponds).

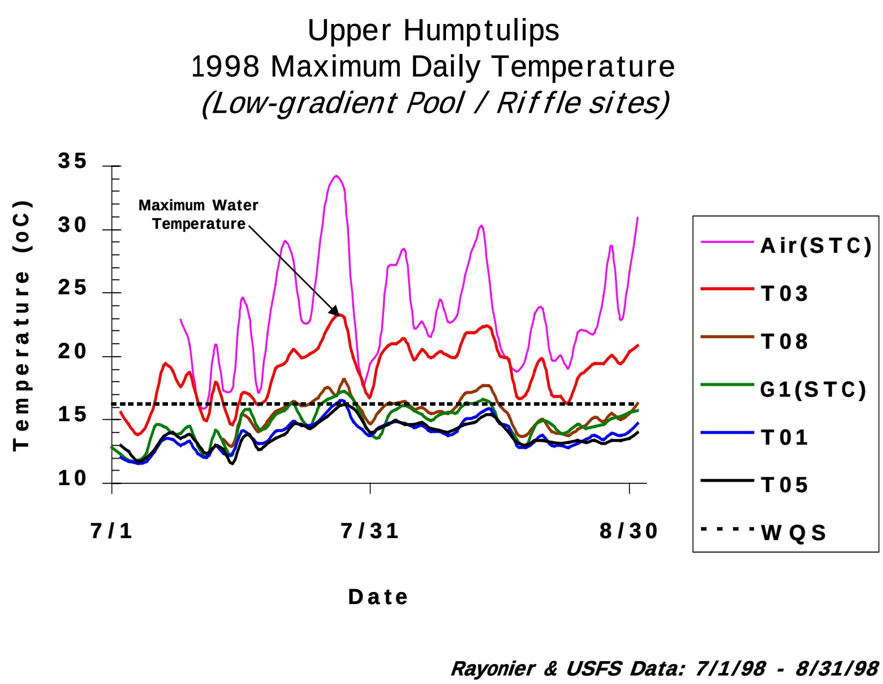
Monitoring data for water temperature has been collected in Goforth Creek, O'Brien Creek, Furlough Creek, and the W.F. Humptulips *(Table C-10)*. These sites are used to summarize water temperatures in the low-gradient pool / riffle channels. As indicated, daily maximum water temperatures observed in 1998 for this GCU exceeded the 16.0°C water quality criteria at all sites.

Table C-10. ***Upper Humptulips Temperature Sites – Low-gradient Pool / Riffle Channels***

GCU	Water Temperature Monitoring Site				Maximum Temperature	
	Site ID	**Name**	*(acres)*	**Shade**	**1997**	**1998**
Lgpr (lgpr)	*T05*	*Goforth Creek*	2168.57	*---%*	N/A	16.23°C
Lgpr (frp)	*T01*	*O'Brien Creek*	1252.45	*---%*	N/A	16.43°C
Lgpr (lgpr)	*T08*	*Furlough Creek*	1137.50	*---%*	N/A	18.19°C
Lgpr (lgpr)	*T03*	*W.F. Humptulips above E.F.*	46974.90	*---%*	N/A	23.19°C

Figure C-9 depicts daily maximum water temperatures observed at these sites in 1998. For comparative purposes, data for Bingham Creek is also displayed. The Bingham site has been used to describe small to medium sized pool riffle and forced pool riffle / plane bed channels that are strongly influenced by groundwater. These systems are resistant to changes in water temperature because flow is strong and comes from a cool source (referred to as Temperature Group G-1). Shade is a secondary influence, except during extreme low flow years.

Figure C-9. *Maximum Water Temperature Patterns: Low-gradient Pool / Riffle Channels*



Flood Plain Migration: This GCU includes the wide, unconfined, low-gradient (< 2 percent, most < 1 percent) channels that occur only in the East and West Fork mainstems. This GCU has extensive gravel bars and low flood plain expanses that are formed by sediment deposition during floods. Channel migration in response to changes in sediment supply and inputs of LWD is a common process leading to the formation of overflow channels, side channels, sloughs, and ponds on the gravel bars and flood plain. Channel morphology in this GCU is typically alternating pool and riffle units with occasional glides. Pools are formed by channel meandering and by in-channel scour elements (i.e. LWD and bedrock outcrops). The stream bed material is predominantly gravel. Overflow channels and side channels on adjacent gravel bars are common. Sloughs and ponds within the current flood plain are rare. Oxbow ponds and wetlands formed by post-glacial channel migration occur on higher terraces.

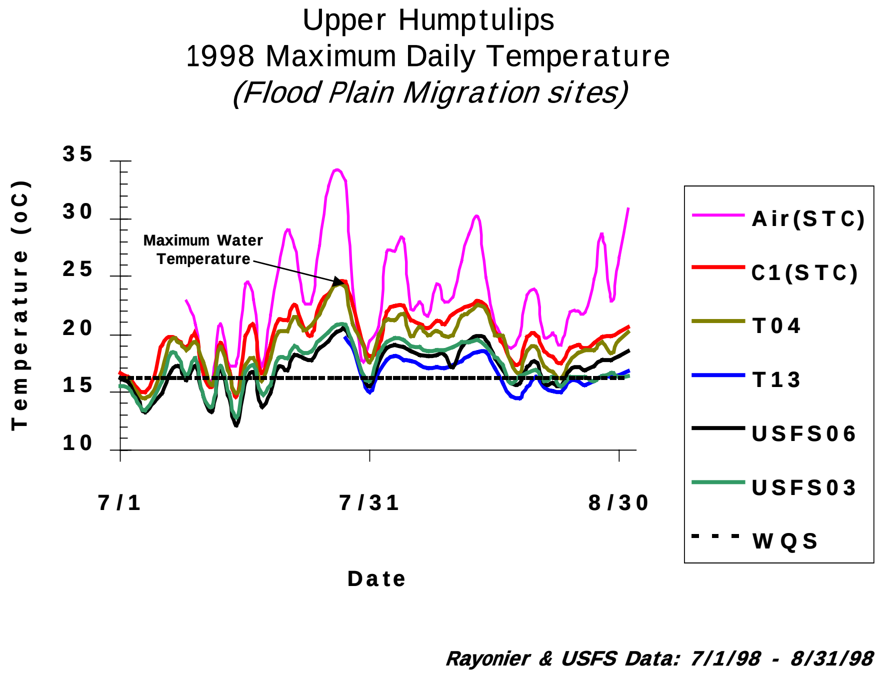
Monitoring data for water temperature has been collected in both the E.F. and the W.F. Humptulips *(Table C-11)*. These sites are used to summarize water temperatures in the flood plain migration channels. As indicated, daily maximum water temperatures observed in 1998 for this GCU exceeded the 16.0°C water quality criteria at all sites.

Table C-11. ***Upper Humptulips Temperature Sites – Flood Plain Migration Channels***

GCU	Water Temperature Monitoring Site				Maximum Temperature	
	Site ID	Name	*(acres)*	Shade	1997	1998
Fpm (brg)	*T13*	*East Fork at Flatbottom*	11480.02	---%	N/A	19.59°C
Fpm (fpm)	*USFS06*	*W.F. above Elk Creek (RM 45.3)*	24217.30	---%	18.3°C	20.36°C
Fpm (lgrp)	*USFS03*	*W.F. blw Rainbow Cr. (RM 41.0)*	30774.30	---%	18.7°C	20.78°C

Figure C-10 depicts daily maximum water temperatures observed at these sites in 1998. For comparative purposes, data for Canyon River is also displayed. The Canyon site has been used to describe large rivers affected by high sediment supply and multiple thread channels over at least some of their length. Temperatures in these systems are strongly influenced by channel patterns and open canopies (referred to as Temperature Group C-1). Current and past sediment supply, long residence times, and channel pattern make it unlikely that water temperatures here will change for decades.

<u>Figure C-10</u>. *Maximum Water Temperature Patterns: Flood Plain Migration Channels*



Riparian Vegetation

The importance of riparian shade to increase effective shade has been well studied. A Riparian Function Assessment in the Watershed Analysis Report *(Module D)* was prepared to analyze the characteristics and functions of riparian areas within the Upper Humptulips. A component of the Watershed Analysis is an assessment of riparian conditions intended to address the following questions:

- ✓ *What was the historical condition of riparian areas, and how have they been altered?*
- ✓ *Is the current composition and age-class distribution of riparian vegetation adequate for the recruitment of large woody debris and stream shading?*
- ✓ *What are the dominant processes affecting riparian areas, and how are the riparian areas functioning to provide for channel quality?*
- ✓ *Where are the proposed interim Riparian Reserves for federal lands?*
- ✓ *What species of concern, regional and local (including Survey and manage Species and Protection Buffer Species), have the proposed benefit from Riparian Reserves? What are their habitat needs?*
- ✓ *Where and what types of restoration actions might maintain or improve riparian processes or function?*
- ✓ *What monitoring (implementation, effectiveness, validation) has occurred and is needed in the future?*

Riparian vegetation in the Upper Humptulips Watershed Analysis area ranges from hardwood stands (Red Alder, Big Leaf Maple) to conifers (Douglas Fir, Western Hemlock) of varying ages. The Riparian Assessment describes the current composition and age class distribution of riparian vegetation relative to recruitment of large woody debris and stream shading. A summary is presented in the Watershed Analysis Report Appendix B Module D.

Channel Condition

The morphology of the upper Humptulips watershed was formed by down cutting through deep glacial deposited from the last glaciation. Sections of each fork of the Humptulips River are highly meandered due to this downcutting while others have cut to bedrock and their lateral movement is confined.

The streams in the upper portion of the upper watershed are very steep and contribute and transport high sediment loads. The streams in the lower two-thirds are generally lower gradient. Potions of some tributaries in the lower portion of the upper watershed are steep gradient where they intercept terraces and outwash surfaces. Waterfalls are seen in some locations in the lower watershed where the stream had downcut to bedrock. Sediment supply is dominated by chronic inputs with most of the sediment budget being contributed by fluvial erosion, small slumps, landslides, and talus creep at higher elevations.

Channels in the upper Humptulips watershed were divided into eleven geomorphic channel units (GCUs) based on the channels morphology, geology and location within the drainage network. These units were grouped by sediment regime into source, transport, or response. These gropes were used to make sediment recommendations in the Watershed Analysis and for functional grouping in the TMDL.

A large number of splash dams were operated in the upper watershed near the turn of the century. These operations are believed to have had a large and detrimental effect on channel morphology and substrate composition. Legacy effects of the splash dams may include lack of large debris dams, bank erosion, and decreased prevalence of side channels on the flood plain.

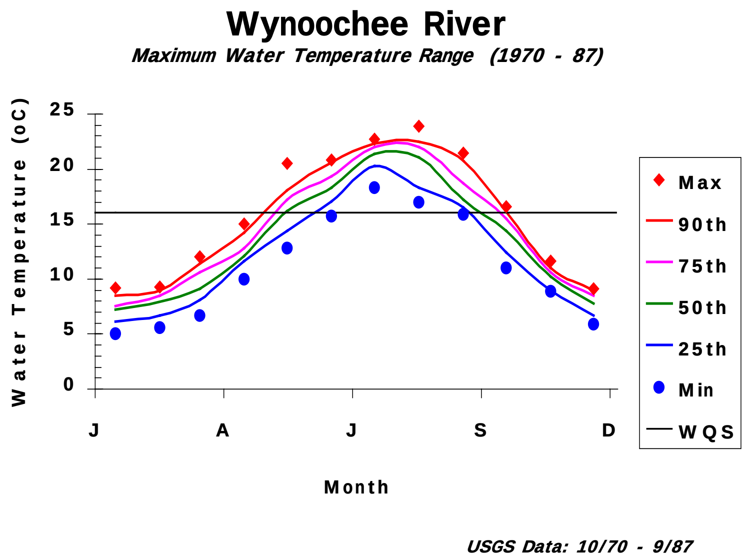
A historical review of aerial photos over a 47-year period (1950 to 1997) showed that yearly variation was small but the maximum area disturbed was large. This is consistent with the understanding of the channel processed being chronic rather than episodic. The average channel migration zone (CMZ) is approximately 0.25 miles on the West fork and 0.15 miles on the East fork.

Seasonal Variation

Stream Temperatures

Existing conditions for stream temperatures in the Upper Humptulips Watershed Analysis area reflect seasonal variation. Cooler temperatures occur in the winter, while warmer temperatures are observed in the summer. Historical data has been collected by the U.S. Geological Survey (USGS) of stream temperatures in the Wynoochee River. Figure C-14 summarizes the distribution of highest daily maximum water temperatures for each month between 1970 and 1987. Although the data was collected in the 1970's and 80's, it is the most comprehensive record for water temperature taken at one site over an extended period of time in the vicinity of the Upper Humptulips Watershed Analysis area. As shown, water quality standards for temperature are only exceeded between May and October. In addition, the data shown in Figure C-14 indicates that the highest seven-day average maximum water temperatures occur between mid-July and mid-August. This time frame is used as the critical period for development and analysis of allocations in the TMDL.

Figure C-14. *Seasonal Variation of Wynoochee Temperature Levels*



Stream Flow

Monthly flow data is another way to describe seasonal variation. As illustrated earlier in Figure C-1, flows peak in December as a result of winter storm runoff. Flows decline through the summer reaching baseflow conditions in August. Figure C-2 depicted the variability of seven-day low flows using data from the Humptulips River near Humptulips. The seven-day low flow recurring every ten years (7Q10) was also shown in Figure C-2. The USGS data has been used to describe the variation of 7Q2 values across the Olympic Peninsula (Amerman and Orsborn, 1987). From this information, a relationship has been developed to estimate 7Q2 values within the Upper Humptulips Watershed Analysis area.

Solar Radiation

Potential solar radiation varies throughout the year. The highest value occurs on the first day of summer when the earth's tilt towards the sun is greatest. Figure C-15 illustrates the effect of seasonal variation on shadow length associated with different tree heights. As shown, shadows are shortest in mid-June. Figure C-16 illustrates the effect of seasonal variation on maximum potential solar radiation. Mid-June is the period when solar radiation values are at their peak. As a result, mid-June can be used a starting point for identifying the loading capacity for effective shade. This is the time that the water surface receives the maximum potential solar radiation and when riparian shade is least effective in reducing heat. This does add to the margin of safety because low flows and maximum water temperatures typically occur between mid-July and mid-August.

Figure C-15. *Seasonal Variation of Shadow Lengths*

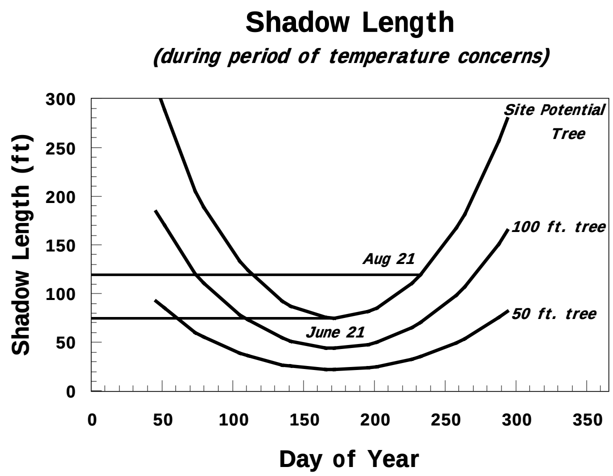
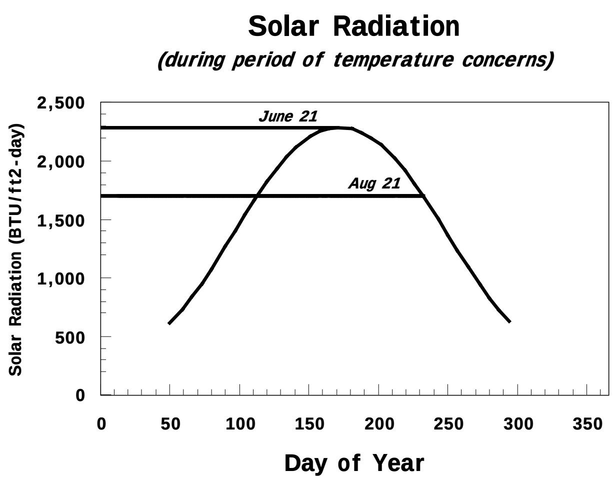


Figure C-16. *Seasonal Variation of Maximum Potential Solar Radiation*



Critical Temperature Conditions

Estimates for streamflow, loading, and water quality parameters need to be taken into account in development of the TMDL. The analysis demonstrating the relationship of channel and riparian conditions to solar radiation loads requires a framework for identifying critical conditions. Based on historical data for the Wynoochee River *(Figure C-17)*, the critical period used for the analysis is mid-July. This represents the time frame for which solar radiation is highest when the earliest summer maximum water temperatures were observed. This time frame is also consistent with water temperature data collected in the Upper Humptulips Watershed Analysis Area *(Figure C-3 through C-10)*.

Streamflow estimates were identified using data from the USGS gage on the Humptulips River near Humptulips. Water yield for the 7-day low flow, 2-year recurrence interval (7Q2), which is also associated with the highest water temperatures observed at the gage, was used as a starting point. This represents a conservative approach and can be refined as additional flow data is collected in the Upper Humptulips Watershed Analysis area. The same conservative approach was used to identify parameters for calculation of solar radiation load (e.g. cloud cover) and water quality (e.g. air temperature, upstream water temperature, etc). Given the importance of stream type in evaluating critical conditions, information has been collected by the USFS to characterize riparian and channel conditions in the Upper Humptulips area.

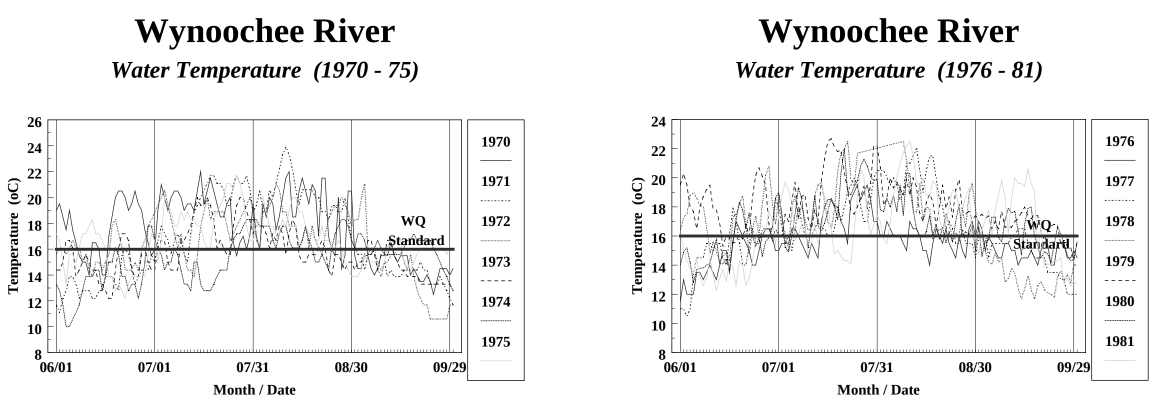
Annual Variability and Sediment

It is important to discuss the annual variability of peak flows and its effect on sediment delivery. USGS (1971) described sediment yield in the Chehalis basin. Consistent with sediment studies in other areas, the report noted that the greatest percentage of sediment transport occurred during peak flows. Figure C-2 showed the variation in peak flows for the Humptulips River.

Historic Conditions and Trends

Historic data on water temperature conditions prior to the start of management activities is not available. The U.S. Geological Survey collected water temperature data on the Wynoochee River from 1970 to 1981 *(Figure C-17)*. As shown, seasonal patterns can be seen, as discussed above. However, long term trends are not evident.

Figure C-17. *Wynoochee River Summer Water Temperatures*



Section D Interpretation

Overview

Interpretation is the place to synthesize water quality information in the context of watershed processes. Within interpretation, similarities, differences, and trends in water quality conditions are explained. Interpretation also involves identifying the capability of the system to achieve water quality management objectives. In short, the focus of interpretation is to answer the question: ***"What are the influences and relationships between water quality and other ecosystem processes in the watershed (e.g. mass wasting, fish habitat, stream channel, etc.)?***. In addressing this question, other subtopics could be considered which include:

Interpretation --- *Other Considerations*
What watershed processes contribute or could potentially contribute input variables to waterbodies adversely affected by water quality? • What potential sources of input variables (e.g. sediment, water, solar radiation, or chemicals) could enter waterbodies not meeting water quality standards? • What is the delivery potential of input variables to waterbodies not meeting water quality standards and at what levels?

Aquatic Resource Considerations

Interpretation of water quality information for streams affected by nonpoint sources presents some inherent challenges. Diffuse sources are often associated with watershed or landscape scale features. Consequently, water quality concerns associated with nonpoint source (NPS) pollutants require a different approach from traditional point source problems. Assessment of water quality data collected within the Upper Humptulips Watershed Analysis area employs several concepts applied at a broader scale. These watershed / landscape scale concepts are evaluated in order to provide an analytical framework. Watershed / landscape scale concepts used to organize information include:

- Channel classification
- Temperature groups

Channel Classification*:*

Conditions in a waterbody are a function of channel morphology (e.g. source, transport, or response reaches). Methods exist to assess the condition of a stream, as well as departure from its potential (Rosgen, 1996). These methods, built around channel classification, are a useful starting point to interpret water quality data for streams in the Upper Humptulips Watershed Analysis area. Consequently, a first level of stratification consists of classifying stream segments of the channel network within each of the WAU.

There are 11 geomorphic channel units (GCUs) within this system *(Table D-1)*. A description of these can be found within the Stream Channel Assessment of the Watershed Analysis Report *(Module E)*. Channels that occur in sediment source areas or that contribute a significant source of sediment from bank erosion were divided into three GCUs. Channels that function as sediment transport zones, but that have different elements causing channel confinement were divided into two GCUs. Channels that are sensitive to sediment or flow changes were grouped as response types and were divided into six GCUs. Additional details on channel characteristics, geology, morphology, large woody debris (LWD) characteristics and recruitment processes, sediment delivery and processing mechanisms, riparian characteristics and biological community features are described in the Watershed Analysis Report. Information on the linkage to instream biological resources is also provided.

Table D-1. ***Upper Humptulips Watershed Analysis Area GCUs***

Sediment Zone	GCU	Length (miles)	Length (percent)	Subwatersheds
Source	sd	6.34	1.9%	East Fork --- Upper West Fork --- Upper, Lower
	spc	115.76	35.3%	East Fork --- Upper, Middle, Lower West Fork --- Upper, abv Chester, abv Donkey, Lower Chester Creek, Donkey Creek
Transport	tt	59.25	18.1%	East Fork --- Upper, Middle, Lower West Fork --- Upper, abv Chester, abv Donkey, Lower Chester Creek, Donkey Creek
	fpr	42.94	13.1%	East Fork --- Upper, Middle, Lower West Fork --- Upper, abv Chester, abv Donkey, Lower Chester Creek, Donkey Creek
	brg	6.38	1.9%	East Fork --- Upper, Middle, Lower West Fork --- above Chester, above Donkey
Response	rw	12.60	3.8%	East Fork --- Middle, Lower West Fork --- above Donkey Donkey Creek
	bb	7.01	2.1%	East Fork --- Middle, Lower West Fork --- above Chester, abv Donkey Donkey Creek
	hsc	0.97	0.3%	East Fork --- Middle
	tc	9.82	3.0%	East Fork --- Upper, Middle, Lower West Fork --- Lower
	lgpr	41.24	12.6%	East Fork --- Upper, Middle, Lower West Fork --- above Donkey, Lower Chester Creek, Donkey Creek
	fpm	25.92	7.9%	East Fork --- Upper, Middle, Lower West Fork --- Upper, abv Chester, abv Donkey, Lower

Temperature Groups

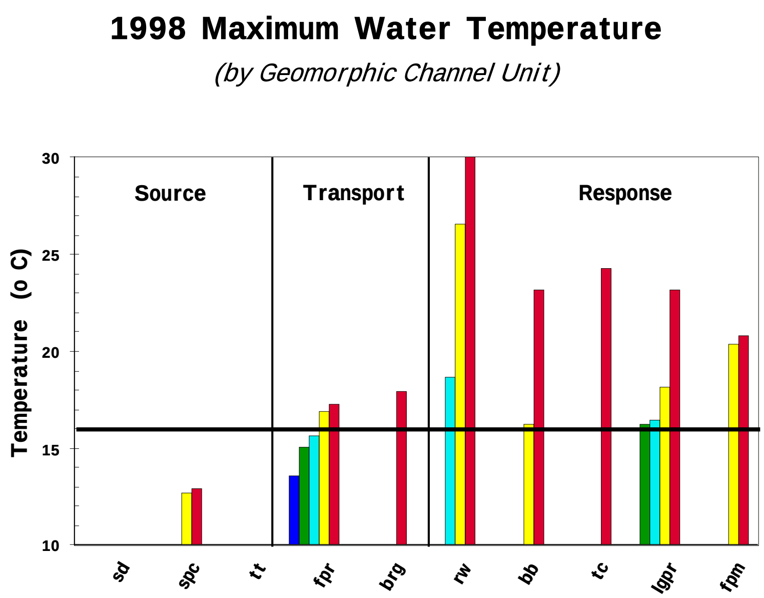
The channel classification system can be used to group stream reaches by the dominant control(s) which affect water temperature. Table D-2 identifies seven groups and describes watershed process features which exert the greatest influence on water temperature in those channel classes. Dominant features include shade, groundwater, and channel morphology.

Table D-2. ***Groups for Identifying Targets to Address Water Temperature***

Group	Features	GCU
Shade		
S-1	Small to medium sized pool riffle and forced pool riffle / plane bed channels of the ROP and SIG. Water temperature is driven by shade and low flows (poor water storage in these watersheds over glacial tills and shallow soils). Headwaters of these systems are usually in wetlands or bogs and beavers frequently pond water within the channel. *RMS: Temperature Sensitive*.	
S-2	Small to medium sized channels in the AGL and SIG. These systems most often have hardwood dominated riparian systems and subtle groundwater influence through wet side slopes. They are subject to heating with the loss of riparian shade which can happen through damage to riparian leave areas by natural factors or through insufficient leave area. *RMS: Alluvial Bedrock Transition or Reverse Break in Slope*.	
S-3	Small to medium sized streams in the recessional outwash sediments of the CIS and SIG. These channels have low summer flows, but the storage and character of the flows is different from the ROP in that lower terraces, floodplains, and valley walls of these systems are composed of fine, but fairly well draining unconsolidated outwash sediments. These materials do not store great quantities of water. However, there is a slow release of groundwater that appears to moderate temperatures, but it is not sufficient to offset heating as a result of riparian canopy loss. With loss of shade, these streams can heat up to moderate levels. *RMS: Channel Migration or Unstable Slopes / Intermittent*.	
S-4	Small to medium sized channels in glacial till landscape with pool riffle and forced pool riffle / plane beds. These systems have moderate to low flows in summer with varying amounts of groundwater influence. Along the continuum, those with minimal groundwater influence are susceptible to elevated water temperatures with loss of shade. Those with significant amounts of groundwater influence are resistant to temperature changes. *RMS: Break in Slope*.	tt fpr
Groundwater		
G-1	Small to medium sized pool riffle and forced pool riffle / plane bed channels of the CIS and ROP that are strongly influenced by groundwater. These systems are resistant to changes to water temperature because flow is strong and comes from a cool source. Shade is a secondary influence, except during extreme low flow years. *RMS: Channel Migration*.	
G-2	Small to medium sized highly confined channels of the AGL, CIS, CUP, and SIG. These are topographically shaded and are *"near"* the water source with substantial groundwater influence which shows as side seeps and springs. These systems are typically cool and are resistant to water temperature changes, even in the absence of riparian vegetation. *RMS: Canyon*.	sd spc
Channel Morphology		
C-1	Large rivers of the AGL, ROP, and SIG are affected by high sediment supply and multiple thread channels over at least some of their length. Applies to the West and Middle Forks of the Satsop, the Canyon, Little and Wynoochee Rivers. Temperatures in these systems are strongly influenced by channel pattern and open canopies. Current and past sediment supply, long residence times, and channel pattern make it unlikely that water temperatures here will change for decades. *RMS: Inner Gorge or Channel Migration*.	
C-2		brg

Water temperature data, discussed in Appendix C, can be used to look at actual responses for different channel types. Figure D-1 depicts information collected in 1998 from sites representative of each GCU. Maximum observations between July 1 and August 31 are shown for each year. This corresponds with the seasonal time frame when maximum water temperatures occur.

Figure D-1-*Maximum Water Temperature by GCU*



Geomorphic Unit Considerations

A synthesis matrix was developed as part of the Upper Humptulips Watershed Analysis. One portion of the synthesis matrix includes a discussion of heat for each GCU by subbasin. To assist with interpretation of the water temperature data, matrix summary information is presented here. Table D-3 lists comments identified in the Watershed Analysis Report relative to water temperature and heat for the Slope Deposit GCU.

Table D-3. ***Upper Humptulips Synthesis Matrix Summary — Slope Deposit GCU***

Slope Deposit GCU		
Sub Watershed	**miles**	**Comments**
E.F. – Upper	1.13	If surface water is present during the hot time of year, then it is probably derived from groundwater.
W.F. – Upper	4.53	
W.F. – Lower	0.68	

Table D-4 summarizes comments identified in the Watershed Analysis Report synthesis matrix relative to water temperature and heat for the Step-pool / Cascade GCU. An assessment of the cumulative frequency can be used to identify patterns in the data that might reflect features used to identify temperature groups, such as the influence of groundwater or the effect of channel morphology. Figure D-2 illustrates such patterns by showing the difference in cumulative frequency distribution at step-pool / cascade sites.

Table D-4. ***Upper Humptulips Matrix Summary — Step-Pool / Cascade GCU***

Step Pool / Cascade GCU		
Sub Watershed	**miles**	**Comments**
E.F. – Upper	7.45	These are small channels that can respond to heat inputs, but they are typically topographically shaded. Sensitivity is therefore Moderate. Actual data, however, suggest that vulnerability to heat inputs is Low.
W.F. – Upper	4.33	
W.F. – above Chester	3.16	These are small channels that can respond to heat inputs, but they are typically topographically shaded. Sensitivity is therefore Moderate. These segments are similar to the Step-pool / Cascade segments in the West Fork Upper subbasin; therefore, vulnerability is assumed to be Low.
Chester Creek	13.86	
E.F. – Middle	18.90	These are small channels that can respond to heat inputs, but they are typically topographically shaded.
E.F. – Lower	32.49	
W.F. – above Donkey	10.95	These are small channels that can respond to heat inputs, but they are typically topographically shaded and are near the water source with groundwater influence, which shows as side seeps and springs. These systems are typically cool and resistant to water temperature changes.
Donkey Creek	6.62	
W.F. – Lower	18.00	

Figure D-2. *Cumulative Frequency Distribution – Step-pool / Cascade Channels*

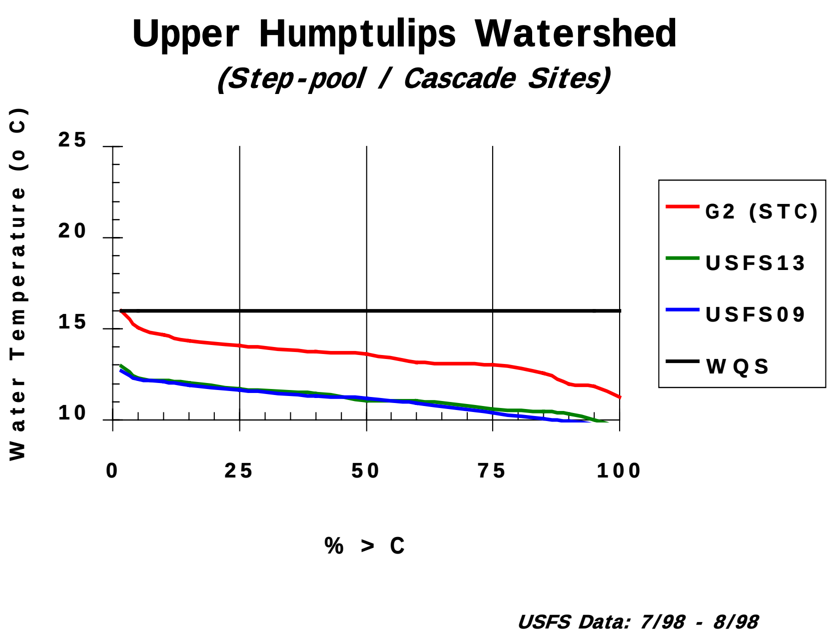


Table D-5 summarizes comments identified in the Watershed Analysis Report synthesis matrix relative to water temperature and heat for the Terrace Transition GCU.

Table D-5. ***Upper Humptulips Synthesis Matrix Summary — Terrace Transition GCU***

Terrace Transition GCU		
Sub Watershed	**miles**	**Comments**
E.F. – Upper	9.27	The narrow, incised channel forms lead to near- complete topographic shading, and groundwater sources from adjacent glacial materials may be substantial.
E.F. – Middle	7.53	
E.F. – Lower	4.78	
W.F. – Upper	10.59	
W.F. – above Chester	7.87	
Chester Creek	3.22	
W.F. – above Donkey	9.53	
Donkey Creek	0.83	
W.F. – Lower	5.64	The narrow, incised channel forms lead to near- complete topographic shading; however, there are limited groundwater inputs. Several of these segments are downstream of Low-gradient Pool / Riffle segments. The temperature regime could be elevated to a level that could create a moderate reduction in fish growth. There may also be effects on other aquatic species.

Table D-6 summarizes comments identified in the Watershed Analysis Report synthesis matrix relative to water temperature and heat for the Forced-pool / Riffle GCU. An assessment of the cumulative frequency can be used to identify patterns in the data that might reflect features used to identify temperature groups, such as the influence of groundwater or the effect of channel morphology. Figure D-3 illustrates such patterns by showing the difference in cumulative frequency distribution at forced-pool / riffle sites.

Table D-6a. ***Upper Humptulips Synthesis Matrix Summary — Forced-Pool / Riffle GCU***

Forced Pool / Riffle GCU		
Sub Watershed	**miles**	**Comments**
E.F. – Upper	3.65	These channels are small and low-gradient and are not topographically shaded; they could therefore respond to heat inputs. Groundwater inputs are possible, however, and actual temperature data suggest that vulnerability to heat inputs is Low.
W.F. – Upper	1.54	
E.F. – Middle	6.28	These channels are small and low-gradient and are not topographically shaded; they could therefore respond to heat inputs. Groundwater inputs are possible. Therefore, sensitivity is Moderate. Actual temperature suggest that these segments are sensitive to heat inputs. The vulnerability is Low, however, because given the moderate potential increase in temperature, no significant biological effect is expected.
E.F. – Lower	7.10	

Table D-6b. ***Upper Humptulips Synthesis Matrix Summary — Forced-Pool / Riffle GCU***

Forced Pool / Riffle GCU		
Sub Watershed	**miles**	**Comments**
W.F. – above Chester	1.89	These channels are small and low-gradient and are not topographically shaded; they could therefore respond to heat inputs. Groundwater inputs are possible, however, and actual temperature data suggest that vulnerability to heat inputs is Low in all segments except W1380.1, which has Moderate vulnerability due to its north-south orientation.
Chester Creek	1.83	These channels are small and low-gradient and are not topographically shaded; they could therefore respond to heat inputs. Some channels are topographically shaded. Groundwater inputs are possible, however, and actual temperature data on similar channels in the West Fork Upper Subbasin suggest that vulnerability to heat inputs is Low.
W.F. – above Donkey	6.52	These systems have moderate to low flows in summer with varying amounts of groundwater influence. Along the continuum, those with minimal groundwater influence are susceptible to elevated water temperatures with loss of shade. Those with significant amounts of groundwater influence are resistant to temperature changes. The sensitivity is Moderate. However, given the moderate potential increase in temperature no significant biological effects are expected. The vulnerability is therefore Low.
Donkey Creek	4.38	These systems have moderate to low flows in summer with varying amounts of groundwater influence. Segments W0711.2, W0711.21, W0711.22 have minimal groundwater influence and are susceptible to elevated water temperatures with loss of shade. The sensitivity and vulnerability for these segments are moderate. The remaining segments have significant amounts of groundwater influence are resistant to temperature changes. The sensitivity for these segments is Moderate; however, given the moderate potential increase in temperature no significant biological effects are expected. The vulnerability is therefore Low.
W.F. – Lower	9.74	These systems have moderate to low flows in summer with varying amounts of groundwater influence. The headwater segments have significant amounts of groundwater influence, similar to the Step-pool / Cascade segments and are resistant to temperature changes. The sensitivity for these segments is Moderate; however, given the moderate potential increase in temperature no significant biological effects are expected. The vulnerability for these segments is therefore Low. The remaining segments have minimal groundwater influence and are susceptible to elevated water temperatures with loss of shade. The sensitivity and vulnerability for these segments are Moderate.

Figure D-3. *Cumulative Frequency Distribution – Forced-pool / Riffle Channels*

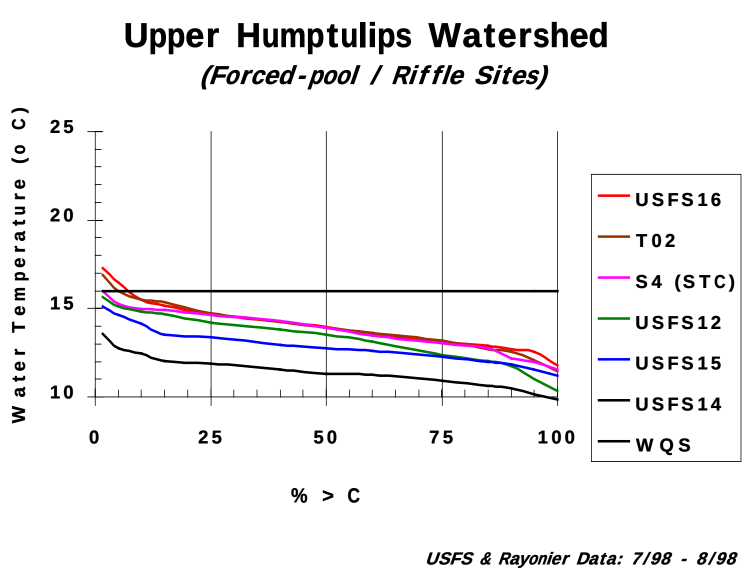


Table D-7 summarizes comments identified in the Watershed Analysis Report synthesis matrix relative to water temperature and heat for the Bedrock Gorge GCU. An assessment of the cumulative frequency can be used to identify patterns in the data that might reflect features used to identify temperature groups, such as the influence of groundwater or the effect of channel morphology. Figure D-4 illustrates such patterns by showing the difference in cumulative frequency distribution at bedrock gorge sites.

Table D-7. ***Upper Humptulips Synthesis Matrix Summary — Bedrock Gorge GCU***

Bedrock Gorge GCU		
Sub Watershed	**miles**	**Comments**
E.F. – Upper	0.88	These channel segments receive near-complete topographic shading, and water is fast and deep.
E.F. – Middle	3.99	
E.F. – Lower	0.68	
W.F. – above Chester	0.43	
W.F. – above Donkey	0.40	

Figure D-4. *Cumulative Frequency Distribution – Bedrock Gorge Channels*

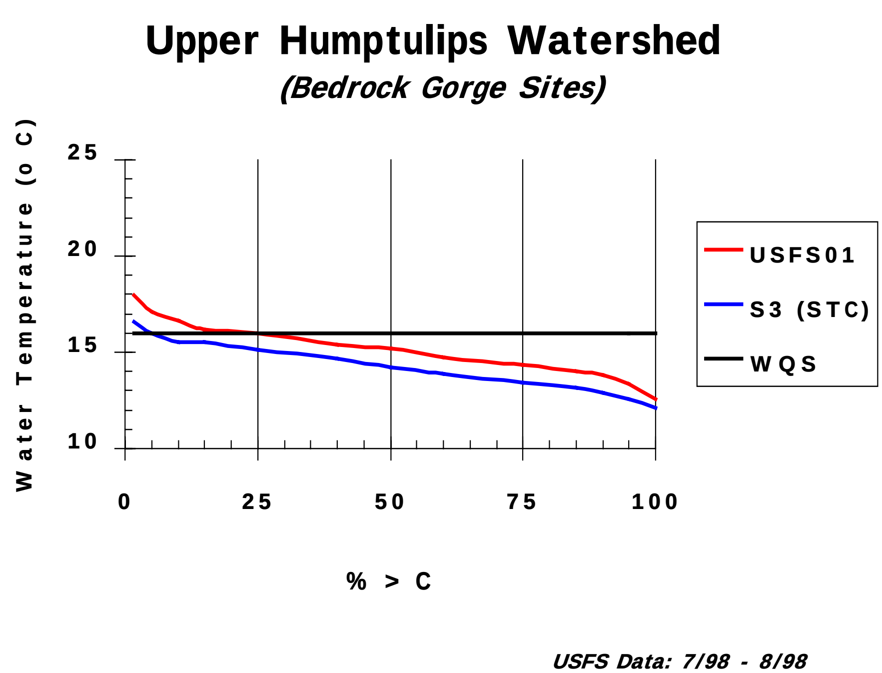


Table D-8 summarizes comments identified in the Watershed Analysis Report synthesis matrix relative to water temperature and heat for the Bedrock Gorge GCU.

Table D-8. ***Upper Humptulips Synthesis Matrix Summary — Riverine Wetland GCU***

Riverine Wetland GCU		
Sub Watershed	**miles**	**Comments**
E.F. – Middle	0.25	Low velocity and naturally open canopy cause this GCU to respond to temperature inputs.
E.F. – Lower	3.58	
W.F. – above Donkey	3.70	
Donkey Creek	5.06	

Table D-9 summarizes comments identified in the Watershed Analysis Report synthesis matrix relative to water temperature and heat for the Babbling Brook GCU. An assessment of the cumulative frequency can be used to identify patterns in the data that might reflect features used to identify temperature groups, such as the influence of groundwater or the effect of channel morphology. Figure D-5 illustrates such patterns by showing the difference in cumulative frequency distribution at babbling brook sites.

Table D-9. ***Upper Humptulips Synthesis Matrix Summary — Babbling Brook GCU***

Babbling Brook GCU		
Sub Watershed	**miles**	**Comments**
E.F. – Middle	2.25	The streams are very shallow, small and low gradient, so they likely respond to heat inputs. Groundwater influence may vary greatly depending on adjacent topography. Sensitivity to heat inputs is High.
E.F. – Lower	3.02	
W.F. – above Chester	0.44	
W.F. – above Donkey	0.92	
Donkey Creek	0.38	

Figure D-5. *Cumulative Frequency Distribution – Babbling Brook Channels*

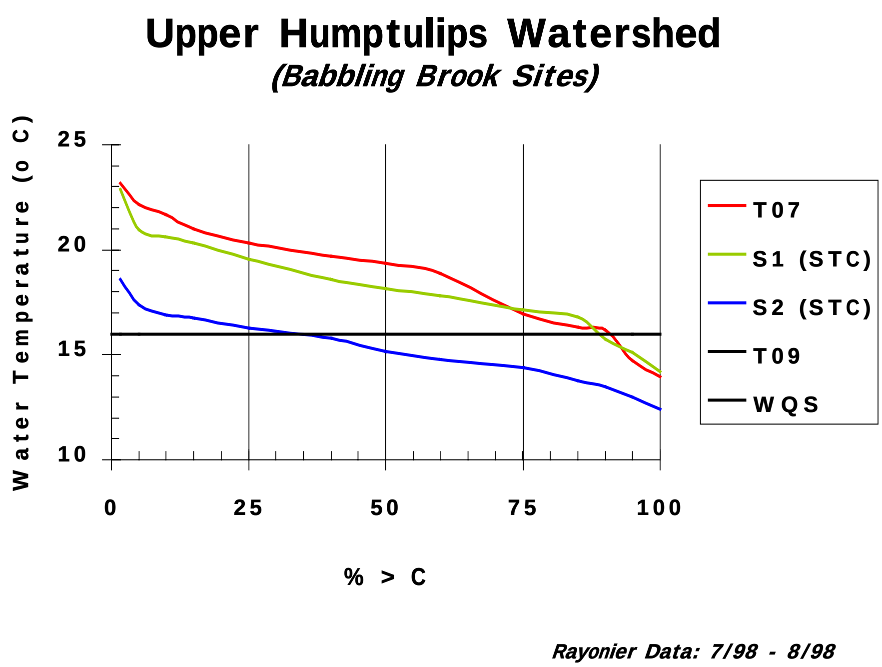


Table D-10 summarizes comments identified in the Watershed Analysis Report synthesis matrix relative to water temperature and heat for the Hillslope Confined GCU.

Table D-10. ***Upper Humptulips Synthesis Matrix Summary — Hillslope Confined GCU***

Hillslope Confined GCU		
Sub Watershed	**miles**	**Comments**
E.F. – Middle	0.97	This segment receives topographic shading provided by confinement and east-west orientation, but groundwater inputs are probably very small and the channel is very shallow, leading to a Moderate vulnerability call.

Table D-11 summarizes comments identified in the Watershed Analysis Report synthesis matrix relative to water temperature and heat for the Terrace Confined GCU.

Table D-11. ***Upper Humptulips Synthesis Matrix Summary — Terrace Confined GCU***

Terrace Confined GCU		
Sub Watershed	**miles**	**Comments**
E.F. – Middle	0.69	Sensitivity to heat is Moderate because the channel has some topographic shading and groundwater inputs are probable.
E.F. – Lower	0.39	Sensitivity to heat is Moderate because the channels have some topographic shading. Groundwater inputs are probable but have limited influence on stream temperature. The vulnerability, however, is High because the temperature data show the temperature can elevate to levels that will affect fish growth and that may affect other aquatic species.
W.F. – Lower	7.87	

Table D-12 summarizes comments identified in the Watershed Analysis Report synthesis matrix relative to water temperature and heat for the Low-gradient Pool / Riffle GCU. An assessment of the cumulative frequency can be used to identify patterns in the data that might reflect features used to identify temperature groups, such as the influence of groundwater or the effect of channel morphology. Figure D-6 illustrates such patterns by showing the difference in cumulative frequency distribution at low-gradient pool / riffle sites.

Table E-12a. ***Upper Humptulips Synthesis Matrix Summary — Low-gradient Pool / Riffle GCU***

Low Gradient Pool / Riffle GCU		
Sub Watershed	**miles**	**Comments**
E.F. – Upper	1.32	This channel is shallow and low-gradient; it could therefore respond to heat inputs. It has some topographic shading and probable groundwater inputs. Sensitivity is therefore Moderate. Vulnerability, however, is Low because the temperature regime is unlikely to elevate to a level that creates adverse biological conditions for aquatic species.
E.F. – Middle	1.77	
E.F. – Lower	7.04	This GCU is shallow and low-gradient; it could therefore respond to heat inputs. Typically it has some topographic shading and probable groundwater inputs. Sensitivity is therefore Moderate. Vulnerability for the mainstem segments — E02, E04x, E05, and E06 — is High because the temperature data show the temperature can elevate to levels that will adversely affect fish and that may affect other aquatic species. Vulnerability for the remaining segments is low because the temperature regime is unlikely to elevate to a level that creates adverse biological conditions for aquatic species.
Chester Creek	4.54	This channel is shallow and low-gradient; it could therefore respond to heat inputs. It has some topographic shading and probable groundwater inputs. Sensitivity is therefore Moderate. Vulnerability is also Moderate because data indicate the temperature regime could elevate to a level that creates adverse biological conditions for aquatic species.

Table E-12b. ***Upper Humptulips Synthesis Matrix Summary — Low-gradient Pool / Riffle GCU***

Low Gradient Pool / Riffle GCU		
Sub Watershed	**miles**	**Comments**
W.F. – above Donkey	5.46	This channel is shallow and low-gradient; it could therefore respond to heat inputs. It has some topographic shading and probable groundwater inputs. Sensitivity is therefore moderate. The vulnerability for Segments W07, W08, W10, and W11 is Moderate due to actual data showing temperature levels in the naturally wide channel that have a potential moderate impact on fish growth. Vulnerability for the remaining segments is low because the temperature regime is unlikely to elevate to a level that creates adverse biological conditions for aquatic species.
Donkey Creek	7.02	This channel is shallow and low-gradient; it could therefore respond to heat inputs. It has some topographic shading and probable groundwater inputs. Sensitivity is therefore Moderate. Vulnerability is also Moderate because the temperature regime could be elevated to a level that could create a moderate reduction in fish growth. There may also be effects on other aquatic species.
W.F. – Lower	14.10	This GCU is shallow and low-gradient; it could therefore respond to heat inputs. Typically it has some topographic shading and probable groundwater inputs. Sensitivity is therefore Moderate. Vulnerability for segments W0331, W0331.1, W0332, W0420x is Moderate because they are topographically shaded and are likely to receive groundwater inputs. Vulnerability for the remaining segments is High because they are not topographically shaded, groundwater inputs are limited, and the temperature data show the temperature can elevate to levels that will adversely affect fish and that may affect other aquatic species.

Figure D-6. *Cumulative Frequency Distribution – Low-gradient Pool / Riffle Channels*

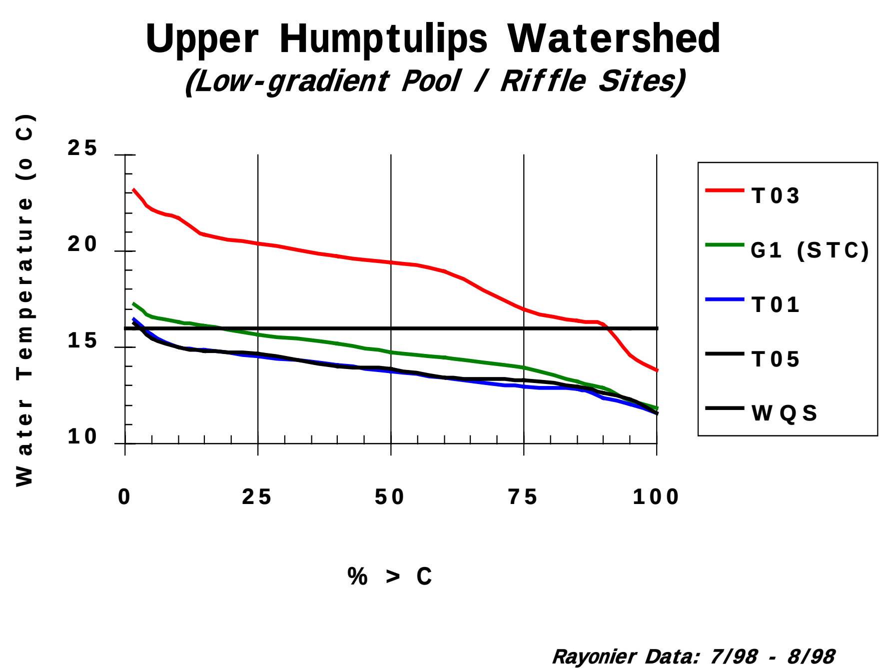


Table D-13 summarizes comments identified in the Watershed Analysis Report synthesis matrix relative to water temperature and heat for the Flood Plain Migration GCU. An assessment of the cumulative frequency can be used to identify patterns in the data that might reflect features used to identify temperature groups, such as the influence of groundwater or the effect of channel morphology. Figure D-7 illustrates such patterns by showing the difference in cumulative frequency distribution at flood plain migration sites.

Table D-13. ***Upper Humptulips Watershed Analysis Synthesis Matrix Summary — Heat***

Flood Plain Migration GCU		
Sub Watershed	**miles**	**Comments**
E.F. – Upper	2.92	The channel is shallow and broad. Because of the high disturbance regime, the riparian zone contains a high percentage of hardwoods, which do not contribute shade to the channel. The natural north-south orientation of the channel also contributes to warming. The influence of groundwater is probably limited. Therefore, the sensitivity is High. Vulnerability, however, is Low because the temperature regime is unlikely to elevate to a level that creates adverse biological conditions for aquatic species.
E.F. – Middle	2.83	The channel is shallow and broad. Because of the high disturbance regime, the riparian zone contains a high percentage of hardwoods, which do not contribute shade to the channel. The natural north-south orientation of the channel also contributes to warming. The influence of groundwater is probably limited. Therefore, the sensitivity is High. Vulnerability, however, is Moderate because data indicate that the temperature regime could be elevated to levels that create a moderate reduction in fish growth. There may be effects on other aquatic species.
W.F. – Upper	5.14	
W.F. – above Chester	6.21	
W.F. – above Donkey	3.38	
E.F. – Lower	0.39	The channel is shallow and broad. Because of the high disturbance regime, the riparian zone contains a high percentage of hardwoods, which contributes limited shade to the channel. The natural north-south orientation of the channel also contributes to warming. The influence of groundwater is probably limited. Therefore, the sensitivity is High. The vulnerability is also High because the temperature data show the temperature can elevate to levels that will affect fish growth and that may affect other aquatic species.
W.F. – Lower	5.06	

Figure D-7. *Cumulative Frequency Distribution – Flood Plain Migration Channels*

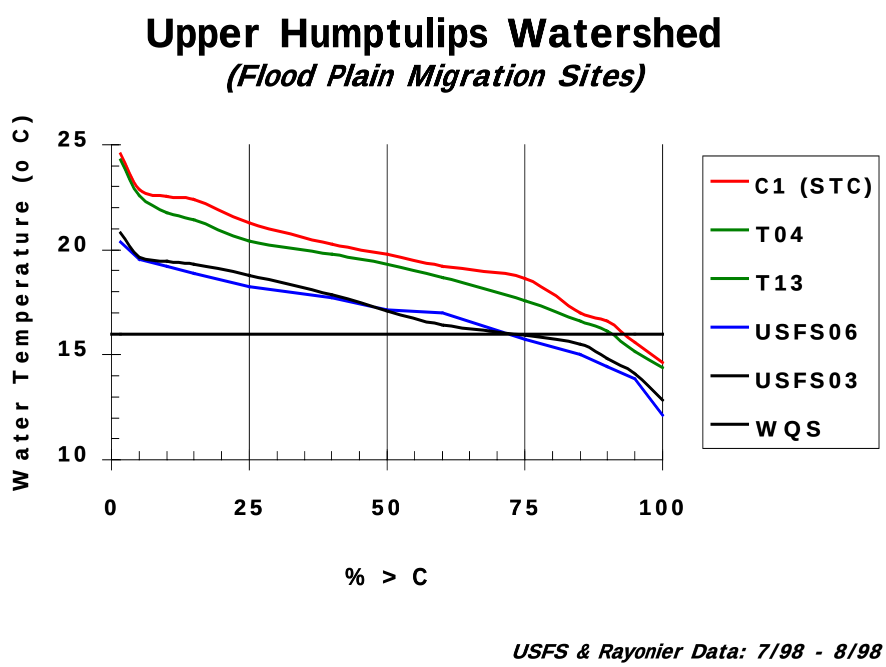
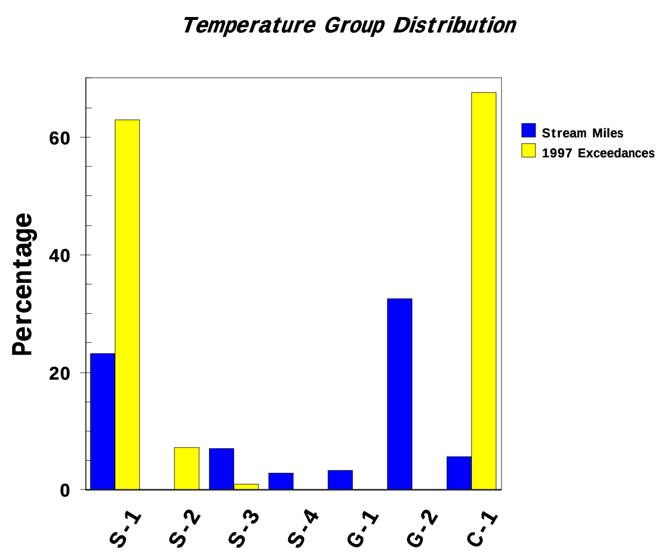


Figure D-8 shows the percentage of streams in the Upper Humptulips Watershed Analysis area that lie within each temperature group as well as the percentage of time that 16EC was exceeded at each site used to represent the temperature group.

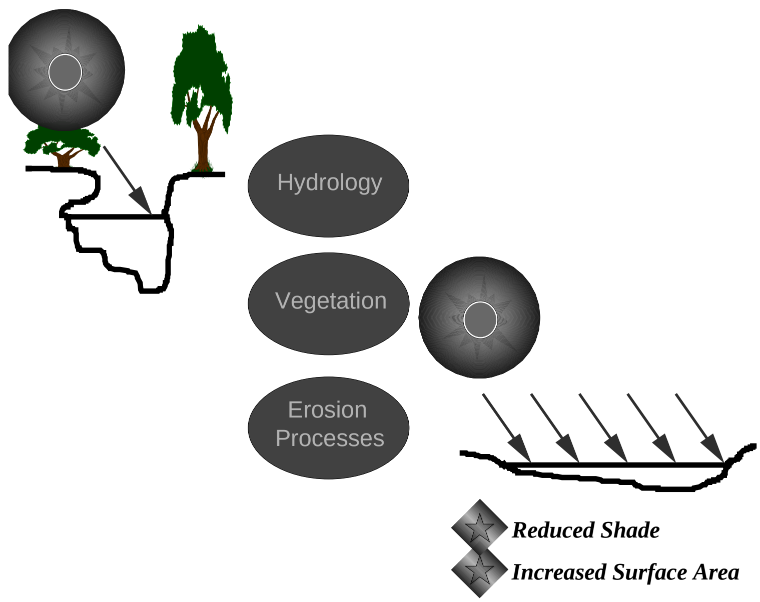
Figure D-8. *Distribution of Temperature Groups*



Relationship to Watershed Processes

Stream temperatures can increase as a result of land management activities which alter basic watershed processes *(Figure D-9)*. Temperature conditions are affected by the amount of stream surface area exposed to direct solar radiation (i.e. sunlight). In forested situations, temperature increases in streams occur when riparian vegetation is reduced (resulting in decreased shade), channels are widened and shallowed from excess sediment (resulting in increased surface area), or the cooling effects of groundwater flows are diminished (resulting in lower dissipative capacity). The result is wide and shallow streams with little shading which experience higher summer water temperatures due to the increased input of solar radiation.

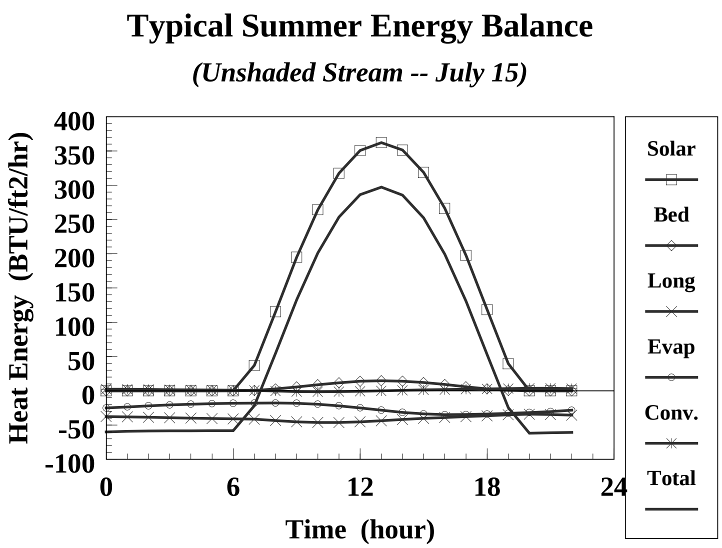
Figure D-9. *Watershed Processes Affecting Stream Temperature*



Stream temperature is an expression of heat energy per unit volume, or an indicator of the rate of heat exchange between a stream and its environment, as discussed in Appendix H *(Figure H-1)*. In terms of water temperature increases, the principle source of heat energy is solar radiation directly striking the stream surface (Brown, 1970). Energy is acquired by a stream system when the heat entering the stream is greater than the heat leaving the stream. When there is a net addition of heat energy to the stream, the water temperature will increase.

As discussed in other studies (Brown 1969, Beschta et al 1987), the daily profile for water temperature typically follows the same pattern of solar radiation delivered to an unshaded stream *(Figure D-10)*. Other processes, such as longwave radiation and convection also introduce energy into the stream, but at much smaller amounts when compared to solar radiation. If a stream is completely unshaded, as is the case in Figure D-10, the solar radiation flux has the potential to deliver large quantities of heat energy, resulting in a rapid increase in water temperature.

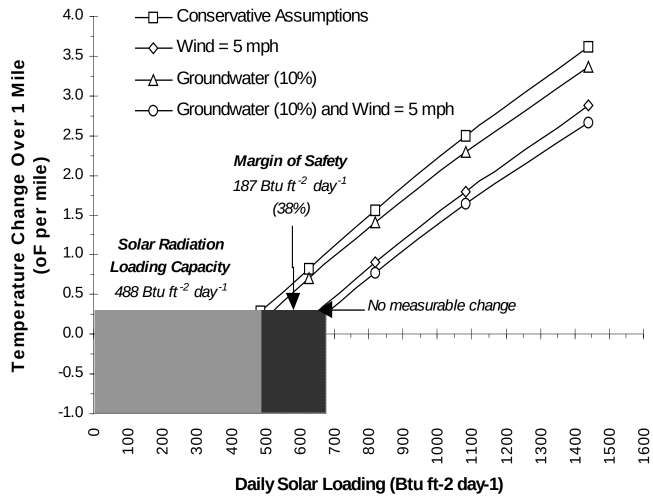
Figure D-10. *Typical Summer Energy Balance for an Unshaded Stream*



Landscape features (e.g. riparian vegetation) directly control the extent of stream surface exposure to solar energy. Natural watershed processes that are most influential in determining stream temperature include solar radiation, air temperature, stream width, stream depth, shading, and water inflow. Temperature regimes altered by forest practices result from changes in the amount of solar radiation striking the water surface. Loss of riparian vegetation and channel widening increase the water surface exposed to sunlight.

Mechanistic models have been developed based on a heat budget approach which estimate water temperature under different heat balance and flow conditions. Brown (1969) was the first to apply a heat budget to estimate water temperatures on small streams affected by timber harvest. This heat budget technique utilizes six variables (solar radiation, long wave radiation, evaporation, convection, bed conduction, and advection) to determine the net gain or loss of stored heat (ΔH) in a known volume of water. This change in ΔH can then be converted to a temperature change. Using mathematical relationships to describe heat transfer processes, the rate of change in water temperature on a summer day can be estimated. Relationships include both the total energy transfer rate to the stream (i.e. the sum of individual processes) and the response of water temperature to heat energy absorbed. Heat transfer processes considered in the analysis include solar radiation, longwave radiation, convection, evaporation, and bed conduction (Wunderlich 1972, Jobson and Keefer 1979, Beschta and Weatherred 1984, Sinokrot and Stefan 1993). Figure D-10 shows that solar radiation is the predominant energy transfer process which contributes to water temperature increases. A general relationship between solar radiation loads and stream temperature can be developed by quantifying heat transfer processes (*Figure D-11)*.

Figure D-11. *General Relationship between Solar Radiation Loads and Water Temperature*



Explanation:

Figure D-11 describes the relationship between solar radiation load and water temperature change. The response of water temperature to solar radiation loads was determined by evaluating the sum of individual heat transfer processes, or:

$$\Phi_{total} = \Phi_{solar} + \Phi_{longwave} + \Phi_{evaporation} + \Phi_{convection} + \Phi_{conduction}$$

Individual heat transfer rates were estimated using the location of the Upper Humptulips Watershed Analysis area (i.e. same latitude / longitude range) and conservative assumptions. The graph contains four curves representing different assumptions on groundwater inflow and wind speed.

Vegetation

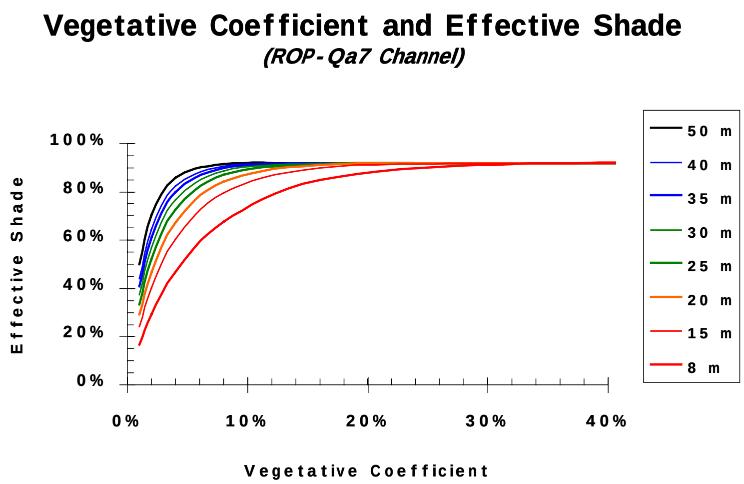
The purpose of evaluating components of shade is to develop meaningful measures which relate riparian characteristics to solar radiation reduction targets. It is important to remember the role that shade plays with respect to stream temperature. Solar radiation is a *"one way"* heating process for the stream. Heat energy gained from the sun must be dissipated by other energy processes, namely: *longwave radiation, evaporation, or convection*. For this reason, while shade does not cool stream water, it does prevent or reduce heating by solar radiation.

In order to assess the ability of riparian vegetation to shield a stream from solar radiation, one needs to consider two basic characteristics of shade: *shade duration* and *shade quality*. Shade duration is the length of time that a stream receives shade. Shade quality is the amount of solar radiation blocked by the shade. To minimize stream heating from solar radiation, two components of shade must occur. First, the stream surface shade must persist throughout the day, even when the sun is very high in the sky. Second, shade quality must be adequate to block the majority of the incoming solar radiation.

Effective shade screens the water's surface from direct rays of the sun. Highly shaded streams often experience cooler stream temperatures due to reduced input of solar energy (Brown 1969, Beschta et al 1987, Holaday 1992, Li et al 1994). Stream surface shade is dependent on both topography as well as riparian vegetation type, condition, and shade quality.

From a management perspective, riparian vegetation has the greatest potential to influence shade, and thus stream temperatures. Over the years, the term shade has been used in several contexts, including its components such as shade angle or shade density. For purposes of this TMDL, effective shade is defined as the percent reduction of potential daily solar radiation load delivered to the water surface. Thus, the role of shade in this TMDL is to prevent or reduce heating by solar radiation. Figure D-12 depicts the relationship between the vegetative coefficient and effective shade is shown for a ROP-Qa7 channel using buffer or Riparian Conservation Reserve (RCR) widths that range from 8 meters to 50 meters.

<u>Figure D-12</u>. *Effect of Vegetative Coefficient on Effective Shade*

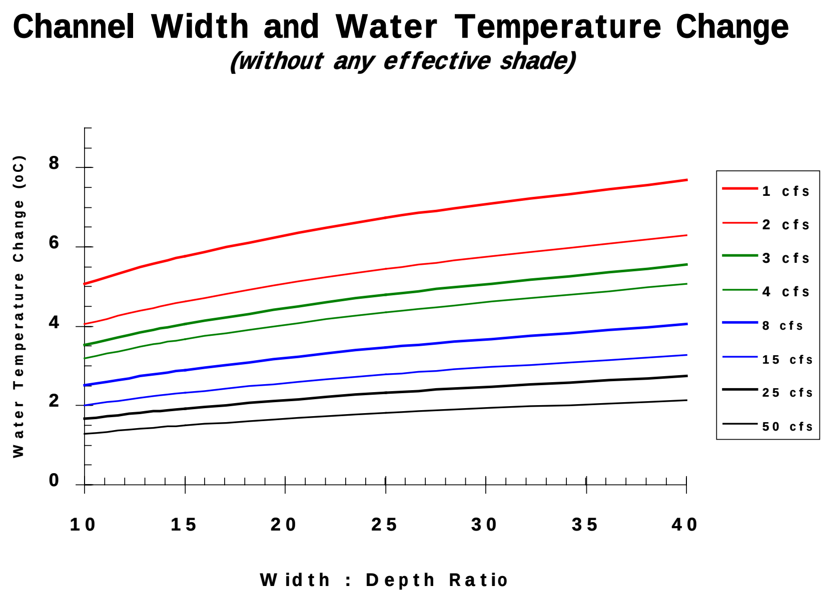


Erosion

Within the Upper Humptulips Watershed Analysis area, large rivers are affected by high sediment supply and multiple thread channels over at least some of their length. Temperatures in these systems are strongly influenced by channel pattern and open canopies. Deposition of sediment can result in channel filling which leads to increases in channel width.

An increase in channel width will increase the amount of solar radiation entering a stream. A wide, shallow will heat up faster than a narrow, deeper stream with the same discharge (Brown, 1972). The effect of an increased channel width : depth ratio in the peak hourly water temperature change is illustrated in Figure D-13. During storm events, management related sources can increase sediment inputs over background. This contributes to channel widening and stream temperature increases.

Figure D-13. *Effect of Channel Width on Water Temperature*



Hydrology

The effect of hydrology, specifically stream flow and groundwater inputs, on water temperature is through the effect on dissipative capacity. Aquatic systems in forested watersheds subject to low flows (e.g. through poor water storage over glacial tills and shallow soils) tend to respond quickly to increased heat. Aquatic systems with headwaters in wetlands or bogs as well as those streams affected by beaver ponds tend to have higher background temperatures. Other drainages may be affected by subtle groundwater influences through wet side slopes. Finally, streams that are "near" the water source with substantial groundwater influence (e.g. side seeps and springs) are typically cool and are more resistant to water temperature changes.

The effect of hydrology on stream temperature is illustrated in two ways. First, Figure D-14 shows the effect of streamflow on peak hourly water temperature. Note that as streamflows increase, water temperature changes become less pronounced. Second, as the relative percentage of groundwater flow increases, the amount of cooling in the stream also increases.

Figure D-14. *Relationship between Streamflow and Temperature Change*

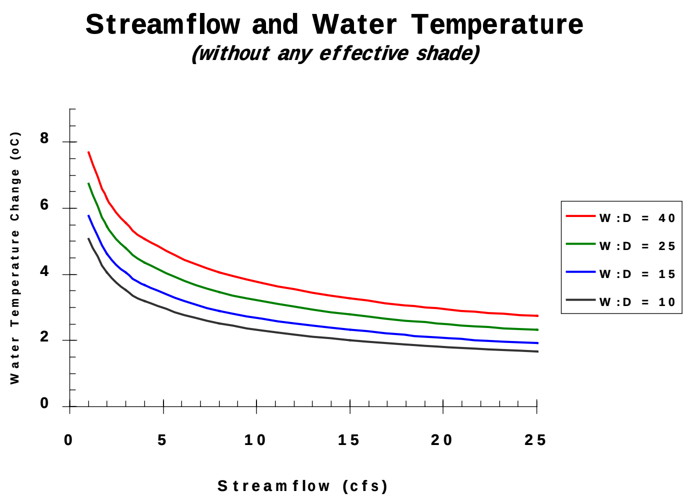
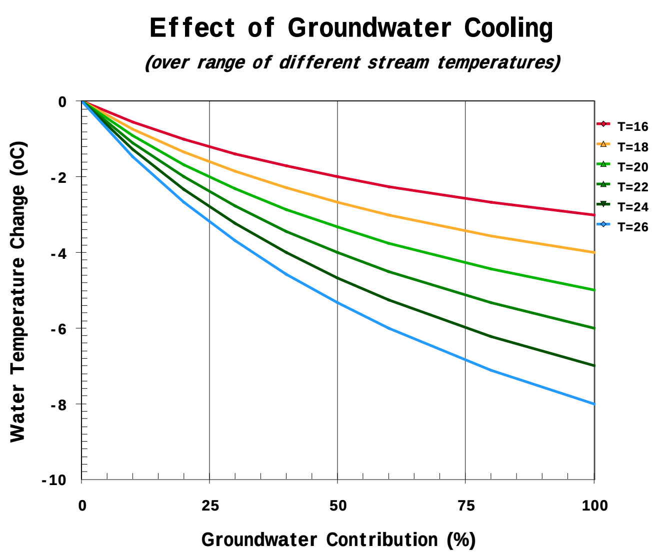


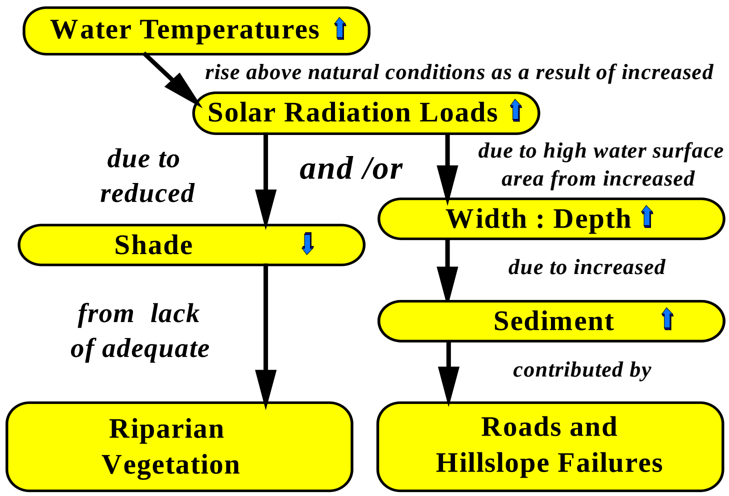
Figure D-15. *Relationship between Groundwater Contribution and Temperature Change*



Role of Source Inputs

Heat delivered through increased solar radiation causes water temperatures to rise above natural conditions. The specific surrogate used in development of the TMDL is percent effective shade. Decreased effective shade is the result of a lack of adequate riparian vegetation available to block sunlight (i.e. heat from incoming solar radiation). Excessive delivery of sediment is associated with road management and hillslope failures that contribute to channel widening. The relationship of water temperature increases to these surrogates is described in Figure D-16.

<u>Figure D-16</u>. *Relationship of Water Temperature to Surrogates*



Management activities can increase the amount of solar radiation delivered to a stream system, both by harvesting riparian shade trees and through the introduction of bedload sediment which can lead to channel widening. The Upper Humptulips Watershed Analysis area has experienced a long history of land management, stemming back to the early twentieth century. This has resulted in degradation of the watershed condition. In the Upper Humptulips Watershed Analysis area, anthropogenic sources of thermal gain and other nonpoint source pollution come from land management practices, specifically:

- Forest management within riparian areas
- Timber harvest in sensitive areas outside the riparian zone
- Sediment, hillslope failures, and roads

Riparian Area Management and Timber Harvest

Riparian vegetation can effectively reduce the total daily solar radiation load. Without riparian shade trees, most incoming solar energy would be available to heat the stream. Harvest of riparian area trees from management activities can result in loss of shade. Limited work has been done to estimate the amount of shade loss due to source activities. The Upper Humptulips Watershed Analysis summarized causes for not meeting target shade requirements.

Sediment, Hillslope Failures, and Roads

Most of the sediment supply that enters stream channels in forested watersheds is generated by several processes: mass wasting (landsliding), surface erosion (especially from roads), soil creep (especially in unstable areas), and bank erosion (from streamside terraces) [*see* Paulson, 1997]. This is especially true where steep unstable terrain is subjected to major weather events that saturate hillslopes with large volumes of precipitation. Mass hillslope failures can occur, which deliver large amounts of surface soils to stream channels. These events can overwhelm the capacity of the channel to transport this material downstream, which in turn can lead to substantial channel widening, attendant bank erosion, and shallowing of surface flows. Important salmonid (and associated life forms) habitat features (such as stable spawning areas, pools, side channel rearing areas) can be significantly affected by these processes.

Categories of sediment delivery identified in the Upper Humptulips Watershed Analysis area, several of which are to some extent controllable, include:

- background sediment yield
- erosion associated with roads, skid trails, and landings
- hillslope erosion
- mass wasting (landslides)
- surface erosion from bare ground (e.g. landslide scars)
- bank erosion

Controllable sediment is sediment delivered as a result of human activities which can affect water quality and can be reasonably controlled.

Section E Effective Shade Targets

Overview

Stream temperatures in western Washington change seasonally, increasing during the summer months, reaching their peak between mid-July and mid-August. Seasonal peak temperatures can be exacerbated through altering heat transfer processes (e.g. increasing channel exposure to solar heating due directly to harvesting of riparian forests or indirectly as a consequence of channel widening and increased solar exposure in response to sediment accumulations from upstream sources). In some cases, streams with headwaters in perched wetland areas may have naturally elevated temperatures.

Different stream temperature regimes occur naturally across the landscape based on watershed characteristics such as geology, elevation, topography, vegetation, and hydrology (both ground and surface water). These variations are considered in the Upper Humptulips Watershed Analysis area TMDL through use of the geomorphic channel units (GCUs). Information that summarizes this variation has been presented in the Condition Assessment *(Appendix C)* and in the Interpretation *(Appendix D)*.

Target Identification

Approach

Because of the difficulty in determining solar radiation loads over each stream mile, initial analyses of water temperature focus on examining patterns associated with different stream types. Studies of longitudinal trends indicate that small headwater stream temperatures are primarily regulated by local channel, riparian, and aquifer conditions. These conditions control the amount of vegetative and topographic shade on the stream surface as well as important cool groundwater inflow. Using information about each stream type (e.g. the range of flows, channel widths, desired riparian vegetation conditions, etc), effective shade targets can be developed for each class of streams.

The geomorphic channel units (GCUs) described in the Stream Channel Assessment of the Watershed Analysis Report *(Module E)* allow refinement of assumptions used to develop effective shade targets. Development of effective shade targets is then based on a better description of site specific conditions. In addition, actual data collected on streams in the Upper Humptulips Watershed Analysis area are used to validate anticipated responses. The approach to develop effective shade targets is as follows:

- *Characterize each GCU* to describe conditions that reflect stream types and to define reasonable assumptions for development of effective shade targets through the use of temperature groups.

- *Evaluate monitoring data* and develop framework for comparison of assessment to results of heat budget analysis method.

- *Analyze* heat budget over a range of expected conditions for each temperature group to examine patterns and confirm that effective shade targets will lead to attainment of water quality standards.

It should be noted that this approach considers channel conditions and desired riparian vegetation in identifying targets. A heat budget analysis is developed for comparison to actual water temperature data. The heat budget (or mechanistic model) describes the linkage between surrogate measures (i.e. effective shade) and improvements in water temperatures.

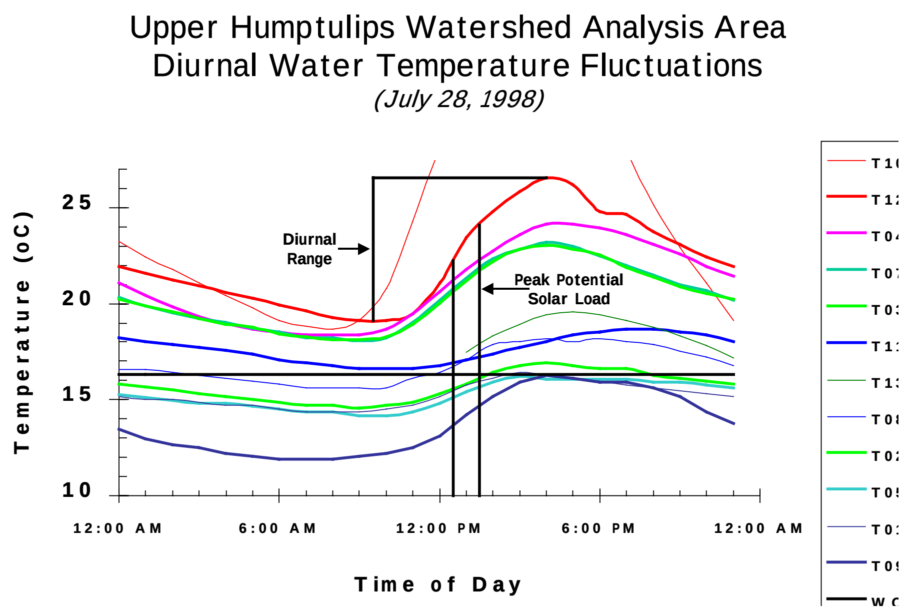
Assessment Framework

Diurnal variation in water temperature occurs naturally in stream systems. The magnitude of the temperature change (both diurnal range and peak hourly increase) has greater meaning in TMDL development for nonpoint sources than a *"no threshold"* criteria (e.g. 16°C). This is because a TMDL is designed to decrease the pollutant load. Assessing hourly water temperature change when the potential solar radiation load is at its peak is much more straightforward than predicting attainment of an absolute water temperature. This approach incorporates consideration of natural conditions by looking at the increase from a base temperature (as opposed to engaging in a debate about what is the actual level of the base temperature).

For instance, water temperatures observed at a site located in a wilderness area situated in an old growth forest (basically natural conditions) might exceed the State criteria of 16°C on a day when air temperatures reach 100°F. It would be nearly impossible to develop a TMDL for that stream which guarantees attainment of the 16°C water quality standard for "AA" waters. The only way to provide that assurance would be to first complete a site specific criteria modification in support of a more appropriate water quality standard.

It is possible to develop a TMDL (e.g. loading capacity and allocations) that focuses on hourly water temperature increase when the potential solar radiation load is at its peak. An analysis can be constructed which evaluates solar radiation inputs and resultant water temperature change through a heat budget analysis (Appendix H). Figures E-1 and E-2 depict the diurnal variation of water temperature monitoring sites on July 28, 1998. This is the day when maximum water temperatures were observed over the 2-year period for monitoring data provided by Rayonier and the U.S. Forest Service. Figure E-3 shows the peak hourly water temperature increase when the potential solar radiation load is greatest across the range of geomorphic channel units (GCUs) in the Upper Humptulips watershed. Figure E-4 shows the relationship between peak hourly increase and daily maximum water temperature. Based on this relationship, a target of 0.5°C is used to derive the maximum peak hourly loading increase that streams in the Upper Humptulips may receive in order to attain the water quality standard for temperature. This maximum peak hourly load then serves as the basis to define effective shade targets.

<u>Figure E-1</u>. *Diurnal Water Temperature Fluctuations – Rayonier Sites*



<u>Figure E-2.</u> *Diurnal Water Temperature Fluctuations – USFS Sites*

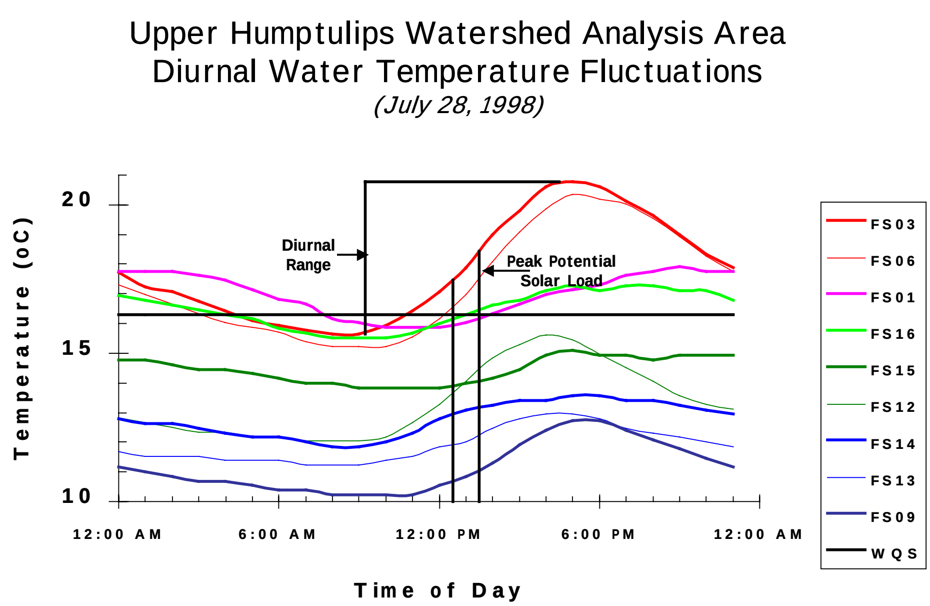


Figure E-3. *Peak Hourly Water Temperature*

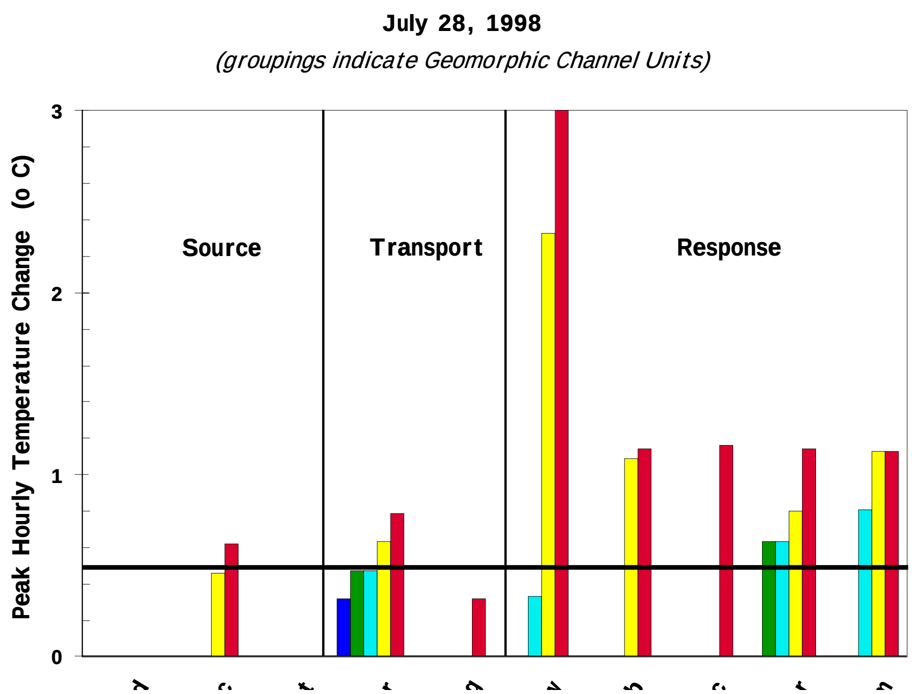
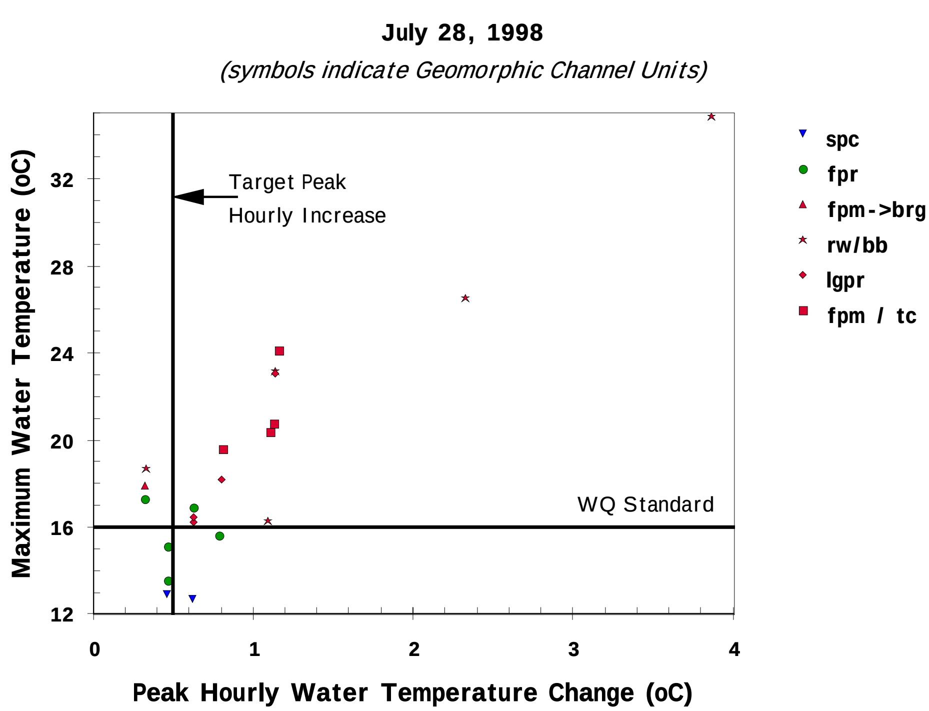


Figure E-4. *Peak Hourly Increase and Daily Maximum Water Temperature*



Temperature Change and Heat Loads*:* As discussed in Appendix H, the temperature of water is an indicator of its internal energy per unit volume *(e.g. temperature α BTU / ft^3)*. The mathematical relationship between water temperature and heat,

$$\Delta T = \Delta H * A / (V * \rho * c_p)$$

Can also be used to estimate the hourly change in heat load when the hourly change in water temperature is known.

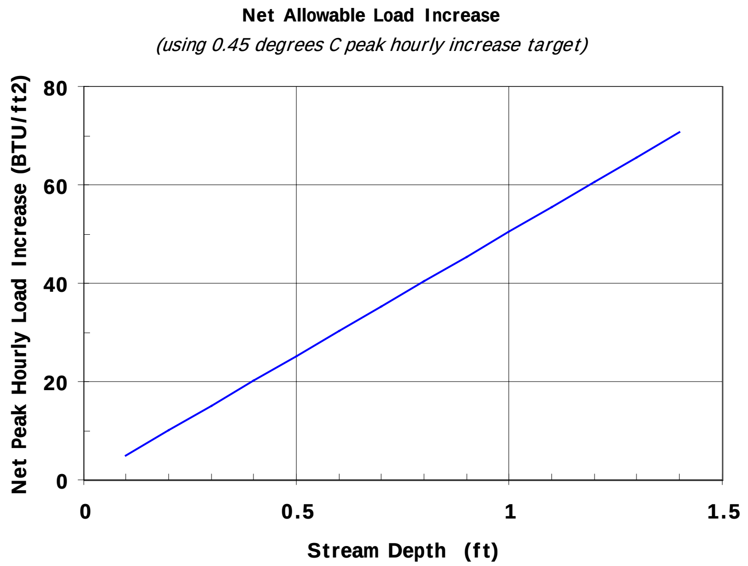
$$\Delta H = \Delta T * (V * \rho * c_p) / A$$

Because the volume divided by the surface area (V/A) is the average stream depth (d), the net change in heat load is:

$$\Delta H = \Delta T * 62.4 * d$$

Figure E-5 shows the relationship between the net allowable hourly increase in heat load and average stream depth when a target peak hourly water temperature increase of 0.45°C (or 0.81°F) is used.

Figure E-5. *Relationship between Stream Depth and Net Heat Load Increase*



Stream characteristics within the watershed analysis area vary across the landscape. Although there is very little streamflow data available for the watershed analysis, methods have been developed to estimate flow from basin area for the Olympic Peninsula (Amerman and Orsborn, 1987). The channel classification system described in the watershed analysis identifies streams as being small (active channel width # 4m), medium (4m < active channel width # 16m), or large (active channel width > 16m). Figure E-6 illustrates the relationship between drainage area and channel width in the Upper Humptulips River TMDL area. Table E-1 summarizes drainage characteristics in TMDL area by GCU.

Figure E-6. *Upper Humptulips Area*

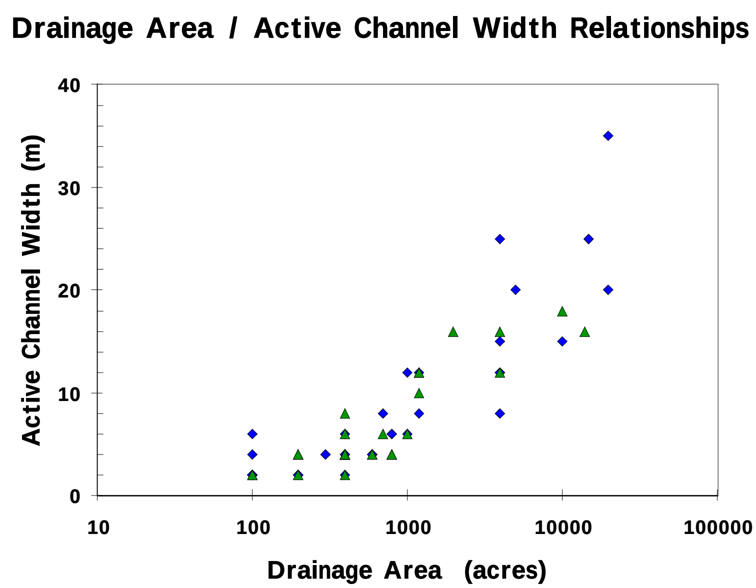


Table E-1. ***Sub Watershed Drainage Characteristics***

Watershed Name	Watershed Area	Stream Miles	Density (*mi / mi²*)	Yield (*cfs / mi²*)	Inflow (*cfs / mi*)
EF – Upper	12.5%	88.1	5.9	1	0.17
EF – Middle	13.3%	101.2	6.4	1	0.16
EF – Lower	12.6%	98.6	6.5	1	0.15
WF – Upper	15.3%	110.2	6.0	1	0.17
WF above Chester	7.0%	37.8	4.6	1	0.22
Chester	8.9%	69.3	6.6	1	0.15
WF above Donkey	12.1%	81.0	5.6	1	0.18
Donkey	6.3%	39.4	5.3	1	0.19
WF – Lower	12.0%	74.4	5.2	1	0.19

✓ Flow yield estimated for each LTU from Amerman and Orsborn, 1987 (Figure 10-5). Represents seven-day, two-year (7Q2) low flow based on Olympic Peninsula gage information.

✓ Inflow is the flow yield divided by the drainage density to provide a rough estimate of flow derived per mile of stream (rough indicator of potential groundwater contribution).

Target Development

Effective shade targets can be developed for each temperature group using a quantitative analysis of heat transfer processes. The Watershed Analysis Report discusses information about each channel class which includes basin area, size of the active channel, slope, etc. Reasonable assumptions can be defined for key factors that affect water temperature, e.g. stream depth, groundwater buffering. A heat budget analysis is then developed based on these assumptions to identify effective shade targets for each channel class.

Load allocations were made for all channel classes with the exception of the Riverine Wetland (RW). These areas are low gradient (<2%) streams within wetland valley bottoms. The channels are typically incised in fine organic and inorganic silt deposits. Stream flows are generally placid and low-velocity and the streams are frequently impounded by beaver dams. The RW are historically non-forested, consisting of some hardwoods, Hemlock, Devil's Club, and Huckleberry. It is difficult to predict what the optimum plant species composition and site-potential shade should be and what effect restoring the composition to pre-European conditions would have on temperature. Due to the wet soils these areas will not support a dense riparian forest. In addition, the channel length of these segments is a very small portion of the total channel length which contributes to the mainstem Humptulips River. The most appropriate methods for dealing with potential elevated temperatures in these sections are by the use of monitoring and adaptive management.

The heat budget analysis used July 28 as the critical day. This is based on an analysis of stream temperature monitoring data from the Upper Humptulips Watershed. A wind speed of five miles per hour was used across the landscape based on sparse meteorological data that is available. To estimate conduction, a value of 75 percent was assumed to represent bedrock conditions. Assumptions for base flow, average width:depth ratio, groundwater flow, and groundwater temperature are summarized in Table E-2. Groundwater flow rates are based on water yield and inflow estimates described above. For several channel types, the percent inflow was increased to account for the effect of intergravel flow. This was based on patterns observed in reviewing stream temperature data. Groundwater temperature was also based on patterns observed in the stream monitoring data. Values assumed used the coolest water temperature for that group on the warmest day in 1997. The assumed groundwater temperatures are actually higher that a standard 10°C used in other modeling efforts which provides some margin of safety.

Table E-2a. ***Effective Shade Target Development — Channel Class Assumptions***

GCU	Order	mi.	Basin Area *(acres)*	Active Channel Width *(m)*	Flow *(cfs)*	W:D	Groundwater		Effective Shade Target
							(%)	*(°C)*	
Source Reaches									
sd	1	4.1	640-1280	1 - 2	1	10	20.0 %	10	70%
	2	2.25	1280-2560	2 - 4	2	10	10.0 %	10	69%
spc	1	103.55	640-1280	1 - 2	1	10	20.0 %	10	70%
	2	11.83	1280-2560	2 - 4	2	10	10.0 %	10	69%
	3	0.38	2560-5120	4 - 8	4	10	5.0 %	10	70%
Transport Reaches									
tt	1	40.75	640-1280	1 -2	1	10	20.0 %	10	70%
	2	12.93	1280-2560	2 - 4	2	10	10.0 %	10	69%
	3	5.18	2560-5120	4 - 8	4	10	5.0 %	10	70%
	4	0.36	5120-10240	8-12	8	10	2.5 %	10	74%
fpr	1	17.69	640-1280	1-2	1	15	20.0 %	11	77%
	2	19.99	1280-2560	2 - 4	2	15	10.0 %	11	76%
	3	4.12	2560-5120	4 - 8	4	15	5.0 %	11	76%
	4	1.13	5120-10240	8-16	8	15	2.5 %	11	78%
brg	3	2.71	2560-5120	4-8	4	25	5.0 %	12	76%
	4	3.68	5120-10240	8 - 16	8	25	2.5 %	12	78%

Table E-2b. ***Effective Shade Target Development — Channel Class Assumptions***

GCU	Order	mi.	Basin Area *(acres)*	Active Channel Width *(m)*	Flow	W:D	Groundwater *(%)*	Groundwater *(°C)*	Effective Shade Target
Response Reaches									
rw	1	10.56	640-1280	1 - 2	1	40	20.0 %	13	†
	2	1.77	1280-2560	2 - 4	1	40	20.0 %	13	†
	3	.25	2560-5120	4 - 8	2	40	10.0 %	13	†
bb	1	5.09	640-1280	1-2	1	25	20.0 %	13	83%
	2	1.67	1280-2560	2-4	2	25	10.0 %	13	82%
	3	.26	2560-5120	4-8	4	25	5.0 %	13	81%
hsc	4	.97	5120-10240	8-16	8	25	2.5 %	13	82%
tc	3	1.09	2560-5120	4-8	4	25	5.0 %	13	81%
	5	8.74	>10240	16-32	16	25	2.0 %	13	81%
	6	.02	>20480	>32	25	25	1.0 %	13	79%
lgpr	1	3.79	640-1280	1-2	1	25	20.0 %	13	83%
	2	12.48	1280-2560	2-4	2	25	10.0 %	13	82%
	3	9.3	2560-5120	4-8	4	25	5.0 %	13	81%
	4	8.58	5120-10240	8-16	8	25	2.5 %	13	82%
	5	7.10	>10240	13-32	16	25	2.0 %	13	81%
fpm	2	.17	1280-2560	2- 4	2	40	10.0 %	13	84%
	3	10.86	2560-5120	4-8	4	40	5.0 %	13	84%
	4	9.4	5120-10240	8-16	8	40	2.5 %	13	84%
	5	5.46	>10240	16-32	16	40	2.0 %	13	83%

† Allocations were not made for RW due to the lack of knowledge on site potential vegitation.

Section F Riparian Vegetation and Shade

Basic Principles of Shade

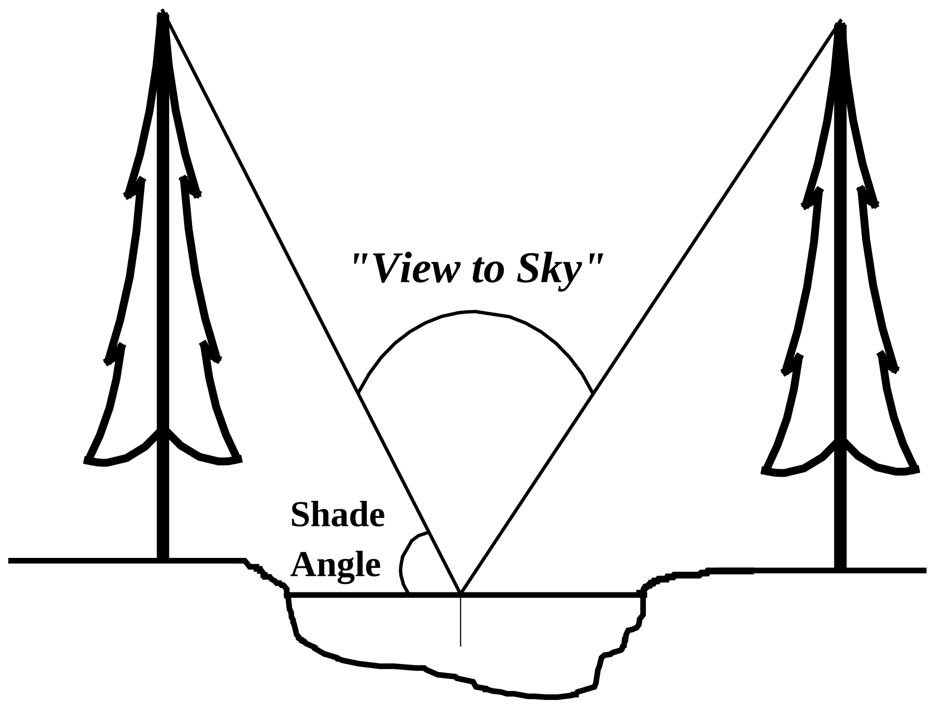
Riparian Shade: The purpose of evaluating components of shade is to develop meaningful measures which relate riparian characteristics to solar radiation reduction targets. It is important to remember the role that shade plays with respect to stream temperature. Solar radiation is a *"one way"* heating process for the stream. Heat energy gained from the sun must be dissipated by other energy processes, namely: *longwave radiation, evaporation, or convection*. For this reason, while shade does not cool stream water, it does prevent or reduce heating by solar radiation.

In order to assess the ability of riparian vegetation to shield a stream from solar radiation, one needs to consider two basic characteristics of shade: *shade duration* and *shade quality*. Shade duration is the length of time that a stream receives shade. Shade quality is the amount of solar radiation blocked by the shade. To minimize stream heating from solar radiation, two components of shade must occur. First, the stream surface shade must persist throughout the day, even when the sun is very high in the sky. Second, shade quality must be adequate to block the majority of the incoming solar radiation.

The earth tilts on its axis, varying throughout the year, the earth tilts away from the sun in winter and towards the sun in summer. Days get longer in the summer months and the sun gets higher in the sky. The vertical position of the sun is known as the *solar altitude*. Due to the northern latitude of the Pacific Northwest, the sun never really gets directly overhead. In summer, the highest the sun gets is about 70°. When applied to riparian shading of a stream, one can ensure that shade spans the full length of a day if the stream side vegetation is tall enough to block the sun when it is at the highest solar altitude.

The *vegetation shade angle* is the angle that exists from the top of the vegetation canopy to the center of the stream surface. As can be seen in Figure F-1, the interaction between the shade angle and the sun's angle (solar altitude) controls the timing and duration of stream shading. Clearly, the *vegetation height* and the position of vegetation relative to the stream play a role in determining the vegetation shade angle. An increased vegetation shade angle lengthens the duration of shading at the stream surface.

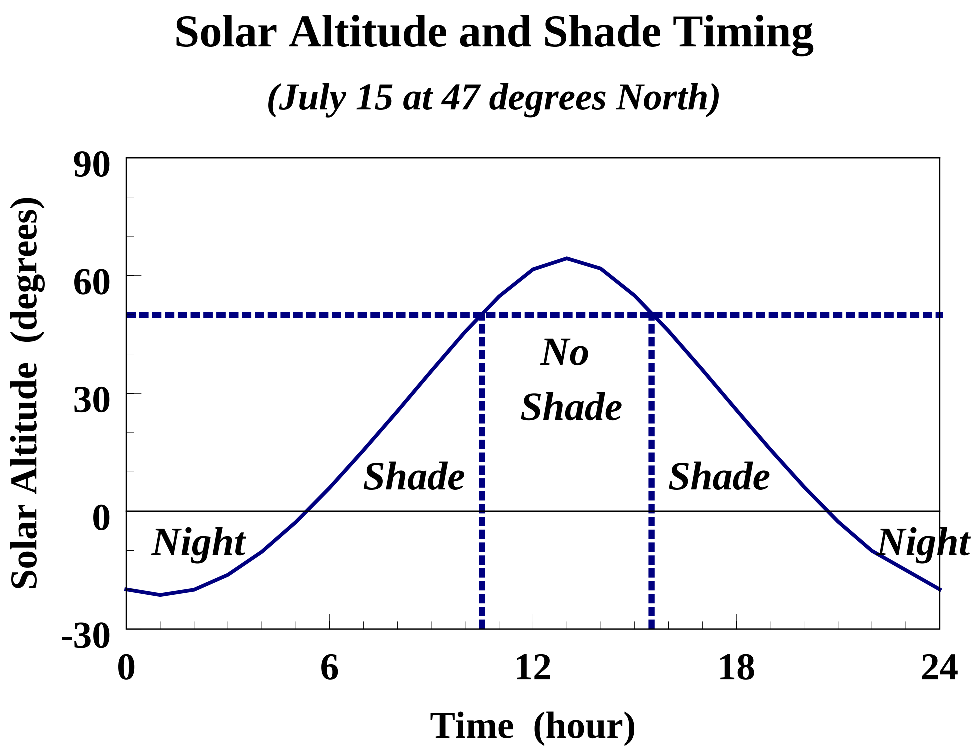
Figure F-1. *Vegetation Shade Angle*



The stream receives shade when the solar altitude (or angle of the sun above the horizon) is less than the vegetation shade angle. Once the solar altitude exceeds the vegetation shade angle, the stream no longer is shaded. Figure F-2 describes the solar altitude in the Watershed Analysis Area on July 15. By comparing the relationship between vegetation shade angle and solar altitude, the timing and duration of shade that a stream receives can be determined.

As illustrated in Figure F-2, one can see that when the vegetation shade angle is 50°, the stream is completely unshaded between 10:30am and 3:30pm. This level of shading exposes the stream to over five hours of solar radiation. Furthermore, the heat transfer from solar radiation is greatest in the unshaded portion of the day as discussed in Section E and Section G. If the stream were to receive a complement of shade that lasted for the entire day length, the vegetation shade angle must be increased to about 70° (approximately equal to the highest daily solar altitude). In summary, vegetation shade angle controls shade duration.

Figure F-2. *Solar Altitude and Shade Timing*

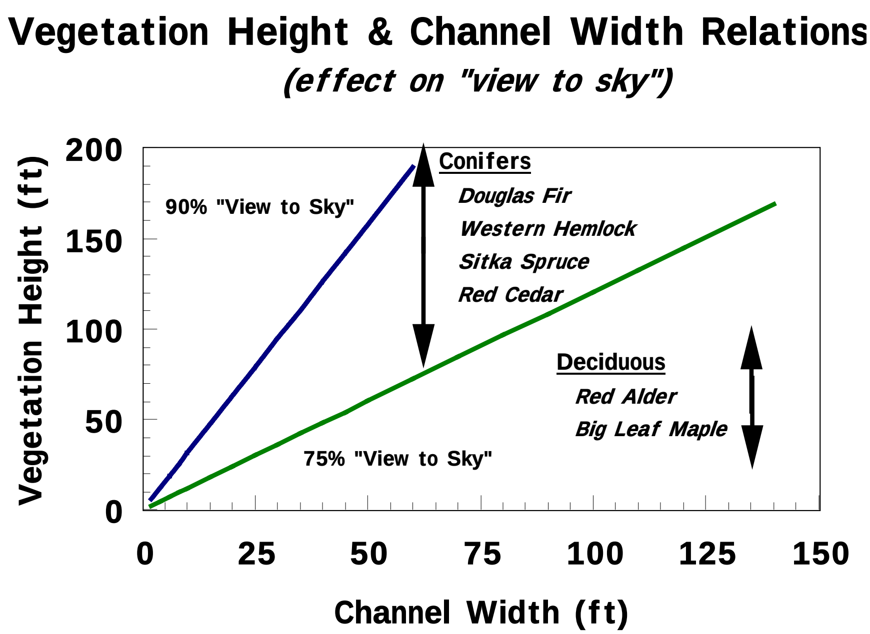


Shade Angle and "View to Sky": The state of Washington has developed a procedure for water temperature assessment within Watershed Analysis (WFPB, March 1997). This procedure addresses water temperature changes associated with the removal of riparian vegetation using the concept of maximum allowable *"view to sky"*. The *"view to sky"* is the fraction of the horizon above the stream that is void of canopy / and or topographic barriers (e.g. stream bank slope, hills, ridges).

In essence, this percentage of open sky is a measure of the absence of shade. *"View to sky"* is calculated by taking the percentage of the half circle (180°) which may be open to the sky and does not block incoming solar radiation. A shade angle of 72°, for example, along each stream bank blocks a total of 144° above the stream (each bank or two times 72°). This represents 80 percent (144° divided by 180°) or 20 percent *"view to sky"*.

In areas where sufficient topographic shading does not exist, riparian vegetation is critical to achieving *"view to sky"* targets. Figure F-3 illustrates the relationship between vegetative height and *"view to sky"* using several riparian community types.

Figure F-3. *Channel Width and Vegetative Height Relationship to* "View to Sky"



<u>Shade Quality and Riparian Vegetation</u>*:* The role of shade in this TMDL is to prevent or reduce heating by solar radiation. Riparian vegetation, particularly coniferous and deciduous trees, can provide significant amounts of shade because of their heights and extensive canopies (Beschta 1997). As discussed earlier, stream surface shade is dependent on riparian vegetation type and condition. The angle of the shade affects shade duration and is controlled by the average height of riparian vegetation and / or adjacent topography.

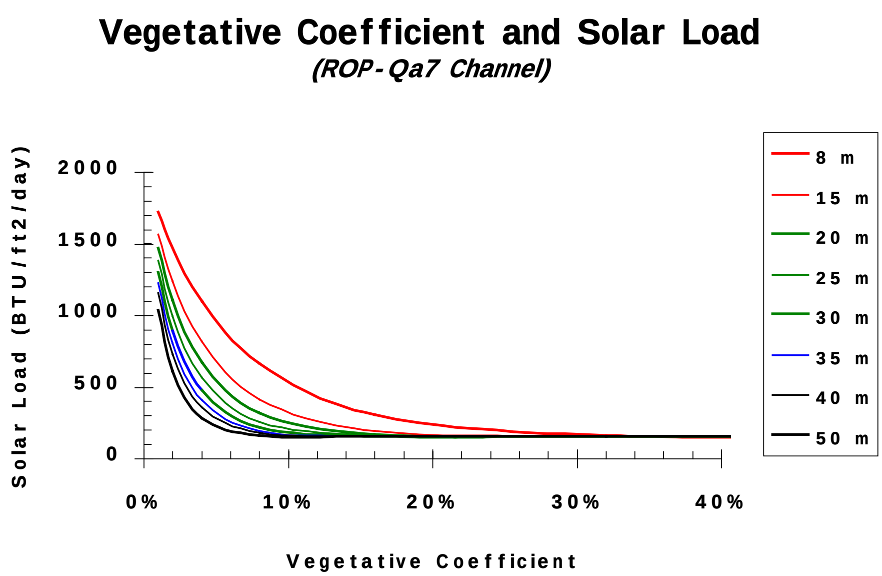
In the Humptulips Watershed Analysis area, undisturbed riparian areas generally progress towards late serial staged woody (mixed hardwood and coniferous) vegetative communities. Few, if any riparian areas in the Humptulips Watershed Analysis are unable to support either late serial riparian vegetation or tall growing herbaceous vegetation. Furthermore, the climate and topography are well suited for growth of large woody vegetative species in riparian areas. A key part of target identification relative to shade quality is to evaluate the amount of shade provided by riparian vegetation.

The quality of shade provided to the stream surface is controlled by *vegetation density* and the *vegetation width*. The vegetation density is the average screening factor of the shade-producing vegetation along the stream. The canopy density reflects the quality of the shade-producing strata of vegetation along the stream. It represents the percent of light filtered by the vegetation's leaves and trunks (i.e. shade quality). Examples of shade quality cited in the literature (Bartholow, 1989; Reifsnyder and Lull, 1965; Brazier and Brown, 1973; Lafferty, 1987) range from about 65 percent for open pine stands to 90 percent for dense emergent vegetation. Vegetation density is actually composed of two parts (USFWS, 1989): the continuity of the vegetative coverage along the stream (quantity) and the percent of light filtered by the vegetation leaves and trunks (quality). For instance, if there is vegetation along 25 percent of the stream and the average density of that coverage is 50 percent, the total vegetation density is 12.5 percent (0.25 times 0.50).

Shade is enhanced by increasing the chance of collision between incoming photons from the sun and riparian vegetation. This is accomplished by augmenting the quantity of vegetation in the riparian zone, either by increasing vegetation density, and / or increasing vegetation width. Wide riparian vegetation corridors and a dense riparian canopy increase the quality of shade offered to the stream. The vegetative coefficient is one measure to evaluate the effect of riparian vegetation corridors on shade.

Attenuation of solar radiation can be calculated as a function of the vegetative coefficient (C_{veg}) and the solar path length through the vegetation (SPL_{veg}). The vegetation coefficient is the fraction of volume within the vegetation zone that attenuates and/or scatters incoming solar radiation (e.g. 0 - 100%). Beschta and Weatherred (1984) describe the vegetative transmissivity coefficient ($TRANS_{veg}$) determined as a function of the vegetative coefficient. Attenuation of incoming solar radiation due to vegetation is then estimated as a function of vegetation transmissivity and the solar path length through the vegetation. Figure F-4 illustrates the effect of the vegetative coefficient (Beschta and Weatherred, 1984) on solar radiation delivered to the stream.

Figure F-4. *Effect of Vegetative Coefficient on Solar Radiation Loads*



Effective Shade screens the water's surface from direct rays of the sun. Highly shaded streams often experience cooler stream temperatures due to reduced input of solar energy (Brown 1969, Beschta et al 1987, Holaday 1992, Li et al 1994). Stream surface shade is dependent on both topography as well as riparian vegetation type, condition, and shade quality *(Table F-1)*. While the interaction of solar mechanics and shade variables may seem complex, the math that describes them is relatively straightforward geometry (much of which was developed decades ago by the solar energy industry).

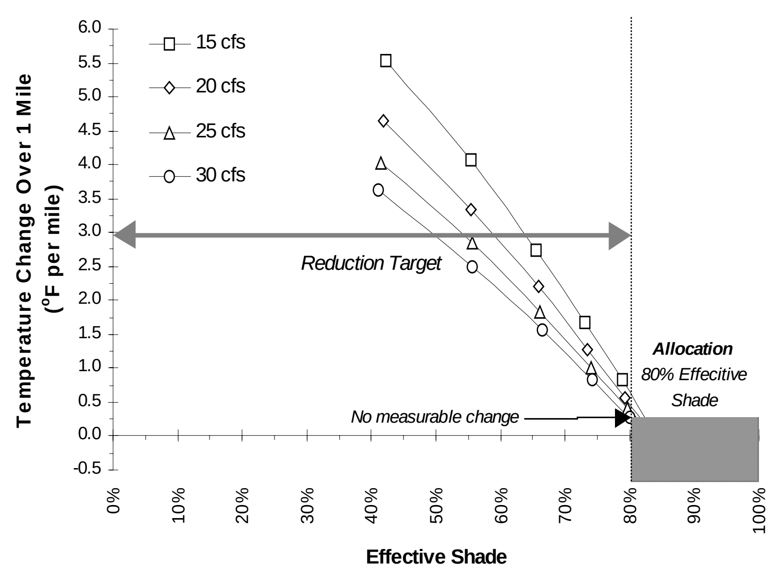
***Table F-1*.** Factors that Influence Stream Surface Shade

Description	Measure
Season	Date
Stream Characteristics	Aspect, Active Channel Width
Geographic Position	Latitude, Longitude
Vegetative Characteristics	Species Composition, Height, Density
Solar Position	Solar Altitude, Solar Azimuth

The percent effective shade is a fairly straightforward determination. It is the difference between the potential daily solar radiation load and the actual daily solar radiation load at the stream surface (expressed as a percentage). The potential daily solar radiation load is determined from solar tables or calculations. The actual solar radiation load can be measured with a Solar Pathfinder© or estimated mathematically using procedures such as SHADOW (Park, 1993). From a management perspective, riparian vegetation has the greatest potential to influence shade, and thus stream temperatures. Over the years, the term shade has been used in several contexts, including its components such as shade angle or shade density. For purposes of this TMDL, effective shade is defined as the percent reduction of potential daily solar radiation load delivered to the water surface. Thus, the role of shade in this TMDL is to prevent or reduce heating by solar radiation.

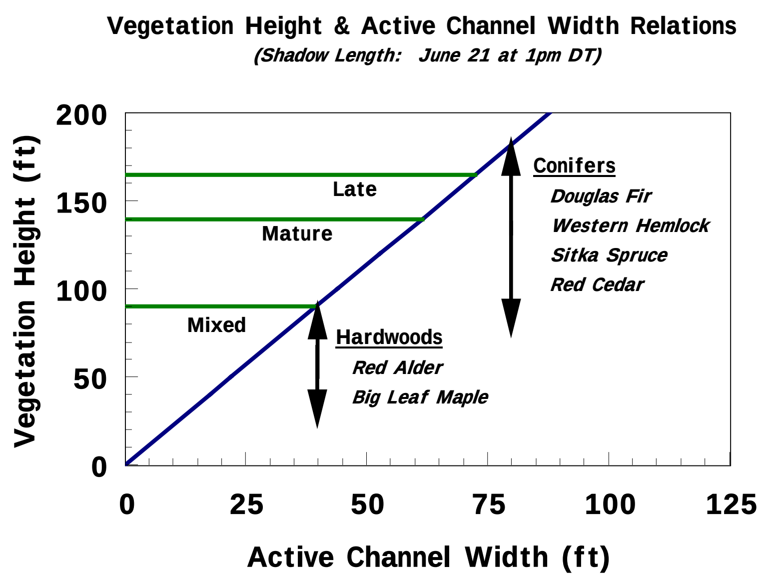
Figure F-5 illustrates the same concept discussed earlier regarding the effect of solar radiation loads on stream temperatures. However, the information is presented in a manner consistent with the definition of effective shade in this TMDL (i.e. the percent reduction of potential daily solar radiation load delivered to the water surface). This provides an alternative target (or surrogate) which relates to stream temperatures, in this case, an 80 percent reduction in potential solar radiation delivered to the water surface.

Figure F-5. *Effect of Solar Radiation Reduction* (Effective Shade) *on Water Temperature*



Relationship Between Effective Shade and Channel Width: One significant consideration in identifying load allocations for effective shade is the relationship between the physical characteristics of the stream and the adjacent riparian zone. In addition to topography, riparian vegetation height and canopy density determine the physical barriers between the stream and the sun that can block incoming solar radiation (i.e. produce shade). In developing targets, the amount of shade provided by riparian vegetation must be considered. A starting point is an analysis of the length of shadow cast by potential riparian vegetation. Figure F-6 depicts the relationship between active channel width and the vegetative height required to completely shade the channel on June 21 when solar altitude is the highest of the year.

Figure F-6. *Vegetative Height Needed to Shade Channel Width*



As shown in Figure F-6, smaller channels can be completely shaded with shorter vegetation, as long as the riparian buffer is wide enough to provide adequate canopy density. However, for larger streams, there are situations where the vegetative height associated with a mature riparian forest is not tall enough to shade the entire active channel. For instance, on June 21 the shadow length of a 170 foot tall Douglas fir at 1pm (daylight time) is only about 75 feet.

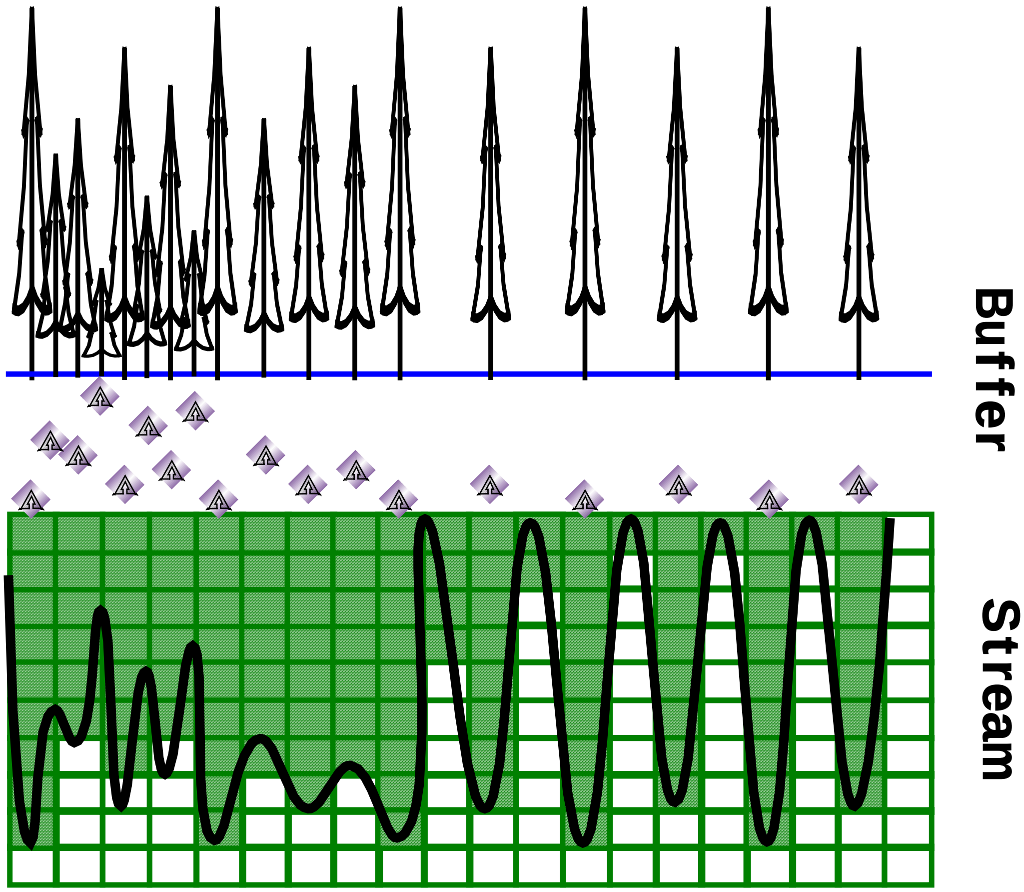
Allocations and TMDL

The objective of the effective shade TMDL is to reduce heat from incoming solar radiation delivered to the water surface. The basis for effective shade allocations follows an analysis of processes that affect water temperature. Development of the effective shade allocations uses information about riparian management strategies.

Effective shade allocations have been developed from targets based on channel class width and characteristics of mature riparian vegetation. Effective shade allocations are a function of the vegetation that will shade the widest active channel for each class. The active channel width, the vegetative density associated with a width, the height associated with the expected riparian community (e.g. mixed conifer / hardwood), and the gorge depth associated with each channel class are used to determine effective shade allocations.

To date, very little work has been done in developing methods to determine the effective shade that results from a fixed riparian buffer width. Many variables and interactions contribute to the complexity of the problem. Figure F-8 depicts the basic framework that was used to estimate base effective shade allocations given an active channel width and RCR dimensions. EPA regulations acknowledge the challenge associated with establishing load allocations for nonpoint sources. The current regulation states: *"Load allocations are best estimates of the loading, which may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading" [40 CFR §130.2(g)]*.

Figure F-7. *Framework for Evaluating Buffer / Stream Interaction*



The framework shown in Figure F-7 allows a conceptual view of several factors that are important in developing estimates for effective shade allocations. These include consideration of the effect of dense, emergent vegetation on both small channels and on the *"sunward"* side of larger channels. It also allows recognition of the maximum shadow cast by a mature tree relative to its position within the RCR and the physical ability of that shadow to reach the stream. These estimates of base effective shade are summarized in Table F-4.

Other methods which could be used to assist in development of effective shade allocations include air photo interpretation of canopy closure. However, current availability of such information is limited. Also, estimation of canopy closure (and riparian shade) using air photo interpretation has a very crude level of accuracy. Recognizing the rough nature used to develop estimates for base effective shade allocations, information from instream monitoring will be used to evaluate effectiveness. One reason for using a peak hourly change target was to provide a link to effective shade in a way that utilizes actual water temperature monitoring data. The monitoring program will continue to use documented methods to collect canopy closure and riparian shade information. However, progress towards meeting load allocations and attaining water quality standards will be measured through assessment of the actual stream temperature monitoring data. Adjustments will be made to the TMDL, as necessary, if supported by information from monitoring and assessment efforts. Key assumptions and allocations for effective shade are summarized in Table F-5.

Table F-4. ***Relationship Between Active Channel Width and Base Effective Shade***

Active Channel Width[1] ***(m)***	**Vegetation Height[2]** ***(feet)***	**Effective Shade**							
		3m	***8m***	***20m***	***25m***	***30m***	***35m***	***40m***	***50m***
2	**21.1**		93%						
4	**42.3**	92%	93%	95%	95%	95%			
6	**63.4**			92%	95%	95%		95%	
8	**84.6**			90%	91%	91%		91%	
10	**105.7**				88%				
12	**126.8**					85%		85%	
15	**158.5**								82%
16	**169.2**					80%		80%	
18	**170.0**					78%			
20	**170.0**						76%	76%	
25	**170.0**					72%		72%	
35	**170.0**							68%	

NOTES:

[1] This table summarizes estimated base effective shade levels by active channel width. Active channel width determines the surface area requiring effective shade.

[2] Riparian vegetation that completely shades a 45E aspect stream at 1pm (daylight time) on 6/21.

Table F-5a. ***Summary of Parameters Used to Calculate Effective Shade LAs for Upper Humptulips***

Stream Order	Group	Estimated Active Channel Width *(m)*	Riparian Strategy	Length *(miles)*	Allocations *(Effective Shade as percent)*		
					TMDL	LA	MOS
Slope Deposit GCU							
sd(1)	G-a	1 - 2	Olympic Forest Plan	3.55	70%	98%	(28%)
sd(1)	G-a	1 - 2	Forest & Fish	0.55	70%	73%	(3%)
sd(2)	G-a	2 - 4	Olympic Forest Plan	2.12	69%	97%	(28%)
sd(2)	G-a	2 - 4	Forest & Fish	0.13	69%	72%	(3%)
Total for GCU				6.35			
Step Pool / Cascade GCU							
spc(1)	G-a	1 - 2	Olympic Forest Plan	54.50	70%	98%	(28%)
spc(1)	G-a	1 - 2	Forest & Fish	49.05	70%	73%	(3%)
spc(2)	G-a	2 - 4	Olympic Forest Plan	4.56	69%	97%	(28%)
spc(2)	G-a	2 - 4	Forest & Fish	7.27	69%	72%	(3%)
spc(3)	G-a	4 - 8	Olympic Forest Plan	0.38	70%	95%	(25%)
Total for GCU				115.76			
Terrace Transition GCU							
tt(1)	G-a	1 - 2	Olympic Forest Plan	34.98	70%	98%	(28%)
tt(1)	G-a	1 - 2	Forest & Fish	5.78	70%	73%	(3%)
tt(2)	G-a	2 - 4	Olympic Forest Plan	9.46	69%	97%	(28%)
tt(2)	G-a	2 - 4	Forest & Fish	3.48	69%	72%	(3%)
tt(3)	G-a	4 - 8	Olympic Forest Plan	3.31	70%	95%	(25%)
tt(3)	G-a	4 - 8	Forest & Fish	1.87	70%	73%	(3%)
tt(4)	G-a	8 – 12	Olympic Forest Plan	0.01	74%	90%	(16%)
tt(4)	G-a	8 – 12	Forest & Fish	0.35	74%	77%	(3%)
Total for GCU				59.24			

Notes:

[1] TMDL currently refers to temperature group. Development of allocations based on maximum active channel width for class. As new data and methods are developed to better estimate effective shade that results from specific riparian strategy for a particular channel class, the TMDL may be revised.

Table F-5b. ***Summary of Parameters Used to Calculate Effective Shade LAs for Upper Humptulips***

Stream Order	Group	Active Channel Width *(m)*	Riparian Strategy	Length *(miles)*	**Allocations** *(Effective Shade as percent)* TMDL	LA	MOS
Forced Pool / Riffle GCU							
fpr(1)	S-d	1 - 2	Olympic Forest Plan	7.26	77%	98%	(21%)
fpr(1)	S-d	1 - 2	Forest & Fish	10.44	77%	79%	(2%)
fpr(2)	S-d	2 - 4	Olympic Forest Plan	11.50	76%	97%	(21%)
fpr(2)	S-d	2 - 4	Forest & Fish	8.48	76%	78%	(2%)
fpr(3)	S-d	4 - 8	Olympic Forest Plan	2.21	76%	95%	(19%)
fpr(3)	S-d	4 - 8	Forest & Fish	1.91	76%	78%	(2%)
fpr(4)	S-d	8 – 16	Forest & Fish	1.13	78%	80%	(2%)
Total for GCU				42.93			
Bedrock Gorge GCU							
brg(3)	S-c	4 - 8	Olympic Forest Plan	2.71	76%	95%	(19%)
brg(4)	S-c	8 - 16	Olympic Forest Plan	2.84	78%	90%	(12%)
brg(4)	S-c	8 – 16	Forest & Fish	0.83	78%	80%	(2%)
Total for GCU				6.38			
Riverine Wetlands GCU							
rw(1)	C-a	1 - 2	Olympic Forest Plan	3.14			
rw(1)	C-a	1 - 2	Forest & Fish	7.43			
rw(2)	C-a	2 - 4	Olympic Forest Plan	0.58			
rw(2)	C-a	2 - 4	Forest & Fish	1.19			
rw(3)	C-a	4 - 8	Olympic Forest Plan	0.25			
Total for GCU				12.59			

Notes:

[1] TMDL currently refers to temperature group. Development of allocations based on maximum active channel width for class. As new data and methods are developed to better estimate effective shade that results from specific riparian strategy for a particular channel class, the TMDL may be revised.

Table F-5c. ***Summary of Parameters Used to Calculate Effective Shade LAs for Upper Humptulips***

Stream Order	Group	Active Channel Width *(m)*		Riparian Strategy	Length *(miles)*	Allocations *(Effective Shade as percent)*		
						TMDL	LA	MOS
Babbling Brook GCU								
bb(1)	S-a	1 - 2		Olympic Forest Plan	2.92	83%	98%	(15%)
bb(1)	S-a	1 - 2		Forest & Fish	2.17	83%	85%	(2%)
bb(2)	S-a	2 - 4		Olympic Forest Plan	0.82	82%	97%	(15%)
bb(2)	S-a	2 - 4		Forest & Fish	0.85	82%	84%	(2%)
bb(3)	S-a	4 - 8		Olympic Forest Plan	0.26	81%	95%	(14%)
Total for GCU					7.02			
Hillslope Confined GCU								
hsc(4)	S-b	8 - 16		Olympic Forest Plan	0.97	82%	90%	(8%)
Total for GCU					0.97			
Terrace Confined GCU								
tc(3)	S-b	4 - 8		Olympic Forest Plan	1.09	81%	95%	(14%)
tc(5)	S-b	16 – 32		Forest & Fish	8.74	81%	83%	(2%)
tc(6)	S-b	> 32		Forest & Fish	0.02	79%	81%	(2%)
Total for GCU					9.85			

Notes:

1 TMDL currently refers to temperature group. Development of allocations based on maximum active channel width for class. As new data and methods are developed to better estimate effective shade that results from specific riparian strategy for a particular channel class, the TMDL may be revised.

Table F-5d. ***Summary of Parameters Used to Calculate Effective Shade LAs for Upper Humptulips***

Stream Order	Group	Active Channel Width *(m)*		Riparian Strategy	Length *(miles)*	Allocations *(Effective Shade as percent)* TMDL	LA	MOS
Low Gradient Pool / Riffle GCU								
lgpr(1)	S-a	1 - 2		Olympic Forest Plan	0.87	83%	98%	(15%)
lgpr(1)	S-a	1 - 2		Forest & Fish	2.97	83%	85%	(2%)
lgpr(2)	S-a	2 - 4		Olympic Forest Plan	7.26	82%	97%	(15%)
lgpr(2)	S-a	2 - 4		Forest & Fish	5.22	82%	84%	(2%)
lgpr(3)	S-a	4 - 8		Olympic Forest Plan	4.48	81%	95%	(14%)
lgpr(3)	S-a	4 - 8		Forest & Fish	4.82	81%	83%	(2%)
lgpr(4)	S-a	8 – 16		Olympic Forest Plan	1.73	82%	90%	(8%)
lgpr(4)	S-a	8 – 16		Forest & Fish	6.84	82%	84%	(2%)
lgpr(5)	S-a	16 - 32		Forest & Fish	7.10	81%	83%	(2%)
Total for GCU					41.24			
Flood Plain Migration GCU								
fpm(2)	C-b	2 - 4		Olympic Forest Plan	0.17	84%	97%	(13%)
fpm(3)	C-b	4 - 8		Olympic Forest Plan	10.86	84%	95%	(11%)
fpm(4)	C-b	8 – 16		Olympic Forest Plan	9.40	84%	90%	(6%)
fpm(5)	C-b	16 - 32		Forest & Fish	5.46	83%	85%	(2%)
Total for GCU					25.89			

Notes:

[1] TMDL currently refers to temperature group. Development of allocations based on maximum active channel width for class. As new data and methods are developed to better estimate effective shade that results from specific riparian strategy for a particular channel class, the TMDL may be revised.

Section G Heat and Water Temperature

Overview

A discussion of heat and temperature begins with a brief review of what each measures. Temperature is simply an indicator of the level of internal energy that an object has. Thus, the temperature of water is an indicator of its internal energy per unit volume *(e.g. temperature* α *BTU / ft*^{3}*)*. Heat, on the other hand, is the passage of energy from one object to another.

It takes a certain amount of energy to heat a volume of water, a phenomena known as the *specific heat*. The specific heat of a substance is the amount of energy transfer needed to raise the temperature of a unit mass of a substance (e.g. one pound or one gram). In the metric system, one calorie will raise the temperature of one gram of water by one degree Celsius. The unit in the English system is known as a British Thermal Unit (BTU). One BTU will raise the temperature of one pound of water by one degree Fahrenheit.

Water has a relatively high specific heat, which is to say that it requires large quantities of heat energy to increase the temperature just 1°F (Wetzel, 1983). Similarly, water must release large quantities of heat energy before the temperature decreases. Table G-1 describes the mathematical relationship between water temperature and heat.

Table G-1. ***Mathematical Relationship between Water Temperature and Heat***

$$\Delta T = \Delta H * A \;/\; (V * \rho * c_p)$$

Where:

ΔT = temperature (EF / hour)
ΔH = rate that heat received (BTU / hour)
A = surface area of water (ft^2)
V = volume of water (ft^3)
ρ = density of water (62.4 lb / ft^3)
c_p = specific heat of water (BTU / lb / °F)

The change in heat to or from a waterbody falls into three major categories which include:

- Heat transfer through the water surface. This represents a key component of a heat budget.
- Inflowing / outflowing water which represent heat changes through temperature differences.
- Heat conduction to or from the earth through the bottom of the waterbody.

The calculation of water temperature by a mechanistic model follows the basic relationship described in Table G-1. A mechanistic model is essentially a bookkeeping of heat transfer to determine potential water temperature changes. Thus, most of the focus on water temperature modeling involves the computation of energy transfer processes.

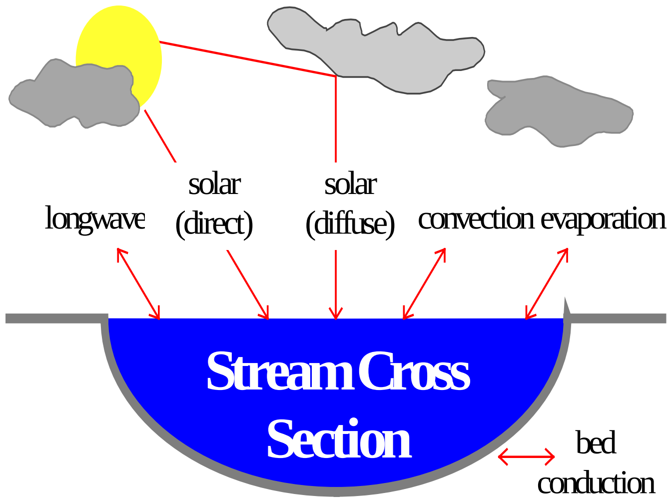
Energy Transfer Processes

Stream temperature is an indicator that reflects the rate of heat exchange between a stream and its environment. When water temperature is described in terms of heat transfer, the processes that cause a stream to gain or lose energy become important. Thus, one approach towards water temperature assessment is built around an analysis of mechanisms that transfer energy across a water surface. There are six major processes that allow heat energy exchange between a stream and its environment which include:

- ➔ solar radiation
- ➔ longwave radiation
- ➔ convection
- ➔ evaporation
- ➔ stream bed conduction
- ➔ groundwater inflow / outflow

These energy processes occur in all streams, rivers, lakes, and water troughs. Furthermore, all of these energy processes have been closely studied and are well understood. Each transfer process contributes to the total heat energy contained in a stream system. While some have a greater effect than others, all processes are significant because land use activities that affect the stream or its surrounding environment may result in changing one or more of the energy transfer processes. Figure G-1 depicts the processes that affect the heat energy contained in a stream system. All of these energy processes, except solar radiation, are capable of both introducing or removing heat energy from the stream system. Solar radiation can only deliver heat energy.

Figure G-1. *Energy Transfer Processes that Affect Water Temperature*

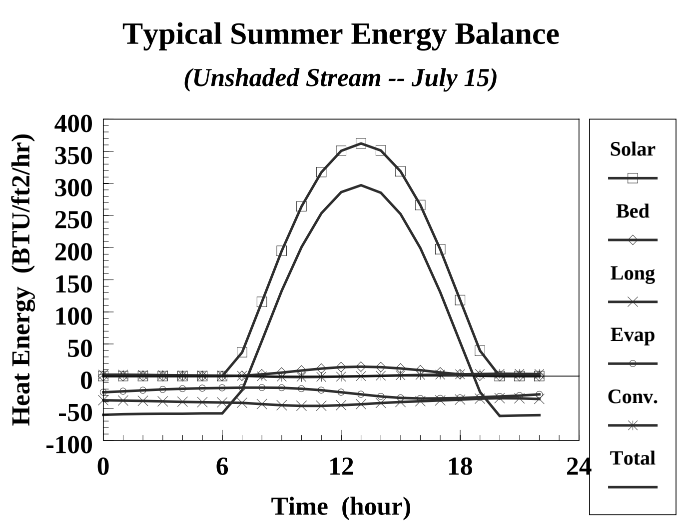


The predominant potential source of heat energy to an aquatic system is *solar radiation*. Secondary sources of heat energy include *longwave radiation* (from both the atmosphere and riparian vegetation), *convection*, *stream bed conduction*, and *groundwater exchange*. Several processes dissipate heat energy at the air-water interface, namely *evaporation* and *back radiation*. The instantaneous heat transfer rate in an aquatic system is the summation of the individual processes:

$$\Phi_{Total} = \Phi_{Solar} + \Phi_{Longwave} + \Phi_{Evaporation} + \Phi_{Convection} + \Phi_{Conduction}$$

Energy is acquired by a stream when the heat energy entering the stream is greater than the heat energy leaving the stream. When there is an addition of heat energy to the stream, the temperature will increase. The converse is also true. If the effect of the six energy processes results in reducing the total heat energy of the stream, the temperature will decrease. Figure G-2 illustrates the energy processes occurring on an unshaded stream over the course of a clear, summer day.

Figure G-2. *Typical Summer Energy Balance for an Unshaded Stream*

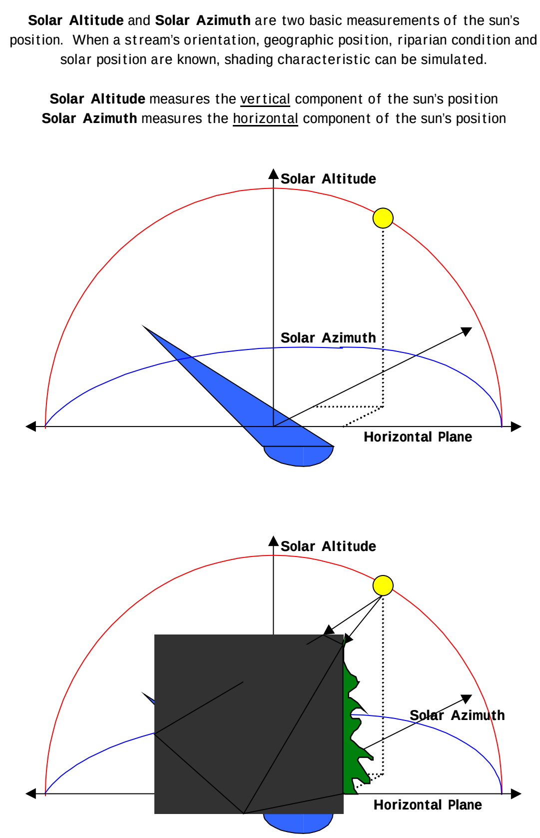


Solar Radiation

In terms of stream heating, the majority of energy is contributed by solar radiation *(Figure G-2)*. Once emitted from the sun, photons travel through space to the edge of the earth's atmosphere. While passing through the atmosphere, a portion of solar radiation is absorbed and scattered by water vapor and other particulates. The remainder continues its journey towards the earth's surface (McCutcheon, 1989). Some of the radiation that is scattered in the atmosphere eventually reaches the earth's surface as *diffuse solar radiation* (Ibqal, 1983). The solar radiation that travels through the atmosphere unobstructed is known as *direct solar radiation*.

In the heat budget, *solar radiation* (Φ_{Solar}) is a function of the solar angle (or altitude), solar azimuth, atmosphere, topography, location, and riparian vegetation *(Figure G-3)*. Simulation of solar radiation is based on methodologies developed by Ibqal (1983) and Beschta and Weatherred (1984). 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). Some of the incoming solar radiation will reflect off the stream surface, depending on the elevation of the sun. All solar radiation outside the visible spectrum (0.36mm to 0.76mm) is absorbed in the first meter below the stream surface and only visible light penetrates to greater depths (Wunderlich, 1972). Sellers (1965) reported that 50 percent of solar energy passing through the stream surface is absorbed in the first 10 cm of the water column. Assuming there are no topographic barriers between the sun and the stream, solar radiation has one last barrier to pass before reaching the water surface: riparian vegetation.

<u>Figure G-3</u>. *Geometric Relationships that Affect Stream Surface Shade*

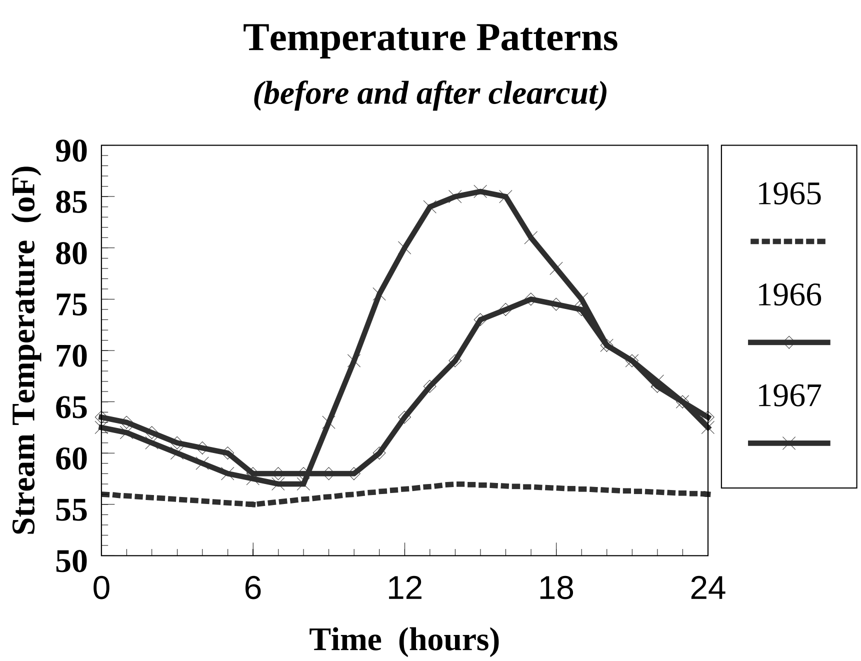


Depending on the characteristics of stream side vegetation, the time of year, and the time of day, an individual photon may or may not encounter riparian vegetation before arriving at the water surface. Removal of riparian vegetation, and the shade it provides, can contribute to elevated stream temperatures (Rishel et al., 1982; Brown, 1983; Beschta et al., 1987). It follows that land use activities that affect riparian vegetation will alter the quality and quantity of shade offered to the stream. When a stream surface is exposed to midday solar radiation, large quantities of heat energy will be delivered to the stream system, usually resulting in a dramatic water temperature increase. When shaded throughout the entire duration of the daily solar cycle, far less heat energy will be transferred to the stream. The ability of riparian vegetation to shade the stream throughout the day depends on vegetation height, density and position relative to the stream.

Anthropogenic increase in heat energy is derived from solar radiation when increased levels of sunlight reach the stream surface and raise water temperature. Some of the largest increases in stream temperatures have been caused by forest practices that removed riparian vegetation. Meehan et. al. (1969) found that an Alaskan stream experienced a 7°F increase in the maximum temperature following a clear cut. Green (1950) reported a maximum weekly temperature that was 13°F greater on a clear cut stream than that recorded on another nearby stream.

One of the most significant studies designed to highlight the importance of riparian vegetation for stream temperature control was part of the Alsea Watershed Study (Brown and Krygier, 1970). Two similar watersheds were selected in the Alsea basin, located in the Oregon Coast Range. One watershed was left undisturbed as a control, while the other was clear cut, fully exposing the stream. Figure G-4 illustrates daily stream temperature profiles observed on days in which the annual maximum temperature occurred.

Figure G-3. *Stream Temperature Profiles Following Clear Cut*



Longwave Radiation

Both the atmosphere and vegetation along stream banks emit longwave radiation that when received by the stream surface has a warming influence. The longwave radiation flux ($\Phi_{Longwave}$) is comprised of both positive and negative components. The intensity of incoming longwave radiation experienced by the stream surface is proportional to atmospheric moisture (Anderson, 1954). Humidity and air temperature greatly influence longwave radiation, while carbon dioxide and other molecules in the atmosphere have less of an influence. Further, Anderson (1954) found that the height of cloud cover affects the intensity of longwave radiation. A water surface generally reflects 3 percent of incoming longwave radiation, while the remaining 97 percent is absorbed (McCutcheon, 1989).

The vegetation canopy is assumed to emit longwave radiation that is readily absorbed by the stream surface. The radiating surface of the streamside vegetation is a function of the maximum angles of vegetation, the average path length through the vegetation on both banks, and the canopy transmissivity. Longwave radiation directed downward from the canopy is the product of the radiating surface area, the canopy emissivity, the Stefan-Boltzmann constant, and the air temperature (Beschta, 1984). Incoming longwave heat energy originating from the atmosphere which is delivered to the stream surface is simply the summation of incoming longwave flux components multiplied by the reflectance of the stream surface (Boyd, 1996).

Water is nearly opaque to longwave radiation and complete absorption of all wavelengths greater than 1.2mm occurs in the first 5 cm below the surface (Wunderlich, 1972). Longwave radiation has a cooling influence when emitted from the stream surface. This factor, termed back radiation, is the second most important component in dissipating heat energy from the stream system (Parker and Krenkel, 1969).

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). In the heat budget, *longwave radiation* ($\Phi_{Longwave}$) is derived by the Stefan-Boltzmann Law and is a function of the emissivity of the body, the Stefan-Boltzmann constant and the temperature of the body (Wunderlich, 1972).

Convection

Convection transfers heat between the stream and the air via molecular and turbulent conduction (Beschta and Weatherred, 1984). Sensible heat will be transferred across the air / water interface when the respective temperatures of the stream and the ambient air are different. From Furrier's heat transfer studies, the rate of heat energy transfer is proportional to the heat gradient (McCutcheon, 1989). The Bowen Ratio is a constant of proportionality between the convection flux and the evaporation flux at the air / water interface. This ratio is a function of the stream and air temperature as well as the vapor pressure (Bowen, 1926).

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 (Parker and Krenkel, 1969; Brown, 1983). In the heat budget, *convection* ($\Phi_{Convection}$) is a function of Bowen's Ratio (1926) and terms include atmospheric pressure, and water and air temperatures.

Evaporation

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 (Parker and Krenkel, 1969). The evaporation flux is the energy process in which a stream loses the most heat energy. As a result, evaporation contributes most to a decrease in stream temperature. The rate of evaporation is derived by assuming that turbulent mixing is responsible for the transport of momentum, heat, and water vapor in the atmospheric boundary layer directly above the stream surface (McCutcheon, 1989).

As stream temperatures increase, so does the rate of evaporation. Air movement (wind) and low vapor pressures increase the rate of evaporation and accelerate stream cooling (Harbeck and Meyers, 1970). In the heat budget, *evaporation* ($\Phi_{Evaporation}$) relies on a Dalton-type equation that utilizes an exchange coefficient, the latent heat of vaporization, wind speed, saturation vapor pressure and vapor pressure (Wunderlich, 1972).

Stream Bed Conduction

Heat energy conduction between the streambed and the stream is driven by heat gradient. Streambed characteristics affect the solar absorption properties of a stream, especially shallow streams. Solid rock, in particular, will absorb solar energy, which will conduct to the stream during and after solar radiation has diminished for the day. Conductive heat from the streambed will broaden the temperature profile, rather than increase the maximum daily water temperature (Beschta, 1984).

The heat energy available for absorption by streambed material is a function of stream depth. Depending on streambed composition, shallow streams (less than 20 cm) may allow solar radiation to warm the streambed (Brown, 1969). Large cobble (> 25 cm diameter) dominated streambeds in shallow streams may store and conduct heat as long as the bed is warmer than the stream. Bed conduction may cause maximum stream temperatures to occur later in the day, possibly into the evening hours. In the heat budget, *bed conduction* ($\Phi_{Conduction}$) simulates the theoretical relationship ($\Phi_{conduction} = K * dT_b/dz$), where calculations are a function of thermal conductivity of the bed (K) and the temperature gradient of the bed (dT_b/dz) (Sinokrot and Stefan, 1993). Bed conduction is solved with empirical equations developed by Beschta and Weatherred (1984).

Groundwater Inflow / Outflow

The interaction between a stream and connected groundwater can affect surface water temperatures. Generally, a particular stream reach is classified as gaining, losing, or impermeable. This can be determined by comparing the magnitude of upstream and downstream flows. A volume of water that adds to the streamflow contributes heat energy (positive or negative) which is proportional to the temperature and flow rate of the groundwater. An energy relationship that reflects this effect can be developed to account for stream / groundwater temperature mixing. The water temperature change is derived from the following relationship:

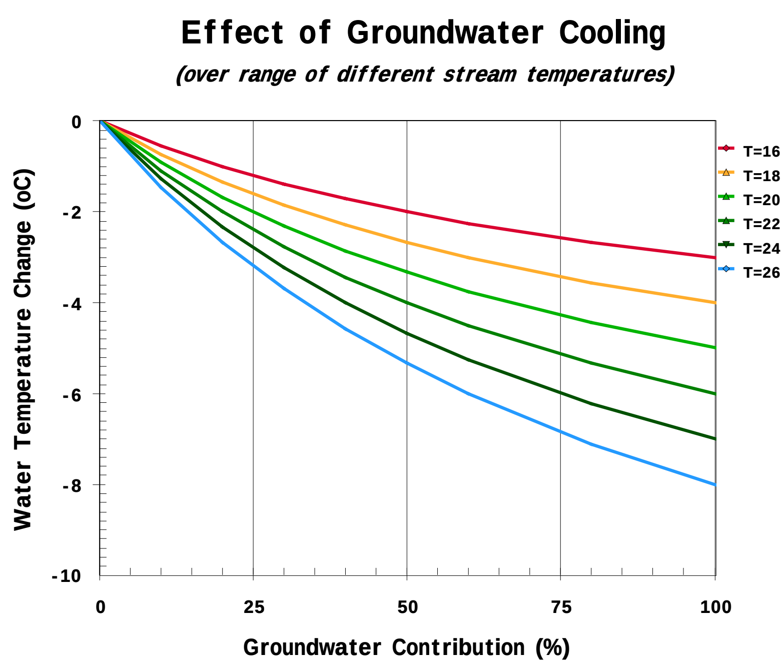
$$\Delta T = T_{upstream} - \{[(T_{upstream} * Q_{upstream}) + (T_{GW} * Q_{GW})] / (Q_{upstream} + Q_{GW})\}$$

where:

ΔT = water temperature change (°C)
$T_{upstream}$ = upstream water temperature prior to groundwater (°C)
$Q_{upstream}$ = upstream flow rate (ft^3 / sec)
T_{GW} = groundwater temperature (°C)
Q_{GW} = groundwater flow rate (ft^3 / sec)

The potential effect of groundwater cooling is shown in Figure G-3. This example assumes a groundwater temperature of 10°C and depicts the relationship across a range of different percent contributions for groundwater flow.

Figure G-4. Relationship between Groundwater Contribution and Temperature Change



Heat Budget

In summary, assessment of water temperature based upon a heat budget uses the basic relationship:

$$\Phi_{Total} = \Phi_{Solar} + \Phi_{Longwave} + \Phi_{Evaporation} + \Phi_{Convection} + \Phi_{Conduction}$$

Chen (1996) has provided a summary of each energy transfer process considered in the heat budget and described the general equation used to quantify each term *(Table G-2)*.

Table G-2. ***Heat Budget Components*** **(from Chen, 1996)**

Heat Transfer Process	General Equation
Net shortwave solar radiation (Φ_{Solar})	(1) Obtained from solar ephemeris, depending on solar angle which is, in turn, a function of season, time of day, and latitude (2) Calculated by using various empirical equations
Net longwave radiation of atmosphere, canopy, and water ($\Phi_{Longwave}$)	Stefan-Boltzmann Law: $\Phi_{Longwave} = \varepsilon\sigma T^4$ where ε is the emmissivity of the body; σ is the Stefan - Boltzmann constant; T is the surface temperature.
Evaporative heat flux at the water surface ($\Phi_{Evaporation}$)	Dalton-type equation: $\Phi_{Evaporation} = k\,L\,U\,(e_w - e_a)$ where k is exchange coefficient; L is the latent heat of vaporization; U is wind speed; e_w is saturated vapor pressure at the stream temperature; e_a is ambient atmospheric vapor pressure.
Convective heat flux ($\Phi_{Convection}$) at the air - water interface	Bowen ratio: $R = \Phi_{Convection} / \Phi_{Evaporation}$ $R = 0.61 \dfrac{(T_w - T_a)}{(e_w - e_a)} \dfrac{P}{1000}$ where T_w is water temperature; T_a is ambient air temperature; P is atmospheric pressure.
Conductive heat flux ($\Phi_{Bed\ Conduction}$) between bedrock and water	(1) Theoretical formula: $\Phi_{Bedrock\ Conduction} = K * dT / dZ$ where K is thermal conductivity of bottom material; dT / dZ is temperature gradient in the bottom material. (2) Empirical equations for calculating the heat fluxes absorbed by water, transmitted through water, and absorbed by stream bed.
Advective heat flux ($\Phi_{Advection}$) from groundwater and tributaries	Energy balance: Adjusted temperature $= \dfrac{(Q_m * T_m) + (Q_t * T_t)}{Q_m + Q_t}$ where Q_m and T_m are flow rate and water temperature of the mainstem; Q_t and T_t are flow rate and temperature of tributary.

References Cited

Amerman, K.S. and J.F. Orsborn. August 1987. *"An Analysis of Streamflows on the Olympic Peninsula in Washington State"*. Albrook Hydraulics Lab, Department of Civil and Environmental Engineering, Washington State University. Pullman, WA.

Bartholow, J.M. June 1989. *"Stream Temperature Investigations: Field and Analytic Methods"*. Instream Flow Information Paper No. 13. Biological Report 89(17). U.S. Fish and Wildlife Service. Fort Collins, CO.

Beschta, R.L. and J. Weatherred. 1984. *"TEMP-84: A Computer Model for Predicting Stream Temperatures Resulting from the Management of Streamside Vegetation"*. Watershed Systems Development Group. USDA Forest Service. Report WSDG-AD-00009. 76 pp.

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra. 1987. *"Stream Temperature and Aquatic Habitat: Fisheries and Forests Interactions"*. Ed. E.O. Salo and T.W. Cundy -- Proceedings of a symposium held February 1986, University of Washington. Seattle, WA: 1991-232.

Beschta, R.L. and R.L. Taylor. 1988. *"Stream Temperature Increases and Land Use in a Forested Oregon Watershed"*. Water Resources Bulletin 24(1): 19-25.

Boyd, M.S. 1996. *"Heat Source©: Stream, River, and Open Channel Temperature Prediction"*. Master's Thesis. Oregon State University. Corvallis, OR.

Bowen, I.S. 1926. *"The Ratio of Heat Losses by Convection and Evaporation From Any Water Surface"*. Physical Review. Series 2, Vol 27: 779-787.

Brazier, J.R. and G.W. Brown. 1973. *"Buffer Strips for Stream Temperature Control"*. Research Paper 15. Forest Research Laboratory, School of Forestry, Oregon State University. Corvallis, OR.

Brown, G.W. 1969. *"Predicting Temperatures of Small Streams"*. Water Resources Research. 5(1): 68-75.

Brown. G.W. 1970. *"Predicting the Effects of Clearcutting on Stream Temperatures"*. Journal of Soil and Water Conservation. 25: 11-13.

Brown, G.W. and J.T. Krygier. 1970. *"Effects of Clear Cutting on Stream Temperatures"*. Water Resources Research. 6(4): 1133-1140.

Brown, G.W. 1971. *"An Improved Temperature Prediction Model for Small Streams"*. Research Report WRRI-16. 20pp. Water Resource Research Institute. Oregon State University. Corvallis, OR.

Brown, L.C. and T.O. Barnwell. May 1987. *"The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Manual"*. U.S. Environmental Protection Agency, Environmental Research Laboratory. EPA/600/3-87/007. Athens, GA.

Chen, Y.D. 1996. *"Hydrologic and Water Quality Modeling for Aquatic Ecosystem Protection and Restoration in Forest Watersheds: A Case Study of Stream Temperature in the Upper Grande Ronde River, Oregon"*. PhD Dissertation. University of Georgia. Athens, GA.

Ibqal, M. 1983. *"An Introduction to Solar Radiation"*. 213 pp. Academic Press. New York, NY.

Jobson, H.E. and T.N. Keefer. 1979. *"Modeling Highly Transient Flow, Mass, and heat Transfer in the Chattahoochee River near Atlanta, Georgia"*. Geological Survey Professional Paper 1136. U.S. Government printing Office, Washington, DC.

Lafferty, B. 1987. *"A Procedure for Evaluating Buffer Strips for Stream Temperature Protection under the Forest Practices Act"*. pp 70 - 77 in Managing Oregon's Riparian Zone for Timber, Fish, and Wildlife. NCASI Technical Bulletin No. 514. 96 pp.

McCutcheon, S.C. 1989. *"Water Quality Modeling: Volume 1, Transport and Surface Exchange in Rivers"*. pp. 183 - 209. CRC Press, Boca Raton, LA.

Parker, F.L. and Krenkel, P.A. 1969. *"Thermal Pollution: Status of the Art"*. Report 3. Vanderbilt University Department of Environmental and Resources Engineering. Nashville, TN.

Paulson, K. 1997. *"Estimating Changes in Sediment Supply Due to Forest Practices: A Sediment Budget Approach Applied to the Skagit River Basin in Northwestern Washington"*. 156 pp. M.S. Thesis. University of Washington. Seattle, WA.

Rashin, E. and C. Graber. 1992. Effectiveness of Washington's Forest Practice Riparian Management Zone Regulations for Protection of Stream Temperature. Publication No. 92-64. Washington Department of Ecology, Olympia. WA.

Rosgen, D.L.. 1996. *"Applied River Morphology"*. Wildland Hydrology. Pagosa Springs, CO.

Sinokrot, B.A. and H.G. Stefan. 1993. *"Stream Temperature Dynamics: Measurement and Modeling"*. Water Resources Research. 29(7): 2299-2312.

USDA Forest Service. February 1993. *"SHADOW: Stream Temperature Management Program User's Manual Version 2.3"*. Pacific Northwest Region. Portland, OR.

U.S. Environmental Protection Agency. 1991. *"Guidance for Water Quality-based Decisions: The TMDL Process"*. EPA 440/4-91-001.

U.S. Environmental Protection Agency. March 1999. *"Redwood Creek Sediment TMDL"*. EPA Region 9. San Francisco, CA.

U.S. Environmental Protection Agency. March 1999. *"South Fork Trinity TMDL"*. EPA Region 9. San Francisco, CA.

Washington State Forest Practices Board. November 1995. *"Standard Methodology for Conducting Watershed Analysis: Version 3.0"*. Olympia, WA.

Washington State Forest Practices Board. March 1997. *"Standard Methodology for Conducting Watershed Analysis -- Water Quality Module: Version 1.0"*. Olympia, WA.

Wetzel, R.G. 1983. *"Limnology"*. pp 10. 2nd Edition. Saunders College Publishing. Philadelphia, PA.

Wunderlich, W.O. 1972. *"Heat and Mass Transfer Between a Water Surface and the Atmosphere"*. pp 4 - 20. Water Resources Research Laboratory Report No. 14. Tennessee Valley Authority. Norris, TN.