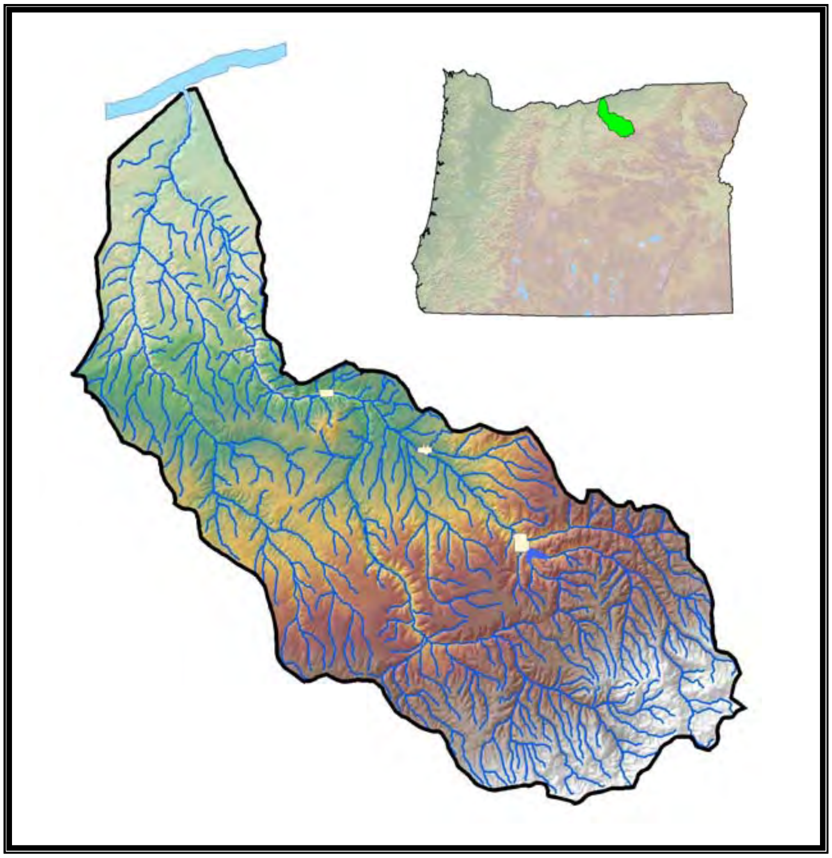
Willow Creek Subbasin TMDL

Appendix D
Stream Temperature Analysis

Vegetation, Hydrology and Morphology



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State of Oregon
Department of Environmental Quality

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River Temperature Analysis

Vegetation, Hydrology and Morphology

Willow Creek Subbasin

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CHAPTER 1. INTRODUCTION

This Appendix is a temperature assessment of the Willow Creek Subbasin, focusing on the mainstem of Willow Creek, for the purpose of establishing a Total Maximum Daily Load (TMDL) of in-stream heat to implement the Oregon water quality standard for temperature. *Part One* of this document is the TMDL policy expression and will rely on the information in this Appendix.

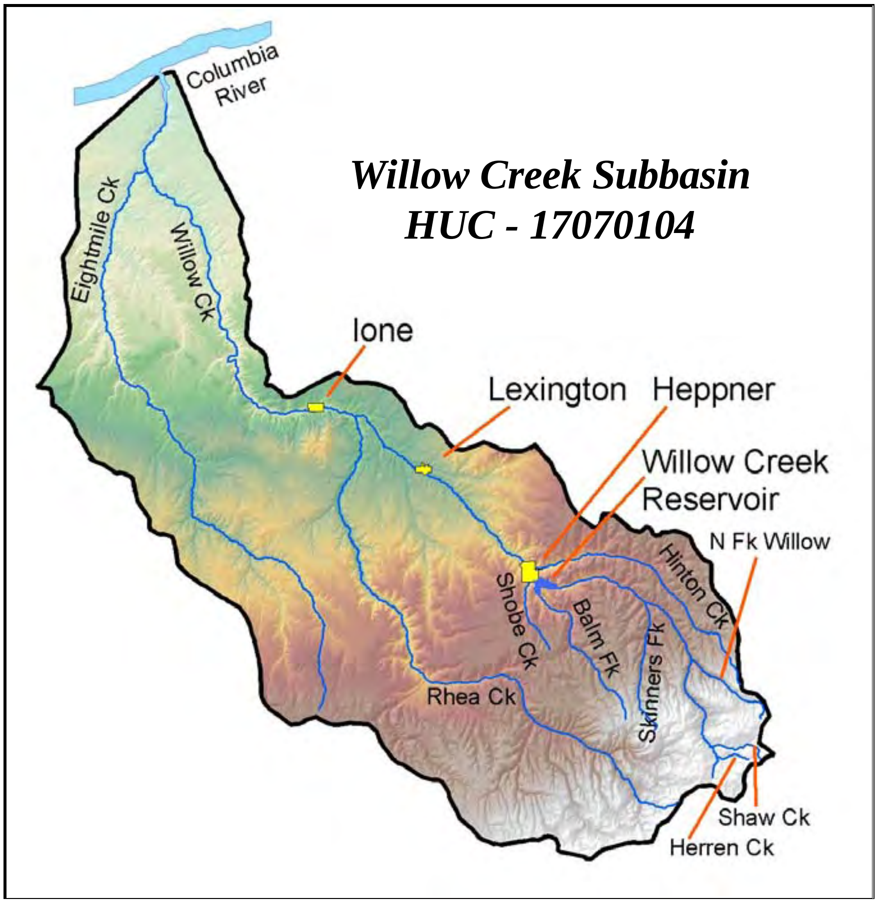


Figure D1-1. *Topographic illustration of the Willow Creek Subbasin showing locations of major streams and towns and the Willow Creek Reservoir.*

A note on Units and Abbreviations

Voluminous hydrologic and geomorphologic data for the United States and Oregon are published in English units. In this text, we have used metric as a general preference and English where otherwise convenient. Where units are metric or from existing reports or figures, conversions may not be provided. As in other chapters and appendices of this document, all but the most obvious abbreviations are defined at first occurrence and/or in **Appendix A**.

1.1 Scale & Location

The lands within the Willow Creek drainage cover 2280 km^2 (880 square miles) in northeastern Oregon. This area comprises one 4^{th} field hydrologic unit: the Willow Creek Subbasin (17070104). While the stream temperature TMDL considers all contributing surface waters within the Subbasin, this analysis focuses on Willow Creek.

Temperature simulation is conducted for Willow Creek from one-half km above Cutsforth Park (river kilometer 119.65), downstream to the mouth of the mainstem (**Figure D1-2**). Temperature model calibration was weak below the City of Ione (river kilometer 51.75) due to low flow. Because of this, model temperature output below this point is typically not included in this assessment, except where relative temperature is informative. Daily effective shade is simulated for perennial tributaries.

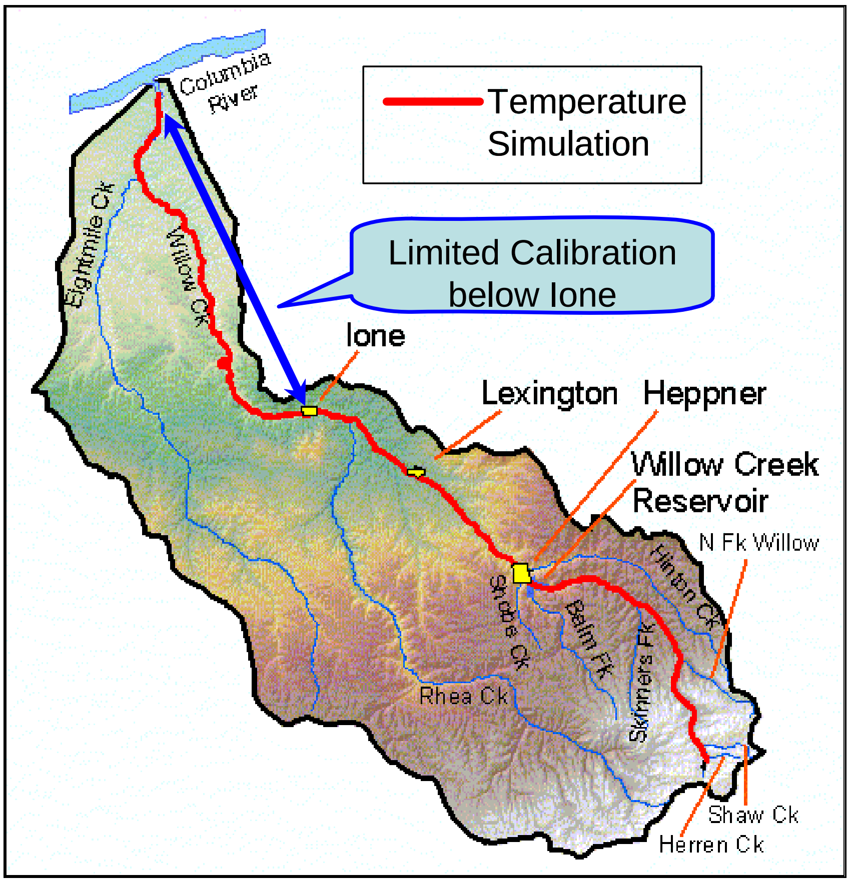


Figure D1-2a. *Longitudinal extent of temperature simulation – Cutsforth Park to the mouth (4,380 feet from Interstate 84 East Bound Bridge)*

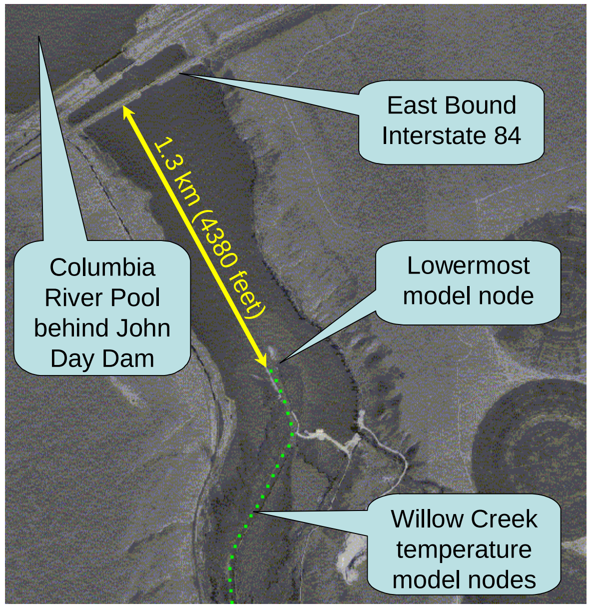


Figure D1-2b. *Location of lower extent of temperature simulation*

1.2 Local Coordination

The Morrow Soil and Water Conservation District, in Heppner, provided an outreach forum and coordinated monitoring with landowners.

1.3 Overview: Analysis and Stream Heating Processes

Parameters that affect stream temperature can be grouped as near-stream vegetation and land cover, channel morphology, and hydrology; including humidity and air temperature. Many of these stream parameters are interrelated (i.e., the condition of one may impact one or more of the other parameters). These parameters affect stream heat transfer processes and stream mass transfer processes to varying degrees. The analytical techniques employed to develop this temperature TMDL are designed to include all of the parameters that affect stream temperature.

Many parameters exhibit considerable spatial variability. For example, channel width measurements can vary greatly over small stream lengths. Some parameters can have a diurnal and seasonal temporal component as well as spatial variability. The current analytical approach developed for subbasin scale stream temperature assessment relies on ground level and remotely sensed spatial data. Techniques employed in this effort are statistical and deterministic modeling of hydrologic and thermal processes.

1.3.1 Stream Heating Processes

Variables that influence stream heating are listed in **Figure D1-3**. The relevant heat transfer processes are identified in **Figure D1-4**.

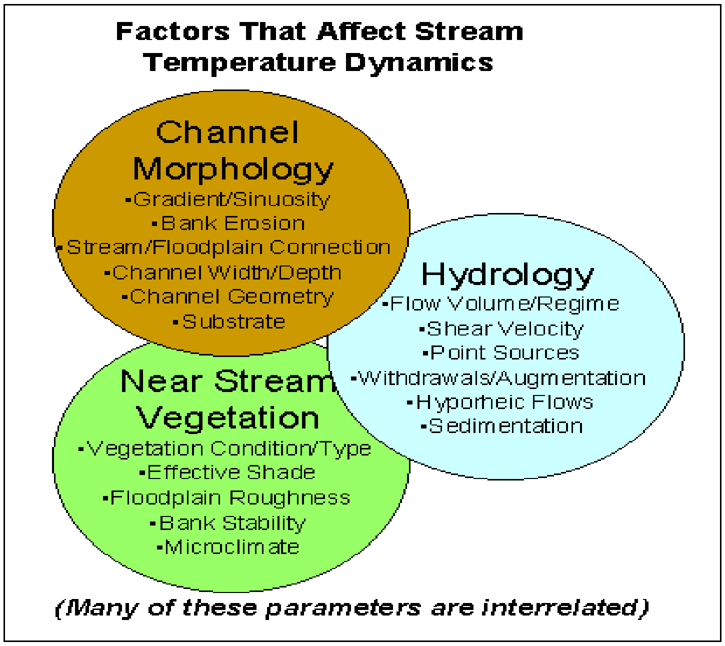


Figure D1-3. *These parameters, along with latitude, elevation, humidity, air temperature, and wind speed; relate to stream temperature and are accounted for in this analytical framework*

The heat transfer processes of **Figure D1-4** can be grouped into surface and subsurface processes. Mass transfer is accounted for above and below ground. Surface processes are related to solar radiation and evaporation. Heat input can be addressed through evaluation of surface processes, and the amount of solar radiation (the ultimate cause of stream heating) attributable to humans can be quantified. Temperature prediction requires quantitative assessment of all relevant heat transfer processes.

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

Heat Energy Processes

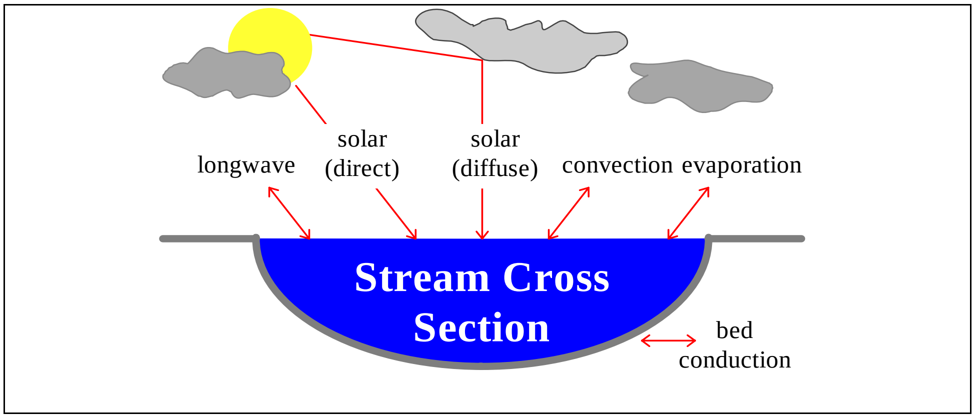
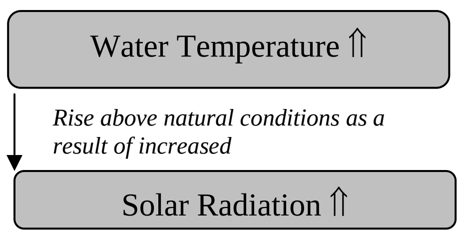


Figure D1-4. *Net Heat Energy Continuity equation. Stream heat transfer processes considered, along with mass transfer, in this analysis. The symbol Φ denotes the change in heat energy per time associated with a specific process.*

Stream temperature is an expression of heat energy per unit volume, which in turn is an indication of the rate of heat exchange between a stream and its environment. The heat transfer processes that control stream temperature include solar radiation, long wave radiation, convection, evaporation and bed conduction (Wunderlich, 1972; Jobson and Keefer, 1979; Beschta and Weatherred, 1984; Sinokrot and Stefan, 1993; Boyd, 1996). With the exception of solar radiation, which only delivers heat energy, these processes are capable of both introducing and removing heat from a stream.

When a stream surface is exposed to midday solar radiation, large quantities of heat will be delivered to the stream system (Brown 1969, Beschta et al. 1987). 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 (0.36µ to 0.76µ) 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% of solar energy passing through the stream surface is absorbed in the first 10 cm of the water column. Removal of riparian vegetation, and the shade it provides, contributes to elevated stream temperatures (Rishel et al., 1982; Brown, 1983; Beschta et al., 1987). Channel widening can similarly increase the solar radiation load. The principal source of heat energy delivered to the water column is solar energy striking the stream surface directly (Brown 1970). Exposure to direct solar radiation will often cause a dramatic increase in stream temperatures. The ability of riparian vegetation to shade the stream throughout the day depends on vegetation height, width, density and position relative to the stream, as well as stream aspect.



Both the atmosphere and vegetation along stream banks emit long wave radiation that can heat the stream surface. Water is nearly opaque to long wave radiation and complete absorption of all wavelengths greater than 1.2µ occurs in the first 5 cm below the surface (Wunderlich, 1972). Long wave radiation has a cooling influence when emitted from the stream surface. The net transfer of heat via long wave 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).

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 a given volume of water (Parker and Krenkel, 1969). 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).

Convection transfers heat between the stream and the air via molecular and turbulent conduction (Beschta and Weatherred, 1984). Heat is transferred in the direction of decreasing temperature. 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). Nevertheless, this should not be interpretted to mean that air temperatures do not affect stream temperature.

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.

Solar Radiation (Φ_{Solar}) is a function of the solar angle, solar azimuth, atmosphere, topography, location and riparian vegetation. Simulation is based on methodologies developed by Ibqal (1983) and Beschta and Weatherred (1984). *Longwave Radiation* (Φ_{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). *Evaporation* ($\Phi_{\text{Evaporation}}$) 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). *Convection* ($\Phi_{\text{Convection}}$) is a function of the Bowen Ratio and terms include atmospheric pressure, and water and air temperatures. *Bed Conduction* ($\Phi_{\text{Conduction}}$) simulates the theoretical relationship ($\Phi_{Conduction} = K \cdot dT_b / dz$), 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).

The ultimate source of heat energy is solar radiation, both diffuse and direct. Secondary sources of heat energy include long-wave radiation from the atmosphere and streamside vegetation, streambed conduction and in some cases, groundwater exchange at the water-stream bed interface. Several processes dissipate heat energy at the air-water interface, namely: evaporation, convection and back radiation. Heat energy is acquired by the stream system when the flux of heat energy entering the stream is greater than the flux of heat energy leaving. The net energy flux provides the rate at which energy is gained or lost per unit area and is represented as the instantaneous summation of all heat energy components.

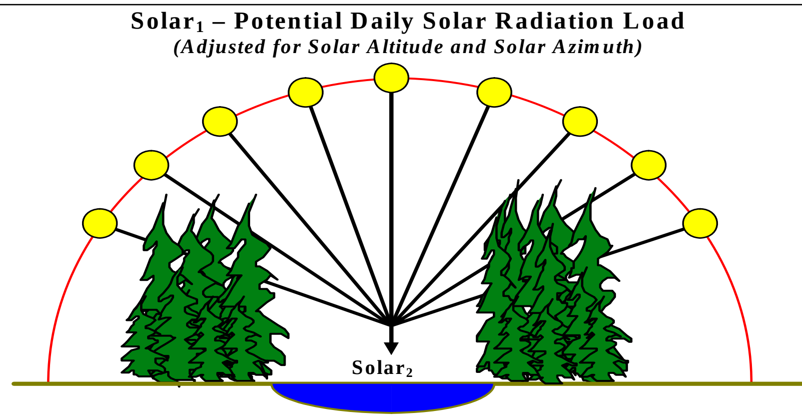
1.3.2 The Dynamics of Shade

Stream surface shade is a function of several landscape and stream geometric relationships. Some of the factors that influence shade are listed in **Table D1-1**. Geometric relationships important for understanding the mechanics of shade are displayed in **Figure D1-5**. In the Northern Hemisphere, the earth tilts on its axis toward the sun during summertime months allowing longer day length and higher solar altitude, both of which are functions of solar declination (i.e., a measure of the earth's tilt toward the sun). Geographic position (i.e., latitude and longitude) fixes the stream to a position on the globe, while aspect provides the stream/riparian orientation. Riparian height, width and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation (i.e., produce shade). The solar position has a vertical component (i.e., altitude) and a horizontal component (i.e., azimuth) that are both functions of time/date (i.e., solar declination) and the earth's rotation (i.e., hour angle). While the interaction of these 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 D1-1. *Factors that Influence Stream Surface Shade*

Description	*Measure*
Season/Time	Date/Time
Stream Characteristics	Aspect, Near-Stream Disturbance Zone Width
Geographic Position	Latitude, Longitude
Vegetative Characteristics	Buffer Height, Buffer Width, Buffer Density
Solar Position	Solar Altitude, Solar Azimuth

Percent effective shade is perhaps the most straightforward stream parameter to monitor and calculate and is easily translated into quantifiable water quality management and recovery objectives. **Figure D1-6** demonstrates how effective shade is monitored and calculated. Using solar tables or mathematical simulations, the *potential daily solar load* can be quantified. The *measured solar load* at the stream surface can easily be measured with a Solar Pathfinder© or estimated using mathematical shade simulation computer programs (Boyd, 1996 and Park, 1993).



Effective Shade Defined:

$$\text{Effective Shade} = \frac{(\text{Solar}_1 - \text{Solar}_2)}{\text{Solar}_1}$$

Where,

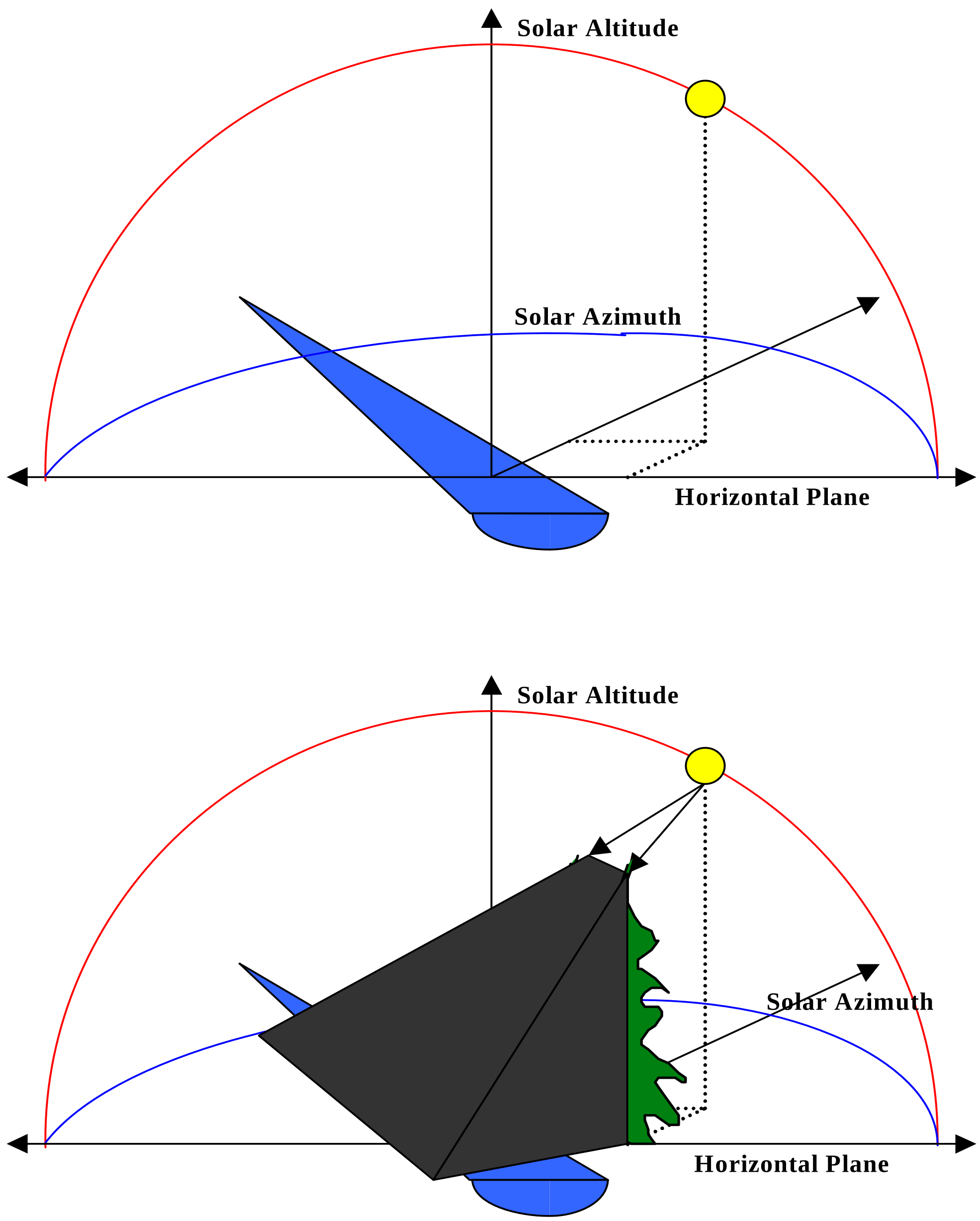
Solar$_1$: Potential Daily Solar Radiation Load
Solar$_2$: Measured Daily Solar Radiation Load at Stream Surface

Figure D1-5. *Effective shade defined*

Figure D1-6. *Geometric Relationships that Affect Stream Surface Shade*

Solar Altitude and **Solar Azimuth** are two basic measurements of the sun's position. When a stream's orientation, geographic position, riparian condition and solar position are known, shadeing characteristic can be simulated.

Solar Altitude measures the vertical component of the sun's position
Solar Azimuth measures the horizontal component of the sun's position



1.4 Stream Assessment for Oregon Temperature Standard

Human activities and aquatic species that are to be protected by water quality standards are deemed beneficial uses. Water quality standards are developed to protect the most sensitive beneficial use within a water body of the State, thereby protecting all beneficial uses. *The stream temperature standard is designed to protect cold water fish, including salmon and trout, through their various life phases, as the most sensitive beneficial use. The standard is described in Part One of this document.*

1.4.1 Summary of Stream Temperature TMDL Approach

Oregon's TMDL approach for temperature is summarized in **Table D1-2**. Stream temperature TMDLs are generally scaled to a subbasin or basin and include all perennial surface waters with salmonid presence or that contribute to areas with salmonid presence. Since stream temperature results from cumulative interactions between upstream and local sources, the TMDL considers all surface waters that affect the temperatures of 303(d) listed water bodies. For example, the Upper Grande Ronde River is water quality limited for temperature. To address this listing in the TMDL, the mainstem and all major tributaries are included in the TMDL analysis and TMDL targets apply throughout the entire stream network. This broad approach is necessary to address the cumulative nature of stream temperature dynamics.

Table D1-2. *Summary of Temperature TMDL Approach*

Temperature Standard* Criteria to protect beneficial uses.
303(d) Listing* When water quality standard criteria are not met, waters are listed and TMDLs are Developed.
Conduct TMDL Source Assessment
Establish TMDL Allocations & Surrogate Measures
Prepare Water Quality Management Plan

*The Oregon temperature standard and 303(d) listings are described in Part 1.

For the Willow Creek Subbasin and other drainage areas in the region, DEQ has simulated conditions reflecting minimized anthropogenic (human-caused) warming. ***These simulations show that numeric biologically-based water quality standard temperature criteria are exceeded in much of the subbasin in the absence of quantifiable human disturbance.*** In such circumstances, the Oregon water quality standard targets a best estimate of natural condition, insofar as stream temperature is concerned, i.e., minimized human-caused heating. Accounting for the amount of human-related temperature increase is therefore central to the analysis. The pollutant is heat. The TMDL assesses the anthropogenic contributions of nonpoint source solar radiation heat loading results from varying levels of decreased stream surface shade throughout the subbasin. Decreased levels of stream shade are caused by near stream land cover disturbance or removal and channel morphology changes. Another anthropogenic source of stream warming is reduction in stream flow.

Natural thermal potential (NTP, *OAR 340-041-0002*) is a key term in the Oregon temperature TMDL context. In rule, *NTP* is defined as "the determination of the thermal profile of a water body using best available methods of analysis and the best available information on the site-potential riparian vegetation, stream geomorphology, stream flows, and other measures to reflect natural conditions." For the purpose of this assessment, **NTP near-stream land cover** is defined as *that vegetation which has the potential to grow and reproduce on a site, given climate, elevation and soil properties, and natural hydrologic and geomorphic processes*. **NTP channel morphology** *is the more stable configuration that would occur with less human disturbance*. NTP does not consider management or land use as limiting factors. **NTP is the design condition used for TMDL analysis.**

NTP is not necessarily an estimate of pre-settlement conditions. Although it is important to consider historic land cover patterns, channel conditions and hydrology, data are often scarce and many areas have been altered to the point that the historic condition is no longer attainable given irreversible changes.

Oregon stream temperature TMDLs allocate heat loading. Nonpoint sources are expected to limit heat input to NTP target levels. Point sources are allowed heating that results in minimal increase outside of a defined mixing zone (**Section 4.5**). The nonpoint source heat allocation is translated to effective shade surrogate measures that linearly translate nonpoint source solar heating allocations. Effective shade surrogate measures provide site-specific targets that are readily measurable locally. Attainment of the surrogate measures ensures compliance with the nonpoint source allocations. Other surrogates or measures of progress are identified as well, such as NTP channel width.

In order to assess and allocate heat loads as called for in the preceding paragraphs, <u>the steps in the TMDL assessment and analytical process are as follows:</u>

1. Conduct monitoring (temperature and variables that influence heating).
2. Conduct data evaluation and Geographic Information System (GIS) analysis to assess and characterize current conditions.
3. Calibrate temperature model (simulate hydrology, heat and temperature). Temperature and heat simulation is both longitudinal and diel through up to 21 consecutive summer days.
4. Estimate NTP conditions.
5. Simulate temperature and heating patterns for NTP conditions.
6. Establish allocations. Allocations are based on NTP conditions, if NTP temperatures are greater than other applicable criteria at the subbasin scale.
7. Translate heat load allocations to surrogate measures.
8. Identify the pattern of water quality standard attainment or departure, comparing current conditions to NTP.

The purpose of stream temperature modeling is to (1) determine temperatures for various scenarios including NTP, (2) assess heat loading for the purpose of TMDL allocation, (3) compute readily measurable surrogates for the allocations, and (4) to better understand heat controls at the local and subbasin scale. As well as providing for quantitative allocation, this informs the questions:

- Can water quality standard numeric biological criteria be met? Where?
- How much of the heating is human caused?
- Where are the greatest deviations from potential or standard criteria?
- How is heat most effectively moderated?

1.4.2 Limitations of Stream Temperature TMDL Approach

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

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

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

- Current analysis is focused on a defined critical condition. This usually occurs in late July or early August when stream flows are low, radiant heating rates are high and ambient conditions are warm. However, there are several other important time periods where data and analysis are less explicit. For example, spawning periods have not received such a robust consideration.
- Current analytical methods fail to capture some upland, atmospheric and hydrologic processes. At a landscape scale, these exclusions can lead to errors in analytical outputs. For example, methods do not currently exist to simulate riparian microclimates at a landscape scale. Regardless, recent studies indicate that forested microclimates play an important, yet variable, role in moderating air temperature, humidity fluctuations and wind speeds. Sinuosity change is typically not simulated, because the selected simulation methods are spatially explicit.
- In some cases, there is not scientific consensus related to riparian, channel morphology and hydrologic potential conditions. This is especially true when confronted with highly disturbed sites, meadows and marshes, and commonly un-assessed hyporheic/subsurface flows.

Other limitations to this effort include:

- The scale of this effort is large with obvious challenges in capturing spatial variability in stream and landscape data. Available spatial data sets for land cover and channel morphology are coarse, while derived data sets are limited to aerial photo resolution, rectification limitations and human error.
- Rigorous quantification techniques for estimating potential subsurface inflows/returns and behavior within substrate are not employed in this analysis. While analytical techniques exist for describing subsurface-stream interactions, it is beyond the scope of this effort with regard to data availability and available time and funding resources. Estimates are based on best professional judgment involving geology, monitoring and mass-thermal balance.
- Land use patterns vary through the drainage from heavily impacted areas to areas with little human impacts. In the middle and lower basin, there are few areas without some level of either current or past human related modifications. The estimation of potential stream conditions reflecting minimal human disturbance is based on best professional judgment and extrapolation from current conditions and historical data. It is acknowledged that as better information is developed assumptions should be refined.

1.5 Basin Description

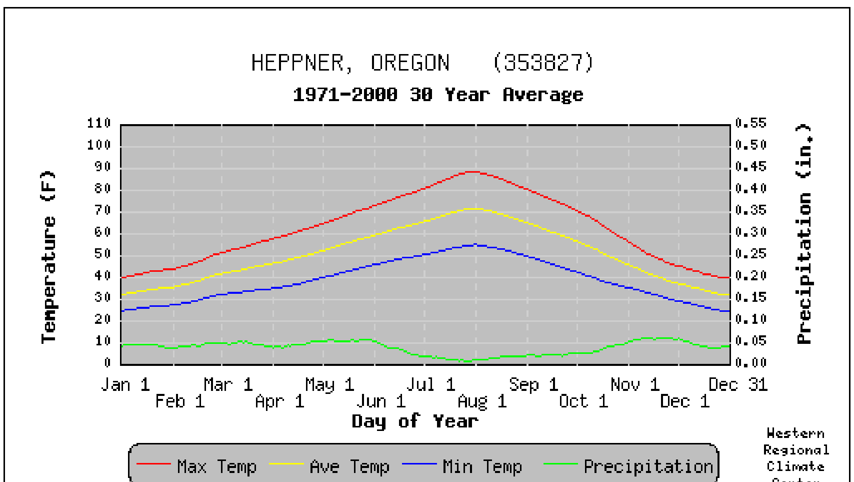
1.5.1 Physiography and Development

The length of the Willow Creek is roughly eighty miles. Basin elevation ranges from 5,700 to 260 feet above sea level (**Figure D1-1** illustrates topography). The relatively shallow Willow Creek Valley is narrow, flat-bottomed and steep walled, draining the basalt plateau of the Blue Mountains. As Willow Creek descends towards the city of Heppner, it is impounded by a dam built by the US Army Corps of Engineers (USACE) in the 1980's. Further basin description can be found in **Part 1**, **Section 1.2**.

The history of human modification of Willow Creek includes levees, irrigation structures, the Willow Creek Reservoir, vegetation removal, straightening and decreased floodplain due to various agriculture and development activities. One response is that the channel is substantially incised or enlarged through much of its length below Heppner, with little stream-side shading. Collectively these alterations have led to modified surface flow patterns, ground-surface water interaction, channel shape and riparian vegetation, influencing heating rates in the Willow Creek.

1.5.2 Climate

Willow Creek Subbasin receives relatively low precipitation, with lower Willow Creek averaging less than ten inches per year. The mean annual precipitation in Heppner is 10 to 14 inches. More rain falls in the upper watershed – however the upper elevations comprise a small fraction of the Subbasin area. Air temperature exhibits a large seasonal variation with common annual occurrences of temperatures above 100 ºF (38 ºC) in the summer and below zero ºF (-18 ºC) in the winter. Heppner's monthly average patterns of precipitation and air temperature are graphed in **Figure D1-7**.



- Max. Temp. is the average of all daily maximum temperatures recorded for the day of the year between the years 1971 and 2000.
- Ave. Temp. is the average of all daily average temperatures recorded for the day of the year between the years 1971 and 2000.
- Min. Temp. is the average of all daily minimum temperatures recorded for the day of the year between the years 1971 and 2000.
- Precipitation is the average of all daily total precipitation recorded for the day of the year between the years 1971 and 2000.

http://www.wrcc.dri.edu/summary/climsmor.html

Figure D1-7. *Monthly average temperature and precipitation for Heppner*

1.5.3 River Flow
Summer flow in Willow Creek below the Willow Creek Reservoir ranges from 0-25 cubic feet per second, with the upper end of the range normally owing to Reservoir releases for irrigation. Willow Creek flow entering the Reservoir is slight during August – September, with the lowest flows often less than 1-3 cubic feet per second. At some point below Lexington or Ione, ranging longitudinally from year to year over many miles, surface flow completely attenuates leaving a dry streambed. This was true through 2001, but with greater Reservoir releases for recent irrigation applications, the downstream extent of surface flow has not been documented. Flow loss mechanisms include evapotranspiration and irrigation diversion.

The major tributaries of Willow Creek are, from top to bottom: Herren Creek, Shaw Creek, North Fork of Willow Creek, Skinner's Fork, Balm Fork, Hinton Creek, Rhea Creek and Eightmile Creek. Of these, Rhea and Eightmile Creeks exhibited dry streambeds in their lower reaches, carrying no surface flow into Willow Creek during the late July and early August (2000 and 2001) TMDL field monitoring.

1.5.4 Population and Land Ownership
The largest population Center in the Subbasin is the City of Heppner, with a population of roughly 1,400. Other urban communities are small and infrequent. Population is discussed further and land ownership maps and percentages are portrayed at the end of **Part 1**, **Section 1.2**.

1.5.5 Point sources
In the Willow Creek Subbasin, there are two sources that are classified as point sources in accordance with the National Pollutant Discharge Elimination System (NPDES): The City of Heppner's municipal sewage treatment plant and a wood-chip fired electrical power generation facility. Both are discussed further in **Part 1, Section 1.2**.

1.5.6 Land Use & Irrigation
The most widespread land use is agriculture: dry land wheat and valley bottom irrigated crops. Other uses include urban, commercial-industrial usage and forest management. Land cover and land use are illustrated at the end of **Section 1.2**, **Part 1**. There are numerous irrigation diversions and structures along Willow Creek and its tributaries.

1.5.7 Vegetation
Riparian vegetation will be addressed in detail subsequently in this Appendix. Land cover, where not developed, can be broadly viewed as pine-fir forest in the upper eastern part of the basin and shrub-steppe and agricultural below. The perennial riparian corridors below the conifer zone were likely dominated by willow, alder and cottonwood. This estimate is based on climate, soils, stream flow, historical accounts, neighboring subbasins and relict existing riparian vegetation.

CHAPTER 2. AVAILABLE DATA

2.1 Ground Level Data

Several ground level data collection efforts have been completed for the Willow Creek Subbasin. Available ground level data sources are discussed in detail in this Chapter. Specifically, this stream temperature analysis relies on the following data types: hourly air and water temperature and humidity; flow volume, wetted width and depth; channel cross-sectional area, width, depth and substrate size; and vegetation types and shading. These data were acquired through gage data and manual in-stream measurements; riparian surveys including effective shade measurements; channel morphology and substrate surveys; automated hourly measurements of stream temperature; and weather station hourly humidity, wind speed and air temperature. Additional discussion of monitoring can be found in **Appendix C**, which generally addresses monitoring for pH, bacteria and temperature.

2.1.1 Continuous Stream Temperature Data

Continuous stream temperature data are used in this analysis to calculate temperature statistics and assess the temporal and spatial pattern of stream temperature. Continuous temperature data was collected at one location for a specified period of time, usually spanning several summertime months. Measurements were collected using recording thermistors[1] and data from these devices were routinely checked for accuracy. The units were set to record measurements hourly. Recorders were placed on or near the streambed, typically in or near riffle thalwags. These locations were selected to represent well-mixed flow. Continuous temperature data were collected by DEQ for the TMDL during 2000. Other organizations provided continuous temperature data, though this was not used for mainstem calibration as the non-DEQ data represented a time or location outside of the simulation. Selected data sets were processed for the seven-day moving averages of daily maximum stream temperature.

Figures D2-1 and **D2-2** displays continuous temperature monitoring locations and summary data. **Figure D2-3** provides reference locations in relation to river kilometer and river mile. **Table D2-1** lists the peak seven-day moving average daily maximum stream temperatures and the monitoring location description. Calculated seven-day moving average maximum stream temperatures indicate that a large extent of the Willow Creek system exceeds the upper level of applicable biologic criteria [20.0 ºC (68.0 ºF)] of Oregon's stream temperature standard [OAR 340-041-0028(4)(e)], designed to protect redband trout. DEQ recognizes that this criterion is not attainable throughout the subbasin in the warm season. A key function of this analysis is to assess feasibly attainable temperature reduction.

Note that as discussed elsewhere in this document, lower Willow Creek became intermittent after the thermistors were installed. Though the thermistors remained underwater in short reaches, these ponded areas were separated by reaches of dry stream bed.

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

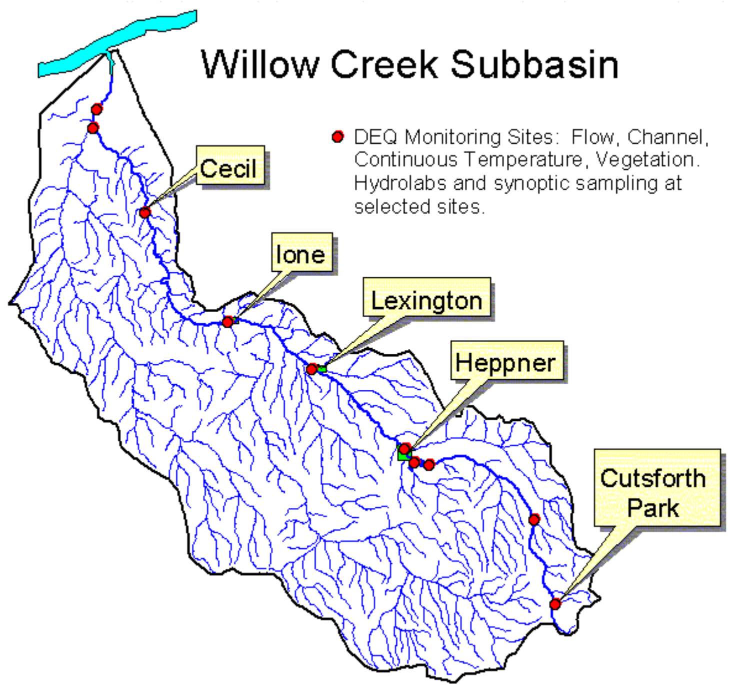


Figure D2-1. *Year 2000 mainstem monitoring locations, including continuous temperature monitoring. Tributary temperature monitoring was implemented as well, at the mouths of Hinton, Shobe, Herren and Shaw Creeks.*

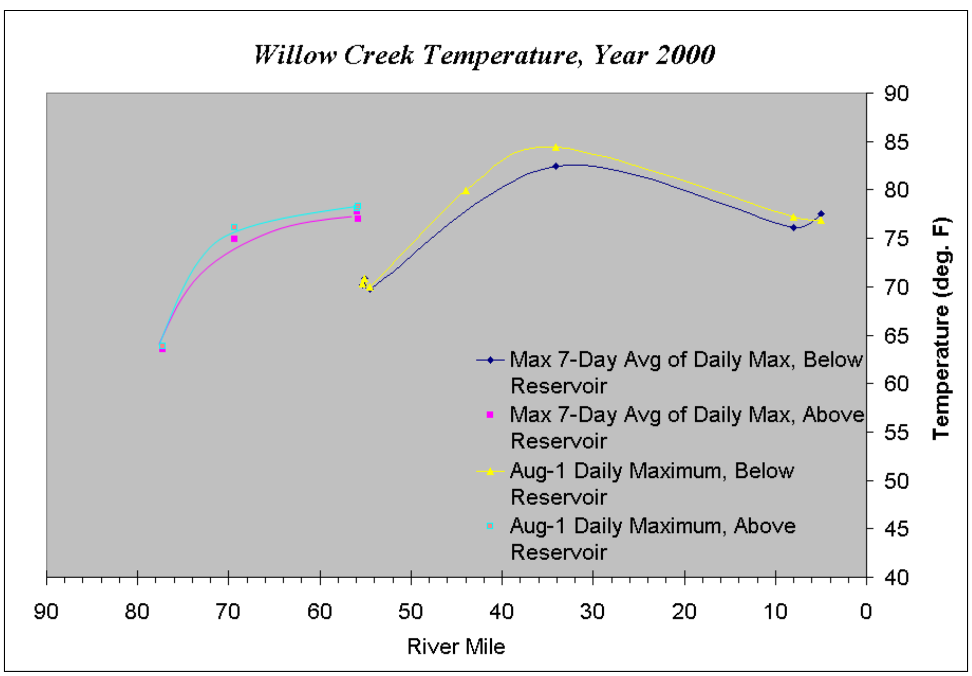


Figure D2-2. *Year 2000 mainstem continuous stream temperature measurement maxima of the 7-day moving average of daily maxima*

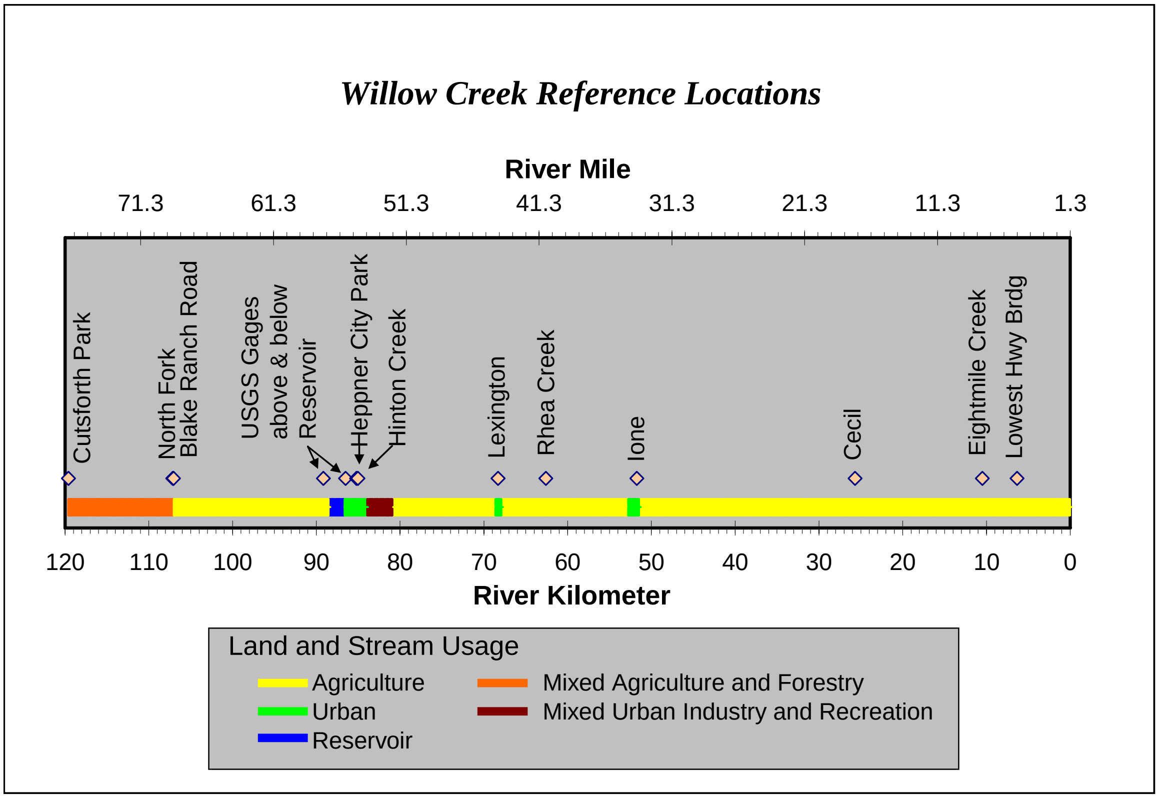


Figure D2-3. ***{Recall Figure 1.2-3}*** *Locations referenced by kilometer and river mile. It should be recognized that the above mileage is imprecise due to river change and varying mapping methods. However, model input and output for simulations of temperature, effective shade and hydrology are precisely referenced at 50-meter intervals based on ortho-imagery (current aerial photographs in GIS). The downstream origin (1.3 km south of I-84) is shown in* ***Figure D1-2b****.*

Table D2-1. *Seasonal peak seven-day moving average daily maximum stream temperatures*

				7-Day Average of Daily Maximum Temperature (°F)								
Stream	**Site Description**	**River Mile (main-stem)**	**Data Source**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Willow Ck	Frontage road at base of Hwy 74 grade where 74 enters valley at its southern extent	5.0	DEQ									77.5
Willow Ck	Bridge below 8 Mile Creek	8.0	DEQ									76.1
Eight Mile Ck	Mouth											
Willow Ck	Bridge at Cecil	17.8	DEQ									
Willow Ck	Bridge by Ione High School	34.1	DEQ									82.4
Rhea Ck	Rhea Creek River Mile 16		ODFW				77.5					
Rhea Ck	Mouth											
WWTP effluent	Heppner WWTP outfall		City									70.2
Willow Ck	Heppner WWTP, golf course bridge above outfall	54.5	City									69.8
Willow Ck	NW Gale St. bridge	55.1	DEQ									70.9
Willow Ck	50 yards below Heppner City Park at Church St	55.3	DEQ									70.2
Balm Fork	USGS gage site, 1/4 mile above reservoir		US COE									64.7
Willow Ck	USGS gage site	55.8	US COE, DEQ									77.7
Willow Ck	1/4 mile above reservoir, directly beneath hwy bridge	55.9	DEQ									77.0
Willow Ck		61.0	ODFW				74.6					
Willow Ck	1/4 mile above Blake Ranch Rd	69.3	DEQ									74.9
Shaw Ck	Mouth		USFS									64.7
Herren Ck	Mouth		USFS	62.6	56.8	63.2		61.5	62.1	64.2		63.5
Willow Ck	1/4 mile above Cutsforth Park, USFS pull-off	77.3	USFS, ODFW, DEQ		60.4		60.8			61.4		63.5
Gray shading for year 2000 indicates that streamflow was intermittent during the monitoring season												

Abbreviations in this table: US Army Corps of Engineers (US COE), US Forest Service (USFS), Oregon Department of Fish and Wildlife (ODFW), Department of Environmental Quality (DEQ).

2.1.2 Flow Volume – Gage Data and In-stream Measurements

Flow volume and cross-sectional measurements were collected during late July through September of 2000 and 2001. These measurements were used to develop longitudinal flow [discharge (**Figure D2-4**), velocity, wetted width and depth] profiles for the purpose of temperature modeling. July and August are of particular concern. These are the warmest months due to combined warm weather and low in-stream flow.

Model input flow data consists of daily average flow from stream gaging stations and discrete measurements from the synoptic sites. During August – September of 2000, flow was measured manually at the ten key monitoring sites along Willow Creek. At the time, only two long-term gaging stations were maintained on the model reach – the USGS gages immediately upstream and downstream from Willow Creek Reservoir. A gage was also maintained by the USGS on Balm Fork. Synoptic flow measurement locations are shown in **Figure D2-1**. Other information included the Oregon Water Rights Information System (WRIS, OWRD). WRIS is a database used to monitor information related to water rights. A separate database tracks points of diversions (POD). Locations of water rights points of diversion are shown in **Figure D2-5**. Information relating to points of diversion assists in developing hydraulic profiles and understanding the dynamics of surface water in the Subbasin.

Based on this combined information, flow profiles were prepared for the length of the model reach. Flow simulation (**Section 3.4** and **3.5**) was calibrated to the August 1, 2000 profile as shown in **Figure D2-4**. During the 21-day model interval, flow varied each day as assessed by stationary gages. The longitudinal flow profile appears generally stable, based on the four dates of synoptic flow assessment identified in **Figure 1.2-2** of the main document.

From river kilometer, 5-45 the flow and temperature model was calibrated to hypothetical flow levels greater than measured. Actual flow in that reach was essentially zero, with isolated pools separated by dry streambed. The model Heat Source does not operate for flows less than 0.25 cubic feet per second and can produce unreliable output at flows less than 0.5-3.0 CFS, depending on local conditions. Because of this, the low flow reach is not processed for NTP temperature determination, but the model was run at artificially higher flow to view the temperature differences that flow, channel geometry and shade can produce in this lower section. It is noted here that the percent effective shade output is accurate because heat flux is not dependant on flow.

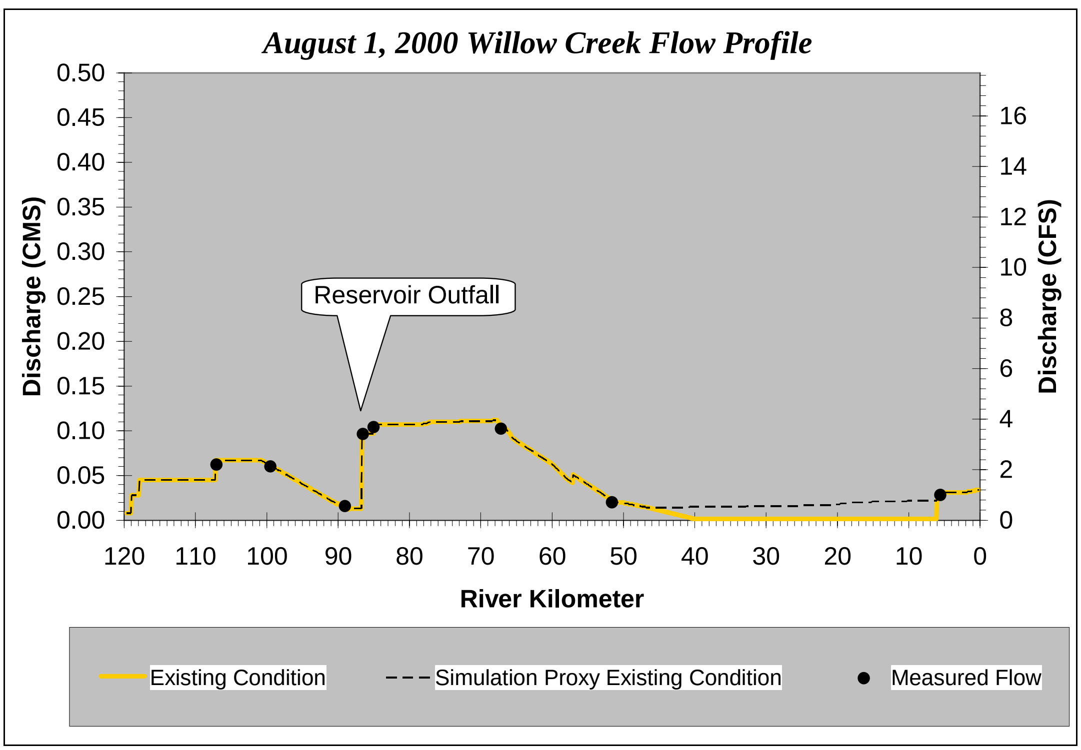


Figure D2-4. *August 1, 2000 flow profile for Willow Creek. The point locations represent measured flow and the line plot is simulated flow.*

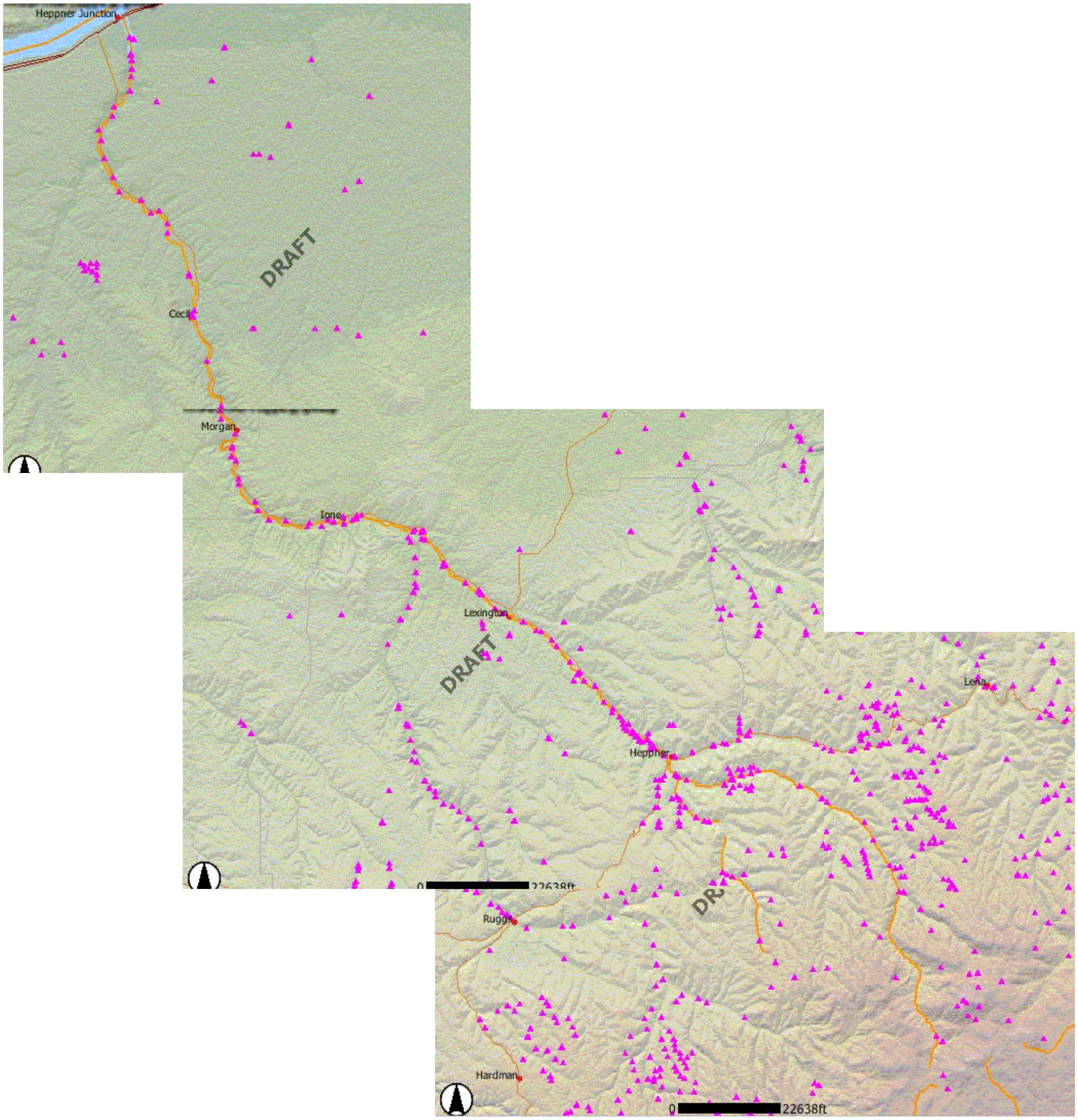


Figure D2-5. *Points of diversion for water rights in willow Creek Subbasin, draft locations, (OWRD website)*

2.1.3 Channel Morphology

This section describes the ground level data used to assess the existing morphologic condition. **Section 3.2** expands on this with GIS-derived data and describes the estimate of NTP channel morphology.

During the summer of 2000, DEQ and others collected stream morphologic data at ten locations on Willow Creek (**Figure D2-1**). A modified Rosgen Level II Inventory (Rosgen 1996) was applied to assess channel cross-sectional geometry and substrate composition. Transects were surveyed using a laser level. Substrate was measured based on modification of the Wolman (1954) pebble count method.

Channel *type (classification), width, depth, gradient and map pattern* and related characteristics were assessed. Stream classification allows comparison of the Willow Creek to other rivers, and reduces the amount of information needed to describe the river system. The reader is referred to Rosgen (1996) for a more thorough explanation of the Rosgen classification (illustrated in **Figure D2-6**), and the following general description may assist in understanding the designations:

- A-type streams are steep, relatively straight and without much floodplain development (e.g., small forest tributaries).
- B-type streams are intermediate in gradient and sinuosity between A and C-types.
- C-type streams are meandering and have floodplains. C-type is the predominant stable channel <u>potential</u> for Willow Creek.
- D-type streams are braided or multi-thread. There were no assessed D-type Willow Creek reaches.
- E-type streams are very meandering and low gradient, often with grassy banks. The only E-type reach assessed is just above Cutsforth Park.
- F-type streams are slot-shaped in cross-section; they are entrenched, typically unstable, and possess fairly low gradients, much like C- and E types. Currently F-types channels are common between Heppner and Lexington.

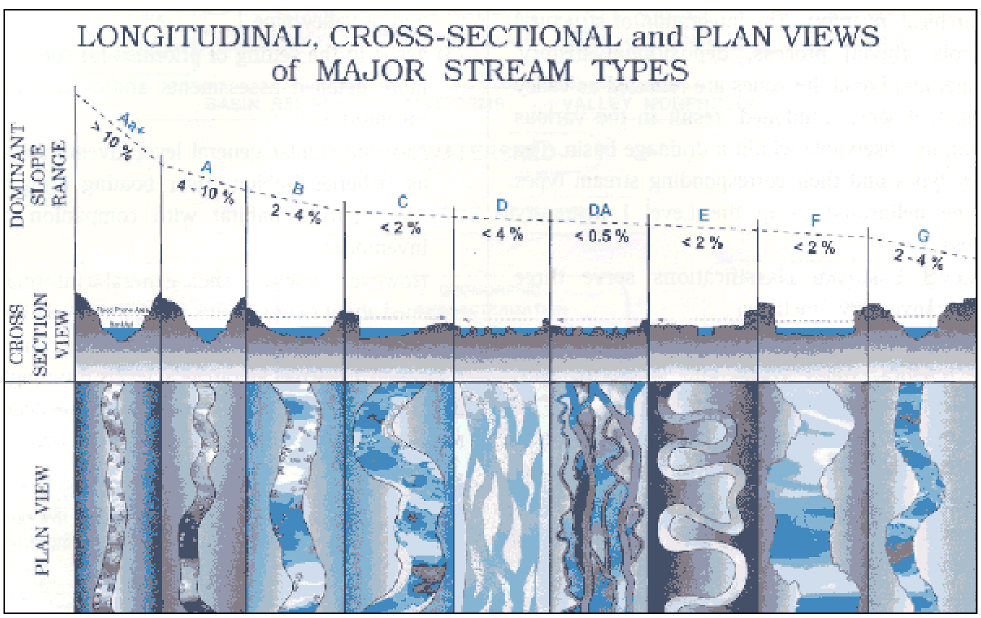


Figure D2-6. *Illustration of gradient, map pattern and cross-section of principal stream types (from Rosgen, 1996)*

Channel morphology assessment relates to the bankfull stage of river flow. **Bankfull stage** is formally defined as the stream level that "*corresponds to the discharge at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels*" (Dunne and Leopold, 1978). Research on bankfull discharge for North American streams has resulted in general agreement that the annual series bankfull discharge recurrence intervals are approximately equal to a 1.5 year event (Dury et al., 1963; Leopold et al., 1964; Hickin, 1968; Dunne and Leopold, 1978; Leopold, 1994). <u>In other words, stream channels are built and maintained by relatively high flows, on a nearly annual basis</u>. Within the neighboring John Day and encompassing Umatilla Basin, research has identified the bankfull discharge recurrence interval range of 1.12-1.84 (Castro and Jackson, 2001).

The data in this section supports thermal source assessment and modeling, either directly, or in the development or validation of derived data as described in Chapter Three. **Figure D2-7** illustrates the surveyed channel cross-sections and **Table D2-2** tabulates summary data. Channel type, bankfull width, width/depth and sinuosity have potential to change, favoring temperature reduction, as human-related disturbance decreases.

Through much of the Willow Creek Subbasin, stream channel modifications have occurred through various human influences. This is particularly evident in the agricultural and urban lowlands. Disturbance of upland and riparian vegetation along with increased erosion, bank soil disturbance, stream re-location, stream straightening and diking are common. These alterations generally lead to channel widening or down-cutting followed by widening. Increased width and reduced shade lead to increased solar heating. Reduced channel disturbance and increased riparian vegetation will support a return toward more natural river temperatures.

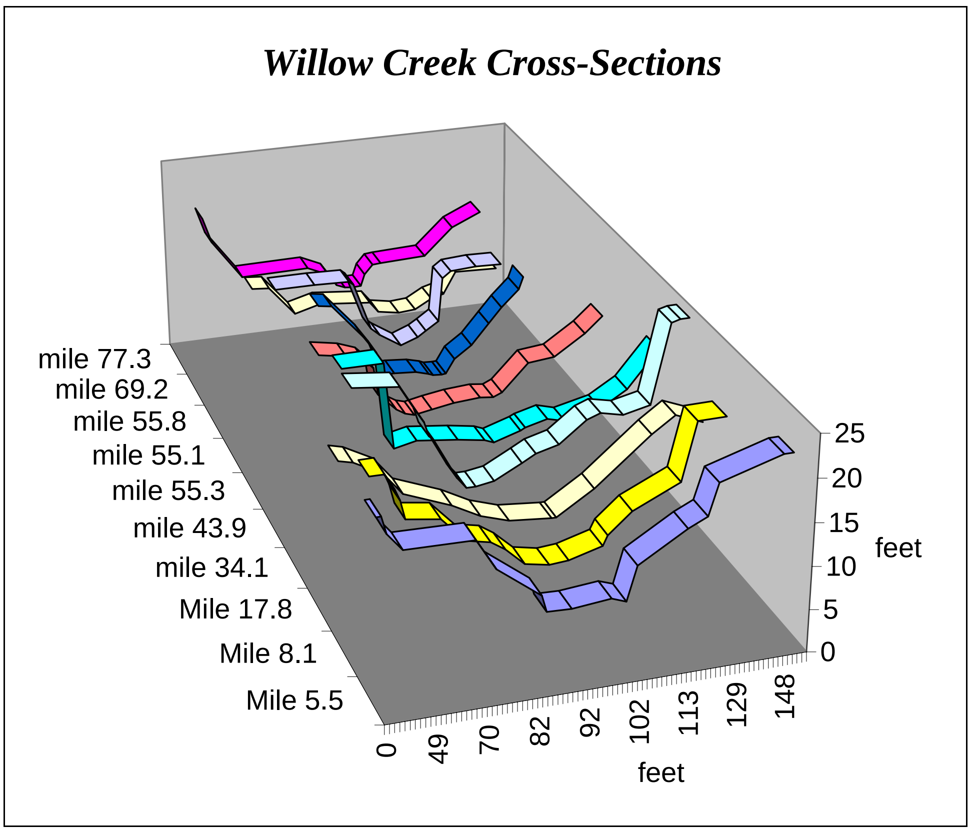


Figure D2-7. *Illustration of channel cross-sections (ribbon ends are at floodprone width)*

Table D2-2. *Summary of channel morphology monitoring data using Rosgen Level II protocol*

Willow Creek Morphology Description, Summer 2000

Site #	Site Description	River Mile	Rosgen (1996) Stream Type	Bankfull Width (feet)	Bankfull $Depth_{mean}$ (feet)	Bankfull Width / $Depth_{mean}$ Ratio	Bankfull $Depth_{max}$ (feet)	Flood-Prone Area Width (feet)	Entrench-ment Ratio	Bankfull Cross-Sectional Area ($feet^2$)	Estimated Channel Gradient (7.5' quad*.9)	Estimated Sinuosity (7.5' quad*1.1)	Channel Materials (D_{50} Index)	Drainage Area ($mile^2$)
1	200 yd below hwy brdg (1/2 mi above thermistor)	5.5	B4g	20.0	2.7	7.4	3.1	38	1.9	54.1	0.0038	1.17	4	854.1
2	200 yd above brdg, 150 yd above 8 Mile Creek	8.1	B3e	19.9	1.8	10.8	2.5	38	1.9	36.6	0.0038	1.82	3	849.1
3	100 yd above Cecil brdg (200 yd above thermistor)	17.8	B4c	29.9	2.0	15.1	3.0	56	1.9	59.2	0.0050	1.17	4	563.5
4	100 yd above brdg by Ione High School (200 yd above thermistor)	34.1	C4	24.2	2.0	11.9	3.7	61	2.5	49.1	0.0058	1.38	4	515.0
5	200 yd below Lexington F-St. bridge (100 yd below thermistor)	43.9	F4	48.9	0.8	64.1	2.0	64	1.3	37.3	0.0058	1.38	4	201.9
9	100 ft below NW Gale St. brdg (at thermistor site)	55.1	F4	15.5	1.1	13.9	1.8	22	1.4	17.2	0.0058	1.38	4	146.4
8	50 yd d/s Heppner City Park at Church St, 200 ft above Main st brdg (at thermistor)	55.3	F4	22.5	0.4	57.5	1.0	28	1.2	8.8	0.0058	1.38	4	96.5 sq. mi. drain to Reservoir
11	1/4 mile u/s reservoir, 200 m below hwy bridge (200 m below thermistor)	55.8	E5	21.2	5.8	3.6	8.1	1000	47.2	123.3	0.0106	1.38	5	67.5
12	Lower end of Ione guardrail section, 1/4 mile below Blake Ranch Rd (100 yd below thermistor)	69.2	B3c	30.3	1.0	30.7	2.1	48	1.6	29.9	0.0058	1.17	3	28.3
13	1/4 mile above Cutsforth Park, USFS paved shoulder pull-off (25 ft above thermistor)	77.3	E4b	11.5	1.6	7.4	2.5	62	5.4	17.9	0.0274	1.16	4	4.0

*Same site numbers were used for thermistors and morphology - actual locations may differ by up to 1/4 mile.

A single cross-section was surveyed at each site tabulated in **Table D2-2**. The vertical and horizontal measurement resolution is approximately ±0.1 foot and ±2.0 feet. Additional uncertainty from interpretation of bankfull indicators exists as well. The pebble counts are composites of 100 measurements from three transects across the full width of the channel up to the bankfull edges. D_{50} is the 50^{th} percentile diameter (intermediate axis) of each site's array of measurements.

2.1.4 Vegetation

A vegetation assessment was carried out during the summer of 2000, generally at the channel morphology survey sites (**Figure D2-1**) and at additional sites as the aerial imagery was interpreted. Riparian vegetation was assessed through field assessment and remote sensing. The field level information includes:

- Solar pathfinder™ measurements of the vegetative horizon expressed as daily solar energy (**Table D2-3**)
- Field identification of shade producing vegetation species
- Vegetation height measurement using a digital range-finder
- Vegetation density was obtained from aerial photography and spherical densiometer measurements, and was expressed as the percentage of solar radiation passing through, and grouped in categories: 0-20, 20-40, 40-60, 60-80, 80-100.

Digital range finder height measurements, aerial photo shadow lengths and personal interviews were incorporated into the final determination of existing vegetation height for the model calibration (**Table D2-4** shows height categories). Aerial photography interpretation was aided by field identification and measurement and on-site comparison of vegetation stands with aerial photos.

Basin vegetation is broadly summarized in **Section 1.5** of this report. Detailed mapping of vegetation is documented in GIS and tabular model entry (refer to **Section 3.3**). The general pattern of existing shade producing riparian vegetation is as follows:

- Conifer dominance above the North Fork of Willow Creek (Grand Fir, Douglas Fir, Ponderosa Pine, Larch, Engelmann Spruce, Rocky Mountain Juniper) with mixed deciduous, particularly in disturbance regimes such as point bars (Alder, Rocky Mountain Maple, various willow, Birch). Herbaceous vegetation is present as well.
- Where trees are present, there is deciduous dominance below the North Fork of Willow Creek, downstream to mouth (Cottonwood, Alder, Willow and other small to medium height deciduous trees). Urban areas exhibit the most trees.
- For much of Willow Creek below the conifer forest, where trees are absent, there is little shade-producing vegetation, except shrub willow, weeds and crops.

Table D2-3. *Solar Pathfinder™ measurements of percent of daily total solar radiation received by water body at mid-stream*

Solar Pathfinder Sites, Willow Creek, Summer 2000						
Site #	**Stream**	**Site Description**	**River Mile (WRD Map)**	**River Km (Ttools)**	**Solar Pathfinder (August % of daily total radiation for all horizontal surfaces)**	**Solar Pathfinder % shade in August**
1	Willow Ck	200 yd below hwy 74 brdg	5.5	6.35	93	7
2	Willow Ck	Bridge (d/s side) below 8 Mile Creek	8.0	10.50	100	0
3	Willow Ck	Bridge (d/s side) at Cecil	17.8	25.70	98	2
4	Willow Ck	Bridge (d/s side) by Ione High School	34.1	51.75	85	15
5	Willow Ck	Lexington F-St. bridge (d/s side)	44.0	67.10	99	1
9	Willow Ck	NW Gale St. bridge (d/s side)	55.1	85.00	78	22
8	Willow Ck	50 meter d/s Heppner City Park at Church St	55.3	85.20	15	86
12	Willow Ck	1/4 mile u/s reservoir, directly beneath hwy bridge	55.9	89.05	79	22
13	Willow Ck	Middle of Ione guardrail section, 1/4 mile d/s Blake Ranch Rd	69.3	107.00	79	21
14	Willow Ck	1/4 mile u/s Cutsforth Park, USFS paved shoulder pull-off	77.3	119.65	21	80

Table notes: Ttools is the name of a software application for sampling GIS layers – it will be discussed further in **Chapter 3**. A solar pathfinder is an instrument that allows tracing of the open sky horizon projected onto a flat surface. The tracing is on a grid surface, scaled to translate the amount of open space to daily potential radiation for any given month. 100 -% radiation = % shade.

Table D2-4. *Model entry vegetation height aggregation (in feet)*

less than 1 (0.6' avg.)
1-6 (3.5' avg.)
5-20 (sm willow, 12.5' avg.)
20-40 (small trees, 30' avg.)
40-80 (large trees, 60' avg.)
80 (cottonwood)
120-160 (larger conifer, 140' avg.)

2.1.5 Meteorological Data

Summer air temperature, wind speed and humidity measurements were retrieved from weather stations near Madison Butte (Snotel, 9 miles southwest of Cutsforth Park on Willow Creek), City of Heppner (PDTWFO) and Patterson Ferry (PAWS, 25 miles northeast of the mouth of Willow Creek). These stations are the nearest available to the upper, mid and lower reaches of Willow Creek, respectively. Weather sources/abbreviations are identified in **Table D2-5**. Hourly data from the Patterson Ferry site was utilized as the core data set, adjusted incrementally upstream based on the normal adiabatic lapse rate and weather data for the other stations, to generate longitudinal arrays of hourly air temperature and humidity throughout the 21-day simulation interval.

Table D2-5. *Various sources of climate data*

PAWS: Public Agricultural Weather System of Washington State University
Agrimet: The Pacific Northwest Cooperative Agricultural Weather Network, US Bureau of Reclamation
METAR: National Weather Service weather data online
PDTWFO: Pendleton Weather Forecast Office (NOAA Cooperative Institute for Regional Prediction)
Oregon Climate Service
Snotel: Natural Resource Conservation Service (US Dept. Agriculture), National Water and Climate Center

Figure D2-8 is included here as examples illustrating temporal variability in summer air temperature, wind speed and humidity**.** In the temperature model, data from the various weather stations were distributed to ten continuous data input nodes based on closest proximity.

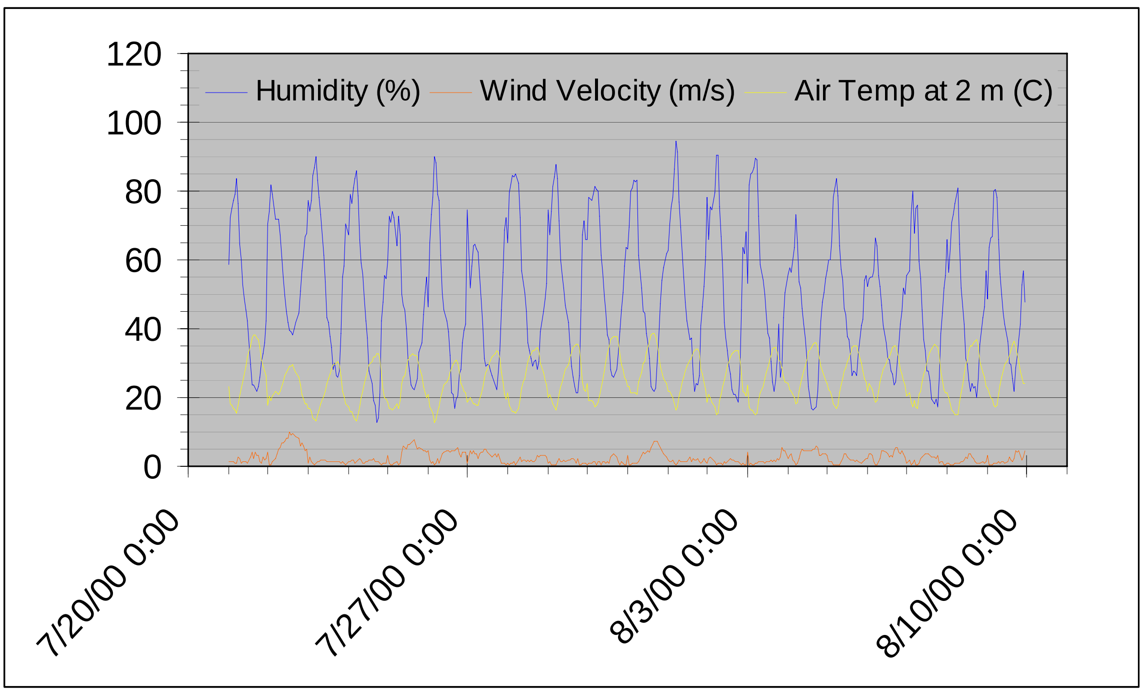


Figure D2-8. *July 21 to August 9, meteorological recordings from Paterson Ferry, Washington*

2.2 GIS and Remotely Sensed Data

2.2.1 Overview – GIS and Remotely Sensed Data

This assessment relies extensively on GIS and remotely sensed data. Temperature controls are complex and distributed over the subbasin. The TMDL analysis strives to capture these complexities using the highest resolution data available. Some of the GIS data used to develop this report are listed in the table below along with the application for which it was used.

Table D2-6. *Spatial Data and Application*

Spatial Data	Application
10-Meter Digital Elevation Models (DEM)	• Specify Channel Elevation, Gradient • Measure Topographic Shade Angles • Provide Basal Elevation for Vegetation
Aerial Imagery – Digital Orthophoto Quads	• Map Near Stream Land Cover • Map Stream Position, Channel Edges, Wetted Channel Edges and Channel Pattern • Map Roads, Development, Structures (Dams, Weirs, Diversions, etc.)

2.2.2 10-Meter Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) data files are representations of cartographic information in a raster form. DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. The U.S. Geological Survey, as part of the National Mapping Program, produces these digital cartographic/geographic data files. Ten-meter DEM grid elevation data is rounded to the nearest meter for ten-meter pixels (vertical resolution is approximately one-meter in flat terrain). DEMs are used to evaluate topography as identified in **Table D2-6**.

2.2.3 Aerial Imagery – True Color and Gray Scale

A digital orthophotoquad (DOQ) is a digital image of an aerial photograph in which camera distortion has been removed. In addition, DOQs are projected in map coordinates combining the image characteristics of a photograph with the geometric qualities of a map. The digital landscape imagery used in this report are of two types: (1) black-and-white DOQs with one-meter pixels, Oregon-wide coverage in a compressed format (MrSID), and (2) sub-meter resolution georeferenced color images provided by the Morrow Soil and Water Conservation District. Examples of both types of imagery at the same location are depicted in **Figures D2-9** and **D2-10** at the scale typically used during temperature TMDL digital mapping. The coverage extent of the black and white DOQs is the entire subbasin. The color images were collected along Willow Creek from eight miles below Ione to one mile below Heppner (OWRD river mile 26-53.5).

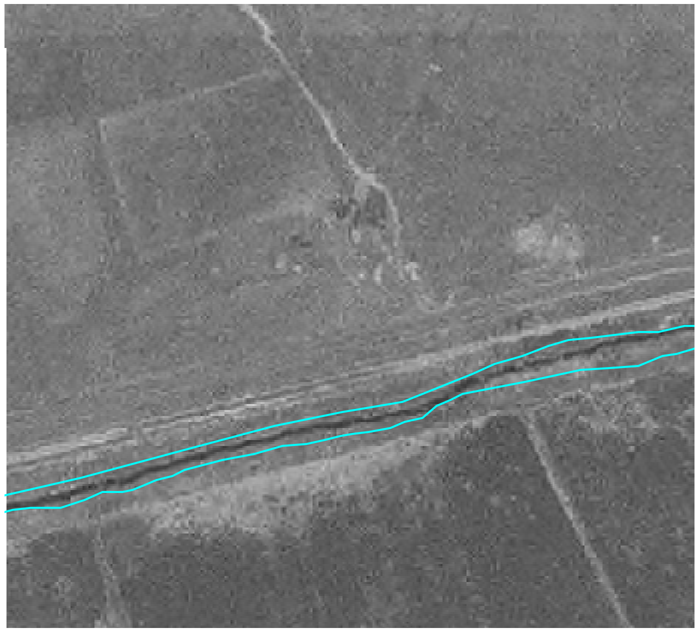


Figure D2-9. *Example of black and white DOQ used in digital mapping of vegetation and channel, with channel lines shown (ArcView™ 1:5000). Tracings are at estimated bankfull channel edges.*

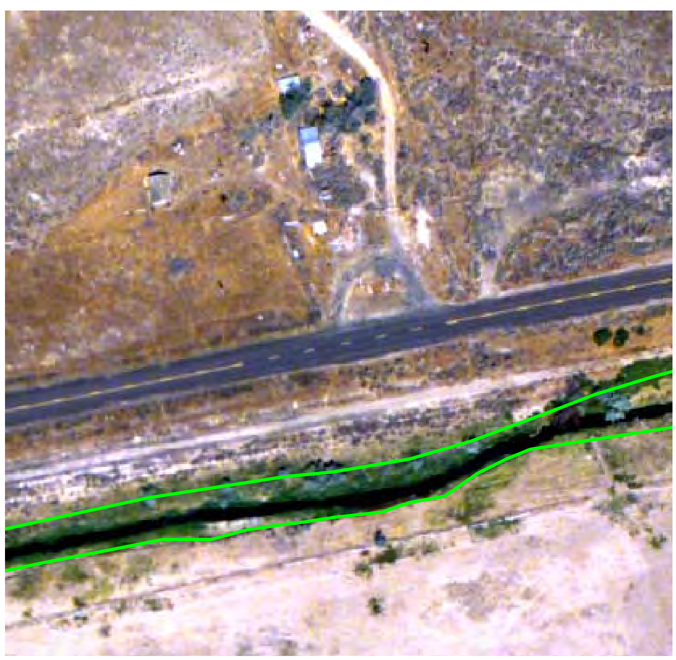


Figure D2-10. *Example of georeferenced color imagery used in digital mapping of vegetation and channel, with channel lines shown (ArcView™ 1:2000). Tracings are at estimated bankfull channel edges.*

2.3 Point Sources

The Oregon Department of Environmental Quality maintains a database for point source information. This database was used to identify potential point sources within the Willow Creek Subbasin, with verification from Pendleton DEQ office NPDES permitting staff. **Section 1.2** of the main document identifies the name, permit numbers, location, effluent discharge rates and other characteristics of point source direct discharges in the Subbasin, with storm water and agricultural drains excluded. There are two individual facility NPDES-permitted discharges in the Subbasin. These include the City of Heppner's municipal waste water treatment plant, discharging to Willow Creek, and a power generation facility located roughly one mile downstream from Heppner's urban growth boundary.

Effluent monitoring data for these facilities is discussed and/or summarized in **Section 1.2** of the main document and **Appendices C** (monitoring) and **E** (pH TMDL assessment).

CHAPTER 3. DERIVED DATA AND INTERPRETATION

3.1 Sampled Parameters

Sampling numeric GIS data sets for landscape parameters and performing simple calculations is done to derive spatial data for several stream parameters. Sampling density is user-defined and generally matches any GIS data resolution and accuracy. The sampled parameters used in this stream temperature analysis are:

- Stream Position and Aspect
- Stream Elevation and Gradient
- Land Cover Base Elevation
- Maximum Topographic Shade Angles (East, South, West)
- Channel Width
- Near Stream Land Cover

Some of these parameters are derived in a fairly routine manner and the method is described by reference and brief description here – stream position, stream elevation, gradient, aspect, topographic shade angles, land cover base elevation. These methods utilize the TMDL GIS application *TTools*. TTools documentation is included as part of the *Heat Source* documentation "*Analytical Methods for Dynamic Open Channel Heat and Mass Transfer: Methodology for Heat Source Model Version 7.0*" (Boyd, Kasper, 2003) and can be found at www.heatsource.info. A stream position (center) line is digitized using orthoimagery and segmented into equidistant longitudinally distributed data nodes (50 meters apart). Stream elevation is sampled from 10-m digital elevation model files and gradient is calculated from the DEM elevation and stream position (**Figure D3-1**. Aspect is sampled at each 50 m node along the digitized stream position line. Topographic shade angles are measured via the same DEM and stream position data file. Topographic shade is assessed with near (bank) and far (hills, valley wall) field reference. Land cover base elevation is developed by simultaneous sampling of the DEM and the land cover position polygon codes as described later in this Chapter.

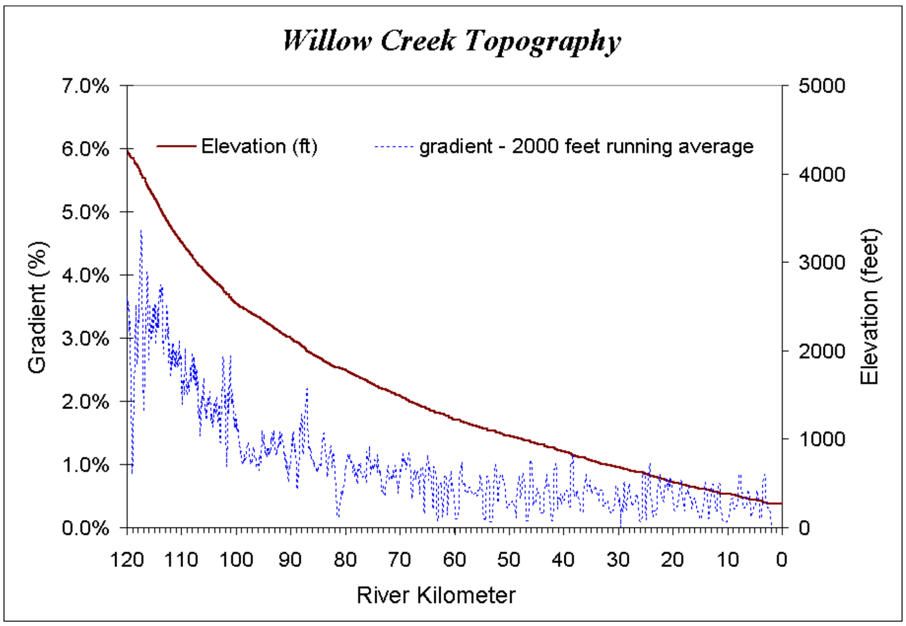


Figure D3-1

The following sections of this Chapter describe the methodologies for derived data types that warrant more specific attention - morphology, land cover, mass balance based input, and in-stream flow. Results and accuracy are discussed as well. **Section 2.2** describes the resolution of currently available GIS data sets.

3.2 Channel Morphology

3.2.1 Overview

Channel width is an important component in stream heat transfer and mass transfer processes. Effective shade, stream surface area, wetted perimeter, stream depth and stream hydraulics are all highly sensitive to channel width. Channel morphology is largely a function of high flow volume and frequency, stream gradient, sediment supply and transportation, stream bed and bank materials and stream bank stability (Rosgen 1996 and Leopold et al. 1964). Channel classification and general characteristics are discussed in **Section 2.1.3**.

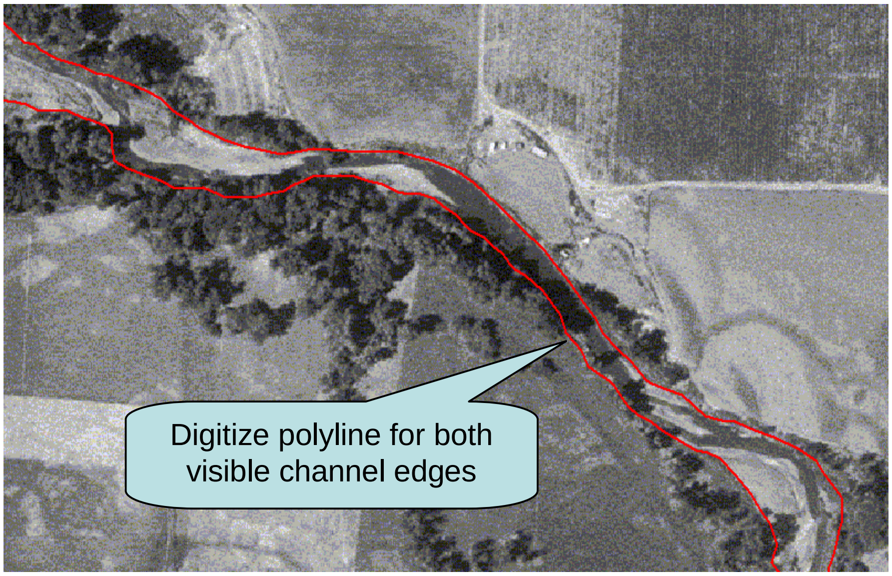
The predominant thermal influence of channel morphology is straightforward. Wider channels result in the combined effect of increased solar radiation loading via decreased stream surface shade and increased stream surface area exposed to solar radiation loading. Other thermal effects that relate to channel morphology include altered stream hydraulics, often associated with increased wetted perimeter and decreased stream depth. Disturbance of surface and groundwater interactions may also result from channel morphology modifications. This disturbance typically manifests as decreased near stream groundwater table elevation – reducing the groundwater inflow, removing cool sources of groundwater that serve to reduce in-stream temperatures. Stream-cooling hyporheic exchange is minimized by the lowered ground water table and through the common practice of channel straightening and relocation. Substrate changes may decrease or impair hyporheic flows (i.e., flows that occur in the interstitial spaces in the bed substrate) that help buffer stream temperature change.

3.2.2 Channel Assessment – Existing Form

The steps for conducting channel width assessment are listed below.

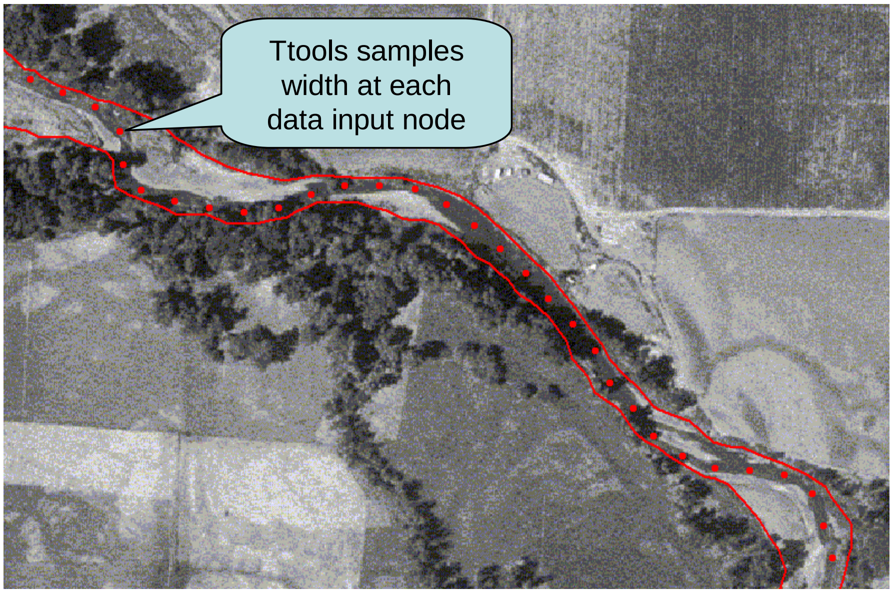
Step 1. **Stream channel edges are digitized from DOQs at 1:5,000 or higher resolution (Figure D3-2)**. Where apparent in aerial photography, indicators of bankfull stage were used to delineate the channel. For example, bank shadows or a row of alders crossing the upper part of a point bar may indicate a bankfull edge. Reference to ground level determinations (**Chapter Two**) at intervals is helpful. Where bankfull indicators are not apparent, channel delineation is based on the corridor width between shade-producing near-stream vegetation. Where near-stream vegetation is absent, the near-stream boundary is used, defined as down-cut stream banks or where the near-stream zone is unsuitable for vegetation growth due to external factors (i.e., roads, railways, buildings, etc.). This method of channel delineation deviates from the normal ground level protocol, (e.g., Rosgen, 1996), yet provides a desirable continuity between field sites, supplementing the field based data set (**Section 2.1.3**) and enabling subbasin-scale analysis. For TMDL purposes, the resultant corridor can be termed 'near stream disturbance zone' (NSDZ).

Figure D3-2.



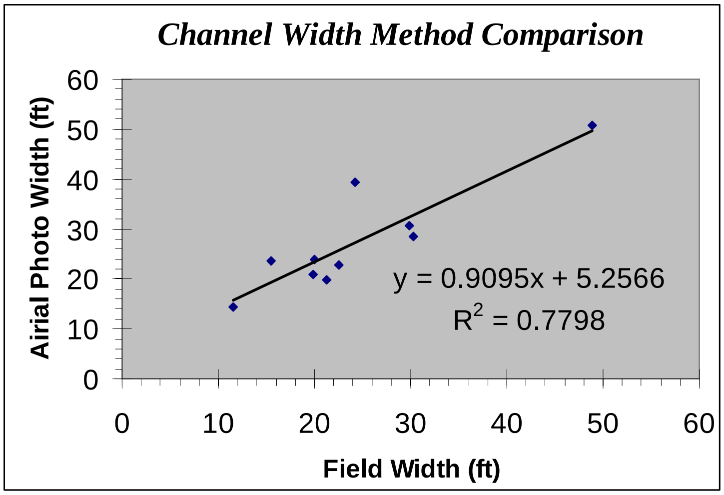
Step 2. **Sample channel width at each stream data node using Ttools (Figure D3-3)**. The sampling algorithm measures the channel width at each data input node in the transverse direction relative to the stream aspect. First, a stream centerline is generated from aerial photography in ArcView™. Next, this line is segmented into equidistant model input nodes using software developed by DEQ (Ttools). Ttools is then used to calculate and record the distance between the digitized channel lines. The resultant data set is a high resolution subbasin-scale array of channel widths.

Figure D3-3.



Step 3. **Compare sampled channel width and ground level measurements**. Establish statistical limitations for near stream disturbance zone width values when sampled from aerial photograph (DOQ) analysis. **Figure D3-4** plots a comparison of the remote NSDZ and field-determined bankfull width from the Willow Creek Subbasin.

Figure D3-4.



The resultant channel width data are displayed in **Figure D3-5**. Note that in the area above kilometer 91 (river mile 59) the aerial photography interpretation is hampered by tree cover. In this reach, model input is based on averaging ground level data coupled with remote sensing.

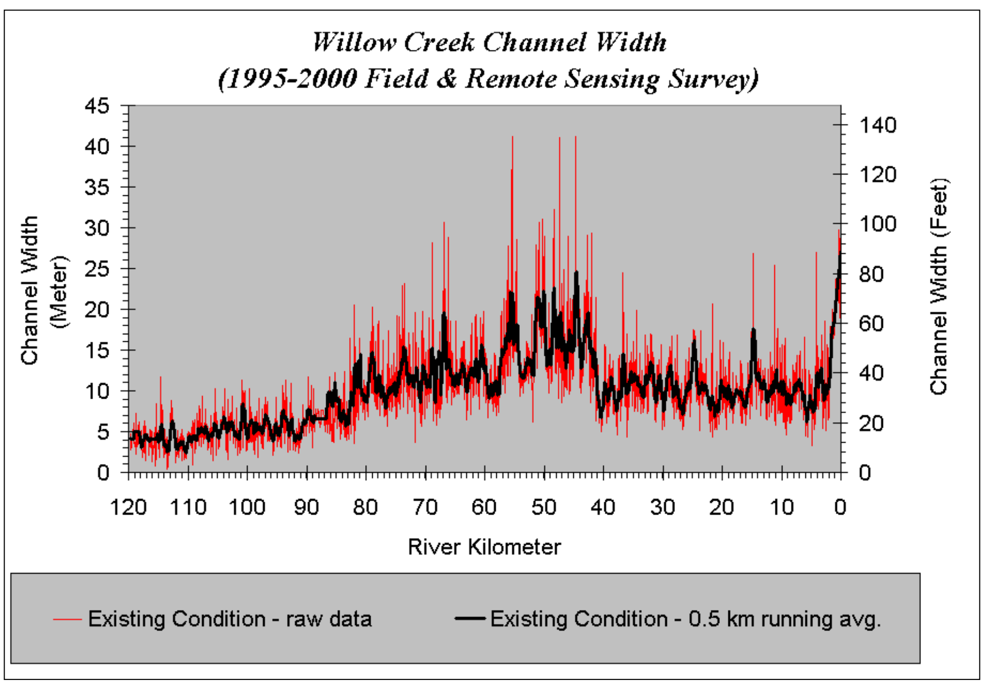


Figure D3-5. *Graph of assessed channel width. Refer to* ***Figure D2-3*** *for river miles and additional location reference. The remote and aerial surveys took place in 1995-1996 and 2000, respectively.*

3.2.3 Channel Assessment – Potential Form

The term *natural potential* describes a condition where the geomorphic influence of past and present human activities is minimized as discussed in **Section 1.4**. Willow Creek's channel cross-sectional area is expected to reduce as recovery enables increased bank strength and sinuosity. This conclusion is based on the established relationships between hydraulics and bank strength as well as empirical evidence cited in hydrologic literature (Dunne and Leopold, 1978; Rosgen, 1996).

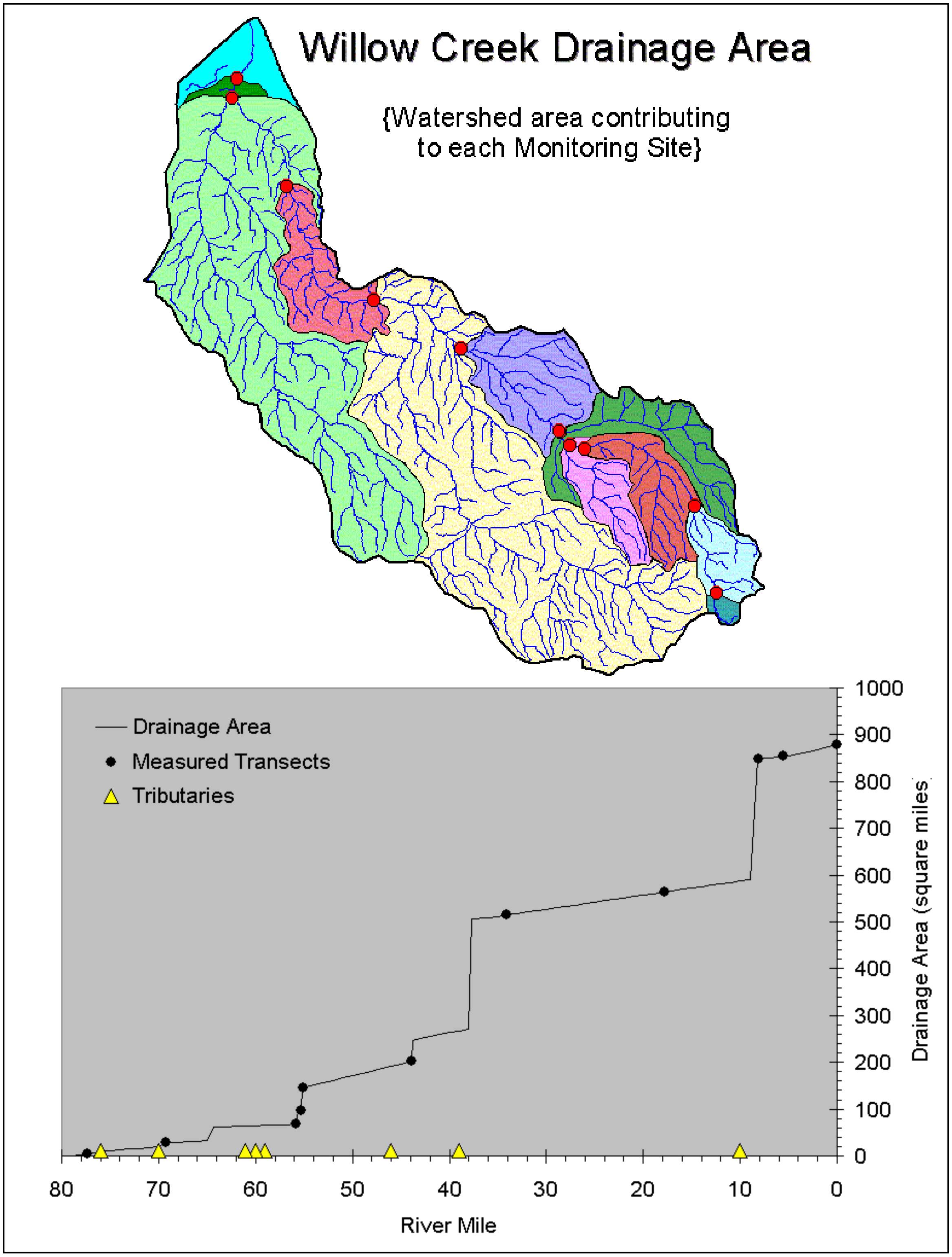
The NTP channel width and depth are quantitatively assessed and used as input in a simulation scenario for estimating temperatures that would result from a more natural channel configuration (**Chapter Four**). It is important to recognize that a limiting factor is that associated changes in sinuosity are not simulated.

This and following sections include references to the Rosgen Stream Classification. To review the classification, refer to the summary in **Figure D2-6** in **Section 2.1.3.**

The steps taken to estimate the NTP channel width are as follows:

1. Assess existing channel width (**Section 3.2.2**), width/depth and type (**Section 2.1.3**)
2. Assess drainage area (**Figure D3-6**)
3. Derive existing channel cross-sectional area as a function of drainage area (**Figure D3-7**) enabling an association between cross-sectional area and longitudinal position (**Figure D3-8**).
4. Determine target width/depth ratios (**Table D3-1**). Compare with existing distribution for feasibility assessment (**Figure D3-9**).
5. Compute potential bankfull width from **Equation 3-1**: Bankfull Width $= \sqrt{A \times (w/d)}$, where A is stream cross-sectional area and w/d is the target width/depth ratio (Rosgen, 1996). Existing and calculated potential widths are shown in **Figure D3-10**.
6. Set the maximum potential bankfull width target at the lesser of (a) existing widths, and (b) calculated potential. This target is illustrated in **Figure D3-11**.

Figure D3-6. *Drainage area contributing to each morphology survey site is estimated along Willow Creek. Measurements were made in ArcView™ utilizing Spatial Analyst™ based on 30-meter digital elevation*



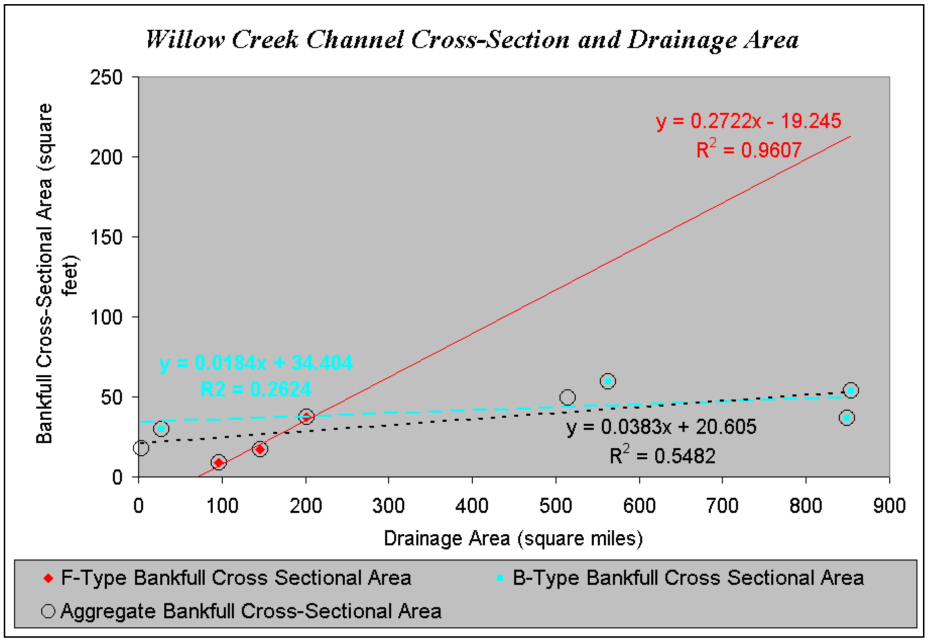


Figure D3-7. *Regression relating channel cross-sectional area to drainage area, stratified by Rosgen stream type*

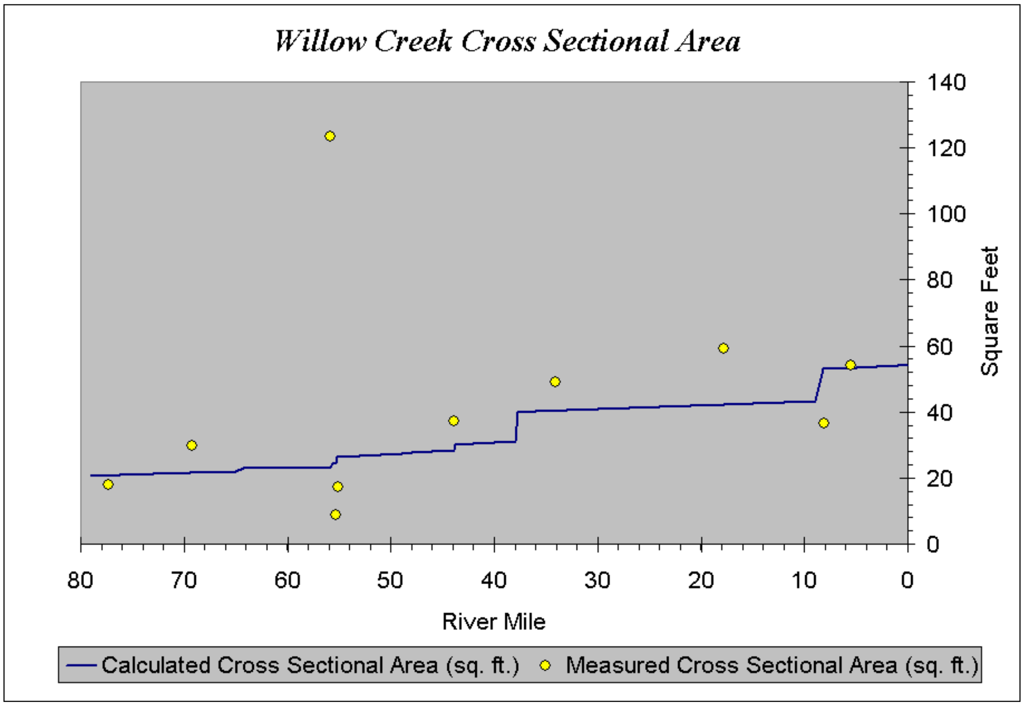


Figure D3-8. *Cross-Sectional area is estimated by applying regression equations of **Figure D3-7** to the longitudinal distribution of drainage area*

Table D3-1. *Width-Depth ratio targets. Values are median width/depth from streams in several states in the US (Rosgen, 1996).*

Measured width/depth ratios				
Stream Type	A	B	C	E
width/depth	7	17	24	5-10

The dependency of cross-sectional area on drainage area is established in the literature (Dunne and Leopold, 1978; Williams, 1986; Rosgen, 1996). As described above, estimating potential width-to-depth ratios is a critical next step in estimating NTP channel width (Step 4). It is generally expected that width/depth is relatively constant for a given stream type within a physiographic province (Rosgen 1996). Willow Creek likely occupies two or more such provinces. However, the available potential width/depth information is not sufficient to characterize each. The selected alternative approach is to screen the measurements for reaches that are minimally disturbed and compare these data with literature values for typical streams of a given stream type. For example, above Cutsforth Park is a relatively stable reach with a low width/depth ratio (w/d = 7.4, **Table D.2-2**, within the range of 5-10, typical of E-type streams). Consideration of the measured w/d ratio distribution is informative. This distribution is portrayed in **Figure D3-9**. Box plots, such as the one employed in **Figure D3-9**, are explained in the beginning of **Appendix F**.

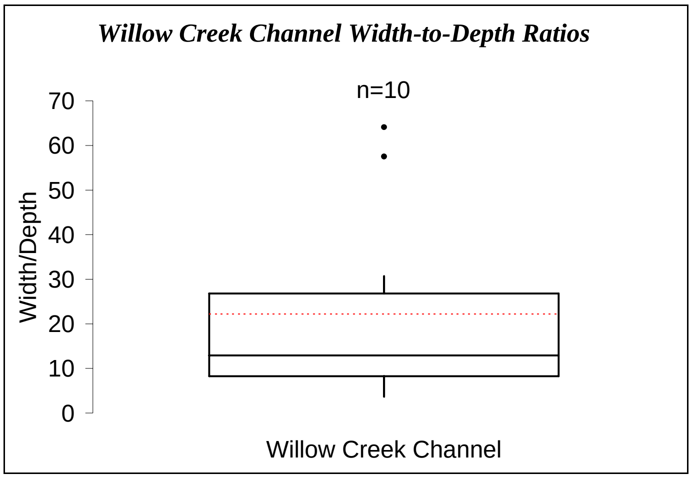


Figure D3-9. *Willow Creek bankfull channel width-to-depth ratios – box plot with interquartile, mean, median and outliers. Data are in* ***Table D2-2****.*

The outcome of this evaluation is to employ the norms measured in various states in the US (**Table D3-1**). These width/depth target estimates fall within the range of existing values for Willow Creek. The most likely potential channel type for much of Willow Creek, as discussed in following text and using the Rosgen classification, is C-type. A C-type target width/depth of 24 represents the 73rd percentile of Willow Creek measurements. It is recognized that this set of targets may over estimate the width/depth natural potential. This is because undisturbed areas are rare and the sample set summarized in **Table D3-1** includes areas of disturbance. In addition, the use of existing cross-sectional area in **Equation 3-1** biases the potential width estimation towards the existing condition. A better estimate could be achieved through future tracking of channel evolution in relation to increased vegetation and sinuosity. For now, **Table D3-1** is deemed to include the best available targets representing NTP width/depth for Willow Creek.

Next (Step 5), potential channel width is calculated using **Equation 3-1** (**Figure D3-10**). As the potential width/depth is based on channel type, this requires a prediction of potential channel type. Given the open valley, alluvial floodplain and valley gradient, a C-type channel potential is predicted for the length of the Willow Creek, except in the upper Basin where the current channel is B-Type. It is acknowledged, however, that channel complexity and meadow areas could evolve into ecologically and thermally beneficial D- and E-Type streams. It is also noted that in non-modeled reaches A-type will be represented. The other principal stream types, G and F types, are often indicative of disturbance and would not be expected in the NTP scenario.

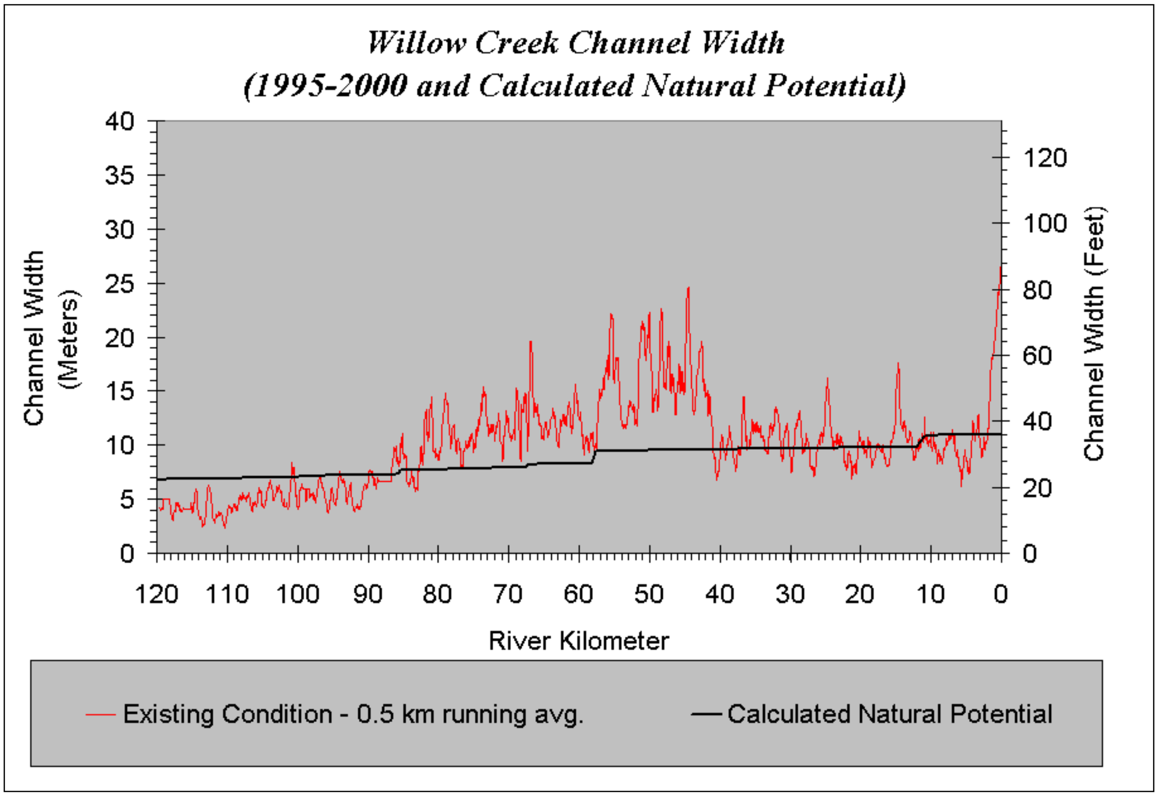


Figure D3-10. *Existing and Calculated Channel Potential Width*

In some reaches, the calculated potential channel width exceeds the current condition (**Figure D3-11**). This is taken as an indication that these areas are nearly at potential. Channels are not expected to widen as they recover (except in instances of interim instability), hence the potential that is most likely *and* supports decreased insolation would be the lesser of the existing condition or calculated potential (Step 6). This is the target potential, illustrated in **Figure D3-11**.

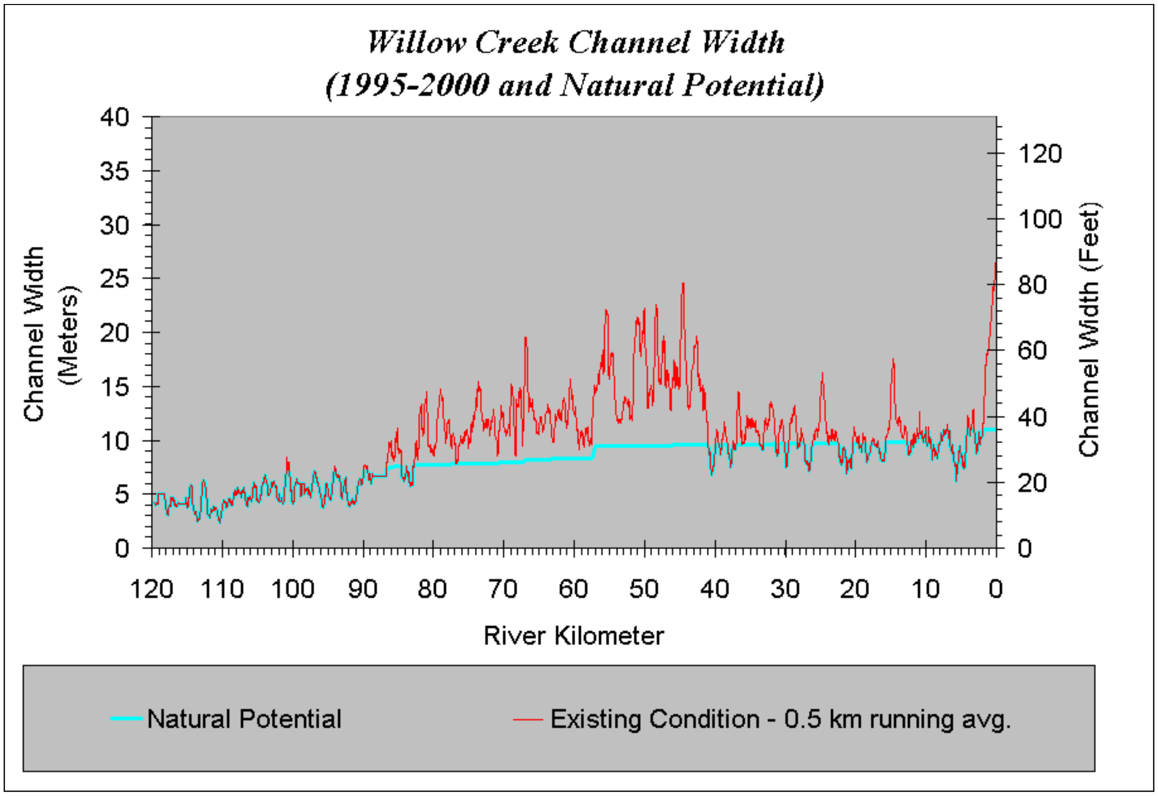


Figure D3-11. *Willow Creek existing and NTP channel width*

3.2.4 More on Channel Potential

For the purposes of determining morphologic potential, basin history is considered. Stream straightening and relocation are apparent through large sections of Willow Creek and its tributaries. Rosgen (1996) reports that through time degraded and disturbed streams (usually D, F, G types) generally return to a stable stream configuration (e.g., C, E, B) after disturbance is minimized. As stated above, for NTP channel goals, C and B channel types are expected on the much of the mainstem. Outside of the modeled river reaches (tributaries to Willow Creek were not modeled), channel type potential is not assumed, however it is generally expected that C, B, A types will prevail. Stream types with gradients above 4% are normally A-types.

3.3 Near Stream Land Cover

3.3.1 Near Stream Land Cover – Method and Overview

The role of near stream land cover in maintaining stream function, ecology and water quality is well documented and accepted in scientific literature (Barton et al., 1985; Beschta et al. 1987; Coleman and Kupfer, 1996; Karr and Schlosser, 1978; Malanson, 1993; Osborne and Wiley, 1988; Roth et al., 1996; Steedman, 1988; Zelt et al, 1995). The list of important benefits that near stream land cover has upon the stream and the surrounding environment is long. A few are mentioned here:

- Near stream land cover plays an important role in regulating radiant heat in stream thermodynamic regimes.
- Channel morphology is often highly influenced by land cover type and condition. Land cover affects flood plain and in-stream roughness, contributes coarse woody debris, and influences sedimentation, stream substrate compositions and stream bank stability.
- Near stream land cover creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity and lower wind speeds along stream corridors.
- Riparian and in-stream nutrient cycles are affected by near stream land cover.

With the recognition that near stream land cover is an important water quality parameter and thermal moderator, detailed mapping of land cover is a high priority. Variable land cover conditions in the Willow Creek Subbasin require a higher resolution than currently available GIS data sources. To meet this need, DEQ has mapped near stream land cover using Digital Orthophoto Quads (DOQs) at 1:5,000 or higher resolution. Land cover features were mapped along the main channel within 300 feet of each stream bank. Land cover data is developed in successive steps.

Step 1. Land cover polygons and stream polylines are digitized from DOQs. All digitized polygons are drawn to capture visually-like land cover features (**Figure D3-12**).

Step 2. Basic land cover types are coded and the codes assigned to individual polygons. The land cover codes used in this effort are defined as aggregate land cover groups, such as: conifers, hardwoods, shrubs, etc. (**Table D3-2**).

Step 3. Ground level land cover data (vegetation height, foliage density) are assigned to each polygon as code attributes.

Step 4. Automated sampling is conducted on classified land cover spatial data sets in 2-dimensions, for the existing condition assessments (TTools GIS application). Every 50 meters along the stream (i.e., in the longitudinal direction), the near stream land cover code is radially sampled in four concentric 15 meters steps, starting at the channel center (**Figure D3-13**).

Step 5. Land cover physical attributes (height and density) can then be described in 2-dimensions since automated sampling occurs in radial directions, repeated longitudinally at each model input node.

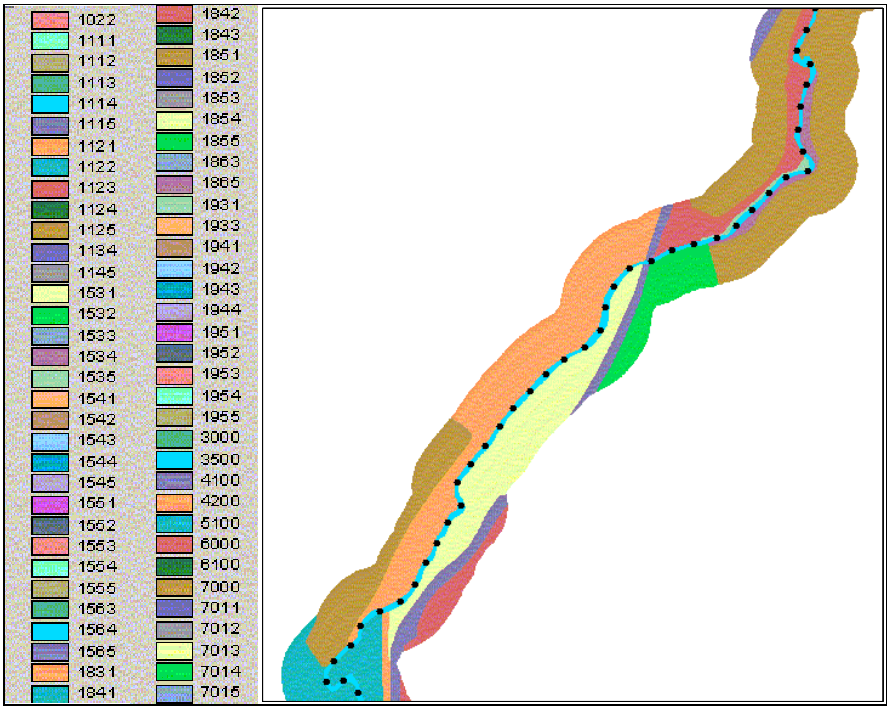
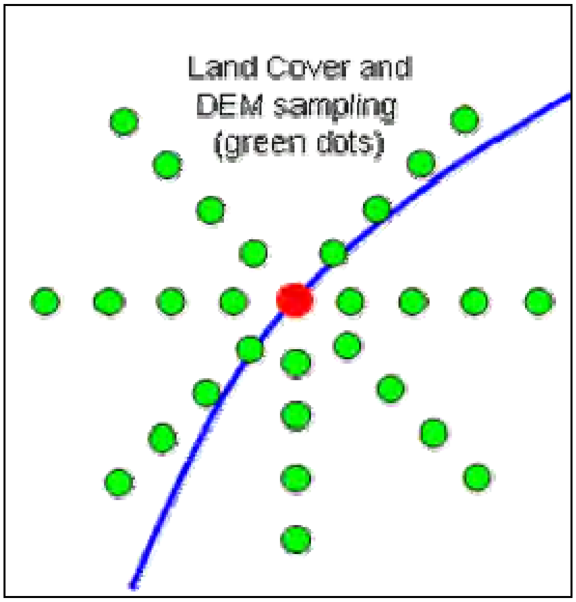


Figure D3-12. *Land Cover codes used in TMDL temperature modeling, with one example reach illustrating mapping detail and model input nodes*

Table D3-2. *Key to land cover codes used in TMDL temperature modeling. Each code is 4 digits. Example: 1644 represents an orchard of 20-40 feet in height and 60-80% density. The green shading highlights land cover that is clearly not of natural origin.*

Existing Land Cover Code Development (4 digit codes)					
1st 2 Digits Land Cover		**3rd Digit** Height (feet)		**4th Digit** Density (%)	
Vegetated		**General height and density**			
		1	less than 1 (0.6' avg.)		
11	shrubs (sm) and grasses,	2	1-6 (3.5' avg.)		
15	deciduous	3	5-20 (sm willow, 12.5' avg.)	1	0-20
16	orchard	4	20-40 (small trees, 30' avg.)	2	20-40
18	conifer	5	40-80 (large trees, 60' avg.)	3	40-60
19	mixed deciduous/conifer	6	80 (cottonwood)	4	60-80
		7	120-160 (larger conifer, 140' avg.)	5	80-100
Other		**Specific assignmens of height and density**			
30	water	0	0	0	0
35	channel	0	0	0	0
41	roadway - paved	0	0	0	0
42	roadway - not paved	0	0	0	0
43	railroad right-of-way	0	0	0	0
50	barren - natural	0	0	0	0
51	barren - developed	0	0	0	0
60	residential	0	0	0	0
61	urban	0	0	0	0
62	industrial	0	0	0	0
70	crops, pasture (<3 feet)	0	0	0	0
80	misc anthropogenic shade producing structures	use general codes			

Figure D3-13. *TTools radial sampling pattern for near stream land cover (sampling interval is user defined). The blue curve represents the simulated stream, and the red dot is the longitudinal model input node. Sampling occurs for every stream data node at four user-defined intervals (15 meters used herein) every 45 degrees from north (North is not sampled since the sun does not shine from that direction in the northern hemisphere). A database of land cover type in created for each stream data node.*



3.3.2 Near Stream Land Cover – Mapping, Classification and Sampling

Aerial images (in Arcview[TM]) were used to digitally map and identify near stream land cover along the Willow Creek using the method described in the previous Section. Field surveys helped identify vegetation species compositions and develop near stream land cover height and density classifications. The subbasin-wide vegetation mapping and coding developed by DEQ is illustrated in **Figure D3-12** and the sampling method portrayed in **Figure D3-13**. For Willow Creek temperature simulation, land cover polygons were sampled every 50 meters longitudinally and every 15 meters radially.

Following digital mapping and coding, land cover data then were classified into various height and density ranges (steps 1-5 of **Section 3.3.1**). This information is assigned to codes as identified in **Figure D3-12** and **Table D3-2**. Height and density were measured at a variety of field sites (**Section 2.1.4**) and then applied via interpretation of aerial imagery and associated ground-truthing.

Tree heights measured in this study and based on local expertise are consistent with regional plant guide literature (e.g., Johnson, 1998).

3.3.3 Near Stream Land Cover – Potential Condition Development

The discussion of developing potential near stream land cover data begins with reference to **Section 1.4**, which includes the definition of *NTP* and discussion of the context in which it is used in the TMDL methodology. Potential near stream land cover does not include considerations for resource management, human use or other human disturbance. Natural disturbance regimes (i.e., fire, disease, wind-throw, etc.) are also not accounted for in this definition. It is assumed that despite natural disturbance, potential near stream land cover types (as defined) will generally survive and recover from a natural disturbance event.

Through simple assumptions regarding land cover succession and by examining land cover types adjacent to major anthropogenic disturbance areas (i.e., clearcuts, roads, cultivated fields, etc.), it is possible to develop a rule set that can be used to estimate ***natural potential land cover*** conditions. For example, small conifers are assumed to have the potential to become large conifers. Codes or attributes for the natural condition approximation are re-assigned to the land cover polygons discussed in **Section 3.3.1**, and steps 4 and 5 are repeated to develop temperature model input.

Since near stream land cover is a controlling factor in stream temperature regimes, the condition and health of land cover is considered a primary parameter in the TMDL. The information sources that supported estimation of potential vegetation type and geometry include the following:

<u>Sources</u>

1. Existing Vegetation (mature native tree species stands)
2. 1858 Mapping for Military Road Reconnaissance, Fort Dalles, Oregon to Fort Taylor, Washington Territory (Mullan, 1858). Part of this map is portrayed in **Figure D3-14**, with journal excerpts in **Figure D3-14**.
3. Historical information from physiographically similar basins, e.g., Umatilla (Nagle, 1989), Journal of Narcissa Whitman.
4. Best professional judgment regarding site potential
5. Soil and climate information
6. Literature values and measurements of undisturbed areas for height and density

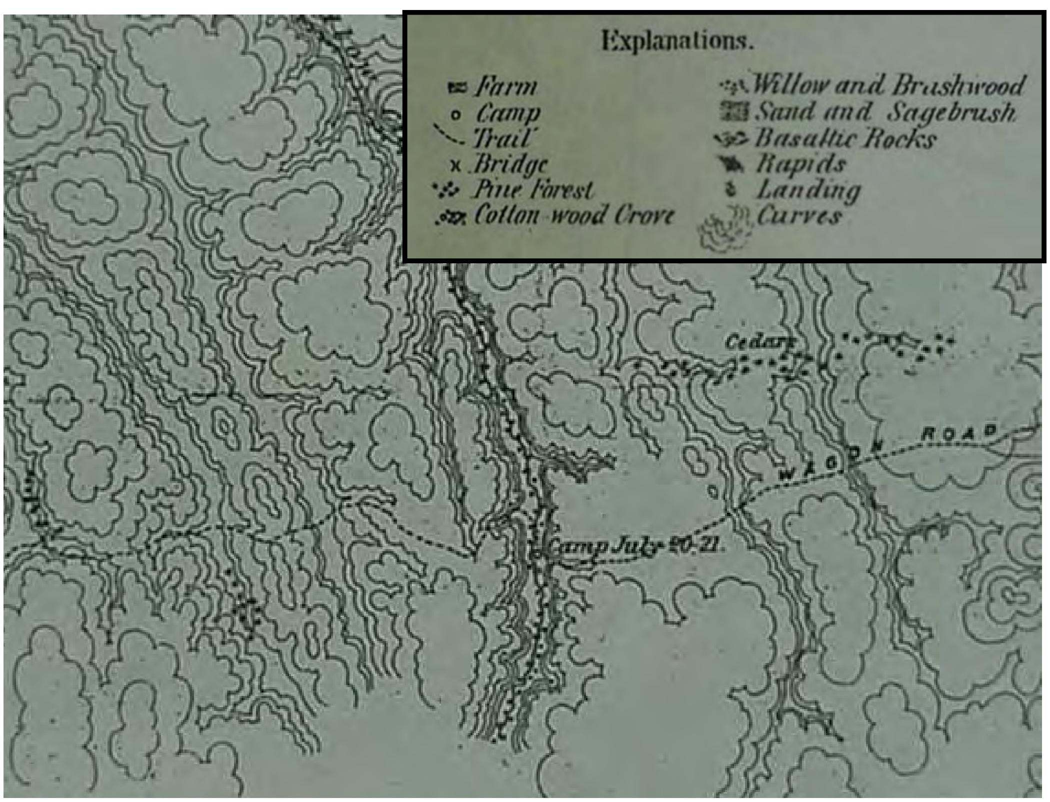


Figure D3-14. *Lieutenant Mullan's 1858 map includes a key roughly addressing riparian tree types*

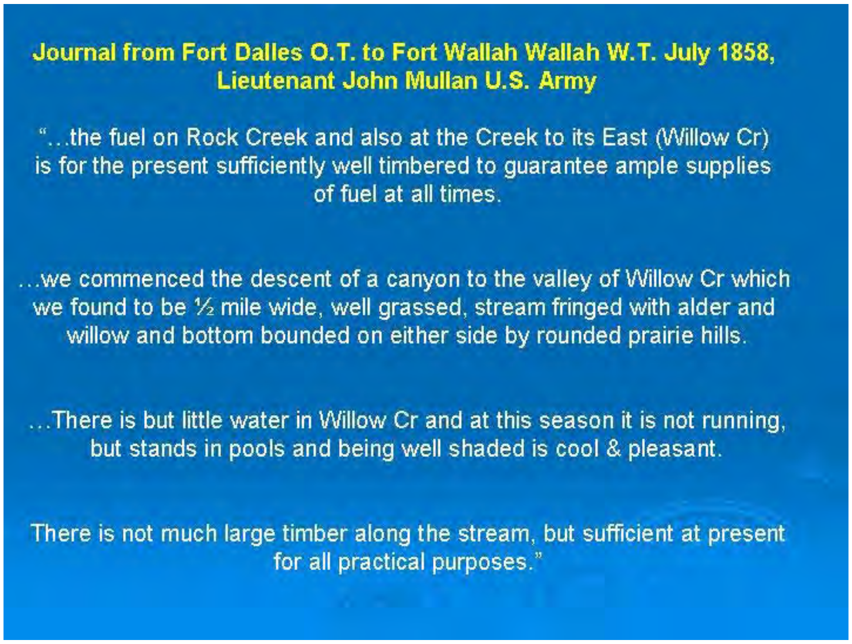


Figure D3-15. *Notes excerpted from Lt. Mullan's 1858 military road reconnaissance*

The following rule set was used to specify types of potential near stream land cover. The existing vegetation codes were modified in accordance with this rule set in order to develop model input for estimating NTP temperature and heat loads. Literature values and measurements of undisturbed areas were employed for height and density. In these areas, density was measured with a spherical densiometer or through aerial photography and heights were measured with a digital range-finder.

<u>General Rules for Developing Potential Near Stream Land cover</u>

1. Barren Land Cover type that can grow land cover (i.e. levee, gravel pit, clear-cut, etc.) are assigned the nearest adjacent non-developed land cover type.
2. Developed Land Cover type that can grow land cover are assigned the nearest adjacent non-developed land cover type.
3. Pastures, Cultivated Fields and Lawn Land Cover type are assigned the nearest adjacent non-developed land cover type.
4. Orchard Land Cover type are assigned the nearest adjacent non-developed land cover type.
5. In-stream and channel structure (i.e. levee, pipeline, dike, etc.) land cover types that can grow land cover are assigned the nearest adjacent non-developed land cover type.
6. Water and barren rock cannot grow land cover and are not changed.
7. Immature or disturbed density tree stands are assumed to grow to maturity.
8. Mature tree stands with normal healthy densities are considered at potential and land cover type and attributes are not changed.
9. When treed areas are assigned modified land cover types, indigenous species attributes are assumed. However, 'non-native' was not a criteria employed to select polygons for reassignment.
10. The riparian wetland/meadow land cover type is considered at potential and land cover type and attributes are not changed.
11. Steep and rocky slopes where soil conditions and/or aspect prohibit tree growth are left unchanged.

Specific modifications to Willow Creek land cover assessment to estimate natural potential

Knowledge of potential land cover in the Willow Creek subbasin is scant, and by far most of the historic land cover has been removed or converted through human activities. Historical accounts of the area are unclear as to whether there was a continuous riparian forest, and what the overall species composition was. Clearly there were willow and cottonwood, based on the name of the creek, historical accounts and relict stumps of large cottonwood. Beyond that, relatively gross estimates had to be made. For instance, in the lower and middle basin which would have been dominated by deciduous trees, a simple average of mature stand heights is employed of a variety of potential land cover: *small willow (20') large Willow (70'), Cottonwood (85'), Alder (60'), and grasses (3') and sedges (1.5')* = ***39.9 feet (12.2 m)***. This likely over-estimates the lower basin land cover height, because Willow Creek was probably not perennial and hence could not support continuous large woody vegetation. In fact, modeled temperature output for the lowermost basin is not used for the NTP scenario. ***The Department acknowledges that when a long-term intermittent reach is identified, NTP vegetation and heat loads should be re-evaluated, or the load allocation should not apply in that reach.*** The upper basin coniferous zone is roughly estimated as well – the shade provided by the tall conifers is highly dependant on tree spacing and shape and the channel and vegetation mapping resolution was low due to tree cover and DOQ resolution issues, relevant to small streams. Natural potential conifer heights were obtained by measuring existing mature stands, usually comprising mixed species.

Due to the uncertainty in estimating vegetation potential types and structure, a range of height was invoked to characterize natural potential. This range consists of a high end estimate and a reduction of that to 75 percent height, as follows:

Scenario 1 (highest estimate)

1. Change all land cover code density attributes to **80 percent**
2. Except for water and channel codes, change all non-conifer land cover code height attributes to 39.9 feet (**12.2 m)** height (average described above)
3. Substitute all conifer height attributes with 120 feet (**36.6 m**)
4. Substitute all mixed deciduous/conifer height attributes with the average of conifer and non-conifer heights – 80 feet (**24.4 m**)

Scenario 2 (lowest estimate)

1. As in Scenario 1, employ **80 percent** as the natural potential density
2. Multiply all heights of Scenario 1 by **0.75**

Accordingly, NTP land cover height or the resultant temperature and heat can be expressed as a range. The mid-point of the land cover height range is used for computing combination scenarios such as NTP vegetation and NTP channel form. This mid-range is a model scenario utilizing land cover height of 87.5 percent of the Scenario 1 land cover height, i.e., the mid-point between Scenarios 1 and 2. The mid-range model run produces heat and temperature output between the values produced by runs of Scenario 1 and 2 land cover. Various graphs appearing subsequently in this document will indicate a mid-range scenario, in terms of output heat load or temperature. This is not a heat or temperature average, but rather the result of vegetation height averaging.

Natural potential land cover is employed in thermal modeling on Willow Creek, providing for load allocation development and natural condition criteria estimation. In addition, NTP is needed for the generalized shade curves that serve as load allocations for non-modeled streams that have the potential to influence Willow Creek temperature. The NTP land cover height will be applied geographically based the following:

- NTP land cover will be applied to the full length of all potentially perennial streams (Herren, Shaw, North Fork, Hinton and Rhea Creeks.
- NTP land cover will be applied to the full length of Willow Creek, where perennial, as described previously in this section.
- NTP land cover will be used to develop the generalized shade curves, with zones delineated based on **Figure D3-16** (**Figure 1-5** of main document recalled here) – *Forestry* represents conifer dominance and the shrub/agriculture category is for deciduous dominance, in relation to the natural potential heights identified in Scenarios 1 and 2.

Figure D3-16. *(Modified from **Figure 1-5** of main document) Willow Creek Subbasin Land Use/Cover*

3.4 Potential In-Stream Flow

This section provides detail in accounting for natural flow in Willow Creek. Existing flow profile development for Willow Creek is described in **Section 2.1.2. Figure D2-5** and flow measurements provide an indication of flow diminution through consumptive use, which occurs primarily during the growing season. In contrast, Willow Creek Reservoir provides for greater than natural warm season flow extending some distance below the Heppner area. Clearly Willow Creek does not currently run at natural levels – in some reaches and seasons it is higher and in some lower. Estimating natural flow is one of the keys in developing a natural thermal profile for Willow Creek. The temperature-simulated flow scenarios are prepared for the model interval of July 21 through August 9, varying daily – the flow profiles shown here are a one-day selection from a 21-day array. **Figure D3-17** illustrates the assessed existing flow profile and four other flow scenarios, for August 1st:

1. Simulation proxy existing condition is the assessed August 1, 2000 flow profile, except higher than measured flow was simulated in the lower river (km 5-45) to enable sufficient flow for modeling (intermittent flow and model flow limits and analytical treatment is described in **Section 2.1.2**). River kilometer 5-45 exhibited reaches of isolated pools and dry streambed during August of 2000 and 2001. Temperature model results for this section should be viewed as rough estimates.

2. Estimated Natural without tributary increase flow is estimated through the assumption that Willow Creek would be a non-losing stream from the headwaters downstream to kilometer 45. In the middle and upper reaches, the existing condition profile is modified by eliminating all losses between points of measurement while preserving all gains. For the lower reach, natural flow is not estimated because there is insufficient information to evaluate natural losses due to evaporation, transpiration and substrate loss. ***Below river kilometer 45, the flow profile is entirely hypothetical***, for the purpose of looking at the relative influence of flow on temperature. In-stream flow loss in this reach, even with natural conditions, is probably significant, based on lower Willow Creek's small size, arid environment and a summer 1858 journal entry from Lieutenant Mullan of the US Army: "There is but little water in Willow Cr and at this season it is not running, but stands in pools and being well shaded is cool and pleasant (**Figure D3-15**)."

3. Estimated natural potential with tributary flow increase and temperature decrease. ***Above river kilometer 45, this scenario is the NTP flow for Willow Creek***. The scenario is shown in **Figure D3-17**, including hypothetically extending flow downstream below km-45 for purposes of comparing model output between scenarios. The actual NTP flow profile does not include the lower section, as portrayed in **Figure D3-18**. The NTP for this TMDL is the estimated natural flow profile for a typical lowest-flow time of year, accounting for natural tributary flow as well as natural mainstem flow. First, mainstem flow was estimated as described in the preceding paragraph (2). Then tributary natural flow was roughly estimated as follows:

   Increase tributary flow (in the encompassing Umatilla Basin, flow is strongly correlated with continuous upland forest area). In the Willow Creek Subbasin, upland forests typically occur at elevations above 4000 feet. Flow is also correlated with watershed area, though to a lesser extent. Due to the paucity of data, regression analysis was not fruitful and published regional curves are more suited to channel-forming winter/spring flows. Given that natural tributary surface water inputs are probably slight throughout the region, except for large forested tributaries, and in lieu of a more reliable method, the following simple calculation was developed for roughly estimating natural base flow for tributaries with potential human-depleted discharge. Note that because forest area in the basin is slight, the parenthetic sum of basin area and forest area fractions in the equation has a maximum of about 1.05.

$$\frac{Q_t}{A_t} = \frac{Q_r}{A_r}\left(\frac{A_t}{A_s} + \frac{A_{t,4000}}{A_t}\right)$$

Q_t = Base flow at tributary mouth

A_t = Drainage area at tributary mouth

Q_r / A_r = Average base flow per drainage area at reference sites with little or no consumptive use

A_s = Willow Creek subbasin drainage area

$A_{t,4000}$ = Drainage area above 4000 feet elevation for a tributary

This did not indicate increases for all tributaries, and was only employed where increased flow resulted, as follows:

- Herren – no increase (assumed near natural)
- Shaw – no increase (assumed near natural)
- North Fork – (no increase indicated)
- Skinners Fork– no increase (too small to make a difference in mainstem flow)
- Balm Fork – increase based on equation above
- Shobe (too small to make a difference in mainstem flow)
- Hinton - (no increase indicated)
- Rhea - increase based on equation above
- 8 Mile - increase based on equation above

Surface water temperature is estimated for NTP tributary inputs. Rhea and Eightmile Creeks were observed to have dry streambeds during most of the model period. Accordingly only groundwater inputs were estimated at these tributaries in the model calibration (existing condition). For temperature estimates of natural base flows in areas of now dry streambeds, the following is implemented – first, assume mainstem temperature diel pattern at nearest upstream continuous node with continuous surface flow from above (Ione, km 52). Second, an adjustment is made to account for temperature reduction associated with channel narrowing, increased vegetation and increased flow, by looking at the relative mainstem reduction at these confluences due to these attributes, when natural morphology and vegetation scenarios are simulated. Temperature is reduced in other tributaries in a similar fashion to account for vegetation, morphologic and flow improvements. This will be implemented as follows:

- Herren – no change (assumed near natural)
- Shaw – no change (assumed near natural)
- North Fork – (-2 ºC)
- Skinners Fork– no change (too small to make a difference in mainstem flow)
- Balm Fork – (-3 ºC)
- Shobe (too small to make a difference in mainstem flow)
- Hinton – (-3 ºC)
- Rhea – (-3 ºC)
- 8 Mile – (-3 ºC)

4. <u>2005 Reservoir Discharge</u>. Finally, an augmented flow scenario profile was prepared. This scenario utilizes the existing flow (August 2000) above the Reservoir. Below the Reservoir the flow profile is that of the existing condition profile except augmented with a daily-varying Reservoir release rate as measured at the USGS gage at Heppner, for July 21 through August 9, 2005. The flow profile presented in **Figure D3-17** is an August 1 snapshot influenced by previous days higher release rates, hence the pulse front at approximately kilometer 70. Downstream from Heppner, the flow profile is hypothetical. According to discussions with residents, the actual August 2005 flow did not continue to the mouth, attenuating to a dry streambed somewhere between Cecil and Ione (refer to **Sections 1.5** and **2.1.2** in this **Appendix**).

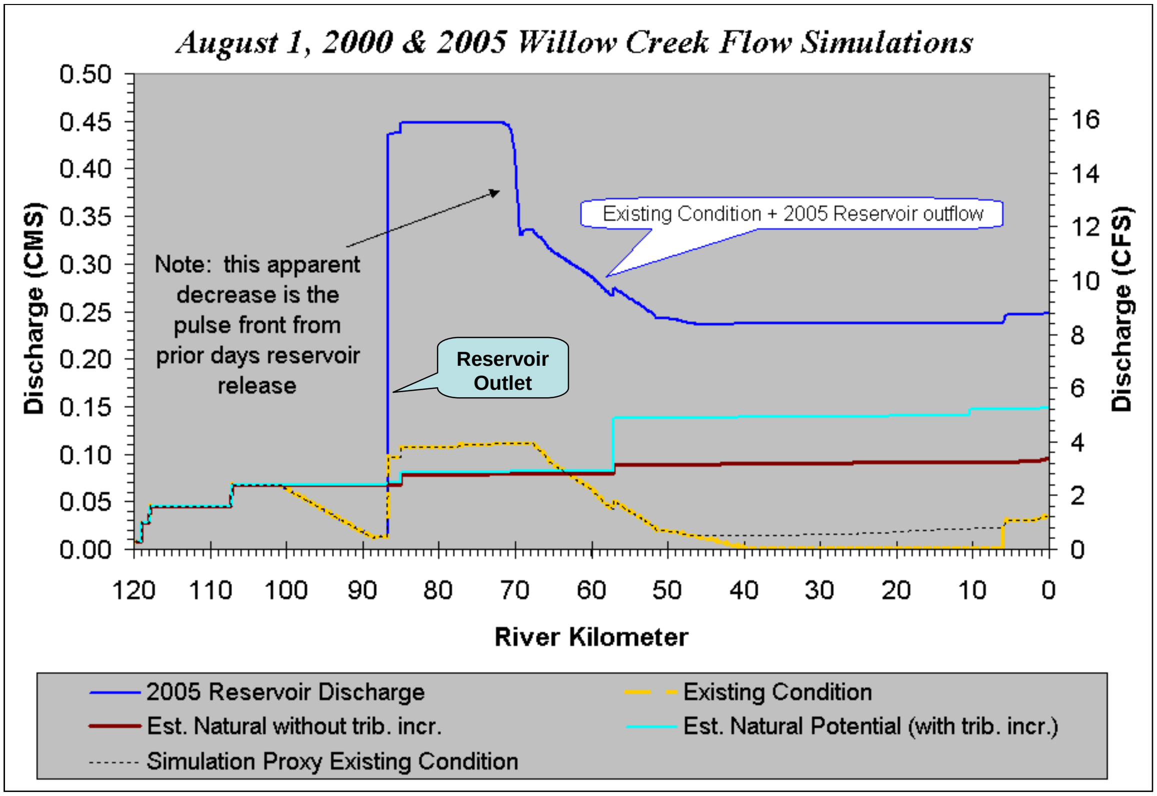


Figure D3-17. *Existing and simulation flow profiles for Willow Creek (refer to adjacent text for explanation)*

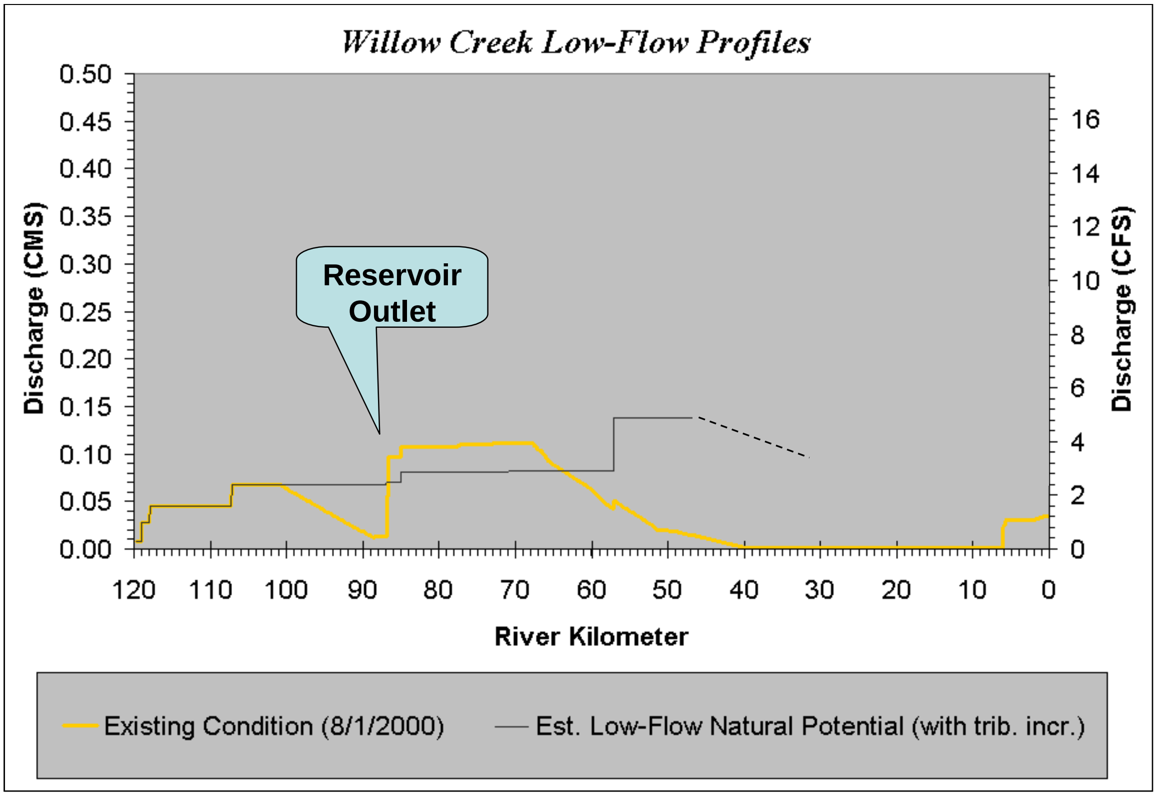


Figure D3-18. *Existing and NTP flow profiles for Willow Creek*

CHAPTER 4. SIMULATIONS

Model

Longitudinal and temporal simulations of flow, effective shade, heat and temperature were conducted using the model *Heat Source 7.0*. *Heat Source* documentation "*Analytical Methods for Dynamic Open Channel Heat and Mass Transfer: Methodology for Heat Source Model Version 7.0*" (Boyd, Kasper, 2003) is available on-line at www.heatsource.info. Temperature simulations are spatial (one-dimensional, longitudinal) and temporal. Model time and distance steps were set at 1.0 minute and 100 meters for Willow Creek simulation. An overview of stream heat transfer processes is provided in **Section 1.3**.

All solar radiation loads are the clear sky received loads that account for Julian time, elevation, atmospheric attenuation and scattering, stream aspect, topographic shading, near stream vegetation, stream surface reflection, water column absorption and stream bed absorption.

Overview of Simulation Scenarios

The 2000 calibration is used as the base model for estimating temperature change that would occur given estimated potential future vegetative conditions, flow and channel shape. Combination scenarios were simulated, all based on the 2000 calibration; where temperature was simulated for more robust vegetation and a narrower and deeper channel. These conditions were simulated for various flow scenarios, including the existing condition, natural mainstem flow and natural mainstem flow with natural tributary input. Another scenario was prepared based on the 2000 July-August profile, with increased flow based on gage data for the Reservoir outlet in 2005.

Wetted width, depth, velocity and flow volume are calculated by *Heat Source* and compared to in-stream measurements (measured at the locations identified in **Section 2.1.2**). The stream roughness coefficient, Manning's n, was adjusted to achieve a close match between measured and calculated values. Hydraulics are calculated from gradient, available volume; and channel width, depth and side slope angle, assuming a trapezoidal channel. The *Heat Source* documentation referenced above details the method.

Simulation Period and Extent

River temperature was simulated for Willow Creek and calibrated to August 2000 measured temperatures (in-stream thermistors). The model is calibrated for a 21-Day period as a function of Julian Day. The selected time frame is July 21 through August 9. The analysis was conducted with data input sampling every 50 meters along the stream. Simulations were performed for a total of 120 km (77 nominal river miles) in the Subbasin – most of the length of Willow Creek. **Table D4-1** lists the spatial extent by river system. **Figure D1-2a** and **1-2b** depict the spatial extent of river simulation.

Table D4-1. *Temperature and Effective Shade Simulation Extent*

Subbasin	River/Stream	Simulation Extent
Willow Creek Subbasin	Willow Creek	Cutsforth Park to Mouth
		Total Simulation Extent: (120 km)

<u>Willow Creek Reservoir</u>
The Reservoir was not simulated. Instead, model calibration was accomplished by minimizing flow to below the model threshold, and then re-instituting flow at the outlet as if a new tributary had entered Willow Creek at that point. Accordingly, the Reservoir region is blanked out on output heat and temperature graphs. For the NTP flow scenario, the Reservoir region was simulated as if there were no Reservoir. Vegetation and morphology from the region immediately above the Reservoir is assumed.

4.1 Overview of Modeling Purpose, Valid Applications & Limitations

4.1.1 Near Stream Land Cover Analysis

Modeling Purpose

- Quantify existing near stream land cover types and physical attributes.
- Develop a methodology to estimate potential conditions for near stream land cover.
- Establish threshold near stream land cover type and physical attributes for the stream network, below which land cover conditions are considered to deviate from a natural potential condition.

Valid Applications

- Estimate current condition near stream land cover type and physical attributes.
- Estimate natural potential condition near stream land cover type and physical attributes.
- Identify site-specific deviations of current near stream land cover conditions from threshold potential conditions.

Limitations

- Methodology is based on ground level and GIS data such as, vegetation surveys, and digitized polygons from air photos. Each data source has accuracy considerations.
- Associations used for land cover classification are assigned median values to describe physical attributes, and in some cases, this methodology significantly underestimates landscape variability.
- At some point below Ione, Willow Creek is likely a naturally intermittent stream. As this point is not known and may have changed, vegetation associated with perennial water is assumed. ***The Department acknowledges that heat load waste load allocations should be updated once this is better understood.***

4.1.2 Hydrology Analysis

Modeling Purpose

- Map and quantify surface and subsurface flow inputs and withdrawal outputs.
- Develop a mass balance for the stream network to quantify existing in-stream flow volume.
- Quantify average velocity and average stream depth as a function of flow volume, stream gradient, average channel width and channel roughness.
- Develop a potential mass balance that estimates flow volumes when withdrawals and artificial surface returns are removed.

Valid Applications

- Estimate current condition flow volume, velocity and stream depth.
- Estimate natural potential condition flow volume, velocity and stream depth.
- Identify site specific deviations of current mass balance from the threshold potential mass balance.

Limitations

- Small mass transfer processes are not accounted.
- Limited ground level flow data limit the accuracy of derived mass balances.
- Some water withdrawals are not directly quantified.
- Return flows are oversimplified.
- Subsurface-to-river flow input and exchange are not measured.
- Return flows may deliver water that is diverted from another watershed.
- Inter-annual variations are not simulated.

4.1.3 Effective Shade Analysis

Modeling Purpose

- Simulate current condition effective shade levels over stream network.
- Simulate natural potential condition effective shade levels based on channel width and land cover types and physical attributes over stream network.
- Establish threshold effective shade values for the stream network, below which current conditions are considered to deviate from a natural potential condition.
- Provide land cover type specific shade curves that allow target development where site-specific targets are not completed (i.e., establish relationships between effective shade and channel width, for a specified aspect and vegetative condition).

Valid Applications

- Estimate current condition effective shade over the stream network.
- Estimate natural potential condition effective shade over the stream network.
- Identify site-specific deviations of current effective shade conditions from threshold potential conditions.

Limitations

- Limitations for input parameters apply (i.e., hydrology and near stream land cover type and physical attributes).
- The period of simulation is valid for effective shade values that occur in late July and early August.
- Assumed channel widths where they were not measurable from aerial photographs may reduce accuracy of the effective shade simulation.
- At some point below Ione, Willow Creek is likely a naturally intermittent stream. As this point is not known and may have changed, vegetation associated with perennial water is assumed. ***The Department acknowledges that heat load waste load allocations should be updated once this is better understood.***

4.1.4 Stream Temperature Analysis

Modeling Purpose

- Analyze current stream temperature over stream network during low-flow/warm season.
- Analyze natural potential condition stream temperature based on potential land cover types and physical attributes and flow volume over stream network.
- Establish threshold stream temperature values for the stream network, above which conditions are considered to deviate from a natural potential condition. Though quantitative analysis of uncertainty and natural variability is limited by practical considerations, these factors are acknowledged in the application of threshold temperatures.
- Evaluate temperature differences between conditions with and without anthropogenic warming.
- Provide riparian condition and temperature goals that are protective of beneficial uses.
- Provide a methodology for stream heating and temperature analysis.

Valid Applications

- Estimate upper range of stream temperatures over the stream network.
- Estimate natural potential upper range stream temperatures over the stream network.
- Identify site-specific deviations of current stream temperatures from natural potential conditions.
- Analyze the sensitivity of single or multiple parameters on stream temperature regimes.
- Identify stream temperature distributions during low-flow/warm season.

Limitations

- Limitations for input parameters apply (i.e., channel morphology, near stream land cover type and physical attributes and hydrology).
- Accuracy of the methodology is limited to validation statistics of results.
- Stream temperature results are limited to the streams for which the analysis is completed (i.e., Willow Creek).
- The simulation is valid for the time frame of the simulation or for July-August intervals with similar flow, air temperature, humidity, wind speed and specified riparian conditions.
- ***At some point below Ione, Willow Creek is likely a naturally intermittent stream, and the lower stream is dry through much of its length during late July and early August, on a typical year. Hypothetically continuous flow was invoked for temperature simulation, for the purposes of evaluating relative temperature differences between flow and shade scenarios. NTP temperature is not evaluated for this reach.***

4.2 Effective Shade

4.2.1 Overview - Description of Shading Processes

Effective shade can be thought of as the amount of daily solar radiation directed toward the stream that is blocked by features such as topography and vegetation, and is defined and described in **Section 1.3**. Factors that influence stream surface effective shade are incorporated into the simulation methodology, and include the following:

Season/Time: Date/Time
Stream Morphology: Aspect, Channel Width, Incision
Geographic Position: Latitude, Longitude, Topography
Land Cover: Near Stream Land Cover Height, Width, Density
Solar Position: Solar Altitude, Solar Azimuth

4.2.2 Effective Shade Simulation Period

The effective shade model is calibrated to analyze and predict heat loads and stream temperature for narrow periods of time as a function of Julian Day, however other periods can be simulated. The period and spatial extent of simulation is identified under *Simulation Period and Extent* in the beginning of **Section 4.0**.

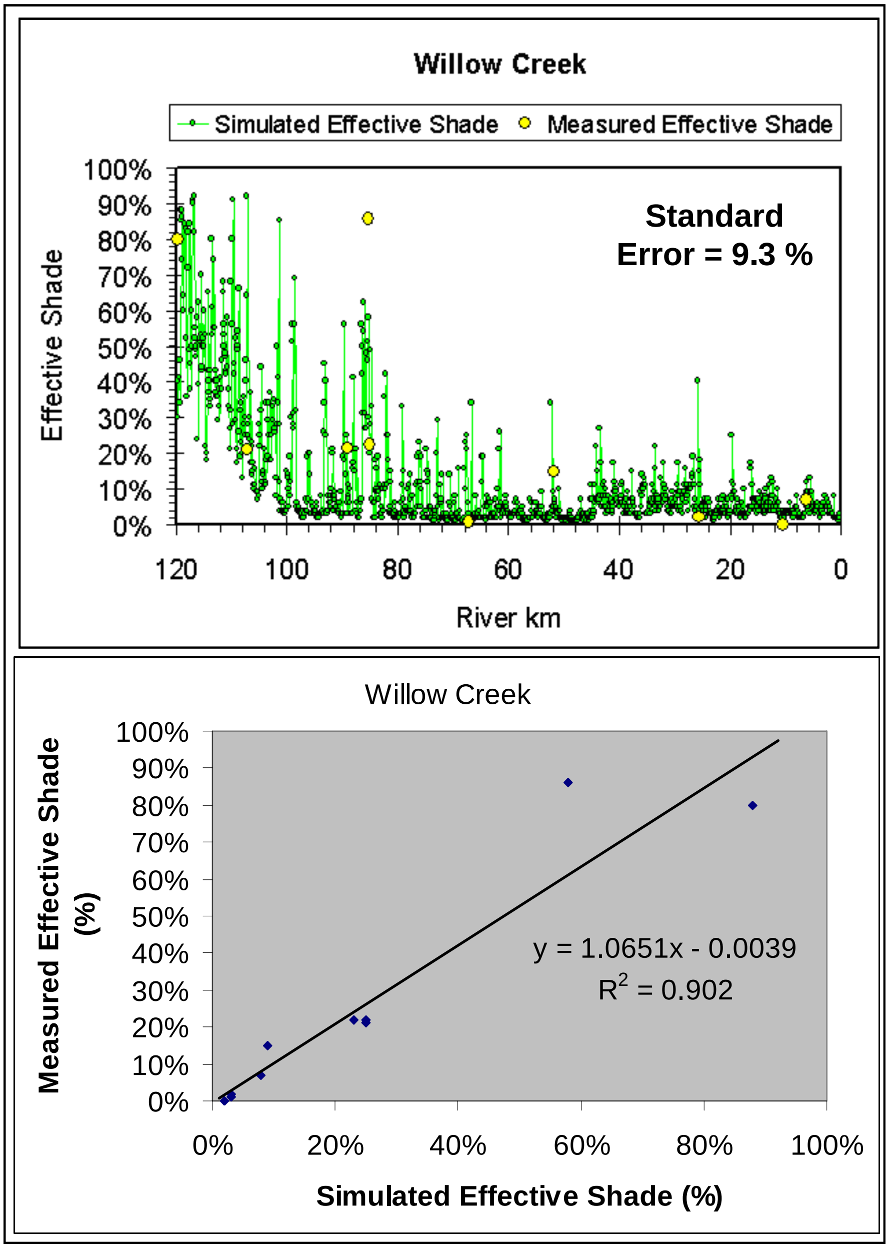
4.2.3 Simulated Effective Shade Scenarios

Once effective shade models are developed, natural potential near stream land cover scenarios are simulated. Natural potential land cover was estimated as described in **Section 3.3.3**.

4.2.4 Validation - Effective Shade Simulation Accuracy

Effective shade simulation validation was conducted by comparing simulated results with ground level measured shade values. Solar Pathfinder® data was used to collect ground level data at ten locations in the Willow Creek Subbasin (**Figure D4-1**). Shade simulations have a standard error of 9.0% when compared to these values. Pearson's correlation coefficient between measured and simulated values is $R^2 = 0.90$. The Department considers these values to be acceptable.

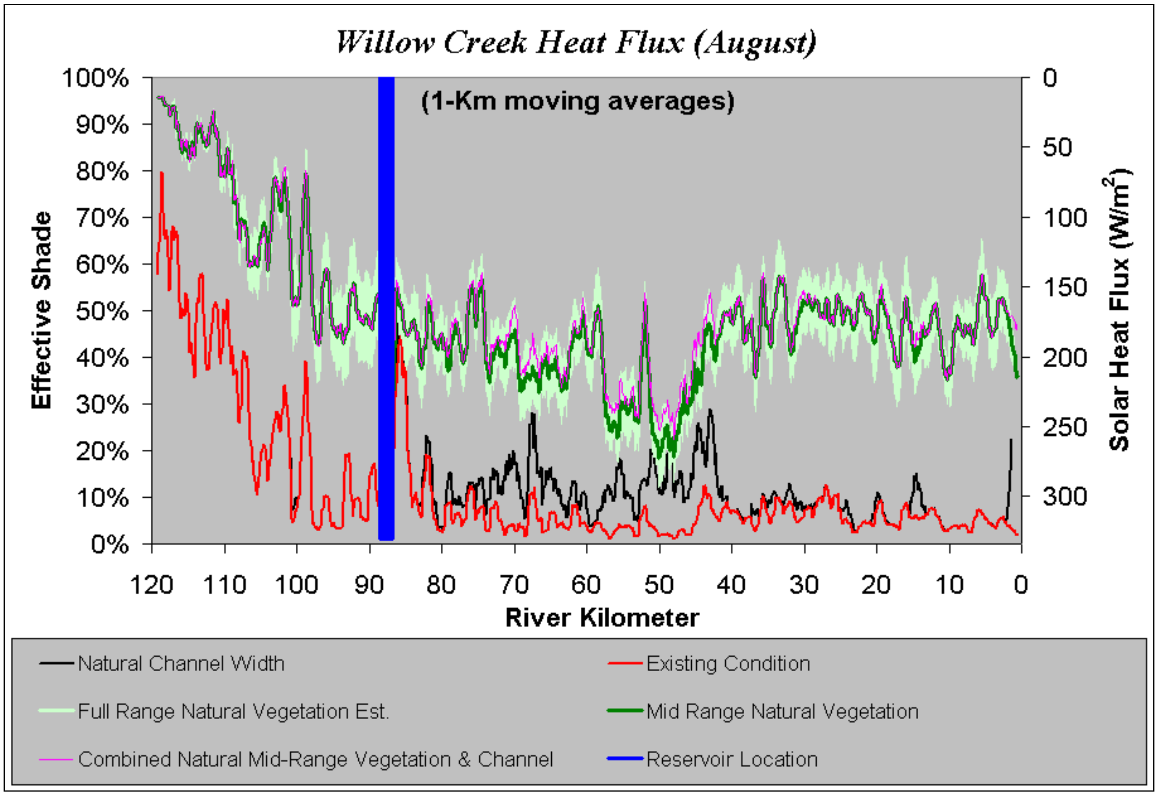
Figure D4-1. *Comparison between effective shade field measurements and August 1, 2000 simulation results*



4.2.5 Effective Shade and Solar Heat Flux Simulations

Effective shade was simulated for the length of Willow Creek based on digitized land cover and assessed height and density attributes for each of 66 vegetation classes (**Section 3.3**). **Figure D4-2** display the current condition effective shade levels (August 1, 2000) for the various shade scenarios that were simulated. As previously mentioned, effective shade is inversely proportional to solar radiation flux. **Figure D4-2** presents effective shade on the left-hand axis and solar loading on the right-hand axis.

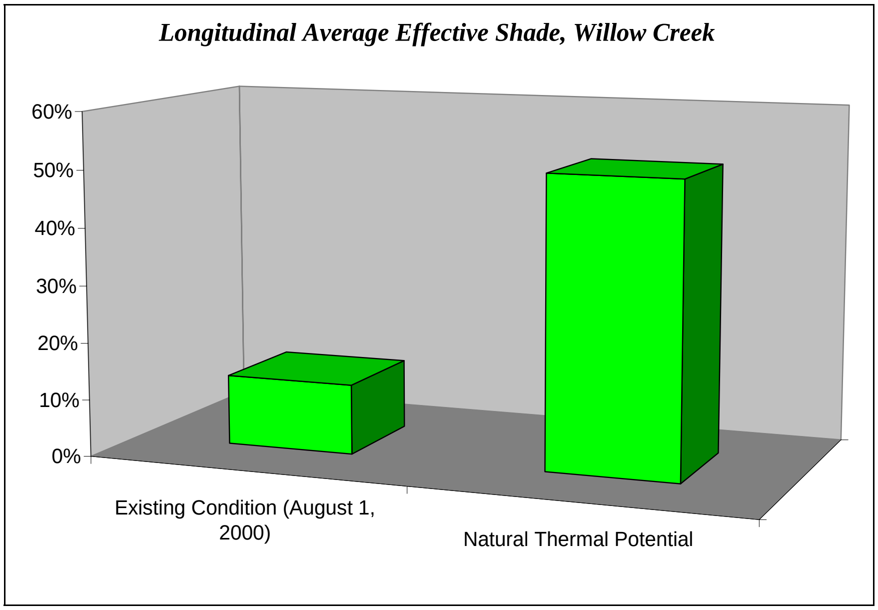
Figure D4-2. *Simulated effective shade and solar heat flux for various Willow Creek scenarios, based on August 1, 2000. Refer to* ***Figure D2-3*** *for river miles and additional location reference.*



The following is a brief discussion of existing and potential shade patterns as seen in **Figure D4-2**. The simulated effective shade output is based on August 1, 2000. Generally, effective shade decreases in the downstream direction, due to valley relief, channel widening and the transition from conifers to lower vegetation height deciduous trees. Topography makes up a significant part of effective shade in the upper reaches of Willow Creek. In the order of generally increasing shade, the lowest scenario in **Figure D4-2** is the measured condition of August 1, 2000. The particularly low shade levels from kilometer 45-72 stem in part from an over-widened channel. Recent channel incision in the lower basin and locally high sinuosity contribute to increased shade levels. Next, *Natural Channel With* scenario simulates a narrower channel, with all other input variables unchanged (**Section 3.2.3** describes natural potential channel determination). Then, *Mid Range Natural Vegetation* scenario simulates the best estimate of natural land cover, again with all else held constant. Note that there is a range shown to account for the uncertainty in natural potential vegetation estimation (**Section 3.3.3** describes NTP land cover determination as a range and explains the mid-range computation). Finally, effective shade was simulated with combinations of natural attributes – *Combined Natural Mid-Range vegetation and Channel*. This scenario is the best estimate of natural solar heat input and is ***deemed to be the NTP radiant heat load for Willow Creek***. A notable feature of **Figure D4-2** is that it clearly indicates that natural riparian shade outweighs channel narrowing in reducing heat loads, and consequently shade is a larger factor in reducing temperature. Comparison of **Figures D4-8**, **D4-9**, **D4-10** shows that increased flow is similar to channel narrowing in having a relatively slight influence on temperature.

Heat loading can be characterized as a heat flux (per unit area) of stream surface (proportional to effective shade, as in **Figure D4-2**); or as a total load received by a given reach or water body. Alternatively, **Figure D4-3** depicts the longitudinal average effective shade (every 100 meters for the length of Willow Creek) for the NTP scenario and the relatively current condition of August 1, 2000. Total heat loading is discussed in the following section.

Figure D4-3. *Longitudinally averaged simulated effective shade data for Willow Creek – Current condition (12.3%) and NTP condition (50.7%)*



4.2.6 Total Daily Solar Heat Load Analysis

Solar heat is established as a primary pollutant in stream heating processes. The total daily solar heat load is the cumulative (entire stream surface area) solar heat received by a stream over one day during the July/August period. For the purposes of this analytical effort, the total solar heat load is calculated as the longitudinal sum of the products of the daily solar heat flux and surface area of exposure for each stream reach (i.e., for each model distance step of 100 meters).

$$H_{solar} = \sum \left(\Phi_{solar} \cdot A_y\right) = \sum \left(\Phi_{solar} \cdot W_{wetted} \cdot dx\right)$$

$$H_{solar}^{anthro} = H_{solar} - H_{solar}^{potential}$$

where,

A_y: Stream surface area unique to each stream segment (m^2)

dx: Stream segment length and distance step in the methodology (m)

Φ_{solar}: Solar heat flux for unique to each stream segment ($MW\ m^{-2}$)

H_{solar}: Total daily solar heat load delivered to the stream (MW)

H_{solar}^{anthro}: Portion of the total daily solar heat load delivered to the stream that originates from anthropogenic nonpoint sources of pollution (MW)

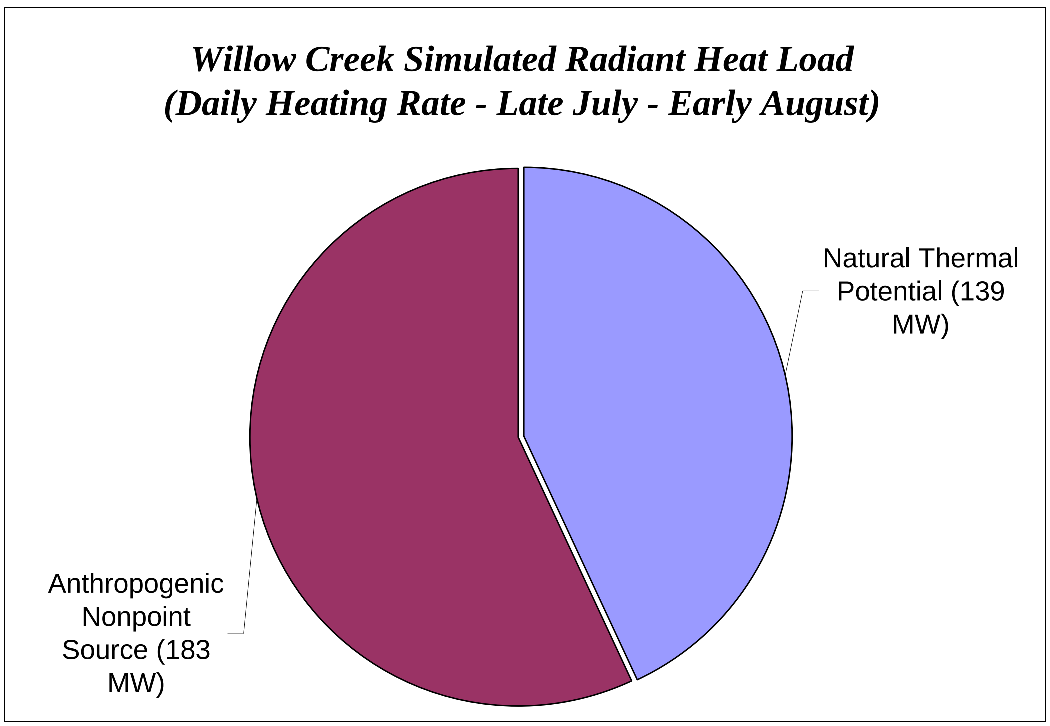
$H_{solar}^{potential}$: Portion of the total daily solar heat load delivered to the stream that originates from solar input not affected by human activities (MW)

W_{wetted}: Wetted width unique to each stream segment (m)

NTP levels of solar heat estimate the portion of the total daily solar heat load that occurs when human-related sources of heat are minimized. This condition, ($H_{solar}^{potential}$), is calculated by substituting the NTP daily solar flux and the NTP wetted width into the equation above. In similar fashion, the total daily solar load is calculated for the current condition (H_{solar}) daily solar flux and wetted width. With the NTP portion of the total daily solar load accounted for, the remaining portion can be attributed to anthropogenic nonpoint sources. In other words, the anthropogenic nonpoint source total daily solar load is the difference between the existing total daily solar load and the NTP total daily solar load. Derived total daily solar loads for ***natural*** sources (no human caused heating = NTP heat load) and anthropogenic nonpoint sources are presented in **Figure D4-4**.

Roughly **57 percent** of the solar loading that occurs in the Willow Creek is from anthropogenic nonpoint sources, while the remaining proportion of the total daily solar load originates from natural sources (see **Figure D4-4**). *For the purposes of this analysis heat loads are calculated from simulated current and NTP conditions.*

Figure D4-4. *Total daily solar heat load for anthropogenic nonpoint and natural sources, derived as the longitudinal sum of the products of the daily solar heat flux and channel surface area*



4.2.7 Effective Shade Curve Development

Effective shade curves are designed to display effective shade levels for a specific land cover type as a function of channel width. These shade curves are intended to provide effective shade targets where site-specific effective shade simulations have not been completed. Effective shade curves presented in this document are developed for the Willow Creek Subbasin (i.e., subbasin latitude and longitude and vegetation types) and are accurate for the July/August time frame. Stream aspect is also considered in the shade curve methodology.

The land cover types used for development of the shade curves are those developed as the NTP land cover types. Land cover physical dimensions for height and density are listed on the shade curves (note that actual shade-producing heights for some conifer species is less than actual mature heights, due to the narrow shape of individual trees – this has been accounted for in the shade model input). The types of vegetation characterized by the heights in the shade curves are identified in **Section 2.1.4**. The height determination method and the geographic application of each curve are identified in **Section 3.3.3**. The geographic application is recalled in **Figure D4-5**.

Figure D4-5. *(Recall **Figure D3-16**) Willow Creek Subbasin land use/cover map showing zones of application of shade curves*

Figure D4-6a through **D4-6c** display the shade curves for potential land cover types. This methodology provides effective shade targets for the un-simulated streams of the Willow Creek Subbasin in Oregon. The shade curves demonstrate the relationship between near stream land cover physical properties, channel width and stream aspect. The curves are not reach-specific and therefore topography is not accounted for; as such a stream may manifest higher levels of shade than indicated by these curves.

Note that in shrub-steppe landscapes where upland trees are uncommon, tree stands are common along perennial streams.

Figure D4-6a. *Effective Shade Curves for natural potential riparian vegetation where conifers are expected to predominate. Captions are color coded corresponding to* ***Figure D4-5*** *where geographic application is identified.*

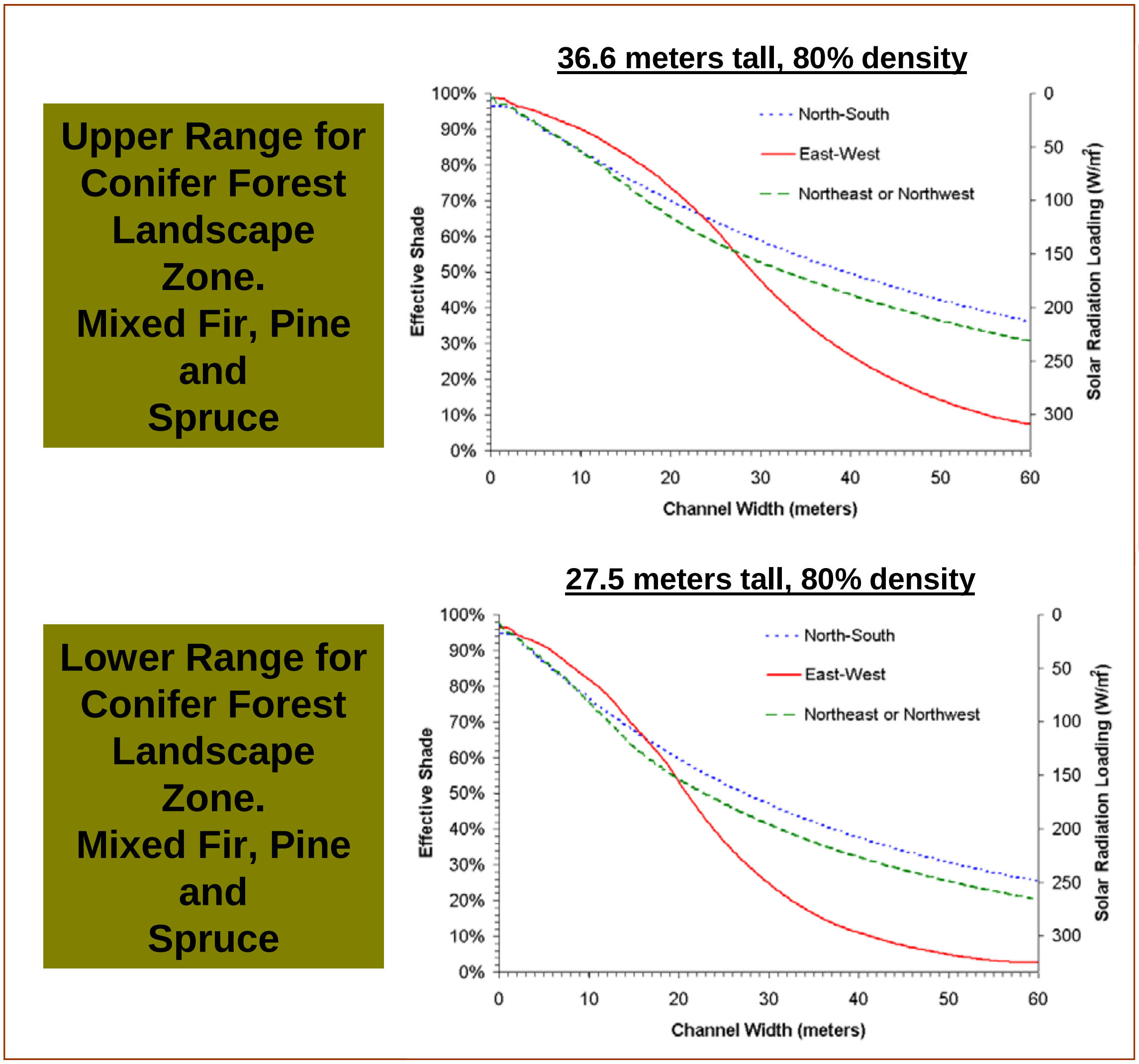
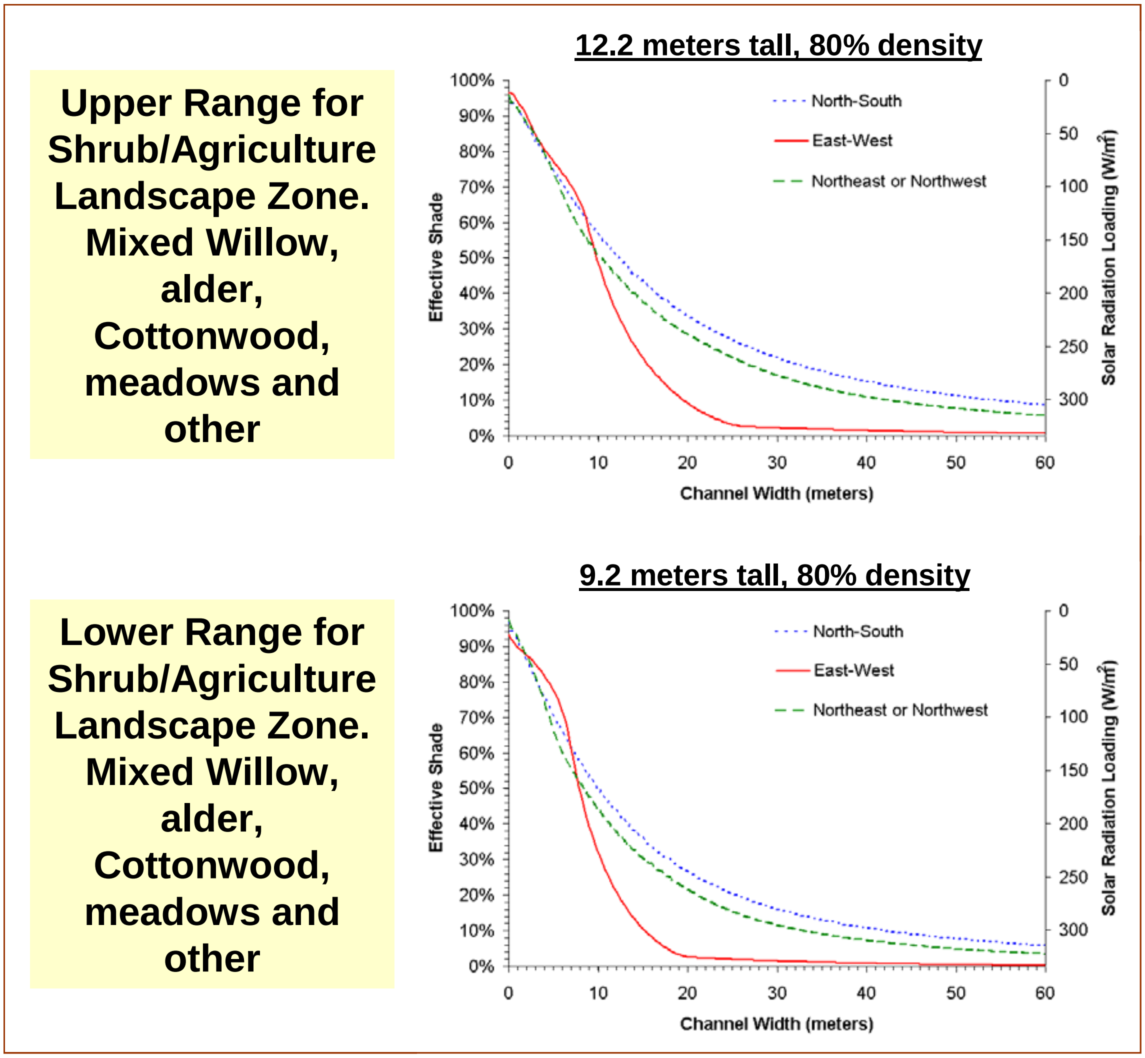
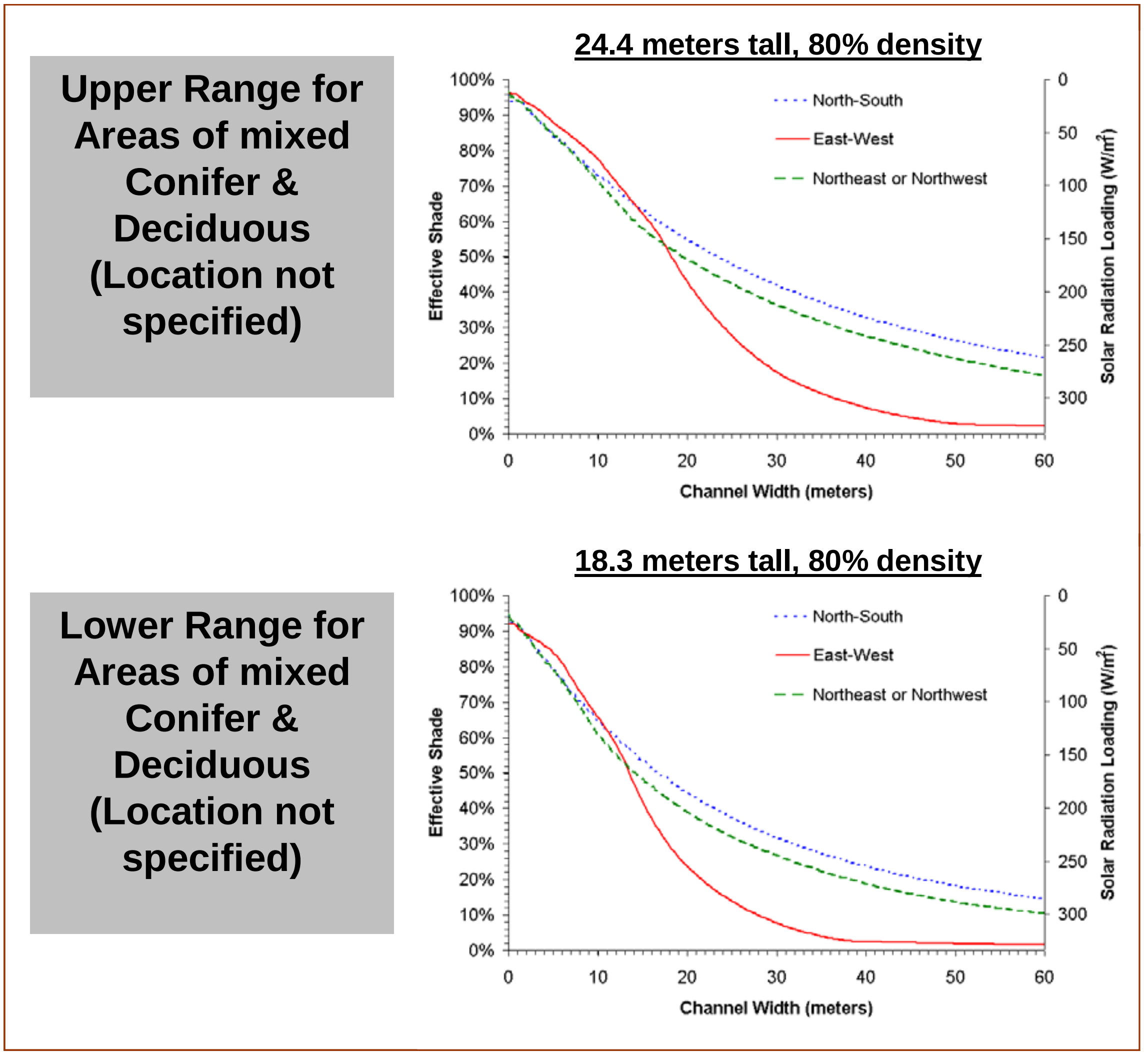


Figure D4-6b. *Effective Shade Curves for natural potential riparian vegetation where deciduous trees are expected to predominate. Captions are color coded corresponding to* ***Figure D4-5*** *where geographic application is identified.*



A third set of curves, for areas of mixed conifer and deciduous areas, is provided in **Figure D4-6c**. These curves are not applied to the specific zones of **Figure D4-5**, because their area of application has not been assessed.   Instead they should be applied where best professional judgment, soils, climate and existing stands guide identification of natural vegetation.

Figure D4-6c. *Effective Shade Curves for natural potential riparian vegetation where mixed conifer and deciduous stands are expected to predominate.*



4.3 Stream Temperature Simulations

4.3.1 Stream Temperature Simulation Methodology

As discussed previously, *Heat Source version 7.0* was used to model stream temperatures in the Willow Creek Subbasin. For detailed information regarding *Heat Source* and the methodologies used, refer to "*Analytical Methods for Dynamic Open Channel Heat and Mass Transfer: Methodology for Heat Source Model Version 7.0*" (Boyd and Kasper, 2003).

4.3.2 Spatial and Temporal Scale

The period and spatial extent of simulation is identified under *Simulation Period and Extent* in the beginning of **Section 4.0**. Model output resolution is set at 1 hour and 100 meters.

4.3.3 Validation - Simulation Accuracy

For the purposes of this analytical effort, validation refers to the statistical comparison of measured and simulated data. Standard error statistics are calculated for in-stream temperature recorder data sets. Each measurement of temperature is discrete and is used to assess model accuracy. Longitudinal and temporal simulation outputs are only accurate to levels that exceed the validation statistics. Validation statistics listed in **Table D4-2**.

Spatial and temporal data is stratified in the validation to test for biases in the simulation methodology. **Table D4-2** displays the validation results for Willow Creek.

Table D4-2. *Stream Temperature Simulation Validation. The year 2000 simulation is validated spatially and temporally. This table compares simulated and measured temperatures. The spatial statistic applies to the fit of the measured and simulated longitudinal profiles during the afternoon (temperature v. river kilometer). The temporal validation assesses the fit of measured and simulated diel curves at each continuous monitoring station (temperature v. time).*

Spatial Validation	Validation Statistic	Willow Creek 8/1/200
Spatial In-stream Data: In-stream Data Loggers	Samples (n)	10
	Standard Error (°C)	1.6

Temporal Validation						**Hourly Temperature Data: Simulated v. Measured**	
Node #	**Stream**	**Site Description**	**River Mile**	**Latitude**	**Longitude**	**Standard Error**	**Number of Samples (21 days of hourly readings)**
10	Willow Ck	1/4 mile u/s Cutsforth Park	77.3	45.27870	-119.35380	1.6	252
9	Willow Ck	1/4 mile d/s Blake Ranch Rd	69.3	45.18630	-119.32340	2.3	252
8	Willow Ck	1/4 mile u/s reservoir, directly beneath hwy bridge	55.9	45.34050	-119.51730	2.4	252
7	Willow Ck	NW Gale St. bridge (d/s side)	55.1	45.35930	-119.55510	1.2	252
6	Willow Ck	50 meter d/s Heppner City Park at Church St	55.3	45.35800	-119.55310	1.3	252
5	Willow Ck	Lexington F-St. bridge (d/s side)	44.0	45.44720	-119.69920	1.5	252
4	Willow Ck	Bridge (d/s side) by Ione High School	34.1	45.49890	-119.82980	1.1	252
3	Willow Ck	Bridge (d/s side) at Cecil	17.8	45.61930	-119.95840	1	252
2	Willow Ck	Mile Creek	8.0	45.71310	-120.03880	1.4	252
1	Willow Ck	Base of Highway grade	5.0	45.74315	-120.02322	0, boundary condition	

4.3.4 Simulated Scenarios

Once the current condition (July/August 2000) stream temperature model was calibrated, several scenarios were simulated by changing one or more stream input parameters. The simulated scenarios focus largely on estimated natural potential conditions for land cover, channel morphology and in-stream flow, as described in previous sections of this report. Combinations of these potential conditions are also simulated to investigate the cumulative thermal effect of attaining potential conditions.

Table D4-3. *Simulated Scenarios – single condition change*

Existing Condition	July 21 – August 9, 2000
Natural Potential Vegetation	Potential Near Stream Land Cover (Vegetation)
Natural Potential Channel	Potential Channel Width
Various Flow Profiles	Flow Profiles were developed as described in **Section 3.4**, and temperature was simulated for each. In addition to increasing mainstem flow, hourly temperature at the mouths of cooling tributaries were reduced to help account for potential (and tributary flow was modified).

Table D4-4. *Simulated Scenario – Combined conditions change*

Natural Potential Vegetation, Channel and mainstem and Tributary Flow	NTP Stream Land Cover (range of vegetation height estimate), NTP Channel Width, and the NTP flow profile identified in **Section 3.4**.

Figure D4-7 displays the July/August 2000 calibrated model longitudinal temperature results. **Figures D4-8** through **D4-10** portray the temperature simulations for the various model single-change scenarios described in **Table D4-3. Figure D4-11** shows the combination-scenario temperature simulation of natural potential flow, channel cross-section and range of vegetation identified in **Table D4-4**. As discussed previously (**Sections 2.1.2** and **4.1.4**), model validation is weak below kilometer 45 due to flow conditions and should only be used as for comparisons between scenarios. This region is shown on **Figures D4-7** through **D4-11** as a hachured pattern. ***The simulation of absolute temperatures in the lower section is not verifiable, and should therefore be viewed only as rough estimates and will not be considered as part of the final NTP for temperature. Whereas the actual condition was intermittent pools, flow was artificially increased just to the level that would allow simulation. This was done to enable comparison of the relative influence of changes in channel form and flow, particularly since the downstream extent of perennial flow is not known, and Reservoir/irrigation management options may provide for extending this well downstream from the current condition. Temperature modeling provides added information for these management decisions.***

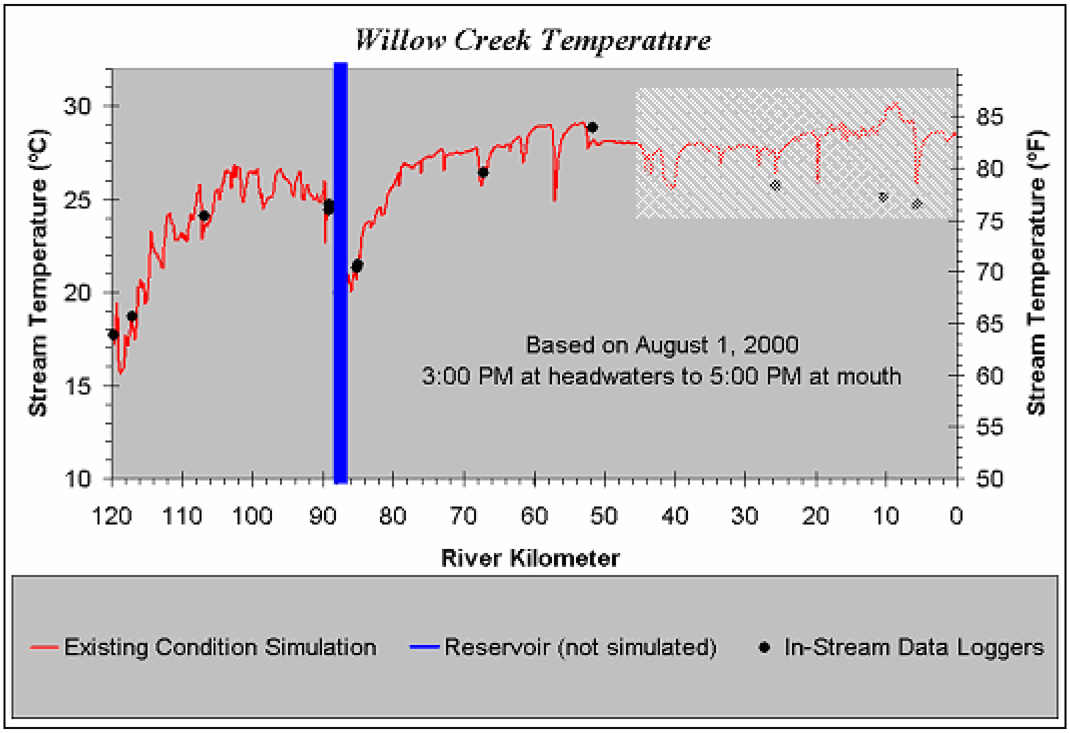


Figure D4-7. *August 1, 2000 Stream Temperature Simulation Calibration*

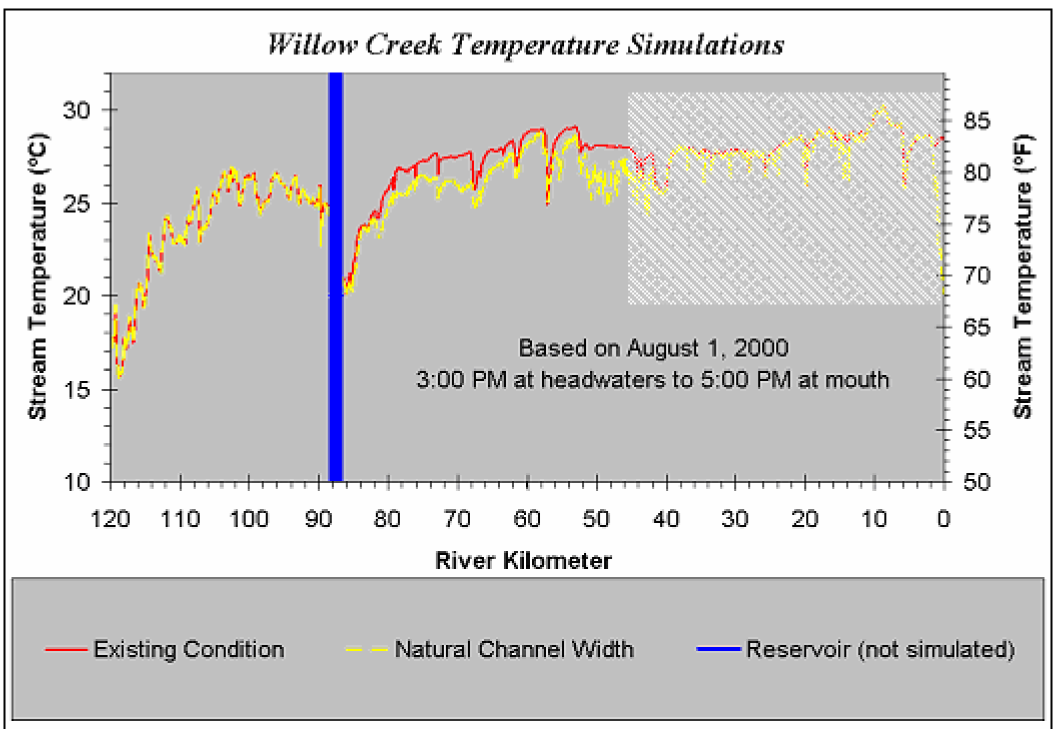


Figure D4-8. *Temperature simulation for August 1, 2000 conditions and, with all else held constant, NTP channel form*

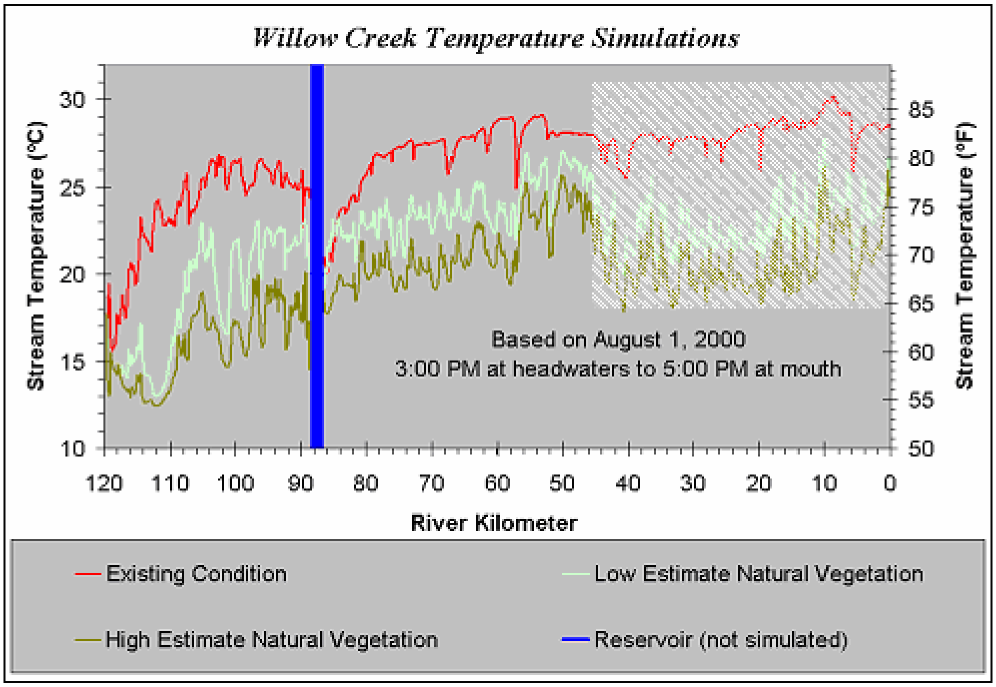


Figure D4-9. *Temperature simulation results for August 1, 2000 and, with all else held constant, the upper and lower estimate of natural potential vegetation*

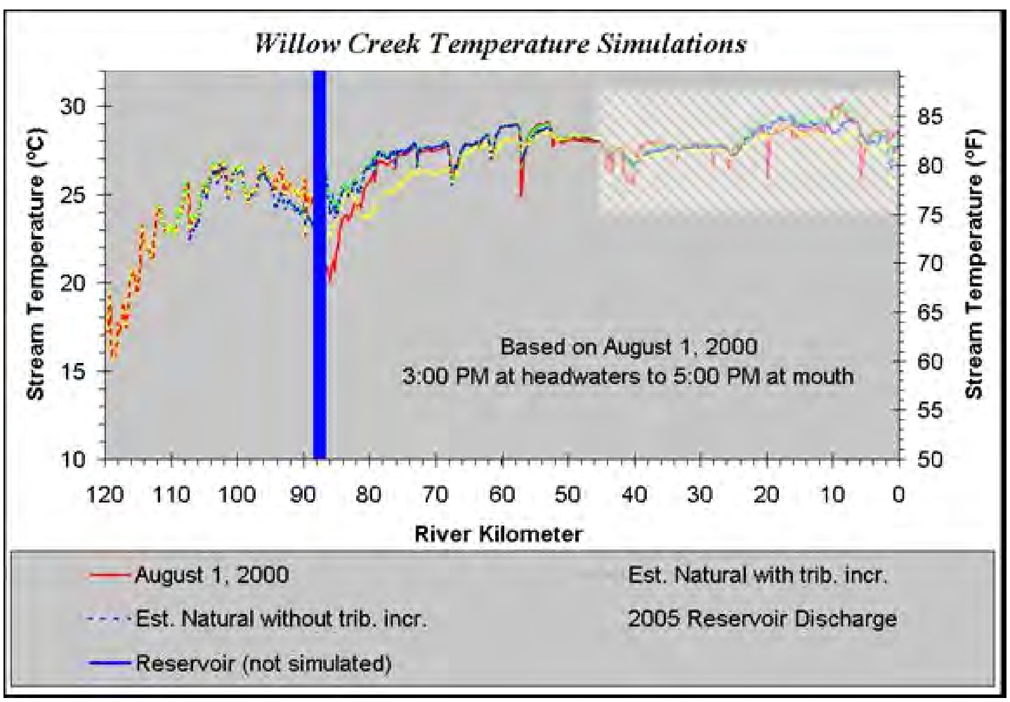


Figure D4-10. *Temperature simulation results for August 1, 2000 (km 120-45) and, with all else held constant, the various flow scenarios portrayed in* ***Figure D3-17****. As shown in* ***Section 3.4,*** *the August 1, 2000 flow was artificially increased below km 45 for simulation purposes.*

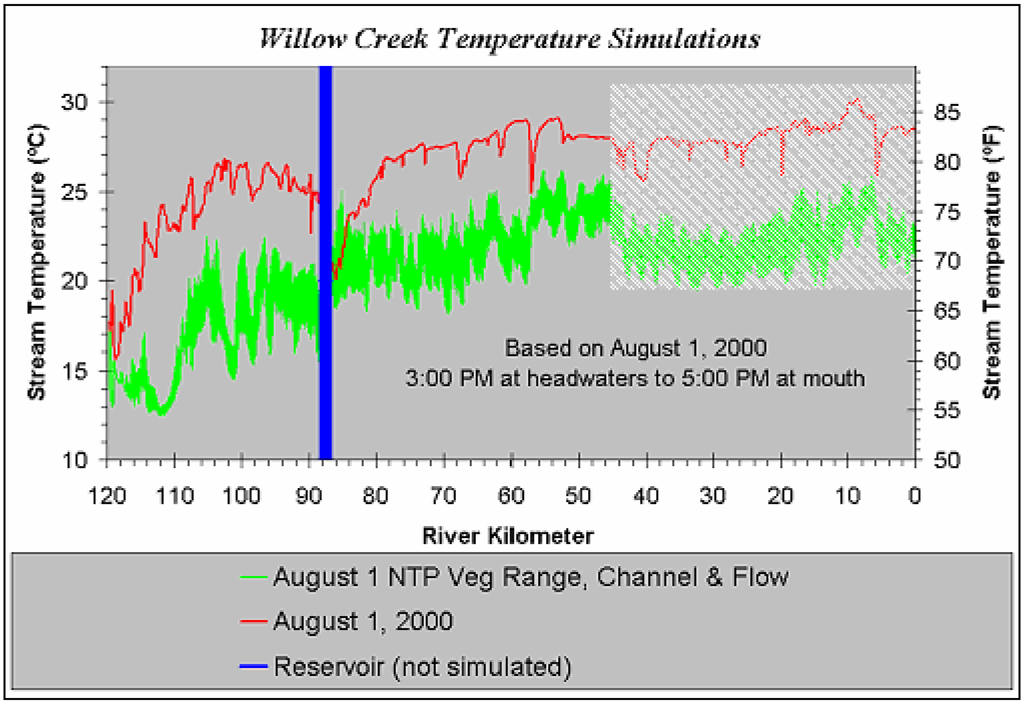


Figure D4-11. *Temperature simulation for August 1, 2000 (km 120-45) and the August 1 NTP based on combined natural potential flow (with tributary increase), channel cross-section the estimated range of vegetation height. The NTP line-width represents the range of estimated potential vegetation height.*

Up to this point the various temperature simulation figures have displayed August 1 afternoon temperatures August 1 is the day where ground level model input data was most abundant and hence a key date for model calibration. The figures are illustrated with a longitudinally variable timeframe, 3:00 – 5:00PM, because there is a tendency for the daily maxima to fall within this time frame, with downstream reaches often peaking later. However, model output is available for every hour of the 21-day simulation period, for the length of Willow Creek. This enables extraction of daily maxima and 7-day averaging, providing for comparison of simulated natural condition and biologically-based temperature standard criteria, each of which are based on the rolling 7-day average of daily maximum temperatures. The 7-day summary statistic for NTP and the summer 2000 temperature simulations is portrayed in **Figure D4-12**. Clearly the natural condition exceeds the biologically-based criterion for Willow Creek (20 ºC). The natural condition is therefore the appropriate criteria for Willow Creek. ***We emphasize that though the heating profiles (Figure D4-2) are analytically robust for the length of Willow Creek, the temperature simulation for the lower 45 kilometers is not, as discussed previously (insufficient flow for validation of model calibration). Accordingly, the load allocations apply the entire length of Willow Creek, and the natural condition temperature criterion is only developed above kilometer 45.***

The Department recognizes that the NTP temperature uncertainty-range displayed in **Figure D4-12** does not, and is not intended to, account for inter-annual variability and sources of computational uncertainty other than that of land cover height estimation (**Section 3.3.3**). However, year 2000 was not an uncommon year in terms of climate and flow, and other sources of potential model input error are relatively slight. Therefore, the Department deems the natural condition temperature profile of **Figure D4-12** to be an appropriate best-estimate range.

Figure D4-12 displays the natural condition temperature profile for Willow Creek, kilometer 45-120, expressed in terms of the 7-day summary temperature statistic, accounting for the natural thermal potential with regard to the best estimates of land cover, channel cross-sectional form and flow.

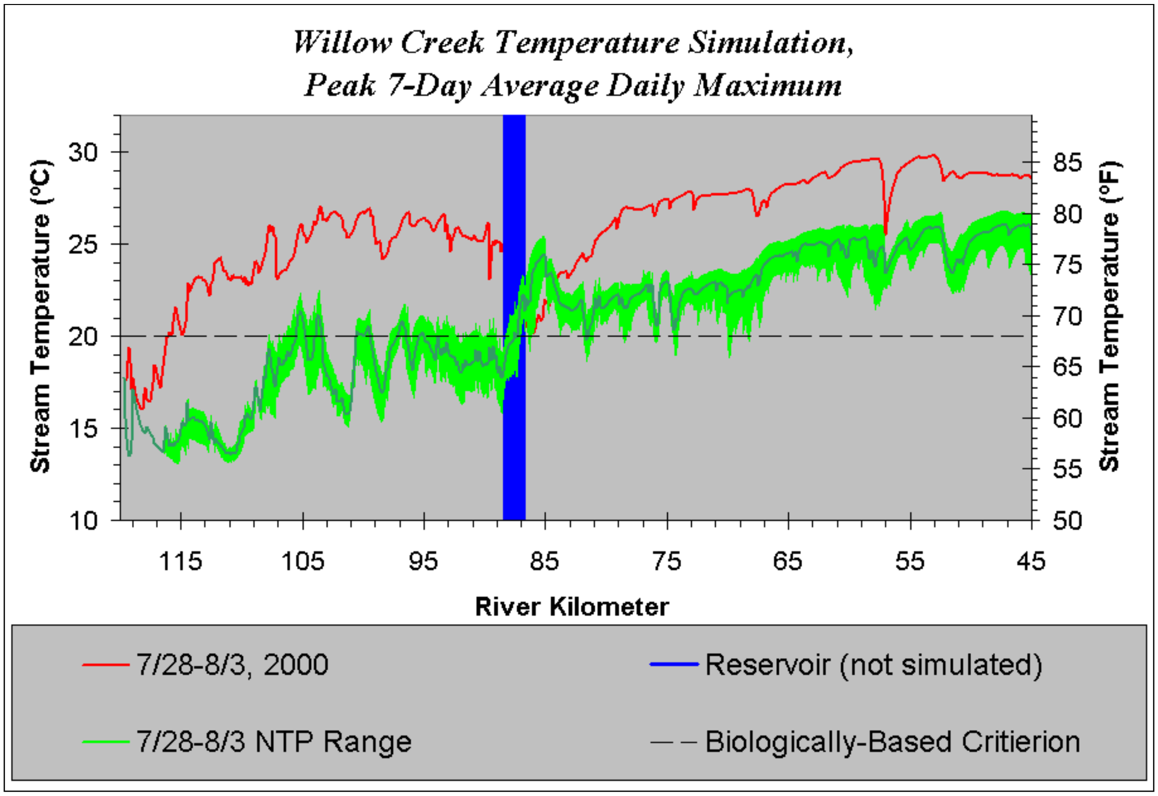


Figure D4-12. *Maximum seven day rolling average of the daily maximum temperatures for summer 2000 and NTP temperature simulations. The light green band and dark green line result from the range and midpoint of natural potential vegetation height estimations, respectively. The maximum 7-day rolling average of the daily maximums for the summer of 2000 was July 28 to August 3.*

August 1 diel range temperature profile simulations for the summer 2000 calibration and the NTP estimate are displayed in **Figure D4-13**. August 1 was selected to characterize the range because it is within the warmest week of year 2000 and is an anchor date for model calibration. Diel temperature ranges serve as a surrogate indicator of thermal stress to aquatic organisms due to stream thermal modification. The NTP and year 2000 August 1 median diel ranges are 6.3 ºC and 9.0 ºC, respectively (**Figure D4-14**). Based on a two-sample T-test, the difference between data sets is significant at the 95% confidence level (P=0.000). The nonparametric Mann-Whitney test yielded a significance at 0.0000, also rejecting similarity (both tests were run because a normality assumption is arguable).

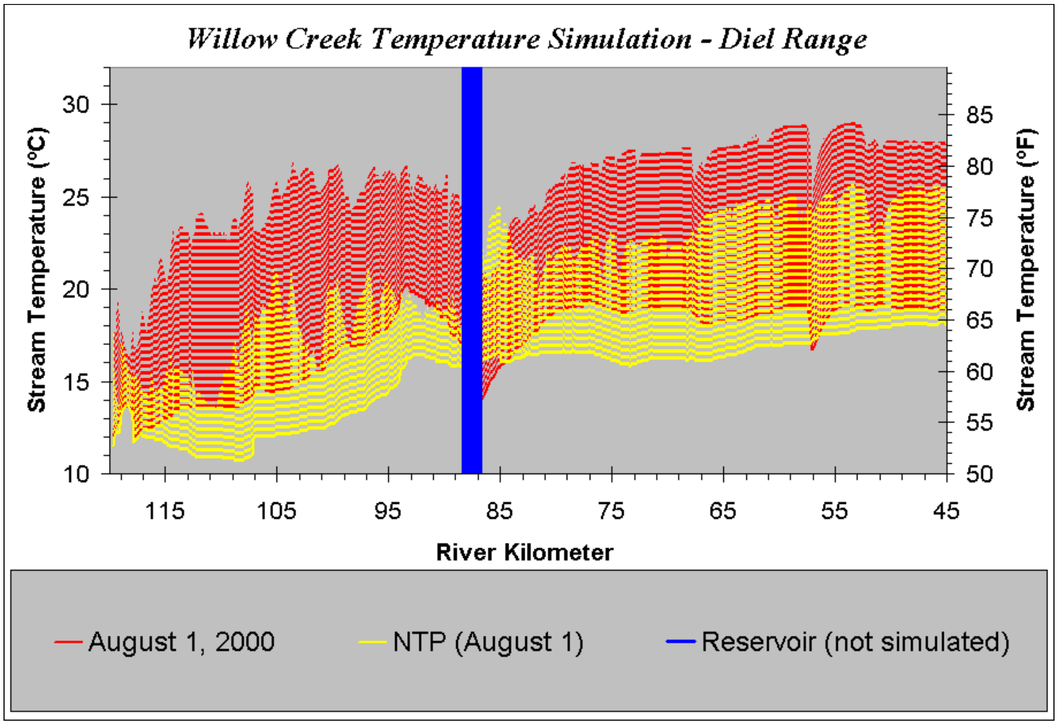


Figure D4-13. *Longitudinal Profile of simulated August 1 diel temperature ranges, for estimated natural and summer 2000 conditions*

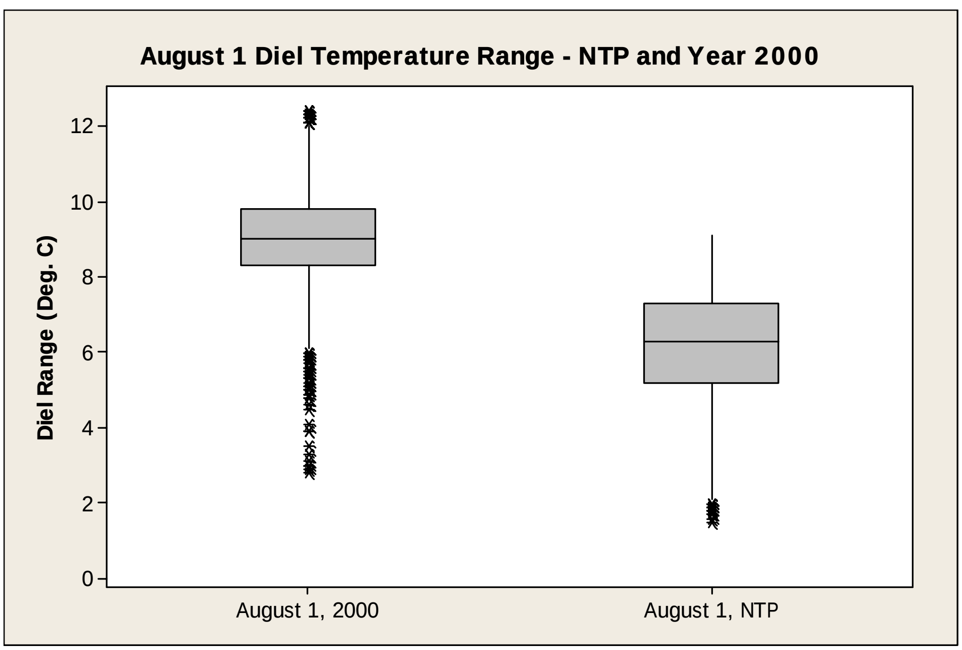


Figure D4-14. *Box plot (with interquartile, median and outliers) of August 1 diel temperature range simulation, for estimated natural and summer 2000 conditions. Sample sets are the longitudinal arrays of diel ranges for each model. Box plots are further explained in the beginning of* ***Appendix F****.*

4.4 Stream Temperature Distributions

The question of proximity to attainment of the natural condition temperature criteria can be evaluated in various ways. The percent of stream length currently in attainment, based on mid-range NTP, during the peak of summer is nearly four percent (**Table D4-5**). The magnitude of temperature reduction needed can be viewed spatially as in **Figure D4-12**, or in aggregation by comparing longitudinal distributions as illustrated in **Figure D4-15**. The spatial median along Willow Creek of the 7-day summary temperature statistic for summer 2000 and NTP below the Reservoir are 27.9 and 25.1 ºC, respectively. Above the Reservoir these values are 25.1 and 18.1 ºC. The evaluation of the standard is based on the warmest time of year and it is expected that in cooler seasons the stream is likely to be at or less than natural condition temperatures. The current time frame of exceedance is not known, other than it is greater than the 21-day simulation period. The broader time-frame is discussed in the next chapter – **Seasonal Variability**.

Table D4-5. *Length of Willow Creek meeting natural condition temperature criteria*

Total stream length evaluated for NTP (km)	Stream length exceeding natural condition temperature criteria (km)	Stream length meeting natural condition temperature criteria (km)	Percent stream length in attainment
74.6	71.9	2.7	3.6

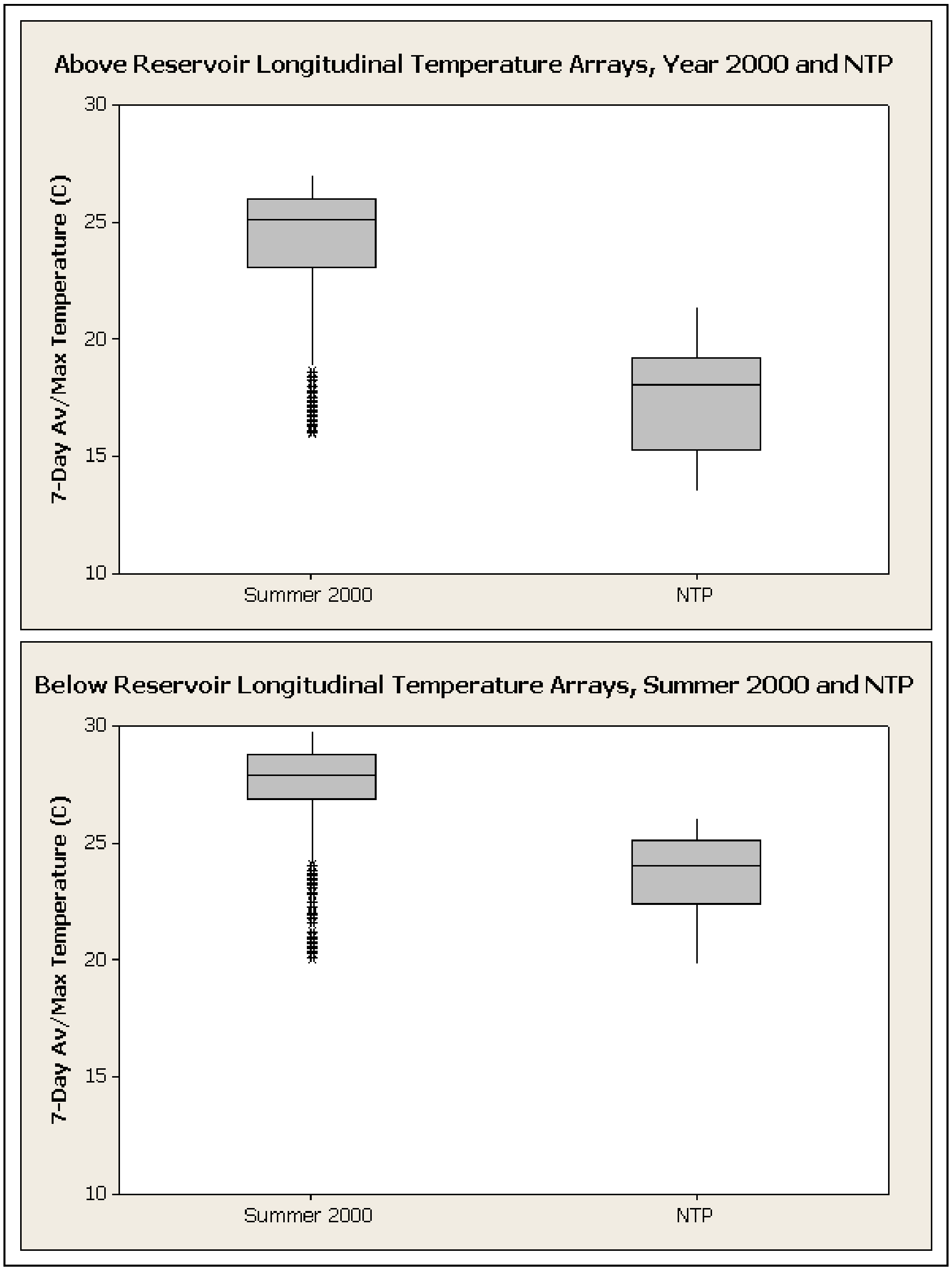


Figure D4-15. *Box plots (with interquartile, median and outliers)of longitudinal temperature profiles above and below Reservoir (but not below river kilometer 45), showing the distribution of 7-day summary statistics. Box plots are explained in the beginning of **Appendix F**.*

4.5 Point Sources and Reservoir Targets

In this Section, Willow Creek stream temperature simulation is applied to TMDL development for the Subbasin's two individual facility NPDES sources and the Willow Creek Reservoir. Specifically, the following elements are addressed: target criteria, point of maximum impact, human use allowance and method of allocation.

4.5.1 Target Criteria

In the Willow Creek Subbasin, natural condition criteria vary spatially as shown in **Figure D4-12** and are of particular significance to individual facility NPDES discharges and the Willow Creek Reservoir. **Table D4-6** lists natural condition criteria simulation outcomes, specific to each of these key facilities or locations. As discussed previously, the natural condition criteria are the applicable criteria. However, in each case the lower end of the range of NTP temperature simulation is indistinguishable, within analytical uncertainty (±1.6ºC, **Table D4-2**), from the otherwise applicable biologically-based criteria of 20 ºC. Given this narrow margin, the Department deems 20ºC to be the target criteria for each site, during the critical period (**Chapter 5.0**).

Table D4-6. *Natural thermal potential temperature simulation results at key locations*

Facility or Location	Distance from mouth of Willow Creek (model input node)	Simulation Range *(7-day average of daily maximum temperature for NTP, ºC)*
Power Generation Plant, EPA Reference # OR-003152-36	Kilometer 81.10	19.9 – 22.3
City of Heppner Waste Water Treatment Plant, EPA Reference # OR-002077-0	Kilometer 82.77	20.3 – 22.4
Willow Creek at Willow Creek Reservoir outlet	Kilometer 86.75	20.2 – 22.7

4.5.2 Point of Maximum Impact

The Oregon water quality standard for temperature asserts that TMDLs "will restrict all NPDES point sources and nonpoint sources to a cumulative increase of no greater than 0.3 ºC above the applicable criteria after complete mixing in the water body, and at the point of maximum impact" (OAR 340-041-0028 (12)(b)(B)). Temperature standard guidelines (DEQ, in preparation) define the point of maximum impact (POMI) as the location where existing condition and criteria deviate most. As discernible in **Figure D4-12**, the first local maximum deviation downstream for all three sources is at river kilometer 78.2, where the difference between the NTP and existing (August 1 afternoon, 2000) temperature is 5.2 ºC. The POMI location is further adjusted as needed to where the greatest cumulative increase in temperature may occur due to the three discrete anthropogenic sources.

4.5.3 Human Use allowance

As quoted in the previous subsection, the temperature standard allows up to 0.3 ºC human use allowance (HUA) for NPDES and other heat sources (OAR 340-041-0028 (12)(b)(B)).

Accordingly, no single source is allowed more than 0.3 ºC HUA, and sources should not collectively exceed 0.3 ºC HUA at any POMI. Dividing the HUA into source components is contingent upon answering certain questions:

1. How much of the HUA is allotted to (a) natural background, (b) human-based nonpoint sources, (c) point sources, (d) and reserve capacity.
2. Does the temperature increase due to an upstream point source extend to a downstream source that is permitted to influence the same POMI? If yes, what temperature increase is resultant from this thermal overlap, at the point of entry of the downstream source?

Addressing the first question, the entire HUA (0.3 ºC) is allotted to NPDES point sources and the Willow Creek Reservoir. In the Willow Creek Subbasin, there would be no benefit to providing nonpoint source HUA, as this would not alter the load allocations. Moreover, because no new NPDES permit application has been received by the Department and the area population has changed little over the years, there is little basis to set aside HUA for Reserve Capacity. This could change in subsequent cycles of TMDL development.

Regarding the second question, 0.3 ºC and 0.2 ºC increases in Willow Creek temperature were simulated at both the Heppner WWTP and Reservoir outlet locations. These model scenarios were developed by invoking tributary input at those points, as shown in **Figure D4-16**. Tributary input was calculated with sufficient flow and temperature to result in specified increases in Willow Creek temperature. The simulated temperature output for the 0.3 ºC increases is described as follows:

- A 0.3 ºC increase at the Reservoir results in warming that extends approximately 5.5 km downstream, heating Willow Creek downstream to below the Heppner WWTP. Warming becomes indistinguishable just above the location of the Power Generation facility. The resultant increase from the Reservoir, at the Heppner WWTP, is 0.1 ºC (**Figure D4-17**).
- A 0.3 ºC increase at the Heppner WWTP results in warming that extends approximately 9 km downstream, well below the Power Generation NPDES facility. The resultant increase from the WWTP, at the Power Generation facility, is 0.2 ºC (**Figure D4-17**).

When the above scenarios are run, temperature increase at the POMI at kilometer 78.2 is 0.1 ºC. Another 0.3 ºC increase from the Power Generation Facility could lead to meeting the maximum HUA of 0.3 ºC at the POMI by only a narrow margin. In addition, cumulative increases of 0.3 ºC at the Reservoir outlet and Heppner produce a potential local exceedance of the 0.3 ºC HUA at or near the Heppner WWTP mixing zone, potentially creating compliance evaluation difficulty. In order to address these two potential concerns and provide equity, the <u>Department deems that the HUA for the two individually permitted NPDES facilities and the Reservoir will be 0.2 ºC for each</u>. A 0.2 ºC increase at the Reservoir and the Heppner WWTP was simulated (**Figure D4-18**). With these two localized increases, the greatest resultant increase in temperature for Willow Creek between the Power Generation facility and the POMI is 0.1 ºC. Given this, another 0.2 C increase at the Power Generation Facility would not lead to an exceedance of the allowable 0.3 ºC below the Power Generation Facility.

Figure D4-16. *Equations and inputs for evaluating thermal overlap for HUA breakdown. Note that these calculations are for single-source scenarios. For temperature increases at plural sources, Q_r and T_r were further adjusted to account for the influence of the additional simulated in-flow upstream.*

Reservoir and NPDES permitted Point Source Discharge
Human Use Allowance Evaluation

Eq. 4.5-1 (simple balance): $Q_aT_a + Q_rT_r = (Q_r + Q_a)(T_r + \Delta T)$

Where:
Q_a = Discharge from anthropogenic source (cubic meter/second)
T_a = Temperature of anthropogenic discharge (ºC)
Q_r = River Discharge immediately upstream from anthropogenic source or at reservoir outlet (cubic meter/second)
T_r = River Temperature immediately upstream from anthropogenic source or at reservoir outlet (ºC)
ΔT = Change in temperature produced by anthropogenic source (ºC)

City of Heppner WWTP 0.3 ºC Scenario

August 1 Q_r (NTP) = 0.082 cubic meter/second

August 1 T_r (NTP) = 21.1

Assume: Q_a = 0.01 cubic meter/second

ΔT = 0.3 ºC

Eq. 4.5-1 becomes: $T_a = [(Q_r + Q_a)(T_r + \Delta T) - Q_rT_r] / Q_a$
= [(0.092 CMS * 21.4 ºC) – (0.082 CMS * 21.1 ºC)] / 0.01 CMS
= 23.86 ºC

City of Heppner WWTP 0.2 ºC Scenario

Same input as above, except ΔT = 0.2 ºC

Eq. 4.5-1 yields: T_a = [(0.092 CMS * 21.3 ºC) – (0.082 CMS * 21.1 ºC)] / 0.01 CMS
= 22.94 ºC

Reservoir 0.3 ºC Scenario

August 1 Q_r (NTP) = 0.07 cubic meter/second

August 1 T_r (NTP) = 21.4

For modeling, invoke a source of 0.01 CMS entering Willow Creek at Reservoir outlet location,

ΔT = 0.3 ºC

Eq. 4.5-1 becomes: $T_a = [(Q_r + Q_a)(T_r + \Delta T) - Q_rT_r] / Q_a$
= [(0.08 CMS * 21.7 ºC) – (0.07 CMS * 21.4 ºC)] / 0.01 CMS
= 23.80 ºC

Reservoir 0.2 ºC Scenario

Same input as above, except ΔT = 0.2 ºC

Eq. 4.5-1 yields: T_a = [(0.08 CMS * 21.6 ºC) – (0.07 CMS * 21.4 ºC)] / 0.01 CMS
= 23.00 ºC

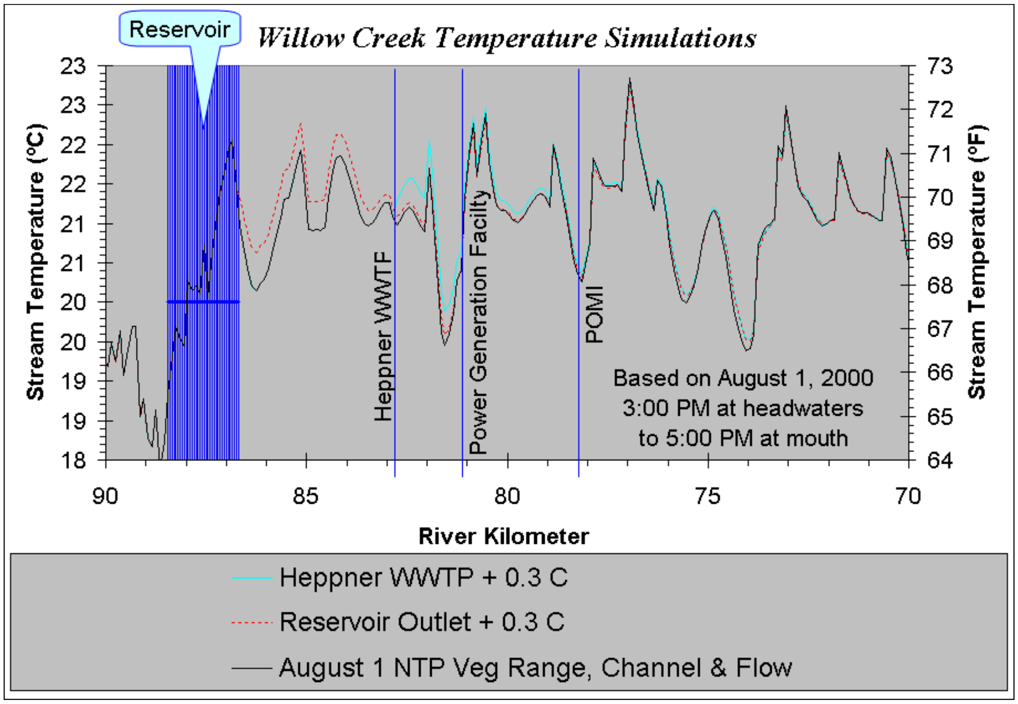


Figure D4-17. *Temperature simulation of three scenarios: (1) NTP, (2) 0.3 ºC increase at the Reservoir, and (3) 0.3 ºC increase at the Heppner WWT. Note that the identified POMI location is based partly on the assessed anthropogenic heating scenario and is likely to change through time.*

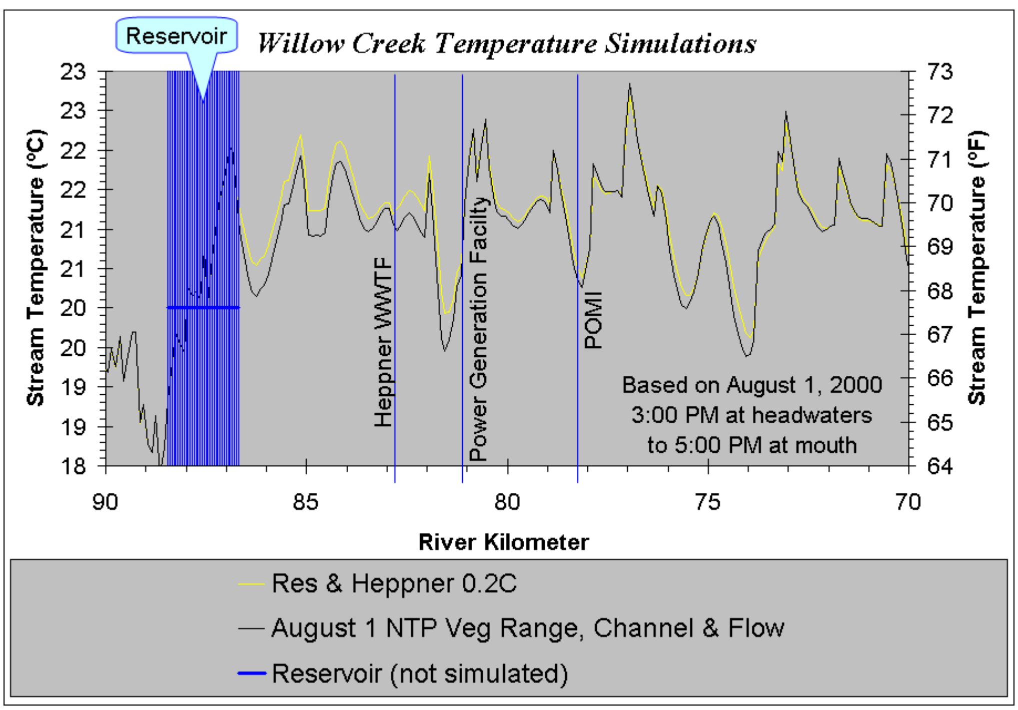


Figure D4-18. *Two temperature simulations: (1) NTP and (2)a scenario consisting of 0.2 ºC increases at both the Reservoir outlet and the Heppner WWTP*

4.5.4 Method of Allocation

This Sub-Section provides the basis for establishing TMDL allocations in **Chapter 1.3** of the main document, for the three sources being discussed. Facility location and allotted HUA are discussed previously in this Section.

The Willow Creek Reservoir is addressed with a load allocation. The allocation is considered applicable regardless of the ultimate legal definition of reservoirs as point or nonpoint sources of potential pollution, and could serve as either a load or waste load allocation. The Heppner WWTP will be issued a waste load allocation for its direct discharge. The land application component of its discharge is likely to cool the stream during the summer, if there is any thermal influence, so no TMDL is considered for that mode of discharge. For the Power Generation facility, waste load allocations will be set for both the direct discharge to Willow Creek and the indirect input via a rapid infiltration basin, the former for obvious reasons and the latter because it is immediately adjacent to the creek in an unlined pond with porous substrate.

Thermal waste load allocations are expressed as heat loads, which are dependent upon upstream river flow and effluent flow. Effluent flow and river flow can change over time. The following equation is used to calculate the thermal waste load allocations in the Willow Creek Subbasin for any given effluent flow and river flow:

Eq. 4.5-2: $H_{WLA} = (HUA)(Q_a + Q_R)(c) / 10^6$

Where,

H_{WLA} = Waste Load Allocation Heat Load (MW)
HUA = Human Use allowance (ºC)
Q_a = Point Source Effluent Flow (Cubic Meter/Second)
Q_R = Upstream River Flow (Cubic Meter/Second)
c = Specific Heat of Water = 1.0 cal/g*ºC = 4.1868×10^6 J/(m^{3}xºC)
10^6 = conversion factor from Joules/Second to Megawatts

In order to translate a thermal waste load allocation into effluent temperature, the applicable criteria for Willow Creek must also be accounted for. The following equation is used to calculate the effluent temperature limit for any given effluent flow, river flow and target criteria:

Eq. 4.5-3: $T_{WLA} = [(Q_a + Q_R)(T_C + HUA) – (Q_R)(T_C)] / Q_a$

Where,

T_{WLA} = Waste Load Allocation Temperature (ºC)
HUA = Human Use allowance (ºC)
Q_a = Point Source Effluent Flow (Cubic Meter/Second)
Q_R = Upstream River Flow (Cubic Meter/Second)
T_C = Target Temperature Criteria for Willow Creek (ºC)

Notes on method. Temperature modeling was performed for part of the summer. Temperatures referred to are daily maximum or 7-day averages of daily maxima. All calculations assume 100% of the River is used for mixing. The Reservoir and waste load allocations apply during the critical period (**Chapter 5.0**).

Heppner WWTP Direct Discharge

Waste Load Allocation: Equation 4.5-2, where HUA = 0.2 ºC

Effluent Temperature Limit: Equation 4.5-3, where:
HUA = 0.2 ºC
T_C = Target Criteria (20 ºC during the critical period)

Power Generation Facility - Direct Discharge

Waste Load Allocation: Equation 4.5-2, where HUA = 0.2 ºC

Effluent Temperature Limit: Equation 4.5-3, where:
HUA = 0.2 ºC
T_C = Target Criteria (20 ºC during the critical period)

Power Generation Facility – Rapid Infiltration Basin

Waste Load Allocation: Same as for direct discharge, assessed at end of pipe entering rapid infiltration Basin. This could be adjusted for heat absorption through groundwater and substrate, or if it can be shown that not all water entering the rapid infiltration Basin enters the stream. However, as a practical matter, compliance would be evaluated via T_{WLA}, and a single waste load allocation is considered sufficient by the Department, provided that temperature compliance is attained.

Effluent Temperature Limit: Same as for direct discharge. For the rapid infiltration Basin, flow will be assessed at the end of pipe entering rapid infiltration Basin (unless evaporation or alternate pathways away from river can be shown) and T_{WLA} can be assessed in groundwater adjacent to the stream.

Willow Creek Reservoir

Load Allocation: The Reservoir does not add effluent to the creek in the manner that a piped point source does. The added heat load from the Reservoir is the amount of heat energy needed to increase the volume of water released from the dam by 0.2 ºC, on a rate basis. This is calculated with a form of **Equation 4.5-2**, as follows:

Eq. 4.5-4: $H_{LA} = (HUA * Q_R * c)/10^6$

Where,
H_{LA} = Load Allocation Thermal Load (MW)
Q_R = Reservoir outlet flow (variable, cubic meter/second)
c = specific heat of water = 4.1868×10^6 J/(m^3xºC)
HUA = Human Use Allowance (**0.2 ºC**)
10^6 = conversion factor from Joules/Second to Megawatts

Temperature Target: As discussed previously in this section, the applicable criteria for the Reservoir outlet is 20.0 ºC during the critical period (**Chapter 5.0**). Adding the HUA as discussed previously in this Section, the target for the Reservoir outlet is 20.2 ºC.

CHAPTER 5. SEASONAL VARIABILITY & CRITICAL PERIOD

Current seasonal patterns are portrayed and compared to Oregon water quality standard biologically-based criteria in **Figure D5-1**. Several years and locations are shown, as data were available.   The 20 ºC biological criterion for redband trout applies throughout the Subbasin except when exceeded by the natural condition criteria (which for Willow Creek happen to be the same, for the specified point sources and Reservoir), or superseded by other criteria or restrictions such as the anti-degradation policy of the temperature standard. The peak 7-day averaged daily maximum natural condition criteria displayed in **Figure D4-12** effectively sets annual maxima criteria at varying levels along Willow Creek.

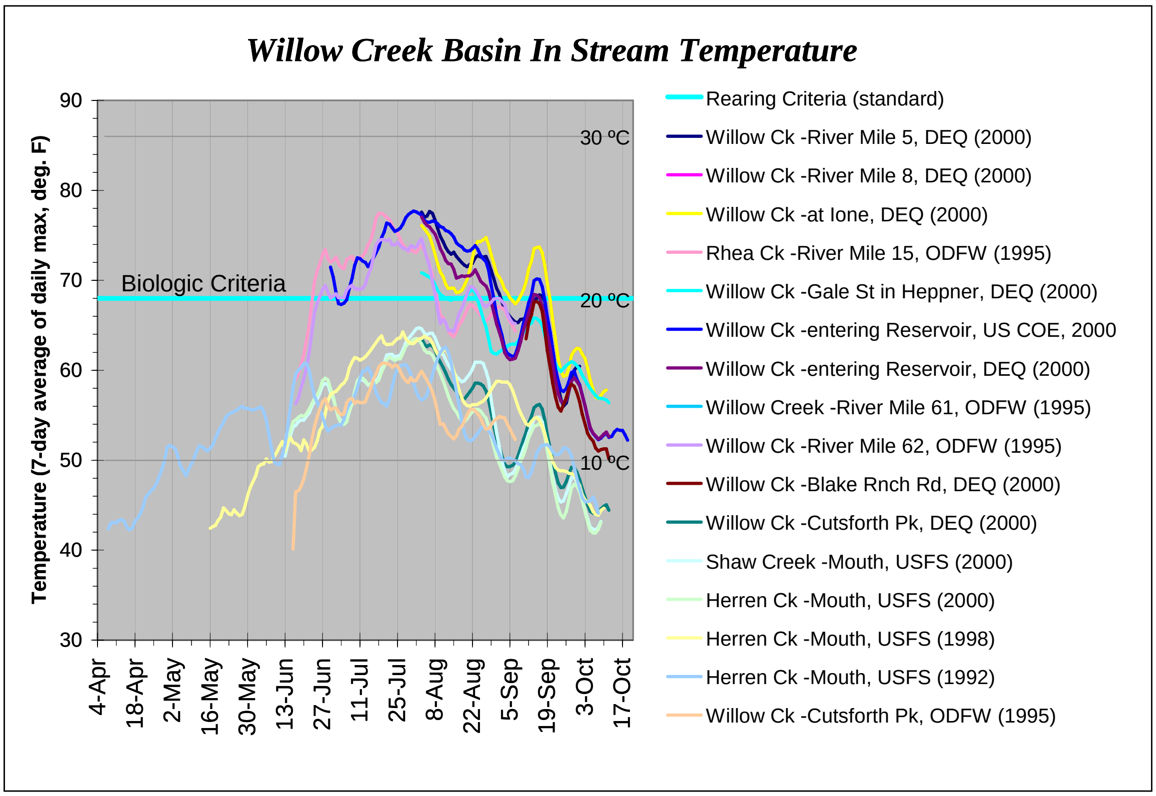


Figure D5-1. *Willow Creek and tributary seasonal pattern seven-day average daily maximum temperature for various years and locations. The applicable biologically-based criterion of the water quality standard is displayed as well.*

Critical Period. For the Reservoir and the two facilities receiving waste load allocations, the critical period (the time frame that this TMDL applies to these sources) is the time during which Willow Creek exceeds 20 ºC – the natural conditions criterion for these sources. This exceedance typically occurs within late June to late September in the Heppner vicinity. During the critical period, the applicable criterion is 20 ºC for these sources. Outside of this time frame, the temperature TMDL does not apply to the Reservoir and NPDES sources.

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