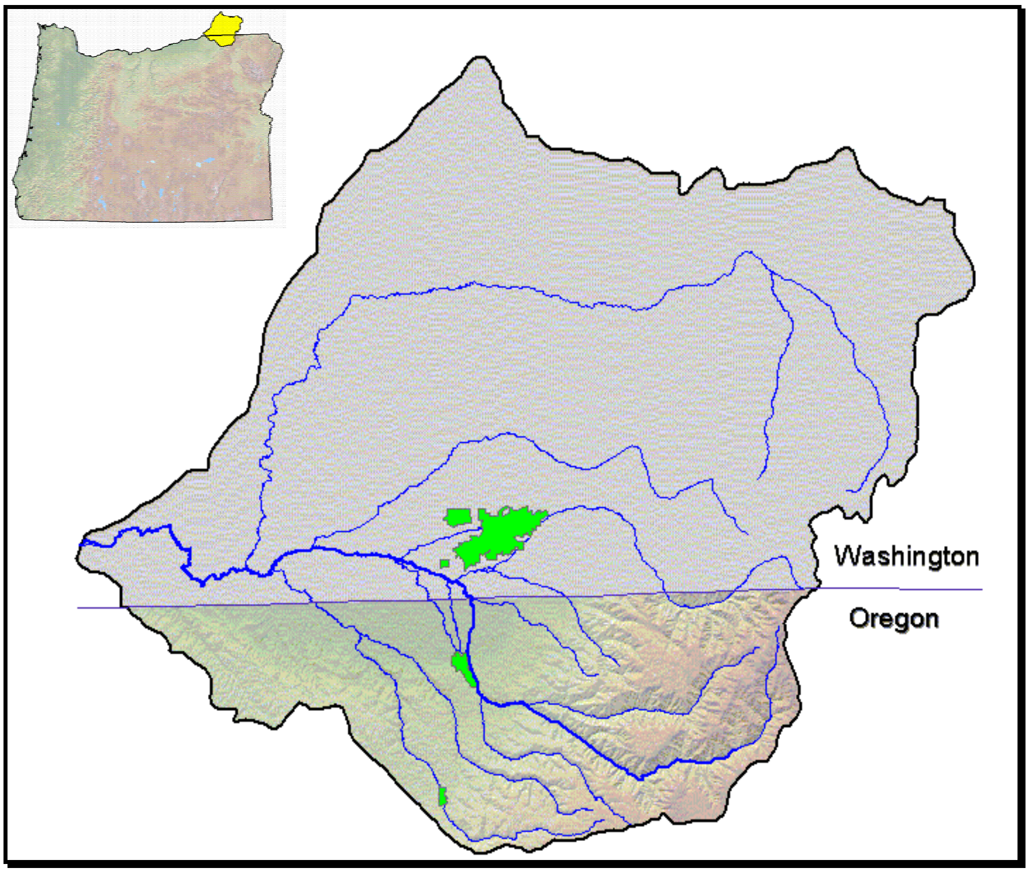
Appendix A
Stream Temperature Analysis

Vegetation, Hydrology and Morphology

<u>Walla Walla Subbasin</u>



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State of Oregon
Department of Environmental Quality

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River Temperature Analysis

Vegetation, Hydrology and Morphology

Walla Walla River Subbasin

Table of Contents

CHAPTER 1. INTRODUCTION

This appendix document is a temperature assessment of the Walla Walla Subbasin, focusing on the mainstem and South Fork of the Walla Walla River, for the purpose of establishing a Total Maximum Daily Load (TMDL) of in-stream heat to implement the Oregon water quality standard for temperature. The effort is also intended to support TMDL development in the Washington part of the subbasin. *Part One* of this document is the TMDL policy expression and will rely on the information in this appendix.

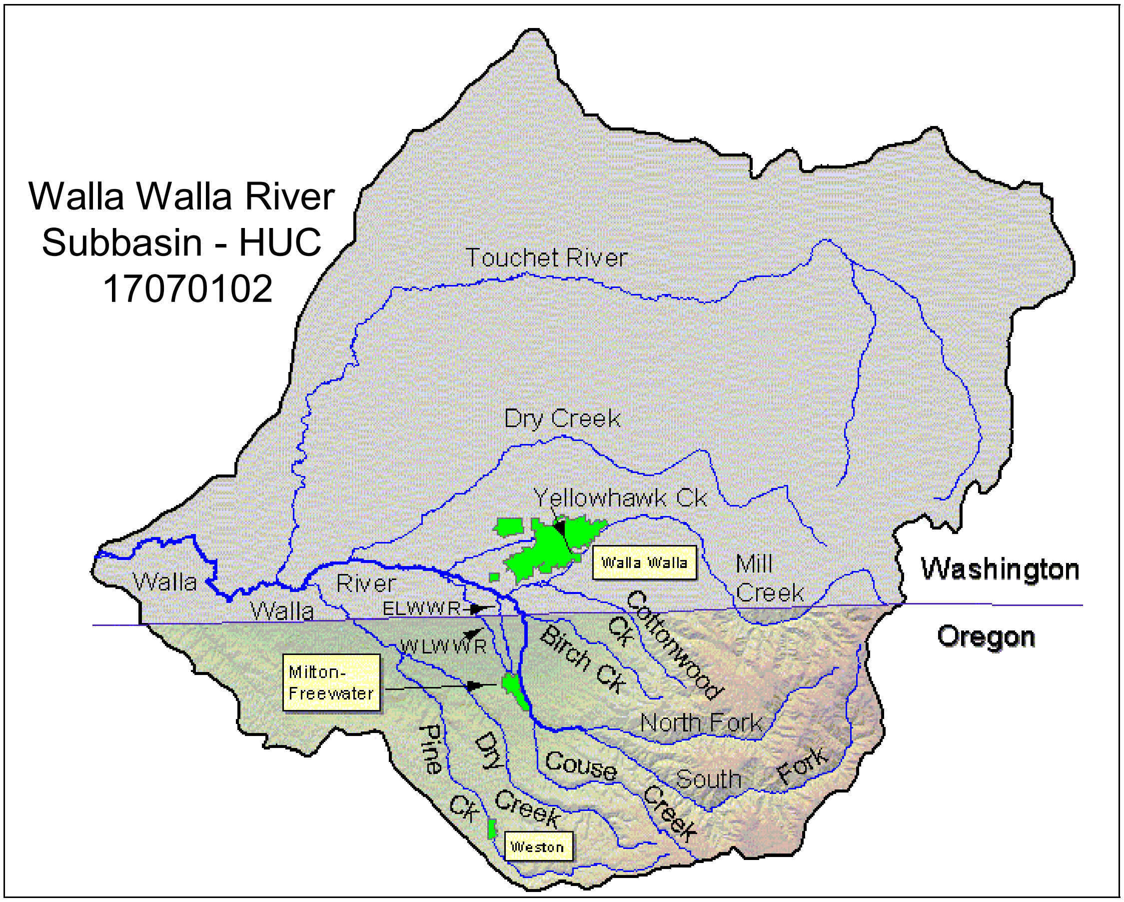


Figure 1-1. *The Walla Walla Subbasin straddles the Oregon-Washington border and drains into the Columbia River. ELWWR and WLWWR are abbreviations for East Little Walla Walla River and West Little Walla Walla River, respectively.*

1.1 Scale & Location

The lands within the Walla Walla River drainage cover 1,760 square miles in northeastern Oregon and Southeastern Washington. This area comprises one 4th field hydrologic unit: the Walla Walla River Subbasin (17070102). Roughly 27 percent of this area lies in Oregon. While the stream temperature TMDL considers all contributing surface waters within the subbasin, this analysis focuses on the Walla Walla River, the South Fork of the Walla Walla River, and tributary inputs to these rivers.

Temperature simulation is conducted for the Walla Walla River and South Fork from the confluence of the South Fork and Skiphorton Creek in the Umatilla National Forest, downstream to the mouth of the mainstem (**Figure 1-2**). Daily effective shade is simulated for perennial tributaries.

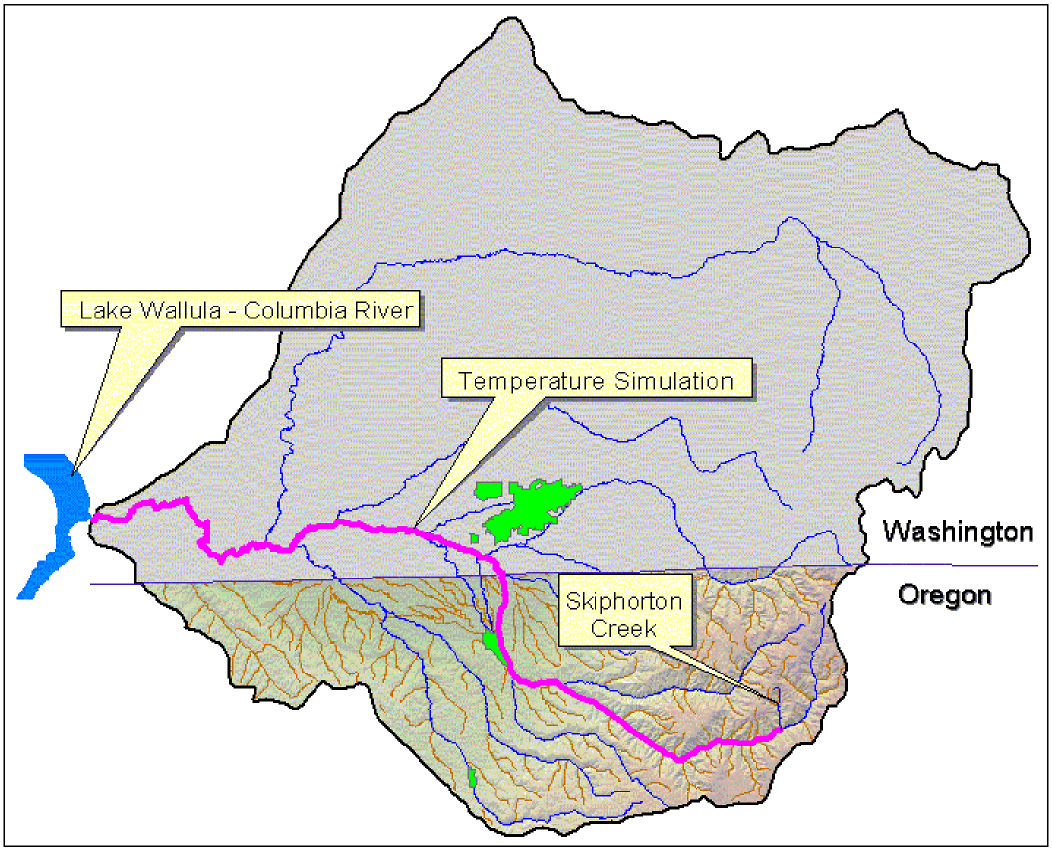


Figure 1-2. *Longitudinal extent of temperature simulation – South Fork at Skiphorton Creek downstream to mainstem mouth*

1.2 Interstate Coordination

In order to provide for interstate coordination, the Oregon Department of Environmental Quality (DEQ) and the Washington State Department of Ecology (WDOE) agreed that DEQ, having an earlier due date for temperature work in the subbasin, would conduct temperature assessment and modeling for the entire mainstem. It was envisioned that Washington would use this assessment to support their subsequent TMDL development. Accordingly, the geographic scope of this analysis (Appendix A) includes the Walla Walla River in both states, whereas the Oregon TMDL and WQMP (Parts 1 & 2 of this document) address only Oregon**.** As part of the cooperative assessment, WDOE supplied thermal infrared remote sensing for the 40 miles of river in Washington; and DEQ, the Walla Walla Basin Watershed Council (WWBWC), WDOE, the Washington Department of Fish and Wildlife (WDFW), and others formed the monitoring team in Washington. In Oregon monitoring and assessment was guided by the WWBWC and DEQ, with support from several contributing organizations.

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.

Stream Heating Processes

Variables that influence stream heating are listed in **Figure 1-3**. The relevant heat transfer processes are identified in **Figure 1-4**.

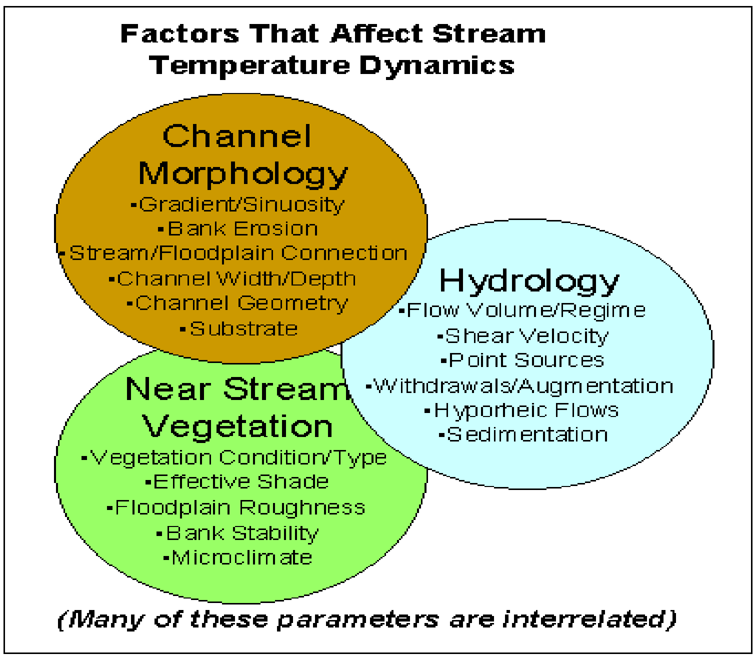


Figure 1-3. *These parameters, along with latitude, elevation, humidity, air temperature, and wind speed; relate to stream temperature and are accounted for in this analytical framework*

The heat transfer processes of **Figure 1-4** 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.

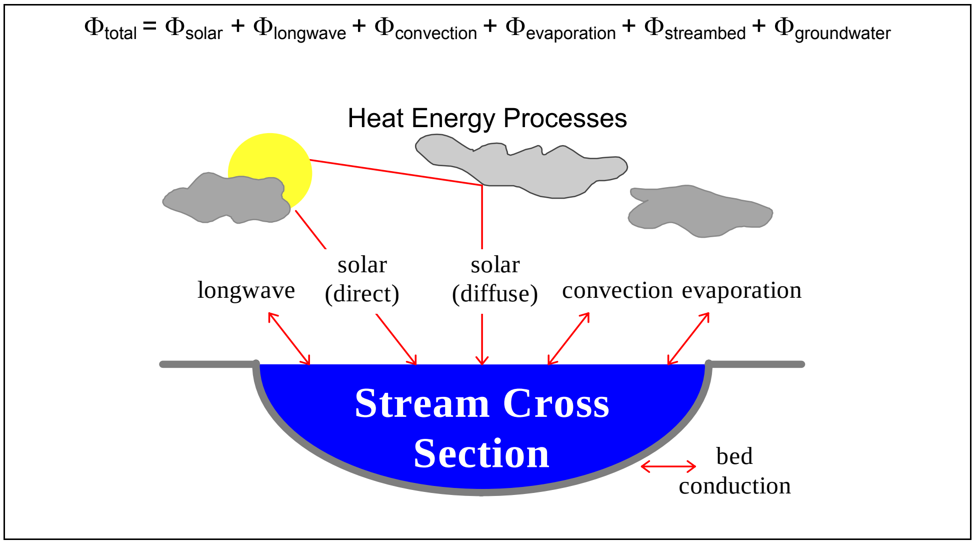
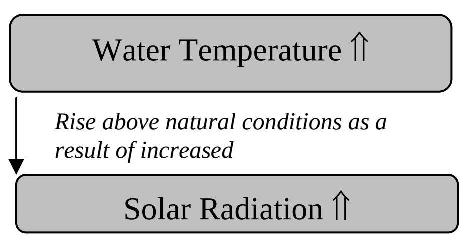


Figure 1-4. *Net Heat Energy Continuity equation. Stream heat transfer processes considered, along with mass transfer, in this analysis. The symbol Φ denotes the change in heat energy per time associated with a specific process.*

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* ($\Phi_{Longwave}$) is derived by the Stefan-Boltzmann Law and is a function of the emissivity of the body, the Stefan-Boltzmann constant and the temperature of the body (Wunderlich, 1972). *Evaporation* ($\Phi_{Evaporation}$) relies on a Dalton-type equation that utilizes an exchange coefficient, the latent heat of vaporization, wind speed, saturation vapor pressure and vapor pressure (Wunderlich, 1972). *Convection* ($\Phi_{Convection}$) is a function of the Bowen Ratio and terms include atmospheric pressure, and water and air temperatures. *Bed Conduction* ($\Phi_{Conduction}$) 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.

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 1-1**. Geometric relationships important for understanding the mechanics of shade are displayed in **Figure 1-5**. 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 1-1. *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 1-6** 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).

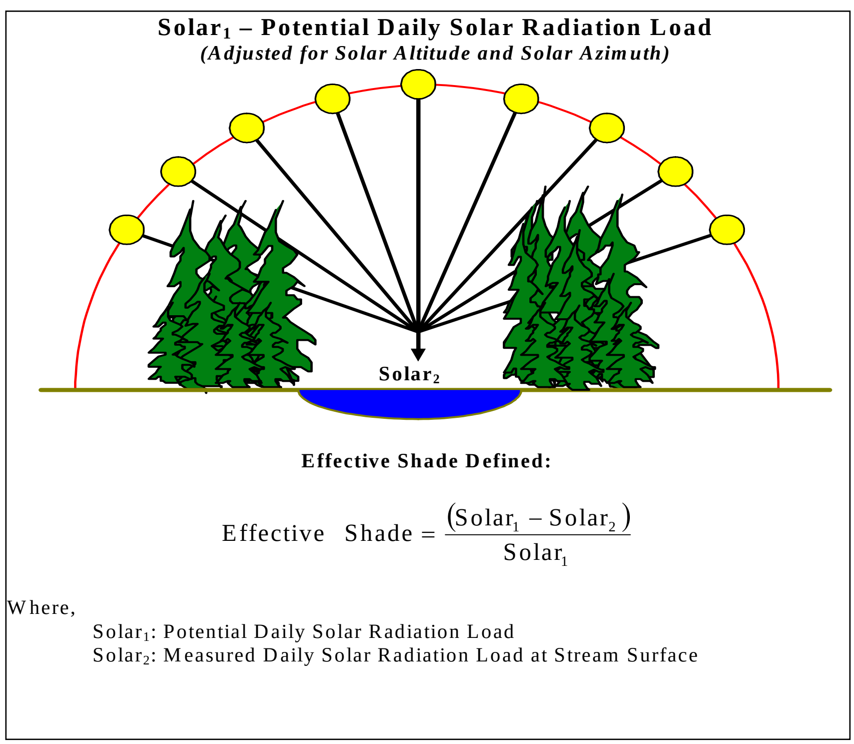
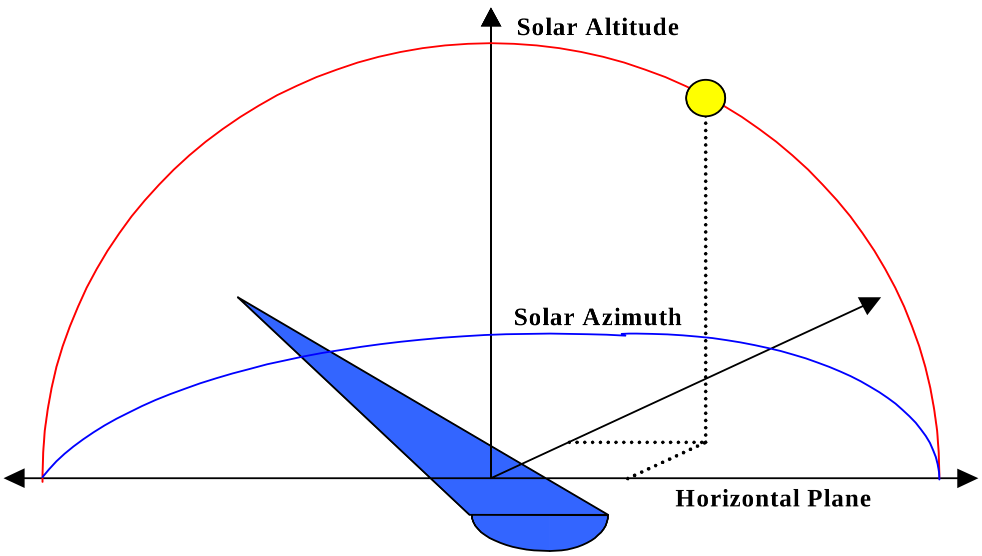


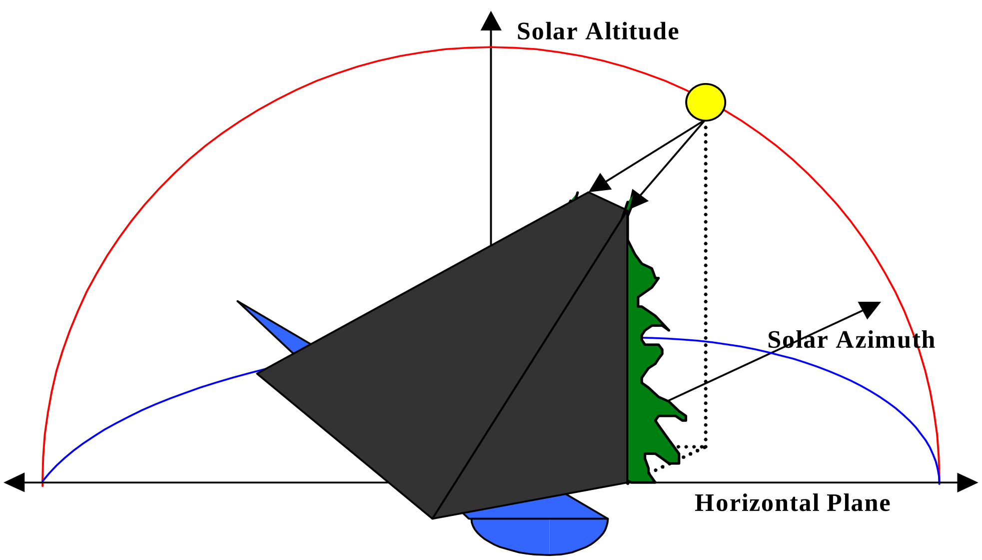
Figure 1-5. *Effective Shade – Defined*

Figure 1-6. *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*. 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 1-2**. 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 1-2. *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.

In the Walla Walla and other subbasins in the region DEQ has simulated conditions reflecting minimized anthropogenic (human-caused) warming. These simulations show that water quality standard temperature criteria (biologic) are exceeded in lower parts of subbasins in the absence of quantifiable human disturbance. In such circumstances, the Oregon water quality standard targets a more natural condition, i.e., minimized human-caused heating. Accounting for the amount of human related temperature increase becomes central to the analysis. The pollutant is heat. The TMDL establishes that the anthropogenic contributions of nonpoint source solar radiation heat loading results from varying levels of decreased stream surface shade throughout the subbasin. Decreased levels of stream shade are caused by near stream land cover disturbance or removal and channel morphology changes. Another anthropogenic source of stream warming is reduction in stream flow.
System potential is a key term in the Oregon temperature TMDL context. *System potential* refers to the best estimate of vegetation, channel shape and other riparian conditions that would occur with past and present human disturbance minimized. For TMDL purposes, **system potential near stream land cover**

is defined as: *that vegetation which can grow and reproduce on a site, given: climate, elevation, soil properties, plant biology and hydrologic processes*. **System potential channel morphology** *is the more stable configuration that would occur with less human disturbance*. System potential does not consider management or land use as limiting factors. **System potential is the design condition used for TMDL analysis.**

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

Oregon stream temperature TMDLs allocate heat loading. Nonpoint sources are expected to limit heat input to system potential target levels. Point sources are allowed heating that results in minimal increase outside of a defined mixing zone (refer to standard for cumulative allowable increase in-stream). Allocated conditions are expressed as heat per unit time (e.g., megawatt per stream surface area) or point source effluent temperature limits. 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, to provide targets in different terms, such as 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 system potential conditions.
5. Simulate temperature and heating patterns for system potential conditions.
6. Establish allocations. Allocations are based on system potential conditions, if system potential 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 system potential.

The purpose of stream temperature modeling is to (1) determine temperatures for various scenarios including system potential, (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 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 major limitations should be recognized:

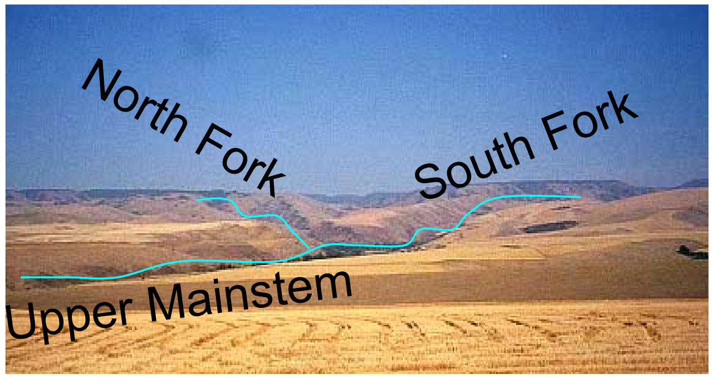
- Current analysis is focused on a defined critical condition. This usually occurs in late July or early August when stream flows are low, radiant heating rates are high and ambient conditions are warm. However, there are several other important time periods where data and analysis are less explicit. 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 Topography and Map View. The combined length of the Walla Walla River and the South Fork of the Walla Walla River is roughly eighty miles. Basin elevation ranges from 6,000 to 400 feet above sea level. The South Fork and upper mainstem valley is narrow and steep walled, draining the basalt plateau of the Blue Mountains. As the Walla Walla River descends through the city of Milton-Freewater, the valley widens to several miles and the channel is constrained through a large flood control levee built by the US Army Corps of Engineers (USACE).



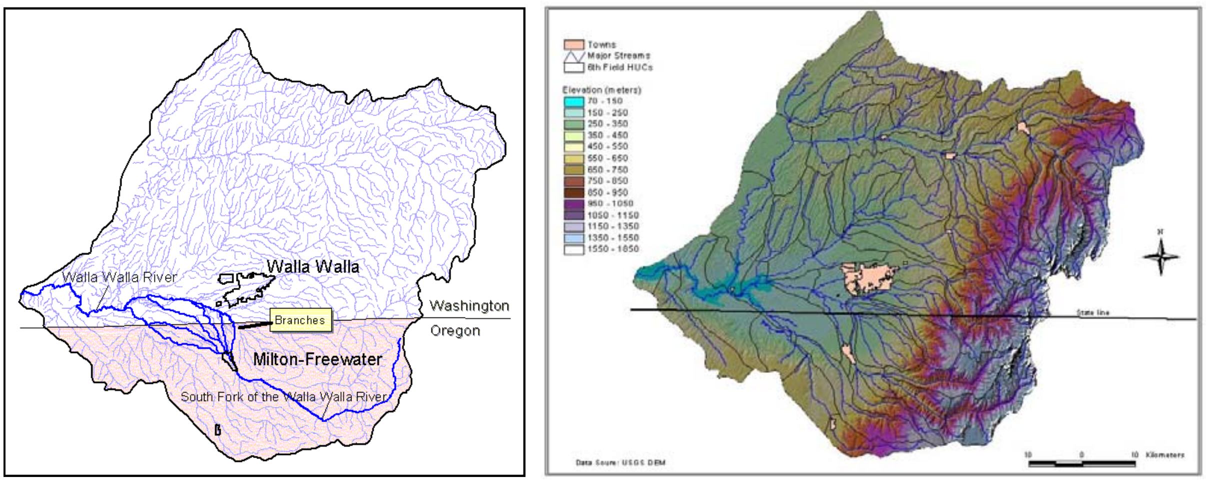


Figure 1-7. *Gross map pattern and elevation*

The river diverges into several branches at Milton-Freewater (**Figure 1-7**). Much of this branching system was modified to serve as an irrigation network, beginning in the late 1800's, and the spring high flow events have since been aggregated into the Tumalum Branch – now considered the mainstem of the Walla Walla River. A more detailed map of the State-Line/Milton-Freewater area is shown as **Figure 1-8.** Downstream of the levee and as the river approaches the state border, gradient decreases and remains nearly flat throughout Washington to the Columbia River. The modern river is relatively straight through much of its course, as a result of management and structural changes, except below Dry Creek (south flowing, in Washington), where sinuosity increases (**Figure 1-9**). This is particularly pronounced between the towns of Lowden and Touchet.

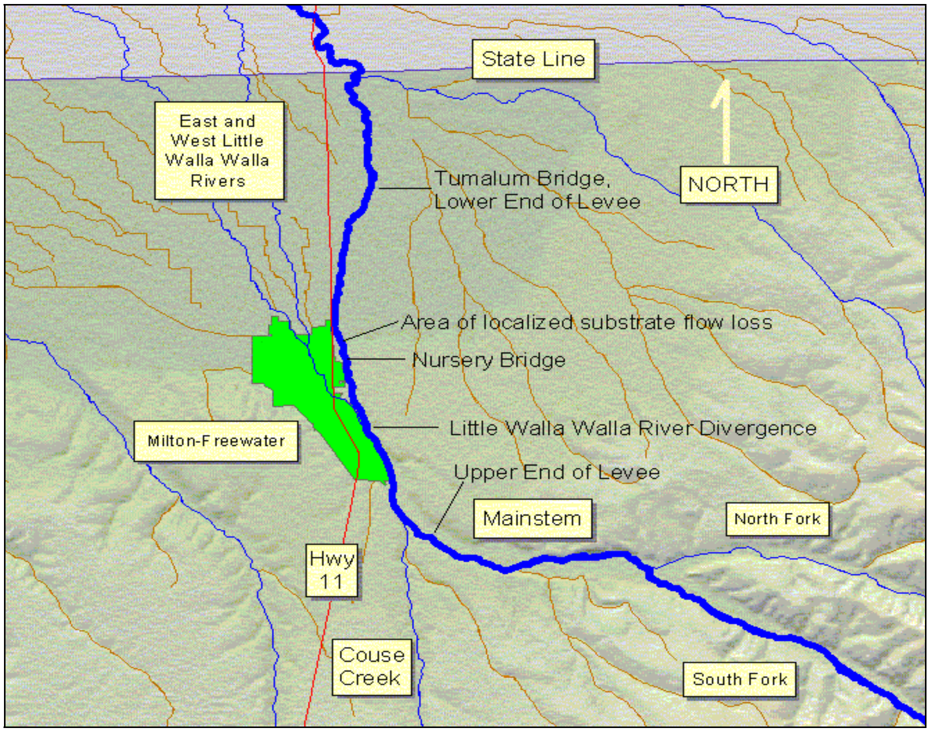
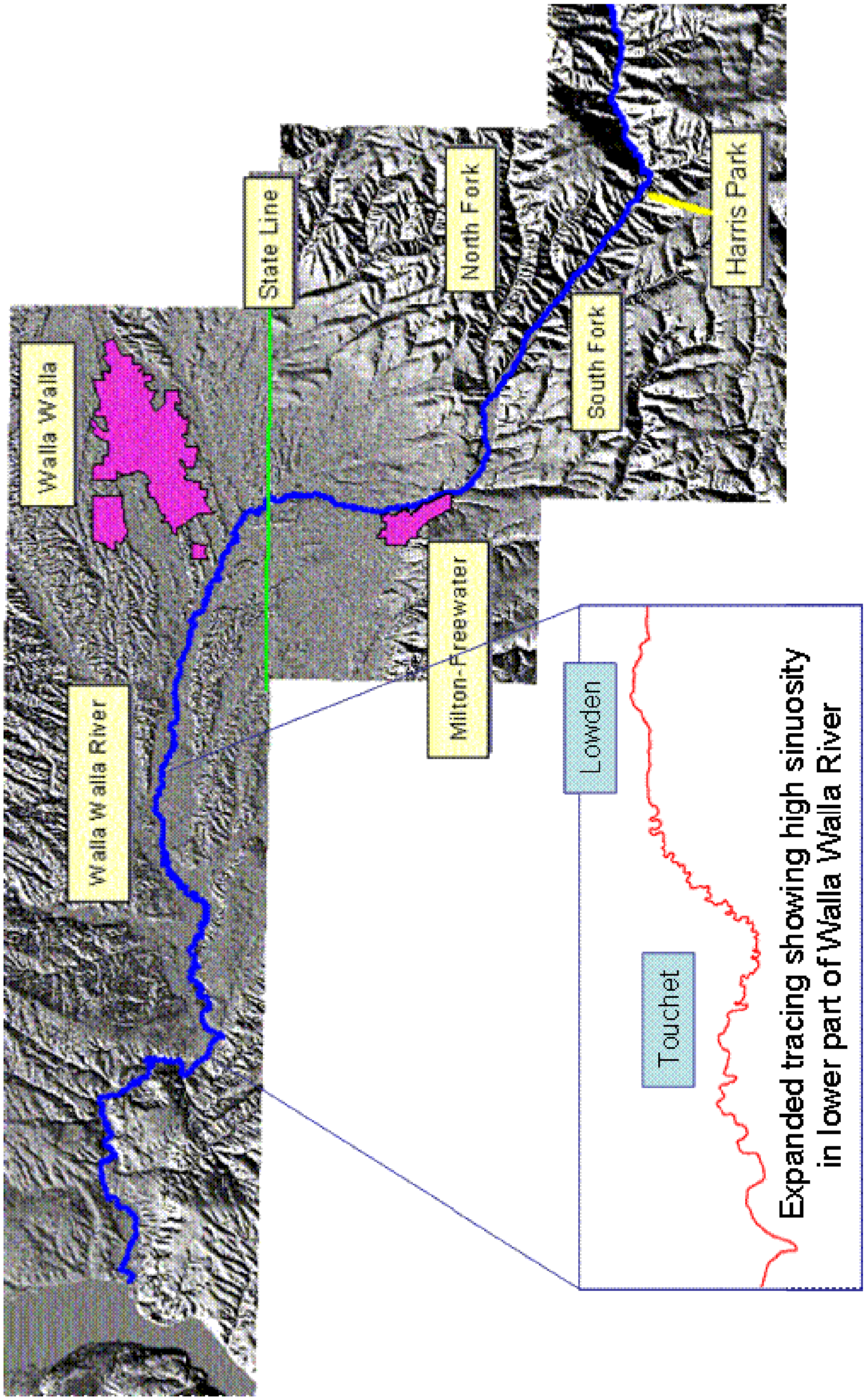


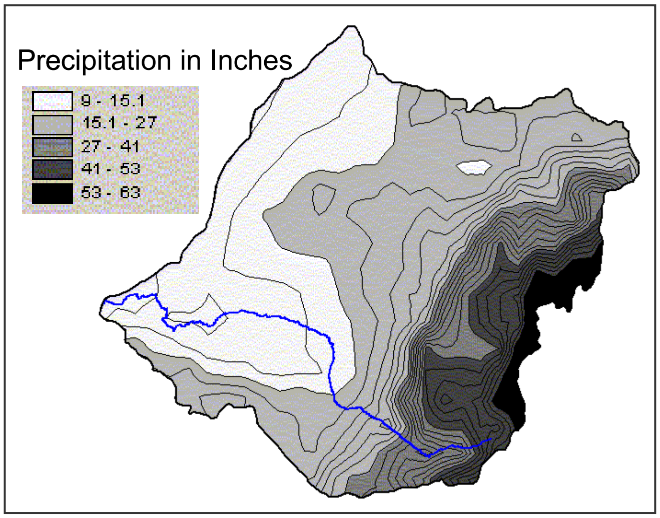
Figure 1-8. *Close-Up map of Milton-Freewater area*

The history of development in the Milton-Freewater area includes the Milton-Freewater Levee, historic gravel mining, irrigation structures, and like much of the river, floodplain area reduction. These developments have led to modified surface flow patterns, ground-surface water interaction, channel shape and riparian vegetation, influencing heating rates in the Walla Walla River. Given this thermal modification, and understanding of the area's history benefits this analysis, and is summarized as follows (historical information provided by WWBWC):

> The second largest town in the Walla Walla River valley is that of Milton-Freewater. It was originally two separate towns: Milton (incorporated in 1886) and Freewater (became official in 1892). The towns were joined and incorporated as Milton-Freewater in 1951. The most dramatic influence along this lower Oregon' portion of river was the construction of a flood control levee above and through the town of Milton-Freewater. The Levee was originally designed and constructed in the 1940s and completed in 1952 (USACE, 1997). A devastating flood early in 1965 destroyed much of the original Levee structure. Following the flood, local groups and USACE rebuilt a reinforced version of the Levee that provides flood control today. While the Levee provides critical flood protection for the citizens of Milton-Freewater, its design and size make it necessary to remove riparian vegetation in and on the Levee control structures. For approximately the past 40 years, most, if not all, of the riparian vegetation was removed creating a straightened, un-shaded, degraded riparian habitat section of the Walla Walla River. While the entire Levee length of the Levee is 5.3 miles, the majority of intensive vegetation management has taken place along the section of Levee near the town of Milton-Freewater.

Figure 1-9. *Inclined illumination map of the Walla Walla River and part of the South Fork (US Geological Survey 10-meter Digital Elevation Model)*





1.5.2 Climate. The upper watershed receives several feet of snow in a typical year. Total precipitation varies across the subbasin from roughly 10 to greater than 40 inches per year. Air temperature exhibits a large seasonal variation with common annual occurrences of temperatures above 100 ºF (38 ºC) in the summer and below 0 ºF (-18 ºC) in the winter. Temperature and precipitation vary substantially with topography.

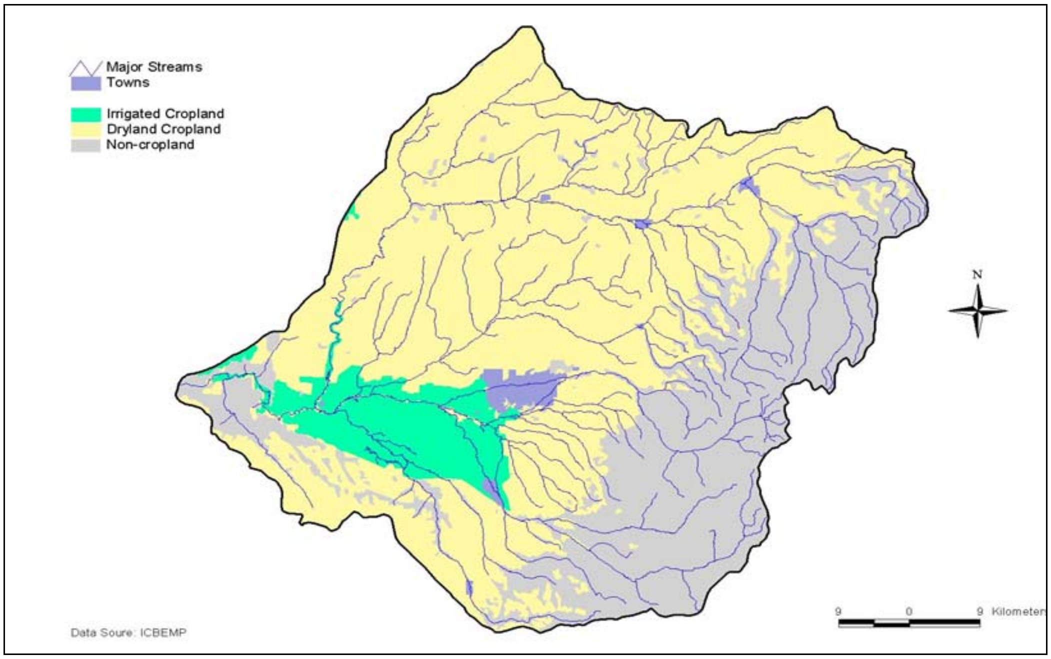
1.5.3 River Flow. The major tributaries of the Walla Walla River in Oregon are the South Fork and the North Fork, with smaller contributions from Couse Creek and Birch Creek in the mid elevations. In the South Fork drainage, substantial flow is collectively provided by the forest area tributaries such as Elbow, Burnt Cabin, Bear, Bear Trap, Skiphorton and Reser Creeks. In Washington, several streams flow into the mainstem. In approximate order of decreasing flow volume, these are: Touchet River, Yellowhawk Creek , East and West branches of the little Walla Walla River, Mill Creek, Pine Creek, Dry Creek, Mud Creek, Garrison Creek and Stone Creek. Two principal factors dominate summer flows in the Walla Walla River – the abundance of flow from the South Fork and irrigation withdrawals along the mainstem. The reader is referred to a discussion of flow patterns later in this Appendix.

Flooding can be intense, typically in December through February, due to snow melt and rain-on-snow events. In seasonal contrast, many lower basin watersheds have intermittent flow.

1.5.4 Population and Local Government. The largest population centers in the Basin are the Cities of Walla Walla, College Place and Milton-Freewater, all within a few miles of each other near the point at which the Walla Walla River crosses the Oregon-Washington border. Of these three cities, only Milton-Freewater includes area abutting the Walla Walla River. The other towns along the mainstem, Touchet and Lowden, are small in comparison, as are the tributary towns in the basin – Weston, Dayton, Waitsburg. The latest entry in the Oregon Blue Book documents a population of 6,560 for Milton Freewater and 715 for Weston (2001). The Municipal Research and Services Center of Washington (http://www.mrsc.org/cityprofiles/citylist.aspx), provides the following recent census population figures: City of Walla Walla (29,710), College Place (8,165), Dayton (2,715) and Waitsburg (1,210). The Walla Walla Subbasin includes parts or all of five counties: Walla Walla and Columbia Counties in Washington and Umatilla, Union and Wallowa County in Oregon. The Walla Walla Subbasin is part of the land area of historical use by the Walla Walla, Cayuse and Umatilla Indian Tribes, ceded to the federal government in the Treaty of 1855. The Tribes maintain reserved rights for this land that include harvesting of salmon, wildlife and vegetative resources. The upper, eastern part of the basin is within the Umatilla National Forest (US Forest Service). The US Forest Service (USFS) is the only large federal landholder in the basin. The US Bureau of Land Management (BLM) oversees a few square miles in the vicinity of Harris Park, on the South Fork of the Walla Walla River.

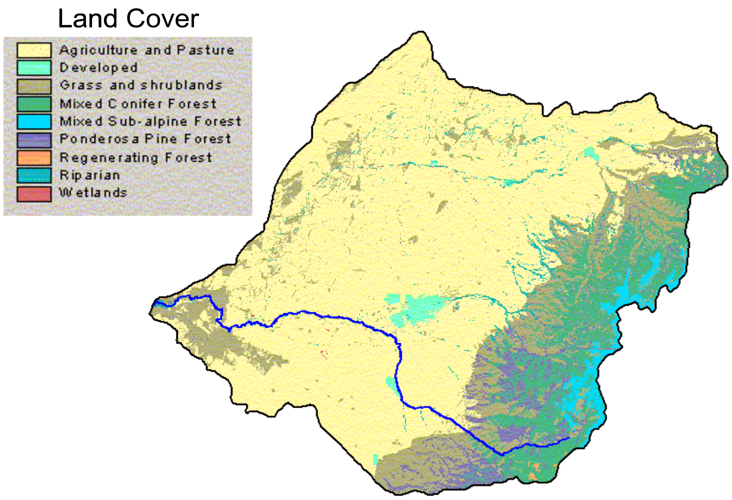
1.5.5 Point sources. The geographic scope of this document is the mainstem Walla Walla River in Washington and Oregon and all perennial tributaries in Oregon. In this area, there are two sources that could potentially be classified as point sources in accordance with the National Pollutant Discharge Elimination System (NPDES): The City of Weston municipal sewage treatment plant and the South Fork Fish Hatchery. Both are discussed further in **Part One** and **Section 2.2.5** of this document. The fish hatchery (5 miles above the North-South Fork confluence) processes less than the amount of fish needed for the Oregon General Permit for hatcheries. Within the Subbasin outside of the area covered by this report, but ultimately draining into it, there are other point sources in Washington. It is assumed that these will be addressed as needed in the Washington TMDL being developed by WDOE.

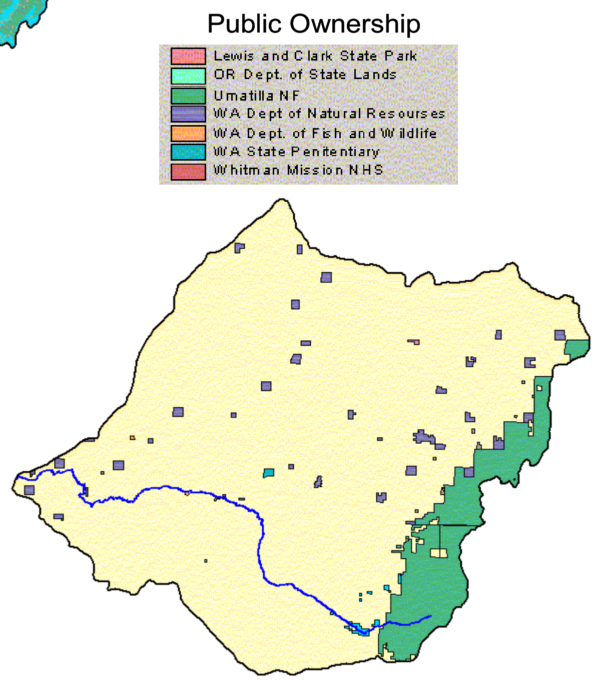
1.5.6 Land Use & Irrigation. The most widespread land use is agriculture: dry land wheat, orchards, and irrigated row crops. Other uses include urban, commercial-industrial usage and forest management. Land cover, areas of public management (ownership) and land use are illustrated in the following page. By area, 77 percent of the subbasin is in agricultural land use. The image below shows the locations and proportions of irrigated and non-irrigated cropland.

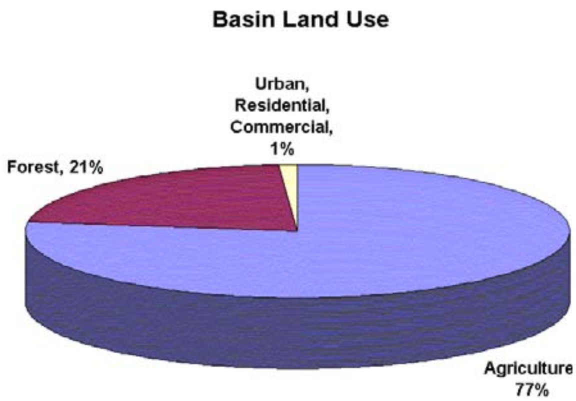


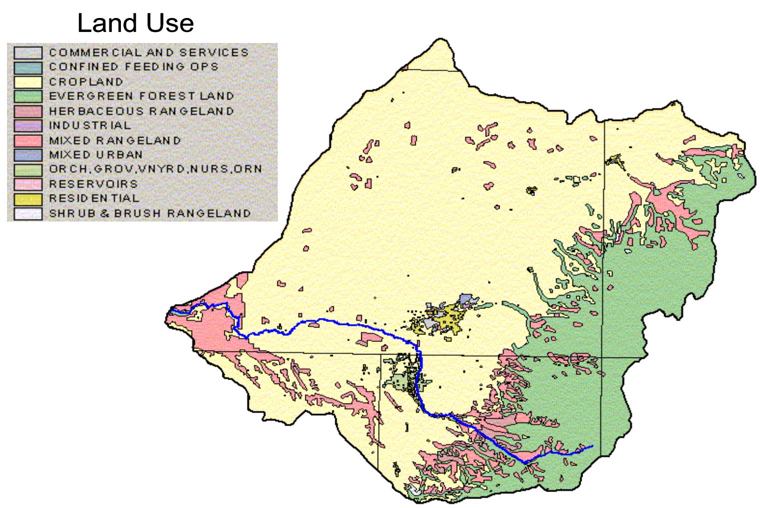
1.5.7 Vegetation. Riparian vegetation will be addressed in detail subsequently in this Appendix. Land cover is mapped on the following page, and where not developed can be broadly viewed as pine-fir forest in the upper eastern part of the basin and shrub-steppe and agricultural vegetation below. The perennial riparian corridors below the conifer zone are dominated by cottonwood, willow and alder except were disturbed and in the shrub-dominated reach from the cities of Lowden to Zangar Junction (roughly river mile 26 to 9, ~km 43 to 14).

The geospatial data in this section are from the following sources: Oregon Geographic Information Center (OGIC) stream layer, US Geological Survey (USGS) digital elevation model topographic data, the Parameter-elevation Regressions on Independent Slopes Model (PRISM) precipitation data, Land cover from the Northeast Habitat Institute, and land ownership compiled by the Regional Ecosystem Office. These data are not part of the analysis of this Appendix and are used here for illustrative purposes.


Land Cover
Agriculture and Pasture
Developed
Grass and shrublands
Mixed Conifer Forest
Mixed Sub-alpine Forest
Ponderosa Pine Forest
Regenerating Forest
Riparian
Wetlands


Public Ownership
Lewis and Clark State Park
OR Dept. of State Lands
Umatilla NF
WA Dept of Natural Resources
WA Dept. of Fish and Wildlife
WA State Penitentiary
Whitman Mission NHS


Basin Land Use
Urban, Residential, Commercial, 1%
Forest, 21%
Agriculture 77%


Land Use
COMMERCIAL AND SERVICES
CONFINED FEEDING OPS
CROPLAND
EVERGREEN FOREST LAND
HERBACEOUS RANGELAND
INDUSTRIAL
MIXED RANGELAND
MIXED URBAN
ORCH,GROV,VNYRD,NURS,ORN
RESERVOIRS
RESIDENTIAL
SHRUB & BRUSH RANGELAND

CHAPTER 2. AVAILABLE DATA

2.1 Ground Level Data

Several ground level data collection efforts have been completed for the Walla Walla Subbasin. Available ground level data sources are discussed in detail in this Chapter. Specifically, this stream temperature analysis relies on the following data types: continuous temperature data; flow volume, width and depth; channel cross-sectional area, width and depth – gage data and manual in-stream measurements; riparian land cover surveys including effective shade measurements; channel morphology and substrate surveys; and hourly measurements of humidity and air temperature.

2.1.2 Continuous Stream Temperature Data

Continuous stream temperature data are used in this analysis to:

- *Calibrate stream emissivity for aerial thermal infrared stream temperature assessment,*
- *Calculate temperature statistics and assess the temporal component of stream temperature,*

Continuous temperature data is 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 are routinely checked for accuracy. Typically the units were set to record measurements hourly. Recorders were placed on or near the streambed, typically in or near riffle thalwags. These locations are selected to represent well-mixed flow. Continuous temperature data were collected during 2000 and 2002. Selected data sets were processed for the seven-day moving average maximum stream temperature (i.e., seven-day statistic).

Figure 2-1 displays continuous temperature data monitoring locations. **Table 2-1** lists the seven-day moving average daily maximum stream temperatures and the monitoring location description. Calculated seven-day moving average maximum stream temperatures indicate that a large extent of the Walla Walla river system exceeds the upper level of applicable biologic criteria [18 ºC (64.4 ºF)] of Oregon's stream temperature standard [OAR 340-041-0028(4)], designed to protect salmon and trout rearing and migration. 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.

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

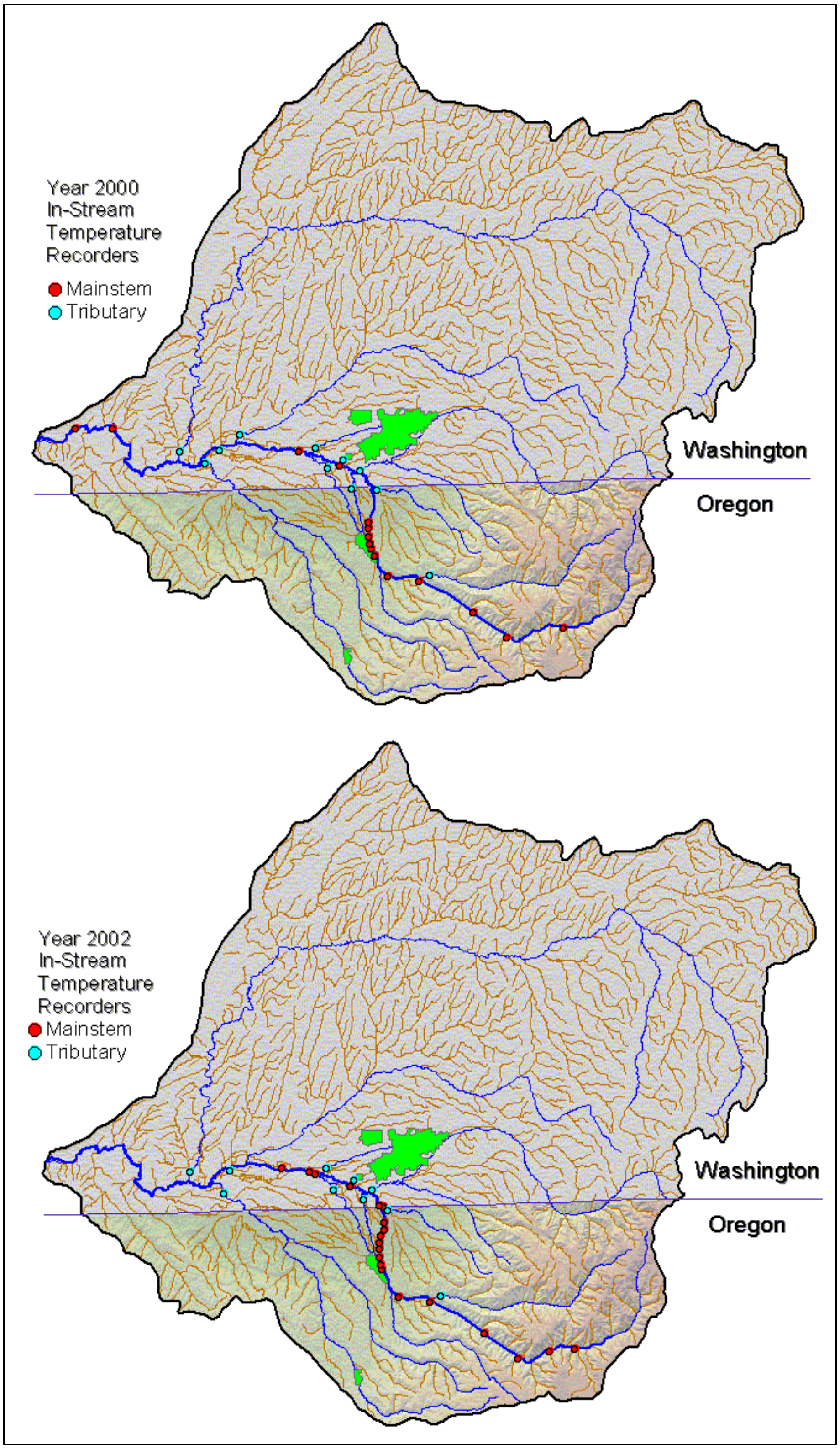


Figure 2-1. *Year 2000 and 2002 mainstem and tributary continuous stream temperature measurement locations. To assess tributary input, data recorders near stream mouths were selected from the available tributary monitoring data set.*

Table 2-1 (2 pages). *Seasonal peak seven-day moving average daily maximum stream temperatures and monitoring locations for selected sites*

Site Name	Organization	Location/ River KM	Date	7-Day Max (ºC)	7-Day Max (ºF)
Walla Walla River and South Fork, 2000					
South Fork at Burnt Cabin Creek	CTUIR	107.70	7/30/2000	11.4	52.6
South Fork at Harris Park	WWBWC	98.25	7/29/2000	14.9	58.9
South Fork at Fish Hatchery	WWBWC	92.65	7/22/2000	15.6	60.1
South Fork Lower Bridge	WWBWC	84.55	8/1/2000	17.0	62.6
Day Road	WWBWC	80.13	8/1/2000	18.8	65.9
Grove School Bridge (M1a)	WWBWC	76.80	8/3/2000	19.8	67.7
Milton-Freewater Levee (M2)	WWBWC	75.75	8/3/2000	20.8	69.5
Milton-Freewater Levee (M3)	WWBWC	75.25	8/1/2000	21.1	70.0
Nursery Bridge (M4)	WWBWC	74.10	7/31/2000	22.0	71.6
Milton-Freewater Levee (M5a)	WWBWC	73.04	7/31/2000	24.4	76.0
Tumalum Bridge (M8)	WWBWC	70.35	6/25/2000	21.6	70.8
Mathew's Lane (M9)	WWBWC	69.43	6/27/2000	21.0	69.8
Pepper's Bridge	WDFW	66.35	7/30/2000	24.1	75.4
Beet Road	WDFW	60.48	7/30/2000	24.3	75.8
Detour Road	WDFW	53.60	7/31/2000	25.4	77.7
Swegle Road	WDFW	54.48	7/31/2000	24.8	76.6
McDonald Road	WDFW	49.90	7/31/2000	28.0	82.4
9-Mile Bridge	DEQ	13.80	8/2/2000	27.7	81.8
Zangar Junction at Gas Pipe-Line	DEQ	6.70	8/1/2000	28.7	83.6

Site Name	Organization	Location/ River KM	Date	7-Day Max (ºC)	7-Day Max (ºF)
Tributaries, 2000					
North Fork	WWBWC	0.70	7/31/2000	22.5	72.5
Birch Creek	WDFW	Mouth	7/30/2000	27.1	80.7
Yellowhawk Creek	WDFW	Mouth	7/23/2000	23.4	74.2
Garrison Creek	WDFW	Mouth	7/31/2000	24.7	76.4
Mill Creek	WDFW	Mouth	7/31/2000	23.6	74.4
Pine Creek	WDFW	Mouth	7/31/2000	28.4	83.2

Abbreviations in this table: Confederated Tribes of the Umatilla Indian Reservation (CTUIR), Washington Department of Fish and Wildlife (WDFW), other abbreviations defined previously in this Appendix.

Table 2-1 Continued…

Walla Walla River and South Fork, 2002					
Site Name	**Organization**	**Location/ River KM**	**Date**	**7-Day Max (ºC)**	**7-Day Max (ºF)**
Umatilla National Forest Boundary	USFS	103.80	7/13/2002	12.5	54.5
Harris Park	WWBWC	98.25	7/13/2002	15.8	60.5
South Fork Lower Bridge	WWBWC	84.55	7/13/2002	17.7	63.8
Day Road	WWBWC	80.13	7/14/2002	19.1	66.3
Grove School Bridge (M1a)	WWBWC	76.80	7/14/2002	20.3	68.5
Milton-Freewater Levee (M2)	WWBWC	75.75	7/14/2002	21.0	69.8
Milton-Freewater Levee (M3)	WWBWC	75.25	7/14/2002	21.1	70.0
Nursery Bridge (M4)	WWBWC	74.10	7/13/2002	22.8	73.1
Milton-Freewater Levee (M5a)	WWBWC	73.04	7/13/2002	23.1	73.6
Milton-Freewater Levee (M6)	WWBWC	72.25	7/13/2002	24.8	76.6
Milton-Freewater Levee (M7)	WWBWC	71.23	7/14/2002	25.5	77.9
Tumalum Bridge (M8)	WWBWC	70.35	7/23/2002	24.1	75.4
Mathew's Lane (M9)	WWBWC	69.43	7/15/2002	23.3	74.0
Pepper's Bridge	WDFW	66.35	7/27/2002	23.9	75.0
Beet Road	WDFW	60.48	8/12/2002	22.7	72.8
Detour Road	WDFW	53.60	7/27/2002	25.4	77.7
Swegle Road	WDFW	54.48	7/14/2002	24.7	76.5
McDonald Road	WDFW	49.90	7/14/2002	28.3	83.0

Tributaries, 2002					
Site Name	**Organization**	**Location/ River KM**	**Date**	**7-Day Max (ºC)**	**7-Day Max (ºF)**
North Fork	WWBWC	0.70	7/13/2002	28.8	83.9
Big Springs/East Little WW	WWBWC	Confluence	6/2/2002	24.2	75.5
West Little Walla Walla River	WWBWC	Near Mouth	7/12/2002	26.2	79.1
Mill Creek	WDOE	2.74	7/17/2002	24.6	76.3
Mill Creek	WDOE	20.61	7/17/2002	23.7	74.7
Mill Creek	WDOE	23.83	7/17/2002	23.1	73.6
Mud Creek	WDFW	Mouth	7/27/2002	29.7	85.4
Touchet River	WDOE	3.22	7/17/2002	29.2	84.5
Touchet River	WDOE	11.27	7/17/2002	29.8	85.7
Touchet River	WDOE	17.39	7/17/2002	30.3	86.5
Touchet River	WDOE	20.61	7/17/2002	29.2	84.5

2.1.2 Flow Volume – Gage Data and In-stream Measurements

Flow volume and cross-sectional measurements were collected during late July through mid-August of 2000 and 2002 by several organizations. These measurements were used to develop mainstem and South Fork longitudinal flow profiles for the purpose of temperature modeling. July and August are critical months due to combined warm weather and low in-stream flow.

Water withdrawal information is used in this analysis to:
- *Map stream in-stream diversions and withdrawals*
- *Associate an estimated flow rate to each diversion and withdrawal*
- *Better delineate gaining and losing reaches*

Model input flow data are daily averages where gage data were available. Longitudinal flow profiles were developed for the 15th of August, 2000, the day of that of a thermal infrared flight (described in **Section 2.2.4**), and for the same day in 2002.

An Intermittent River. Since 1880 or earlier, and until 2001, irrigation withdrawals and substrate loss resulted in a dry streambed in parts of the mainstem between Tumalum and Nursery Bridges (refer to **Figure 1-8** for bridge locations), usually in the month of August. In 2000/2001 the irrigation districts, US Fish and Wildlife Service (USFW) and a consortium of environmental groups negotiated to improve irrigation efficiency, and in 2001, in-stream flow became continuous year round. In subsequent years in-stream flow has increased further yet. Note the marked contrast between the 2000 and 2002 flow profiles (following in this Section) in the state line area.

Summer of 2000. Between August 13 and August 20 of 2000, flow was measured manually at 30 sites in the subbasin. Most of the measurements took place on or near August 15. At the time only two long-term hourly gages were maintained on the model reach, a USGS gage downstream from the town of Touchet and an Oregon Water Resources Department (OWRD) gage at Harris Park. Gages were also maintained on major tributaries. Flow measurement locations for all available data are shown in **Figure 2-2**. Other information included:

- In Oregon, gages on major diversions (OWRD)
- Discussions with irrigators and Irrigation District Managers
- Discussions with Water Masters from both the OWRD and the WDOE
- In Oregon, the 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). **Figure 2-3** provides a rough view of the quantity and location of POD along the main channel in Oregon
- Where tributary data were lacking (small tributaries), mass balance calculations using temperature (thermal infrared flight data or in-stream thermometer or thermistor measurements) provided for estimation of tributary input flow (**Section 3.5**)

Based on this combined information, the WWBWC developed a flow profile of high resolution for the length of the model reach. Flow simulation (**Section 3.4** and **3.5**) was calibrated to this profile (**Figure 2-4**). **Figure 2-5** is provided for location reference.

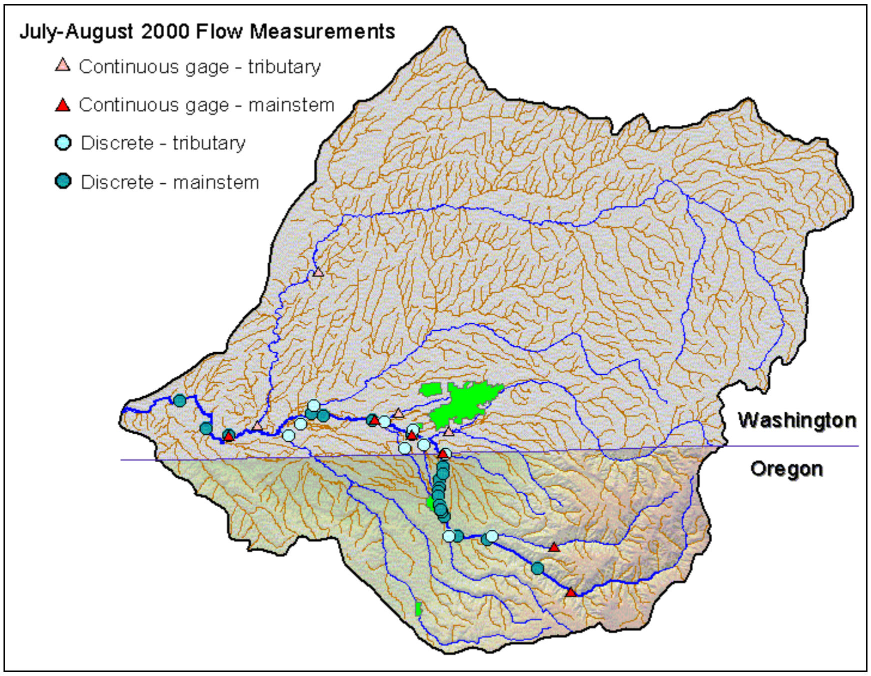


Figure 2-2. *Flow measurement locations (late July –August, 2000). WWBWC, WDFW, OWRD, USGS, WDOE, DEQ collected in-stream measurements during this period. The term "discrete" refers to manual measurements with a flow meter, not related to stage/discharge curve development for a gage site.*

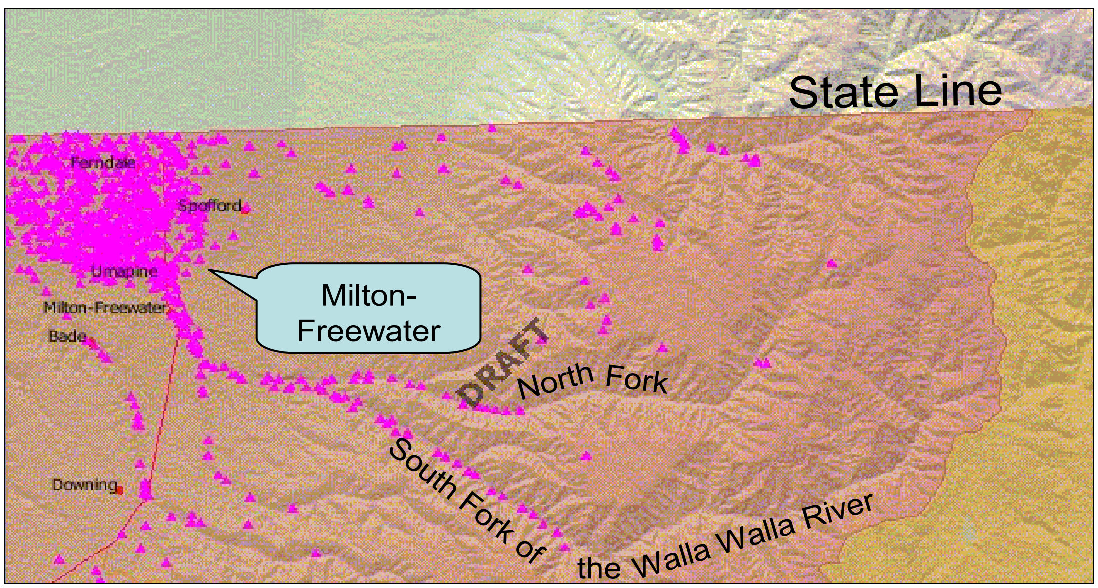


Figure 2-3. *Point of diversion for water rights in the Oregon near the Walla Walla River and the North and South Forks of the Walla Walla River (OWRD On-line draft data, WRIS)*

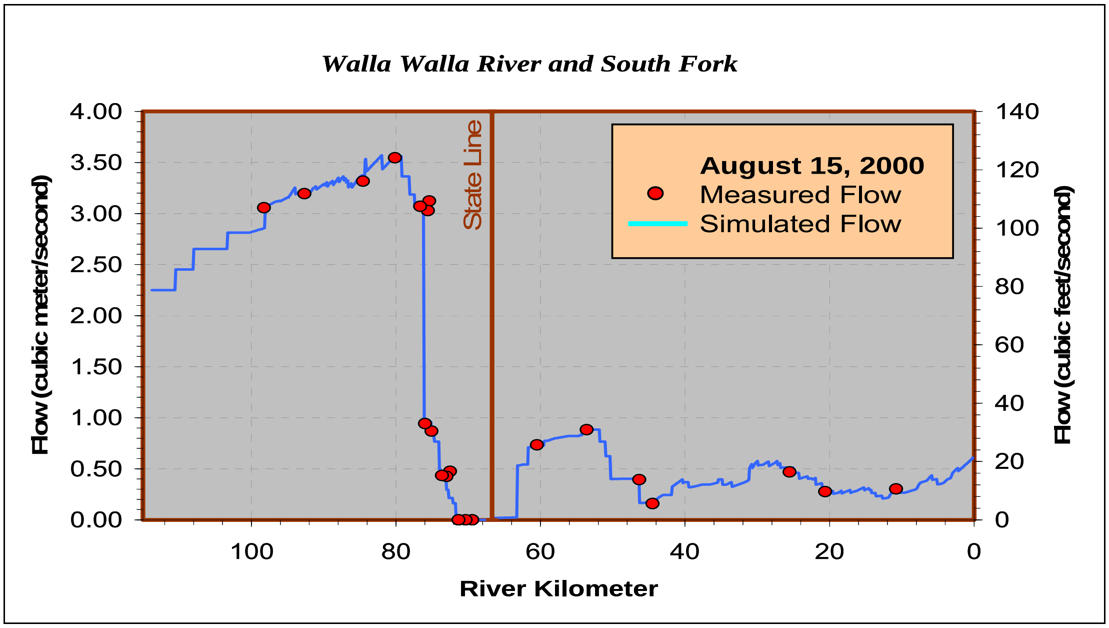


Figure 2-4. August 15, 2000 *flow profile for the Walla Walla River and the South Fork of the Walla Walla River, from Skiphorton Creek to the Columbia River*

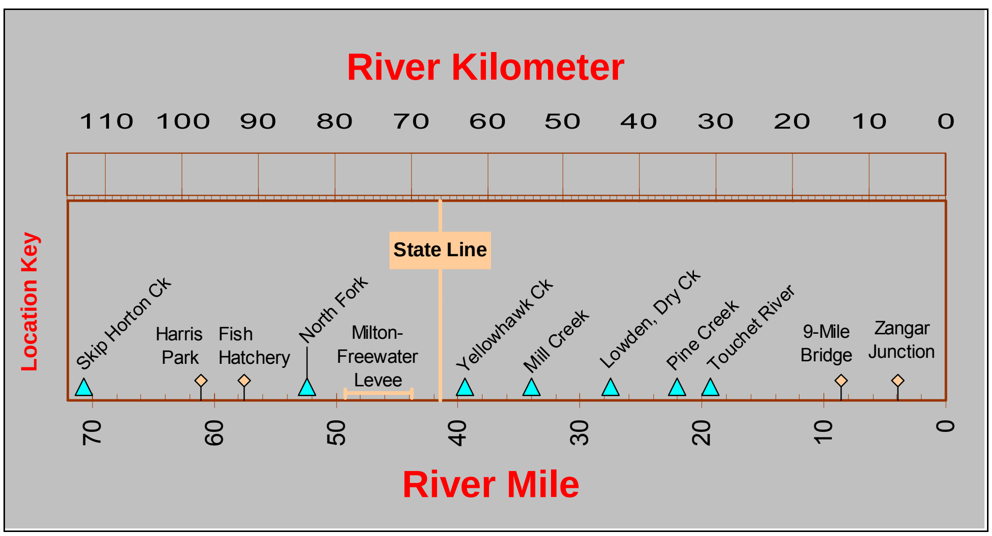


Figure 2-5. *Locations referenced by kilometer and river mile. It should be recognized that the above mileage is imprecise due to river change and varying mapping methods. However, model input and output for simulations of temperature, effective shade and hydrology are precisely referenced at 25-meter intervals based on ortho-imagery (current aerial photographs in GIS). The model distance origin reference is kilometer zero at the Highway 12 Bridge (~USGS river mile 4) near the mouth of the Walla Walla River. USGS mileage is based on the pre-McNary Dam inundation of the historic confluence. OWRD mileage differs from USGS at State Line by roughly 1.5 miles.*

Summer of 2002. During and prior to the summer of 2002 several more flow gages were installed, and flow was again measured with a portable flow meter at a suite of sites in the subbasin. In Oregon, field measurements and inventories of diversions and inputs as well as in-stream measurements (WWBWC Seepage Run) were conducted along the entire model reach. The locations of Summer 2002 manual and continuous flow measurements are shown in (**Figure 2-6**). Flow was simulated as described in **Sections 3.4** and **3.5**, in part using the assumption that withdrawal and inflow rates were generally similar to those identified in 2000 - a substantial number of in-stream gages verify the overall accuracy of this assumption and provide for calibration. **Figure 2-7** displays the resultant flow profile. Further refinement was provided through the mass balance method described in **Section 3.4**.

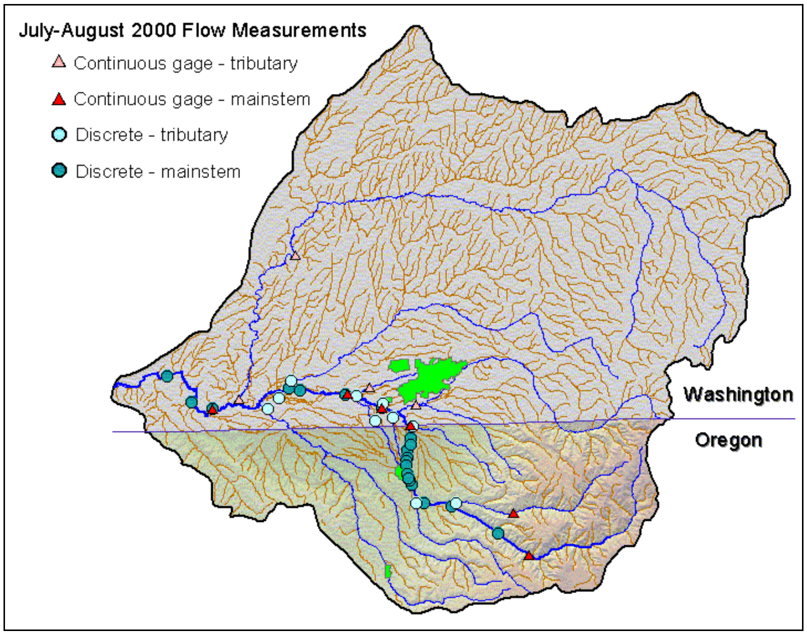


Figure 2-6. *Flow measurement locations (late July –early August, 2002). WWBWC, WDFW, OWRD, USGS, WDOE, DEQ collected in-stream measurements during this period.*

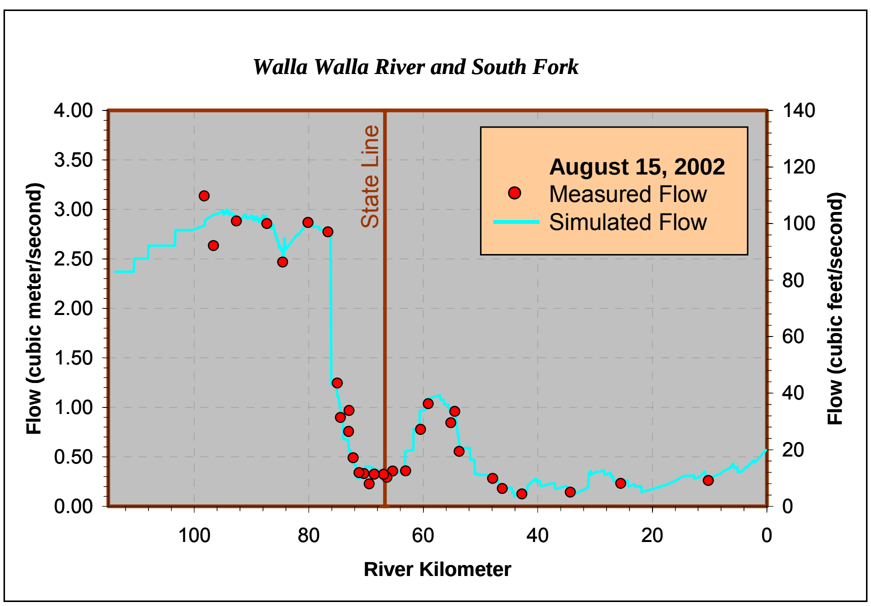


Figure 2-7. August 15, 2002 *flow profile for the Walla Walla River and the South Fork of the Walla Walla River, from Skiphorton Creek to the Columbia River.*

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 system potential channel morphology.

During the summer of 2000, DEQ, WWBWC, Oregon Department of Fish and Wildlife (ODFW), and Umatilla National Forest personnel guided teams in collecting stream morphologic data at twenty locations on the Walla Walla River and the South Fork of the Walla Walla River, below Harris County Park. WDOE, CTUIR and citizens supported the effort. A modified Rosgen Level II Inventory (Rosgen 1996) was applied to assess channel cross-sectional geometry and substrate composition. Transects were surveyed using engineering or laser levels. Substrate was measured based on the Wolman (1954) pebble count method. Data for five additional sites was supplied by the Umatilla National Forest for upstream locations. **Figure 2-8** displays the combined survey locations.

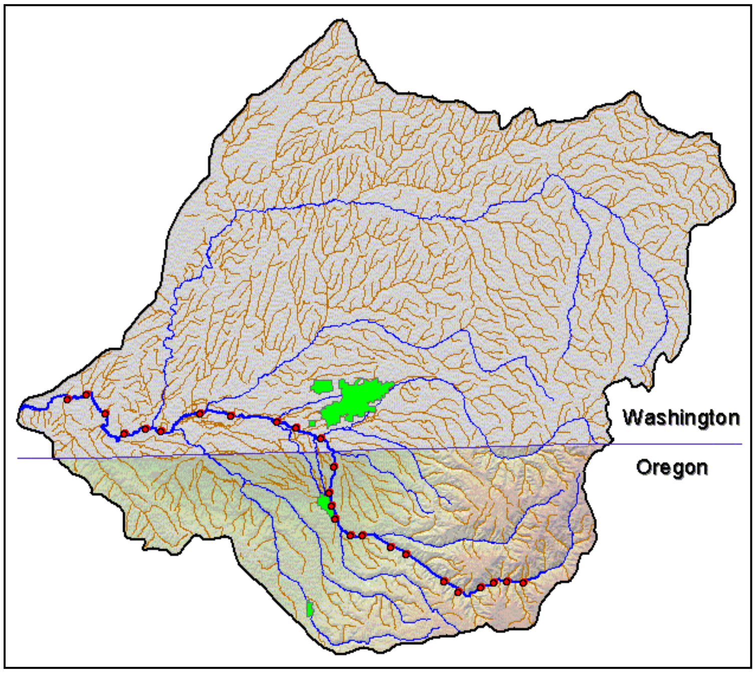


Figure 2-8. *Rosgen Level II transect locations*

Channel *type (classification), width, depth, gradient and map pattern* and related characteristics were assessed. Stream classification allows comparison of the Walla Walla River 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 2-9**), but 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 (e.g., relatively steep and straight reaches of the South Fork above Harris Park - intermixed with C-types).
- C-type streams are meandering and have floodplains. C-type is the predominant stable channel potential for the Walla Walla and South Fork Rivers, below Harris Park.
- D-type streams are braided or multi-thread. The only assessed D-type reach is just below the Milton-Freewater Levee.
- E-type streams are very meandering and low gradient, often with grassy banks (none were identified in the basin).
- 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 below Lowden.

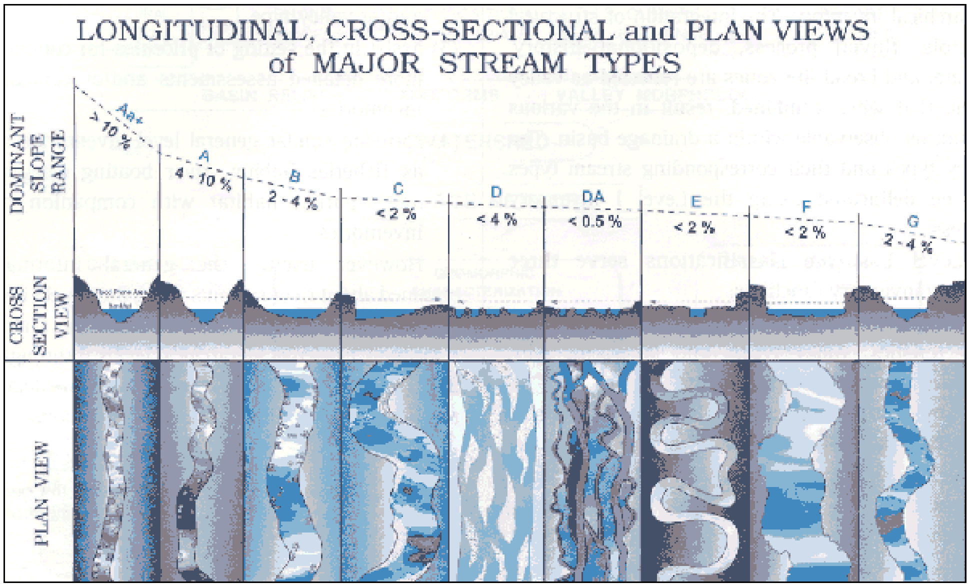


Figure 2-9. *Illustration of gradient, map pattern and cross-section of various stream types (from Rosgen, 1996).*

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 Walla Walla Subbasin, research has identified the bankfull discharge recurrence interval for the Walla Walla River, based on the Touchet gage-site on the Walla Walla River (1.03 year) and the Touchet River (1.15 year) gage-site (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 2-10** illustrates the surveyed channel cross-sections and **Table 2-2** 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 Walla Walla 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. Though opportunities for this improvement occur throughout the basin, there are possible limiting factors, or structures: Lake Wallula, parts of the Milton-Freewater Levee and early 20th century conversion of multiple alluvial fan channels to irrigation ditches.

General Observations – Walla Walla and South Fork Rivers:

- The average channel width ranges from 45 to 160 feet. The channel is widest between Milton-Freewater, Oregon and Lowden, Washington and near the Columbia River (note – the highest observed temperatures are observed near Lowden in year 2000).
- Other than the one braided reach just below the Milton-Freewater Levee, recent channel width/depth field measurements vary from 15-72 with a mean of 35.
- Historic aerial photos indicate that in some locations sinuosity has decreased substantially (USDA 1939-1946).
- Measured sinuosity within the Milton-Freewater Levee ranges from 1.0 to 1.2. The mean sinuosity measured above and below Milton-Freewater is 1.2 and 1.6, respectively.
- A review of recent and historic aerial photography (USDA 1939-1946) indicates stream straightening and widening have occurred over much of the length of the combined Walla Walla and South Fork Rivers. Levees, roads, urban development and agricultural fields limit or reduce sinuosity. Straightening is most obvious between Harris Park and the northern Dry Creek.
- The irrigation diversions do not divert a large proportion of the wet season high flows. Consequently, after the consolidation of flow into the Tumalum branch many decades ago, the irrigation diversions should have little influence on mainstem channel morphology.

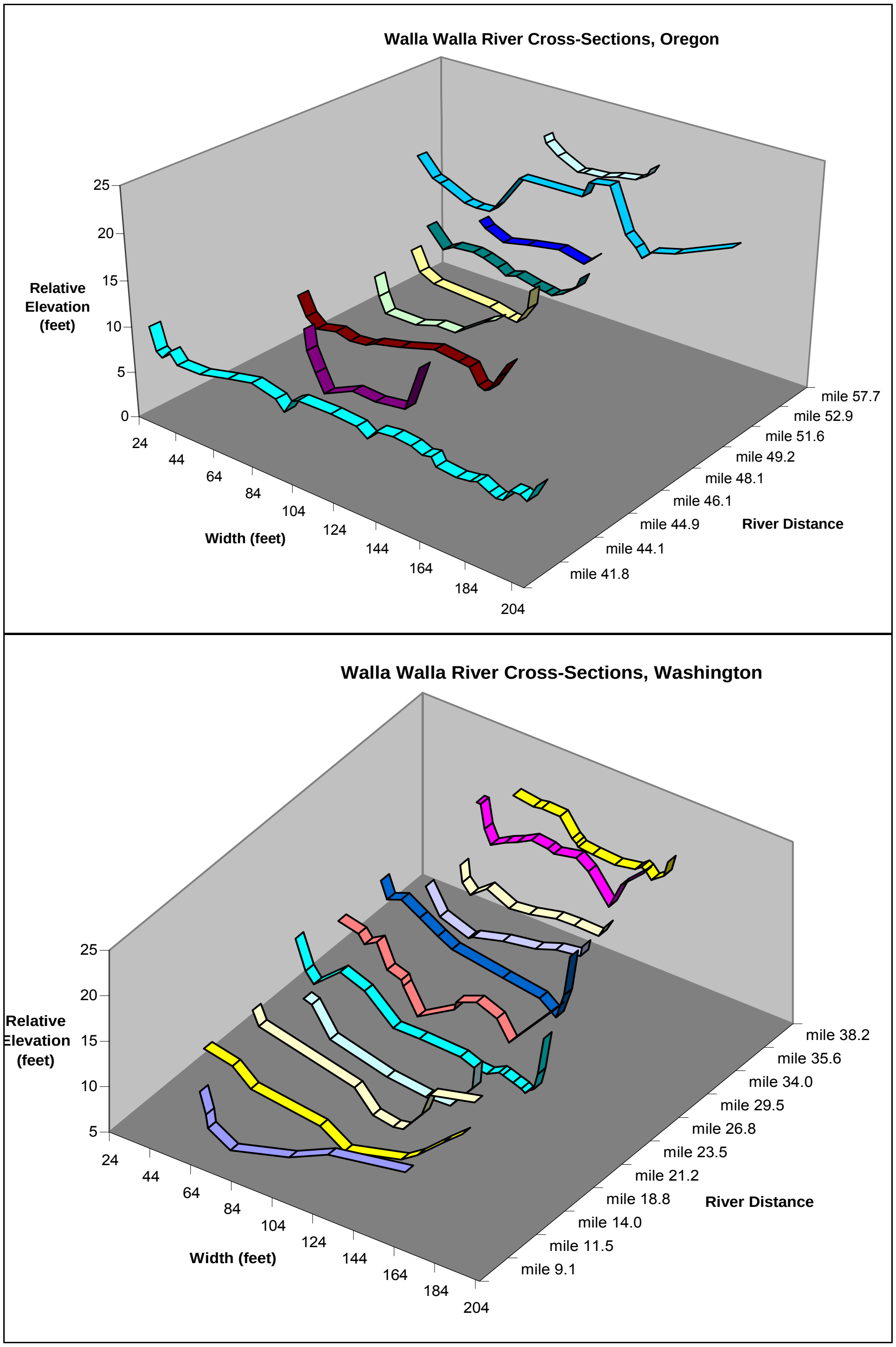


Figure 2-10. *Illustration of channel cross-sections (ribbon ends are at bankfull)*

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

Walla Walla River Morphology Description [Summer 2000 exept where shaded]														
Site ID & River Mile	**Site Description (all on Walla Walla River)**	**Rosgen (1996) Stream Type**	**Bankfull Width (feet)**	**Bankfull $Depth_{mean}$ (feet)**	**Bankfull Width / $Depth_{mean}$ Ratio**	**Bankfull $Depth_{max}$ (feet)**	**Flood- prone Width (feet)**	**Entrench-ment Ratio**	**Bankfull Cross-Sectional Area ($feet^2$)**	**Estimated Channel Gradient (7.5' quad*)**	**Estimated Sinuosity**	**Channel Material D_{50} (mm)**	**Channel Material Descrip-tion**	**Drainage Area ($miles^2$)**
MNWW9.1	Private Property (near gas pipeline river crossing)	F4	104.5	2.4	43.7	5.2	114.3	1.1	250.1	0.0017	1.403	32-48	gravel	1752.24
MNWW11.5	Nine Mile Ranch	F4	130.3	3.9	33.4	6.6	146	1.1	508.1	0.0030	1.593	24-32	gravel	1705.45
MNWW14.0	Cummins Bridge (1.5 miles downstream of bridge)	F5/F6	90.0	3.1	29.3	6.5	110	1.2	276.6	0.0030	1.630	1-2	sand/ clay	1691.03
MNWW18.8	Touchet Gage Station Site	B3c	85.2	4.1	21.0	5.4	127	1.5	345.5	0.0030	1.505	128-192	cobble	1643.99
MNWW21.2	Private Property (South of landing strip)	F5/F6	122.3	4.7	25.8	6.8	144	1.2	579.9	0.0002	1.770	1-2	sand/ clay	1641.82
MNWW23.5	Private Property	F5/F6	110.0	3.3	33.4	5.8	117	1.1	362.0	0.0010	2.430	1-2	sand/ clay	888.58
MNWW26.8	Private Property	C5/C6	93.6	4.2	22.5	7.3	206	2.2	389.5	0.0030	1.345	1-2	sand/ clay	673.35
MNWW29.5	MacDonald Bridge, WDFW Fishing Area (2000 feet upstream of bridge)	C4	78.4	2.5	31.5	1.3	194	2.5	195.1	0.0030	1.293	24-32	gravel	419.41
MNWW34.0	Swegle Bridge, WDFW Fishing/Hunting Area (500 yards upstream of bridge)	B4c	72.3	1.7	41.9	2.6	103	1.4	124.7	0.0030	1.464	24-32	gravel	301.18
MNWW35.6	Near Whitman Mission (1/4 mile upstream of Last Chance Road bridge)	B4c	81.3	2.4	34.2	5.4	176	2.2	193.0	0.0050	1.441	32-48	gravel	298.59
MNWW38.2	Old Milton HWY Bridge (150 Yards upstream of bridge)	C4	53.2	2.5	21.7	2.8	181	3.4	130.3	0.0130	1.621	32-48	gravel	212.19
MNWW41.8	Private Property , Mathew's Lane	D4	134.4	0.9	156.6	1.9	189	1.4	115.3	0.0060	1.620	16-24	gravel	163.08
MNWW44.1	Willow Lane (Milton-Free. levee section, 0.5 miles downstream from Nursury Bridge)	C4	51.4	3.0	17.3	4.5	162	3.2	153.1	0.0130	1.062	48-64	gravel	161.57
MNWW44.9	1st Street Milton-Freewater (Milton-Free. levee section)	C3	97.9	1.8	54.2	2.9	314	3.2	176.7	0.0160	1.240	64-96	cobble	160.81
MNWW46.1	Near Frasier Farmstead Museum (Milton-Free. levee section)	C4	59.0	2.6	22.7	3.6	143	2.4	153.0	0.0100	1.030	48-64	gravel	159.55
MNWW48.1	Private Property (Off Day Road)	B4c	58.0	2.9	20.0	3.7	117	2.0	168.3	0.0060	1.231	48-64	gravel	131.81
MNWW49.2	Private Property (1/4 mile upstream from bridge)	F4	76.0	1.8	42.6	3.0	94	1.2	135.5	0.0040	1.242	48-64	gravel	125.54
SFWW51.6	Private Property	C4	55.8	0.8	71.8	1.5	128	2.3	43.4	0.0100	1.242	48-64	gravel	80.67
SFWW52.9	Private Property	C4	77.9	3.1	25.5	1.0	181	2.3	238.1	0.0100	1.235	48-64	gravel	78.60
SFWW57.7	Private Property	F4	52.0	2.0	26.5	2.7	60	1.1	102.2	0.0050	1.234	48-64	gravel	66.94
21 (rm 59.2)	Stream Gage (transect 3 of 3)	B3c	51.5	2.7	18.8		64	1.2	141.1	0.0140	moderate	66 (1996)	cobble	62.95
22 (rm 61.2)	2 Miles Above Gage (transect 3 of 3)	B4b	64.0	3.1	21.0		148	2.3	195.2	0.0240	moderate	64 (1999)	cobble	53.22
23 (rm 62.4)	USFS Boundary (mean of 2 transects)	B4c	48.5	3.2	15.0		176	2.7	156.7	0.0160	moderate	51 (1997)	gravel	49.38
24 (rm 64.0)	Campgroud (mean of 2 transects)	C3	48.6	3.0	16.2		180	3.7	145.8	0.0180	moderate	51 (1997)	gravel	44.60
25 (rm 65.9)	Near Table Creek (transect 1 of 3)	B4c	47.0	1.8	26.6		82	1.7	83.2	0.0120	moderate	44 (1996)	gravel	32.79
Data Sources: TMDL Data Collection in summer 2000 DEQ, WWBWC, et al (Sites 1-20); USFS 1996-2000 (Sites 21-25 (shaded)) [used mid-range values of 3 transects, mean of 2; if multiple transects at a site]														

A single cross-section was surveyed at each site tabulated in **Table 2-2**. 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 2 transects across the full base of the channel. D_{50} is the 50^{th} percentile diameter (intermediate axis) of each site's array of measurements.

2.1.4 Vegetation

DEQ and WWBWC staff conducted vegetation assessment during the summer of 2000, generally at the channel morphology survey sites (**Figure 2-8**) and at additional sites over the course of numerous months 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 2-3**)
- Field identification of shade producing vegetation species
- Vegetation height measurement using a digital range-finder (**Table 2-4)**
- Umatilla National Forest field botanical data (**Table 2-5,** refer to the public ownership figure in **Section 1.5.7** for a map showing Umatilla National Forest area)

Table 2-4 displays some of the vegetation height data used for model entry. Additional information from field notes, aerial photo shadow lengths and personal interviews were incorporated into the final determination of existing vegetation height (**Table 2-6**) for the two model calibrations (for August 10-16 in 2000 and 2002). Aerial photography provided for vegetation characterization between field sites, and this interpretation was aided by the 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 Harris County Park (Grand Fir, Douglas Fir, Ponderosa Pine, Engelmann Spruce, Pacific Yew, Western Red Cedar, Rocky Mountain Juniper) with mixed deciduous, particularly in disturbance regimes such as point bars (Alder, Rocky Mountain Maple, Mackenzie's Willow, Water Birch). Quaking Aspen and herbaceous vegetation are present as well.
- Mixed Conifer-Deciduous below Harris Park for four miles.
- Deciduous dominance below Mixed Conifer-Deciduous zone, downstream to Milton-Freewater (Cottonwood galleries common, also mixed Cottonwood, Alder, Willow and other small to medium height deciduous trees)
- Milton-Freewater Levee (limited vegetation through substantial parts of the Levee)
- Milton-Freewater Levee to Dry Creek (mixed Alder, large and small Willow, Cottonwood dominance with Box Elder, Ailanthus, Russian Olive, Black and Honey Locust, Red Osier Dogwood, other small deciduous trees)
- Dry Creek to Zangar Junction (mixed small willows and herbaceous vegetation)
- Below Zangar Junction (Cottonwood galleries common, also mixed Cottonwood, Alder, Willow and other small to medium height deciduous trees including non-natives)

Table 2-3. *Solar Pathfinder™ measurements of percent of daily total solar radiation received by water body at mid-stream*

Location	Distance from Mouth (river km)	Solar Pathfinder
South Fork Walla Walla River - Harris County Park	98.325	74%
South Fork Walla Walla River - CTUIR Fish Hatchery	92.65	86%
South Fork Walla Walla River - Lowermost South Fork Bridge	84.55	83%
Walla Walla River - Day Road	82.175	98%
Walla Walla River - Frasier Farmstead	77.1	27%
Walla Walla River - Above Nursery Bridge	76.175	12%
Walla Walla River - Below Nursery Bridge	74.375	33%
Walla Walla River - Tumalum Bridge	70.4	15%
Walla Walla River - Mathew's Lane	69.625	23%
Walla Walla River - Old Milton HWY Bridge	63.725	20%
Walla Walla River - Swegle Road (below of Whitman Mission)	55.775	32%
Walla Walla River - Touchet Road	31.825	0%

Vegetation Height Measured With Height-Computing Range Finder

Description		Height in feet – River Mile																	Average
		3.8	9.0	27.3	32.8	40.0	43.5	45.0	45.8	49.0	49.2	49.5	50.5	55.0	56.0	57.0	59.0	59.5	
Orchard	Various											14							14
Large Deciduous	cottonwood gallery				70, 67	106, 75	113		58, 62	68, 70				94	94	96	100, 68		68
Medium Deciduous	mixed willow, alder, box elder, cottonwood, locust, birch, ailanthus, choke cherry, red osier dogwood, box elder	41		56	66, 38, 63	47	52						48, 50				40		50
Small Deciduous	mixed willow, alder, box elder, cottonwood, locust, birch, ailanthus, choke cherry, red osier dogwood, box elder	29				22	34		30	31	27		37	36, 37			32	23, 36	31
Willow Brush	mostly coyote willow	9, 20, 16.5	10	14	9		18		12		22							9	14
Shrubs and grasses	average height 1.5 feet																	1.5	
Large Conifer	mature grand fir, ponderosa pine, douglas fir																	108	
Medium Conifer	grand fir, ponderosa pine, douglas fir																	50	
Small Conifer	grand fir, ponderosa pine, douglas fir																	30	

► Data are typically averages of 2-4 multiple measurements in various directions at a site.
► Values represent stand height except where shaded in gray. Gray shaded values represent individual trees.

Table 2-4. *Vegetation height measurement using a digital range-finder*

Table 2-5. *Umatilla National Forest assessment of existing vegetation height in the National Forest part of the Walla Walla Subbasin.*

Ecoclass	Species Expected	Potential Average Tree Height	Potential Average Crown Height
1. CDG121			
(Douglas fir/Pinegrass)	Douglas Fir	100’	70’
	Ponderosa Pine		
	Grand Fir		
2. CDS611			
(Douglas fir/Oceanspray)			
	Douglas Fir	110’	75’
	Ponderosa Pine		
3. CDS622			
(Douglas fir/Snowberry)			
	Douglas Fir	110’	75’
	Ponderosa Pine		
	Western Larch		
4. CDS711			
(Douglas fir/Ninebark)			
	Douglas Fir	110’	75’
	Ponderosa Pine		
	Western Larch		
5. CPG221			
(Ponderosa Pine/Pinegrass)			
	Ponderosa Pine	100’	70’
	Douglas Fir		
6. CWC811			
(Grand Fir/Pacific Yew/			
queen’s cup beadlily)	Grand Fir	130’	80’
	Engelmann Spruce		
	Douglas Fir		
	Western Larch		
7. CWF612			
(Grand Fir/Sword Fern)			
	Grand Fir	140’	85’
	Douglas Fir		
	Western Larch		
	Engelmann Spruce		
8. CWS412			
(Grand Fir/Maple)	Grand Fir	130’	80’
	Engelmann Spruce		
	Douglas Fir		
	Western Larch		
	Western White Pine		

Table 2-6. *Model entry vegetation codes, heights and density. Density was derived from aerial photography. The code is used for combining mapped zones into categories of same height and density, for temperature model input. Density refers to the relative amount of solar radiation that can pass through vegetation and can be approximated by the spatial density of foliage visible in aerial photographs.*

Land Cover Name	Code	Height (m)	Density (%)
Water	301	0.0	0%
River Bottom - Within bankfull	3011	0.0	0%
Pastures/Cultivated Field/Lawn	302	0.1	65%
Young Orchard	3025	4.5	65%
Mature Orchard	303	7.5	65%
Barren - Rock	304	0.0	0%
Barren - Embankment	305	0.0	0%
Barren - Campground/Park	306	0.0	0%
Barren - Gravel Pit	307	0.0	0%
Barren - Clearcut	308	0.0	0%
Barren - Paved Road, shoulder, prism, park lot	400	0.0	0%
Barren - Non-paved Road and Shoulder & Prism	401	0.0	0%
Barren - Railroad	402	0.0	0%
Barren: Milton-Freewater levee road	403	0.0	0%
Barren - Other	309	0.0	0%
Adjacent to MF levee at road elev. - willow brush	4041	4.3	25%
Adjacent to MF levee at road elev. - willow brush	4042	4.3	50%
Adjacent to MF levee at road elev. - willow brush	4043	4.3	65%
Adjacent to MF levee at road elev. - small deciduous	4051	9.4	25%
Adjacent to MF levee at road elev. - small deciduous	4052	9.4	50%
Adjacent to MF levee at road elev. - small deciduous	4053	9.4	70%
Adjacent to MF levee at road elev. - large deciduous	4061	20.7	25%
Adjacent to MF levee at road elev. - large deciduous	4062	20.7	50%
Adjacent to MF levee at road elev. - large deciduous	4063	20.7	70%
Small Mixed Con/Hard	5061	9.3	25%
Small Mixed Con/Hard	5062	9.3	50%
Small Mixed Con/Hard	5063	9.3	70%
Large Mixed Con/Hard	5071	20.0	10%
Large Mixed Con/Hard	5072	20.0	25%
Large Mixed Con/Hard	5073	20.0	35%
Extra Large Mixed Con/Hard	5074	25	75%
Medium Mixed Con/Hard	5081	10.0	10%
Medium Mixed Con/Hard	5082	10.0	25%
Medium Mixed Con/Hard	5083	10.0	35%
Large Deciduous	6001	28.0	25%
Large Deciduous	6002	28.0	50%
Large Deciduous	6003	28.0	70%
Dense Large Deciduous	6004	28.0	75%
Mixed Deciduous	2003	22.0	70%
Medium Deciduous	6071	12.0	25%
Medium Deciduous	6072	12.0	50%
Medium Deciduous	6073	12.0	70%
Small Deciduous	6011	8.0	25%
Small Deciduous	6012	8.0	50%
Small Deciduous	6013	8.0	70%
Willow Brush	6031	4.3	25%
Willow Brush	6032	4.3	50%
Willow Brush	6033	4.3	70%
Shrubs and grasses	8001	0.5	25%
Shrubs and grasses	8002	0.5	50%
Shrubs and grasses	8003	0.5	70%
Large Conifer	7001	25.0	15%
Large Conifer	7002	25.0	35%
Large Conifer	7003	25.0	55%
Dense Large Conifer	7004	25.0	65%
Medium Conifer	7031	15.2	25%
Medium Conifer	7032	15.2	50%
Medium Conifer	7033	15.2	70%
Small Conifer	7011	9.1	25%
Small Conifer	7012	9.1	50%
Small Conifer	7013	9.1	70%
Grasses	9001	0.5	25%
Grasses	9002	0.5	50%
Grasses	9003	0.5	70%
Developed - Rural Residential	3248	3.0	10%
Developed - Industrial	3249	4.0	5%
Developed urban - much impervious	3250	3.0	5%
Developed Area - dirt or gravel (unpaved)	3252	3.0	5%
Pipeline	3253	0.0	0%
Canal	3255	0.0	0%
Dike	3256	0.0	0%
Riparian Wetland/Meadow	4000	0.8	75%

2.1.5 Meteorological Data

Hourly summer air temperature and humidity measurements were collected at the locations identified in **Table 2-7**.

Table 2-7. *Dates, Locations and sources of weather data for years that encompass the two temperature model calibration timeframes*

Year	Location	Type	Data Source
2000	LeGrow, WA	temperature, humidity	Agrimet
	Walla Walla, WA	temperature, humidity	WSU PAWS
	South Fork and lower mainstem	temperature	Landowner Stations
2002	LeGrow, WA	temperature, humidity	Agrimet
	Walla Walla, WA	temperature, humidity	METAR
	Lower Mill Creek	temperature	WA Dept. Ecology
	Upper Mill Creek	temperature	WA Dept. Ecology

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

Figures 2-11 and **2-12** are included here as examples illustrating temporal and spatial variability in summer air temperature**. Figure 2-11** shows the July-August air temperature for the years 2000 through 2002 at LeGrow, Washington, a site which was selected to represent the mouth of the Walla Walla River. Station locations for 2001 are not shown in **Table 2-7** because the temperature model was not calibrated for that year, but are included in **Figure 2-11** for a more complete example of inter-annual variability. **Figure 2-12** displays the main channel longitudinal temperature range for year 2002. In the temperature model, data from the various weather stations were distributed to 16 model continuous data input nodes based on closest proximity.

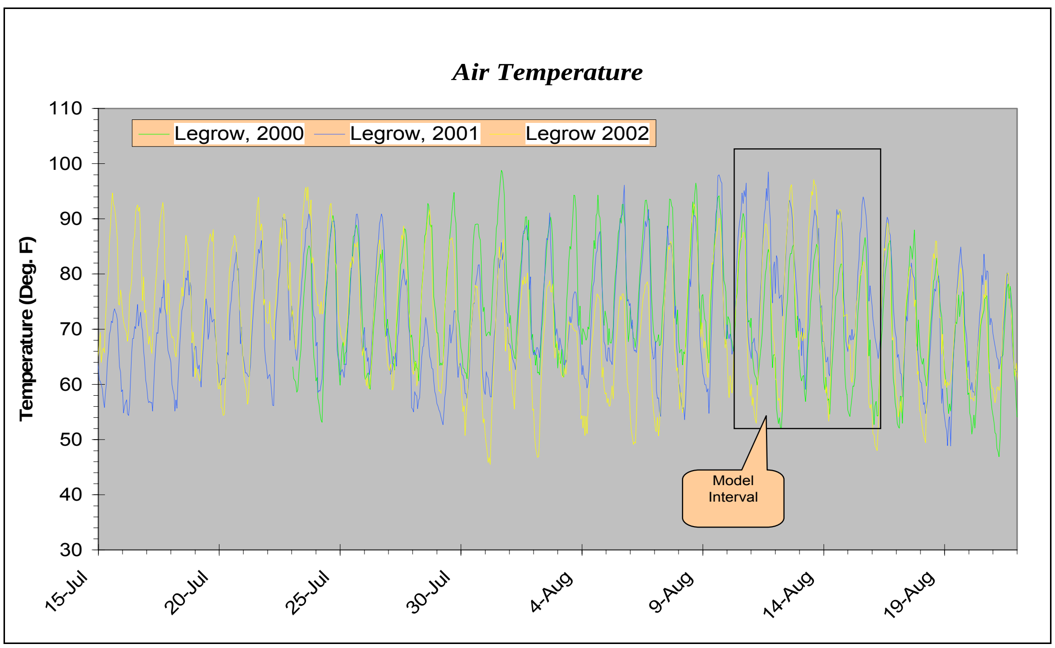


Figure 2-11*. July-August 2000-2002 air temperature at Legrow, WA.*

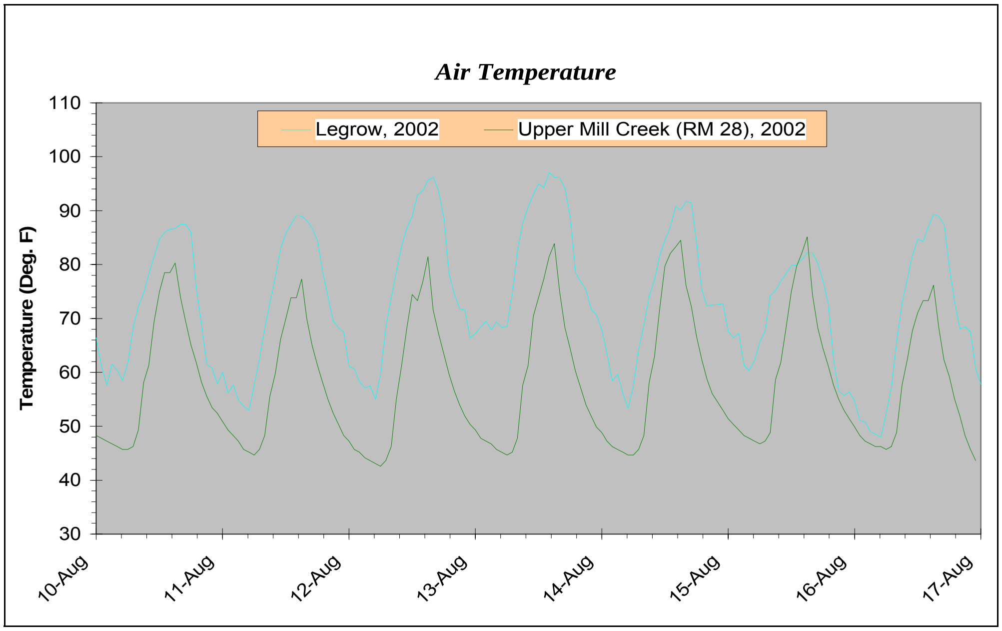


Figure 2-12. *July-August 2000-2002 air temperatures in the upper and lower subbasin.*

2.2 GIS and Remotely Sensed Data

2.2.1 Overview – GIS and Remotely Sensed Data

This report 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 2-8. 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.)
Thermal Infrared Temperature Data	• Measure Surface Temperatures • Develop Longitudinal Temperature Profiles • Calculate Flow Mass Balance – Assists Development of Flow Profile and Inputs • Map/Identify Significant Thermal Features • Indication of Subsurface Hydrology, Groundwater Inflow, Springs • Validate Simulated Stream Temperature

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 1 meter in flat terrain). DEMs are used to evaluate topography as identified in **Table 2-8**.

2.2.3 Aerial Imagery – True Color and Gray Scale

A digital orthophoto quad (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 orthophotos used in this report are black-and-white with one-meter pixels covering a USGS quarter quadrangle. The images, collected in May through July of 1994, 1995 and 1996, were provided through the Natural Resources Conservation Service National Cartography and Geospatial Center.

The mapping and interpretation of the DOQs was aided by frequent reference to high resolution Day TV images, collected August 15, 2000. This enabled adjustments for changes that had occurred in more recent years, and assisted channel and vegetation delineation where the DOQs lacked sufficient resolution. The Day TV aerial photos were synchronously collected with infrared data from a helicopter, forming thermal infrared radiometry (FLIR, see **Section 2.2.4**) and true color image pairs. The resultant images are not corrected for camera distortion, nor geo-referenced with a coordinate system. However, the images are in color with <0.5 meter/pixel resolution, providing substantially more clarity for vegetation identification and channel delineation. FLIR is discussed in greater detail in the following section.

2.2.4 Thermal Infrared (FLIR) Temperature Data

Thermal Infrared Temperature data is probably best abbreviated as *TIR*. However, because of familiar usage and previous nomenclature, for this document the term *Forward Looking Infrared* (FLIR) will be employed, taking the name of the original technology prior to its adaptation to watershed analysis. It is likely that in subsequent TMDLs and for DEQ purposes in general, the term *TIR* will be used.

Thermal infrared temperature data was used to validate and calibrate temperature simulation for the summer of 2000, and to better understand thermal patterns of the Walla Walla River and South Fork. As mentioned above, the true color images paired with the FLIR images supported channel delineation and vegetation identification.

2.2.4.1 FLIR Data Background Information

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

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

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

In-stream temperature data loggers (Onset Stowaway^{TM} or VEMCO^{TM}) are distributed in each subbasin prior to the survey to ground truth (i.e., verify the accuracy) the radiant temperatures measured by the FLIR. The FLIR data is formatted for viewing as GIS point coverages or FLIR imagery.

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

2.2.4.2 FLIR Derived Longitudinal Heating and Imagery

Longitudinal river temperatures were sampled using thermal infrared (FLIR) in single continuous flight on August 15, 2000 at the times and locations described in **Table 2-9**. The flight began at the Walla Walla – Columbia River confluence and continued upstream through the City of Milton-Freewater and upward along the South Fork to just below the mouth of Skiphorton Creek. Flow was continuous except in the reach immediately downstream from Milton-Freewater, in the lower Levee section. In August of 2000 and prior years, irrigation diversions and infiltration resulted in a dry river bed upstream of Tumalum Bridge for approximately one kilometer (0.6 miles).

Table 2-9. *Date, time, and distance for streams surveyed in the Walla Walla Subbasin.*

Stream	Date	Local Time (PM)	Miles Surveyed
Walla Walla River	15 August 00	14:07 – 15:48	50.6
South Fork Walla Walla River	15 August 00	15:49 – 16:20	17.1
Total Miles Surveyed			**67.7**

Stream temperature data sampled from the FLIR imagery reveals spatial patterns that are variable due to localized stream heating, tributary input, and groundwater influences. **Figures 2-13** and **2-14** display graphics of FLIR-sampled temperatures for the Walla Walla Subbasin. **Figures 2-15a** through **2-15m** depict FLIR and digital video imagery for selected areas of interest.

It is important to note that, when present, thermal stratification often can be identified in FLIR imagery and by comparison with the in-stream temperatures loggers. For example, the imagery may reveal a sudden temperature decrease at a riffle or downstream of an in-stream structure, where water was rather stagnant or deep just upstream. In the case of the Walla Walla Subbasin August 15, 2000 FLIR flights, no stream reaches were identifiably stratified. The rivers where FLIR data was collected are generally well-mixed.

The abbreviations 'TIR' and 'FLIR' are synonymous.

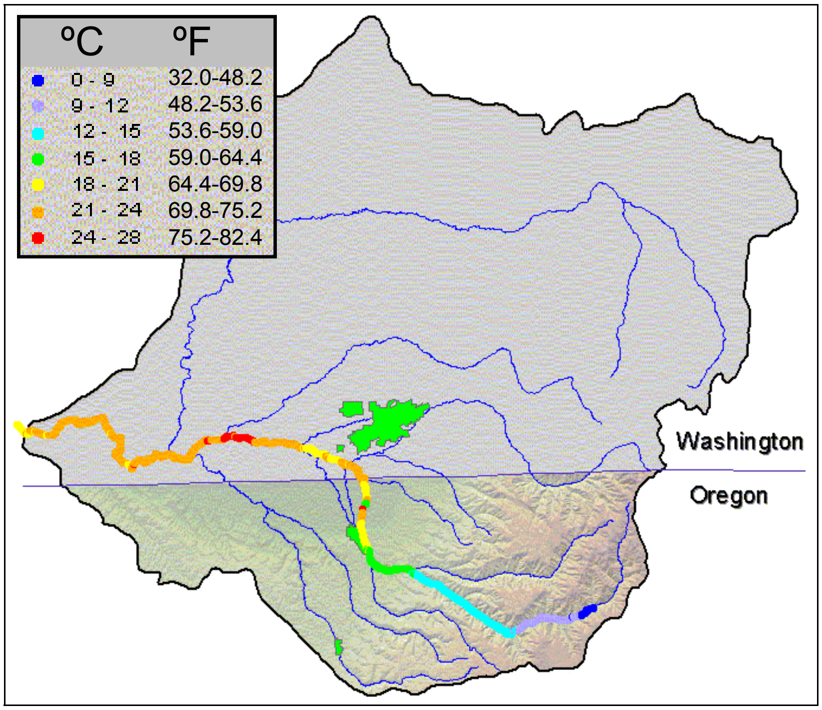


Figure 2-13. August 15, 2000 *River Sampled FLIR Surface Temperatures on the mainstem and South Fork of the Walla Walla River.*

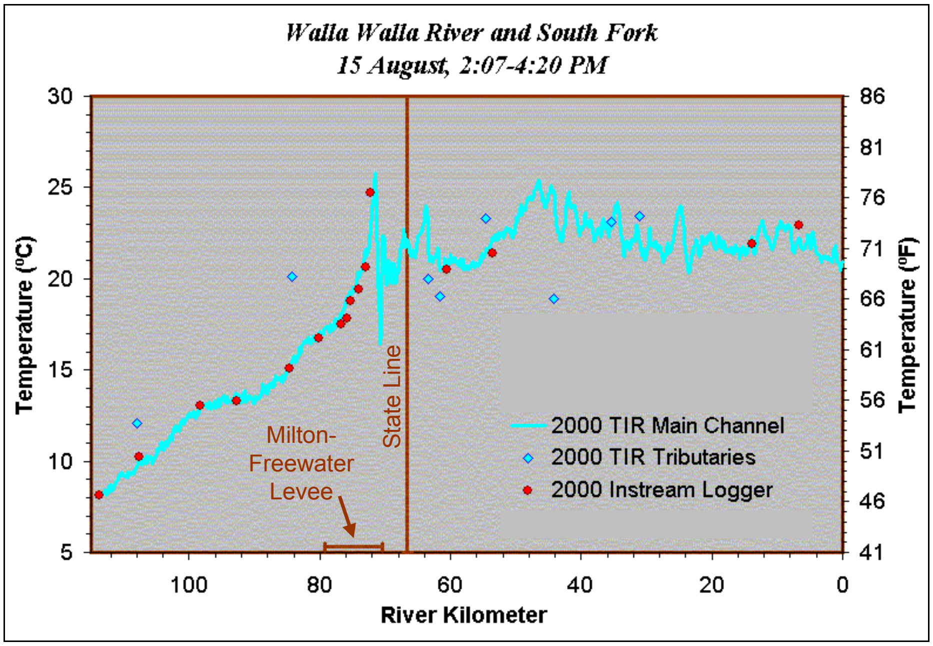


Figure 2-14. *Measured stream temperature longitudinal profiles. Refer to* ***Figure 2-5*** *for river miles and additional location reference.*

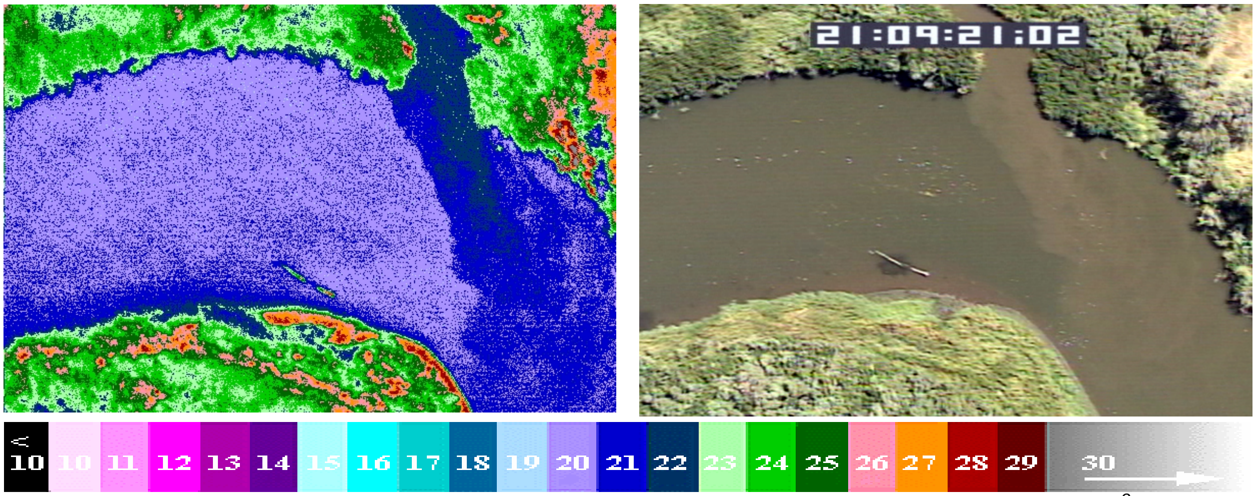


Figure 2-15a. *FLIR/Day TV image pair (frame: wall0058) showing the Walla Walla River (20.5°C) and an unnamed tributary (22.4°C) on the left bank at river mile 1.6 (~km 2).*

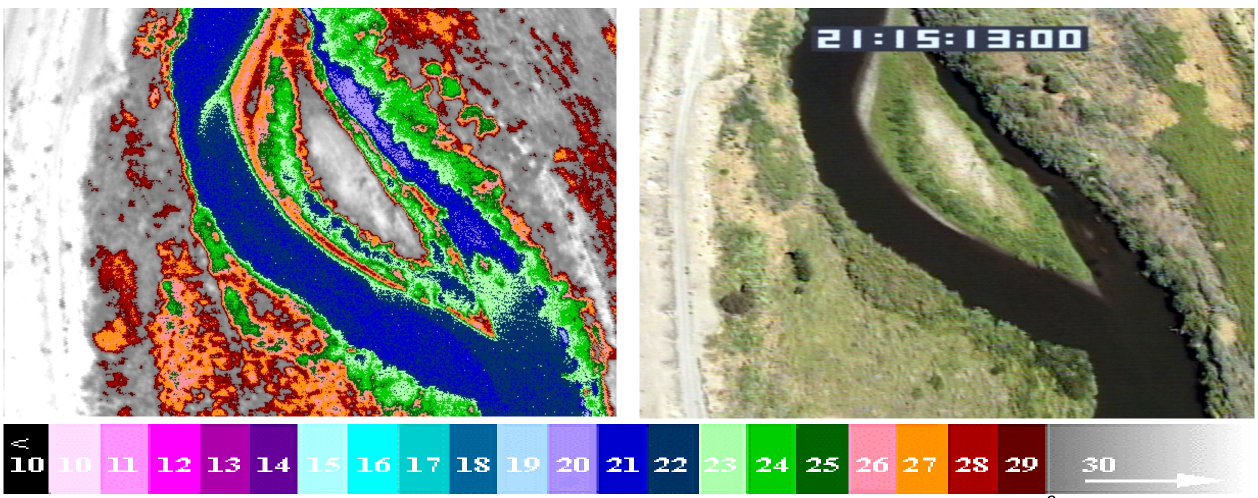


Figure 2-15b. *FLIR/Day TV image pair (frame: wall0234) showing a side-channel (22.6°C) along the left bank (looking downstream) at river mile 5.5 (~km 9) of the Walla Walla River (21.9°C).*

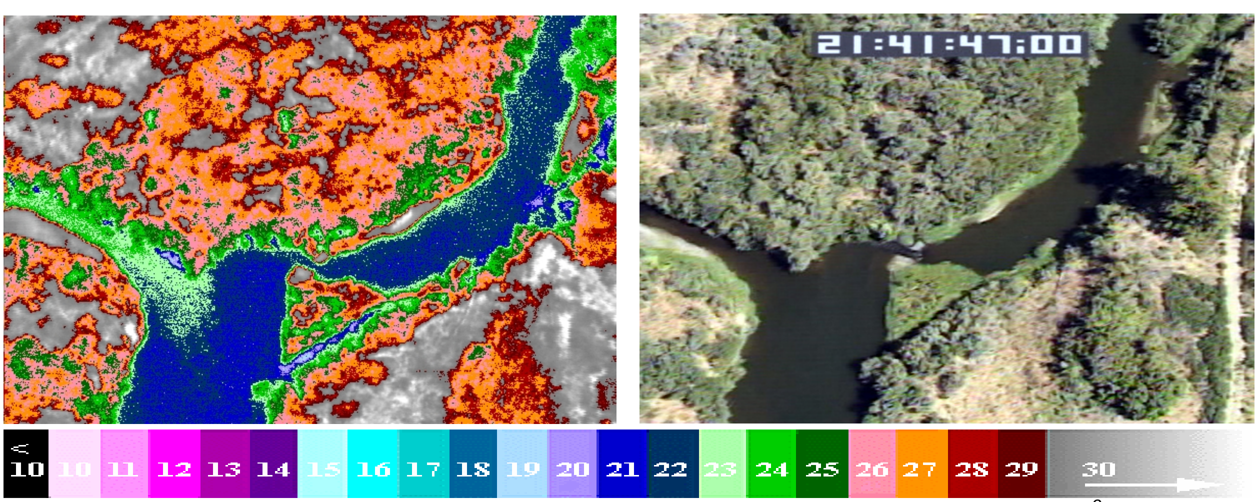


Figure 2-15c. *FLIR/Day TV image pair (frame: wall1000) showing the Touchet River (23.4°C) entering the Walla Walla River (21.9°C) on the right bank at river mile 19.4 (~km 30).*

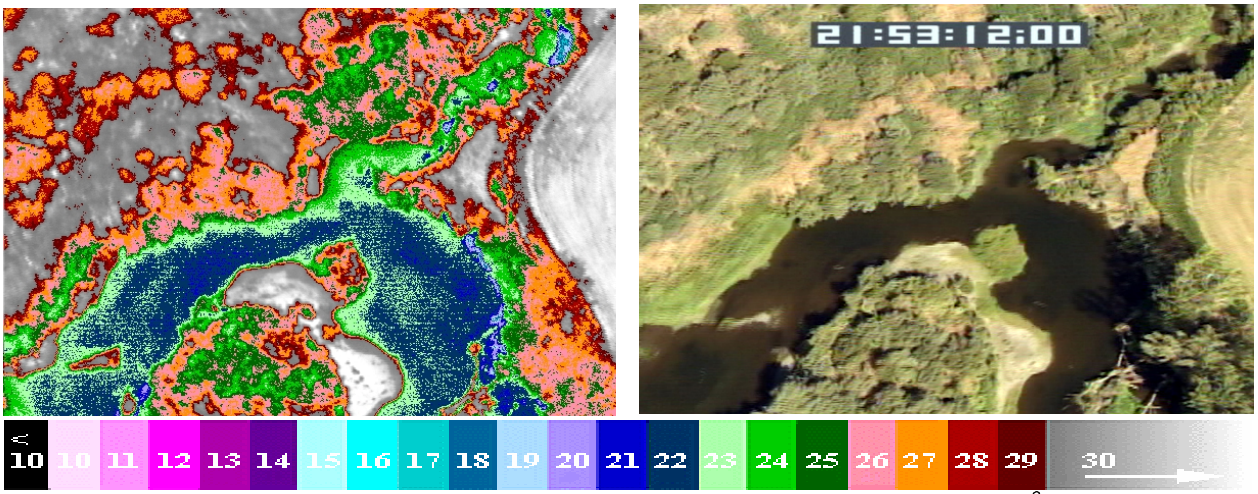


Figure 2-15d. *FLIR/Day TV image pair (frame: wall1239) showing Pine Creek (23.1°C) entering the Walla Walla River (22.8°C) on the left bank at river mile 21.8 (~ km 34).*

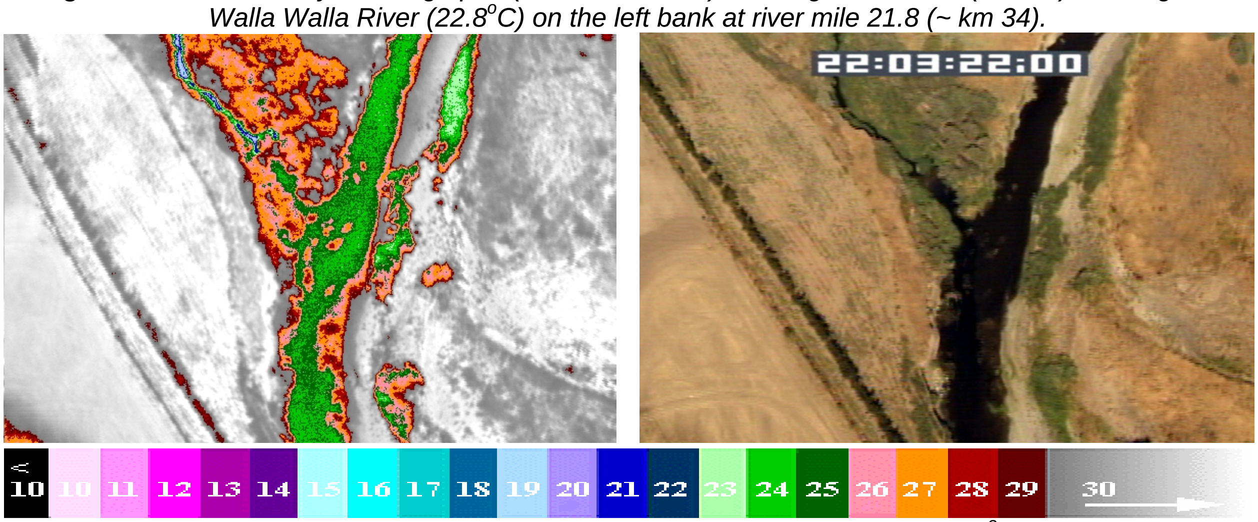


Figure 2-15e. *FLIR/Day TV image pair (frame: wall1527) showing Dry Creek (18.9°C) entering the Walla Walla River (24.6°C) on the right bank at river mile 27.0 (~km 54).*

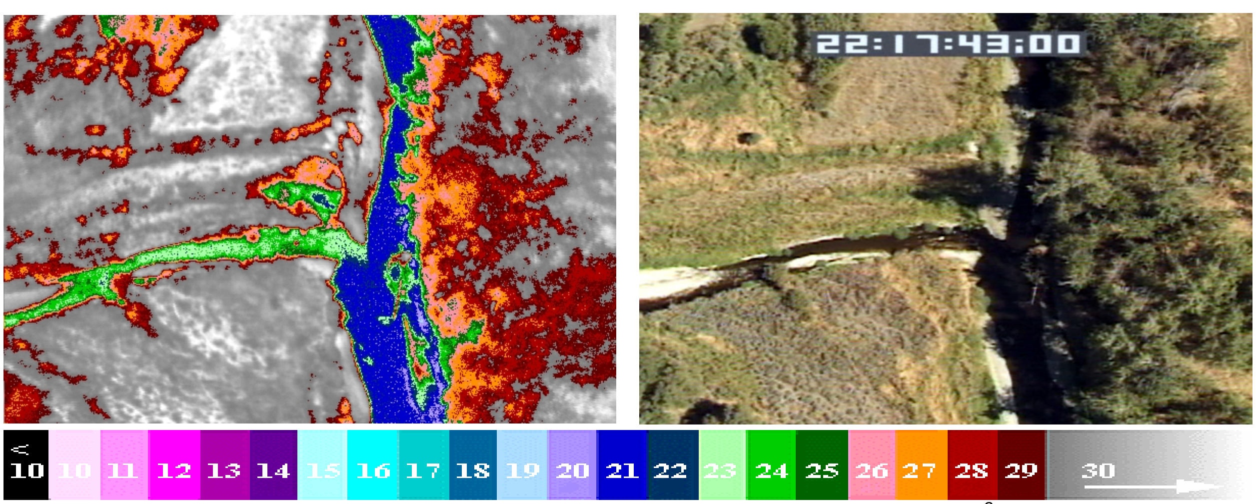


Figure 2-15f. *FLIR/Day TV image pair (frame: wall1887) showing Mill Creek (23.3°C) entering the Walla Walla River (21.6 °C) on the right bank at river mile 33.4 (~km 53).*

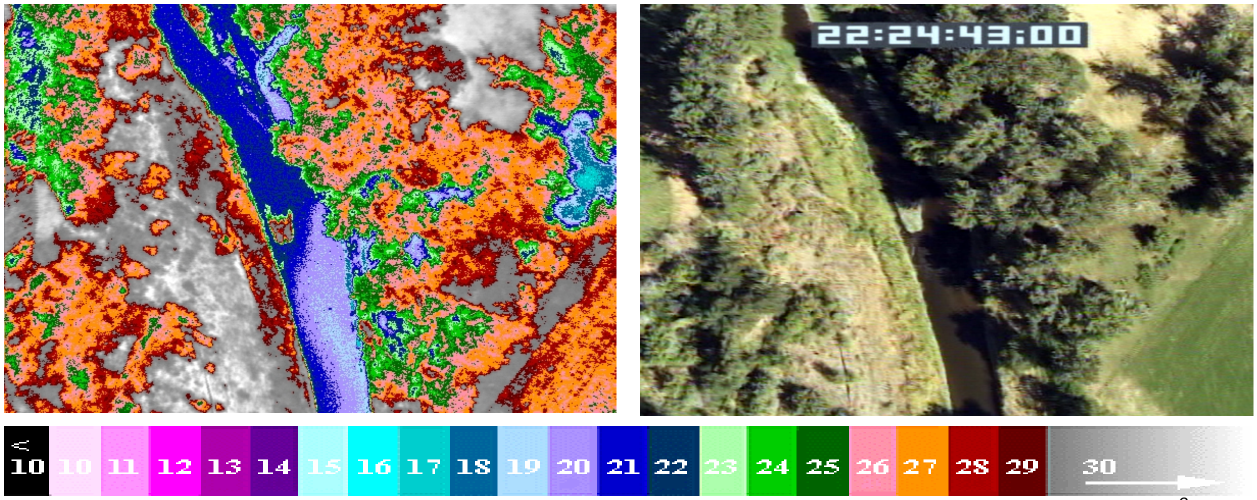


Figure 2-15g. *FLIR/Day TV image pair (frame: wall2097)- the East Little Walla Walla River (19.0°C) entering the Walla Walla River (21.4 °C) on the left bank at river mile 37.5 (~km 60).*

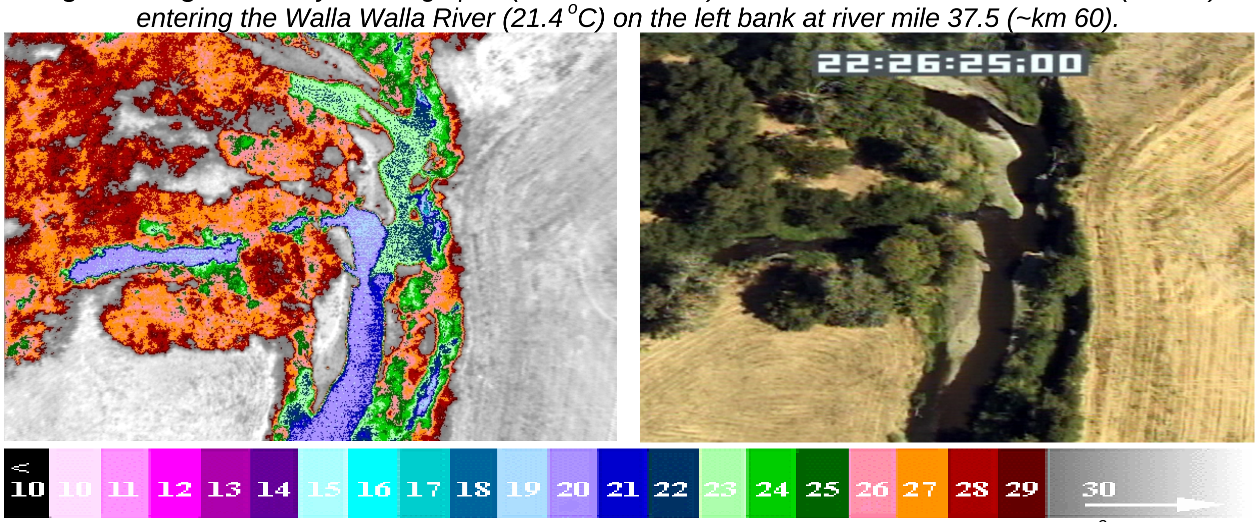


Figure 2-15h. *FLIR/Day TV image pair (frame: wall2148) showing Yellowhawk Creek (20.0°C) entering the Walla Walla River (23.2°C) on the right bank at river mile 38.4 (~km 61).*

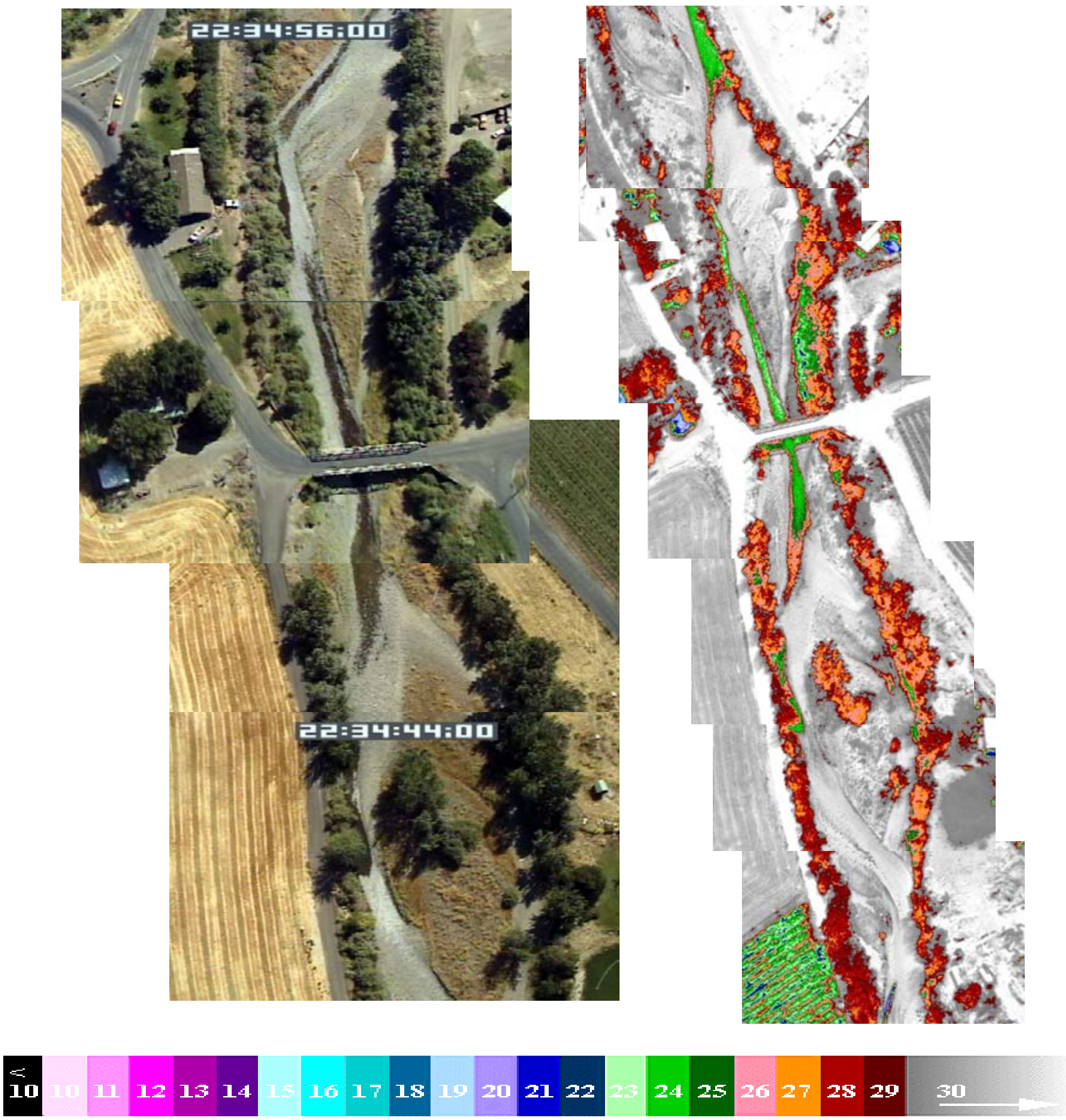


Figure 2-15i. *FLIR/Day TV image mosaic showing the Walla Walla mainstem in the Tumalum Bridge area, where flow was intermittent in 2000.*

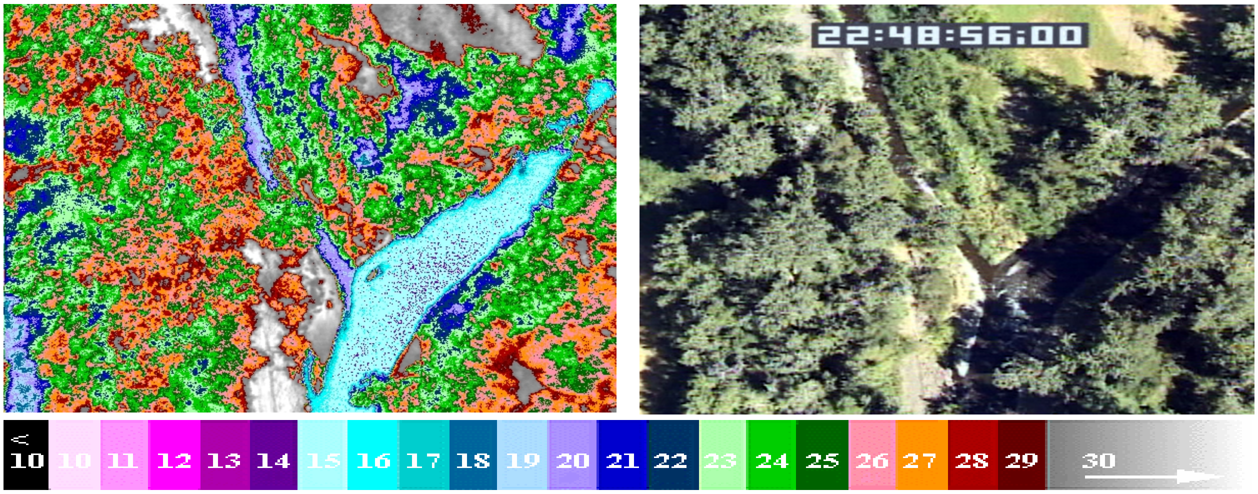


Figure 2-15j. *FLIR/Day TV image pair (frame: wall2787) showing the North Fork Walla Walla River (20.1°C) entering the Walla Walla River (15.4°C) on the RB at river mile 50.6 (~km 80).*

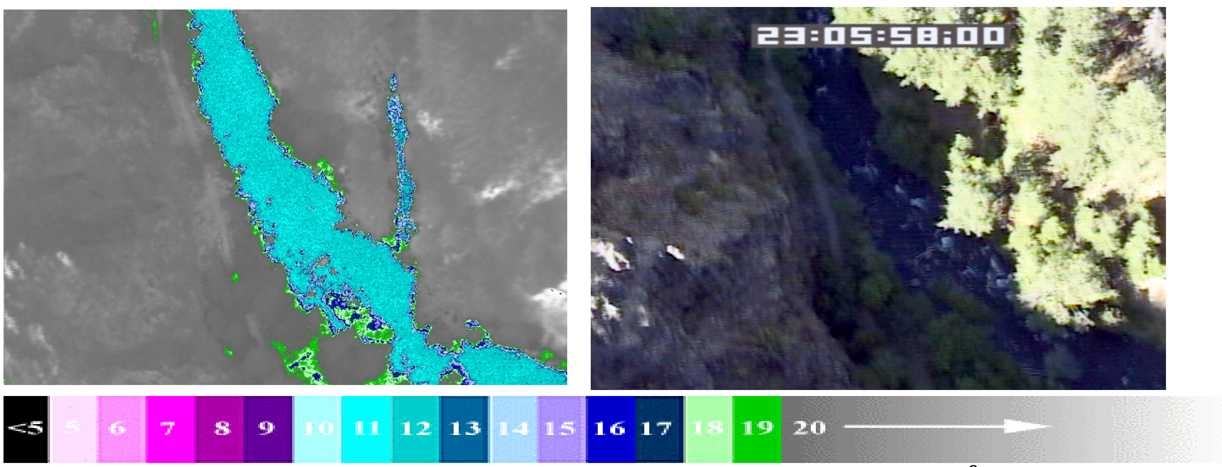


Figure 2-15k. *FLIR/Day TV image pair (frame: wall3298) - a side channel (12.9°C) entering the South Fork of the Walla Walla River (12.3°C) along the left bank at river mile 60.3 (~km 95).*

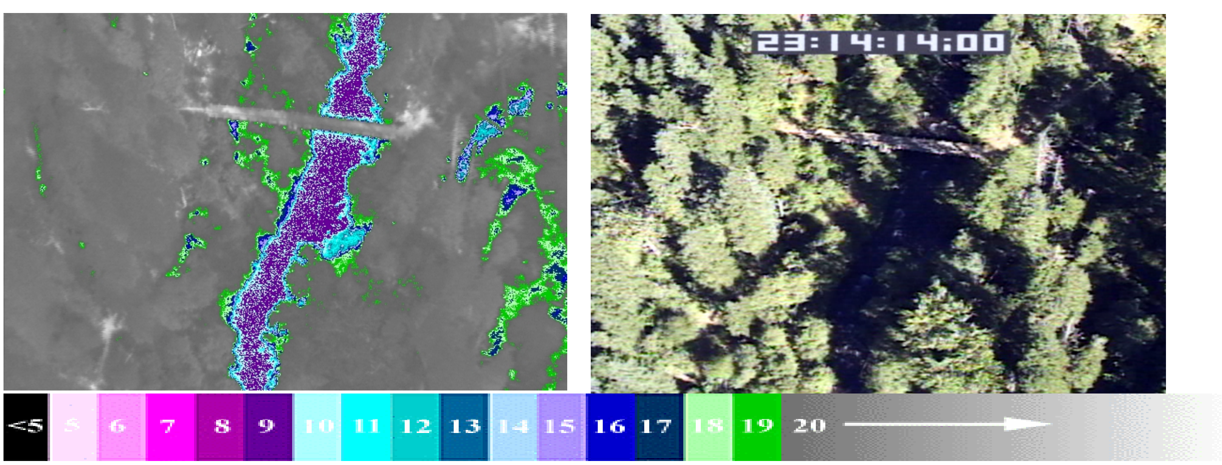


Figure 2-15l. *FLIR/Day TV image pair (frame: wall3546) showing Burnt Creek (12.1°C) entering the South Fork of the Walla Walla River (10.0°C) on the left bank at river mile 64.7(~km 103).*

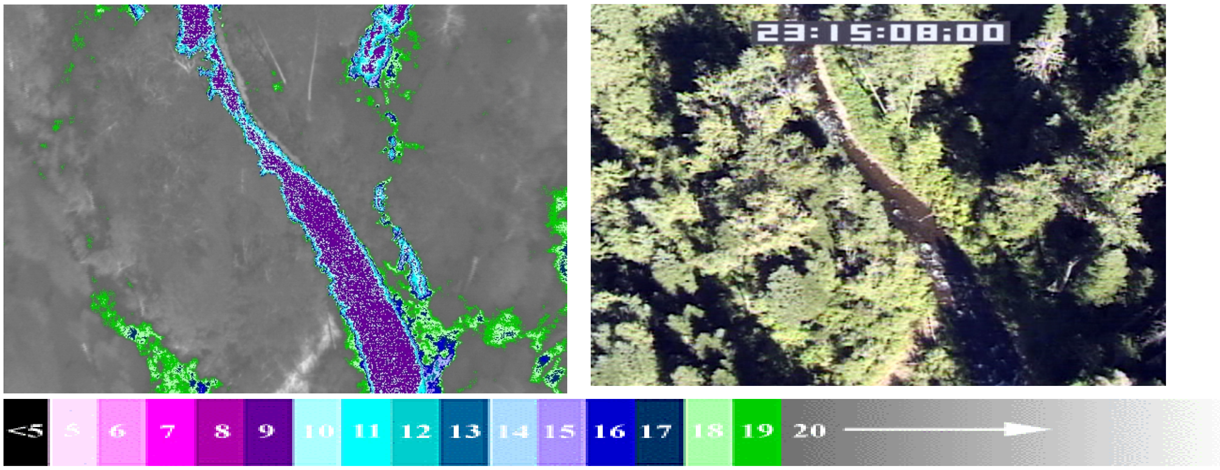


Figure 2-15m. *FLIR/Day TV image pair (frame: wall3573) showing and unnamed tributary entering the South Fork of the Walla Walla River (12.6°C) on the left bank at river mile 65.2 (~km 104). Due to the small channel width and intervening vegetation, an accurate sample of the tributary's temperature at its mouth could not be sampled*.

2.3 Point Sources Description and Data

The Oregon Department of Environmental Quality maintains a database for point source information. This data and discussions with DEQ and Washington Department of Ecology personnel were used to identify potential point sources within the Walla Walla Subbasin in Oregon and along the mainstem in Washington. **Figure 2-16** identifies the name and location of point source direct discharges in Oregon, with storm water and agricultural drains excluded. There are three existing direct discharges from waste water treatment plants in Washington. These include the City of College Place, discharging to Garrison Creek, and the cities of Dayton and Waitsburg discharge to the Touchet River (personal communication with Dept. Ecology, Dave Knight, July 31, 2000). Washington point sources are not assessed in this report and are expected to be addressed as needed during TMDL development by the Washington Department of Ecology.

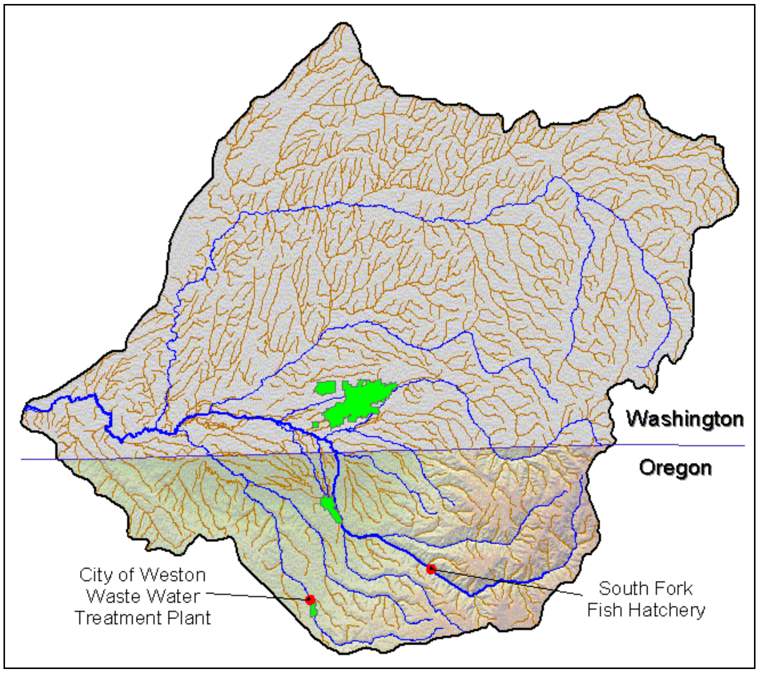


Figure 2-16. *Direct Discharge Point Sources in Oregon (storm water and agricultural drains excluded).*

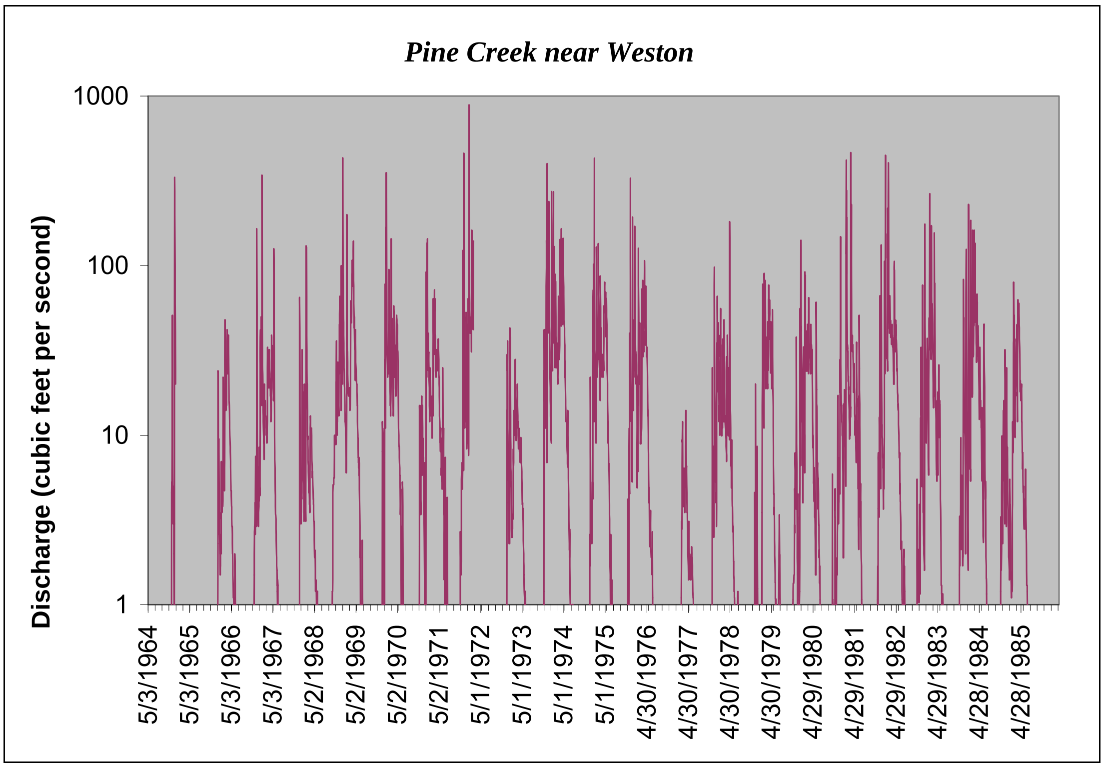
City of Weston Waste Water Treatment Plant (WWTP). The Weston WWTP discharges into an intermittent stream, Pine Creek, near the City's western boundary. The outfall average dry weather design flow is 0.1 million gallons per day. The permit limits effluent discharge to no more than $1/30^{th}$ of the stream's flow. The facility is permitted to discharge during July 1 to October 31. In practice, however, the facility rarely discharges after June 1.

Typical facility flow and a historic Pine Creek gage record are displayed in **Table 2-10** and **Figure 2-17.** Based on the permit limitation of $1/30^{th}$ minimum dilution and the dry weather design flow, the facility should not discharge to Pine Creek when creek flow is less than 4.6 cubic feet per second. A review of the most recent years of available data (1979-1985) reveals that Pine Creek flow has been consistently less than 4.6 cubic feet per second during the interval beginning May 8 to June 1 and ending November 21 to December 20. During some years flow was less than this threshold in January as well. This indicates that, with regard to the existing permit relative flow limit, the only months that are routinely appropriate for direct discharge are February, March and April.

Table 2-10. *Reported City of Weston waste water treatment plant flow in units of million gallons per day*

Month	1995	1996	1997	1998	1999	2000
Jan	0.129	0.115	0.128	0.087	0.129	0.116
Feb	0.135	0.136	0.136	0.098	0.138	0.128
Mar	0.132	0.133	0.135	0.091	0.137	0.138
Apr	0.128	0.126	0.135	0.099	0.136	0.13
May	0.129	0.125	0.116	0.1	0.138	0.109
Dec	0.106	0.124	0.07	0.108	0.112	
total	0.759	0.759	0.72	0.583	0.79	0.621
avg	0.127	0.127	0.120	0.097	0.132	0.124

Figure 2-17. *Log graph of historic gage data for Pine Creek near the city of Weston.*



The facility is currently operating under NPDES permit issued in 2004 and a Mutual Agreement and Order (MAO) administered by DEQ. In accordance with this MAO, the City submitted an Engineering Evaluation (March of 2004) which identifies “alternative improvements capable of meeting all applicable water quality standards and waste discharge limitations…”. The alternative proposed in this evaluation eliminates discharge to Pine Creek and was approved by DEQ.

The approved alternative includes partial use of the existing plant with irrigation re-use (land application) rather than discharge to Pine Creek. The engineering evaluation recommends the expansion of the facility to include a new mechanical fine screen following the existing headworks grit channels and flume, conversion of the existing clarifier into a primary clarifier, refurbishing of the existing biosolids facilities, and development of a reclaimed water irrigation site. Additional features will include a lift station, polishing and storage pond system, and disinfection for the irrigation system.

For the purpose of this TMDL, the facility receives no wasteload allocation. This is based on the permit prohibition of discharge during Pine Creek flow levels encountered during May through January, encompassing the TMDL season. In addition, not issuing a waste load allocation is consistent with the facility’s pending elimination of discharge to Pine Creek.

South Fork Fish Hatchery. The South Fork Fish Hatchery is an adult spring chinook salmon holding structure. It is a flow-through facility, receiving water from the South Fork of the Walla Walla River and returning it over a relatively short distance. This facility was originally permitted by Bonneville Power Administration and is operated by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR). The facility operated under a State general NPDES permit for fish hatcheries during the late 1990’s. The permit was withdrawn because the facility processes less fish than the minimum amount for which a permit is required. The permit is applicable when production is greater than 20,000 pounds of fish per year.

DEQ evaluated thermal data for the facility. CTUIR provided temperature data from temperature data loggers placed to evaluate upstream and final effluent temperature. The data logger output, shown graphically in **Figure 2-18** indicates no measurable difference (usually less than 0.1ºC) in daily maximum temperature between the upstream and downstream sensors. In addition, the surface temperature patterns were documented via the August 15, 2000 FLIR flight (accuracy is normally within 0.5 ºC). No detectable temperature increase from the facility is apparent in the FLIR image shown in **Figure 2-19**.

Because CTUIR is not requesting a wasteload allocation, the function of the facility is such that heating must be minimized, and the facility data shows no measurable increase to the daily maximum temperatures of the river, no wasteload allocation is developed for the facility and DEQ does not expect that the facility should constrain its operation, given the current levels of discharge and processing.

Figure 2-18. *Continuous temperature record for the South Fork Fish Hatchery outlet and South Fork of the Walla Walla River above and below the Hatchery.*

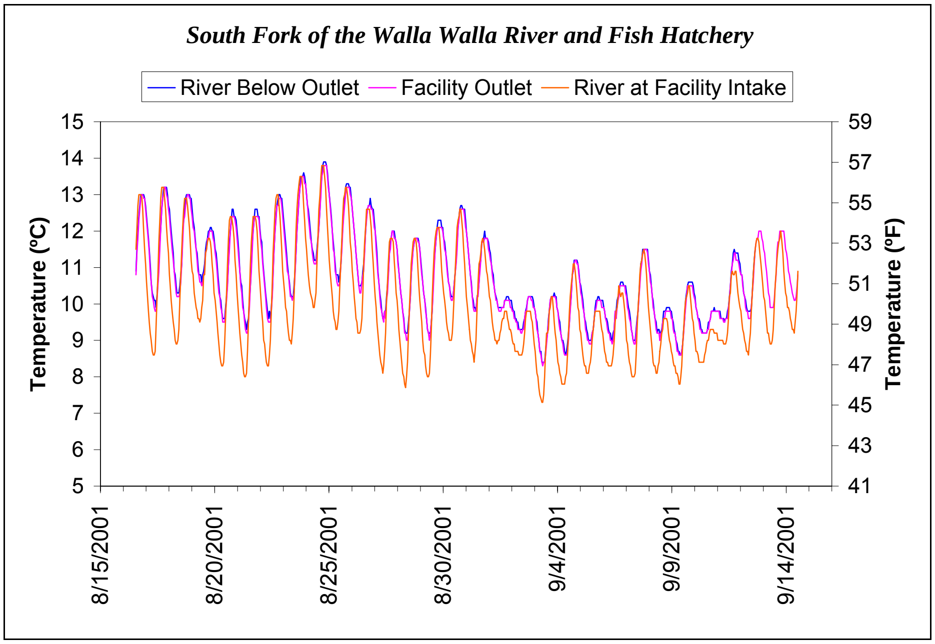
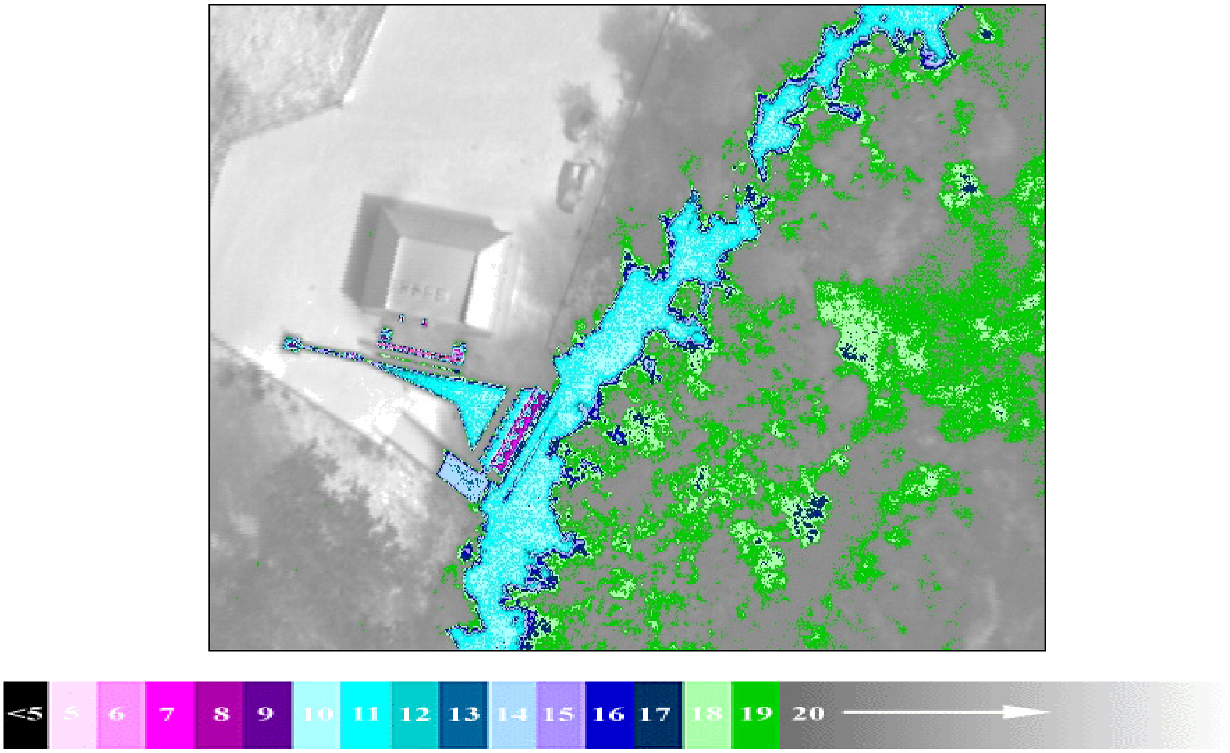


Figure 2-19. *2:00 PM August 15, 2000, thermal infrared image of the South Fork Fish Hatchery and South Fork of the Walla Walla River.*



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
- FLIR Temperature Data Associations
- 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, FLIR data association. 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. Stream position is assessed through digitization on orthoimagery and segmented into equidistant longitudinally distributed data nodes (25 meters apart). Stream elevation is sampled from 10-m digital elevation model files and gradient is calculated from the DEM elevation and stream position. Aspect is sampled along the digitized stream position line. Topographic shade angles are assessed 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.

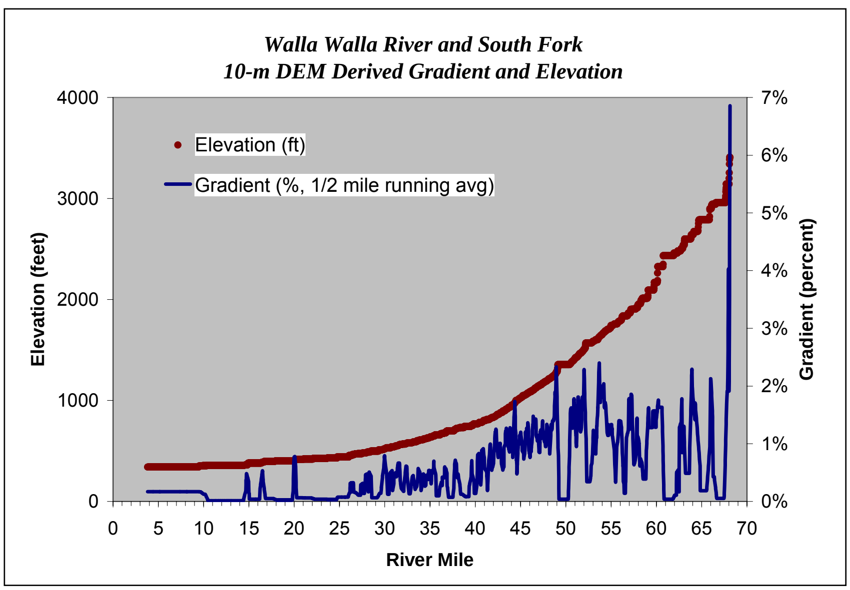


Figure 3-a

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 magnitude 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**. An overview of observations specific to the Walla Walla Subbasin is also provided in that section as well.

The predominant thermodynamic 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. A wider stream has greater area exposed to surface thermal processes in general. Other thermal effects that relate to channel morphology include altered stream hydraulics caused by increased wetted perimeter and decreased stream depth. Disturbance of surface and groundwater interactions may also result from channel morphology modifications and typically has the combined effects of lowering near stream groundwater tables, reducing the groundwater inflow, removing cool sources of groundwater that serve to reduce in-stream temperatures and modifying hyporheic flows. 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.

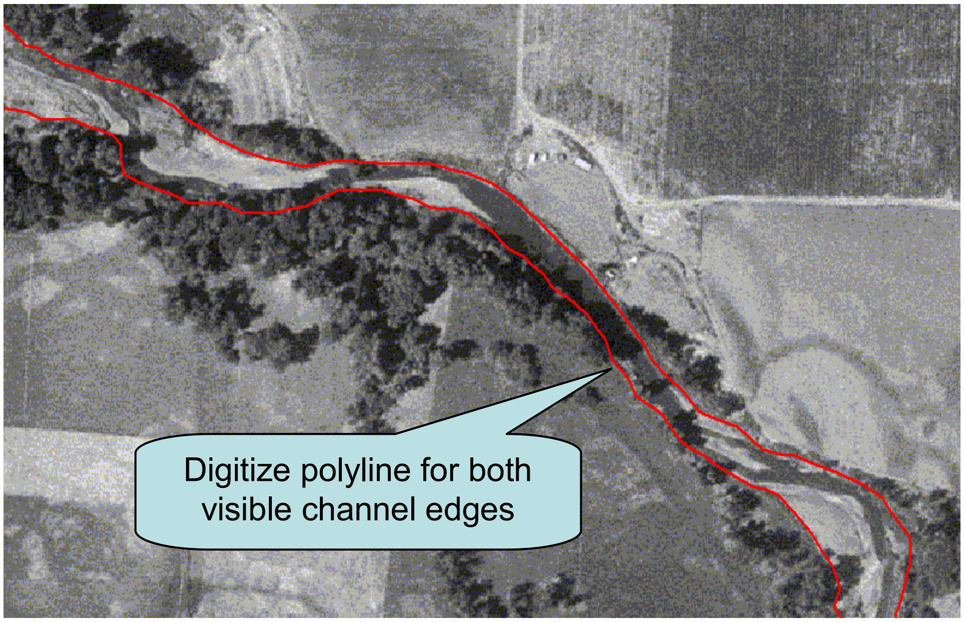
Passive restoration is a viable mechanism of addressing stream temperature in the Walla Walla Subbasin. Passive restoration efforts could include: removing sources of channel disturbance that are known to degrade and slow or prevent restoration. Near stream land cover is a primary component in shaping channel form and function and should be a significant emphasis in all restoration planning and activities. Active restoration should be considered where severe channel disturbances cannot be remedied via passive restoration techniques. Example situations where active restoration could be considered could include severe vertical down cutting, diked channels and removal of in-stream structures that prevent progress towards the desired stream channel condition. Other in-stream structures can serve as beneficial components in channel restoration such as rock barbs, sediment catchments, etc.

3.2.2 Channel Assessment – Existing Condition

3.2.2.1 Existing Channel Width
The steps for conducting channel width assessment are listed below.

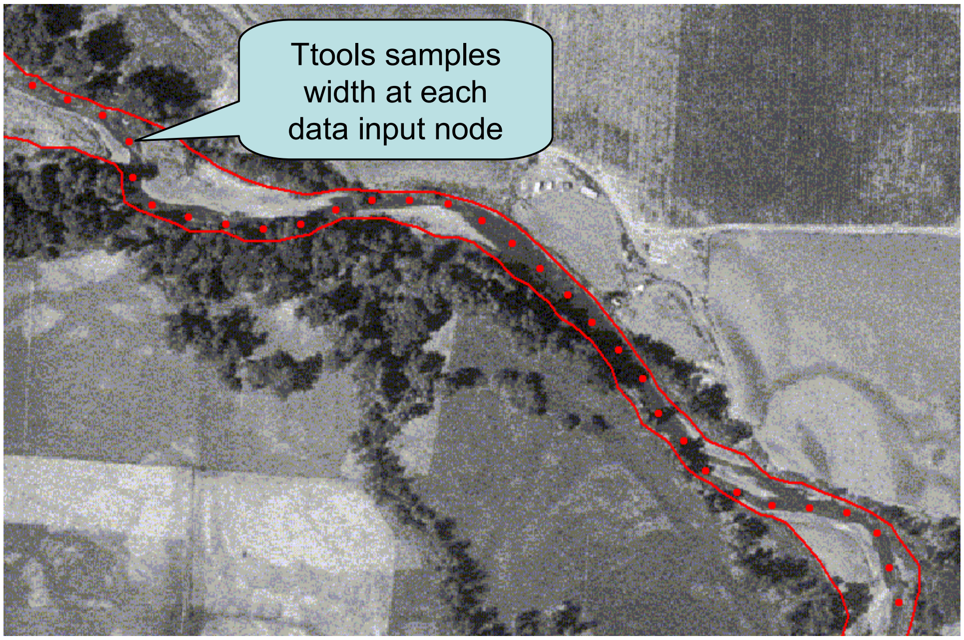
Step 1. **Stream channel edges are digitized from DOQs at 1:5,000 or higher resolution**. Where apparent in aerial photography, indicators of bankfull stage were used to delineate the channel. For example, bank shadows or a row of alders crossing the upper part of a point bar may form a likely bankfull edge. Reference to ground level determinations (**Chapter Two**) at intervals is helpful. Frequent reference to FLIR/Day TV images (not georeferenced) aided delineation. 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.’

Figure 3-1.



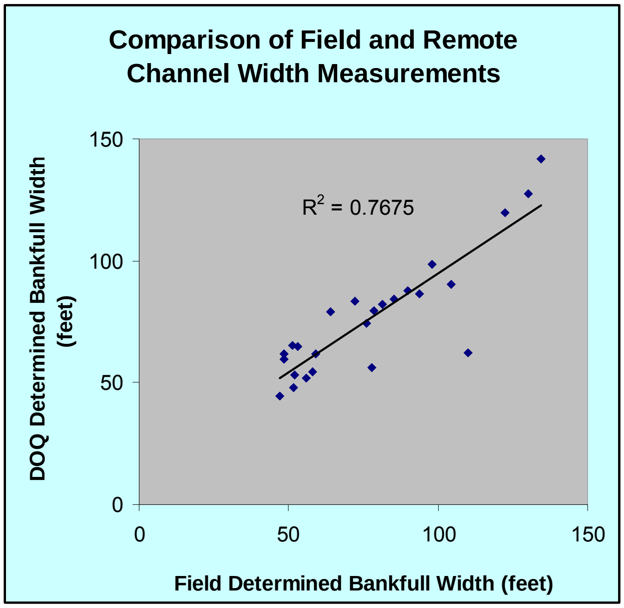
Step 2. **Sample channel width at each stream data node using TTools**. The sampling algorithm measures the channel width at each data input node in the transverse direction relative to the stream aspect.

Figure 3-2.



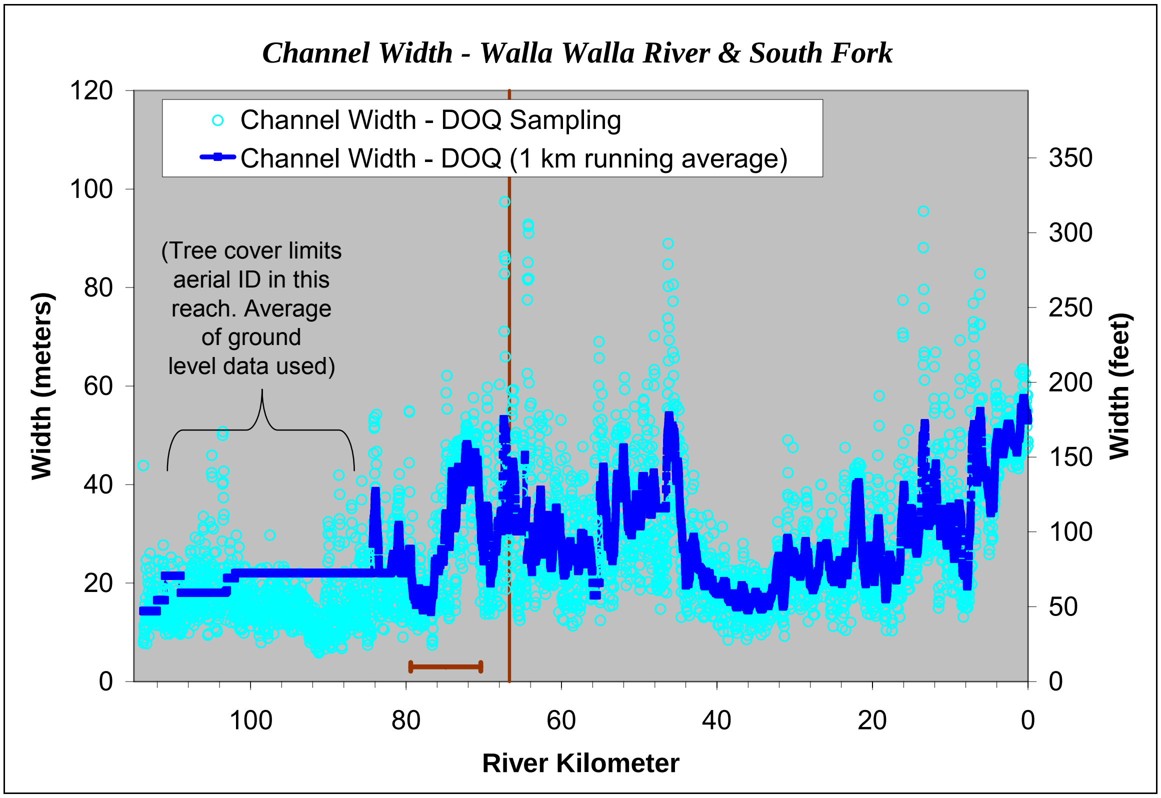
Step 3. **Compare sampled channel width and ground level measurements**. Establish statistical limitations for near stream disturbance zone width values when sampled from aerial photograph (DOQ) analysis. **Figure 3-3** plots a comparison of remote and field-determined bankfull widths.

Figure 3-3.



The resultant channel width data are displayed in **Figure 3-4**. Note that in the area above river mile 57 (kilometer 85) the aerial photography interpretation is hampered by tree cover. In this reach, model input is based on averaging ground level data rather than remote sensing.

Figure 3-4. *Graph of DOQ sampled channel width. Refer to* ***Figure 2-5*** *for river miles and additional location reference.*



3.2.2.2 Existing Sinuosity

Mainstem and South Fork sinuosity measurements are tabulated in **Table 2-2**, **Section 2.1.3** of this Appendix. Sinuosity (**Table 2-2**) was measured by tracing (digitizing) the stream and valley centerline on 1-m pixel digital orthophotoquads in ArcView 3.2, through 2-3 km continuous segments of valley length (specific segment length was chosen based on preference for uniformity), and dividing stream by valley line lengths.

As an example DOQ image, **Figure 3-5** illustrates the existing sinuosity near the town of Lowden in Washington. In this figure, the 1939 pattern is overlain to illustrate change.

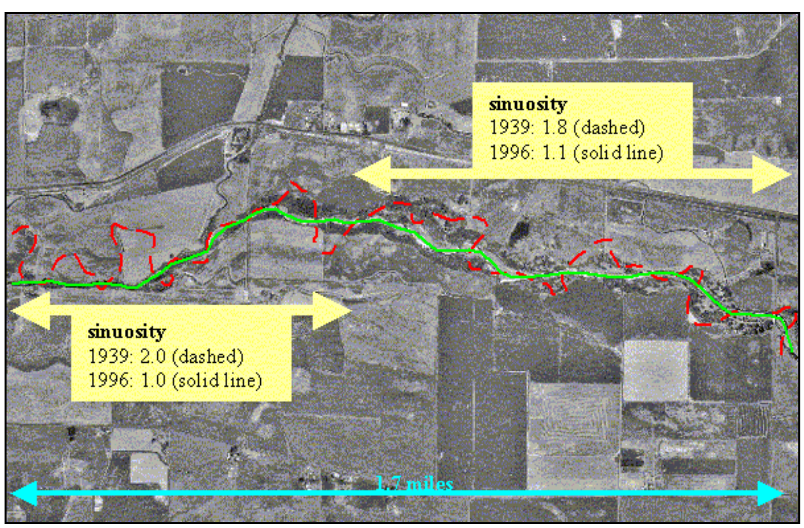


Figure 3-5. *Photograph of the Walla Walla River near Lowden, WA. The red line is a tracing from a 1939 aerial photograph. The green line is the modern pattern based on this 1996 DOQ. The location is approximately at river mile 27 (~km 44), where Dry Creek joins the Walla Walla River.*

3.2.3 Channel Assessment – Potential Condition

3.2.3.1 Potential Channel Width and Type

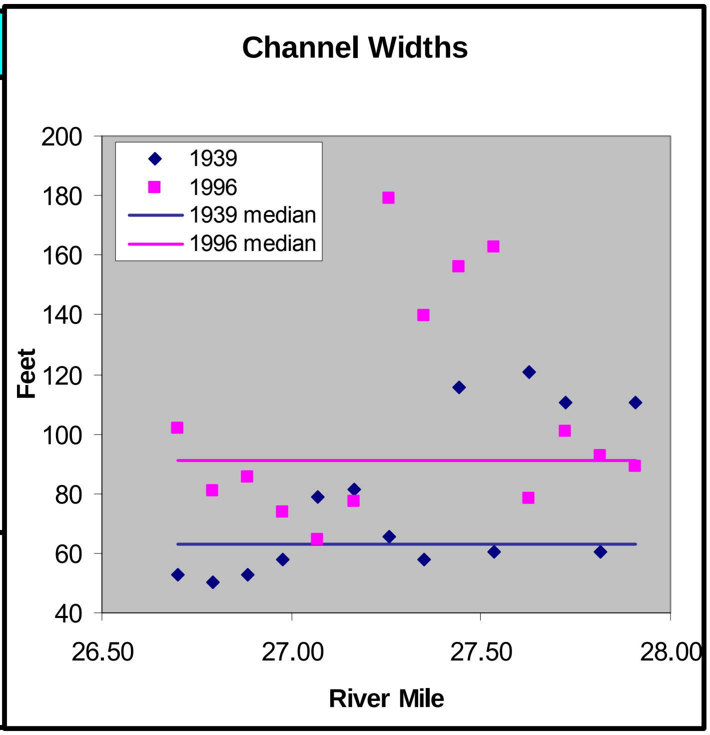
The term *potential* describes a condition where human caused stresses are minimized as discussed in **Section 1.4**. The Walla Walla River and the lower-middle South Fork are expected to narrow as restoration or decreased disturbance enables increased bank strength and sinuosity. This conclusion is 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) and confirmed by local observations comparing current and historical widths. For example, in the reach depicted in **Figure 3-5**, historic and existing widths are compared (**Figure 3-6**), revealing that the straightened river has widened to 144% of the 1939 reach-median width and channel width variance has increased through time.

The potential channel width is quantitatively assessed and input as a simulation scenario for estimating temperatures that would result from a more stable channel configuration (**Chapter Four**).

This and following sections include references to the Rosgen Stream Classification. To review the classification, refer to the summary in **Figure 2-9** in **Section 2.1.3.**

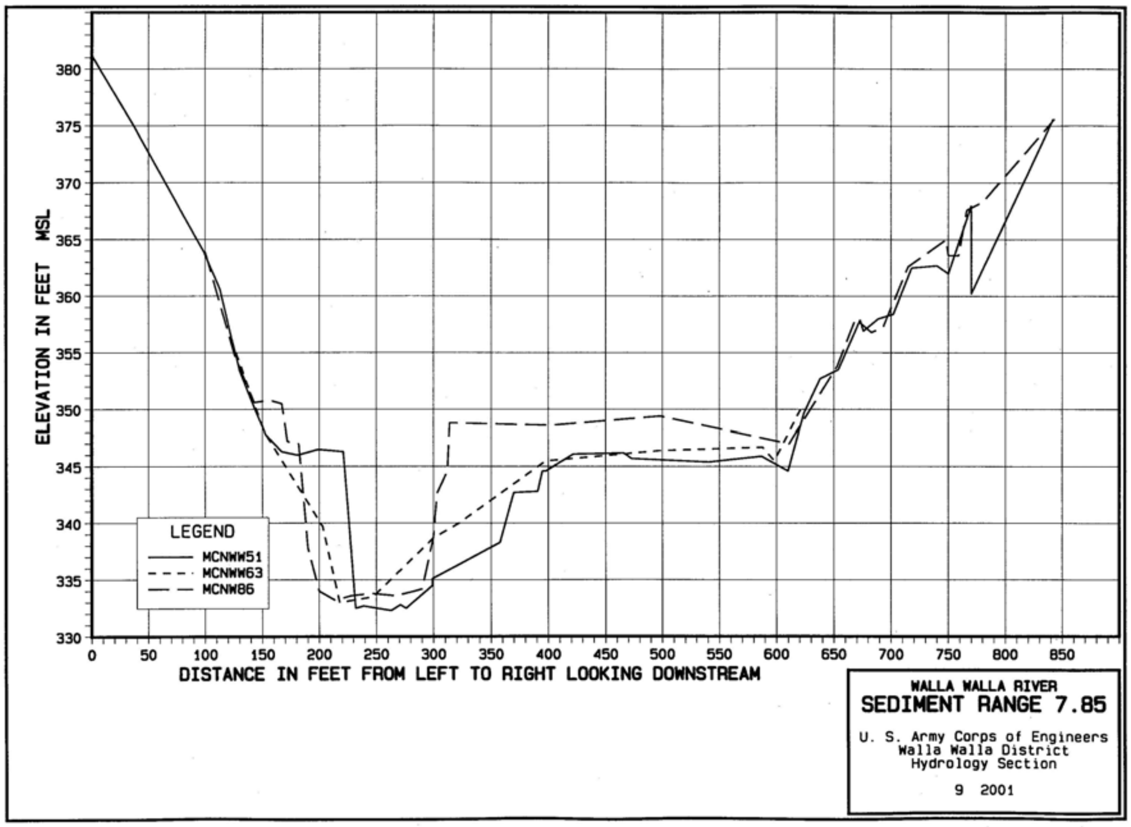
Figure 3-6. *Widths are measured on a 1939 aerial photograph (USDA 1939-1946) taken near Lowden, WA and compared to the existing condition.*

River Mile	Channel Width (feet) 1939	1996
26.70	52.6	101.7
26.79	50.0	81.0
26.89	52.6	85.3
26.98	57.9	73.6
27.07	78.9	64.5
27.16	81.5	77.2
27.26	65.8	178.8
27.35	57.9	139.5
27.44	115.7	156.1
27.54	60.5	162.7
27.63	121.0	78.1
27.72	110.5	100.7
27.81	60.5	92.5
27.91	110.5	89.1
Minimum	50.0	64.5
Mean	76.8	105.8
Median	63.1	90.8
Maximum	121.0	178.8
Standard Deviation	26.3	37.3



An example of narrowing associated with decreased gradient is documented for the lower Walla Walla River. USACE has surveyed cross-sections at repeated locations in the lowermost reach, where gradient has been diminished by increased base level resulting from the construction of McNary Dam. **Figure 3-7** shows this narrowing and dramatic reduction in width/depth of the channel.

Figure 3-7. *Time sequence of surveyed cross-sections - lower Walla Walla mainstem near the mouth, USACE. The year of measurement is denoted in the legend as 'MCNWW51' for 1951, etc.*



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

1. Assess existing morphology (**Section 2.1.3 and 3.2.2)**
2. Assess drainage area (**Figure 3-8, Table 2-2**).
3. Derive existing channel cross-sectional area as a function of drainage area (**Figures 3-9** and **3-10**).
4. Determine target width/depth ratios (**Table 3-1**).
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 3-11**.
6. Set the maximum potential bankfull width target at the lesser of (a) existing widths, and (b) calculated potential. This target is illustrated in **Figures 3-12**.

Figure 3-8. *Drainage area contributing to each morphology survey sites is estimated on the Walla Walla and South Fork Rivers, and for the larger tributaries. Measurements were made in ArcView™ based on a 1:100,000 stream layer. This figure is a site map with contributing drainage areas and a corresponding longitudinal graph of these areas by river mile.*

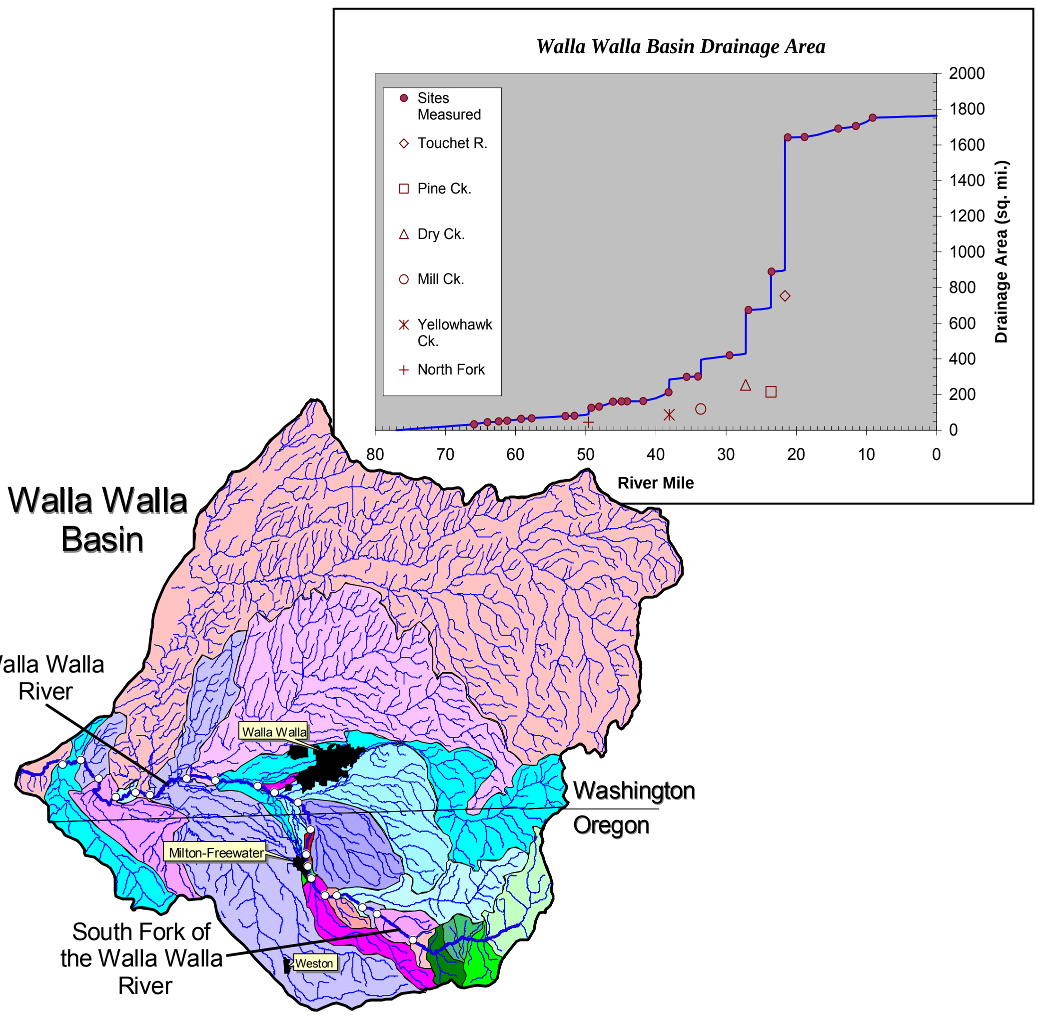


Figure 3-9. *Regression relating channel cross-sectional area to drainage area, stratified by Rosgen stream type.*

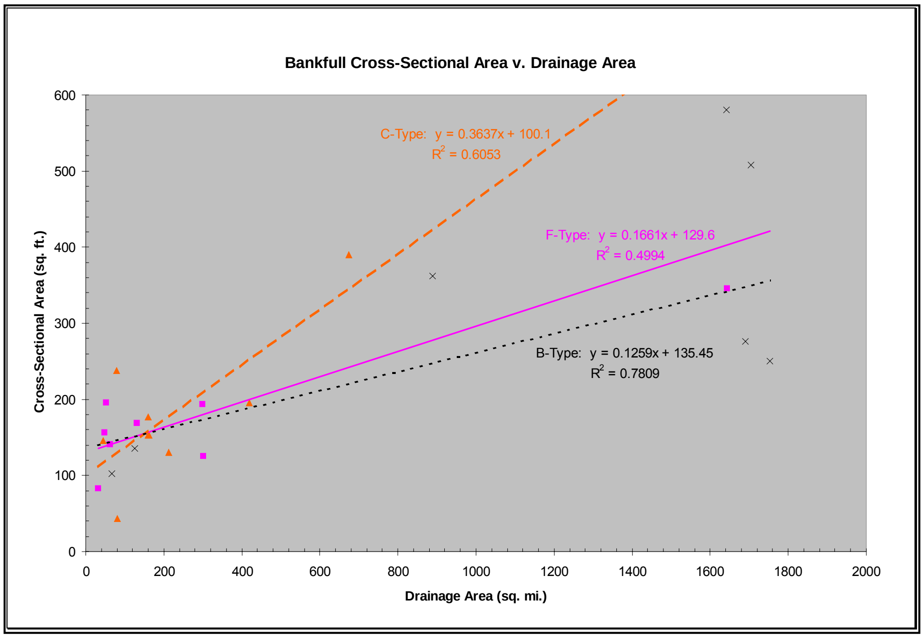
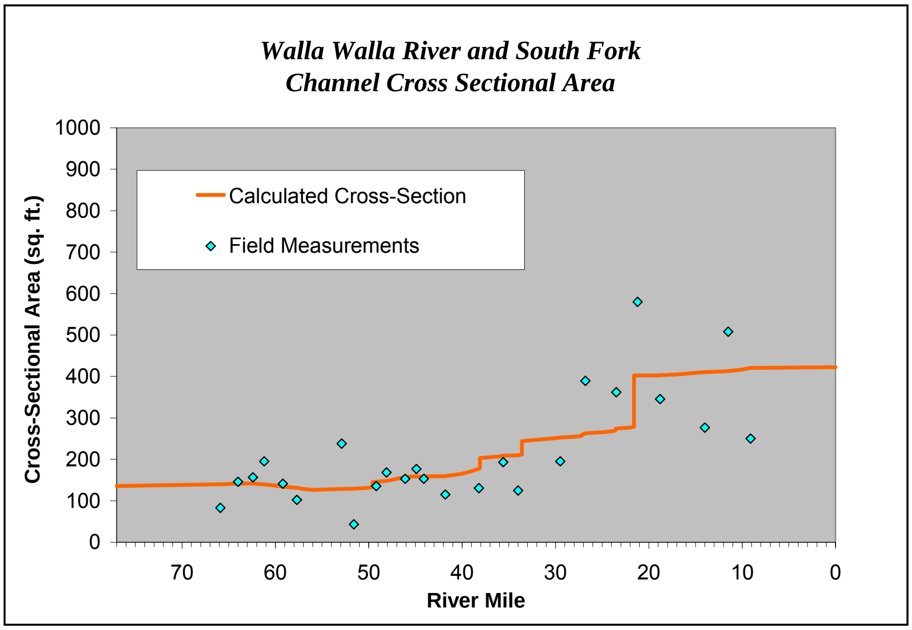


Figure 3-10. *Cross-Sectional area is estimated by applying the regression equations above to the longitudinal distribution of drainage area.*



The dependency of cross-sectional area on drainage area is established in the literature (Dunne and Leopold, 1978; Williams, 1986; Rosgen, 1996). Using **Equation 3-1**, bankfull width can be derived from cross-sectional area and desired width/depth ratio (Rosgen, 1996). Drainage area was determined as a step in the estimation of system potential bankfull width (Step 2, **Figure 3-8**). Cross-Sectional area is estimated based on drainage area in the two preceding figures (Step 3). Estimating potential width-to-depth ratios is a critical next step in estimating channel width potential (Step 4). It is generally expected that width/depth is relatively constant for a given stream type within a physiographic province (Rosgen

1996). The Walla Walla River and South Fork likely occupy 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 existing distribution for reaches that are less disturbed and compare these data with literature values for typical streams of a given stream type. Relatively stable areas include: above Harris Park on the South Fork and the upper end of the sinuous reach below the city of Lowden (width/depth=23). Another site below Pepper's Bridge (downstream from the state line, width/depth=35) was suggested by WDFW fish biologists, though highway and bridge associated river manipulation and constraint is evident in this area. The outcome of this evaluation was to employ the norms in **Table 3-1** as width/depth target estimates that fall within the lower range of existing values for the Walla Walla River and South Fork. It is important to recognize that this set of targets likely over estimates the width/depth potential. This is because undisturbed areas are rare and the sample set summarized in **Table 3-1** 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.

Table 3-1. *Width-Depth ratio targets. Values are median width/depth from streams in several states in the US (Rosgen, 1996).*

Measured width/depth ratios (mid-range of the greatest mode)				
Stream Type	A	B	C	F
width/depth	7	17	24	29

Next (Step 5), potential channel width is calculated using **Equation 3-1** (**Figure 3-11**). As the potential width/depth is based on channel type, this requires a prediction of potential channel type. Given the open valley, valley gradient and historic patterns, a C-type channel potential is predicted for the length of the Walla Walla River and South Fork, except where the current channel is B-Type (upper South Fork). 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 a common potential channel type. This can be true for type F channels as well, but often an F-type classification is indicative of disturbance.

Note that the area between river km 114 and 102 is estimated to be at potential. This determination was made with the recognition that the area has long been protected from forest harvest, road building and other activities that could compromise vegetation or destabilize the channel (refer to **Figure 3-18** USFS memo). Verification of this through quantitative assessment was limited due to lack of data - channel delineation via remote sensing was hindered by the abundance of overhanging tree cover in this reach. However, field observations made by DEQ, USFS and WWBWC staff validate that the area is little disturbed.

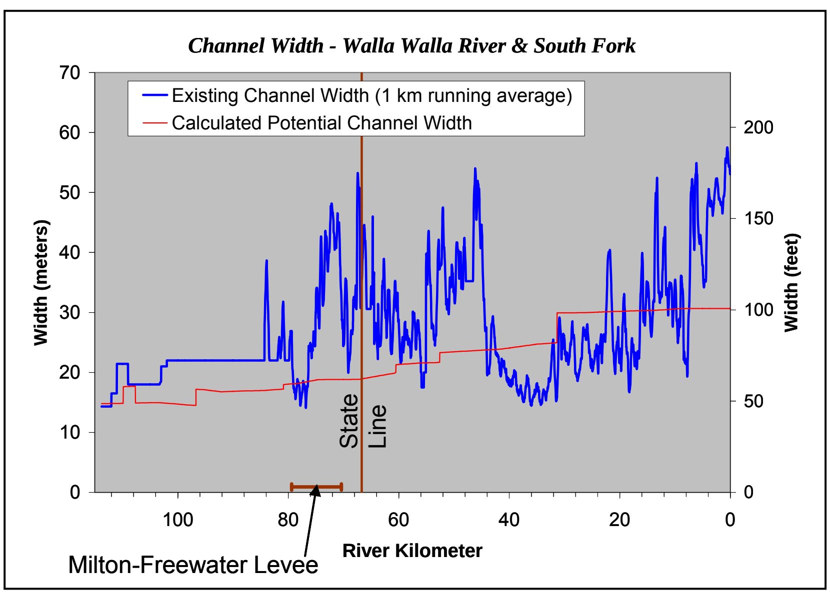
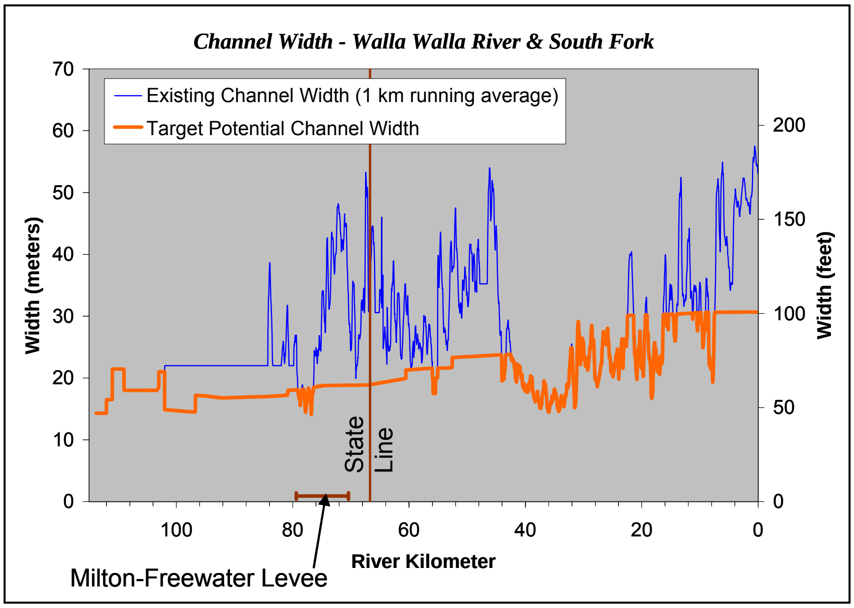


Figure 3-11.
Existing and Calculated Channel Potential Width

In some reaches, the calculated potential channel width exceeds the current condition (**Figure 3-11**). This is taken as an indication that these areas are nearly at potential. Channels are not expected to widen, 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 3-12**.

Figure 3-12.



More on Channel Potential. For the purposes of determining morphologic potential, basin history is considered. Historic aerial photographs and professional judgment indicate that much of the Walla Walla and South Fork Rivers was at one time C-type, interspersed with B reaches above Harris Park (South Fork river mile 9, ~km 98) and that the system has evolved locally to F, B and D types under the influence of human activities.   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 system potential channel goals, C and B channel types are expected on the much of the mainstem and South Fork. Outside of the modeled river reaches, 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.

3.2.3.2 Potential Sinuosity (not addressed in temperature simulation)

Sinuosity is defined as channel length divided by valley length. There is consensus within the scientific community that sinuosity is part of river quasi-equilibrium and that once established it is abnormal for it to diminish. For example, Leopold (1997) states: "It must be understood that river channels are curved, sinuous, or meandering because that is the natural and most probable form. It is the form that conserves energy and tends at the same time to make energy expenditure along the streamline most uniform. The physical forces act to promote a curvilinear form. A reach of stream that is straight tends to become curved, and in no known instance does a curved form become straight through any appreciable distance."

Sinuosity is key to maintaining a stable and narrow channel. The decreased gradient of a sinuous reach leads to less erosive force on the banks. Sinuosity also promotes stable stream position. Rivers move about in geologic time, but on the scale of a hundred years they are relatively stable and even with natural disturbance the basic hydraulic relations are expected to hold. For instance, a 50-year flood may locally "blow out" a channel, but post-flood measurements indicate that overall sinuosity and bankfull width are preserved. In fact, these stable hydraulic relations are in large part a product of work done by 1-2 year recurrence high flows (Dunne and Leopold, 1978; Rosgen, 1996; Leopold, 1997).

The Walla Walla River and South Fork (Harris Park and below) have been substantially straightened, as evidenced by the lack of expected sinuosity, historic aerial photographs, documented channelization (e.g. the Milton-Freewater Levee) and polygonal path of the river. Furthermore, human causes of straightening in the basin are apparent: dikes and levees, rip-rap, plowing and crops, roads, vegetation removal.

Probably much alteration occurred before the earliest available aerial photography (1939), particularly upstream of the Oregon-Washington Border where there is larger population density and evidence of straightening prior to the earliest air photography. Research of historical information in the neighboring Umatilla Basin reveals substantial river straightening early in and prior to the 20th century (Nagle 1998). It is recognized that historic potential is not always attainable, though it provides important information. It is also recognized that in some areas recovery may be occurring now, leading to increased sinuosity.

Potential Sinuosity. One method of estimating the potential river pattern is to review historic aerial photographs. Historic sinuosity is measured on 1939 -1950 aerial photographs. **Figure 3-5** is an example comparison of historic and recent sinuosity of two reaches of the Walla Walla River at 4 25-27, (~km 40-43) near Lowden, Washington. **Table 3-2** tabulates sinuosity measured from available historic photographs.

Another method of assessing potential sinuosity is provided by the following equation (Williams, 1986).

$$\text{sinuosity} = \left[\frac{D}{0.09 \times W^{0.59}}\right]^{(1/1.46)}$$

where D=mean bankfull depth and W=bankfull width

Inputting the system potential widths and width/depth ratios described previously, potential sinuosity is calculated (**Table 3-2**).

Evaluation of sinuosity in the headwaters (above Harris Park at river mile 59) is less important than in the mid and lower Basin. Unlike the lower reaches, the potential for sinuosity and for human-caused sinuosity reduction is low in the relatively confined upper South Fork valley, and the upper river is relatively undisturbed (**Figure 3-18**). This upper region is assumed to be at or near potential sinuosity.

Table 3-2. *Current, historic and calculated system potential sinuosity*

Site ID	River Mile	Site Description	Existing Sinuosity (Rosgen Inventory)	1939-1950 Sinuosity (approx. 2-mile reaches)	Calculated Potential Sinuosity (C-Type)
MNWW9.1	9.1	Private Property (near gas pipeline river crossing)	1.4	1.7	2.2
MNWW11.5	11.5	Nine Mile Ranch	1.6	1.7	2.1
MNWW14.0	14	Cummins Bridge (1.5 miles downstream of bridge)	1.6	1.5	2.1
MNWW18.8	18.8	Touchet Gage Station Site	1.5	1.3	2.1
MNWW21.2	21.2	Private Property (South of landing strip)	1.8	2.1	2.1
MNWW23.5	23.5	Private Property	2.4	2.1	2.0
MNWW26.8	26.8	Private Property	1.3	2.1	2.0
MNWW29.5	29.5	MacDonald Bridge, WDFW Fishing Area (2000 feet upstream of bridge)	1.3	1.4	2.0
MNWW34.0	34	Swegle Bridge, WDFW Fishing/Hunting Area (500 yards upstream of bridge)	1.5	1.4	2.0
MNWW35.6	35.6	Near Whitman Mission (1/4 mile upstream of Last Chance Road bridge)	1.4	1.5	2.0
MNWW38.2	38.2	Old Milton HWY Bridge (150 Yards upstream of bridge)	1.6	1.6	1.9
MNWW41.8	41.8	Private Property , Mathew's Lane	1.6	no data	1.9
MNWW44.1	44.1	Willow Lane (Milton-Free. levee section, 0.5 miles downstream from Nursery Bridge)	1.1	1.2	1.9
MNWW44.9	44.9	1st Street Milton-Freewater (Milton-Free. levee section)	1.2	1.2	1.9
MNWW46.1	46.1	Near Frasier Farmstead Museum (Milton-Free. levee section)	1.0	1.1	1.9
MNWW48.1	48.1	Private Property (Off Day Road)	1.2	1.2	1.9
SFWW49.2	49.2	Private Property (1/4 mile upstream from bridge)	1.2	1.1	1.9
SFWW51.6	51.6	Private Property	1.2	1.1	1.8
SFWW52.9	52.9	Private Property	1.2	1.1	1.8
SFWW57.7	57.7	Private Property	1.2	1.1	1.8
21 (rm 59.2)	59.2	Stream Gage	1.2	Narrow Valley Floor Limits Sinuosity	
22 (rm 61.2)	61.2	2 Miles Above Gage	1.1		
23 (rm 62.4)	62.4	USFS Boundary	1.1		
24 (rm 64.0)	64	Campground	1.1		
25 (rm 65.9)	65.9	Near Table Creek	1.1		

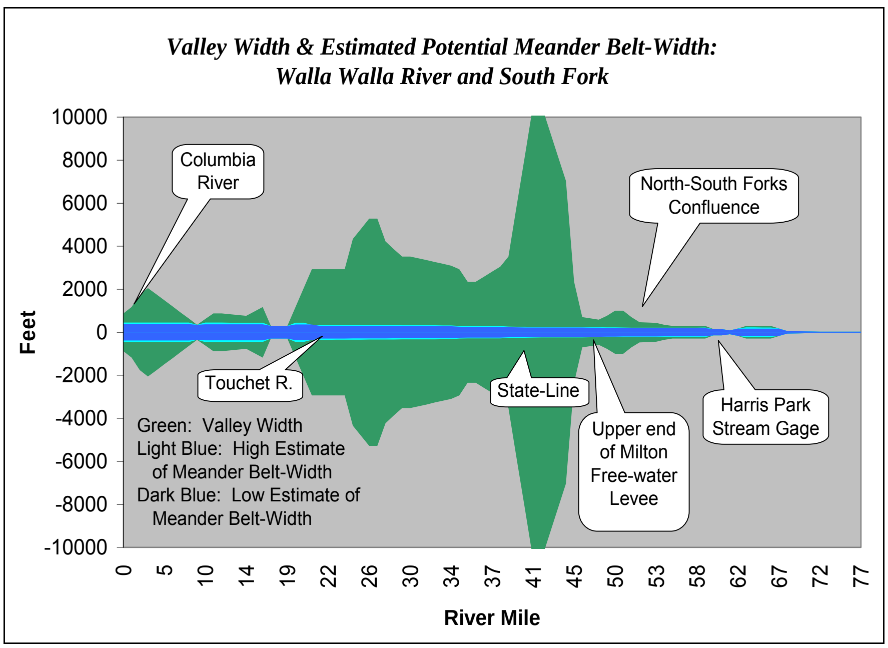
The calculated potential sinuosity values (**Table 3-2**, furthest column to right) provide a best available estimate of potential sinuosity. These values represent a stable hydraulic configuration expected for a low disturbance river channel and are corroborated by the amount of change observed in aerial photographs from 1939 to present.

Potential Meander Belt-Width. *Meander belt-width* is the width of the longitudinal zone between valley-parallel lines that envelope a stream's path - a measure of meander amplitude. Williams et al., 1986, developed regression equations for meander belt-width based on bankfull width and depth. The regressions were prepared for unconstrained alluvial channels. This condition is generally true for the Walla Walla mainstem. The process employed to evaluate meander belt-width potential is as follows:

- Determine potential channel width as described previously in this section.
- Determine potential channel depth as the ratio of potential channel width to target width/depth.
- Compute meander belt-width (**Figure 3-13**) using the equations of Williams et al. (1986). For comparative basis, compute two meander belt-width estimates, based on channel width, then depth.

Meander belt width = 4.3 x (bankfull width)$^{1.12}$
Meander belt width = 148 x (bankfull mean depth)$^{1.52}$

Figure 3-13. *Longitudinal graph of meander belt-width. The graph is arranged to illustrate valley width as if symmetrical about a center line at zero on the y-axis. The inner blue zone is the estimate based on channel width, and the outer, light blue zone is based on depth.*



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 and warrants listing.

- 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, detailed mapping of land cover is a high priority. Variable land cover conditions in the Walla Walla Subbasin require a higher resolution than currently available GIS data sources. To meet this need, DEQ and WWBWC have mapped near stream land cover using Digital Orthophoto Quads (DOQs) at a 1:4,000 scale. Land cover features were mapped along the main channel within 500 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. All digitized line work is completed at 1:4,000 or higher resolution.

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 2-6** lists coded categories).

Step 3. USFS derived ***existing vegetation*** coverage (USFS, 2001) is merged with the TMDL 1:4000 land cover polygons where appropriate. The USFS vegetation layer was developed mainly for forested lands and thus applies to upper stream reaches.

Step 4. 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 ***potential land cover*** conditions. For example, small conifers are assumed to have the potential to become large conifers.

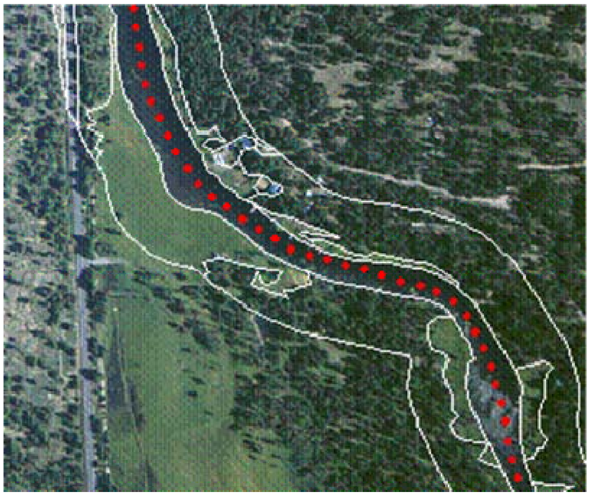
Step 5. Automated sampling is conducted on classified land cover spatial data sets in 2-dimensions, for both the existing and potential condition assessments. Every 25 meters along the stream (i.e., in the longitudinal direction), the near stream land cover code is radially sampled every 15 meters, starting at the channel center, out to 60 meters. This sampling rate results in 1,856 sub-samples of land cover type per every mile of stream.

Step 6. Ground level land cover data (vegetation height, foliage density, **Tables 2-4 and 2-6**) are assigned to each polygon as code attributes. USFS data and personal communication were used for the National Forest (**Table 2-5**). Field measurement and remote sensing were used in the remainder of the basin.

Step 7. Land cover physical attributes (height and density) can then be described in 2-dimensions since automated sampling occurs in both the longitudinal and transverse directions.

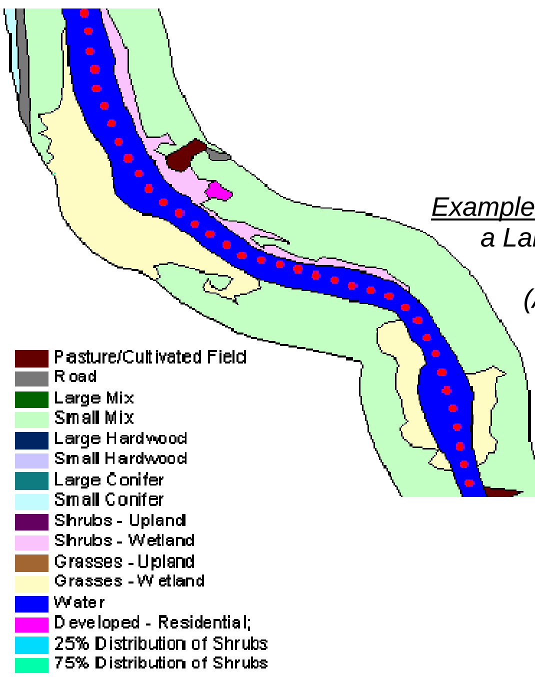
Figure 3-14 summarizes the steps followed for near stream land cover classification (note that the aerial photos used in the Walla Walla Subbasin assessment are grayscale rather than color).

Figure 3-14. *Illustration of automated land cover data compilation*



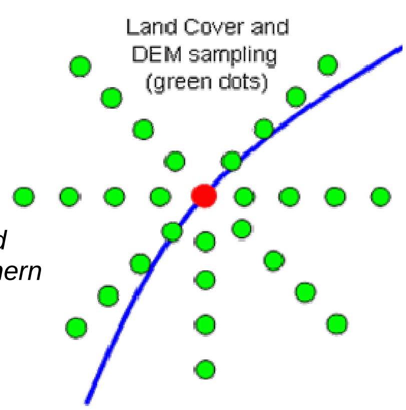
<u>Example</u> of Polygon Mapping of Near Stream Land Cover from Aerial Color Imagery

(At this point only the line work is complete and no data is associated with the polygons.)



<u>Example</u> of Classification of the Land Cover Polygons Associating a Land Cover Type to Each of the Polygons

(At this point a land cover type numeric code is associated with each polygon.)



TTools radial sampling pattern for near stream land cover (sampling interval is user defined). Sampling occurs for every stream data node at four user-defined intervals 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 Walla Walla River and South Fork using the method described in the previous Section. Field surveys and existing data addressing the mainstem and South Fork helped identify vegetation species compositions and develop near stream land cover height and density classifications. This ground level data is described in **Section 2.1.4** In the upper watershed, digital riparian mapping benefited from available USFS vegetation information. **Figure 3-15** shows the location of the Umatilla National Forest and the associated USFS GIS coverage of vegetation. The USFS vegetation coverage was classified based on remote sensing and ground level data collection. Though helpful, the USFS mapping was not designed to address the high degree of complexity in riparian areas. In TMDL development, The USFS vegetation layer was assessed on a site-specific basis via comparison to aerial photography (DOQs) and DEQ/WWBWC digitized land cover. The final product is a combination land cover delineation and classification, with greater riparian area resolution than previously available.

The subbasin-wide vegetation mapping and coding developed by DEQ and WWBWC is illustrated in **Figure 3-16**. The GIS software TTools version 7.0 was used to sample this near-stream land cover. Data was sampled every 25 meters longitudinally. The following pages discuss the vegetation mapping and sampling in more detail.

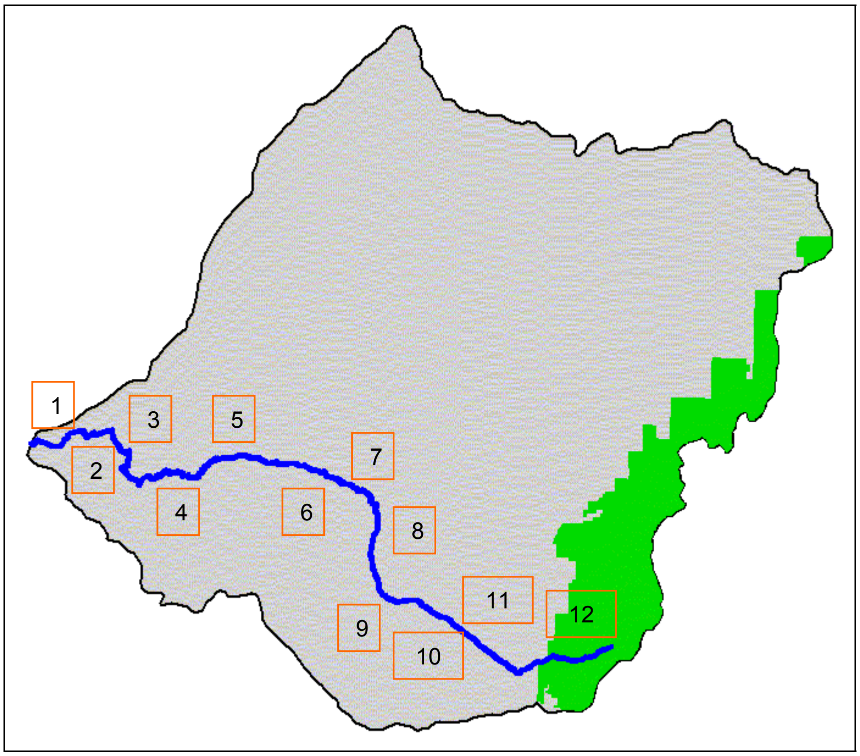
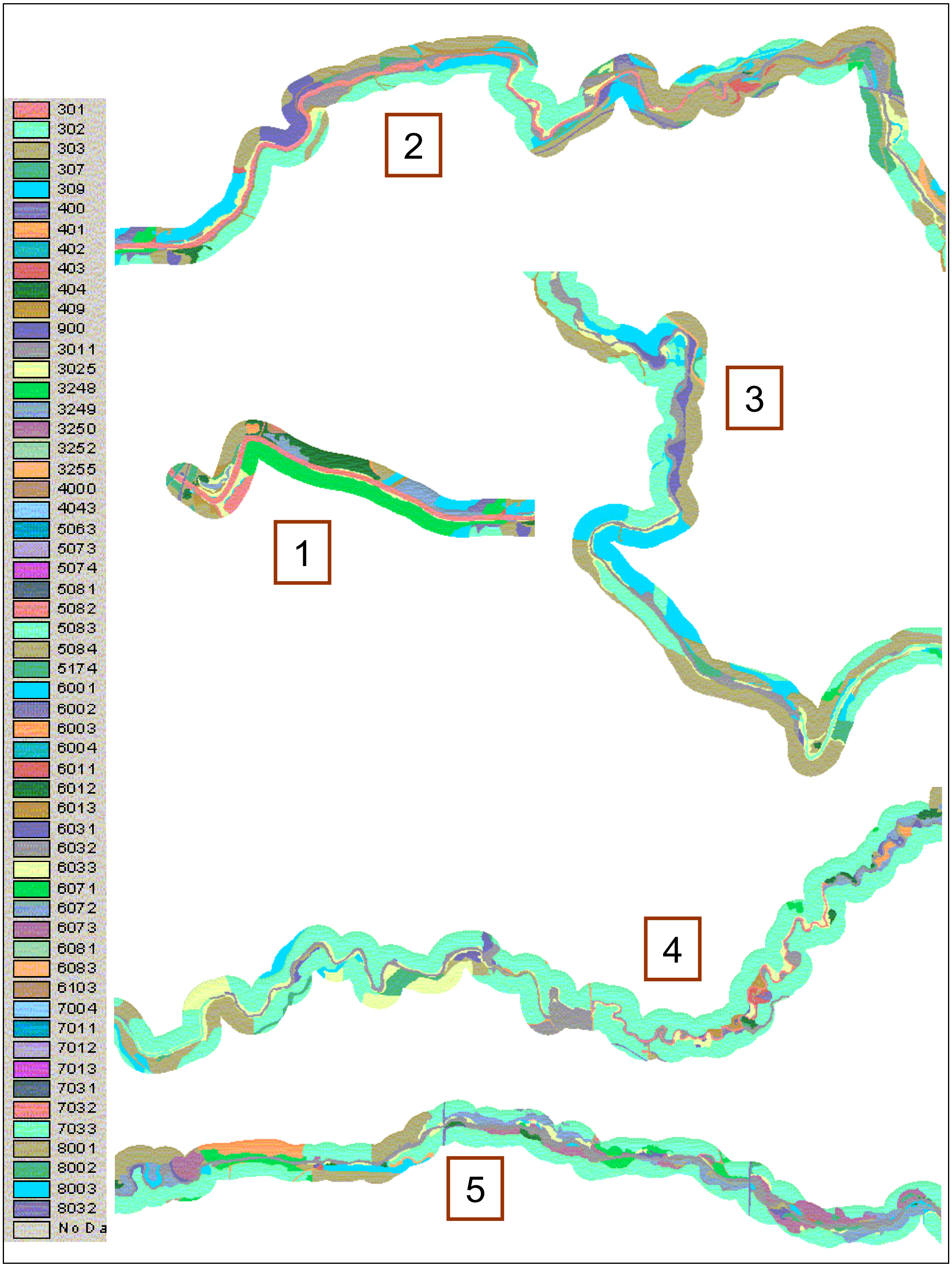


Figure 3-15. *USFS existing vegetation GIS coverage (green area) and locations of digital vegetation map segments shown in next figure.*

Figure 3-16 (Next Three Pages). *Digital vegetation map prepared by DEQ and WWBWC. The numbers adjacent to each segment indicate longitudinal order, beginning at the mouth of the Walla Walla River. Connected end to end, these segments form a continuous map of ground cover within 500 feet of the river, from the Columbia River to Skip Horton Creek. Segment locations are shown in **Figure 3-15**. A key for the vegetation codes is displayed on the first page of the figure. Code definitions can be found in **Section 2.1.4, Table 2-6.***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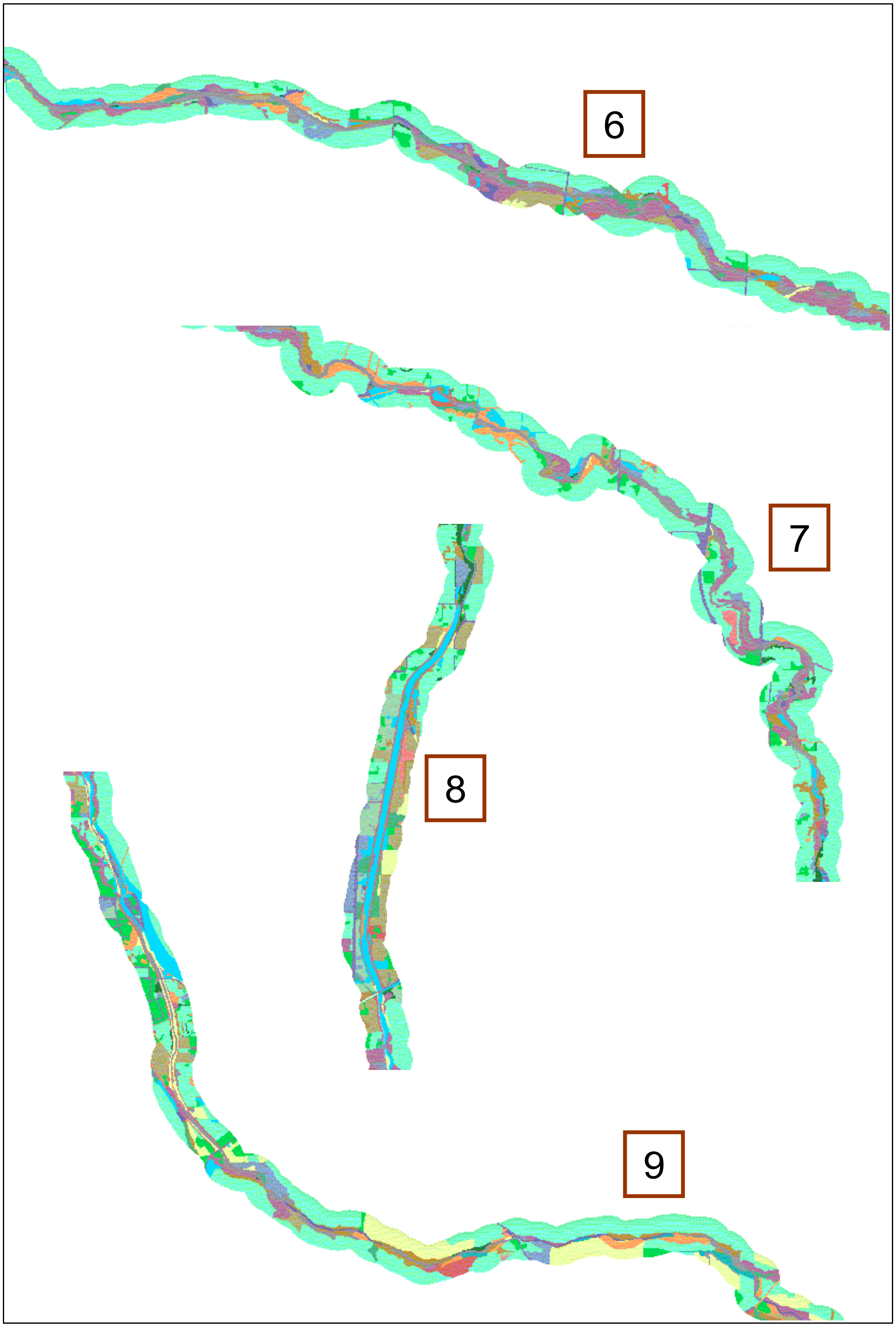
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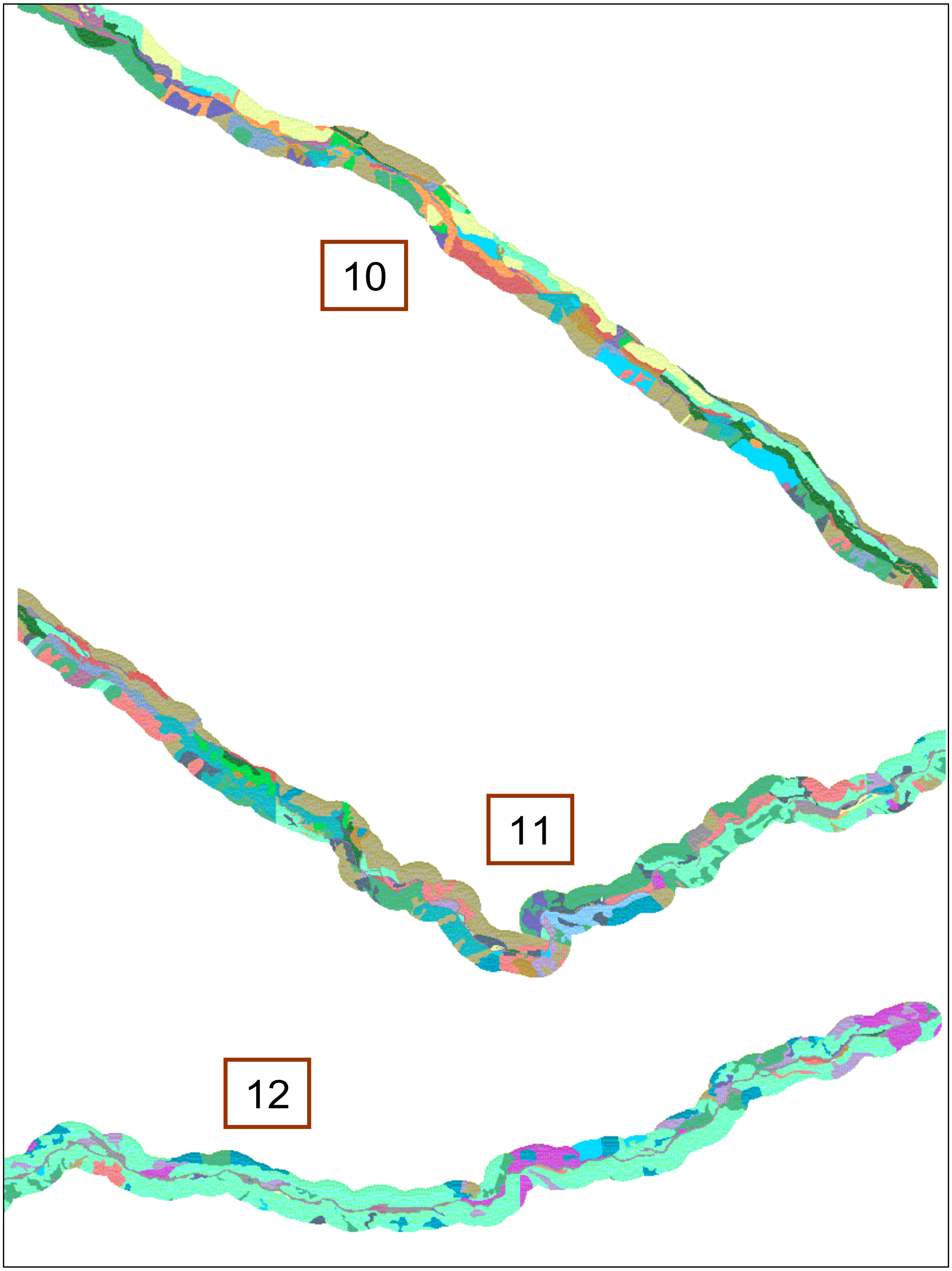
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Following digital mapping and coding, land cover data then were classified into various height and density ranges. This information is assigned to codes as listed in **Section 2.1.4, Table 2-6**. Height and density were measured at a variety of field sites (**Section 2.1.4**) and then applied via interpretation of DOQs and Day TV color photographs and associated ground-truthing.

Tree heights measured in this study and based on local expertise are consistent with regional plant guide literature (Johnson and Simon,1987; Johnson, 1998).

3.3.3 Near Stream Land Cover - Potential Condition Development

The process of developing potential near stream land cover data should start with reference to **Section 1.4**, which includes the definition of *system potential* 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 survive and recover from a natural disturbance event.

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. *Potential near stream land cover* is a key condition targeted in the TMDL. **Table 3-3** lists the species and heights of potential near stream vegetation.

The information sources that supported estimation of potential vegetation type and geometry include the following:

<u>Oregon Sources</u>

1. Existing Vegetation [large tree species stands, currently below river mile 8 (~km 13)
2. 27 (~km 44) to headwaters] including but not limited to relatively undisturbed reaches
3. 1858 Mapping for Military Road Reconnaissance, Fort Dalles, Oregon to Fort Taylor, Washington Territory (Mullan, 1858)

Figure 3-17. *Lieutenant Mullen's 1858 map includes a key roughly addressing riparian tree types.*

4. Journal entries published and unpublished (refer to Annotated Bibliography – Historical Conditions and Vegetation - in the *Literature Cited Section* of this Appendix)
5. 1939-1946 aerial photographs ((USDA 1939-1946) currently stored in the archives of the Whitman College Library) and 1950's aerial photography of the Milton-Freewater (loaned by the US Army Corps of Engineers, Walla Walla Office)
6. US Forest Service existing and potential natural vegetation GIS covers (note that the potential vegetation in the South Fork riparian area differed little from existing)
7. Historical information from physiographically similar basins, e.g., Umatilla (Nagle, 1989)
8. Best professional judgment regarding site capability
9. Climatic information
10. Literature values and measurements of undisturbed areas for height and density

Washington Sources

- Some of the same sources as for Oregon: above #'s 1, 2, 3, 4, 6, 7, 8, and
- Journals from Lewis and Clark expedition (refer to Annotated Bibliography – Historical Conditions and Vegetation - in the *Literature Cited Section* of this Appendix)
- Whitman Mission historical documents (refer to Annotated Bibliography – Historical Conditions and Vegetation - in the *Literature Cited Section* of this Appendix)
- Historical drawings (1847, 1882) show medium to large deciduous trees along the river, and mention of balm (cottonwood) and large willow (refer to Annotated Bibliography – Historical Conditions and Vegetation - in the *Literature Cited Section* of this Appendix)
- Fort Wallah Wallah historical documentation (refer to Annotated Bibliography – Historical Conditions and Vegetation - in the *Literature Cited Section* of this Appendix)

The following rule set was used to specify types of potential near stream land cover. The existing vegetation map was modified in accordance with this rule set in order to develop model input for estimating potential temperature and heat loads. Once the spatial distribution of vegetation was estimated, literature values and measurements of undisturbed areas were employed for height and density. Density measurements were made with a spherical densiometer or through aerial photography interpretation. Heights were measured with a digital range-finder.

General Rules for Developing Potential Near Stream Land cover

1. Barren Land Cover type that can grow land cover (i.e. levee, gravel pit, clearcut, 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. Milton-Freewater Levee area is assigned the nearest adjacent non-developed land cover type.
7. Water and barren rock cannot grow land cover and are not changed.
8. Immature or disturbed density tree stands are assumed to grow to maturity.
9. Mature tree stands with normal healthy densities are considered at potential and land cover type and attributes are not changed.
10. 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.
11. The riparian wetland/meadow land cover type is considered at potential and land cover type and attributes are not changed.
12. Steep and rocky slopes where soil conditions and/or aspect prohibit tree growth are left unchanged.

Assessment of Potential Near Stream Land Cover in Unique Areas

13. In the geographic areas identified in the following two paragraphs, additional rules or criteria were applied to identify potential vegetation because either specific studies had been conducted (Umatilla National Forest) or the information needed to apply the above rule set was lacking.

13b. *Zangar Junction to Pine Creek.* This reach is located roughly between river mile 8 (~km 13) and 23 (~km 37). Incision and land conversion are apparent through much of the reach and, in contrast with most of the Walla Walla River, virtually no trees are present, other than small willows. Historical information for the area is lacking or unclear. As such, its potential is unknown. To address this reach a range of possibilities was defined, and effective shade and temperature simulated for each: (1) the existing condition, (2) a low percentage of trees larger than the shrubby willows there now, and (3) a relatively high percentage of large trees. A continuous riparian forest was not considered - this is consistent with the limited available historical information. In early mapping (Mullan, 1858) there is no indication that more than isolated tree stands were present. Potential species, height and density estimations for the low and high range tree distributions are set out in **Table 3-3**.

13a. *Umatilla National Forest.* The National Forest riparian area is assessed to be at potential along the South Fork and uncertain regarding the Mill Creek and the North Fork watersheds. This is based on communication with Walla Walla Ranger District Personnel and field assessment conducted within the TMDL assessment. The following USFS memos (**Figure 3-18a** and **3-18b**) were provided by the Umatilla National Forest as summary documentation of the low level of disturbance of the riparian area in the South Fork of the Walla Walla River drainage above the USFS boundary and of the condition of the North Fork and Mill Creek watersheds.

Figure 3-18a. *Memo from Umatilla National Forest – South Fork conditions and management.*

United States Department of Agriculture
Forest Service
Walla Walla Ranger District
1415 West Rose
Walla Walla, WA 99362

File Code: 2500 Watershed **Date:** February 2, 2004

Subject: Potential vegetation inside of streamside buffers
South Fork Walla Walla River

To: Don Butcher, Oregon Department of Environmental Quality
From: Stacia Peterson

Steve Anderson and I cooperated on this memo in a response to your request for information about management effects to stream shade in the South Fork of the Walla Walla River. Stream shade on the NFS portions of the South Fork Walla Walla is at potential.

The Umatilla Forest Plan has a special management designation for the Walla Walla River.

> F4 Walla Walla River Watershed
> Goal: Provide high quantity and quality of water and elk habitat effectiveness while sustaining or enhancing other resource values. Management Activities will not substantially change the level of water discharge from the National Forest during the May 1 through September 30 period.

All roads are situated on the ridge tops. The trail, while it follows the River in the canyon, is usually not adjacent to the channel. There is no clearing of trees or changes to shading of the channel, only trees blocking the trail are cut and removed from the trail. Drainage structures are maintained annually to insure the goal of the management strategy area. No channel modifying activities have been documented on NFS lands and are unlikely to have occurred due to the very narrow, V-shaped valley bottom. The width to depth ratio is at potential for this river.

There have been few harvest entries and they have generally been limited to the upper plateau portion of the watershed. The District GIS system was used to query the harvest history records for the South Fork Walla Walla. About 800 acres of harvest took place within 300 feet of mapped streams over the last 40 years. This is about 5% of the total area within 300 feet of these streams. This figure over estimates the effect to stream shade since harvest prescriptions aren't considered in the total, not all vegetation within 300 feet of streams provides shade to the stream, and shade to intermittent streams has limited effect on water temperature due to the limited season of flow in these channels. In addition, our GIS stream mapping typically errs in classifying ephemeral streams as intermittent streams.

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Figure 3-18b. *Memo from Umatilla National Forest – North Fork and Mill Creek conditions and management.*

United States Department of Agriculture **Forest Service** **Walla Walla Ranger District** **1415 West Rose Walla Walla, WA 99362**

File Code: 2500 Watershed **Date:** August 9, 2005

Subject: Effects to potential vegetation inside perennial stream buffers of NFS lands in the North Fork Walla Walla River and of Middle Mill Creek

To: Don Butcher, Oregon Department of Environmental Quality

From: Stacia Peterson, Umatilla National Forest, North Zone Hydrologist

National Forest System (NFS) lands in the Oregon portion of the Walla Walla basin are organized into several subwatersheds which were delineated using the national, interagency Hydrologic Unit Code (HUC). These subwatersheds are:
Upper South Fork Walla Walla
Middle South Fork Walla Walla
North Fork Walla Walla
Upper Mill Creek
Middle Mill Creek

- Upper **South Fork Walla Walla and the Middle South Fork Walla Walla** subwatersheds were the subject of a February 2, 2004 memo.

- The **North Fork Walla Walla** subwatershed has the same Forest Plan management direction as the South Fork:
F4 Walla Walla River Watershed
Goal: Provide high quantity and quality of water and elk habitat effectiveness while sustaining or enhancing other resource values. Management Activities will not substantially change the level of water discharge from the National Forest during the May 1 through September 30 period.

A review of harvest history in the North Fork of the Walla Walla shows 320 acres of harvest occurring within 300 feet of perennial streams and about 145 acres within 150 feet since 1959. Harvest occurred on or near perennial tributaries to the mainstem. No harvest occurred inside of 300 feet of the mainstem of the North Fork Walla Walla. This amounts to about 11 % to 12 % of near channel vegetation. Reduction in shade is overstated by these numbers since aspect was not included in the evaluation. There are numerous road crossings of perennial streams in midslope positions, but no roads are located along the length of any channel.

The most recent harvest in near channel locations occurred in 1979. Regrowth in the last 25 to 30 years is likely to be providing shade to most channels affected by harvest, since these are narrow, V shaped valleys with relatively small channels. No channel modifying activities have been documented on NFS lands and are unlikely to have occurred. A 1991 stream survey recorded substantial large wood debris in NFS portions of the mainstem of the North Fork; 49 and 111 pieces per mile in Reach 2 and 3 respectively, which exceeds PACFISH standards and is near potential.

The Umatilla National Forest Land and Resource Management Plan as amended by PACFISH identifies standards and guidelines to maintain Riparian Habitat Conservation Areas (RHCAs) and allow for the recovery of conditions necessary to meet Riparian Management Objectives (RMO). Shade, bank stability, and large woody inputs are some of the measured components that are protected by the standards. Current management practices provide for recovery of components that control water temperature.

The North Fork Walla Walla subwatershed is on the way to recovering potential vegetation characteristics near channels that were harvested and recovery is protected by the Umatilla Land and Management Plan as amended by PACFISH.

- Upper Mill Creek and portions of Middle Mill Creek subwatersheds have been recognized as the municipal water supply for Walla Walla since a 1918 agreement between the Secretary of Agriculture and the city of Walla Walla. This agreement set aside Mill Creek Municipal Watershed as a restricted management area. There has been no harvest or other vegetation manipulation in the watershed though wildfires have been suppressed as rapidly as possible.

- Some harvest has taken place in the remainder of NFS lands in **Middle Mill Creek** subwatershed, along Tiger Canyon. Aerial photos of acquired lands in subwatershed were reviewed and show no evidence of harvest. A review of harvest history on proclaimed NFS lands shows 159 acres of harvest occurring within 300 feet of perennial streams and 60 acres within 150 feet since 1959. No harvest has occurred within these buffers since 1996. This amounts to about 3 % to 4 % of near channel vegetation. Reduction in shade is overstated by these numbers since aspect was not included in the evaluation. Forest Road 6500 is located on the north east side of Tiger Canyon Creek for about 1 ½ miles, before it climbs up slope. Other roads in this subwatershed are located in upper slope of ridge top positions with few or no perennial stream crossings.

Stream survey data collected on NFS lands in 1996 identified 21 pieces of large wood per mile and 97 pieces of smaller wood. Tiger Canyon is a relatively small stream and this quantity and size range of wood is adequate to provide structure and channel stability, protecting fish habitat and overall stream morphology. Near channel vegetation in this subwatershed is at or very near potential for shade and woody input.

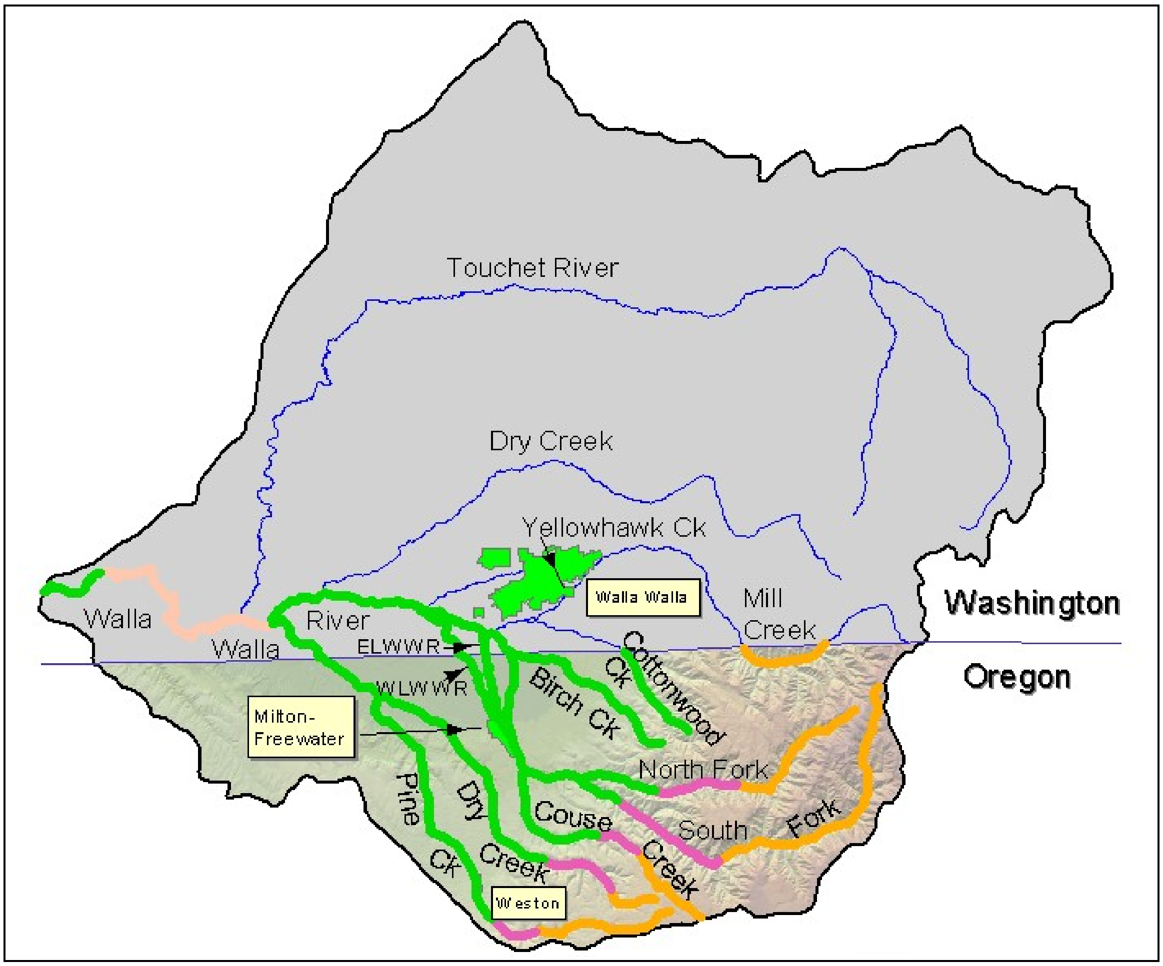
Specification of height and map distribution

Table 3-3. *Assessment of potential vegetation composition, height and density. Attributes for codes referenced in this table can be found in* ***Table 3-4*** *as well. The description columns below are color coded in relation to the following map (* ***Figure 3-19****) of potential vegetation zones.*

River Mile	Riparian Zone Name	Height Dominant Plants	Percent stream length with trees	Percent stream length with shrubs	Average Tree Canopy Height (m)	Average Willow - Shrub Height (m)	Canopy Density (%)	Longitudinal Distance-weighted Average Height (m)
Mouth to 7.8 (Zangar Junction)	Lower Deciduous Zone	Black Cottonwood, Large Willows, Red Osier Dogwood, Mixed Shrubs	100%	N/A	N/A	N/A	80	approximately 22 (or Cottonwood Gallery-28)
7.8 to 11.8 (Nine Mile Bridge)	Indefinite Lower Shrub-Deciduous Zone	Black Cottonwood, Large Willows, Red Osier Dogwood, Mixed Shrubs	25%	75%	14.6	4.3	80	6.9
			50%	50%	14.6	4.3	80	9.4
11.8 to 19.8 (~2.5 miles downstream from Touchet confluence)	Indefinite Shrub-Deciduous Zone	Black Cottonwood, Large Willows, Red Osier Dogwood, Mixed Shrubs	5%	95%	14.6	4.3	80	4.8
			25%	75%	14.6	4.3	80	6.9
19.8 to 23.0 (Confluence with Pine Creek)	Indefinite Upper Shrub-Deciduous Zone	Black Cottonwood, Large Willows, Red Osier Dogwood, Mixed Shrubs	25%	75%	14.6	4.3	80	6.9
			50%	50%	14.6	4.3	80	9.4
23.0 to 52.2 (South Fork - 2.8 miles upstream of North Fork Confluence)	Deciduous Zone	Mixed Willow, Mixed Alder, interspersed Black Cottonwood	100%	0%	dominant class (code 2003) is 22.0 meter	N/A	80	approximately 22 (or Cottonwood Gallery-28)
52.2 to 59.0 (BLM Trailhead)	Deciduous-Conifer Zone	**Deciduous -** Quaking Aspen, Black Cottonwood, Mixed Willow, Mixed Alder, Red Osier Dogwood. **Conifer -** Grand Fir, Douglas Fir, Ponderosa Pine	100%	0%	dominant classes (codes 2003, 6003, 5074) are 22.0, 28.0 & 25.0 meter	N/A	80	approximately 22 (or Cottonwood Gallery-28)
59.0 to Model Upper Boundary	Conifer Zone	**Deciduous -** Quaking Aspen, Mixed Willow, Mixed Alder, Red Osier Dogwood, Paper Birch, etc. **Conifer -** Mixed Firs, Ponderosa Pine, Engelmann Spruce	100%	0%	dominant classes (codes 7003, 5074, 2003) are 25.0, 25.0 & 22.0 meter	N/A	80	approximately 24
			Grey area - low range					
			Blue areas - high range					

The vegetative zones of **Table 3-3** are estimated to apply as mapped in **Figure 3-19**. In addition, note that cottonwood galleries (height approximately 28 meter) are interspersed and often dominant on the lower- and upper-most mainstem, and along much of the South Fork below the conifers (~ 2 miles downstream from Harris Park).

Figure 3-19. *Map of potential vegetation zones. Refer to* ***Table 3-3*** *for color coding and description of zones.*



Assigning Potential Land Cover attributes

The model *Heat Source* assigns land cover height and density to mapped land cover via a classification table as shown below. **Table 3-4** lists the codes and associated height and density for the potential land cover in the Subbasin. As discussed previously, much of the simulated conversion from existing to potential conditions was accomplished by replacing codes. For example, a code for 'small mixed deciduous' may be replaced by a code representing full grown mixed deciduous trees. Accordingly, few code attributes were modified, as indicated in the **Table 3-4**. This also explains the use of fewer codes to describe potential. Immature trees, for instance, are assumed to not be at potential - eliminating the need for the code assigned to immature trees.

Table 3-4. *Land Cover Codes and attributes used in potential land cover shade and temperature simulation. Mention of "New Code" below occurs for the zone of uncertain potential shade producing vegetation. In this less understood reach, three vegetation scenarios were simulated: existing condition (not shown),, mid range enhanced vegetation (codes 101,102, 103) and high range enhanced vegetation (201, 202, 203).*

Potential Land Cover			
Description	Code	Height (m)	Density (%)
New Code: Lower Shrub-Deciduous Zone (mile 7.8-11.8)*	101	6.9	80
New Code: Shrub Deciduous Zone (mile 11.8-19.8)*	102	4.8	80
New Code: Upper Shrub Deciduous Zone (mile 19.8-23)*	103	6.9	80
New Code: Lower Shrub-Deciduous Zone (mile 7.8-11.8)**	201	9.4	80
New Code: Shrub Deciduous Zone (mile 11.8-19.8)**	202	6.9	80
New Code: Upper Shrub Deciduous Zone (mile 19.8-23)**	203	9.4	80
Water -No Change	301	0.0	80
Barren - Rock - No Change	304	0.0	80
Mixed Deciduous - No Height Change	2003	22.0	80
Near Stream Disturbance Zone - No Change	3011	0.0	80
Riparian Wetland/Meadow - No Change	4000	0.8	80
Large Mixed Conifer/Deciduous	5074	25.0	80
Cottonwood Trees - No Height Change***	6003	28.0	80
Small Deciduous - No Height Change	6013	8.0	80
Willow Brush - No Height Change	6033	4.3	80
Large Conifer - No Height Change	7003	25.0	80
Shrubs and Grasses - No Change	8003	0.5	70
Grasses - No Change	9003	0.5	70

*lower range estimation of increased vegetation for zone
**upper range estimation for zone
***Mostly Cottonwood

3.4 Methodology Used to Assess Unmeasured Inflow

This section provides detail in accounting for unmeasured inflows. Existing flow profile development is described and flow profiles are illustrated in **Section 2.1.2**. The flow profiles of **Section 2.1.2** incorporate the method described below in this section.

Unmeasured Inflow

FLIR sampled stream temperature data can be used to develop a mass balance for stream flow using minimal ground level data collection points. Simply identifying mass transfer areas is an important step in quantifying heat transfer within a stream network. For example, using FLIR temperature data - tributary, spring and probable groundwater input locations were identified. That said, in some situations there can be significant uncertainty associated with this method. Due to the abundance of flow data and local knowledge of water usage in the Walla Walla Subbasin, FLIR mass balance calculations were not relied on heavily. The mainstem and South Fork flow profiles used in temperature simulations were derived largely from in-stream measurements; available for much of the mainstem and all the major tributaries. For surface inflow, mass balance using FLIR was employed only for small tributaries.

Mass balance calculations assisted in the assessment of subsurface mass transfer. FLIR mass balance computations were used for a culvert groundwater drain in the Milton-Freewater Levee, and as a cross-check where groundwater input was assessed. Hyporheic influence and tributary groundwater input have strong thermal influence, particularly through much of the river downstream from Tumalum Bridge near Milton-Freewater. Thermal buffering and mass transfer in this area were inferred in reaches of otherwise unexplained mainstem temperature anomalies, where the geology and geomorphology indicated the plausibility of subsurface inflow. However, as with surface water, FLIR mass balance was not employed extensively. Groundwater and hyporheic activity are not discernable via FLIR along large sections of the river, partly due to entrenchment. Apparent warm season spring activity is minimal for the Walla Walla River and South Fork, except on the upper South Fork.

Mass Balance Method

All stream temperature changes that result from mass transfer processes (i.e., tributary confluence, point source discharge, groundwater inflow, etc.) can be described mathematically using the following relationship:

$$T_{mix} = \frac{(Q_{up} \cdot T_{up}) + (Q_{in} \cdot T_{in})}{(Q_{mix})} = \frac{(Q_{up} \cdot T_{up}) + (Q_{in} \cdot T_{in})}{(Q_{up} + Q_{in})}$$

where,

Q_{up}: Stream flow rate upstream from mass transfer process
Q_{in}: Inflow volume per time
Q_{mix}: Resulting volume or flow rate from mass transfer process ($Q_{up} + Q_{in}$)
T_{up}: Stream temperature directly upstream from mass transfer process
T_{in}: Temperature of inflow
T_{mix}: Resulting stream temperature from mass transfer process assuming complete mix

All water temperatures (i.e., T_{up}, T_{in} and T_{mix}) are apparent in the FLIR sampled stream temperature data. Provided that at least one in-stream flow rate is known, the other flow rates can be calculated.

Water volume losses are often visible in FLIR imagery since diversions and water withdrawals usually contrast with the surrounding thermal signature of landscape features. Highly managed stream flow regimes can become complicated where multiple diversions and return flows mix or where flow diversions and returns are unmapped and undocumented. In such cases it becomes important to establish the direction of flow (i.e., influent or effluent). With the precision afforded by FLIR sampled stream temperatures, effluent flows can be determined when temperatures are the same. Temperature differences indicate that the flow is influent. This holds true even when observed temperature differences are very small. The rate of water loss from diversions or withdrawals cannot be easily calculated. Water withdrawal flow rates are estimated from field data, communication with OWRD and Irrigation District staff and the water right information maintained by Oregon Water Resources Department (OWRD).

Discussion of Assumptions and Limitations for Mass Balance Methodology

1. **Small mass transfer processes are not accounted**. A limitation of the methodology is that only mass transfer processes with measured ground level flow rates or those that cause a quantifiable change in stream temperature with the receiving waters (i.e., identified by FLIR data) can be analyzed and included in the mass balance. For example, a tributary with an unknown flow rate that cause small temperature changes (i.e., less than $\pm 0.5^{o}$F) to the receiving stream cannot be accurately included. *This assumption can lead to an under estimate of influent mass transfer processes.*

2. **Limited ground level flow data limit the accuracy of derived mass balances**. Errors in the calculations of mass transfer can become cumulative and propagate in the methodology since validation can only be performed at sites with known flow rates. *These mass balance profiles should be considered estimates of a steady state flow condition*.

3. **It is not possible to determine the amount of return flows derived from ground water withdrawals relative to those derived from in-stream withdrawals.** Some of the irrigated water comes from ground water sources. Therefore, one should assume that portions of the return flows are derived from ground water sources. Return flows can occur over long distances from irrigation application and generally occur at focal points down gradient from multiple irrigation applications. It is not possible to estimate the portion of irrigation return flow that was pumped from ground water rights. In the potential flow condition all return flows are removed from the mass balances. *This assumption can lead to an under estimate of potential flow rates.*

4. **Return flows may deliver water that is diverted from another watershed.** In some cases, irrigation canals transport diverted water to application areas in another drainage. This is especially common in low gradient meadows, cultivated fields and drained wetlands used for agriculture production. The result is that accounting for a tributary flow in the potential flow condition is extremely difficult. DEQ is unable to track return flows to withdrawal origins between drainage areas. *When return flows are removed in the potential flow condition this assumption can lead to an under estimate of potential tributary flow rates.*

3.5 Potential In-Stream Flow

Figure 1-8 is a map of key geographic locations in the Milton-Freewater area, where much of the mainstem flow is controlled through natural and human causes. **Figure 3-20** displays several longitudinal flow profile scenarios and the August 15, 2000 and 2002 assessed flow profile for the Walla Walla River and South Fork. All scenarios are based on the year 2002 assessed flow with incremental reduction in mainstem diversion above the Oregon-Washington border, and an accounting for documented loss to the subsurface in the Milton-Freewater area. The diversion reduction calculation begins with less flow exiting at the Little Walla Walla River Distributary in lower Milton-Freewater Levee. Increasing in-stream flow is assigned through decreased diversion at this point, and then at points upstream, until the flow at Nursery Bridge in Milton-Freewater is roughly equal to the flow at the Harris Park gage on the South Fork (South Fork of the Walla Walla River, river mile 9 (~km 14), above the uppermost diversions). In the Milton-Freewater area, part of the increase is reduced due to streambed loss, much of which is localized between Nursery Bridge in Milton-Freewater and Tumalum Bridge approximately 2 miles downstream. **Table 3-5** and **Figure 3-21** display the diversion reduction quantities and bed-loss equation. Nursery Bridge is used as a reference point due to the presence of the Hudson Bay Company Irrigation District gage, its location downstream from the bulk of Oregon diversions and its utilization as an in-stream checkpoint for Irrigation District diversion management.

The array of potential flows was finely incremented at the request of the WWBWC and temperature was simulated for each. Ecological planning and discussions, river management and collaboration in the Basin have provided for restoration opportunities and the critical need for informed decision making. Important decisional input includes the weighing of the relative benefits of river flow, vegetation and morphology. DEQ and WWBWC have worked together closely on this temperature study in the hope of supporting such evaluations.

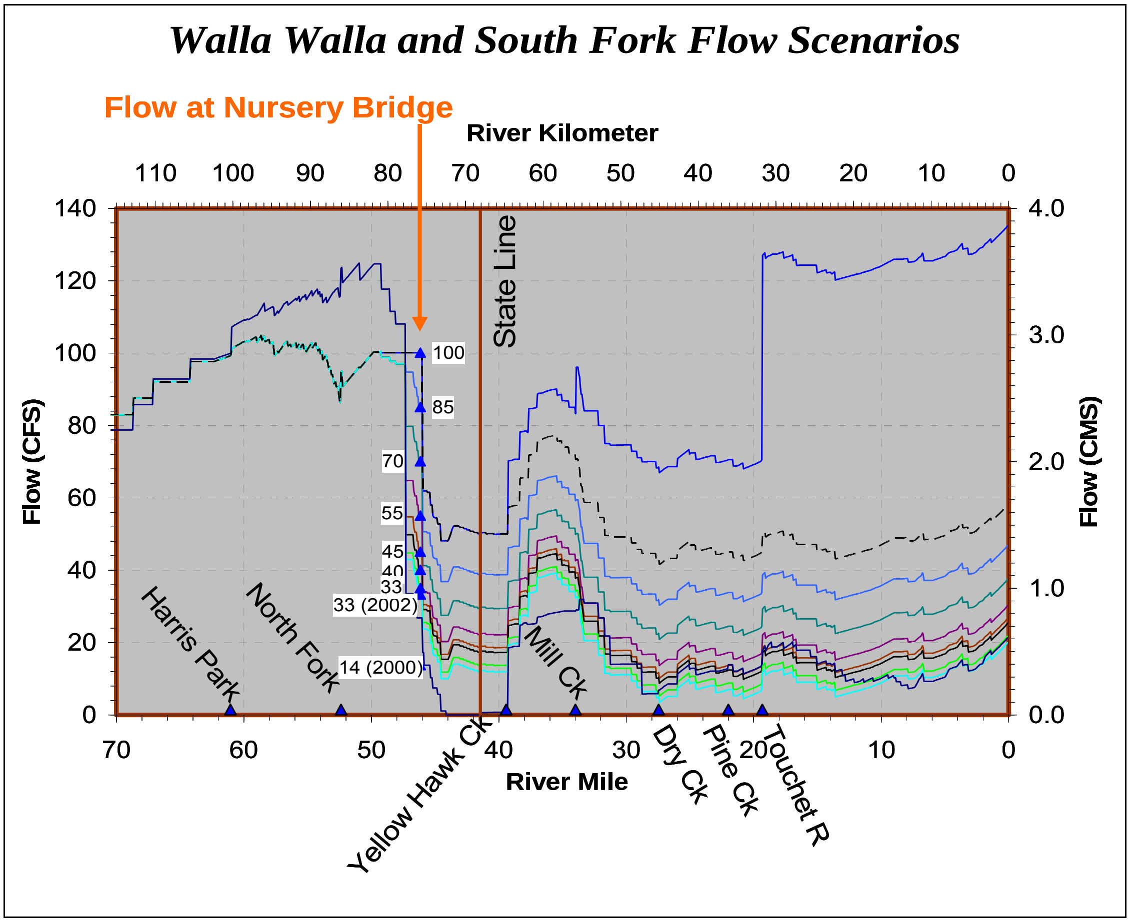


Figure 3-20. *Main Channel Flow Scenarios, with reference flow at Nursery Bridge in Milton-Freewater. The 100 CFS label addresses two scenarios, one with and one without increased flow at Yellowhawk Creek, Mill Creek and the Touchet River.*

The flow scenarios of **Figure 3-20** employ existing (August 15, 2002) tributary input, except for the scenario apparent as the highest flow level in Washington (one of the two scenarios with 100 CFS at Nursery Bridge). For this scenario, tributary inputs were assigned the flow measured at points upstream from most of the irrigation diversion. Major tributaries were addressed: North Fork, Mill Creek, Yellowhawk Creek and the Touchet River. The remaining tributaries have little potential to substantially increase mainstem flow. Where historical or present gage data was available above most points of diversion, an inter-annual average August-mean flow was utilized to represent potential flow. During 2002 the North Fork was at its August norm (8 CFS), so no increase was assigned. The upper Mill Creek inter-annual August mean flow (33 CFS) was divided (in proportion to existing flow) between Mill Creek and its distributary, Yellowhawk Creek (note that like the Little Walla Walla River, Yellowhawk Creek is a natural distributary that is controlled for irrigation purposes). The Touchet River lacks a gage above the areas of diversion. Manual measurements were used in lieu of continuous gage data - WDFW reported flow measurements in 2002 for the upper forks of the Touchet River, totaling 56 CFS.

Flow quantities in each scenario are within the amount of stream flow available hydrologically. The 100 CFS plus tributary potential and the 45 CFS scenario as described above are assumed to approximate a near-natural condition (potential), for the purpose of applying temperature standards, depending on which is considered more natural – the prehistoric branching channel system with roughly 45 CFS in the main channel, or modern enlarged mainstem channel with sufficient flow to have a natural wetted width/depth ratio. This is described in more detail at the end of **Section b** of the main document.

It is important to recognize that the various flow scenarios and the approximation of potential, though based on reduced irrigation diversion, should not be interpreted to imply a requirement to reduce irrigation. The purpose is to estimate a more natural condition, for the purpose of water quality assessment.

It is also important to recall that the existing Walla Walla mainstem is one branch of several that spread across the valley floor (Section 1.5.1). Since the late 1800's the aggregate flood season flow of these branches has been routed into the Tumalum Branch (the existing mainstem). The branches have been modified to serve as an irrigation system during the growing season.

Table 3.5. *Array of diversion and bed loss quantities for August 2002 and for the various flow scenarios used for temperature simulation. This provides for a range of hypothetical flows with incremental in-stream increase above the Oregon-Washington border. Walla Walla River longitudinal distance and in-stream flow are tabulated in the gray shaded area. Estimated diversion and bed loss amounts are show in the yellow-shaded area - each yellow column is a different flow scenario (changes in bold), referenced to in-stream flow at Nursery Bridge.*

	River KM	2002 Flow (CFS)	Flow Scenarios, referenced at Nursery Bridge (CFS) 35.0	40.0	45.0	55.0	70.0	85.0	100.0	
	89.000	1.77	1.8	1.8	1.8	1.8	1.8	1.8	1.8	
	88.700	1.80	1.8	1.8	1.8	1.8	1.8	1.8	1.8	
	87.900	1.80	1.8	1.8	1.8	1.8	1.8	1.8	1.8	
	87.425	1.77	1.8	1.8	1.8	1.8	1.8	1.8	1.8	
	87.250	1.68	1.7	1.7	1.7	1.7	1.7	1.7	1.7	
	86.950	1.80	1.8	1.8	1.8	1.8	1.8	1.8	1.8	
	86.650	2.77	2.8	2.8	2.8	2.8	2.8	2.8	2.8	Values to left
	86.100	1.80	1.8	1.8	1.8	1.8	1.8	1.8	1.8	represent
	86.000	1.06	1.1	1.1	1.1	1.1	1.1	1.1	1.1	estimated
	85.900	1.77	1.8	1.8	1.8	1.8	1.8	1.8	1.8	diversion or
	85.725	1.77	1.8	1.8	1.8	1.8	1.8	1.8	1.8	bed loss
	85.550	1.77	1.8	1.8	1.8	1.8	1.8	1.8	1.8	(CFS).
	85.350	1.69	1.7	1.7	1.7	1.7	1.7	1.7	1.7	
	85.225	1.77	1.8	1.8	1.8	1.8	1.8	1.8	1.8	
	84.950	1.77	1.8	1.8	1.8	1.8	1.8	1.8	1.8	
	84.625	2.12	2.1	2.1	2.1	2.1	2.1	2.1	2.1	
	84.525	2.12	2.1	2.1	2.1	2.1	2.1	2.1	2.1	
	84.375	1.06	1.1	1.1	1.1	1.1	1.1	1.1	1.1	
	84.125	4.41	4.4	4.4	4.4	4.4	4.4	4.4	4.4	
	81.950	0.55	0.5	0.5	0.5	0.5	0.5	0.5	0.5	Where text is
	79.175	1.63	1.6	1.6	1.6	1.6	1.6	1.6	**0.3**	bold, values
	78.150	1.06	1.1	1.1	1.1	1.1	1.1	1.1	**0.0**	were adjusted
	77.375	0.71	0.7	0.7	0.7	0.7	0.7	0.7	**0.0**	to account for
Little Walla Walla Diversion	76.150	54.06	**52.3**	**47.3**	**42.3**	**32.3**	**17.3**	**2.3**	**0.0**	increased
	75.100	2.83	2.8	2.8	2.8	2.8	2.8	2.8	**0.0**	instream flow
	75.025	1.41	1.4	1.4	1.4	1.4	1.4	1.4	**0.0**	associated
	74.675	2.47	2.5	2.5	2.5	2.5	2.5	2.5	**0.0**	with reduced
	74.500	2.94	2.9	2.9	2.9	2.9	2.9	2.9	**0.0**	diversion
Nursery Bridge	74.275	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Large Bed-loss Placeholder	74.000	9.54	**9.5**	**11.0**	**14.6**	**21.1**	**28.9**	**34.5**	**38.2**	
	73.375	0.35	0.4	0.4	0.4	0.4	0.4	0.4	0.4	
	73.075	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	73.000	3.53	3.5	3.5	3.5	3.5	3.5	3.5	3.5	
	72.750	2.83	2.8	2.8	2.8	2.8	2.8	2.8	2.8	
	72.625	0.53	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
	72.450	0.18	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
	72.150	1.77	1.8	1.8	1.8	1.8	1.8	1.8	1.8	
	71.750	4.59	4.6	4.6	4.6	4.6	4.6	4.6	4.6	
	70.725	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	70.475	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total Diversion		104.1	102.3	97.3	92.3	82.3	67.3	52.3	37.3	

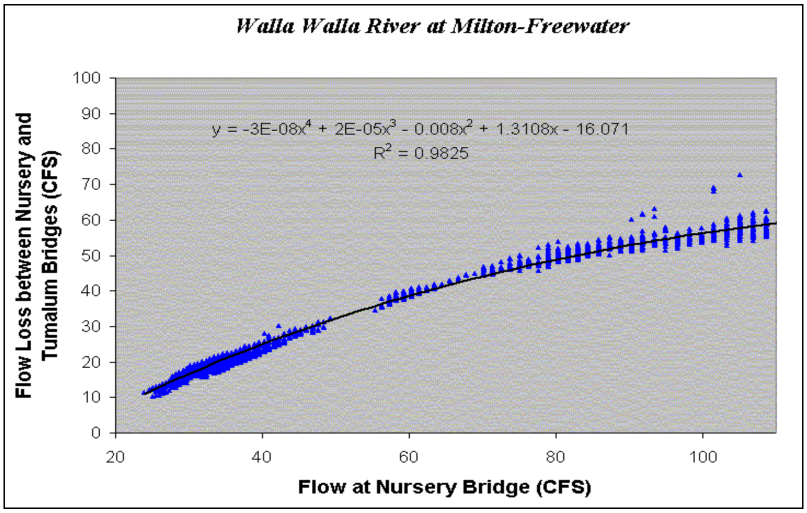


Figure 3-21. *Regression comparing mainstem flow measured at Nursery and Tumalum Bridges (WWBWC and Hudson Bay Company Irrigation District gages).*

The loss of flow between Nursery and Tumalum Bridges in the Milton-Freewater area is clearly bed-loss. There are no diversions within the large Levee encompassing the reach and an obvious insufficiency of vegetation and river length to provide for an evaporation/uptake explanation. There is a culvert input (thought to be a highway project drain) between the gages, but it has been observed that this flow remains constant during the low-flow season at approximately 2 CFS. Loss of mainstem flow is documented by WWBWC from Couse Creek to Tumalum Bridge, typically 13-15 CFS during lowest flow. Through portable flow meter measurements, WWBWC has shown that much of this loss takes place abruptly at a section of the Levee (historic in-stream gravel mining area) roughly one-half mile downstream from Nursery Bridge, though there is documentation that loss occurred prior to quarrying and Levee construction. To better evaluate the loss, the WWBWC installed continuous flow gages at both bridges, approximately two miles apart, bracketing this losing reach. The relationship between the two gages, ***based on preliminary data***, is displayed in **Figure 3-21**. Interpretation can be attempted based on this data and associated historical information, well data and field assessment Levee construction and quarrying apparently penetrated low permeability cemented gravel lenses (still visible), early in the 20th century, exacerbating existing leakage. The underlying coarse gravel aquifer is utilized by numerous wells in the area. Given this withdrawal and/or geologic subsurface loss, during its low-flow the Walla Walla River does not supply enough infiltration to maintain the groundwater table at river level. This accounts for the surface loss.

*In the low-flow season, loss was thought to increases as upstream flow increase (**Figure 3-21)**. Temperature simulations carried out in 2003 & 2004 were based on this. As the preliminary gage data were finalized, it became apparent that the flow loss is relatively constant. DEQ elected not to generate new flow scenarios at this time, deferring to further evaluation and subsequent iterations of the temperature TMDL – an accounting for re-computed loss would not change the allocations, nor would it change the flow profile in much of the Oregon part of the simulations.*

Regardless of the explanation of controlling factors, it is important to account for the loss phenomenon in any assessment of the river's flow potential and management. The large drop in flow apparent in **Figure 3-20** in the vicinity of Nursery Bridge is due to both the bed loss in the quarry area and the Little Walla Walla River Diversion. As described in **Section 2.1.2**, prior to 2001, part of the reach between Nursery and Tumalum Bridges exhibited a dry streambed in mid-late summer, since 1880 or earlier. In-stream flow increase has occurred through irrigation conservation and discussions relating to the threatened status of bull trout and summer steelhead (Endangered Species Act) in the Basin.

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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 one-dimensional (longitudinal) and temporal. Model time and distance steps are 1.0 minute and 100 meters. 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.

Two Calibration Time-Frames
River temperature was simulated for the Walla Walla River and calibrated to August 2000 measured temperatures (in-stream thermistors and thermal infrared flight data). As described in **Chapter Two**, in 2000 and prior river flow was discontinuous in the reach below Milton Freewater and above Tumalum Bridge. In order to model conditions all along the river, the 2000 base model was re-run using August 2002 flow, climate and tributary data.

Overview of Simulation Scenarios
The 2002 simulation is used as the base model for estimating temperature change that would occur given estimated potential future vegetative conditions and channel shape. The 2002 simulation is also used to estimate temperatures for a range of hypothetical flows. Lastly, combination scenarios were simulated, all based on the 2002 model; where temperature was simulated for increased vegetation and a narrower and deeper channel. These conditions were simulated for three hypothetical flow profiles.

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
The analysis was conducted with data input sampling every 25 meters along the stream. The model is calibrated for a 7-Day period as a function of Julian Day, however other periods can be simulated. The selected periods of simulation are August 10-16 in both 2000 and 2002. Simulations were performed for a total of 67 stream miles in the subbasin. **Table 4-1** lists the spatial extent by river system. **Figure 1-2** is a map showing the spatial extent of river simulation.

Table 4-1. *Temperature and Effective Shade Simulation Extent*

Subbasin	River/Stream	Simulation Extent
Walla Walla River Subbasin	Walla Walla River	South Fork to Mouth
	South Fork of the Walla Walla River	Skiphorton Creek to Mouth
		Total Simulation Extent: 67 miles (114 km)

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 potential condition.

Valid Applications

- Estimate current condition near stream land cover type and physical attributes.
- Estimate 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.

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 by 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 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 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 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 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.

4.1.4 Stream Temperature Analysis

Modeling Purpose

- Analyze stream temperature over stream network during low-flow/warm season.
- Analyze 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 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 potential upper range stream temperatures over the stream network.
- Identify site-specific deviations of current stream temperatures from 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., Walla Walla River and the South Fork of the Walla Walla River). Application of the stream temperature output to other streams within or outside of the subbasin is not valid.
- 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.

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 stream temperature for narrow periods of time as a function of Julian Day, however other periods can be simulated. The selected periods of simulation are August 10-16 in both 2000 and 2002 and output data is reliable for the July through August period. 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

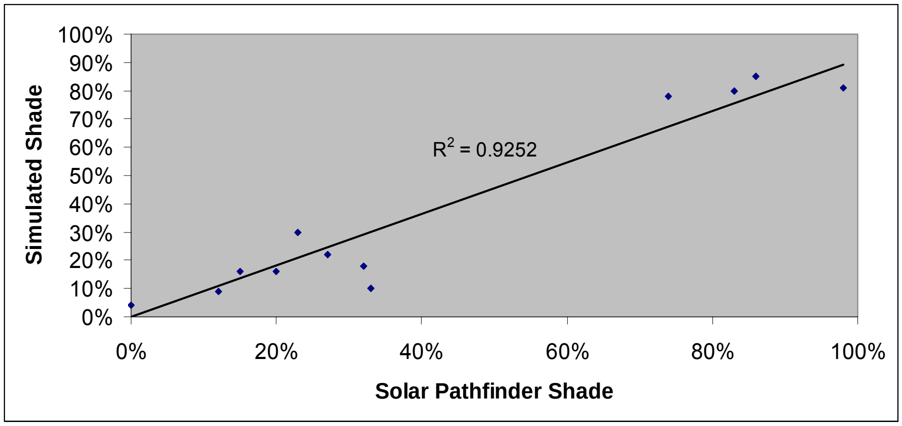
Once effective shade models are developed, potential near stream land cover scenarios are simulated. Potential land cover was estimated as described in **Section 3.3.3**. Six scenarios were modeled: the observed conditions of August 15, 2000 and 2002, and then based on the 2002 calibration – topographic shade only (vegetation removed) with all other inputs unchanged, system potential land cover with all other inputs unchanged, system potential channel width and width/depth with all other inputs unchanged, and the combined effect of system potential land cover and channel morphology with all other inputs unchanged.

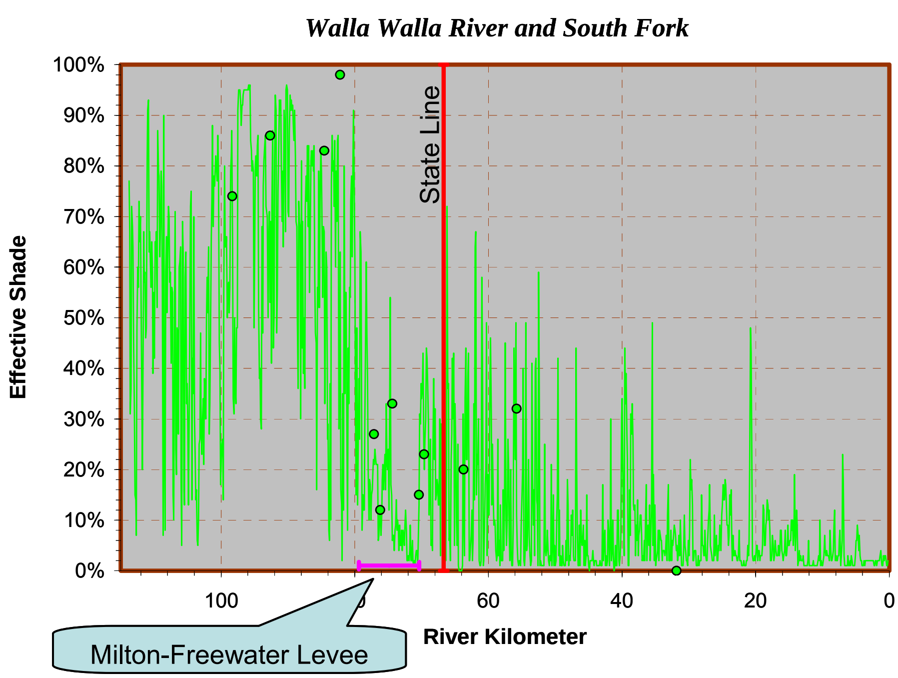
4.2.4 Validation - Effective Shade Simulation Accuracy

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 twelve locations in the Walla Walla Subbasin (**Figure 4-1**). Shade simulations have a standard error of 9.0% when compared to these values. The correlation coefficient between measured and simulated values is high (i.e., R^2 = 0.93).

Figure 4-1. *Comparison between Effective Shade Measurements and August 15, 2002 Simulation Results*

Approximate Location	River KM	Solar Pathfinder Measurement	Heat Source 7.0 Simulation
Harris Park	98.325	74%	78%
Fish Hatchery	92.65	86%	85%
Lower South Fork Highway Bridge	84.55	83%	80%
Mainstem Uppermost Bridge	82.175	98%	81%
0.4 km Upstream from Historic Frasier Farmstead	77.1	27%	22%
0.5 km Downstream from Historic Frasier Farmstead	76.175	12%	9%
Nursery Bridge	74.375	33%	10%
Tumalum Bridge	70.4	15%	16%
0.9 km downstream from Tumalum Bridge	69.625	23%	30%
Last Chance Road	63.725	20%	16%
Swegle Road	55.775	32%	18%
Touchet	31.825	0%	4%

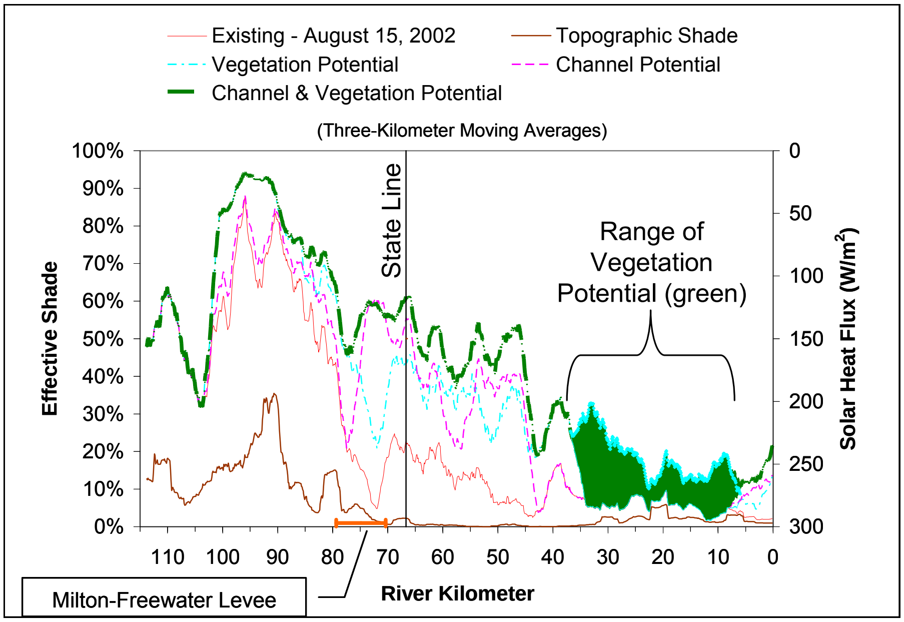




4.2.5 Effective Shade and Solar Heat Flux Simulations

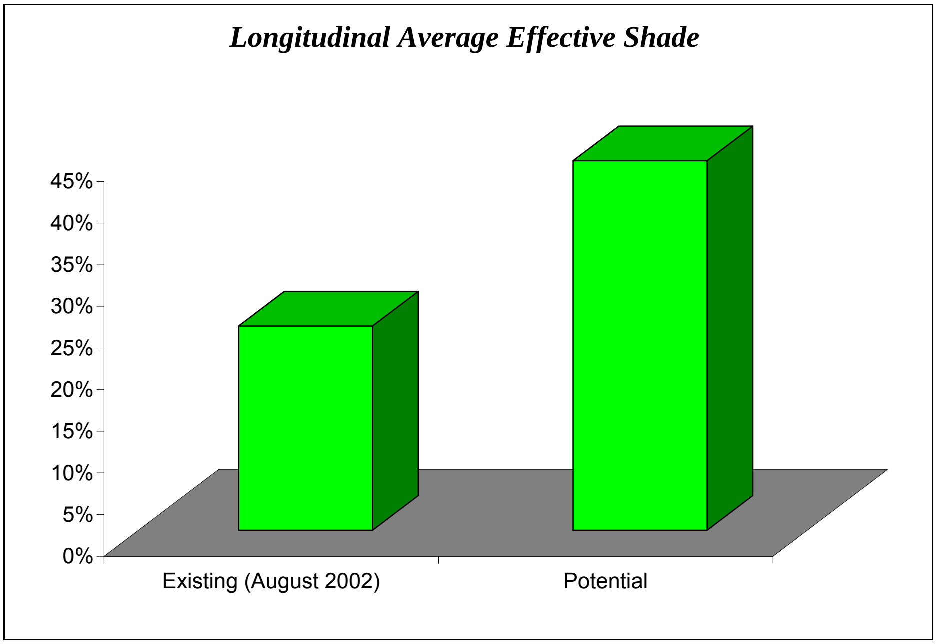
Effective shade was simulated for the rivers where near stream land cover was digitized. **Figure 4-2** display the current condition effective shade levels (August 15, 2002) and the various shade scenarios that were simulated. As previously mentioned, effective shade is inversely proportional to solar radiation flux. The following chart present effective shade on the left-hand axis and solar loading on the right-hand axis.

Figure 4-2. Simulated *Effective Shade and Solar Heat Flux. Refer to **Figure 2-5** for river miles and additional location reference.*



The following is a brief discussion of existing and potential shade patterns as seen in **Figure 4-2**. The effective shade simulated output for August of both 2000 (not shown) and 2002 are essentially the same, except that the simulation was not performed for 2002 where flow was too low for temperature modeling, between Nursery and Tumalum Bridges. Generally, effective shade decreases in the downstream direction, due to valley relief, channel widening and an overall trend of lower vegetation height. The topographic shade simulation indicates that topography makes up a significant part of effective shade in the upper reaches of the South Fork. In the order of generally increasing shade, the next scenario above topographic shade in **Figure 4-2** is the measured condition in the summer of 2002. The upper South Fork is considered at potential as discussed previously, and has lower shade than the mid-South Fork due to aspect, valley wall proximity and the predominance of conifers in the upper basin (less dense and less overhanging foliage). Effective shade decreases rapidly in the Milton-Freewater Levee due to aspect, limited vegetation and a wide channel. Shade increases below the Levee though the river is unusually wide, first due to increased vegetation and then aspect change as the river turns westward. At Lowden (river mile 27, ~km 44) and continuing downstream, shade values are low because tall vegetation is sparse and hills are distant. Next, vegetation potential was simulated, with all other input variables unchanged. Note that there is a range shown along the lower river, to account for the uncertainty in potential vegetation in that area (refer to **Section 3.3.3**). Showing similar reduction in solar input, a narrower channel potential was simulated, again with all else held constant. Finally, effective shade was simulated with channel and vegetation at potential. This scenario is indicative of an approximately natural condition in terms of solar heat input. For comparison, **Figure 4-3** depicts the longitudinal average effective shade for this scenario and the relatively current condition of August, 2002. ***Potential channel width and depth, vegetation and flow were simulated along the entire length of the Walla Walla River and the South Fork up to Skiphorton Creek.***

Figure 4-3. *Average simulated effective shade data - Current condition and system potential condition.*



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).

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

System potential levels of solar heat estimate the portion of the total daily solar heat load that occurs when nonpoint sources of heat are minimized. This condition, ($H_{solar}^{potential}$), is calculated by substituting the system potential daily solar flux and the system potential 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 system potential 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 system potential total daily solar load. Derived total daily solar loads for ***background*** sources (no human caused heating = system potential heat load) and anthropogenic nonpoint sources are presented in **Figure 4-4**.

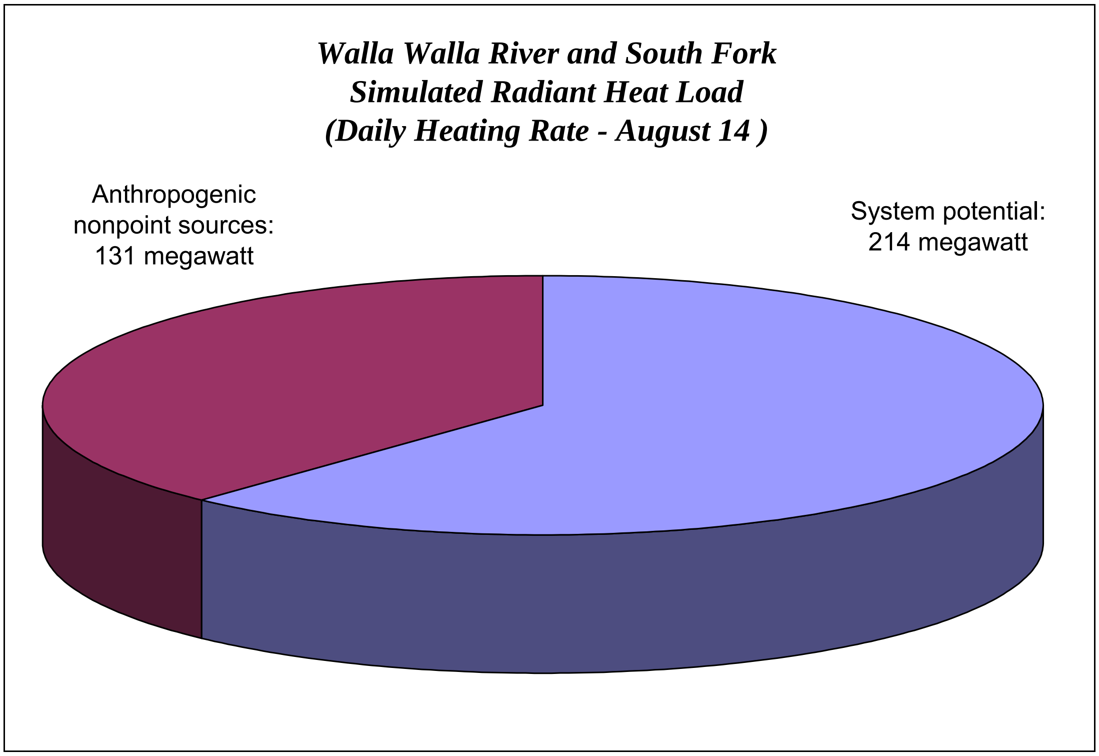
$$H_{solar}^{anthro} = H_{solar} - H_{solar}^{potential}$$

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)

Roughly **thirty-eight** percent of the solar loading that occurs in the Walla Walla River and the modeled part of the South Fork is from anthropogenic nonpoint sources, while the remaining proportion of the total daily solar load originates from background sources (see **Figure 4-4**). *For the purposes of this analysis heat loads are calculated from simulated current and system potential conditions.* For Oregon part of the same simulations, **fifty-one** percent of the solar loading is anthropogenic. This is largely because vegetation height and channel width make a larger difference on a smaller river.

Figure 4-4. *Total daily solar heat load for anthropogenic nonpoint and background sources, derived as the 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 Walla Walla 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 system potential 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 the height listed on the figure, due to the narrow shape of individual trees – this has been accounted for in the shade model input). The type of vegetation characterized by the heights in the shade curves is identified in **Section 3.3.3** (**Table 3-3**), as is the geographic application of each curve (**Figure 3-19**). The final set of curves in **Figure 4-8** is for cottonwood galleries. Because galleries are interspersed across much of the basin and provide distinctive shade levels, it seemed logical to describe them separately from the zones they occur in. Along the mainstem and lower South Fork, cottonwood galleries occur intermittently throughout, except for the area between river mile 8 and 23 (~km 13 and 37), as discussed previously.   Their potential occurrence was determined using existing locations and the nearest neighbor approach referred to in **Section 3.3.3**.

Figure 4-5 displays the shade curves for potential land cover types. This methodology provides effective shade targets for the un-simulated streams of the Walla Walla Subbasin in Oregon. The shade curves demonstrate the relationship between near stream land cover physical properties, channel width and stream aspect. Not being location specific, topography is not accounted for; as such a stream may manifest higher levels of shade than indicated by these curves.

Figure 4-5 (3 pages). *Effective Shade Curves. Captions are color coded corresponding to* ***Table 3-3*** *and* ***Figure 3-19*** *where vegetation potential types and locations are identified.*

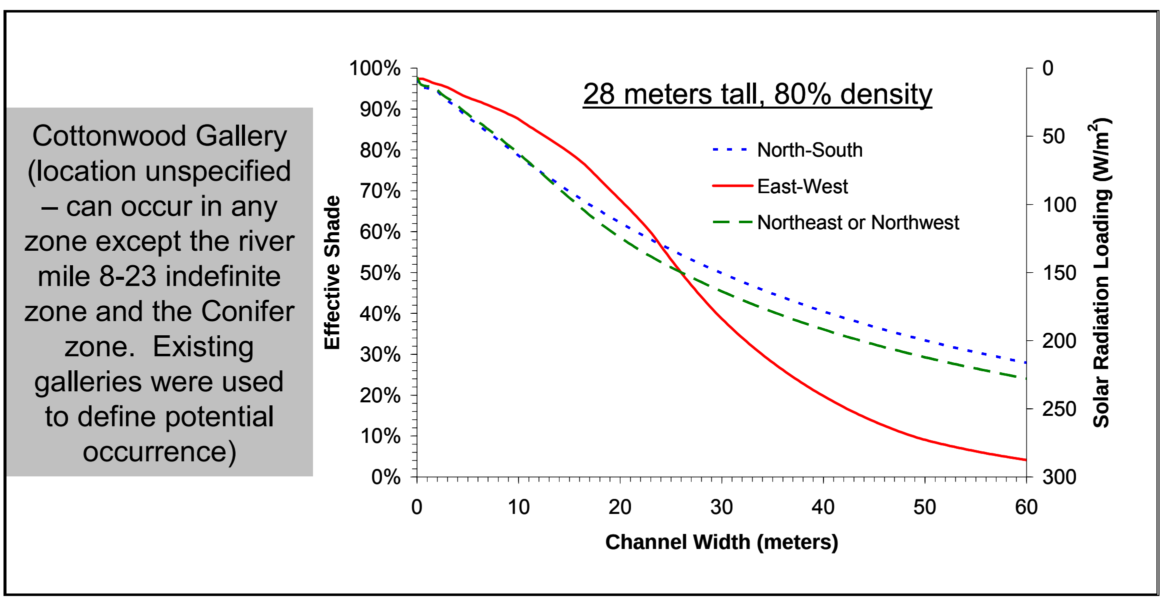


Figure 4-5 (continued). *Effective Shade Curves*

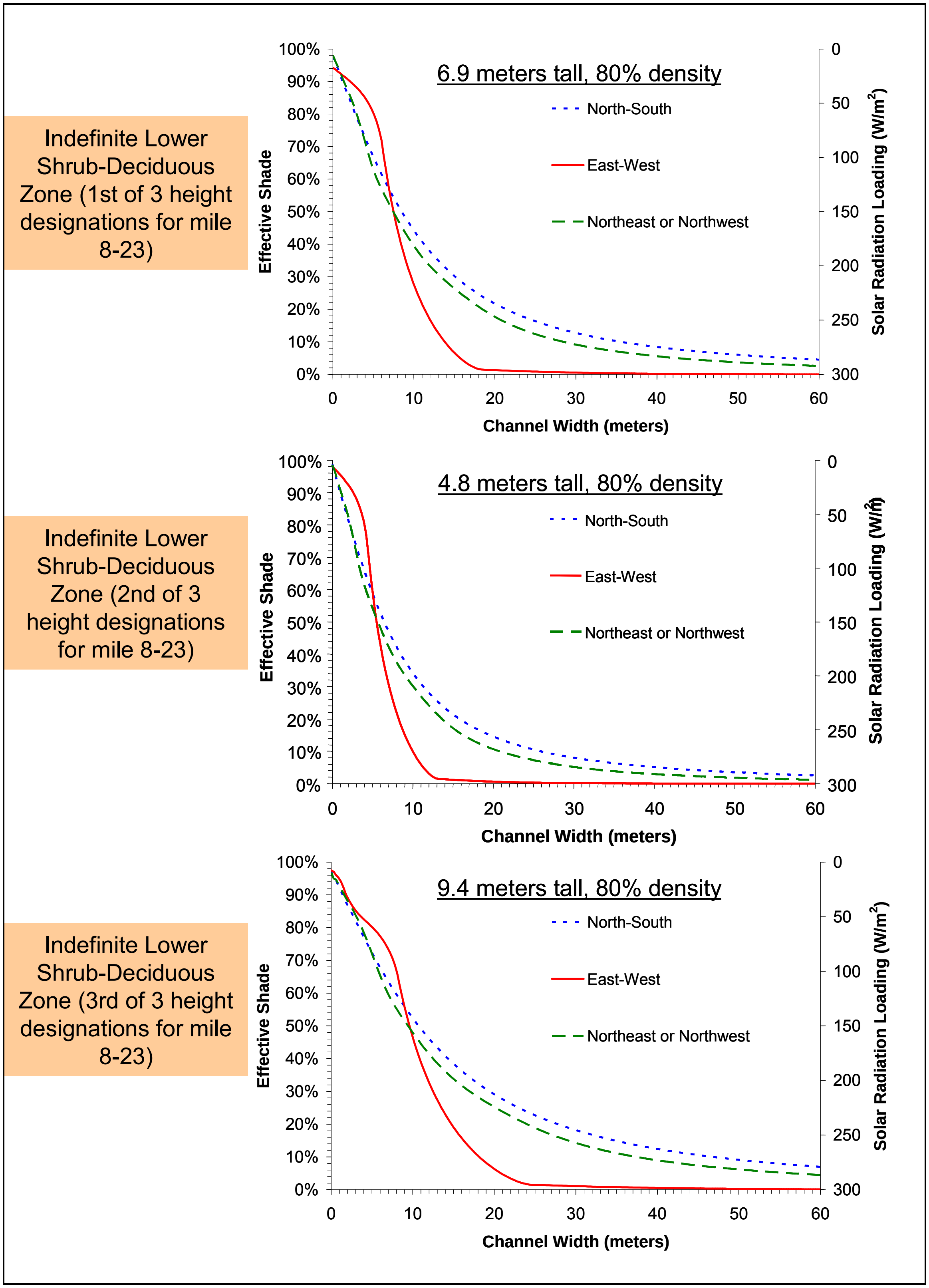
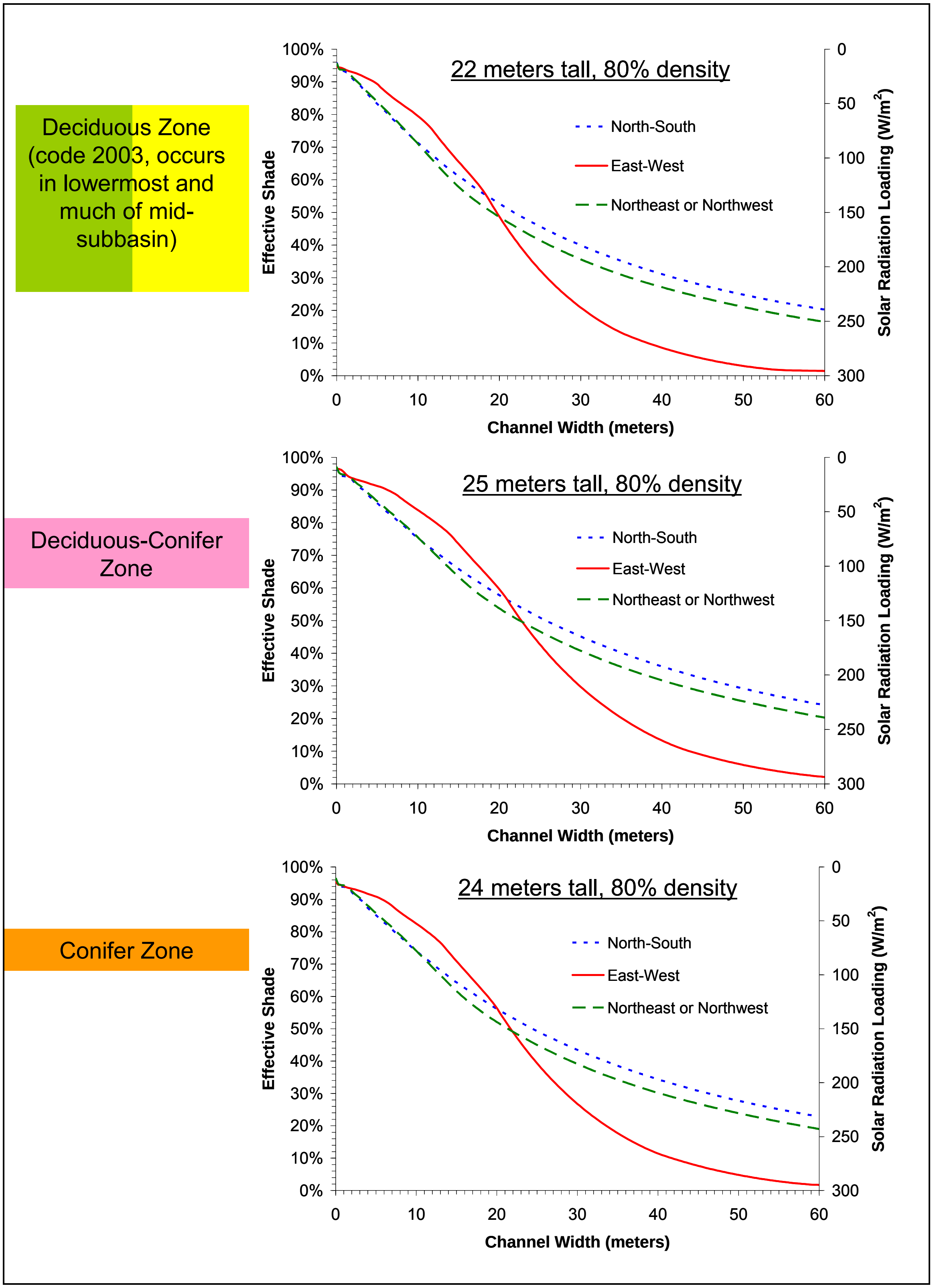


Figure 4-5 (continued). *Effective Shade Curves*



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 Walla Walla 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, Kasper, 2003).

4.3.2 Simulated Scenarios

Once stream temperature models were calibrated, several scenarios were simulated by changing one or more stream input parameters. The simulated scenarios focus largely on defined potential conditions for land cover and derived in-stream flow described in previous sections of this report. Combinations of these potential conditions are also simulated to investigate the cumulative thermal effect of attaining defined conditions.

Table 4-3. *Simulated Scenarios – single condition change*

Existing Condition of 2000	August 10-16 2000
Existing Condition of 2002	August 10-16 2002
Potential Vegetation	Potential Near Stream Land Cover (Vegetation)
Potential Channel	Potential Channel Width
Various Flow Profiles (flow volume referenced at Nursery Bridge in Milton-Freewater, OR)	Flow Profiles were developed as described in **Section 3.5**, 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 (flow was not changed). Temperatures of Yellowhawk Cr, Mill Ck and Touchet River were reduced by: 4.2, 1.6, 1.4 ºC; preserving the existing 3:00 PM, August 15 difference between the tributary mouths and the mainstem.

Table 4-4. *Simulated Scenarios – Combined conditions change*

Potential Vegetation, Channel at August 15, 2002 Flow	Potential Near Stream Land Cover (Vegetation) ***and*** Channel Width, at August 15, 2002 flow.
Potential Vegetation, Channel and 45 CFS at Nursery Bridge	Potential Near Stream Land Cover (Vegetation) ***and*** Channel Width, and 45 CFS at Nursery Bridge (flow scenario shown in **Section 3.5**).
Potential Vegetation, Channel and 100 CFS at Nursery Bridge and increased Tributary Flow	Potential Near Stream Land Cover (Vegetation) ***and*** Channel Width, and the 100 CFS (at Nursery Bridge in Milton-Freewater) plus increased tributary flow scenario described in **Section 3.5**.

4.3.2.1 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.

4.3.2.1 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 FLIR derived spatial temperature data sets and in-stream temperature recorder data sets. Each measurement of temperature is discrete and is used to assess model accuracy. Simulation outputs are only accurate to levels that exceed the validation statistics. A statistically significant simulated result is one that produces a temperature change greater than validation statistics listed in **Table 4-5**.

Stream temperatures derived from FLIR data offer an extremely robust validation data set for spatial stream temperature simulation tools. Since the FLIR temperature data is spatially continuous, the number of simulated temperatures available for model validation is limited to model resolution. With FLIR temperature data, the spatial scalability for any given methodology is unlimited by validation data. This represents a significant improvement over previous data sources.

Spatial and temporal data is stratified in the validation to test for biases in the simulation methodology. Since FLIR temperature data sets are robust spatially, there is a possibility that the simulation could be calibrated to the specific time when FLIR data was obtained, yet perform poorly for other periods of the day. However, validation statistics demonstrate that this is not the case. **Table 4-5** displays the validation results for each simulated stream and river in the Walla Walla Subbasin.

Table 4-5. *Stream Temperature Simulation Validation. The year 2000 simulation is divided into the sections above and below the dry reach downstream from Milton-Freewater. This table compares simulated and measured temperature.*

	Validation Statistic	Walla Walla River and South Fork, 8/15/2002	Walla Walla River and South Fork, 8/15/2000, above Nursery Bridge	Walla Walla River, 8/15/2000, below Tumalum Bridge
Temporal In-stream Data (In-stream Data Loggers)	Samples (n)	940	652	376
	Standard Error (°C)	0.6	0.54	0.8
Spatial Data: FLIR (2000), In-stream Data Loggers (2002)	Samples (n)	21	398	641
	Standard Error (°C)	1.1	0.3	0.4

Figures 4-6 and **4-7** display the calibrated model longitudinal temperature results. The 2002 model, though having less calibration resolution due to the lack of FLIR data, is utilized for the various predictive scenarios because river flow was longitudinally continuous that summer, enabling un-interrupted simulation of heat and temperature. The 2002 model is based on the 2000 model in that it utilizes year 2000 riparian and morphologic input, modified only slightly for vegetation growth. Bed roughness and channel side-slope refinements were made to account for the newly calibrated intermittent reach below Milton-Freewater. For the later simulation, climate, mainstem flow, tributary mouth flow and temperature, validation temperatures, and to some extent groundwater inputs for the later model are based on 2002 assessment. Channel width, Manning's n, vegetation inputs, are largely the same as for the 2000 simulation. The same time-frame is used and similar withdrawal patterns are assumed. Accordingly, the 2002 model carries the finely-patterned temperature profile enabled by FLIR. This is consistent with similarities in multi-year FLIR patterns seen in other rivers. The model temperature profile for 2002 was compared with 2000 FLIR patterns and with FLIR data from a 2003 Walla Walla River flight, confirming that the longitudinal patterns are quite similar. **Figures 4-8** through **4-11** portray the temperature simulations, longitudinally, for the various model scenarios described in **Tables 4-3 and 4-4**. Some of the scenarios in **Figures 4-8** through **4-10** exhibit a graphically discernable band-width or range of temperatures. This is due to the uncertainty of vegetation potential in the lower basin, as described in **Section 3.3.3** and as shown in **Figure 4-2**.

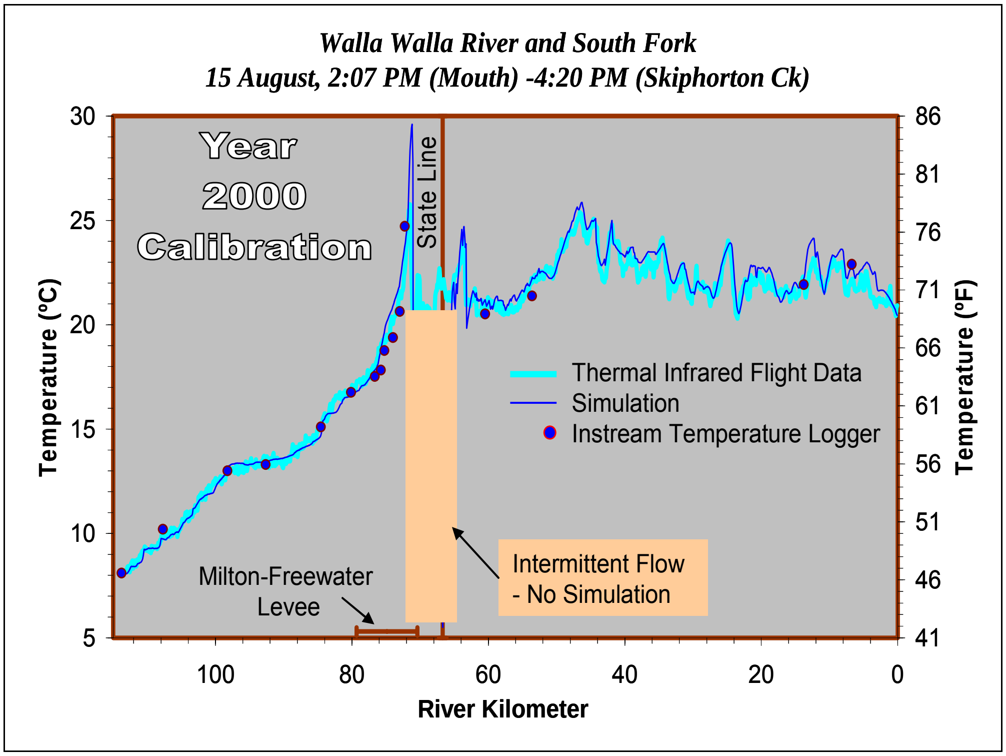


Figure 4-6. *August 15, 2000 Stream Temperature Simulation Calibration*

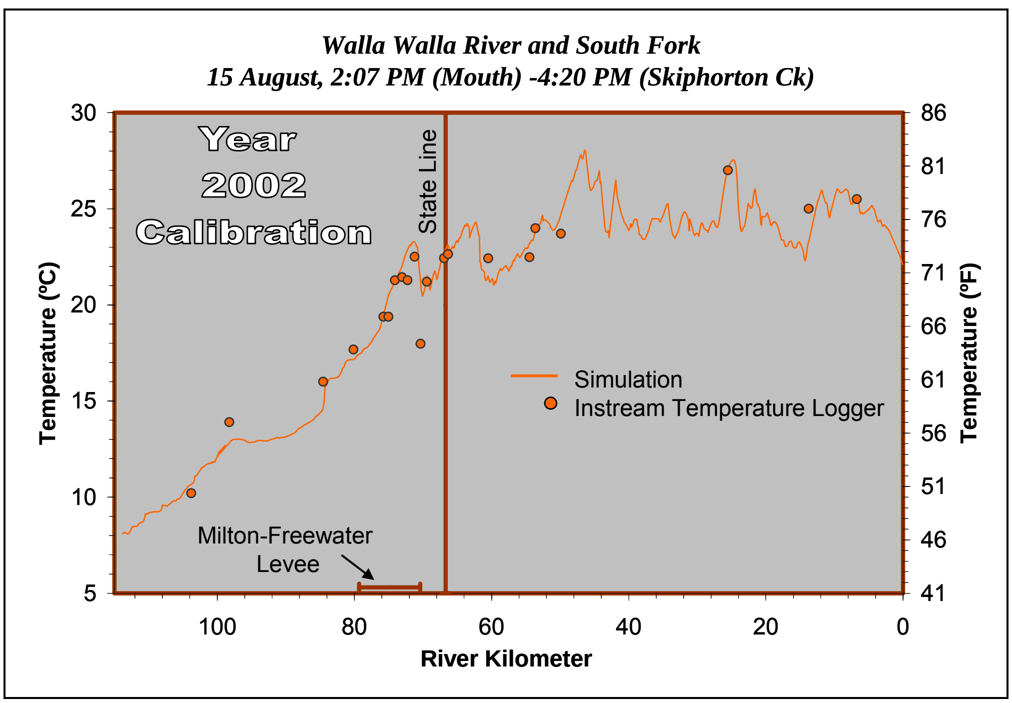


Figure 4-7. *August 15, 2002 Stream Temperature Simulation Calibration*

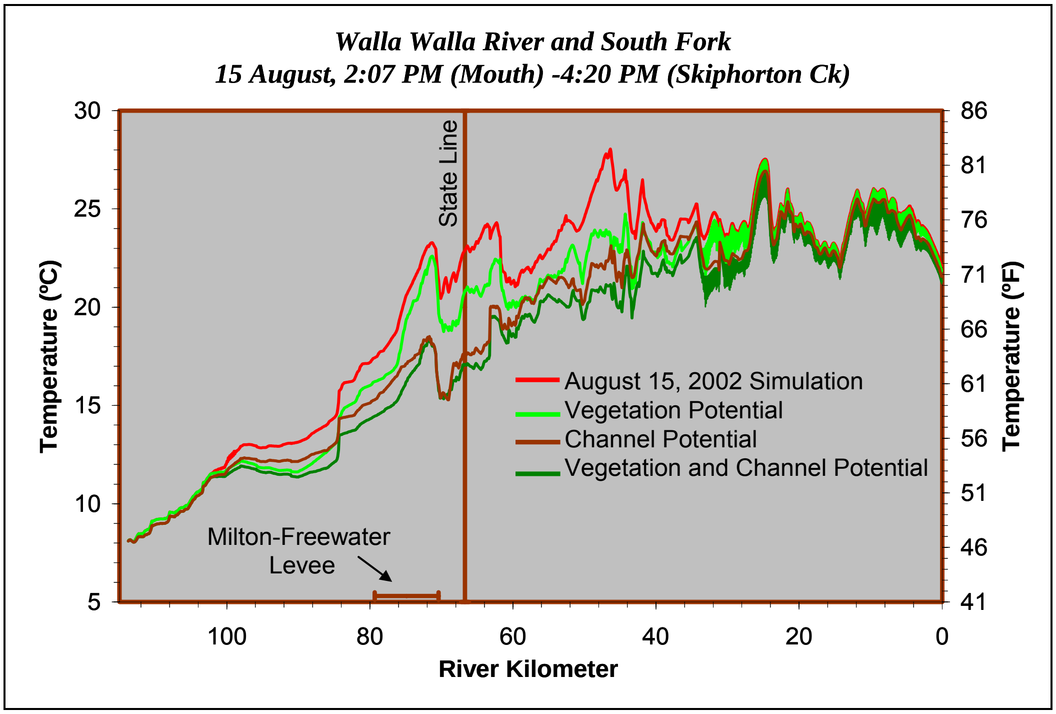


Figure 4-8. *Longitudinal temperature simulation results for existing, vegetation and morphologic scenarios. Each is based on August 2002 flow.*

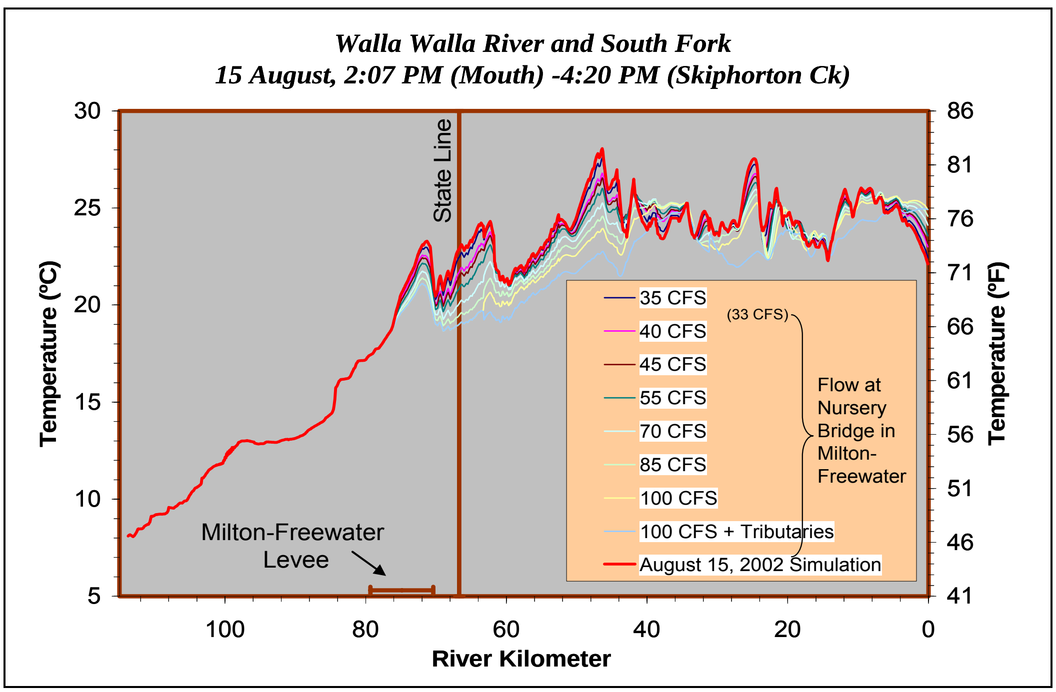


Figure 4-9. *Longitudinal temperature simulation results for various in-stream flow scenarios. Discharge profiles are displayed in* ***Figure 3-21***.

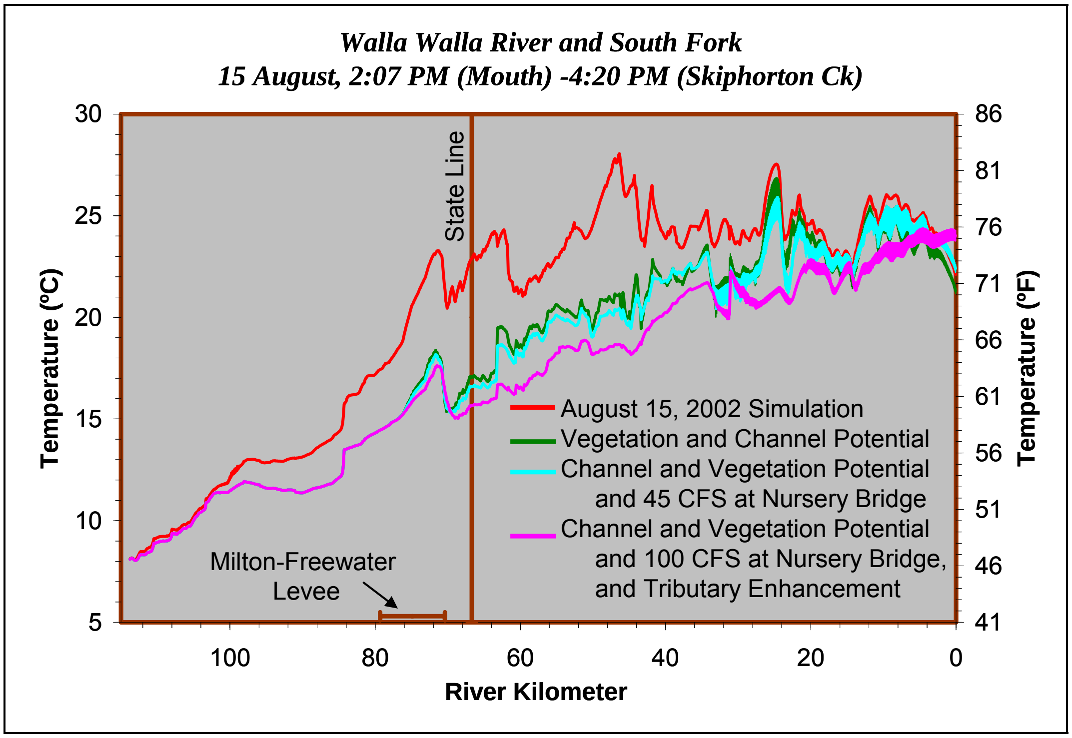


Figure 4-10. *Longitudinal temperature simulation results for vegetation and morphology combination scenarios at selected flow levels. Discharge profiles are displayed in* ***Figure 3-21****.*

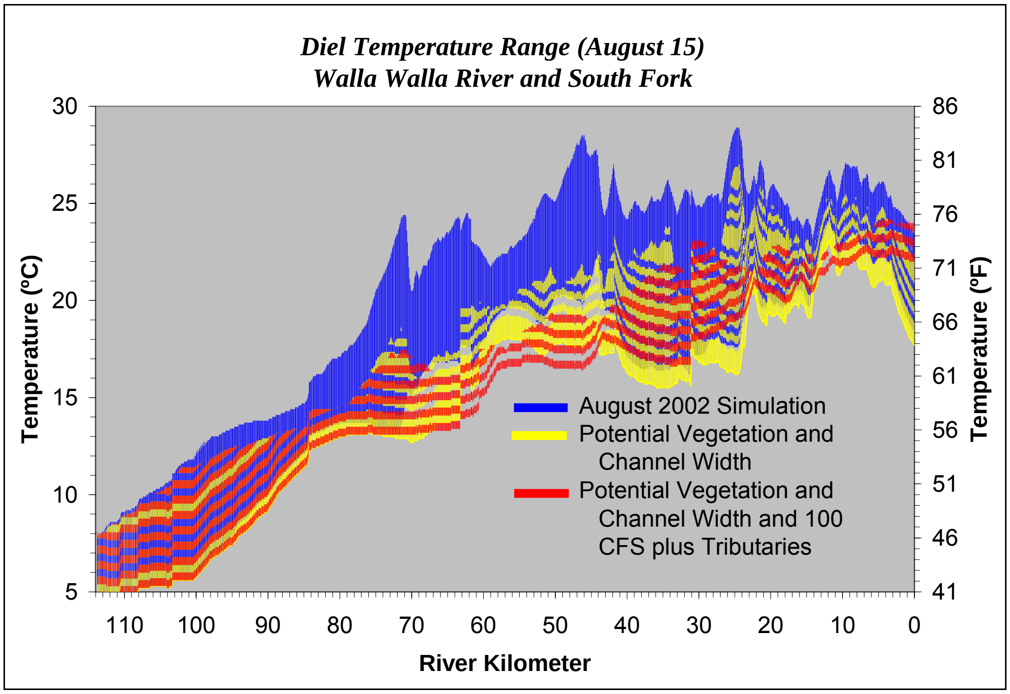


Figure 4-11. *Diurnal range temperature simulation results, including August 2002 and two potential scenarios. The two 'potential condition' scenarios are the first and third listed in* ***Table 4-4****. Discharge profiles are displayed in* ***Figure 3-21.***

4.4 Stream Temperature Distributions

Maximum daily stream temperature distributions are presented in **Figures 4-12** and **4-13**. Currently 68% of the modeled river length in the Walla Walla Subbasin exceeds 18°C (64.4 °F). Under system potential land cover and channel width, only 57% of the simulated stream segments exceed 64.4°C. This percentage decreases to 49% if in-stream flow was substantially increased. The most dramatic spatial temperature reduction occurs at about 22.2 ºC (72 ºF). Forty-two percent of the simulated stream length is currently at 22 ºC (71.6 ºF); whereas at system potential conditions, with high flow, 84% of the river is less than 71.6 ºF. For reference, temperatures that are generally protective of salmonid rearing and migration are around 17.8 ºC (64 ºF), and sublethal temperatures for chinook salmon and steelhead are 25 ºC (77 ºF) and 25.6 ºC (78 ºF), respectively (Brett, 1952; Hokanson et al., 1977; OAR 340-041).

An overriding emphasis of this analysis is the focus on spatial distributions of stream temperatures in the Walla Walla Subbasin. Comparisons of stream temperature distributions capture the variability that naturally exists in stream thermodynamics. Spatial variability is observed in all of the stream segments sampled and analyzed. With the advent of new sampling technologies and analytical tools that include landscape scaled data and computational methodologies, an improved understanding of stream temperature dynamics is emerging (Boyd, 1996, Faux et al. 2001, Torgersen et al., 1995, Torgersen et al., 1999, Torgersen et al., 2001, DEQ 2000a, DEQ 2001a, DEQ 2001b, DEQ 2001c, DEQ 2002). This understanding accommodates spatial and temporal variability that includes departures from biologically derived temperature threshold conditions.

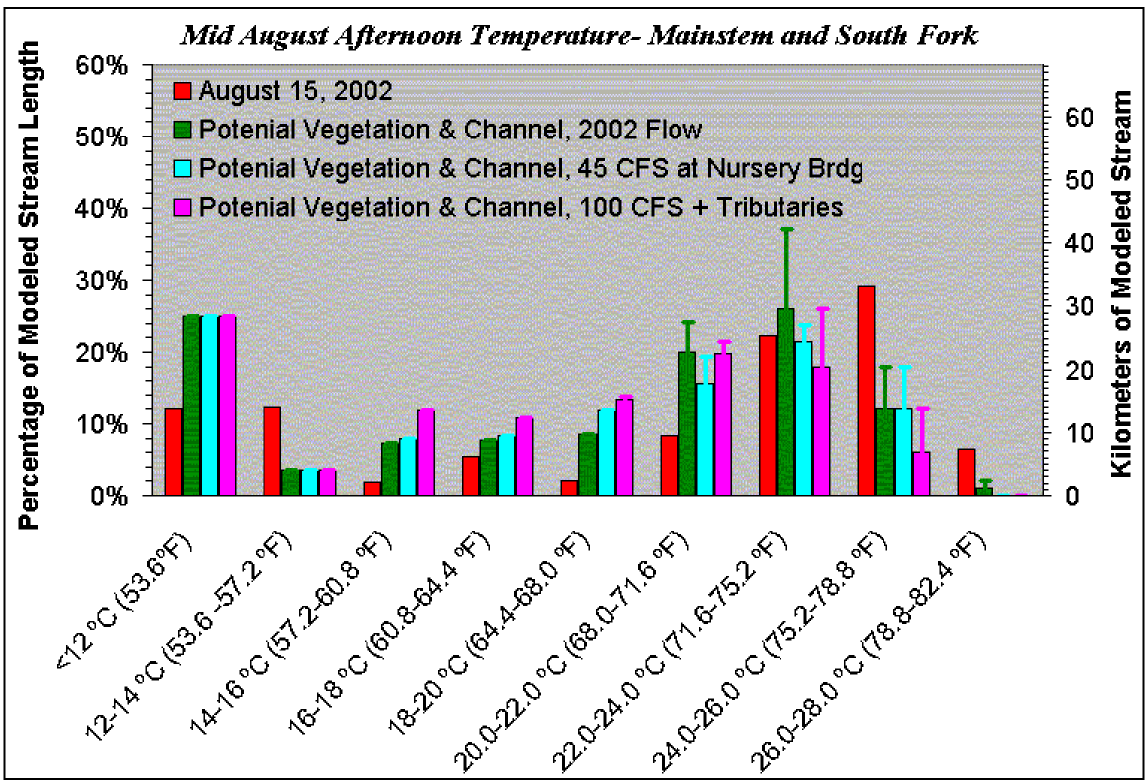


Figure 4-12. *Spatial temperature distribution for modeled stream segments. The tails on the graph bars illustrate a range due to the uncertainty in vegetation potential in the lower Basin.*

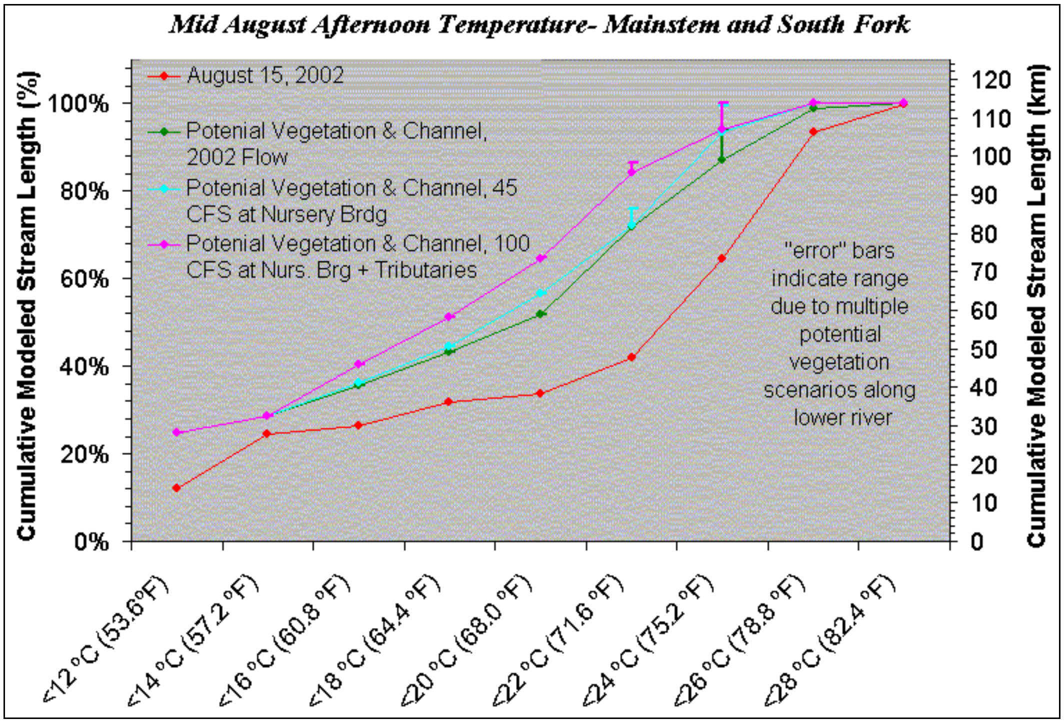


Figure 4-13. *Cumulative spatial temperature distribution for modeled stream segments*

CHAPTER 5. SEASONAL VARIABILITY

Current seasonal patterns are portrayed and compared to Oregon water quality standard biological criteria in the following figures. **Figures 5-1** and **5-2** show mainstem and South Fork annual patterns of daily maximum temperature for 2000 and 2002, respectively. The 16 ºC biological criterion for core cold water habitat applies throughout the Oregon mainstem drainage area year round, except where and when superseded by the lower temperature bull trout and salmonid spawning biological criteria in specified months or geographic areas. **Figures 5-3** and **5-4** display seasonal patterns from both model years. **Figure 5-3** illustrates the salmonid spawning criteria of 13 ºC in relation to data from the area of recognized spawning potential (above the Oregon-Washington state line on the mainstem). The spawning potential time frame is from January 1 to June 15. Bull trout spawning and rearing criteria are also shown. **Figure 5-4** data are from sites where the Bull Trout criterion is applicable (roughly above Cemetery Bridge in Milton-Freewater).

Clearly the biological criteria are currently exceeded. It is important to recognize that in addition to the biological criteria, the Oregon water quality standard for temperature includes superseding natural condition criteria - applicable when natural temperatures are greater than the biological criteria. The simulations of **Figure 4-10** demonstrate that system potential temperatures, reflecting more natural conditions, parts of the mainstem and South Fork exceed the biological criteria. Therefore it is expected that *natural condition* is the applicable criteria for the Walla Walla Subbasin TMDL. Further discussion of this can be found in **Part One** of this document.

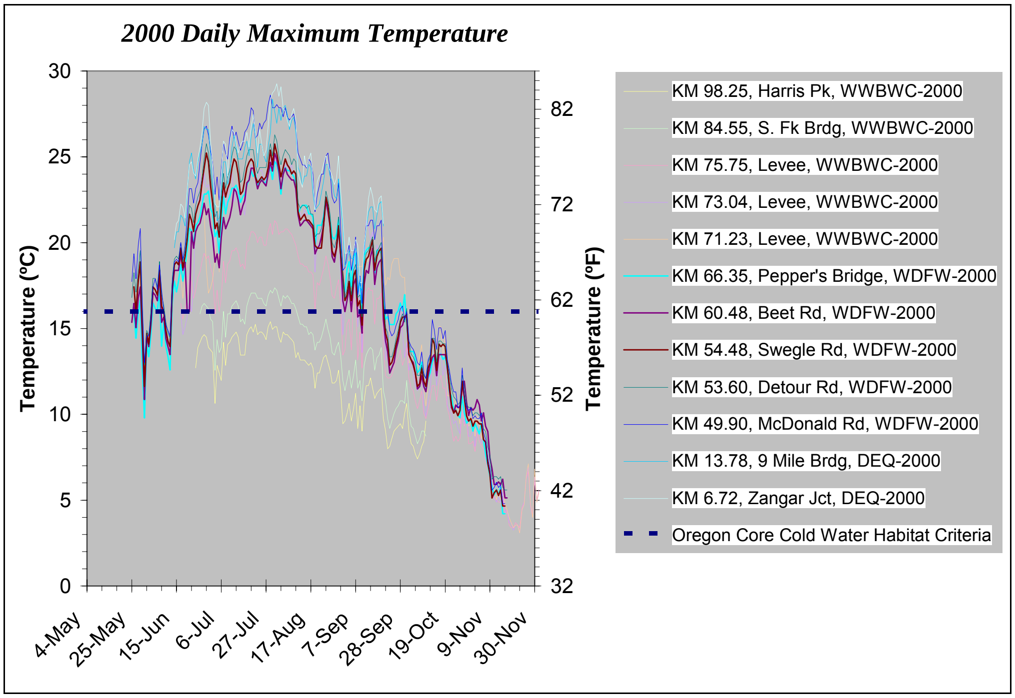


Figure 5-1. *Mainstem and South Fork seasonal pattern of daily maximum temperature for 2000. The core cold-water habitat biological criterion from Oregon's temperature standard is displayed.*

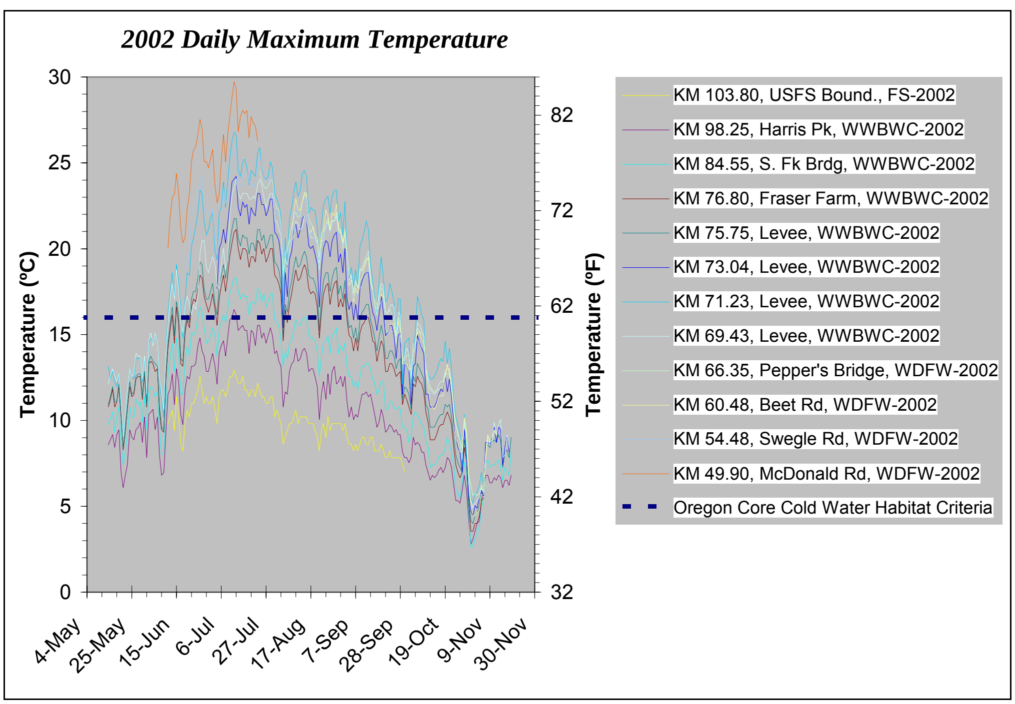


Figure 5-2. *Mainstem and South Fork seasonal pattern of daily maximum temperature for 2002. The core cold-water habitat biological criterion from Oregon's temperature standard is displayed.*

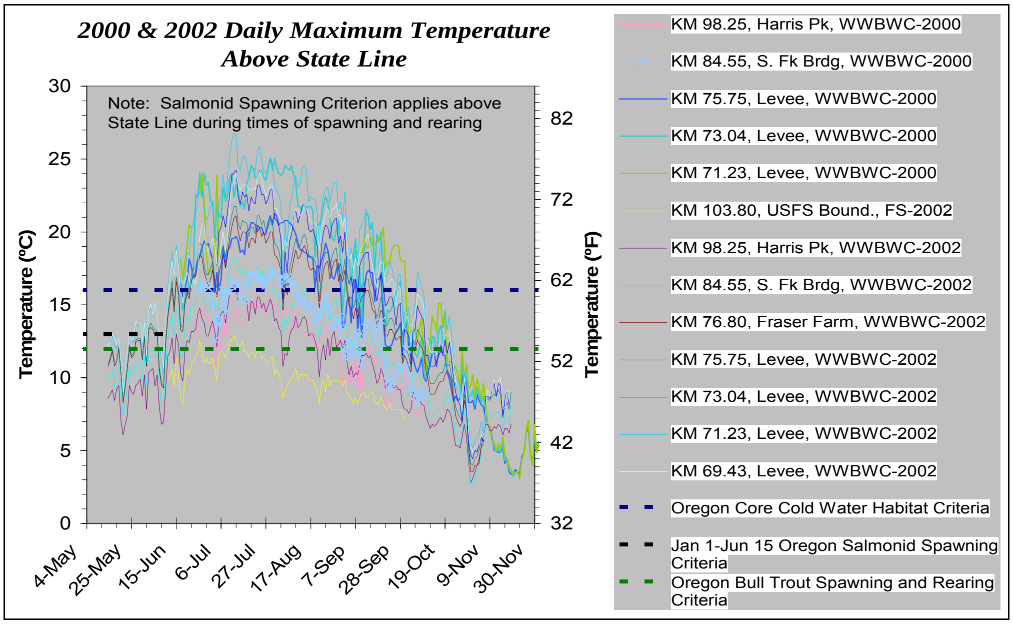


Figure 5-3. *Mainstem and South Fork seasonal pattern of daily maximum temperature for 2000 and 2002. Data representing the area of Oregon temperature standard spawning criterion applicability are shown, along with the criterion.*

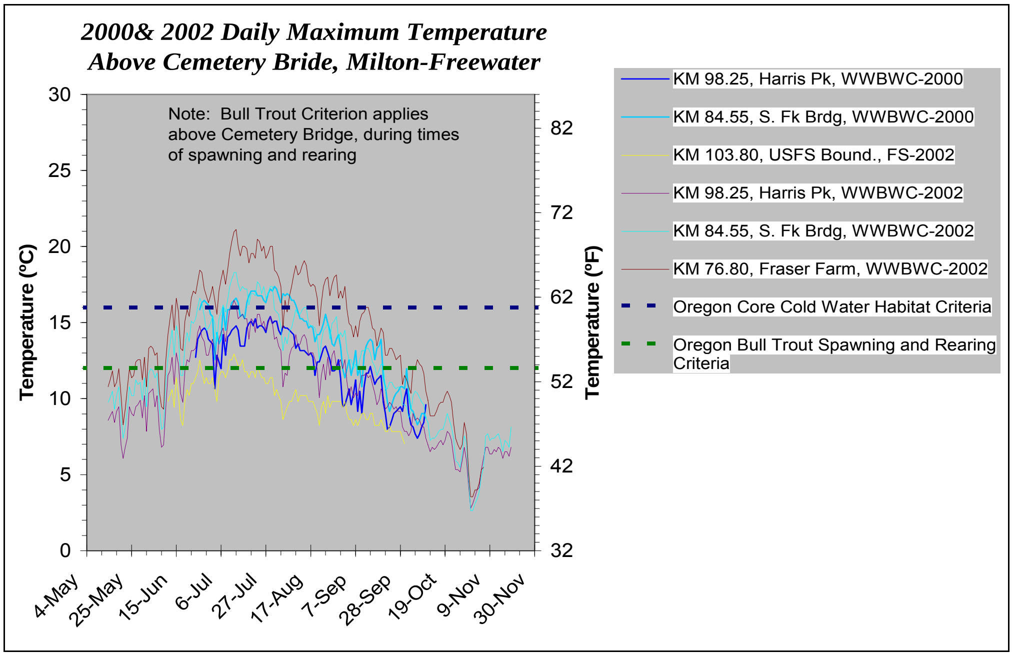


Figure 5-4. *Mainstem and South Fork seasonal pattern of daily maximum temperature for 2000 and 2002. Data representing the area of Oregon temperature standard bull trout spawning and rearing criterion applicability are shown, along with the criterion.*

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Additional Annotated References – Historical Conditions and Vegetation

Vegetation Historical Data Review, Bob Bower, WWBWC

6/4/02

Purpose: To document early historical accounts of riparian vegetation along the Walla Walla River and adjacent valley.

Outline: A full bibliography of relevant historical documents. A time line laying out historical information as it relates to the riparian area. A supporting paper laying out the history from the review of the historical documents.

List of sources of information and references:

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Cecil S.G. Cummings, My life in the Walla Walla Valley, Whitman Library (Call # E897.w2.C8)
Simpson Report 1829. Whitman Library
Historical Aerial Photographs, 1939, Whitman Library Archives.
Journal of David Douglas, 1923-1827 (Botanist who toured the

Contact Washington State Preservation Office.
Fort Walla Walla Museum
Whitman Mission Museum
Whitman Library Archives (basement)

From Cecil Cummings "My life in the Walla Walla valley". Whitman Library 1974

Beaver actively trapped …beavers created habitat through ponding… etc creating channel incision

1818 Fort Nez Perce Built near mouth by Northwest Fur Company

1821 Fort Walla Walla taken over by Hudson Bay Company

- 1910-13 Concrete dam put in (Attalia ditch) on Walla Walla River (photograph) dam and ditches supplied water for people and irrigation (Wallula)
- McNary Dam (page 124) information on construction.

Old Walla Walla County Volume I. Lyman Whitman College: Nwest F 897.W18L92 vol.1 copy 1

- Chapter I:
  - 1918 (Precipitation) 31 years of record prior to 1918 at City of Walla Walla. (17.37 inches average in these 31 years)
  - Page 38: "In the general journal, called the Edition of 1814, in which the contributions of all the party are merged, there seems to be some confusion as to the mouth of the Walla Walla River." The record mentions an island near the right short fourteen and ½ miles from the mouth of the Lewis River and a mile and ½ beyond that of small brook under the high hill on the left, 'seeming to run its whole course through the high country.' This evidently must be the Walla Walla River, though it can hardly be called a "small brook", even in the low season, and it flows quite distinctly in a valley, through the highlands begin immediately below."
  - Lewis/Clark on the way back: "Reaching the country of the 'Wallawollahs,' they again came in contact with… Yellept…. They found themselves on the Wallawollah. They do not now describe it as before as a "small brook", but as a handsome stream, about fifty yards wide and four and half feet in depth."
  - April 30, 1806 the party turned their horses heads' eastward up the Wallawollah River across sandy expanses, which, however they soon discovered to improve in verdure <u>and in groves of trees</u>." Having followed the main stream fourteen miles, they reached "a bold, deep stream, about ten yards wide, which seems navigable for canoes.". They found a profusion of trees along the course of this creek and were delighted to see all the evidences of increasing timber. This stream, which they now followed for a number of miles, was evidently the Touchet, and the point where they turned to follow it was at the present Town of Touchet. Their course was up the creek for about twelve miles to a point where the creek bottom widened into a pleasant country two or three miles in width. … Bolles Junction… "Of all the Indians whom we have met since leaving the United States, the Wollawollhas were the most hospitable, honest and sincere."
  - Fur Traders: Hudson Bay and Northwesterners
      - Prior to Lewis and Clark
  - 1790-1818 were 108 American Vessels working the Oregon Coast
  - Alexander Ross: (Clerk for Hudson Bay Company) Wrote: "Adventures of the first settlers on the Oregon and Columbia River:
    - July, 22, 1811 – start of first journey into the interior.
    - "Passing through the "colonnade rocks," the party soon found themselves at a bluff where there "issues the meandering Walla Walla, <u>a beautiful little river, lined with weeping Willows."</u> Here they found a great concourse of Indian's "Walla Wallas, Shaw Haptens, and Cajouses, altogether 1,500 souls." …." The plains were literally

covered with horses, of which there could not have been less than four thousand in sight of the camp."

- Ross Cox gives an interesting account of his journey from Astoria to Spokane in 1812. … commends the Wallah Wallah Indians for honesty … He describes the immense numbers of rattle snakes around the mouth of the Wallah Wallah

- Circa 1850s
  - The Valley of Waters must have been at that time, a genuine Indian paradise. The broad flats of Mill Creek and the Walla Walla were covered with grass and spangled with flowers. Numerous clear cold streams, gushing in springs from the ground and overhung by birches and cottonwoods, with wild roses drooping over them, made their gurgling way to a junction with the creek. Countless horses grazed on the bunch-grass hills and farther back in the foothills there was an abundance of game.

- March 3rd 1853 Territory of Washington Created – Old Walla Walla County formed.
- 1845-55 Indian Wars
- Another Indian War in 1877

Simpson Report 1829, p 51. Cayuse "as their country is becoming exhausted by the ravages of our won and the American trappers, the annual return must soon diminish rapidly. (referring to beaver populations).

Waiilatpu means "the place of rye grass

Cattle and Sheep introduced circa 1860s for support of mining workers. Settlers brought some before that date.

"Walla Walla ...the name is commonly supposed to mean the "Valley of Waters, " referring to the numerous springs in the vicinity of the city. The author has been told by "Old Bones", an Indian of the Cayuse tribe who lived for many years near Lyons Ferry on Snake River and was known to all old-timers, that the name was understood by the natives to signify that section of country below Waiilatpu, "where the four creeks meet;" viz. the Walla Walla, Touchet, Mill Creek, and Dry Creek. The Walla Walla above that point commonly known to the Indians as "Tum-a-lum".

Among others, Joaquin Miller, "Poet of the Sierras," insisted that when the French voyageurs first looked down from the Blue Mountains ("Les Montagnes Bleues" in their Gallic speech) upon the fair fertile valley, they exclaimed "Voila Voila! (Behold Behold!) and thus the name became fixed. This fantastic idea is easily disproved by the fact that Lewis and Clark, who entered the country by the Snake River, got the name from the Indians on the Columbia near the mouth of the Walla Walla.

Mill Creek was referred to as "Pasha" (also spelled Pashki, Paskau, Pashkee) which seems to signify "sunflower". Also a name was Imachacha.

From *The Walla Walla Country: 1805 –1902 A century of man and the land* by Donald William Meinig Whitman College: Nwest F 897.W18M4

Sequence of Land Utilization The Walla Walla Country
1800 to 1855 100 % Indian Nomadic Culture (Whitman mission and Fur Post had livestock and gardens)
circa 1857 – 1860 7% Range/Livestock
1860 – 1870 95% Range/Livestock 5% Farming
… continue steady increase to midpoint at 1890 where 50% Range/Livestock 50% Farming
1910 92% Farming 8% Range/livestock

Page 37 Lewis and Clark described the area as:

In proceeding up the Walla Walla River he described the plains as being poor and sandy although the narrow bottom of the creek was very fertile. Cottonwood, birch, haw, willows and various bushes were noted and labeled as being "A good store of timber", but its goodness was undoubtedly seen in contrast to the barren plains traversed in previous days.[2] These features, plus a plentiful supply of game birds ("curloos, crains, ducks, prairie cocks"), when viewed on a fine first day of May, prompted them to pronounce it a "pleasant looking country."

Page 137 Walla Walla pioneer (1863) "In looking over this valley, the first thing that strikes the attention of the stranger, is the want of timber. There is really no good timber in the valley. Some trees of cotton wood and alder, and smaller growth, fringe the streams; but we seek in vain for good timber for fences.

Page 293. " The data published on Washington Territory provided the first reliable measure of the historical climate of the Walla Walla Country. Data for the three stations reported were:

	Length of Record	Average annual Precipitation
Walla Walla	16 yrs 1 mo.	20.69 inches
Dayton	6 yrs 0 mo.	26.76 inches
Pomeroy	2 yrs. 1 mo.	20.33 inches

Cited from A.W. Greely, Rainfall of the Pacific Slope and the Western States and Territories, Senate Exec. Doc 91, 50th Congress, 1st Session, 1888, pp. 6-7.

According to the report the lowest annual precipitation at Walla Walla for any one crop year (September to August) was 16.44 inches in 1858-59. The highest was 28.96 in 1860-1, the year of the heavy snows.

This book as isohyetal maps of Walla Walla area.

Walla Walla Precipitation was updated with records to 1910 to an average of 17.3 inches (Greely has 20.69 inches)

Citations:

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[2] Ibid. p 341 (must be Lewis and Clark notes/writings)

The Expeditions of Johns Charles Fremont Volume 1 Travels from 1838 to 1844
Edited by Donald Jackson and Mary Lee Spence

October 24th

"… immediately below us was the great Nez Perce' prairie, in which dark lines of timber indicated the course of many affluents to a considerable stream that was seen pursuing its way across the plain towards what appeared to be the Columbia River. This I knew to be the Walahwalah [Walla Walla] River, and *occasional* spots along its banks, which resembled clearings, were supposed to be mission or Indian settlements; but the weather was smokey and unfavorable…" (page 550).

Uplands had "black spruce measuring 15 feet in circumference". Other trees species he saw were *hemlock* spruce (*perusse)*. "Pines here were 11 and 12 feet in circumference and 110 feet high."

"…we had an extensive view along the course of the river, which was divided and spread over its bottom in a net work of water, receiving several other tributaries from the mountains. There was a band of several hundred horses grazing on the hills about two miles ahead; and as we advanced on the road we met other bands, which Indians were driving out to pasture in the hills. True to its general character, the reverse of the other countries, the hills and mountains here were in rich in grass, the bottoms barren and sterile."

Passed Whitman mission

October 25
This day starts 4 miles below Whitman Mission.

"and the country offered to the eye only a sandy, undulating plain, through which a scantily timbered river takes its course. We halted about three miles above the mouth, on account of grass; and the next morning arrived at Nez Perce fort [Fort Walla Walla]…. We made our camp in a little grove of willows on the Walahwalah, which were the only trees to be seen in the neighbourhood; but were obligated to send the animals back to the encampment we had left, as there was scarcely a blade of grass to be found." (page 553).

Route Across the Rocky Mountains with Description of Oregon and California 1846, By Overton Johnson and WM. H. Winter, of the Emigration of 1843. Printer: John B Semans

*** Called Entire Columbia basin (middle) the Walla Walla Valley. "The extent of the Walawala Valley, is not known, but it is probably three hundred miles long, with an average width of about fifty miles…. With the exceptions of a few Cotton wood trees on some of the streams, this is not timber in the valley, but there is an abundance on the neighboring mountains.

The Journals of Captain Nathaniel J. Wyeth's Expeditions to the Oregon Country 1831-1836
Edited by Don Johnson University of Idaho, Ye Galleon Press Fairfield, Washington

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Journal kept by David Douglas During his Travels in North America 1823-1827
Together with a particular description of Thirty three species of American Oaks and Eighteens Species of Pinus. With Appendices. Published under direction of the Royal Horticultural Society. Antiquarian Press LTD.

A Bird Census at Prescott, Walla Walla County, Washington. Lee Raymond Dice (with photo) May, 1921

"The area chosen is located in the Touchet Valley, two miles east of Prescott, … The valley at this place is about ½ mile in width, and the hills rise abruptly… On account of the relatively scanty rainfall, trees, under natural conditions are confined to the to ground along the small river and along a little slough. Irrigation now is practiced in the valley…" (page 87)

Study area "… a small strip near the river and along the west side of the area had been allowed to grow up thickly to trees, bushes and briers;…. The conditions in general are typical of those found along the valley at the present time, and different considerably from the natural state."

"The native trees and shrubs are willow, wild cherry, dogwood, cottonwood, alder, birch, tghorn and elderberry. Introduced trees and scrubs growing on the area are apple, pear, plum, peach, apricot, cherry, locust; hazelnut, walnut, chestnut and osage. The cottonwoods and locusts attain a height of 80-100 feet.

Botanical Observations of Captains Lewis and Clark in the Walla Walla County 1805-1806.
Walt Gary, WSU Extension

"On April 30th, … At the place the where this trail hit the Touchet River, there was adequate firewood, the first such amount since they left the Dalles. Trees in this location consisted of cottonwood, birch (like water birch), crimson haw (likely black hawthorn), red willow, sweet willow, chokecherry, yellow currants (likely golden currants), gooseberries, white-berried honeysuckle, rose bushes, seven bark, and shoemate (likely smooth sumac). They also observed corn grass (likely basin wild rye) and rushes (possibly Scirpus or Equisetum) in some parts of the river bottom.

On May 1st, 1806, the proceeded further along the Touchet River going east. They noted that in going eastward in timber on the creek became more abundant. They noted more timber than usual along the river and the presence of long leafed pine (likely Ponderosa pine) in an area of about 50 acres in size east of present day Waitsburg. They also observed considerable quantities of camas in bloom in the bottom land they now were passing through after leaving the pine grove. In the course of… Indians eat the …appears to be cow parsnip.

Allium Textile	Textile onion, collected at the mouth of Walla Walla River, April 30 1806
Aster Oregonensis	Oregon White-topped aster, collected on Snake River, Washington, October 1805.
Crataegus douglasii	Black Hawthorn, collected at the mouth of Walla Walla River, April 29, 1806.
Lomatium Cous	Cous, collected at the mouth of the Walla Walla River, April 29, 1806
Coreopsis tinctoria	Calleopsis, collected on Snake River, Washington, October 1805.

]Report of Captain John Mullan on 1858 reconnaissance of military road

"The valley bottoms are nearly all densely settled; the land in the bottom being sufficient for farms of considerable size, and the hill-sides bowed..

2001 Colombia Basin Ag Research Center Annual Report Station Report 1026
In cooperation with USDA (OSU) John Williams and Stuart Wuest

Scrub-Steppe into the Palouse
"Drainage networks and riparian corridors developed in this mosaic of shrub-steppe and bunch-grass prairie, generally following folds of structural fractures in the underlying basalt. First and second order streams originate in both the Blue mountains and within the croplands area of the plateau. On the plateau, the riparian communities appear to have been composed of halophytes or willow or cottonwood galleries, judging from the current soil characteristics and relic vegetation stands.

Concomitant with geophysical influences, beaver (Castor Canadensis) and fire influenced on hydrology and stream channel development would have been direct and indirect. Beaver, believed to have been abundant throughout North America, would have directly influenced channel development through structure and side channel development and indirectly through manipulation of riparian plant communities.

Timeline Information:

Fires set by Indians changed the landscape
Horses arrived in the plateau in the 1790s and lacking the evidence of large grazing animals for at least 11,000 bp, they had the potential of initiating the first human-related changes of the region's hydrology. Concentrations of horses probably began having localized impacts on riparian areas shortly after arriving in the region…" Alternatively, the animals could have been dispersed, and thick riparian vegetation might have limited extensive access to streams, reducing the biological or geophysical impact.

Lower Walla Walla River Wetland and Riparian Restoration Project Phase I – Wallula Wetlands and Riparian Restoration Project
April 2001 USFWS, McNary National Wildlife Refuge
Wallula, Walla Walla County

"Incising of stream channels and sedimentation processes have degraded wetlands." (page 2)

"Sedimentation within the Wallula Unit since the construction of McNary Dam has resulted in the growth of the delta area by as much as 7 million cubic feet at the mouth of the river (Van Auken, 1998)."

"Prior to farming, these lands were likely dominated by woody riparian vegetation and/or seasonally flooded floodplain wetlands, although the historical assemblage of native plants and their acreage is difficult to ascertain." (page 2)

Wetland Vegetation:
Native: Primarily emergent hardstem bulrush, sedges, and cattail.
Non-native: Invasive non-native (on site) include purple loosestrife, phragmites, perennial pepperweed and cocklebur.

Riparian Zones: consist of riparian woodlands dominated by black (native) and plains (non-native) cottonwoods with an under story primarily of non-native riparian species such as Russian olive and false indigo are common in the shrub-scrub zone.

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