Habitat Conservation Planning: Evaluating the Thermal Impacts of Streamflow and Irrigation Bypass in the Walla Walla River

by

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Units and Symbols

m^3/s = cubic meters per second
cfs = cubic feet per second
m = meters
ft = feet
RKm = river kilometers
RM = river miles
mi^2 = square miles
km^2 = square kilometers
7Dmax = average seven-day maximum temperature

* The authors of this paper have made an attempt to include both metric and standard units when describing the model.

** There are two river mile (RKm) systems used in this model, for agency established gauges that use USGS standards, those are used. For specific model locations, the actual 2002 river miles (determined by digitizing the entire river length using aerial photos in 2002) are used. These two systems may have some slight discrepancies.

1.0 Introduction

The Walla Walla River Basin is an important aquatic resource that empties into the Columbia River downstream of the Snake River confluence and upstream of McNary Dam at approximately River Mile 315 (RKm 507). As illustrated in Figure 1, the main stem of the Walla Walla River originates in the Blue Mountains of eastern Oregon before crossing the state line into Washington near the towns of Milton-Freewater, Oregon and Walla Walla, Washington. Because of increasing concerns for resident bull trout and anadromous salmonid species in the basin, fish and water management agencies have begun to examine steps needed to protect several important rearing and spawning reaches in the river system. One issue concerns the impact of water temperatures in the main stem of the Walla Walla River. However, because natural flow and temperature conditions likely restricted the usability of the lower river, the primary focus area is the reach below Grove School Bridge in Milton-Freewater and upstream of the Mill Creek confluence (Figures 1 and 2).

Traditional use of all the water in the river became a more pressing legal concern once bull trout were listed in 1998 and steelhead in 1999 as threatened species in the Walla Walla River under the Endangered Species Act. Federal agencies considered legal intervention and conservation groups considered lawsuits against the irrigation districts to enforce the law. But something different happened in the Walla Walla Basin. Irrigators, whose livelihoods depend on water for their farms, stepped forward and negotiated a compromise solution.

Beginning in 2000, three irrigation districts pledged to keep a minimum water flow in the river and signed an agreement to this effect with the U.S. Fish and Wildlife Service. Two of the irrigation districts that signed the agreement divert water in Oregon (Hudson Bay District Improvement Company and Walla Walla River Irrigation District). During the driest part of the season, they left 13 cfs (0.368 m^3/s) in the river. The third district (Gardena Farms Irrigation District #13) is located in Washington, west of the City of Walla Walla, and left 10 cfs (.283 m^3/s) in the river. The instream water improved flows and helped provide a continuous flow for passage to upriver for any bull trout and other fish in the mid to lower river sections.

This agreement was further amended in 2001 and then in 2002, when it was found that high channel bed infiltration rates in Milton-Freewater's flood control lower levee reach allowed very little water to make it to the end of the levee system. In order to get enough flow so that the entire river was at least "wetted", further increases in bypassed flows were negotiated and them monitored. Starting in 2001, the Oregon irrigation districts bypassed 18 cfs (0.5097 m^3/s) and the Washington irrigation district bypassed 14 cfs (0.397 m^3/s). Subsequently in 2002 the agreement was revised further with the Oregon districts leaving 27 cfs (0.7641 m^3/s) from January 1st to June 30th and 25 cfs (0.706 m^3/s) from July 1st to December 31st each year. The Washington district increased its bypass to 18 cfs year throughout the year. They have also reduced river fluctuations caused by their operations to prevent the stranding of fish.

Shortly after the start of the USFWS-Irrigation Districts agreements the irrigation districts also made the decision to enter into a Habitat Conservation Planning (HCP) process. Under this federal mitigation process, the irrigation districts would be protected

against the threat of any further legal actions if they agreed to and implement a set of restoration steps to mitigate for any effect that their irrigation practices have on the Basin's ESA listed fish species. In the HCP process, the impacts of the HCP participants needed to be assessed in relation to how much impact or "take" their actions (in this instance, irrigation withdrawals) had on the listed species. In order to assess the amount of take for irrigation diverters, a technical assessment of how past, current and potential flow conditions effect the ESA fisheries both directly through adequate passage flows and indirectly through impacts to overall habitat conditions.

Fortuitously for this assessment, during the time of these agreements, the State of Oregon Department of Environmental Quality and the Walla Walla Basin Watershed Council were collaborating on a required Total Maximum Daily Load (TMDL) assessment for temperature. As a part of this process a temperature model (*Heat Source*) of the Walla Walla River was developed to simulated changes to river temperatures based on changes in the various habitat components, including flow.

This HCP project utilized a combination of field information, flow balance calculations and the above-mentioned, previously developed temperature model in order to estimate changes to flow and habitat conditions for this HCP process. The output from this project was then used by fisheries scientists at HDR Inc. to assess the impacts to the fisheries based on changes in habitat conditions. Two life cycle or population response models were developed by Keith Underwood at HDR and calibrated for habitat conditions using the information provided by this HCP project along. These specifics of these two models are described in *Walla Walla River Bull Trout Population Response Model* (HDR, 2007), and *Walla Walla River Steelhead Population Response Model* (HDR, 2007).

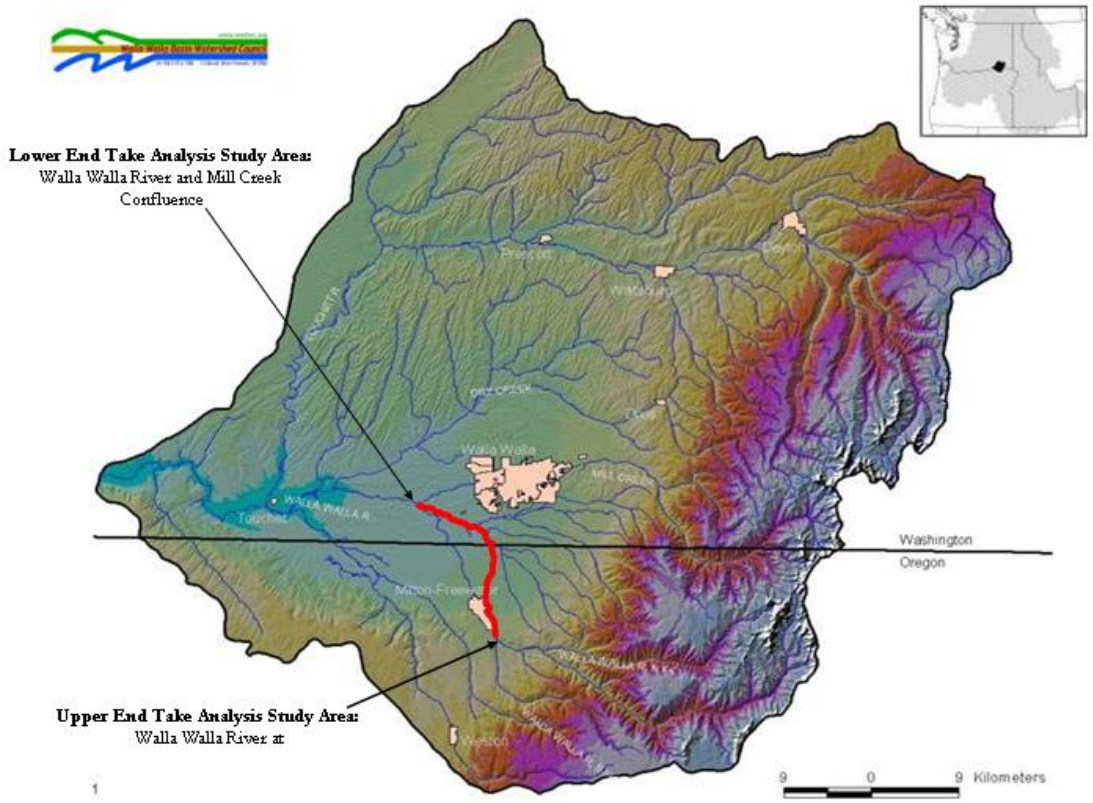


Figure 1: Map of Walla Walla Basin with Study Reach

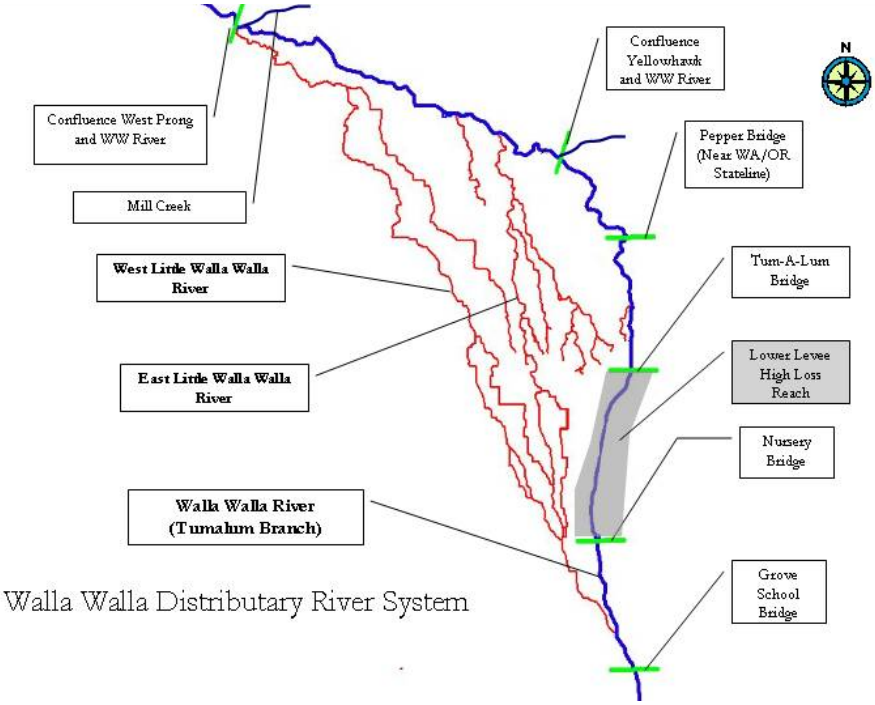


Figure 2: Map of Study Reach

1.1 Background

1.2 Fisheries Concerns

While there are a number of important species potentially present and of concern in the Walla Walla Basin, this study focuses on spawning and rearing temperature requirements for steelhead and bull trout; which are all listed as threatened under the Endangered Species Act (ESA). Understanding the interpretation and limitations of the *Heat Source* modeling results requires a brief overview of the life history patterns of these species. For example, it is critical to realize that flow without proper water temperatures will not achieve the desired results. It is also important to realize that predicted temperatures need to be examined in terms of the life cycle of the fish. For instance, since spawning may take place only for a relatively short period of time, it does not make sense to look at temperatures needed for spawning outside the normal window when performing simulations. During those periods, temperatures needed for the rearing of the fisheries would be more applicable.

This study has focused primarily on two time periods, June and August, both for their relevance to the ESA listed fisheries and to that of the operations of the three irrigation districts participating in the HCP. June is the time period when all irrigation districts are diverting from the Walla Walla River and the river is in transition from the high flows of the spring freshet to that of the lower steady baseflows of the summer months. While only one district is diverting in August, it is a critical time period for river flows, water temperatures and habitat conditions for the fisheries. For readers wanting more information concerning Walla Walla basin fish populations, a thorough description of salmonid and bull trout utilization can be found in a number of reports including Mendel et al. 1999; Contor et al. 2000; and Saul et al. 2001, Parametrix, 2003 and HDR, 2007.

1.3 Flow Conditions in the Walla Walla River

The elevation of the Walla Walla Basin rises from approximately 400 ft (122 m) at the mouth to 6,401 ft (1951 m) at the headwaters in the Blue Mountains. Because of the elevation differences, much of the runoff is generated at higher levels in the basin (Butcher and Bower 2005). This is indicated by the high flows generated by snowmelt in April and May. The total watershed drainage area is approximately 1760 mi^2 (4558 km^2) upstream of the mouth of the Walla Walla River at its confluence with the Columbia River. There are several significant tributaries to the Walla Walla River (in terms of flow) including the Touchet River and the Mill Creek drainages. In addition, there are numerous diversions that make gauge data reflect net runoff rather than total system response.

This temperature study was focused the mainstem of the Walla Walla River upstream of its confluence with the Mill Creek drainage (RKm 54.7, RM 34) , to the 15th Avenue Bridge (RKm 77.0, RM 47.9) (Grove School Bridge) in Milton-Freewater, Oregon (Figure 1). This specific reach was selected based on the aforementioned fisheries and diversions issues.

Perhaps the most telling of general flow conditions in the Walla Walla Basin is depicted by the data generated by the US Geological Survey's Walla Walla near Touchet

gauge (14018500)[1]. This online, real-time station is located at 18.2 RM (29.3 RKm) approximately 15.8 river miles (25.4 RKm) downstream of the Walla Walla-Mill Creek confluence (the lower end of the study area)[2]. Figure 3 illustrates the temporal change in discharge for the most recent period. Nearly continuous records have been kept on the stream since 1952. In order to provide readers with more useful information on the annual fluctuations, the most recent nine year subset of the data record is provided in Figure 4. As illustrated, the flows vary considerably over the course of a water year (Oct-Sep).

It is evident from Figure 4 that average daily streamflows in ten years have ranged from approximately 10 cfs (0.283 m^3/s) during the summer months to over 2000 cfs (56.6 m^3/s) at least briefly during the winter periods. This figure also illustrates the rapid decline in streamflows as soon as the snowmelt ends. Given the scarcity of summer precipitation, this is typical of all streams in the area. Figure 5 provides a look at mean daily flows in June since the inception of the gauging results. Flows at the beginning of June average close to 500 cfs (14.15 m^3/s) while flows at the end of the month are close to 100 cfs (2.83 m^3/s).

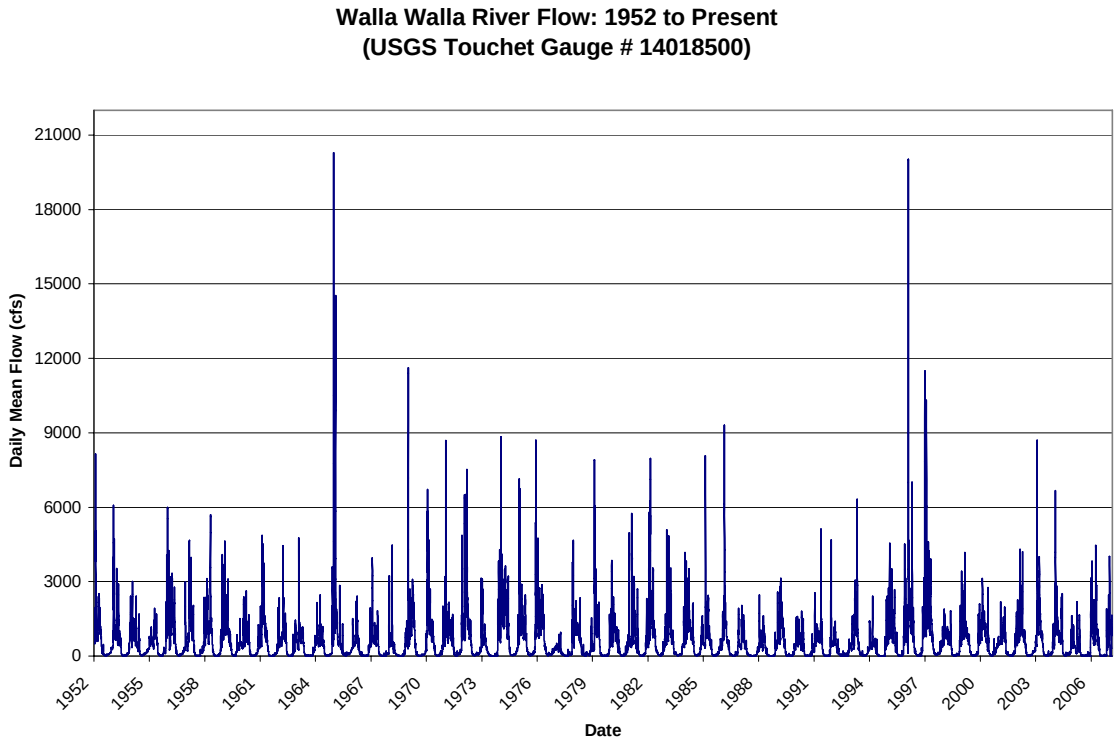


Figure 3: Daily flow at Walla Walla near Touchet gauge (18.2 RM (29.3 RKm))

Note: Update website references throughout

[1]USGS. Water Resources Division. Year. National Water Information System. http://waterdata.usgs.gov/wa/nwis/uv/?station=14018500. Date Accessed.

[2] It should be noted that this gauge includes the contributions from the Touchet River basin.

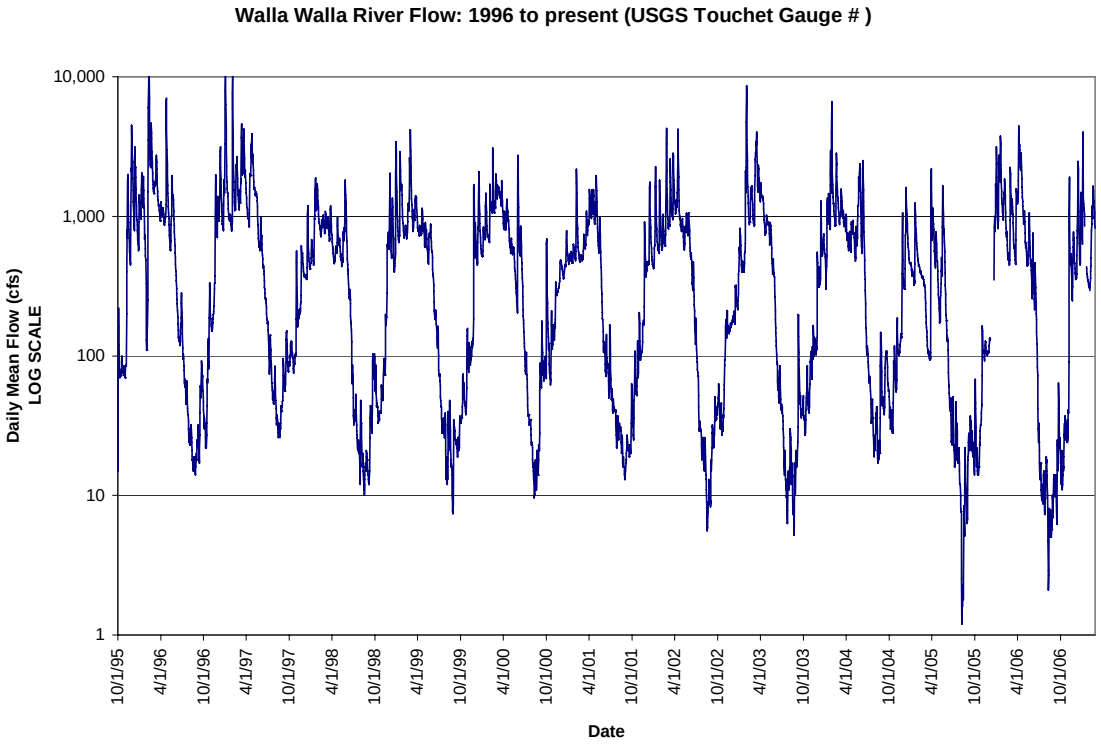


Figure 4: Daily flows at the Walla Walla near Touchet gauge since 1996

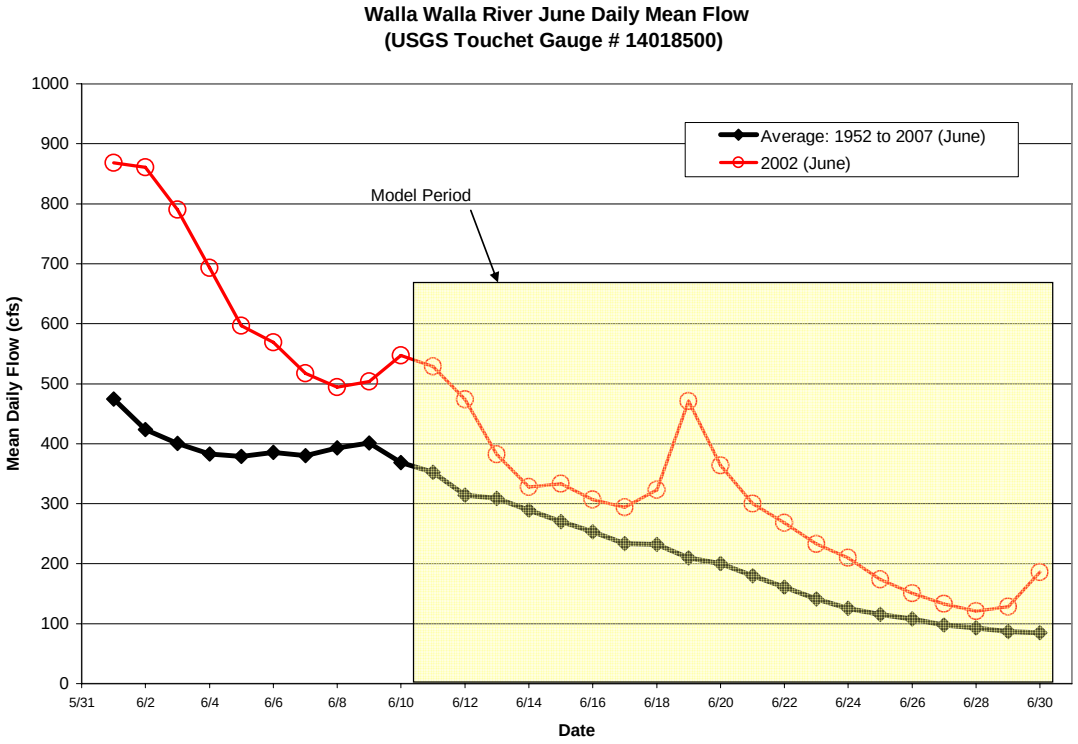


Figure 5: Comparison of June 2002 versus Historical Average Flow

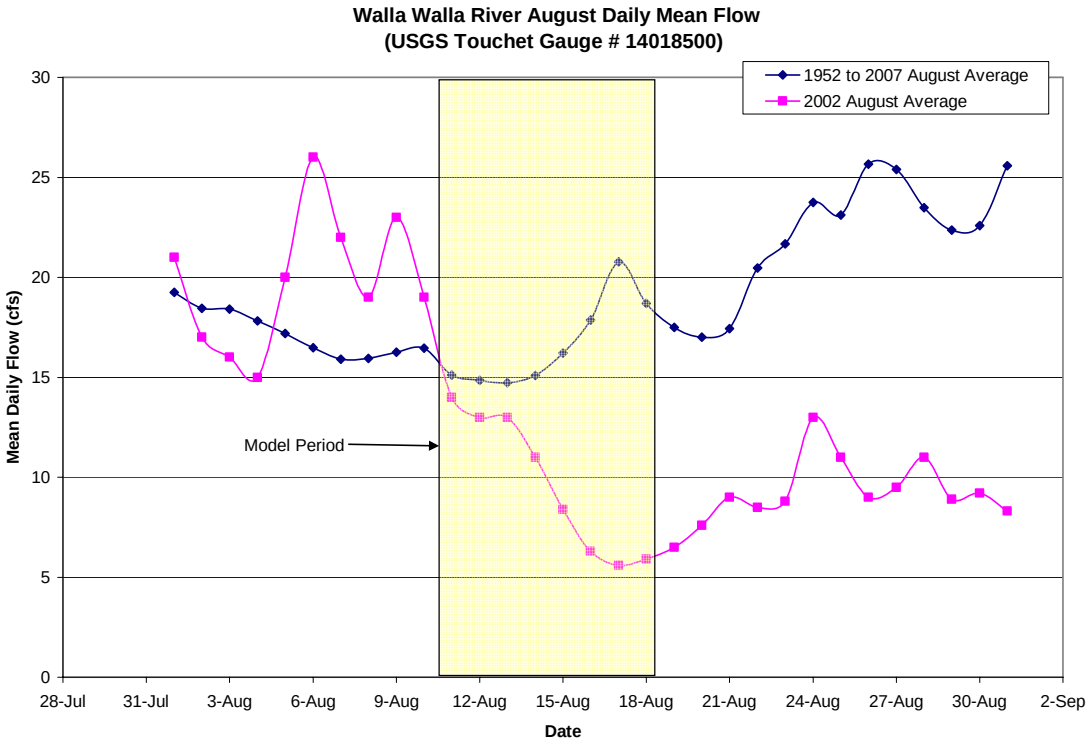


Figure 6: Comparison of August 2002 versus Historical Average Flow

Looking at historical averages versus the two model periods for this study, June and August appear to vary slightly from average (Figures 5 and 6). June 2002 was a wetter than average year when comparing the 1952 to 2007 average daily mean flows to June 2002. August appears to be slightly drier than average when make a similar historical comparison.

The primary source water for our study area comes from both the South and North Forks of the Walla Walla River (Oregon) and Mill and Yellowhawk Creeks (Washington). Since the *Heat Source* used for this project's analysis was a one-dimensional model, the upstream flow or boundary condition was established using data from the North and South Fork Gauges. Other gauges, such as the USGS gauges on Mill Creek, are utilized in the modeling as boundary condition inflows at their spatial relevance to Walla Walla River flow.

To establish the upper inflow conditions, long-term gauging stations located on both the North and South Forks of the Walla Walla River were utilized. The gauge on the North Fork Walla Walla River (14011000) began operation in January of 1930 and recorded approximately 43.8 mi^2 (113.4 km^2) of the watershed until 1969. At that time, the gauge was moved upstream (14010800) to have a tributary area of 34.4 mi^2 (89.1 km^2) Figure 6 illustrates the typical season variation in discharges from 1969 until present.

Two gauges were also operated on the South Fork of the Walla Walla both dating back to 1903. The lower gauge (14010500) had a tributary area of 80 mi^2 (207.2 km^2) and was discontinued in 1945. The upper gauge (14010000) had a tributary area of 63 mi^2 (163.2 km^2) although, as illustrated in Figure 7, several gaps exist in the period of record. Currently the Oregon Water Resource Department (OWRD) now maintains both gauges on the North

(14010800) and South Fork (14010000) locations, but only data prior to 1991 was available online at the time of this portion of the analysis[3]. During the temperature and flow modeling phase of this project, more recent data was utilized from the OWRD gauges sites.

Since no significant diversions occurred upstream of these gauging stations, the sum of the North Fork and South Fork gauges is locally considered to be an accurate estimate of the inflow in the study area. Additional diversions and channel bed gains and losses between the gauges and the start of the study area were considered in the flow calculations made for this project. Figure 8 illustrates an interesting characteristic of these flows. Although somewhat variable early in the summer, an HDR/EES analysis indicated that by early July there is very little difference between the typical combined inflow of the two streams defined by the narrow range of flows between the lowest 10% line and the average (50%) line. This suggests that the selection of any typical August period will produce similar flow results. Also it should be noted that the 2002 flow data used for this project indicates that spring flows (June) were above normal while summer (August) are slightly below normal.

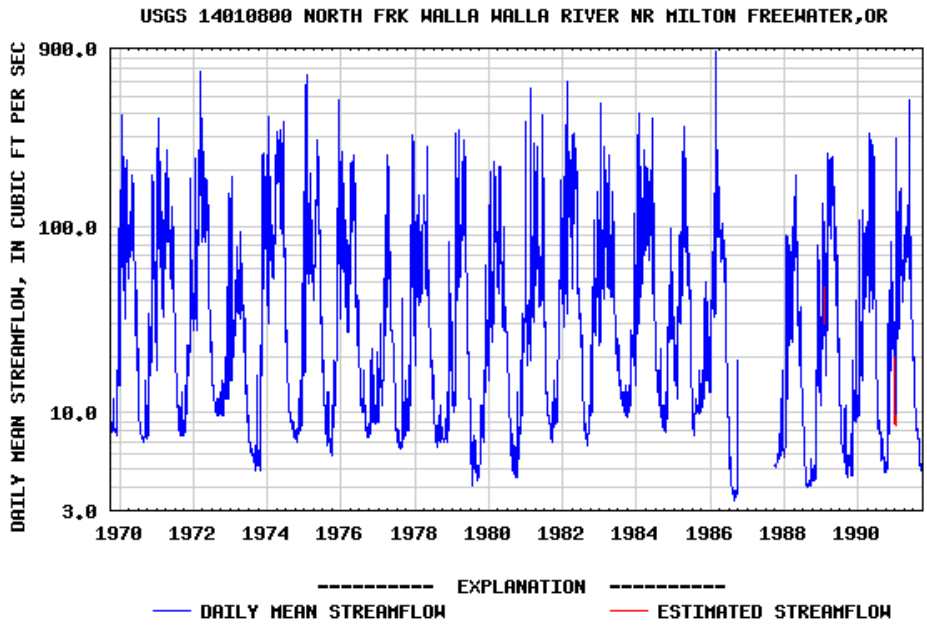


Figure 7: Daily flows at the North Fork Walla Walla gauge since 1969

[3] http://www1.wrd.state.or.us/cgi-bin/choose_gage.pl?huc=17070102

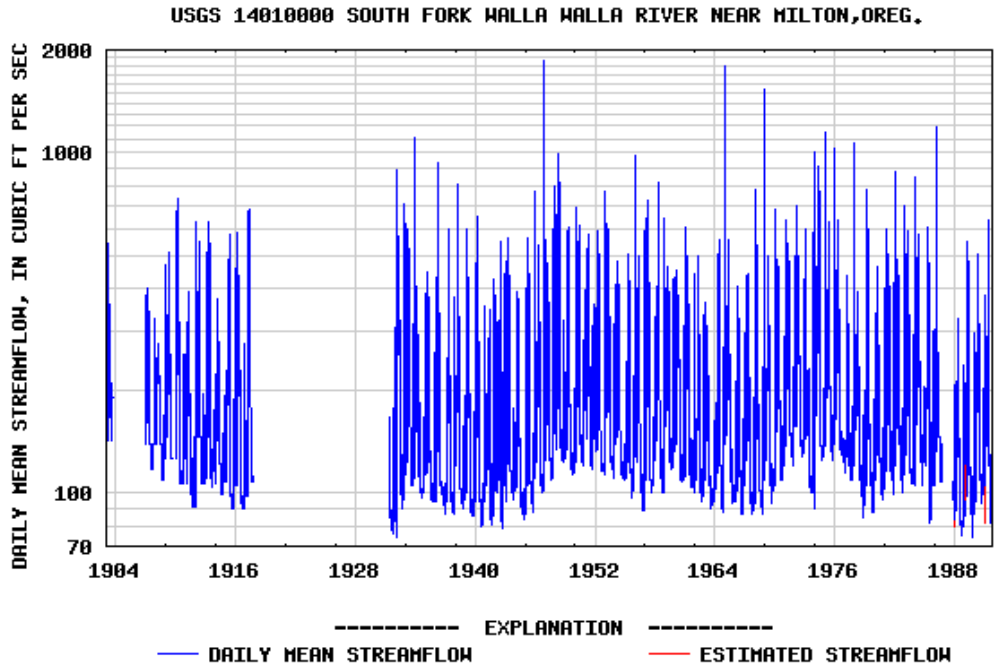


Figure 8: Daily flows at the South Fork Walla Walla gauge since 1903

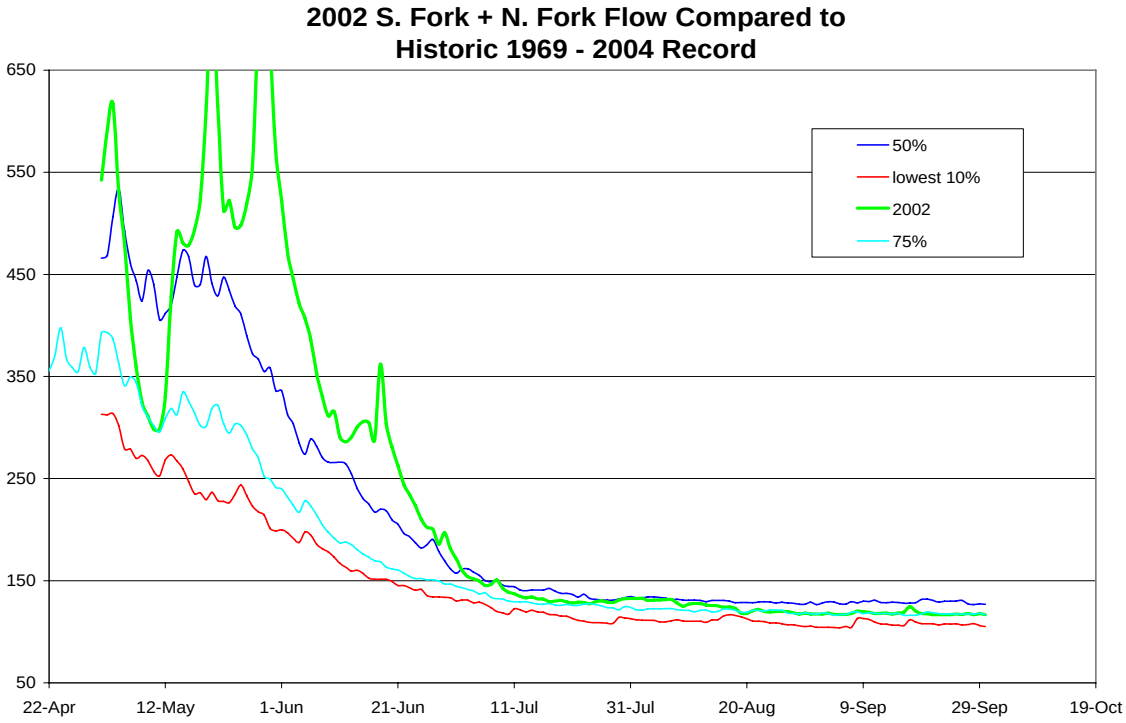


Figure 9: Comparison of Walla Walla River Flows for 2002 model periods

Flows in the Mill and Yellowhawk Creeks distributary system are measured at two USGS gauges in that subwatershed (USGS #14015000 and #14013000)[4]. Water flows through this system are dictated by a United States Corp of Engineers flood control project through the City of Walla Walla, Washington. During higher flow periods, a majority of the water flows down Mill Creek and past the Bennington Lake reservoir. During the lower flow periods, nearly all of Mill Creek's flows are bypassed into Yellowhawk Creek. Flows at these gauges mimic the runoff pattern shown at the Walla Walla River gauges, but are considerably lower in volume due to both drainage area size and other hydrogeologic influences.

In recent years, gauging efforts on the Walla Walla River have expanded through various public and private data collection efforts. For example, as part of the settlement agreement between the US Fish and Wildlife Service, the three irrigation districts have been monitoring flow at a number of sites beginning in Oregon at Grove School Bridge (RM 47.8, RKm 77.0) and extending downstream to just below the Beet Road, at the Gardena Farms Irrigation Diversion (RM 37.6, RKm 60.5) in Washington. The Washington Department of Ecology has established a number of real-time gauges[5] throughout the Washington portion of the watershed.

1.4 Temperature Considerations and Conditions

Temperature is a critical water quality parameter affecting the suitability of river segments for spawning and rearing purposes. Table 1 summarizes typical water temperature requirements for various life history patterns of species of interest in the basin. These values should not be taken as absolutes. Fisheries experts are continuing to study refugia issues and thresholds that are unique to local species; however the temperatures are indicative of acceptable norms.

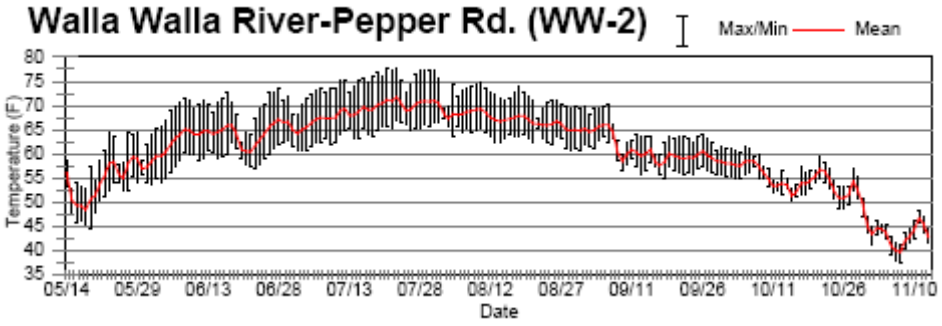
Table 1: Temperature (°F) requirements of key fish species in the Walla Walla Basin.

Life History Pattern	Steelhead		Bull Trout[d]	
	^{0}F	^{0}C	^{0}F	^{0}C
Spawning migration	< 63.5[a]	< 17.5	50.0 - 54.0	10.0 – 12.2
Spawning	39.0 – 49.0[b]	3.9 – 9.4	39.0 - 50.0	3.9 – 10.0
Embryonic development & emergence	47.3 – 57.2[a]	8.5 – 14.0	34.0 - 43.0	1.1 – 6.1
Juvenile rearing	45.1 – 58.3[c]	7.3 – 14.6	39.0 - 50.0	3.9 – 10.0
Juvenile migration	< 58.0[a]	< 14.4	N/A	N/A
[a] Hicks 1999 [b] Bell, 1986 [c] Beschta *et al.* 1987 [d] Buchanan and Gregory 1997				

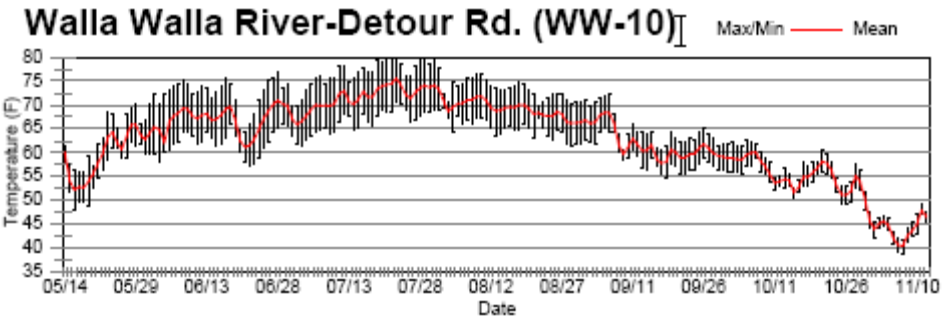
[4] waterdata.usgs.gov/nwis/uv?14015000 and waterdata.usgs.gov/nwis/uv?14013000
[5] https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=32A120

The Oregon Department of Environmental Quality uses bull trout criteria of 50 °F (10 °C) and other salmonid rearing criteria of 64 °F (17.8 °C) as the maximum allowable temperature. Based on these criteria, Oregon's 1998 303(d) list cited the Walla Walla River in Oregon from RM 40.6 to RM 50.6 (65.3 RKm to 81.4 RKm) the North Fork of the Walla Walla from RM 0 to RM.18.7 (30.1 RKm), and the South Fork from RM 0 to RM 27.1 (43.6 RKm) as impaired reaches (ODEQ 2005). The 10 mile reach (16.1 RKm) of the mainstem of the Walla Walla was in violation of the salmonid rearing criteria whereas the other reaches were listed due to the bull trout criteria.

Agencies such as the Washington Department of Fish and Wildlife and NGOs such as the WWBWC have been collecting continuous temperature data in the Walla Walla system for several years. Mendel et al. (2004) summarized their extensive network of stream temperature probes for the Walla Walla River Basin. Figure 9 illustrates three of the profiles for sites on the mainstem of the river. As indicated, the temperature at all three sites routinely exceeds the 64 °F (17.8 °C) criteria for salmonid rearing habitat during summer periods. Recently other agencies have become involved with real time information such as the WDOE gauges at Pepper Bridge [6] (RM 39.6, RKm 63.7) and Beet Road[7] (RM 36.5, RKm 58.7). Figure 10 shows the type of temperature and flow information available on the web by WDOE.

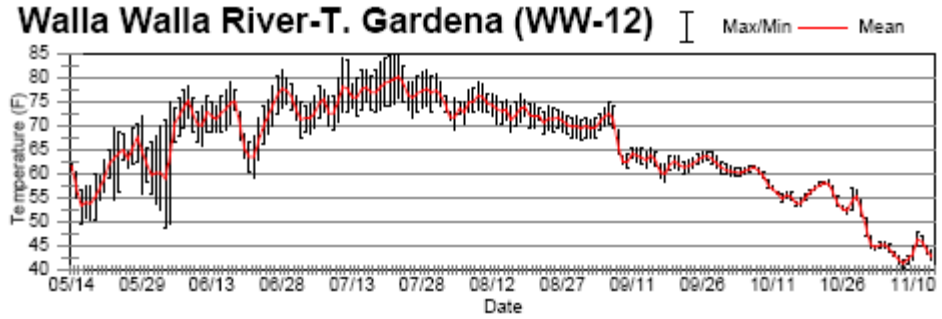


(RM 39.6, RKm 63.7)



(RM 32.8, RKm 52.7)

[6] https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=32A120
[7] https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=32A105



(RM 20.5, RKm 33.0)

Figure 10: Water temperatures in Walla Walla River watershed during 2003 (Mendel et al. 2004)

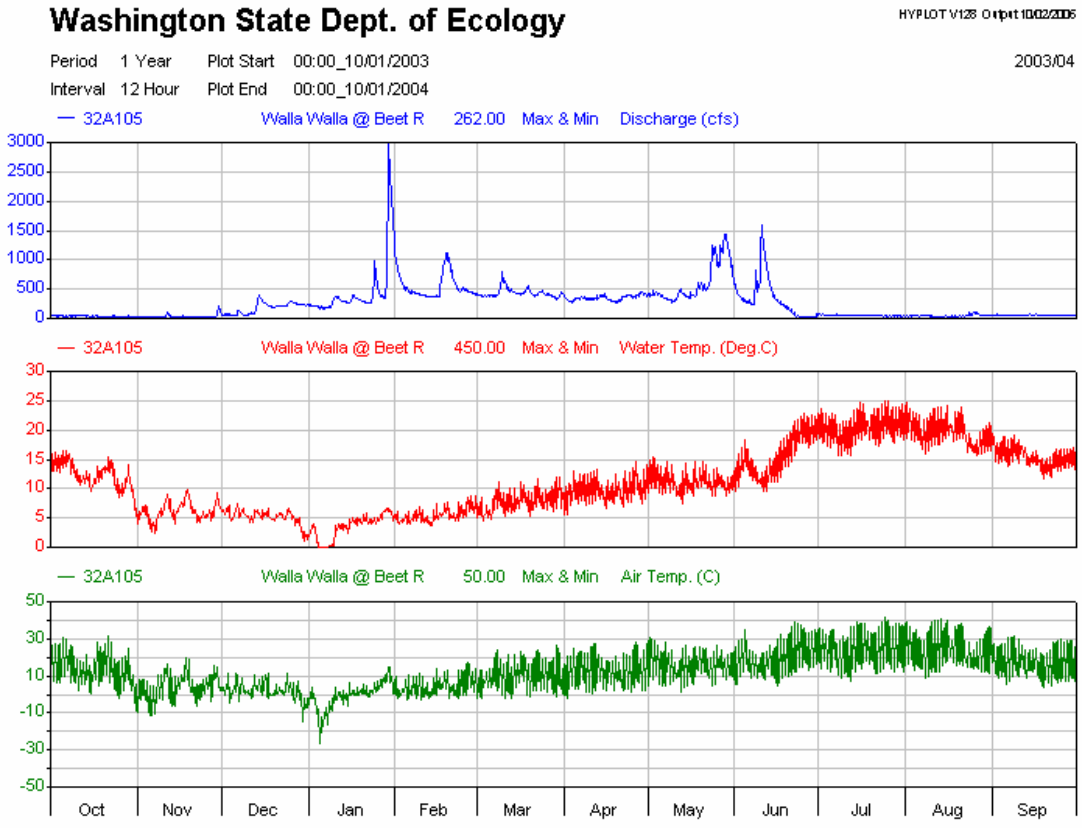


Figure 11: Annual Walla Walla River flow, water and air temperatures at Beet Road Gauge (2004)

1.5 *Heat Source* Approach to Modeling Stream Temperatures

Citing several different sources, Bormann (2000) lists 45 environmental and physical variables capable of influencing stream water temperature. Among these factors are climatic conditions such as air temperature, relative humidity and wind speed, stream site physical characteristics such as stream width, depth and roughness, and the presence of shading vegetation and topography. Accurately accounting for all of the complex interaction of these parameters is necessary to produce reliable estimates of water temperature. Moreover,

because small streams carry smaller volumes of water, the temperature of small streams is more responsive to net energy inputs than larger rivers and therefore more accuracy is required of an energy balance model to achieve a given accuracy in temperature prediction.

Energy balance methods account for predicted incoming and outgoing heat fluxes to result in an estimate of the net flux of energy received by a segment of water in a stream. The following equation is a general energy balance equation similar to the one used by Brown (1969):

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

Equation 1: *Heat Source* general balance equation.

where Φ_{solar} is the sum of shortwave direct and short wave diffuse solar radiation penetrating the stream's surface $\Phi_{longwave}$ is the sum of long-wave solar radiation reaching the water's surface through the canopy opening and streamside vegetation $\Phi_{evaporation}$ is the heat loss flux due to evaporation $\Phi_{convection}$ is the loss of heat due convection at the air water interface and $\Phi_{streambed}$ is the flux due to conduction between the water column and stream bed. The magnitudes of the heat flux terms have been outlined by McCutcheon and Martin (1999) as follows:

> short wave solar radiation ranges from approximately 50 to 500 W/m^2, long wave atmospheric radiation ranges from approximately 30 to 450 W/m^2, long wave radiation emitted from a water body ranges from approximately 300 to 500 W/m^2, evaporative heat loss ranges approximately 100 to 600 W/m^2, and convective heat exchange ranges approximately 100 to 600 W/m^2.

Computer simulation models have been widely used to predict stream temperatures for some time although the complexity and capabilities of most models continues to improve as access to input data becomes more readily available and computer resources increase. Models such as Q2k (formerly Qual2E), SNTEMP, and HSPF to name a few common examples, have been used to simulate stream temperatures. Another model that has been successfully used in this area is a 1-dimensional model called *Heat Source*.

The first *Heat Source* model was a simple reach scale model using the methods described by Beschta and Weatherred (1984) to account for the shade of riparian vegetation. *Heat Source* has since evolved into a watershed scale model capable of accepting data to represent great spatial detail in channel morphology and riparian vegetation. The latest model of *Heat Source*, *Version 7.0*, is a physically based model capable of sampling GIS data to provide a detailed description of channel morphology and near stream conditions over large geographic areas to calculate heat and mass transfer using physically descriptive mathematical relationships. The *Heat Source* methodology was circulated nationally for review with results being summarized on the ODEQ web site[8] (ODEQ 2006). One of the most

[8] http://www.deq.state.or.us/wq/TMDLs/tools.htm

significant challenges in applying this model is providing input data with the spatial extent and accuracy that this model can effectively utilize.

The *Heat Source* program is written in Visual Basic for Applications in Excel. The model includes the critical considerations of shading from topographical features and riparian vegetation. It simulates water temperature on an hourly basis accepting weather and flow data records on an hourly basis. It is suited for diurnal temperature prediction to support dissolved oxygen modeling as well as TMDL applications and is readily adaptable for use as a reach scale model. The model also accepts detailed information describing the dimensions and density of riparian vegetation, including the vegetation's actual overhang length. *Heat Source* is a widely available share-ware program. Because it is written in Visual Basic for Excel, the model does not require management or formatting of external data input files for required data such as hourly weather data. Weather and other input data may be formatted and pasted directly into designated worksheet locations in the *Heat Source* Model. This system is convenient because all the input data used in simulation is stored with results and can be easily changed to simulate the next scenario (Shepard, 2005).

In accordance with Equation 1, *Heat Source* describes the rate of temperature change in an element of stream water as the sum of the rate change in temperature due to advection, dispersion and heat energy flux. *Heat Source* methodology estimates the amount of energy exchanged between an element of water and its surrounding as a function of air temperature, channel bed characteristics, and radiation dependent on the time of day, time of year, the location of the element of interest on the earth and its orientation to the sun (Boyd 1996). Because the model has been previously used to simulate water temperatures in the Walla Walla River basin, it was the obvious model of choice for this study. Typical data requirements were summarized by the California Department of Environmental Protection in an application on the Scott River TMDL and are shown in Table 1. Fortunately, much of this information existed for the Walla Walla River due to the TMDL efforts of the ODEQ and the WWBWC (Butcher and Bower 2005).

Type of data:	Parameter	Comment
Spatially Distributed Data:		Required at every computational node (every 100 meters in this analysis):
	Longitude (deg)	Derived from GIS
	Latitude (deg)	Derived from GIS
	Stream Elevation (m)	Derived from GIS
	Aspect (deg)	Derived from GIS
	Topo Shade Angle (deg) - West	Derived from GIS
	Topo Shade Angle (deg) - South	Derived from GIS
	Topo Shade Angle (deg) - East	Derived from GIS
	Gradient	Derived from GIS
	Mannings n	Calibration parameter in this analysis
	W:D Ratio	Based on Rosgen channel type
	Bankfull Width (m)	Digitized from aerial imagery, used
	Channel Angle -z	Channel side slope
	X Factor (0.0-0.5)	Hydraulic storage factor
	Bed Particle Size (mm)	Estimated from habitat typing data and professional judgment, used in hyporheic calculations
	Horizontal Bed Conductivity (mm/s)	Estimated from bed particle sizes, used in hyporheic calculations
	Embeddedness	Estimated from habitat typing data and professional judgment, used in hyporheic calculations
	Valley Aspect (degrees)	Derived from GIS, used in hyporheic calculations
	Accretion Flow (cms)	Developed from flow measurements and FLIR data
	Withdrawal Flows (cms)	Estimated form water rights and discussions with diversion operator
Upstream Boundary Condition:		Information used to define starting conditions
	Flow (cms)	Based on flow measurements
	Stream Temperature (°C)	Measured
Continuous Data:		Required for every hour of simulation
	Cloudiness (0-1)	Based on solar radiation data
	Wind Speed (m/s)	Measured in some locations, extrapolated to other locations
	Relative Humidity (%)	Measured
	Air Temp (°C)	Measured
	Stream Temp (°C)	Measured
Tributary Information:		
	Inflow Rate (cms)	Estimated based on measurements, drainage areas, or FLIR data
	Inflow Temp (°C)	Most measured, some minor tribs estimated using records from similar streams
Land Cover Information:		
	Height (m)	Estimated from measurements
	Density (%)	Estimated using default values
	Overhang (m)	Set to 0

Table 1: Overview of *Heat Source* Data Requirements (California EPA 2006)

2.0 Overview of Temperature Modeling the Walla Walla River System

As indicated in Table 1, *Heat Source* requires a considerable amount of input. Fortunately, because Oregon's TMDL process had used the *Heat Source* model for a TMDL analysis and because groups such as the WDFW and the WWBWC were already conducting field work in the area, a considerable amount of additional effort was avoided.

During the development of the *Walla Walla Subbasin Stream Temperature Total Maximum Daily Load and Water Quality Management Plan* (Butcher, 2005) the temperature modeling software *Heat Source* ™ was used to simulate current and potential conditions along the mainstem Walla Walla River. A thorough review of this model's development including calibration and validation can be found in *Appendix A Stream Temperature Analysis: Vegetation, Hydrology and Morphology Walla Walla Subbasin* (Butcher and Bower 2005*).*

For the HCP take analysis two distinctive models were developed for the focal time periods, June 2002 and August 2002. June 2002 appeared to represent a wetter than average year while August was slightly drier than average (Figure 8). As the TMDL process had already provided a validated version of the August 2002 model, it was only a matter of establishing a flow profile for each of the August flow scenarios[9] and then rerunning the model using each of these flow alternatives. June was a much more involved process because its modeling required the recalibration of the *Heat Source* model for water temperature, weather and flow conditions. This chapter briefly discusses how the information gathered was used to modify each of the models and summarizes any additional work related to the project.

2.1 Seepage Studies

Generating a flow profile of the Walla Walla River for August and June 2002 was conducted mainly with the information provided by the WWBWC's *Walla Walla River Surface Water Budget Assessment* (Bower 2005). Starting in 2002, a group of agencies and NGOs from Washington and Oregon starting conducting seasonal instream flow, diversion inventories, and tributary flow surveys termed "seepage runs". This was conducted in order to quantify the spatial variations in water volume for the Walla Walla River. These inventories were conducted by a group of agencies and NGOs over a couple of days period during 2002, 2003, and 2004. Seepage runs were conducted in two primary seasons of concern; June when listed fish species are moving from the lower to upper watershed to either spawn or rear for the summer months and August when water quality issues and low flow volumes are at their most critical levels.

The seepage analysis was conducted by applying a simple mass-balance approach to a reach-by-reach basis water budget. Reaches were defined by the closest upstream and downstream instream flow measurement. All water calculations were performed from a given instream flow site upriver to the next nearest instream flow site. The calculations for net tributary inputs and diversion withdrawals are straight forward sums of all values in a defined reach. The basic equations for water budget analysis were:

[9] Revised channel loss information needed to be incorporated into the August 2002 flow profile.

Net Channel Gains and Losses (N_{GL}) = ($\sum (T_R) - \sum (D_R)$) + ($Q_{DN} - Q_{UP}$)

Where: $\sum (T_R)$ = Sum of all Tributary Inputs for given reach
$\sum (D_R)$ = Sum of all Diversion withdrawals for a given reach
Q_{DN} = Flow value at reach's downstream site
Q_{UP} = Flow value at reach's upstream site

Units: cubic-feet-per-second/reach

Equation 2: Net Channel Bed Gains and Losses for Seepage Run Analysis

Therefore this report provided the HCP modeling project with reasonable estimates of areas where the Walla Walla River shows channel bed gains and losses. More importantly it provided field-verified diversion, tributary and instream flow values to calibrate the temperature models.

Model simulations are based on single month meteorological data and steady-state reach gain and loss relationships that do not include year-to-year and seasonal changes or the potential secondary effects of diversion reductions on downstream return flows. These simplifications may limit the applicability of the predicted results. In particular, the secondary effects on groundwater levels and return flows could be significant and could result in instream flows being over-estimated and temperatures being under-estimated.

2.2 Channel Bed Infiltration Analysis

The mainstem of the Walla Walla River in Milton-Freewater's flood control levee between Nursery Bridge and Tumalum Bridge is an area of particular interest when establishing a longitundal flow profile of the Walla Walla River (Figure 2). During the summer and fall months, this area of the river had been dry for over a hundred years due both to irrigation diversions and from the high volume of channel bed infiltration prior to the USFWS-Districts agreement. There are thought to be interactions that contribute to these rates due to a number of factors including fluvial geology, high evaporation rates, levee construction and surface-groundwater. From the construction of the Milton-Freewater Flood Control Levee, it is also an area of rapid water temperature increases due to the lack of riparian vegetation and poor channel morphology (wide and shallow). These high flow losses and direct solar heating make it an area of particular concern for fisheries issues and this HCP take assessment.

This area was originally assessed during the development of the TMDL (Butcher and Bower 2005) and a relationship of instream flow volume (inflow) to channel bed loss volume was established using regression analysis and gauge data from beginning (Nursery Bridge) and end (Tum-a-Lum Bridge) of the reach (Butcher and Bower 2005). During the course of this HCP take analysis modeling, errors in the original gauge data were discovered and corrected. This revised gauge data was used in combination with the aforementioned seepage studies, in addition to an Oregon State University study of hydraulic conductivity (Metcalf 2004) to establish a more accurate flow-to-infiltration-rate relationship. A review of the revised gauge data, including time shifts and seasonal hydraulic conductivity changes (colmation), concluded that the best solution for estimating losses for flows between 0 and

100 cfs (2.83 m^3/s) is that shown in Figure 11 and Equation 3 . It should be noted that this relationship is based on all available data and not just data from June. While it represents the best information available on channel gains and losses, it may not completely describe the range of hydraulic variability, particularly during rapid flow changes in the month of June

$$\text{Tumalum Q} = -6.2032664 + 0.1912016*((\text{Nursery Q})*\text{LN (Nursery Q)})^{10}$$

Equation 3: Lower Levee Channel Loss Regression

where Q represents the stream flow in cfs at the respective location. This relationship was applied only to the low flow, August flow scenarios modeled during this project when the river is in a more steady state condition. June channel bed losses were calculated during the flow balancing process described in Chapter 3.4.

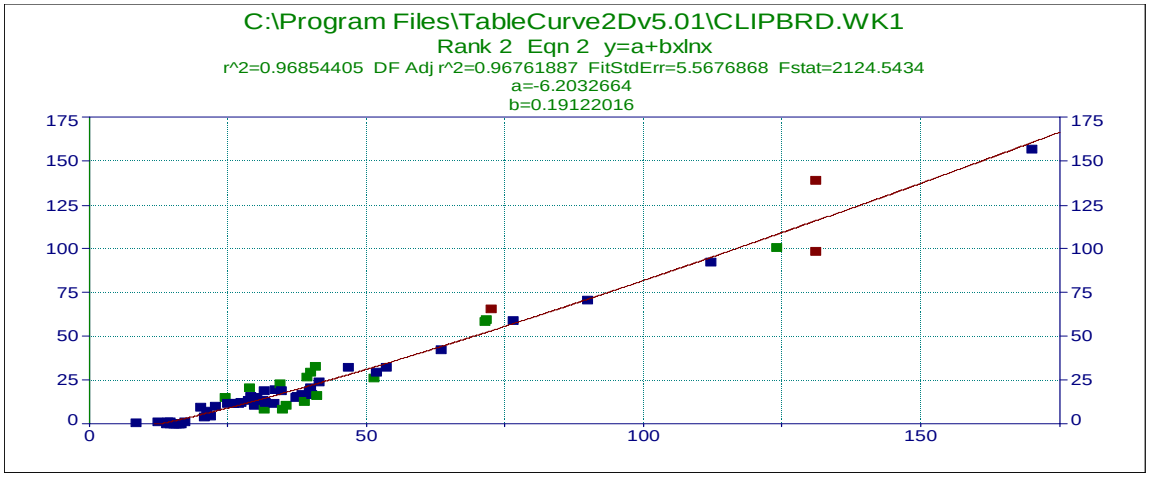


Figure 12: Oregon's Lower Levee Loss Regression (X-axis = Water entering upstream (Nursery Bridge), Y-axis = Water leaving downstream (Tum A Lum Bridge)

2.3 Walla Walla River: A Distributary System

As is depicted in Figure 2, the Walla Walla River is a distributary river system consisting of a number of branches and springs. The Walla Walla River was originally called the Tum A Lum Branch[11] before being selected in the early 1900s as the primary route for flood control (levee construction) and more recently for fish passage and is now considered by some federal and state agencies to be the Walla Walla River 'mainstem'. The East and West Little Walla Walla Rivers are today primarily used for irrigation with a majority of the surface water being withdrawn from the Walla Walla River (Oregon) being utilized from these two branches.

Following the USFWS-Districts flow agreement, water bypassed into the Tum A Lum or mainstem branch meant less water flowing down the East and West Little Walla

[11] Verbal Communications with Confederated Trives of the Umatilla Indian Reservation (CTUIR), Tribal Elder, 2003. Walla Walla Indian language for "*place of shiny rocks*".

Walla Rivers. Consequently, the lower sections of these rivers (mainly in Washington) have been reported as being dried up and local area wells also showed declines. Changes in groundwater recharge from the upgradient system and through flow from Oregon are suspected to have changed these down gradient conditions. NGOs, such as the Native Creek Society,[12] were formed in order to voice concerns over this and other water management policies and to look for ways to mitigate unexpected consequences of change.

As the HCP Take Analysis's primary assessment was to look at various flow scenarios that would increase the amount of water being bypassed to the Walla Walla River 'mainstem', an assessment of consequences to the other distributaries was attempted. With the lack of pre-agreement flow and temperature data for the East and West Little Walla Walla Rivers and the immense complexity of surface-groundwater interactions between the Little Walla Walla Diversion, the Walla Walla River, and the Little Walla Walla system, certain assumptions were necessary. The following flow scenario methodologies were developed to model the temperature impacts on the WW River mainstem.

2.4 Flow Scenarios for August and June Model Runs

To restate, the purpose of modeling increasing flow scenarios is to find the appropriate instream flow level that allows for the recovery of the ESA listed fish species and minimizes take to the furthest extent practical. Only after an array of bypassed flow volumes has been assessed can this appropriate value be established. The models were run for various scenarios based on the incremental addition of 25 cfs (0.71 m^3/s) at the Little Walla Walla Diversion at Cemetery Bridge (RM 47.5, RKm 76.5). The Little Walla Walla Diversion is primarily where both Hudson Bay District Improvement Company (HBDIC) and the Walla Walla River Irrigation District (WWRID) divert their water. WWRID also has a significantly smaller diversion just above the Nursery Bridge (45.9, RKm 73.8) called the Eastside Diversion (Figure 12). As these two sites are managed by the same district, it was easiest to assume that bypass flow scenarios could be managed at the primary Little Walla Walla River Diversion. Other non-district diversions throughout the study reach were accounted for during the construction of the longitudinal flow profiles described in Chapter 3.

Based on flow data being collected by the WWBWC and from historical data collected on many of the distributaries and springs, we found it necessary to make some assumptions on generalized tributaries inputs from the Little Walla Walla River system. The East Little Walla Walla system has two primary tributaries, the East Prong and the Big Spring subwatershed. Big Spring has steady year round flows and water chemistry suggest that it is primarily supplied by the water infiltrating from the lower levee section[13] (Oregon) and from other upgradient recharge sources. This makes this spring system less susceptible (in theory) to diversion changes at the Little Walla Walla diversion (Figure 12). The East Prong however, like it's more westerly neighboring systems (Mud and West Prong), is more dependent on upgradient waters for its base flow. Therefore, for the flow modeling scenarios, the East Little Walla Walla flow contribution to the two sub-watershed system was

[12] Native Creek Society is a local nonprofit group, formed by stakeholders in the Little Walla Walla River watershed.
[13] Described in Section 2.2

zeroed out while the Big Spring contribution was left to return to the mainstem via the Lower East Little Walla Walla River. This resulted in approximately half the current irrigation season inflow from the East Little Walla Walla..

These allocations of return flows seemed the most practical given the complexity of the surface-groundwater interactions in this system. What was observed anecdotally from the years following the USFWS-Districts agreement was that as more water was bypassed in the mainstem, less water flowed in the Little Walla Walla System. This set of scenarios uses those observations to establish this Zero and ½ flow relationship as noted Tables 3 and 4. As *Heat Source* is a 1-Dimenisional model, it treats these changes to tributaries inflows to the mainstem as boundary conditions.

For all of the June 2002 flow scenarios, the Little Walla System was assumed to respond according to the Zero and ½ flow scenario explained above (Table 3). This assumption does not include the potential secondary effects on channel gains and losses and on return flows associated with the water use changes that would likely result from these scenarios. June represents the time of year when the river is transitioning from the higher flows of the spring freshet to that of the lower baseflows of the summer months (Figure 8). This transitional period may include significant differences in flow conditions from year to year.

In addition to the original flow scenarios for the HCP, where incremental increases 25 cfs up to 100 cfs (0.71 to 2.83 m^3/s) were evaluated, two additional scenarios were run in June. These "All Diverted Water" runs were done for a complementary study that was being done by the USACE and the CTUIR. In this feasibility study a number of flow modification projects including above ground storage and pumping from the Columbia River were being evaluated to boast flows in the Walla Walla River.

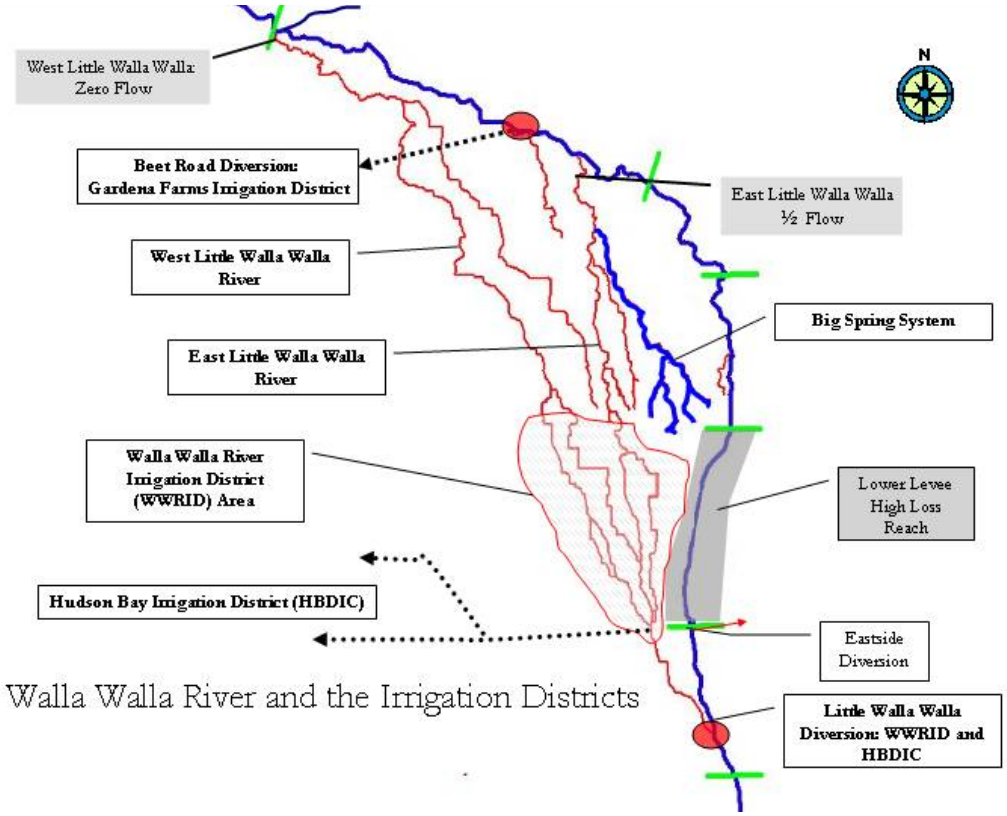


Figure 13: Map of Little Walla Walla and Walla Walla River system

June 2002 Bypassed Flow Scenarios	Additional Flow Bypassed at Little Walla Walla (cfs)	Additional Flow Bypassed at Gardena Farms (cfs)
Base case Conditions (validation model)	0	0
25 cfs	25 cfs	0
50 cfs	50 cfs	0
75 cfs	75 cfs	0
100 cfs	100 cfs	0
*All Diverted Water	Approximately 100-140 cfs	0
*All Diverted Water	Approximately 100-140 cfs	All Gardena's diverted water (approximately 0-80cfs)
**These scenarios was completed for an augmented flow study being conducted by the USACE and the CTUIR.*		

Table 2: Various Modeled June Flow Scenarios

August represents the time when flow and water temperatures are at their most critical. August scenarios were also done in 25 cfs (0.71 m^3/s) incremental increases up to a total bypass flow of 87.2 cfs (2.478 m^3/s) (Table 4). In order to insure that each of the actual bypass flows were modeled, it was necessary to adjust the actual flow conditions at (Nursery Bridge Gauge) downward to the target baseflow of 25 cfs (0.71 m^3/s). During the August modeling scenarios one Little Walla Walla inflow tributary reduction scenario was ran to estimate the changes to Walla Walla River temperature conditions.

August 2002 Bypassed Flow Scenarios	Additional Flow Bypassed at Little Walla Walla (cfs)	Additional Flow Bypassed at Gardena Farms (cfs)
Base case conditions (Measured flow 33.2 cfs)	0	0
25 cfs**	- 8 cfs	0
50 cfs	17 cfs (+25 cfs)	0
50 cfs (Little Walla Walla In-Flow Reduction)	17 cfs (+25 cfs)	0
75 cfs	42 cfs (+25 cfs)	0
All Water Bypassed: 87.2 cfs**	+ 62.5 cfs (all remaining flow)	0
* This scenario was completed in order to align the actual flow (measured in field) with the flow values being modeled for the HCP. This mean 8 cfs less water was bypassed at the Little Walla Walla Diversion. ** Only 87.2 cfs was actually available during August 2002.		

Table 3: Various Modeled August Flow Scenarios

3.0 Developing the Temperature Models

Modeling the effects of various flow scenarios on temperature for June proved to be the more rigorous of the two projects to develop. The TMDL process had provided a calibrated model for August 2002 however creating a June 2002 *Heat Source* model meant starting with the August 2002 model and recalibrating it for June conditions. Fortunately, the original August model did provide the following model parameters that were not changed for the June set up:

- River Morphology[14]:
  - Including: channel aspect, stream elevation, gradient, substrate size, channel diameters, wetted and flood prone widths, etc.
- Vegetative Shade and Stream Side Conditions[15]:
  - Including: vegetation types, canopy density, percentage of effective shade, land uses, topographic shade, etc.

The portions of the model that were changed for June 2002 conditions were:

- Climate and water temperature conditions[16]:
  - Including: boundary conditions, wind speed, relative humidity, cloudiness, air and stream temperatures.
- Flow conditions[17]:
  - Spatially explicit instream flows, groundwater[18] gains/losses, diversions, tributary flows and water temperatures.

The following chapter sections cover the set up and calibration process for the June *Heat Source* model.

3.1 Overview of June Model Preparation

The June 2002[19] model was set up to model 20 days (June 11- June 30, 2002) from Harris Park (RM 61.1, 98.3 RKm) to the confluence with the Columbia River (RM/RKM 0). The time-distance steps were based on an assessment of peak flow velocities and determined to be dT (minutes) = 1, dX (meters) = 300. The original model's time/distance step was calibrated for dT/dX = 1/100 but because of the much higher flow-velocities in June, the distance was tripled to offset any overflow issues. Overflow issues occur when the flow velocities exceed the time-distance step based on the 25 meter (82 ft) sample length. A

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[14] T-tools data and morphology data worksheets in *Heat Source Version 7.0* interface
[15] Land Cover Codes worksheet in *Heat Source Version 7.0* interface
[16] Continuous Data worksheet in *Heat Source Version 7.0* interface
[17] Flow Data worksheet in *Heat Source Version 7.0* interface
[18] Groundwater gains and losses are called "accretion flow" in *Heat Source Version 7.0* and are fixed value inputs.
[19] The TMDL precalibrated August 2002 Heat Source Version 7 would not run using the date June, 2002 and therefore the August 2000 version was used, but all environmental parameters were setup for conditions in June 2002. The only difference in the two models would be the slight difference in solar aspect from 2000 to 2002.

comparison was made between the original calibration and this new increased time-distance step using the TIR flight versus simulated temperature outputs. In the original calibrated model the Standard Error (SE) for this comparison was 1.1 SE The dT/dX = 1/300 scenario revealed a S.E. of 1.6. Graphical comparisons of longitudinal profiles of flow and temperature determined that increasing the distance step would not dramatically alter the original calibration of the model.

Based on the availability of June data, the model was shortened from its original length of 70.2 Miles (113 Km) to 61.1 Miles (98.3 Km) moving the upstream boundary condition site to Harris Park OWRD gauge and establishing the reference inflow boundary condition. The longitundal sample distance was set at 25 meters (82 ft) and the land cover sample distance was left at 15 meters (49.2 ft). The initial flush condition was determined to be 13 days and done by calculating the total time required to allow the lowest flows (0.09 m^3/s, 3.2 cfs) to cover the complete distance of the model (98.3 RKm).

3.2 June Climate and Water Temperature Conditions

The Continuous Data worksheet in *Heat Source Version 7.0* requires that continuous (15 minute) weather and water temperatures be entered for the model's upstream boundary as well as instream conditions at designated nodes along the rivers length. Based on the data available, 13 nodes were selected and are shown in Table 5.

Continous Data Nodes: June 2002 Model

Locational Information (optional)	Continuous Node	Stream km	Data Source:
Boundary Condition (Harris Park OWRD Gauge)	1	98.3	OWRD/WWBWC
South Fork Walla Walla River (WWR) Bridge	2	84.4	WWBWC
Day Road, WWR	3	80.4	WWBWC
Grove School Bridge (M1a)	4	77.0	WWBWC
Levy, WWR (M2)	5	75.6	WWBWC
Nursery Bridge, WWR (M4)	6	73.8	WWBWC
Levy, WWR (M7)	7	71.6	WWBWC
Levy, WWR (M8)	8	70.2	WWBWC
Mauer, WWR (M9)	9	69.3	WWBWC
Beet Rd Bridge, WWR	10	60.4	WDFW
Swegle Bridge, WWR	11	55.4	WDFW
Detour Bridge, WWR	12	53.6	WDFW
Touchet-Gardena Bridge, WWR	13	33.0	WDFW

Table 4: Location information for Continuous Data worksheet input for *Heat Source* June 2002 Walla Walla River Model

Climate data including air temperature, relative humidity, and wind speed was collected by both WDOE and by Washington State Universities (WSU) Public Agricultural Weather System (P.A.W.S). weather system[20]. WDOE collected air temperature data using *Tidbit* loggers at three locations in the Walla Walla River basin on Mill Creek (RM 14.8, RKm 23.8) watershed, Dry Creek (RM 3.0, RKm 4.8), and on the Walla Walla River at the Touchet-Gardena Road Bridge (RM 20.5, RKm 33.0). A comparison between the WSU

[20] http://index.prosser.wsu.edu

weather stations and the WDOE loggers indicated that the WDOE's deployment of near-stream temperature loggers were representative of the cooler, streamside conditions along the Walla Walla River and thus were used for this modeling exercise. Wind speed and humidity (not recorded at WDOE sites) were used from the P.A.W.S stations at Touchet and College Place.

Air temperature data were adjusted for each of the continuous node using the standardize equation for dry adiabatic rate of 10^0C per 1000 meters[21] (16.2 F per 3281 ft) to adjust temperature based variance in elevation for each continuous river node (Table 6 and Figure 13). Wind speed and humidity were adjusted for each continuous node by using the P.A.W.S. data nearest to site as representative of conditions.

[21] "*The rate at which air cools or warms depends on the moisture status of the air. If the air is dry, the rate of temperature change is 1°C/100 meters and is called the* **dry adiabatic rate** *(DAR)".*
http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/atmospheric_moisture/lapse_rates_1.html

WDOE Tidbit Air Temp loggers	Elevation (meters) DAR: 0.3048
Touchet Cummings Brg	135.60
Dry Creek (3.0)	173.70
Mill Creek (14.8)	450.00

WDOE TMDL Air Temperature Data Stations:dry adiabatic rate adjusted by elevation

Locational Information (optional)	Stream km	Elevation (meters)	Elevation difference	Temperature Adjustor for
Harris Park	98.3	621.0	171.0	-1.71
SF Bridge	84.4	414.0	-36.0	0.36
Day Road, Mainstem	80.1	378.0	-72.0	0.72
Grove Brg (M1a)	76.8	329.0	-121.0	1.21
Levy, M2	75.8	318.0	-132.0	1.32
Levy, M3	75.0	313.0	-137.0	1.37
Nursery Bridge (M4)	74.1	301.0	127.3	-1.273
Levy, M6	71.8	271.0	97.3	-0.973
Levy, M7	71.1	265.0	91.3	-0.913
Tumalum Brg, M8	70.2	257.0	83.3	-0.833
Mathew's Lane, M9	69.3	250.0	76.3	-0.763
Beet Rd Brg	60.4	204.0	30.3	-0.303
WDFW, Swegle Road	55.3	183.0	9.3	-0.093
WDFW, Detour Road	53.6	177.0	3.3	-0.033
Touchet-Gardena Brg	33.0	130.0	-5.6	0.056

Touchet Air	Dry Creek 3.0	Mill Creek 14.8
WDOE TMDL Air Temp	WDOE TMDL Air temp	WDOE TMDL Air temp
Tidbit Serial #1	**Tidbit Serial #1**	**Tidbit Serial #1**
453800	452909	452919
Elevation:	Elevation:	Elevation:
135.6	173.7	450.0

Table 5: June 2002 Air Temperatures (WDOE)

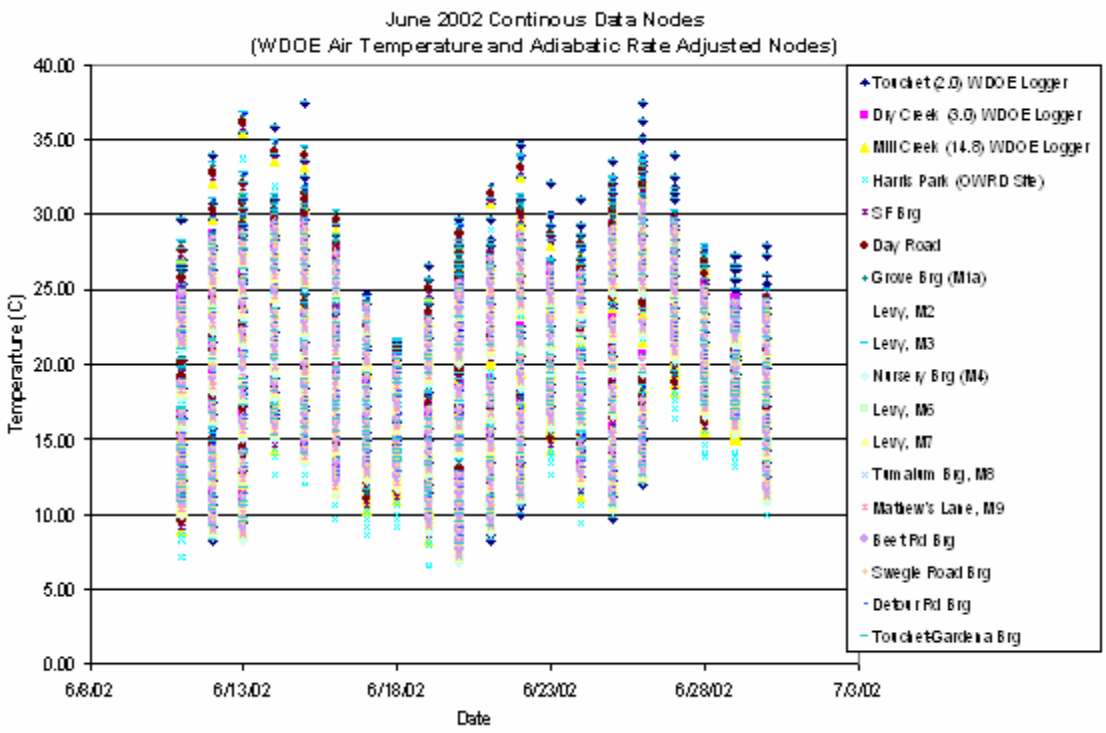


Figure 14: Air Temperatures for June 2002 *Heat Source* Modeling

Water temperature data for each of the continuous nodes were obtained from a variety of sources. Table 5 cites the data sources by location. When water temperature data was assessed graphically, it appeared to be relatively consistent spatially with the exception of the temperature data collected at Touchet Gardena Bridge which appeared to have less diurnal flux than would normally be expected (Figure 14 and 15). It is thought that the logger may have been placed near the constant temperature influence of groundwater accretion flow or that this might in fact be representative of the slower moving lower Walla Walla River water temperatures.

Since the focus of this model was on the lower portion of the Walla Walla River system the model length and boundary condition were reset to make the Oregon Water Resource Gauge at the Bureau of Land Management trail head at Harris Park (98.3 RKm) the upper boundary condition.

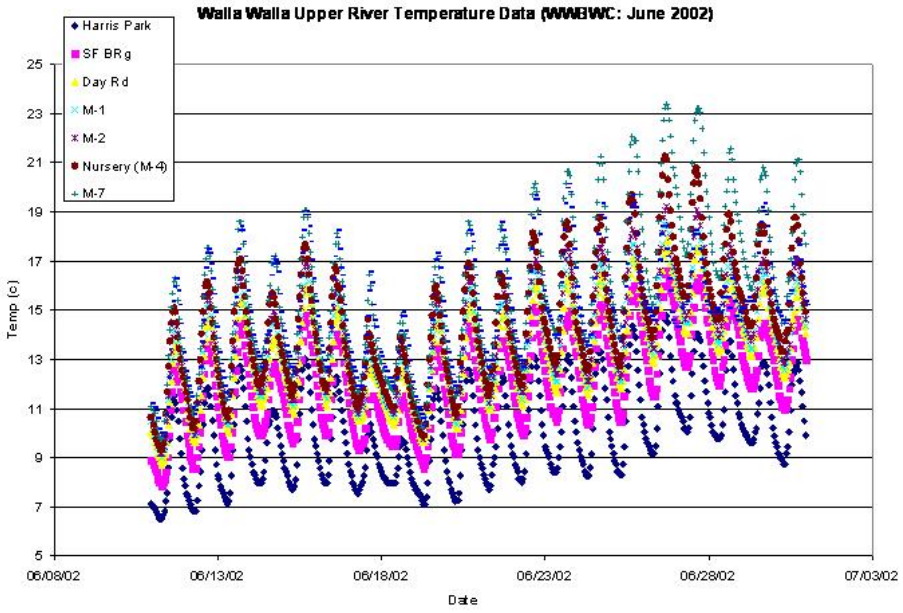


Figure 15: Upper River Mass Transfer Temperature Data (Oregon)

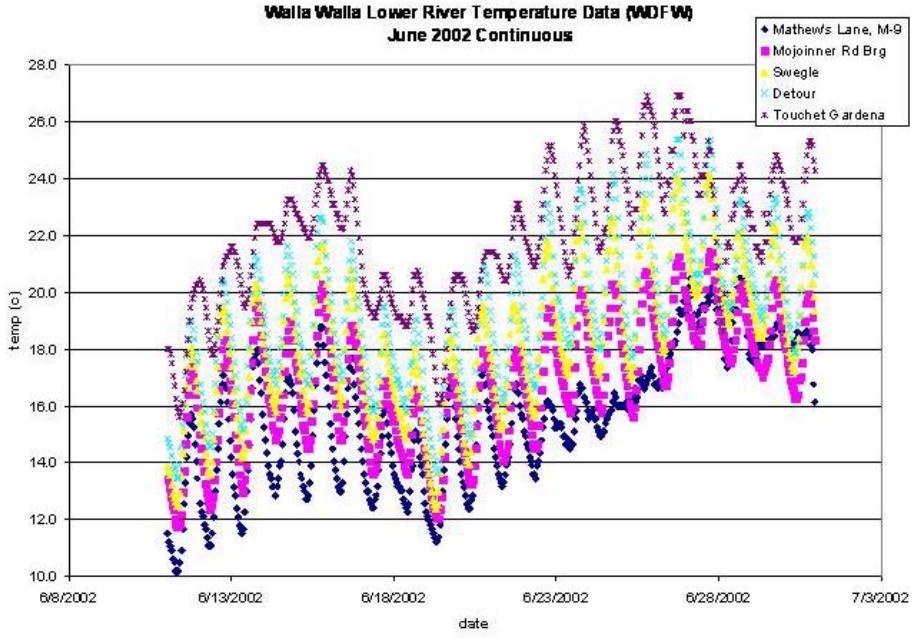
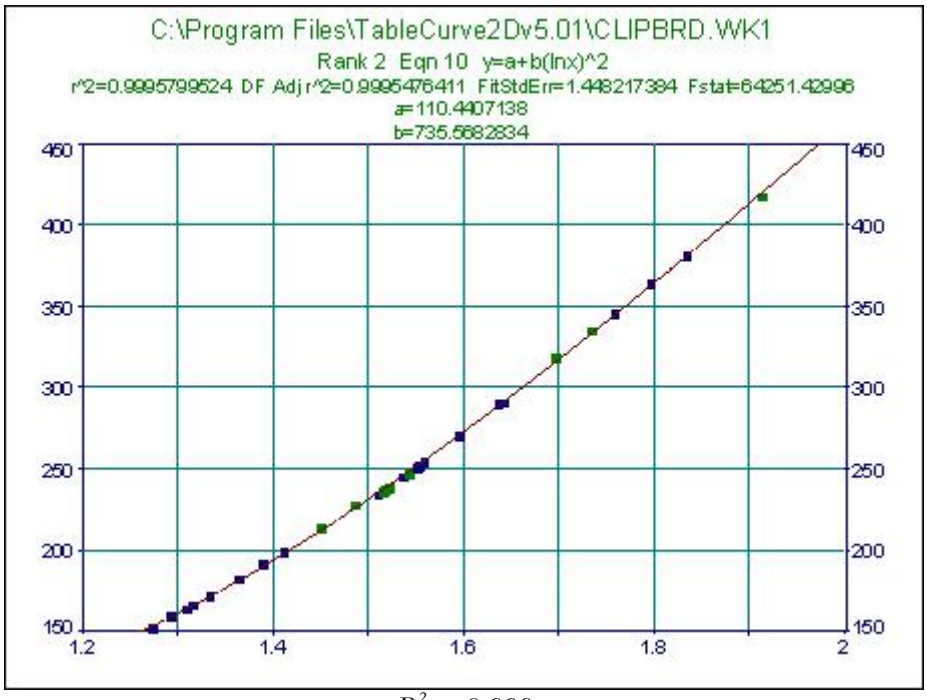


Figure 16: Lower River Mass Transfer Temperature Data (Washington)

3.3 June's Upstream Boundary Conditions

The Continuous Data worksheet in *Heat Source* requires that the upstream Walla Walla River boundary conditions including water temperature and flow be inputted. OWRD's gauge at Umatilla County's Harris Park (OWRD #14010000) was used to establish these boundary condition flows. However at the time of this modeling project, neither the 15-minute flow nor the rating measurements were available for use. In order to generate the required data a numerical comparison was made between the OWRD's daily-average-flow and the average 15-minute stage recordings for that same period. These calculations generated a stage-discharge rating equation[22] (Figure 16) that was then applied to the 15-minute stage data to generate the required flow.



$R^2 = 0.999$

Figure 17: Comparison regression for OWRD's daily average stage (x-axis) and daily average flow (y-axis) for stage-discharge rating equation

Water temperature data for the boundary conditions were available from a WWBWC logger placed near the OWRD gauge site in 2002. Due to recommendations from ODEQ's modeling staff,[23] the final model input for the *Heat Source* boundary conditions is *Cloudiness* which was not changed from the original model setting of "zero".

[22] Harris Park Flow (y) = 110.4407138 + 735.5682834 *[LN (OWRD 15-minute stage (x)]^2
[23] Verbal communication with Don Butcher January, 2005

3.4 June Model's Flow: Diversions, Groundwater, Instream and Tributaries

Heat Source's Flow Data worksheet requires that a spatially explicit flow profile of the river be created. The flow profile includes an inventory of instream flow values, diversion withdrawals, groundwater gains and losses and tributary inputs. In order to create this information a separate analysis was conducted and termed a *water budget* or *balance* that accounted for the total surface flow of the Walla Walla River. This balance was done by using a simple mass-balance approach and applied both to the entire river (Equation 4) and to each gauge-to-gauge reach in the river.

USGS Touchet Flow Gauge (cfs)	≈	Sum of Flow Balance (cfs)	=	Boundary and Tributary Inflows (cfs)	+/-	Groundwater (gains/losses) (cfs)	-	Diversion Withdrawals (cfs)

Equation 4: June 2002 Walla Walla River Simple Flow Balance

Inflow to the flow balance was generated from OWRD's South Fork Walla Walla River at Harris Park (14010000) and North Fork Walla Walla River gauges (14010800). The downstream gauge used as the graphical check and balance for this flow balance was the USGS Touchet Gauge[24] (USGS #14018500).

In June 2002, there were only a handful of continuous stream gauges in operation on the Walla Walla River and its tributaries. Therefore it was necessary to generate synthetic flow data from existing synoptic measurements, gauges, and the seepage inventories. Where synthetic flow was needed it was created using a variety of techniques. A majority of the tributaries did have synoptic measurements taken during June 2002 (Bower 2005). Where available, synoptic measurements were plotted and then a linear interpretation was done to estimate the 15-minute flow for the modeling time period. Figure 17 shows a typical synthetic tributary site using this synoptic-linear-interpretation method for Garrison Creek. Table 7 provides a complete list of the 37 data nodes used to generate the June 2002 flow profile.

When continuous data was available, it sometimes was used in conjunction with the synthetic data sets to generate the needed data (Figure 18). In most cases there were synoptic measurements that fell within the model period providing some assurance that this method was reasonably representative of flow conditions. However, in the case of the Touchet River, it was discovered that the lack of synoptic measurements during the model period (Figure 19, shaded area) made this linear interpolation inaccurate. This was a period discovered to have a peak flow that was not captured in the linear interpolation method. This was corrected by calculating the Touchet River tributary input by assuming it to be the difference between all upriver flow and the downstream USGS gauge flow. Since the spatial scope of this model was not focused on this lower river area, this approach did not seem problematic

[24] http://waterdata.usgs.gov/wa/nwis/uv?station=14018500

and the total flow balance seemed to be a reasonable estimate of Walla Walla flow conditions. All of tributary inputs were assessed graphically and appear to follow the general June 2002 hydrograph pattern (Figure 20).

Locational Information (optional)	Inflow Mass Transfer Process	Stream km	Data Type		Source Agency
			Flow	Temperature	
Groundwater	1	95.3	syth.	syth.	WWBWC
North Fork WW River	2	84.2	gauge	logger	OWRD/WWBWC
Couse Creek	3	78.4	synoptic	logger	WWBWC*
Channel 1: Upriver to Grove (OR Irr)	4	77.0	calc.	logger	WWBWC*
Channel 2: LWW and Eastside Diversion (inverted)	5	76.2	gauges	logger	WWBWC/OWRD/WWRID
Channel 3: Grove to M4 Loss (inverted)	6	73.9	calc.	logger	WWBWC*
Levy Pipe	7	73.1	synoptic	logger	WWBWC*
Channel 4: M4 to Tumalum (Bush's) Loss (Inverted)	8	70.3	calc.	logger	WWBWC*
Groundwater#3	9	70.0	syth.	syth.	WWBWC*
Birch Creek	10	66.8	synoptic	syth.	WWBWC
Yellowhawk	11	63.4	gauge	logger	WDFW
Ground Water	12	62.3	syth.	syth.	WWBWC*
East LWWR	13	61.8	gauge	logger	WWBWC/WDFW
Ground Water	14	61.5	syth.	syth.	WWBWC*
Gardena Farm Diversion	15	60.5	gauge	logger	Gardena Farms
Ground Water	16	60.5	syth.	syth.	WWBWC*
Stone Creek	17	60.4	gauge	logger	WDFW
Groundwater	18	59.7	syth.	syth.	WWBWC*
Garrison Creek	19	59.5	gauge	logger	WDFW
Garrison Accretion #A	20	59.2	syth.	syth.	WWBWC*
Garrison Accretion #B	21	56.9	syth.	syth.	WWBWC*
Mill Creek	22	54.7	gauge	logger	WDFW
Mill Creek Accretion #A	23	54.5	syth.	syth.	WWBWC*
Mill Creek Accretion #B	24	54.4	syth.	syth.	WWBWC*
West Little WW River	25	54.3	gauge	logger	WDFW
West Little WW River: Accretion #A	26	54.0	syth.	syth.	WWBWC*
West Little WW River: Accretion #B	27	49.1	syth.	syth.	WWBWC*
Dry Creek	28	44.5	synoptic	logger	WDFW
Dry Creek: Accretion #A	29	43.9	syth.	syth.	WWBWC*
Dry Creek: Accretion #B	30	42.9	syth.	syth.	WWBWC*
Mud Creek	31	41.9	synoptic	logger	WDFW
Mud Creek Accetion #A	32	41.6	syth.	syth.	WWBWC*
Mud Creek Accetion #B	33	38.5	syth.	syth.	WWBWC*
Pine Creek	34	35.5	synoptic	logger	WDFW
Pine Creek Accetion #A	35	35.2	syth.	syth.	WWBWC*
Pine Creek Accetion #B	36	33.0	syth.	syth.	WWBWC*
Touchet River	37	31.1	gauge	logger	WDOE

syth.= sythetically calculated using existing data
gauge(s)= data from existing gauge station
logger = data from existing temperature logger
calc. = calculated during flow balance process
synoptic = data from combination of manual instream measurements and sythetic calculations

Table 6: Location information for Flow Data worksheet (Mass Transfer) input for *Heat Source* June 2002 Walla Walla River Model

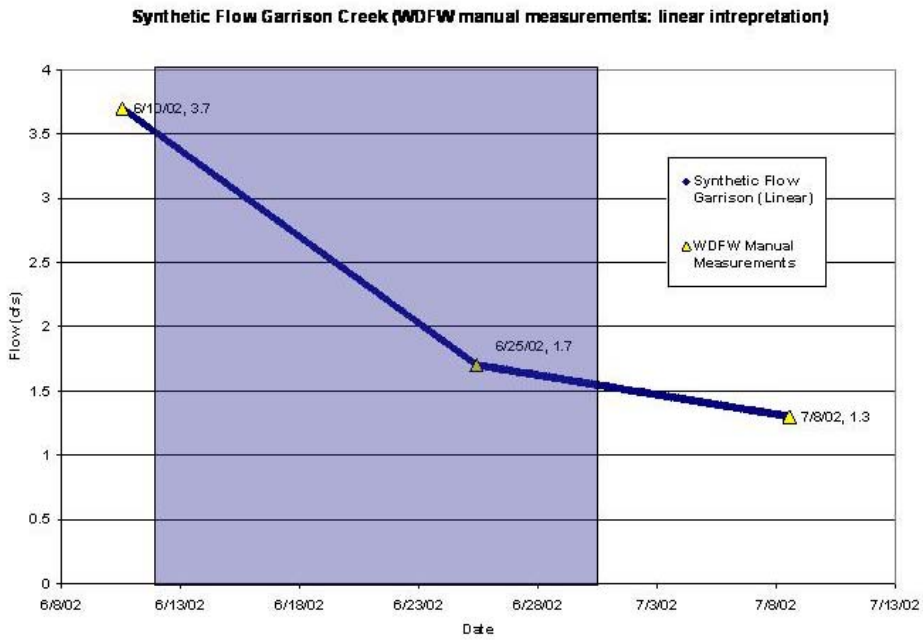


Figure 18: June 2002 Flow Balance Garrison Creek (RM 37.0, RKm 59.5), shaded area June 20th day model period)

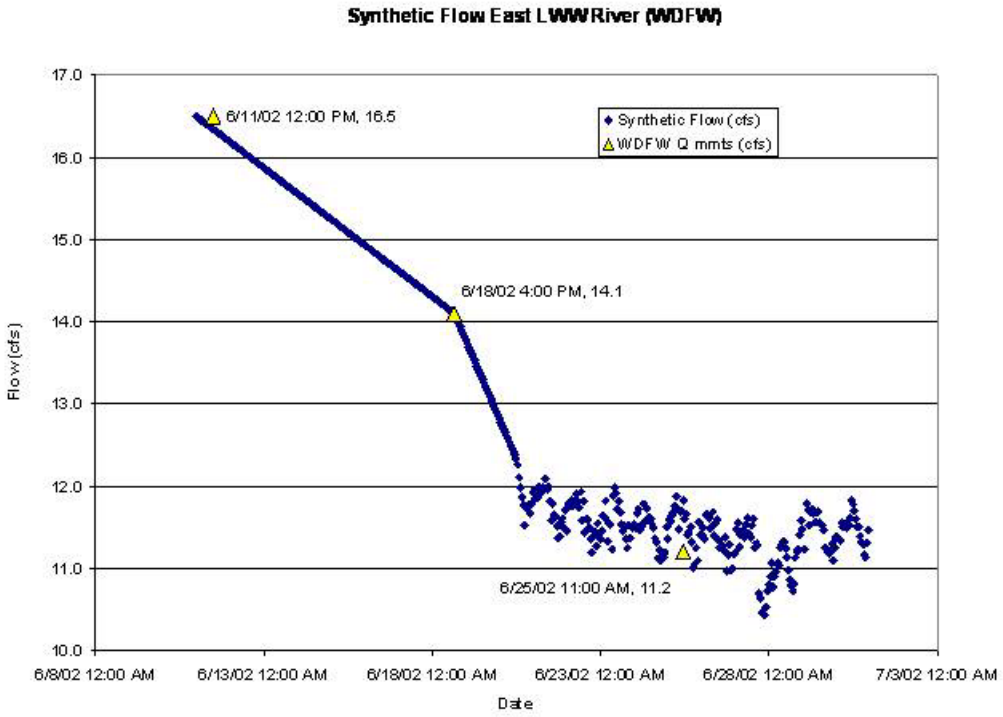


Figure 19: East Little Walla Walla River Flow for June 2002 Flow Balance (RM 38.4, RKm 61.8)

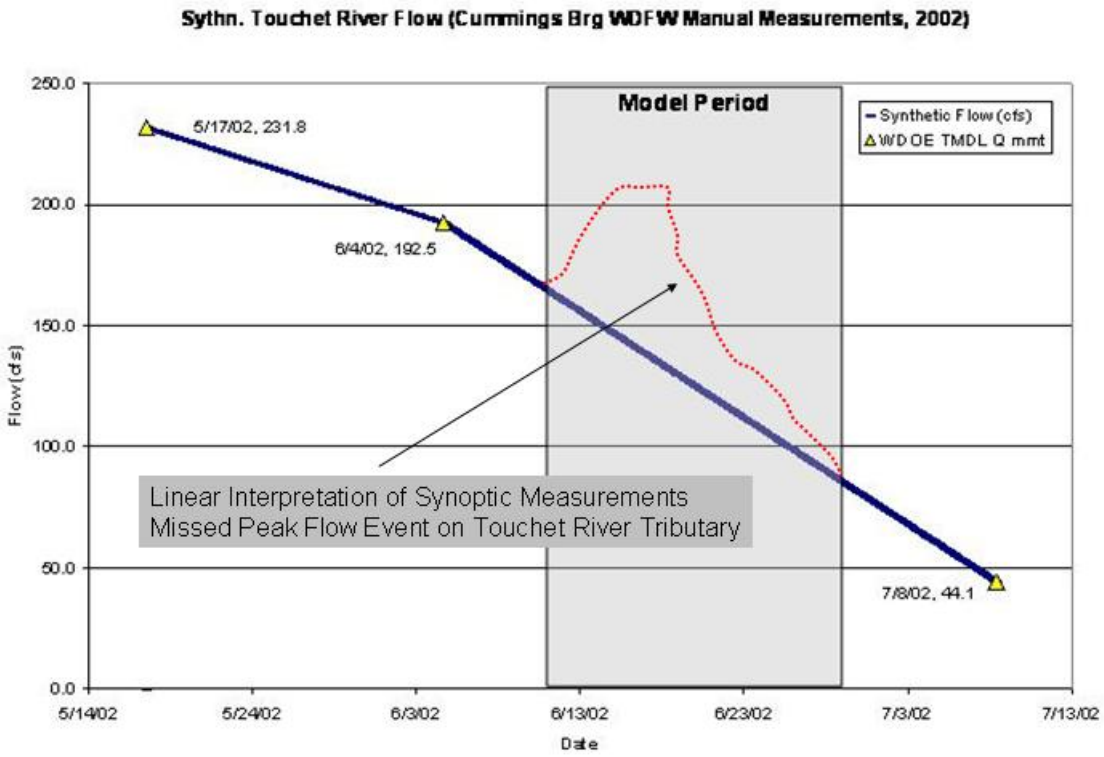


Figure 20: Touchet River Flow for June 2002 Flow Balance (RM 19.3, RKm 31.1)

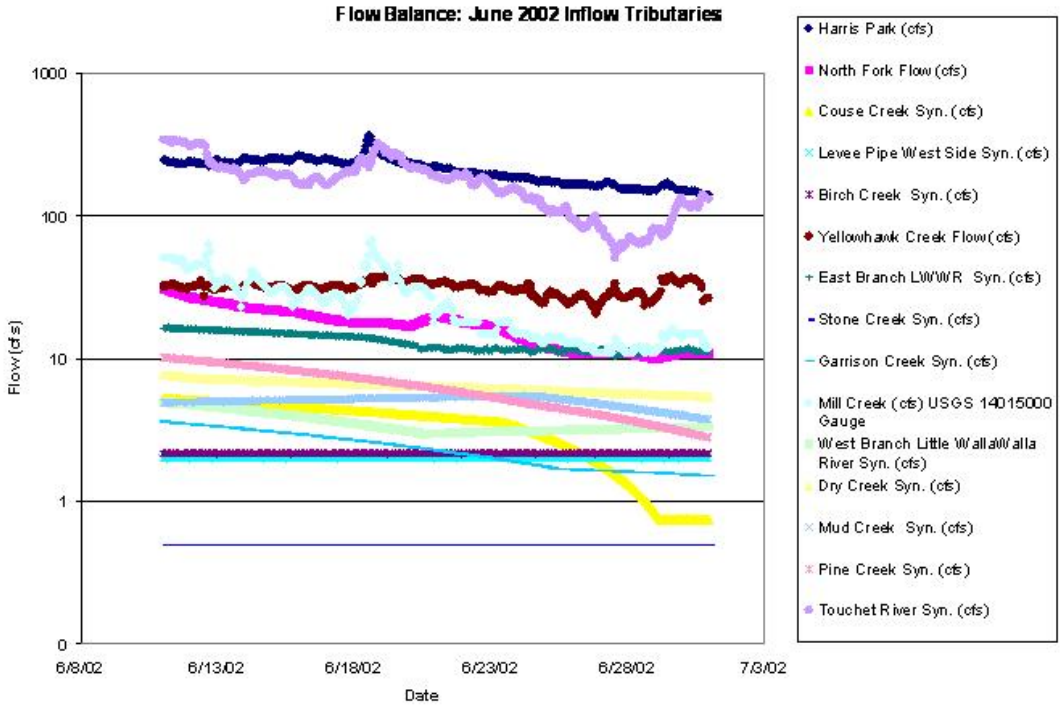


Figure 21: All Tributary Inflows for June 2002 Model

With the addition of all inflowing tributary mass transfer data (from the above discussed process) the sum total was compared against the downstream check point, USGS Touchet Gauge (Figure 21). As might be expected the sum of all upstream tributaries was greater than the downstream check point because at this point, no diversions or channel bed losses had been accounted for in the flow balance.

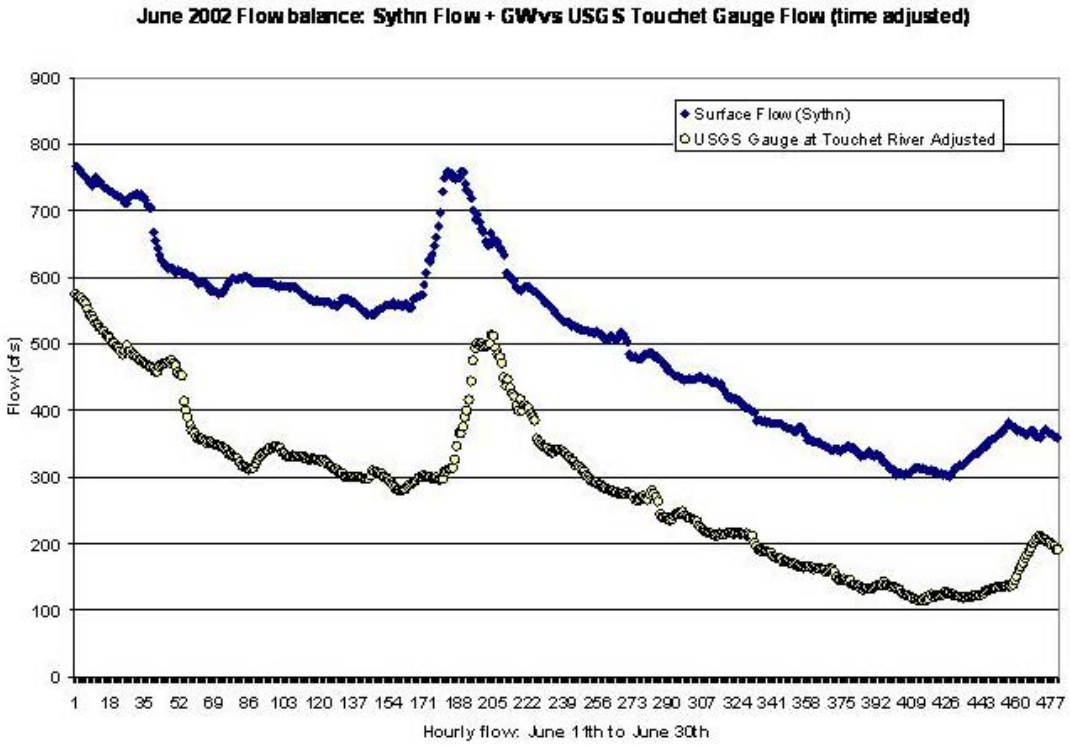


Figure 22: Flow balancing: Sum of all inflows compared to downstream check at USGS Touchet Gauge (X-axis = total time of modeling period in hours, Y-axis = cfs)

The next step in the flow balancing process was to adjust the flow balance by integrating the channel bed gains, losses and irrigation diversions into the balance. Starting at the upper boundary condition area and moving downstream on a reach-by-reach basis, diversions and channel bed gains and losses were used to adjust flow. Utilizing the upstream and downstream gauges as reference points, known diversions were subtracted from each reach's instream flow values. Where channel bed losses were not specifically studied (e.g. Oregon's Lower Levee), synoptic instream flow measurements were used to adjust instream flows through regression comparison analysis. Figure 22 shows that after diversions were subtracted from the instream flow balance, synoptic (manual) measurements at Grove School Bridge showed a net groundwater gain. This meant that flow needed to be added in order to calibrate it to field conditions.

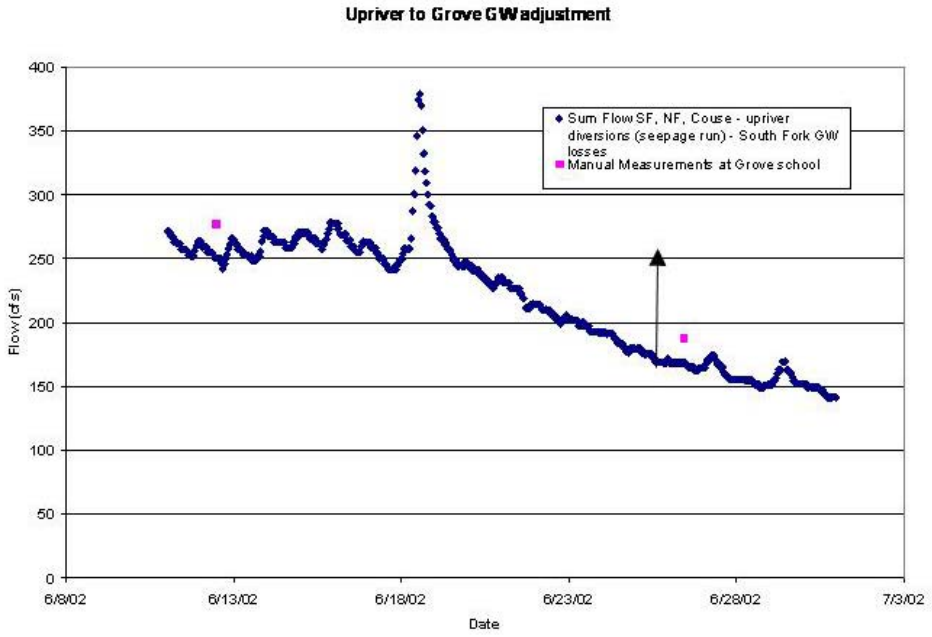


Figure 23: Synoptic flow measurements at Grove School Bridge provide adjustment information for flow balance

Although this simple linear adjustment did not account for the time-distance relationship dictated by varying flow velocities and volumes; the assumption was made that the flow routing functions in the *Heat Source 7.0* model would account for this issue. Again, the primary goal for this flow balance was to get flow within a reasonable range with reference to the USGS Touchet gauge and the synoptic measurements along the river.

As mentioned earlier, all of the flow scenarios were implemented at the Little Walla Walla River diversion at Cemetery Bridge (RM 47.3, RKm 76.15) in Milton-Freewater, Oregon. Diversion data from the OWRD's Little Walla Walla Gauge (14012100) was used to further adjust the flow balance (Figure 23). Diversion withdrawals during the modeling period remained relatively constant relative to river flow, ranging from 124 to 140 cfs (3.5 to 4.0 m^3/s). When diversion adjusted instream flows were plotted against synoptic measurements, further adjustments were needed to account for channel bed losses[25] between Grove School and Nursery Bridges (Figure 24). To make it easier to graphically assess the June flow balance against the downstream USGS gauge, upstream and tributary flows were adjusted forward 20 hours to offset the peak flow movement from upper to lower watershed (Figure 24).

[25] Groundwater gains and losses should be solely viewed as model flow balance adjustments and not as definitive values for channel bed gain and loss volumes.

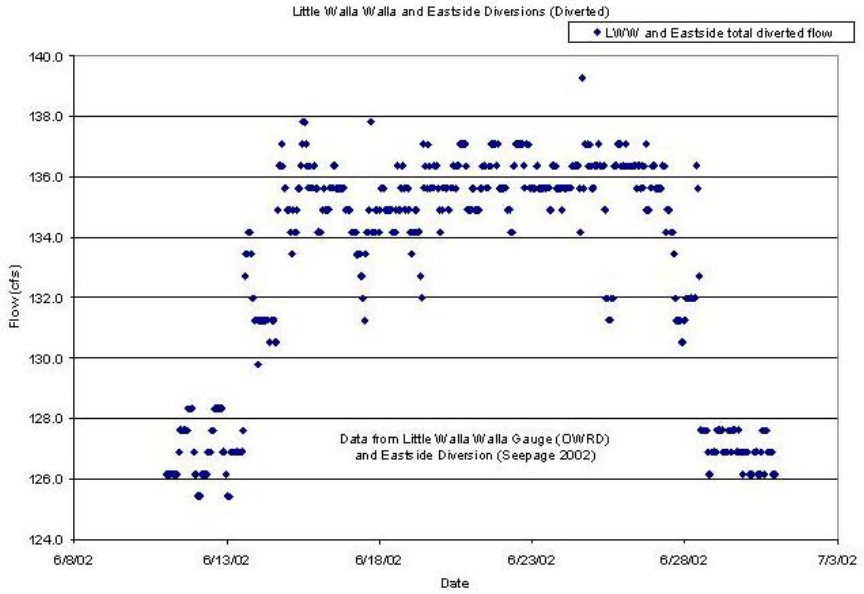


Figure 24: Little Walla Walla River Diversion flow, June modeling period 2002 (cfs)

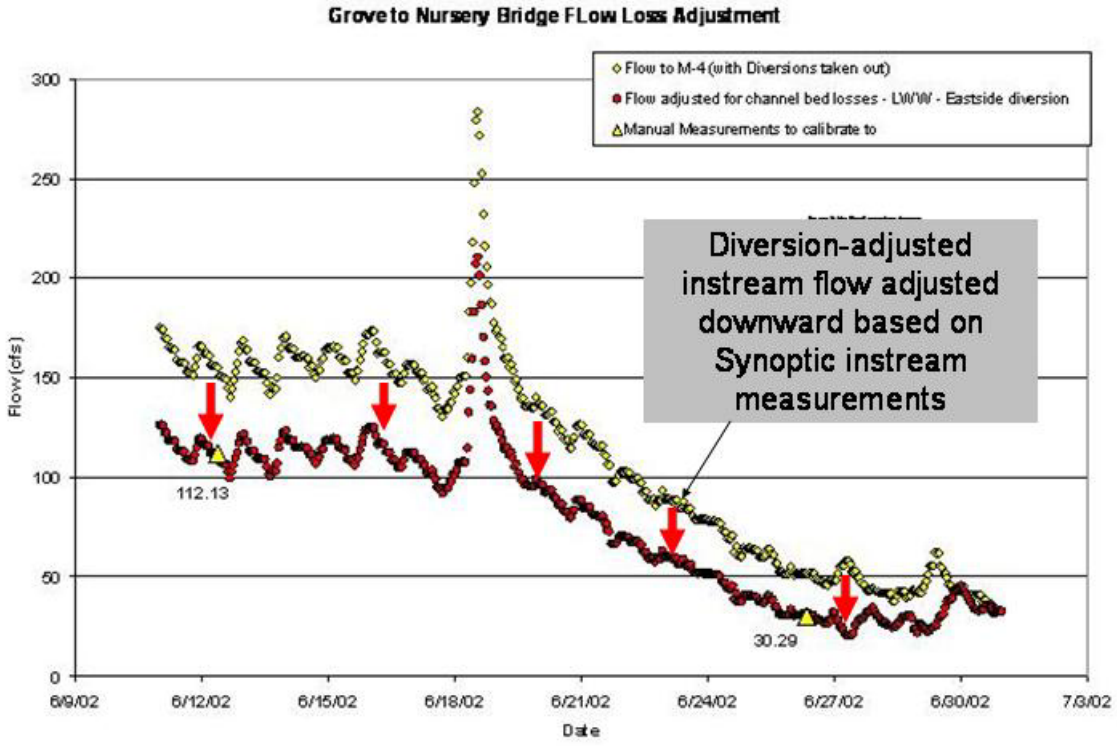


Figure 25: Channel bed adjustment on Grove to Nursery Bridge Walla Walla River Reach

As discussed earlier in Section 2.2 of this report, the Nursery to Tum A Lum Bridges (Oregon's Lower Levee) reach of the Walla Walla River is an area of well documented high infiltration rates through the irrigation season (May through November). Losses in this reach were accounted for using Equation 2. The area just downstream from Tum A Lum

Bridge north to the Oregon-Washington Stateline is an area where groundwater has been shown to reemerge in the river (Butcher and Bower 2005). Specific values for groundwater inflow were accounted for as discrete accretion additions in the Flow Data worksheet.

Further downstream into the Washington reaches, the flow balance appeared to calibrate well with independent instream synoptic flows. A synoptic to flow balance comparison at Beet Road, (near Gardena Farms No.13) was found to be representative. Since this marked the end of the HCP study area, no further *specific* groundwater gains and losses were incorporated into the June flow balance below this point in the project. The continuous gauge and synoptic data that was available downstream of Beet Road was saved for model validation purposes.

After all adjustments were made the flow balance was still significantly less than that at the USGS gauge and therefore needed to be adjusted. Unmeasured flow additions from (a) unaccounted for tributaries, (b) irrigation return-flow, and (c) groundwater gains (difference in flow balance and USGS gauge values) were added incrementally through the rest of the lower Walla Walla River. Through out the process, the flow balance data was checked graphically (Figure 25). All flow balance parameters (Mass Transfer inputs in *Heat Source)* are shown in Figure 26 including the amount of diversions, instream flows and groundwater gains and losses during the June modeling period.

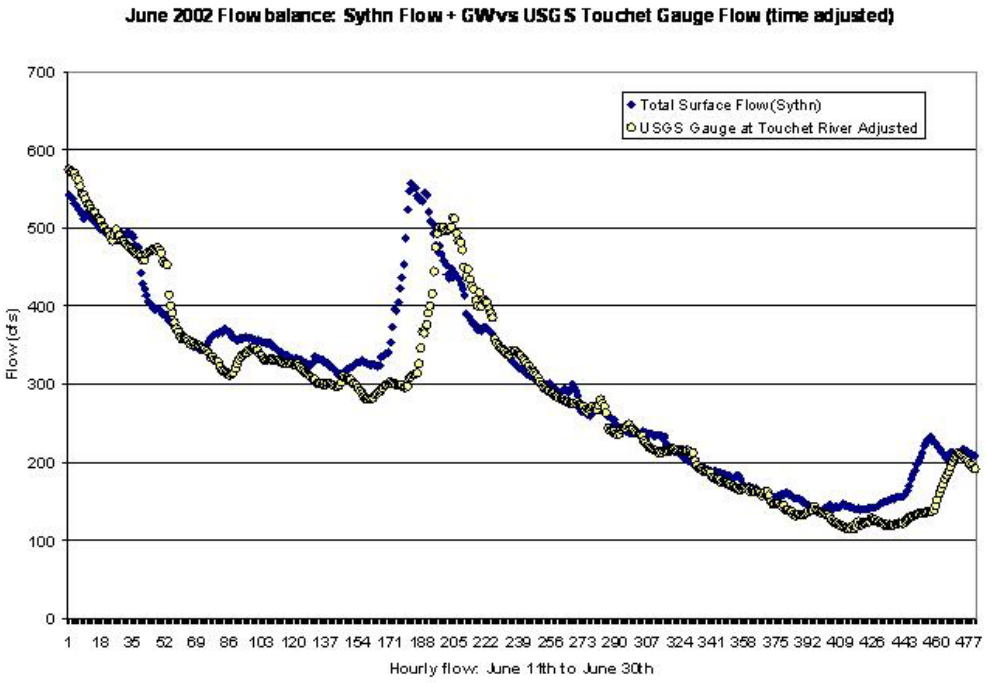


Figure 26: Comparing USGS Touchet Flows with total surface flow created synthetically (June 2002)

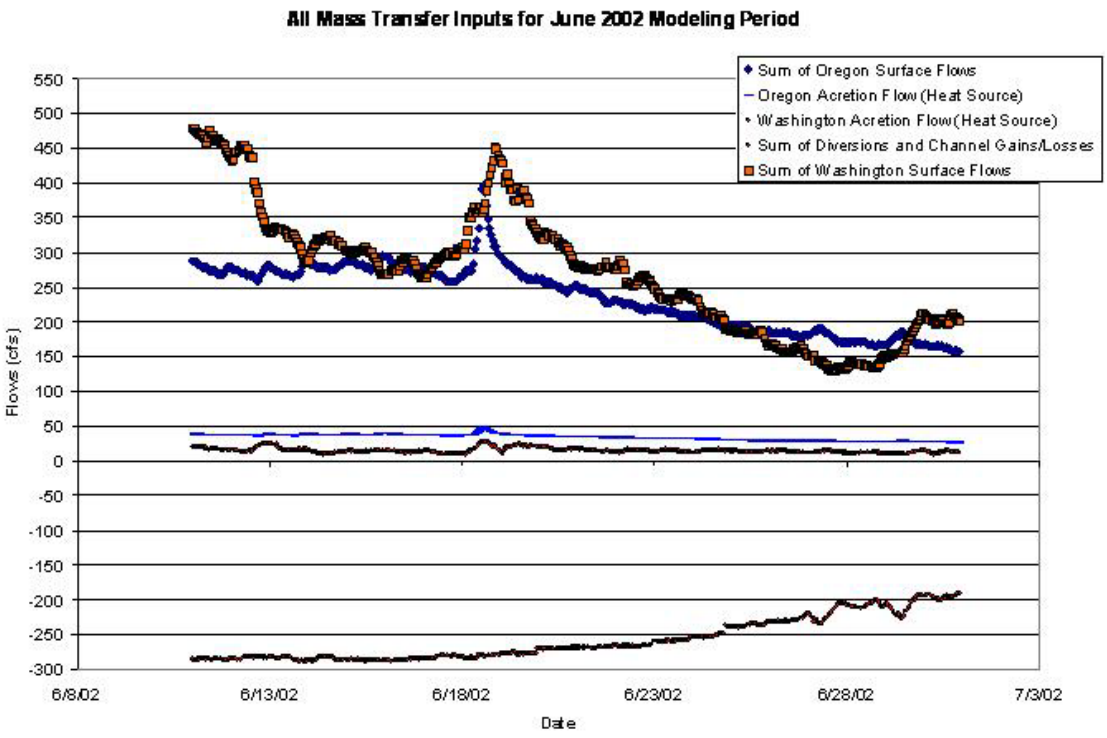


Figure 27: All flow balance parameters for June 2002 Model.

3.5 *Heat Source* Modeling: Converting channel bed losses and diversions into time-series datasets.

One of the drawbacks to the *Heat Source* model is its inability to account for groundwater or diversion flows that vary in rate over time. The model is set up to allow only fixed values to be either added or lost from the instream flows. During the June model development, this was particularly problematic due to the highly variable instream volumes and the subsequent amount of irrigation withdrawals and channel bed gains and losses. ODEQ modeling staff[26] recommended a solution to this issue.

For each diversion or groundwater gain-loss (Flow Data worksheet in *Heat Source*) needing volume variations, a fixed-maximum-value for the withdrawal was subtracted[27]. Simultaneously, a portion of the inverse of that withdrawal was added back as continuous inflow data. The flow was added in as a tributary flow and therefore provided a method to account for the net value of the variable withdrawals over the entire model period. These types of adjustments were made at five separate locations: Channels 1-4 and the Gardena Diversion (Table 2). To insure that modeled water temperatures were not altered by this method, temperatures at each site were compared and no discernable variation was detected.

[26] Verbal Communication, Don Butcher ODEQ, January 2005.
[27] *Heat Source Version 7.0:* Flow Data worksheet, Column G.

3.6 Using *Heat Source* Model for June 2002 Flow Calibration

Heat Source was populated with the June 2002 flow, temperature and weather data outlined in the prior sections. *Heat Source* was ran based on these reference conditions and the output used to help calibrate the flow balance. Flow balance data was longitudinally accurate when compared to June 12th synoptic flow measurements[28] (Figure 27) as far downstream as the end of the Lower Levee (Oregon). Synoptic flows from other dates in further downstream locations also validate the modeled flow. The solid line in Figure 27 is the flow profile generated by *Heat Source*. The circles represent the June 12th synoptic flow measurements.

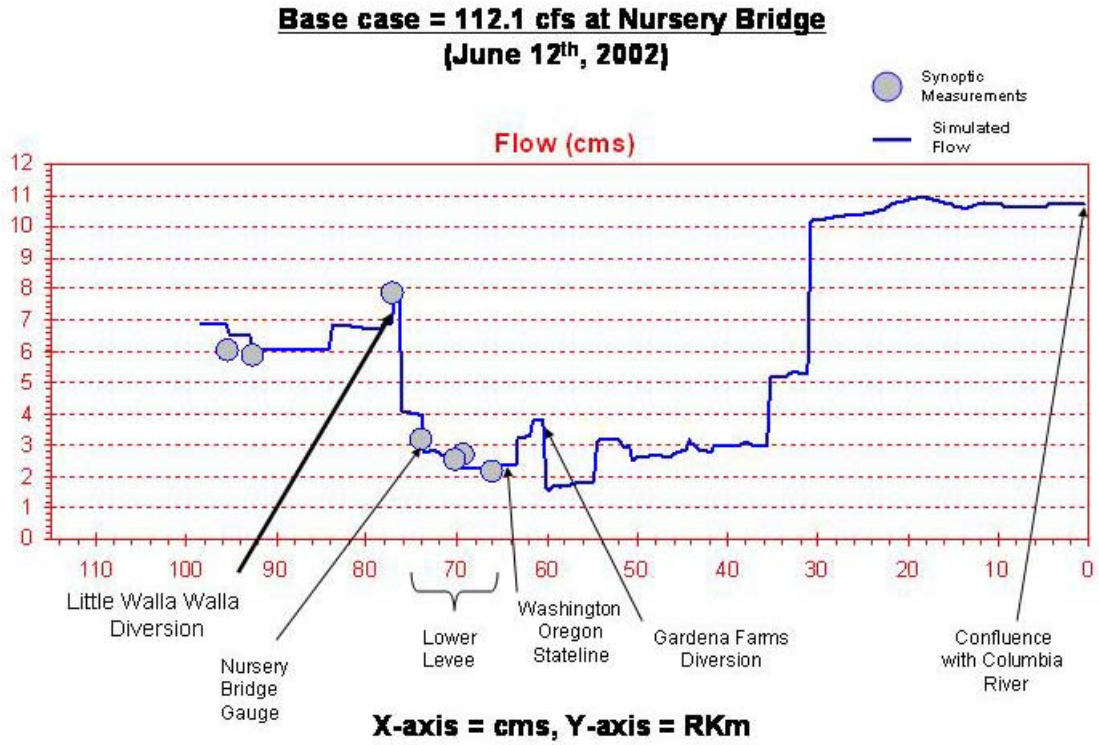


Figure 28: Simulated June 12th, 2002 flow profile versus synoptic measurements (X-axis in River Kilometers. Y-axis = cubic meters per second (m^3/s))

Flow output from *Heat Source* was further verified by comparing it to that of gauge stations (Figure 28 and 29). Aside from some variance in the timing of the peak flow event (Figure 29) the model appeared to simulate flow accurately throughout the 20-day model period at key points along the Walla Walla River. The variance in peak flow was most likely due to the flow balance process. Figure 29 represents the culmination of the flow balance process (Equation 4). It was concluded that the flow generated from the flow-balancing exercise appeared to be representative of June conditions in the river and was thus used for the HCP temperature modeling scenarios.

28

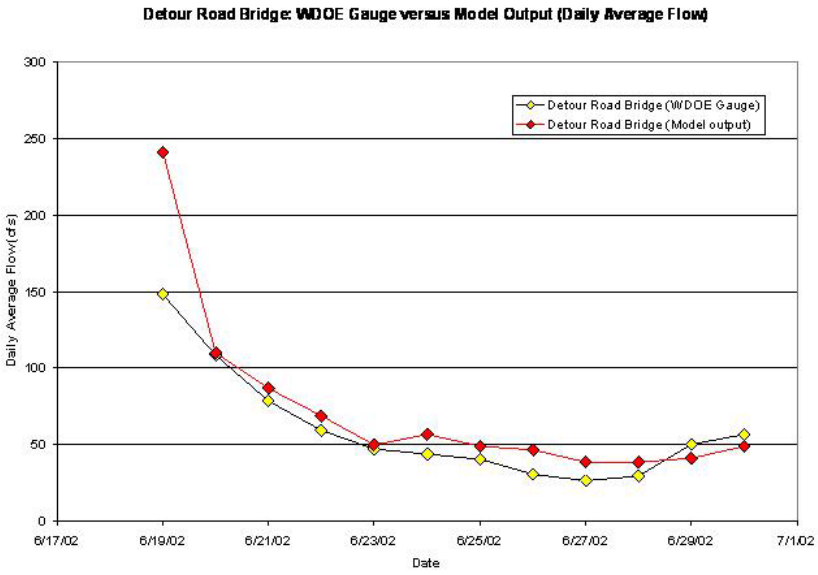


Figure 29: *Heat Source* Model output versus Detour Road Gauge (WDFW)[29]

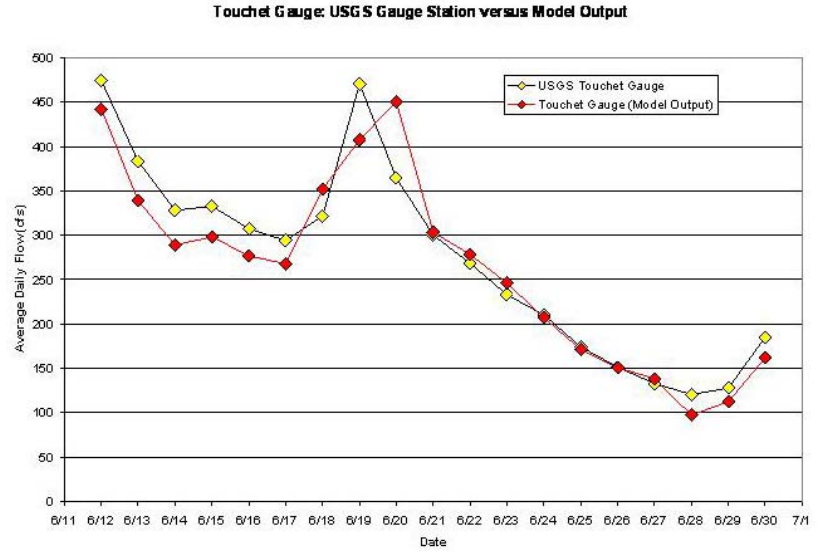


Figure 30: *Heat Source* Model flow continuous flow output versus Touchet Gauge (USGS)

3.7 Verifying *Heat Source* June 2002 River Temperatures

Heat Source also showed that it simulated June 2002 water temperatures accurately throughout the HCP study area. Water temperatures simulated by the model compared well with instream loggers at 13 continuous data points along the river. Figures 30 and 31 show *Heat Source's* simulated river temperatures plotted against actual stream temperatures recorded at two of the key HCP Take Analysis locations. Standard Error for each of the

[29] WDFW Detour Road Gauge (Walla Walla River) provided data after 6/19/2002

simulated temperature points ranged from 0.6 to 0.9. A graphical assessment of all the temperature comparisons showed that the model tended to slightly over and under predict the diurnal temperature flux (highs and lows). It was assumed however, that the SE rates were within an acceptable range and that the June 2002 *Heat Source* model was ready for HCP Take Analysis scenarios.

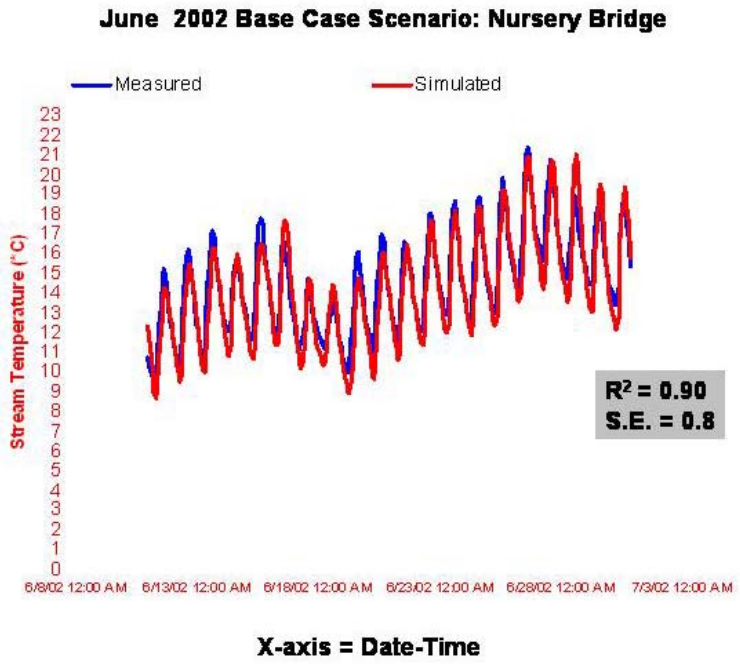


Figure 31: Simulated versus measured water temperatures at Nursery Bridge, Oregon (RM 43.6, RKm 70.3)

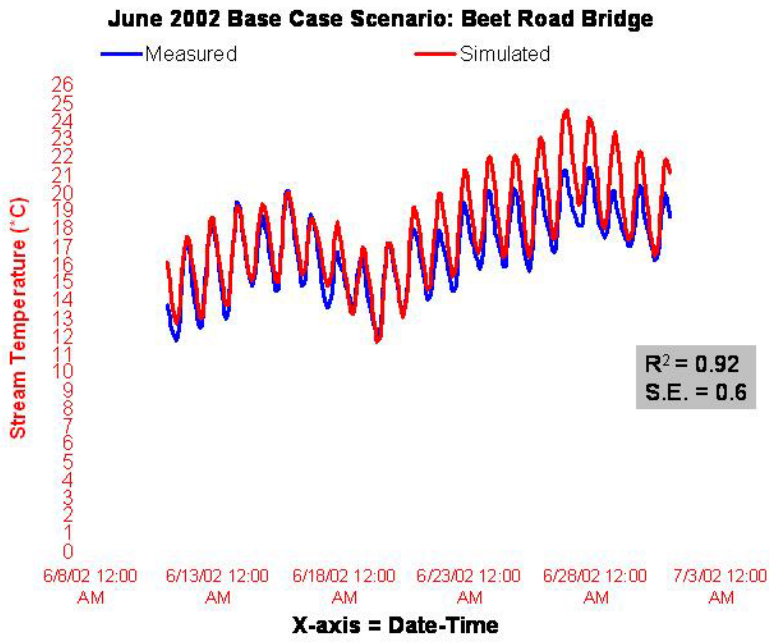


Figure 32: Simulated versus measured water temperatures at Beet Road Bridge, Washington (RM 37.6, RKm 60.5)

3.8 August *Heat Source* Modeling

As mentioned previously in this document, the August models used for this project were originally developed during Oregon's TMDL process. A detailed description of all the field work and modeling that went in to its development are presented in *Walla Walla Subbasin Stream Temperature Total Maximum Daily Load and Water Quality Management Plan* (Butcher 2005) and in *Appendix A Stream Temperature Analysis: Vegetation, Hydrology and Morphology Walla Walla Subbasin* (Butcher and Bower 2005).

The August 2002 model was set up to model 7 days (August 10- August 17, 2002) with the upper boundary condition just downstream from Skip Horton Creek (RM 70.7, RKm 113.8) to the confluence with the Columbia River. The time-distance steps were determine based on an assessment of peak flow velocities and determined to be dT (minutes) = 1, dX (meters) =100. The longitundal sample distance was set at 25 meters (82 ft) and the land cover sample distance remained at 15 meters (49.2 ft). The initial flush condition was determined to be 8 days and calculated using the lowest flow velocity (ft/s) and the total model distance. There were 16 continuous data sites set up in the original August model along with 32 inflow data sites (mass transfer worksheet) that included tributaries, and groundwater inputs (accretion flows). August flows in the Walla Walla River are on average considered steady (Figure 8). In this type of steady-state flow conditions, irrigation diversions were treated as fixed value withdrawals[30]. The original TMDL model utilized the first WWBWC-led seepage run to establish the August longitundal flow profile which included an inventory of diversions (Bower 2005).

[30] Diversions denoted in model as Withdrawals in Flow Data worksheet

Heat Source simulated flow profile was verified with synoptic measurements and a graphical comparison shown in Figure 32. It was decided that *Heat Source* reasonably simulated August flows through the Walla Walla River and was usable for the HCP scenarios. Simulated temperatures were also verified at continuous data locations and verified against field measurements. Statistically simulated temperatures consistently corresponded with instream measurements with R^2 values ranging from 0.75 to 0.96 and SE of 0.4 to 1.0. Figures 33 and 34 show measured versus simulated continuous data for key HCP Take Analysis points at Nursery Bridge and Beet Road Bridge gauges.

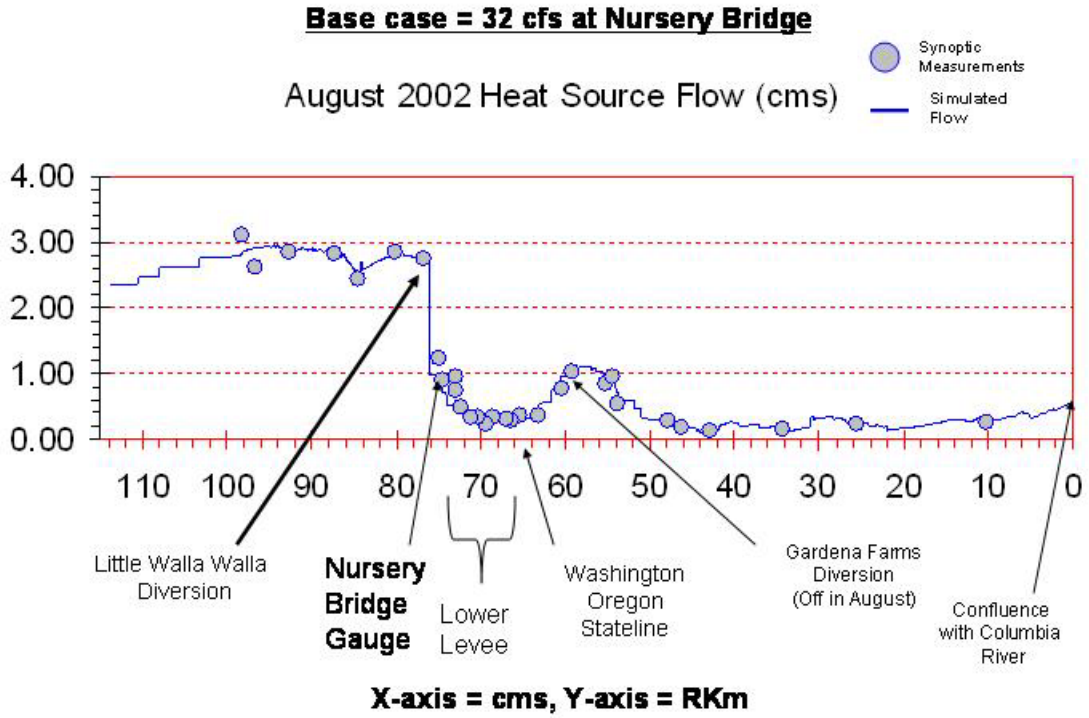


Figure 33: August *Heat Source* base case flows (August 10th, 2002)

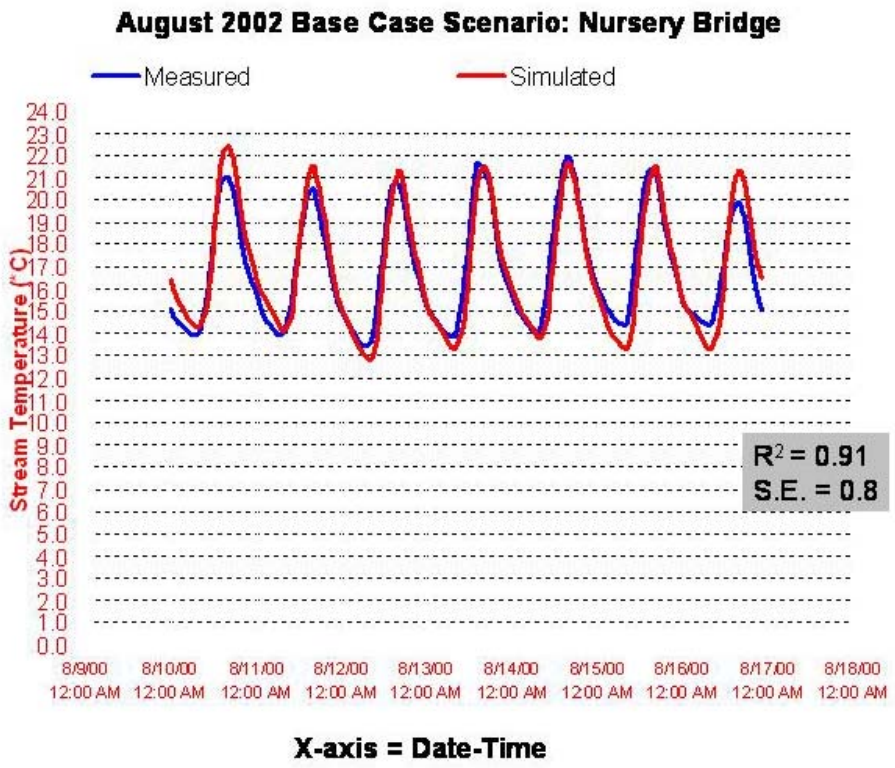


Figure 34: August *Heat Source* temperature simulation, Nursery Bridge, Oregon (RM 43.6, RKm 70.3)

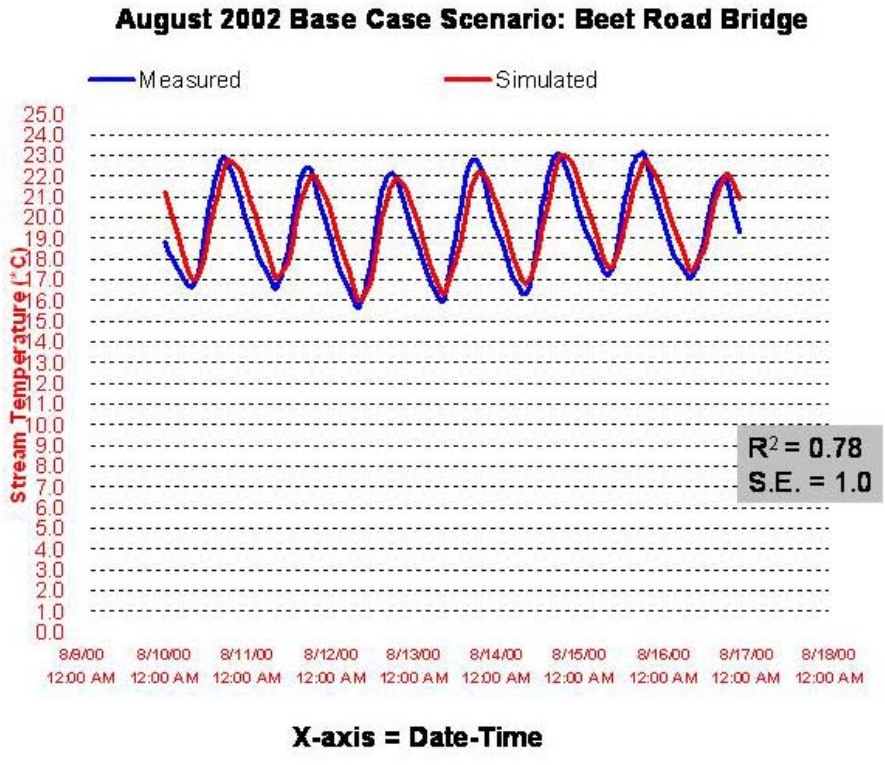


Figure 35: August *Heat Source* temperature simulation, Beet Road Bridge (RM 37.6, RKm 60.5)

As was mentioned in Section 2.4, the scenarios run for the August time period were very similar to those used in June except that the Gardena Farm's and Hudson Bay diversions have been curtailed by this time in the year (Table 4). The updated 'base case' TMDL model was run to mimic the existing conditions with the revised channel infiltration values added for the lower levee reach. The 25 cfs (0.71 m^3/s) bypass run was set up such that 35 cfs (0.99 m^3/s) went by the Little Walla Walla Diversion so that the streamflow was 25 cfs (0.708 m^3/s) at the Nursery Bridge gauge. This was done to account for channel bed losses between the point of diversion (Little Walla Walla Diversion) and the Nursery Bridge Gauge measurement point. Subsequent runs, i.e. the 50 cfs and 75 cfs bypass, reduced the LWWD incrementally by 25 cfs (0.708 m^3/s). The losses in the lower levee reach were adjusted according to the regression equation (Equation 3) presented earlier. It should be reiterated that the original goal to simulate a 100 cfs (2.83 m^3/s) bypass scenario was not feasible due to the fact that the river does not typically yield that volume of flow at the Little Walla Walla diversion in the summer months.

An interesting artifact regarding the lower levee regression equation is that it predicts less relative losses at higher flows. This created an interesting artifact during the all bypass (87.2 cfs) scenario. According to the equation, 87.2 cfs at Nursery Bridge results in 68.3 cfs (1.94 m^3/s) at Tumalum; a net difference of 18.9 cfs (0.54 m^3/s). This loss is less than that predicted for the 75 cfs (2.21 m^3/s) bypass scenario. It was speculated that high discharges are correlated to high groundwater levels thus have less loss. This may not be the situation in a typical August release but no additional information was available and it was decided to use the losses predicted by Equation 3.

4.0 June Modeling Results and Discussion

Heat Source simulations were run from June 11-June 30, 2002 for each of the cases presented in Table 3. As would be expected, increasing bypassed flows at the Little Walla Walla and Beet Road diversions meant increased flow volumes downstream (Figure 35). Water temperatures decreased with increased flow volumes and this change could be observed as far down as the confluence with the Columbia River (Figure 36).

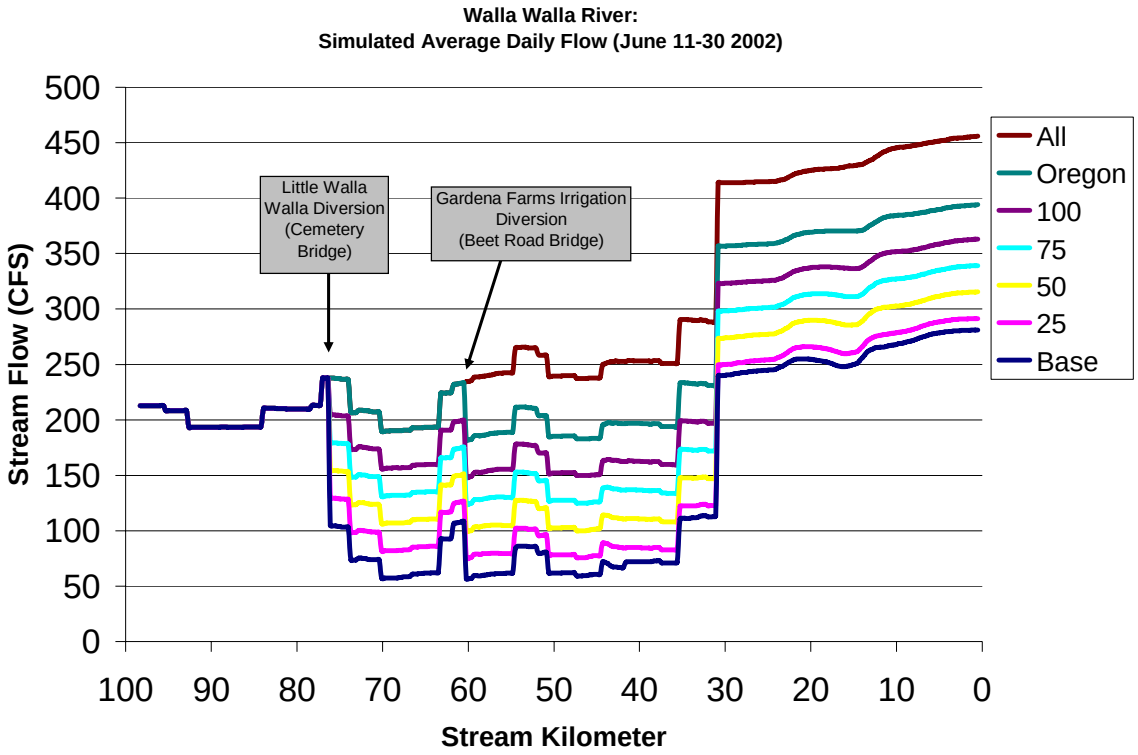


Figure 36: June 2002 Flow Scenarios for Walla Walla River (June 12 2002)

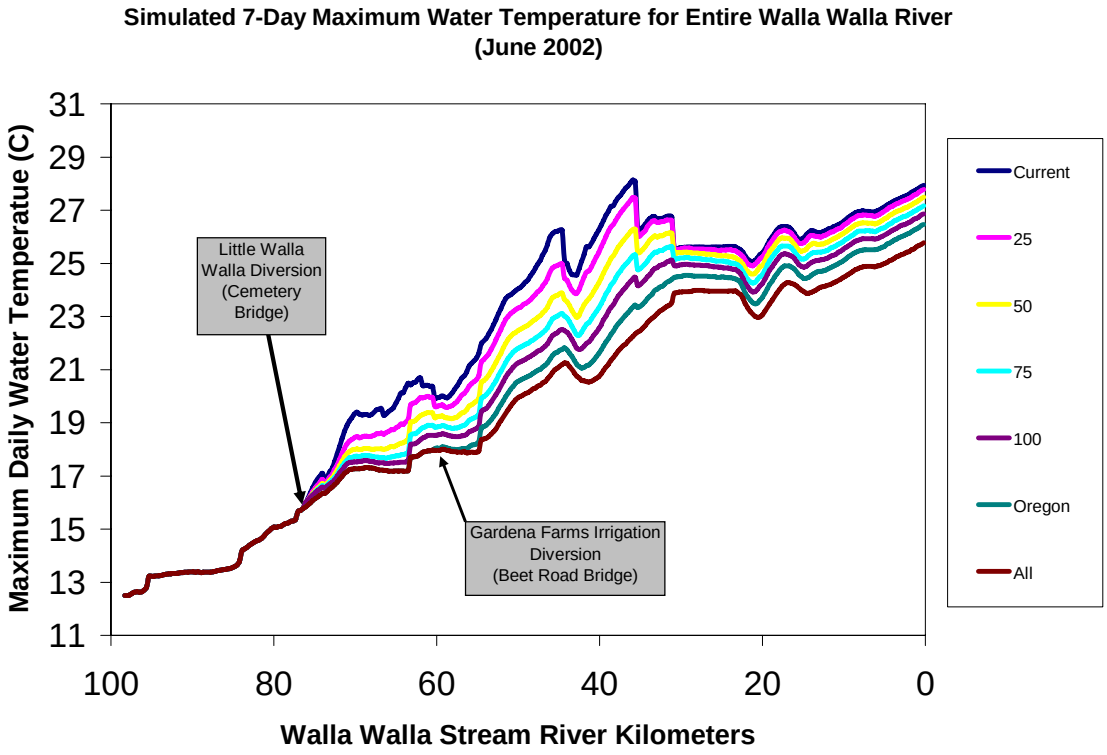


Figure 37: Simulated Walla Walla River Average 7-day Maximum temperatures corresponding to flow scenarios (June 12 2002)

Utilizing the various maximum life history pattern temperatures from Table 1, a reach comparison was conducted for the HCP Take Analysis area. Figure 37 shows that the spawning migration temperature of 17.5 ^{0}C can only be obtained for a portion of this river reach. Since spawning and spawning migration for the Walla Walla basin's Steelhead population tends to occur during the fall, winter, and spring; it is not likely that this threshold would be applicable for a June temperature analysis. However the other life history patterns including Juvenile Rearing, Juvenile Migration and Embryonic Development may apply to this reach of the river. It appears that none of the simulated flow scenarios influence the river enough to reduce stream temperature below these maximum thresholds. It appears the Oregon Department of Environmental Quality salmonid rearing criteria of 17.8 ^{0}C could be met, at least through to the Stateline (RM 41.2, RKm 66.0), under the All Flow scenario (250 cfs, 7.1 m^3/s). However that would mean zero flow would be available to flow down the East and West Little Walla Walla River systems.

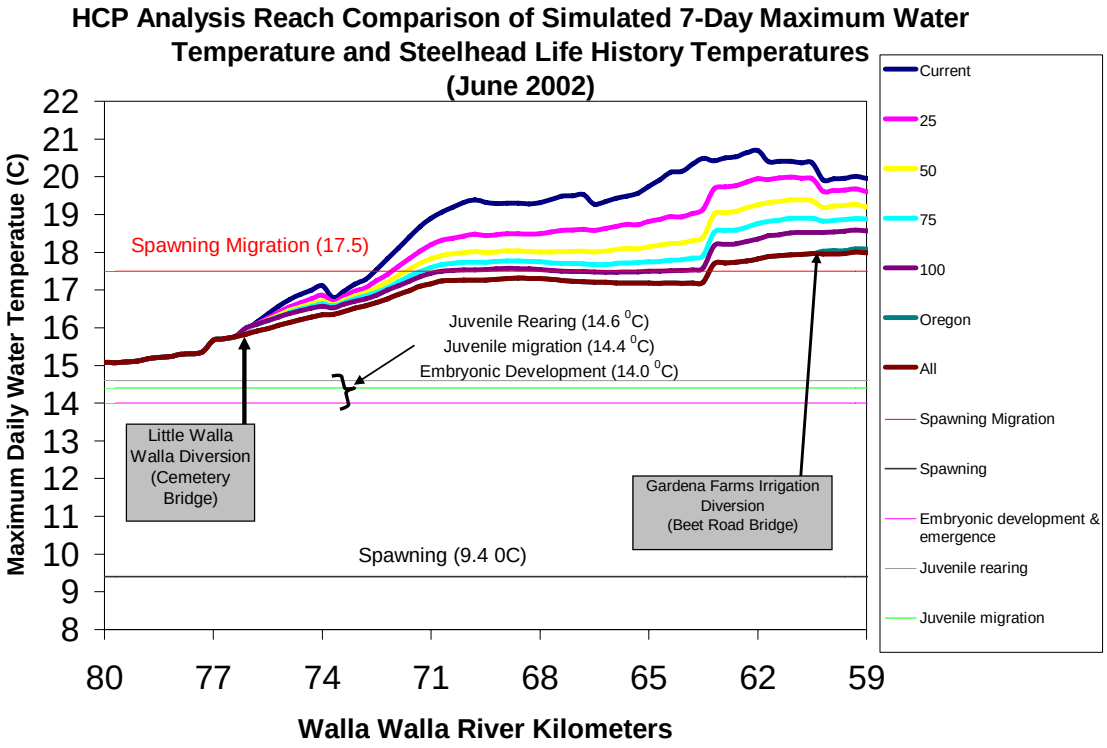


Figure 38: Comparison of Simulated temperatures and Steelhead Life History Patterns (June 12, 2002)

Bull Trout, whose life history pattern thresholds require even cooler water temperatures (Table 1), appear to not be achievable by any of the June flow simulations for June 12th 2002 (Figure 38). Oregon Department of Environmental Qualities Bull Trout criteria of 10.0 ^{0}C (50.0 ^{0}F) is not met at any point in the analysis reach. As temperatures tend to increase through the model period (June 11-June 30), it unlikely that any of these standards can be achieved during the later parts of June.

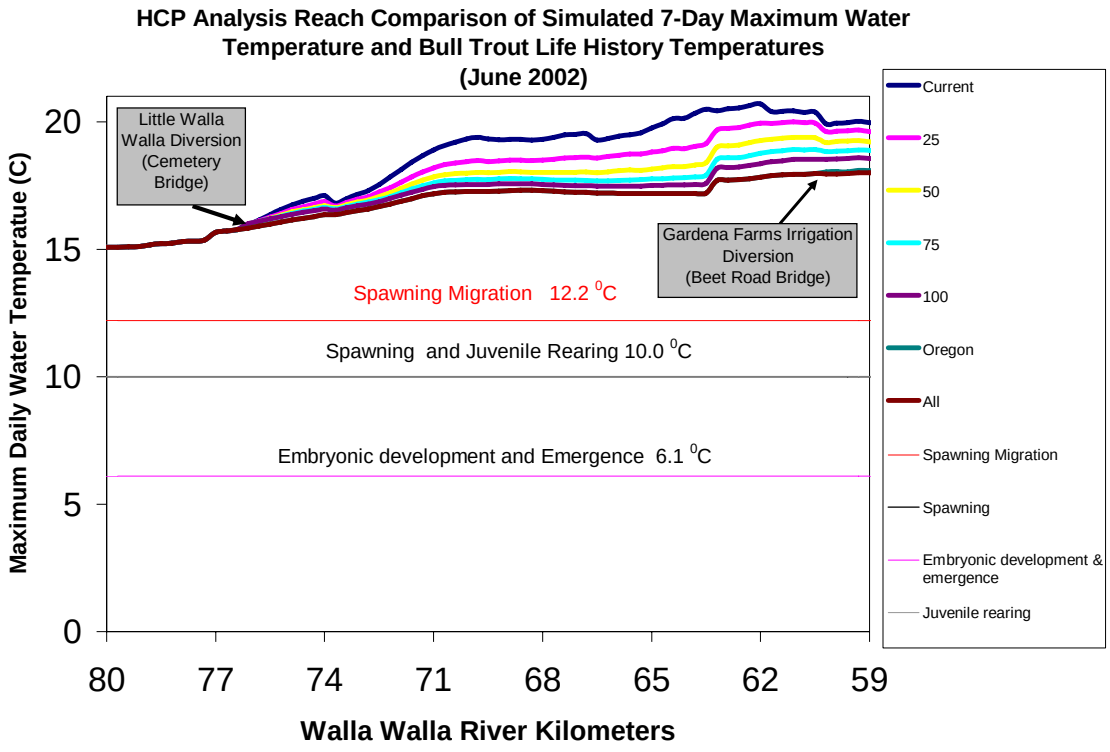


Figure 39: Comparison of simulated temperatures and Bull Trout Life History Patterns (June 12, 2002)

The average 7-day maximum (7Dmax) water temperature for the base case scenario is shown in Figure 39 for four representative stations (at Harris Park RKm 98.3, Nursery Bridge RKm 74, above Mill Creek RKm 54.8, and above Touchet River confluence RKm 31.4). These are seven-day moving averages of the maximum daily temperatures (e.g., period 1 represents June 11-June 17, period 2 represents June 12-18, etc.). As illustrated in the figure, river temperatures warm up as the flows decrease throughout the month. This is particularly evident after period 7 (June 17-June 23) where the average 7Dmax temperature in the Walla Walla River above Mill Creek increases from approximately 20°C to 25°C (68 F to 77 F) in just five days.

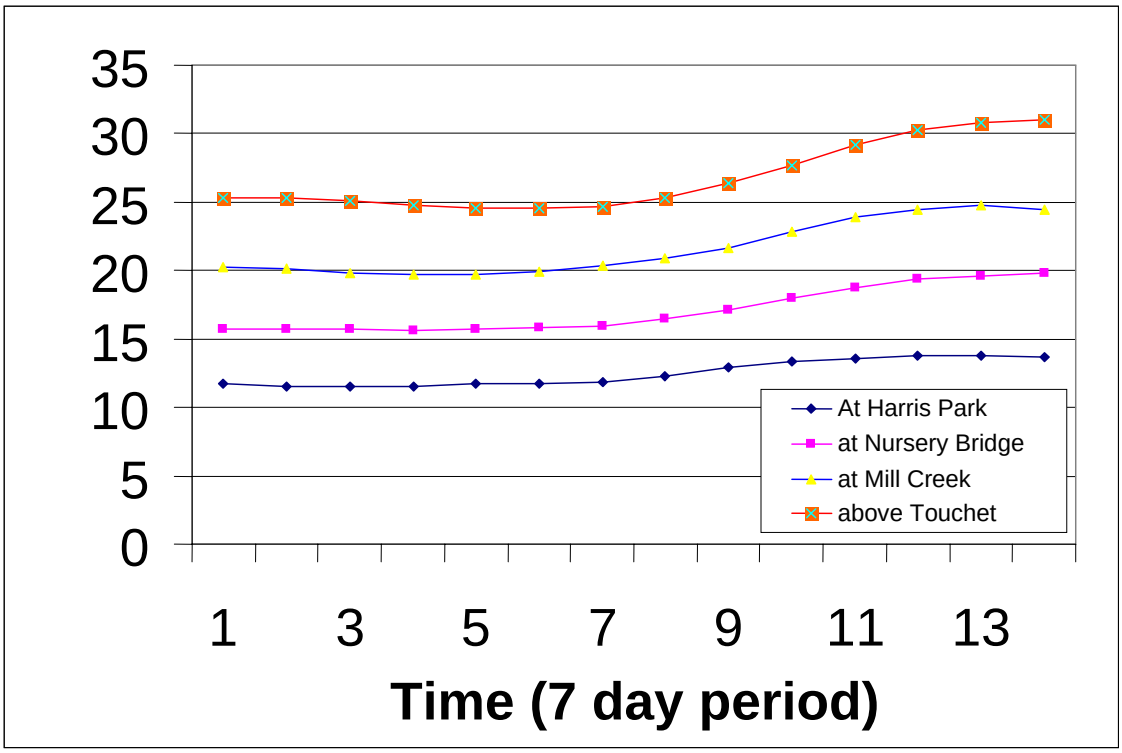


Figure 40: Average 7Dmax water temperatures for June 'base case' scenario [Y-axis = Temperature (Celsius)]

Figure 40 illustrates the variation in maximum daily temperature throughout the June study reach for three distinct time periods (June 11, June 20, and June 30) under the base case scenario. Using ODEQ's 17.8°C (64 F) as a reference temperature, approximately 57.0 RKm (35.4 RM) of river becomes too warm for steelhead between June 11 and June 30.

A comparison of the maximum daily temperatures for the various flow bypass scenarios is shown in Figure 41 for the river segment immediately above the Mill Creek confluence (RM 34.1, Km 54.8). While each successive incremental flow increase does marginally improve temperature, if the general goal is to keep the temperature below the 17.8°C threshold (realizing that this value is based on a 7Dmax), then it appears adding all the flow in the river, still would be well short of getting the HCP study reach below this criteria. The all bypass scenario is the closest with 12 of the 20 days in June falling below that critical temperature. After June 22, 2002, none of the bypass scenarios have enough cooling-by-volume effect to make water drop below the general temperature goals.

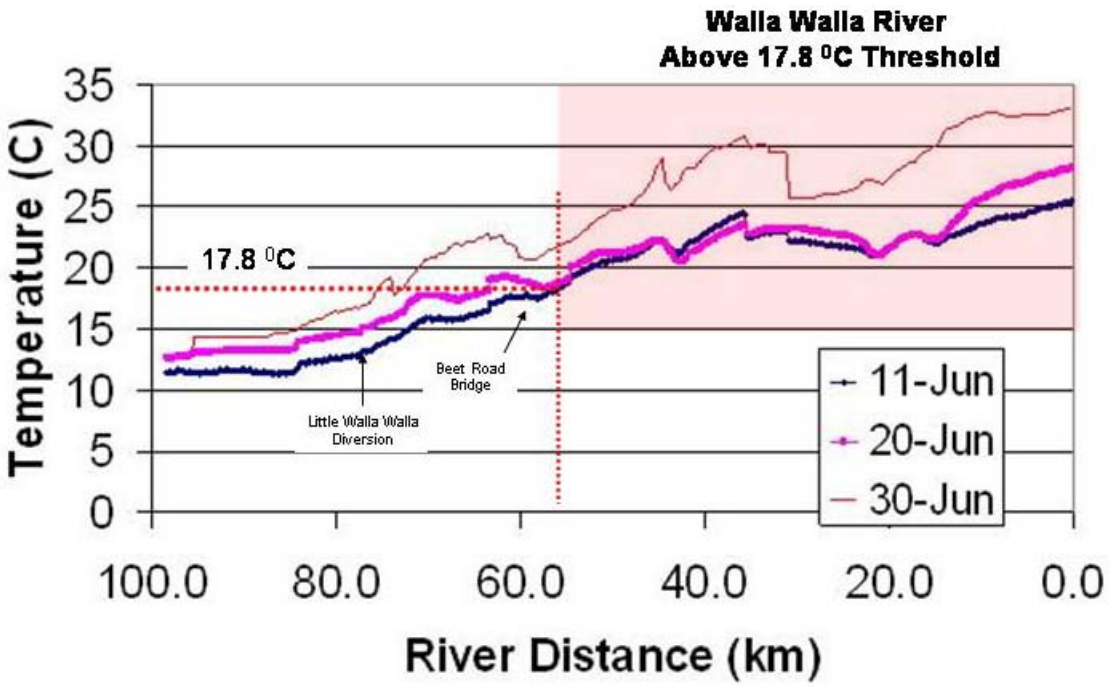


Figure 41: Maximum daily temperatures for June base case scenario at beginning, middle, and end of simulation period.

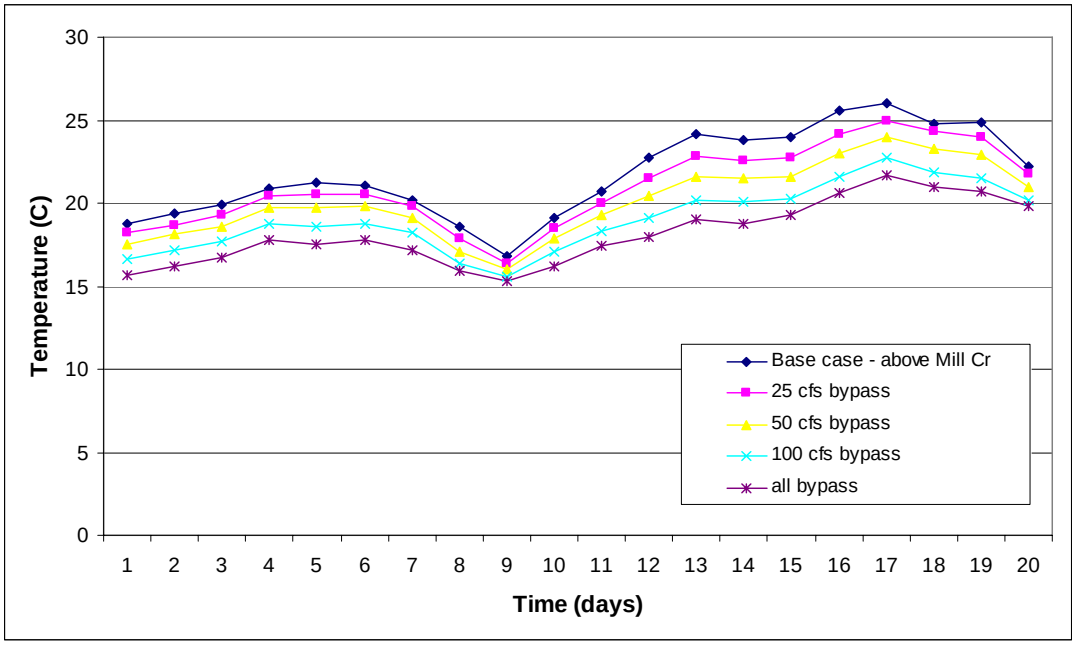


Figure 42: Maximum daily June temperatures in Walla Walla River just above Mill Creek confluence for all diversion scenarios

As discussed earlier, June is a time period of significant transition with regards to flows and temperatures on the Walla Walla River. To place this fact in better context, a comparison between maximum and average June temperatures for the beginning and end of base case scenario is presented in Figure 42. The difference between average and maximum temperature increases slightly between June 11 and June 30 as the air temperatures and direct

solar influence increases and the flow diminishes. Also, as indicated by the larger sudden temperature drops, the impact of cooler tributary inflows generally becomes more significant as the mainstem flow decreases toward the later part of the month. Some of the inflows are warmer than others so this trend is not universal.

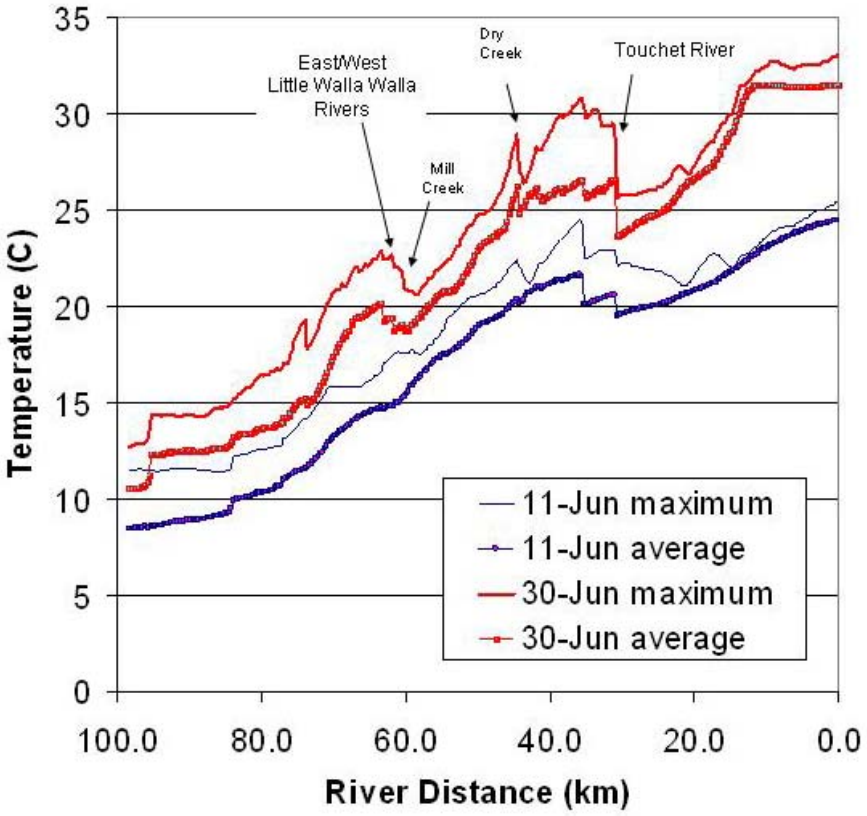


Figure 43: Comparison between maximum and average June temperatures for beginning and end of base case scenario

5.0 August Modeling Results and Discussion

Heat Source simulations were run from August 10-August 17, 2002 for each of the cases presented in Table 4. In terms of improving stream flow and presumably temperature, was the all water bypass scenario. This scenario bypassed all of the flow naturally available in June 2002 from the upriver North and South Forks of the Walla Walla River. It should be noted that this scenario would leave zero flow for the other Walla Walla River distributaries, the East and West Little Walla Walla Rivers.

A comparison of the 7-day average maximum (7Dmax) hourly temperature predicted during the simulation between the base case and the all bypass scenario is shown in Figure 43. While the improvement in water temperature is evident in the figure, it should be noted that the addition of all available flows does not reduce temperatures in the lower segments below the critical 17.8°C Oregon criteria for steelhead and is well short of the 10.0 ^{0}C Bull Trout criteria. Areas of groundwater and tributary returns also emphasize the positive influence of groundwater inflows on water temperatures. Because groundwater inflows could decrease as a result of bypassing higher flow volumes, there may be a counter-

productive influence on stream temperatures associated with higher bypass rates. As discussed in chapter 2.3, as additional water is diverted from the other distributaries that lay west of the 'mainstem (Tum A Lum) branch, the amount of spring and groundwater flows decrease. Furthermore, both of the Oregon temperature criteria are exceeded even upstream of the LWWD diversion (RKm 76.2) an area over which none of the three districts participating in the HCP have an influence.

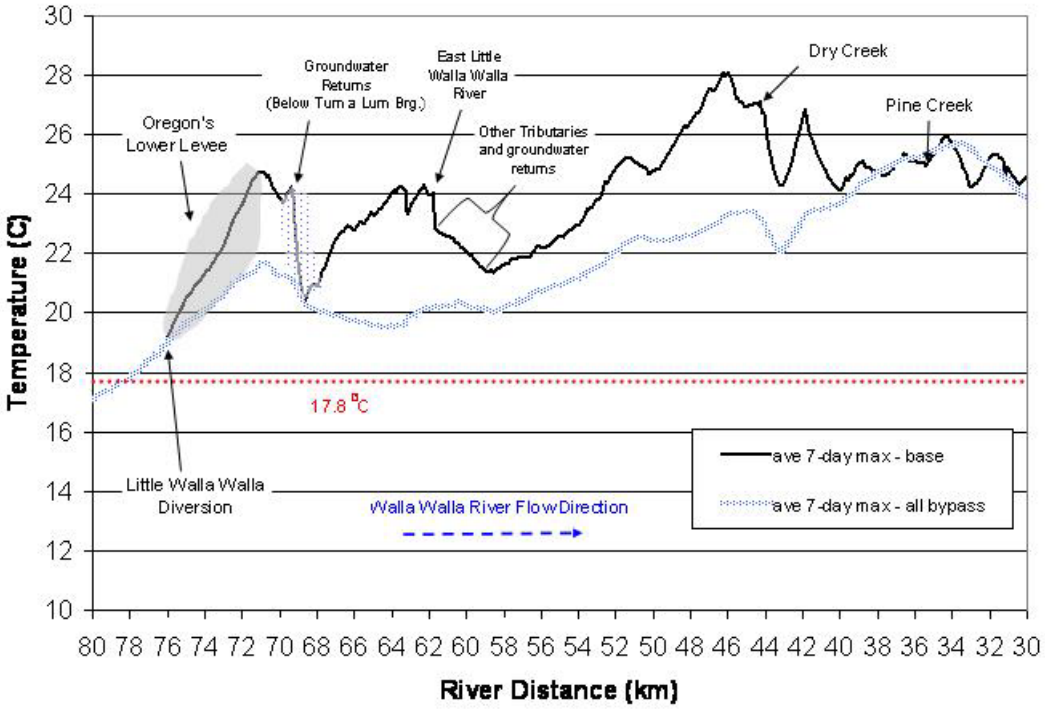


Figure 44: Maximum hourly temperatures during 7-day simulation period

Another possible way to review this temperature data is to look at the maximum, average and minimum temperature values relative to river location for the various August flow scenarios. Daily maximum temperatures tend to occur in the late afternoon to early evening, daily average temperatures around mid-day, and daily minimum temperatures near sunrise. Figure 44 shows the range of these values from the all bypass scenario and the locations on the Walla Walla River where temperatures cross the 17.8 ^{0}C steelhead threshold (for reference only, as it is a 7Dmax standard). The maximum daily temperatures cross this threshold well upstream of the Little Walla Walla River diversion (Joe West Bridge). The average daily temperatures cross in Oregon's lower levee, and the minimum daily temperatures are exceeded downstream of the confluence with Dry Creek. This type of analysis might be useful if salmonids are utilizing cold water refuge during the hotter times of the day, and feeding and moving during the early morning hours.

Figure 45 illustrates the changes in water temperature in the Walla Walla River caused by changes in the Little Walla Walla System for the 50 cfs (1.42 m^3/s) bypass simulation. As points of reference, the East Little Walla Walla confluence with the mainstem Walla Walla River is at RM 38.3 (RKm 61.7) and the Mud Creek confluence is at RM 26.0 (RKm 41.85). As shown, lack of tributary inflow only slightly increases the mainstem temperature. However, since the tributaries themselves were treated as fixed boundary

conditions in the current model, the impact of changing flows on tributary water temperature is unknown.

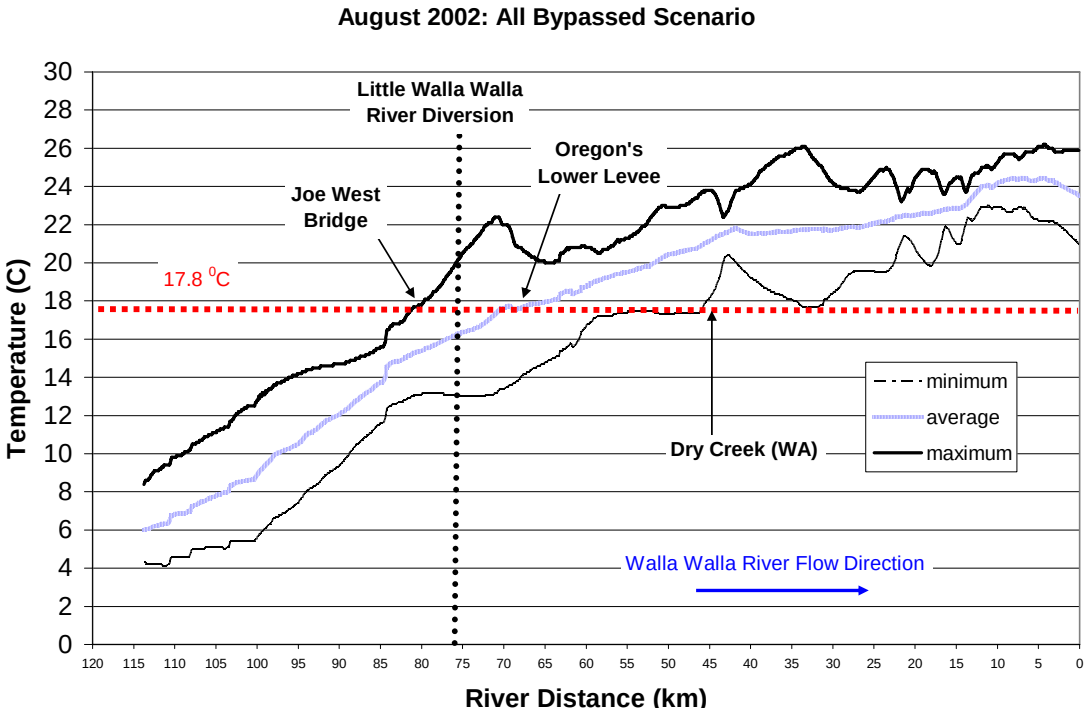


Figure 45: Range of water temperatures experienced in all bypass scenario

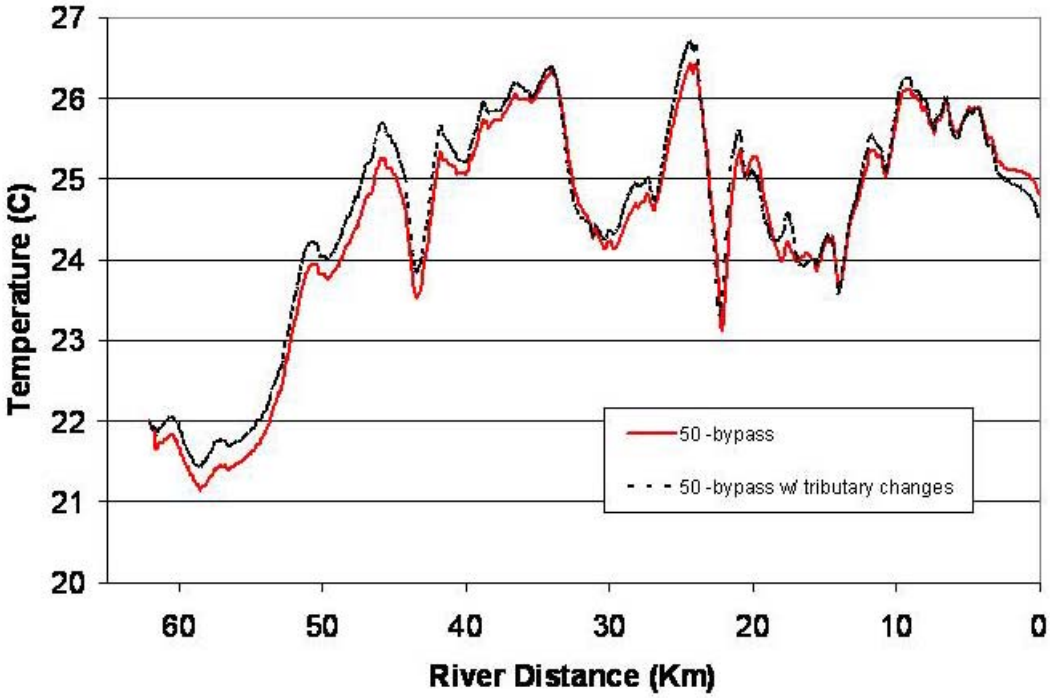


Figure 46: Comparison of 7Dmax temperature with tributary inflow changes

6.0 Conclusions

The purpose of this project was to develop two flow and temperature models for the Walla Walla River and the three Irrigation Districts participating in the Habitat Conservation Planning process. The physical outputs from these model scenarios were utilized by HDR fisheries biologists to develop two life-cycle models; creating the first step in the HCP Take Analysis. The results from these life cycle models are described in *Walla Walla River Bull Trout Population Response Model* (HDR 2007), and *Walla Walla River Steelhead Population Response Model* (HDR 2007). While the authors of this document attempted to put the modeling output into a fisheries context, the life cycle models developed by HDR are much more refined and specific to the goals of the HCP Take Analysis and should be reviewed.

The June 2002 Flow balance and *Heat Source* modeling appeared to simulate Walla Walla River flow and temperature conditions relatively accuracy. SE for the June 2002 simulated versus measured temperatures ranged from 0.6 to 0.9. The June model did appear to slightly over predict the diurnal flux range but still was within an acceptable range for HCP scenario purposes. However additional fine tuning of the model could better calibrate flow conditions and temperature simulations. To further improve the June model and help its flow balance calculations, more recent years might be modeled to validate this project's output. Validation data for flow (spatially) and temperature below Detour bridge was not available for June 2002 (aside from USGS Gauge). Caution should be applied when using this model below that location due to this issue.

The August 2002 *Heat Source* model also appears to simulate Walla Walla River flow and temperature conditions. Standard Errors (S.E.) for the August 2002 simulated versus measured temperatures ranged from 0.4 to 0.9 (August 2002). with relatively low statistical error and was determined to be within an acceptable range for the HCP scenario purposes. If the desire is to increase usable habitat in August, mechanisms for preventing the water from warming must begin further upstream. An evaluation is necessary to determine if restoration activities could be used to improve water temperatures beginning around RM 52.5 (RKm 84.5) when the average 7Dmax temperature is around 15^{o}C (59.0 ^{0}F).

Both the June and the August model flow scenarios appeared to fall short of most of the temperature criteria set by ODEQ. During Oregon's TMDL temperature modeling TMDL, ODEQ and the WWBWC looked at a variety of temperature reducing scenarios aside from just increasing flow. These scenarios included improving riparian shade, channel sinuosity, and morphology. Improvements to riparian shade would reduce the direct solar influence on the Walla Walla River temperatures. Improvements to sinuosity and subsequently to channel morphology (creating a deeper and narrower channel) would help to limit the amount of evaporation and increase the passage depths for fish.

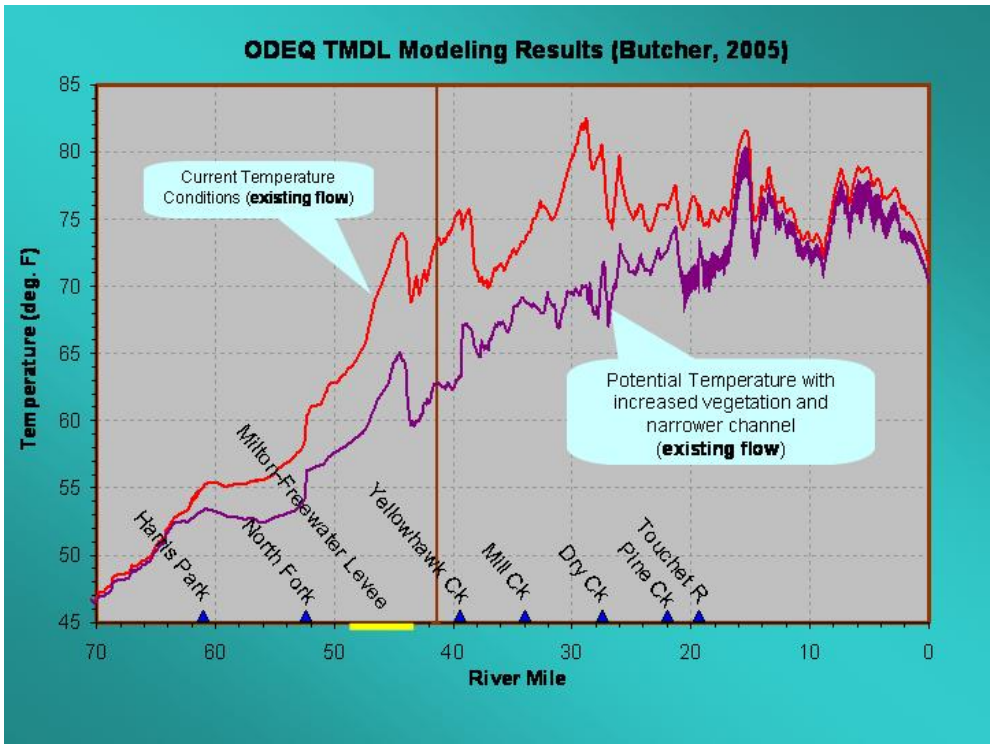


Figure 47: Oregon's TMDL August 2002 Temperature Scenario: Shade and Channel Improvements Only (Butcher 2005)

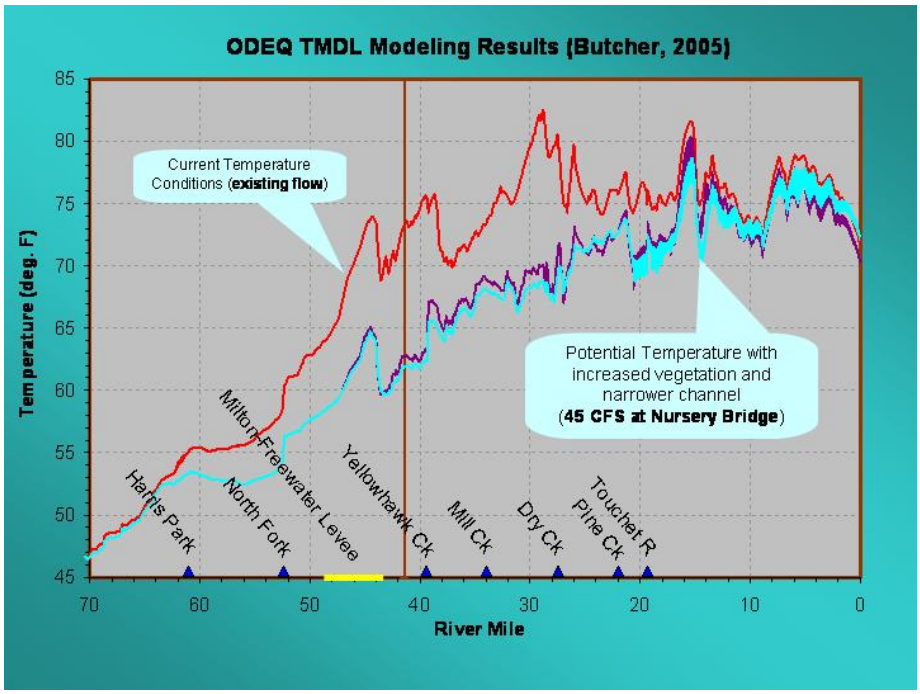


Figure 48: Oregon's TMDL August 2002 Temperature Scenario: Shade, Channel and Flow Improvements (Butcher 2005)

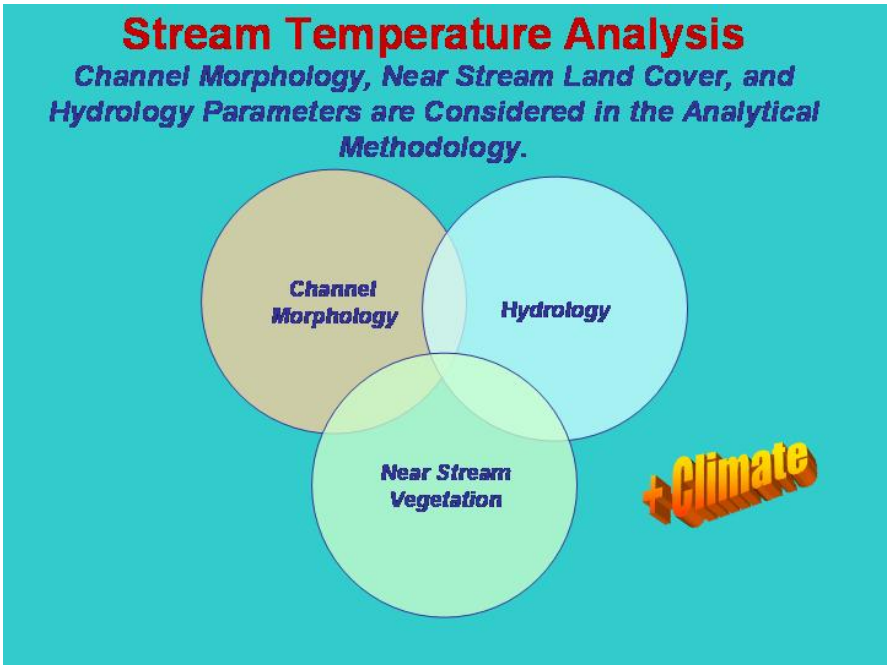


Figure 49: Three major spheres of influence on stream temperatures (Butcher 2005)

The results from two of these TMDL scenarios are depicted in Figures 46 and 47. Figure 46 compares August 2002 temperature baseline conditions against a scenario with improvements to stream habitat (i.e.,shade and morphology changes including increases to sinuosity and channel depth with decreased total channel width). Figure 47 adds a second comparison where additional bypassed flow (45 cfs, 1.3 m^3/s) is added to the stream habitat improvements. There is virtually no difference between the scenarios. This suggests that there are many things to consider changing when looking to restore a river for an endangered fishery. Figure 48 shows the three primary spheres of influence on water temperatures in a river system, and all need to be taken into consideration when assessing the impact of any one parameter. Climate change too will play an important part in dictating stream temperatures of the future.

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