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Little Klickitat River Watershed Temperature Total Maximum Daily Load

July 2002

Publication No. 02-03-031
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Little Klickitat River Watershed Temperature Total Maximum Daily Load

by
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Environmental Assessment Program
Olympia, Washington 98504-7710

July 2002

Waterbody Numbers: See Table 1

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Abstract

The Little Klickitat River watershed encompasses approximately 285 square miles in south-central Washington State. The Little Klickitat River and its tributaries – East Prong, West Prong, and Butler Creek – are listed on the 1996 and 1998 Washington State 303(d) list for elevated water temperatures. Field work by Ecology, the Central Klickitat Conservation District, and Yakama Nation Fisheries confirmed further temperature problems throughout the watershed.

Effective shade is used as a surrogate measure of heat flux to fulfill the requirements of Section 303(d) for a Total Maximum Daily Load (TMDL) for temperature. Effective shade is defined as the fraction of incoming solar shortwave radiation above the vegetation and topography that is blocked from reaching the surface of the stream. The load allocations for effective shade under this TMDL are as follows:

- For perennial streams in the entire Little Klickitat watershed, including East Prong, West Prong, and Butler Creek, the load allocation ranges from 95 to 50% which is the effective shade produced by a mature riparian corridor and the existing topography.
- For portions of the Little Klickitat River and West Prong, additional temperature reduction may be possible through reduction of the wetted width-to-depth ratio. A Level II Rosgen Channel classification indicated that the mainstem Little Klickitat is a Class C and has an average wetted W/D ratio of 28. As mature riparian vegetation is established, reduction of the current wetted W/D ratio may occur on portions of the Little Klickitat.
- For all perennial streams in the Little Klickitat watershed, including Bowman, Mill, Spring, and Blockhouse creeks, that were not specifically modeled and that exceeded the water quality standard, 73% effective shade produced by mature riparian vegetation is the load allocation. An effective shade of 73% is the average load allocation for all modeled segments on the Little Klickitat River, West Prong, East Prong, and Butler Creek. Additionally, Bloodgood Creek, which does not exceed water quality standards, provides the only source of cooling water to the Little Klickitat River, and efforts should be made to preserve and protect the cooling influence of the waters from Bloodgood Creek.

In addition to the load allocations for effective shade, other management activities are recommended for reduction of water temperature, including measures to reduce sediment loading and promote water-use efficiency.

The Goldendale Wastewater Treatment Plant (WWTP) is the sole point source in the Little Klickitat watershed. Under current load allocations, the upstream temperature complies with the water quality standard of 18^{o}C; consequently, the wasteload allocation for the Goldendale WWTP effluent is established as 18.3^{o}C.

Acknowledgements

We would like to thank the following people for their contributions to this study:

- Dave Clayton (Central Klickitat Conservation District) for assistance with data collection, report review, and valuable input and advice throughout this project.
- Will Conely, Bill Sharp, and Jeff Spencer (Yakama Nation) for assistance with data collection and report review.
- Ray Hennekey (Klickitat County) and Pat Irle (Washington State Department of Ecology) for field assistance and review of the Quality Assurance Project Plan.
- Matt Boyd (Oregon Department of Environmental Quality) for valuable assistance with HeatSource modeling.
- Dave Ragsdale (U.S. Environmental Protection Agency) for assistance with data collection, report review, and valuable input and advice throughout this project.
- Bruce Cleland (U.S. Environmental Protection Agency) for report review and guidance throughout the TMDL process.
- These staff of the Washington State Department of Ecology:
  - Tara Galuska for help during field work and stream surveys.
  - Mindy Roberts for assistance with data collection and land owner permissions.
  - Brad Hopkins and Chris Evans for continuous streamflow gauging setup and reporting.
  - Greg Pelletier for reviewing the report and providing valuable suggestions and modeling input throughout the project.
  - Will Kendra, Karol Erickson, Darrel Anderson, and Max Linden for managerial support and suggestions.
  - Ryan Anderson for coordinating public participation and report review.
  - Joan LeTourneau for final editing and formatting of the report.

Introduction

Section 303(d) of the federal Clean Water Act mandates that the state establish Total Maximum Daily Loads (TMDLs) for surface waters that do not meet standards after application of technology-based pollution controls. The U.S. Environmental Protection Agency (EPA) has promulgated regulations (40 CFR 130) and developed guidance (EPA, 1991) for establishing TMDLs.

Under the Clean Water Act, every state has its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of designated uses, such as cold water biota and drinking water supply, and criteria, usually numeric criteria, to achieve those uses. When a lake, river, or stream fails to meet water quality standards after application of required technology-based controls, the Clean Water Act requires the state to place the waterbody on a list of "impaired" waterbodies and to prepare an analysis called a TMDL.

The goal of a TMDL is to ensure the impaired water will attain water quality standards. A TMDL includes a written, quantitative assessment of water quality problems and of the pollutant sources that cause the problem. The TMDL determines the amount of a given pollutant that can be discharged to the waterbody and still meet standards, determines the loading capacity, and allocates that load among the various sources. If the pollutant comes from a discrete (point) source such as an industrial facility's discharge pipe, that facility's share of the loading capacity is called a wasteload allocation. If it comes from a diffuse (nonpoint) source such as a farm, that facility's share is called a load allocation.

The TMDL must also consider seasonal variations and include a margin of safety that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. The sum of the individual allocations and the margin of safety must be equal to or less than the loading capacity.

Pollutants and Surrogate Measures

The Little Klickitat watershed TMDL will be developed by the Washington State Department of Ecology (Ecology) for heat (i.e., incoming solar radiation). Heat is considered a pollutant under Section 502(6) of the Clean Water Act. Heat generated by solar radiation reaching the stream provides energy to raise water temperatures. Channel morphology, hydrology, and near-stream riparian vegetation influence stream temperature (Figure 1). Elevated summer stream temperatures due to anthropogenic causes in the Little Klickitat watershed result from the following conditions:

- Channel widening (increased width:depth ratios) that increases the stream surface area exposed to energy processes, namely solar radiation.
- Riparian vegetation disturbance that compromises stream surface shading through reductions in riparian vegetation height and density (shade is commonly measured as percent effective shade).

- Reduced summer baseflows that result from instream withdrawals, wells in hydraulic continuity with the stream, and loss of floodplain connectivity.

Temperature is a water quality concern because most aquatic organisms, including salmonids, are “cold-blooded” and are strongly influenced by water temperature (Schuett-Hames et al., 1999). Temperature is a major concern in the lower Little Klickitat River and Bowman Creek because of the use of its waters by steelhead, a species listed as threatened under the Endangered Species Act, as a migration corridor and as spawning and rearing habitat. Elevated temperature and altered channel morphology resulting from various land-use activities, such as timber harvest and agriculture, limit available spawning and rearing habitat for steelhead.

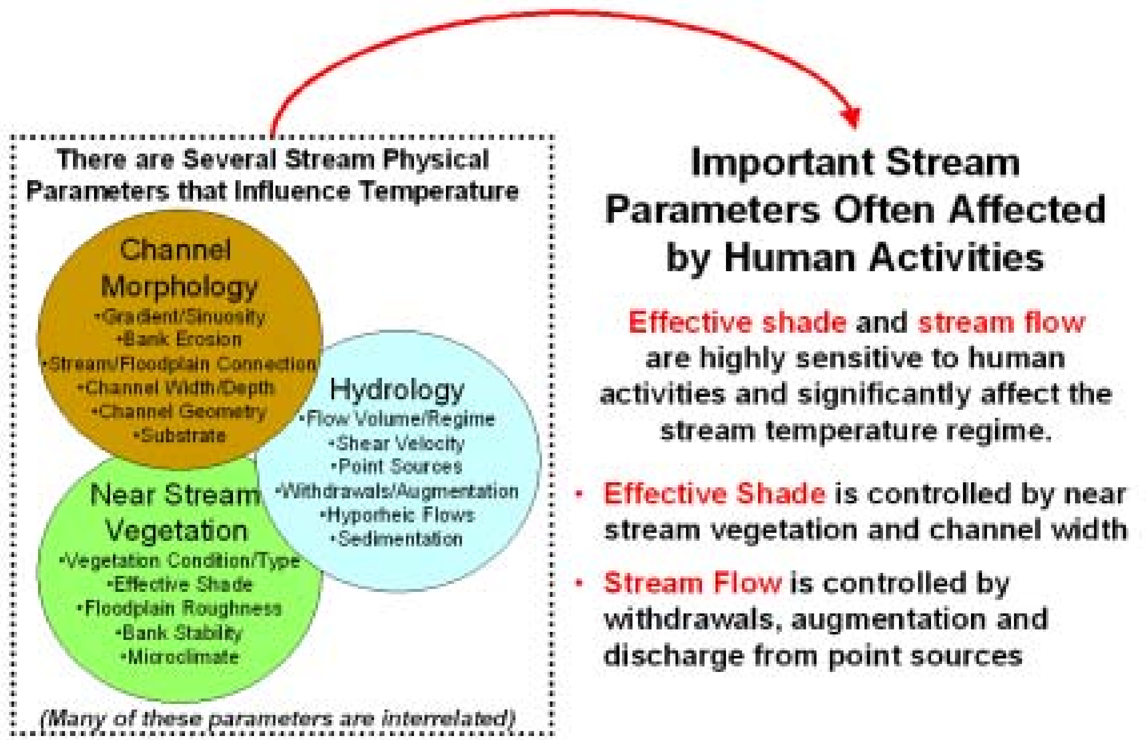

Figure 1. Shade and channel characteristics that impact water temperature (ODEQ, 2002).

Figure 2 shows the heat energy processes or fluxes that control heat energy transfer to and from a given volume of water. Figure 3 shows the relative importance of the fluxes in the heat budget for the Little Klickitat near Goldendale for the current condition of riparian vegetation and a mature riparian corridor defined as a 20-foot, near-stream zone of small dense deciduous vegetation and a 140-foot, outer zone of 104-foot trees with 55 percent canopy density.

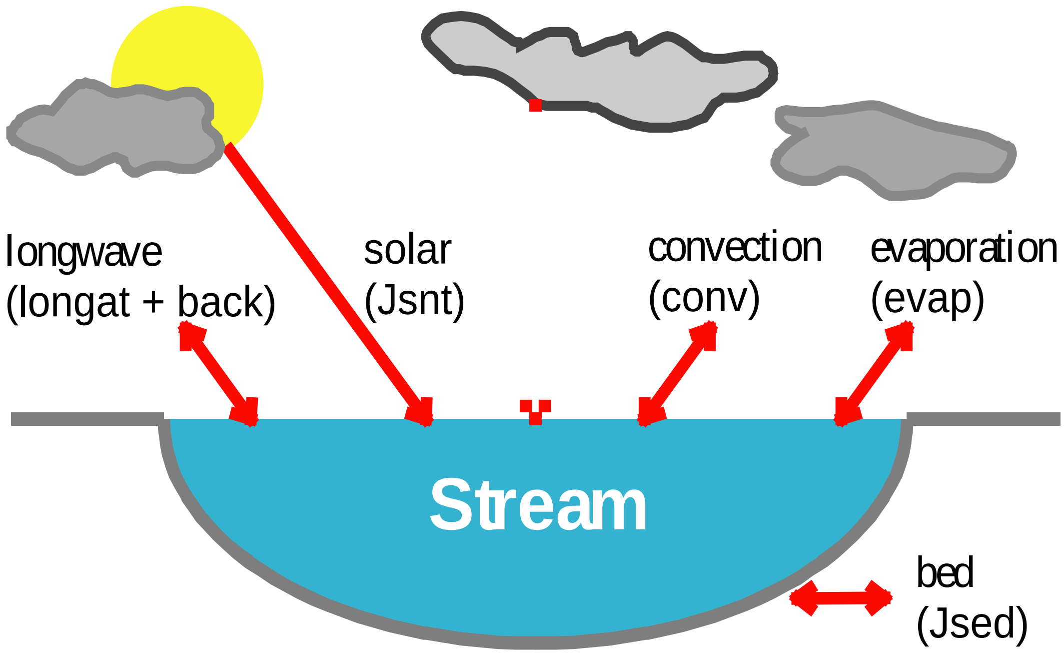

Figure 2. Heat transfer processes in the QUAL2K model that affect water temperature (net heat flux = Jsnt + longat + back + conv + evap + Jsed).

The solar shortwave radiation flux (Jsnt) is typically the dominant component of the heat budget in unshaded streams. The daily changes in water temperature typically follows the same pattern as solar radiation delivered to a stream. The solar shortwave flux can be controlled by managing vegetation in the riparian areas adjacent to the stream. Shade produced by riparian vegetation can reduce the solar shortwave flux (Figure 3). The net heat flux to a stream can be managed by increasing the shade from vegetation, which reduces the shortwave solar flux and causes a reduction in the water temperature in a stream.

Other processes, such as longwave radiation and convection, also introduce energy into a stream but at much smaller rates when compared to solar shortwave radiation (Beschta and Weatherred, 1984; Boyd, 1996). If streamflow increased the volume of water available, these same heat processes would be in place but would result in a smaller temperature increase to the stream.

Research in California (Ledwith, 1996), Washington (Dong et al., 1998), and Maine (Hagan and Whitman, 2000) shows that riparian buffers affect microclimate factors such as air temperature and relative humidity proximal to the stream. Ledwith (1996) found an air temperature increase of 6.5^{o}C between a 150-meter buffer and a 0-meter buffer, with the greatest change occurring in the first 30 meters where it changed 1.0^{o}C per 10 meters. A decrease in the air temperature proximal to the stream would result in a smaller convective flux to the stream during the day.

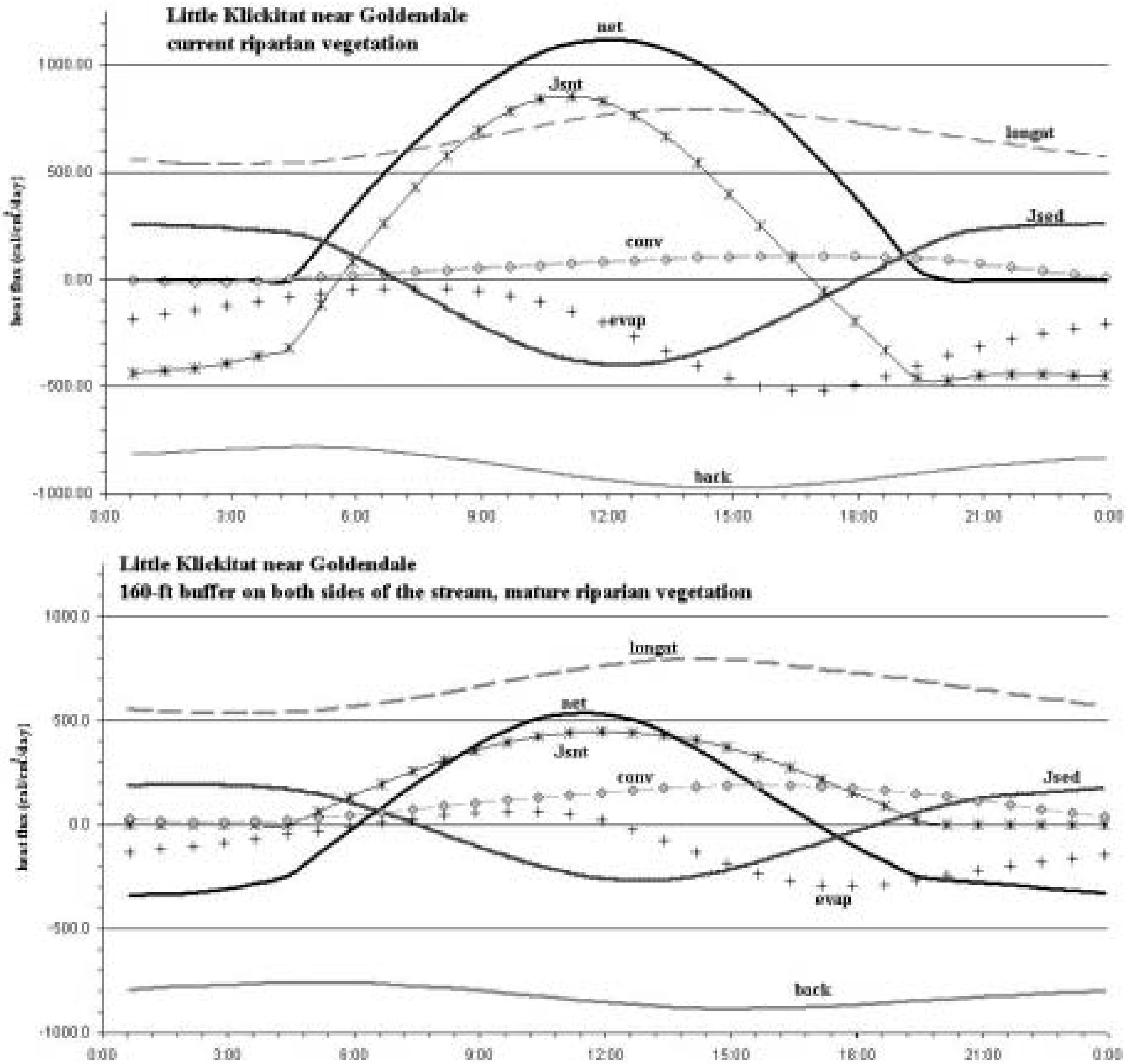

Figure 3. Heat fluxes for current and mature riparian vegetation (Station: LK@Rimrock).

Microclimate effects are under much study and were not included in this analysis because currently it is not possible to define the precise quantitative effect a 160-foot buffer would have on the air temperature in south-central Washington.

This TMDL technical assessment for the Little Klickitat watershed uses effective shade as a surrogate measure of heat flux to fulfill the requirements of Section 303(d). Effective shade is defined as the fraction of incoming solar shortwave radiation above the vegetation and topography that reaches the surface of the stream. Effective shade accounts for the interception of solar radiation by vegetation and topography.

Heat loads to the stream are calculated in the numerical model (in units of calories per square centimeter per day or $cal/cm^2/day$). However, heat loads are of limited value in guiding management activities needed to solve identified water quality problems. Shade is used as a surrogate to thermal load as allowed under EPA regulations [defined as other appropriate measure in 40 CFR §130.2(i)]. A decrease in shade due to inadequate riparian vegetation causes an increase in solar radiation and thermal load upon the affected stream section. Human-caused activities in the riparian zone that can contribute to lack of shade include livestock grazing, recreation, agriculture, and logging. Other factors influencing the distribution of the solar heat load have also been assessed, including increases in the wetted width:depth ratios of stream channels and instream flow.

The Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program (EPA, 1998) provides guidance on the use of surrogate measures for TMDL development. The FACA Report indicates the following:

"When the impairment is tied to a pollutant for which a numeric criterion is not possible, or where the impairment is identified but cannot be attributed to a single traditional "pollutant," the state should try to identify another (surrogate) environmental indicator that can be used to develop a quantified TMDL, using numeric analytical techniques where they are available, and best professional judgment (BPJ) where they are not. The criterion must be designed to meet water quality standards, including the waterbody's designated uses. The use of BPJ does not imply lack of rigor; it should make use of the "best" scientific information available, and should be conducted by "professionals." When BPJ is used, care should be taken to document all assumptions, and BPJ-based decisions should be clearly explained to the public at the earliest possible stage. If they are used, surrogate environmental indicators should be clearly related to the water quality standard that the TMDL is designed to achieve. Use of a surrogate environmental parameter should require additional post-implementation verification that attainment of the surrogate parameter results in elimination of the impairment. If not, a procedure should be in place to modify the surrogate parameter or to select a different or additional surrogate parameter and to impose additional remedial measures to eliminate the impairment."

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Background

The Little Klickitat River watershed is located in south-central Washington State. It flows from the southwest flank of the Simcoe Mountains, west across the Munson Prairie, and through the Little Klickitat canyon to its confluence with the Klickitat River. The Little Klickitat watershed (Figure 4), a sub-basin of the Horseheaven/Klickitat watershed, encompasses approximately 285 square miles and falls solely in Klickitat County.

Land ownership in the watershed is a mix of private (logging companies/land holders), city (Goldendale), state (DNR), federal (BLM), and tribal (Yakama Nation) land. The elevation ranges from 600 feet at the confluence with the Klickitat River to 5823 feet at Indian Rock. Land use in the area is comprised of agriculture (farming and ranching) in the lower elevations, forestry/timber management and limited mining in the upper elevations, and urban lands around the city of Goldendale. Most of the timberlands are currently leased for grazing. The higher elevation range areas are grazed in summer by cattle and during spring through fall by elk and deer (Clayton, 1999a,b; Raines et al., 1999; Cusimano, 1993).

The climate in the watershed is characteristic of south-central Washington, consisting of warm, dry summers and cold winters with the majority of precipitation falling from November to March. Snowmelt, surface runoff, and groundwater feed the Little Klickitat River and its tributaries.

The mainstem of the Little Klickitat River begins with the convergence of the West Prong of the Little Klickitat River and East Prong Little Klickitat River at river mile (RM) 25.7. The river flows southwesterly across the Munson Prairie to the eastern edge of the town of Goldendale at RM 16.3. At RM 14.1, the river passes the outfall of the Goldendale Wastewater Treatment Plant (WWTP). The outfall pipe is the outlet of the lagoon settling ponds of the WWTP. Effluent is typically only released during high flow periods (Joy, 1985).

From Goldendale the river continues westerly to RM 8.3 where it enters a 4.5-mile long canyon area before bending northwesterly and flowing to its confluence with the Klickitat River (RM 19.8) north of Wahkiacus.

Principle tributaries to the Little Klickitat River include Butler Creek (RM 26), Jenkins Creek (RM 20.2), Bloodgood Creek (RM 14.9), Spring Creek (RM 8.6), Blockhouse Creek (RM 6.3), Mill Creek (RM 3.6), Bowman Creek (RM 1.2) and Dry Canyon Creek (RM 1.2) (Caldwell and Hirschey, 1990).

Central Klickitat Conservation District

A majority of the field data for this project were obtained from an ongoing watershed study managed by Dave Clayton of the Central Klickitat Conservation District (CKCD). Monitoring by the CKCD is part of the CKCD Little Klickitat Watershed Management Plan (WMP) which outlines goals to maintain the highest water quality and quantity in the Little Klickitat River that are reasonably and economically practical (Clayton, 1999a,b). Under the WMP, monitoring has occurred at sites throughout the watershed (Figure 5) every summer, May through October, since 1995. Data measurements taken at each site include water temperature recorded continuously with Onset Optic Stowaway Loggers; instream flow with a Flow Probe; stream width, depth, and canopy cover with a spherical densiometer; and a limited habitat assessment.

Yakama Nation Fisheries

The Yakama Nation Fisheries Program has collected stream temperature and habitat data in the area. Three year-round water temperature sites have been in operation on the mainstem Little Klickitat River since November 1996 (Figure 5). Water temperature data are measured using an Onset Hobo Temperature Data Logger. Watershed-wide sampling includes:

- Water quality data collected using a Hydrolab logger.
- Past collection of sediment samples using McNeal cores.
- Seven stream surveys performed over 1,500-foot transects. Data collected includes bankfull width, width-to-depth ratio, pool-riffle ratios, instream wood count, and channel canopy cover.
- Spawning ground surveys.

All survey field measurement protocols and methods follow the TFW Ambient Monitoring Program Manual (Schuett-Hames, 1994).

Additionally, James Matthews (1992) of the Yakama Nation compiled temperature data within five watersheds in eastern Washington. The purpose of the study was to:

- Gather baseline data in several basins within Yakama's Ceded Area, including the Little Klickitat River watershed.
- Identify streams at greatest risk for impacts to salmonid populations.
- Determine the adequacy of proposed temperature sensitivity models for eastern Washington.
- Investigate the influence of elevation, canopy, and distance from the divide on stream water temperature.

Matthews observed that the Little Klickitat River and Big White Salmon River watersheds had the highest observed maximum water temperatures. He concluded that high summer air temperatures are a significant factor in causing these problems. However, most of the temperature sites in the Little Klickitat and Big White Salmon watersheds also had been impacted by significant human disturbance in the past, which has aggravated an already tenuous condition. The more intensively disturbed sites, such as Butler Creek and the lower Little Klickitat River, were quite open and had unnaturally wide channels and shallow depths.

Matthews observed considerable past riparian harvest, relocation of channels, roads/skid trails adjacent to waters, and grazing impacts near monitoring stations. Regression analysis found canopy cover as the primary influencing factor on stream temperatures in the Little Klickitat River watershed. He concluded that greater canopy cover is necessary in the basin to meet state water quality standards.

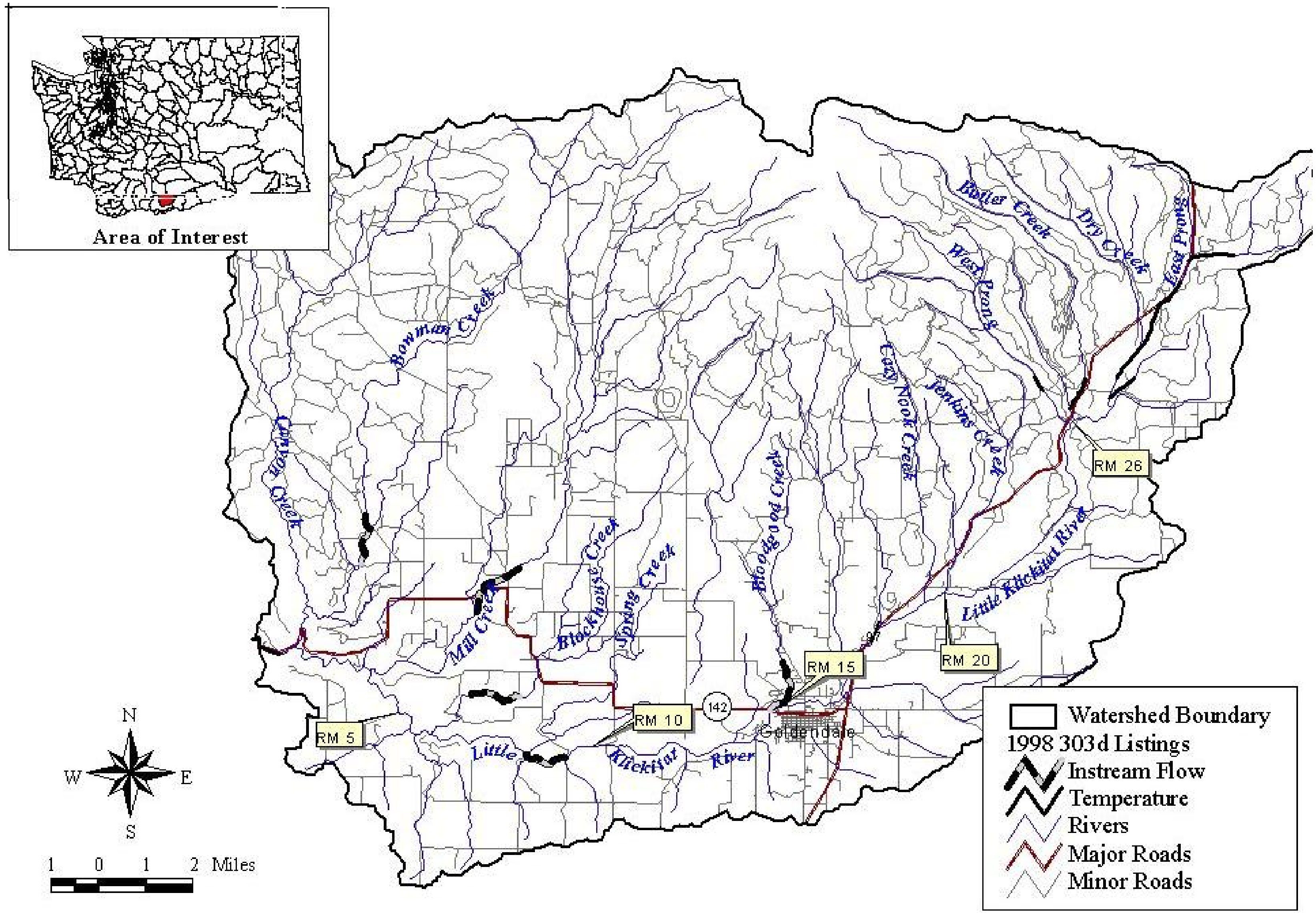

Figure 4. Little Klickitat River temperature TMDL study area.

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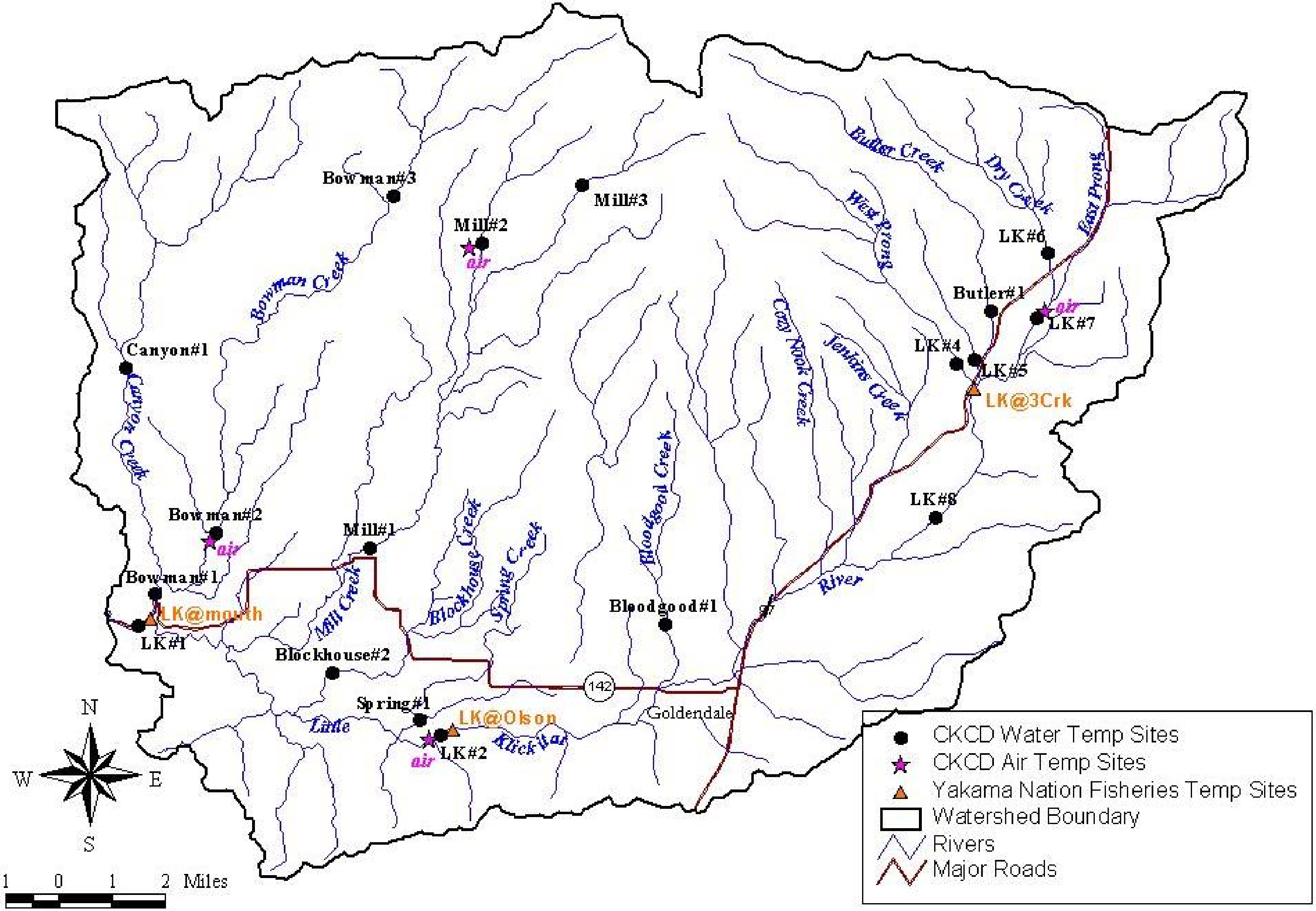

Figure 5. Central Klickitat Conservation District and Yakama Nation Fisheries monitoring sites.

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Washington State Department of Ecology

Two studies by Joy (1985 and 1986) evaluated the impact of the Goldendale Wastewater Treatment Plant on the Little Klickitat River receiving water. The study area for both surveys was comprised of 5.8 miles of the Little Klickitat River between RM 10.5 and 16.3. The 1985 study focused on the effect of effluent discharge during a low flow event (August 27-28, 1985). A similar field study, completed in 1986, compared low-flow (August 27-28, 1985) and high-flow (March 11-12, 1986) surveys. Both surveys measured the following field parameters: temperature, dissolved oxygen, pH, conductivity, discharge/flow, fecal coliform, nutrients (phosphorus and nitrogen), turbidity, chloride, sodium, magnesium, and calcium. Of primary concern to the current Little Klickitat TMDL are the temperature findings.

The data reveals that the temperature of the Little Klickitat River exceeded the numeric water quality standard for Class A waters of 18.0°C at some stations monitored. The summer low-flow survey shows that the Goldendale WWTP effluent, which had a mean temperature of 19.5°C upon release to the river, increased the water temperature from a mean of 12.9°C to 17.3°C. Water quality standards state that if natural conditions are below 18°C, incremental increases occurring from point sources can not exceed $t = 28/(T+7)$, where t is the maximum incremental increase and T is the background temperature measured at a point unaffected by the discharge. The mean background temperature of the water prior to effluent discharge was 12.9°C during the 1985 low-flow survey.

Using the formula above, the maximum allowable incremental increase in stream temperature caused by the point source is 1.4°C. The stream temperature downstream from the effluent discharge is 17.3°C. Therefore, the incremental water temperature increase due to the effluent discharge during the summer low-flow survey exceeded water quality standards at the time. Conversely, the high-flow survey did not result in any instances of temperature exceedance.

Caldwell and Hirschey (1990) conducted an Instream Flow Incremental Methodology study on the lower Little Klickitat River (below Goldendale) to determine minimum instream flows. The method predicts how fish habitat may respond to incremental changes in streamflow. The majority of the information presented focuses on computer model output and the instream flow requirement for tributaries in the watershed. However, as part of the field surveys conducted for the project, temperature was collected at each monitoring station during site visits. The sites were visited once a month from May through September during 1987. Their data shows that July water temperatures exceed those recorded for other months in the 1987 sampling season. They report a total of six instances of water temperature exceedance (based on numeric criteria of 18.0°C) out of 31 data points presented for all stations and all sampling events.

The River and Ambient Water Monitoring Report for Water Year 1995 (Hallock, Ehinger, and Hopkins, 1996) and Timber/Fish/Wildlife Ecoregion Bioassessment Pilot Project (Plotnikoff, 1992) surveyed one site on the Little Klickitat River as part of their assessment. The Ambient Water Monitoring Report provides monthly temperature, flow, and suspended sediment data, among the other surface water quality data collected. The Ecoregion Bioassessment provides an invertebrate inventory and surface water quality data, including temperature and discharge, for the 1991 water year. Both reports show summer water temperatures in excess of 18°C and the occurrence of minimum streamflows during the summer months.

TFW and the Forests and Fish Report

Two-thirds of the upper watershed is privately owned timber land. These forested lands are addressed under the Forests and Fish Report, which prescribes Forest Practice Board regulations to private land owners for attainment of water quality standards.

In 1986, as an alternative to competitive lobbying and court cases, four caucuses (Tribes, the timber industry, the state, and the environmental community) decided to try to resolve contentious forest practices problems on non-federal land through negotiations. This resulted in the first Timber Fish Wildlife (TFW) agreement in February 1987. Recent events have caused the TFW caucuses to once again come together at the policy level to address a new round of issues. Under the federal Endangered Species Act, several salmonid populations have been listed or considered for listing. In addition, over 660 Washington streams have been included on a 303(d) list identifying stream segments with water quality problems under the federal Clean Water Act.

In November 1996, the caucuses – now expanded from four to six, with the addition of federal and local governments – decided to work together to develop joint solutions to these problems. The Forests and Fish Report was presented to the Forest Practices Board of the state Department of Natural Resources and the Governor's Salmon Recovery Office in February 1999. The goals of the forestry module discussions of the Forests and Fish Report are fourfold:

- Provide compliance with the Endangered Species Act for aquatic and riparian-dependent species on non-federal forest lands.
- Restore and maintain riparian habitat on non-federal forest lands to support a harvestable supply of fish.
- Meet the requirements of the Clean Water Act for water quality on non-federal forest lands.
- Keep the timber industry economically viable in Washington State.

To achieve the overall objectives of the Forests and Fish initiative, significant changes in current riparian forest management policy are prescribed. The goal of riparian management and conservation as recommended in the Forests and Fish Report is to achieve restoration of high levels of riparian function and maintenance of these levels once achieved. For eastern Washington forests, such as in the Little Klickitat watershed, the Forests and Fish Report specifies riparian silvicultural treatments and conservation measures that are designed to result in riparian conditions on growth and yield trajectories towards what are called "desired future conditions." Desired future conditions are the stand conditions of a mature riparian forest and the attainment of resource objectives. These desired future conditions are a reference point on the pathway to restoration of riparian functions, not an endpoint of riparian stand development.

Boise-Cascade

Raines et al. (1999) characterized the biological and physical conditions of watershed processes and resource conditions associated with sediment in the upper Little Klickitat River watershed. Ultimately, the assessment resulted in the development of specific forest practices prescriptions to protect public resources in the watershed, including fish and water quality. Sediment transport and delivery in the watershed is of concern because of the potential for sediment (erosion, deposition, or transport in the water column) to alter the temperature regime of the stream channel through channel widening, shallowing, and incision.

The report by Raines et al., prepared for the Boise-Cascade Corporation, divides the physical and biological assessment into the following modules: mass wasting, surface erosion, hydrology, riparian function, stream channels, fish distribution and habitat, water supply and public works, and water quality. The mass wasting, surface erosion, hydrologic condition, and riparian condition modules address hillslope hazards. The vulnerability of resources is addressed by the fish habitat, stream channel, water quality, and public works/water supply modules. In general, the assessment found that in the upper Little Klickitat watershed:

- Mass wasting is not the major source of sediment in the basin.
- Channel incision produces a large amount of sediment, although it is not clear if the source of incision is management related (removal of large woody debris, riparian harvest, stream skidding, increased drainage from roads) or climate related.
- Road surface erosion and gullying produce the largest input of management-related sediment in the basin.
- The total amount of sediment delivered to streams from current land management activities in the basin is well above background levels.
- Bank erosion was widespread in channels of all gradients.
- Much uncertainty remains regarding whether or not forest road drainage has a significant effect on peak flows.
- To attain water quality standards for temperature on streams at 2,800 feet of elevation or more, target canopy coverage is approximately 70%.
- Only 18% (by number) of the channel reaches in which functional large woody debris was counted had good levels of functional wood, and 60% had poor levels.

U.S. Geological Survey

Brown (1979) completed a study to inventory the geology and water resources of Klickitat County to facilitate the understanding and subsequent management of the area’s valuable water resources. The study was designed to present basic information about Klickitat County and the upper Klickitat River watershed. It combined existing data on meteorology, geology, surface and ground water, and water quality with information gathered during additional field work.

Due to the extent of the area studied and the parameters researched, very little of the data available in the report pertains to the Little Klickitat River watershed. However, the report does offer relevant discharge and surface water quality data, including temperature, for selected streams in the Little Klickitat watershed. The report also presents data on water quality for selected wells and springs in the Little Klickitat watershed.

Applicable Water Quality Criteria

Section 303(d) of the federal Clean Water Act mandates that Washington State establish Total Maximum Daily Loads (TMDLs) for surface waters that do not meet water quality standards after application of technology-based pollution controls.

The goal of a TMDL is to ensure the impaired waterbody will attain water quality standards. The TMDL determines the maximum amount of a given pollutant that can be discharged to the waterbody and still meet the state water quality standards (referred to as the loading capacity) and allocates that load among the various sources. If the pollutant comes from a discrete (point) source such as an industrial facility discharge pipe, that facility's share of the loading capacity is called a wasteload allocation. If it comes from a diffuse (nonpoint) source such as a farm, that facility's share is called a load allocation.

The TMDL must also consider seasonal variations and include a margin of safety that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. The sum of the individual allocations and the margin of safety must be equal to or less than the calculated loading capacity for the specific pollutant.

The Little Klickitat River and its tributaries are classified as Class A, excellent, as defined by the Water Quality Standards for Surface Waters of the State of Washington (Hicks, 2000; Chapter 173-201A-030 WAC). The standards establish beneficial uses of waters and incorporate specific numeric and narrative criteria for parameters such as water temperature. The criteria are intended to define the level of protection necessary to support the beneficial uses (Rashin and Graber, 1992). The beneficial uses of the waters in the Little Klickitat watershed are:

- *Recreation:* Fishing and swimming.
- *Fish and Shellfish:* There is local debate over the location of steelhead in the Little Klickitat River and its tributaries. Steelhead use lower reaches for spawning, rearing, and as a migration corridor to Bowman Creek. In high-flow years, steelhead may migrate above the 16-foot waterfall located at RM 6.1 and spawn in the upper reaches of the Little Klickitat and Butler Creek. Resident rainbow trout use the waters for migration, rearing, and spawning. Spring chinook, cutthroat, and coho use the lower reaches of the Little Klickitat for rearing and spawning during the winter months.
- *Municipal Water Supply:* The city of Goldendale has limited municipal water rights on Bloodgood Creek; however the majority of the city water comes from wells in the upper Little Klickitat watershed.
- *Water Supply and Stock Watering:* Agriculture extracts water for irrigation and stock watering.
- *Wildlife Habitat:* Riparian areas are used by a variety of wildlife species which are dependent on the habitat.

Numeric water quality criteria for Class A freshwater streams state that temperature shall not exceed 18.0°C due to human activities. When natural conditions exceed 18.0°C, no temperature increases will be allowed which will raise the receiving water temperature greater than 0.3°C. If natural conditions are below 18.0°C, incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C or bring the stream temperature above 18.0°C at any time (Chapter 173-201A-030 WAC).

During critical periods, natural conditions may exceed the numeric temperature criteria mandated by the water quality standards. In these cases, the antidegradation provisions of those standards apply.

"Whenever the natural conditions of said waters are of a lower quality than the criteria assigned, the natural conditions shall constitute the water quality criteria."
(Chapter 173-201A-030 WAC).

Water Quality and Resource Impairments

As a result of data showing temperature criteria are exceeded, the 14 segments listed in Table 1 are addressed in this TMDL. Thirteen of these segments are included on Washington State's 1996 and 1998 Section 303(d) lists of impaired waters. Table 1 provides a list of all river segments and corresponding parameters identified as limited, according to the Water Quality Standards for Surface Waters of the State of Washington. Because instream flow is not considered a "pollutant," load allocations were not developed. However, flow does impact temperature, and its effect on temperature was considered.

Table 1. Little Klickitat watershed 303(d) listings and waterbodies addressed in this TMDL report .

Name	T	R	S	New Waterbody Number	Old Waterbody Number	Parameter	1996 List	1998 List	Assessed by TMDL
Butler Creek	05N	17E	17	YU86SG	WA-30-1029	Temperature	yes	yes	yes
East Prong	06N	17E	35	PU81CT	WA-30-1028	Temperature	yes	yes	yes
East Prong	05N	17E	10	PW77VQ	WA-30-1028	Temperature	yes	yes	yes
East Prong	05N	17E	03	PW77VQ	WA-30-1028	Temperature	yes	yes	yes
East Prong	05N	17E	09	PW77VQ	WA-30-1028	Temperature	yes	yes	yes
East Prong	05N	17E	16	AG85MX	WA-30-1028	Temperature	yes	yes	yes
Little Klickitat River	04N	14E	09	AY21LB	WA-30-1020	Temperature	yes	yes	yes
						Instream Flow	yes	yes	no
West Prong	05N	17E	18	XU61EK	WA-30-1027	Temperature	yes	yes	yes
Blockhouse Creek	04N	15E	17	ID95ML	WA-30-1023	Instream Flow	yes	yes	no
						Temperature	no	no	yes
Bloodgood Creek	04N	16E	17	XU61DO	WA-30-1025	Instream Flow	yes	yes	no
Bowman Creek	05N	14E	35	TN94DB	WA-30-1021	Instream Flow	yes	yes	no
						Temperature	no	no	yes
Little Klickitat River	04N	15E	28	AY21LB	WA-30-1020	Instream Flow	yes	yes	no
						Temperature	no	no	yes
Mill Creek	04N	15E	05	FF43IZ	WA-30-1022	Instream Flow	yes	yes	no
						Temperature	no	no	yes
Spring Creek	04N	15E	15			*Temperature*	no	no	yes

Italicized parameters were not in the 303(d) list but are part of this TMDL evaluation.

Instream flow is not considered a pollutant by EPA and thus is not regulated under a TMDL.

The 303(d) listings for temperature are also confirmed by the recent and ongoing monitoring by Ecology, Central Klickitat Conservation District, and Yakama Nation (Figures 6 and 7, Appendix A). Data demonstrate that for 18 of 20 segments, water temperatures exceed the Class A standard of 18°C greater than 50% of the time during July and August 2000 (Figure 8). While a simple TMDL that addresses only the listed segments could be done, due to the large amount of data that are available and the dependence of downstream reaches on upstream temperatures, it is more efficient to develop the present TMDL to address water temperature in the entire watershed.

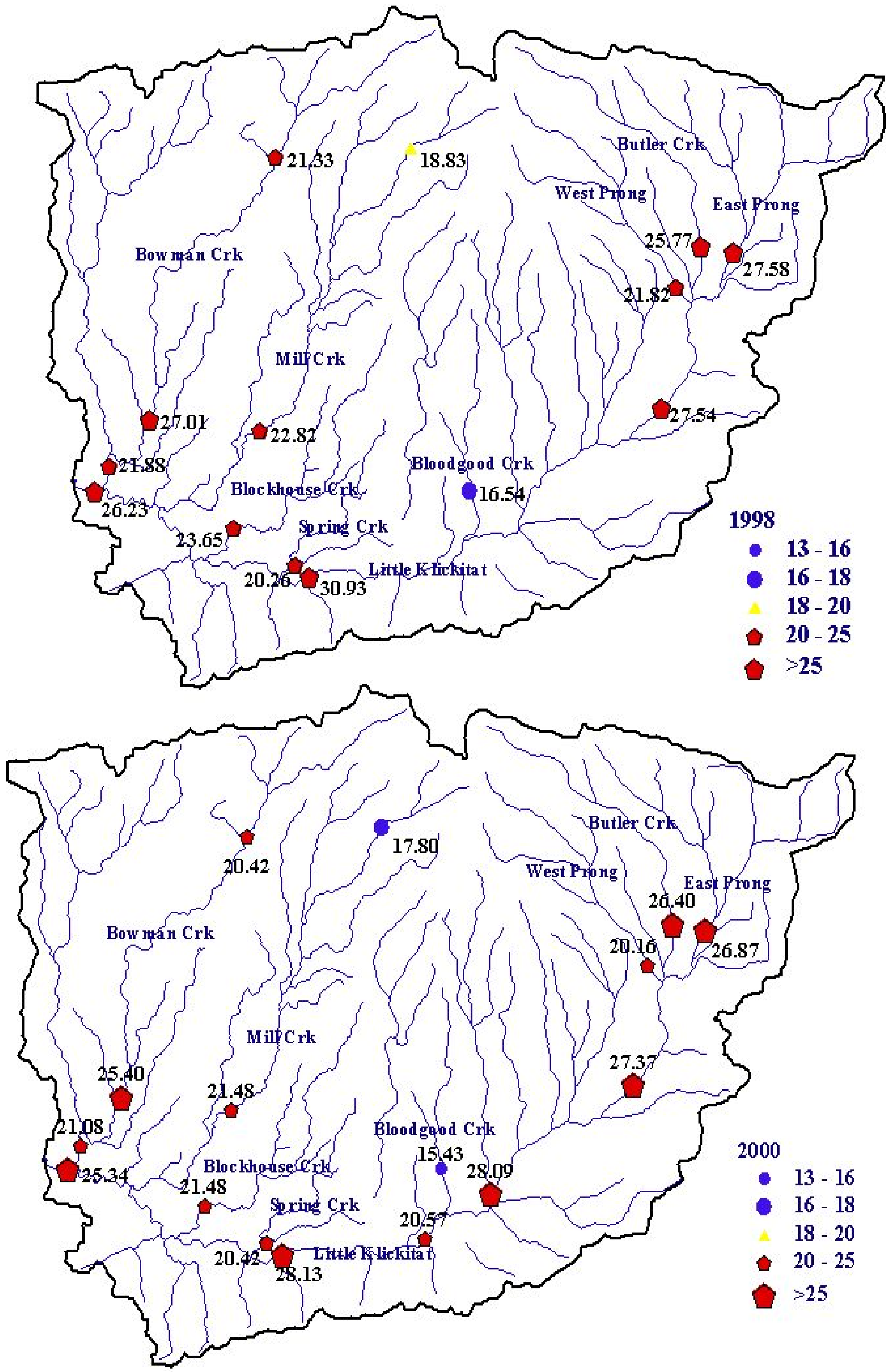

Figure 6. Maximum daily temperatures in the Little Klickitat and tributaries in 1998 and 2000 on the hottest day of the year at each station.

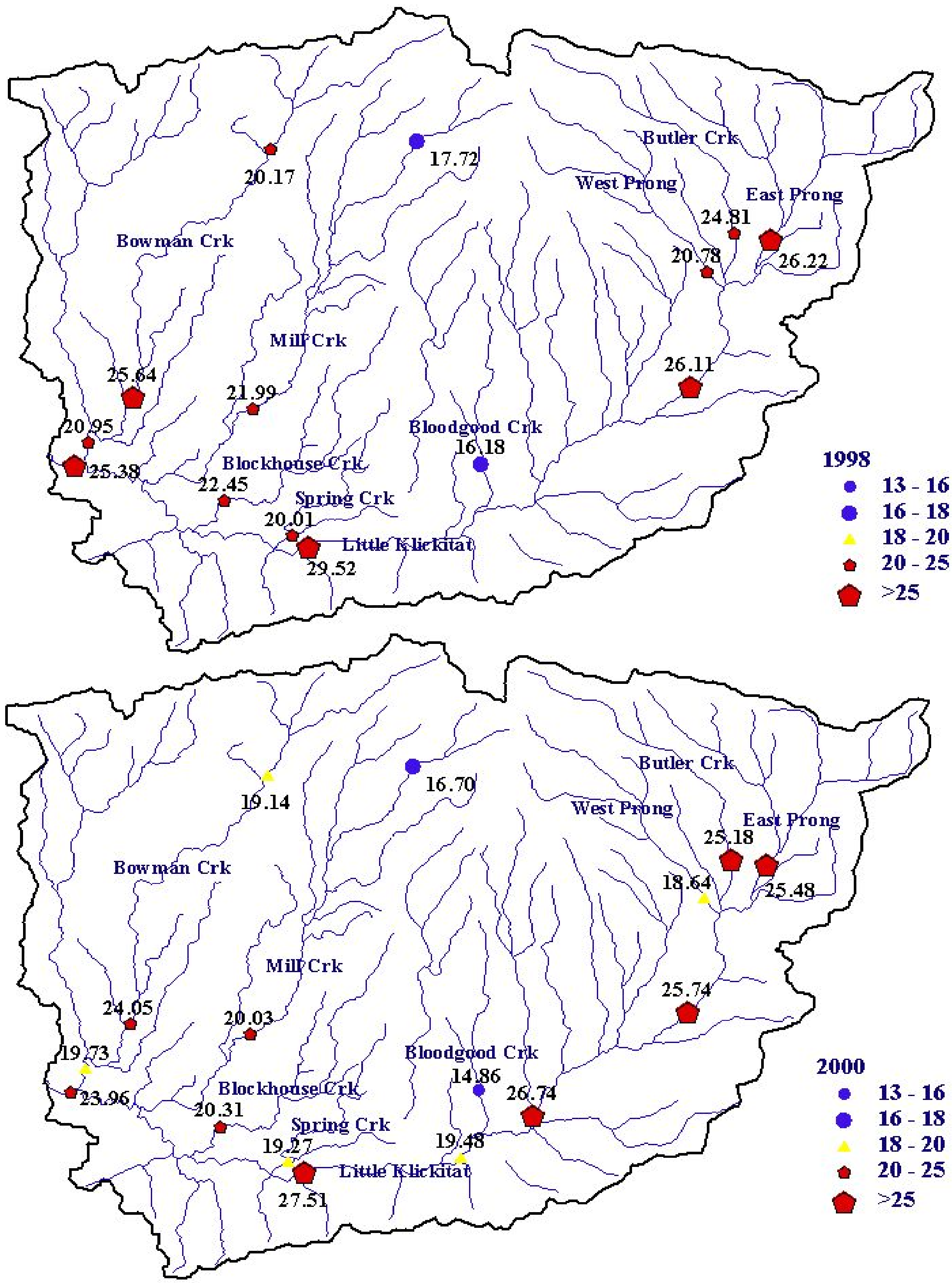

Figure 7. Maximum 7-day-averages of daily maximum temperatures in the Little Klickitat and tributaries in 1998 and 2000.

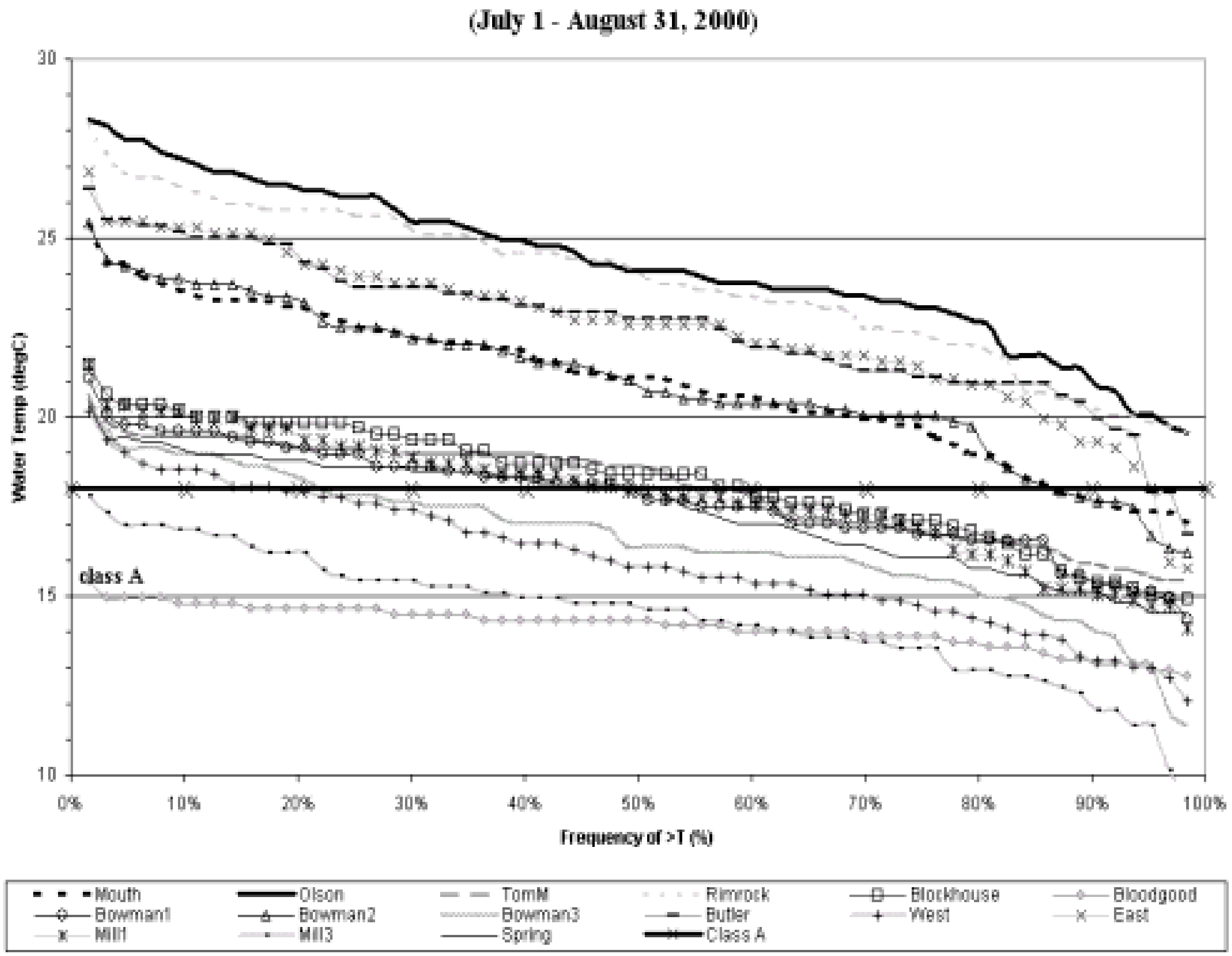

Figure 8. Daily maximum water temperature exceedance frequency distribution for July-August 2000.

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Seasonal Variation

Clean Water Act Section 303(d)(1) requires that TMDLs "be established at a level necessary to implement the applicable water quality standards with seasonal variations". The current regulation also states that determination of TMDLs "shall take into account critical conditions for streamflow, loading, and water quality parameters" [40 CFR 130.7(c)(1)]. Finally, Section 303(d)(1)(D) suggests consideration of normal conditions, flows, and dissipative capacity.

Existing conditions for stream temperatures in the Little Klickitat watershed reflect seasonal variation. Cooler temperatures occur in the winter, while warmer temperatures are observed in the summer. Figures 6 and 7 summarize the highest daily maximum and the highest 7-day average maximum water temperatures for 1998 and 2000. Monitoring data show that the majority of the temperature measurements exceeding the criteria occur in July and August (Figure 9). Since it is not possible to change allocations of shade over a season, they were set based on this critical summer period. The modeling analysis used climatic conditions during this critical period for TMDL development.

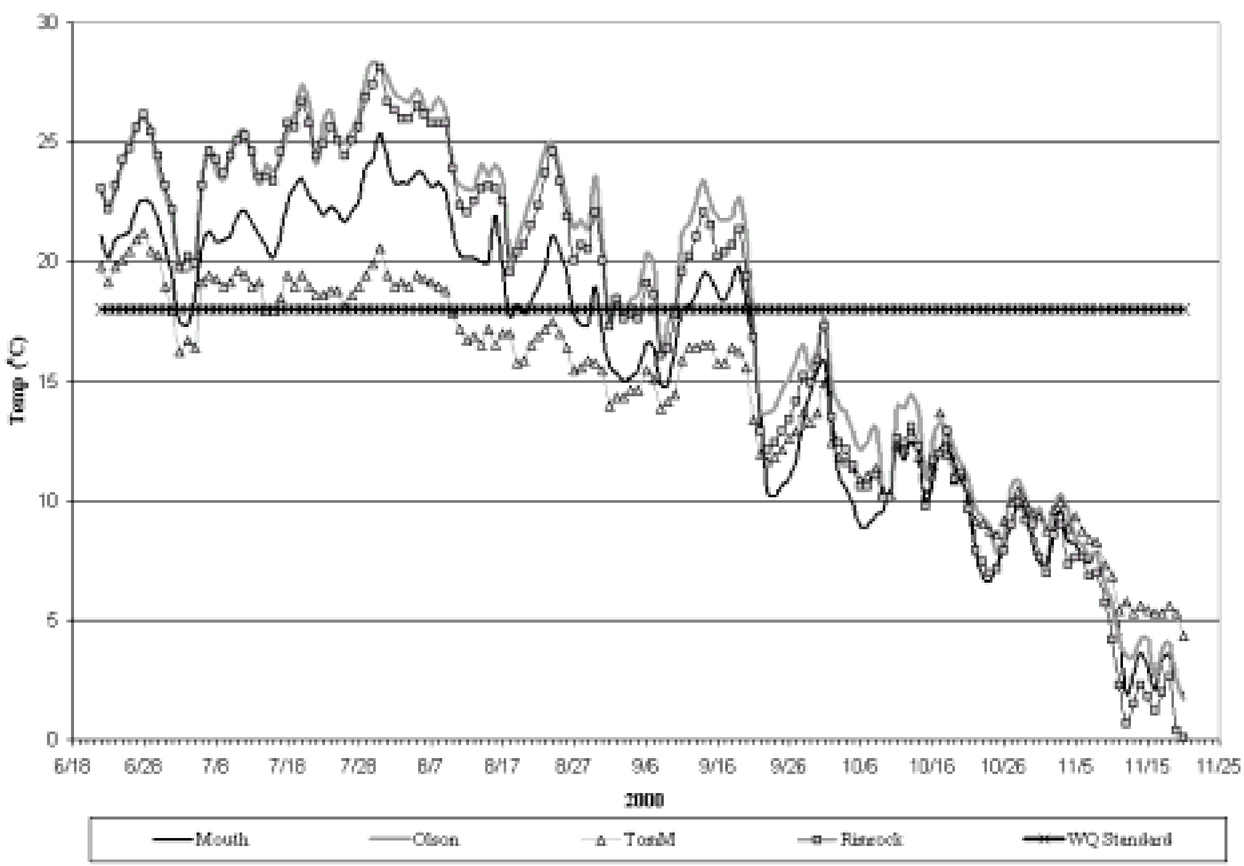

Figure 9. Mainstem Little Klickitat temperature profile.

Seasonal estimates for streamflow, solar flux, and climatic variables for the TMDL are taken into account to develop critical conditions for the TMDL model. The critical period for evaluation of solar flux and effective shade was assumed to be July 15, because it is the approximate mid-point between solar equinox and the period when maximum air and water temperatures occur.

Critical streamflows for the TMDL were evaluated as the lowest 7-day average flows with a 2-year recurrence interval (7Q2) and 10-year recurrence interval (7Q10) for the months of July and August. The 7Q2 streamflow was assumed to represent conditions that would occur during a typical climatic year, and the 7Q10 streamflow was assumed to represent a reasonable worst-case climatic year.

Critical conditions for air temperature were represented by the minimum and maximum air temperatures which occurred on the hottest days of 2000 and 1998 (35^{th} percentile and reasonable worst-case climatic conditions, respectively). The design years for the 35^{th} percentile and worst-case climatic conditions (2000 and 1998) were selected based on the distribution of maximum 1-day-average-daily-maximum air temperatures for each year of observation at the Goldendale Airport from 1931 through 2000. Climatic data from 2000, a 35^{th} percentile year, was used instead of data from a median year, because extensive monitoring by Ecology, Central Klickitat Conservation District, and the Yakama Nation Fisheries show that water temperatures for all stations, except four, exceed the Class A (18^{o}C) Water Quality Standard over 50% of the time for the critical period of July and August (Figure 10). Additionally, streamflows measured during 2000 correspond with 7Q2 streamflows for the watershed (Williams and Pearson, 1985).

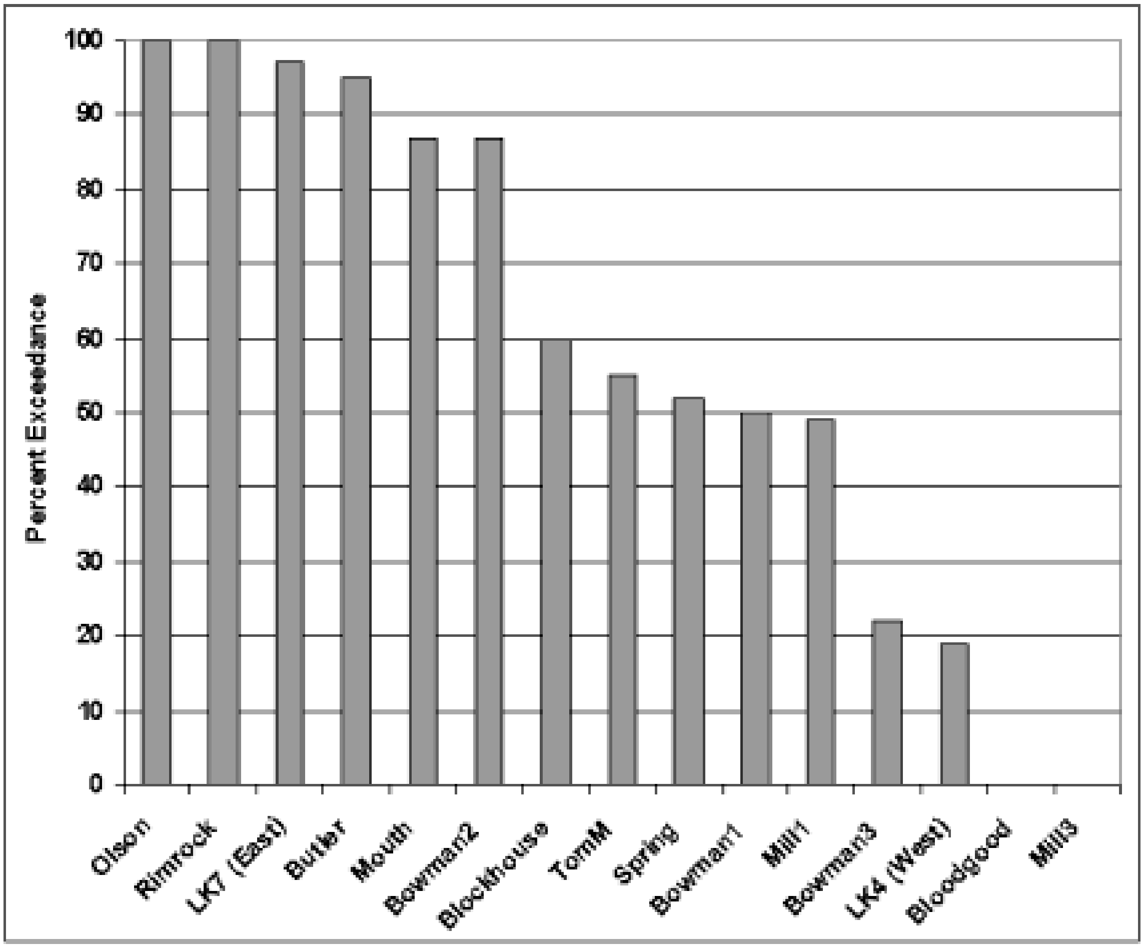

Figure 10. Class A (18^{o}C) exceedances for July 1 to August 31, 2000.

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Technical Analysis

Stream Heating Processes

Riparian vegetation, stream morphology, hydrology, climate, and geographic location influence stream temperature. While climate and geographic location are outside of human control, riparian condition, and channel morphology and hydrology are affected by land-use activities. Specifically, the elevated summer stream temperatures attributed to anthropogenic sources in the Little Klickitat watershed result from the following:

- Riparian vegetation disturbance reduces stream surface shading via decreased riparian vegetation height, width, and/or density, thus increasing the amount of solar radiation reaching the stream surface. Reductions in riparian shade are often due to past agricultural and forestry practices, which includes removal of vegetation for pastures, crops, harvest, and road construction (Clayton, 1999a,b).

- Channel widening (increased width-to-depth ratios) increases the stream surface area exposed to energy processes, namely solar radiation. Causes of widening in the watershed include bank erosion and channel incision due to timber harvest, agricultural practices, and road construction (Raines et al., 1999)

- Near-Stream Disturbance Zone (NSDZ) widening decreases potential shading effectiveness of shade-producing, near-stream vegetation. In the Little Klickitat watershed, riparian vegetation removal and heavy grazing by livestock prevents recruitment of large woody debris and prevents regeneration and propagation of willows and shrubs that successfully dissipate stream energy over the landscape. The NSDZ of Butler Creek was significantly widened during a blowout in 1998 (Clayton, 1999a,b; Raines et al., 1999).

- Reduced summer baseflows may result from instream withdrawals. Reducing the amount of water in a stream can also increase stream temperature (Brown, 1972). Within the Little Klickitat watershed, the cumulative water rights are of significant magnitude to alter low flows and consequently affect stream temperatures in the Little Klickitat River around Goldendale (Clayton, 1999a,b).

Effective Shade

Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. Effective shade is a function of several landscape and stream geometric relationships. Some of the factors that influence shade include the following:

- latitude and longitude
- time of year
- stream aspect and width
- vegetation buffer height, width, overhang, and canopy density
- topographic shade angles

In the Northern Hemisphere, the earth tilts on its axis toward the sun during summer months, allowing longer day length and higher solar altitude, both of which are functions of solar declination (i.e., a measure of the earth's tilt toward the sun). Geographic position (i.e., latitude and longitude) fixes the stream to a position on the globe, while aspect provides the stream/riparian orientation. Riparian height, width, and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation (i.e., produce shade). The solar position has a vertical component (i.e., altitude) and a horizontal component (i.e., azimuth) that are both functions of time/date (i.e., solar declination) and the earth's rotation (i.e., hour angle). While the interaction of these shade variables may seem complex, the math that describes them is relatively straightforward geometry, much of which was developed decades ago by the solar energy industry.

Percent effective shade can be monitored or calculated, and is easily translated into quantifiable water quality management and recovery objectives. Using solar tables or mathematical simulations, the potential daily solar load can be quantified. The solar load at the stream surface can easily be measured with hemispherical photography, a solar pathfinder, or estimated using mathematical shade simulation computer programs (Boyd, 1996).

Effective shade was calculated for the Little Klickitat River and East Prong, West Prong, and Butler creeks using the HeatSource model developed by the Oregon Department of Environmental Quality (ODEQ, 2000). Effective shade calculations were verified with field data. Table 2 illustrates the accuracy of the effective shade calculations against field measurements.

The difference between measured and calculated effective shade is attributed to two factors. First the measured effective shade includes effective shade produced by vegetation only. It does not include the topographic shade features in the area. The model was run to determine the percent effective shade attributed by topographic shade and was added as a column to Table 2. Secondly, the aspect of the stream, which affects the path length of the sun through the vegetation, is not accounted for. For example, the portion of the Little Klickitat near Tom Miller Road has a more north-south orientation than the east-west orientation of the Olsen Road site. Therefore, the path length for the site at Tom Miller Road is longer and attributes to a higher calculated effective shade.

Table 2. Comparison of calculated and measured effective shade.

Station/ Tributary	Distance downstream from headwater (km)	Calculated Effective Shade (%)	Measured Effective Shade (%) by vegetation only	Calculated Effective Shade (%) by topography only
Butler (trib)		55.0	47.5	4.6
East Prong (trib)		62.3	45.7	4.6
West Prong (trib)		77.5	60.8	4.6
Rimrock	14.1	60.0	49.0	1.4
Tom Miller	19.1	46.4	35.0	0.0
Olson	27.2	30.0	38.1	0.0
Mouth	42.9	48.1	45.2	2.9

Current Conditions

Available Water Temperature Data

Continuous temperature dataloggers were deployed and maintained in the Little Klickitat watershed by the Central Klickitat Conservation District and Yakama Nation Fisheries every summer since 1995 (Figures 6 and 7, Appendix A). Additionally, Ecology established continuous water and air thermistors at four locations in the watershed from June 22, 2000 to November 20, 2000 (Figure 11). The 2000 water temperature data show that temperatures in excess of 18^{o}C are common throughout the watershed (Figure 10). Although the year 2000 registered a maximum air temperature in the 35th percentile for data from 1931 to 2000, all but four stations exceed the water quality standard of 18^{o}C fifty percent of the time. These basin-wide exceedances are confirmed by data collected during 1998, the hottest year on record. Temperature and effective shade data from 1998 and 2000 show that in the Little Klickitat watershed water temperatures rise as effective shade decreases (Figure 12).

Stream Flow Data

Ecology installed three continuous flow measurement stations during 2000 (Figure 11). The Ecology stations recorded stage height continuously from June 14, 2000 to November 14, 2000. Instantaneous flow measurements at all stations were taken monthly during the summer of 2000 to represent the range of flows in the watershed during this period. Rating curves to estimate the continuous flows at each station were developed by applying power curves using linear regression of log-transformed stage and discharge (Appendix C1).

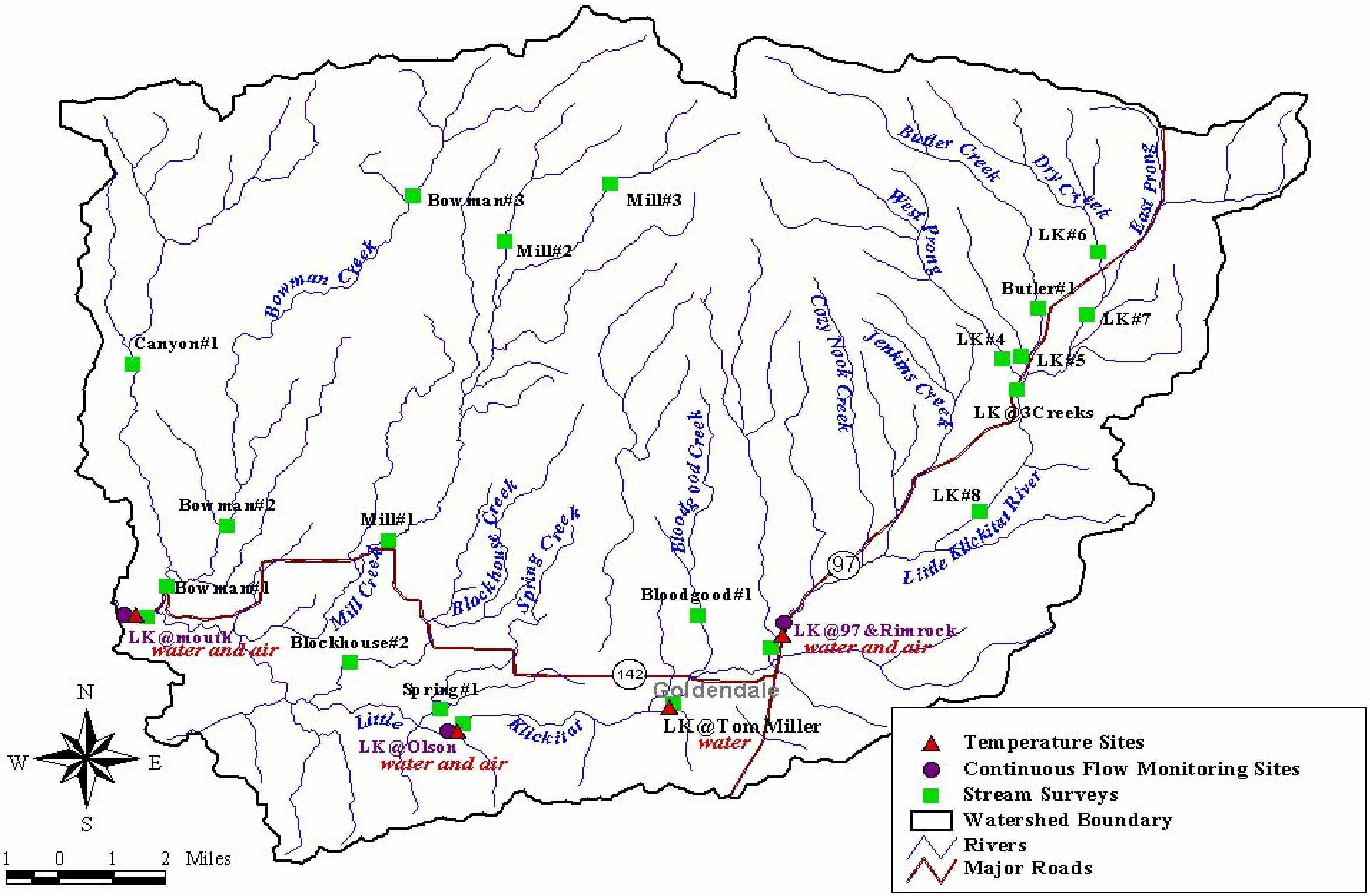

Figure 11. Ecology established monitoring sites.

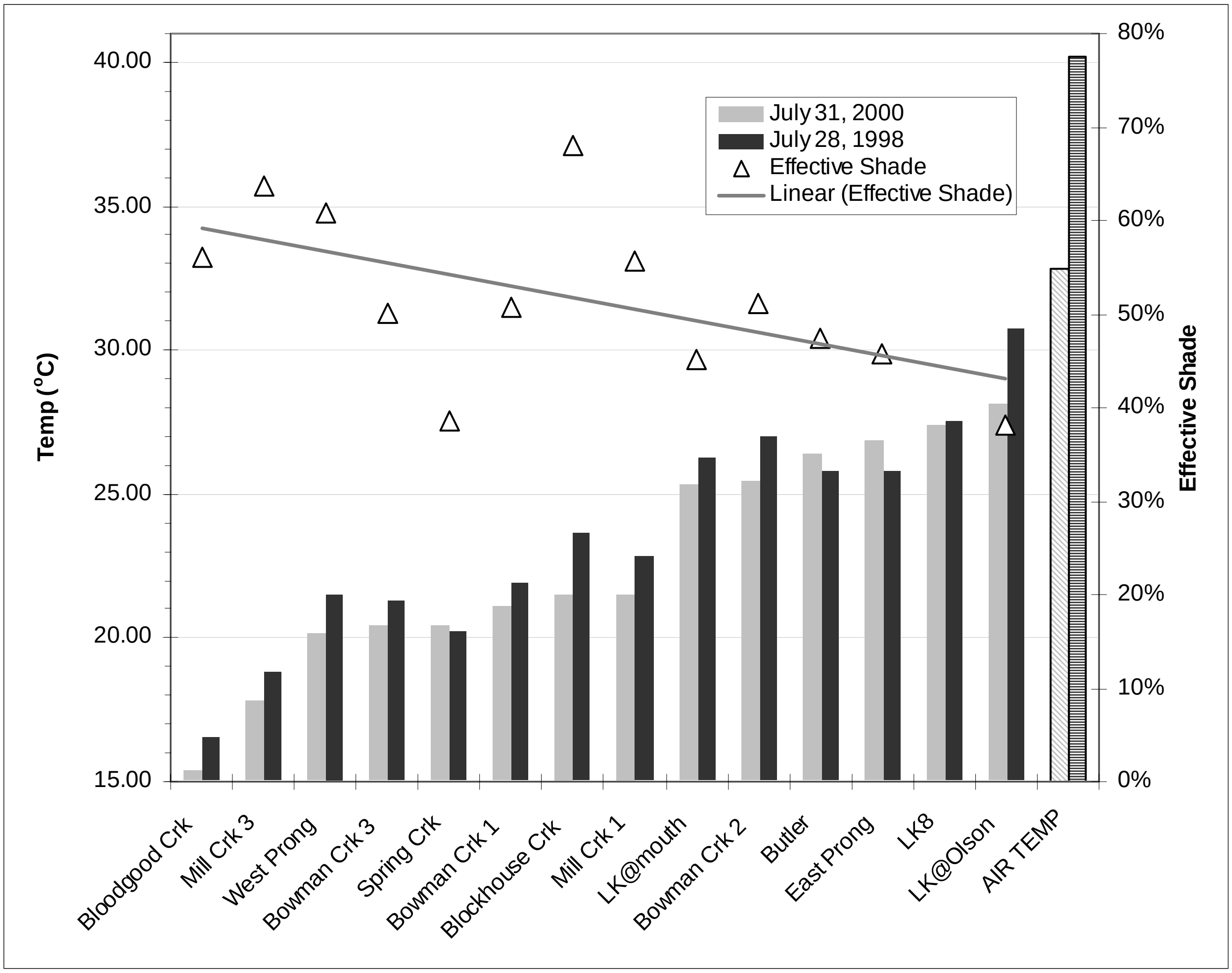

Figure 12. Effective shade and maximum observed stream temperatures.

Groundwater Data

A synoptic flow survey was performed on July 19, 2000 to determine the influence of groundwater in the watershed. The survey consisted of measuring instantaneous flow at each tributary and at regular intervals along the mainstem Little Klickitat on one day during low-flow conditions in the watershed. The flow data, coupled with the adjudicated water rights in the basin, obtained from the WRATs database, determined gaining and losing groundwater reaches. This analysis determined there was significant groundwater inflow or outflow in several reaches of the Little Klickitat River (Figure 13). Figure 13 presents a linear diagram of the Little Klickitat which illustrates reaches with groundwater inflow with a heavy dashed line and reaches with irrigation withdrawal with a solid line. These findings were consistent with the hydrogeologic data available in the watershed (Appendix D; Erickson, 2001).

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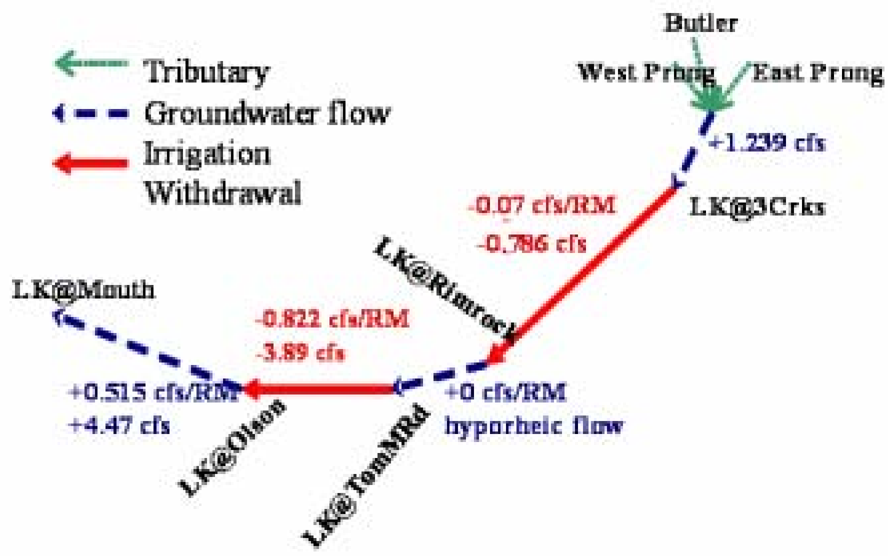

Figure 13. Groundwater influences in the Little Klickitat watershed.

Hydraulic Geometry

The width (w), depth (d), and velocity (u) of a stream are typically related to discharge (Q) by power functions (Leopold, 1994) as follows:

- $w = aQ^b$ (b is approximately 0.26 at a station)
- $d = cQ^f$ (f is approximately 0.40 at a station)
- $u = kQ^m$ (m is approximately 0.34 at a station)

The coefficients are also related to each other by continuity such that the product of the coefficients (a * c * k) should equal 1 and the sum of the exponents (b + f + m) should equal 1.

The channel width and the ratio of width/depth also have an important influence on the sensitivity of water temperature to the flux of heat. Stream widths at low flow were measured by Ecology during field surveys of nineteen 1000-foot stream segments in the Little Klickitat watershed. The surveys, which follow Rosgen stream morphology classification system protocol, consist of field measurements of bankfull width and depth, wetted width and depth, floodplain width, canopy closure with a concave densionmeter, and riparian vegetation characteristics such as height, density, and type (Rosgen, 1996). Substrate material was sampled using the 1-ft^2 substrate grid and protocols described in Plotnikoff and Wiseman (2001). Measurements were taken every 100 feet over a 1000-foot thermal reach. Gradient and sinuosity, also required for a Level II Rosgen Classification, were collected from digital topographic maps. Analysis of the data results in a description of channel characteristics for the Little Klickitat basin (Table 3) which is helpful in determining what morphological parameters are contributing to elevated water temperatures in the watershed.

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Table 3. Rosgen classification and width measurements for the Little Klickitat watershed.

Station	Wetted Width (m)	Entrench-ment (m)	Bankfull W/D	Sinuosity*	Slope	Channel Material**	Rosgen Class
West Prong (trib)	2.72	1.74	11.70	1.06	0.0279	Cob, Gr, B	B3
Butler (trib)	2.63	1.69	15.24	1.09	0.0228	Cob, B, Gr	B3
East Prong (trib)	2.58	2.03	13.84	1.11	0.0075	Cob, Gr, B	B3c
Highland (trib)	-	1.99	12.58	1.02	0.0041	C,G,B	B3c
Dry (trib)	-	2.78	19.86	1.13	0.025	C, G, B	C3b
Rimrock (LK)	6.02	1.71	18.95	1.15	0.0057	G, C, Sa	B4c
Bloodgood (trib)	3.62	5.66	6.78	1.07	0.013	Sa, C, Si	E5
TomM (LK)	6.09	2.39	11.74	1.15	0.0067	B, C, G	C2
Olson (LK)	6.60	3.42	14.76	1.15	0.0062	G, B, C	C4
Spring (trib)	4.42	4.32	13.15	1.25	0.006	Si, C, B	C6
Blockhouse (trib)	1.43	7.56	4.22	1.17	0.018	Sa, G, C	E5
Mill3 (trib)	2.01	1.83	8.25	1.01	0.0068	C, G, B	G3c
Mill2 (trib)	2.77	2.65	8.63	1.06	0.046	G, C, Sa	A4
Mill1 (trib)	3.37	2.89	8.93	1.16	0.013	G, C, Si	E4
Bowman3 (trib)	2.90	1.71	14.79	1.08	0.032	C, G, Sa	B3
Bowman2 (trib)	2.55	1.62	7.75	1.11	0.012	B, C, G	B2c
Bowman1 (trib)	4.50	1.79	10.56	1.06	0.017	C, B	B3c
Mouth (LK)	12.35	2.79	22.94	1.15	0.0049	C, B, G	C3

(trib) indicates a tributary
(LK) indicates Little Klickitat
*Sinuosity is the length of the stream to the length of the valley
** Channel material abbreviations follow Rosgen Classification (Rosgen, 1996)

Manning's equation is commonly used to estimate depth (d) from flow (Q), Manning's roughness coefficient (n), width (w), and slope (S), assuming the hydraulic radius equals the depth and the width is large compared to the depth (Lindeburg, 1989; metric units):

$$d = [(n * Q)/(S^{0.5} * w)]^{0.6}$$

If the flow (Q), width (w), and depth (d) are known, then the continuity equation can be used to estimate velocity (u):

$$u = Q / (w * d)$$

Manning's n typically varies with flow and depth (Gordon et al., 1992). As the depth decreases at low flow, the relative roughness increases. Typical published values of Manning's n, which range from about 0.02 for smooth channels to about 0.15 for rough natural channels, are representative of conditions when the flow is at the bankfull capacity (Rosgen, 1996). Critical conditions of depth for evaluating the period of highest stream temperatures are generally much less than bankfull depth, and the relative roughness may be much higher. Values of Manning's n between 0.09 and 0.5 were measured at flow gaging stations in the watershed. Reach-averaged values of Manning's n may be higher than those measured at the gaging stations, because the locations of the gaging stations were typically selected for laminar flow conditions. Reach-averaged depth may be considerably less than the depth at the flow measurement stations.

Therefore, reach-averaged relative roughness may be greater than the measured roughness at the flow stations.

Riparian Vegetation and Effective Shade

The Washington Department of Fish and Wildlife (WDFW) and Department of Natural Resources (DNR) created and maintain a Geographic Information System (GIS) database with Priority Habitat and Species Digital data. These GIS coverages were obtained from the WDFW to describe the vegetation species and percent of canopy closure (Figure 14). The GIS coverage provides species and density data but does not describe tree heights. Ecology collected tree height data to enhance the GIS coverages during summer stream surveys.

Effective shade was calculated using the HeatSource model (Figures 15 and Table 4). Riparian vegetation size and density was sampled at 30-meter intervals along the Little Klickitat River, West Prong, East Prong, and Butler Creek using the Ttools extension for ArcView that was developed by ODEQ. At each stream transect location, the vegetation grid was sampled orthogonal to the stream at 20-foot-wide riparian zone intervals starting at the wetted edge and progressing to 160 feet from each side of the stream. Other spatial data calculated at each transect location include stream aspect, as well as topographic shade angles to the west, south, and east. Stream widths were determined from field measurements taken during Ecology stream surveys (Table 3).

Effective shade calculations were made for four scenarios of vegetation. Two of these scenarios, the current and mature vegetation described below, are used in the TMDL load allocation analysis. The additional vegetation scenarios are used in a sensitively analysis of mature riparian vegetation which is discussed in Appendix E.

- Current vegetation based on field and spatial data for height and canopy density.
- Maximum effective shade from mature riparian vegetation buffers (Table 5). For this temperature analysis, mature riparian vegetation is defined as the climax riparian vegetation which would occur over time under natural conditions. The vegetation heights and density were obtained from a study by Boise-Cascade, conversations with the Central Klickitat Conservation District, and knowledge of vegetation present in watersheds in the vicinity of the Little Klickitat watershed (Raines et al., 1999; Clayton, 2001; ODEQ, 2001; Sizemore, 2002).

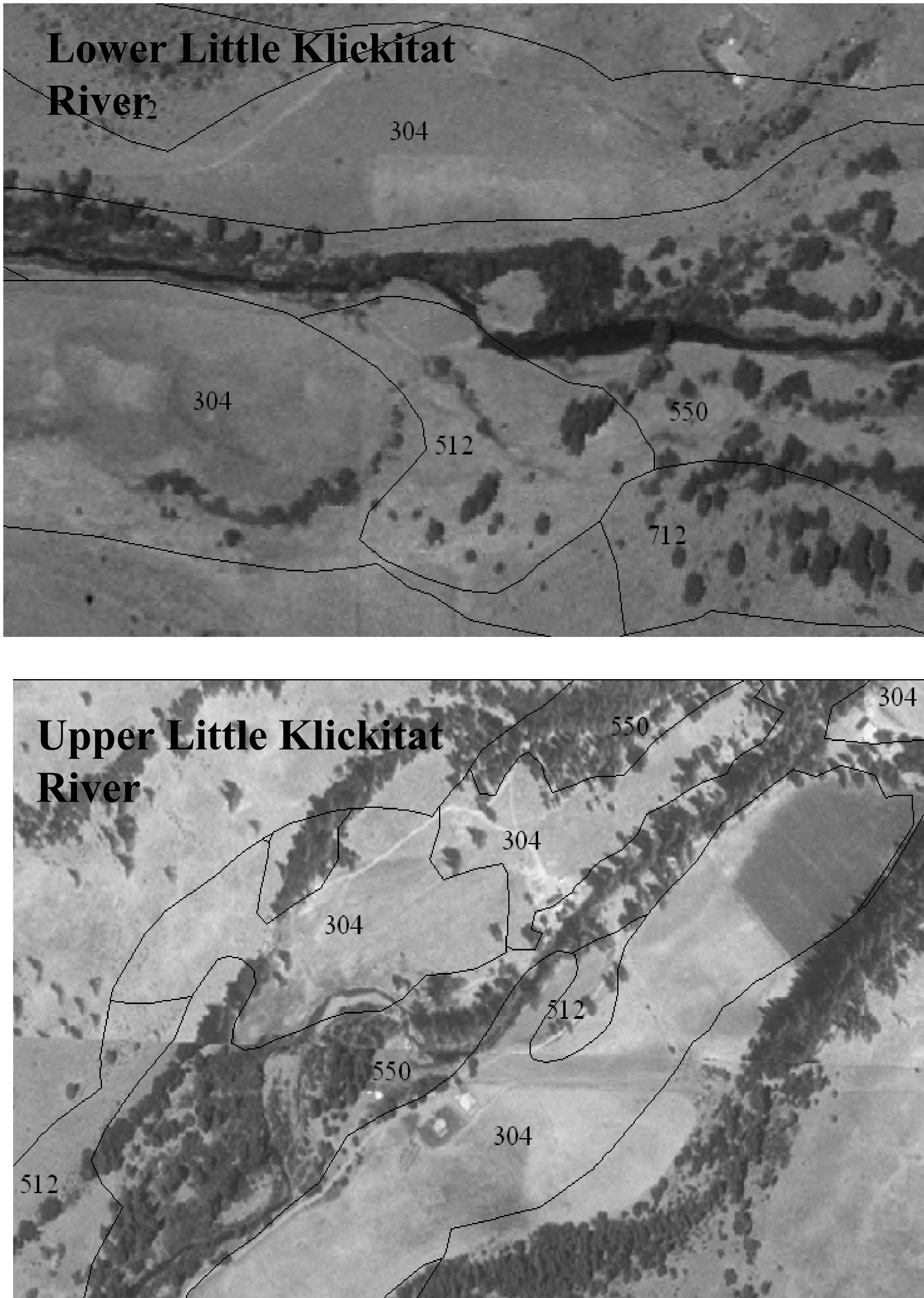


Figure 14. Example of the vegetation coverage for the Little Klickitat basin.
A 3-digit code developed by ODEQ was assigned to vegetation polygons (Appendix F).

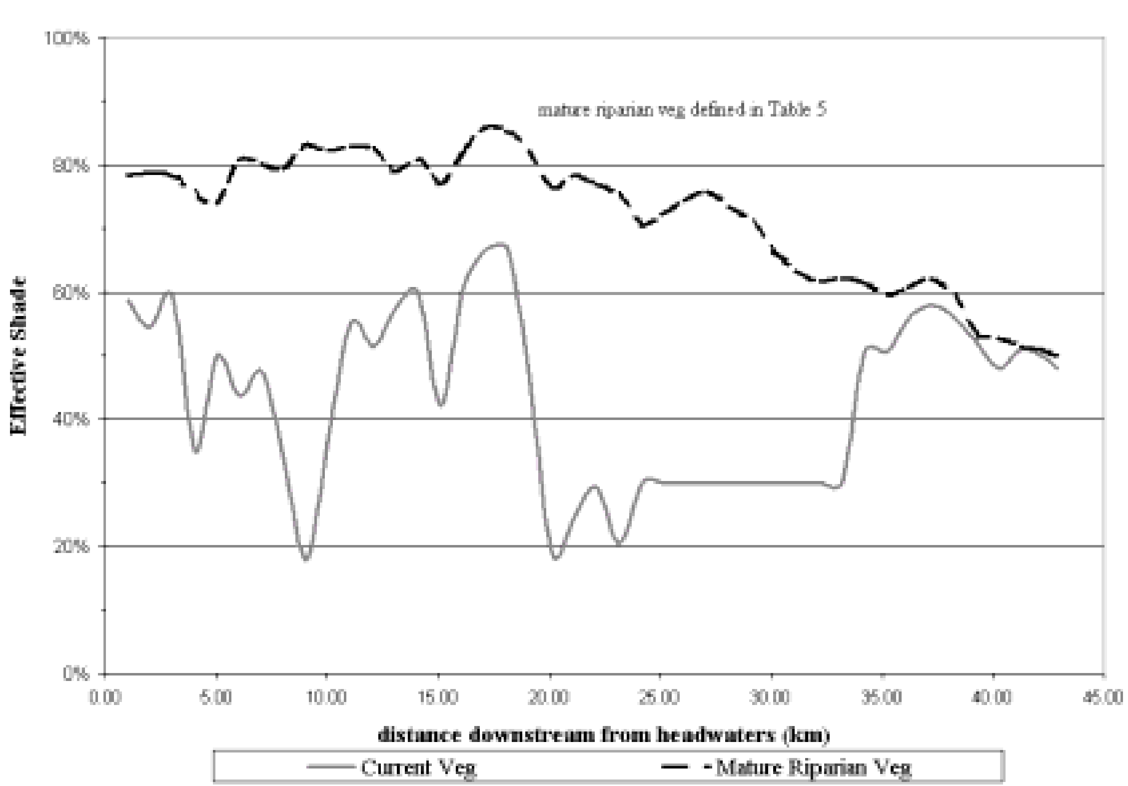


Figure 15. Current and mature riparian effective shade for the Little Klickitat River.

Table 4. Current and mature riparian effective shade for West Prong, East Prong, and Butler Creek.

	Percent Effective Shade*	
	Current (%)	Mature Riparian+ (%)
West Prong	77.5	93.0
East Prong	62.3	94.0
Butler Creek	55.0	95.0

* includes shade provided by topography and vegetation
+ mature riparian assumes 125-ft height and 80% density

Table 5. Mature riparian vegetation in the Little Klickitat watershed (Raines et al., 1999; Clayton, 2001; ODEQ, 2001; Sizemore, 2002).

Reaches	Near Stream (20 feet)			Outer Zone (140 feet)		
	Vegetation Type	Density	Average Mature Height	Vegetation Type	Density	Average Mature Height
Tributaries - West Prong, East Prong, and Butler Creek	2-Story Deciduous	80%	30 feet / 10 meters	Coniferous	80%	127 feet / 38.7 meters
Upper – above Goldendale	2-Story Deciduous	80%	30 feet / 10 meters	Coniferous	55%	104 feet / 31.7 meters
Lower – below Goldendale	2-Story Deciduous	80%	30 feet / 10 meters	Coniferous / Deciduous	50%	65 feet / 19.8 meters

Analytical Framework

Data collected during this TMDL effort has allowed the development of a temperature simulation methodology that is both spatially continuous and spans full-day lengths. The GIS and modeling analysis was conducted using three specialized software tools:

- ODEQ's Ttools extension for Arcview (ODEQ, 2001) was used to sample and process GIS data for input to the HeatSource and QUAL2K models.
- ODEQ's HeatSource model (ODEQ, 2000) was used to estimate effective shade along the mainstem of the Little Klickitat River, West Prong, East Prong, and Butler Creek (Figure 15). Effective shade was calculated using the HeatSource model at 30-meter intervals along the lengths of the mainstems of the Little Klickitat River, West Prong, East Prong, and Butler Creek and then averaged over 1000-meter intervals for input to the QUAL2K model.
- The QUAL2K model (Chapra, 2001) was used to simulate water temperatures. QUAL2K is a model of water quality for streams and rivers that simulates diurnal variations in stream temperature for a steady flow condition. QUAL2K was applied by assuming that flow remains constant for a given condition such as a 7-day or 1-day period, but key variables were allowed to vary with time over the course of a day. For temperature simulation, the solar radiation, air temperature, relative humidity, headwater temperature, and tributary water temperatures were specified or simulated as diurnally varying functions. QUAL2K uses the kinetic formulations for the components of the surface water heat budget that are shown in Figure 2 and described in Chapra (1997). Diurnally varying water temperatures at 1000-meter intervals along the lengths of the mainstems of the Little Klickitat River, West Prong, East Prong, and Butler Creek were simulated using a finite difference numerical method.

All input data for the HeatSource and QUAL2K models is longitudinally referenced, allowing spatial and/or continuous inputs to apply to certain zones or specific river segments. Model input data were determined from available GIS coverages using the Ttools extension for Arcview, or from data collected by Ecology, Central Klickitat Conservation District, Yakama Nation Fisheries, or other data sources. Detailed spatial data sets were developed for the following parameters for model calibration and verification (for the mainstems of the Little Klickitat River, West Prong, East Prong, and Butler Creek):

- River and tributary mapping at 1:3,000 scale from 1-meter-resolution Digital Orthophoto Quads.

- Riparian vegetation type and density mapping at 1:6,000 scale, sampled along the stream at 30-meter intervals. At each stream transect location, the vegetation grid (1 meter pixel size) was sampled orthogonal to the stream at 6.1-meter intervals starting at the wetted edge and progressing to 48.8 meters (160 feet) from each side of the stream.

- Near-stream disturbance zone (NSDZ) width measurements from Ecology field surveys.

- West, east and south topographic shade angles: Calculations were made from the 30-meter DEM grid for the river segments above Goldendale and a 10-meter DEM grid for segments below Goldendale using ODEQ's Ttools extension for ArcView,

- Stream elevation was sampled from a 30-meter DEM grid for the upper watershed and a 10-meter DEM grid for the lower watershed with the ArcView Ttools extension. Gradient was estimated from the topographic contours on the USGS 7.5-minute Quad maps.

- Aspect (stream flow direction in decimal degrees from north): Calculated by the Ttools extension for Arcview.

- Boundary headwater and tributary water temperatures: The daily minimum and maximum observed temperatures for the headwaters and tributaries were used as input to the QUAL2K model for the calibration and verification periods. The QUAL2K model was calibrated and verified using data collected during July and August 2000 (Tables 6 and 7, and Appendix A).

- Flow balances for the calibration and verification periods were determined from field measurements of flow made by Ecology (Figure 16). The lowest 7-day-average flows during the July-August period with recurrence intervals of two years (7Q2) and ten years (7Q10) were estimated based on low-flow statistics from the Little Klickitat at the mouth (USGS station, period of record from 1911-1970, July-August 7Q2=21.7 m^3/sec, July-August 7Q10=12.0 m^3/sec). The flows measured by Ecology in the watershed during 2000 corresponded with 7Q2 flow statistics reported by USGS. The 7Q10 at various other locations were estimated by holding Irrigation Withdrawals, derived from the WRATs database detailing adjudicated water rights, in the watershed constant and adjusting all other flows by the percent difference between the 2000 measured low flows and the USGS 7Q10 flows. A flow balance spreadsheet of the stream networks for the Little Klickitat River watershed was constructed to estimate groundwater inflows or outflows by differences between the gaging stations (Table C2).

Table 6. Daily maximum and minimum and 7-day average temperatures for the hottest 7-day period of July-August 2000 in the Little Klickitat watershed.

Station	Date	Maximum Temp (°C)		Minimum Temp (°C)	
		Daily	7-day ave	Daily	7-day ave
3Creeks	7/31/00	26.7	24.21	15.9	13.67
Blockhouse	7/31/00	21.48	20.31	17.74	15.92
Bloodgood	7/31/00	15.43	14.86	11.86	11.19
Bowman1	7/31/00	21.08	19.73	16.56	14.71
Bowman2	7/31/00	25.4	24.05	18.75	16.47
Bowman3	7/31/00	20.42	19.14	12.92	11.08
Butler	7/31/00	26.40	25.18	16.59	14.89
East Prong	7/31/00	26.87	25.48	17.04	14.79
LK8	7/31/00	27.37	25.74	19.72	17.61
Mill1	7/31/00	21.48	20.03	15.52	13.75
Mill3	7/31/00	17.80	16.70	12.45	10.90
Mouth	7/31/00	25.34	23.96	20.93	19.17
Olson	7/31/00	28.13	27.51	21.05	18.70
Rimrock	7/31/00	28.09	26.74	21.02	18.37
Spring	7/31/00	20.42	19.27	14.99	13.79
TomM	7/31/00	20.57	19.48	14.78	13.51
West Prong	7/31/00	20.16	18.64	15.19	13.12

7-day period = 7/29/00 to 8/4/00

Table 7. Daily maximum and minimum and 7-day average temperatures for the subsequent hottest 7-day period of July-August 2000 in the Little Klickitat watershed.

Station	Date	Maximum Temp (^oC)		Minimum Temp (^oC)	
		Daily	7-day ave	Daily	7-day ave
3Creeks	8/24/00	21.3	19.49	13.3	10.77
Blockhouse	8/24/00	18.55	17.25	15.06	12.58
Bloodgood	8/24/00	14.33	13.80	11.08	10.26
Bowman1	8/24/00	19.78	17.82	13.88	11.87
Bowman2	8/24/00	22.2	20.28	15.08	12.62
Bowman3	8/24/00	17.49	16.19	10.59	8.72
Butler	8/24/00	24.31	22.93	13.91	12.27
East	8/24/00	23.41	21.58	14.21	11.74
LK8	8/24/00	24.57	22.42	16.99	14.27
Mill1	8/24/00	18.39	16.88	12.71	11.09
Mill3	8/24/00	15.25	14.02	10.12	8.62
Mouth	8/24/00	21.1	19.42	16.89	15.16
Olson	8/24/00	24.95	23.41	17.32	14.80
Rimrock	8/24/00	24.57	22.49	17.44	14.65
Spring	8/24/00	17.20	15.93	13.28	11.67
TomM	8/24/00	17.49	16.69	12.28	11.11
West	8/24/00	16.62	14.91	12.55	10.47

7-day period = 8/21/00 to 8/27/00

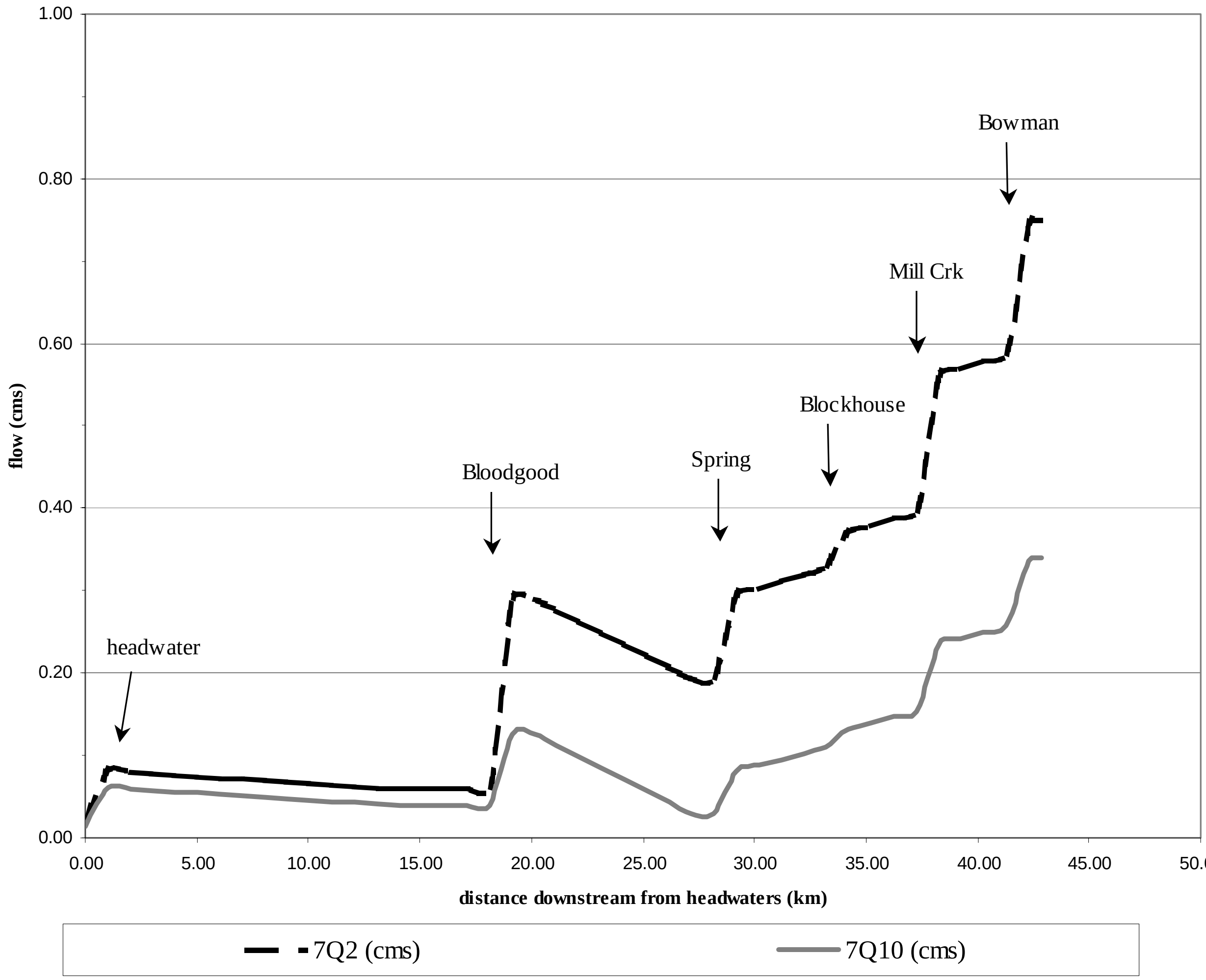


Figure 16. Flow profile for the Little Klickitat River.

- Hydraulic geometry (wetted width, depth, and velocity as a function of flow): Hydraulic geometry of the stream is used to simulate different flow conditions in the model (i.e., 7Q10 flows). Stream width at low flow was determined from Ecology field measurement data (Table 3). The Leopold power functions were used to extrapolate the hydraulic geometry to various river flow regimes. The coefficients for the Leopold power functions were calculated by setting the exponents equal to 0.26, 0.40, and 0.34 for width, depth, and velocity (Leopold, 1994). The first step was to calculate the Leopold coefficient for width. The Ecology width data represented the flow regime for the calibration period in July and August 2000. The Leopold coefficient for width was then determined with a Leopold exponent for width of 0.26. Next the Leopold coefficient for depth was determined with an exponent of 0.40. Finally, the velocity was calculated with the continuity equation (flow = width * depth * velocity), and the Leopold coefficient for velocity was determined using an exponent of 0.34. The values for Manning's n were selected during model calibration to provide the best fit of the model to the observed water temperatures during the calibration period of 7/29/2000 - 8/4/2000. The values of Manning's n that produced the best fit for prediction of water temperatures were n=0.5 to 1.2 for the Little Klickitat River, n=2.5 for West Prong, n=2.0 for Butler Creek, and n=2.0 for East Prong. The calibration values for Manning's n are slightly higher than the range of observed values. However, comparison of measured values of width, depth, velocity and flow with those predicted by the calibration Manning's n indicate that these are reasonable low-flow values for Manning's n.

- Groundwater temperature: As a first approximation, the temperature of groundwater is often assumed to be similar to the mean annual air temperature (Theurer et al., 1984). The mean annual air temperature at the Goldendale Airport weather station is approximately 9.4^{o}C. Regional potentiometric contour maps and well log data, from wells less than 200 feet deep, show groundwater temperatures that are typically 12 to 13^{o}C (Erickson, 2001). A groundwater inflow temperature of 12.5^{o}C was input into Qual2K for the Little Klickitat River.

- Air temperature, relative humidity, and cloud cover: The observed minimum and maximum air temperatures and relative humidity at the Goldendale Airport weather station were used to represent the conditions for the calibration and verification periods. Cloud cover data are not available from within the Little Klickitat watershed and were estimated from reported data at the National Weather Service station at The Dalles, Oregon.

Calibration and Verification of the QUAL2K Model

The hottest 7-day period of 2000, July 29 through August 4, was used for calibration of the QUAL2K model (Figures 17 and 18). The subsequent warmest 7-day period of August 2000, the 21st through 27th, was used for verification to test the model calibration (Figures 17 and 18). Comparison of model predictions for the Little Klickitat River under critical conditions (1998 weather data and 7Q10 low–flow conditions) to data collected by the Central Klickitat Conservation District and Yakama Nation Fisheries during 1998 (Figure 19) reveals strong correlation and suggests a robust and accurate model was selected.

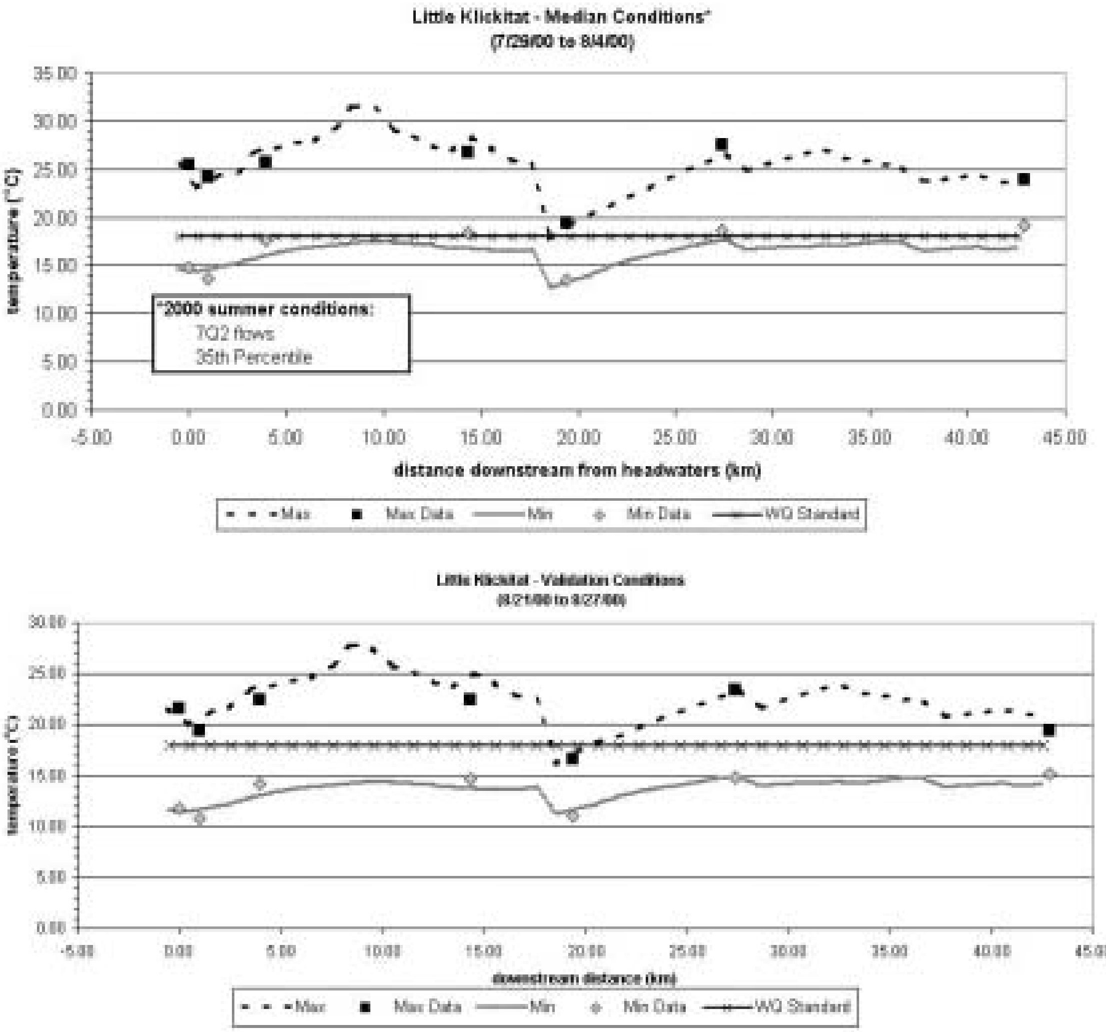


Figure 17. Comparison of predicted and measured temperatures for the calibration and verification periods for the Little Klickitat River.

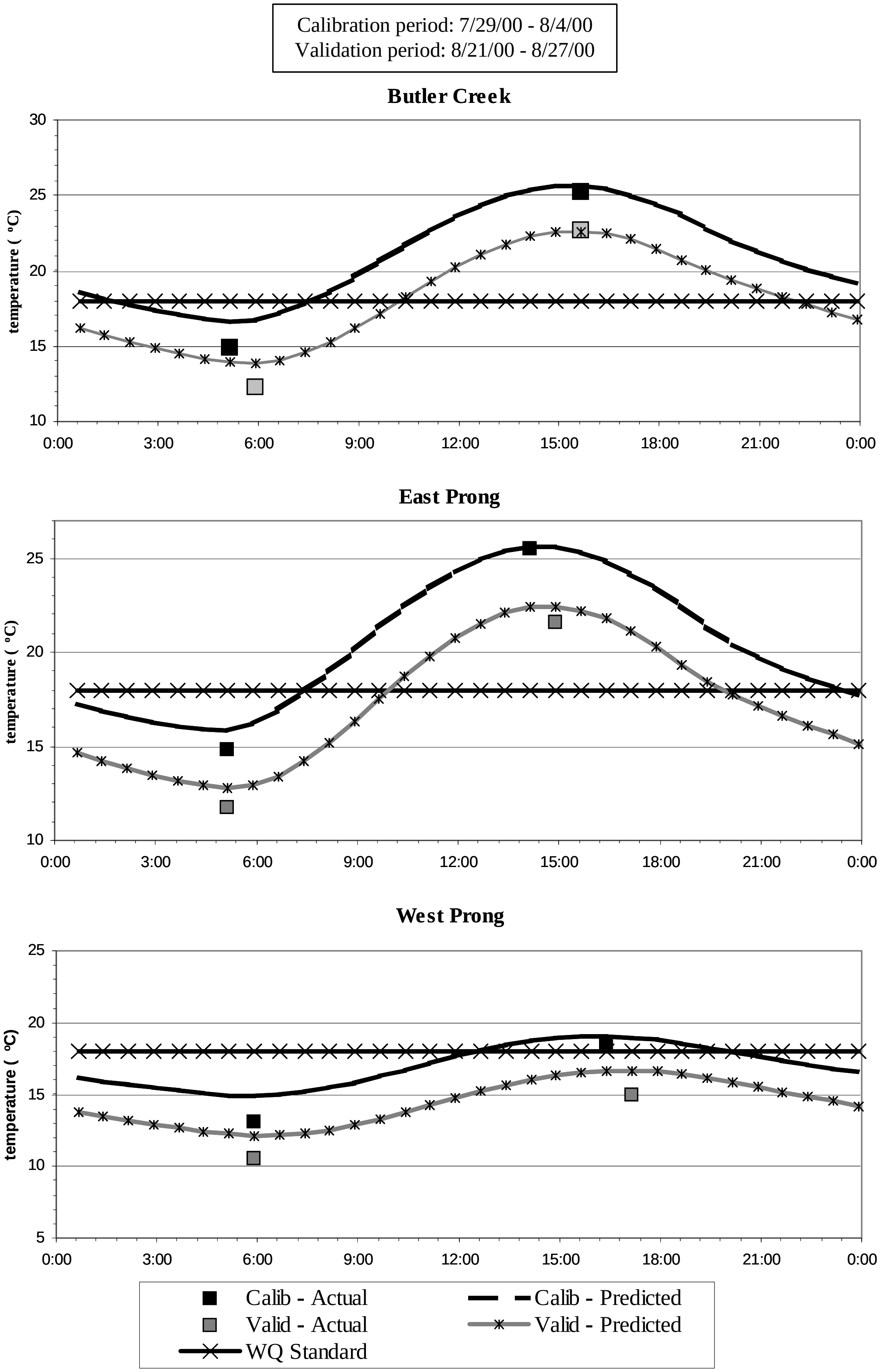


Figure 18. Comparison of predicted and measured temperatures for the calibration and verification periods for Butler Creek, East Prong, and West Prong.

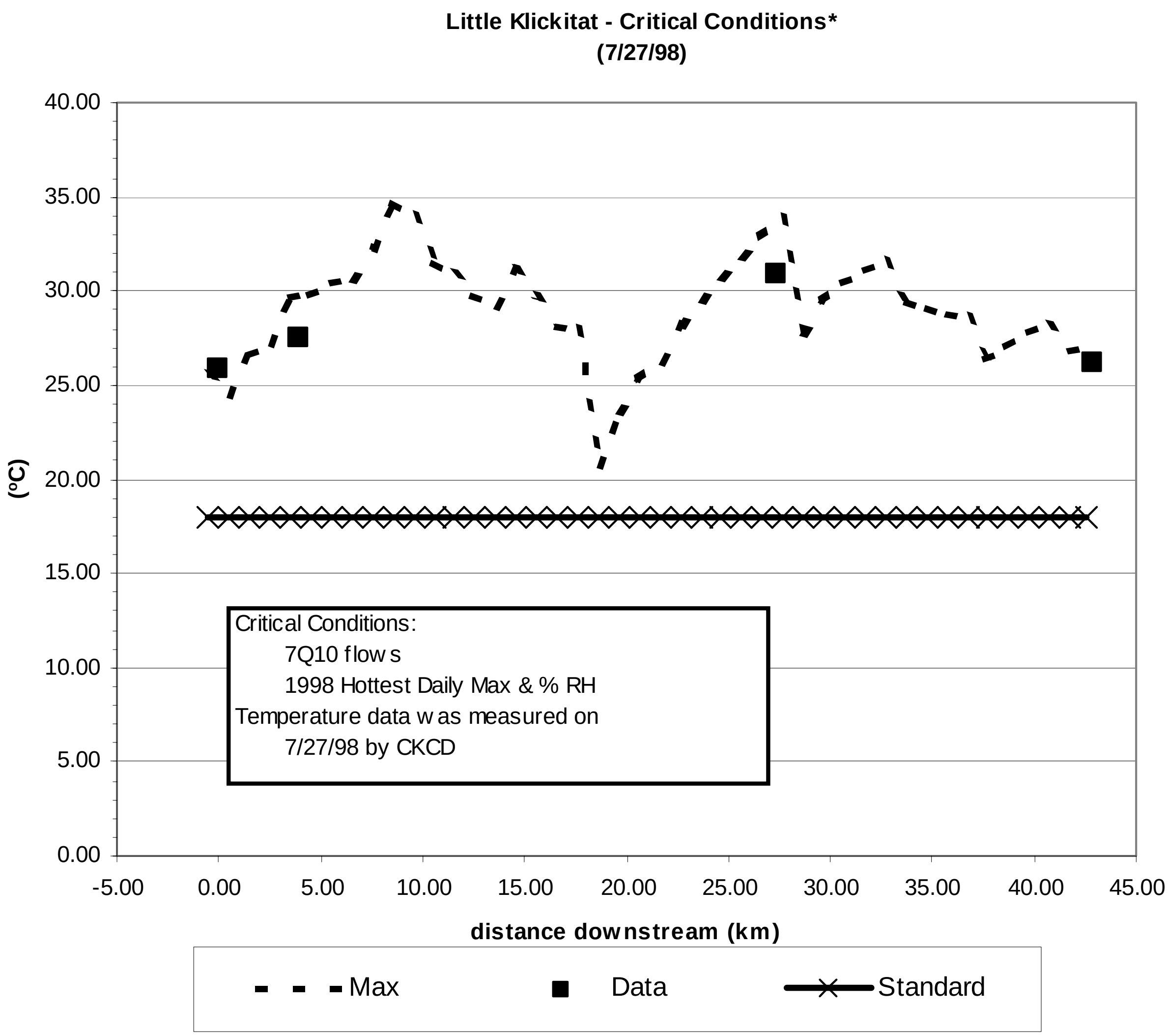


Figure 19. Comparison of predicted and measured temperatures in the Little Klickitat River during critical conditions.

The uncertainty of the predicted temperatures from the QUAL2K model was assessed by calculating the root mean squared error (RMSE) of the predicted versus observed temperatures. For the calibration period, the RMSE of the predicted versus observed daily maximum temperatures in the Little Klickitat River, Butler Creek, East Prong, and West Prong were 0.85, 0.36, 0.14, 0.33 degrees C. For the verification period, the RMSE of the predicted versus observed daily maximum temperatures in the Little Klickitat River, Butler Creek, East Prong, and West Prong predictions was 1.23, 0.22, 0.62, 1.25 degrees C. Table 8 displays the RMSE statistics and average temperature difference between predicted and observed minimum and maximum temperatures for the calibration and verification periods.

Table 8. Calibration and verification statistics.

	Calibration Period - 7/29 to 8/4/00					Validation Period - 8/21 to 8/27/00				
	Max Temp		Min Temp		Overall	Max Temp		Min Temp		Overall
	RMSE	Δ Ave	RMSE	Δ Ave	RMSE	RMSE	Δ Ave	RMSE	Δ Ave	RMSE
Little Klickitat	0.85	0.69	1.32	1.1	1.11	1.23	0.96	0.78	0.66	1.03
Butler Creek	0.36	0.25	1.28	0.91	0.94	0.22	0.15	1.12	0.79	0.81
East Prong	0.14	0.1	0.77	0.55	0.56	0.62	0.43	0.77	0.54	0.7
West Prong	0.33	0.24	1.34	0.94	0.97	1.25	0.88	1.21	0.85	1.23

Loading Capacity

The calibrated QUAL2K model was used to determine the loading capacity for effective shade for streams in the Little Klickitat watershed. Loading capacity was determined based on prediction of water temperatures under typical and extreme conditions of flow and climate, combined with a range of effective shade conditions.

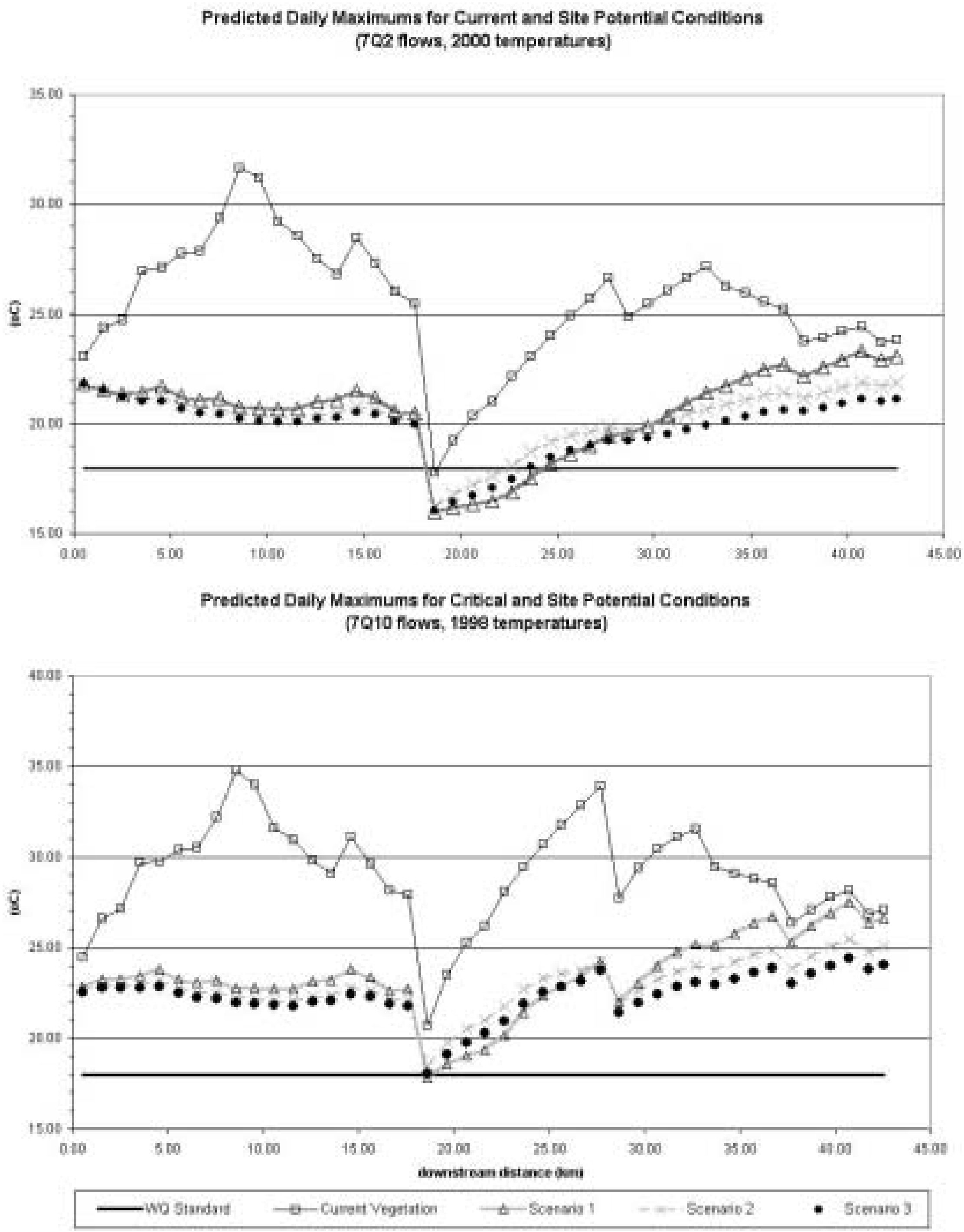
The 7Q2 low flow was selected to represent a typical climatic year, and the 7Q10 low flow was selected to represent a reasonable worst-case condition for the July-August period. Air temperatures and weather conditions for the 7Q2 condition were assumed to be the same as those observed on the hottest day of 2000, which was the 35th percentile condition from the historical record at the Goldendale Airport. The air temperatures and weather conditions for the 7Q10 condition were assumed equal to the hottest day of 1998, which is the hottest year of record.

The following scenarios for effective shade were evaluated for the 7Q2 and 7Q10 flow and climate conditions:

- Current vegetation from field data and sampled from the Washington Department of Fish and Wildlife (WDFW) and Department of Natural Resources (DNR) Priority Habitat and Species Digital database.
- Mature riparian vegetation defined in Table 5 as 160-foot buffers on each side of the stream, with a 20-foot near-stream zone of small dense deciduous vegetation and a 140-foot outer zone with variable tree height and density.
- Mature riparian vegetation (Table 5) and a channel wetted width-to-depth (W/D) ratio of 24. A W/D ratio of 24 corresponds to the average W/D measured during stream surveys throughout the Little Klickitat watershed.
- Mature riparian vegetation and a channel wetted W/D ratio of 16. Some stream segments in the Little Klickitat watershed may be able to reduce their W/D as a mature riparian corridor is established; therefore, a W/D ratio of 16 was modeled as a sensitivity analysis.

Little Klickitat River

Figure 20 shows the predicted water temperature in the Little Klickitat River for the lowest 7-day average flow during July-August, with a 2-year recurrence interval (7Q2) and a 10-year recurrence interval (7Q10). Figure 20 shows that an increase in effective shade from riparian vegetation buffers have the potential to significantly decrease the water temperatures in the mainstem of the Little Klickitat River. Additional riparian vegetation significantly attenuates the irregular thermal profile on the mainstem Little Klickitat and brings the portion of the Little Klickitat below Bloodgood Creek into compliance with the Class A water quality standard of 18^{o}C. Decreasing the channel average wetted W/D ratio decreases the water temperature further, with the exception of the section below Bloodgood Creek which has a low W/D ratio due to mechanical channelization.



Scenario 1:	**Scenario 2:**	**Scenario 3:**
NSDZ equals BFW	NSDZ equals BFW	NSDZ equals BFW
Mature Riparian Veg	Mature Riparian Veg	Mature Riparian Veg
	W/D equals 24	W/D equals 16

Figure 20. Predicted daily maximum temperature for Little Klickitat River under critical conditions.

Butler Creek

Figure 21 shows the predicted water temperature in Butler Creek for the 7Q2 and 7Q10 conditions. The same four riparian vegetation and morphology conditions were evaluated for Butler Creek as was done for Little Klickitat River. A mature riparian corridor does not bring the maximum temperature in compliance with the Class A water quality standard of $18^{o}C$; however, it does decrease the maximum daily temperature significantly during critical conditions. Figure 21 illustrates that added riparian shade decreases the difference between the daily maximum and minimum temperatures. This attenuation of the diurnal thermal range on Butler Creek is beneficial to salmonids and other fish species using the creek for refugia. Changing the W/D ratio to 24 or 16 actually increases the maximum temperature slightly, because the current W/D ratio is less than 24 or 16.

East Prong of the Little Klickitat River

Figure 22 shows the predicted water temperature in East Prong for the 7Q2 and 7Q10 conditions. Increases in effective shade from the vegetation buffers have the potential to significantly reduce water temperatures in the mainstem of East Prong. Again, added riparian shade decreases the difference between the daily maximum and minimum temperatures. This attenuation of the diurnal thermal range on East Prong is beneficial to salmonids and other fish species using the creek for refugia. Changing the W/D ratio to 24 or 16 actually increases the maximum temperature slightly, because the current W/D ratio is less than 24 or 16.

West Prong of the Little Klickitat River

Figure 23 shows the predicted water temperature in West Prong for the 7Q2 and 7Q10 conditions. Increases in effective shade from the vegetation buffers have the potential to decrease maximum water temperatures under critical conditions on the mainstem of West Prong. Added riparian shade decreases the difference between the daily maximum and minimum temperatures. This attenuation of the diurnal thermal range on West Prong is beneficial to salmonids and other fish species using the creek for refugia. Changing the channel W/D ratio decreases the temperature very slightly, because the current W/D ratio is between 16 and 24.

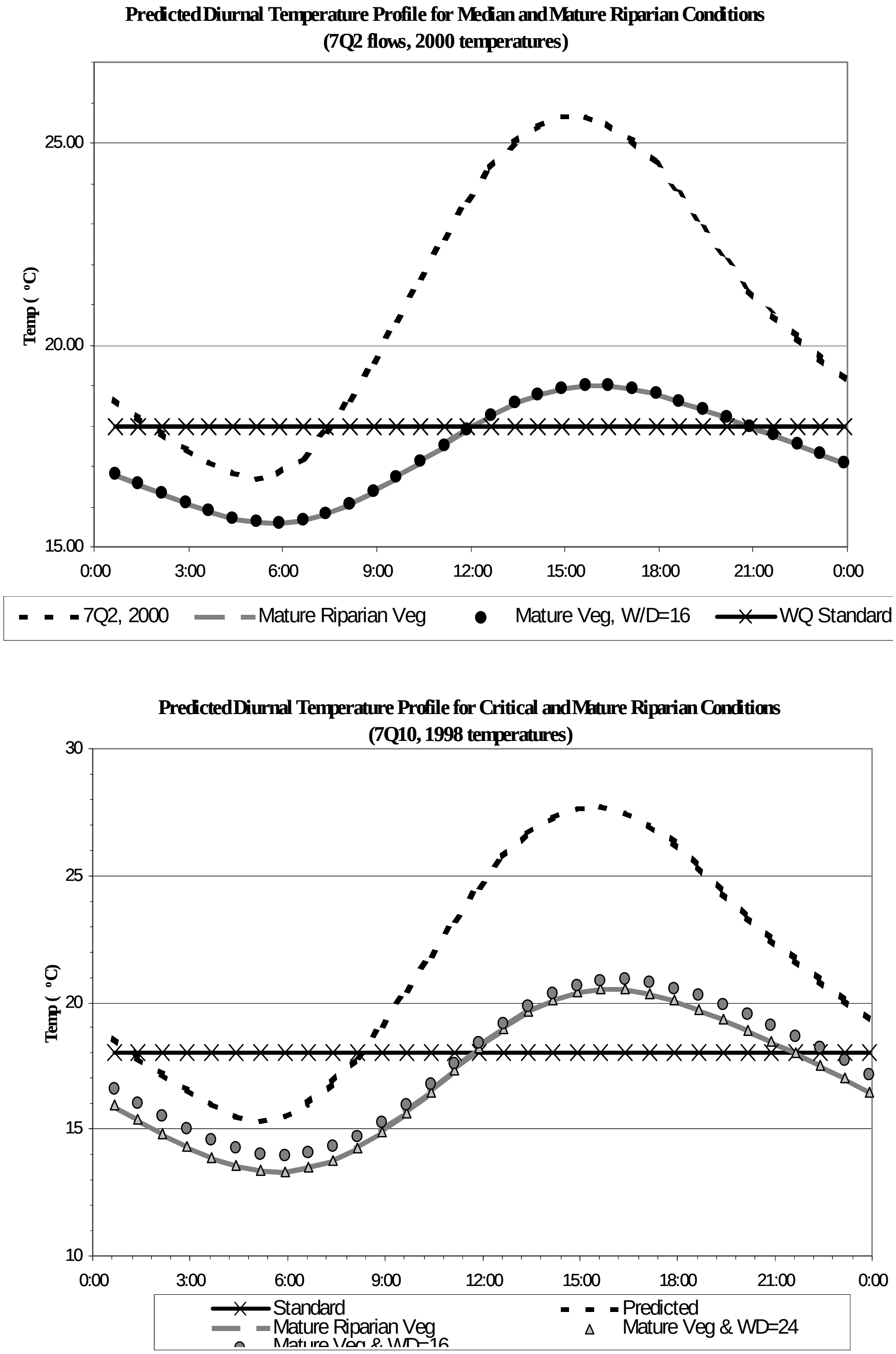
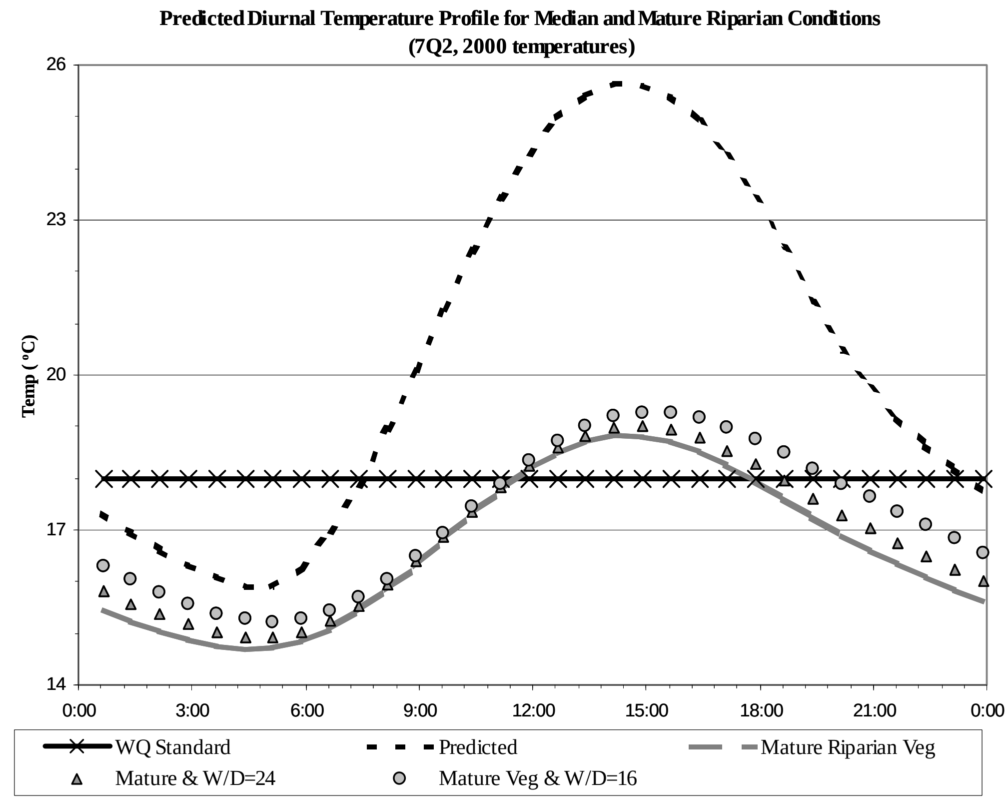


Figure 21. Predicted daily temperature for Butler Creek under critical conditions.



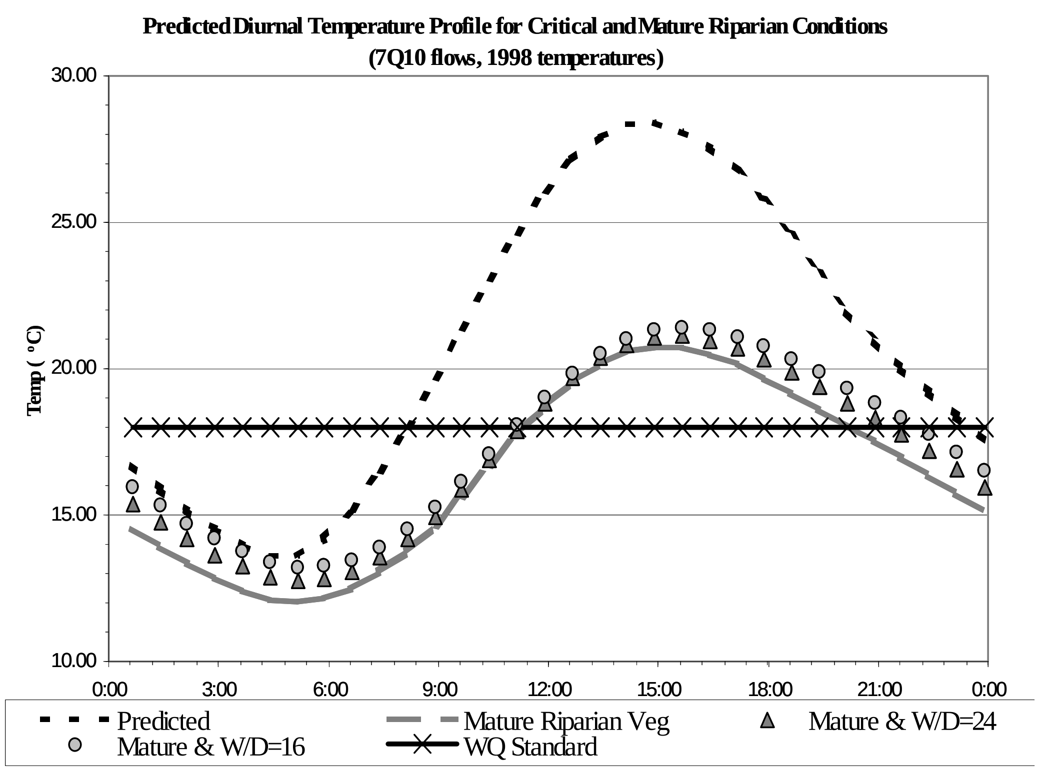
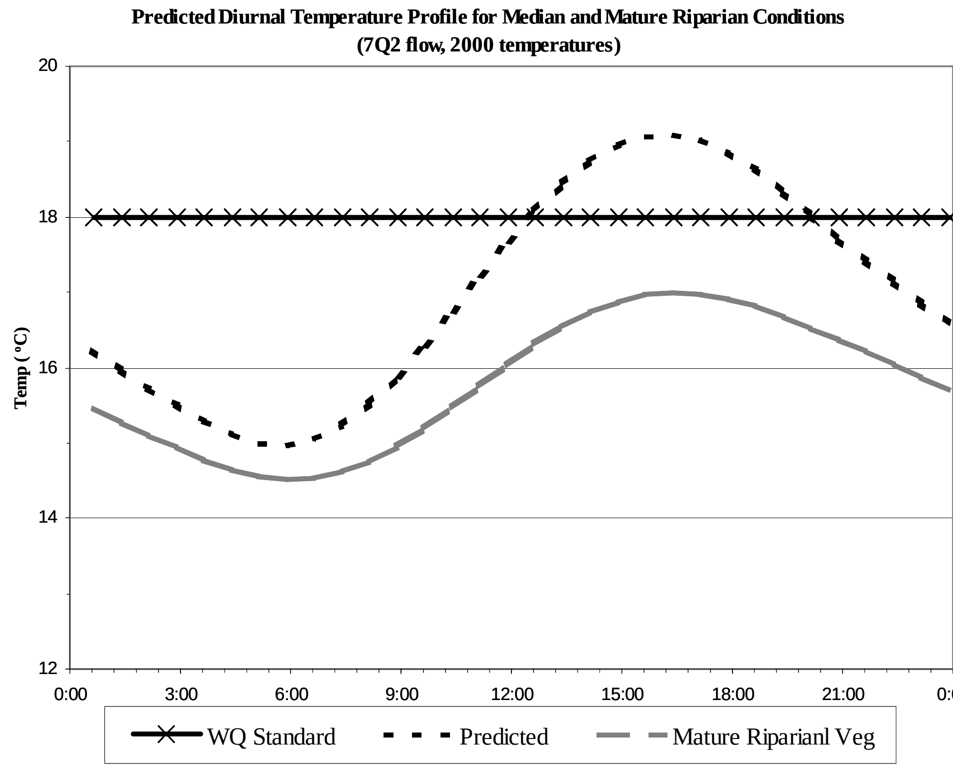


Figure 22. Predicted daily temperature for East Prong under critical conditions.



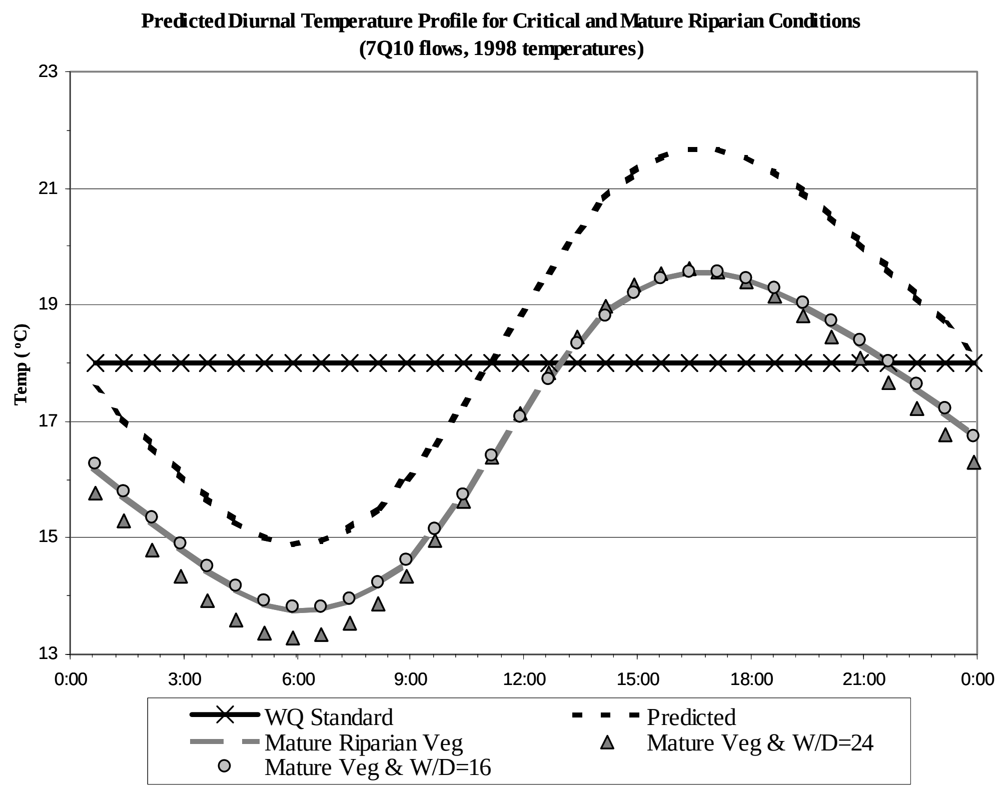


Figure 23. Predicted daily temperature for West Prong under critical conditions.

Estimated Solar Flux at Loading Capacity for Effective Shade

The loading capacity in terms of the flux of short-wave solar radiation to the water surface was estimated as the flux that would occur due to the effective shading from the recommended riparian vegetation condition (Figure 24, and Table 9 and 10). The loading capacity was translated into the solar flux that would occur under mature riparian vegetation (Table 5). The recommended load allocations for target effective shade are predicted to result in significant reductions on the flux of solar radiation to streams in the Little Klickitat watershed.

Table 9. Load capacity and load allocation for Butler Creek, East Prong, West Prong, and all unmodeled tributaries in the watershed.

			Load Allocation		
Tributary	Current Effective Shade (%)	Current Solar Load (ly/day)	Target Solar Load (ly/dy)	Required Solar Reduction (%)	Target Effective Shade (%)
Butler (mod)	55.0	284	111	44	95
East Prong (mod)	62.3	224	33	75	94
West Prong (mod)	77.5	36	12	50	93
Spring Creek	38.6				73
Blockhouse Creek	68.1				73
Mill Creek	59.2				73
Bowman Creek	50.7				73

(mod) indicates that the tributary was modeled using Q2K

Table 10. Load capacity and load allocation for the Little Klickitat River.

				Load Allocation		
Station	Distance downstream from headwater (km)	Current Effective Shade (%)	Current Solar Load (ly/day)	Target Solar Load (ly/dy)	Required Solar Reduction (%)	Target Effective Shade (%)
3Creeks	1.0	58.7	10274	5397	31	78
	2.0	54.4				79
	3.0	59.4				79
	4.0	34.9				76
	5.0	50.0				74
	6.0	43.7				81
	7.0	47.4				80
	8.1	33.5				79
	9.1	17.8				83
	10.1	37.2				82
	11.1	55.1				83
	12.1	51.5				83
	13.1	57.4				79
Rimrock	14.1	60.0	14413	5746	43	81
	15.1	42.1				77
	16.1	60.2				82
	17.1	66.6				86
	18.1	66.7				86
Tom Miller	19.1	46.4	20203	5894	55	82
	20.1	18.9				76
	21.1	24.8				78
	22.1	29.4				77
	23.1	20.4				75
	24.2	30.0				71
	25.2	30.0				72
	26.2	30.0				74
Olson	27.2	30.0	17432	6577	45	76
	28.2	30.0				74
	29.2	30.0				71
	30.2	30.0				66
	31.2	30.0				63
	32.2	30.0				62
	33.2	30.0				62
	34.2	50.8				62
	35.2	50.7				59
	36.2	55.9				61
	37.2	58.0				62
	38.2	56.0				60
	39.3	52.3				54
	40.3	48.0				53
	41.3	51.1				52
	42.3	49.7				51
Mouth	42.9	48.1	12930	12451	2	50

Load Allocations

The load allocations for effective shade for the Little Klickitat River, Butler Creek, East Prong, and West Prong are presented in Table 9 and 10. The solar flux estimated at the load allocations for effective shade is presented in Figure 24. In general, the load allocations for effective shade are as follows:

- For the entire Little Klickitat watershed, including Butler Creek, East Prong, and West Prong, 95 to 50% effective shade produced by a mature riparian corridor is the load allocation for shade from riparian vegetation.

- For portions of the Little Klickitat River and West Prong, additional temperature reduction may be possible through reduction of the wetted width-to-depth (W/D) ratio. A Level I1 Rosgen Channel classification indicated that the mainstem Little Klickitat is a Class C and has an average wetted W/D ratio of 28. As mature riparian vegetation is established, reduction of the current wetted W/D ratio may occur on portions of the Little Klickitat.

- For all perennial streams in the Little Klickitat watershed that were not specifically modeled, including Bowman, Mill, Spring, and Blockhouse creeks, and that exceeded the water quality standard during critical and median conditions (Figures 6 and 7), 73% effective shade produced by mature riparian vegetation is the load allocation. An effective shade of 73% is the average load allocation for all modeled segments on the Little Klickitat, West Prong, East Prong, and Butler Creek; therefore, all unmodeled tributaries were assigned an effective shade load allocation of 73%. Additionally, Bloodgood Creek, which does not exceed water quality standards, provides the only source of cooling water to the Little Klickitat River, and efforts should be made to preserve and protect the cooling influence of the waters from Bloodgood Creek.

In addition to the load allocations for effective shade, the following management activities are recommended by the Central Klickitat Conservation District in the Little Klickitat River Draft Watershed Management Plan (Clayton, 1999) for attainment and maintenance of temperature reductions in the watershed:

- Encourage conversion to more efficient irrigation systems, such as drip systems, wherever practical.

- Place and secure large logs in streams to increase spawning habitat and increase survival of juvenile fish.

- Repair eroded streambanks by re-shaping and re-vegetating them.

- Develop farm plans that would address water quality issues.

- Recommend no-till farming to help reduce runoff rates during rapid spring snow melting or during periods of heavy precipitation. More natural or controlled runoff would result in less scouring of stream channels.

- Construct fencing, where necessary, to protect riparian vegetation.

- Through proposed or current restoration projects, protect riparian vegetation or stream bank erosion, including root wads for bank stabilization and removal of fish barriers such as improperly installed culverts.

- Develop off-channel water sources for grazing animals.

- Construct retention ponds to collect and retain sediment, and provide watering opportunities for livestock.

- Abandon non-essential roads within 60 feet of streams by ripping and re-vegetation. Abandonment and treatment of non-essential roads will occur at a rate of 25% of the road distance identified for abandonment per year (approximately 2.5 miles per year). Additionally, no new roads will be constructed within 100 feet of fish bearing streams, except for approved crossings (Raines et al., 1999).

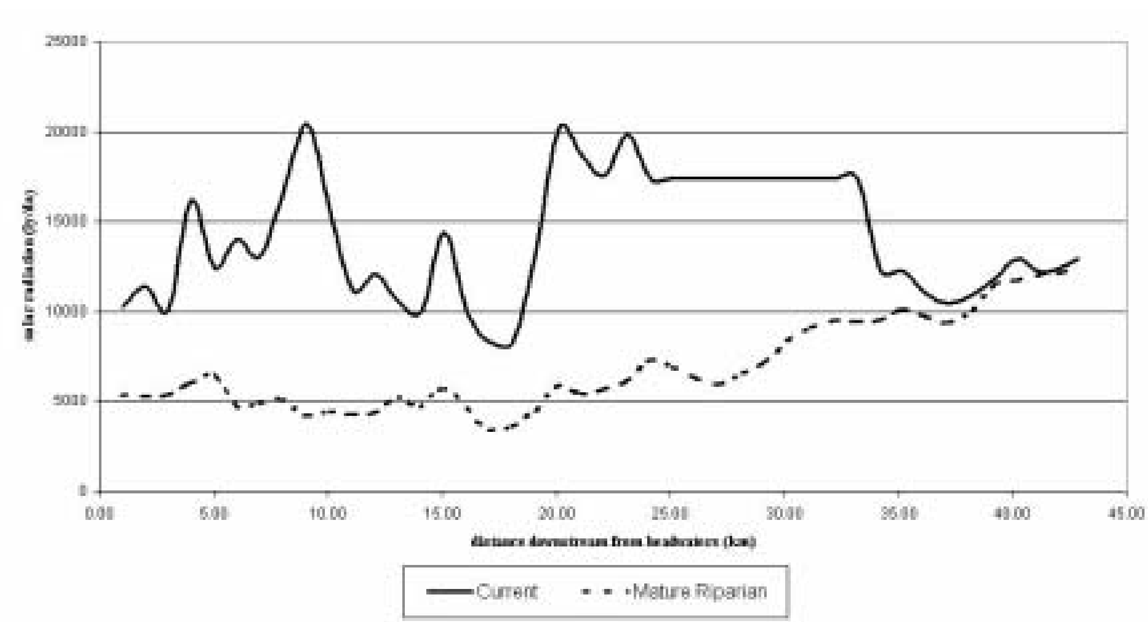


Figure 24. Solar radiation load allocation for Little Klickitat River.

Wasteload Allocations

Goldendale Wastewater Treatment Plant

The Goldendale Wastewater Treatment Plant (WWTP) is the sole point source in the Little Klickitat basin. The NPDES permit, filed in the 1970s, authorized discharge to the mainstem Little Klickitat River during November through May only. During June through October the effluent is stored in ponds or spray irrigated on nearby fields. In 1999, the city of Goldendale initiated the process to upgrade the plant with a cascade-pool cooling system in order to discharge during the summer low-flow months.

The water quality standard states, "no temperature increase will be allowed which raises the receiving water temperature greater than 0.3^{o}C." These rules govern the wasteload allocation for the Goldendale WWTP.

Upstream of the Goldendale WWTP discharge, which occurs at RM 14.1 (20.2 kilometers from the headwaters), Bloodgood Creek enters the system and lowers the Little Klickitat temperature significantly. Additional effective shade in this section will bring the water temperature into compliance with the Class A water quality standard of 18^{o}C (Figure 20).

Because the best estimate of background temperature after nonpoint controls are in place is 18.0^{o}C, the Water Quality Standard stipulates that the wasteload allocation for the Goldendale WWTP is 18.3^{o}C (Table 11). No mixing zone analysis was performed because there is no dilution available. The wasteload allocation is 18.3ºC at the point of discharge. If, at a future time, dilution becomes available the actual temperature of the effluent could be higher, but should not cause greater than 0.3 degree increase over system potential temperature at the edge of the mixing zone.

Table 11. Wasteload allocation for Goldendale Wastewater Treatment Plant.

				Wasteload Allocation		
Receiving Waterbody, RM	7Q10 Low Flow (cfs)	Facility Design Flow	System Potential Temperature	Current Effluent Temperature	Allowable Temperature Change at Edge of Mixing Zone	Allowable Effluent Temperature (ºC)
Little Klickitat, RM 14.0	4.48	0.774	18	n/a	0.3	18.3

Bloodgood Creek and Goldendale Energy Plant

The city of Goldendale owns limited municipal water rights on Bloodgood Creek. Bloodgood Creek is the primary source of cold, constant flow to the Little Klickitat River. Figure 20 shows that as Bloodgood Creek enters the system at RM 14.8 (19.5 kilometers from the headwaters) the Little Klickitat temperature drops significantly. An impact analysis, which used a simple mixing equation, illustrates that as flow is removed from Bloodgood Creek the temperature of the Little Klickitat increases exponentially (Figure 25). Water resources on the Bloodgood system should be managed to lessen the impact on the Little Klickitat River.

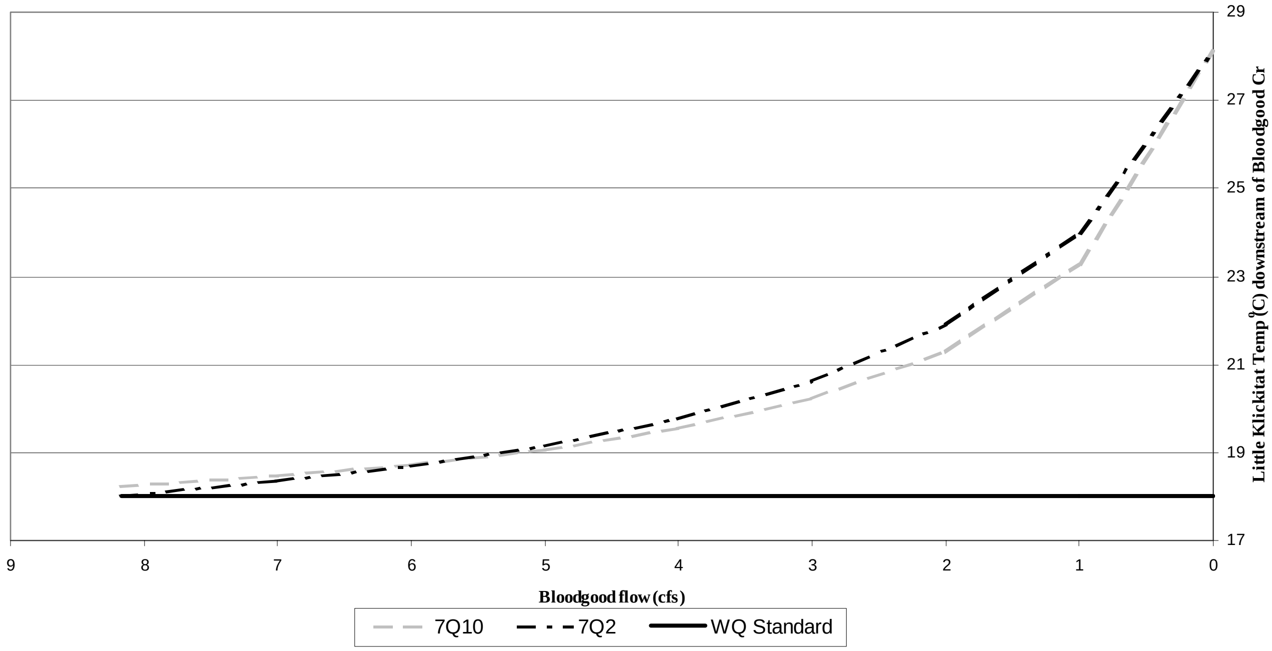


Figure 25. Water withdrawal impact analysis for Bloodgood Creek

In anticipation of future water demands, the city of Goldendale recently bought water rights on Swale Creek. These water rights include water to supply a newly constructed Energy Plant in Goldendale's Industrial Park.

Margin of Safety

A margin of safety must be identified to account for uncertainty when establishing a Total Maximum Daily Load (TMDL). The margin of safety can be explicit in the form of an allocation, or implicit in the use of conservative assumptions in the analysis. Several assumptions and critical conditions used in the modeling analysis of the Little Klickitat Temperature TMDL provide an inherent margin of safety over uncertainty as required by the statute. In this TMDL, the margin of safety is addressed by using critical climatic conditions in the modeling analysis. Conservative assumptions for critical conditions include the following:

- Climatic conditions measured during 1998, the hottest year of record at the Goldendale Airport weather station, were used to represent reasonable worst-case conditions.
- Cloud cover of 0% was used to model maximum solar load available.
- 7Q10 flow conditions were used to represent reasonable worst-case conditions in this analysis. Typical conditions were evaluated using 7Q2 flow conditions.
- Boundary and tributary water temperatures were held constant in the loading capacity and load allocation analysis.

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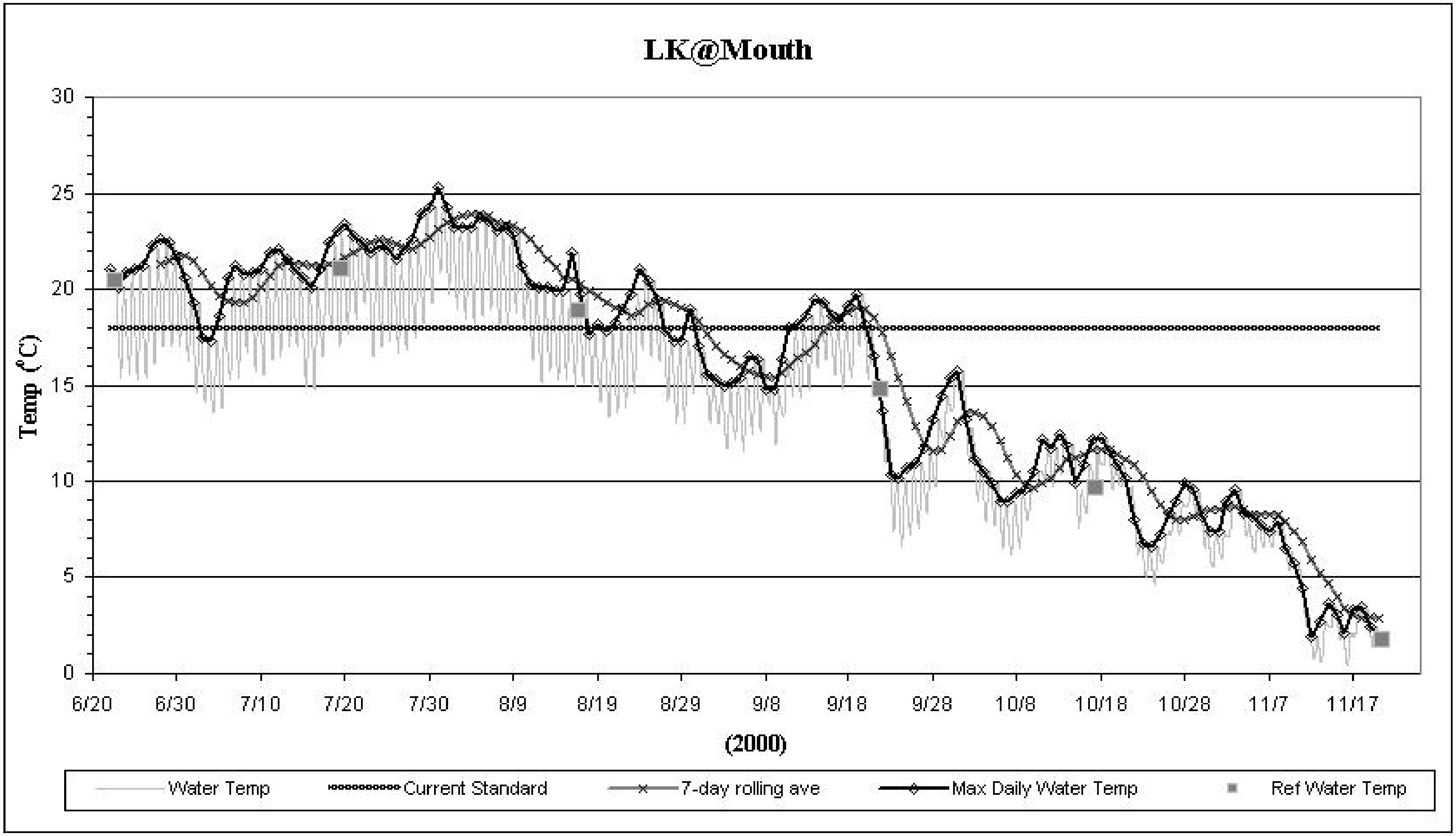
Appendices

Appendix A

Graphical representation of air and water temperatures collected during summer 2000

The following diagrams illustrate graphical representation of air and water temperature data collected by Ecology, the Central Klickitat Conservation District, and the Yakama Nation Fisheries in the Little Klickitat watershed during summer 2000.

Figure A1. Water temperature data for Little Klickitat at mouth.



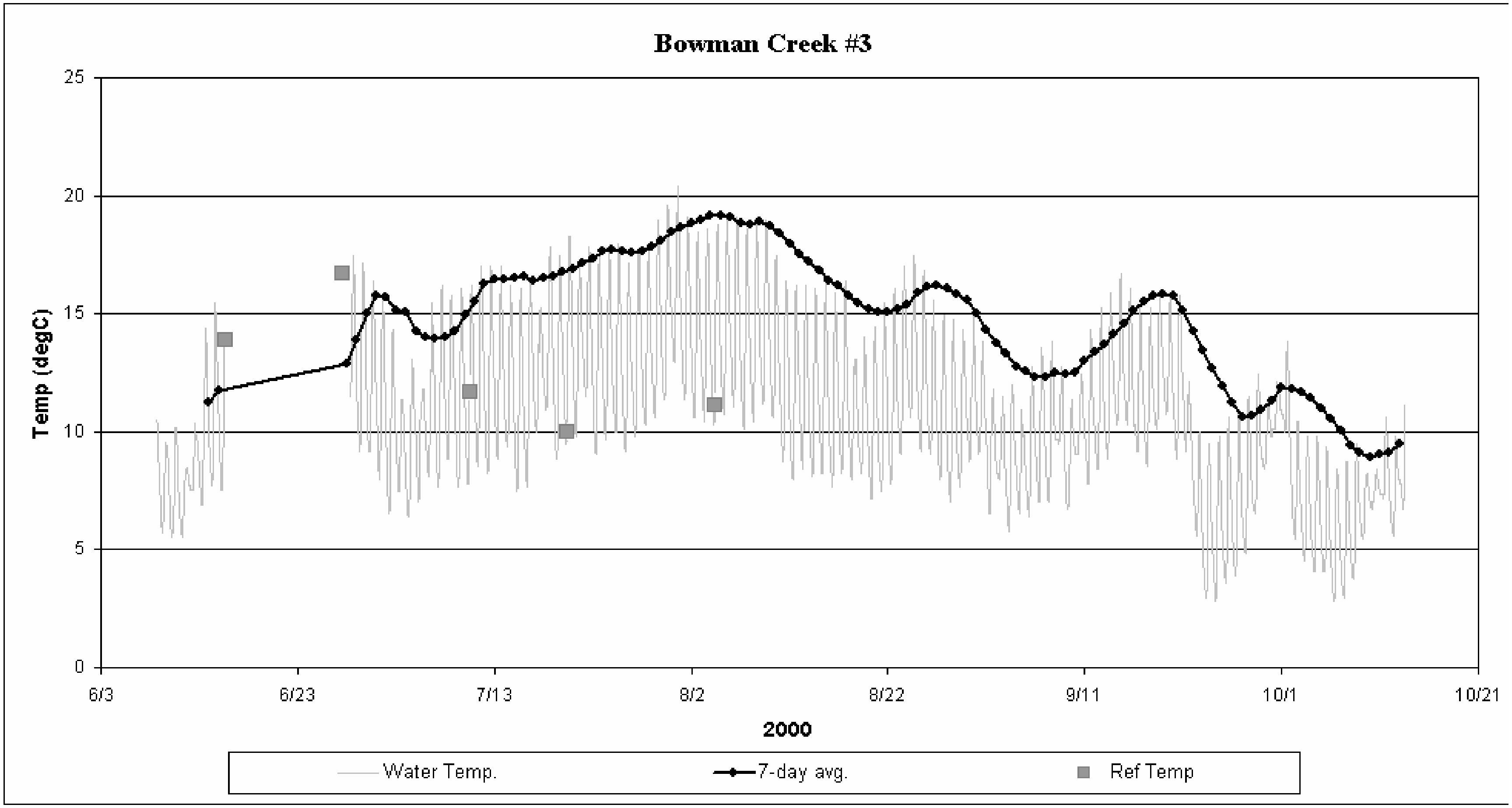


Figure A2. Water temperature data for Bowman Creek at headwaters.

Figure A3. Water temperature data for Bowman Creek at Zelinski Road.

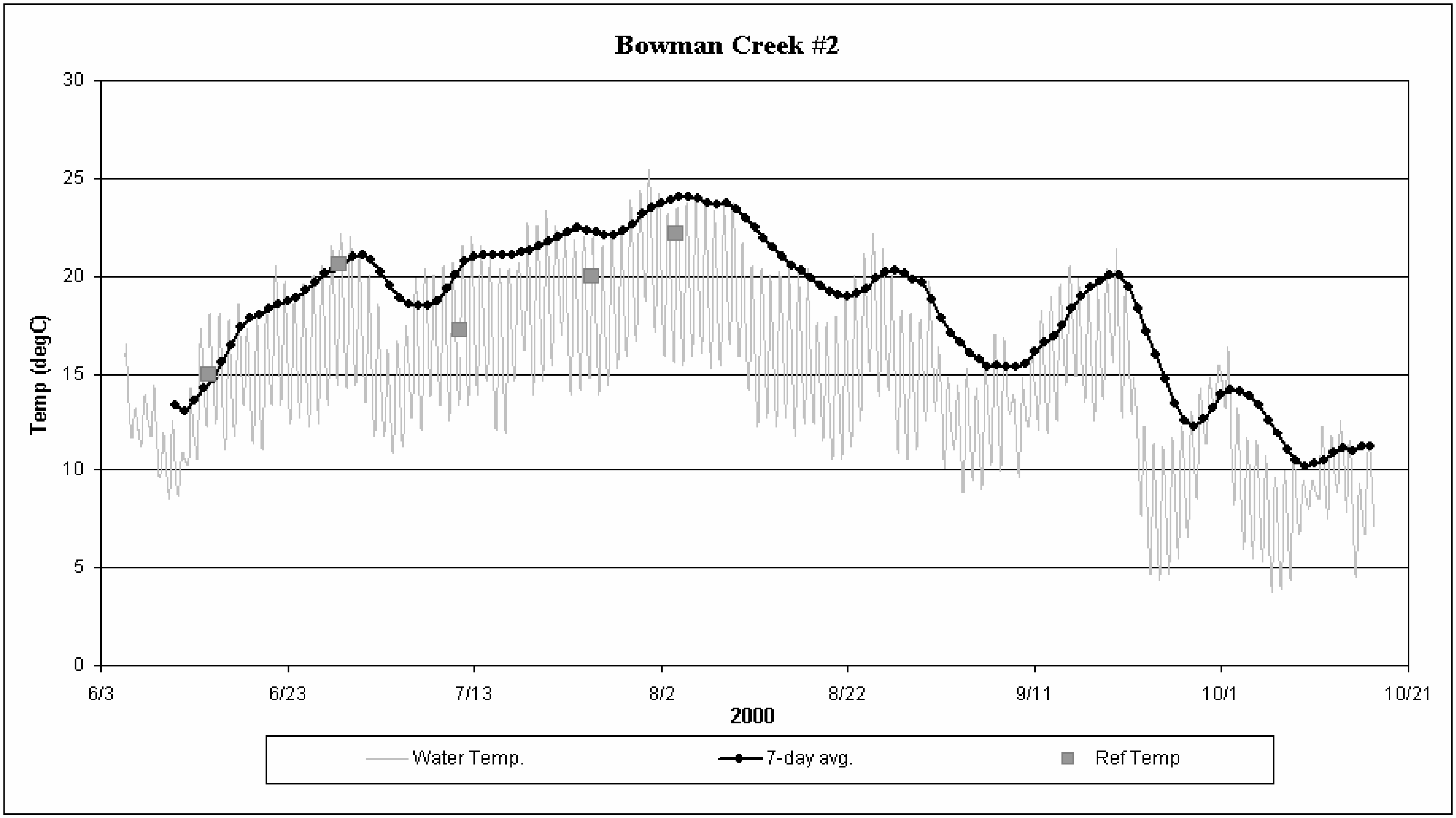


Figure A4. Water temperature data for Bowman Creek at mouth.

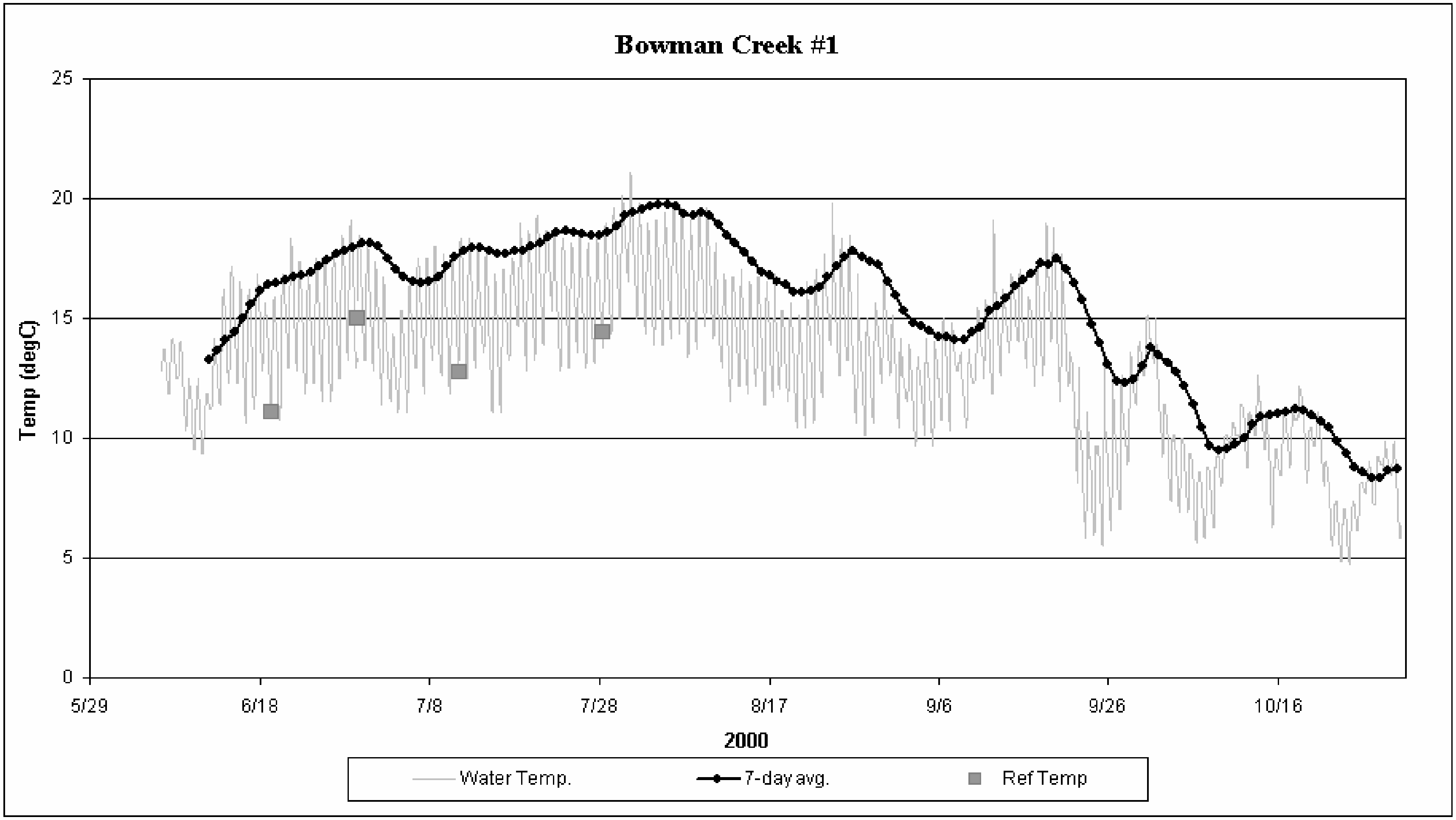
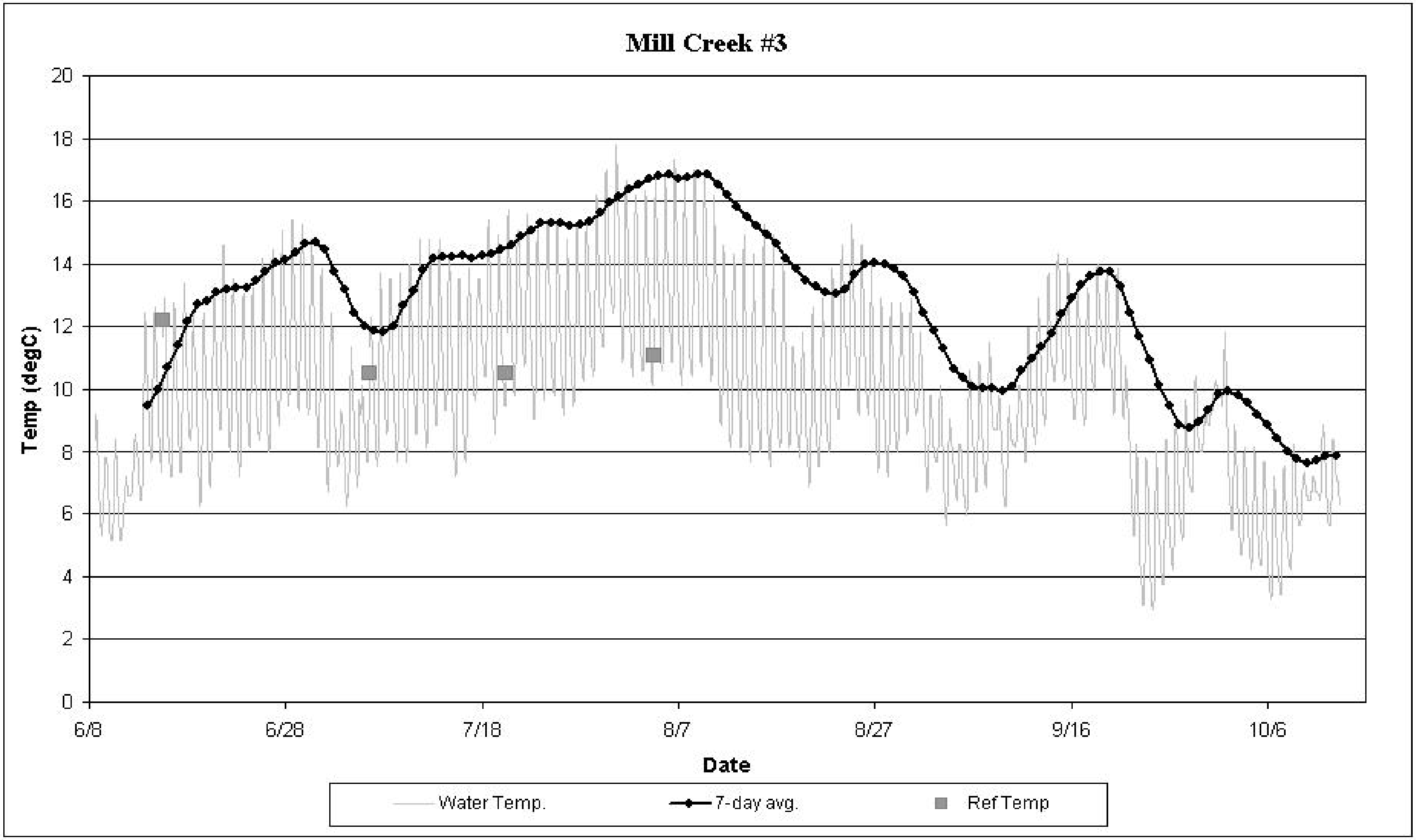


Figure A5. Water temperature data for Mill Creek at headwater site.



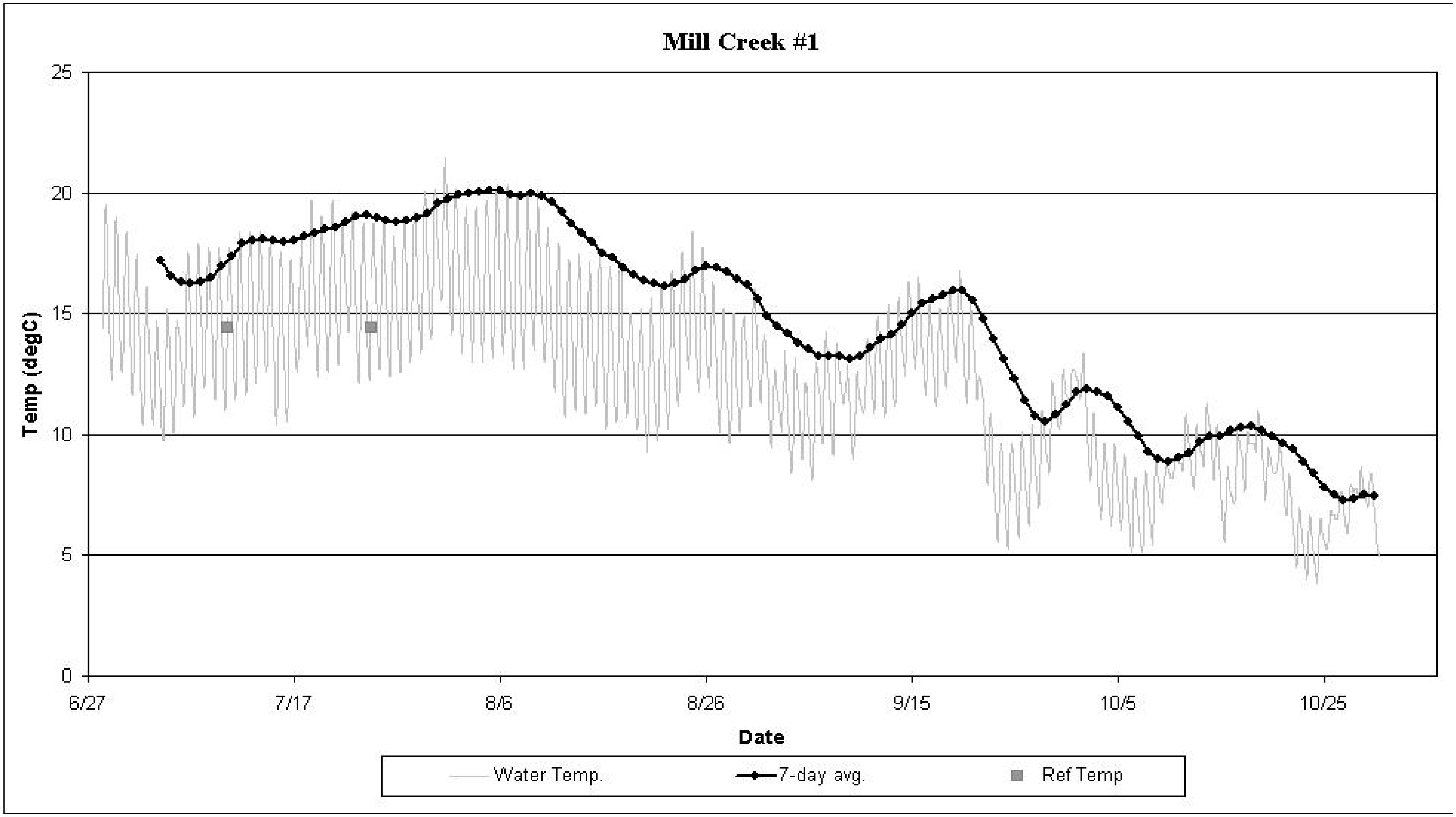


Figure A6. Water temperature data for Mill Creek at mouth.

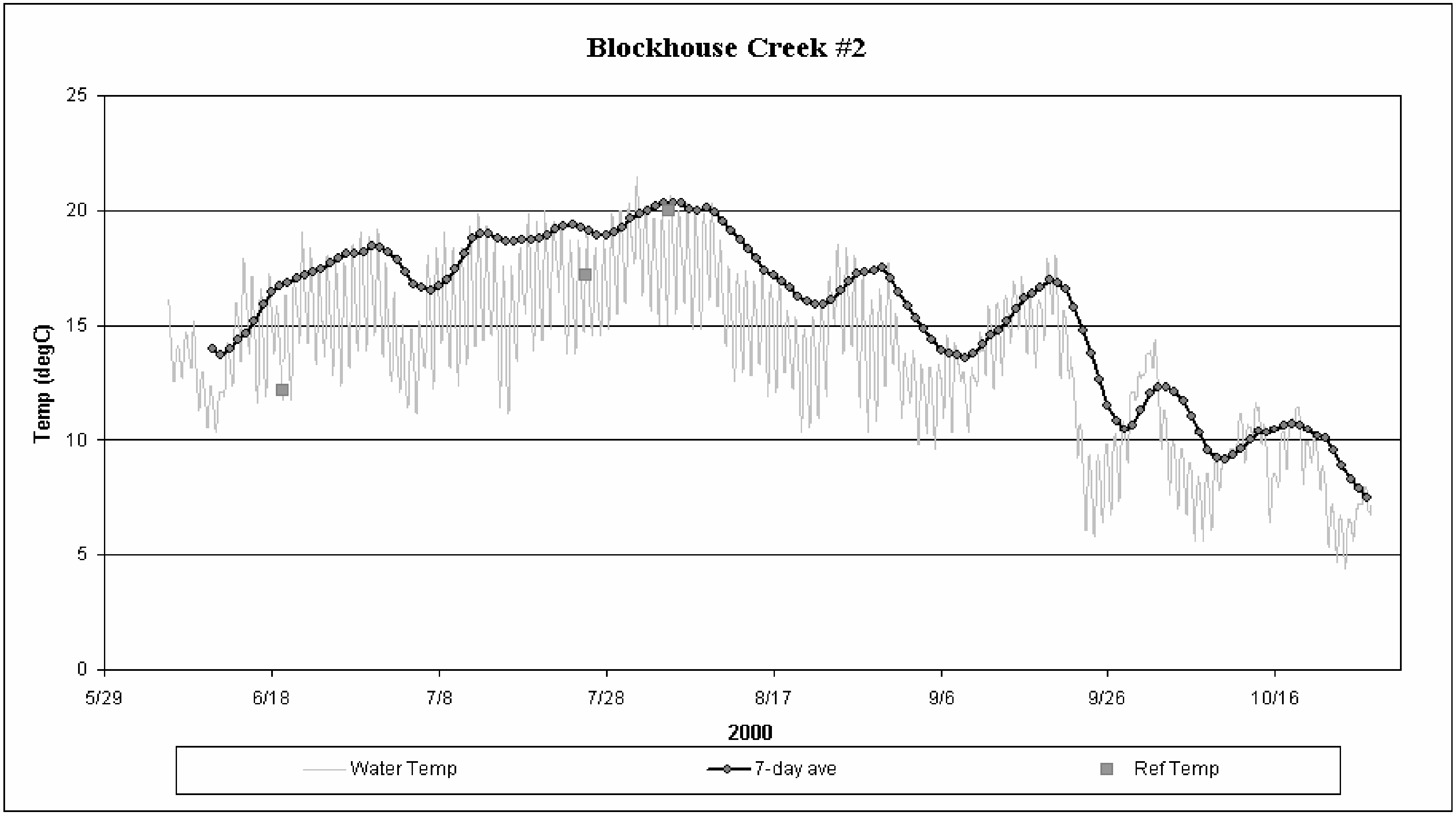
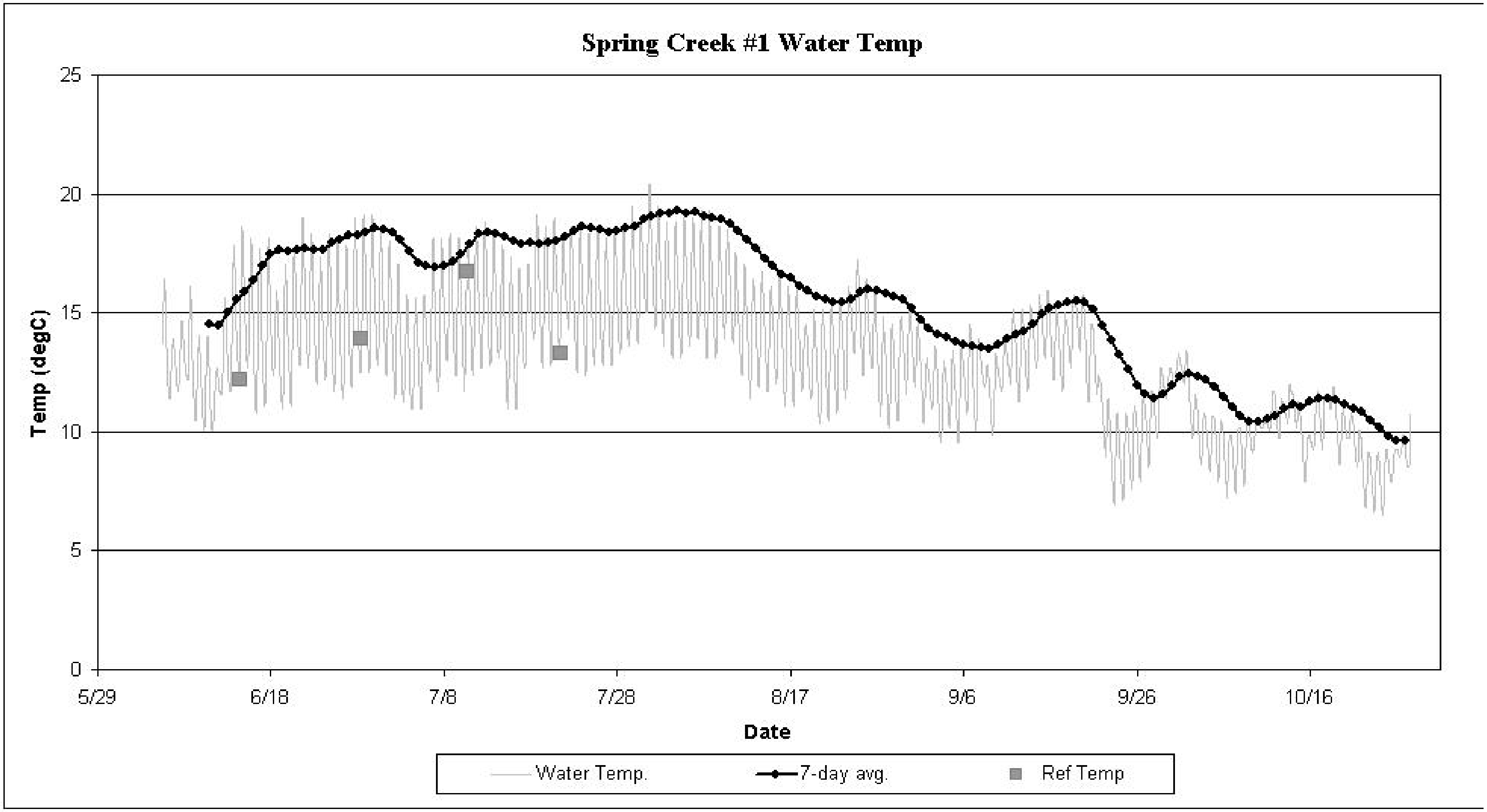


Figure A7. Water temperature data for Blockhouse Creek.

Figure A8. Water temperature data for Spring Creek.



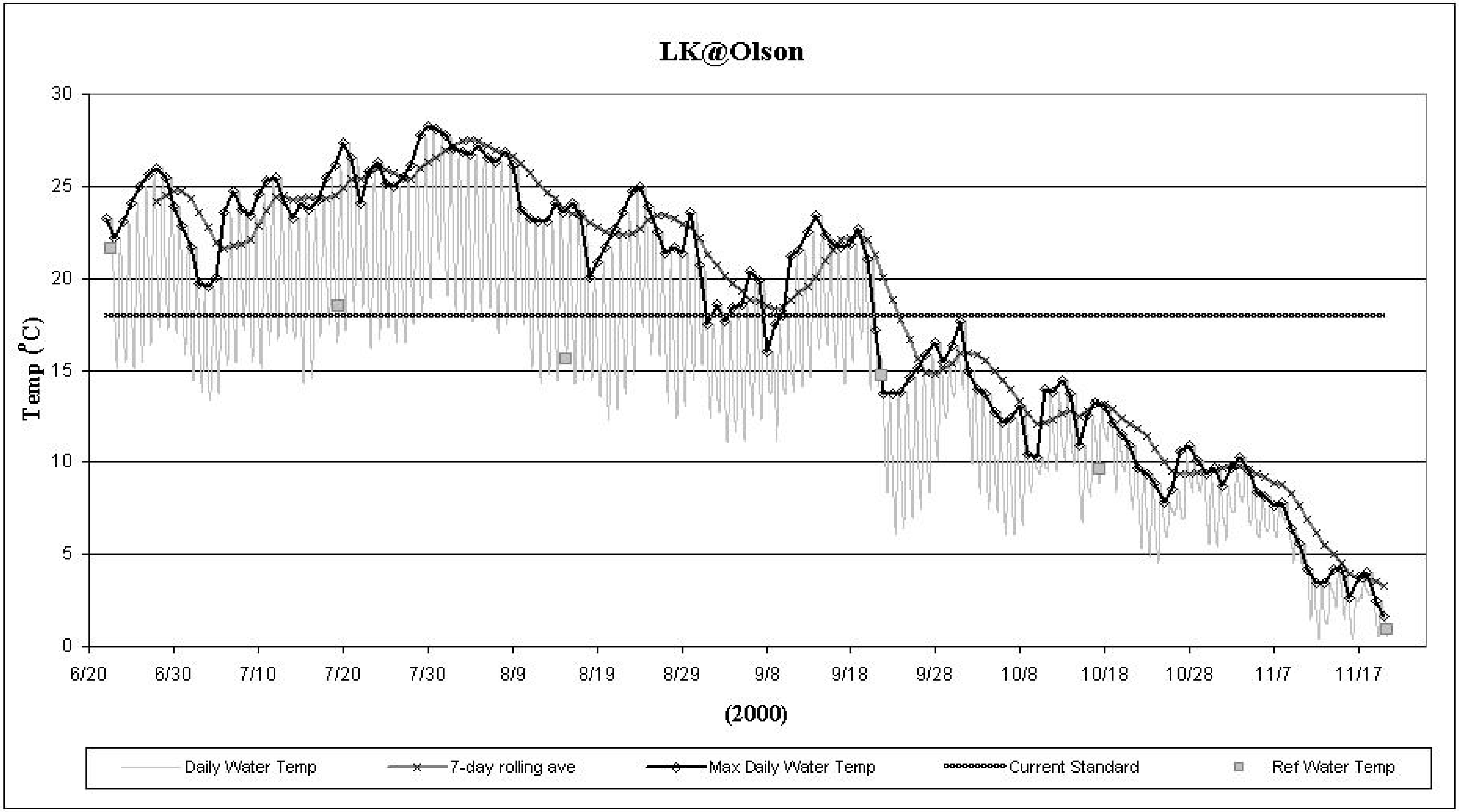


Figure A9. Water temperature data for Little Klickitat at Olson Road.

Figure A10. Water temperature data for Little Klickitat at Tom Miller Road..

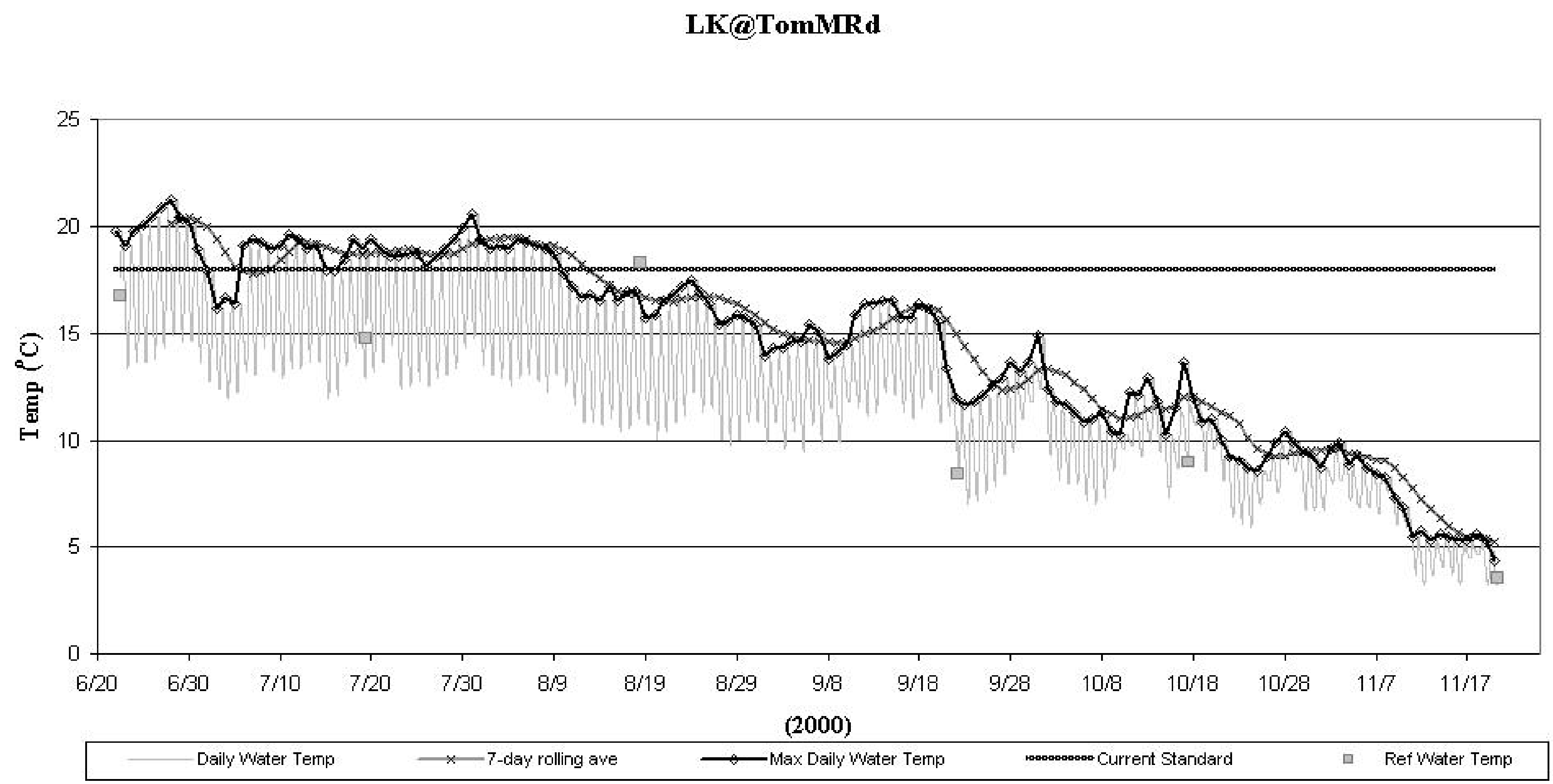
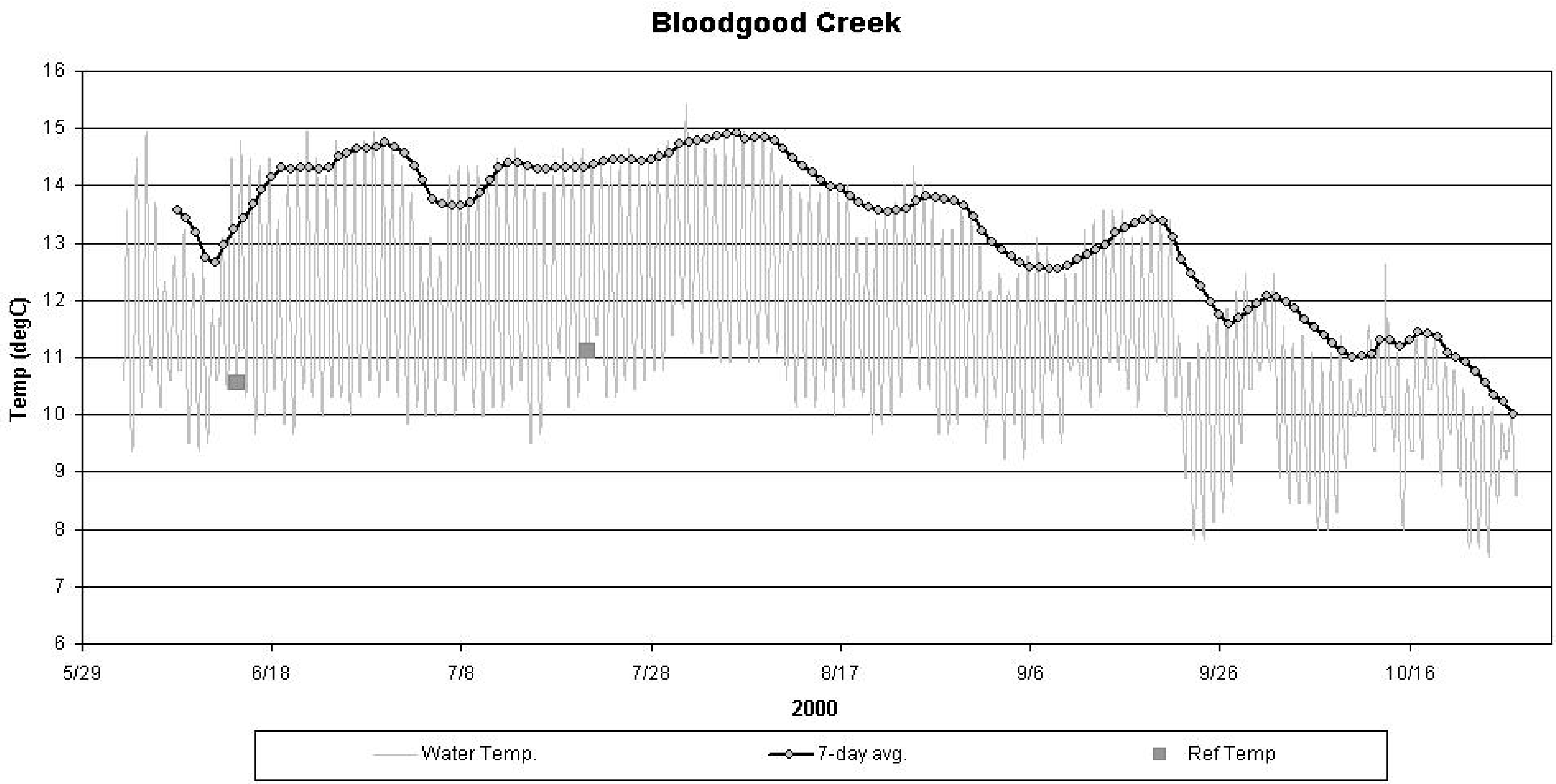


Figure A11. Water temperature data for Bloodgood Creek.



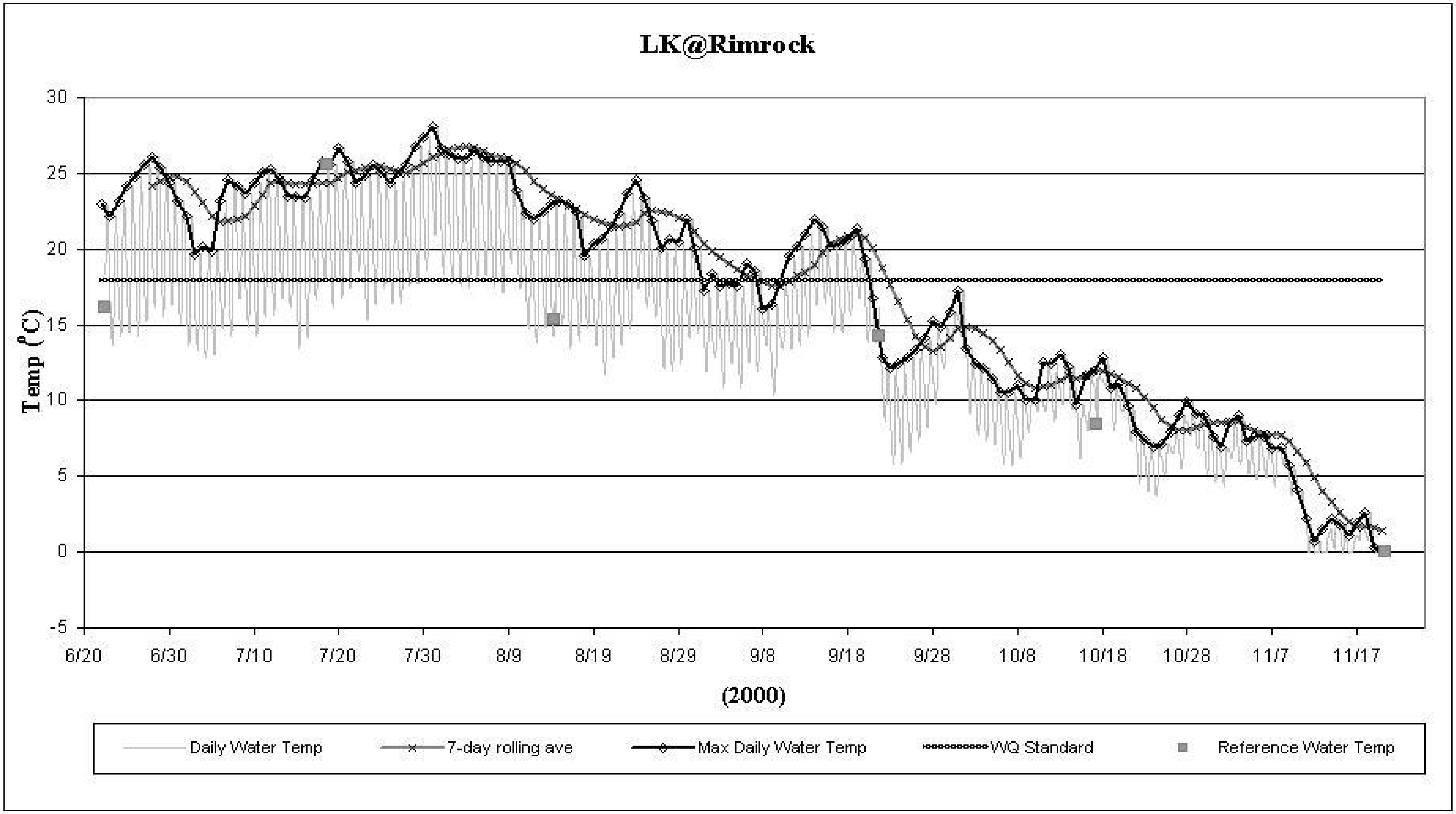


Figure A12. Water temperature data for Little Klickitat at Rimrock Road.

Figure A13. Water temperature data for Little Klickitat, station #8.

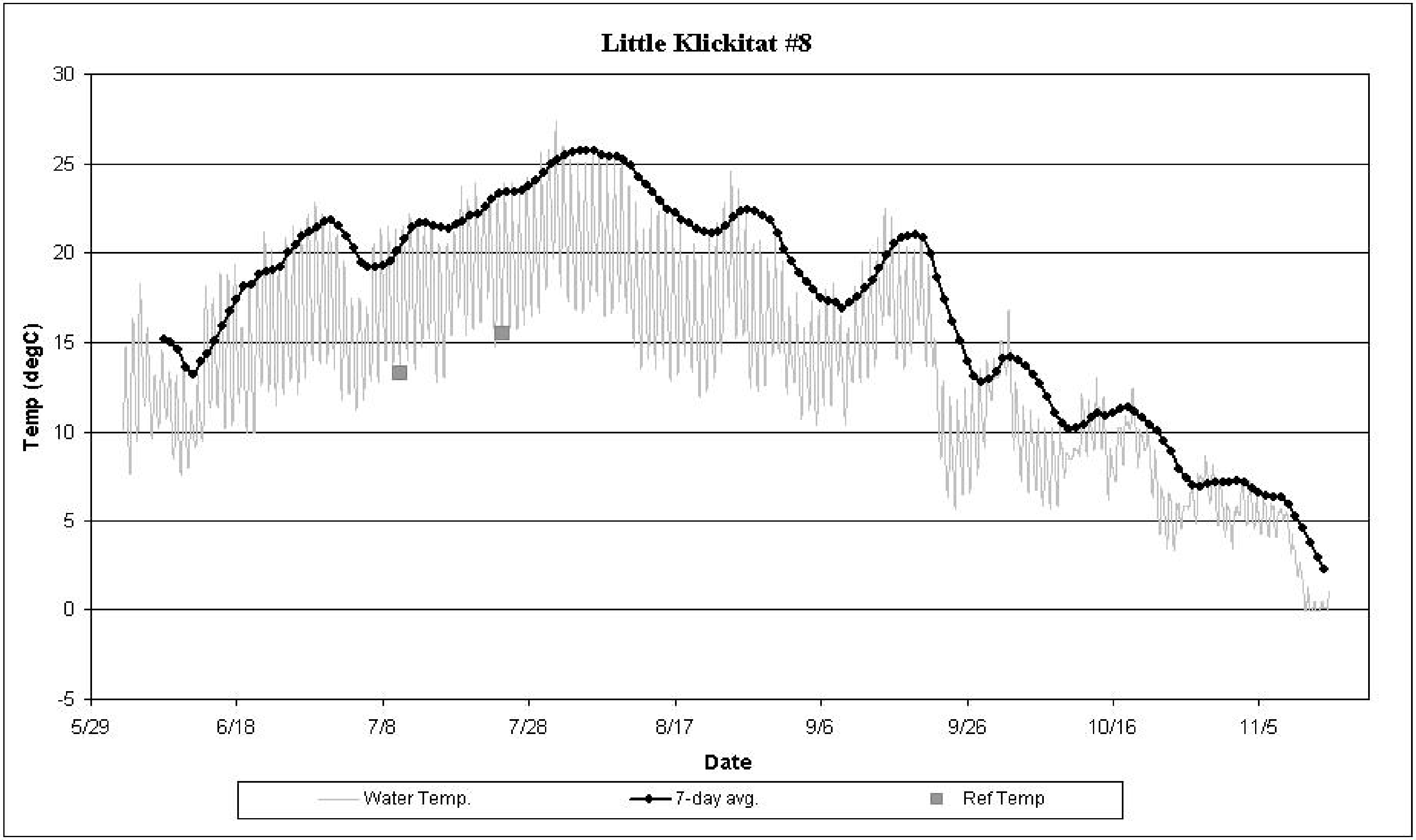


Figure A14. Water temperature data for Butler Creek.

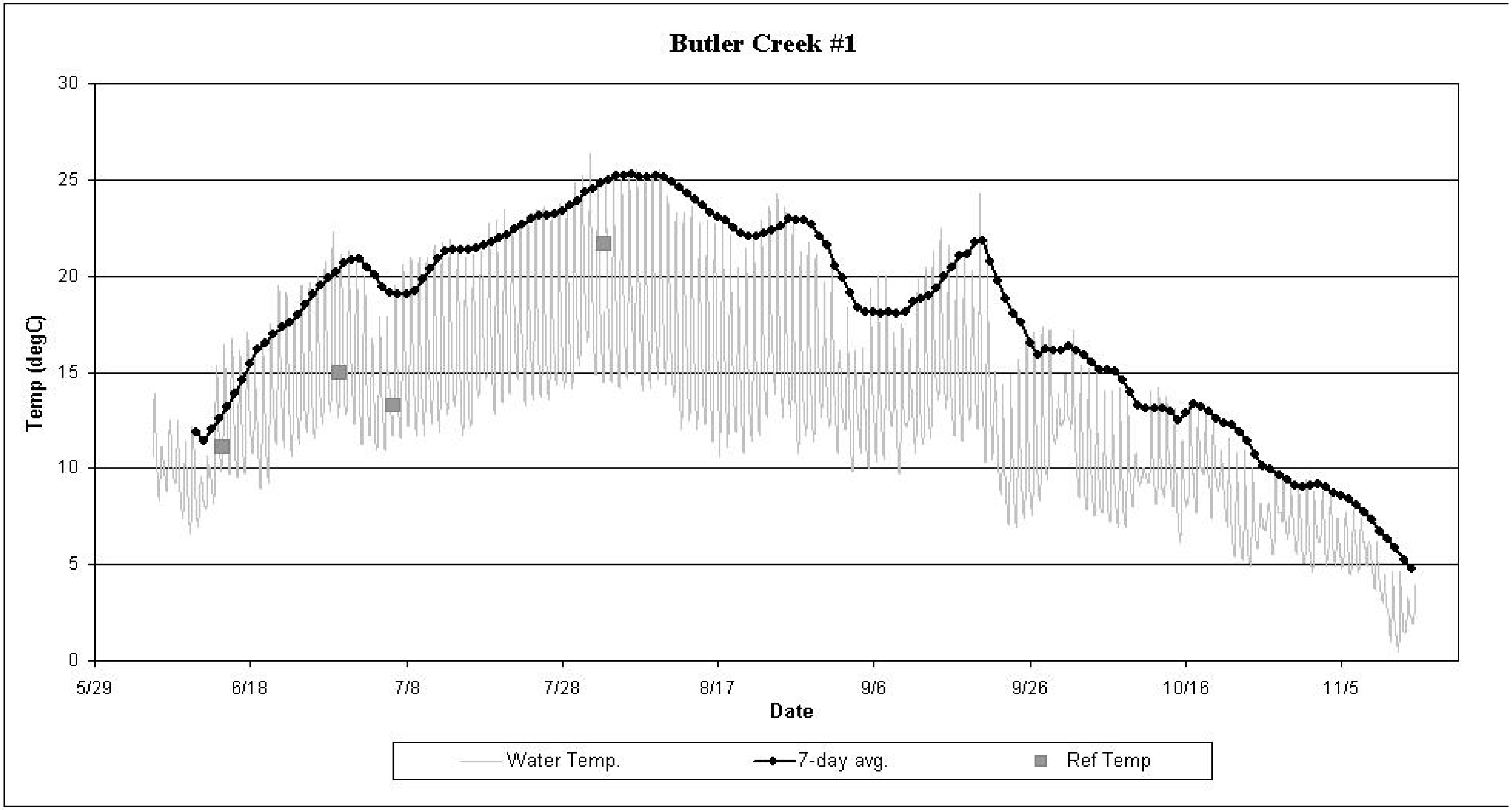
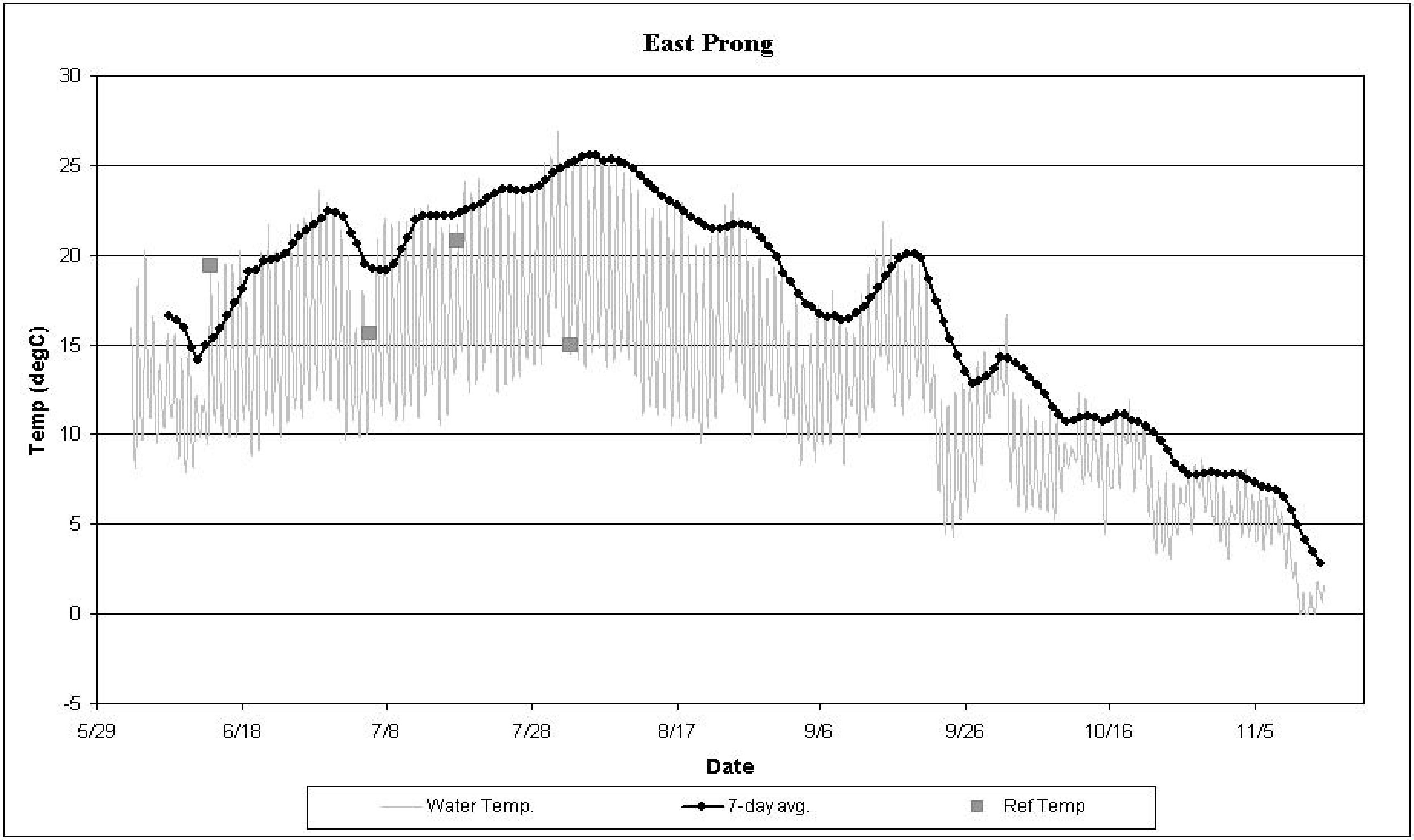


Figure A15. Water temperature data for East Prong Little Klickitat.



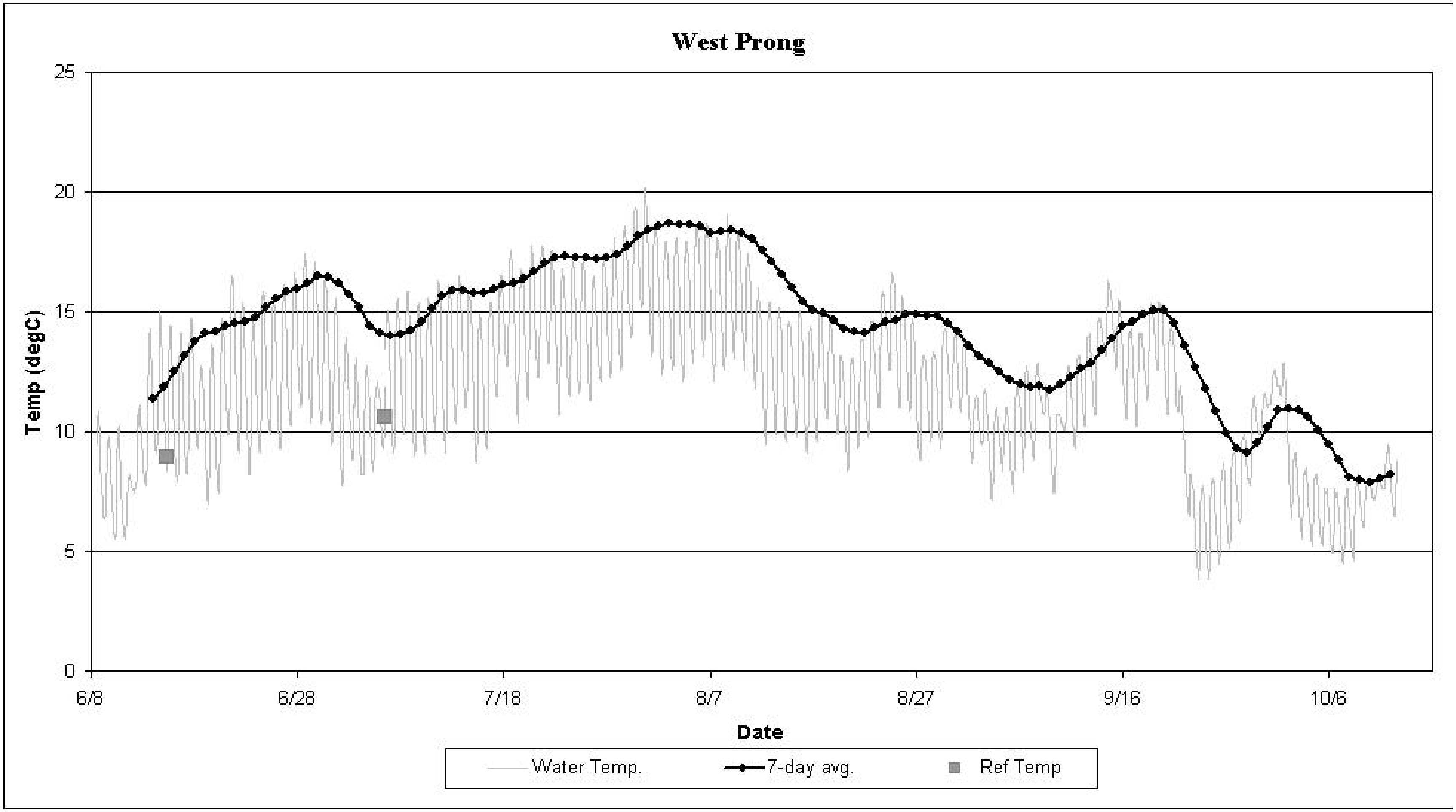


Figure A16. Water temperature data for West Prong Little Klickitat.

Appendix B

Field data collected during summer 2000.

Table B1 is an example of the field data collected by Ecology in the Little Klickitat watershed during summer 2000. The data table includes streamflow, stream surveys, and routine monthly field checks.

A complete set of these data tables for all stations sampled can be downloaded in Excel format at http://www.ecy.wa.gov/biblio/0203031.html (same address as this report).

Table B1. West Prong Little Klickitat field data collected at the CKCD site by Ecology during summer 2000.

		Date	7/19/00	7/19/00	8/18/00	8/18/00	8/18/00	8/18/00	8/18/00	8/18/00	8/18/00	8/18/00	8/18/00	8/18/00	8/18/00
		Time	10:30:0C	10:50	8:15		8:40	8:50	8:55	9:05		9:20	9:30	9:40	10:00
		participant 1	Becky Tatso	Becky Tatso	Steph Brock	Steph Brock	Steph Brock	Steph Brock	Steph Brock	Steph Brock	Steph Brock	Steph Brock	Steph Brock	Steph Brock	Steph Brock
		participant 2	Pat Irle	Pat Irle	Tara Galuska	Tara Galuska	Tara Galuska	Tara Galuska	Tara Galuska	Tara Galuska	Tara Galuska	Tara Galuska	Tara Galuska	Tara Galuska	Tara Galuska
		participant 3			Becky Tatso	Becky Tatso	Becky Tatso	Becky Tatso	Becky Tatso	Becky Tatso	Becky Tatso	Becky Tatso	Becky Tatso	Becky Tatso	Becky Tatso
		TRANSECT #	0	0	0	1	2	3	4	5	6	7	8	9	10
		cum. distance (ft)	0	0	0	100	200	300	400	500	600	700	800	900	1000
	Probes	**water**	n/a	n/a											
		air	n/a	n/a											
		Ref air temp (C)	17.25	17.25	Thermo broke										
		Ref water temp (C)		11.75	14.40	13.30	13.30	13.30	13.30	14.40	14.40	14.40	14.40	15.00	15.00
	Flow Info	**Staff gauge**													
		Flow (cfs)	2.795	1.68	1.73										1.62
		Cross-section area (ft^2)	3.15	2.01	2.03										2.75
		Wetted Perimeter (ft)	6.56	9.7	10.21										6.9
		Average Velocity (ft/s)	0.89	0.84	0.85										0.589
Densio-meter Readings		**UP**			4	29	49	65	12	30	28	4	39	56	64
		LB			34	36	56	82	44	81	49	52	48	81	72
		DN			7	0	18	31	19	9	52	17	49	18	80
		RB			15	18	10	24	63	39	62	29	63	86	91
		Canopy Closure*C41			15.6	21.58	34.58	52.52	35.88	41.34	49.66	26.52	51.74	62.66	79.82
Riparian Management Zone	**Over-hang**	**RB**			1.5	0	0	4	4	2	5	1	5	6	8
		LB			5	0	5	4	2	4.5	1	2	1	3	4
	RB	**Width**			300	300	300	300	300	300	300	300	300	300	300
		Cover			road next to strm, ald & pp & fir @ 80	ald, fir & pp @ 40'	100' of ald, road, then slope w/fir @ 250'	road, birch, ald, fir @ 150	ald, fir, road in middle of riparian	ald, pine, fi	road, fir, pp, a ld	fir, ald, road @ 100'	road@100', ald, birch, fir, pp	M-ald, birch, pp, fir	M-road @ 50', ald, shr, fir, birch, pp
		Size			7, 220	10, 210	20, 200	10, 200	20, 20C	20, 110	20, 200	10, 80, 15C	30, 20C	25, 20C	30, 20C
		Density			H	S-ald/H-fi	H	H	H	H	H	H	H	H	H
		Windthrow			N	N	N	N	N	N	N	N	N	N	N
	LB	**Width**			300	300	300	300	300	300	300	300	300	300	300
		Cover			will, ald, fi	road, fir & oak @ 30'	ald, fir, pp, 20' rock wall @ 30	ald, fir	ald, fir, pp, wil	ald, pine, fi	ald, fir, birch	ald, fir, pp	slope w/fir, ald, pp	M- ald, fi	M-ald, birch, fir, pp on steep slope
		Size			30, 21C	90, 200	20, 200	15, 250	20, 20C	20, 200	5, 150	10, 20C	5, 200	25, 20C	20, 21C
		Density			H	H	H	H	H	H	H	H	S	H	H
		Windthrow			N	N	N	N	N	N	N	N	N	N	N
		Wetted Width	6.1	9.2	9.5	10.3	5	6.1	14.1	8.1	8.9	12.9	7.2	9.3	6.6
		Wetted Depth (ft)			0.263	0.246	0.439	0.229	0.263	0.357	0.227	0.258	0.254	0.250	0.486
		Bankful Width (ft)	0	0	12.3	13.3	8.2	10.7	18	15.5	11.1	16	10.4	12	13.6
		Bankfull Depth (ft)			0.6	0.9	1.1	1.2	0.8	1.3	1.2		1.1	0.9	1.2
		Flood Prone Width (ft)			14.3	15.3	16.2	14.7	23.0	20.5	15.1	32.0	14.4	40.0	38.6
		Flood Prone Depth (ft)	0.0	0.0	2.0	3.6	3.0	2.8	2.0	3.4	2.8		2.6	2.4	3.0
		Gradient (degree)											8.5deg or 15'/100'		
		W/D			19.3	14.9	7.3	9.2	22.1	11.5	9.2		9.8	12.8	11.1
		Entrenchment			1.2	1.2	2.0	1.4	1.3	1.3	1.4	2.0	1.4	3.3	2.8
Substrate	**Boul-der**	**count**			11	17	7	6	4	6	0	0	3	9	7
		percent			22	34	14	12	8	12	0	0	6	18	14
	Cobble	**count**			39	30	43	32	26	30	26	30	43	39	37
		percent			78	60	86	64	52	60	52	60	86	78	74
	Gravel	**count**			0	3	0	12	18	14	21	15	4	1	3
		percent			0	6	0	24	36	28	42	30	8	2	6
	Sand	**count**			0	0	0	0	2	0	3	5	0	1	3
		percent			0	0	0	0	4	0	6	10	0	2	6
	Silt	**count**			0	0	0	0	0	0	0	0	0	0	0
		percent			0	0	0	0	0	0	0	0	0	0	0

CKCD - Central Klickitat Conservation District

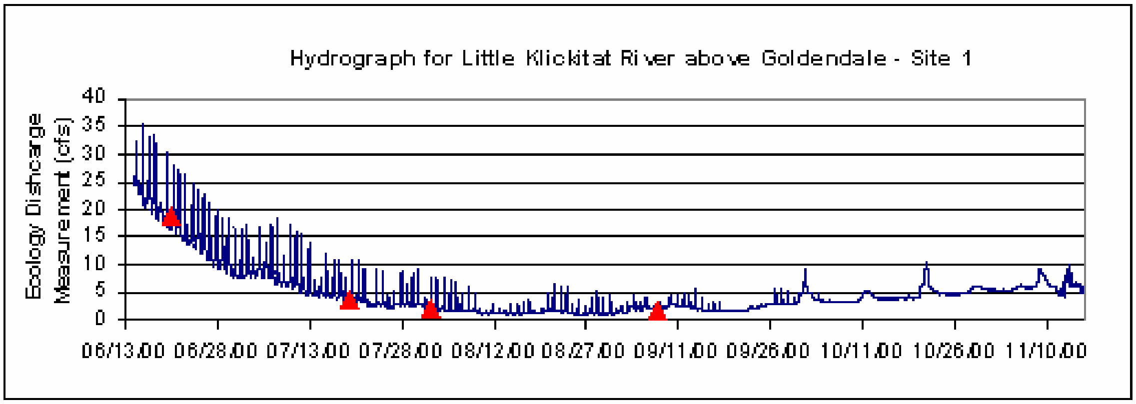
* Canopy cover taken with a concave densiometer

Appendix C-1

Flow summary at three seasonal gaging stations on the Little Klickitat River

Appendices C-1 and C-2 contain details about streamflow in the Little Klickitat watershed.

C1 figures contain rating curves presented in *Flow Summary at Three Seasonal Gaging Stations on the Little Klickitat River* by Chris Evans. This report is available on the web at http://www.ecy.wa.gov/biblio/013006.html.



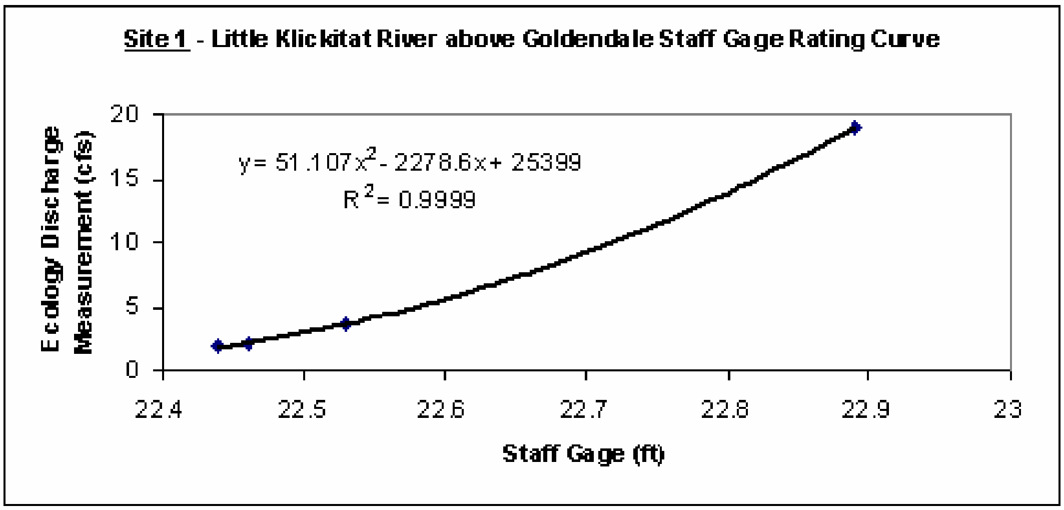


Figure C1a. Hydrograph and Rating Curve for Site 1 – Little Klickitat River above Goldendale.

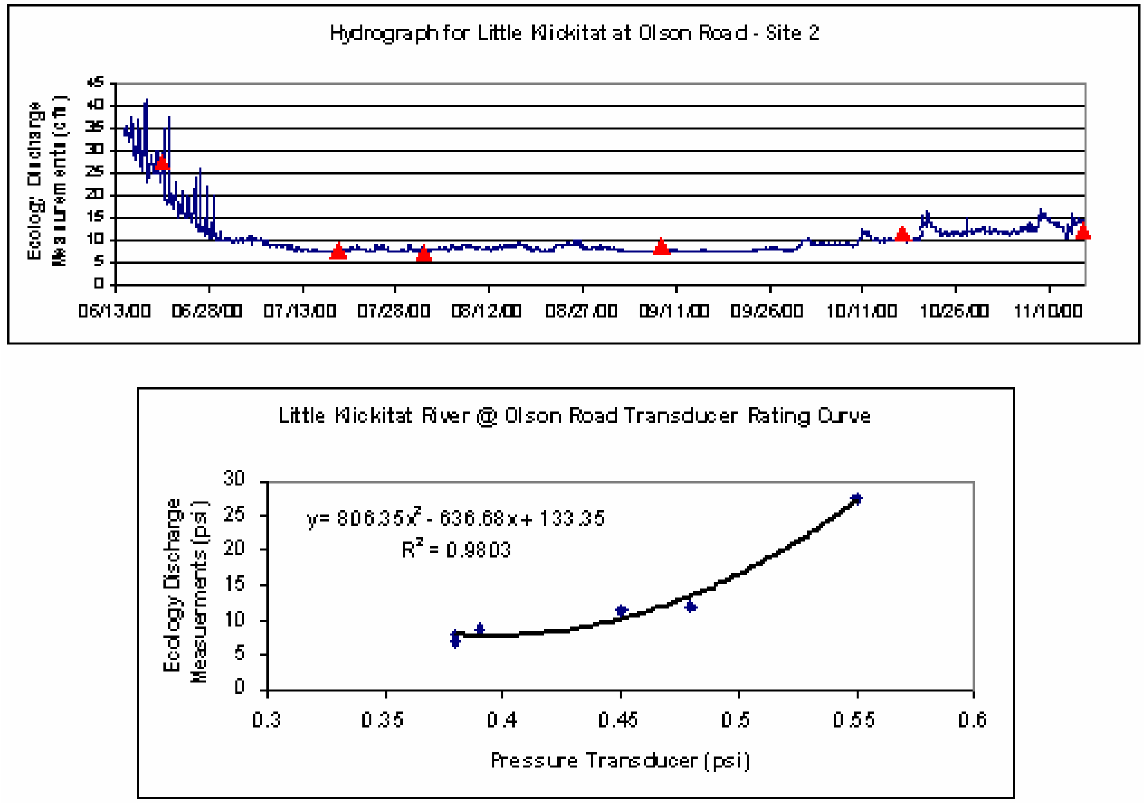
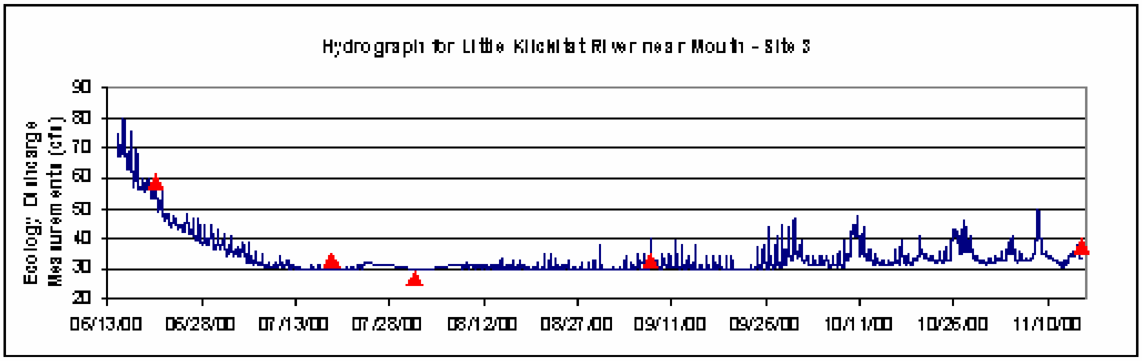


Figure C1b. Hydrograph and Rating Curve for Site 2 – Little Klickitat River at Olson Road



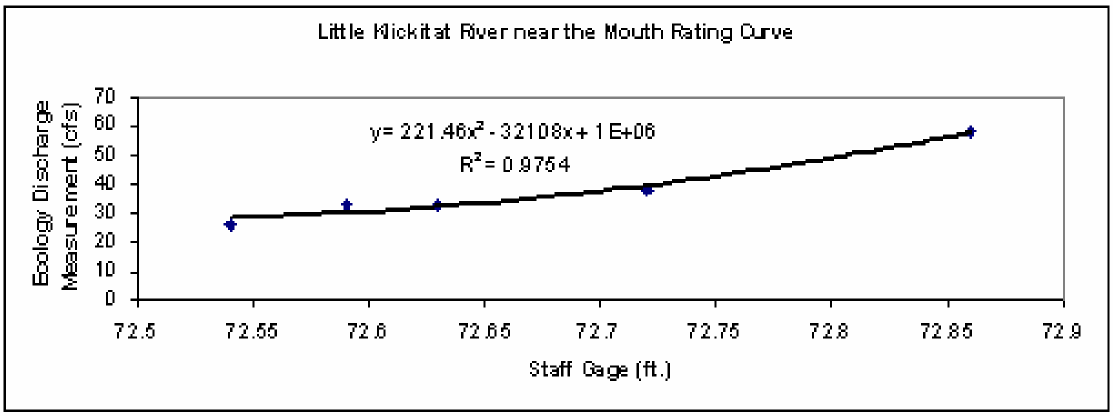


Figure C1c. Hydrograph and Rating Curve for Site 3 – Little Klickitat River near Mouth

Appendix C-2

Flow balance for the Little Klickitat River

Table C2 is the flow balance spreadsheet used for the Little Klickitat River for both 7Q2 and 7Q10 conditions.

Table C2. Flow Balance for the Little Klickitat River.

Station	Trib/Station	Downstream Dist (m)	7/19/00 (cfs)	7/19/00 (cms)	7Q2 (cfs)	7Q2 (cms)	7Q10 (cfs)	7Q10 (cms)	%change 7/19 & 7Q10
Butler	TRIB	0	1.90	0.05	1.36	0.04	0.92	0.03	0.49
LK4(West)	TRIB	0	2.80	0.08	2.00	0.06	1.36	0.04	0.49
LK7(East)	TRIB	0	1.03	0.03	0.74	0.02	0.50	0.01	0.49
3Creeks	MONITOR	0	4.50	0.13	2.88	0.08	2.19	0.06	0.49
Irrigation Withdrawal		8839 - 14326	-0.79	-0.02	-0.79	-0.02	-0.79	-0.02	
Rimrock	MONITOR	14326	3.71	0.11	2.09	0.06	**1.40**	0.04	0.38
Bldgd	TRIB	18379	8.17	0.23	8.17	0.23	3.08	0.09	0.38
TomM	MONITOR	19385	11.69	0.33	10.26	0.29	4.48	0.13	0.38
Irrigation Withdrawal		21824 - 27402	-3.87	-0.11	-3.40	-0.10	-3.40	-0.10	
Olson	MONITOR	27402	7.82	0.22	6.86	0.19	1.08	0.03	0.14
Groundwater Inflow		27432	4.47	0.13	4.47	0.13	3.64	0.10	0.81
Spring	TRIB	28926	4.07	0.12	3.21	0.09	1.55	0.04	0.38
Blkhs	TRIB	33345	1.46	0.04	1.15	0.03	0.55	0.02	0.38
Mill	TRIB	37521	6.96	0.20	5.50	0.16	2.65	0.07	0.38
Bowman	TRIB	41544	6.68	0.19	5.28	0.15	2.54	0.07	0.38
Mouth	MONITOR	42885	31.46	0.89	26.47	0.75	**12.00**	0.34	0.38

Bold = 7Q10 flows reported by the U.S. Geological Survey (Williams and Pearson, 1985).

Appendix D

Groundwater interaction with the Little Klickitat River along the Goldendale Reach

Appendix D is a memorandum from Denis Erickson, hydrogeologist for Ecology, about groundwater interaction with the Little Klickitat River along the Goldendale Reach.

DEPARTMENT OF ECOLOGY

August 29, 2001

To: Stephanie Brock

From: Denis Erickson
Hydrogeologist

Subject: Groundwater Interaction with the Little Klickitat River along the Goldendale Reach

Purpose

At your request I reviewed readily available hydrogeologic information to assess the potential for groundwater interaction with a reach of the Little Klickitat River between stations "97&Rimrock" (River Mile 15.6) and "TomMiller" (River Mile 14.5), herein referred to as the Goldendale Reach. Sources of information included existing regional hydrogeologic reports and well logs in the Ecology Well Imaging System. I understand that summer water temperatures for the downstream station (Tom Miller) were substantially cooler than temperatures observed at the upstream station (97&Rimrock) but flow at both stations was essentially the same. Based on your modeling results with HeatSource, a possible mechanism to account for this observation is a contribution of cold groundwater to this reach of the river. The purpose of this assessment was to determine using existing data whether hydrogeologic conditions at the reach would suggest that groundwater is contributing cool water to the river. This memorandum describes the findings of this assessment.

Literature Review

The predominate geologic unit in the Goldendale vicinity is the Wanapum Basalt of the Yakima Basalt Subgroup and the Columbia Basalt Group (Drost et al , 1986 and Drost et al, 1990). The Wanapum Basalt consists of up to ten individual basalt flows with each flow typically a few tens of feet thick. Near Goldendale the total thickness of the Wanapum Basalt is about 400 feet. In general, the occurrence and movement of groundwater in basaltic flows is related to the presence of one or more of the following: fractures and jointing, vesicular layers associated with the tops and bottoms of the individual basalt flows, and sedimentary interbeds between basalt flows.

Luzier (1969) described the regional hydrogeology of the Goldendale area. In addition to the basalt he mapped outcrops of a sedimentary interbed on both sides of the river in the vicinity of the 97&Rimrock station. The sedimentary interbed consisted of pebble-cobble gravel in a micaceous sand matrix. The presence of a sedimentary interbed is potentially significant because, if present in the shallow subsurface along the Goldendale Reach, it represents a potential pathway for groundwater interaction with the Little Klickitat River. Luzier (1969) and Brown (1979) reported well logs for three wells along the Goldendale Reach showed near-surface sand and sandy gravel deposits ranging in thickness from

10 to 60 feet. The depths of these wells ranged from 88 to 200 feet deep and reported water levels were 6 feet deep or less. This suggests but does not confirm that the sand and sandy gravel deposits were saturated.

Luzier also constructed a regional potentiometric contour map based on the altitude of water levels in wells less than 500 feet deep. A potentiometric contour map depicts lines of equal hydraulic potential for a hydrogeologic unit which can be used to infer groundwater flow direction. Based on the potentiometric contour map reported by Luzier, groundwater in the upper 500 feet in the vicinity of the Goldendale Reach was flowing toward the Little Klickitat River. Bauer, et al. (1985) prepared a potentiometric map for the Wanapum Basalt based on 1983 water levels. The pattern of potentiometric contours in 1983 are consistent with Luzier's results, indicating that groundwater in the Wanapum Basalt near Goldendale Reach, at least on a regional basis, was flowing toward the Little Klickitat River. It should be noted that actual local groundwater flow patterns adjacent to a river can be more complex than those depicted by regional data. Also, if major changes in groundwater usage and withdrawal occurred since the early 1980s, the regional groundwater flow pattern may also have changed in response.

Ecology Well Logs

The Ecology Well Log Imaging System (Department of Ecology, 2001) identified about 45 wells with well logs within about ¼ mile of each side of the Goldendale Reach. Locations for these wells are reported by the well driller to the nearest 40 acres (1/4-1/4 section) but are not field-verified. Well logs for eight shallow monitoring wells at a Chevron station in Goldendale were included in the database. These wells showed an 18-foot sequence of silt, fine to medium silty sand, and coarse gravel overlying basalt. Portions of these unconsolidated materials were saturated at depths ranging from four to 18 feet. The remainder of the 45 wells are water-supply wells that derive water from the Wanapum Basalt or deeper units, typically at depths greater than 100 feet. Other than defining stratigraphy, most of these wells have limited use for determining hydrologic properties of the shallow aquifer that may be interacting with Little Klickitat River. Five of these wells indicated the presence of near-surface sand and gravel deposits that potentially could serve as pathway for groundwater interaction with the river.

Groundwater in shallow fractured or vesicular basalt may also be interacting with the river. However, water-supply wells are usually drilled deeper than this shallow occurrence of water to provide adequate and safe sources of water. As a result, little is known about the distribution and hydraulic properties of the shallow water-bearing zones in the basalt.

Groundwater Temperatures

Luzier (1969) reported water temperatures in four wells less than 200 feet deep in the Goldendale Reach to range from 12 to 13°C. Of the 45 wells in the Ecology Well Log Imaging System within a ¼ mile of the Goldendale Reach, 14 wells less than 200 feet deep had reported water temperatures. Water temperatures in these wells ranged from 11.1 to 13.9°C (52 to 57°F) with a mean of 12.8°C (55 °F). There was no apparent trend of water temperature and well depth.

Conclusions

The potential exists for groundwater to contribute cool water to the Little Klickitat River along portions of the Goldendale Reach. Based on well logs, saturated sand and sandy gravel deposits occur in the shallow subsurface in the vicinity of portions of the Goldendale Reach. These deposits could serve as a pathway for groundwater interaction with the Little Klickitat River. Groundwater in shallow fractured and vesicular basalt may also be interacting with river but little is known about the distribution of these zones. Based on the heterogeneity of the aquifer materials, it is likely that the degree of interaction between groundwater and river would show substantial spatial variation. Based on regional potentiometric contour maps, groundwater in the upper basalt unit flows toward the Little Klickitat River in the vicinity of Goldendale Reach. Groundwater temperatures are typically 12 to 13°C based on water temperatures in wells less than 200 feet deep.

References

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Appendix E

Sensitivity analysis of mature riparian vegetation

Appendix E is a sensitivity analysis of various types and densities of vegetation to determine its impacts on effective shade and stream temperature on the mainstem Little Klickitat River.

During the initial TMDL development, Ecology defined the vegetation species, heights, and densities of the mainstem Little Klickitat based on a report by Boise Cascade, field data collected during the summer of 2000, the Washington Department of Fish and Wildlife Priority Habitat and Species Database, and vegetation present in similar watersheds in Oregon (Raines et al., 1999; Clayton, 2001; ODEQ, 2001).

The vegetation data used are presented as scenario "Veg 1" in Table E1. After presentation of the results and discussion of the numbers modeled, the densities and heights were deemed overly optimistic for the area, especially the reach west of Goldendale (below Goldendale).

The Central Klickitat Conservation District compiled soil data from Natural Resources Conservation Service in Spokane and field data measurements of tree heights and densities to determine the potential tree species, heights, and densities (Sizemore, 2002). These numbers are reported as scenario "Veg 2" in Table E1.

Table E1. Vegetation Scenarios for Sensitivity Analysis.

		Near Stream (20 feet)			Outer Zone (140 feet)		
	Reaches	Vegetation Type	Density	Average Mature Height	Vegetation Type	Density	Average Mature Height
Veg 1	*Upper* - above Goldendale	2-Story Deciduous	80%	30 feet / 10 meters	Coniferous	80%	127 feet / 38.7 meters
	Lower - below Goldendale	2-Story Deciduous	80%	30 feet / 10 meters	Coniferous / Deciduous	80%	98 feet / 30 meters
Veg 2	*Upper* - above Goldendale	2-Story Deciduous	60%	30 feet / 10 meters	Coniferous	55%	104 feet / 31.7 meters
	Lower - below Goldendale	2-Story Deciduous	50%	30 feet / 10 meters	Coniferous / Deciduous	50%	65 feet / 19.8 meters
Veg 3	*Upper* - above Goldendale	2-Story Deciduous	80%	30 feet / 10 meters	Coniferous	55%	104 feet / 31.7 meters
	Lower - below Goldendale	2-Story Deciduous	80%	30 feet / 10 meters	Coniferous / Deciduous	50%	65 feet / 19.8 meters

For development of the load allocation the Central Klickitat Conservation District vegetation heights and densities was modeled for the outer zone (140 feet); however, for the inner zone the initial heights and densities were based on the density of vegetation observed in the inner zone during field work by Ecology (Table E1, Figure E1 and E2).

Figures E1 and E2 illustrate that while the outer zone vegetation decreases as the distance from the stream increases, the inner zone vegetation tends to be more dense in comparison.

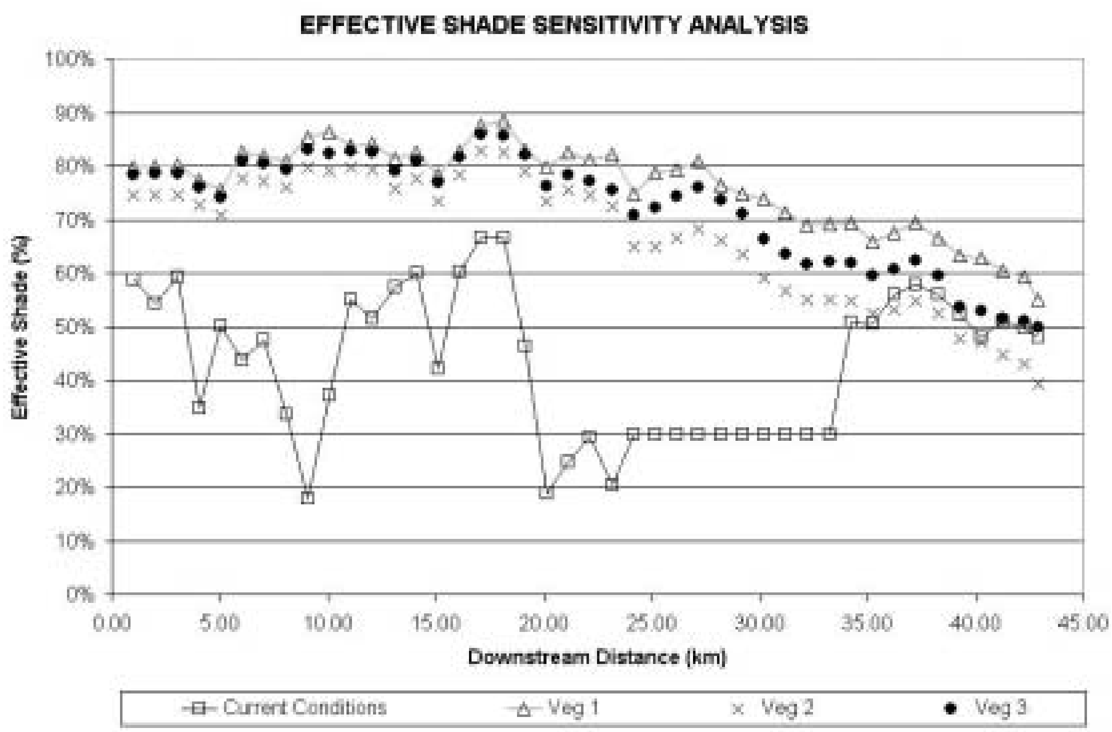
Figure E1. Little Klickitat at Olson Road view of inner zone riparian vegetation.

Figure E-2. Little Klickitat at Three Creek Lodge view of inner zone riparian vegetation.

Figures E3 and E4 illustrate the effects of the various vegetation types on effective shade and temperatures. As expected:

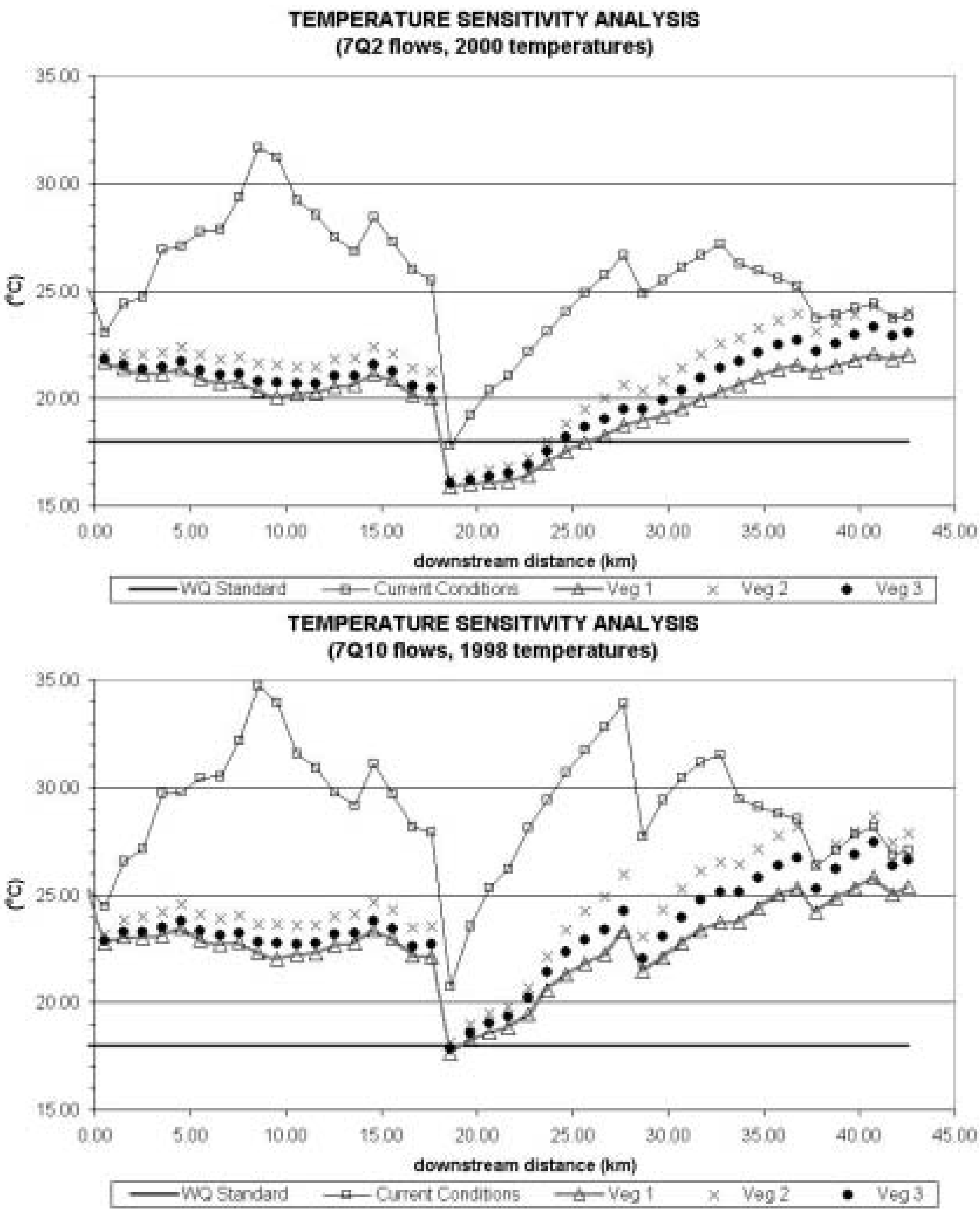
- Veg 1, which has densities of 80%, offers the highest effective shade and greatest temperature reductions over current vegetation conditions.
- Veg 2 generates the lowest effective shade and the least temperature reduction because the densities are between 50-60%.
- Veg 3, which combines Veg 1 and Veg 2, falls between the two for effective shade and temperature reduction.

For the final analysis and development of the load allocation, Ecology modeled Veg 3.



Veg 1, Veg 2, Veg 3 defined in Table E1.

Figure E3. Little Klickitat effective shade produced by different vegetation scenarios.



Veg 1, Veg 2, Veg 3 defined in Table E1.

Figure E4. Little Klickitat temperature produced by different vegetation scenarios.

Appendix F

Riparian codes used for HeatSource vegetation classification

Appendix F lists riparian vegetation codes used to describe vegetation along the Little Klickitat River and its tributaries for modeling in HeatSource (ODEQ, 2000)

Table F. Riparian Codes used for HeatSource Vegetation Classification.

Code	Source	Description	(m)	(%)	(m)
301	DEQ	Water	0.0	0%	0.0
302	DEQ	Agriculture	0.5	95%	0.5
304	DEQ	Barren/Lawn/Grass	1.0	95%	1.0
306	DEQ	Timber Harvest < 10 years	3.0	90%	1.0
400	DEQ	General Road	0.0	0%	0.0
401	DEQ	Forest Road	0.0	0%	0.0
402	DEQ	Improved Road	0.0	0%	0.0
403	DEQ	Highway	0.0	0%	0.0
404	DEQ	Culvert - Subsurface	0.0	0%	0.0
405	DEQ	Bridge	0.0	0%	0.0
500	DEQ	Conifer/Deciduous	24.4	90%	4.6
512	ECY	Conifer/Deciduous	24.4	12%	4.6
550	DEQ	Conifer/Deciduous	24.4	50%	4.6
580	ECY	Conifer/Deciduous	30.0	80%	4.6
600	DEQ	Deciduous	18.3	90%	4.6
612	ECY	Deciduous	18.3	12%	4.6
680	ECY	Deciduous	18.3	80%	4.6
650	DEQ	Deciduous	18.3	50%	4.6
700	DEQ	Conifer	30.5	90%	4.6
712	ECY	Conifer	30.5	12%	4.6
750	DEQ	Conifer	30.5	50%	4.6
780	ECY	Conifer	38.7	80%	4.6
800	DEQ	Scrub/Shrub	6.1	90%	0.9
850	DEQ	Scrub/Shrub	6.1	50%	0.9
900	DEQ	Grass	1.0	95%	1.0
3247	DEQ	General Urban	6.1	100%	0.0
3248	DEQ	Residential	6.1	100%	0.0
3249	DEQ	Industrial	9.1	100%	0.0
1	WODIP	Water	0.0	0%	0.0
2	WODIP	Agriculture	0.5	95%	0.0
3	WODIP	Non_Forest	3.0	80%	0.6
4	WODIP	Grass/Bushes	0.8	95%	0.8
5	WODIP	Other	3.0	80%	0.6
6	WODIP	Clearcut	0.8	95%	0.0
7	WODIP	Conifer-Small-1Story	11.2	5%	1.1
8	WODIP	Conifer-Small-1Story	11.2	15%	1.1
9	WODIP	Conifer-Small-1Story	11.2	25%	1.1
10	WODIP	Conifer-Small-1Story	11.2	35%	1.1
11	WODIP	Conifer-Small-1Story	11.2	45%	1.1
12	WODIP	Conifer-Small-1Story	11.2	55%	1.1
13	WODIP	Conifer-Small-1Story	11.2	65%	1.1
14	WODIP	Conifer-Small-1Story	11.2	75%	1.1
15	WODIP	Conifer-Small-1Story	11.2	85%	1.1
16	WODIP	Conifer-Small-1Story	11.2	95%	1.1
17	WODIP	Conifer-Medium-1Story	27.5	5%	2.7
18	WODIP	Conifer-Medium-1Story	27.5	15%	2.7

Code	Source	Description	(m)	(%)	(m)
19	WODIP	Conifer-Medium-1Story	27.5	25%	2.7
20	WODIP	Conifer-Medium-1Story	27.5	35%	2.7
21	WODIP	Conifer-Medium-1Story	27.5	45%	2.7
22	WODIP	Conifer-Medium-1Story	27.5	55%	2.7
23	WODIP	Conifer-Medium-1Story	27.5	65%	2.7
24	WODIP	Conifer-Medium-1Story	27.5	75%	2.7
25	WODIP	Conifer-Medium-1Story	27.5	85%	2.7
26	WODIP	Conifer-Medium-1Story	27.5	95%	2.7
27	WODIP	Conifer-Large-1Story	40.3	5%	4.0
28	WODIP	Conifer-Large-1Story	40.3	15%	4.0
29	WODIP	Conifer-Large-1Story	40.3	25%	4.0
30	WODIP	Conifer-Large-1Story	40.3	35%	4.0
31	WODIP	Conifer-Large-1Story	40.3	45%	4.0
32	WODIP	Conifer-Large-1Story	40.3	55%	4.0
33	WODIP	Conifer-Large-1Story	40.3	65%	4.0
34	WODIP	Conifer-Large-1Story	40.3	75%	4.0
35	WODIP	Conifer-Large-1Story	40.3	85%	4.0
36	WODIP	Conifer-Large-1Story	40.3	95%	4.0
37	WODIP	Conifer-Xlarge-1Story	50.4	5%	5.0
38	WODIP	Conifer-Xlarge-1Story	50.4	15%	5.0
39	WODIP	Conifer-Xlarge-1Story	50.4	25%	5.0
40	WODIP	Conifer-Xlarge-1Story	50.4	35%	5.0
41	WODIP	Conifer-Xlarge-1Story	50.4	45%	5.0
42	WODIP	Conifer-Xlarge-1Story	50.4	55%	5.0
43	WODIP	Conifer-Xlarge-1Story	50.4	65%	5.0
44	WODIP	Conifer-Xlarge-1Story	50.4	75%	5.0
45	WODIP	Conifer-Xlarge-1Story	50.4	85%	5.0
46	WODIP	Conifer-Xlarge-1Story	50.4	95%	5.0
47	WODIP	Conifer-Small-2Story	11.2	5%	1.1
48	WODIP	Conifer-Small-2Story	11.2	15%	1.1
49	WODIP	Conifer-Small-2Story	11.2	25%	1.1
50	WODIP	Conifer-Small-2Story	11.2	35%	1.1
51	WODIP	Conifer-Small-2Story	11.2	45%	1.1
52	WODIP	Conifer-Small-2Story	11.2	55%	1.1
53	WODIP	Conifer-Small-2Story	11.2	65%	1.1
54	WODIP	Conifer-Small-2Story	11.2	75%	1.1
55	WODIP	Conifer-Small-2Story	11.2	85%	1.1
56	WODIP	Conifer-Small-2Story	11.2	95%	1.1
57	WODIP	Conifer-Medium-2Story	27.5	5%	2.7
58	WODIP	Conifer-Medium-2Story	27.5	15%	2.7
59	WODIP	Conifer-Medium-2Story	27.5	25%	2.7
60	WODIP	Conifer-Medium-2Story	27.5	35%	2.7
61	WODIP	Conifer-Medium-2Story	27.5	45%	2.7
62	WODIP	Conifer-Medium-2Story	27.5	55%	2.7
63	WODIP	Conifer-Medium-2Story	27.5	65%	2.7
64	WODIP	Conifer-Medium-2Story	27.5	75%	2.7
65	WODIP	Conifer-Medium-2Story	27.5	85%	2.7
66	WODIP	Conifer-Medium-2Story	27.5	95%	2.7

Code	Source	Description	(m)	(%)	(m)
67	WODIP	Conifer-Large-2Story	40.3	5%	4.0
68	WODIP	Conifer-Large-2Story	40.3	15%	4.0
69	WODIP	Conifer-Large-2Story	40.3	25%	4.0
70	WODIP	Conifer-Large-2Story	40.3	35%	4.0
71	WODIP	Conifer-Large-2Story	40.3	45%	4.0
72	WODIP	Conifer-Large-2Story	40.3	55%	4.0
73	WODIP	Conifer-Large-2Story	40.3	65%	4.0
74	WODIP	Conifer-Large-2Story	40.3	75%	4.0
75	WODIP	Conifer-Large-2Story	40.3	85%	4.0
76	WODIP	Conifer-Large-2Story	40.3	95%	4.0
77	WODIP	Conifer-Xlarge-2Story	50.4	5%	5.0
78	WODIP	Conifer-Xlarge-2Story	50.4	15%	5.0
79	WODIP	Conifer-Xlarge-2Story	50.4	25%	5.0
80	WODIP	Conifer-Xlarge-2Story	50.4	35%	5.0
81	WODIP	Conifer-Xlarge-2Story	50.4	45%	5.0
82	WODIP	Conifer-Xlarge-2Story	50.4	55%	5.0
83	WODIP	Conifer-Xlarge-2Story	50.4	65%	5.0
84	WODIP	Conifer-Xlarge-2Story	50.4	75%	5.0
85	WODIP	Conifer-Xlarge-2Story	50.4	85%	5.0
86	WODIP	Conifer-Xlarge-2Story	50.4	95%	5.0
87	WODIP	Deciduous-Small-1Story	10.0	5%	1.5
88	WODIP	Deciduous-Small-1Story	10.0	15%	1.5
89	WODIP	Deciduous-Small-1Story	10.0	25%	1.5
90	WODIP	Deciduous-Small-1Story	10.0	35%	1.5
91	WODIP	Deciduous-Small-1Story	10.0	45%	1.5
92	WODIP	Deciduous-Small-1Story	10.0	55%	1.5
93	WODIP	Deciduous-Small-1Story	10.0	65%	1.5
94	WODIP	Deciduous-Small-1Story	10.0	75%	1.5
95	WODIP	Deciduous-Small-1Story	10.0	85%	1.5
96	WODIP	Deciduous-Small-1Story	10.0	95%	1.5
97	WODIP	Deciduous-Medium-1Story	20.9	5%	3.1
98	WODIP	Deciduous-Medium-1Story	20.9	15%	3.1
99	WODIP	Deciduous-Medium-1Story	20.9	25%	3.1
100	WODIP	Deciduous-Medium-1Story	20.9	35%	3.1
101	WODIP	Deciduous-Medium-1Story	20.9	45%	3.1
102	WODIP	Deciduous-Medium-1Story	20.9	55%	3.1
103	WODIP	Deciduous-Medium-1Story	20.9	65%	3.1
104	WODIP	Deciduous-Medium-1Story	20.9	75%	3.1
105	WODIP	Deciduous-Medium-1Story	20.9	85%	3.1
106	WODIP	Deciduous-Medium-1Story	20.9	95%	3.1
107	WODIP	Deciduous-Large-1Story	26.9	5%	4.0
108	WODIP	Deciduous-Large-1Story	26.9	15%	4.0
109	WODIP	Deciduous-Large-1Story	26.9	25%	4.0
110	WODIP	Deciduous-Large-1Story	26.9	35%	4.0
111	WODIP	Deciduous-Large-1Story	26.9	45%	4.0
112	WODIP	Deciduous-Large-1Story	26.9	55%	4.0
113	WODIP	Deciduous-Large-1Story	26.9	65%	4.0
114	WODIP	Deciduous-Large-1Story	26.9	75%	4.0

Code	Source	Description	(m)	(%)	(m)
115	WODIP	Deciduous-Large-1Story	26.9	85%	4.0
116	WODIP	Deciduous-Large-1Story	26.9	95%	4.0
117	WODIP	Deciduous-XLarge-1Story	30.3	5%	4.5
118	WODIP	Deciduous-XLarge-1Story	30.3	15%	4.5
119	WODIP	Deciduous-XLarge-1Story	30.3	25%	4.5
120	WODIP	Deciduous-XLarge-1Story	30.3	35%	4.5
121	WODIP	Deciduous-XLarge-1Story	30.3	45%	4.5
122	WODIP	Deciduous-XLarge-1Story	30.3	55%	4.5
123	WODIP	Deciduous-XLarge-1Story	30.3	65%	4.5
124	WODIP	Deciduous-XLarge-1Story	30.3	75%	4.5
125	WODIP	Deciduous-XLarge-1Story	30.3	85%	4.5
126	WODIP	Deciduous-XLarge-1Story	30.3	95%	4.5
127	WODIP	Deciduous-Small-2Story	10.0	5%	1.5
128	WODIP	Deciduous-Small-2Story	10.0	15%	1.5
129	WODIP	Deciduous-Small-2Story	10.0	25%	1.5
130	WODIP	Deciduous-Small-2Story	10.0	35%	1.5
131	WODIP	Deciduous-Small-2Story	10.0	45%	1.5
132	WODIP	Deciduous-Small-2Story	10.0	55%	1.5
133	WODIP	Deciduous-Small-2Story	10.0	65%	1.5
134	WODIP	Deciduous-Small-2Story	10.0	75%	1.5
248	ECY	Deciduous-Small-2Story	10.0	80%	4.6
135	WODIP	Deciduous-Small-2Story	10.0	85%	1.5
136	WODIP	Deciduous-Small-2Story	10.0	95%	1.5
137	WODIP	Deciduous-Medium-2Story	20.9	5%	3.1
138	WODIP	Deciduous-Medium-2Story	20.9	15%	3.1
139	WODIP	Deciduous-Medium-2Story	20.9	25%	3.1
140	WODIP	Deciduous-Medium-2Story	20.9	35%	3.1
141	WODIP	Deciduous-Medium-2Story	20.9	45%	3.1
142	WODIP	Deciduous-Medium-2Story	20.9	55%	3.1
143	WODIP	Deciduous-Medium-2Story	20.9	65%	3.1
144	WODIP	Deciduous-Medium-2Story	20.9	75%	3.1
145	WODIP	Deciduous-Medium-2Story	20.9	85%	3.1
145a	ECY	Deciduous-Medium-2Story	20.9	80%	4.6
146	WODIP	Deciduous-Medium-2Story	20.9	95%	3.1
147	WODIP	Deciduous-Large-2Story	26.9	5%	4.0
148	WODIP	Deciduous-Large-2Story	26.9	15%	4.0
149	WODIP	Deciduous-Large-2Story	26.9	25%	4.0
150	WODIP	Deciduous-Large-2Story	26.9	35%	4.0
151	WODIP	Deciduous-Large-2Story	26.9	45%	4.0
152	WODIP	Deciduous-Large-2Story	26.9	55%	4.0
153	WODIP	Deciduous-Large-2Story	26.9	65%	4.0
154	WODIP	Deciduous-Large-2Story	26.9	75%	4.0
155	WODIP	Deciduous-Large-2Story	26.9	85%	4.0
156	WODIP	Deciduous-Large-2Story	26.9	95%	4.0
157	WODIP	Deciduous-XLarge-2Story	30.3	5%	4.5
158	WODIP	Deciduous-XLarge-2Story	30.3	15%	4.5
159	WODIP	Deciduous-XLarge-2Story	30.3	25%	4.5
160	WODIP	Deciduous-XLarge-2Story	30.3	35%	4.5

Code	Source	Description	(m)	(%)	(m)
161	WODIP	Deciduous-XLarge-2Story	30.3	45%	4.5
162	WODIP	Deciduous-XLarge-2Story	30.3	55%	4.5
163	WODIP	Deciduous-XLarge-2Story	30.3	65%	4.5
164	WODIP	Deciduous-XLarge-2Story	30.3	75%	4.5
165	WODIP	Deciduous-XLarge-2Story	30.3	85%	4.5
166	WODIP	Deciduous-XLarge-2Story	30.3	95%	4.5
167	WODIP	Mixed-Small-1Story	9.9	5%	1.2
168	WODIP	Mixed-Small-1Story	9.9	15%	1.2
169	WODIP	Mixed-Small-1Story	9.9	25%	1.2
170	WODIP	Mixed-Small-1Story	9.9	35%	1.2
171	WODIP	Mixed-Small-1Story	9.9	45%	1.2
172	WODIP	Mixed-Small-1Story	9.9	55%	1.2
173	WODIP	Mixed-Small-1Story	9.9	65%	1.2
174	WODIP	Mixed-Small-1Story	9.9	75%	1.2
175	WODIP	Mixed-Small-1Story	9.9	85%	1.2
176	WODIP	Mixed-Small-1Story	9.9	95%	1.2
177	WODIP	Mixed-Medium-1Story	22.4	5%	2.8
178	WODIP	Mixed-Medium-1Story	22.4	15%	2.8
179	WODIP	Mixed-Medium-1Story	22.4	25%	2.8
180	WODIP	Mixed-Medium-1Story	22.4	35%	2.8
181	WODIP	Mixed-Medium-1Story	22.4	45%	2.8
182	WODIP	Mixed-Medium-1Story	22.4	55%	2.8
183	WODIP	Mixed-Medium-1Story	22.4	65%	2.8
184	WODIP	Mixed-Medium-1Story	22.4	75%	2.8
185	WODIP	Mixed-Medium-1Story	22.4	85%	2.8
186	WODIP	Mixed-Medium-1Story	22.4	95%	2.8
187	WODIP	Mixed-Large-1Story	30.8	5%	3.9
188	WODIP	Mixed-Large-1Story	30.8	15%	3.9
189	WODIP	Mixed-Large-1Story	30.8	25%	3.9
190	WODIP	Mixed-Large-1Story	30.8	35%	3.9
191	WODIP	Mixed-Large-1Story	30.8	45%	3.9
192	WODIP	Mixed-Large-1Story	30.8	55%	3.9
193	WODIP	Mixed-Large-1Story	30.8	65%	3.9
194	WODIP	Mixed-Large-1Story	30.8	75%	3.9
195	WODIP	Mixed-Large-1Story	30.8	85%	3.9
196	WODIP	Mixed-Large-1Story	30.8	95%	3.9
197	WODIP	Mixed-XLarge-1Story	36.7	5%	4.6
198	WODIP	Mixed-XLarge-1Story	36.7	15%	4.6
199	WODIP	Mixed-XLarge-1Story	36.7	25%	4.6
200	WODIP	Mixed-XLarge-1Story	36.7	35%	4.6
201	WODIP	Mixed-XLarge-1Story	36.7	45%	4.6
202	WODIP	Mixed-XLarge-1Story	36.7	55%	4.6
203	WODIP	Mixed-XLarge-1Story	36.7	65%	4.6
204	WODIP	Mixed-XLarge-1Story	36.7	75%	4.6
205	WODIP	Mixed-XLarge-1Story	36.7	85%	4.6
206	WODIP	Mixed-XLarge-1Story	36.7	95%	4.6
207	WODIP	Mixed-Small-2Story	9.9	5%	1.2
208	WODIP	Mixed-Small-2Story	9.9	15%	1.2

Code	Source	Description	(m)	(%)	(m)
209	WODIP	Mixed-Small-2Story	9.9	25%	1.2
210	WODIP	Mixed-Small-2Story	9.9	35%	1.2
211	WODIP	Mixed-Small-2Story	9.9	45%	1.2
212	WODIP	Mixed-Small-2Story	9.9	55%	1.2
213	WODIP	Mixed-Small-2Story	9.9	65%	1.2
214	WODIP	Mixed-Small-2Story	9.9	75%	1.2
215	WODIP	Mixed-Small-2Story	9.9	85%	1.2
216	WODIP	Mixed-Small-2Story	9.9	95%	1.2
217	WODIP	Mixed-Medium-2Story	22.4	5%	2.8
218	WODIP	Mixed-Medium-2Story	22.4	15%	2.8
219	WODIP	Mixed-Medium-2Story	22.4	25%	2.8
220	WODIP	Mixed-Medium-2Story	22.4	35%	2.8
221	WODIP	Mixed-Medium-2Story	22.4	45%	2.8
222	WODIP	Mixed-Medium-2Story	22.4	55%	2.8
223	WODIP	Mixed-Medium-2Story	22.4	65%	2.8
224	WODIP	Mixed-Medium-2Story	22.4	75%	2.8
225	WODIP	Mixed-Medium-2Story	22.4	85%	2.8
226	WODIP	Mixed-Medium-2Story	22.4	95%	2.8
227	WODIP	Mixed-Large-2Story	30.8	5%	3.9
228	WODIP	Mixed-Large-2Story	30.8	15%	3.9
229	WODIP	Mixed-Large-2Story	30.8	25%	3.9
230	WODIP	Mixed-Large-2Story	30.8	35%	3.9
231	WODIP	Mixed-Large-2Story	30.8	45%	3.9
232	WODIP	Mixed-Large-2Story	30.8	55%	3.9
233	WODIP	Mixed-Large-2Story	30.8	65%	3.9
234	WODIP	Mixed-Large-2Story	30.8	75%	3.9
235	WODIP	Mixed-Large-2Story	30.8	85%	3.9
236	WODIP	Mixed-Large-2Story	30.8	95%	3.9
237	WODIP	Mixed-XLarge-2Story	36.7	5%	4.6
238	WODIP	Mixed-XLarge-2Story	36.7	15%	4.6
239	WODIP	Mixed-XLarge-2Story	36.7	25%	4.6
240	WODIP	Mixed-XLarge-2Story	36.7	35%	4.6
241	WODIP	Mixed-XLarge-2Story	36.7	45%	4.6
242	WODIP	Mixed-XLarge-2Story	36.7	55%	4.6
243	WODIP	Mixed-XLarge-2Story	36.7	65%	4.6
244	WODIP	Mixed-XLarge-2Story	36.7	75%	4.6
245	WODIP	Mixed-XLarge-2Story	36.7	85%	4.6
246	WODIP	Mixed-XLarge-2Story	36.7	95%	4.6
247	WODIP	Urban	7.6	100%	0.0

DEQ – Oregon Department of Environmental Quality
ECY – Washington State Department of Ecology
WODIP – Western Oregon Digital Imagery Project (project that created the code for that specific type of vegetation)