WILLAMETTE BASIN

TOTAL MAXIMUM DAILY LOAD (TMDL)

APPENDIX C: TEMPERATURE

September 2006

Prepared by

DEQ
State of Oregon
Department of
Environmental
Quality

Willamette TMDL Technical Appendix C

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I. TEMPERATURE CRITERIA AS OF MARCH 2004

Oregon Administrative Rule (OAR) 340-041-0028:

(1) Background: Water temperatures affect the biological cycles of aquatic species and are a critical factor in maintaining and restoring healthy salmonid populations throughout the State. Water temperatures are influenced by solar radiation, stream shade, ambient air temperatures, channel morphology, groundwater inflows, and stream velocity, volume, and flow. Surface water temperatures may also be warmed by anthropogenic activities such as discharging heated water, changing stream width or depth, reducing stream shading, and water withdrawals.

(2) Policy: It is the policy of the Enviromental Quality Commission (Commission) to protect aquatic ecosystems from adverse warming and cooling caused by anthropogenic activities. The Commission intends to minimize the risk to cold-water aquatic ecosystems from anthropogenic warming, to encourage the restoration and protection of critical aquatic habitat, and to control extremes in temperature fluctuations due to anthropogenic activities. The Commission recognizes that some of the State's waters will, in their natural condition, not provide optimal thermal conditions at all places and at all times that salmonid use occurs. Therefore, it is especially important to minimize additional warming due to anthropogenic sources. In addition, the Commission acknowledges that control technologies, best management practices and other measures to reduce anthropogenic warming are evolving and that the implementation to meet these criteria will be an iterative process. Finally, the Commission notes that it will reconsider beneficial use designations in the event that man-made obstructions or barriers to anadromous fish passage are removed and may justify a change to the beneficial use for that water body.

(3) Purpose: The purpose of the temperature criteria in this rule is to protect designated temperature-sensitive, beneficial uses, including specific salmonid life cycle stages in waters of the State.

(4) Biologically Based Numeric Criteria: Unless superseded by the natural conditions criteria described in section (8) of this rule, or by subsequently adopted site-specific criteria approved by EPA, the temperature criteria for State waters supporting salmonid fishes are as follows:

(a) The seven-day-average maximum temperature of a stream identified as having salmon and steelhead spawning use on subbasin maps and tables set out in OAR 340-041-0101 to OAR 340-041-0340: Tables 101B, and 121B, and Figures 130B, 151B, 160B, 170B, 220B, 230B, 271B, 286B, 300B, 310B, 320B, and 340B, may not exceed 13.0 degrees Celsius (55.4 degrees Fahrenheit) at the times indicated on these maps and tables;

(b) The seven-day-average maximum temperature of a stream identified as having core cold water habitat use on subbasin maps set out in OAR 340-041-101 to OAR 340-041-340: Figures 130A, 151A, 160A, 170A, 220A, 230A, 271A, 286A, 300A, 310A, 320A, and 340A, may not exceed 16.0 degrees Celsius (60.8 degrees Fahrenheit);

(c) The seven-day-average maximum temperature of a stream identified as having salmon and trout rearing and migration use on subbasin maps set out at OAR 340-041-0101 to OAR 340-041-0340: Figures 130A, 151A, 160A, 170A, 220A, 230A, 271A, 286A, 300A, 310A, 320A, and 340A, may not exceed 18.0 degrees Celsius (64.4 degrees Fahrenheit);

(d) The seven-day-average maximum temperature of a stream identified as having a migration corridor use on subbasin maps and tables OAR 340-041-0101 to OAR 340-041-0340: Tables 101B, and 121B, and Figures 151A, 170A, and 340A, may not exceed 20.0 degrees Celsius (68.0 degrees Fahrenheit). In addition, these water bodies must have coldwater refugia that's sufficiently distributed so as to allow salmon and steelhead migration without significant adverse effects from higher water temperatures elsewhere in the water body. Finally, the seasonal thermal pattern in Columbia and Snake Rivers must reflect the natural seasonal thermal pattern;

(e) The seven-day-average maximum temperature of a stream identified as having Lahontan cutthroat trout or redband trout use on subbasin maps and tables set out in OAR 340-041-0101 to OAR 340-

041-0340: Tables 120B, 140B, 190B, and 250B, and Figures 180A, 201A, and 260A may not exceed 20.0 degrees Celsius (68.0 degrees Fahrenheit);

(f) The seven-day-average maximum temperature of a stream identified as having bull trout spawning and juvenile rearing use on subbasin maps set out at OAR 340-041-0101 to OAR 340-041-0340: Figures 130B, 151B, 160B, 170B, 180A, 201A, 260A, 310B, and 340B, may not exceed 12.0 degrees Celsius (53.6 degrees Fahrenheit). From August 15 through May 15, in bull trout spawning waters below Clear Creek and Mehlhorn reservoirs on Upper Clear Creek (Pine Subbasin), below Laurance Lake on the Middle Fork Hood River, and below Carmen reservoir on the Upper McKenzie River, there may be no more than a 0.3 degrees Celsius (0.5 Fahrenheit) increase between the water temperature immediately upstream of the reservoir and the water temperature immediately downstream of the spillway when the ambient seven-day-average maximum stream temperature is 9.0 degrees Celsius (48 degrees Fahrenheit) or greater, and no more than a 1.0 degree Celsius (1.8 degrees Fahrenheit) increase when the seven-day-average stream temperature is less than 9 degrees Celsius.

(5) Unidentified Tributaries: For waters that are not identified on the fish use maps and tables referenced in section (4) of this rule, the applicable criteria for these waters are the same criteria as is applicable to the nearest downstream water body depicted on the applicable map.

(6) Natural Lakes: Natural lakes may not be warmed by more than 0.3 degrees Celsius (0.5 degrees Fahrenheit) above the ambient condition unless a greater increase would not reasonably be expected to adversely affect fish or other aquatic life.

(7) Oceans and Bays: Except for the Columbia River above river mile 7, ocean and bay waters may not be warmed by more than 0.3 degrees Celsius (0.5 degrees Fahrenheit) above the ambient condition unless a greater increase would not reasonably be expected to adversely affect fish or other aquatic life.

(8) Natural Conditions Criteria. Where the Oregon Department of Enviromental Quality (Department) determines that the natural thermal potential of all or a portion of a water body exceeds the biologically-based criteria in section (4) of this rule, the natural thermal potential temperatures supersede the biologically-based criteria, and are deemed to be the applicable temperature criteria for that water body.

(9) Cool Water Species: Waters that support cool water species may not be warmed by more than 0.3 degrees Celsius (0.5 degrees Fahrenheit) above the ambient condition unless a greater increase would not reasonably be expected to adversely affect fish or other aquatic life. Cool waters of the State are described on subbasin tables set out in OAR 340-041-0101 to OAR 340-041-0340: Tables 140B, 180B, 201B, and 250B.

(10) Borax Lake Chub: State waters in the Malheur Lake Basin supporting the borax lake chub may not be cooled more than 0.3 degrees Celsius (0.5 degrees Fahrenheit) below the ambient condition.

(11) Protecting Cold Water:

(a) Except as described in subsection (c) of this rule, waters of the State that have summer seven-day-average maximum ambient temperatures that are colder than the biologically based criteria in section (4) of this rule, may not be warmed by more than 0.3 degrees Celsius (0.5 degrees Fahrenheit) above the colder water ambient temperature. This provision applies to all sources taken together at the point of maximum impact where salmon, steelhead or bull trout are present.

(b) A point source that discharges into or above salmon & steelhead spawning waters that are colder than the spawning criterion, may not cause the water temperature in the spawning reach where the physical habitat for spawning exists during the time spawning through emergence use occurs, to increase more than the following amounts after complete mixing of the effluent with the river:

(A) If the rolling 60 day average maximum ambient water temperature, between the dates of spawning use as designated under subsection (4)(a) of this rule, is 10 to 12.8 degrees Celsius, the allowable increase is 0.5 Celsius above the 60 day average; or

(B) If the rolling 60 day average maximum ambient water temperature, between the dates of spawning use as designated under subsection (4)(a) of this rule, is less than 10 degrees Celsius, the allowable increase is 1.0 Celsius above the 60 day average, unless the source provides analysis showing that a greater increase will not significantly impact the survival of salmon or steelhead eggs or the timing of salmon or steelhead fry emergence from the gravels in downstream spawning reach.

(c) The cold water protection narrative criteria in subsection (a) does not apply if:

(A) There are no threatened or endangered salmonids currently inhabiting the water body;

(B) The water body has not been designated as critical habitat; and

(C) The colder water is not necessary to ensure that downstream temperatures achieve and maintain compliance with the applicable temperature criteria.

(12) Implementation of the Temperature Criteria:

(a) Minimum Duties. There is no duty for anthropogenic sources to reduce heating of the waters of the State below their natural condition. Similarly, each anthropogenic point and nonpoint source is responsible only for controlling the thermal effects of its own discharge or activity in accordance with its overall heat contribution. In no case may a source cause more warming than that allowed by the human use allowance provided in subsection (b) of this rule.

(b) Human Use Allowance. Insignificant additions of heat are authorized in waters that exceed the applicable temperature criteria as follows:

(A) Prior to the completion of a temperature TMDL or other cumulative effects analysis, no single NPDES point source that discharges into a temperature water quality limited water may cause the temperature of the water body to increase more than 0.3 degrees Celsius (0.5 Fahrenheit) above the applicable criteria after mixing with either twenty five (25) percent of the stream flow, or the temperature mixing zone, whichever is more restrictive; or

(B) Following a temperature TMDL or other cumulative effects analysis, waste load and load allocations will restrict all NPDES point sources and nonpoint sources to a cumulative increase of no greater than 0.3 degrees Celsius (0.5 Fahrenheit) above the applicable criteria after complete mixing in the water body, and at the point of maximum impact.

(C) Point sources must be in compliance with the additional mixing zone requirements set out in OAR 340-041-0053(2)(d).

(D) A point source in compliance with the temperature conditions of its NPDES permit is deemed in compliance with the applicable criteria.

(c) Air Temperature Exclusion. A water body that only exceeds the criteria set out in this rule when the exceedance is attributed to daily maximum air temperatures that exceed the 90^{th} percentile value of annual maximum seven-day average maximum air temperatures calculated using at least 10 years of air temperature data, will not be listed on the section 303(d) list of impaired waters and sources will not be considered in violation of this rule.

(d) Low Flow Conditions. An exceedance of the biologically-based numeric criteria in section (4) of this rule, or an exceedance of the natural condition criteria in section (8) of this rule will not be considered a permit violation during stream flows that are less than the 7Q10 low flow condition for that water body.

(e) Forestry on State and Private Lands. For forest operations on State or private lands, water quality standards are intended to be attained and are implemented through best management practices and other control mechanisms established under the Forest Practices Act (ORS 527.610 to 527.992) and rules thereunder, administered by the Oregon Department of Forestry. Therefore, forest operations that are in compliance with the Forest Practices Act requirements are (except for the limits set out in ORS 527.770) deemed in compliance with this rule. ODEQ will work with the Oregon Department of Forestry to revise the Forest Practices program to attain water quality standards.

(f) Agriculture on State and Private Lands. For farming or ranching operations on State or private lands, water quality standards are intended to be attained and are implemented through the Agricultural Water Quality Management Act (ORS 568.900 to 568.933) and rules thereunder, administered by the Oregon Department of Agriculture. Therefore, farming and ranching operations that are in compliance with the Agricultural Water Quality Management Act requirements will not be subject to ODEQ enforcement under this rule. ODEQ will work with the Oregon Department of Agriculture to revise the Agricultural Water Quality Management program to attain water quality standards.

(g) Agriculture and Forestry on Federal Lands. Agriculture and forestry activities conducted on federal land must meet the requirements of this rule and are subject to the department's jurisdiction. Pursuant to Memoranda of Agreement with the U.S. Forest Service and the Bureau of Land Management, water quality standards are expected to be met through the development and implementation of water quality restoration plans, best management practices and aquatic conservation strategies. Where a Federal Agency is a Designated Management Agency by the Department, implementation of these plans, practices and strategies is deemed compliance with this rule.

(h) Other Nonpoint Sources. The department may, on a case-by-case basis, require nonpoint sources (other than forestry and agriculture), including private hydropower facilities regulated by a 401 water quality certification, that may contribute to warming of State waters beyond 0.3 degrees Celsius (0.5

degrees Fahrenheit), and are therefore designated as water-quality limited, to develop and implement a temperature management plan to achieve compliance with applicable temperature criteria or an applicable load allocation in a TMDL pursuant to OAR 340-042-0080.

(A) Each plan must ensure that the nonpoint source controls its heat load contribution to water temperatures such that the water body experiences no more than a 0.3 degrees Celsius (0.5 degree Fahrenheit) increase above the applicable criteria from all sources taken together at the maximum point of impact.

(B) Each plan must include a description of best management practices, measures, effluent trading, and control technologies (including eliminating the heat impact on the stream) that the nonpoint source intends to use to reduce its temperature effect, a monitoring plan, and a compliance schedule for undertaking each measure.

(C) The Department may periodically require a nonpoint source to revise its temperature management plan to ensure that all practical steps have been taken to mitigate or eliminate the temperature effect of the source on the water body.

(D) Once approved, a nonpoint source complying with its temperature management plan is deemed in compliance with this rule.

(i) Compliance Methods. Anthropogenic sources may engage in thermal water quality trading in whole or in part to offset its temperature discharge, so long as the trade results in at least a net thermal loading decrease in anthropogenic warming of the water body, and does not adversely affect a threatened or endangered species. Sources may also achieve compliance, in whole or in part, by flow augmentation, hyporheic exchange flows, outfall relocation, or other measures that reduce the temperature increase caused by the discharge.

(ii) Release of Stored Water. Stored cold water may be released from reservoirs to cool downstream waters in order to achieve compliance with the applicable numeric criteria. However, there can be no significant adverse impact to downstream designated beneficial uses as a result of the releases of this cold water, and the release may not contribute to violations of other water quality criteria. Where the Department determines that the release of cold water is resulting in a significant adverse impact, the Department may require the elimination or mitigation of the adverse impact.

(13) Site-Specific Criteria: The Department may establish, by separate rulemaking, alternative site-specific criteria for all or a portion of a water body that fully protects the designated use.

(a) These site-specific criteria may be set on a seasonal basis as appropriate.

(b) The Department may use, but is not limited by the following considerations when calculating site-specific criteria:

(A) Stream flow;

(B) Riparian vegetation potential;

(C) Channel morphology modifications;

(D) Cold water tributaries and groundwater;

(E) Natural physical features and geology influencing stream temperatures; and

(F) Other relevant technical data.

(c) ODEQ may consider the thermal benefit of increased flow when calculating the site-specific criteria.

(d) Once established and approved by EPA, the site-specific criteria will be the applicable criteria for the water bodies affected.

OAR 340-041-0053

Mixing Zones

(1) The Department may allow a designated portion of a receiving water to serve as a zone of dilution for wastewaters and receiving waters to mix thoroughly and this zone will be defined as a mixing zone;

(2) The Department may suspend all or part of the water quality standards, or set less restrictive standards in the defined mixing zone, provided that the following conditions are met:

(a) A point source for which the mixing zone is established may not cause or significantly contribute to any of the following:

(A) Materials in concentrations that will cause acute toxicity to aquatic life as measured by a Department approved bioassay method. Acute toxicity is lethal to aquatic life as measured by a significant difference in lethal concentration between the control and 100 percent effluent in an acute bioassay test. Lethality in 100 percent effluent may be allowed due to ammonia and chlorine only when it is demonstrated on a case-by-case basis that immediate dilution of the effluent within the mixing zone reduces toxicity below lethal concentrations. The Department may on a case-by-case basis establish a zone of immediate dilution if appropriate for other parameters;

(B) Materials that will settle to form objectionable deposits;

(C) Floating debris, oil, scum, or other materials that cause nuisance conditions; and

(D) Substances in concentrations that produce deleterious amounts of fungal or bacterial growths.

(b) A point source for which the mixing zone is established may not cause or significantly contribute to any of the following conditions outside the boundary of the mixing zone:

(A) Materials in concentrations that will cause chronic (sublethal) toxicity. Chronic toxicity is measured as the concentration that causes long-term sublethal effects, such as significantly impaired growth or reproduction in aquatic organisms, during a testing period based on test species life cycle. Procedures and end points will be specified by the Department in wastewater discharge permits;

(B) Exceedances of any other water quality standards under normal annual low flow conditions.

(c) The limits of the mixing zone must be described in the wastewater discharge permit. In determining the location, surface area, and volume of a mixing zone area, the Department may use appropriate mixing zone guidelines to assess the biological, physical, and chemical character of receiving waters, effluent, and the most appropriate placement of the outfall, to protect instream water quality, public health, and other beneficial uses. Based on receiving water and effluent characteristics, the Department will define a mixing zone in the immediate area of a wastewater discharge to:

(A) Be as small as feasible;

(B) Avoid overlap with any other mixing zones to the extent possible and be less than the total stream width as necessary to allow passage of fish and other aquatic organisms;

(C) Minimize adverse effects on the indigenous biological community, especially when species are present that warrant special protection for their economic importance, tribal significance, ecological uniqueness, or other similar reasons determined by the Department and does not block the free passage of aquatic life;

(D) Not threaten public health;

(E) Minimize adverse effects on other designated beneficial uses outside the mixing zone.

(d) Temperature Thermal Plume Limitations. Temperature mixing zones and effluent limits authorized under 340-041-0028(12)(b) will be established to prevent or minimize the following adverse effects to salmonids inside the mixing zone:

(A) Impairment of an active salmonid spawning area where spawning redds are located or likely to be located. This adverse effect is prevented or minimized by limiting potential fish exposure to temperatures of 13 degrees Celsius (55.4 Fahrenheit) or less for salmon and steelhead, and 9 degrees Celsius (48 degrees Fahrenheit) for bull trout;

(B) Acute impairment or instantaneous lethality is prevented or minimized by limiting potential fish exposure to temperatures of 32.0 degrees Celsius (89.6 degrees Fahrenheit) or more to less than 2 seconds);

(C) Thermal shock caused by a sudden increase in water temperature is prevented or minimized by limiting potential fish exposure to temperatures of 25.0 degrees Celsius (77.0 degrees Fahrenheit) or more to less than 5 percent of the cross section of 100 percent of the 7Q10 low flow of the water body; the Department may develop additional exposure timing restrictions to prevent thermal shock; and

(D) Unless the ambient temperature is 21.0 degrees of greater, migration blockage is prevented or minimized by limiting potential fish exposure to temperatures of 21.0 degrees Celsius (69.8 degrees Fahrenheit) or more to less than 25 percent of the cross section of 100 percent of the 7Q10 low flow of the water body.

(e) The Department may request the applicant of a permitted discharge for which a mixing zone is required, to submit all information necessary to define a mixing zone, such as:

(A) Type of operation to be conducted;

(B) Characteristics of effluent flow rates and composition;

(C) Characteristics of low flows of receiving waters;

(D) Description of potential environmental effects;

(E) Proposed design for outfall structures.

(f) The Department may, as necessary, require mixing zone monitoring studies and/or bioassays to be conducted to evaluate water quality or biological status within and outside the mixing zone boundary;

(g) The Department may change mixing zone limits or require the relocation of an outfall, if it determines that the water quality within the mixing zone adversely affects any existing beneficial uses in the receiving waters.

(h) Alternate requirements for mixing zones: For some existing or proposed discharges to some receiving streams, it may not be practical to treat wastewater to meet instream water quality standards at the point of discharge or within a short distance from the point of discharge. Some of these discharges could be allowed without impairing the overall ecological integrity of the receiving streams, or may provide an overall benefit to the receiving stream. This section specifies the conditions and circumstances under which a mixing zone may be allowed by the Department that extends beyond the immediate area around a discharge point, or that extends across a stream width. An alternate mixing zone may be approved if the applicant demonstrates to the Department's satisfaction that the discharge (A) creates an overall environmental benefit, or (B) is to a constructed water course, or (C) is insignificant. The three circumstances under which alternate mixing zones may be established are described further below.

(A) Overall environmental benefit.

(i) Qualifying for alternate mixing zone based on overall environmental benefit: In order to qualify for an alternate mixing zone based on a finding of overall environmental benefit, the discharger must demonstrate to the Department's satisfaction the following:

(I) All practical strategies have been, or will be, implemented to minimize the pollutant loads in the effluent; and

(II) For proposed increased discharges, the current actual discharge and mixing zone does not meet the requirements of a standard mixing zone; and

(III) Either that, on balance, an environmental benefit would be lost if the discharge did not occur, or that the discharger is prepared to undertake other actions that will mitigate the effect of the discharge to an extent resulting in a net environmental benefit to the receiving stream.

(IV) For the purposes of this rule, the term "practical" must include environmental impact, availability of alternatives, cost of alternatives and other relevant factors.

(ii) Studies required and evaluation of studies: In order to demonstrate that, on balance, an environmental benefit will result from the discharge, the following information must be provided by the applicant:

(I) The effluent flow and pollutant loads that are detected or expected in the effluent, by month, both average and expected worst case discharges: The parameters to be evaluated include at a minimum: temperature, biochemical oxygen demand, total suspended solids, total dissolved solids, pH, settleable solids, *E. coli* bacteria, oil and grease, any pollutants listed in Table 20 of this rule division, and any pollutant for which the receiving stream has been designated by the Department as water quality limited; and

(II) Receiving stream flow, by month; and

(III) The expected impact of the discharge, by month, on the receiving stream for the entire proposed mixing zone area for all of the pollutants listed above. Included in this analysis must be a comparison of the receiving stream water quality with the discharge and without the discharge; and

(IV) A description of fish, other vertebrate populations, and macroinvertebrates that reside in, or are likely to pass through, the proposed mixing zone, including expected location (if known), species identification, stage of development, and time of year when their presence is expected. For existing discharges, the applicant must provide the same information for similar nearby streams that are unaffected by wastewater discharges. In addition, any threatened or endangered species in the immediate vicinity of the receiving stream must be identified; and

(V) The expected impact of the discharge on aquatic organisms and/or fish passage, including any expected negative impacts from the effluent attracting fish, where that is not desirable; and

(VI) A description of the expected environmental benefits to be derived from the discharge or other mitigation measures proposed by the applicant, including but not limited to improvements in water quality, improvements in fish passage, and improvements in aquatic habitat. If the applicant proposes to undertake mitigation measures designed to provide environmental benefits (e.g., purchasing water or water conservation rights to increase stream flows or establishing stream cover to decrease temperature), the applicant must describe the mitigation measures in detail, including a description of the steps it will take to ensure that the benefits of the mitigation measures are attained and are not lost or diminished over time.

(VII) Some or all of the above study requirements may be waived by the Department, if the Department determines that the information is not needed. In the event that the Department does waive some or all of the above study requirements, the basis for waiving the requirements will be included in the permit evaluation report upon the next permit renewal or modification relating to the mixing zone.

(VIII) Upon request of the Department, the applicant must conduct additional studies to further evaluate the impact of the discharge, which may include whole effluent toxicity testing, stream surveys for water quality, stream surveys for fish and other aquatic organisms, or other studies as specified by the Department.

(IX) In evaluating whether an existing or proposed increase in an existing discharge would result in a net environmental benefit, the applicant must use the native biological community in a nearby, similar stream that is unaffected by wastewater discharges. The Department will consider all information generated as required in this rule and other relevant information. The evaluation will only consider benefits to the native aquatic biological community.

(iii) Permit conditions: Upon determination by the Department that the discharge and mitigation measures (if any) will likely result in an overall environmental benefit, the Department will include appropriate permit conditions to ensure that the environmental benefits are attained and continue. Such permit conditions may include, but not be limited to:

(I) Maximum allowed effluent flows and pollutant loads;

(II) Requirements to maintain land ownership, easements, contracts, or other legally binding measures necessary to assure that mitigation measures, if any, remain in place and effective;

(III) Special operating conditions;

(IV) Monitoring and reporting requirements; and

(V) Studies to evaluate the effectiveness of mitigation measures.

(B) Constructed water course: A mixing zone may be extended through a constructed water course and into a natural water course. For the purposes of this rule, a constructed water course is one that was constructed for irrigation, site drainage, or wastewater conveyance, and has the following characteristics:

(i) Irrigation flows, stormwater runoff, or wastewater flows have replaced natural streamflow regimes;

(ii) The channel form is greatly simplified in lengthwise and cross sectional profiles;

(iii) Physical and biological characteristics that differ significantly from nearby natural streams;

(iv) A much lower diversity of aquatic species than the diversity found in nearby natural streams; and

(v) Effective fish screens if the constructed water course is an irrigation canal.

(C) Insignificant discharges: Insignificant discharges are those that either by volume, pollutant characteristics, and/or temporary nature are expected to have little if any impact on beneficial uses in the receiving stream, and for which the extensive evaluations required for discharges to smaller streams are not warranted. For the purposes of this rule, only filter backwash discharges and underground storage tank cleanups are considered insignificant discharges.

(D) Other requirements for alternate mixing zones: The following are additional requirements for dischargers requesting an alternate mixing zone:

(i) Most discharges that qualify for an alternate mixing zone will extend through the receiving stream until a larger stream is reached, where thorough mixing of the effluent can occur and where the edge of the allowed mixing zone will be located. The portion of the mixing zone in the larger stream must meet all of the requirements of the standard mixing zone, including not blocking aquatic life passage; and

(ii) An alternate mixing zone may not be granted if a municipal drinking water intake is located within the proposed mixing zone, and the discharge has a significant adverse impact on the drinking water source; and

(iii) The discharge will not pose an unreasonable hazard to the environment or pose a significant health risk, considering the likely pathways of exposure; and

(iv) The discharge may not be acutely toxic to organisms passing through the mixing zone; and

(v) An alternate mixing zone may not be granted if the substances discharged may accumulate in the sediments or bioaccumulate in aquatic life or wildlife to levels that adversely affect public health, safety or welfare, aquatic life, wildlife, or other designated beneficial uses; and

(vi) In the event that the receiving stream is water quality limited, the requirements for discharges to water quality limited streams supersede this rule.

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Stats. Implemented: ORS 468B.030, 468B.035, 468B.048
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II. POTENTIAL NEAR-STREAM LAND COVER IN THE WILLAMETTE BASIN FOR TEMPERATURE TOTAL MAXIMUM DAILY LOADS (TMDLS)

State of Oregon Department of Environmental Quality

Water Quality Division
Oregon Department of Environmental Quality

(January 2004)

Preface

This document is one component of work by the Oregon Department of Environmental Quality to support development of water quality improvement plans in the Willamette Basin. Specifically, this document supports the development of surrogate measures used in temperature Total Maximum Daily Loads in the Willamette Basin, as required under 40 CFR 130 Federal Clean Water Act.

Pamela Wright, a riparian ecologist, was the primary author of this document.

For more information about this document or other aspects of determining Total Maximum Daily Loads for waters of the Willamette Basin, please contact:

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Also please refer to ODEQ's Willamette Basin TMDL webpage: http://www.deq.state.or.us/wq/willamette/WRBHome.htm .

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Introduction

Potential near-stream land cover is an aspect of stream temperature that is critical to determining temperature Total Maximum Daily Loads (TMDLs) for surface waters in the Willamette Basin. Potential near-stream land cover is commonly referred to as system potential vegetation. In this document the Oregon Department of Environmental Quality (ODEQ) explains the methodology and analysis results for predicting potential near-stream land cover in the basin. The work presented in this document reflects the analysis conducted by ODEQ and knowledge from local experts from outside the agency that reviewed and gave comments regarding the analysis and assumptions made from the analysis. A list of experts who participated in this process is available in Appendix 1. ODEQ also provides documentation of possible model scenarios to predict vegetation distribution given a range of potential near-stream land cover for various riparian environments in the Willamette Basin. The potential near-stream land cover approach described in this document applies to ten of the twelve subbasins in the Basin: Clackamas, Middle Willamette, Upper Willamette, North Santiam, South Santiam, McKenzie, Middle Fork Willamette, Coast Fork Willamette, Yamhill, and Molalla-Pudding. The Tualatin and Lower Willamette subbasin potential near-stream land cover approach is described in the 2001 Tualatin Subbasin TMDL, Appendix A: Temperature Technical Analysis, Tualatin River Subbasin Vegetation Conditions section starting on page A-6, http://www.deq.state.or.us/wq/TMDLs/Tualatin/AppendixA.pdf .

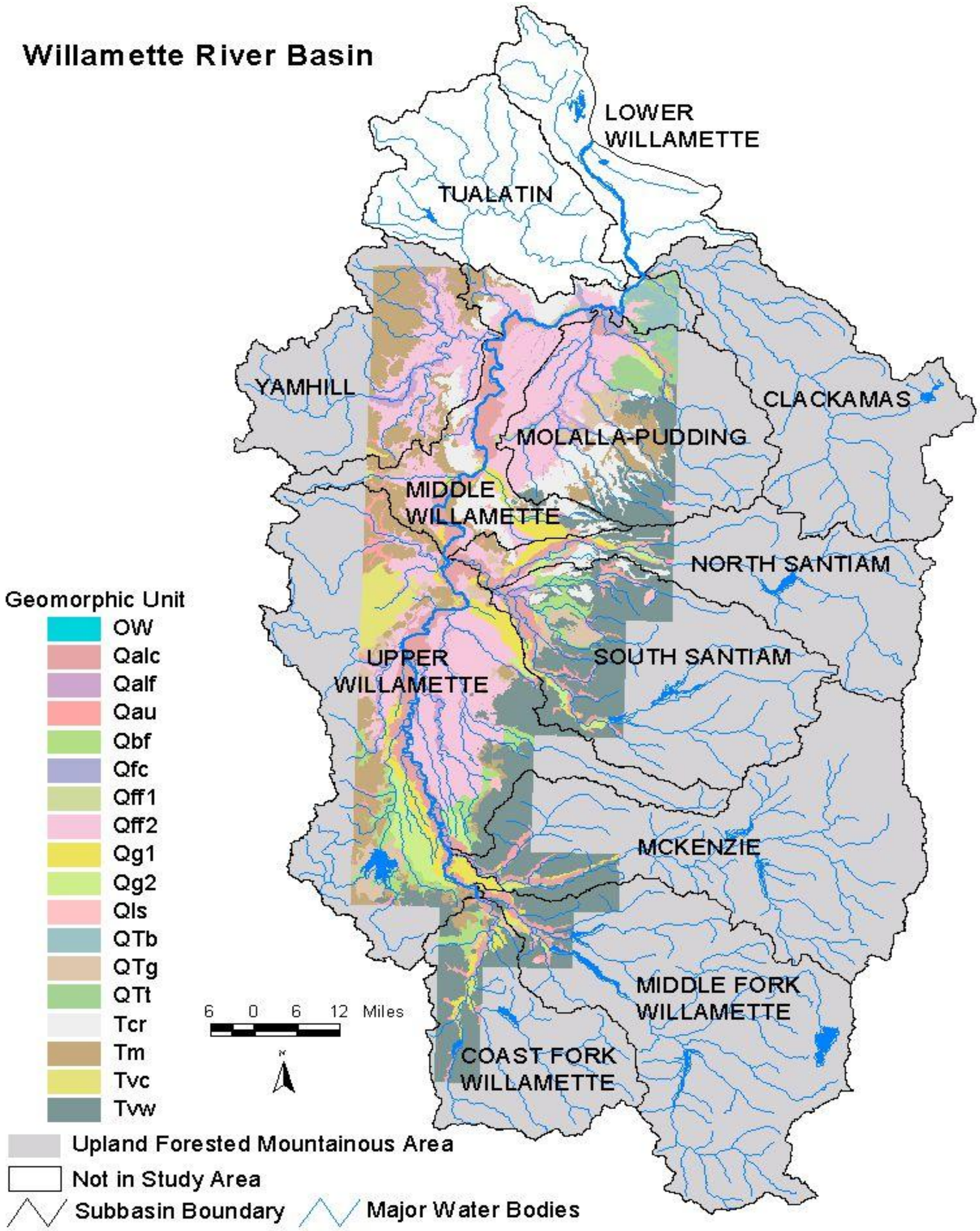
Temperature in many Willamette Basin streams currently exceeds the temperature criteria in Oregon's temperature standard. Riparian vegetation is known to be one of the primary factors controlling stream temperature (Boyd and Sturdevant, 1997) http://www.deq.state.or.us/wq/standards/WQStdsTempStdSciBasis.pdf . ODEQ needs to determine potential near-stream land cover, or system potential vegetation, and use this information to predict stream temperatures in the absence of anthropogenic heat. The potential near-stream land cover is the basis of the load allocation for nonpoint source sectors of heat. This methodology is therefore the basis for preparing system potential vegetation and shade targets for the temperature TMDLs. The shade targets developed take into account a natural disturbance regime that is reflected in the diversity of species composition derived for each geomorphic unit and upland forest.

The Willamette Valley is bounded on the east by the Cascade Range, and by the Coast Range on the west. To predict potential near-stream land cover in the upland forested mountainous areas, ODEQ is using the plant associations developed by the US Forest Service for the Willamette Basin (Logan, et.al. 1987).

Currently, there are no plant association data sets available for the Willamette Valley bottom, similar to what the US Forest Service has compiled for the upland forest mountainous area. For the valley, ODEQ is using landscape level environmental data (geomorphology, ecoregions, geology, soils, ODFW 1998 Willamette Vegetation, in-field current conditions) and a historic 1850's vegetation layer developed from notes of General Land surveys to predict potential near-stream land cover. ODEQ's objective is not to model a particular point in history, but to use historic data to understand the relationship between the relatively undisturbed vegetation of the mid-1800s and the corresponding environments that currently exist along the various streams in the Willamette Valley. ODEQ is using that understanding, information about plant physiology and silviculture, and environmental data to predict future potential near-stream land cover.

The Willamette Valley bottom potential near-stream land cover is assigned a vegetation component defined by the geomorphic unit; Figure 1 below illustrates the extent of the upland forest coverage provided by the US Forest Service and the geomorphic unit coverage for the valley bottom.

Figure 1 Willamette Basin potential near-stream land cover area for stream temperature modeling of the upland forest mountainous area and Willamette Valley, Oregon.



In addition to describing ODEQ's objectives, methodology, and results of the technical analysis, this document includes general "rules" and principles that other entities can use for implementing potential near-stream land cover to improve water quality.

Background and Objectives

The process of developing data on potential near-stream land cover is specific to the context in which the data are used in ODEQ's TMDL methodology. In this context, potential near-stream land cover is defined as that which can grow and reproduce on a site given plant biology, site elevation, soil characteristics, and local climate. Potential near-stream land cover does not include considerations for resource management, human use, or other human disturbance, however natural disturbance regimes (i.e. fire, disease, wind-throw, etc.) are accounted for in this definition. The ODEQ assumes that potential near-stream land cover types (as defined) survive and recover from natural disturbance events.

Oregon water temperature criteria's limit anthropogenic warming to a small amount of no more than 0.3ºC when specific numeric criteria are exceeded. This condition is one in which stream warming related to human activities is minimized. Because near-stream land cover is a controlling factor in stream temperature regimes, the condition and health of land cover is a primary parameter considered in determining the temperature TMDL. Reversing or removing human disturbance from near-stream land cover is a pathway for compliance with Oregon's water temperature standard even when the numeric temperature criteria are not met.

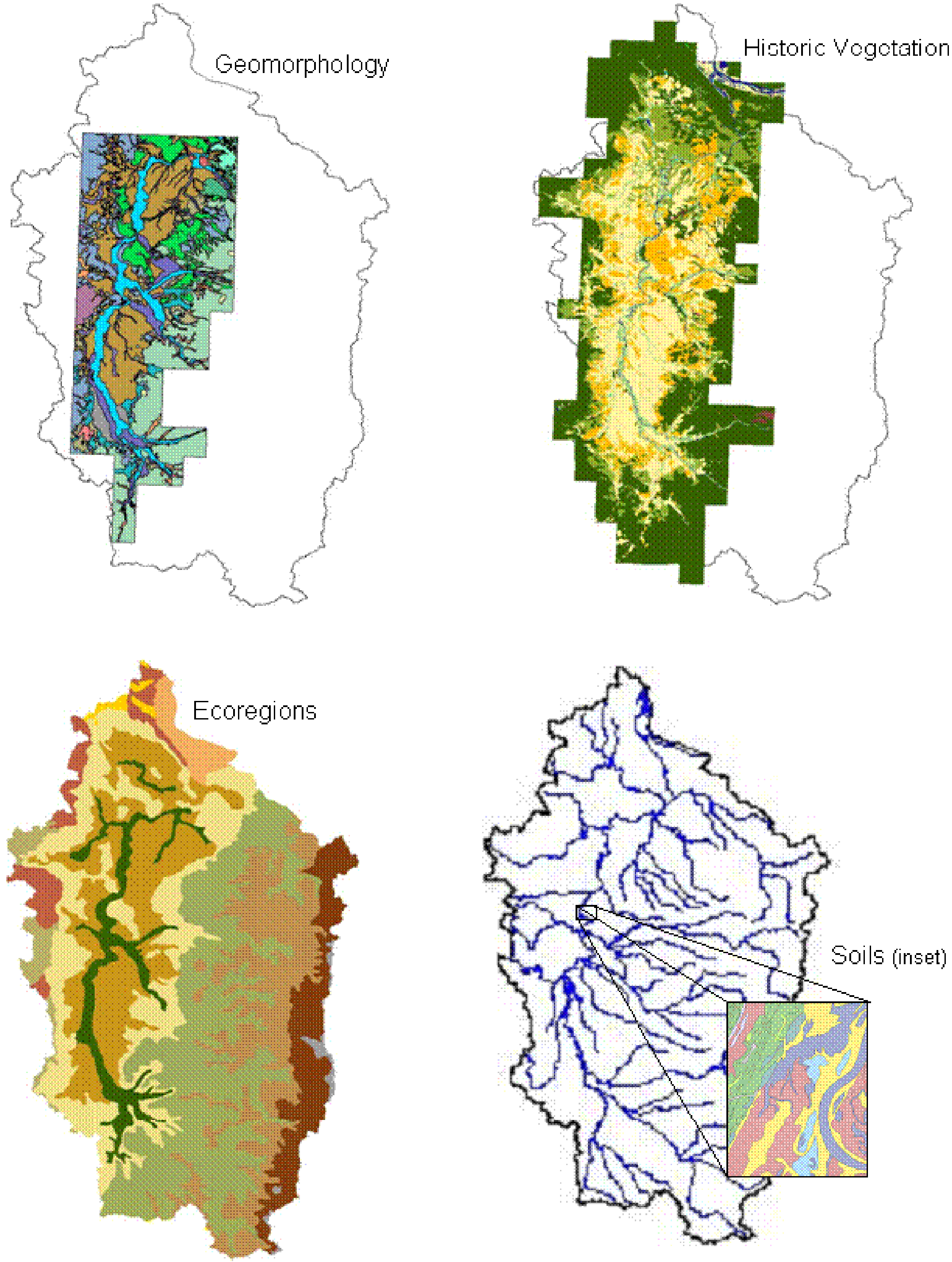
Developing potential near-stream land cover can often be complex because natural systems are highly variable. ODEQ has developed simple rules to determine potential near-stream land cover data sets based on physical characteristics and clearly stated assumptions. ODEQ acknowledges that determining the potential near-stream land cover type and distribution for some areas is not easily done. This is particularly true for the Willamette Valley bottom, where vegetation has been removed near low gradient streams altering channels by constructing dikes and revetments. Literature on the land cover potential and local knowledge in the universities and federal and state agencies is limited. Consequently, for areas where land cover potential is not documented in the literature or evident in ground level studies and data, ODEQ is using a range of land cover types and attributes in the TMDL.

Methodology

The Analysis

Step 1. Geomorphic units, geology, soils, ODFW 1998 Willamette Vegetation, ecoregions, and historic 1850's vegetation maps, were examined to assess the availability of data and to understand the variability in the Basin, Figure 2.

Figure 2 Data sets used in the analysis, from clockwise upper left: geomorphology, historic vegetation, ecoregions, and soils (inset near Willamette River)



Step 2. Using the existing data sets, together with ground level riparian data collected by ODEQ in 2000 and 2001, ODEQ selected a set of 30 streams that represent the various conditions that exist within the Willamette Valley. The frequency of occurrence of factors that would influence vegetation height and canopy density for each type of stream throughout the Willamette Valley was quantified by geomorphic unit. The water bodies selected for this analysis are representative of the Willamette Valley and include the Willamette River, it's major tributaries, and streams of large and small watersheds (4th, 5th and 6th level hydrologic units). These waterbodies represent a range of geomorphic surfaces and other environmental conditions, and streams that are highly- to relatively little-altered from historic conditions. The sampled water bodies include the McKenzie, South Santiam, Pudding, Yamhill, Long Tom, Row, Mohawk, Mary's, Calapooia, and Luckiamute Rivers; Thomas, Crabtree, Mosby, Rickreall, Muddy, West Muddy, Oak, Mill, Flat, Lake, Patterson, Howell Prairie, Palmer, Ash, N. Fork Ash, Berry, and Beaver Creeks; and Walton and Sucker Sloughs. Each water body was sampled to 300 feet upland from the left bank and right bank. A Geographic Information System (GIS) was used to clip, intersect, and manage environmental data.

Step 3. Analysis of geomorphology, ecoregions, geology, soils, ODFW 1998 Willamette Vegetation, and 1850s vegetation data sets examined the near-stream land cover along water bodies of different environments and characteristics. The goal was to assess the relationship between tree stands and other environmental factors along 1850s Willamette Valley water bodies. Based on this assessment, ODEQ estimated which environments supported large coniferous trees, versus smaller deciduous trees, and environments that supported dense tree stands (forest) compared to sparse trees (savannas) or no trees (prairie). This approach does not attempt a return to historic conditions, but rather to establish what tree species are suitable to specific environments and determine the size of trees that may grow in a given area.

Step 4. ODEQ invited experts from outside the agency to review the analysis and assumptions made from the analysis at this stage. Reviewers, listed in Appendix A, provided suggestions that were incorporated into the final analysis to quantify the acreage for the historic vegetation of each type of geomorphic surface and soil drainage, as indicated in Table 1.

Table 1. Proportions of forest, savanna and prairie to be used in temperature models to quantify potential near-stream land cover by geomorphic unit

Geomorphic unit[1]	Sampled streams dominated by geomorphic unit (surface)	Vegetation structure	Acres	Model Scenario: Tree Distribution
Qff1	Lower Mainstem Willamette	Forest	154	0.81
		Savanna	97	0.19
		Prairie	0	0.00
		Total	**251**	**1.00**
Qfc	Lower Mainstem Willamette	Forest	20	0.56
		Savanna	148	0.44
		Prairie	0	0.00
		Total	**168**	**1.00**
Qalc	Lower Willamette	Forest	7973	0.80
		Savanna	1132	0.17
		Prairie	1393	0.03
		Total	**10498**	**1.00**
Qg1	Mill Cr.	Forest	260	0.41
		Savanna	1196	0.44
		Prairie	646	0.15

Geomorphic unit[1]	Sampled streams dominated by geomorphic unit (surface)	Vegetation structure	Acres	Model Scenario: Tree Distribution
		Total	**2102**	**1.00**
Qau	Mohawk, upper Luckiamute, upper Oak Cr., middle Thomas	Forest	1337	0.60
		Savanna	288	0.23
		Prairie	811	0.17
		Total	**2436**	**1.00**
Qalf	Pudding, Muddy Cr, Marys, Yamhill, SF Yamhill, Calapooia	Forest	3112	0.52
		Savanna	1150	0.28
		Prairie	2806	0.20
		Total	**7068**	**1.00**
Qff2	Berry Cr., Ash & NF Ash Cr. , upper Muddy (east), upper Lake Cr.	Forest	2729	0.43
		Savanna	2261	0.35
		Prairie	4049	0.22
		Total	**9039**	**1.00**
Qbf	Long Tom, upper Amazon, upper Crabtree Cr.	Forest	1170	0.47
		Savanna	479	0.30
		Prairie	1381	0.23
		Total	**3030**	**1.00**
Qg2	Amazon Cr., Flat Cr.	Forest	40	0.08
		Savanna	0	0.46
		Prairie	446	0.46
		Total	**486**	**1.00**
Tvc	Headwaters Rickreall Cr.	Forest	29	0.60
		Savanna	104	0.39
		Prairie	4	0.01
		Total	**137**	**1.00**
QTg	Small portions of upper Rickreall, Marys, Beaver Cr.	Forest	387	0.77
		Savanna	42	0.14
		Prairie	102	0.09
		Total	**531**	**1.00**
Tvw	Upper Thomas, upper Crabtree, Headwaters Muddy Cr (east)	Forest	510	0.57
		Savanna	390	0.39
		Prairie	220	0.04
		Total	**1120**	**1.00**
Tcr	Upper Mill Cr.	Forest	121	0.63
		Savanna	972	0.27
		Prairie	302	0.10
		Total	**1395**	**1.00**

Geomorphic unit[1]	Sampled streams dominated by geomorphic unit (surface)	Vegetation structure	Acres	Model Scenario: Tree Distribution
Tm	Upper Ash & NF Ash Cr, upper Berry Cr.	Forest	175	0.56
		Savanna	511	0.39
		Prairie	85	0.05
		Total	**771**	**1.00**
QTt	Small sample size (10 ac)	Forest	2	
		Savanna	8	
		Prairie	0	
		Total	**10**	

[1]Geomorphic units are described in Appendix 4.

Step 5. A data matrix was examined to identify the frequency of occurrence among environmental factors such as soil type, geomorphic unit, and the 1850s vegetation types. This information is found in Appendix 3.

Step 6. ODEQ developed tables identifying the dominant paths of near-stream land cover, specifically mixed conifer-hardwood forest, hardwood forest, savanna, and prairie. ODEQ and other agencies ground-verified existing vegetation during TMDL fieldwork in 2000 and 2001, and also verified it with the US Fish and Wildlife Service wetlands inventory and current vegetation maps (ODFW's 1998 Willamette Vegetation coverage). The successional path of the various 1850s vegetation types was projected and combined to produce a range of potential near-stream land cover types to be modeled for each geomorphic surface. The shade produced by the potential near-stream land cover is a surrogate target for the TMDL. Also, a healthy near-stream land cover will support important ecological processes associated with riparian vegetation.

Step 7. The final step in the analysis was to develop a set of "rules" for predicting potential near-stream land cover based on environmental conditions. These rules are intended to guide the TMDL temperature model simulations for potential land cover. Species composition for the various ecoregions in the Willamette Valley will be based on ecological knowledge of plant communities and historic vegetation. The corresponding tree heights will be estimated from current forest inventory plots for the Willamette Basin. Tree heights are listed Appendix 2.

Data Sources and Scale

ODEQ analyzed sources of data that have been peer-reviewed and published, in addition to field observations conducted by ODEQ. Data sources are available in an electronic format that can be used with Arcview GIS software by ESRI. Each GIS data source was clipped to 300 feet of the right and left bank.

A map of ecoregions by USGS-EPA provided the broadest scale environmental data. Ecoregions are vegetation classifications derived from physical data such as elevation, rainfall, temperature, and geology (Pater, et al. 1998). Ecoregions were used to estimate site productivity for forested areas. These are associated with the Forest Service derived Plant Associations, which are the basis of potential vegetation for Coast and Cascade Mountain Range forests.

The Quaternary geology map and report (USGS, 2001) provided information on the dominant geomorphic features and floodplain development for the Willamette Valley. It delineates areas of the Willamette Valley floodplain, older terraces, Missoula Flood Deposits, and other geomorphic surfaces that influence vegetation.

Soils maps were used from County Soil Surveys developed by the USDA Soil Conservation Service (SCS). Soil drainage was available from the SCS database.

The source of the historic, 1850s vegetation is a map and species list compiled by the Natural Heritage Program and Nature Conservancy from records of the General Land Office Surveyors, 1851 to 1865. Notes of their surveys along transects of section lines provide descriptions of streams and vegetation including tree species and size identification at each section corner.

Ecoregions were mapped at the coarsest scale, while soils were mapped at the finest scale. Geomorphology was mapped at relatively coarse scales, and historic vegetation was mapped at an intermediate scale.

Range and Assumptions for Modeling Natural Variability

An analysis that seeks to describe the relationship between plants and their physical environment must account for known natural spatial and temporal variability, and also for uncertainty. ODEQ used a level of uncertainty and expected variability to determine the range of potential land cover for use in modeling stream temperatures. To achieve this, ODEQ randomly distributed the range of potential vegetation types over each geomorphic surface.

Various researchers on historic fire disturbance in the Willamette Valley have drawn conclusions on the frequency, extent, and ignition sources of fires prior to Euro-American settlement. The 1850s vegetation reported in General Land Office (GLO) Survey Notes reflects recent disturbance, including fires that may have resulted from Native American or Euro-American activity, and from lightning strikes. To consider relatively undisturbed vegetation for the purpose of modeling stream temperatures, ODEQ estimated a range of potential vegetation cover given a level of disturbance. The level of disturbance is based on the belief that there are more trees today than in the 1850s due to a reduction in fire disturbance.

Savannas and prairies of the 1850s were maintained primarily by fire. Now these areas have soil and water levels capable of supporting more trees than existed at the time of the GLO surveys. Areas that were forests in the 1850s, have the potential to be forest again. Considering current knowledge about succession, ODEQ estimates that today the potential vegetation of areas that were savanna in the 1850s is half forest and half savanna. For areas that were prairies in the 1850s, ODEQ estimate the potential vegetation to be half savanna and half prairie.

Tree heights for hardwood and conifer species are estimated from the published literature for high quality site conditions, Appendix 2. For modeling purposes, ODEQ will assign a percent density canopy cover to each of the vegetation structures. For forested areas ODEQ has assigned a tree density canopy cover of 85 percent, 50 percent for savanna, and 0 percent for prairie. Density is defined as the canopy closure. ODEQ assumes that stands designated as coniferous in the 1850s GLO survey data, Appendix C, were mixed conifer-hardwoods in the riparian areas, because pure conifer riparian stands are rare or nonexistent in the Willamette Valley riparian area.

For Willamette TMDL development, ODEQ modeled an expected range of variability in the coniferous upland riparian areas to account for the patchy nature of riparian vegetation. To calculate the expected range, ODEQ determined the potential vegetation from US Forest Service Plant Association Guides. Based on literature values for natural disturbance in forest stands (Teensma, 1990), ODEQ assumes that at any given time about 25% of the near-stream vegetation would be disturbed.

Results of GIS Analysis and Planned Model Scenarios

The results of the analysis, summarized in Figure 3 and in Appendix 3, suggest that three geomorphic surfaces dominate the fluvial and riparian environments of the Willamette Valley bottom, the Willamette River floodplain deposits (Willamette River and major tributaries), alluvium of smaller streams, and the main body of the Missoula Flood deposits (medium and small streams).

Figure 3 1850s General Land Survey Office Vegetation (forest, savanna, or prairie) by geomorphic surface

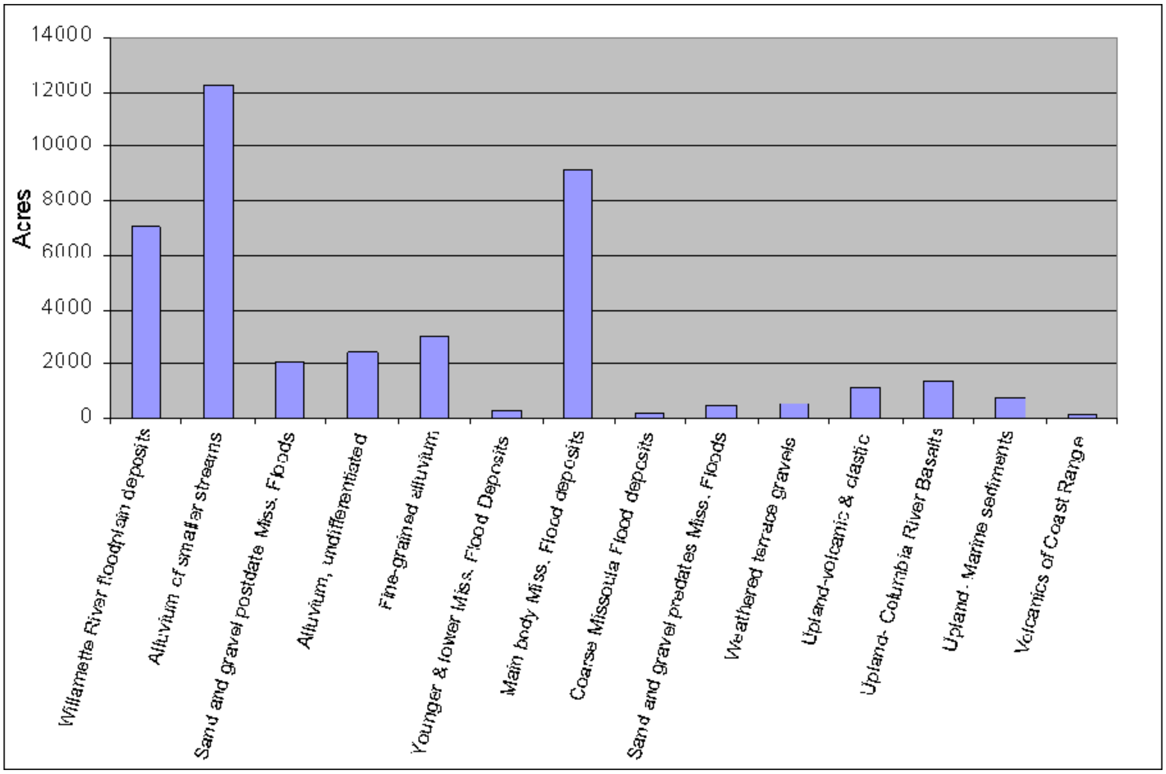
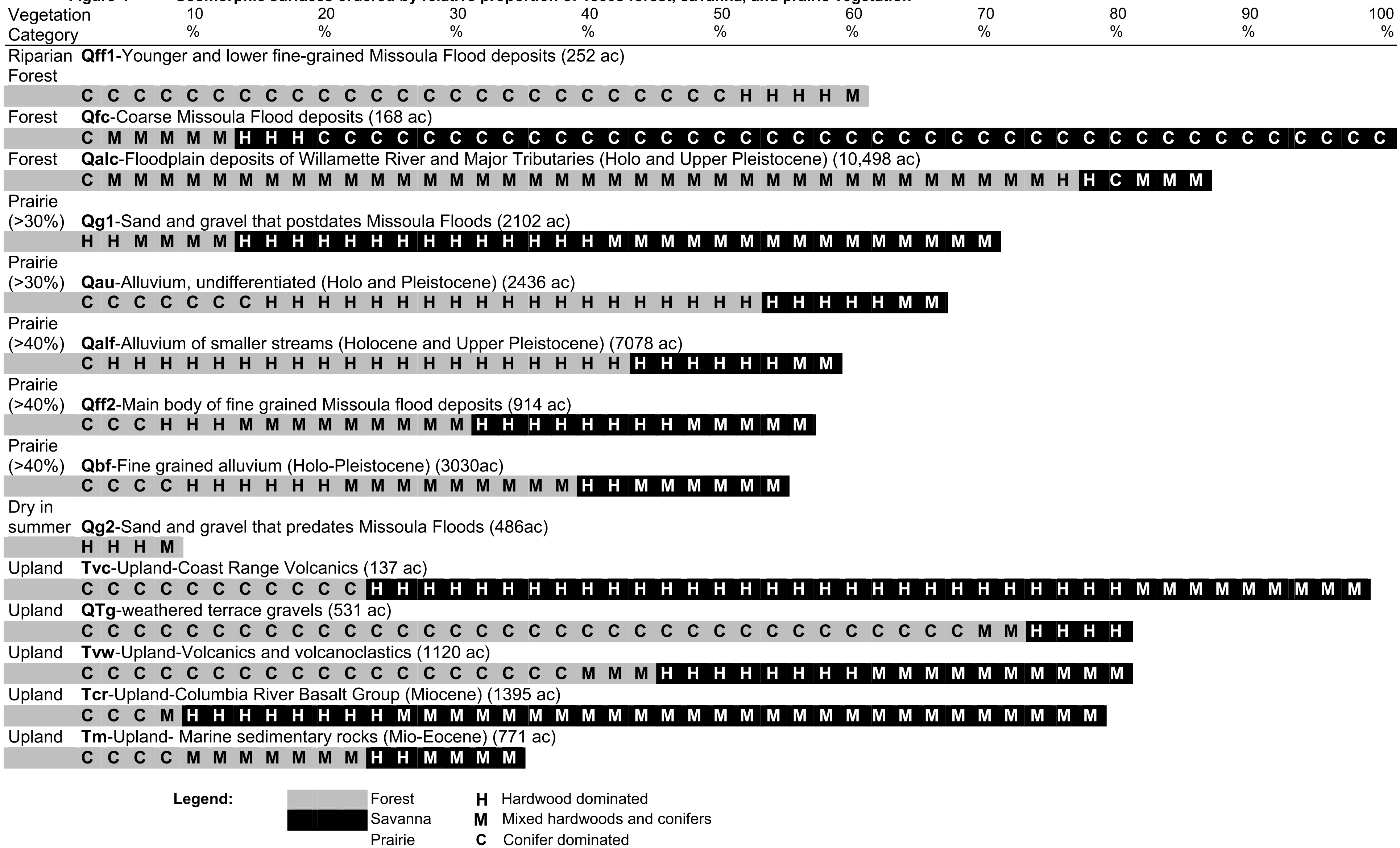


Figure 4 **Geomorphic surfaces ordered by relative proportion of 1850s forest, savanna, and prairie vegetation**



The historic vegetation for all geomorphic surfaces within the Willamette Valley, summarized in Figure 4, indicates that although there is a continuum of relationships between vegetation structure (forest, savanna, and prairie), and that the geomorphic surfaces can be grouped into four broad categories. The first category is geomorphic surfaces dominated by forest (Qff1, Qfc, Qalc). The second is geomorphic surfaces that were dominated by forest or savanna, and had considerable non-forest (prairie) vegetation (Qg1, Qau, Qalf, Qff2, and Qbf). The third category is a geomorphic surface that had 90% prairie, and dry streams in summer (Qg2). The fourth category is geomorphic surfaces in the upland areas (Tvc, QTg, Tvw, Tcr, and Tm). As already noted, for upland surfaces US Forest Service Plant Associations will be used where available, rather than the 1850 vegetation mapped upland surfaces. The Willamette Valley geomorphic surfaces in Figure 4 are ordered from those with the greatest proportion of forest and savanna (tree covered) when surveyed in the 1850s to those with the greatest proportion of prairie (non tree covered) (Qg2). Figure 4 also indicates the proportion of hardwoods (H) versus mixed conifer-hardwood stands (M) for forest and savanna vegetation types. Average tree heights for conifer stands are greater than for mixed conifer-hardwood stands, which are greater than for hardwood stands.

Analysis indicates that forest dominated three geomorphic surfaces in the 1850s: Qalc, Qff1, and Qfc. The vast majority of the 7498 acres of these geomorphic types occur within or adjacent to the active floodplain of the Willamette River and major tributaries. Qalc are the recent floodplain deposits of the Willamette River and its major tributaries. Qff1 are fine-grained Missoula Flood deposits, and Qfc are coarse Missoula Flood deposits. Qff1 and Qfc occur adjacent to Qalc along the lower Willamette River. Additional information about geomorphic types is provided in Appendix 4.

Forest and savanna dominated five geomorphic surfaces, historically, though four surfaces had a considerable proportion (30 to 46 percent) of prairie vegetation, Qalf, Qff2, Qbf, and Qfb. Qalf is alluvium of relatively small streams, Qff2 is the main body of Missoula Flood deposits, and Qbf is made of fine-grained alluvium deposits. The data indicates that 42 to 46 percent of the Qalf, Qff2, and Qfb units were prairie at the time of the GLO surveys. Together Qalf, Qff2, and Qbf made up the largest area (14,442 acres) of our sampled streams, reflecting the historic vegetation of the small and medium sized valley bottom streams, Figure 3.

Prairie units account for 30-34 percent of the landscape, and native prairie openings are considered an important part of the Willamette Valley ecosystem. The best function of these areas is to remain as native prairie rather than be planted with trees. According to mapping by Christy, et al, 1997, the geomorphic surface Qg2, sand and gravel, that pre-dates the Missoula Floods, had 90% prairie vegetation in the 1850s. The two streams sampled on this surface, Amazon Cr. and Flat Cr., historically ran dry in the summer with water flowing subsurface.

The surfaces of the Cascade foothills and Coast Ranges were primarily forested in the 1850s. Where data are available, the USFS plant associations will be used to determine potential land cover for these upland coniferous forest landforms. For purposes of modeling, the upland coniferous forest vegetation types presented in Appendix 2 will be used.

Rules for Developing Potential Near-Stream Land Cover for Modeling Stream Temperature

The rules that follow document the logic for specific riparian vegetation inputs for modeling to predict stream temperature correlated with potential near-stream land cover for the Willamette Basin, except for the Tualatin and Lower Willamette Subbasins. The proportion of vegetation types listed in Table 1 were distributed over each appropriate geomorphic unit and inserted into the temperature model. The temperature model potential near-stream land cover was defined for each 50 foot by 100 foot sampled polygon. The potential near-stream land cover lookup table used in the temperature model to define each polygon is provided in Appendix 5.

Shade targets defining the effective shade for each geomorphic unit have been developed and apply to all streams within the Willamette Basin TMDL analysis area. The shade targets are presented in the form of a shade-curve for each geomorphic unit and the upland forest mountainous area, they are based on the water bodies measured bankful width and aspect, Appendix 6. Shade-curves follow the rules presented for developing potential near-stream land cover, below. Shade-curves may be used to determine the appropriate potential effective shade for unmodeled streams, based on the extent of the specific geomorphic units for the water body.

1. In upland coniferous forests, large conifers are the potential near-stream land cover. The upland coniferous forest is defined as the area within the Willamette Basin outside of the geomorphic unit GIS coverage. Species composition and tree heights used are from the forested plant associations developed by the U. S. Forest Service (Logan, et. al. 1987).

2. Where native Willamette Valley wet and dry prairies remain well-established, native prairie ecosystems should be preserved and/or maintained.

3. Willamette Valley geomorphic units for which plant associations have not been developed; the vegetation types should be managed according to the following rules and ranges, after examining the results of temperature modeling. The proportion of hardwood stands and mixed conifer-hardwood stands have been derived from the 1850s GLO Survey vegetation database, Appendix 3. The proportions of forest, savanna, and prairie composition for each geomorphic unit are listed in Table 1.

A. For Qalc, Qff1, and Qfc, which were historically forested geomorphic surfaces, the potential near-stream land cover is primarily mixed conifer hardwood forest.

- For Qalc (Lower Willamette), ODEQ will model forest cover at 80%, savanna 17%, and prairie 3%. For forestland cover, the portion of conifer is 4%, the portion of mixed hardwood-conifer is 93% and the portion of hardwoods is 3%. For savanna land cover, the portion of mixed hardwood-conifer is 80%, and the portion of hardwoods is 20% (Appendix B).

- For Qff1 (Lower Mainstem Willamette), ODEQ will model forest cover at 81%, savanna 19% and no prairie. For forestland cover, the portion of conifer is 84%, the portion of mixed hardwood-conifer is 3%, and the portion of hardwoods is 13%. For savanna land cover, the portion of mixed hardwood-conifer is 60%, and the portion of hardwoods is 40%.

- For Qfc (Lower Mainstem Willamette), ODEQ will model forest at 56%, savanna 44% and no prairie. For forestland cover, the portion of conifer is 15%, and the portion of mixed hardwood-conifer is 85%. For savanna land cover, the portion of conifer is 93%, and the portion of hardwoods is 7%.

B. The Qg1, Qau, Qalf, Qff2, Qbf, and Qg2 geomorphic units historically had primarily forest and savanna vegetation, but also had considerable prairie. For these units, ODEQ will model forest, savanna and prairie similar to historic conditions and an increased tree cover based on knowledge of current vegetation and soil conditions.

- For Qg1 (Mill Creek), ODEQ will model forest cover at 41%, 44% savanna, and 15% prairie. For forestland cover, the portion of conifer is 8%, the portion of mixed hardwood-conifer is 59% and the portion of hardwoods is 33%. For savanna land cover, the portion of mixed hardwood-conifer is 50%, and the portion of hardwoods is 50%.

- For Qau (Mohawk, upper Luckiamute, upper Oak, middle Thomas Creeks), ODEQ will model forest cover at 60%, 23% savanna, and 17% prairie. For forestland cover, the portion of conifer is 29% and the portion of hardwoods is 71%. For savanna land cover, the portion of conifer is 5%, the portion of mixed hardwood-conifer is 17%, and the portion of hardwoods is 78%.

- For Qalf (Pudding, Muddy Cr, Marys, Yamhill, South Fork Yamhill, Calapooia Rivers), ODEQ will model forest at 52%, 28% savanna, and 20% prairie. For forestland cover, the portion of conifer is 4% and the portion of hardwoods is 96%. For savanna land cover, the portion of mixed hardwood-conifer is 22%, and the portion of hardwoods is 78%.

- For Qff2 (Berry, Ash and North Fork Ash Creeks, upper Muddy (east), upper Lake Creek), ODEQ will model forest at 43%, 35% savanna, and 22% prairie. For forestland cover, the portion of conifer is 19%, the portion of mixed hardwood-conifer is 59% and the portion of hardwoods is 22%. For savanna land cover, the portion of conifer is 5%, the portion of mixed hardwood-conifer is 34%, and the portion of hardwoods is 61%.

- For Qbf (Long Tom, upper Amazon, upper Crabtree Cr.), ODEQ will model forest cover at 47%, 30% savanna, and 23% prairie. For forestland cover, the portion of conifer is 21%, the portion of mixed hardwood-conifer is 48% and the portion of hardwoods is 31%. For savanna land cover, the portion of mixed hardwood-conifer is 81%, and the portion of hardwoods is 19%.

C. For Qg2 (Amazon and Flat Creeks), which had 90% prairie vegetation along streams that historically became subsurface in the summer and for which water is currently artificially diverted to maintain summer flows, historic vegetation is probably not a good guideline for modeling potential present day stream temperature. Instead, ODEQ will use nearest adjacent land potential land cover (see Upper Klamath TMDL for example).

D. For the upland geomorphic surfaces, Tvc, QTg, Tvw, Tcr, and Tm, ODEQ will model using U.S. Forest Service plant associations and the Plant Association Group Model, and incorporate a range of land cover using disturbance suggested by the GIS analysis.

- Where plant associations are not available, for Tvc (Rickreall Creek headwaters), ODEQ will model forest at 60%, 39% savanna, and 1% prairie. For forestland cover, the portion of conifer is 21%, the portion of mixed hardwood-conifer is 79%. For savanna land cover, the portion of mixed hardwood-conifer is 26%, and the portion of hardwoods is 74%.

- For QTg (Small portions of upper Rickreall, Marys, Beaver Creek), ODEQ will model forest cover at 77%, 14% savanna, and 9% prairie. For forestland cover, the portion of conifer is 95%, the portion of mixed hardwood-conifer is 4% and the portion of hardwoods is 1%. For savanna land cover, the portion of mixed hardwood-conifer is 90%, and the portion of hardwoods is 10%.

- For Tvw (Upper Thomas, upper Crabtree, and east headwaters Muddy Creeks), ODEQ will model forest cover at 57%, 39% savanna, and 4% prairie. For forestland cover, the portion of conifer is 84%, the portion of mixed hardwood-conifer is 16%. For savanna land cover, the portion of mixed hardwood-conifer is 45%, and the portion of hardwoods is 55%.

- For Tcr (Upper Mill Creek), ODEQ will model forest cover at 63%, 27% savanna, and 10% prairie. For forestland cover, the portion of conifer is 93 %, the portion of mixed hardwood-conifer is 7%. For savanna land cover, the portion of mixed hardwood-conifer is 77%, and the portion of hardwoods is 23%.

- For Tm (Upper Ash, North Fork Ash, and upper Berry Creeks), ODEQ will model forest cover at 56%,39% savanna, and 5% prairie. For forestland cover, the portion of conifer is 40%, and the portion of mixed hardwood-conifer is 60%. For savanna land cover, the portion of mixed hardwood-conifer is 59%, and the portion of hardwoods is 41%.

Principles for Implementing Willamette Valley Potential Near-Stream Land Cover

The implementation of the modeling and analysis of potential land cover types, to meet temperature TMDL requirements, will be based on three principles. This analysis in not intended to provide a blanket prescription for near-stream vegetation, but rather to recommend appropriate management direction for the areas pertinent to each recommendation.

The first principle is to plant trees in places that previously had tree cover, as indicated by the analysis. Areas that were historically forested and are currently not forested are the highest priority for reforestation.

The second principle is that areas that were historically savanna or prairie, but are currently forested, do not offer further opportunities for increasing stream shade. Existing trees should be retained on these areas.

The third principle is that areas that historically had prairie vegetation, due to fire or to soil and moisture conditions, are the lowest priority for establishing of tree cover. The analysis indicates that landscape diversity in the Willamette Valley is important. Maintaining some open areas can be ecologically important; however, other public goals may lead to establishing trees in these open areas.

In general, areas where the greatest difference is observed between historic/potential land cover and current land cover are the areas that provide the greatest opportunity for establishing near-stream vegetation. These areas are ODEQ’s highest priority for improving stream temperature for aquatic life.

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Appendix 1. Scientists Who Participated in Peer Review

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Appendix 2. Tree heights used for modeling coniferous forest, mixed forest (hardwood and conifer), hardwood forest, and prairie.

System Potential Vegetation for Willamette Valley Ecoregion. Savanna tree heights are the same as forest, except the density of the canopy cover is reduced.

Vegetation type	Height (ft)	Density (%)	Overhang (m)	Height (m)
Forest--Mature Coniferous	160	75%	4.9	48.8
Forest--Mature Mixed Conifer-Hardwood	90	75%	3.3	27.4
Forets--Mature Hardwood	67	75%	3.1	20.4
Savanna--Mature Coniferous	160	50%	4.9	48.8
Savanna--Mature Mixed Conifer-Hardwood	90	50%	3.3	27.4
Savanna--Mature Hardwood	67	50%	3.1	20.4
Prairie--Grassland	3	75%	0.0	0.9

System Potential Vegetation for upland forest mountainous area with USFS Plant Associations available (Logan, et. al. 1987). Range for forests with and without disturbance.

Vegetation type		Height (ft)	Density (%)	Overhang (m)	Height (m)
Disturbed	Forest Semi-closed mixed--25% probability	56	25%	2.0	17.1
No Disturbance	Forest--Mature Coniferous-75% probability	160	75%	4.9	48.8

Appendix 3. Geomorphic surface, 1850s vegetation type, and soil drainage acres

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres: Excessively drained	Acres: Well-drained	Acres: Mod.-Well drained	Acres: Poorly drained	Acres: Total Veg.	Hdwd, Con, Mix
Forest	Ash swamp and ash swale, sometimes with alder	Qalc	H			4	8	*12*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	Qalc	H				10	*10*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	Qalc	H				5	*5*	
Forest	Black cottonwood forest, sometimes with willow	Qalc	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	Qalc	H	10	109	13	31	*163*	
Forest	White oak forest, oak brush, or oak and hazel brush	Qalc	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in	Qalc	H					*0*	
Forest	Swamp, composition unknown	Qalc	H		5		5	*10*	
Forest	Willow swamp, sometimes with ninebark, including riparian	Qalc	H		7		27	*34*	234
Forest	Conifer-dominated woodland; various combinations of Douglas	Qalc	C		3	16		*19*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	Qalc	C		90	5	88	*183*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	Qalc	C	3	44	4	10	*61*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	Qalc	C		6			*6*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	Qalc	C		72	4	3	*79*	348
Forest	Red alder-mixed conifer riparian forest; combinations of red	Qalc	M	9	453	62	164	*688*	
Forest	White oak-Douglas fir-ponderosa pine forest	Qalc	M			3		*3*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	Qalc	M	392	4835	534	939	*6700*	7391
	Total Qalc Forest			**414**	**5624**	**645**	**1290**	***7973***	**7973**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	Qalc	H					*0*	
Savanna	White oak savanna	Qalc	H		123	53	52	*228*	
Savanna	White oak-ash savanna	Qalc	H					*0*	
Savanna	White oak-black oak savanna	Qalc	H					*0*	228
Savanna	Douglas fir savanna	Qalc	C		26	9		*35*	
Savanna	Douglas fir-ponderosa pine savanna	Qalc	C			17	6	*23*	
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	Qalc	C	5	35	25		*65*	
Savanna	Ponderosa pine savanna.	Qalc	C	29	19			*48*	
Savanna	FF, but burned, often with scattered trees surviving fire	Qalc	C		10	3		*13*	184
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	Qalc	M					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres					
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	Qalc	M		64	22	60	*146*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	Qalc	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	Qalc	M	20				*20*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	Qalc	M		8	16	4	*28*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	Qalc	M		353	25	45	*423*	
Savanna	White oak-ponderosa pine savanna	Qalc	M	5	83	5		*93*	
Savanna	FFA, but burned, often with scattered trees surviving fire	Qalc	M		10			*10*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	Qalc	M					*0*	720
	Total Qalc Savanna			**59**	**731**	**175**	**167**	***1132***	**1132**
Prairie	Seasonally Wet prairie	Qalc	O				56	*56*	
Prairie	Upland prairie, xeric	Qalc	O	109	1043	128	5	*1285*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	Qalc	O	149	1023	53	489	*0*	
Prairie	Gravel bar	Qalc	O	4	42			*46*	
Prairie	Sand bar and sandy barrens	Qalc	O					*0*	
Prairie	Marsh, composition unknown; includes "Wet meadow"	Qalc	O					*0*	
Prairie	Brush, unknown; includes "thickets" if no species or other	Qalc	O					*0*	
Prairie	Fern openings, fern hills, or open fern land	Qalc	O				6	*6*	
	Total Qalc Prairie			**262**	**2108**	**181**	**556**	***1393***	**10498**
Forest	Ash swamp and ash swale, sometimes with alder	Qalf	H				19	*19*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	Qalf	H			5	156	*161*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	Qalf	H	14		1492	715	*2221*	
Forest	Black cottonwood forest, sometimes with willow	Qalf	H			18	26	*44*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	Qalf	H			260	265	*525*	
Forest	White oak forest, oak brush, or oak and hazel brush	Qalf	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in	Qalf	H					*0*	
Forest	Swamp, composition unknown	Qalf	H					*0*	
Forest	Willow swamp, sometimes with ninebark, including riparian	Qalf	H			7	19	*26*	2996
Forest	Conifer-dominated woodland; various combinations of Douglas	Qalf	C					*0*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	Qalf	C		22	80	9	*111*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres: Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Forest	Douglas fir-white oak (bigleaf maple) forest,	Qalf	C					*0*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	Qalf	C					*0*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	Qalf	C					*0*	111
Forest	Red alder-mixed conifer riparian forest; combinations of red	Qalf	M				5	*5*	
Forest	White oak-Douglas fir-ponderosa pine forest	Qalf	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	Qalf	M					*0*	5
	Total Qalf Forest			**14**	**22**	**1862**	**1214**	***3112***	**3112**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	Qalf	H		3	19	5	*27*	
Savanna	White oak savanna	Qalf	H		115	227	264	*606*	
Savanna	White oak-ash savanna	Qalf	H		53	94	113	*260*	
Savanna	White oak-black oak savanna	Qalf	H					*0*	893
Savanna	Douglas fir savanna	Qalf	C			6		*6*	
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	Qalf	C				4	*4*	
Savanna	Douglas fir-ponderosa pine savanna	Qalf	C					*0*	
Savanna	Ponderosa pine savanna.	Qalf	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	Qalf	C					*0*	10
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	Qalf	M					*0*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	Qalf	M		19	66	12	*97*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	Qalf	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	Qalf	M					*0*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	Qalf	M					*0*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	Qalf	M					*0*	
Savanna	White oak-ponderosa pine savanna	Qalf	M		68	45	37	*150*	
Savanna	FFA, but burned, often with scattered trees surviving fire	Qalf	M					*0*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	Qalf	M					*0*	247
	Total Qalf Savanna			**0**	**258**	**457**	**435**	***1150***	**1150**
Prairie	Seasonally Wet prairie	Qalf	O				1099	*1099*	
Prairie	Upland prairie, xeric	Qalf	O		484	1134	65	*1683*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	Qalf	O		5	5		*10*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres					
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Prairie	Gravel bar	Qalf	O					*0*	
Prairie	Sand bar and sandy barrens	Qalf	O					*0*	
Prairie	Marsh, composition unknown; includes "Wet meadow"	Qalf	O					*0*	
Prairie	Brush, unknown; includes "thickets" if no species or other	Qalf	O		6	4	14	*24*	
Prairie	Fern openings, fern hills, or open fern land	Qalf	O					*0*	
	Total Qalf Prairie			**0**	**495**	**1143**	**1178**	***2816***	**7078**
Forest	Ash swamp and ash swale, sometimes with alder	Qau	H				13	*13*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	Qau	H					*0*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	Qau	H	48	448	210	40	*746*	
Forest	Black cottonwood forest, sometimes with willow	Qau	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	Qau	H					*0*	
Forest	White oak forest, oak brush, or oak and hazel brush	Qau	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in	Qau	H					*0*	
Forest	Swamp, composition unknown	Qau	H					*0*	
Forest	Willow swamp, sometimes with ninebark, including riparian	Qau	H				188	*188*	947
Forest	Conifer-dominated woodland; various combinations of Douglas	Qau	C					*0*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	Qau	C	7	105	140	65	*317*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	Qau	C		9			*9*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	Qau	C		3			*3*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	Qau	C		52	4		*56*	385
Forest	Red alder-mixed conifer riparian forest; combinations of red	Qau	M		5			*5*	
Forest	White oak-Douglas fir-ponderosa pine forest	Qau	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	Qau	M					*0*	5
	Total Qau Forest			**55**	**622**	**354**	**306**	***1337***	**1337**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	Qau	H					*0*	
Savanna	White oak savanna	Qau	H	4	89	114	19	*226*	
Savanna	White oak-ash savanna	Qau	H					*0*	
Savanna	White oak-black oak savanna	Qau	H					*0*	226
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	Qau	C					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres					
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Savanna	Douglas fir savanna	Qau	C					*0*	
Savanna	Douglas fir-ponderosa pine savanna	Qau	C			13		*13*	
Savanna	Ponderosa pine savanna.	Qau	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	Qau	C					*0*	13
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	Qau	M					*0*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	Qau	M					*0*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	Qau	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	Qau	M	8				*8*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	Qau	M		13	8		*21*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	Qau	M				14	*14*	
Savanna	White oak-ponderosa pine savanna	Qau	M		6			*6*	
Savanna	FFA, but burned, often with scattered trees surviving fire	Qau	M					*0*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	Qau	M					*0*	49
	Total Qau Savanna			**12**	**108**	**135**	**33**	***288***	**288**
Prairie	Seasonally Wet prairie	Qau	O				238	*238*	
Prairie	Upland prairie, xeric	Qau	O	17	213	239	90	*559*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	Qau	O					*0*	
Prairie	Gravel bar	Qau	O					*0*	
Prairie	Sand bar and sandy barrens	Qau	O					*0*	
Prairie	Marsh, composition unknown; includes "Wet meadow"	Qau	O				10	*10*	
Prairie	Brush, unknown; includes "thickets" if no species or other	Qau	O		4			*4*	
Prairie	Fern openings, fern hills, or open fern land	Qau	O					*0*	
	Total Qau Prairie			**17**	**217**	**239**	**338**	***811***	**2436**
Forest	Ash swamp and ash swale, sometimes with alder	Qbf	H			7	33	*40*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	Qbf	H					*0*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	Qbf	H					*0*	
Forest	Black cottonwood forest, sometimes with willow	Qbf	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	Qbf	H	2	14	115	193	*324*	
Forest	White oak forest, oak brush, or oak and hazel brush	Qbf	H					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Forest	Wetland, composition unknown; includes "slough" & "swale" in	Qbf	H					*0*	
Forest	Swamp, composition unknown	Qbf	H					*0*	
Forest	Willow swamp, sometimes with ninebark, including riparian	Qbf	H					*0*	364
Forest	Conifer-dominated woodland; various combinations of Douglas	Qbf	C					*0*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	Qbf	C		221	14		*235*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	Qbf	C			15		*15*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	Qbf	C					*0*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	Qbf	C					*0*	250
Forest	Red alder-mixed conifer riparian forest; combinations of red	Qbf	M					*0*	
Forest	White oak-Douglas fir-ponderosa pine forest	Qbf	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	Qbf	M	8	297	157	94	*556*	556
	Total Qbf Forest			**10**	**532**	**308**	**320**	***1170***	**1170**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	Qbf	H			4		*4*	
Savanna	White oak savanna	Qbf	H		24	45	16	*85*	
Savanna	White oak-ash savanna	Qbf	H					*0*	
Savanna	White oak-black oak savanna	Qbf	H					*0*	89
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	Qbf	C					*0*	
Savanna	Douglas fir savanna	Qbf	C					*0*	
Savanna	Douglas fir-ponderosa pine savanna	Qbf	C					*0*	
Savanna	Ponderosa pine savanna.	Qbf	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	Qbf	C					*0*	0
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	Qbf	M					*0*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	Qbf	M					*0*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	Qbf	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	Qbf	M			29		*29*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	Qbf	M		161	49	43	*253*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	Qbf	M				18	*18*	
Savanna	White oak-ponderosa pine savanna	Qbf	M	4	59	27		*90*	
Savanna	FFA, but burned, often with scattered trees surviving fire	Qbf	M					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres					
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Savanna	FFHC, but burned, often with scattered trees surviving fire	Qbf	M					*0*	390
	Total Qbf Savanna			**4**	**244**	**154**	**77**	***479***	**479**
Prairie	Seasonally Wet prairie	Qbf	O				826	*826*	
Prairie	Upland prairie, xeric	Qbf	O	5	103	357	90	*555*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	Qbf	O					*0*	
Prairie	Gravel bar	Qbf	O					*0*	
Prairie	Sand bar and sandy barrens	Qbf	O					*0*	
Prairie	Marsh, composition unknown; includes "Wet meadow"	Qbf	O					*0*	
Prairie	Brush, unknown; includes "thickets" if no species or other	Qbf	O					*0*	
Prairie	Fern openings, fern hills, or open fern land	Qbf	O					*0*	
	Total Qbf Prairie			**5**	**103**	**357**	**916**	***1381***	**3030**
Forest	Ash swamp and ash swale, sometimes with alder	Qfc	H					*0*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	Qfc	H					*0*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	Qfc	H					*0*	
Forest	Black cottonwood forest, sometimes with willow	Qfc	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	Qfc	H					*0*	
Forest	White oak forest, oak brush, or oak and hazel brush	Qfc	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in	Qfc	H					*0*	
Forest	Swamp, composition unknown	Qfc	H					*0*	
Forest	Willow swamp, sometimes with ninebark, including riparian	Qfc	H					*0*	0
Forest	Conifer-dominated woodland; various combinations of Douglas	Qfc	C					*0*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	Qfc	C					*0*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	Qfc	C					*0*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	Qfc	C					*0*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	Qfc	C		3			*3*	3
Forest	Red alder-mixed conifer riparian forest; combinations of red	Qfc	M		3	14		*17*	
Forest	White oak-Douglas fir-ponderosa pine forest	Qfc	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	Qfc	M					*0*	17
	Total Qfc Forest			**0**	**6**	**14**	**0**	***20***	**20**

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres					
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	Qfc	H		11			*11*	
Savanna	White oak savanna	Qfc	H					*0*	
Savanna	White oak-ash savanna	Qfc	H					*0*	
Savanna	White oak-black oak savanna	Qfc	H					*0*	11
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	Qfc	C		39			*39*	
Savanna	Douglas fir savanna	Qfc	C			98		*98*	
Savanna	Douglas fir-ponderosa pine savanna	Qfc	C					*0*	
Savanna	Ponderosa pine savanna.	Qfc	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	Qfc	C					*0*	137
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	Qfc	M					*0*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	Qfc	M					*0*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	Qfc	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	Qfc	M					*0*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	Qfc	M					*0*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	Qfc	M					*0*	
Savanna	White oak-ponderosa pine savanna	Qfc	M					*0*	
Savanna	FFA, but burned, often with scattered trees surviving fire	Qfc	M					*0*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	Qfc	M					*0*	0
	Total Qfc Savanna			**0**	**50**	**98**	**0**	***148***	**148**
Prairie	Seasonally Wet prairie	Qfc	O					*0*	
Prairie	Upland prairie, xeric	Qfc	O					*0*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	Qfc	O					*0*	
Prairie	Gravel bar	Qfc	O					*0*	
Prairie	Sand bar and sandy barrens	Qfc	O					*0*	
Prairie	Marsh, composition unknown; includes "Wet meadow"	Qfc	O					*0*	
Prairie	Brush, unknown; includes "thickets" if no species or other	Qfc	O					*0*	
Prairie	Fern openings, fern hills, or open fern land	Qfc	O					*0*	
	Total Qfc Prairie			**0**	**0**	**0**	**0**	***0***	**168**
Forest	Ash swamp and ash swale, sometimes with alder	Qff1	H					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomorphic surface		Acres					
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	Qff1	H			6	7	*13*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	Qff1	H					*0*	
Forest	Black cottonwood forest, sometimes with willow	Qff1	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	Qff1	H					*0*	
Forest	White oak forest, oak brush, or oak and hazel brush	Qff1	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in	Qff1	H					*0*	
Forest	Swamp, composition unknown	Qff1	H					*0*	
Forest	Willow swamp, sometimes with ninebark, including riparian	Qff1	H			8		*8*	21
Forest	Conifer-dominated woodland; various combinations of Douglas	Qff1	C					*0*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	Qff1	C		16	49	7	*72*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	Qff1	C		36	16	5	*57*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	Qff1	C					*0*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	Qff1	C					*0*	129
Forest	Red alder-mixed conifer riparian forest; combinations of red	Qff1	M			4		*4*	
Forest	White oak-Douglas fir-ponderosa pine forest	Qff1	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	Qff1	M					*0*	4
	Total Qff1 Forest			**0**	**52**	**83**	**19**	***154***	**154**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	Qff1	H			25	14	*39*	
Savanna	White oak savanna	Qff1	H					*0*	
Savanna	White oak-ash savanna	Qff1	H					*0*	
Savanna	White oak-black oak savanna	Qff1	H					*0*	39
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	Qff1	C					*0*	
Savanna	Douglas fir savanna	Qff1	C					*0*	
Savanna	Douglas fir-ponderosa pine savanna	Qff1	C					*0*	
Savanna	Ponderosa pine savanna.	Qff1	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	Qff1	C					*0*	0
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	Qff1	M		7			*7*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	Qff1	M					*0*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	Qff1	M					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres					Hdwd, Con, Mix
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	
Savanna	White oak-black oak-ponderosa pine savanna	Qff1	M					*0*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	Qff1	M			51		*51*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	Qff1	M					*0*	
Savanna	White oak-ponderosa pine savanna	Qff1	M					*0*	
Savanna	FFA, but burned, often with scattered trees surviving fire	Qff1	M					*0*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	Qff1	M					*0*	58
	Total Qff1 Savanna			**0**	**7**	**76**	**14**	***97***	**97**
Prairie	Seasonally Wet prairie	Qff1	O					*0*	
Prairie	Upland prairie, xeric	Qff1	O					*0*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	Qff1	O					*0*	
Prairie	Gravel bar	Qff1	O					*0*	
Prairie	Sand bar and sandy barrens	Qff1	O					*0*	
Prairie	Marsh, composition unknown; includes "wet meadow"	Qff1	O					*0*	
Prairie	Brush, unknown; includes "thickets" if no species or other	Qff1	O					*0*	
Prairie	Fern openings, fern hills, or open fern land	Qff1	O					*0*	
	Total Qff1 Prairie			**0**	**0**	**0**	**0**	***0***	**251**
Forest	Ash swamp and ash swale, sometimes with alder	Qff2	H			25	175	*200*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	Qff2	H				3	*3*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	Qff2	H			26	33	*59*	
Forest	Black cottonwood forest, sometimes with willow	Qff2	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	Qff2	H		26	118	159	*303*	
Forest	White oak forest, oak brush, or oak and hazel brush	Qff2	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in	Qff2	H					*0*	
Forest	Swamp, composition unknown	Qff2	H		6			*6*	
Forest	Willow swamp, sometimes with ninebark, including riparian	Qff2	H		8	26		*34*	605
Forest	Conifer-dominated woodland; various combinations of Douglas	Qff2	C					*0*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	Qff2	C		50	390	72	*512*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	Qff2	C					*0*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	Qff2	C					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres: Excessively drained	Acres: Well-drained	Acres: Mod.-Well drained	Acres: Poorly drained	Total Veg.	Hdwd, Con, Mix
Forest	Mesic mixed conifer forest with mostly deciduous understory	Qff2	C					*0*	512
Forest	Red alder-mixed conifer riparian forest; combinations of red	Qff2	M			6		*6*	
Forest	White oak-Douglas fir-ponderosa pine forest	Qff2	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	Qff2	M	3	419	780	404	*1606*	1612
	Total Qff2 Forest			**3**	**509**	**1371**	**846**	***2729***	**2729**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	Qff2	H		17	5	9	*31*	
Savanna	White oak savanna	Qff2	H		99	430	720	*1249*	
Savanna	White oak-ash savanna	Qff2	H		7	32	63	*102*	
Savanna	White oak-black oak savanna	Qff2	H					*0*	1382
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	Qff2	C		5	88	8	*101*	
Savanna	Douglas fir savanna	Qff2	C		8	84		*92*	
Savanna	Douglas fir-ponderosa pine savanna	Qff2	C			26		*26*	
Savanna	Ponderosa pine savanna.	Qff2	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	Qff2	C					*0*	118
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	Qff2	M					*0*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	Qff2	M			543	121	*664*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	Qff2	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	Qff2	M					*0*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	Qff2	M	7	7	32	13	*59*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	Qff2	M					*0*	
Savanna	White oak-ponderosa pine savanna	Qff2	M		6	16	16	*38*	
Savanna	FFA, but burned, often with scattered trees surviving fire	Qff2	M					*0*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	Qff2	M					*0*	761
	Total Qff2 Savanna			**7**	**149**	**1256**	**950**	***2362***	**2261**
Prairie	Seasonally Wet prairie	Qff2	O		4		1391	*1395*	
Prairie	Upland prairie, xeric	Qff2	O		396	1544	625	*2565*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	Qff2	O		4	9	4	*17*	
Prairie	Gravel bar	Qff2	O					*0*	
Prairie	Sand bar and sandy barrens	Qff2	O					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres					
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Prairie	Marsh, composition unknown; includes "Wet meadow"	Qff2	O				41	*41*	
Prairie	Brush, unknown; includes "thickets" if no species or other	Qff2	O			18	13	*31*	
Prairie	Fern openings, fern hills, or open fern land	Qff2	O					*0*	
	Total Qff2 Prairie			**0**	**404**	**1571**	**2074**	***4049***	**9140**
Forest	Ash swamp and ash swale, sometimes with alder	Qg1	H				3	*3*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	Qg1	H			3	9	*12*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	Qg1	H				36	*36*	
Forest	Black cottonwood forest, sometimes with willow	Qg1	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	Qg1	H			8	6	*14*	
Forest	White oak forest, oak brush, or oak and hazel brush	Qg1	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in	Qg1	H					*0*	
Forest	Swamp, composition unknown	Qg1	H					*0*	
Forest	Willow swamp, sometimes with ninebark, including riparian	Qg1	H				22	*22*	87
Forest	Conifer-dominated woodland; various combinations of Douglas	Qg1	C					*0*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	Qg1	C		11			*11*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	Qg1	C					*0*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	Qg1	C		10			*10*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	Qg1	C					*0*	21
Forest	Red alder-mixed conifer riparian forest; combinations of red	Qg1	M		47		5	*52*	
Forest	White oak-Douglas fir-ponderosa pine forest	Qg1	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	Qg1	M	5	51	36	8	*100*	152
	Total Qg1 Forest			**5**	**119**	**47**	**89**	***260***	**260**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	Qg1	H					*0*	
Savanna	White oak savanna	Qg1	H		105	43	97	*245*	
Savanna	White oak-ash savanna	Qg1	H		39	15	298	*352*	
Savanna	White oak-black oak savanna	Qg1	H					*0*	597
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	Qg1	C					*0*	
Savanna	Douglas fir savanna	Qg1	C			10		*10*	
Savanna	Douglas fir-ponderosa pine savanna	Qg1	C					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Savanna	Ponderosa pine savanna.	Qg1	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	Qg1	C					*0*	10
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	Qg1	M					*0*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	Qg1	M		111		48	*159*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	Qg1	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	Qg1	M					*0*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	Qg1	M		63	109	253	*425*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	Qg1	M			5		*5*	
Savanna	White oak-ponderosa pine savanna	Qg1	M					*0*	
Savanna	FFA, but burned, often with scattered trees surviving fire	Qg1	M					*0*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	Qg1	M					*0*	589
	Total Qg1 Savanna			**0**	**318**	**182**	**696**	***1196***	**1196**
Prairie	Seasonally Wet prairie	Qg1	O				131	*131*	
Prairie	Upland prairie, xeric	Qg1	O		161	240	89	*490*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	Qg1	O		25			*25*	
Prairie	Gravel bar	Qg1	O					*0*	
Prairie	Sand bar and sandy barrens	Qg1	O					*0*	
Prairie	Marsh, composition unknown; includes "Wet meadow"	Qg1	O					*0*	
Prairie	Brush, unknown; includes "thickets" if no species or other	Qg1	O					*0*	
Prairie	Fern openings, fern hills, or open fern land	Qg1	O					*0*	
	Total Qg1 Prairie			**0**	**186**	**240**	**220**	***646***	**2102**
Forest	Ash swamp and ash swale, sometimes with alder	Qg2	H					*0*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	Qg2	H					*0*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	Qg2	H					*0*	
Forest	Black cottonwood forest, sometimes with willow	Qg2	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	Qg2	H			14	11	*25*	
Forest	White oak forest, oak brush, or oak and hazel brush	Qg2	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in	Qg2	H					*0*	
Forest	Swamp, composition unknown	Qg2	H					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres					
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Forest	Willow swamp, sometimes with ninebark, including riparian	Qg2	H					*0*	25
Forest	Conifer-dominated woodland; various combinations of Douglas	Qg2	C					*0*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	Qg2	C					*0*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	Qg2	C					*0*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	Qg2	C					*0*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	Qg2	C					*0*	0
Forest	Red alder-mixed conifer riparian forest; combinations of red	Qg2	M					*0*	
Forest	White oak-Douglas fir-ponderosa pine forest	Qg2	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	Qg2	M		6	6	3	*15*	15
	Total Qg2 Forest			**0**	**6**	**20**	**14**	***40***	**40**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	Qg2	H					*0*	
Savanna	White oak savanna	Qg2	H					*0*	
Savanna	White oak-ash savanna	Qg2	H					*0*	
Savanna	White oak-black oak savanna	Qg2	H					*0*	0
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	Qg2	C					*0*	
Savanna	Douglas fir savanna	Qg2	C					*0*	
Savanna	Douglas fir-ponderosa pine savanna	Qg2	C					*0*	
Savanna	Ponderosa pine savanna.	Qg2	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	Qg2	C					*0*	0
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	Qg2	M					*0*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	Qg2	M					*0*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	Qg2	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	Qg2	M					*0*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	Qg2	M					*0*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	Qg2	M					*0*	
Savanna	White oak-ponderosa pine savanna	Qg2	M					*0*	
Savanna	FFA, but burned, often with scattered trees surviving fire	Qg2	M					*0*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	Qg2	M					*0*	0
	Total Qg2 Savanna			**0**	**0**	**0**	**0**	***0***	**0**

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Prairie	Seasonally Wet prairie	Qg2	O				238	*238*	
Prairie	Upland prairie, xeric	Qg2	O		20	103	85	*208*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	Qg2	O					*0*	
Prairie	Gravel bar	Qg2	O					*0*	
Prairie	Sand bar and sandy barrens	Qg2	O					*0*	
Prairie	Marsh, composition unknown; includes "Wet meadow"	Qg2	O					*0*	
Prairie	Brush, unknown; includes "thickets" if no species or other	Qg2	O					*0*	
Prairie	Fern openings, fern hills, or open fern land	Qg2	O					*0*	
	Total Qg2 Prairie			**0**	**20**	**103**	**323**	***446***	**486**
Forest	Ash swamp and ash swale, sometimes with alder	QTg	H				4	*4*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	QTg	H					*0*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	QTg	H					*0*	
Forest	Black cottonwood forest, sometimes with willow	QTg	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	QTg	H					*0*	
Forest	White oak forest, oak brush, or oak and hazel brush	QTg	H					*0*	
Forest	ODEQ	QTg	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in Swamp, composition unknown	QTg	H					*0*	
Forest	Willow swamp, sometimes with ninebark, including riparian	QTg	H					*0*	4
Forest	Conifer-dominated woodland; various combinations of Douglas	QTg	C					*0*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	QTg	C		106	206	31	*343*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	QTg	C					*0*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	QTg	C		4			*4*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	QTg	C		19			*19*	366
Forest	Red alder-mixed conifer riparian forest; combinations of red	QTg	M					*0*	
Forest	White oak-Douglas fir-ponderosa pine forest	QTg	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	QTg	M			17		*17*	17
	Total QTg Forest			**0**	**129**	**223**	**35**	***387***	**387**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	QTg	H					*0*	
Savanna	White oak savanna	QTg	H		27	6	5	*38*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres					
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Savanna	White oak-ash savanna	QTg	H					*0*	
Savanna	White oak-black oak savanna	QTg	H					*0*	38
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	QTg	C					*0*	
Savanna	Douglas fir savanna	QTg	C					*0*	
Savanna	Douglas fir-ponderosa pine savanna	QTg	C					*0*	
Savanna	Ponderosa pine savanna.	QTg	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	QTg	C					*0*	0
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	QTg	M					*0*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	QTg	M					*0*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	QTg	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	QTg	M					*0*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	QTg	M		4			*4*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	QTg	M					*0*	
Savanna	White oak-ponderosa pine savanna	QTg	M					*0*	
Savanna	FFA, but burned, often with scattered trees surviving fire	QTg	M					*0*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	QTg	M					*0*	4
	Total QTg Savanna			**0**	**31**	**6**	**5**	***42***	**42**
Prairie	Seasonally Wet prairie	QTg	O				34	*34*	
Prairie	Upland prairie, xeric	QTg	O		17	20	24	*61*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	QTg	O	3	4			*7*	
Prairie	Gravel bar	QTg	O					*0*	
Prairie	Sand bar and sandy barrens	QTg	O					*0*	
Prairie	Marsh, composition unknown; includes "Wet meadow"	QTg	O					*0*	
Prairie	Brush, unknown; includes "thickets" if no species or other	QTg	O					*0*	
Prairie	Fern openings, fern hills, or open fern land	QTg	O					*0*	
	Total QTg Prairie			**3**	**21**	**20**	**58**	***102***	**531**
Forest	Ash swamp and ash swale, sometimes with alder	QTt	H					*0*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	QTt	H					*0*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	QTt	H					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Forest	Black cottonwood forest, sometimes with willow	QTt	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	QTt	H					*0*	
Forest	White oak forest, oak brush, or oak and hazel brush	QTt	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in	QTt	H					*0*	
Forest	Swamp, composition unknown	QTt	H					*0*	
Forest	Willow swamp, sometimes with ninebark, including riparian	QTt	H					*0*	0
Forest	Conifer-dominated woodland; various combinations of Douglas	QTt	C					*0*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	QTt	C					*0*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	QTt	C					*0*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	QTt	C					*0*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	QTt	C					*0*	0
Forest	Red alder-mixed conifer riparian forest; combinations of red	QTt	M					*0*	
Forest	White oak-Douglas fir-ponderosa pine forest	QTt	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	QTt	M		2			*2*	2
	Total QTt Forest			**0**	**2**	**0**	**0**	***2***	**2**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	QTt	H					*0*	
Savanna	White oak savanna	QTt	H					*0*	
Savanna	White oak-ash savanna	QTt	H					*0*	
Savanna	White oak-black oak savanna	QTt	H					*0*	0
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	QTt	C		5	3		*8*	
Savanna	Douglas fir savanna	QTt	C					*0*	
Savanna	Douglas fir-ponderosa pine savanna	QTt	C					*0*	
Savanna	Ponderosa pine savanna.	QTt	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	QTt	C					*0*	0
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	QTt	M					*0*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	QTt	M					*0*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	QTt	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	QTt	M					*0*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	QTt	M					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres					Hdwd, Con, Mix
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	
Savanna	White oak-Douglas fir-ponderosa pine savanna	QTt	M					*0*	
Savanna	White oak-ponderosa pine savanna	QTt	M					*0*	
Savanna	FFA, but burned, often with scattered trees surviving fire	QTt	M					*0*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	QTt	M					*0*	0
	Total QTt Savanna			**0**	**5**	**3**	**0**	***8***	**0**
Prairie	Seasonally Wet prairie	QTt	O					*0*	
Prairie	Upland prairie, xeric	QTt	O					*0*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	QTt	O					*0*	
Prairie	Gravel bar	QTt	O					*0*	
Prairie	Sand bar and sandy barrens	QTt	O					*0*	
Prairie	Marsh, composition unknown; includes "Wet meadow"	QTt	O					*0*	
Prairie	Brush, unknown; includes "thickets" if no species or other	QTt	O					*0*	
Prairie	Fern openings, fern hills, or open fern land	QTt	O					*0*	
	Total QTt Prairie			**0**	**0**	**0**	**0**	***0***	**10**
Forest	Ash swamp and ash swale, sometimes with alder	Tcr	H					*0*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	Tcr	H					*0*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	Tcr	H					*0*	
Forest	Black cottonwood forest, sometimes with willow	Tcr	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	Tcr	H					*0*	
Forest	White oak forest, oak brush, or oak and hazel brush	Tcr	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in	Tcr	H					*0*	
Forest	Swamp, composition unknown	Tcr	H					*0*	
Forest	Willow swamp, sometimes with ninebark, including riparian	Tcr	H					*0*	0
Forest	Conifer-dominated woodland; various combinations of Douglas	Tcr	C					*0*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	Tcr	C		47	41	24	*112*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	Tcr	C					*0*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	Tcr	C					*0*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	Tcr	C					*0*	112
Forest	Red alder-mixed conifer riparian forest; combinations of red	Tcr	M					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres					
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Forest	White oak-Douglas fir-ponderosa pine forest	Tcr	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	Tcr	M			9		*9*	9
	Total Tcr Forest			**0**	**47**	**50**	**24**	***121***	**121**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	Tcr	H					*0*	
Savanna	White oak savanna	Tcr	H		120	81	25	*226*	
Savanna	White oak-ash savanna	Tcr	H					*0*	
Savanna	White oak-black oak savanna	Tcr	H					*0*	226
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	Tcr	C		46	61	31	*138*	
Savanna	Douglas fir savanna	Tcr	C					*0*	
Savanna	Douglas fir-ponderosa pine savanna	Tcr	C					*0*	
Savanna	Ponderosa pine savanna.	Tcr	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	Tcr	C					*0*	0
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	Tcr	M					*0*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	Tcr	M		46	17	33	*96*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	Tcr	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	Tcr	M					*0*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	Tcr	M		322	185	5	*512*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	Tcr	M					*0*	
Savanna	White oak-ponderosa pine savanna	Tcr	M					*0*	
Savanna	FFA, but burned, often with scattered trees surviving fire	Tcr	M					*0*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	Tcr	M					*0*	746
	Total Tcr Savanna			**0**	**534**	**344**	**94**	***972***	**972**
Prairie	Seasonally Wet prairie	Tcr	O				19	*19*	
Prairie	Upland prairie, xeric	Tcr	O		193	42	23	*258*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	Tcr	O				22	*22*	
Prairie	Gravel bar	Tcr	O					*0*	
Prairie	Sand bar and sandy barrens	Tcr	O					*0*	
Prairie	Marsh, composition unknown; includes "Wet meadow"	Tcr	O					*0*	
Prairie	Brush, unknown; includes "thickets" if no species or other	Tcr	O			3		*3*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres					
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Prairie	Fern openings, fern hills, or open fern land	Tcr	O					*0*	
	Total Tcr Prairie			**0**	**193**	**45**	**45**	***302***	**1395**
Forest	Ash swamp and ash swale, sometimes with alder	Tm	H					*0*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	Tm	H					*0*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	Tm	H					*0*	
Forest	Black cottonwood forest, sometimes with willow	Tm	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	Tm	H					*0*	
Forest	White oak forest, oak brush, or oak and hazel brush	Tm	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in	Tm	H					*0*	
Forest	Swamp, composition unknown	Tm	H					*0*	
Forest	Willow swamp, sometimes with ninebark, including riparian	Tm	H					*0*	0
Forest	Conifer-dominated woodland; various combinations of Douglas	Tm	C					*0*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	Tm	C					*0*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	Tm	C		40			*40*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	Tm	C			30		*30*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	Tm	C					*0*	70
Forest	Red alder-mixed conifer riparian forest; combinations of red	Tm	M					*0*	
Forest	White oak-Douglas fir-ponderosa pine forest	Tm	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	Tm	M		20	26	59	*105*	105
	Total Tm Forest			**0**	**60**	**56**	**59**	***175***	**175**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	Tm	H					*0*	
Savanna	White oak savanna	Tm	H		27	120	60	*207*	
Savanna	White oak-ash savanna	Tm	H					*0*	
Savanna	White oak-black oak savanna	Tm	H					*0*	207
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	Tm	C					*0*	
Savanna	Douglas fir savanna	Tm	C					*0*	
Savanna	Douglas fir-ponderosa pine savanna	Tm	C					*0*	
Savanna	Ponderosa pine savanna.	Tm	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	Tm	C					*0*	0

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres					
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	Tm	M					*0*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	Tm	M		151	118	28	*297*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	Tm	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	Tm	M					*0*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	Tm	M		7			*7*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	Tm	M					*0*	
Savanna	White oak-ponderosa pine savanna	Tm	M					*0*	
Savanna	FFA, but burned, often with scattered trees surviving fire	Tm	M					*0*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	Tm	M					*0*	304
	Total Tm Savanna			**0**	**185**	**238**	**88**	***511***	**511**
Prairie	Seasonally Wet prairie	Tm	O				9	*9*	
Prairie	Upland prairie, xeric	Tm	O		13	48	15	*76*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	Tm	O					*0*	
Prairie	Gravel bar	Tm	O					*0*	
Prairie	Sand bar and sandy barrens	Tm	O					*0*	
Prairie	Marsh, composition unknown; includes "Wet meadow"	Tm	O					*0*	
Prairie	Brush, unknown; includes "thickets" if no species or other	Tm	O					*0*	
Prairie	Fern openings, fern hills, or open fern land	Tm	O					*0*	
	Total Tm Prairie			**0**	**13**	**48**	**24**	***85***	**771**
Forest	Ash swamp and ash swale, sometimes with alder	Tvc	H					*0*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	Tvc	H					*0*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	Tvc	H					*0*	
Forest	Black cottonwood forest, sometimes with willow	Tvc	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	Tvc	H					*0*	
Forest	White oak forest, oak brush, or oak and hazel brush	Tvc	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in	Tvc	H					*0*	
Forest	Swamp, composition unknown	Tvc	H					*0*	
Forest	Willow swamp, sometimes with ninebark, including riparian	Tvc	H					*0*	0
Forest	Conifer-dominated woodland; various combinations of Douglas	Tvc	C					*0*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	Tvc	C					*0*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	Tvc	C		6			*6*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	Tvc	C					*0*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	Tvc	C					*0*	6
Forest	Red alder-mixed conifer riparian forest; combinations of red	Tvc	M					*0*	
Forest	White oak-Douglas fir-ponderosa pine forest	Tvc	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	Tvc	M		20	3		*23*	23
	Total Tvc Forest			**0**	**26**	**3**	**0**	***29***	**29**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	Tvc	H					*0*	
Savanna	White oak savanna	Tvc	H	5	27	35	10	*77*	
Savanna	White oak-ash savanna	Tvc	H					*0*	
Savanna	White oak-black oak savanna	Tvc	H					*0*	77
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	Tvc	C					*0*	
Savanna	Douglas fir savanna	Tvc	C					*0*	
Savanna	Douglas fir-ponderosa pine savanna	Tvc	C					*0*	
Savanna	Ponderosa pine savanna.	Tvc	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	Tvc	C					*0*	0
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	Tvc	M					*0*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	Tvc	M		18	7	2	*27*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	Tvc	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	Tvc	M					*0*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	Tvc	M					*0*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	Tvc	M					*0*	
Savanna	White oak-ponderosa pine savanna	Tvc	M					*0*	
Savanna	FFA, but burned, often with scattered trees surviving fire	Tvc	M					*0*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	Tvc	M					*0*	27
	Total Tvc Savanna			**5**	**45**	**42**	**12**	***104***	**104**
Prairie	Seasonally Wet prairie	Tvc	O					*0*	
Prairie	Upland prairie, xeric	Tvc	O		4			*4*	

Vegetation Type	General Land Survey Vegetation Type	Geomor-phic surface		Acres: Excessively drained	Acres: Well-drained	Acres: Mod.-Well drained	Acres: Poorly drained	Total Veg.	Hdwd, Con, Mix
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	Tvc	O					*0*	
Prairie	Gravel bar	Tvc	O					*0*	
Prairie	Sand bar and sandy barrens	Tvc	O					*0*	
Prairie	Marsh, composition unknown; includes "Wet meadow"	Tvc	O					*0*	
Prairie	Brush, unknown; includes "thickets" if no species or other	Tvc	O					*0*	
Prairie	Fern openings, fern hills, or open fern land	Tvc	O					*0*	
	Total Tvc Prairie			**0**	**4**	**0**	**0**	***4***	**137**
Forest	Ash swamp and ash swale, sometimes with alder	Tvw	H					*0*	
Forest	Ash-alder-willow swamp, sometimes with bigleaf maple	Tvw	H					*0*	
Forest	Ash-willow swamp, sometimes w/ ninebark & briars; "very thick"	Tvw	H					*0*	
Forest	Black cottonwood forest, sometimes with willow	Tvw	H					*0*	
Forest	White oak-ash riparian forest, sometimes with ponderosa pine,	Tvw	H					*0*	
Forest	White oak forest, oak brush, or oak and hazel brush	Tvw	H					*0*	
Forest	Wetland, composition unknown; includes "slough" & "swale" in	Tvw	H					*0*	
Forest	Swamp, composition unknown	Tvw	H					*0*	
Forest	Willow swamp, sometimes with ninebark, including riparian	Tvw	H					*0*	0
Forest	Conifer-dominated woodland; various combinations of Douglas	Tvw	C					*0*	
Forest	Douglas fir forest, often with bigleaf maple, grand fir,	Tvw	C	3	76	139	16	*234*	
Forest	Douglas fir-white oak (bigleaf maple) forest,	Tvw	C		20	4		*24*	
Forest	Low-elevation mix of (1) xeric Douglas fir-chinquapin-madrone	Tvw	C		11			*11*	
Forest	Mesic mixed conifer forest with mostly deciduous understory	Tvw	C		104	57		*161*	430
Forest	Red alder-mixed conifer riparian forest; combinations of red	Tvw	M		14	4		*18*	
Forest	White oak-Douglas fir-ponderosa pine forest	Tvw	M					*0*	
Forest	Ash-mixed deciduous riparian forest with combinations of red	Tvw	M	5	30	15	12	*62*	80
	Total Tvw Forest			**8**	**255**	**219**	**28**	***510***	**510**
Savanna	"Scattering" or "thinly timbered" white oak woodland, brushy	Tvw	H					*0*	
Savanna	White oak savanna	Tvw	H		31	96	87	*214*	
Savanna	White oak-ash savanna	Tvw	H					*0*	
Savanna	White oak-black oak savanna	Tvw	H					*0*	214

Vegetation Type	General Land Survey Vegetation Type	Geomorphic surface		Acres					
				Excessively drained	Well-drained	Mod.-Well drained	Poorly drained	Total Veg.	Hdwd, Con, Mix
Savanna	Douglas fir woodland or "timber" often with bigleaf maple, alder	Tvw	C			3		*3*	
Savanna	Douglas fir savanna	Tvw	C					*0*	
Savanna	Douglas fir-ponderosa pine savanna	Tvw	C					*0*	
Savanna	Ponderosa pine savanna.	Tvw	C					*0*	
Savanna	FF, but burned, often with scattered trees surviving fire	Tvw	C					*0*	3
Savanna	"Scattering" or "thinly timbered" Douglas fir-white oak-ponderosa	Tvw	M					*0*	
Savanna	Scattering or thinly timbered Douglas fir-white oak woodland	Tvw	M					*0*	
Savanna	White oak-black oak-Douglas fir-ponderosa pine savanna	Tvw	M					*0*	
Savanna	White oak-black oak-ponderosa pine savanna	Tvw	M					*0*	
Savanna	White oak-Douglas fir savanna, mostly herbaceous undergrowth	Tvw	M		91	51		*142*	
Savanna	White oak-Douglas fir-ponderosa pine savanna	Tvw	M				26	*26*	
Savanna	White oak-ponderosa pine savanna	Tvw	M			5		*5*	
Savanna	FFA, but burned, often with scattered trees surviving fire	Tvw	M					*0*	
Savanna	FFHC, but burned, often with scattered trees surviving fire	Tvw	M					*0*	173
	Total Tvw Savanna			**0**	**122**	**155**	**113**	***390***	**390**
Prairie	Seasonally Wet prairie	Tvw	O				33	*33*	
Prairie	Upland prairie, xeric	Tvw	O		86	75	13	*174*	
Prairie	Water bodies 1 or more chains across, including rivers, sloughs,	Tvw	O		7			*7*	
Prairie	Gravel bar	Tvw	O					*0*	
Prairie	Sand bar and sandy barrens	Tvw	O					*0*	
Prairie	Marsh, composition unknown; includes "Wet meadow"	Tvw	O					*0*	
Prairie	Brush, unknown; includes "thickets" if no species or other	Tvw	O		6			*6*	
Prairie	Fern openings, fern hills, or open fern land	Tvw	O					*0*	
	Total Tvw Prairie			**0**	**99**	**75**	**46**	***220***	**1120**

Appendix 4. Geomorphic Surfaces identified in Origin, Extent, and Thickness of Quaternary Geologic Units in the Willamette Valley, Oregon. (O'Connor et al, 2001)

Qalc—Floodplain deposits of the Willamette River and major tributaries (Holocene and upper Pleistocene)--Unconsolidated silt, sand, and gravel of the Willamette River and major Cascade Range tributaries. Includes active channel and modern floodplain surfaces. Meander-scroll topography with surfaces as high as 15 meters above summer water stage. Drillers' logs and exposures indicate that unit thickness ranges up to 15 meters. Isotopic dating, tephrochronology, and stratigraphic relations within the Willamette Valley indicate that these deposits are mostly younger than 12 ka.

Qalf—Alluvium of smaller streams (Holocene and upper Pleistocene)—Unconsolidated clay, silt, sand, and minor gravel deposited in floodplains and active channels of smaller streams and rivers. Variable surface morphology. Thickness not defined, but probably less than 10 meters. Differentiated from units Qbf and Qau where clearly younger than Missoula Flood deposits. Mostly younger than 12 ka.

Qg1—Sand and Gravel that postdates Missoula Floods (upper Pleistocene)— Alluvial sand and gravel deposited in broad braidplains within Willamette Valley and traced upstream as alluvial fills in major Cascade Range tributary valleys. Forms surfaces of large fans where major Cascade Range tributaries enter the Willamette Valley. Deposits now preserved as planar to slightly undulating terraces 0 to 15 meters above the modern floodplain. Drillers' logs and stratigraphic exposures indicate that unit is up to 30 meters thick. Stratigraphic relations and isotopic dating indicate that deposits primarily date from about 12 ka, although some areas mapped as Qg1 in the Eugene-Springfield area within the Cascade Range foothills may be substantially older.

Missoula Flood deposits (upper Pleistocene)—Unconsolidated clay, silt, sand, and gravel deposited by floods originating in glacial Lake Missoula that flowed down the Columbia River and backflooded into the Willamette Valley (Glenn, 1965; Allison, 1978). Largest flows reached stages of about 120 meters above sea level in the map area. Maximum thickness of deposits about 35 meters in northern Willamette Valley, thins to less than 1 meter at elevations above about 100 meters. Radiocarbon dating, tephrochronology, and straigraphic relations from within and outside the map area indicate that most units date from about 15 to 12.7 ka. Divided into the following three types:

> **Qff1—Younger and lower fine-grained Missoula Flood deposits**—Clay, silt, sand, and minor gravel forming benches along Labish channel and Pudding River, and locally flanking Willamette River in northern Willamette Valley. Planar to undulating surface almost everywhere 40-50 meters above sea level. Set into main-body fine facies (Qff2). Probably mostly deposited by latest Pleistocene Missoula Floods between 13.5 and 12.7 ka, but possibly includes late Pleistocene and early Holocene deposits of units Qalf and Qalc.
>
> **Qff2—Main body of fine-grained Missoula Flood deposits—**Stratified silt and clay with minor sand. Underlies much of Willamette Valley lowland floor. Many sections show rhythmic bedding, with up to 40 individual beds between 0.1 and 1.0 meter thick. Encloses sparse pebbles to boulders of types exotic to Willamette Basin. Forms undulating to planar topography in lowlands; mantles foothills below altitudes of 120 meters. Mapped where thickness is sufficient to obscure previous topography. Commonly capped by up to two meters of late Pleistocene and Holocene alluvium, colluvium, and loess.
>
> **Qfc—Coarse Missoula Flood deposits**—Bouldery, cobbly, sandy gravel fans deposited by Missoula Floods as they spilled into northern Willamette Valley through the Oregon City and Rock Creek gaps. Crudely stratified commonly with south-dipping foresets. Commonly capped by several meters of sandy silt, especially south of Willamette River. Drillers' logs indicate that thickness locally exceeds 30 meters.

Qg2—Sand and gravel that predates Missoula Floods (Pleistocene)—Unconsolidated to semiconsolidated sand and gravel deposited in broad braidplains and meandering floodplain environments within Willamette Valley and upstream as alluvial fills along major Cascade Range tributaries. Locally contains lahar deposits. Forms planar to slightly undulating terrace surfaces 0 to 20 meters above the modern floodplain and generally at slightly higher elevations than adjacent surfaces of unit Qg1. Thickness not systematically determined but locally exceeds 100 meters in braod fans formed where major Cascade Range tributaries enter the Willamette lowlands. Isotopic dating and tephrochronology indicate these deposits range from greater than 0.41 Ma to about 22ka.

Qau—Alluvium, Undifferentiated (Holocene and Pleistocene)—Sand, silt, clay, and minor gravel deposited by smaller streams and rivers that enter the Willamette Valley, and by larger streams and rivers outside the area of detailed mapping. Age and thickness not determined.

Qbf—Fine-grained alluvium (Holocene and Pleistocene)—Clay, silt, sand, and minor gravel deposited in small basins flanking the Willamette Valley. Planar surfaces. Age and thickness not determined. Distinction with unit Qau locally arbitrary.

Qls—Landslide deposits and colluvium (Holocene and Pleistocene)—Unconsolidated and heterogeneous mixtures of rock fragments and soil. Some landslide deposits have hummocky surfaces. Colluvium mapped on steep debris-mantled slopes where underlying bedrock is not known. Only larger deposits mapped, mostly after Walker and McLeod (1991). Age and thickness not defined.

QTg—Weathered terrace gravel (Pleistocene and Pliocene?)—Alluvial sand and gravel preserved as terraces flanking Willamette Valley and tributary valleys. Terrace surfaces planar to undulating, with thick, strongly-developed soils, and severely weathered clasts. Terrace surfaces up to 100 meters above modern floodplains. Drillers' logs and stratigraphic exposures indicate sand and gravel 0 to 60 meters thick. May be in part equivalent to Troutdale Formation (QTt) as mapped near Molalla. Probably mostly deposited between 2.5 and 0.5 Ma.

UPLAND UNITS (primarily compiled from previous sources.)

QTb—Boring Lava (Pleistocene and Pliocene)—Gray to light-gray, open-textured olivine basalt lava flows. Only mapped in the northern part of map area after Hampton (1973). Up to 60 meters thick. Ten radiometric ages on separate flows near Oregon City span 0.427+/-0.026 Ma to 3.15 +/-0.062 Ma (Madin, 1994).

QTt—Troutdale Formation (Pleistocene? And Pliocene)—Sand, gravel, sandstone, conglomerate, siltstone, and mudstone. Only mapped in northern part of map area after Trimble (1963) and Hampton (1972) where it is up to 150 meters thick. May be locally equivalent to the weathered terrace gravel (QTg) near Molalla. Overlain by Boring Lava near Oregon City.

Tvw—Volcanic and volcaniclastic rocks in the Western Cascade Range, undivided (upper Eocene to Pliocene)—Lava flows, tuff, breccia, and volcaniclastic sediment of variable composition. Locally interfingers with marine sedimentary rocks (Tm) in the southern portion of map area. Includes the Fisher Formation, "volcanic rocks of the Western Cascade Range", and Sardine Formation as compiled by Gannett and Caldwell (1998). Youngest rocks are ridge-capping basalt flows in Santiam River drainage with reported ages as young as 2.8 +/- 0.3 Ma (Verplanck, 1985, cited in Walker and Duncan, 1989).

Tcr--Columbia River Basalt Group (Miocene)—Lava flows of dark gray to black, locally porphyritic basalt. Locally deeply weathered. Mostly between 16 and 15 Main northern Willamette Valley (M.H. Beeson, Portland State University, written communication, 1998). Also includes small areas of alluvium, colluvium, loess, and landslide debris. Distribution after Gannett and Caldwell (1998).

Tm—Marine sedimentary rocks (lower Miocene to Eocene)—Marine sandstone, siltstone, shale, and claystone,with lesser conglomerate; locally tuffaceous. Also includes numerous small mafic intrusions, and small areas of alluvium, colluvium, loess, and landslide debris. Distribution after Gannett and Caldwell (1998).

Tvc—Volcanic rocks of the Coast Range (Eocene)—Basaltic pillow lava, tuff breccia, subaerial basalt lava flows, and sills, with interbeds of basaltic sandstone, siltstone, and conglomerate. Includes small areas of alluvium, colluvium, loess, and landslide debris. Distribution after Gannett and Caldwell (1998).

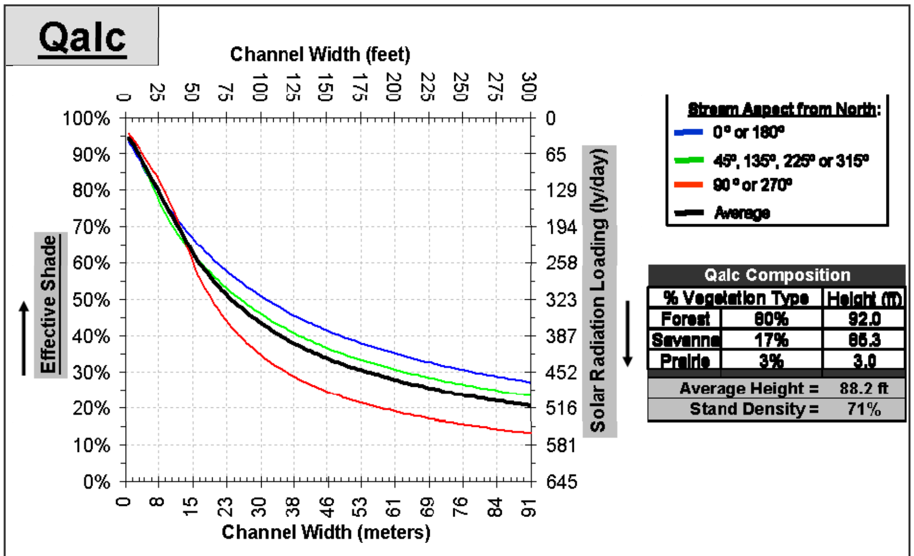
Note: "Am" refers to millions of years before present, and in this report is used to indicate radiometric and fission track ages on volcanic rocks. "ka" refers to kiloannum, indicating thousands of radiocarbon years before present.

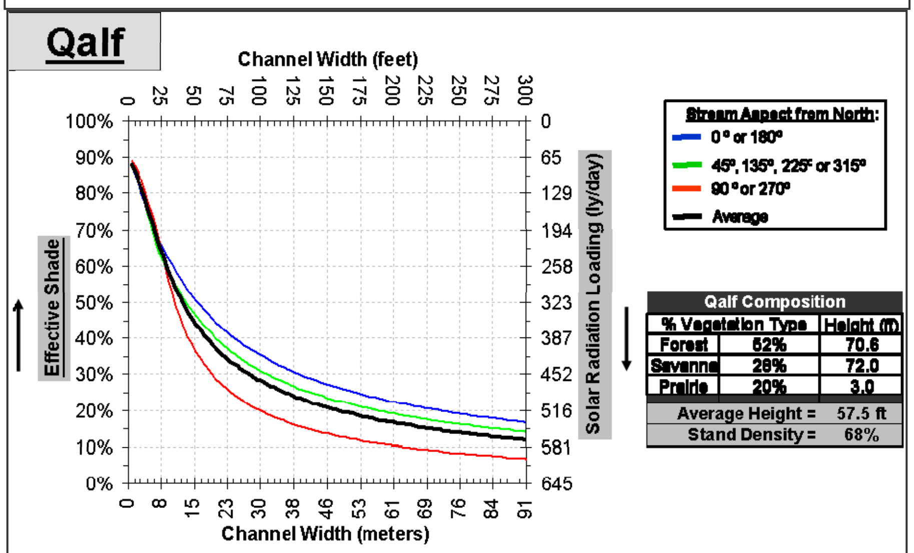
Appendix 5. Geomorphic Unit Potential Near-Stream Land Cover Quantitative Look-up Table for the Temperature Model Input

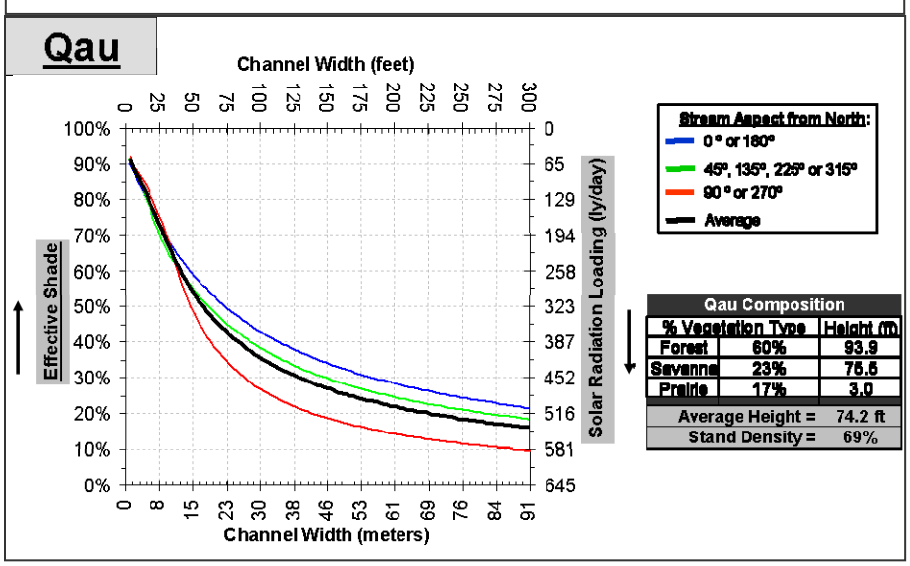
Code	Source	Description	Height (m)	Density (%)	OH (m)
3011	DEQ	Water	0.0	0%	0.0
101	DEQ	Qff1 Forest	44.5	75%	5.3
102	DEQ	Qff1 Savanna	24.6	50%	3.0
103	DEQ	Qff1 Prairie	0.9	75%	0.0
111	DEQ	Qff1 Forest	44.5	75%	5.3
112	DEQ	Qff1 Savanna	24.6	50%	3.0
113	DEQ	Qff1 Prairie	0.9	75%	0.0
201	DEQ	Qfc Forest	30.6	75%	3.7
202	DEQ	Qfc Savanna	46.8	50%	5.6
203	DEQ	Qfc Prairie	0.9	75%	0.0
211	DEQ	Qfc Forest	30.6	75%	3.7
212	DEQ	Qfc Savanna	46.8	50%	5.6
213	DEQ	Qfc Prairie	0.9	75%	0.0
301	DEQ	Qalc Forest	28.0	75%	3.4
302	DEQ	Qalc Savanna	26.0	50%	3.1
303	DEQ	Qalc Prairie	0.9	75%	0.0
311	DEQ	Qalc Forest	28.0	75%	3.4
312	DEQ	Qalc Savanna	26.0	50%	3.1
313	DEQ	Qalc Prairie	0.9	75%	0.0
401	DEQ	Qg1 Forest	26.8	75%	3.2
402	DEQ	Qg1 Savanna	23.9	50%	2.9
403	DEQ	Qg1 Prairie	0.9	75%	0.0
411	DEQ	Qg1 Forest	26.8	75%	3.2
412	DEQ	Qg1 Savanna	23.9	50%	2.9
413	DEQ	Qg1 Prairie	0.9	75%	0.0
501	DEQ	Qau Forest	28.6	75%	3.4
502	DEQ	Qau Savanna	23.0	50%	2.8
503	DEQ	Qau Prairie	0.9	75%	0.0
511	DEQ	Qau Forest	28.6	75%	3.4
512	DEQ	Qau Savanna	23.0	50%	2.8
513	DEQ	Qau Prairie	0.9	75%	0.0
601	DEQ	Qalf Forest	21.5	75%	2.6
602	DEQ	Qalf Savanna	21.9	50%	2.6
603	DEQ	Qalf Prairie	0.9	75%	0.0
611	DEQ	Qalf Forest	21.5	75%	2.6
612	DEQ	Qalf Savanna	21.9	50%	2.6
613	DEQ	Qalf Prairie	0.9	75%	0.0
701	DEQ	Qff2 Forest	29.9	75%	3.6
702	DEQ	Qff2 Savanna	24.2	50%	2.9
703	DEQ	Qff2 Prairie	0.9	75%	0.0
711	DEQ	Qff2 Forest	29.9	75%	3.6
712	DEQ	Qff2 Savanna	24.2	50%	2.9
713	DEQ	Qff2 Prairie	0.9	75%	0.0
801	DEQ	Qbf Forest	29.7	75%	3.6
802	DEQ	Qbf Savanna	26.1	50%	3.1
803	DEQ	Qbf Prairie	0.9	75%	0.0
811	DEQ	Qbf Forest	29.7	75%	3.6
812	DEQ	Qbf Savanna	26.1	50%	3.1
813	DEQ	Qbf Prairie	0.9	75%	0.0

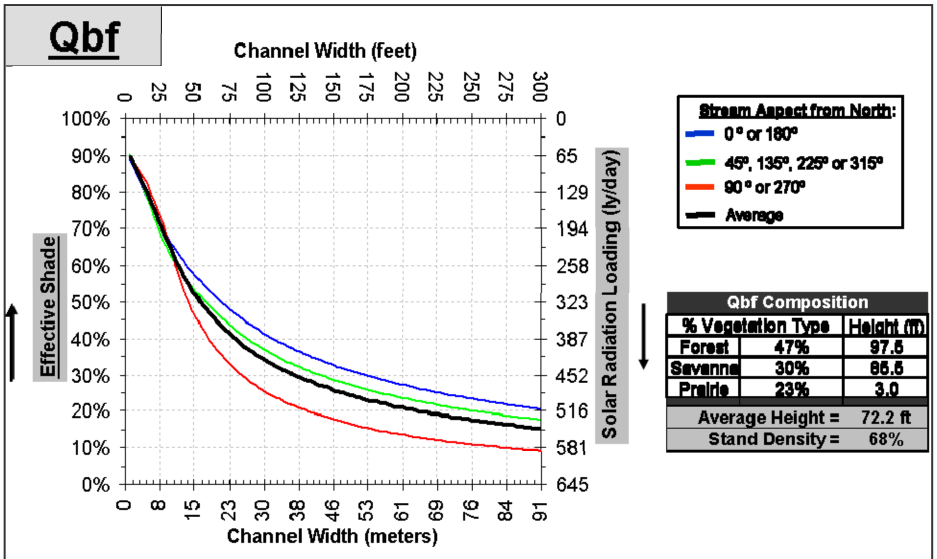
Code	Source	Description	Height (m)	Density (%)	OH (m)
1001	DEQ	Tvc Forest	31.9	75%	3.8
1002	DEQ	Tvc Savanna	22.2	50%	2.7
1003	DEQ	Tvc Prairie	0.9	75%	0.0
1011	DEQ	Tvc Forest	31.9	75%	3.8
1012	DEQ	Tvc Savanna	22.2	50%	2.7
1013	DEQ	Tvc Prairie	0.9	75%	0.0
1101	DEQ	Qtg Forest	47.7	75%	5.7
1102	DEQ	Qtg Savanna	26.7	50%	3.2
1103	DEQ	Qtg Prairie	0.9	75%	0.0
1111	DEQ	Qtg Forest	47.7	75%	5.7
1112	DEQ	Qtg Savanna	26.7	50%	3.2
1113	DEQ	Qtg Prairie	0.9	75%	0.0
1201	DEQ	Tvw Forest	45.4	75%	5.4
1202	DEQ	Tvw Savanna	23.6	50%	2.8
1203	DEQ	Tvw Prairie	0.9	75%	0.0
1211	DEQ	Tvw Forest	45.4	75%	5.4
1212	DEQ	Tvw Savanna	23.6	50%	2.8
1213	DEQ	Tvw Prairie	0.9	75%	0.0
1301	DEQ	Tcr Forest	47.3	75%	5.7
1302	DEQ	Tcr Savanna	25.8	50%	3.1
1303	DEQ	Tcr Prairie	0.9	75%	0.0
1311	DEQ	Tcr Forest	47.3	75%	5.7
1312	DEQ	Tcr Savanna	25.8	50%	3.1
1313	DEQ	Tcr Prairie	0.9	75%	0.0
1401	DEQ	Tm Forest	36.0	75%	4.3
1402	DEQ	Tm Savanna	24.5	50%	2.9
1403	DEQ	Tm Prairie	0.9	75%	0.0
1411	DEQ	Tm Forest	36.0	75%	4.3
1412	DEQ	Tm Savanna	24.5	50%	2.9
1413	DEQ	Tm Prairie	0.9	75%	0.0
1925	DEQ / USFS	Disturbed: Forest Mature Conifer	17.1	25%	1.7
1950	DEQ / USFS	Not Disturbed: Forest Mature Conife	48.8	75%	4.9
1511	DEQ	Qtt Forest	36.0	75%	4.3
1512	DEQ	Qtt Savanna	27.4	50%	2.9
1513	DEQ	Qtt Prairie	0.9	75%	0.0
2011	DEQ	Ow Forest	0.0	75%	4.3
2012	DEQ	Ow Savanna	20.4	50%	2.9
2013	DEQ	Ow Prairie	0.9	75%	0.0
2111	DEQ	Qtb Forest	40.2	75%	4.3
2112	DEQ	Qtb Savanna	33.3	50%	2.9
2113	DEQ	Qtb Prairie	0.9	75%	0.0
2211	DEQ	Qls Forest	48.8	75%	4.3
2212	DEQ	Qls Savanna	37.0	50%	2.9
2213	DEQ	Qls Prairie	0.9	75%	0.0

Appendix 6. Shade Curves

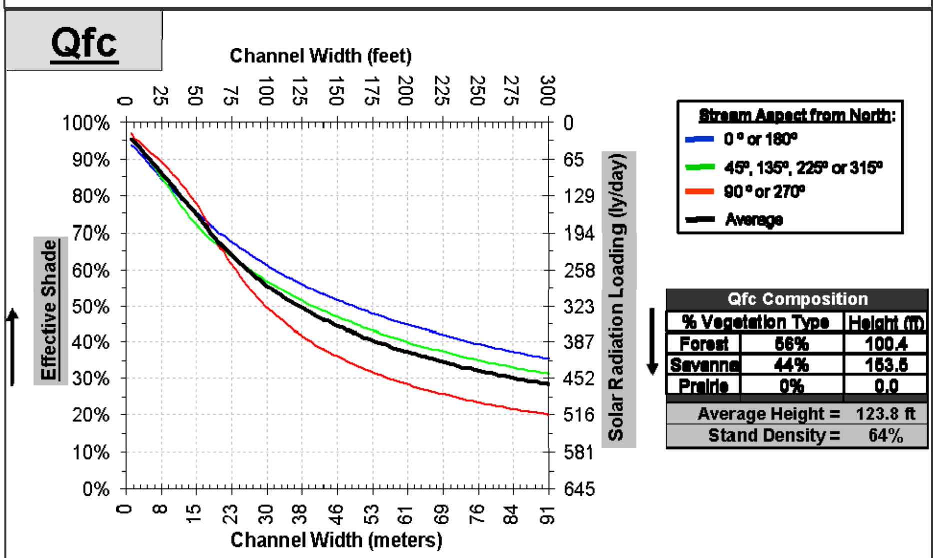




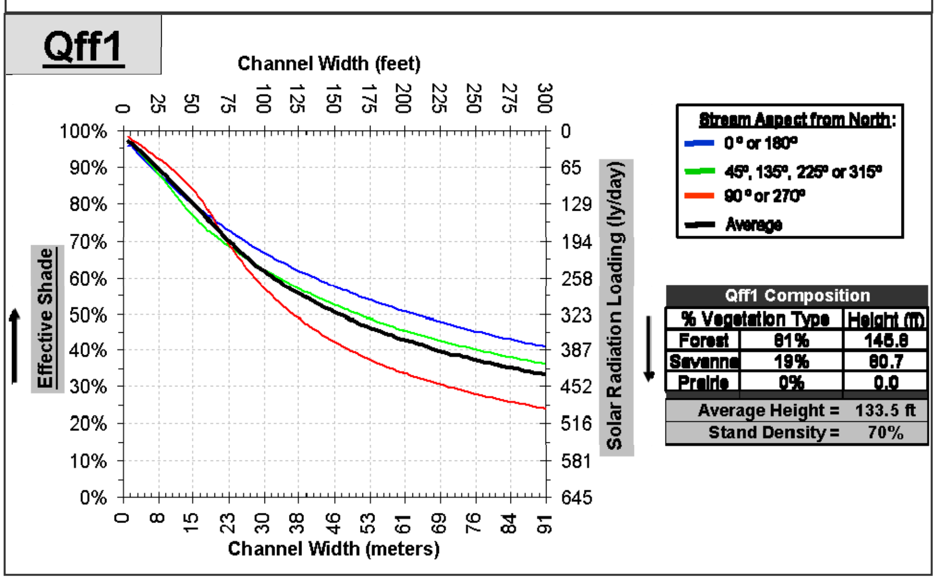




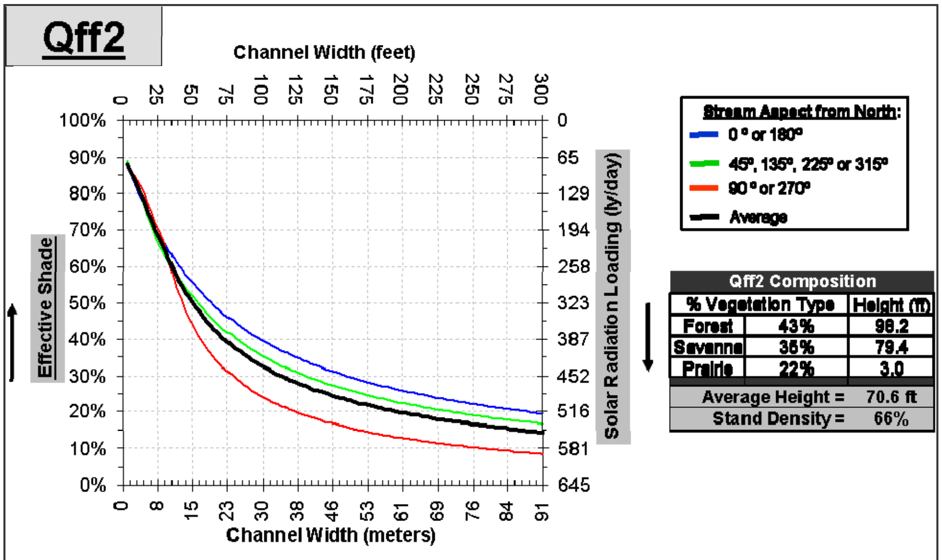
Qbf Composition		
% Vegetation Type		Height (ft)
Forest	47%	97.5
Savanna	30%	85.5
Prairie	23%	3.0
Average Height =		72.2 ft
Stand Density =		68%



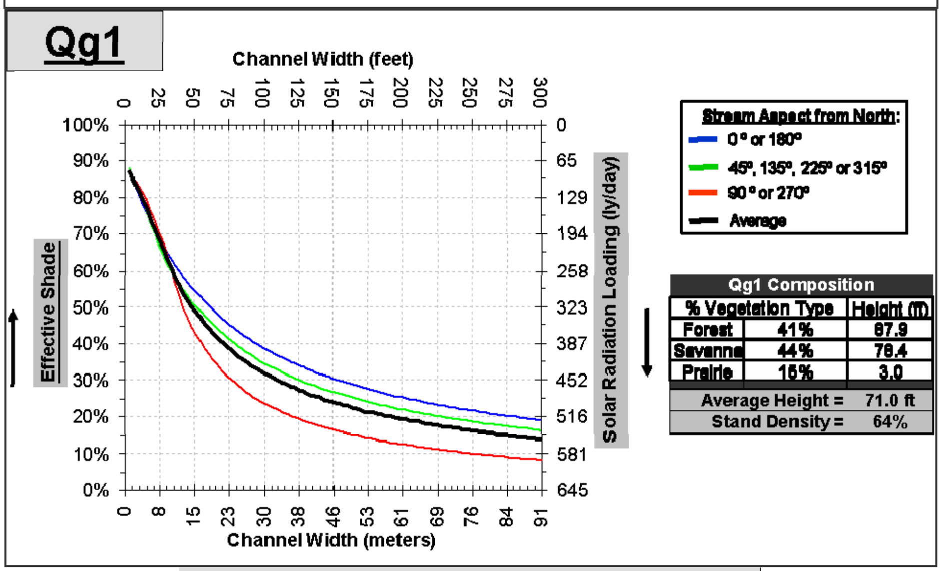
Qfc Composition		
% Vegetation Type		Height (ft)
Forest	56%	100.4
Savanna	44%	153.5
Prairie	0%	0.0
Average Height =		123.8 ft
Stand Density =		64%



Qff1 Composition		
% Vegetation Type		Height (ft)
Forest	81%	145.8
Savanna	19%	80.7
Prairie	0%	0.0
Average Height =		133.5 ft
Stand Density =		70%

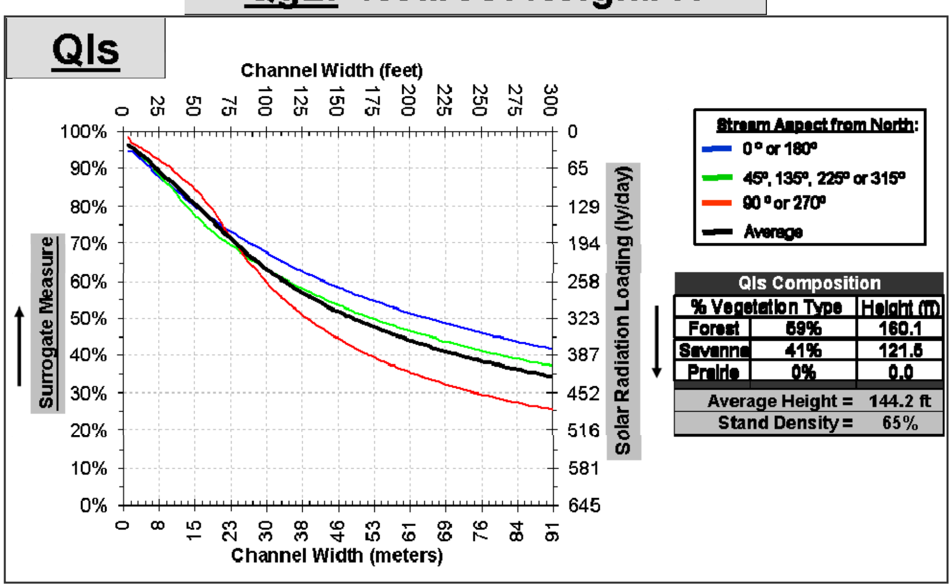


Qff2 Composition		
%	Vegetation Type	Height (ft)
Forest	43%	98.2
Savanna	35%	79.4
Prairie	22%	3.0
Average Height =		70.6 ft
Stand Density =		66%

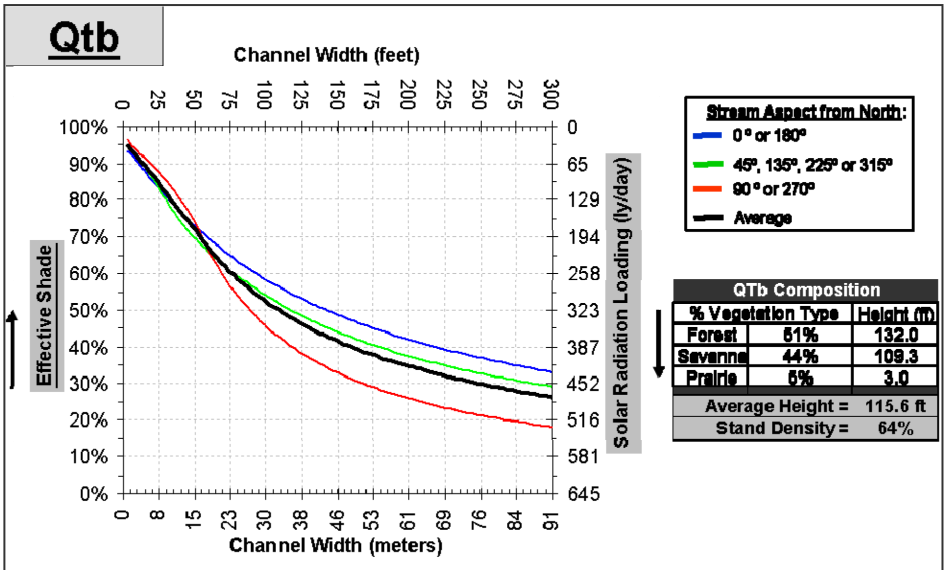


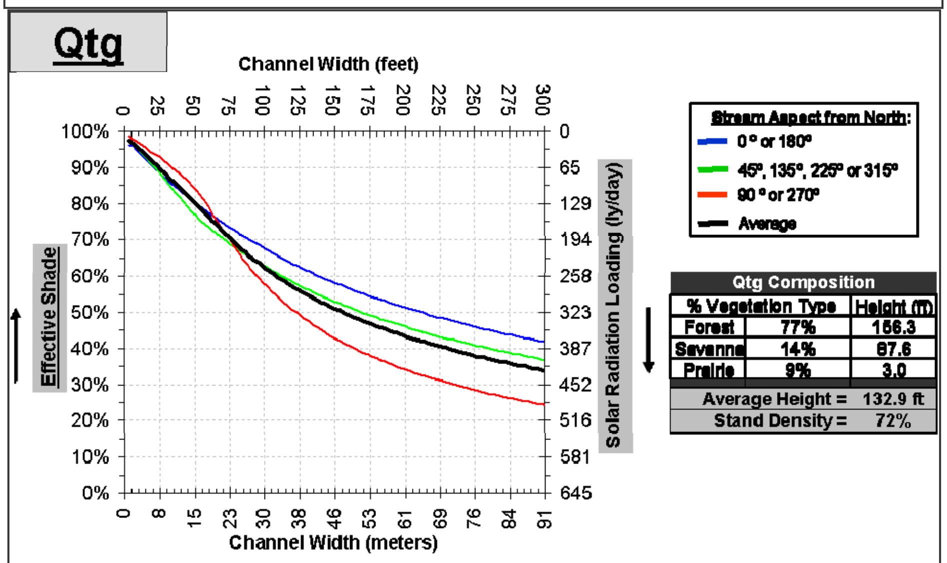
Qg1 Composition		
%	Vegetation Type	Height (ft)
Forest	41%	87.9
Savanna	44%	78.4
Prairie	15%	3.0
Average Height =		71.0 ft
Stand Density =		64%

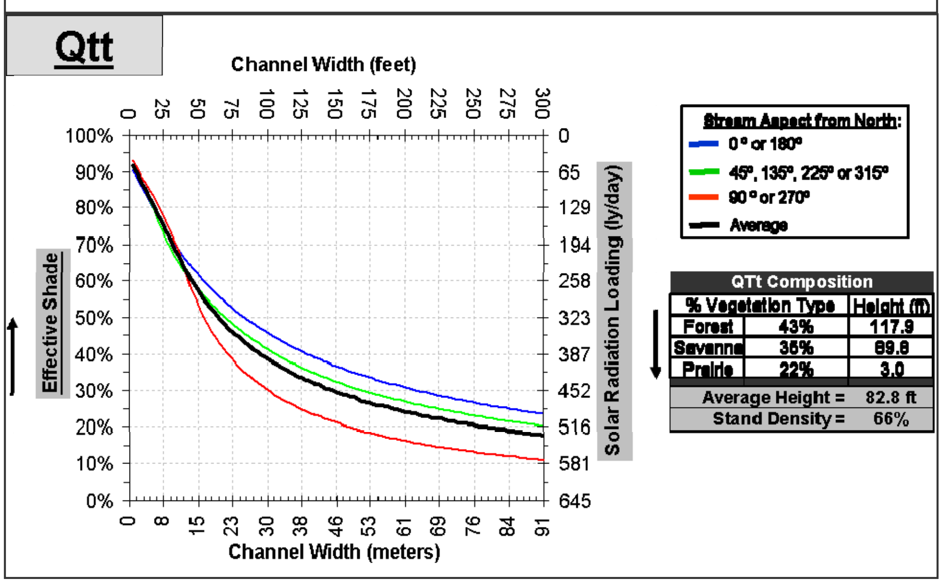
Qg2: Nearest Neighbor

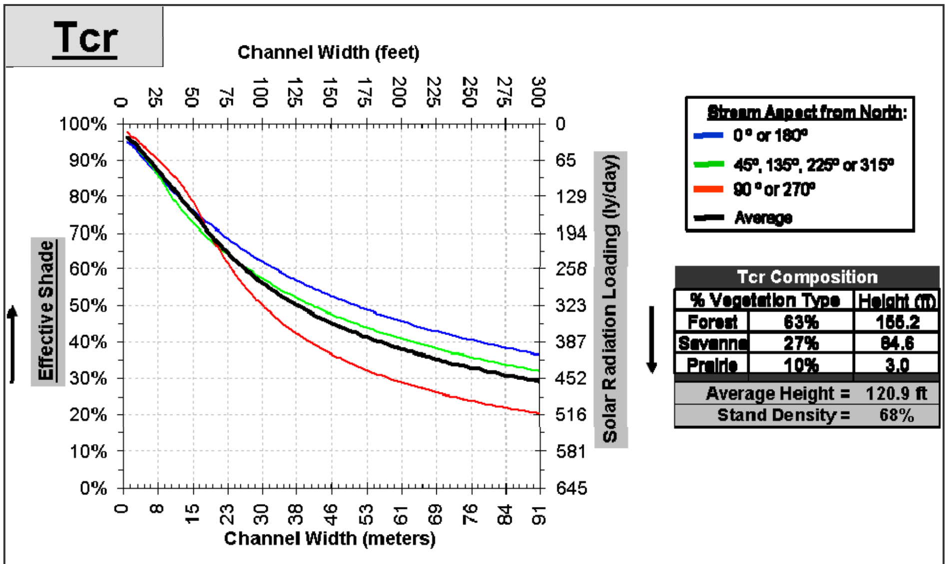


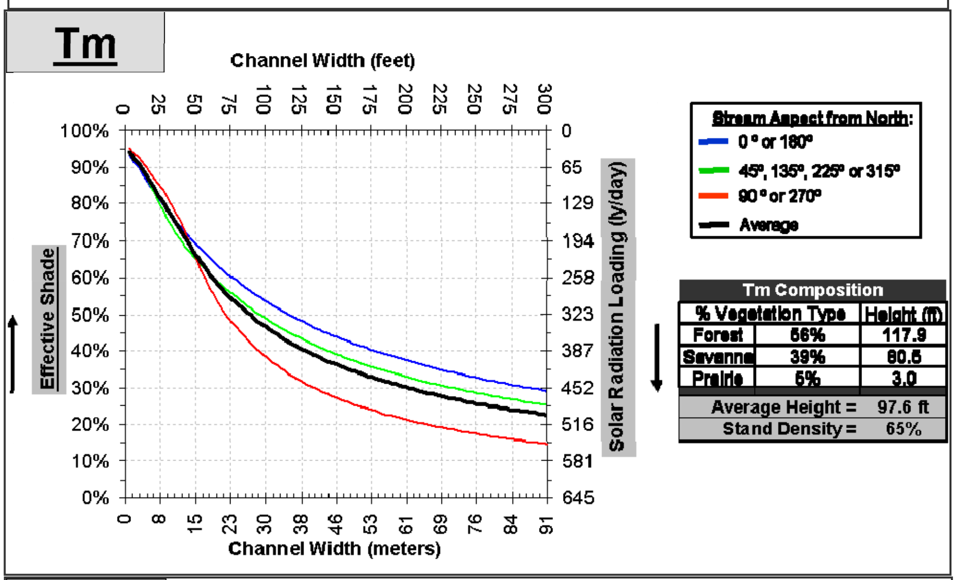
Qls Composition		
%	Vegetation Type	Height (ft)
Forest	59%	160.1
Savanna	41%	121.5
Prairie	0%	0.0
Average Height =		144.2 ft
Stand Density =		65%

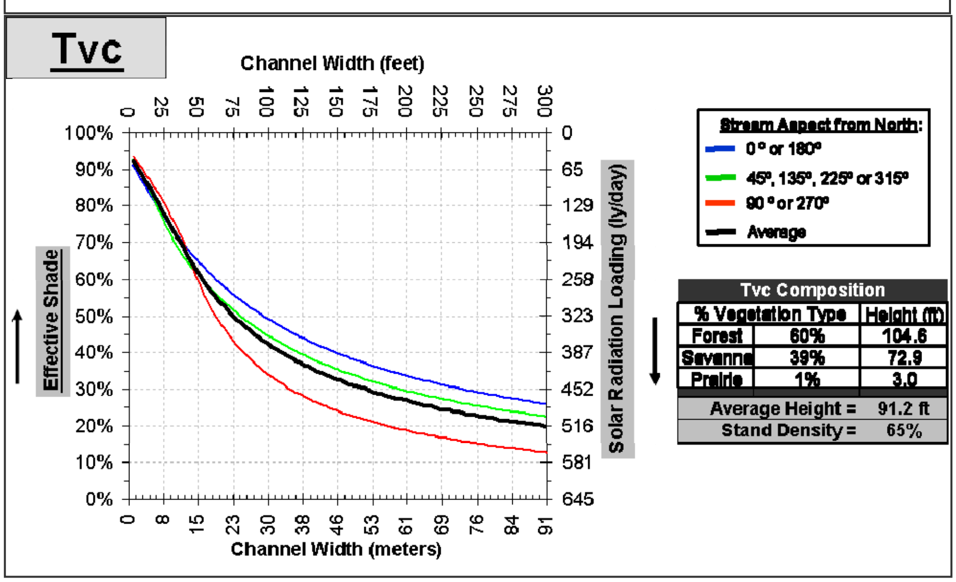

Qtb
Channel Width (feet)
0 25 50 75 100 125 150 175 200 225 250 275 300
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0%
Effective Shade
0 65 129 194 258 323 387 452 516 581 645
Solar Radiation Loading (ly/day)
0 8 15 23 30 38 46 53 61 69 76 84 91
Channel Width (meters)
Stream Aspect from North:
0° or 180°
45°, 135°, 225° or 315°
90° or 270°
Average
QTb Composition
% Vegetation Type | Height (ft)
Forest 51% 132.0
Savanna 44% 109.3
Prairie 5% 3.0
Average Height = 115.6 ft
Stand Density = 64%


Qtg
Channel Width (feet)
0 25 50 75 100 125 150 175 200 225 250 275 300
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0%
Effective Shade
0 65 129 194 258 323 387 452 516 581 645
Solar Radiation Loading (ly/day)
0 8 15 23 30 38 46 53 61 69 76 84 91
Channel Width (meters)
Stream Aspect from North:
0° or 180°
45°, 135°, 225° or 315°
90° or 270°
Average
Qtg Composition
% Vegetation Type | Height (ft)
Forest 77% 156.3
Savanna 14% 87.6
Prairie 9% 3.0
Average Height = 132.9 ft
Stand Density = 72%

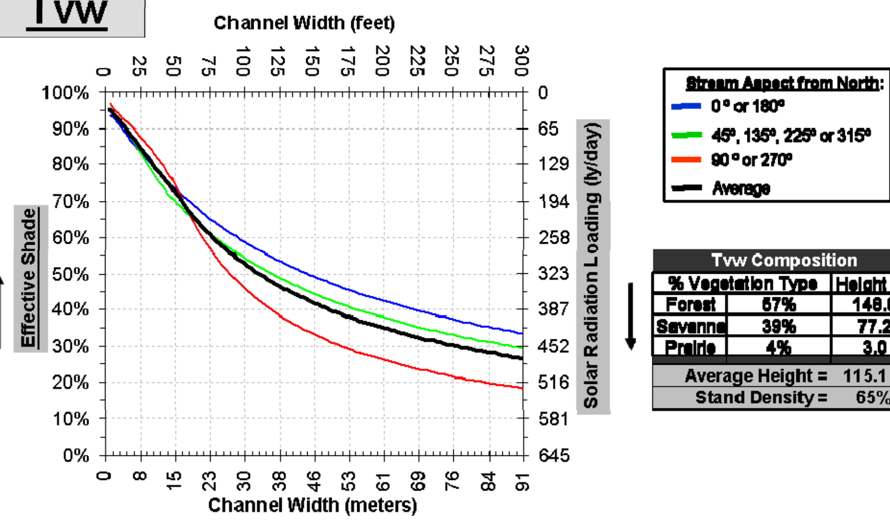

Qtt
Channel Width (feet)
0 25 50 75 100 125 150 175 200 225 250 275 300
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0%
Effective Shade
0 65 129 194 258 323 387 452 516 581 645
Solar Radiation Loading (ly/day)
0 8 15 23 30 38 46 53 61 69 76 84 91
Channel Width (meters)
Stream Aspect from North:
0° or 180°
45°, 135°, 225° or 315°
90° or 270°
Average
QTt Composition
% Vegetation Type | Height (ft)
Forest 43% 117.9
Savanna 35% 89.8
Prairie 22% 3.0
Average Height = 82.8 ft
Stand Density = 66%


Tcr
Channel Width (feet)
Effective Shade
Solar Radiation Loading (ly/day)
Channel Width (meters)
Stream Aspect from North:
0° or 180°
45°, 135°, 225° or 315°
90° or 270°
Average
Tcr Composition
% Vegetation Type | Height (ft)
Forest 63% 156.2
Savanna 27% 84.6
Prairie 10% 3.0
Average Height = 120.9 ft
Stand Density = 68%


Tm
Channel Width (feet)
Effective Shade
Solar Radiation Loading (ly/day)
Channel Width (meters)
Stream Aspect from North:
0° or 180°
45°, 135°, 225° or 315°
90° or 270°
Average
Tm Composition
% Vegetation Type | Height (ft)
Forest 56% 117.9
Savanna 39% 80.5
Prairie 5% 3.0
Average Height = 97.6 ft
Stand Density = 65%

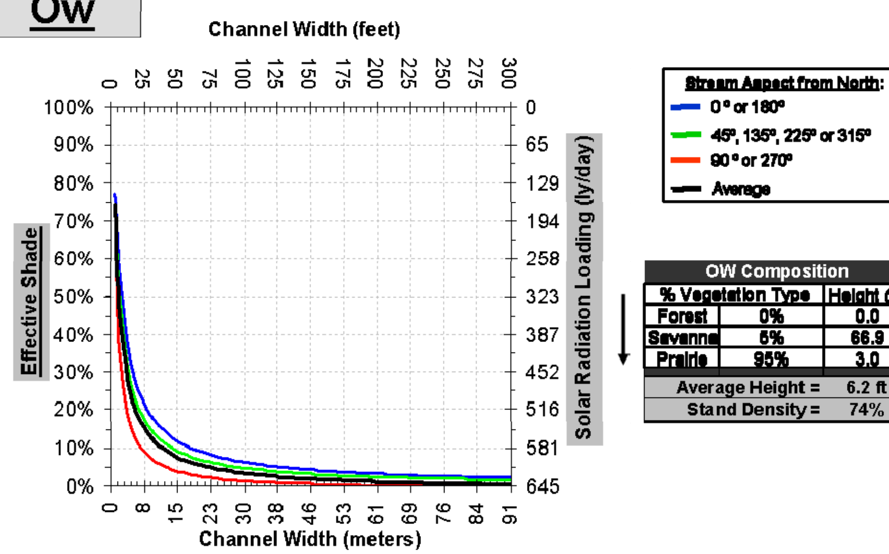

Tvc
Channel Width (feet)
Effective Shade
Solar Radiation Loading (ly/day)
Channel Width (meters)
Stream Aspect from North:
0° or 180°
45°, 135°, 225° or 315°
90° or 270°
Average
Tvc Composition
% Vegetation Type | Height (ft)
Forest 60% 104.6
Savanna 39% 72.9
Prairie 1% 3.0
Average Height = 91.2 ft
Stand Density = 65%

Tvw



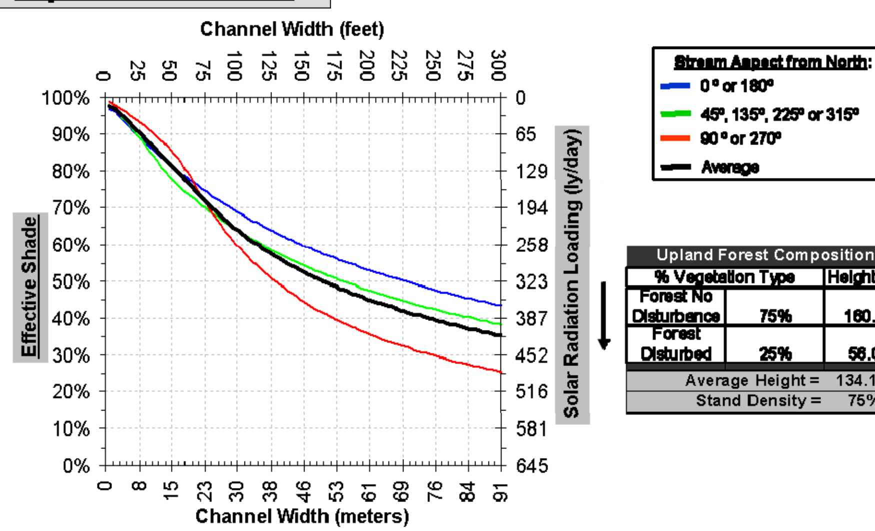
Tvw Composition		
%	Vegetation Type	Height (ft)
Forest	57%	146.6
Savanna	39%	77.2
Prairie	4%	3.0
Average Height =		115.1 ft
Stand Density =		65%

Ow



OW Composition		
%	Vegetation Type	Height (ft)
Forest	0%	0.0
Savanna	5%	66.9
Prairie	95%	3.0
Average Height =		6.2 ft
Stand Density =		74%

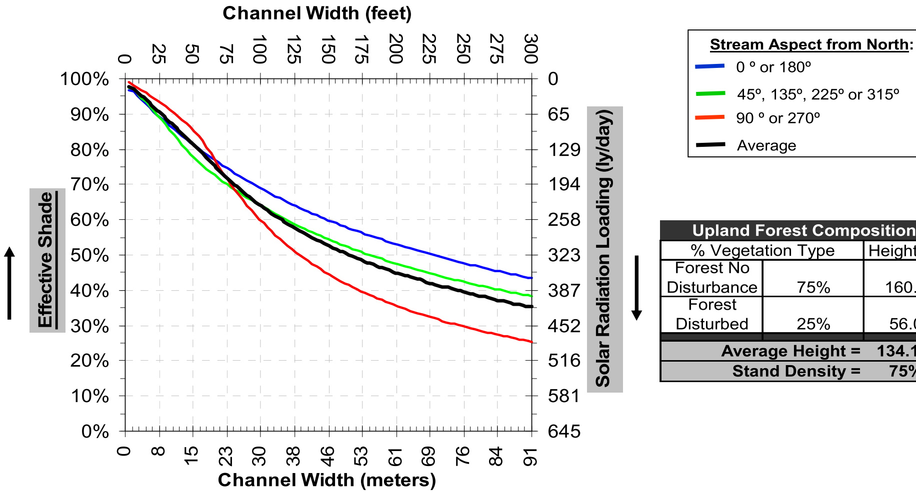
Upland Forest



Upland Forest Composition		
%	Vegetation Type	Height (ft)
Forest No Disturbance	75%	160.0
Forest Disturbed	25%	56.0
Average Height =		134.1 ft
Stand Density =		75%

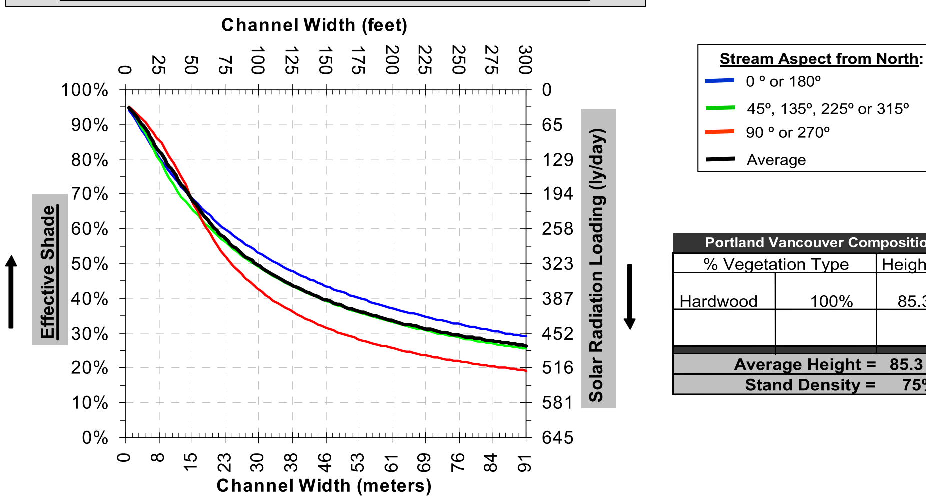
Lower Willamette Subbasin Shade Curves based on Ecoregion

Upland Forest



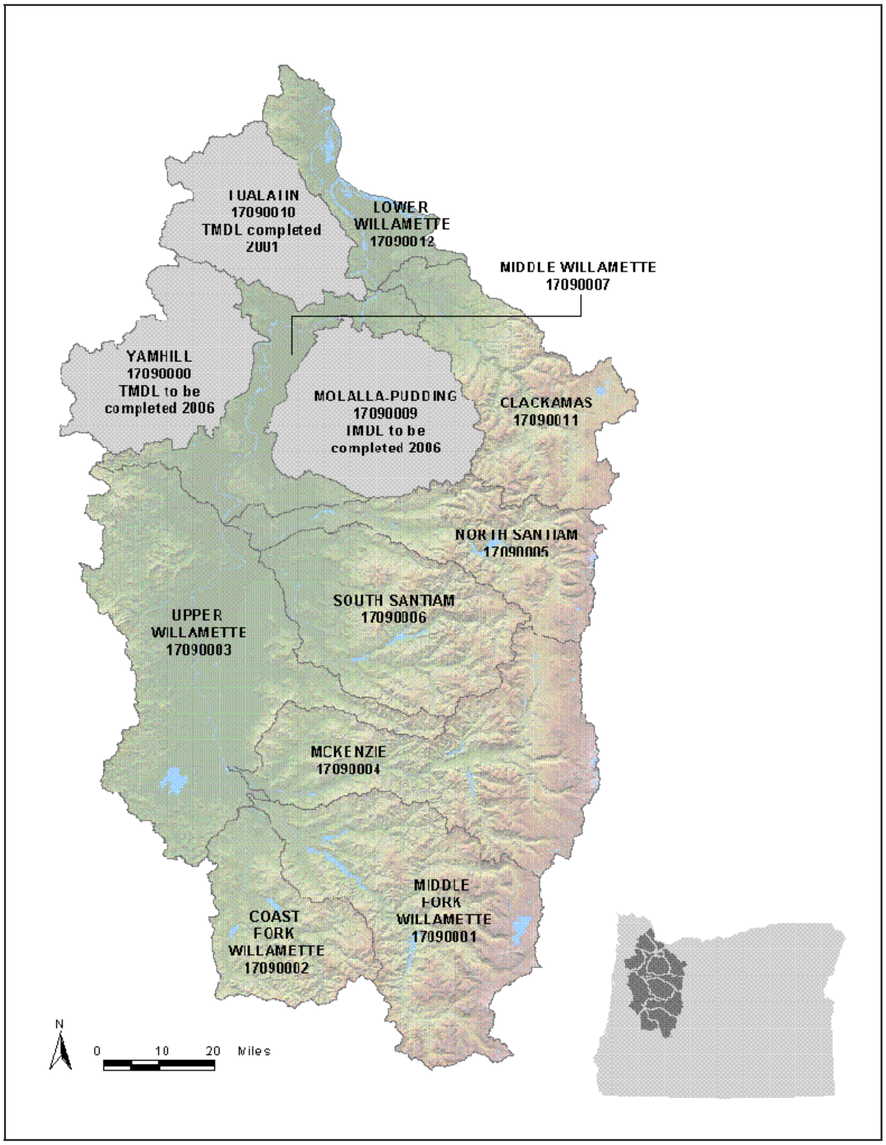
Upland Forest Composition		
% Vegetation Type		Height (ft)
Forest No Disturbance	75%	160.0
Forest Disturbed	25%	56.0
Average Height =		134.1 ft
Stand Density =		75%

Portland Vancouver Basin



Portland Vancouver Composition		
% Vegetation Type		Height (ft)
Hardwood	100%	85.3
Average Height =		85.3 ft
Stand Density =		75%

III. SUBBASINS STREAM TEMPERATURE ANALYSIS



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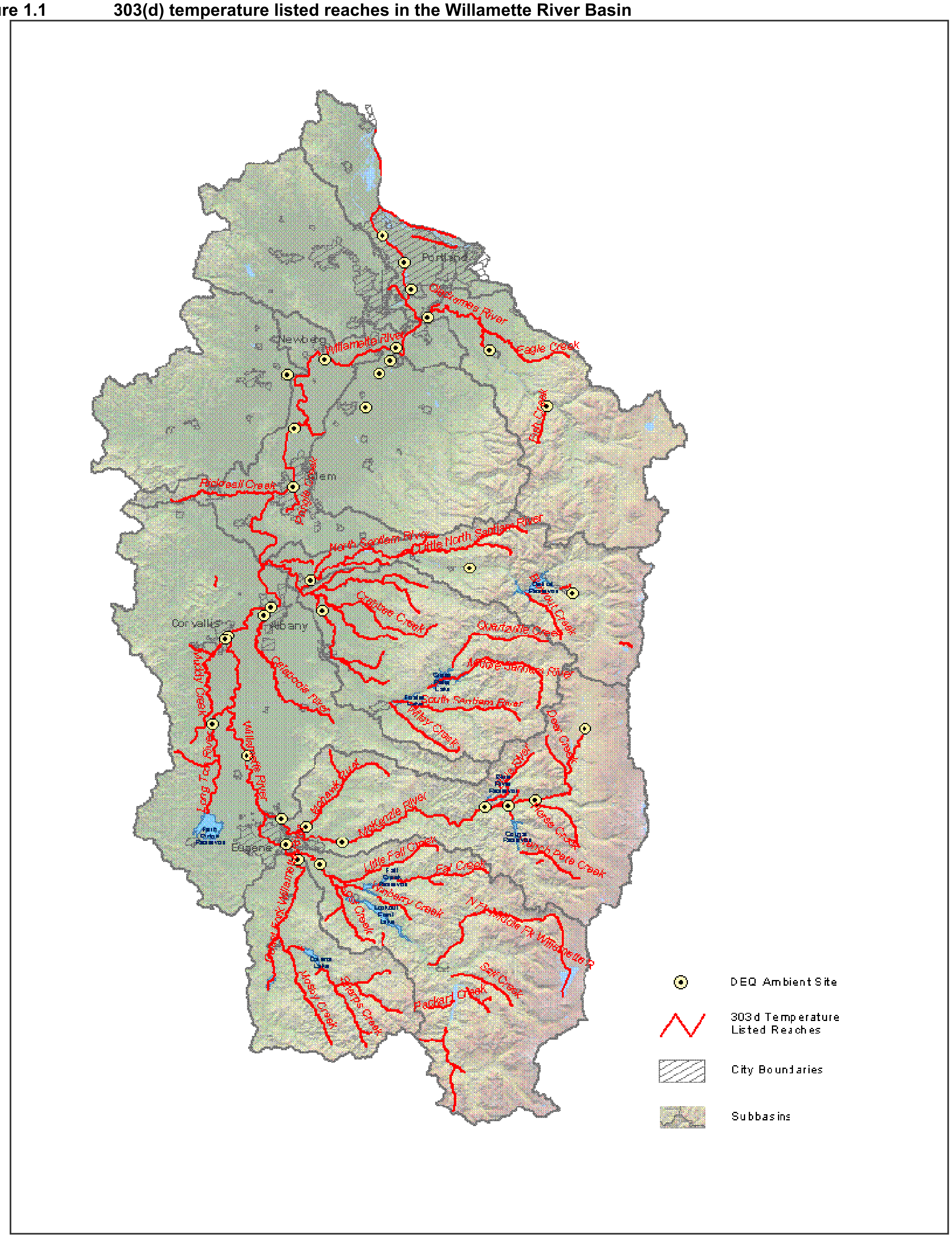
Chapter 1. Introduction

Figure 1.1 **303(d) temperature listed reaches in the Willamette River Basin**



1.1 Scale

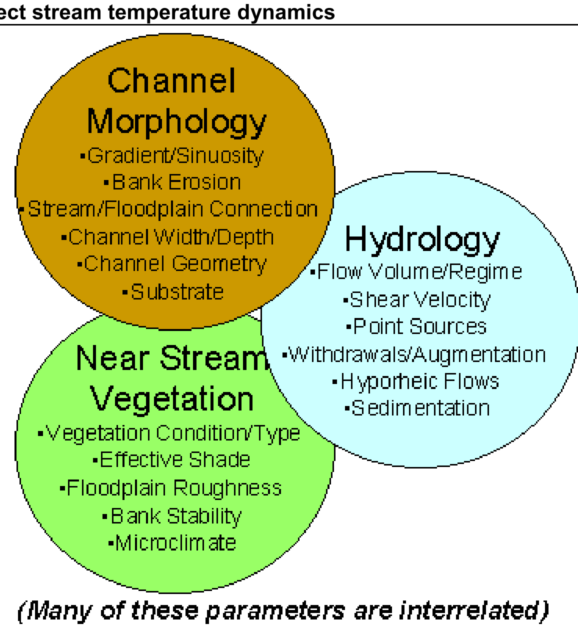
The Willamette Basin has twelve 4th field hydrologic unit subbasins. The nine included in this analysis occupy 9,120 square miles. These subbasins are Lower Willamette Subbasin (17090012), Clackamas Subbasin (17090011), Middle Willamette Subbasin (17090007), North Santiam Subbasin (17090005), South Santiam Subbasin (17090006), Upper Willamette (17090003), McKenzie (17090004), Middle Fork Willamette (17090001), and Coast Fork Willamette (17090002). While the stream temperature TMDL considers all surface waters within these subbasins, this analysis largely focuses on the largest water bodies within each subbasin.

1.2 Scope

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

Stream temperature dynamics are complicated when these parameters are evaluated on a watershed or subbasin scale. Many parameters exhibit considerable spatial variability. For example, channel width measurements can vary greatly over small stream lengths. Some parameters can have a diurnal and seasonal temporal component as well as spatial variability. The current analytical approaches developed for stream temperature assessment considers all of these parameters. It relies on ground level and remotely sensed spatial data. To understand temperature on a landscape scale is difficult and often resource intensive. General analytical techniques employed in this effort are statistical and deterministic modeling of hydrologic and thermal processes.

Figure 1.2 Factors that affect stream temperature dynamics



Stated Purpose:

The overriding intent of this analytical effort is to improve the understanding of stream temperature dynamics in both spatial and temporal scales.

Acknowledged Limitations:

It should be acknowledged that there are limitations to this effort:

- The scale of this effort is large with obvious challenges in capturing spatial variability in stream and landscape data. Available spatial data sets for land cover and channel morphology are coarse, while derived data sets are limited to aerial photo resolution, rectification limitations and human error.
- Data are insufficient to describe high-resolution instream flow conditions making validation of derived mass balances difficult.
- The water quality issues are complex and interrelated. The state of the science is still evolving in the context of comprehensive landscape scaled water quality analysis. For example, quantification techniques for microclimates that occur in near stream areas are not developed and available to this effort. Regardless, recent studies indicate that forested microclimates play an important, yet variable, role in moderating air temperature, humidity fluctuations and wind speeds.
- Quantification techniques for estimating potential subsurface inflows/returns and behavior within substrate are not employed in this analysis. While analytical techniques exist for describing subsurface/stream interactions, it is beyond the scope of this effort with regard to data availability, technical rigor and resource allocations.
- Land use patterns vary through the drainage from heavily impacted areas to areas with little human impacts. However, it is extremely difficult to find large areas without some level of either current or past human impacts. The development of potential conditions that estimate stream conditions when human influences are minimized is statistically derived and based on stated assumptions within this document. Limitations to stated assumptions are presented where appropriate. It should be acknowledged that as better information is developed these assumptions will be refined.

While these limitations outline potential areas of weakness in the methodology used in the stream temperature analysis, the Oregon Department of Environmental Quality has undertaken a comprehensive approach. All important stream parameters that can be accurately quantified are included in the analysis. In the context of understanding of stream temperature dynamics, these areas of limitations should be the focus for future study.

1.2.1 Summary of Stream Temperature TMDL Approach

Stream temperature TMDLs are generally scaled to a subbasin or basin and include all perennial surface waters with salmonid presence or that contribute to areas with salmonid presence. Since stream temperature results from cumulative interactions between upstream and local sources, the TMDL considers all surface waters that affect the temperatures of 303(d) listed water bodies (see **Figure 1.1**). For example, the Willamette River is water quality limited for temperature. To address this listing in the TMDL, most major tributaries are included in the TMDL analysis and TMDL targets apply throughout the entire stream network. This broad approach is necessary to address the cumulative nature of stream temperature dynamics.

An important step in the TMDL is to examine the anthropogenic contributions to stream heating. The pollutant is heat. The TMDL establishes that that the anthropogenic contributions of nonpoint source solar radiation heat loading results from varying levels of decreased stream surface shade throughout the sub-basin. Decreased levels of stream shade are caused by near stream land cover disturbance/removal and channel morphology changes. Other anthropogenic sources of stream warming include stream flow reductions and warm surface water return flows.

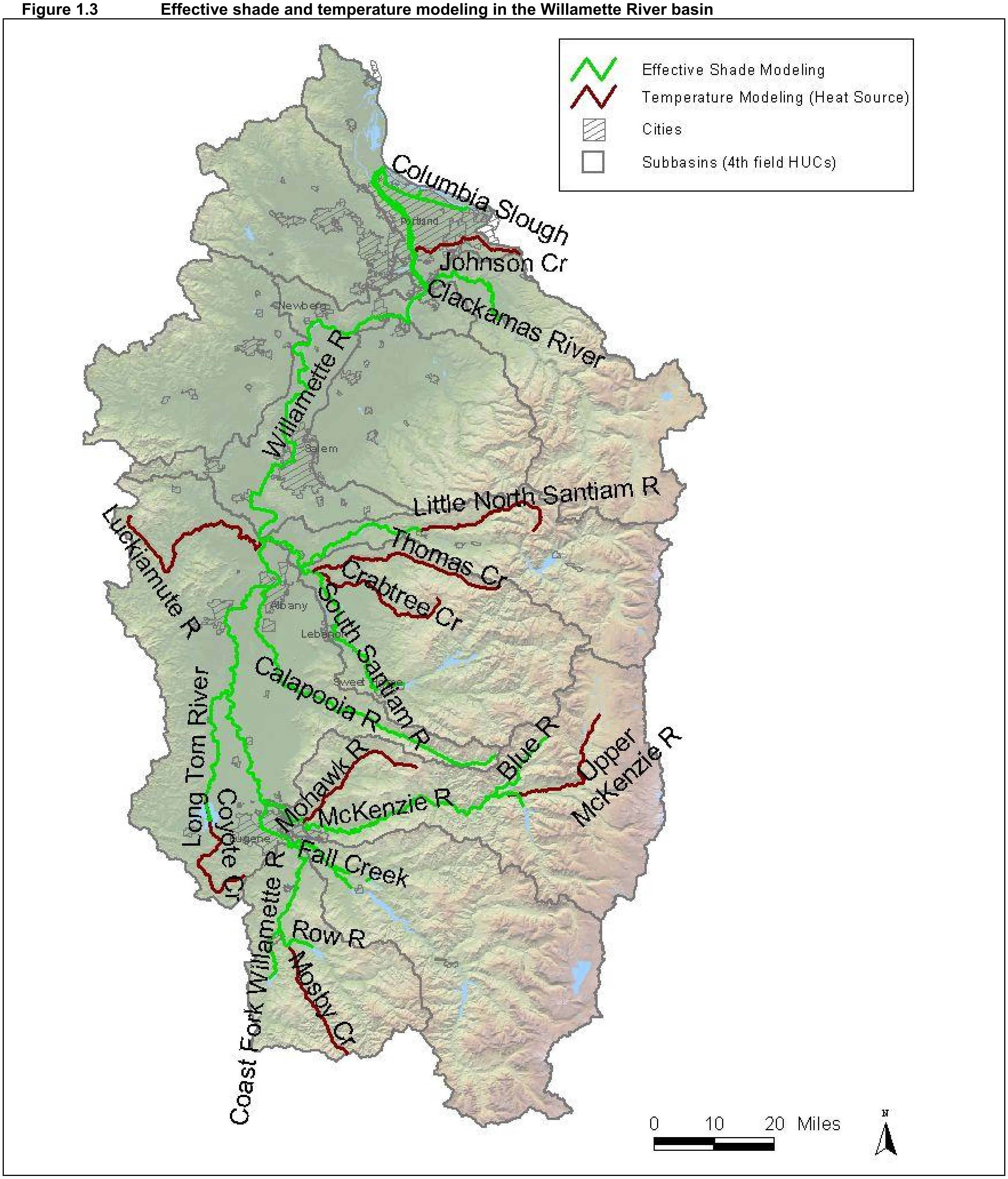
System potential vegetation for the Willamette subbasins, as defined in **Appendix C Chapter 2 – Potential Near-Stream Land Cover in the Willamette Basin for TMDLs**, is the potential near stream land cover condition. Potential near stream land cover is that which can grow and reproduce on a site, given: climate, elevation, soil properties, plant biology and hydrologic processes. System potential does not consider management or land use as limiting factors. **In essence, system potential is the design condition used for TMDL analysis that meets the temperature standard by minimizing human related warming.**

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

All stream temperature TMDLs allocate heat loading. Allocated conditions are expressed as heat per unit time (kcal per day). The nonpoint source heat allocation is translated to effective shade surrogate measures that linearly translates the nonpoint source solar radiation allocation. Effective shade surrogate measures provide site-specific targets for land managers. Attainment of the surrogate measures ensures compliance with the nonpoint source allocations.

Some streams in this TMDL analysis will undergo temperature modeling, while others will only be modelded for solar flux and effective shade. ODEQ choose temperature modeling on those streams that most typify subbasin tributaries. Temperature modeling will help set stream temperature targets and establish the natural thermal potential on subbasin tributaries.
Figure 1.3 shows which streams were modeled for temperature and which were modeled for solar flux and effective shade.

Figure 1.3 Effective shade and temperature modeling in the Willamette River basin



1.2.2 Limitations of Stream Temperature TMDL Approach

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

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

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

- Current analysis is focused on a defined critical condition. This usually occurs in late July or early August when stream flows are low, radiant heating rates are high and ambient conditions are warm. However, there are several other important time periods where data and analysis are less explicit. For example, spawning periods have not received such a robust consideration.
- Current analytical methods fail to capture some upland, atmospheric and hydrologic processes. At a landscape scale these exclusions can lead to errors in analytical outputs. For example, methods do not currently exist to simulate riparian microclimates at a landscape scale.
- In some cases, there is not scientific consensus related to riparian, channel morphology and hydrologic potential conditions. This is especially true when confronted with highly disturbed sites, meadows and marshes, potential hyporheic/subsurface flows, and sites that have been altered to a state where potential conditions produce an environment that is not beneficial to stream thermal conditions (such as a dike).

Chapter 2. Available Data

2.1 Ground Level Data

Several ground level data collection efforts have been completed for the Willamette subbasins. Available ground level data sources are included and are discussed in this chapter. Specifically, this stream temperature analysis relied on the following data types: continuous temperature data, flow volume (gage data and instream measurements), channel morphology surveys, and effective shade measurements.

2.1.1 Continuous Temperature Data

Continuous temperature data are used in this analysis to:

- *Calibrate stream emissivity for TIR, thermal infrared radiometry,*
- *Calculate temperature statistics and assess the temporal component of stream temperature,*
- *Calibrate temporal temperature simulations.*

Continuous temperature data are collected at one location for a specified period of time, usually spanning several summertime months. Measurements were collected using thermistors[1] and data from these devices are routinely checked for accuracy. Continuous temperature data were collected in 2000, 2001, and 2002 at many sites. ODEQ processed all of these data sets for the moving seven-day average daily maximum stream temperature (i.e., seven-day statistic). **Figure 1.4** displays continuous temperature data monitoring locations.

The seven-day moving average daily maximum stream temperatures and the monitoring location descriptions are presented in **Table 1.1 through Table 1.22**. Calculated seven-day moving average maximum stream temperatures indicate a large extent of the Willamette subbasins stream systems exceed the biological criteria in Oregon's stream temperature standard.

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

Figure 1.4 Continuous stream temperature measurement and stream survey locations

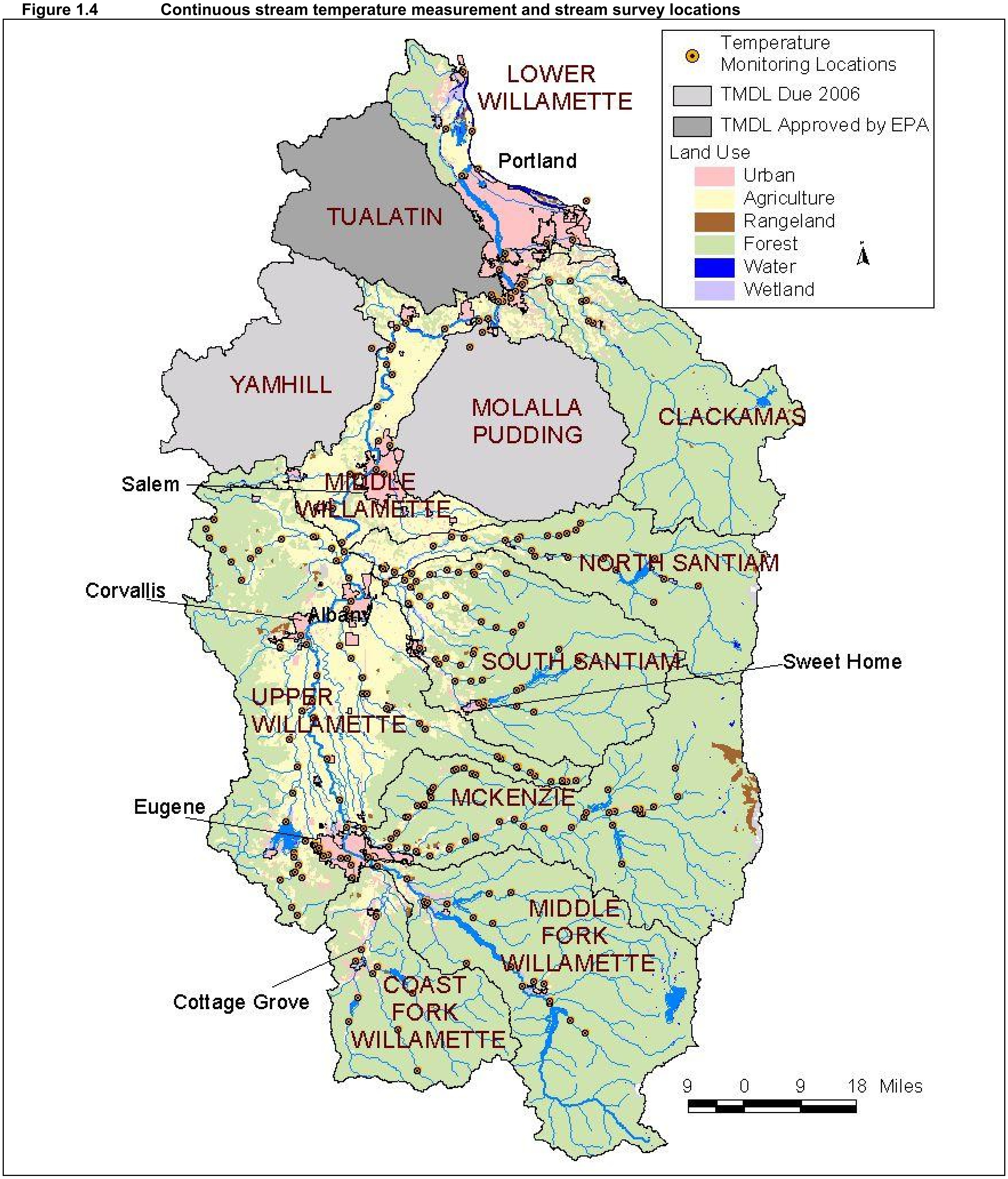


Table 1.1 Clackamas Subbasin seven day moving average daily maximum stream temperatures.

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
CLACKAMAS	brc00a01	Bear Creek Summer 2000	BLM	45.3278	-122.2810	8/2/2000	17.1
	del06a01	Delph Creek Summer 2000	BLM	44.6145	-122.5211	8/2/2000	13.1
	nfe00a01	NF Eagle Creek Summer 2000	BLM	44.2261	-123.6202	8/2/2000	18.5

Table 1.2 Coast Fork Willamette Subbasin seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
COAST FORK WILLAMETTE	28103	Mosby Creek below Row River Trail	BLM	43.7790	-123.0071	7/27/2002	25.8
	30368	Mosby Creek at Layng Road	ODEQ	43.7779	-123.0045	7/12/2002	24.2
	28799	Mosby Creek at Blue Mountain Park (u/s Perkins Creek)	ODEQ	43.7278	-122.9769	7/27/2002	25.0
	28101	Mosby Creek Above Cedar Creek	BLM	43.6486	-122.9201	7/10/2002	23.9
	28102	Mosby Creek Above West Fork	ODEQ	43.5551	-122.8501	7/24/2002	18.3
	10380	Coast Fork Willamette at Creswell	ODEQ	43.9113	-122.9972	07/13/02	24.2
	10381	Coast Fork Willamette River at Saginaw	ODEQ	43.8325	-123.0427	07/23/02	20.9
	29643	Coast Fork Willamette Above Cottage Grove STP	ODEQ	43.8070	-123.0580	07/27/02	20.0
		Big River below Edwards Creek	ODEQ	43.5833	-122.9824	08/12/01	17.0
		Big River below Edwards Creek	ODEQ	43.5833	-122.9824	07/26/02	17.2
		King Creek - #6	ODEQ	43.7097	-122.9167	08/12/01	14.2
		King Creek - Lower #3	ODEQ	43.7167	-122.9111	08/12/01	14.8
		King Creek - Lower Stream #1	ODEQ	43.7194	-122.9125	08/12/01	15.2
		King Creek - Middle Stream # 3	ODEQ	43.7125	-122.9153	08/12/01	14.7
		King Creek - Upper Stream # 1	ODEQ	43.7139	-122.9167	08/12/01	15.5
		Mosby Creek above Cedar Creek	ODEQ	43.6486	-122.9201	08/12/01	23.5
		Mosby Creek above Cedar Creek	ODEQ	43.6486	-122.9201	07/13/02	23.9
		Mosby Creek above West Fork	ODEQ	43.5551	-123.8501	08/12/01	18.2
		Mosby Creek above West Fork	ODEQ	43.5551	-123.8501	07/27/02	18.3
		Mosby Creek below Row River Trail	ODEQ	43.7790	-123.0071	08/10/01	25.1
		Mosby Creek below Row River Trail	ODEQ	43.7790	-123.0071	07/27/02	25.9
		Row River above Sharps Creek	ODEQ	43.6958	-122.8347	08/12/01	24.3
		Row River below Dorena Reservoir	ODEQ	43.7889	-123.9667	10/01/02	18.5
		Sharps Creek near confluence with Row River	ODEQ	43.6944	-122.8375	08/12/01	22.3
		Sharps Creek near confluence with Row River	ODEQ	43.6944	-122.8375	07/12/02	23.0
		Sharps Creek near Windy Mtn. Road	ODEQ	43.6111	-122.7708	08/12/01	20.2
		Sharps Creek near Windy Mtn. Road	ODEQ	43.6111	-122.7708	07/27/02	20.8

Table 1.3 Lower Willamette Subbasin seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
LOWER WILLAMETTE	10853	Johnson Creek at 92nd Avenue near Flavel RM 6.2 (Trib to Willamette RM 18.5)	ODEQ	45.4678	-122.5683	07/13/02	25.9
	26745	Willamette River at Roehr Park 10ft.	ODEQ	45.4078	-122.6578	07/25/02	23.6
	26745	Willamette River at Roehr Park 10ft.	ODEQ	45.4078	-122.6578	09/01/02	21.5
	26745	Willamette River at Roehr Park 3ft.	ODEQ	45.4078	-122.6578	07/20/02	24.0
	26745	Willamette River at Roehr Park 3ft.	ODEQ	45.4078	-122.6578	09/01/02	21.9
	10856	Johnson Creek at 122nd and Leach Botanical Gardens RM 8.7 (Trib to Willamette RM 18.5)	ODEQ	45.4735	-122.5368	07/23/02	21.9
	11201	Columbia Slough @ St. Johns Landfill Bridge(SJB)	ODEQ	45.6104	-122.7553	07/11/01	26.3
	11201	Columbia Slough at St. Johns Landfill Bridge - 3ft	ODEQ	45.6105	-122.7545	07/13/02	26.4
	11201	Columbia Slough at St. Johns Landfill Bridge - 3ft	ODEQ	45.6105	-122.7545	08/26/02	23.4
	11321	Johnson Creek at 17th Avenue RM 0.2 (Trib to Willamette RM 18.5)	ODEQ	45.4472	-122.6423	07/13/02	23.5
	11323	Johnson Creek at 45th Avenue Footbridge RM 3.0 (Trib to Willamette RM 18.5)	ODEQ	45.4617	-122.6161	07/13/02	22.9
	11326	Johnson Creek at Pleasantville / 190th Ave. RM 12.8 (Trib to Willamette RM 18.5)	ODEQ	45.4880	-122.4676	07/23/02	23.5
	11327	Johnson Creek at Regner Gage RM 15.1(Trib to Willamette RM 18.5)	ODEQ	45.4867	-122.4206	07/23/02	21.9
	11329	Crystal Springs Creek at Johnson Creek Park RM 0.1 (Trib to Johnson Creek RM 1.3 to Wil	ODEQ	45.4615	-122.6422	07/13/02	24.7
	11626	Johnson Creek at Palmblad Road RM 17.8 (Trib to Willamette RM 18.5)	ODEQ	45.4728	-122.4035	07/23/02	22.3
	14211550	Johnson Creek at Milwaukie	USGS	45.4531	-122.6419	10/04/01	16.5
	14211550	Johnson Creek at Milwaukie	USGS	45.4531	-122.6419	07/23/02	23.6
	14211720	Willamette R at Portland	USGS	45.5186	-122.6667	11/05/01	11.3
	14211720	Willamette R at Portland	USGS	45.5186	-122.6667	11/30/01	8.1
	14211720	Willamette R at Portland	USGS	45.5186	-122.6667	07/21/02	24.3
	26745	Willamette River @ Roehr water front park - 10ft	ODEQ	45.4156	-122.6578	08/15/01	23.7
	26745	Willamette River @ Roehr water front park - Shallow	ODEQ	45.4156	-122.6578	08/15/01	24.0
	26760	Multnomah Channel D/S Gilbert River	ODEQ	45.7288	-122.8596	07/27/02	22.9
	28506	Willamette River at RM 18.76 - North of Deer Island - Buoy 1 - 4ft	ODEQ	45.4379	-122.6470	07/20/02	24.4
	28506	Willamette River at RM 18.76 - North of Deer Island - Buoy 1 - 58ft	ODEQ	45.4379	-122.6470	07/27/02	23.4
	28506	Willamette River at RM 18.8 - Buoy - North of Deer Island - TOP	ODEQ	45.4381	-122.6473	08/14/01	24.4
	28506	Willamette River at RM 18.8 - Buoy - North of Deer Island -BOTTOM	ODEQ	45.4381	-122.6473	08/16/01	23.5
	28507	Willamette River Upstream of Kellogg Outfall - Bouy - BOTTOM	ODEQ	45.4393	-122.6446	08/16/01	23.6
	28507	Willamette River Upstream of Kellogg Outfall - Bouy - TOP	ODEQ	45.4393	-122.6446	08/14/01	24.1
	28507	Willamette River upstream of Kellogg Outfall - Buoy 2 - 4ft	ODEQ	45.4390	-122.6446	07/20/02	24.3
	28507	Willamette River upstream of Kellogg Outfall - Buoy 2 - 50ft	ODEQ	45.4390	-122.6446	07/20/02	23.4
	28508	Willamette River Downstream of Kellogg Outfall - Buoy - BOTTOM	ODEQ	45.4404	-122.6439	08/16/01	23.6

Table 1.4 Lower Willamette Subbasin (contd.) seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date /	Temp (ºC)
LOWER WILLAMETTE	28508	Willamette River Downstream of Kellogg Outfall - Buoy - TOP	ODEQ	45.4404	-122.6439	08/14/01	24.2
	28508	Willamette River downstream of Kellogg Outfall - Buoy 3 - 2ft	ODEQ	45.4407	-122.6437	07/19/02	24.2
	28508	Willamette River downstream of Kellogg Outfall - Buoy 3 - 40ft	ODEQ	45.4407	-122.6437	07/19/02	23.5
	28729	Johnson Creek at Revenue Road RM 21.6 (Trib to Willamette RM 18.5)	ODEQ	45.4616	-122.3369	07/23/02	19.1
	28730	Johnson Creek at Short Road RM 20.5 (Trib to Willamette RM 18.5)	ODEQ	45.4627	-122.3575	07/23/02	21.3
	28731	Johnson Creek at SE Circle Avenue RM 11.7 (Trib to Willamette RM 18.5)	ODEQ	45.4864	-122.4880	07/23/02	23.1
	28732	Johnson Creek at Bell Road and Johnson Creek Blvd RM 4.6 (Trib to Willamette RM 18.5)	ODEQ	45.4557	-122.5927	07/23/02	25.9
	28765	Willamette River at Saint John's Rail Road Bridge 3 ft. probe (h-lab site).	ODEQ	45.5734	-122.7460	10/15/01	15.8
	28765	Willamette River at St. Johns RR Bridge 10ft	ODEQ	45.5758	-122.7468	07/26/02	24.0
	28765	Willamette River at St. Johns RR Bridge 3 ft	ODEQ	45.5758	-122.7468	07/25/02	24.7
	29746	Willamette River u/s of Oregon Steel Mills 10ft	ODEQ	45.6218	-122.7933	07/26/02	23.2
	29746	Willamette River u/s of Oregon Steel Mills 10ft	ODEQ	45.6218	-122.7933	08/26/02	22.1
	29746	Willamette River u/s of Oregon Steel Mills 3ft	ODEQ	45.6218	-122.7933	07/25/02	24.2
	29746	Willamette River u/s of Oregon Steel Mills 3ft	ODEQ	45.6218	-122.7933	08/26/02	22.9
	29747	Willamette River at Waverley Country Club 10 ft	ODEQ	45.4536	-122.6604	07/27/02	24.0
	29747	Willamette River at Waverley Country Club 10 ft - QA	ODEQ	45.4536	-122.6604	07/27/02	24.0

Table 1.5 McKenzie Subbasin seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp	(ºC)
MCKENZIE	10663	Mohawk River at Hill Road	ODEQ	44.0923	-122.9593	8/10/2001	25.3
	22651	Mohawk River at WEYCO Gate	ODEQ	44.2542	-122.7561	8/10/2001	21.2
	22654	Mohawk River at Wendling Road	ODEQ	44.1729	-122.8541	8/12/2001	22.2
	25496	Mohawk River at Old Mohawk Road	ODEQ	44.1042	-122.9403	8/10/2001	26.0
	25498	Mohawk River at Sunderman Rd.	ODEQ	44.1414	-122.9073	8/10/2001	23.5
	25502	Mohawk River at Paschelke Rd	ODEQ	44.2014	-122.8368	8/10/2001	21.1
	25607	Mohawk River at WEYCO shop	ODEQ	43.9869	-124.1177	8/12/2001	18.8
	25608	Mohawk River on East Street	ODEQ	43.9869	-124.1178	8/12/2001	17.9
	29645	McKenzie River Above Mohawk River	ODEQ	44.0775	-122.9691	07/23/02	20.2
	10376	McKenzie River at Coburg Rd.	ODEQ	44.1120	-123.0446	07/23/02	20.3
	10663	Mohawk River at Hill Road	ODEQ	44.0926	-122.9566	07/27/02	25.7
	14159500	S F McKenzie R nr Rainbow	USGS	44.1361	-122.2472	10/04/01	14.5
	14159500	S F McKenzie R nr Rainbow	USGS	44.1361	-122.2472	01/11/02	5.7
	14159500	S F McKenzie R nr Rainbow	USGS	44.1361	-122.2472	07/30/02	17.4
	14162200	Blue River at Blue River	USGS	44.1625	-122.3319	10/04/01	18.4
	14162200	Blue River at Blue River	USGS	44.1625	-122.3319	10/19/02	16.3
	14162500	McKenzie River nr Vida	USGS	44.1250	-122.4694	10/04/01	12.9
	14162500	McKenzie River nr Vida	USGS	44.1250	-122.4694	07/22/02	16.5
	14163900	McKenzie R nr Walterville	USGS	44.0703	-122.7700	10/04/01	13.7
	14163900	McKenzie R nr Walterville	USGS	44.0703	-122.7700	07/27/02	18.1

Table 1.6 McKenzie Subbasin (contd.) seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
MCKENZIE		Bear Creek (McKenzie)	ODEQ	44.1329	-122.4831	08/12/01	16.7
		Bear Creek (McKenzie)	ODEQ	44.1329	-122.4831	07/23/02	16.7
		Camp Creek (McKenzie)	ODEQ	44.1218	-122.7883	08/10/01	16.5
		Camp Creek (McKenzie)	ODEQ	44.1218	-122.7883	07/23/02	16.5
		Cartwright Creek (McKenzie)	ODEQ	44.1719	-122.8314	08/12/01	17.7
		Cartwright Creek (McKenzie)	ODEQ	44.1719	-122.8314	07/13/02	18.5
		Cash Creek	ODEQ	44.2138	-122.8524	08/12/01	17.7
		Cash Creek (McKenzie)	ODEQ	44.2138	-122.8524	07/23/02	17.8
		Deer Creek (McKenzie)	ODEQ	44.1092	-122.4550	08/12/01	18.3
		Deer Creek (McKenzie)	ODEQ	44.1092	-122.4550	07/23/02	18.7
		Drury Creek	ODEQ	44.2622	-122.8322	07/24/01	18.5
		Drury Creek (McKenzie)	ODEQ	44.2622	-122.8323	07/23/02	16.8
		Finn Creek	ODEQ	44.1687	-122.6243	08/12/01	15.8
		Finn Creek	ODEQ	44.1687	-122.6243	07/23/02	15.6
		McGowan Creek	ODEQ	44.1521	-122.9511	07/23/02	17.7
		McGowan Creek (McKenzie)	ODEQ	44.1521	-122.9511	08/12/01	17.7
		Owl Creek (McKenzie)	ODEQ	44.2632	-122.8771	08/12/01	17.0
		Owl Creek (McKenzie)	ODEQ	44.2633	-122.8771	08/14/02	16.7
		Seeley Creek	ODEQ	44.2508	-122.8640	08/12/01	16.3
		Seeley Creek (McKenzie)	ODEQ	44.2508	-122.8640	07/27/02	16.2
		Shotgun Creek #1	ODEQ	44.2644	-122.8771	08/12/01	17.6
		Shotgun Creek #1 (McKenzie)	ODEQ	44.2261	-122.8455	08/14/02	17.4
		Shotgun Creek #2 (McKenzie)	ODEQ	44.2261	-122.8455	08/12/01	18.1
		Shotgun Creek #2 (McKenzie)	ODEQ	44.2644	-122.8771	07/24/02	18.0

Table 1.7 Middle Fork Willamette Subbasin seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
MIDDLE FORK WILLAMETTE	14150000	MF Willamette R nr Dexter	USGS	43.9458	-122.8361	10/04/01	18.6
	14150000	MF Willamette R nr Dexter	USGS	43.9458	-122.8361	09/22/02	18.8
	14151000	Fall Creek nr Fall Creek	USGS	43.9444	-122.7736	10/17/01	16.6
	14151000	Fall Creek nr Fall Creek	USGS	43.9444	-122.7736	08/31/02	21.3
	14152000	MF Willamette R at Jasper	USGS	43.9983	-122.9047	10/16/01	16.8
	14152000	MF Willamette R at Jasper	USGS	43.9983	-122.9047	08/31/02	19.3
	27974	Hills Creek at Road 5875 - Trib to MF Willamette RM 44.6	ODEQ	43.6542	-122.3203	08/12/01	20.1
	27976	Pinto Creek at Road 23 - Trib to Hills Crk RM 13.3	ODEQ	43.5819	-122.1850	08/12/01	12.5
	27980	Juniper Creek at Mouth - Trib to Hills Crk RM 8.3	ODEQ	43.6388	-122.3063	08/12/01	14.4
	27981	Mike Creek at Mouth RM 0.7-Trib to Hills Crk RM 6.1	ODEQ	43.6693	-122.3238	06/20/01	18.4
	27983	Buckhead Creek at 5821 - Trib to MF Willamette RM 33.3	ODEQ	43.7754	-122.5249	08/12/01	17.6
	27984	Packard Creek at Ownership Bdy. - Trib to MF Willamette RM 47.5	ODEQ	43.6469	-122.5082	08/13/01	15.2
	27987	Gold Creek at Mouth - Trib to MF Willamette RM 53.3	ODEQ	43.5926	-122.4584	08/13/01	18.3
	27989	Snake Creek at Mouth - Trib to MF Willamette RM 57.6	ODEQ	43.5402	-122.4526	08/13/01	17.7

Table 1.8 Middle Fork Willamette Subbasin (contd.) seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
MIDDLE FORK WILLAMETTE	27990	Indian Creek at Mouth - Trib to MF Willamette RM 59.7	ODEQ	43.5162	-122.4494	08/13/01	18.3
	27991	Coal Creek at Mouth - Trib to MF Willamette RM 61.3	ODEQ	43.5000	-122.4196	08/13/01	20.0
	27992	Middle Fork Willamette River at Road 2127 RM 58.0	ODEQ	43.5412	-122.4571	08/08/01	17.6
	27993	Eighth Creek at Mouth - Trib to NF of MF Willamette RM 9.5	ODEQ	43.8340	-122.3999	08/13/01	15.4
	27994	Christy Creek at Mouth - Trib to NF of MF Willamette RM 13.9	ODEQ	43.8924	-122.3919	08/12/01	18.9
	27995	Chalk Creek at Mouth - Trib to NF of MF Willamette RM 12.9	ODEQ	43.8707	-122.4000	08/12/01	23.6
	27996	McKinley Creek at Mouth - Trib to NF of MF Willamette RM 12.1	ODEQ	43.8666	-122.4132	08/13/01	16.5
	27997	Hammer Creek at Mouth - Trib to NF of MF Willamette RM 11.6	ODEQ	43.8586	-122.4121	08/13/01	15.0
	27998	North Fork of Middle Fork Willamette at Road 1919 RM 10.09	ODEQ	43.8394	-122.4063	08/12/01	18.8
	27999	High Creek at Mouth - Trib to NF of MF Willamette RM 9.9	ODEQ	43.8353	-122.4056	08/12/01	15.7
	28000	Huckleberry Creek at Mouth - Trib to NF of MF Willamette RM 8.1	ODEQ	43.8149	-122.4078	08/13/01	15.4
	28001	North Fork of Middle Fork Willamette River at Road 1912 RM 6.39	ODEQ	43.8029	-122.4356	08/12/01	19.8
	28002	North Fork of Middle Fork Willamette River at Road 1910 RM 2.40	ODEQ	43.7691	-122.4888	08/12/01	20.3
	28003	North Fork of Middle Fork Willamette River at Mouth	ODEQ	43.7755	-122.5236	08/10/01	22.2
	28724	Middle Fork Willamette River #1	ODEQ	44.0240	-123.0198	08/31/02	19.6
	28724	Middle Fork Willamette River #2 - QA	ODEQ	44.0240	-123.0198	08/30/02	19.6
		Anthony Creek	ODEQ	43.8744	-122.8610	08/12/01	18.5
		Anthony Creek	ODEQ	43.8744	-122.8610	08/14/02	22.7
		Gosage Creek	ODEQ	43.8444	-122.6821	08/12/01	16.4
		Gosage Creek	ODEQ	43.8444	-122.6821	07/23/02	16.5
		Guiley Creek	ODEQ	43.8371	-122.7946	08/12/01	16.7
		Guiley Creek	ODEQ	43.8371	-122.7945	07/13/02	16.9
		Hill Creek	ODEQ	43.9944	-122.8087	08/09/01	19.2
		Hills Creek	ODEQ	43.9944	-122.8087	07/23/02	17.9
		Little Fall Creek # 1	ODEQ	43.9926	-122.6940	08/10/01	25.9
		Little Fall Creek #1	ODEQ	43.9926	-122.6940	07/27/02	20.2
		Little Fall Creek #2	ODEQ	43.9858	-122.7262	08/10/01	21.2
		Little Fall Creek #2	ODEQ	43.9858	-122.7262	07/23/02	21.8
		Lost Creek	ODEQ	43.8425	-122.7786	08/12/01	17.1
		Lost Creek	ODEQ	43.8425	-122.7786	07/23/02	17.5
		Middle Creek	ODEQ	43.8673	-122.8219	08/12/01	17.5
		Middle Creek	ODEQ	43.8673	-122.8219	08/14/02	17.7
		Nelson Creek (MFW)	ODEQ	44.0986	-123.6244	08/15/02	16.1

Table 1.9 Middle Willamette Subbasin seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
MIDDLE WILLAMETTE	10344	Willamette River at Wheatland Ferry RM 71.9	ODEQ	45.0888	-123.0457	7/13/2002	23.3
	10340	Willamette River at I-5 Wilsonville	ODEQ	45.2925	-122.7761	07/15/02	24.4
	10344	Willamette River at Wheatland Ferry RM 72	ODEQ	45.0888	-123.0457	08/11/01	24.1
	10347	Willamette River at S. River Road	ODEQ	44.8460	-123.1789	07/13/02	22.3
	10348	Willamette River at Buena Vista Ferry	ODEQ	44.7701	-123.1447	08/14/02	21.7
	11102	Rickreall Creek at State Farm Road RM 0.8	ODEQ	44.9311	-123.1283	07/11/01	23.3
	26759	Mill Creek at State Street	ODEQ	44.9346	-123.0174	07/13/02	21.9
	28254	Willamette River above Rickreall Creek RM 88.2	ODEQ	44.9266	-123.1115	08/11/01	23.1
	28254	Willamette River Above Rickreall Creek RM 88.2	ODEQ	44.9265	-123.1114	07/13/02	22.4
	28255	Willamette River Above WLTP Outfall RM 78.1	ODEQ	45.0093	-123.0371	07/13/02	23.1
	28255	Willamette River at RM 78.1 above WLTP Outfall 78.1	ODEQ	45.0094	-123.0371	08/12/01	24.1
	11102	Rickreall Creek at State Farm Road	SECOR	44.9311	-123.1283	7/12/2001	23.7
	26759	Mill Creek at State Street	SECOR	44.9346	-123.0176	8/10/2001	22.8
	26759	Mill Creek at State Street	SECOR	44.9346	-123.0176	7/13/2002	21.9
		Mill Creek at Front Street	City of Salem			7/30/1999	20.6
		Pringle Creek at Pringle Road	City of Salem			7/25/1998	25.0
		Patterson Creek	ODEQ			6/27/2000	19.9

Table 1.10 Molalla-Pudding Willamette Subbasin seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
MOLALLA-PUDDING	10637	Molalla River at Knights Bridge Rd.	ODEQ	45.2674	-122.7103	07/23/02	26.2
	10917	Pudding River at Highway 99E	ODEQ	45.2339	-122.7504	07/25/02	25.3

Table 1.11 North Santiam Subbasin seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
NORTH SANTIAM	10792	North Santiam River at Green's Bridge	ODEQ	44.7098	-122.9720	08/13/02	20.0
	14181500	N Santiam River at Niagara	USGS	44.7528	-122.2972	10/04/01	15.8
	14181500	N Santiam River at Niagara	USGS	44.7528	-122.2972	10/17/02	13.7
	14182500	Little North Santiam R nr Mehama	USGS	44.7917	-122.5667	10/04/01	15.3
	14182500	Little North Santiam R nr Mehama	USGS	44.7917	-122.5667	08/14/02	24.4
	14183000	N Santiam River at Mehama	USGS	44.7889	-122.7817	10/04/01	16.9
	14183000	N Santiam River at Mehama	USGS	44.7889	-122.7817	06/07/02	11.1
	14183000	N Santiam River at Mehama	USGS	44.7889	-122.7817	07/23/02	16.5
	14189050	Santiam River near Jefferson	USGS	44.7389	-123.0486	10/04/01	16.2
	14189050	Santiam River near Jefferson	USGS	44.7389	-123.0486	07/23/02	21.3
	24339	Santiam River u/s Jefferson Treatment Plant RM 8.9	ODEQ	44.7234	-123.0167	08/10/01	22.5
	24571	Santiam River Downstream Chehulpum Creek RM 3.25	ODEQ	44.7469	-123.0947	08/10/01	21.8
	24572	Chehulpum Creek at Interstate 5	ODEQ	44.7581	-123.0475	08/10/01	21.9
	25798	North Santiam River Upstream Bear Branch RM 11.4	ODEQ	44.7533	-122.8579	08/10/01	21.9
	25817	Santiam River at RM 11.0	ODEQ	44.6953	-123.0165	08/10/01	22.4
	25975	Stout Creek at mouth (Trib to North Santiam RM 24.7) RM 0.06	ODEQ	44.7807	-122.6606	08/12/01	26.7
	25976	North Santiam River Upstream Stout Creek RM 24.8	ODEQ	44.0839	-122.6593	08/09/01	19.8
	25977	North Santiam River Downstream Stout Creek RM 22.18	ODEQ	44.7783	-122.6769	08/10/01	20.3
	25980	North Santiam River Upstream Marion Creek RM 4.0	ODEQ	44.7213	-122.9565	08/10/01	22.0
	25981	Bear Branch at Shelburn Dr. (Trib to North Santiam RM 11.2) RM 0.66	ODEQ	44.7530	-122.8503	08/10/01	22.7
	25984	Santiam River Upstream Chehulpum Creek RM 3.41	ODEQ	44.7475	-123.0913	08/10/01	21.9
	25985	North Santiam River Downstream Bear Branch RM 9.9	ODEQ	44.7545	-122.8739	08/10/01	21.5
	25987	North Santiam River near North Santiam St. Park	ODEQ	44.7684	-122.5597	08/08/01	18.8
	26751	North Santiam River near RM 47.6 - Detroit Lake Tailrace	ODEQ	44.7255	-122.2552	08/22/02	11.7
	26751	North Santiam River near RM 47.6 - Detroit Lake Tailrace	ODEQ	44.7255	-122.2552	10/03/02	13.2
	26756	Santiam River at Mouth	ODEQ	44.7512	-123.1377	08/13/02	21.2
	26761	North Santiam River Near RM 31.3	ODEQ	44.7669	-122.5316	08/13/02	15.1
	28157	Divide Creek at Road 1011 - Trib to Blowout Creek RM 6.0	ODEQ	44.6448	-122.1114	08/13/01	17.2
	28158	Ivy Creek at Road 10 - Trib to Blowout Creek RM 6.8	ODEQ	44.6381	-122.1222	08/14/01	15.0
	28161	North Santiam River at Bruno Mtn Rd 2242 Bridge RM 64.6	ODEQ	44.6914	-121.9868	08/13/01	15.4
	28162	North Santiam River d/s of Marion Creek confluence RM 71.5	ODEQ	44.6216	-121.9464	08/13/01	15.0
	28163	North Santiam River at Hwy. 22 bridge - Big Meadow RM 81.7	ODEQ	44.5018	-122.0027	07/06/01	12.5
	28164	Straight Creek at Mouth across from HWY 22 - Trib to North Santiam RM 76.3	ODEQ	44.5724	-121.9974	08/14/01	15.7
	28165	Lynx Creek at Mouth - Trib to North Santiam RM 76.8	ODEQ	44.5659	-122.0012	08/13/01	14.2
	28171	East Humbug Creek at RM 1.7 - Trib to Humbug	ODEQ	44.8001	-122.0576	08/14/01	16.2
	28175	Mansfield Creek at Road 46 - Trib to Breintenbush RM 11.4	ODEQ	44.7871	-121.9758	08/14/01	16.8

Table 1.12 North Santiam Subbasin (contd.) seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
NORTH SANTIAM	28256	North Santiam River at Geren Island RM 31	ODEQ	44.7911	-122.7500	08/10/01	20.2
	29642	North Santiam River at RM 12.2	ODEQ	44.7703	-122.8477	07/14/02	17.5
	14182500	Little North Santiam Near Meham, USGS site	USGS	44.7917	-122.5778	8/3/2000	25.1
	bdc00a01	Boulder Creek Summer 2000	BLM	44.5696	-122.4056	8/2/2000	16.2
	cas00a1	Canyon Creek Summer 2000	BLM	44.8015	-122.4808	8/2/2000	16.9
	elk00a01	Elkhorn Creek Summer 2000	BLM	45.2660	-122.1600	8/2/2000	17.4
	faw00a01	Fawn Creek Summer 2000	BLM	44.8150	-122.3875	8/2/2000	16.2
	lns02a01	Little North Santiam River @ County Park Summer 2000	BLM	44.5477	-122.6519	8/3/2000	24.1
	lns10a01	Little North Santiam @ Elkhorn Campground Summer 2000	BLM	44.7965	-122.5673	8/2/2000	22.8
	lns14a01	Little North Santiam Below Salmon Falls Summer 2000	BLM	44.8018	-122.4428	8/1/2000	19.3
	nsr45a01	North Santiam @ Fishbend Summer 2000	BLM	44.6922	-122.6496	8/1/2000	15.2
	sin00a01	Sinker Creek Summer 2000	BLM	44.8088	-122.4170	8/2/2000	16.8

Table 1.13 South Santiam Subbasin seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
SOUTH SANTIAM	23788	S. Santiam River d/s Foster Dam at staff gauge	ODEQ	44.4148	-122.6729	08/13/00	12.9
	23788	S. Santiam River d/s Foster Dam at staff gauge	ODEQ	44.4148	-122.6729	09/15/00	12.3
	23789	S. Santiam U/S McDowell Cr.	ODEQ	44.4603	-122.7684	08/06/00	16.9
	23791	S. Santiam River @ Linn Co. boat launch d/s HWY 226 (Old Bridge Drive)	ODEQ	44.6365	-122.9271	08/06/00	21.3
	10783	Thomas Cr. @ Kelly Rd. (Riverside School)	ODEQ	44.6907	-122.9369	08/02/00	26.4
	10784	Crabtree Cr. @ Riverside School Road	ODEQ	44.6734	-122.9178	08/03/00	26.2
	10784	Crabtree Creek at Riverside School Road near Mouth	ODEQ	44.6732	-122.9192	07/25/02	25.9
	10791	Quartzville Creek above Green Peter Reservoir,Old USGS Gage 14185900	ODEQ	44.5441	-122.4307	08/12/01	22.3
	11419	Hamilton Cr. @ Hamilton school (Lebanon).	ODEQ	44.5110	-122.8337	08/02/00	24.6
	14187200	S Santiam River nr Foster	USGS	44.4125	-122.6875	10/09/01	13.2
	14187200	S Santiam River nr Foster	USGS	44.4125	-122.6875	07/19/02	13.1
	14187500	S Santiam River at Waterloo	USGS	44.4986	-122.8222	10/04/01	14.5
	14187500	S Santiam River at Waterloo	USGS	44.4986	-122.8222	12/16/01	7.7
	14187500	S Santiam River at Waterloo	USGS	44.4986	-122.8222	08/12/02	17.4
	21834	Roaring River at RM 0.1	ODEQ	44.6303	-122.7378	08/02/00	15.7
	23742	Crabtree Cr. At Main Line Bridge at F and S lines.	ODEQ	44.5945	-122.5567	08/06/00	19.7
	23743	Crabtree Cr. @ Road 311 bridge.	ODEQ	44.5781	-122.5816	08/02/00	21.9
	23766	Crabtree Cr. At Willamette Main Line Rd. mile 11.6	ODEQ	44.5883	-122.6373	08/06/00	23.6
	23767	Crabtree @ CR 843 swinging foot bridge	ODEQ	44.5983	-122.6872	08/06/00	24.0
	23768	Crabtree Creek at Larwood Covered Bridge	ODEQ	44.6294	-122.7411	08/02/00	24.9
	23769	Crabtree Cr. @ Richardson Gap Rd.	ODEQ	44.6581	-122.8045	08/02/00	24.2
	23770	Beaver Cr. Fish hatchery Dr. near HWY 226 (SSant)	ODEQ	44.6336	-122.8549	08/02/00	23.3
	23771	Crabtree Cr. @ Hoffman Covered Bridge (Hungry Hill Drive)	ODEQ	44.6534	-122.8903	08/03/00	26.2

Table 1.14 Santiam Subbasin (contd.) seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
SOUTH SANTIAM	23772	Hamilton Cr. @ Upper Berlin Rd. u/s South Fork Hamilton Cr.	ODEQ	44.5325	-122.7061	08/02/00	20.1
	23773	South Fork Hamilton @ Upper Berlin Rd. @ SC120.	ODEQ	44.5259	-122.7111	08/02/00	18.4
	23774	Hamilton Cr. @ Upper Berlin Rd. near Berlin Ridge Rd.	ODEQ	44.4974	-122.7500	08/06/00	26.2
	23775	Hamilton Cr. @ Belinger Scale Rd. @ golf course.	ODEQ	44.5136	-122.7979	08/02/00	25.8
	23776	McDowell Cr. @ McDowell Cr. Falls Park	ODEQ	44.4639	-122.6807	08/02/00	17.7
	23777	McDowell Cr. At bridge 5.7 mi up McDowell Cr. Rd.	ODEQ	44.4610	-122.7174	08/02/00	19.6
	23778	McDowell Cr. Near mouth	ODEQ	44.4607	-122.7676	08/02/00	23.8
	23779	Thomas Cr. @ bridge @ Willamette Ind. Gate of Thomas Cr. Dr.	ODEQ	44.7122	-122.6087	08/02/00	22.0
	23780	Thomas Cr. @ Jordan Rd.	ODEQ	44.7265	-122.6995	08/03/00	26.6
	23781	Thomas Cr. At Hannah Covered Bridge (Morrison Rd.)	ODEQ	44.7123	-122.7182	08/02/00	25.1
	23782	Neal Cr. @ Lulay Bridge near Hannah Covered Bridge.	ODEQ	44.7076	-122.7124	08/02/00	20.2
	23783	Thomas Cr. @ USGS gauge @ Shindler Bridge Dr..	ODEQ	44.7110	-122.7668	08/02/00	26.3
	23784	Thomas Cr. @ Shimanek Covered Bridge (Richardson Gap Rd).	ODEQ	44.7162	-122.8045	08/01/00	25.2
	23785	Thomas Cr. @ .6 miles west of Scio off NW 1st.	ODEQ	44.7038	-122.8588	08/01/00	27.6
	23787	Sucker Slough @ Robinson Rd.	ODEQ	44.7059	-122.9171	09/15/00	24.4
	23787	Sucker Slough @ Robinson Rd.	ODEQ	44.7059	-122.9171	06/27/00	23.7
	23802	Wiley Creek near Mouth	ODEQ	44.4072	-122.6728	08/14/00	22.2
	23803	(#111) S. Santiam R. U/S of Foster Dam	ODEQ	44.4054	-122.5653	08/01/00	27.9
	23805	Middle Santiam at Gaging station above green Peter Res.	ODEQ	44.5155	-122.3715	08/02/00	22.2
	26774	South Santiam River at Mouth	ODEQ	44.6783	-122.9897	06/17/02	15.6
	26774	South Santiam River at Mouth	ODEQ	44.6783	-122.9897	08/12/02	21.6
	28615	South Santiam River above Foster Reservoir	ODEQ	44.4008	-122.5864	08/12/01	24.7
	10783	Thomas Cr. @ Kelly Rd. (Riverside School)	ODEQ	44.6907	-122.9369	8/2/2000	25.9
	10784	Crabtree Cr. @ Riverside School Road	ODEQ	44.6734	-122.9178	8/1/2000	25.6
	11419	Hamilton Cr. @ Hamilton school (Lebanon).	ODEQ	44.5110	-122.8337	8/1/2000	23.7
	21834	Roaring River at RM 0.1	ODEQ	44.6303	-122.7378	8/1/2000	15.2
	23742	Crabtree Cr. At Main Line Bridge at F and S lines.	ODEQ	44.5945	-122.5567	8/1/2000	19.2
	23743	Crabtree Cr. @ Road 311 bridge.	ODEQ	44.5781	-122.5816	8/1/2000	21.4
	23766	Crabtree Cr. At Willamette Main Line Rd. mile 11.6	ODEQ	44.5883	-122.6373	8/1/2000	21.9
	23767	Crabtree @ CR 843 swinging foot bridge	ODEQ	44.5983	-122.6872	8/1/2000	23.1
	23768	Crabtree Creek at Larwood Covered Bridge (u/s Roaring River)	ODEQ	44.6294	-122.7411	8/1/2000	24.2
	23769	Crabtree Cr. @ Richardson Gap Rd.	ODEQ	44.6581	-122.8045	8/1/2000	23.4
	23770	Beaver Cr. Fish hatchery Dr. near HWY 226	ODEQ	44.6336	-122.8549	8/1/2000	22.6
	23771	Crabtree Cr. @ Hoffman Covered Bridge (Hungry Hill Drive)	ODEQ	44.6534	-122.8903	8/1/2000	25.6
	23772	Hamilton Cr. @ Upper Berlin Rd. u/s South Fork Hamilton Cr.	ODEQ	44.5325	-122.7061	8/1/2000	19.2

Table 1.15 South Santiam Subbasin (contd.) seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
SOUTH SANTIAM	23773	South Fork Hamilton @ Upper Berlin Rd. @ SC120.	ODEQ	44.5259	-122.7111	8/1/2000	17.7
	23774	Hamilton Cr. @ Upper Berlin Rd. near Berlin Ridge Rd.	ODEQ	44.4974	-122.7500	8/1/2000	25.4
	23775	Hamilton Cr. @ Belinger Scale Rd. @ golf course.	ODEQ	44.5136	-122.7979	8/1/2000	24.9
	23776	McDowell Cr. @ McDowell Cr. Falls Park	ODEQ	44.4639	-122.6807	7/31/2000	16.8
	23777	McDowell Cr. At bridge 5.7 mi up McDowell Cr. Rd.	ODEQ	44.4610	-122.7174	8/1/2000	18.8
	23778	McDowell Cr. Near mouth	ODEQ	44.4607	-122.7676	8/1/2000	22.9
	23779	Thomas Cr. @ bridge @ Willamette Ind. Gate of Thomas Cr. Dr.	ODEQ	44.7122	-122.6087	7/31/2000	21.0
	23780	Thomas Cr. @ Jordan Rd.	ODEQ	44.7265	-122.6995	8/1/2000	25.9
	23781	Thomas Cr. At Hannah Covered Bridge (Morrison Rd.)	ODEQ	44.7123	-122.7182	8/1/2000	24.2
	23782	Neal Cr. @ Lulay Bridge near Hannah Covered Bridge.	ODEQ	44.7076	-122.7124	8/1/2000	19.5
	23783	Thomas Cr. @ USGS gauge @ Shindler Bridge Dr.	ODEQ	44.7110	-122.7668	8/1/2000	25.6
	23784	Thomas Cr. @ Shimanek Covered Bridge (Richardson Gap Rd).	ODEQ	44.7162	-122.8045	8/1/2000	24.2
	23785	Thomas Cr. @ .6 miles west of Scio off NW 1st.	ODEQ	44.7038	-122.8588	8/1/2000	26.8
	23787	Sucker Slough @ Robinson Rd.	ODEQ	44.7059	-122.9171	6/27/2000	22.1
	23788	S. Santiam River d/s Foster Dam at staff gauge	ODEQ	44.4148	-122.6729	8/1/2000	12.6
	23789	S. Santiam U/S McDowell Cr.	ODEQ	44.4603	-122.7684	8/5/2000	16.6
	23791	S. Santiam River @ Linn Co. boat launch d/s HWY 226	ODEQ	44.6365	-122.9271	8/6/2000	21.1
	23802	Wiley Creek near Mouth	ODEQ	44.4072	-122.6728	8/14/2000	21.6
	23803	S. Santiam R. U/S of Foster Dam	ODEQ	44.4054	-122.5653	8/1/2000	21.9
	23805	Middle Santiam at Gauge just u/s Green Peter Res.	ODEQ	44.5155	-122.3715	8/1/2000	21.4
	can00a01	Canal Creek Summer 2000	BLM	44.5878	-122.3475	8/1/2000	20.7
	chu00a01	Church Creek lower Summer 2000	BLM	44.6179	-122.5443	8/2/2000	18.7
	chu00b01	Church Creek Upper Summer 2000	BLM	44.6025	-122.6861	8/2/2000	16.2
	cra31a01	Crabtree Creek Summer 2000	BLM	44.6083	-122.6848	8/5/2000	17.7
	flu00a01	Flush Creek Summer 2000	BLM	44.8320	-122.3723	8/6/2000	15.7
	frb00a01	Fourbit Creek Summer 2000	BLM	44.5461	-122.4296	8/2/2000	16.4
	ham11a01	Hamilton Creek @ Falls Summer 2000	BLM	44.5547	-122.4249	8/3/2000	18.5
	hcn00a01	North Fork Hamilton Creek Summer 2000	BLM	44.5449	-122.6738	8/2/2000	17.1
	nlc04a01	Neal Creek Summer 2000	BLM	45.3275	-122.2816	8/2/2000	17.0
	pan00a01	Panther Creek Summer 2000	BLM	44.7531	-122.5183	8/1/2000	21.3
	pcg00a01	Packers Gulch Summer 2000	BLM	44.5893	-122.3934	8/1/2000	18.1
	qua09a01	Quartzville Creek above Yellowbottom	BLM	44.5406	-122.4362	8/2/2000	22.6
	qua09b01	Quartzville above Boulder Creek	BLM	44.5640	-122.4121	8/8/2000	21.6
	qua11a01	Quartzville Creek above Packers Gulch	BLM	44.5700	-122.4065	8/1/2000	22.5
	qua12a01	Quartzville Creek above Yellowstone	BLM	44.5895	-122.3927	8/6/2000	22.1
	qua14a01	Quartzville Creek @ Forest Service Boundry Summer 2000	BLM	44.5902	-122.3925	8/13/2000	17.1
	roc02a01	Rock Creek 2000	BLM	44.5876	-122.3716	8/6/2000	11.3
	ror05a01	Roaring River 2000	BLM	44.5811	-122.3345	8/2/2000	12.1
	rrt01a01	Trib to Roaring River 2000	BLM	44.6414	-122.6332	7/30/2000	17.7

Table 1.16 South Santiam Subbasin (contd.) seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
SOUTH SANTIAM	scc00a01	Spring to Canal Creek Summer 2000	BLM	44.6497	-122.7038	8/10/2000	7.3
	sch00a01	Schafer Creek 2000	BLM	44.6012	-122.3365	7/28/2000	12.4
	sch00a02	Schafer Creek 2000	BLM	44.6192	-122.4666	8/7/2000	13.2
	sco01a01	Scott Creek Summer 2000	BLM	44.5275	-122.6816	8/2/2000	16.6
	sfd01a01	South Fork Scott Creek Lower Site Summer 2000	BLM	44.5170	-122.6921	8/1/2000	15.9
	sfn00a01	SF Neal Creek Summer 2000	BLM	44.6787	-122.6670	8/2/2000	16.9
	sfu00a01	South Fork Scott Creek Upper Site Summer 2000	BLM	44.5076	-122.6519	8/2/2000	13.2
	sla00a01	Slash Creek Lower Summer 2000	BLM	44.6496	-122.4417	8/11/2000	14.7
	sla00b01	Slash Creek Upper Site Summer 2000	BLM	44.6482	-122.4437	8/3/2000	12.0
	tho25a01	Lower Thomas Creek Summer 2000	BLM	44.7025	-122.5589	8/2/2000	19.4
	tho31a01	Upper Thomas Creek Summer 2000	BLM	44.6823	-122.4827	8/3/2000	20.7
	utt00a01	unnamed trib to Thomas Summer 2000	BLM	44.6481	-122.4175	8/7/2000	13.5
	wrc01a01	White Rock Creek Summer 2000	BLM	44.5916	-122.5097	8/7/2000	12.6
	yel00a01	Yellowstone Creek Summer 2000	BLM	44.5637	-122.4128	8/6/2000	16.9
	ylb00a01	Yellowbottom Creek Summer 2000	BLM	44.5881	-122.3712	8/8/2000	13.7

Table 1.17 Tualatin Subbasin seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
TUALATIN	26773	Tualatin River at West Linn	ODEQ	45.3503	-122.6771	07/24/02	24.3

Table 1.18 Upper Willamette Subbasin seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
UPPER WILLAMETTE	26770	McKenzie River at RM 49 (Below Cougar River)	ODEQ	44.1321	-123.3785	07/22/02	15.6
	10349	Willamette River at Conser Road	ODEQ	44.6900	-123.1203	07/13/02	22.4
	10353	Willamette River at Corvallis Water Intake RM 132.5	ODEQ	44.5344	-123.2498	07/25/01	22.0
	10353	Willamette River at Corvallis Water Intake WQL-001 RM 134.5	ODEQ	44.5344	-123.2498	07/13/02	21.6
	10359	Willamette River at Highway 126	ODEQ	44.0463	-123.0297	08/31/02	19.5
	10658	Luckiamute River at Buena Vista Road	ODEQ	44.7302	-123.1624	07/13/02	24.0
	10658	Luckiamute River at Lower Bridge (Buena Vista Rd.)	ODEQ	44.7304	-123.1614	08/12/01	24.4
	10659	Luckiamute River at Helmick State Park RM 13.57	ODEQ	44.7828	-123.2353	08/12/01	24.4
	11056	Mary's R. @ Bellfountain Rd. RM 9.3	ODEQ	44.5252	-123.3345	08/10/01	23.3
	11056	Marys River @ Bellfountain Road WQL-003	ODEQ	44.5252	-123.3345	07/13/02	23.7
	11111	Luckiamute River at Hoskins RM 38.47	ODEQ	44.6817	-123.4678	08/10/01	21.7
	11114	Little Luckiamute River at Elkins Rd. RM 0.65 (Trib to Luckiamute RM 18.2)	ODEQ	44.7972	-123.2915	08/12/01	23.2
	11182	Calapooia River At Hwy 99e - Rm 17.13	ODEQ	44.5046	-123.1075	08/11/01	25.6
	11188	Oak Creek At Hwy 99e - Rm 1.37 (Albany) (Trib To Calapooia River Rm 3.6)	ODEQ	44.6035	-123.1123	07/10/01	21.4
	14169000	Long Tom River at Alvadore	USGS	44.1149	-123.3016	10/04/01	17.8
	14169000	Long Tom River at Alvadore	USGS	44.1149	-123.3016	12/16/01	8.1
	14169000	Long Tom River at Alvadore	USGS	44.1149	-123.3016	07/24/02	24.1
	14170000	Long Tom River at Monroe	USGS	44.3131	-123.2953	10/04/01	17.1

	14170000	Long Tom River at Monroe	USGS	44.3131	-123.2953	07/14/02	24.7

Table 1.19 Upper Willamette Subbasin (contd.) seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
UPPER WILLAMETTE	14174000	Willamette River at Albany	USGS	44.6389	-123.1056	10/04/01	16.6
	14174000	Willamette River at Albany	USGS	44.6389	-123.1056	07/13/02	22.1
	25450	Calapooia River at Mouth (Bryant Park)	ODEQ	44.6366	-123.1124	07/12/02	23.2
	25450	Calapooia River At Mouth (Bryant Park) - Rm 0.10	ODEQ	44.6383	-123.1124	07/11/01	22.1
	25451	Calapooia River At Tangent Drive - Rm 12.83	ODEQ	44.5329	-123.1441	08/12/01	24.8
	25454	Sodom Ditch At Boston Mill Drive - Rm 1.40 (Trib To Butte Creek Rm 0.5 - To Calapooia R	ODEQ	44.4616	-123.0668	08/17/01	24.2
	25455	Calapooia River At Linn West Road - Rm 26.47	ODEQ	44.4252	-123.0643	08/28/01	22.0
	25456	Sodom Ditch At Linn West Road - Rm 4.24 (Trib To Butte Creek Rm 0.5 - To Calapooia Rive	ODEQ	44.4252	-123.0488	08/17/01	23.6
	25457	Calapooia River At Brownsville - Rm 33.13	ODEQ	44.3909	-122.9844	08/17/01	23.7
	25458	Calapooia River At Mckercher Park - Rm 39.94	ODEQ	44.3599	-122.8780	08/10/01	25.4
	25459	Brush Creek At Courtney Creek Road - Rm 0.85 (Trib To Calapooia River Rm 40.4)	ODEQ	44.3468	-122.8583	08/10/01	21.9
	25461	Calapooia River At Weyerhauser Milepost 1.5 - Rm 56.55	ODEQ	44.2896	-122.6229	07/11/01	22.1
	25462	Biggs Creek At Mouth - Rm 0.08 (Trib To Calapooia River Rm 57.6)	ODEQ	44.2845	-122.6129	08/12/01	18.4
	25463	Blue Creek At Mouth - Rm 0.04 (Trib To Calapooia River Rm 57.8)	ODEQ	44.2821	-122.6106	08/12/01	15.9
	25464	Washout Creek At Mouth - Rm 0.04 (Trib To Calapooia River Rm 60.9)	ODEQ	44.2645	-122.5560	08/12/01	21.3
	25465	Mckinley Creek At Mouth - Rm 0.03 (Trib To Calapooia River Rm 60.6)	ODEQ	44.2645	-122.5617	08/12/01	19.6
	25466	Calapooia River Just U/S Of Washout Creek Rm 60.92	ODEQ	44.2635	-122.5563	08/10/01	22.6
	25467	Hands Creek At Mouth Rm 0.1 (Trib To Calapooia River Rm 64.0)	ODEQ	44.2532	-122.5152	08/12/01	21.9
	25468	Potts Creek At Mouth Rm 0.09 (Trib To Calapooia River Rm 65.0)	ODEQ	44.2458	-122.5015	08/12/01	15.8
	25469	Kings Creek At Mouth Rm 0.13 (Trib To Calapooia River Rm 67.5)	ODEQ	44.2324	-122.4484	08/12/01	16.3
	25470	North Fork Calapooia River At Mouth Rm 0.11	ODEQ	44.2357	-122.4145	08/12/01	16.8
	25471	Calapooia River Just U/S Of North Fork Calapooia Rm 69.68	ODEQ	44.2347	-122.4138	08/12/01	16.5
	25472	Calapooia River Rm 70.6 Unnamed Trib At Weyerhauser Mainline And 3400 - Rm 0.08	ODEQ	44.2339	-122.3966	08/12/01	13.4
	25473	Calapooia River At Usfs Bridge (Rocinante Claim) - Rm 72.13	ODEQ	44.2362	-122.3678	08/12/01	16.5
	25474	Soap Creek at Buena Vista Rd. (Trib to Luckiamute RM 2.31)	ODEQ	44.7264	-123.1628	08/10/01	22.6
	25475	Luckiamute River at Corvallis Rd. RM 5.82	ODEQ	44.7567	-123.1814	08/11/01	24.2
	25477	Luckiamute River at Airlie Rd. Bridge RM 23.61	ODEQ	44.7761	-123.3432	08/10/01	24.7
	25478	McTimmonds Creek at State HWY 223 RM 0.71 (Trib to Luckiamute RM 27.7)	ODEQ	44.7601	-123.4107	08/10/01	18.4
	25480	Luckiamute River at Ira Hooker Rd. RM 29.36	ODEQ	44.7465	-123.4158	08/10/01	25.0

Table 1.20 Upper Willamette Subbasin (contd.) seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
UPPER WILLAMETTE	25481	Pedee Creek at Kings Highway RM 0.56 (Trib to Luckiamute RM 30.2)	ODEQ	44.7445	-123.4392	08/10/01	21.4
	25482	QA- Ritner Creek at Ritner Wayside RM 0.05 (Trib to Luckiamute RM 31.2)	ODEQ	44.7281	-123.4418	08/10/01	21.3
	25482	Ritner Creek at Ritner Wayside RM 0.05 (Trib to Luckiamute RM 31.2)	ODEQ	44.7281	-123.4418	08/10/01	21.4
	25483	Luckiamute River just U/S Ritner Creek RM 31.38	ODEQ	44.7281	-123.4411	08/10/01	23.3
	25484	Maxfield Creek at HWY 223 RM 0.45 (Trib to Luckiamute RM 34.0)	ODEQ	44.6947	-123.4323	08/10/01	18.3
	25485	Price Creek at HWY 223 (Trib to Luckiamute RM 35.2)	ODEQ	44.6855	-123.4339	08/10/01	17.3
	25486	Luckiamute River at Gaging Site RM 42.73	ODEQ	44.6817	-123.4678	08/10/01	21.1
	25488	Luckiamute River at Boise Roadmile 1 RM 45.62	ODEQ	44.7476	-123.5335	08/10/01	20.5
	25489	Slick Creek at Mouth RM 0.05 (Trib to Luckiamute RM 48.6)	ODEQ	44.7625	-123.5669	08/12/01	14.7
	25490	Luckiamute River at Boise Roadmile 4 RM 48.9	ODEQ	44.7717	-123.5795	08/10/01	18.8
	25491	Rock Pit Creek at Mouth RM 0.05 (Trib to Luckiamute RM 49.8)	ODEQ	44.7727	-123.5850	08/12/01	15.6
	25492	Miller Creek at Mouth RM 0.17 (Trib to Luckiamute RM 50.5)	ODEQ	44.7762	-123.5966	08/10/01	19.7
	25493	Luckiamute River at Road 1440 crossing RM 51.36	ODEQ	44.7940	-123.5925	08/10/01	17.8
	25494	Luckiamute River at Road 1430 crossing (Roadmile 3) RM 53.90	ODEQ	44.8158	-123.5667	08/12/01	14.9
	26749	Long Tom River Near RM 19.8	ODEQ	44.1906	-123.2784	07/11/02	25.8
	26750	Long Tom River Near RM 12.3	ODEQ	44.2509	-123.2670	07/13/02	25.8
	26753	Willamette River Near RM 147	ODEQ	44.4058	-123.2265	07/13/02	21.4
	26755	Willamette River Above Long Tom River	ODEQ	44.3651	-123.2196	07/13/02	21.0
	26771	Coyote Creek Above Fern Ridge Reservoir	ODEQ	44.0415	-123.2669	08/15/02	24.6
	26772	Willamette River Near RM 141.7	ODEQ	44.4569	-123.2108	06/10/02	16.6
	26772	Willamette River Near RM 141.7	ODEQ	44.4569	-123.2108	07/27/02	21.3
	26775	Marys River @ RM 0.5 WQL-002	ODEQ	44.5543	-123.2692	08/13/02	24.7
	26775	Marys River at RM 0.5	ODEQ	44.5543	-123.2692	08/11/01	24.3
	28723	Willamette River Upstream of McKenzie #1	ODEQ	44.0993	-123.1039	08/30/02	19.6
	28723	Willamette River Upstream of McKenzie #1QA	ODEQ	44.0993	-123.1039	08/30/02	19.5
	28766	East Channel Muddy Creek at Stahlbusch Road (Trib to Willamette RM 132.6)	ODEQ	44.5495	-123.2295	07/13/02	24.6
	28767	Muddy Creek at Peoria Road (Trib to Willamette RM 133.7)	ODEQ	44.5270	-123.2037	07/13/02	24.5
	28768	Muddy Creek at Oakville Road (Trib to Willamette RM 133.7)	ODEQ	44.5034	-123.1899	07/13/02	24.4
	28771	Muddy Creek at Abraham Drive (Trib to Willamette RM 133.7)	ODEQ	44.4552	-123.1474	07/13/02	25.8
	28772	Muddy Creek at Oakplain Road (Trib to Willamette RM 133.7)	ODEQ	44.4207	-123.1434	07/13/02	24.4
	28773	Muddy Creek at Crook Road (Trib to Willamette RM 133.7)	ODEQ	44.3780	-123.1336	07/13/02	25.1

Table 1.21 Upper Willamette Subbasin (contd.) seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
UPPER WILLAMETTE	28775	Little Muddy Creek at Nixon Road (Trib to Muddy Creek RM 27.7	ODEQ	44.3520	-123.1413	07/11/02	27.9
	28776	Muddy Creek at Nixon Road (Trib to Willamette RM 133.7)	ODEQ	44.3518	-123.1425	07/12/02	24.2
	28778	Muddy Creek at Diamond Hill Road (Trib to Willamette RM 133.7)	ODEQ	44.2853	-123.1269	07/13/02	24.1
	28779	Dry Muddy Creek at Dale Road (Trib to Muddy Creek RM 40.9	ODEQ	44.2375	-123.1106	07/13/02	24.4
	28780	Muddy Creek at Dale Road (Trib to Willamette RM 133.7)	ODEQ	44.2415	-123.0979	07/23/02	23.8
	28783	Muddy Creek at Wilkins Road (Trib to Willamette RM 132.6)	ODEQ	44.1672	-123.0635	07/23/02	20.1
	28784	Dry Muddy Creek at N. Coburg Road (Trib to Muddy Creek RM 40.9	ODEQ	44.1670	-123.0716	07/23/02	25.7
	29644	Long Tom River Near Mouth	ODEQ	44.3755	-123.2616	07/13/02	27.2
		Cogswell Creek	ODEQ	44.1386	-123.4892	08/12/01	16.0
		Cogswell Creek (McKenzie)	ODEQ	44.1386	-123.4892	07/24/02	16.0
		Long Tom River	ODEQ	44.1802	-123.4510	08/10/01	20.0
		Long Tom River	ODEQ	44.1802	-123.4510	07/27/02	19.1
		Muddy Creek at Brattain Road (Trib to Willamette RM 133.7)	ODEQ	44.4737	-123.1846	07/13/02	24.2
		Muddy Creek at Bush Garden Road (Trib to Willamette RM 132.6)	ODEQ	44.2124	-123.0757	07/23/02	22.7
	lob33a01	Lobster Creek below log jam	BLM	44.8312	-122.3717	8/1/2000	16.1
	lob33b01	Lobster Creek above log jam 2000	BLM	44.2277	-123.6242	8/1/2000	18.0
	lob33c01	Lobster Creek above SF Lobster	BLM	44.2265	-123.6224	7/31/2000	16.7
	sfl33a01	South Fork Lobster Creek Summer 2000	BLM	44.2264	-123.6198	8/1/2000	16.7
	10151	Coyote Creek at Petzold Rd.	ODEQ	44.0053	-123.2686	6/7/2001	30.8
	11148	Coyote Creek at Crow Rd.	ODEQ	43.9918	-123.3061	6/7/2001	31.4
	25627	Coyote Creek at Gillespie Corners	ODEQ	43.9081	-123.2505	7/6/2001	32.5

Table 1.22 Yamhill Subbasin seven day moving average daily maximum stream temperatures

Subbasin	Site #	Site Name	Agency	Latitude	Longitude	seven day Average Daily Max Date / Temp (ºC)	
YAMHILL	10363	Yamhill River at Dayton	ODEQ	45.2232	-123.0719	07/15/02	25.0

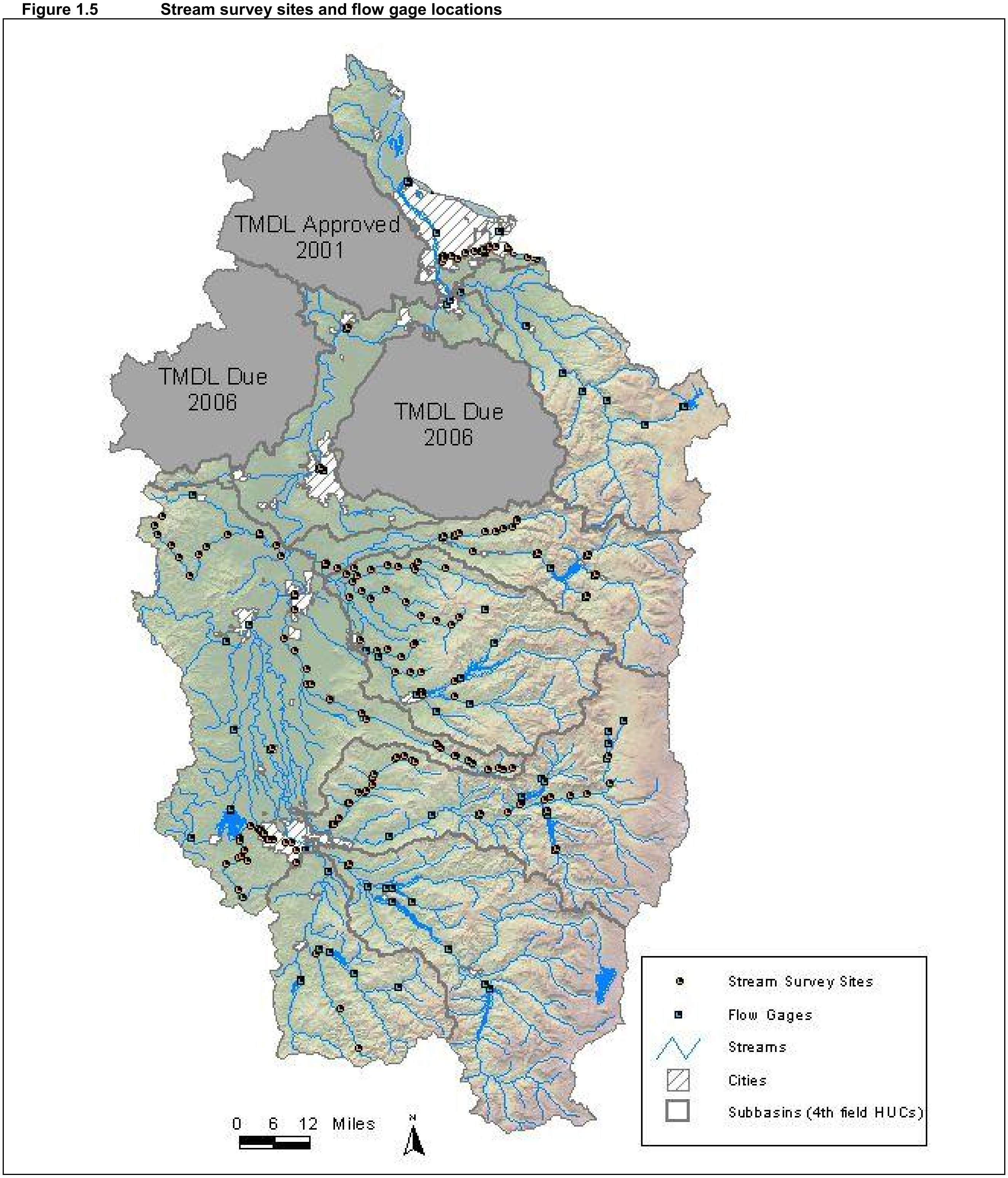
2.1.2 Stream Surveys

During the summers of 2000, 2001, and 2002 Oregon DEQ collected ground-level habitat data at many sites in the Willamette subbasins. Stream survey data focuses on near stream land cover classification and measurements, channel morphology measurements, and stream shade measurements. **Figure 1.5** displays the ODEQ stream survey locations.

2.1.3 Flow Volume – Gage Data and Instream Measurements

Flow volume data was collected at stream survey sites and from existing flow gages during the critical stream temperature period in summer of 2000, 2001, and 2002 by the Oregon DEQ and other agencies as stated in the subbasin TMDLs. These instream measurements were used to develop flow mass balances for the streams that were modeled for temperature. Flow gages and stream survey sites are presented in **Figure 1.5**.

Figure 1.5 Stream survey sites and flow gage locations



2.2 GIS and Remotely Sensed Data

2.2.1 Overview – GIS and Remotely Sensed Data

A wealth of spatial data has been developed for the Willamette subbasins. This report relies extensively on GIS and remotely sensed data. Water quality issues in the Willamette subbasins are interrelated, complex and spread over hundreds of square miles. The TMDL analysis strives to capture these complexities using the highest resolution data available. Some of the GIS data used to develop this report are listed in **Table 1.23** along with the application for which it was used.

Table 1.23 Spatial data and application

Spatial Data	Application
10-Meter Digital Elevation Models (DEM)	• Measure Valley Morphology • Measure Topographic Shade Angles
Aerial Imagery – Digital Orthophoto Quads and Rectified Aerial Photos	• Map Near Stream Land Cover • Map Channel Morphology • Map Roads, Development, Structures
Water Rights Information System (WRIS) and Points of Diversion (POD) Data	• Map locations and estimate quantities of water withdrawals
TIR Temperature Data	• Measure Surface Temperatures • Develop Longitudinal Temperature Profiles • Identify Subsurface Hydrology, Groundwater Inflow, Springs

2.2.2 10-Meter Digital Elevation Model (DEM)

DEM data are used in this analysis to:
- *Delineate drainage area,*
- *Sample stream elevation,*
- *Sample topographic shade.*

The Digital Elevation Model (DEM) data files are representations of cartographic information in a raster form. DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. The U.S. Geological Survey, as part of the National Mapping Program, produces these digital cartographic/geographic data files. DEM grid data are rounded to the nearest meter for ten-meter pixels. DEMs are used to determine stream elevation, stream gradient, valley gradient, valley shape/landform and topographic shade angles.

2.2.3 Aerial Imagery – Digital Orthophoto Quads and Rectified Aerial Photos

Aerial imagery is used in this analysis to:
- *Map stream features such as stream position, channel edges and wetted channel edges,*
- *Map near stream land cover,*
- *Map instream structures such as dams, weirs, unmapped diversions/withdrawals, etc.*

A digital orthophoto quad (DOQ) is a digital image of an aerial photograph in which displacements caused by the camera angle and terrain have been removed. In addition, DOQs are projected in map coordinates combining the image characteristics of a photograph with the geometric qualities of a map. The standard digital orthophoto is black-and-white with one-meter pixels covering a USGS quarter quadrangle.

2.2.4 WRIS and POD Data – Water Withdrawal Mapping

WRIS and POD Data are used in this analysis to:
- *Map stream instream diversions/withdrawals,*
- *Associate an estimated flow rate to each diversion/withdrawal.*

The Oregon Water Resources Department (OWRD) maintains the Water Rights Information System (WRIS). WRIS is a database used to monitor information related to water rights. A separate database tracks points of diversions (POD). These two databases were linked by ODEQ to map the locations of diversions, rates of water use and types of water use in the Willamette subbasins (see **Figure 1.6**). POD locations reflects information downloaded from WRD website in April of 2002. Consumptive use was estimated using these data and incorporated in developing mass balance flow profiles for some modeled streams. POD locations used for temperature modeling are displayed in **Figure 1.7**.

Figure 1.6 Mapped points of diversion in Willamette subbasins

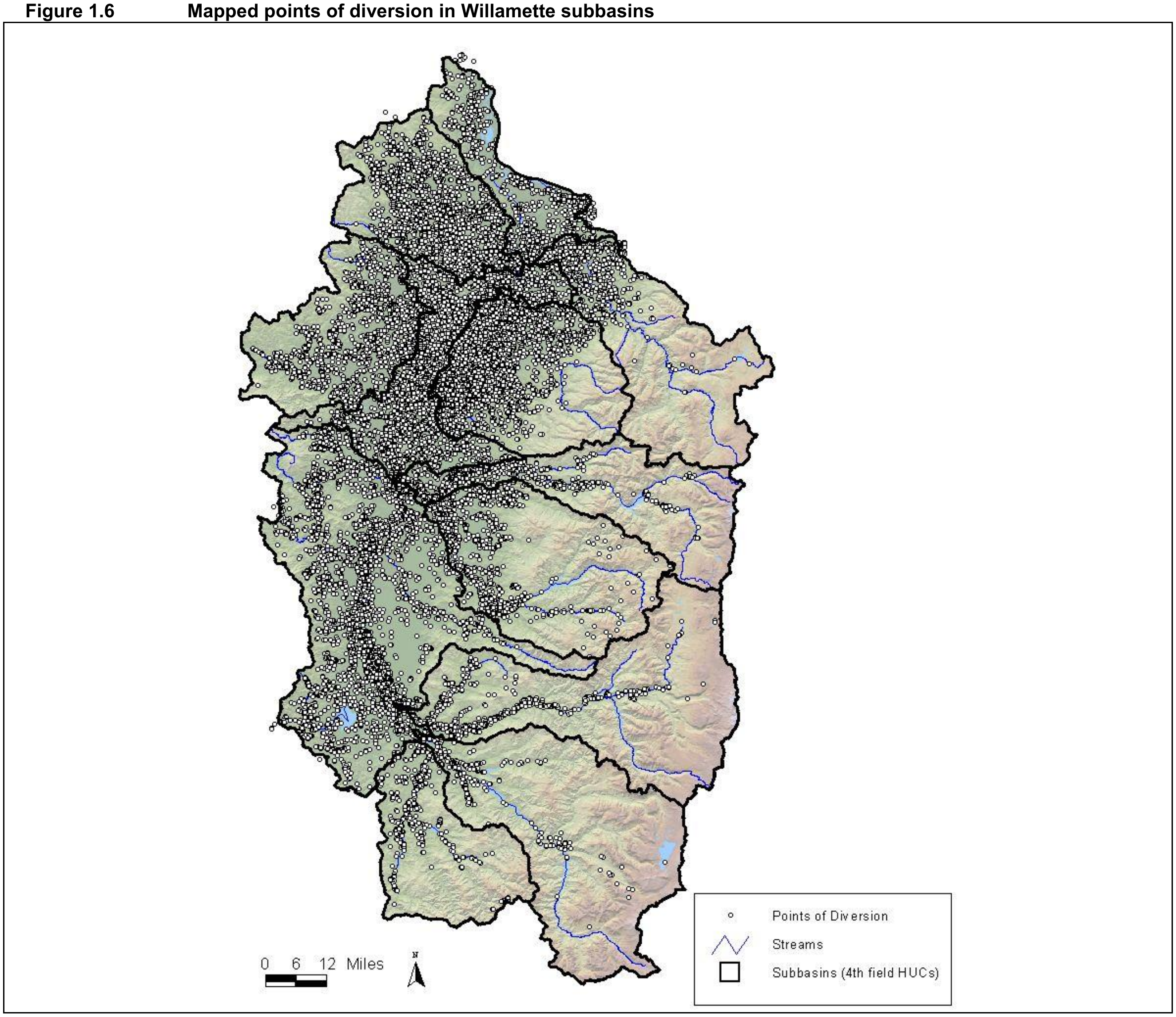
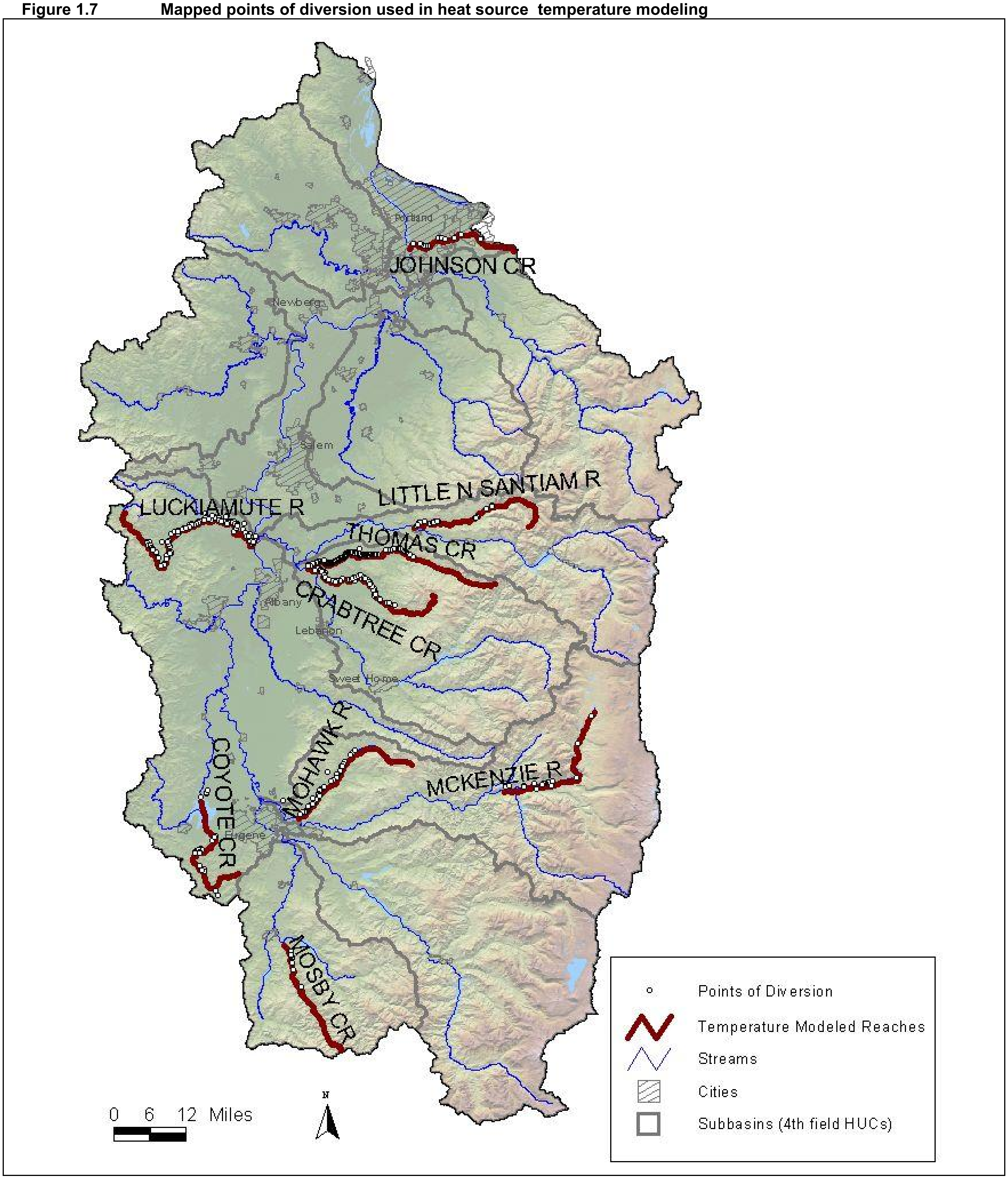


Figure 1.7 Mapped points of diversion used in heat source temperature modeling



2.2.5 Thermal Infrared Radiometry (TIR) Temperature Data

TIR temperature data are used in this analysis to:

- *Develop continuous spatial temperature data sets,*
- *Calculate longitudinal heating profile/gradients,*
- *Visually observe complex distributions of stream temperatures at a large landscape scale,*
- *Map/Identify significant thermal features,*
- *Develop flow mass balances,*
- *Validate simulated stream temperatures.*

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

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

Data collection is timed to capture maximum daily stream temperatures, which typically occur between 14:00 and 18:00 hours. The helicopter is flown longitudinally over the center of the stream channel with the sensors in a vertical (or near vertical) position. In general, the flight altitude is selected so that the stream channel occupies approximately 20-40% of the image frame. A minimum altitude of approximately 300 meters (984 ft) is used both for maneuverability and for safety reasons. If the stream splits into two channels that cannot be covered in the sensor's field of view, then the survey is conducted over the larger of the two channels.

In-stream temperature data loggers (Onset Stowaways or VEMCOs) are distributed in each subbasin prior to the survey to ground truth (i.e., verify the accuracy) the radiant temperatures measured by the TIR. TIR data can be viewed as GIS point coverages or TIR imagery.

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

TIR Derived Longitudinal Heating and Imagery
Longitudinal river temperatures were sampled using thermal infrared (TIR) in separate flights for each stream. Temperature data sampled from the TIR imagery reveals spatial patterns that are variable due to localized stream heating, tributary mixing, and groundwater influences. **Figures 1.8 through 1.14** display graphics of TIR-sampled temperatures in the Willamette subbasins (note: tributary/spring temperatures are from TIR imagery).

It is important to note that thermal stratification can be identified in TIR imagery and by comparison with the instream temperatures loggers. For example, the imagery may reveal a sudden cooling at a riffle or downstream of an instream structure, where water was rather stagnant or deep just upstream.

Figure 1.8 **TIR Temperatures on the Little North Santiam River, North Santiam Subbasin**

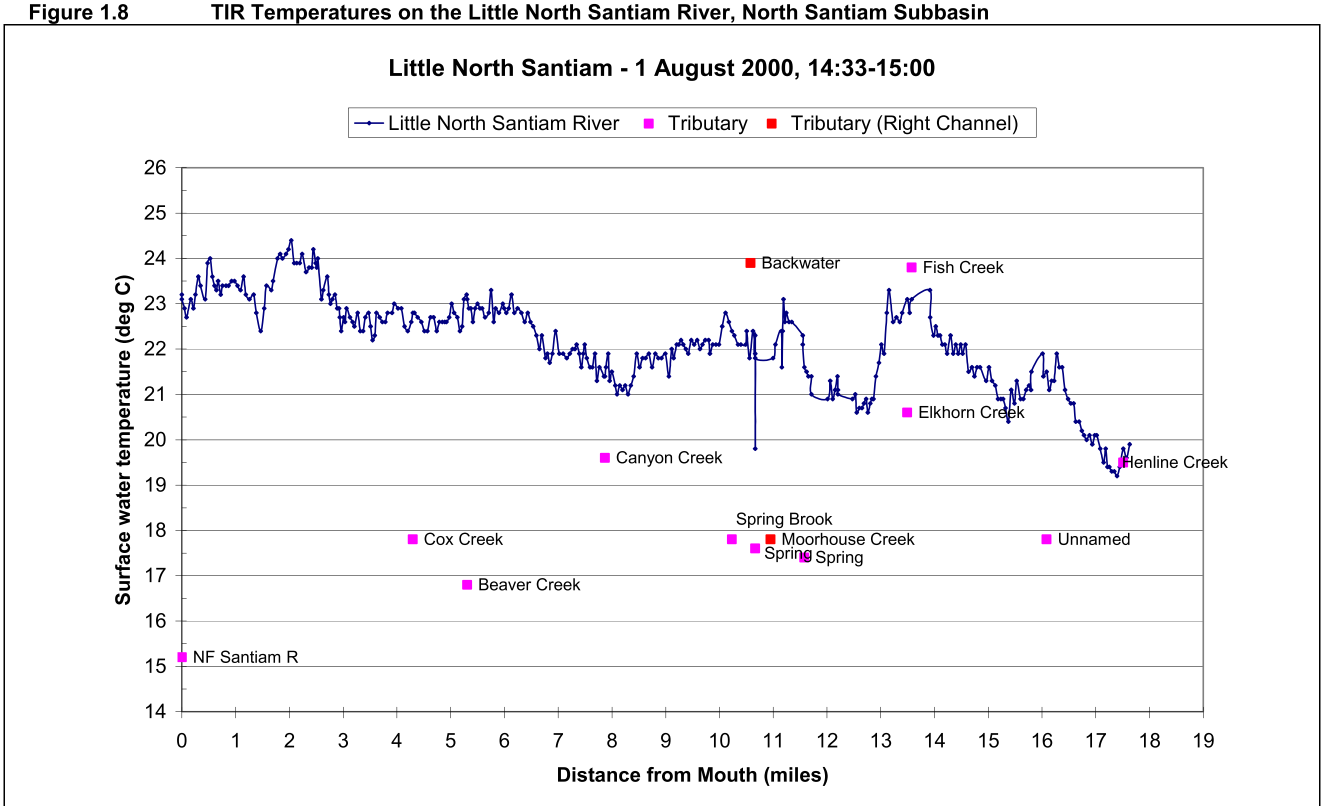


Figure 1.9 TIR Temperatures on Coast Fork Willamette, Coast Fork Willamette Subbasin

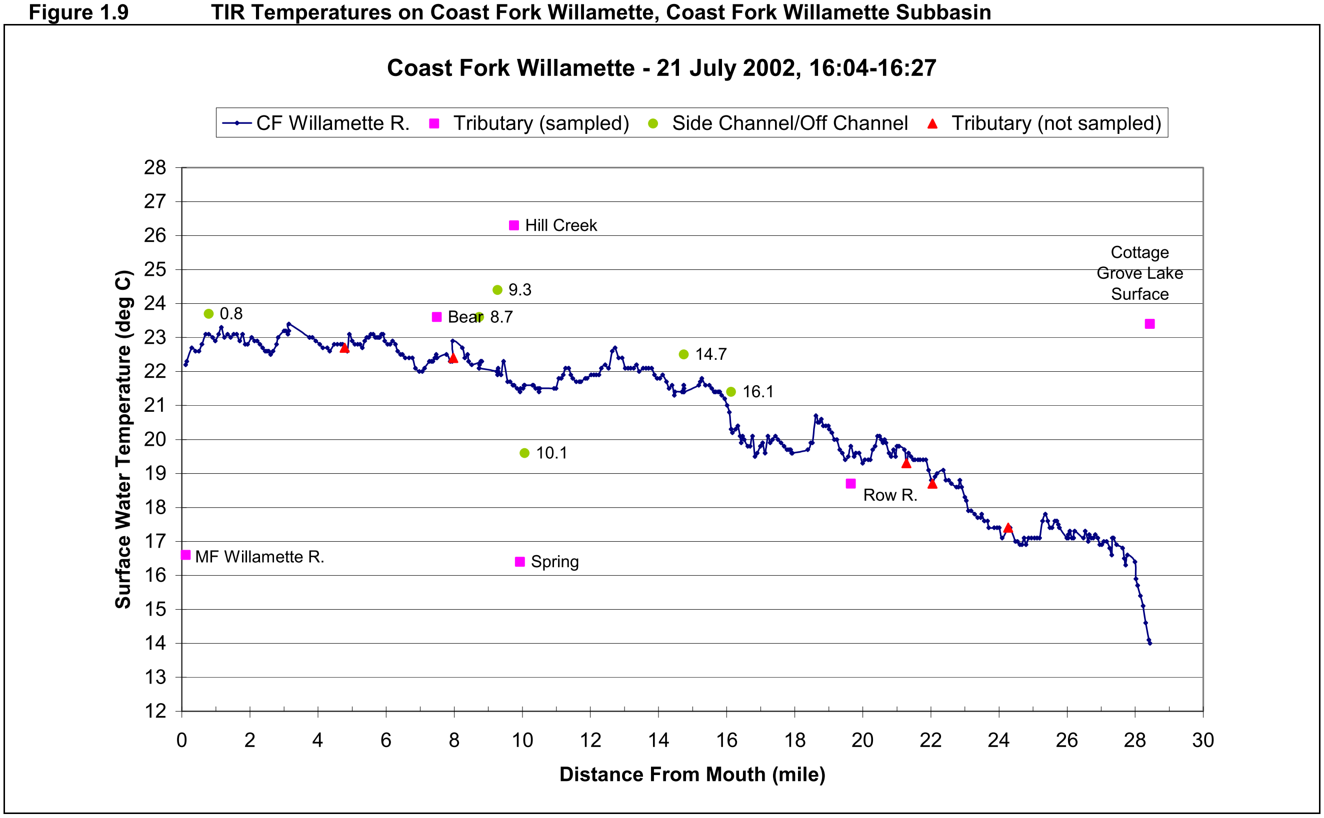


Figure 1.10 Temperatures on Mosby Creek, Coast Fork Willamette Subbasin

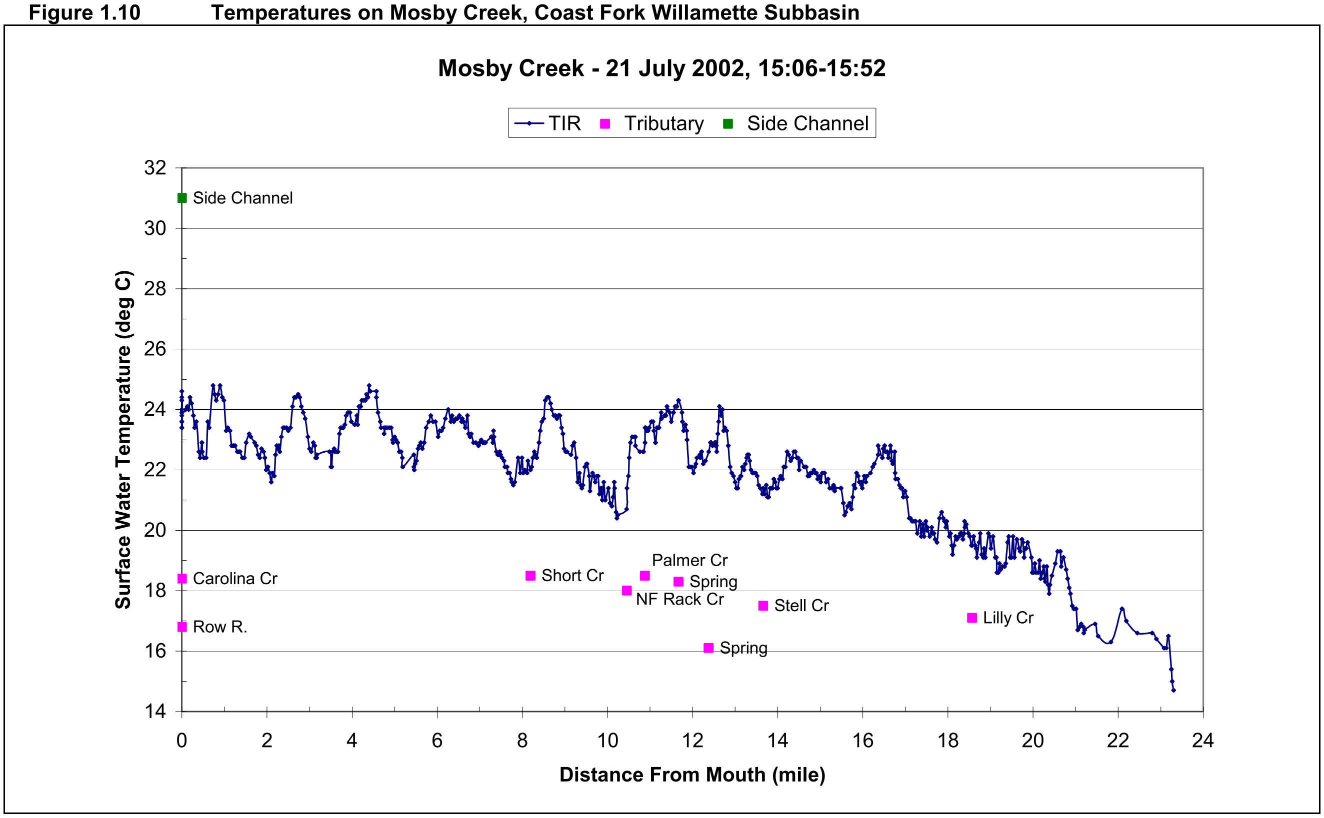


Figure 1.11 TIR Temperatures on Johnson Creek, Lower Willamette Subbasin

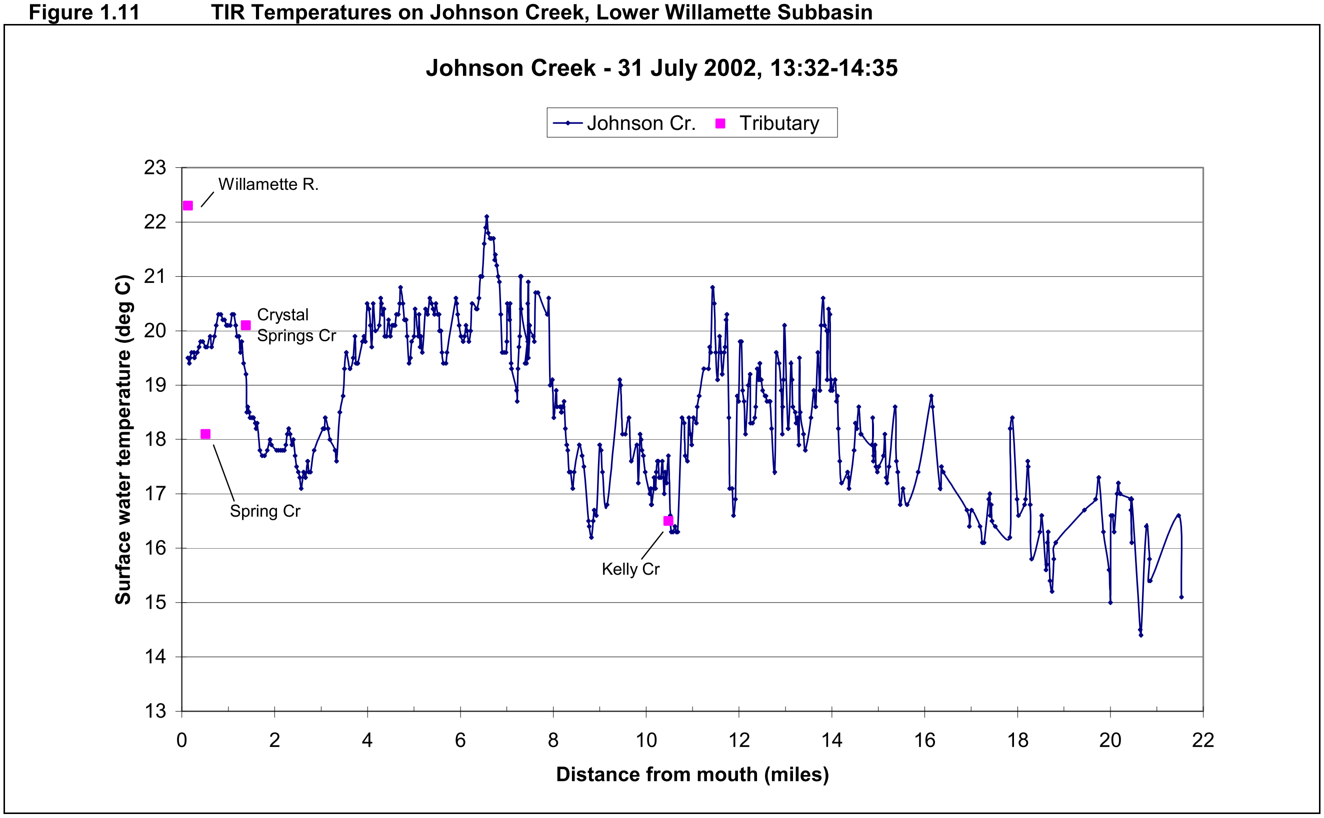


Figure 1.12 TIR Temperatures on Thomas Creek, South Santiam Subbasin

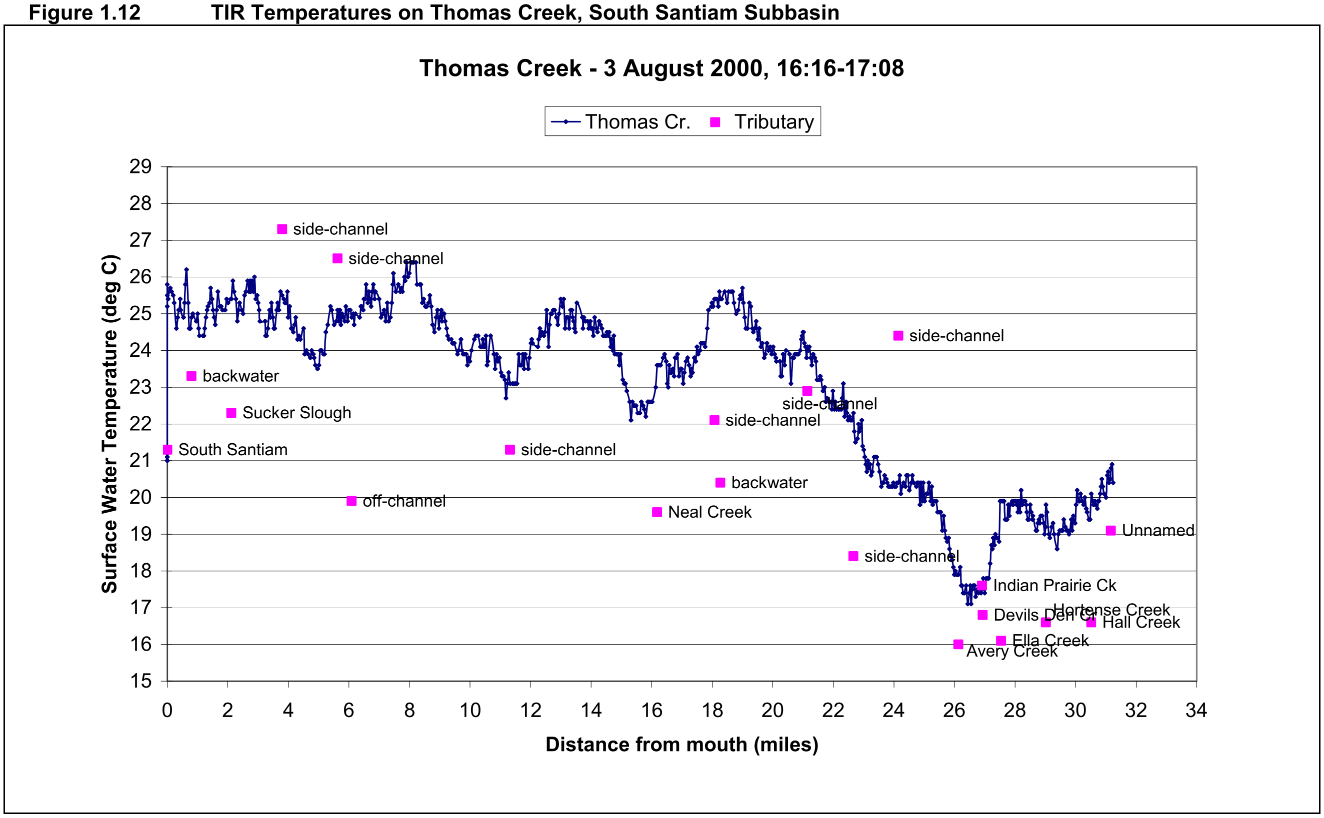


Figure 1.13 TIR Temperatures on Middle Fork Willamette, Middle Fork Willamette Subbasin

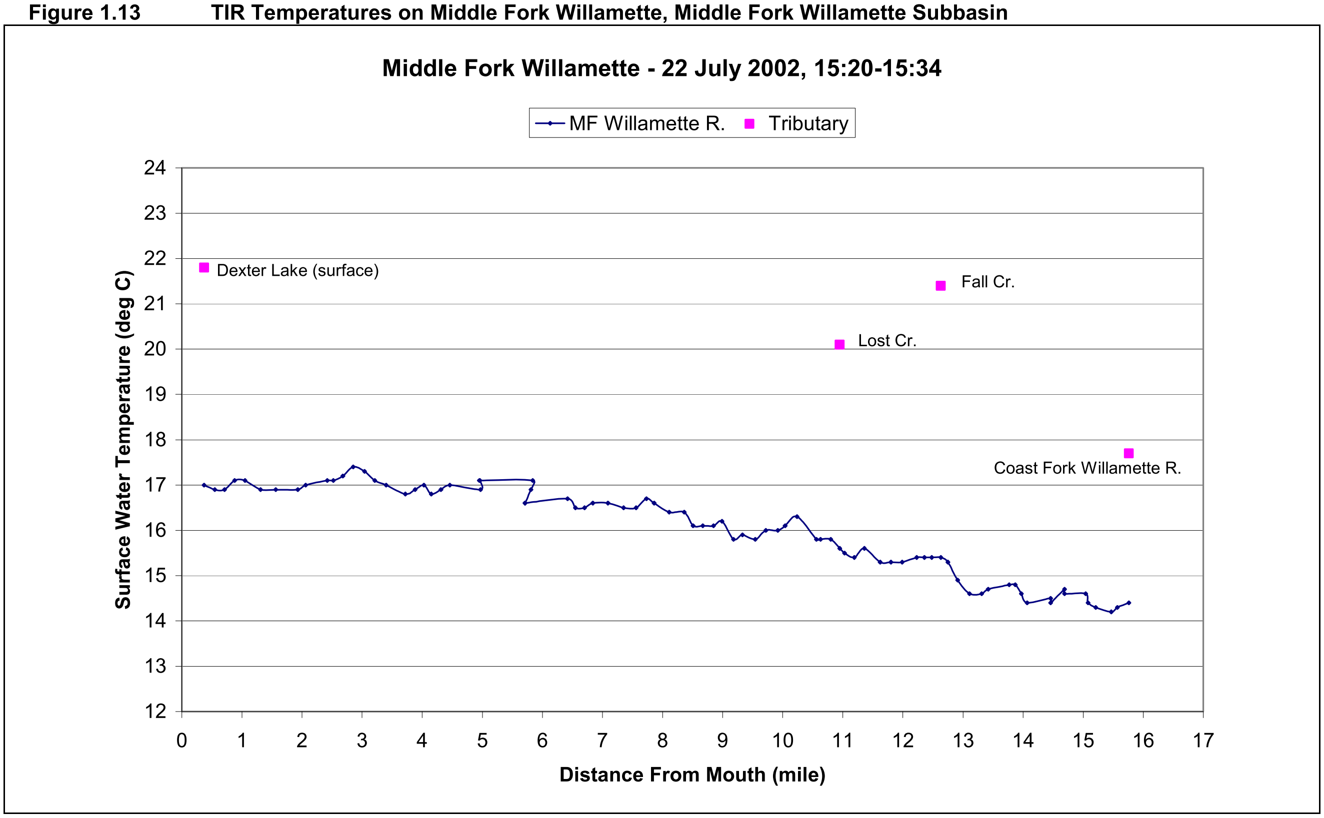
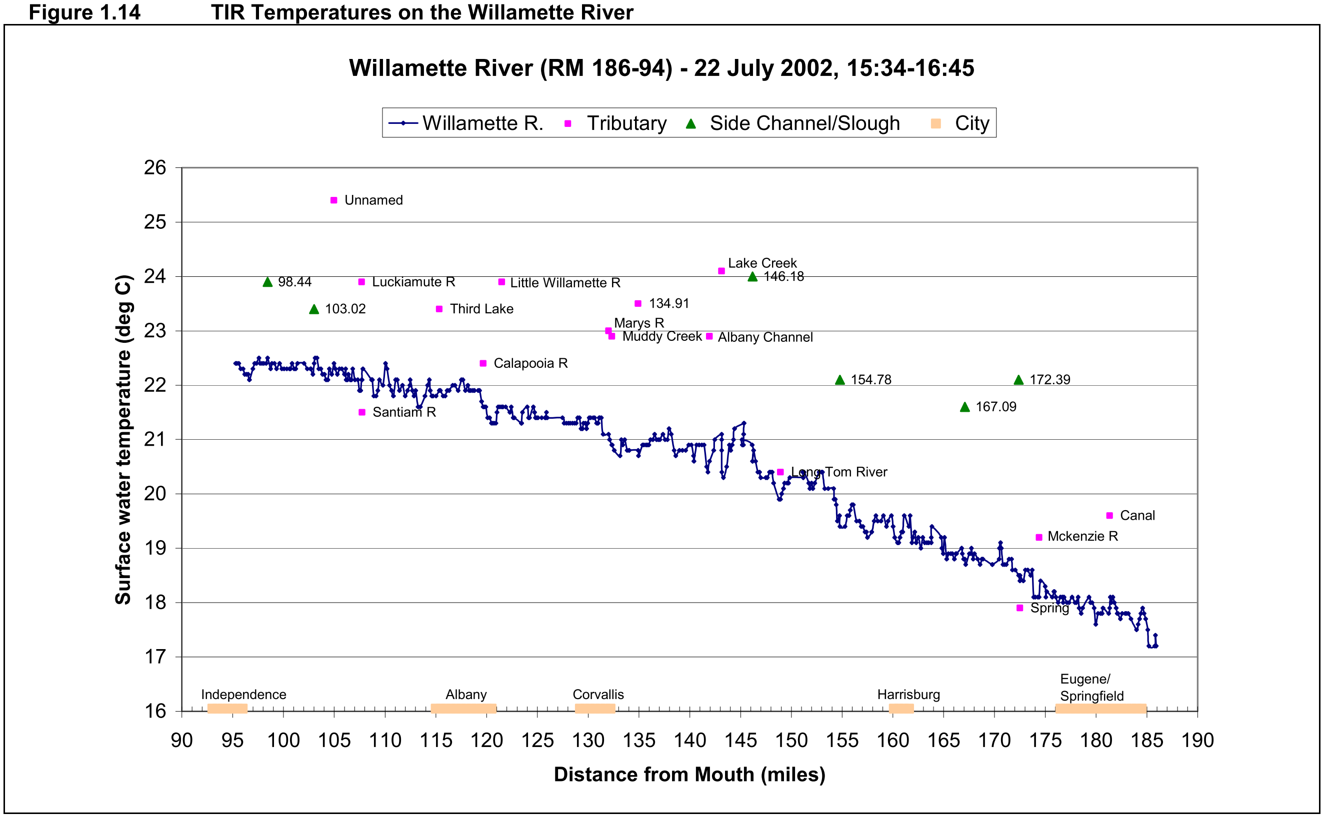


Figure 1.14 TIR Temperatures on the Willamette River



Chapter 3. Derived Data and Sampled Parameters

3.1 Sampled Parameters

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

- Stream Position and Aspect
- Stream Elevation and Gradient (stream bed, valley – transverse and longitudinal)
- Maximum Topographic Shade Angles (East, South, West)
- Channel Width
- TIR Temperature Data Associations
- Near Stream Land Cover

The following sections of this chapter detail the methodologies, results, resolution and accuracy for each derived data type.

3.2 Channel Morphology

3.2.1 Overview

Channel morphology is largely a function of high flow volume magnitude and frequency, stream gradient, sediment supply and transportation, stream bed and bank materials, and stream bank stability (Rosgen 1996 and Leopold et al. 1964).

The predominant thermodynamic influence of channel morphology is quite simple. Wider channels result in the combined effect of increased solar radiation loading via decreased stream surface shade and increased stream surface area exposed to solar radiation loading. A wider stream has a larger surface exposed to surface thermal processes. Other thermal effects that relate to channel morphology include altered stream hydraulics caused by increased wetted perimeter and decreased stream depth. Disturbance of surface and groundwater interactions may also result from channel morphology modifications and have the combined effects of lowering near stream groundwater tables, reducing the groundwater inflow, removing cool sources of groundwater that serve to reduce instream temperatures and modifying hyporheic flows. Substrate changes may decrease or impair hyporheic flows (i.e., flows that occur in the interstitial spaces in the bed substrate) that help buffer stream temperature change.

If channel morphology is anthropogenically disturbed, resulting in decreased effective shade levels, passive restoration could be a primary focus of temperature related restoration efforts in the Willamette subbasins. Passive restoration efforts could include removing sources of channel disturbance that are known to degrade and slow or prevent restoration. Near stream land cover is a primary component in shaping channel form and function and should be a significant emphasis in all restoration planning and activities. Active restoration could be considered where severe channel disturbances cannot be remedied via passive restoration techniques. Examples of areas where active restoration could be considered could include severe vertical down cutting, diked channels, and removal of instream structures that prevent progress towards the desired stream channel condition. Other instream structures can serve as beneficial components in channel restoration such as rock barbs and sediment catchments.

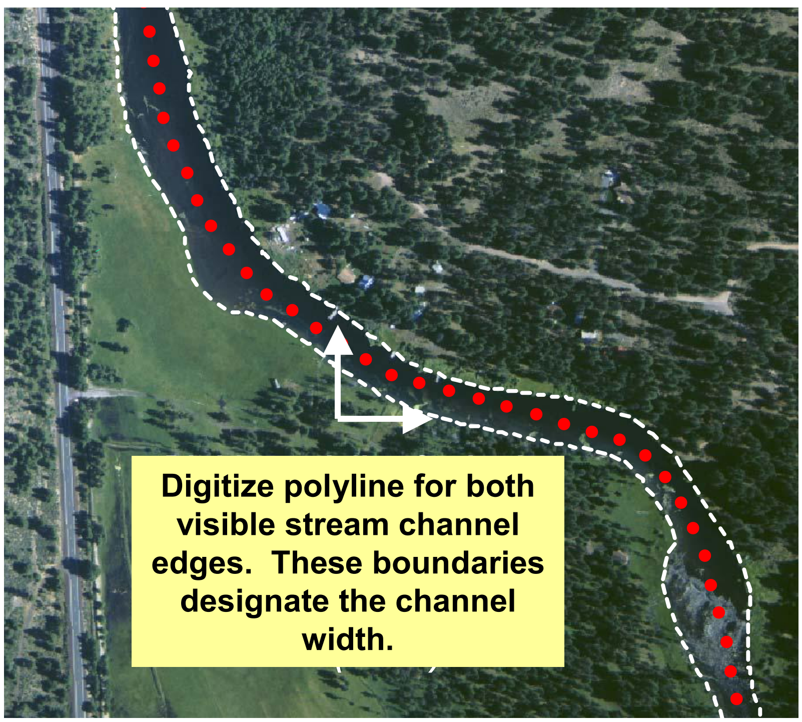
3.2.2 Channel Width Assessment

Channel width is an important component in stream heat transfer and mass transfer processes. Effective shade, stream surface area, wetted perimeter, stream depth and stream hydraulics are all highly sensitive to channel width. Accurate measurement of channel width across the stream network, coupled with other derived data, allows a comprehensive analytical methodology for assessing channel morphology. The steps for conducting channel width assessment are listed below.

Step 1. **Bankfull Channel Boundaries are digitized from DOQs at 1:5,000 or less**. The digitized bankfull channel boundaries are defined for purposes of the TMDL, as the width between shade-producing near-stream vegetation. Where near-stream vegetation is absent, the bankfull channel boundary is defined as the downcut stream banks or where the near-stream zone is unsuitable for vegetation growth due to external factors (i.e., roads, railways, buildings, etc.).

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

Step 3. **Compare GIS sampled channel widths and ground level measurements**. Establish statistical limitations for near stream disturbance zone width values when sampled from aerial photograph (DOQ) analysis.



3.2.3 Results – Channel Widths

Results comparing channels widths derived from GIS and modeling to those measured in the field are presented in **Figures 1.15 through 1.23**. Results shows channel widths only from streams modeled for temperature with Heat Source.

Figure 1.15 **Channel widths on Mosby Creek, Coast Fork Willamette Subbasin**

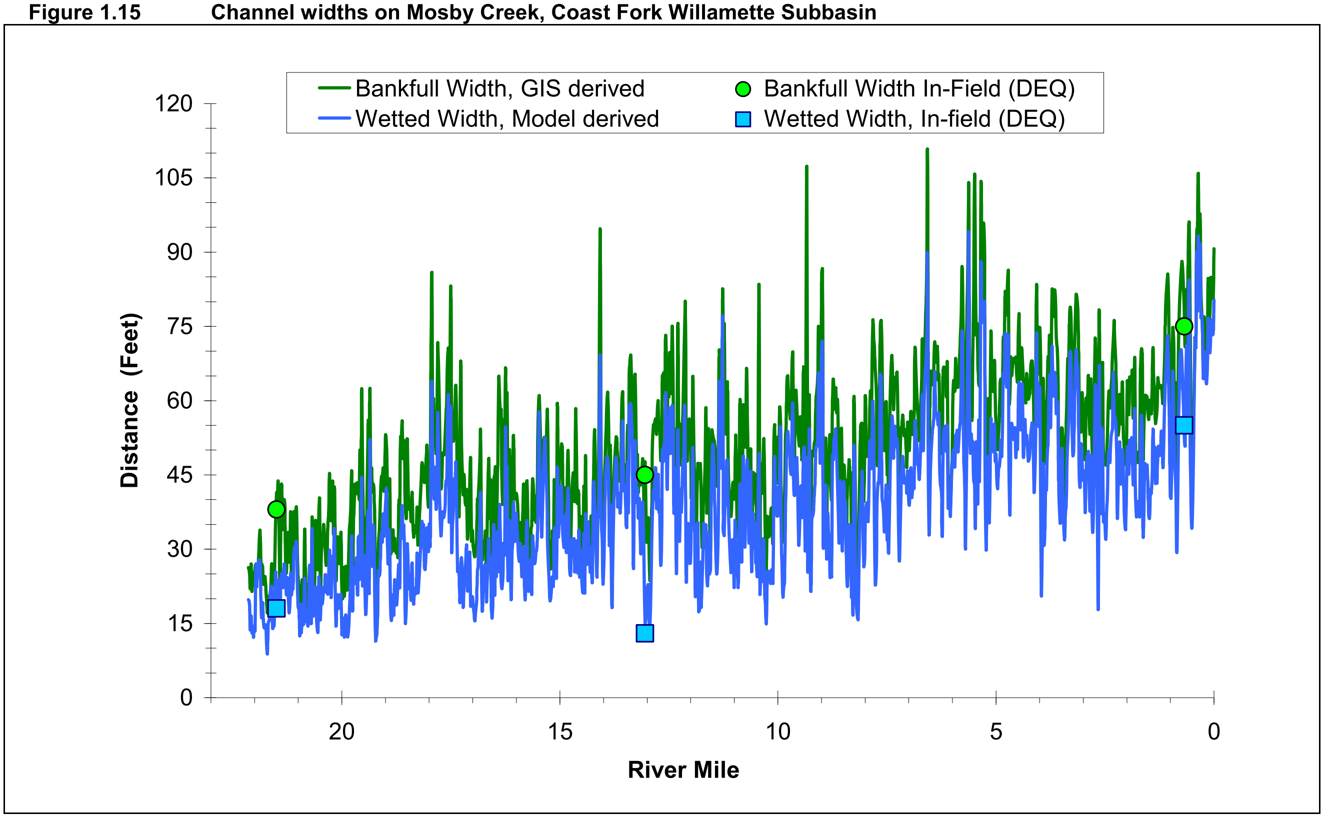


Figure 1.16 **Channel widths on Johnson Creek, Lower Willamette Subbasin**

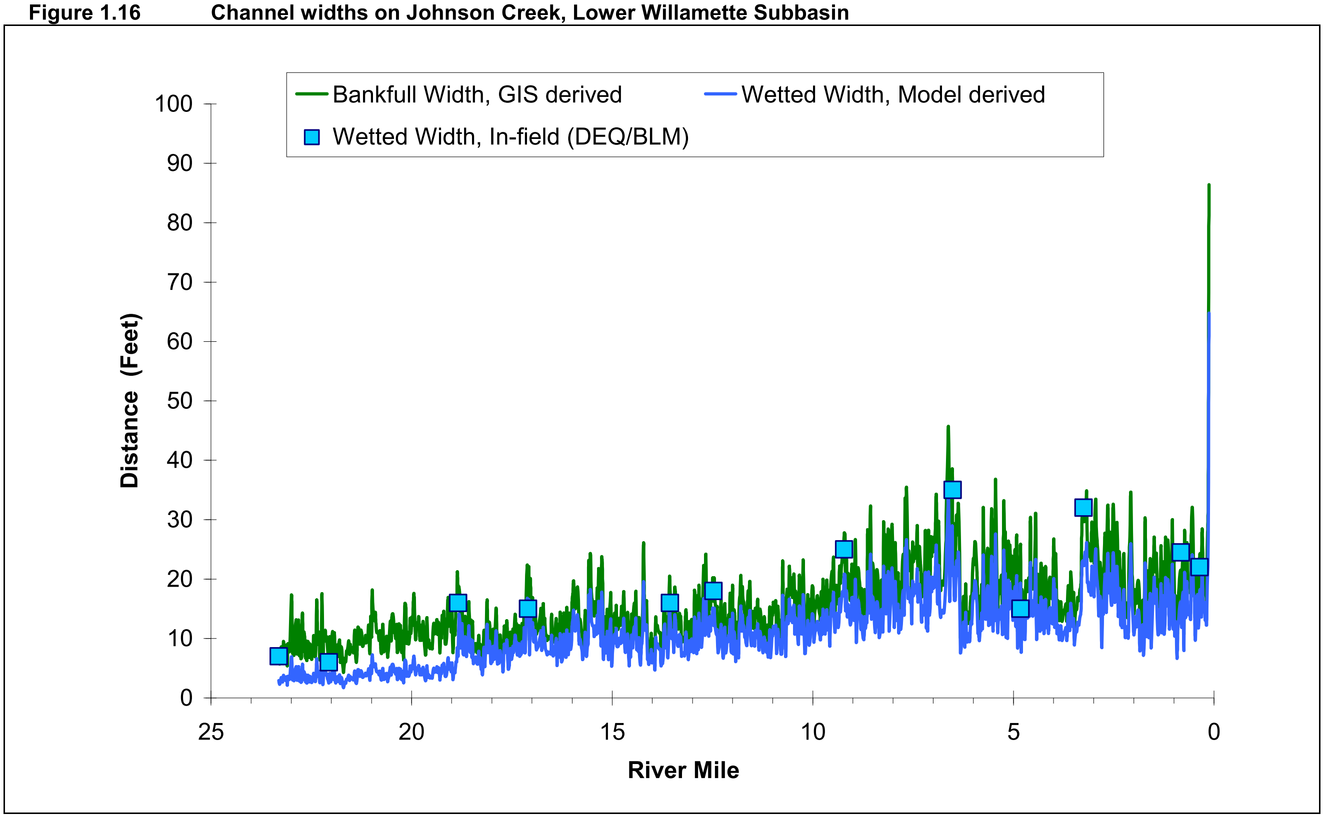


Figure 1.17 **Channel widths on Upper McKenzie River, McKenzie Subbasin**

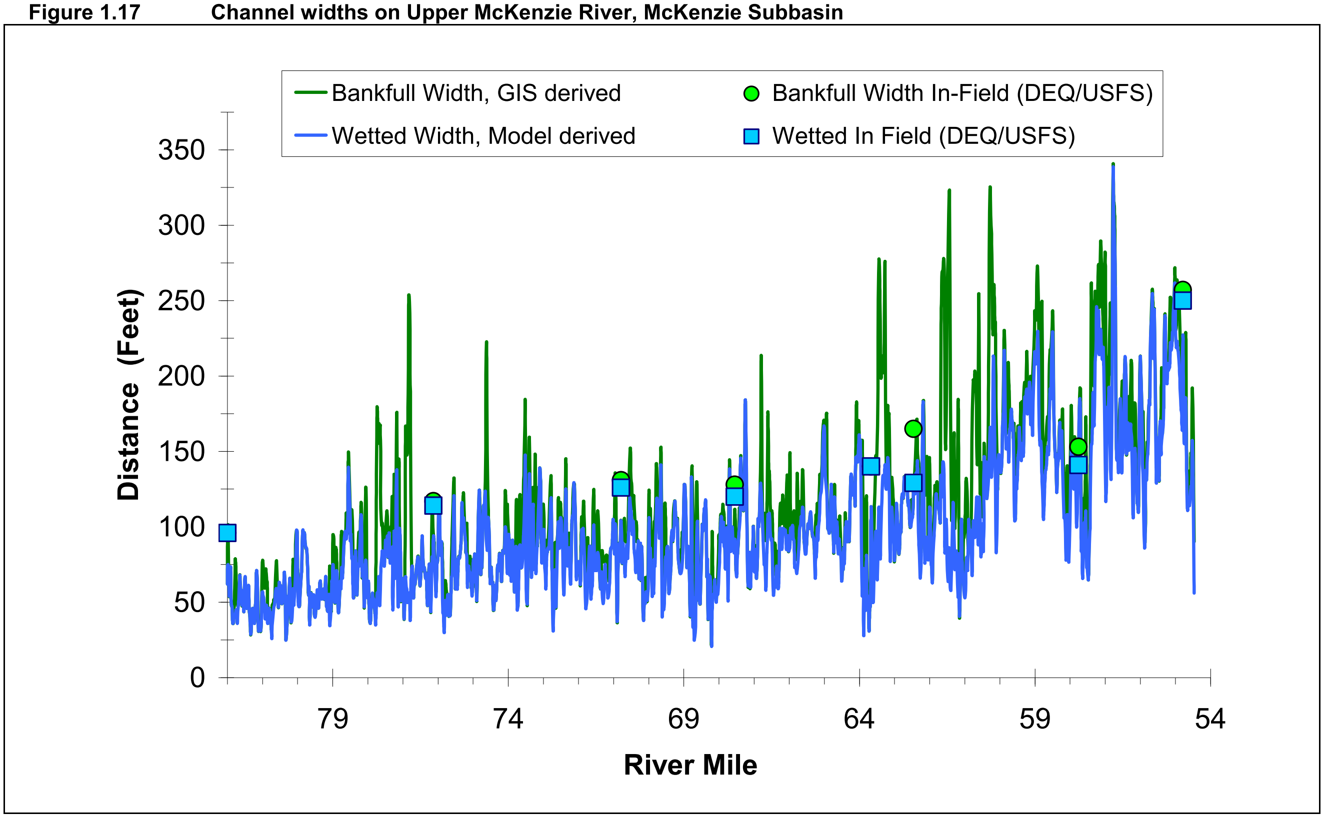


Figure 1.18 **Channel widths on Mohawk River, McKenzie Subbasin**

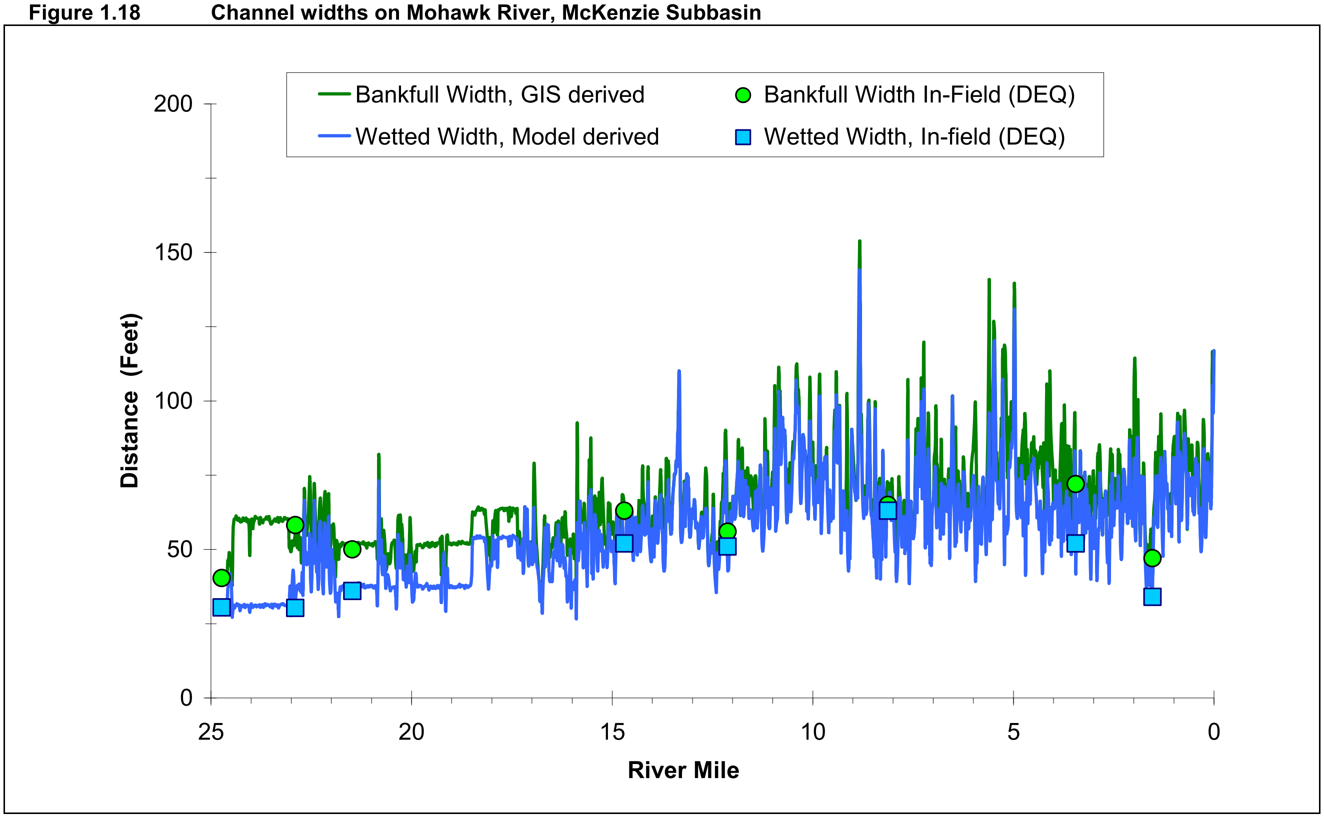


Figure 1.19 Channel widths on Little North Santiam River, North Santiam Subbasin

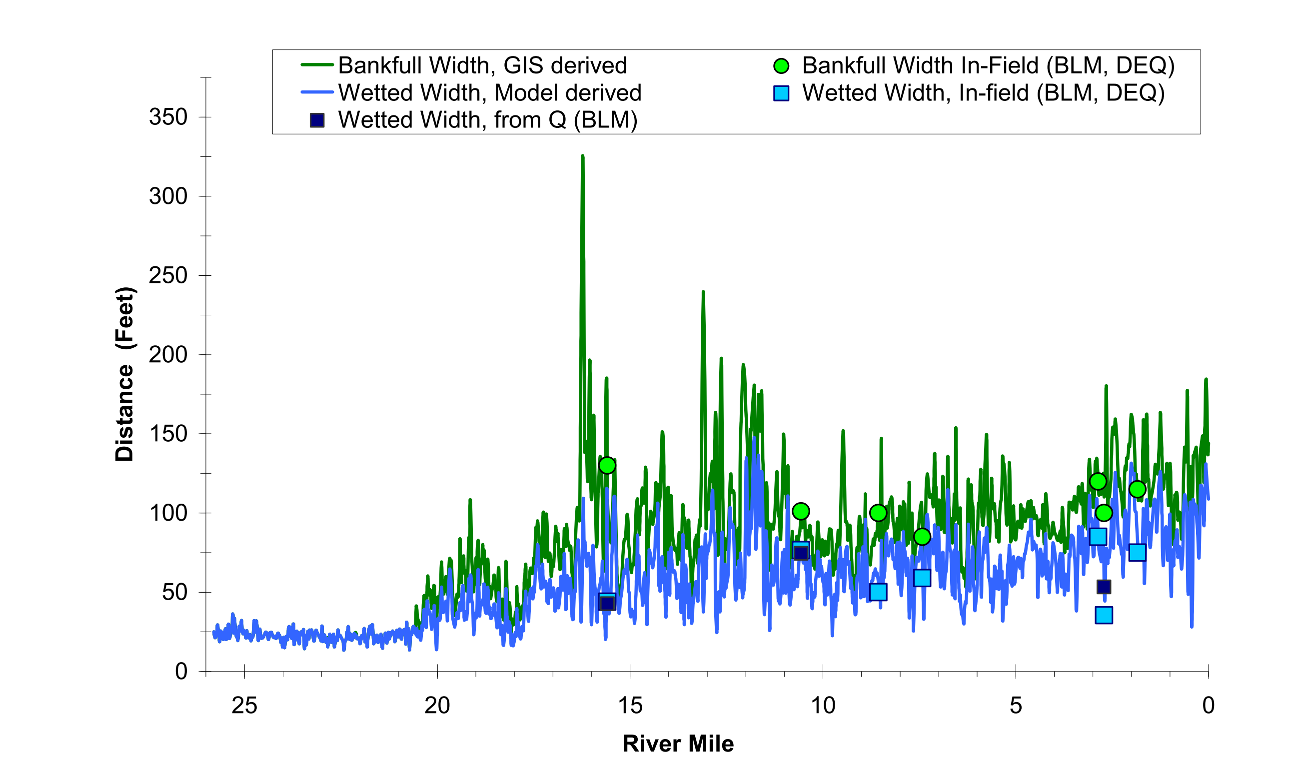


Figure 1.20 Channel widths on Crabtree Creek, South Santiam Subbasin

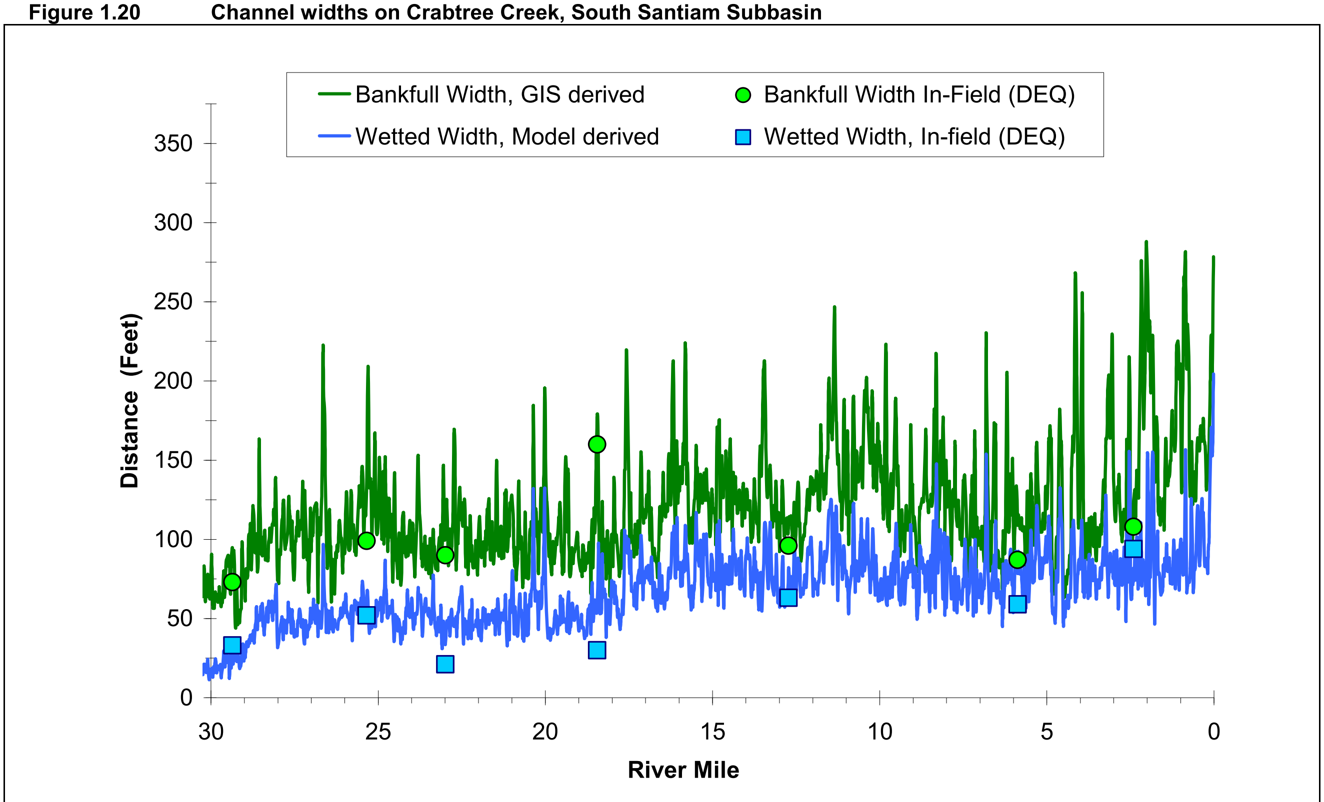


Figure 1.21 **Channel widths on Thomas Creek, South Santiam Subbasin**

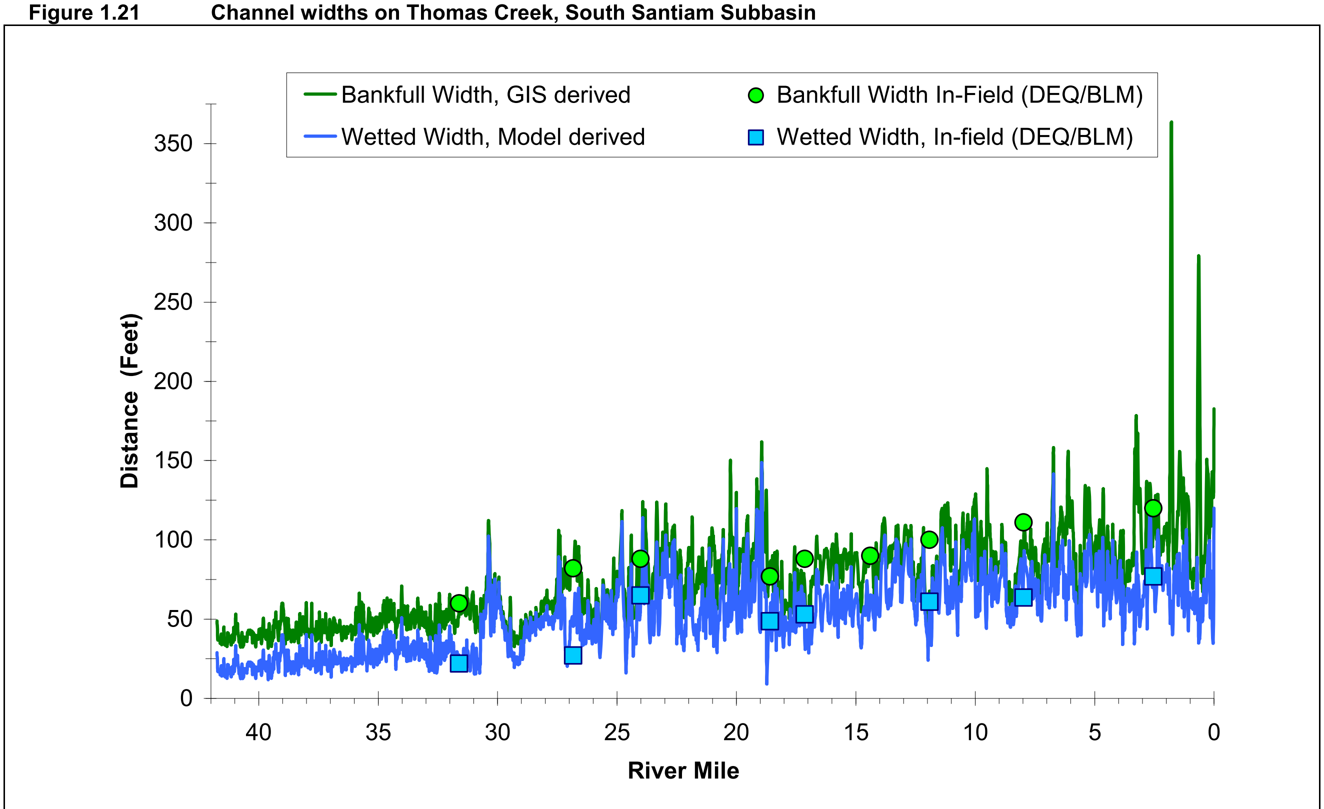


Figure 1.22 **Channel widths on Coyote Creek, Upper Willamette Subbasin**

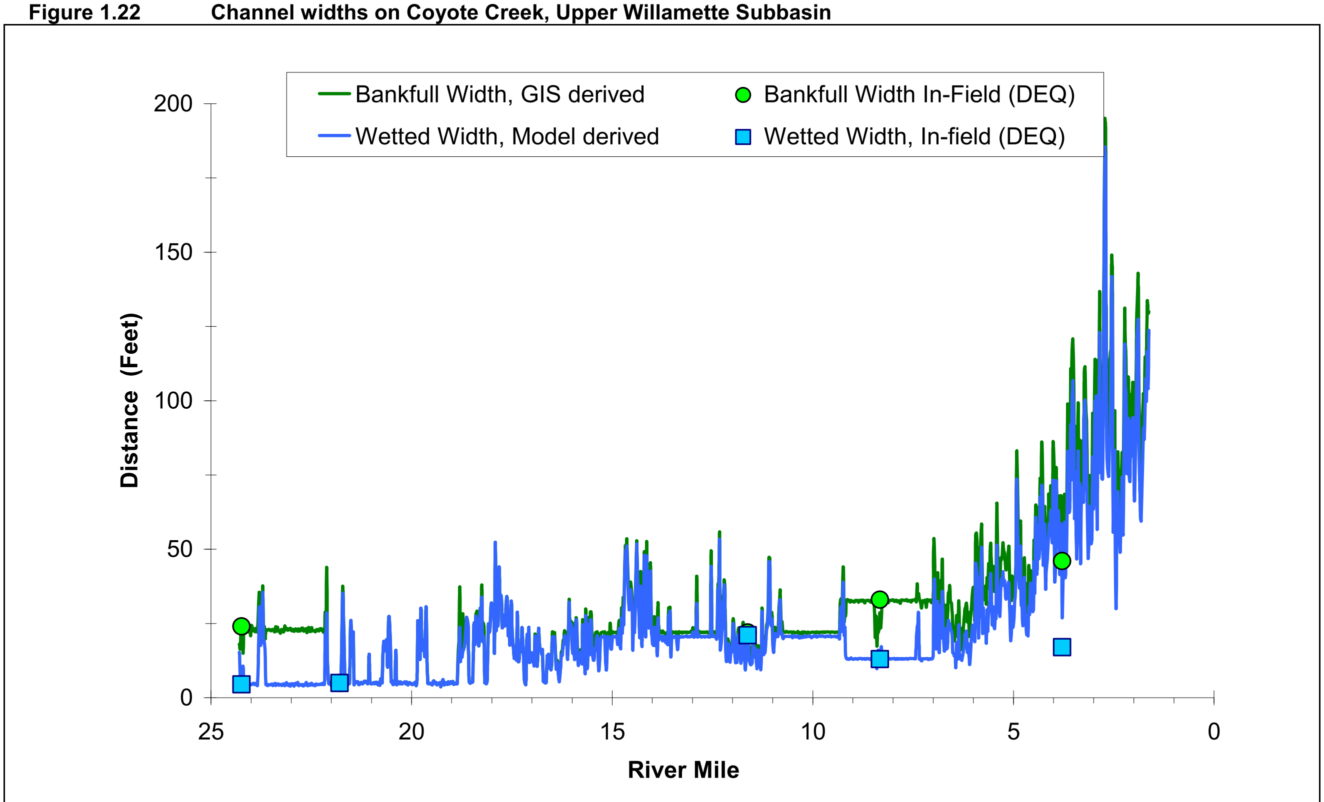
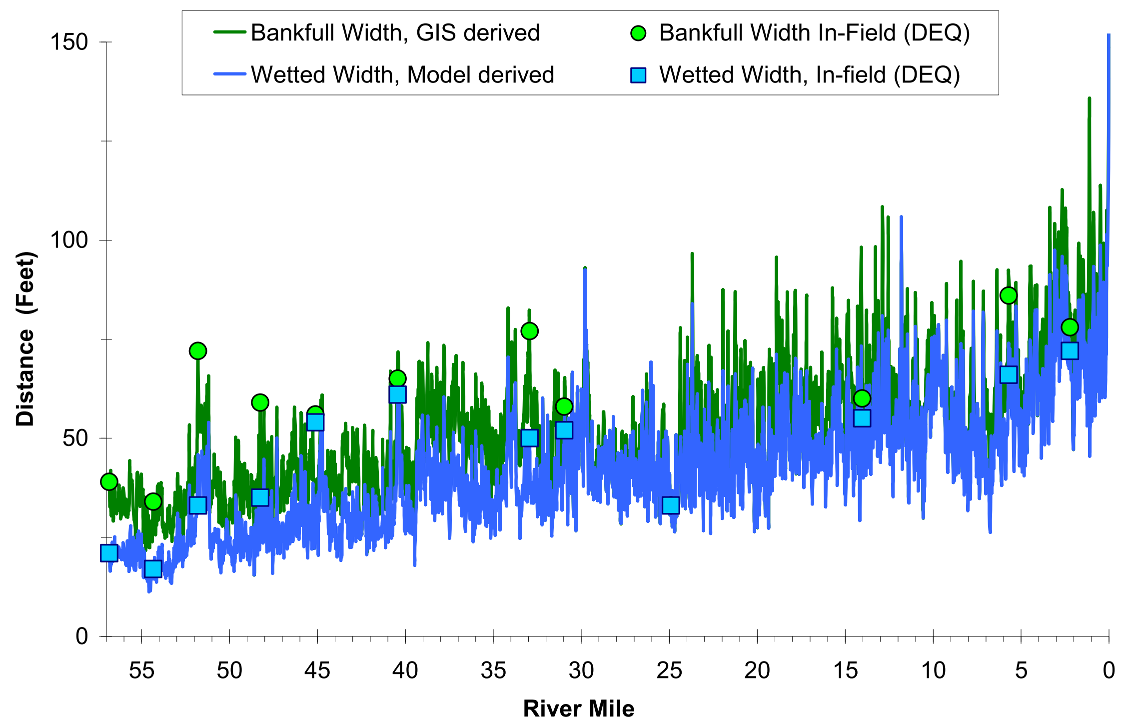


Figure 1.23 Channel widths on Luckiamute River, Upper Willamette Subbasin



3.3 Near Stream Land Cover

3.3.1 Overview

The role of near stream land cover in maintaining a healthy stream condition and water quality is well documented and accepted in scientific literature (Beschta et al. 1987). The list of important impacts that near stream land cover has upon the stream and the surrounding environment is long and warrants listing.

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

Near stream land cover is an important parameter in influencing water quality. Oregon DEQ has mapped near stream land cover using Digital Orthophoto Quads (DOQs) at a 1:5,000 scale, ODFW's Willamette Valley landuse/landcover GIS database (ODWF, 1998), and PNWERC's Willamette River Basin Landuse and Landcover ca. 1990 GIS dataset (PNWERC/ISE, 1999) . Land cover features were mapped 300 feet in the transverse direction from each stream bank. Land cover data are developed by ODEQ in successive steps.

Step 1. Land cover polygons and stream polylines are digitized from DOQs and integrated with ODFW and PNWERC datasets. All digitized polygons are drawn to capture visually like land cover features. All ODEQ digitized line work is verified at 1:5,000 or less.

Step 2. Basic land cover types are developed and assigned to individual polygons. The land cover types used in this effort are aggregate land cover groups, such as: conifers, hardwoods, shrubs, etc., and as defined by ODFW's Willamette Valley database (ODFW, 1998) and PNWERC's Willamette River Basin Landuse and Landcover ca 1990 dataset (PNWERC/ISE, 1999). See Table 3-1 for lancover classifications and attributes used to describe current condtion near stream landcover.

Step 3. Automated sampling is conducted on classified land cover spatial data sets in 2-dimensions. Every 100 feet along the stream (i.e., in the longitudinal direction), the near stream land cover is sampled every 15 meters in a transverse direction; starting at the channel center, out to 60 meters.

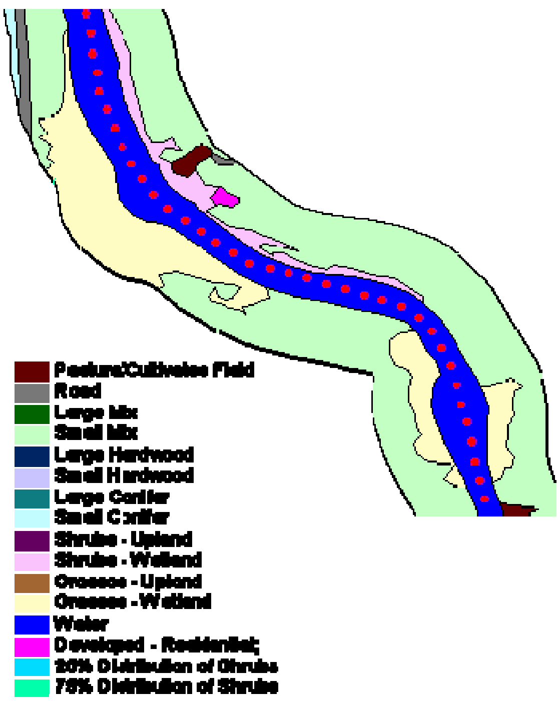
Step 4. Ground level land cover data are statistically summarized and sorted by land cover type.

Step 5. Land cover physical attributes can then be described in 2-dimensions since automated sampling occurs in both the longitudinal and transverse directions.

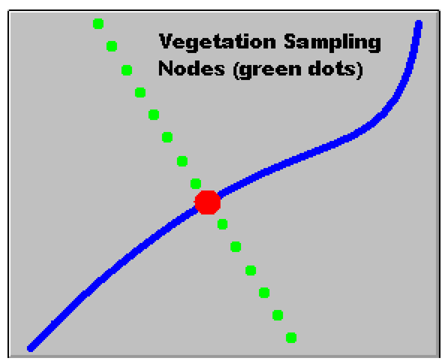
The following images in **Figure 1.24** summarize the steps followed for near stream land cover classification.

Figure 1.24 Examples of classifying near stream land cover

Example of Polygon Mapping of Near Stream Land Cover



Example of Classification of the Land Cover Polygons Associating a Land Cover Type to Each of the Polygons (At this point a land cover type numeric code is associated with each polygon.)



TTools longitudinal sampling pattern for near stream land cover (sampling interval is user defined). Sampling occurs for every stream data node at 9 user-defined intervals at 90 degrees from the stream centerline. A database of land cover type is created for each stream data node

Table 1.24 Current condition land cover classifications and attributes.

ODFW Landcover Code	PNWERC Landcover Code	ODEQ Landcover Code	Landcover Type	Height (ft)	Density
9	32 , 33	**3011**	Water	0	0%
N/A	N/A	**304**	Barren - Rock	0	0%
N/A	N/A	**308**	Barren - Clearcut	0	0%
N/A	N/A	**400**	Barren - Road	0	0%
N/A	N/A	**401**	Barren - Forest Road	0	0%
N/A	N/A	**402**	Barren - Railroad	0	0%
N/A	N/A	**403**	Barren - Ag. Road	0	0%
N/A	N/A	**3011**	River Bottom - Floodplain	0	0%
N/A	N/A	**3248**	Developed - Residential	20	100%
3	N/A	**3249**	Urban Industrial	30	100%
N/A	N/A	**3249**	Developed - Industrial	30	100%
N/A	N/A	**3252**	Dam	0	0%
N/A	N/A	**3254**	WWTP	0	0%
2.1	N/A	**21**	Annual Row Crops	0	0%
2.2	N/A	**22**	Annual Grass	3	75%
2.3	N/A	**23**	Perennial Grass	3	75%
2.4	N/A	**24**	Orchards, Vineyards, Berries, Christmas Trees, Nursery Stock	10	75%
2.4	N/A	**28**	Orchards, Vineyards, Berries, Christmas Trees, Nursery Stock	40	75%
2.5	N/A	**25**	Unmanaged Pasture	0	0%
2.6	N/A	**26**	Parks and Cemeteries	0	0%
3	N/A	**3248**	Urban Residential	20	100%
20	N/A	**202**	Black Hawthorn, Hedgerows, Brushy Fields	19	25%
20	N/A	**204**	Black Hawthorn, Hedgerows, Brushy Fields	26	25%
20	N/A	**206**	Black Hawthorn, Hedgerows, Brushy Fields	19	75%
20	N/A	**208**	Black Hawthorn, Hedgerows, Brushy Fields	26	75%
21	N/A	**212**	Cottonwood	75	25%
21	N/A	**214**	Cottonwood	105	25%
21	N/A	**216**	Cottonwood	75	75%
21	N/A	**218**	Cottonwood	105	75%
22	N/A	**222**	Willow	28	25%
22	N/A	**224**	Willow	43	25%
22	N/A	**226**	Willow	28	75%
22	N/A	**228**	Willow	43	75%
30	N/A	**30**	Reed Canary Grass	6	75%
30	N/A	**35**	Reed Canary Grass	6	25%
31	N/A	**31**	Cattial, Bulrush	5	75%
31	N/A	**315**	Cattial, Bulrush	5	25%
463	N/A	**4632**	Ash, Cottonwood - Bottomland Pasture Mosaic	33	25%
463	N/A	**4634**	Ash, Cottonwood - Bottomland Pasture Mosaic	93	25%
463	N/A	**4636**	Ash, Cottonwood - Bottomland Pasture Mosaic	33	75%
463	N/A	**4638**	Ash, Cottonwood - Bottomland Pasture Mosaic	93	75%
476	N/A	**4762**	Oak, Douglas Fir - >50% Oak	53	25%
476	N/A	**4764**	Oak, Douglas Fir - >50% Oak	93	25%
476	N/A	**4766**	Oak, Douglas Fir - >50% Oak	53	75%
476	N/A	**4768**	Oak, Douglas Fir - >50% Oak	93	75%
505	N/A	**5052**	Douglas Fir, Oak - < 50% Oak	53	25%
505	N/A	**5054**	Douglas Fir, Oak - < 50% Oak	91	25%
505	N/A	**5056**	Douglas Fir, Oak - < 50% Oak	53	75%
505	N/A	**5058**	Douglas Fir, Oak - < 50% Oak	91	75%
506	N/A	**5062**	Oak, Madrone, Douglas Fir	50	25%
506	N/A	**5064**	Oak, Madrone, Douglas Fir	87	25%
506	N/A	**5066**	Oak, Madrone, Douglas Fir	50	75%
506	N/A	**5068**	Oak, Madrone, Douglas Fir	87	75%
510	N/A	**5102**	Maple, Alder, Fir	65	25%
510	N/A	**5104**	Maple, Alder, Fir	93	25%
510	N/A	**5106**	Maple, Alder, Fir	65	75%
510	N/A	**5108**	Maple, Alder, Fir	93	75%
512	N/A	**5122**	Douglas Fir or any Conifer	102	25%
512	N/A	**5124**	Douglas Fir or any Conifer	160	25%
512	N/A	**5126**	Douglas Fir or any Conifer	102	75%
512	N/A	**5128**	Douglas Fir or any Conifer	160	75%
999	N/A	**999**	Gravel and Sand	0	0%
1000	N/A	**1002**	Unclassified Forest	56	25%
1000	N/A	**1004**	Unclassified Forest	89	25%
1000	N/A	**1006**	Unclassified Forest	56	75%
1000	N/A	**1008**	Unclassified Forest	89	75%

Table 1.25 Current condition land cover classifications and attributes (condt.)

ODFW Landcover Code	PNWERC Landcover Code	ODEQ Landcover Code	Landcover Type	Height (ft)	Density
N/A	1	**3248**	Residential 0-4 DU/ac	20	100%
N/A	6	**3249**	Commercial	30	100%
N/A	7	**3249**	Comm/Industrial	30	100%
N/A	8	**3249**	Industrial	30	100%
N/A	11	**11**	Urban non-vegetated unknown	0	0%
N/A	12	**12**	Civic/open space	0	0%
N/A	16	**16**	Rural structures	20	100%
N/A	18	**402**	Railroad	0	0%
N/A	19	**400**	Primary roads	0	0%
N/A	20	**400**	Secondary roads	0	0%
N/A	21	**400**	Light duty roads	0	0%
N/A	24	**88**	Rural non-vegetated unknown	0	0%
N/A	29	**301**	Channel non-vegetated	0	0%
N/A	32	**301**	Stream orders 5-7	0	0%
N/A	33	**301**	Water	0	0%
N/A	49	**492**	Urban tree overstory	19	25%
N/A	49	**494**	Urban tree overstory	26	25%
N/A	49	**496**	Urban tree overstory	19	75%
N/A	49	**498**	Urban tree overstory	26	75%
N/A	51	**51**	Forest open	0	0%
N/A	52	**52**	Forest Semi-closed mixed	56	25%
N/A	52	**525**	Forest Semi-closed mixed	90	25%
N/A	53	**53**	Forest Closed hardwood	38	75%
N/A	53	**535**	Forest Closed hardwood	67	75%
N/A	54	**54**	Forest Closed mixed	56	75%
N/A	54	**545**	Forest Closed mixed	90	75%
N/A	55	**55**	Forest Semi-closed conifer	101	25%
N/A	55	**555**	Forest Semi-closed conifer	162	25%
N/A	56	**56**	Conifers 0-20 yrs (20)	50	25%
N/A	56	**565**	Conifers 0-20 yrs (20)	50	75%
N/A	57	**57**	FCC 21-40 yrs (30)	86	25%
N/A	57	**575**	FCC 21-40 yrs (30)	86	75%
N/A	58	**58**	FCC 41-60 yrs (50)	129	25%
N/A	58	**585**	FCC 41-60 yrs (50)	129	75%
N/A	59	**59**	FCC 61-80 yrs (70)	156	25%
N/A	59	**595**	FCC 61-80 yrs (70)	156	75%
N/A	60	**60**	FCC 81-200 yrs (140)	205	25%
N/A	60	**605**	FCC 81-200 yrs (140)	205	75%
N/A	61	**61**	FCC >200 yrs * (140)	205	25%
N/A	61	**615**	FCC >200 yrs * (140)	205	75%
N/A	62	**62**	Forest Semi-closed hardwood	38	25%
N/A	62	**625**	Forest Semi-closed hardwood	67	25%
N/A	68	**21**	Irrigated annual rotation	0	0%
N/A	71	**22**	Grains	3	75%
N/A	72	**24**	Nursery	10	75%
N/A	72	**28**	Nursery	40	75%
N/A	73	**24**	Caneberries & Vineyards	10	75%
N/A	73	**28**	Caneberries & Vineyards	40	75%
N/A	75	**24**	Hops	10	75%
N/A	79	**21**	Row crop	0	0%
N/A	82	**21**	Field crop	0	0%
N/A	83	**22**	Hay	3	75%
N/A	84	**21**	Late field crop	0	0%
N/A	85	**85**	Pasture	0	0%
N/A	86	**23**	Natural grassland	3	75%
N/A	87	**87**	Natural shrub	15	25%
N/A	87	**875**	Natural shrub	15	75%
N/A	88	**88**	Bare/fallow	0	0%
N/A	89	**301**	Flooded/marsh	0	0%
N/A	90	**21**	Irrigated field crop	0	0%
N/A	91	**91**	Turfgrass/park	0	0%
N/A	92	**24**	Orchard	10	75%
N/A	92	**28**	Orchard	40	75%
N/A	93	**932**	Christmas trees	10	75%
N/A	93	**934**	Christmas trees	40	75%
N/A	N/A	**156**	Oak - Bottomland	40	25%
N/A	N/A	**158**	Oak - Bottomland	40	75%
N/A	N/A	**152**	Oak - Bottomland	20	25%
N/A	N/A	**154**	Oak - Bottomland	20	75%

3.3.2 Near Stream Land Cover – Mapping, Classification and Sampling

ODEQ used GIS to digitally map and identify near stream land cover on major streams throughout the Willamette subbasins. To the extent possible, existing near stream land cover was digitized and sampled for all of the streams shown in **Figure 1.25** and **Table 1.26**. These waterbodies were sampled for both the subbasins and mainstem Willamette River analysis.

Figure 1.25 Streams where near stream land cover and channel morphology was digitized and sampled

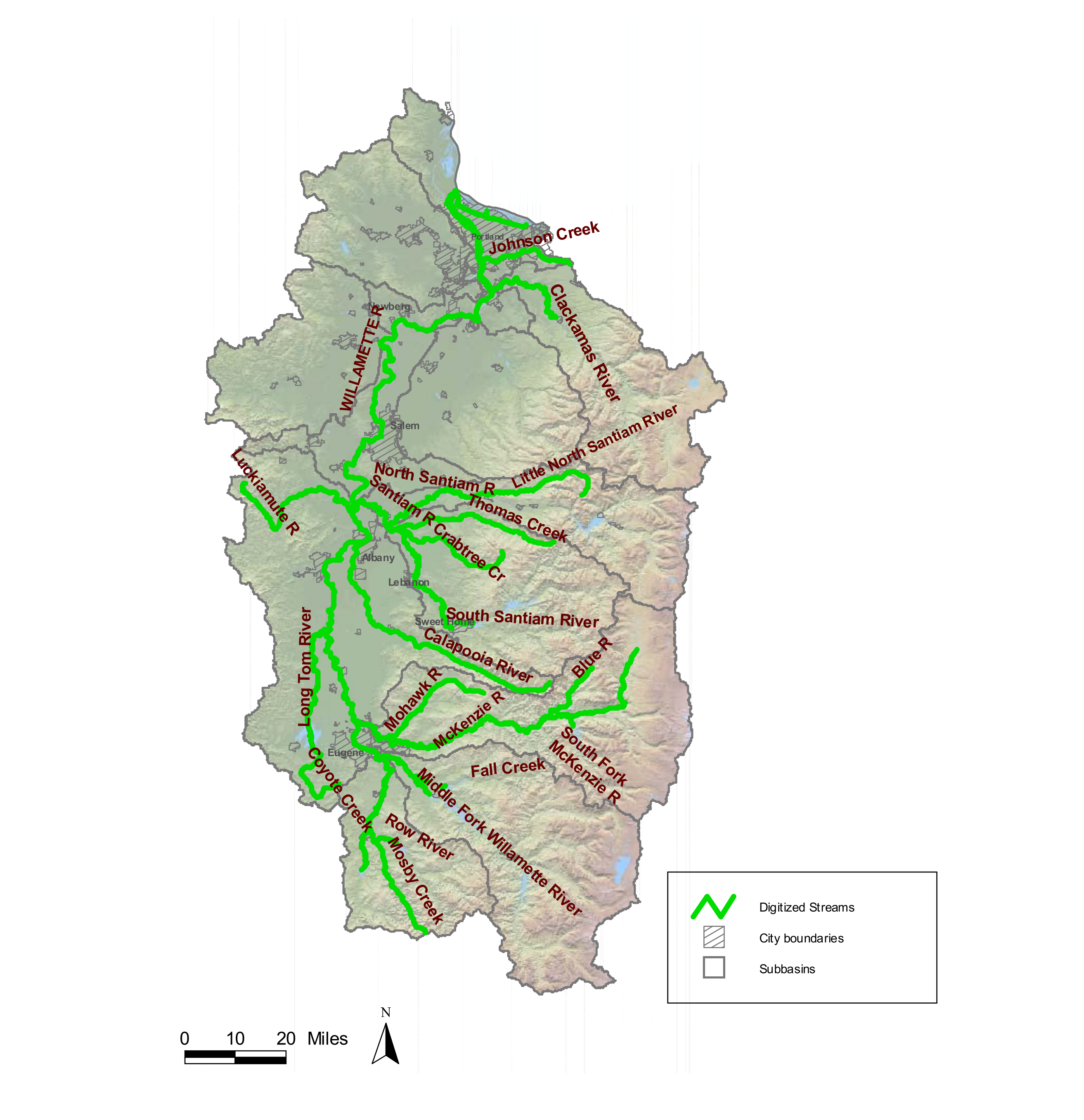


Table 1.26 Streams where near stream land cover was mapped and sampled

• Blue River	• McKenzie River
• Calapooia River	• Middle Fork Willamette River
• Clackamas River	• Mohawk River
• Coast Fork Willamette River	• Mosby Creek
• Columbia Slough	• North Santiam River
• Coyote Creek	• Row River
• Crabtree Creek	• Thomas Creek
• Fall Creek	• Santiam River
• Johnson Creek	• South Fork McKenzie River
• Long Tom River	• South Santiam River
• Lower North Santiam River	• Willamette River
• Luckiamute River	

TTools version 3.3 was used to sample the near-stream land cover for all of the streams shown in **Table 1.26**. Data was sampled every 100 feet longitudinally The result of TTools sampling was a land cover input data set that consisted digitized land cover classifications for the stream of interest.

3.3.3 Potential Condition Development

The process of developing potential near stream land cover is described in Appendix C Chapter 2 – Potential Near Stream Land Cover in the Willamette Basin for TMDLs. **Potential near stream land cover** is that which can grow and reproduce on a site given plant biology, site elevation, soil characteristics and local climate. Potential near stream land cover does not include considerations for resource management, human use or other human disturbance.

3.4 Hydrology

3.4.1 Methodology Used for Mass Balance Development

TIR sampled stream temperature data can be used to develop a mass balance for stream flow using minimal ground level data collection points. Simply identifying mass transfer areas is an important step in quantifying heat transfer within a stream network. For example, using TIR temperature data, Oregon DEQ identified mass transfer areas occurring in the Willamette subbasin streams. Several of the subsurface mass transfer areas were unmapped and the relative thermal and hydrologic impact to the stream system was not previously quantified.

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

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

where,

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

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

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

In this fashion, a mass balance can be developed from relatively few instream measurements, TIR stream temperature data and water rights data. **Potential flow rates** are calculated by removing all water withdrawals and agriculture return flows. The influences of potential flow rates on temperature were modeled in the Thomas Creek analysis.

Discussion of Assumptions and Limitations for Mass Balance Methodology

1. **Small mass transfer processes are not accounted**. A limitation of the methodology is that only mass transfer processes with measured ground level flow rates or those that cause a quantifiable change in stream temperature with the receiving waters (i.e., identified by TIR data) can be analyzed and included in the mass balance. For example, a tributary with an unknown flow rate that cause small temperature changes (i.e., less than $\pm 0.5^{o}F$) to the receiving stream cannot be accurately included. *This assumption can lead to an under estimate of influent mass transfer processes.*
2. **Limited ground level flow data limit the accuracy of derived mass balances**. Errors in the calculations of mass transfer can become cumulative and propagate in the methodology since validation can only be performed at sites with known flow rates. *These mass balance profiles should be considered estimates of a steady state flow condition*.
3. **Water withdrawals are not directly quantified**. Instead, water right data are obtained from the POD and WRIS OWRD databases and discussion with the water master. An assumption is made that these water rights are being used if water availability permits. *This assumption can lead to an over estimate of water withdrawals.*
4. **Water withdrawals are assumed to occur only at OWRD mapped points of diversion sites.** There may have been additional diversions occurring throughout the stream network. *This assumption can lead to an underestimate of water withdrawals and an under estimate of potential flow rates.*
5. **It is not possible to determine the amount of return flows derived from ground water withdrawals relative to those derived from instream withdrawals.** Some of the irrigated water comes from ground water sources. Therefore, one should assume that portions of the return flows are derived from ground water sources. Return flows can occur over long distances from irrigation application and generally occur at focal points down gradient from multiple irrigation applications. It is not possible to estimate the portion of irrigation return flow that was pumped from ground water rights. In the potential flow condition all return flows are removed from the mass balances. *This assumption can lead to an under estimate of potential flow rates.*
6. **Return flows may deliver water that is diverted from another watershed.** In some cases, irrigation canals transport diverted water to application areas in another drainage. This is especially common in low gradient meadows, cultivated fields and drained wetlands used for agriculture production. The result is that accounting for a tributary flow in the potential flow condition is extremely difficult. ODEQ is unable to track return flows to withdrawal origins between drainage areas. *When return flows are removed in the potential flow condition this assumption can lead to an under estimate of potential tributary flow rates.*

3.4.2 Results – Mass Balances and Depths

Modeled stream depths as well as the longitudinal flow mass balances derived from measured flows, OWRD points of diversion data, and TIR temperature data are presented in **Figures 1.26** through **1.34**. Only mass balances and depths from streams modeled for temperature with heat source are presented.

Figure 1.26 Longitudinal flow mass balance for Mosby Creek, Coast Fork Willamette Subbasin

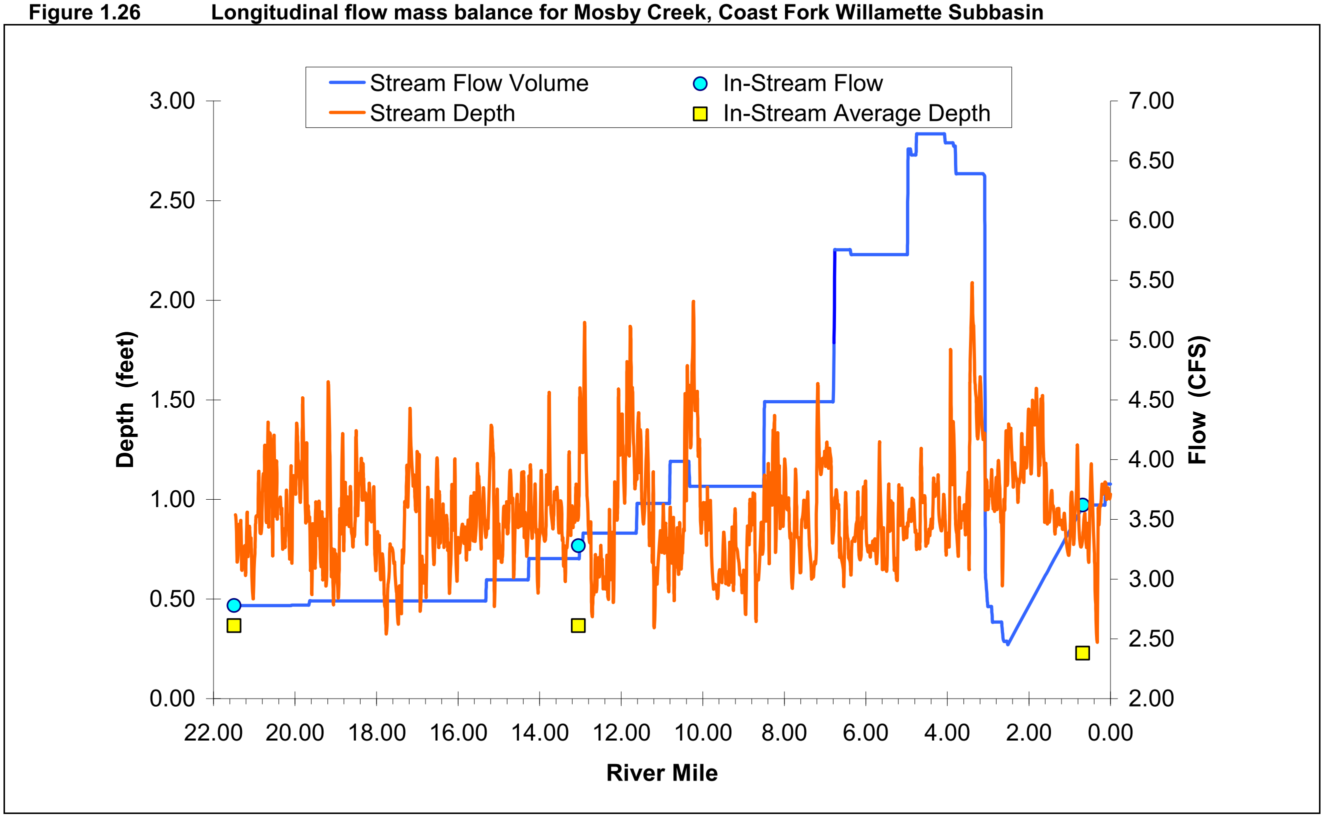


Figure 1.27 Longitudinal flow mass balance for Johnson Creek, Lower Willamette Subbasin

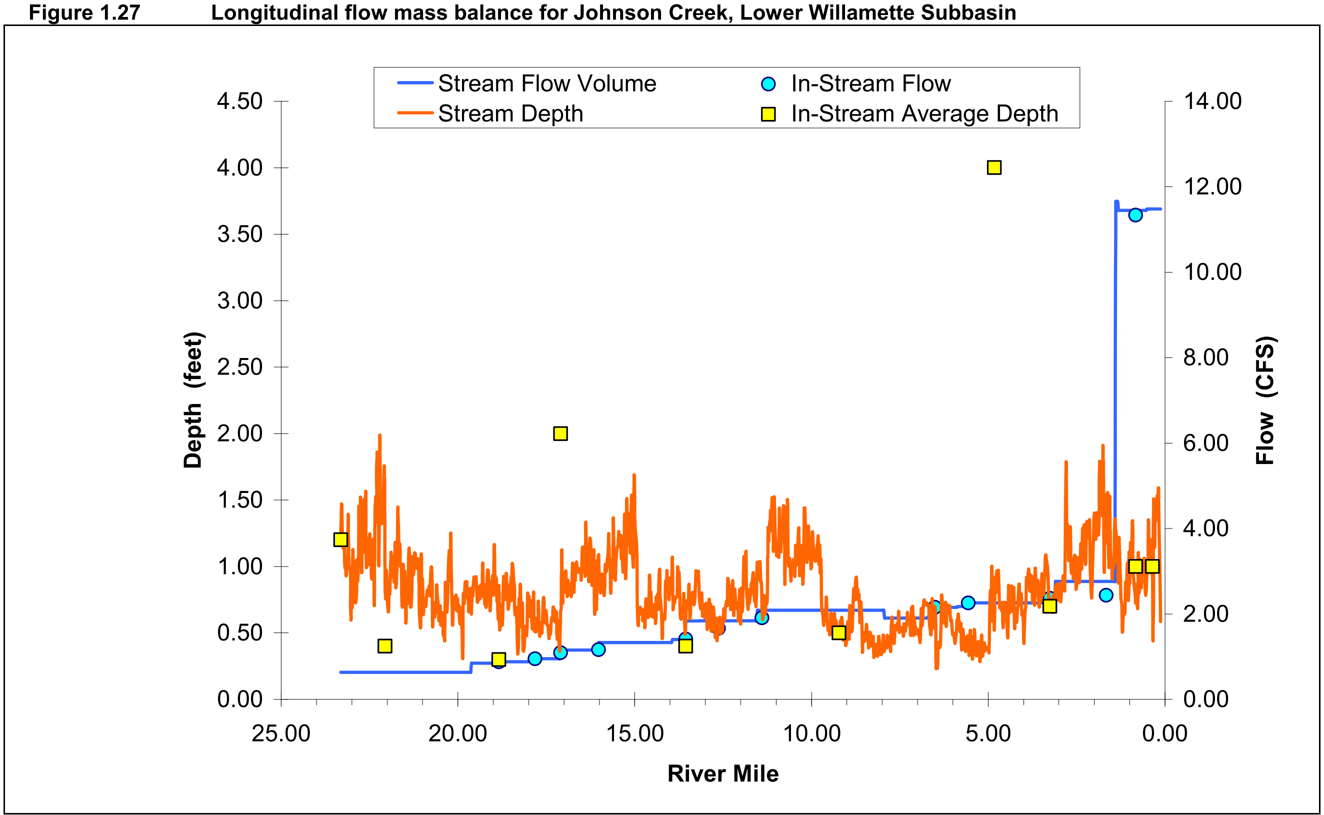


Figure 1.28 Longitudinal flow mass balance for the Mohawk River, McKenzie Subbasin

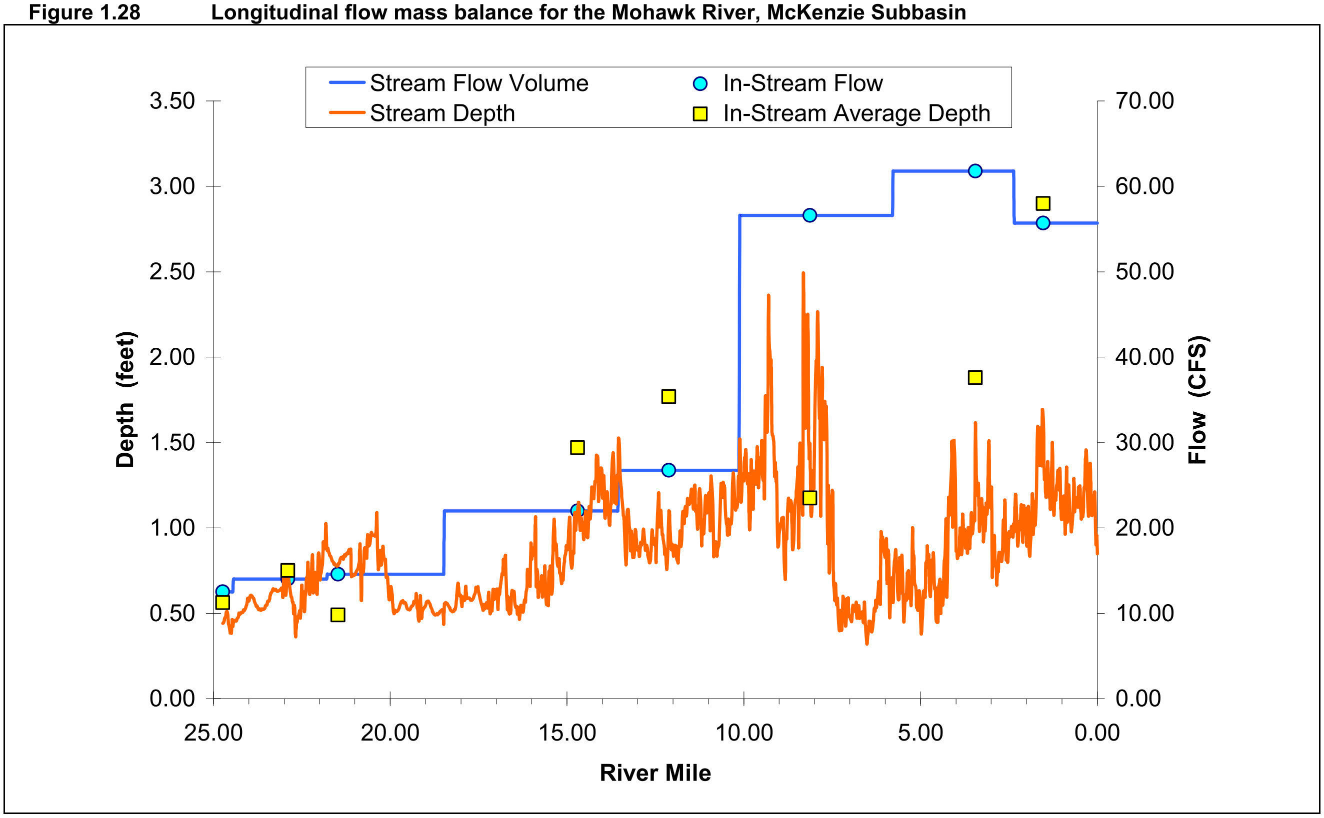


Figure 1.29 Longitudinal flow mass balance for the McKenzie River (Upper), McKenzie Subbasin

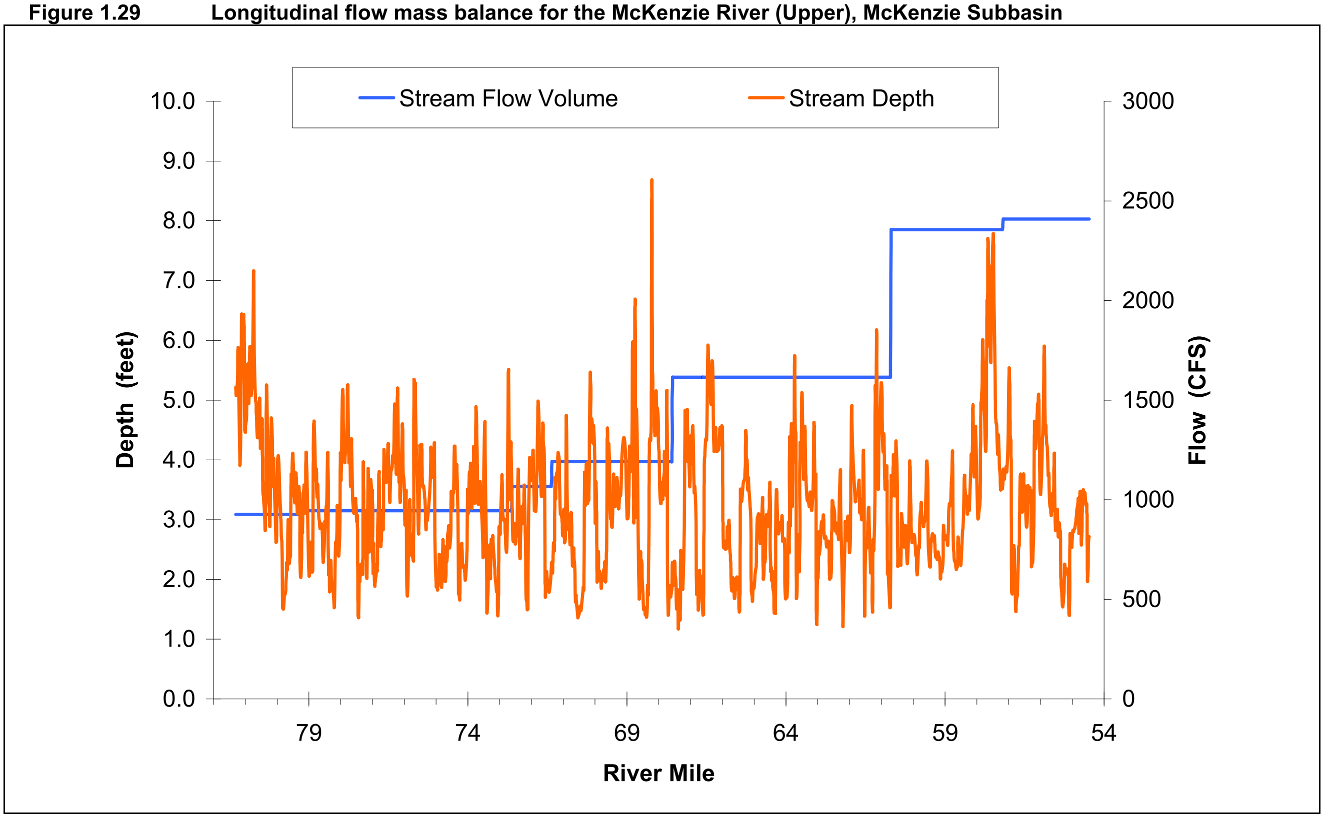


Figure 1.30 Longitudinal flow mass balance for Little North Santiam River, North Santiam Subbasin

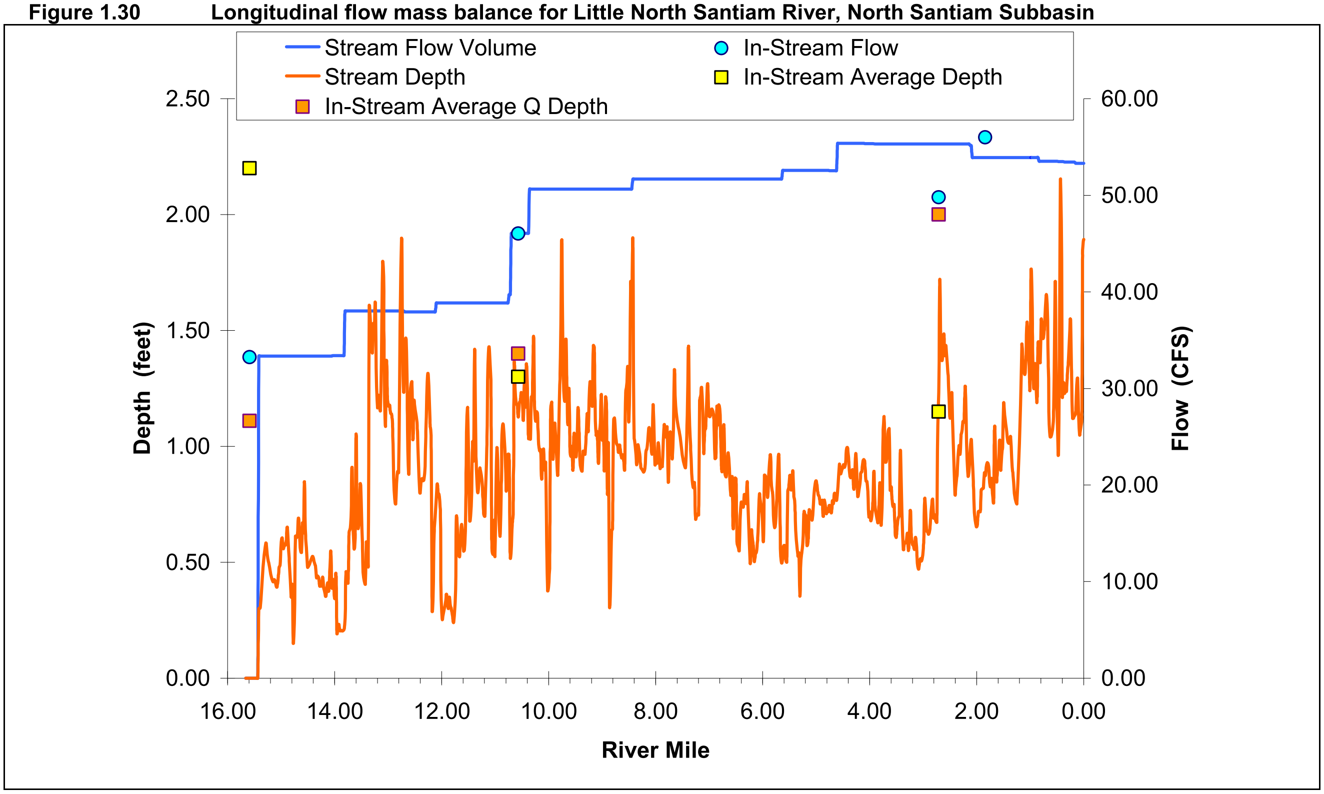


Figure 1.31 Longitudinal flow mass balance for the Crabtree Creek, South Santiam Subbasin

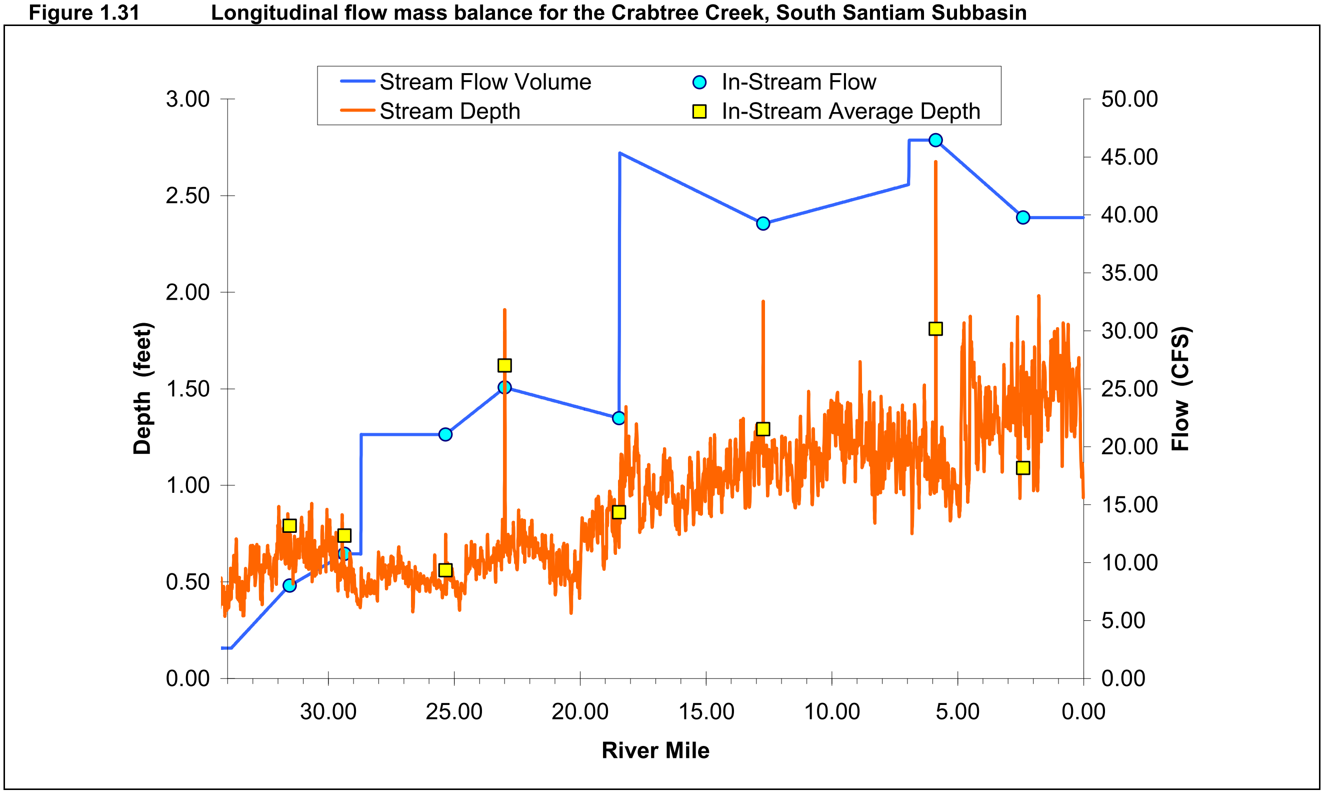


Figure 1.32 Longitudinal flow mass balance for the Thomas Creek, South Santiam Subbasin

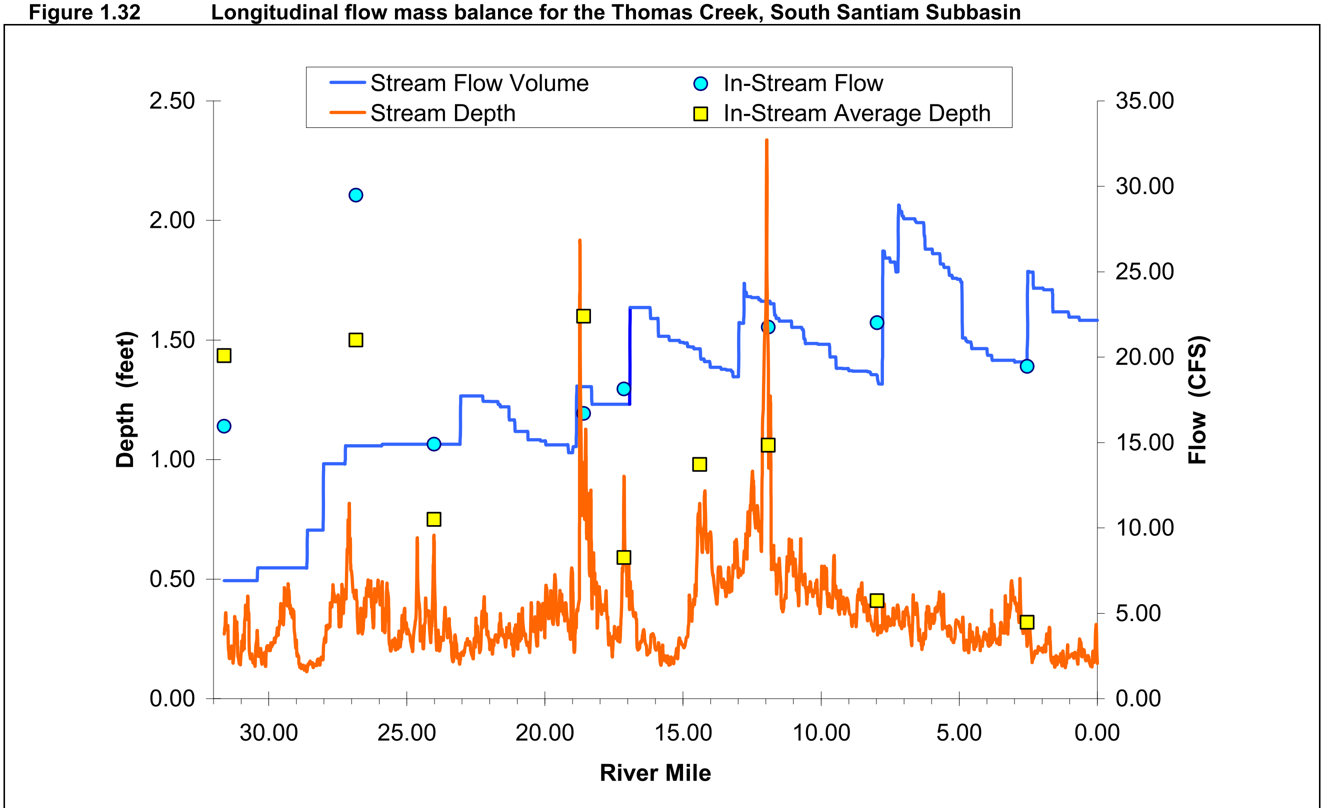


Figure 1.33 Longitudinal flow mass balance for Coyote Creek, Upper Willamette Subbasin

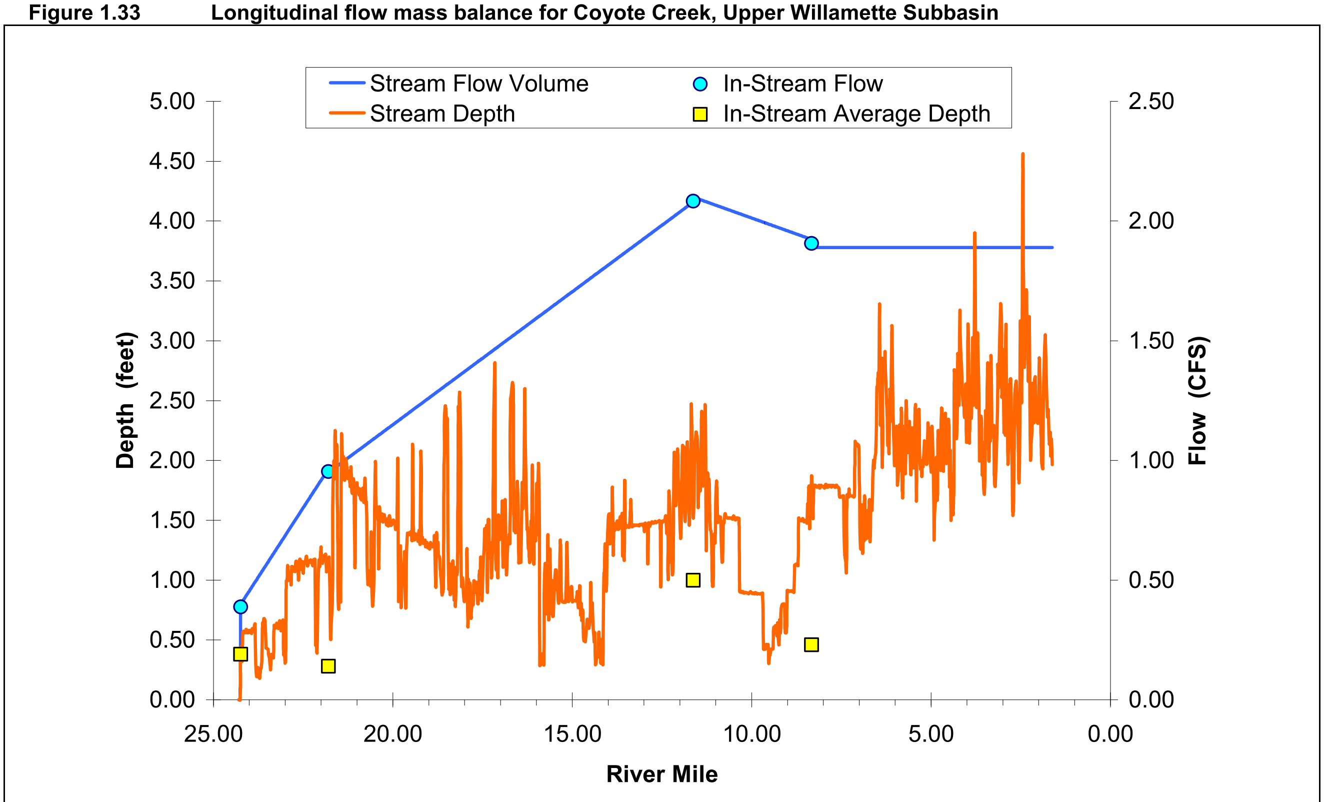
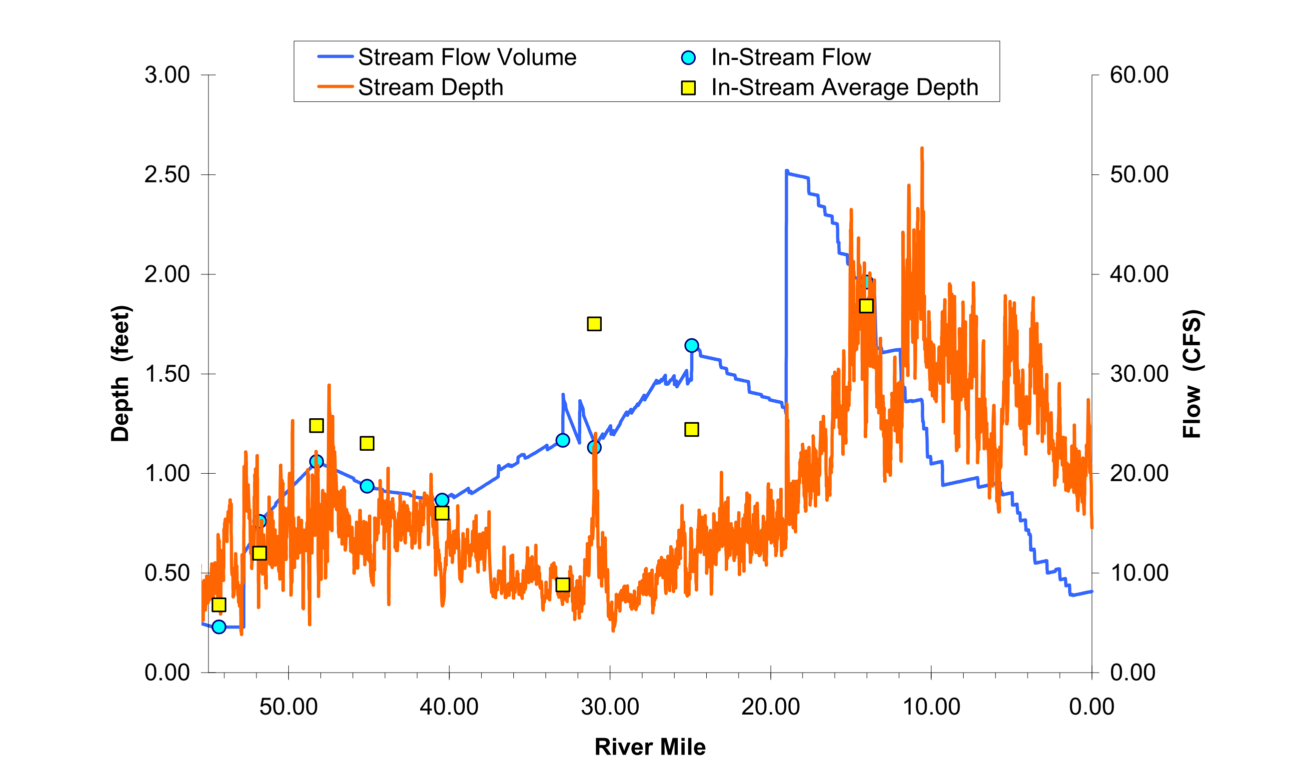


Figure 1.34 Longitudinal flow mass balance for the Luckiamute River, Upper Willamette Subbasin



Chapter 4. Simulations

4.1 Overview of Modeling Purpose, Valid Applications & Limitations

4.1.1 Near Stream Land Cover Analysis

Modeling Purpose

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

Valid Applications

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

Limitations

- Methodology is based on ground level and GIS data such as, vegetation surveys, and digitized polygons from air photos. Each data source has accuracy considerations.
- Associations used for land cover classification are assigned median values to describe physical attributes, and in some cases, this methodology significantly underestimates landscape variability.

4.1.2 Hydrology Analysis

Modeling Purpose

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

Valid Applications

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

Limitations

- Small mass transfer processes are not accounted.
- Limited ground level flow data limit the accuracy of derived mass balances.
- Water withdrawals are not directly quantified
- Water withdrawals are assumed to occur only at OWRD mapped points of diversion.
- Return flows are oversimplified.
- It is not possible to determine the amount of return flows derived from ground water withdrawals relative to those derived from instream withdrawals.
- Return flows may deliver water that is diverted from another watershed.
- Inter-annual variations are not simulated.
- Intra-annual variations are not simulated.

4.1.3 Effective Shade Analysis

Modeling Purpose

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

Valid Applications

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

Limitations

- Limitations for input parameters apply (i.e., hydrology, near stream land cover type and physical attributes).
- The period of simulation is valid for effective shade values that occur in July and early August.
- Assumed channel widths where they were not measurable from aerial photographs may reduce accuracy of the effective shade simulation.

4.1.4 Stream Temperature Analysis

Modeling Purpose

- Analyze critical condition stream temperature over stream network.
- Analyze potential condition stream temperature based on potential land cover types.
- Establish threshold stream temperature values for the stream network, above which current conditions are considered to deviate from a potential condition.
- Demonstrate that stream temperature regimes are significantly different in a condition that minimizes anthropogenic warming.
- Provide a reasonable assurance that beneficial uses are protected in the potential condition to the extent possible given the natural constraints for channel morphology, land cover type, and physical attributes.
- Provide a robust methodology for stream temperature analysis, provided data and analytical constraints.

Valid Applications

- Estimate critical condition stream temperatures over the stream network.
- Estimate potential critical condition stream temperatures over the stream network.
- Identify site-specific deviations of current stream temperatures from potential conditions.
- Analyze the sensitivity of single or multiple parameters on stream temperature regimes for Thomas Creek.
- Identify stream temperature distributions during critical conditions.

Limitations

- Limitations for input parameters apply (i.e., channel morphology, near stream land cover type and physical attributes and hydrology).
- Accuracy of the methodology is limited to validation statistics of results.
- Stream temperature results are limited to the streams for which the analysis is completed (i.e., Temperature modeled streams with Heat Source). Application of the stream temperature output to other streams within or outside of the subbasins is not valid.
- The period of simulation is valid for stream temperature values that occur in July and August.
- Inter-annual variations are not simulated.

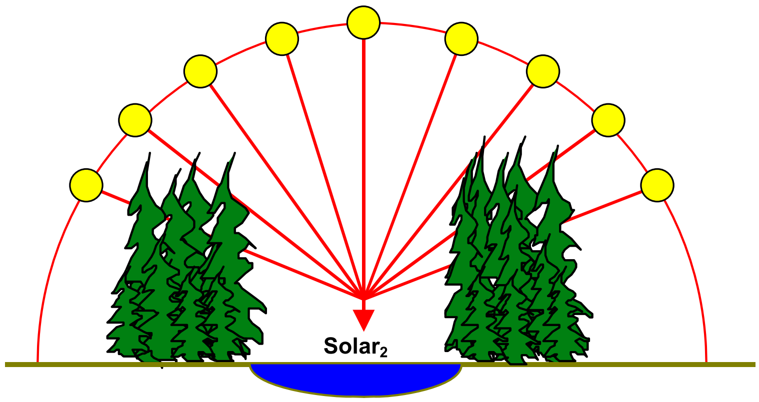
4.2 Effective Shade Simulations

4.2.1 Overview - Description of Shading Processes

Stream surface shade is an important parameter that controls the stream heating derived from solar radiation. Solar radiation has the potential to be the largest heat transfer mechanism in a stream system. Human activities can degrade near stream land cover and/or channel morphology, and in turn, decrease effective shade. Human caused reductions in stream surface shade have the potential to cause significant increases in heat delivery to a stream system. Stream shade levels can also serve as an indicator of near stream land cover and channel morphology condition. For these reasons, stream shade is a major focus of this analytical effort.

Figure 1.35 Effective Shade Defined

Solar$_1$ – Potential daily direct beam solar radiation load adjusted for julian day, solar altitude, solar azimuth and site elevation.



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

Where,

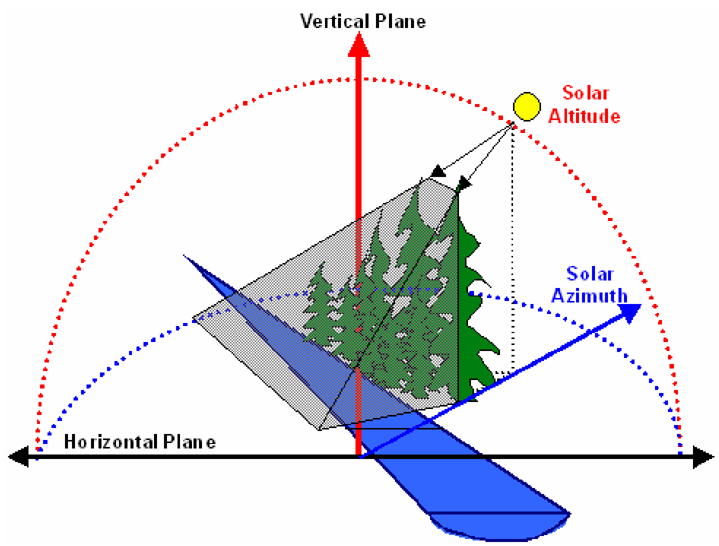
Solar$_1$: Potential Daily Direct Beam Solar Radiation Load
Solar$_2$: Daily Direct Beam Solar Radiation Load Received at the Stream Surface

In the Northern Hemisphere, the earth tilts on its axis toward the sun during summertime months allowing longer day length and higher solar altitude, both of which are functions of solar declination (i.e., a measure of the earth's tilt toward the sun). Geographic position (i.e., latitude and longitude) fixes the stream to a position on the globe, while aspect provides the stream/riparian orientation. Near stream land cover height, width and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation or solar flux (i.e., produce shade). The solar position has a vertical component (i.e., solar altitude) and a horizontal component (i.e., solar azimuth) (see **Figure 1.36**) that are both functions of time/date (i.e., solar declination) and the earth's rotation (i.e., hour angle measured as 15^{o} per hour). While the interaction of these shade variables may seem complex, the mathematics that describes them is relatively straightforward geometry. Using solar tables or mathematical simulations, the *potential daily solar load* can be quantified. The *measured solar load* at the stream surface can easily be measured with a Solar Pathfinder© or estimated using mathematical shade simulation computer programs (Boyd, 1996 and Park, 1993).

Factors that influence stream surface effective shade are incorporated into the simulation methodology, and include the following:

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

Figure 1.36 Solar Altitude and Solar Azimuth



The temperature model Heat Source and a subset model of Heat Source called Shade-a-lator were used to model solar flux, potential daily solar load, measured solar load at the stream surface, and effective shade. For detailed information on Heat Source, refer to **Chapter 5 - Heat Source Analytical Framework**, or "*Analytical Methods for Dynamic Open Channel Heat and Mass Transfer: Methodology for Heat Source Model Version 7.0*" (Boyd, Kasper, 2003).

4.2.2 Effective Shade Simulation Period and Extent

The effective shade analysis was conducted with data input sampling and a computation rate every 100 longitudinal feet along the stream. The effective shade model is calibrated to analyze and predict effective shade for narrow periods of time as a function of Julian Day. For this analysis, the day of simulation is August 1st. August 1st output data are reliable for mid July through mid September. Effective shade simulations were performed for a total of 850 stream miles in the Willamette River subbasins. This includes streams modeled for temperature with Heat Source and CE-QUAL W2. **Table 1.27** lists the simulation extent by river system.

Table 1.27 Effective shade simulation extents

Subbasin	River/Stream	Simulation River Miles
Clackamas Subbasin	Clackamas River	0-23
Coast Fork Willamette Subbasin	Coast Fork Willamette	0-30
	Mosby Creek	0-22
	Row River	0-8
Lower Willamette Subbasin	Columbia Slough	28
	Johnson Creek	0-23
	Willamette River	0-25
McKenzie Subbasin	Blue River	0-1
	McKenzie River	0-57 / 58-83
	Mohawk River	0-81
	South Fork McKenzie River	0-4
Middle Fork Willamette Subbasin	Fall Creek	0-7
	Middle Fork Willamette River	0-17
Middle Willamette Subbasin	Willamette River	25-109
North Santiam Subbasin	Little North Santiam River	0-15
	North Santiam River	0-27
	Santiam River	0-12
South Santiam Subbasin	Crabtree Creek	0-35
	South Santiam River	0-38
	Thomas Creek	0-32
Upper Willamette Subbasin	Calapooia River	0-79
	Coyote Creek	0-24
	Long Tom River	0-26
	Luckiamute River	0-57
	Willamette River	109-187
		Total Simulation Extent: 850 miles (1,367 km)

4.2.3 Simulated Effective Shade Scenarios

Once effective shade models are calibrated, potential near stream land cover scenarios are simulated. For discussion on how effective shade and potential near stream land cover were established, see Appendix C Chpater 2 – Potential Near Stream Land Cover in the Willamette Basin for TMDLs.

Shade Scenario 1: Current Condition

Shade Scenario 2: (TMDL Allocations) System Potential Near Stream Land Cover
All other inputs remain unchanged

4.2.4 Results - Effective Shade and Solar Flux Simulations

Effective shade modeling (shown in **Figure 1.37** through **1.46**) was simulated for all of the streams where near stream land cover was digitized. The figures in this section are results for those streams that were not modeled for temperature. For effective shade results for temperature modeled streams see the appropriate subbasin temperature chapter. The figures display one mile averaged current condition and system potential target effective shade levels.

As previously mentioned, effective shade is inversely proportional to solar radiation flux. The following charts present effective shade on the left-hand axis and solar flux on the right-hand axis. Note that the potential daily solar flux is also a function of elevation. The maximum daily solar flux for each chart is the average maximum potential for the applicable stream.

Figure 1.37 One mile averaged effective shade and solar flux for the Clackamas River, Clackamas Subbasin

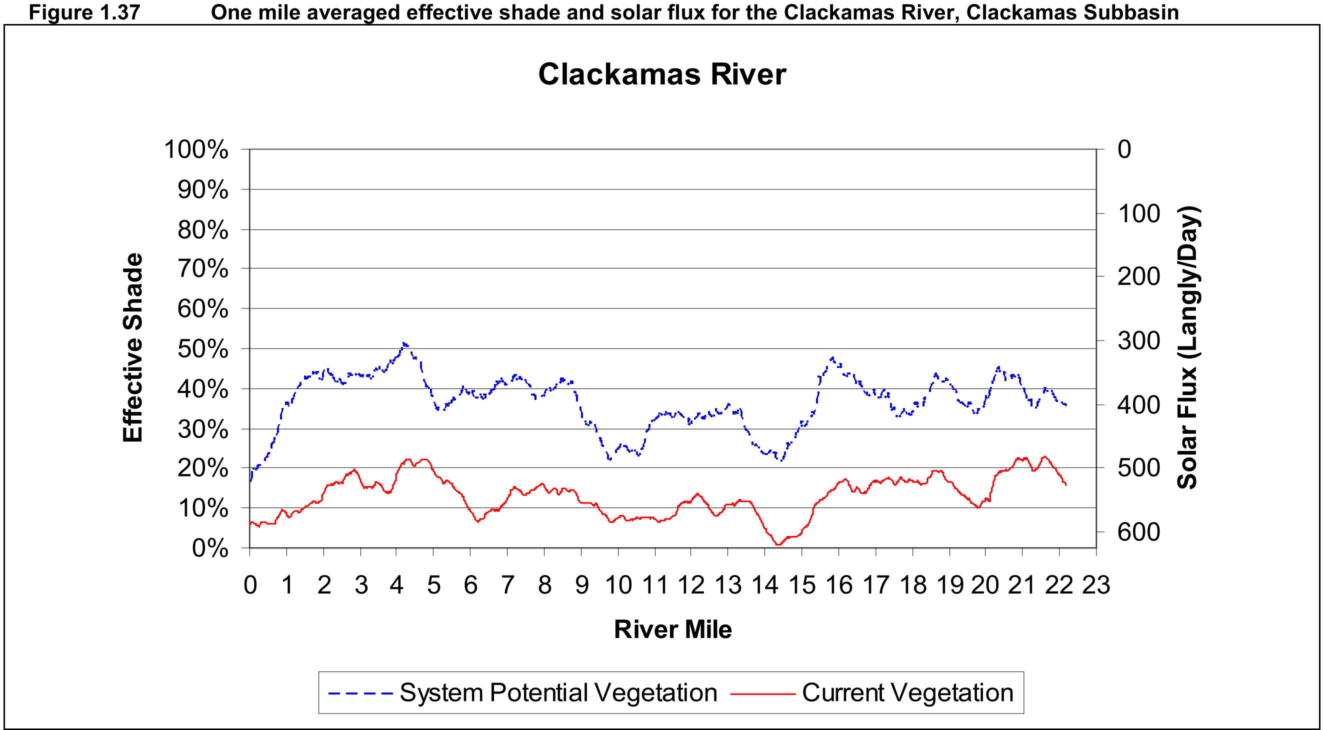


Figure 1.38 One mile averaged effective shade and solar flux for the Coast Fork Willamtte River, Coast Fork Willamette Subbasin

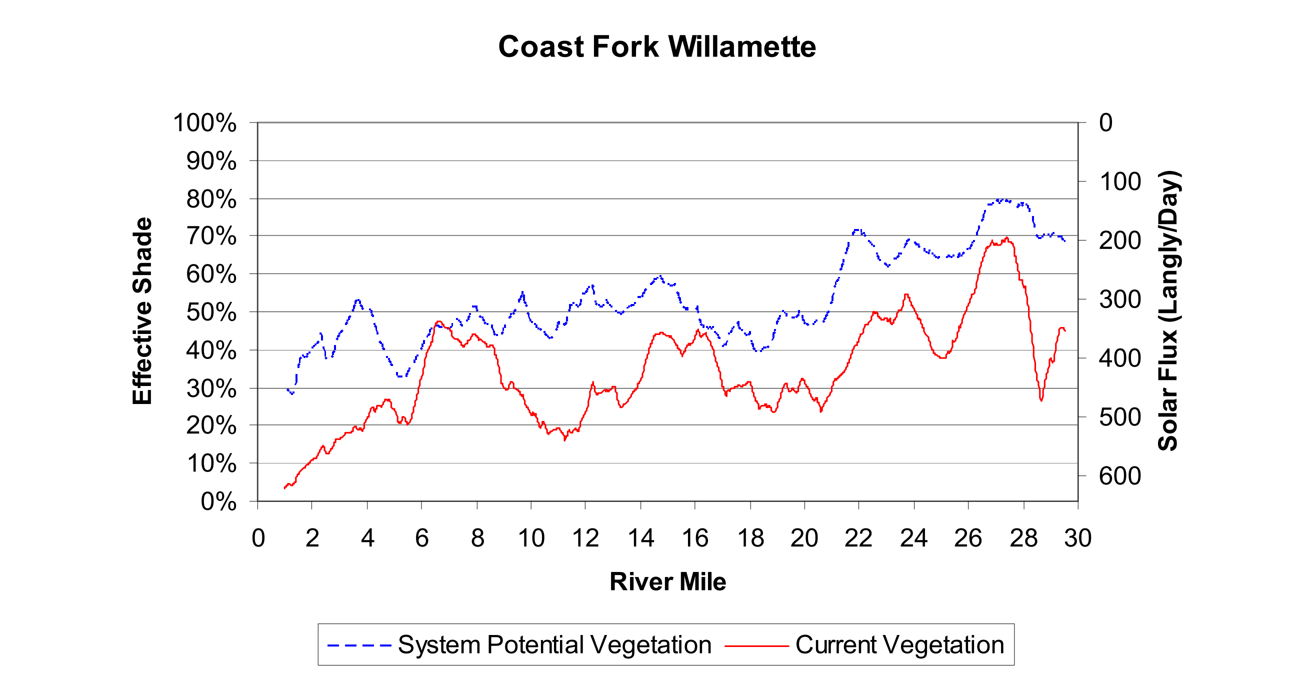


Figure 1.39 One mile averaged effective shade and solar flux for Blue River, McKenzie Subbasin

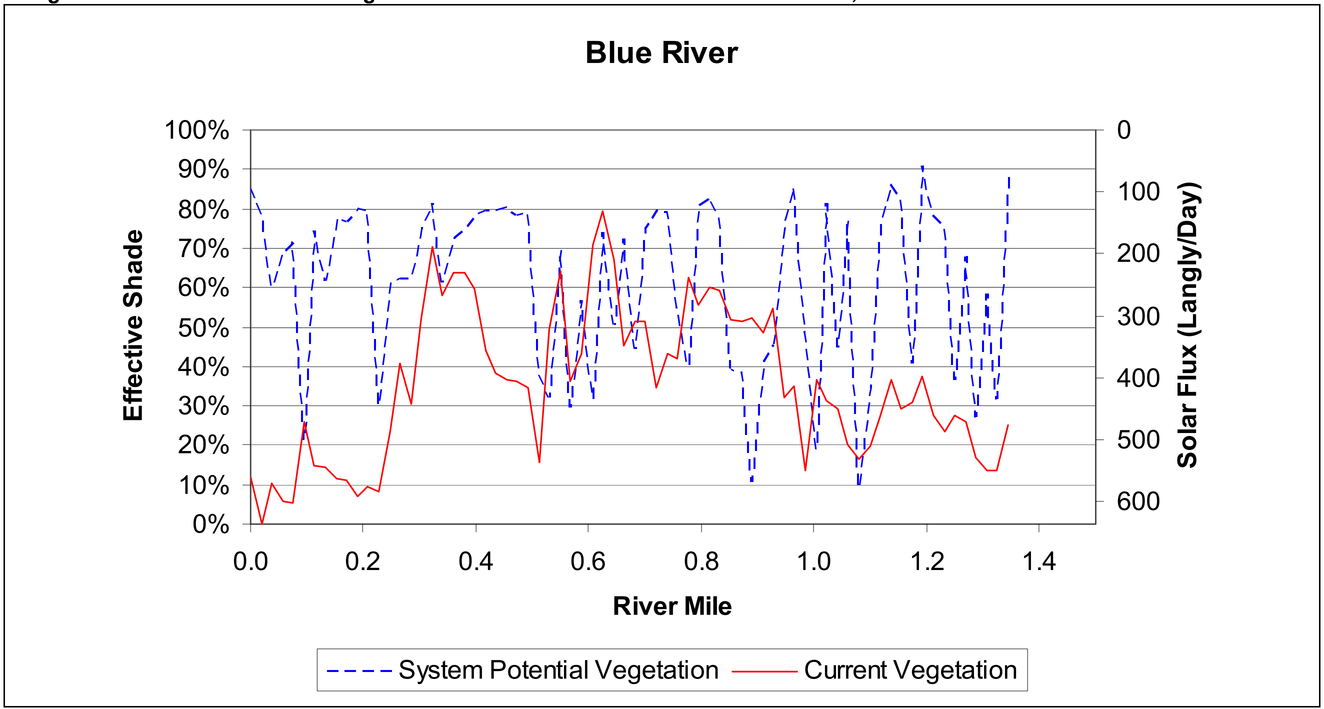


Figure 1.40 One mile averaged effective shade and solar flux for the South Fork McKenzie River, McKenzie Subbasin

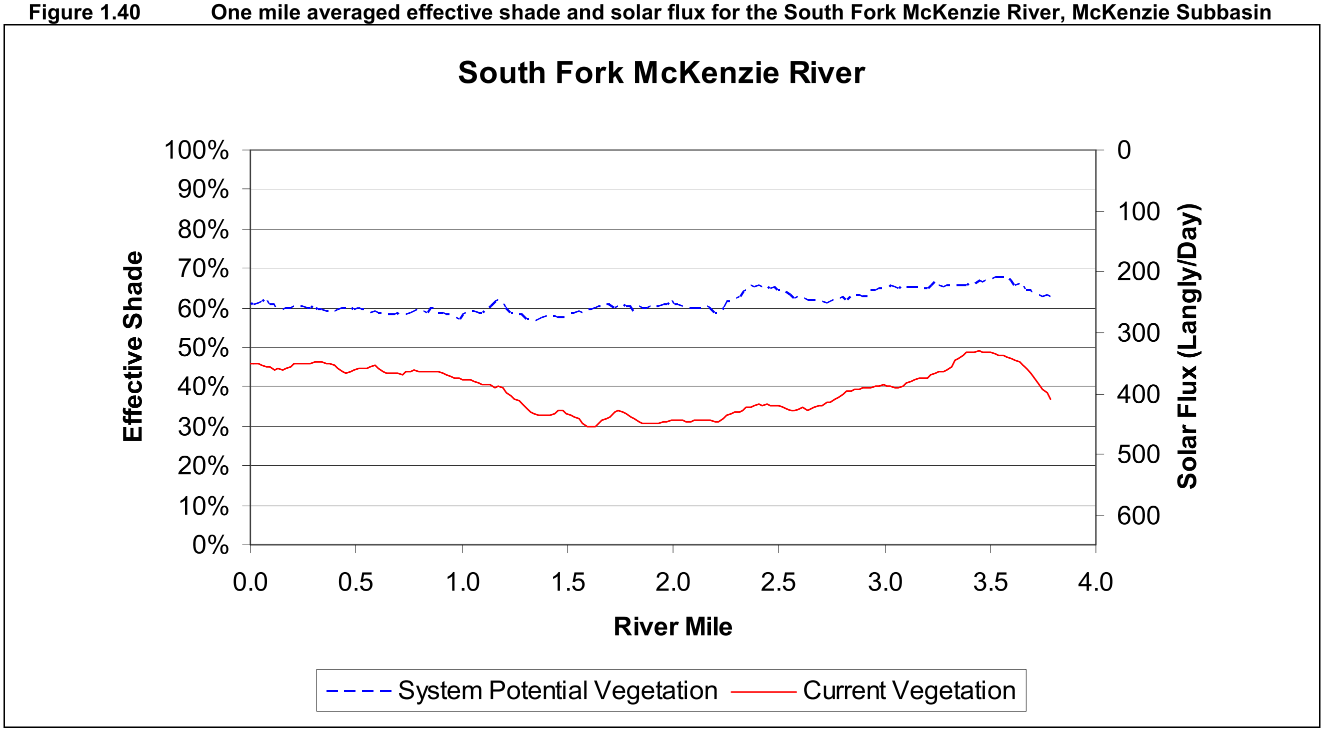


Figure 1.41 One mile averaged effective shade and solar flux for Fall Creek, Middle Fork Willamette Subbasin

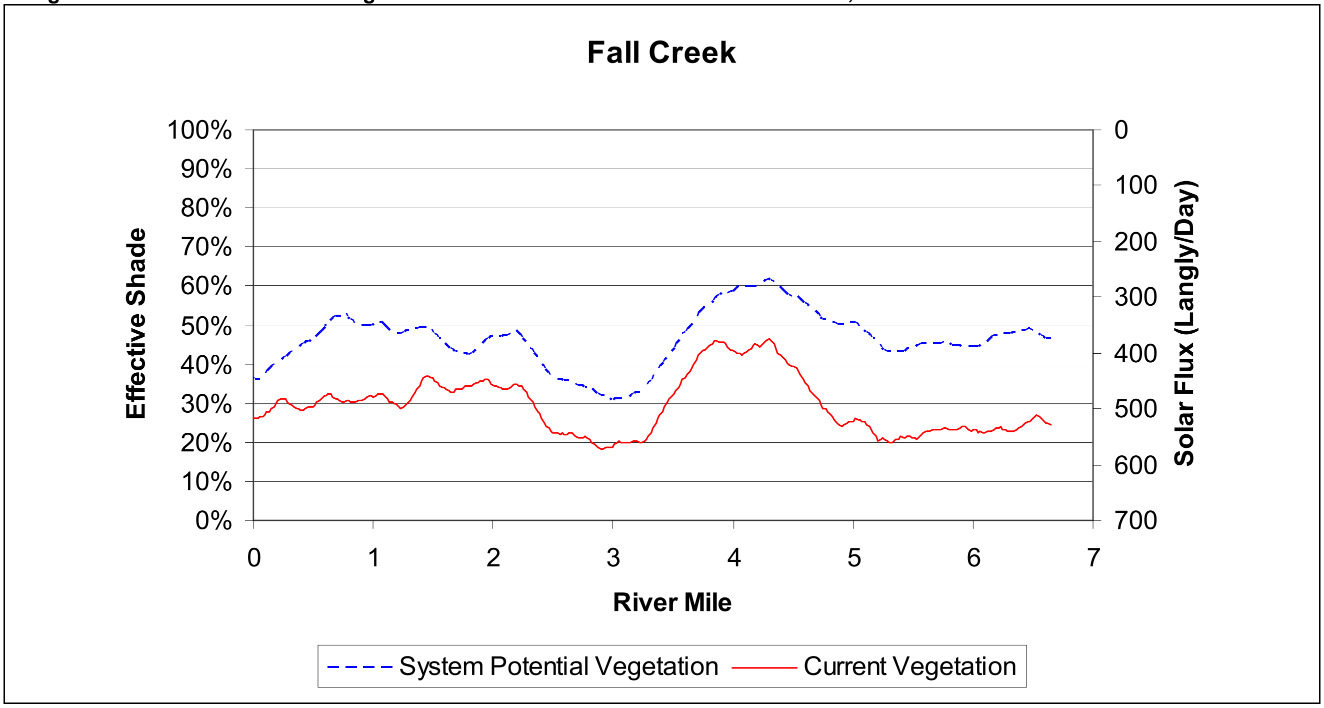


Figure 1.42 One mile averaged effective shade and solar flux for the Middle Fork Willamette River, Middle Fork Willamette Subbasin

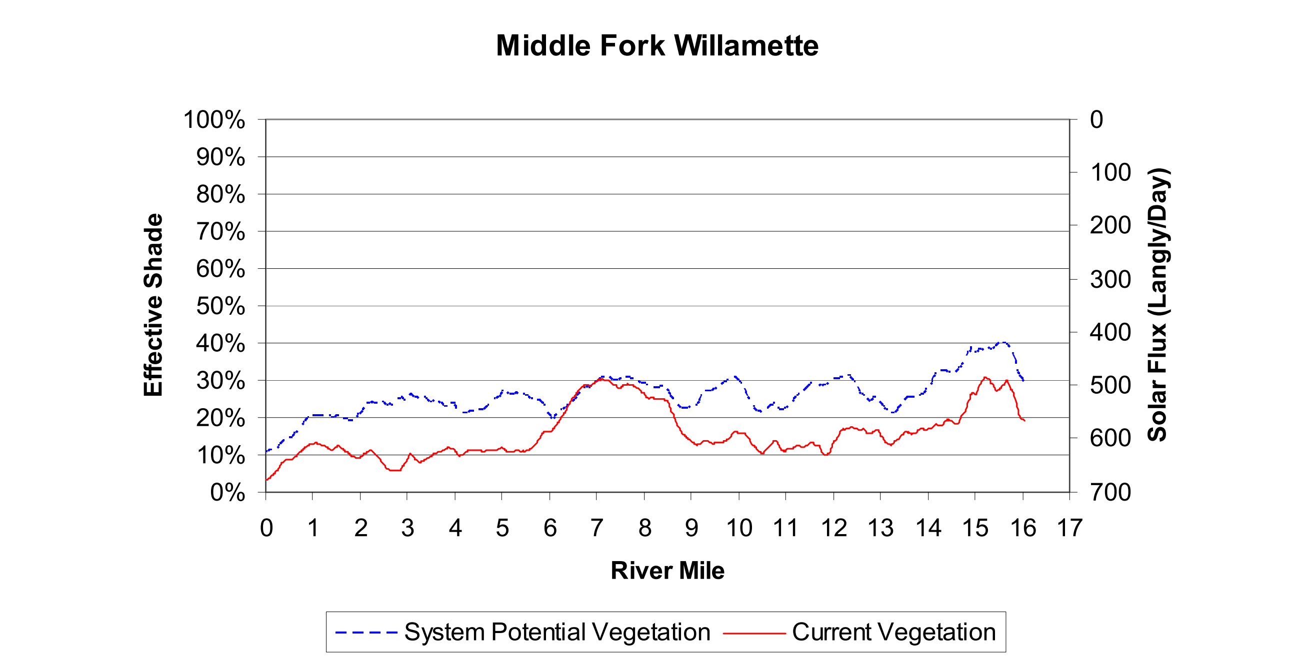


Figure 1.43 One mile averaged effective shade and solar flux for the North Santiam River, North Santiam Subbasin

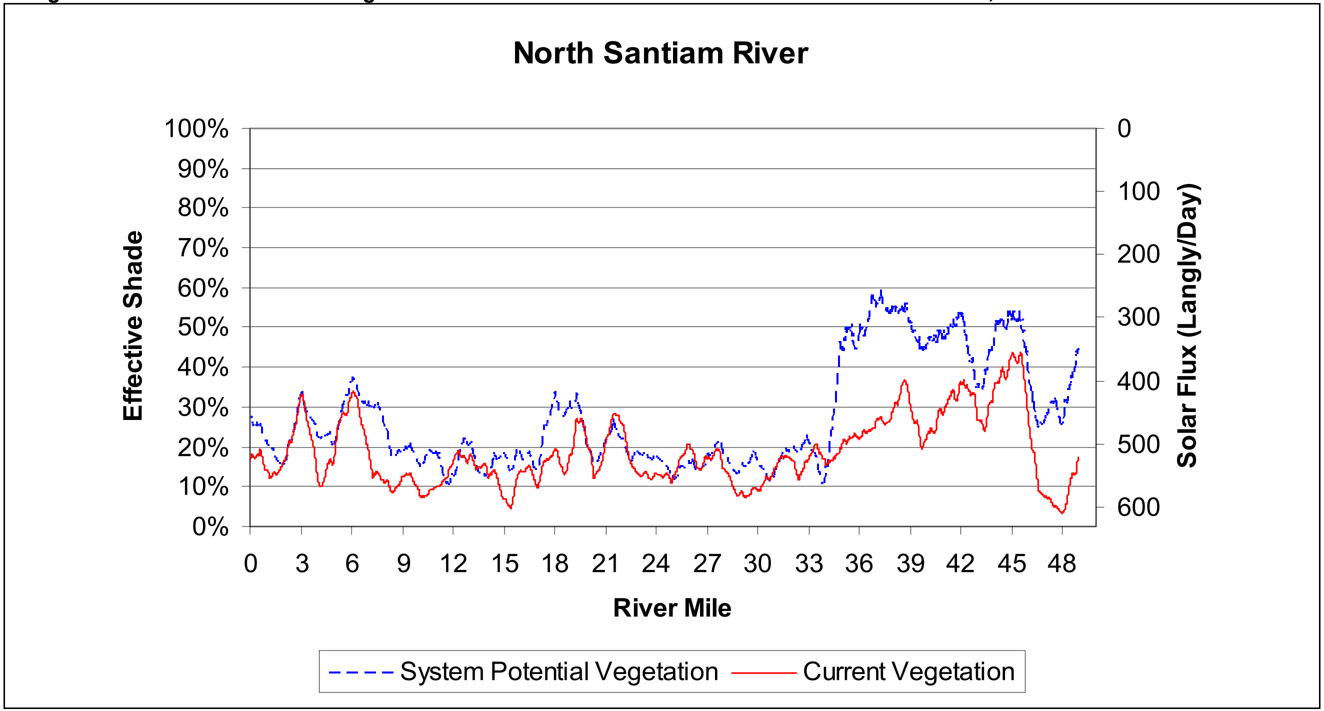


Figure 1.44 One mile averaged effective shade and solar flux for the Santiam River, North Santiam Subbasin

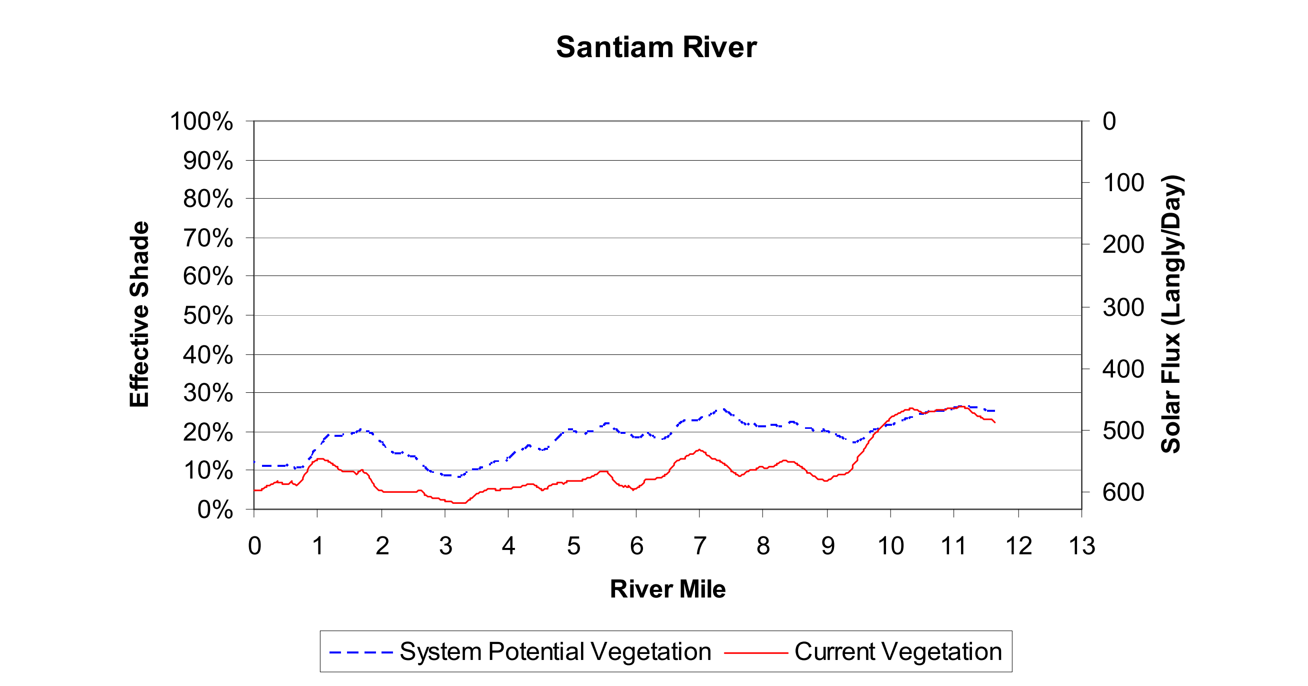


Figure 1.45 One mile averaged effective shade and solar flux for the South Santiam River, South Santiam Subbasin

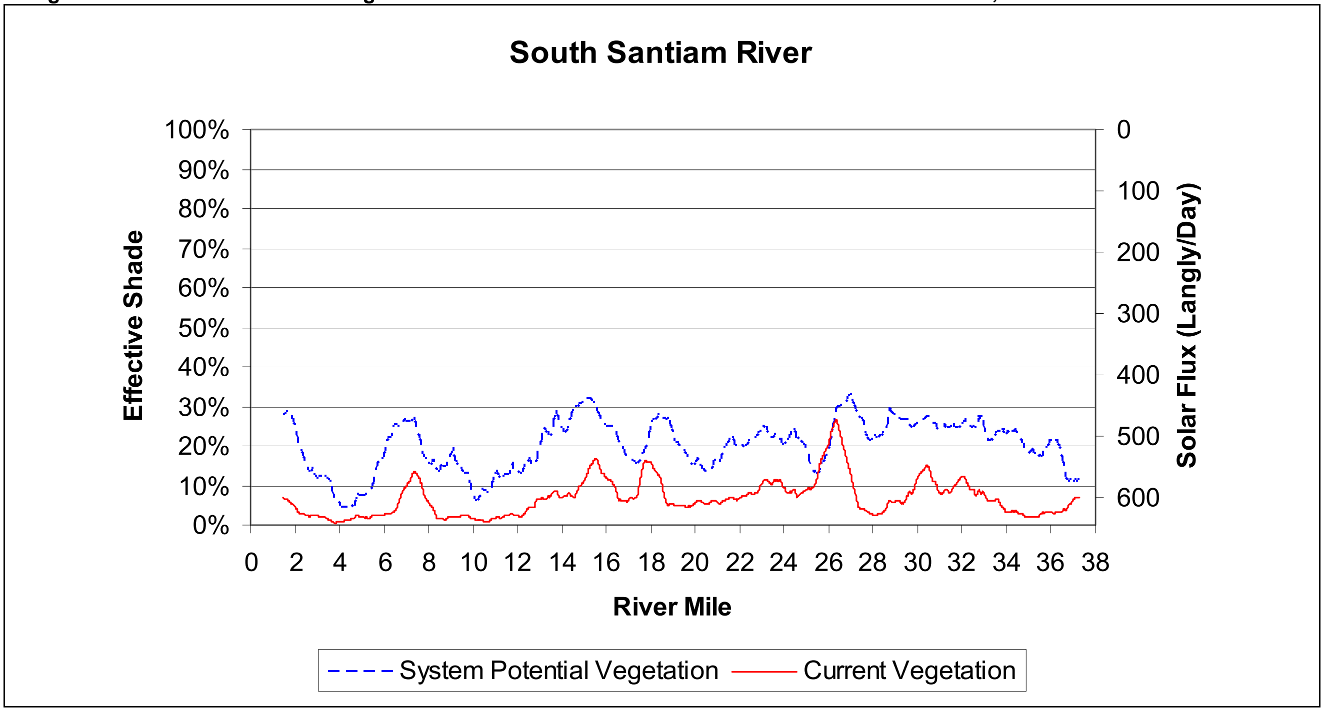
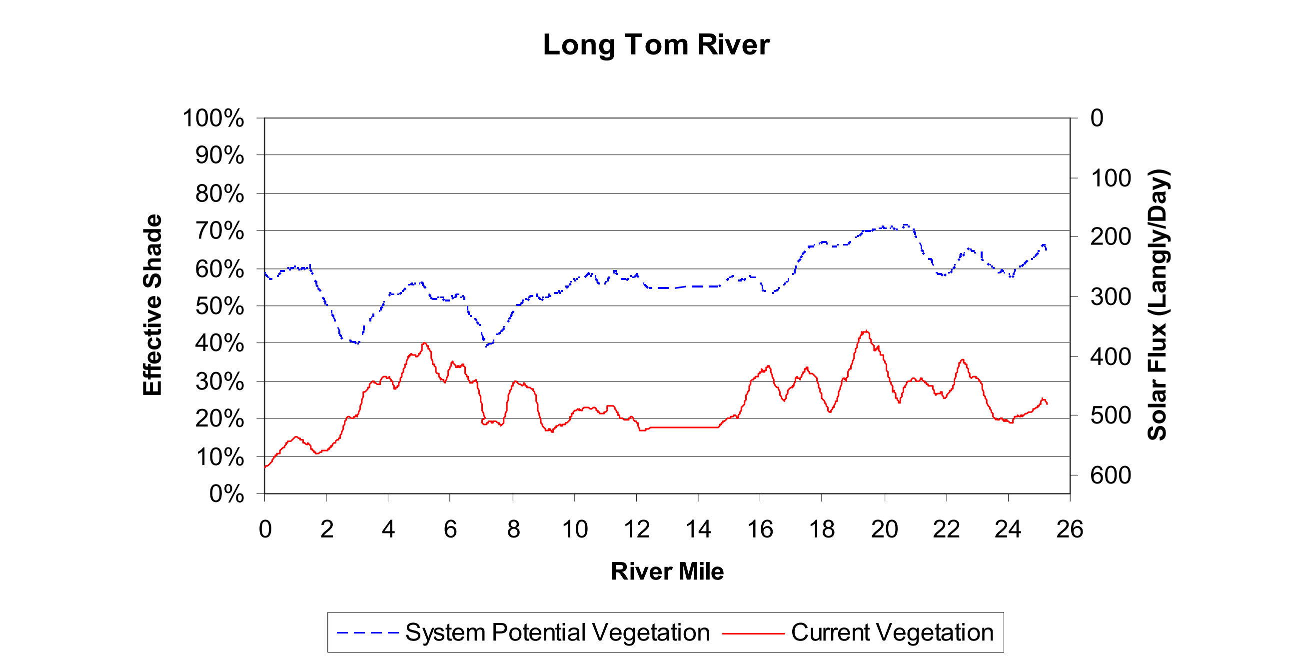


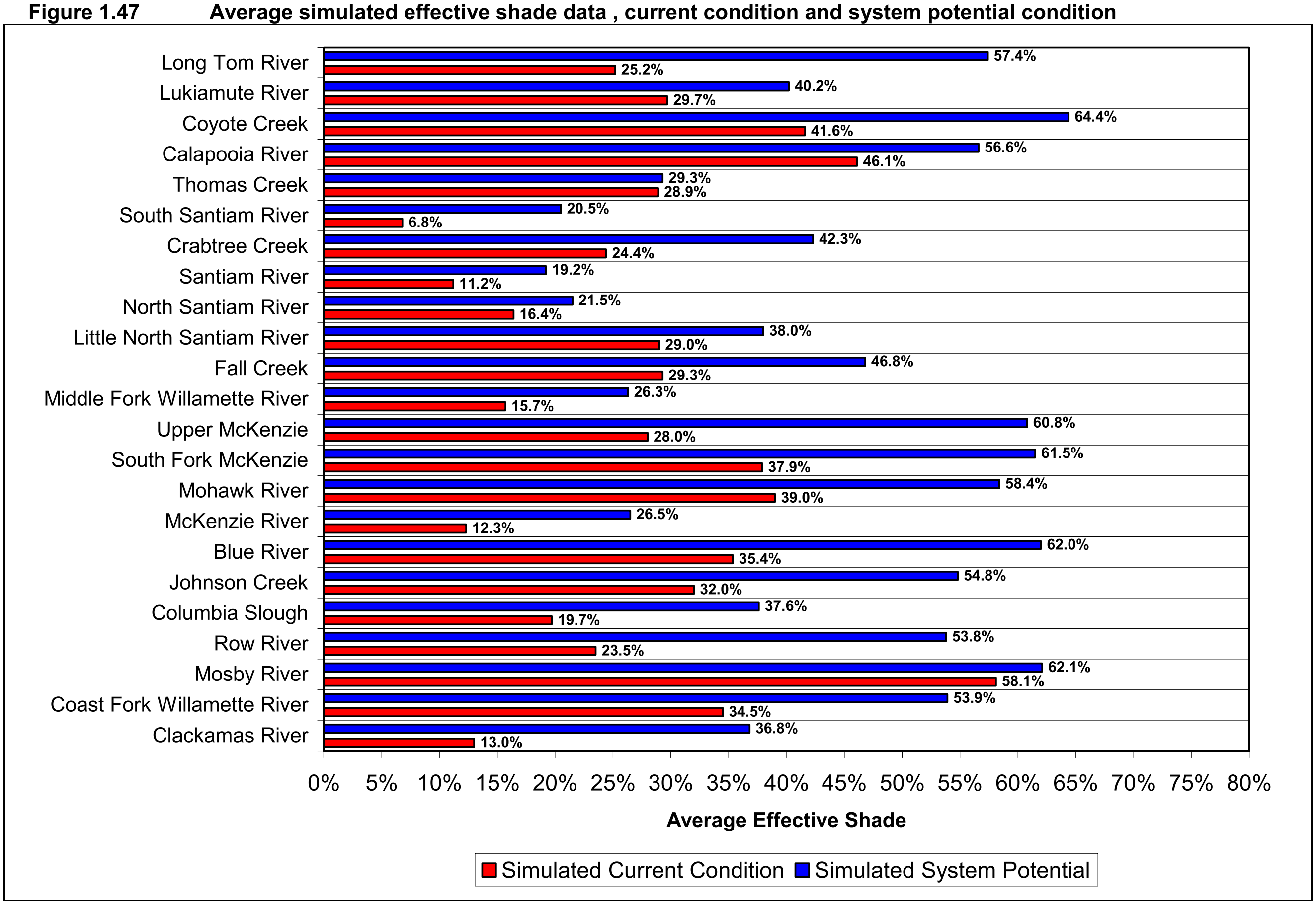
Figure 1.46 One mile averaged effective shade and solar flux for the Long Tom River, Upper Willamette Subbasin



For the sake of comparison, average effective shade values under both current condition and system potential conditions are presented in **Figure 1.47**. Several observations can be made from the simulation results. Effective shade levels range from fair to good in most subbasins. Increases in stream shade will directly reduce solar radiation and reduce both daily maximum stream temperatures and daily fluctuation of stream temperature. This holds true when shade levels are increased from any level. Even minor increases in shade will reduce the heat transfer to the stream system.

Another observation is that the bigger tributaries generally have less shade than upper tributaries. This is particularly evident in the Santiam and McKenzie River. This results from larger channel widths. Large channels combined with shorter or more often disturbed land cover dominate this area of the river and limits the amount of shade received. The opposite is also observed in the average shade data. Higher shade levels generally occur in upper reaches with narrower channels where taller land cover types typically grow.

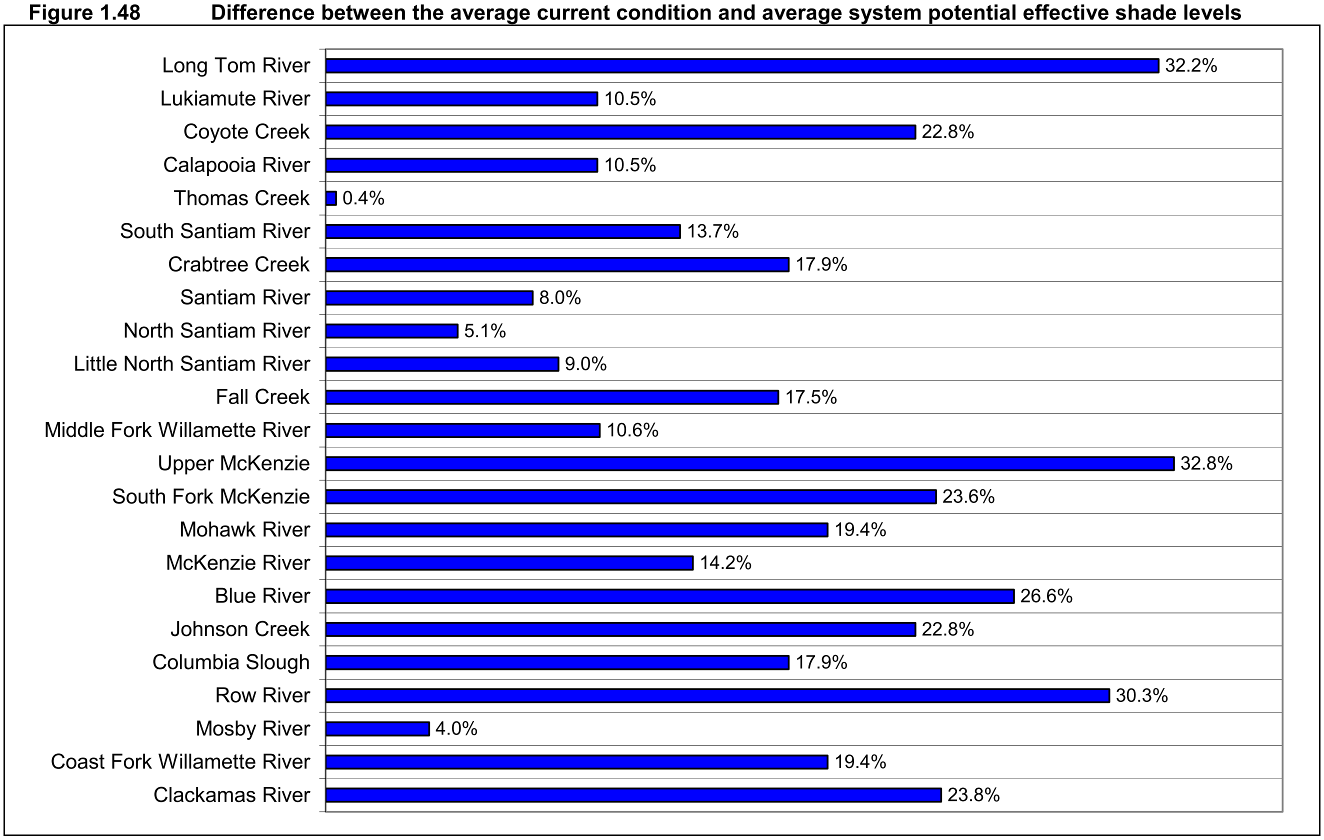
Figure 1.47 Average simulated effective shade data , current condition and system potential condition



Typically system potential vegetation provides greater percent effective shade values to the river, however some rivers under the currently simulated system potential vegetation conditions may have a lower percent effective shade calculated value than at current conditions in specific reaches. This decrease in effective shade under system potential conditions is due in part to the monte carlo simulated natural disturbance scenario developed as part of the system potential vegetation scenario described in Appendix C Chapter 2 – Potential Near Stream Land Cover in the Willamette Basin for TMDLS. For example, the system potential condition on Thomas Creek may have accounted for a disturbance in the riparian community when in fact under current conditions there may not have a disturbed riparian community.

The relative differences between the current and system potential average effective shade values for each stream analyzed are summarized in **Figure 1.48**. Most streams have a potential for less than 20% more shade than currently exists. Row River, Long Tom River, Upper McKenzie River, Little North Santiam, and Coyote Creek are notable since they could have the largest increase in effective shade under system potential conditions with a 30% increase or more. This is due to the fact that these streams have relatively narrow channels and/or have very little current shade. The effects of local climate, soil conditions, hill slope aspects, natural disturbance, and wide channel widths and flow volume combine to reduce the amount of potential effective shade on streams in the Willamette subbasins.

Figure 1.48 Difference between the average current condition and average system potential effective shade levels



4.3 Stream Temperature Simulations

4.3.1 Stream Temperature Simulation Methodology

Heat Source version 6.5 was used to model stream temperatures in the Willamette subbasins. For detailed information regarding Heat Source and the methodologies used, refer to Chapter 5 -Heat Source Analytical Framework or "*Analytical Methods for Dynamic Open Channel Heat and Mass Transfer: Methodology for Heat Source Model Version 7.0*" (Boyd, Kasper, 2003).

Heat Source Simulated Scenarios

The first simulation step is to calibrate the model to current condition stream temperatures. Once current conditions stream temperature models were calibrated, several scenarios were simulated by changing one or more stream input parameters. Descriptions of simulated scenarios are described in **Table 1.28**. The simulated scenarios focus largely on defined potential conditions for land cover and derived flow mass balances. Combinations of these potential conditions were simulated to investigate the cumulative thermal effect of attaining defined conditions in Thomas Creek as part of a sensitivity analysis. Modeling results comparing simulated current condition to streams for which TIR was collected are presented in **Figure 4-6**. Modeling results comparing simulated current conditions to that of potential conditions, referred to as natural thermal potential, are presented in **Figure 4-7**.

Table 1.28 Heat Source simulated scenarios

Current Calibrated Simulation	Current Conditions
Natural Thermal Potential	Potential Near Stream Land Cover (Vegetation) Conditions
Natural Thermal Potential /No PODS (Thomas Creek Only)	Potential Near Stream Land Cover (Vegetation) Conditions No Water Withdrawals
Natural Thermal Potential /Tribs (Thomas Creek Only)	Potential Near Stream Land Cover (Vegetation) Conditions Tributaries set at Maximum Biological Criteria (16/18^{o}C)
Natural Thermal Potential /No PODs /Tribs (Thomas Creek Only)	Potential Near Stream Land Cover (Vegetation) Conditions Tributaries Maximum Biological Criteria (16/18^{o}C) No Water Withdrawals

Spatial and Temporal Scale

The lengths of the defined finite difference and data input sampling rate is 100 feet. The temperature model is calibrated to analyze and predict stream temperature for one day. Prediction time steps are limited by stability considerations for the finite difference solution method. Days of simulation were in July and August. Simulations were performed for a total of 314 stream miles in the Willamette subbasins. **Table 4-3** lists the spatial extent and simulation day by river system.

Table 1.29 Stream temperature simulation day and extent

Subbasin	Stream	Simulation Day	Simulation River Miles
Coast Fork Willamette Subbasin	Mosby Creek	July 21, 2002	0-22
Lower Willamette Subbasin	Johnson Creek	July 31, 2002	0-23
McKenzie Subbasin	Mohawk River	Aug 9, 2001	0-81
	McKenzie River (upper)	Sept 3, 1999	58-83
North Santiam Subbasin	Little North Santiam River	Aug 1, 2000	0-15
South Santiam Subbasin	Crabtree Creek	Aug 2, 2000	0-35
	Thomas Creek	Aug 3, 2000	0-32
Upper Willamette Subbasin	Coyote Creek	July 11, 2001	0-24
	Luckiamute River	Aug 12, 2001	0-57
Total Simulation Extent: 314 stream miles (505 Km)			

4.3.2 Results – Temperature Simulations

Figure 1.49 TIR and simulated current stream temperatures, Mosby Creek, Coast Fork Willamette Subbasin

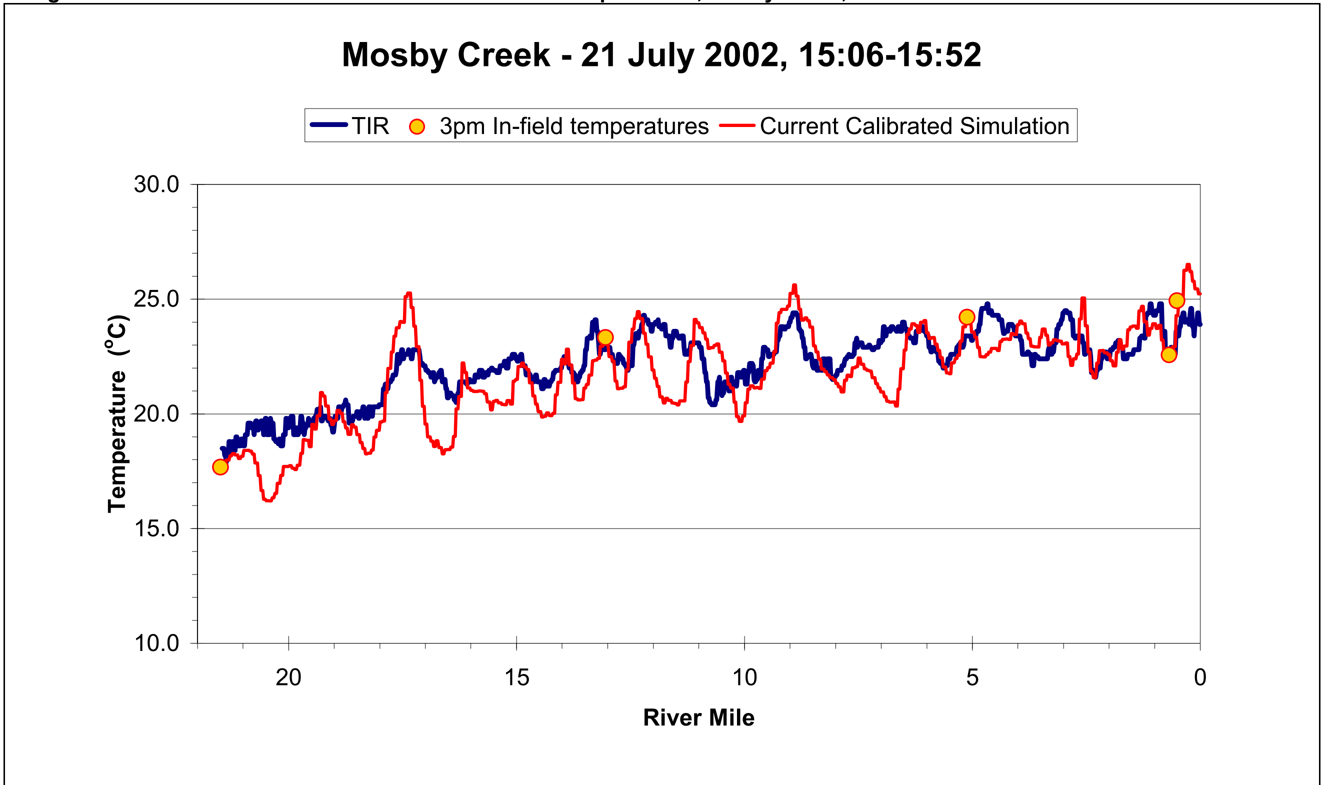


Figure 1.50 TIR and simulated current stream temperatures, Johnson Creek, Lower Willamette Subbasin

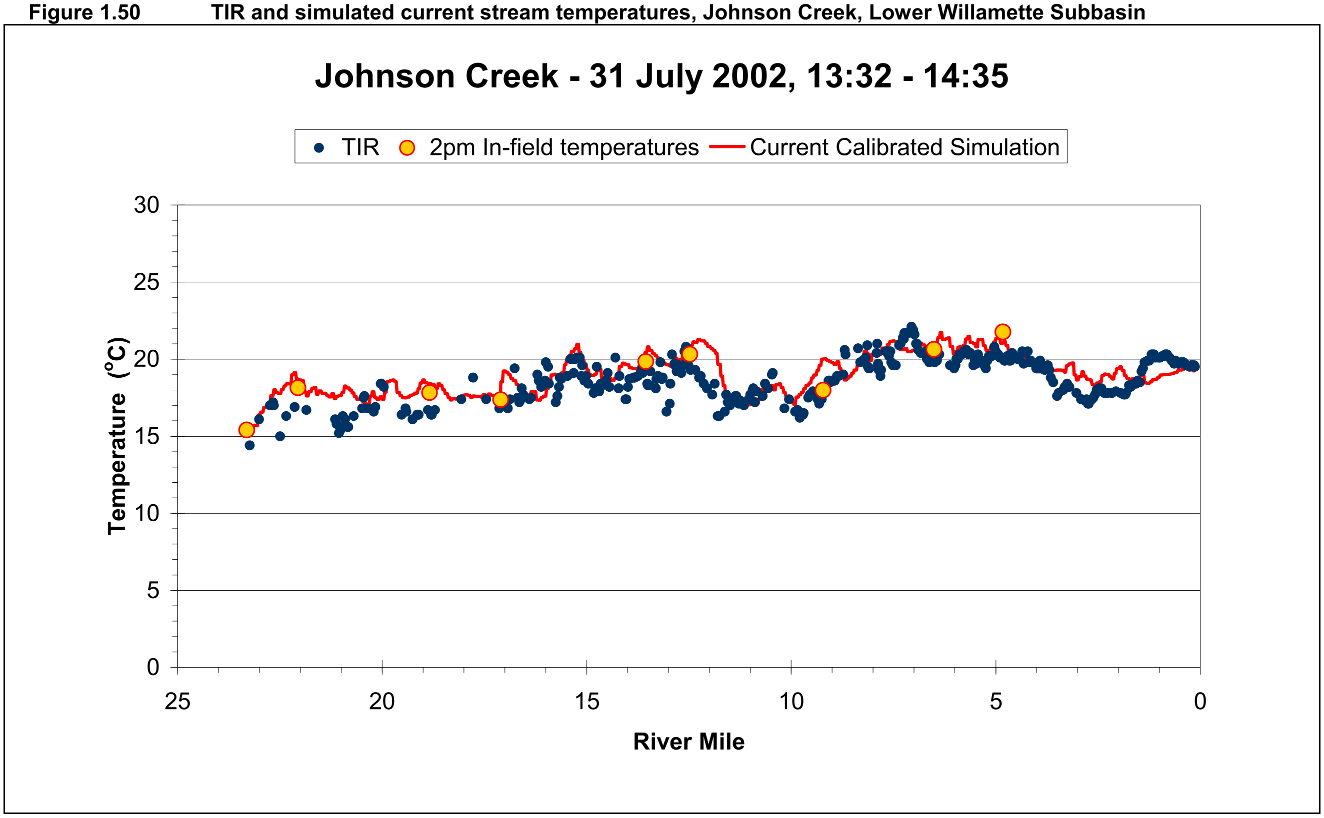


Figure 1.51 TIR and simulated current stream temperatures, McKenzie River (upper), McKenzie Subbasin

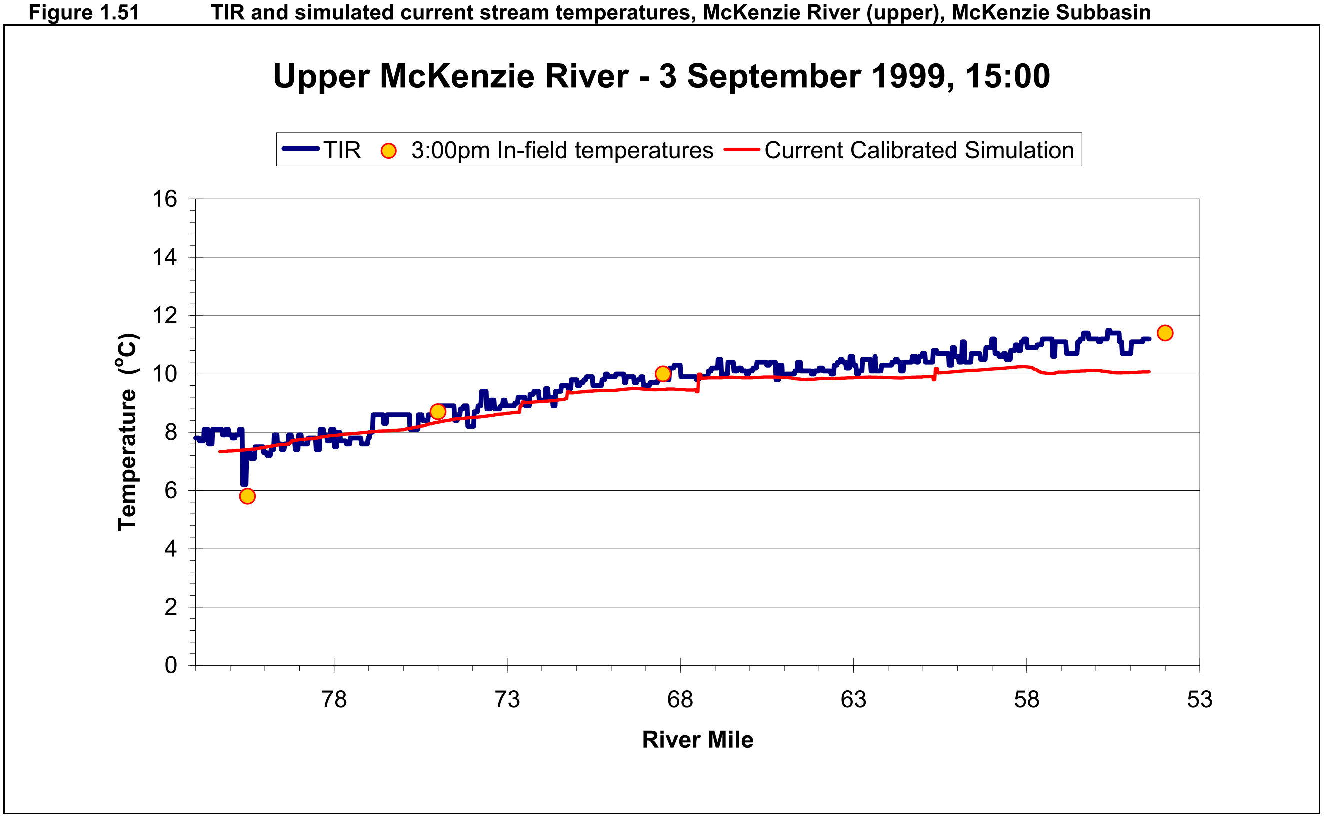


Figure 1.52 TIR and simulated current stream temperatures, Little North Santiam R., North Santiam Subbasin

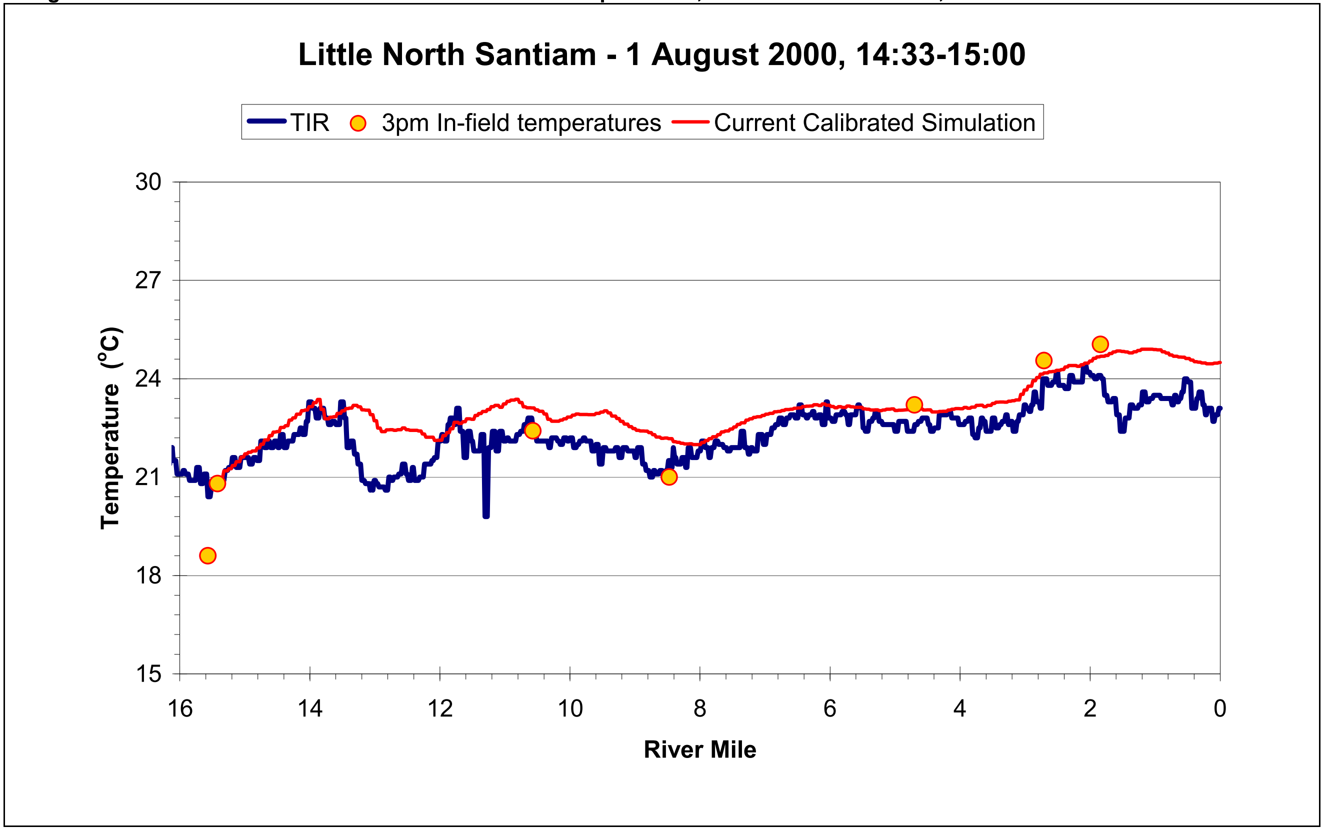


Figure 1.53 TIR and simulated current stream temperatures, Thomas Creek, South Santiam Subbasin

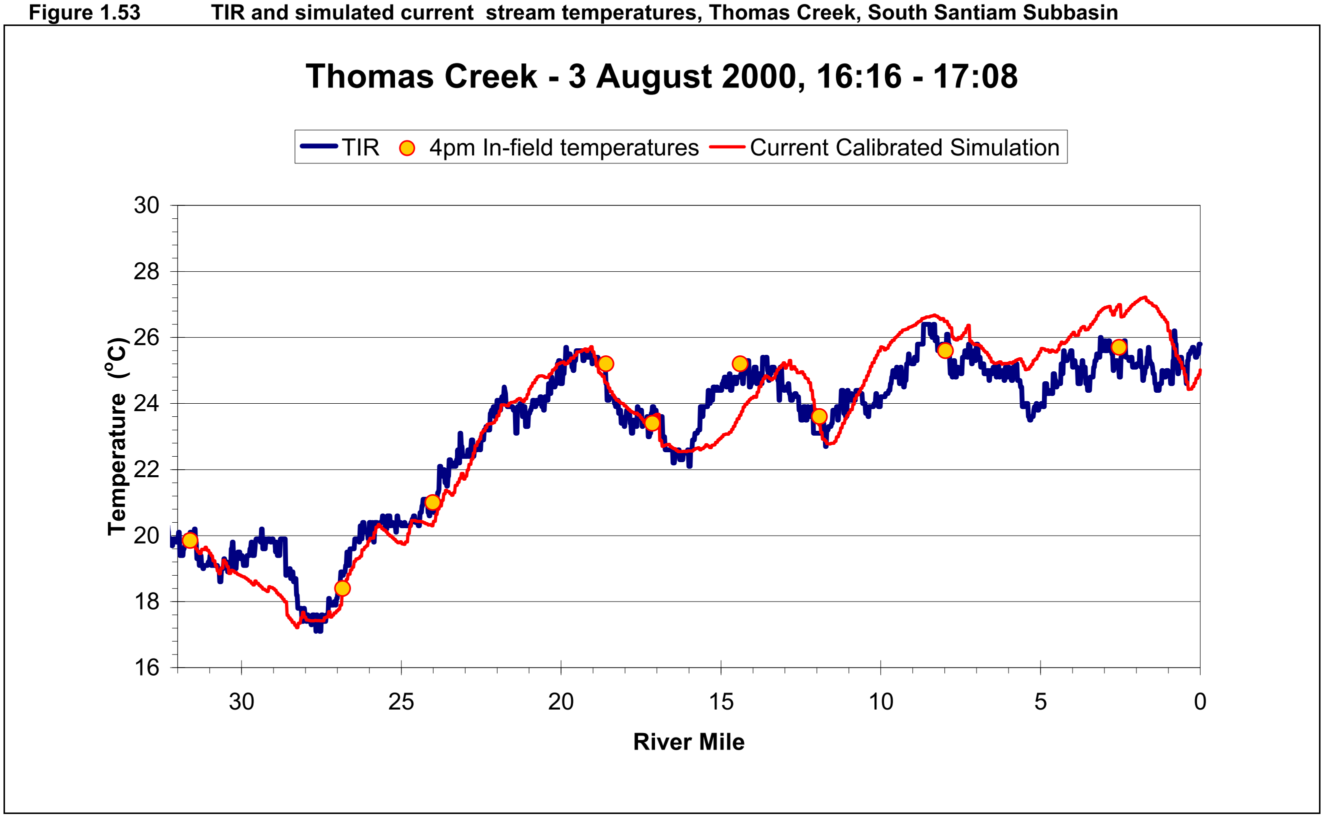


Figure 1.54 **Simulation scenario results, Mosby Creek, Coast Fork Willamette Subbasin**

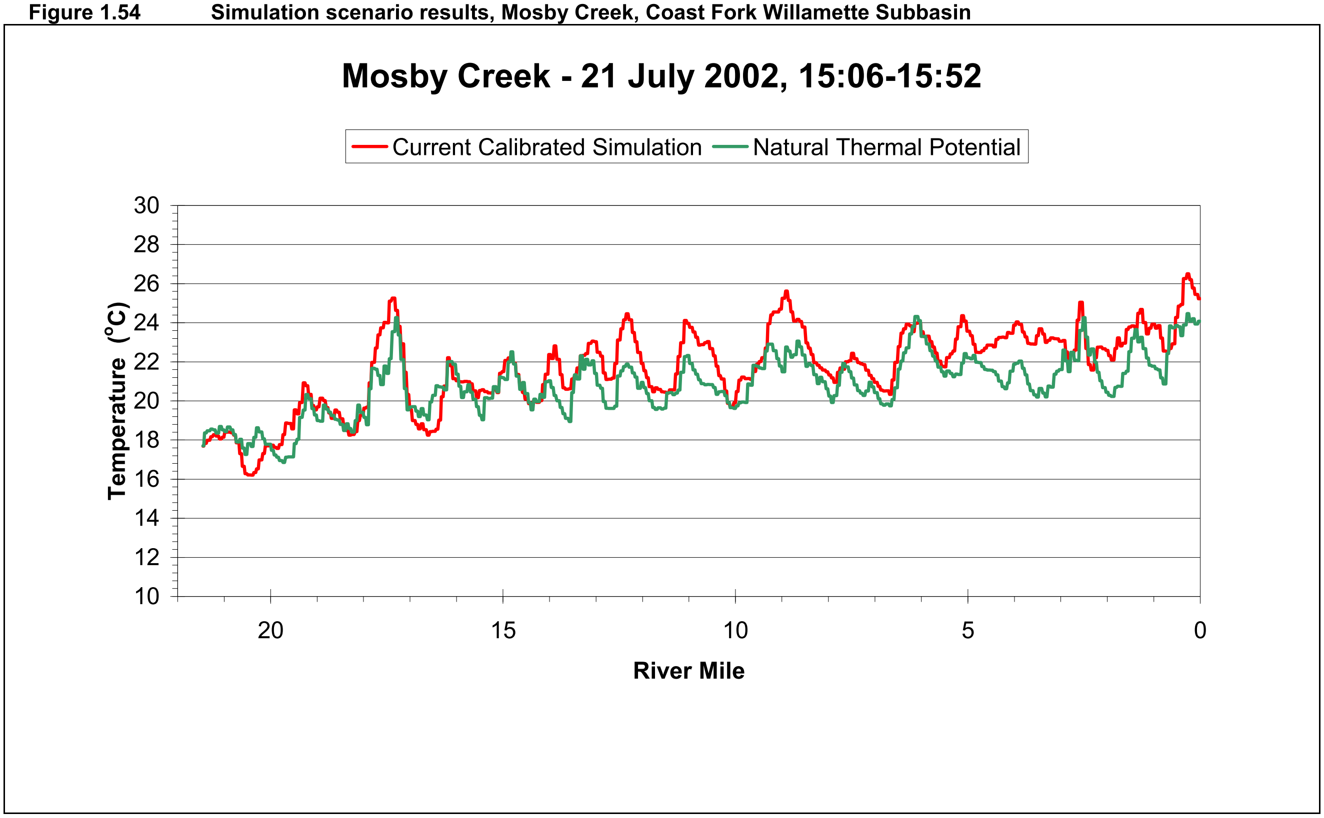


Figure 1.55 **Simulation scenario results, Johnson Creek, Lower Willamette Subbasin**

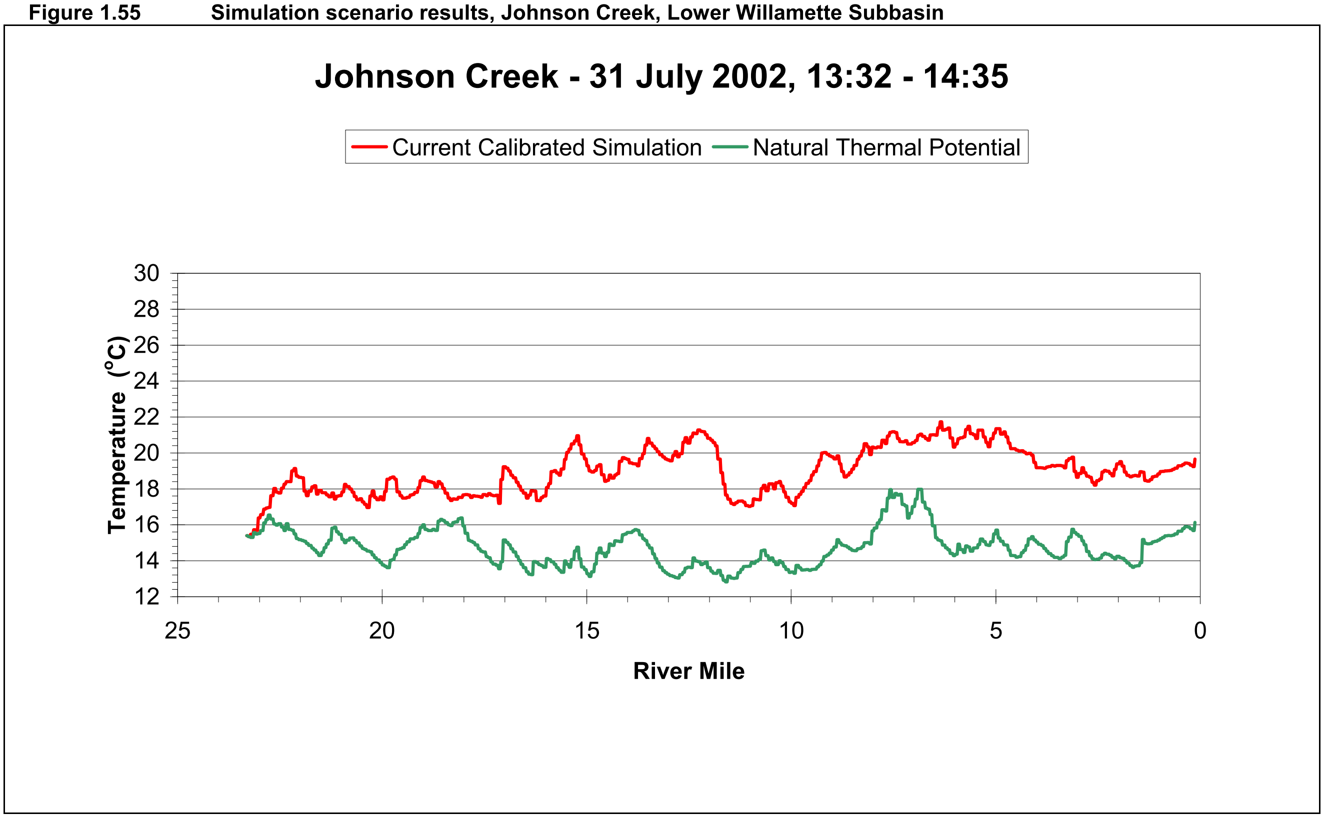


Figure 1.56 Simulation scenario results, Mohawk River, McKenzie Subbasin

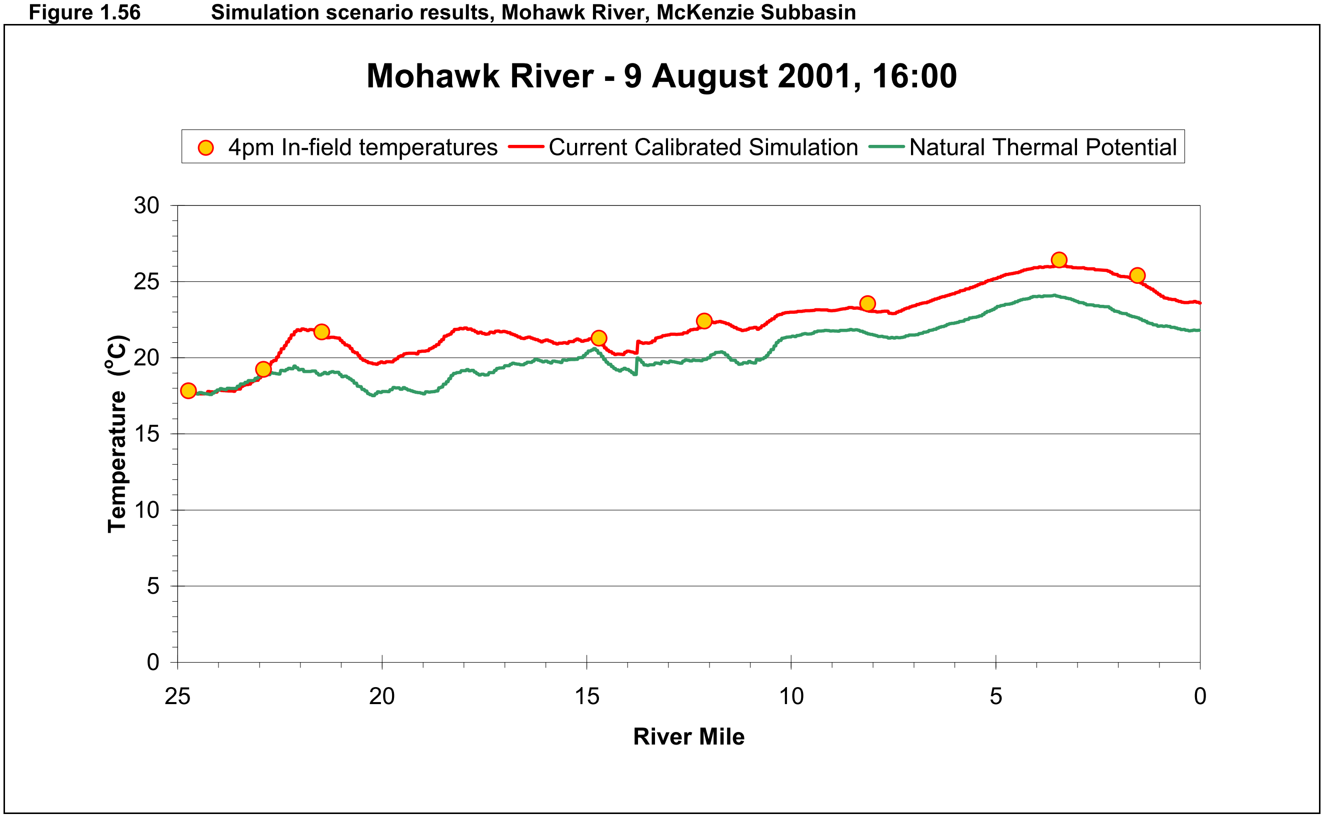


Figure 1.57 Simulation scenario results, McKenzie River (upper), McKenzie Subbasin

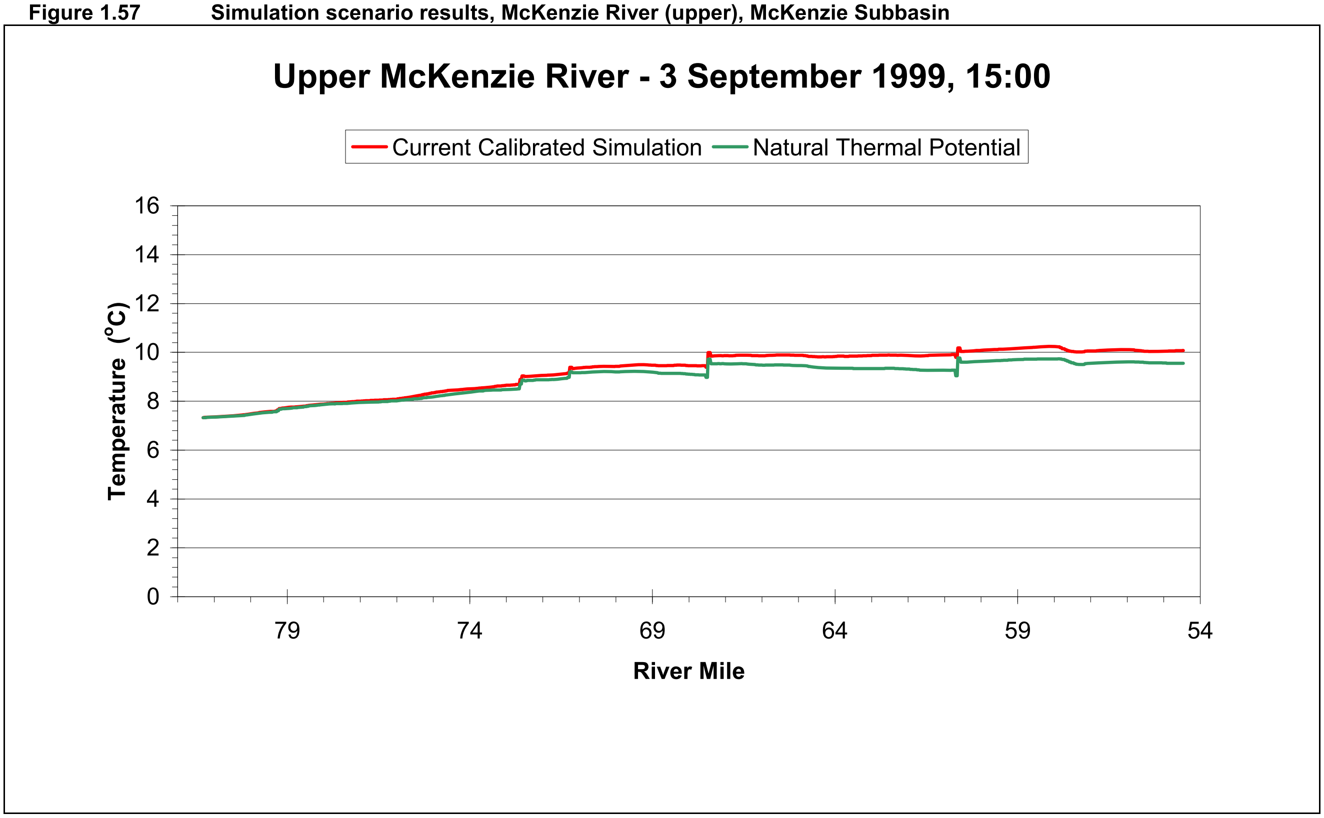


Figure 1.58 **Simulation scenario results, Little North Santiam River, North Santiam Subbasin**

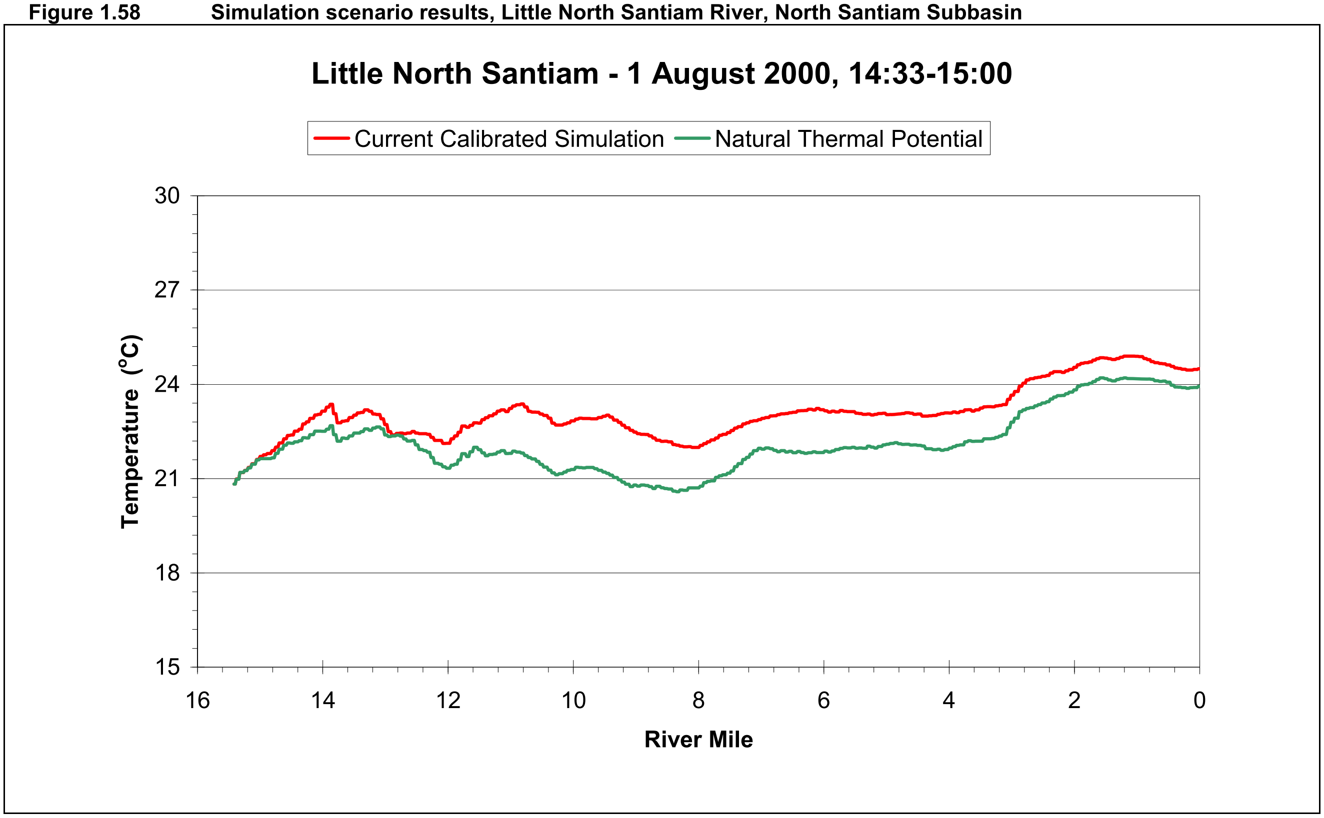


Figure 1.59 **Simulation scenario results, Crabtree Creek, South Santiam Subbasin**

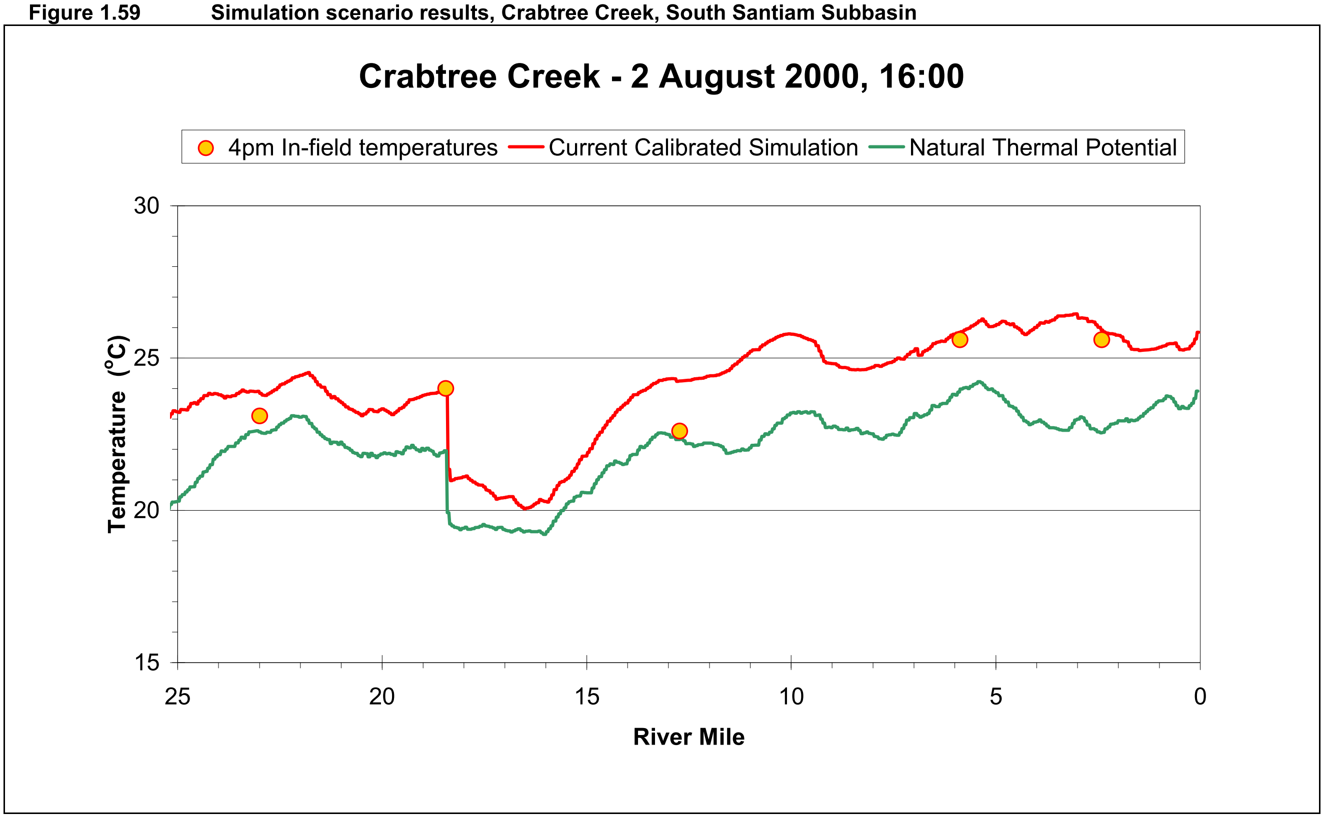


Figure 1.60 Simulation scenario results, Thomas Creek, South Santiam Subbasin

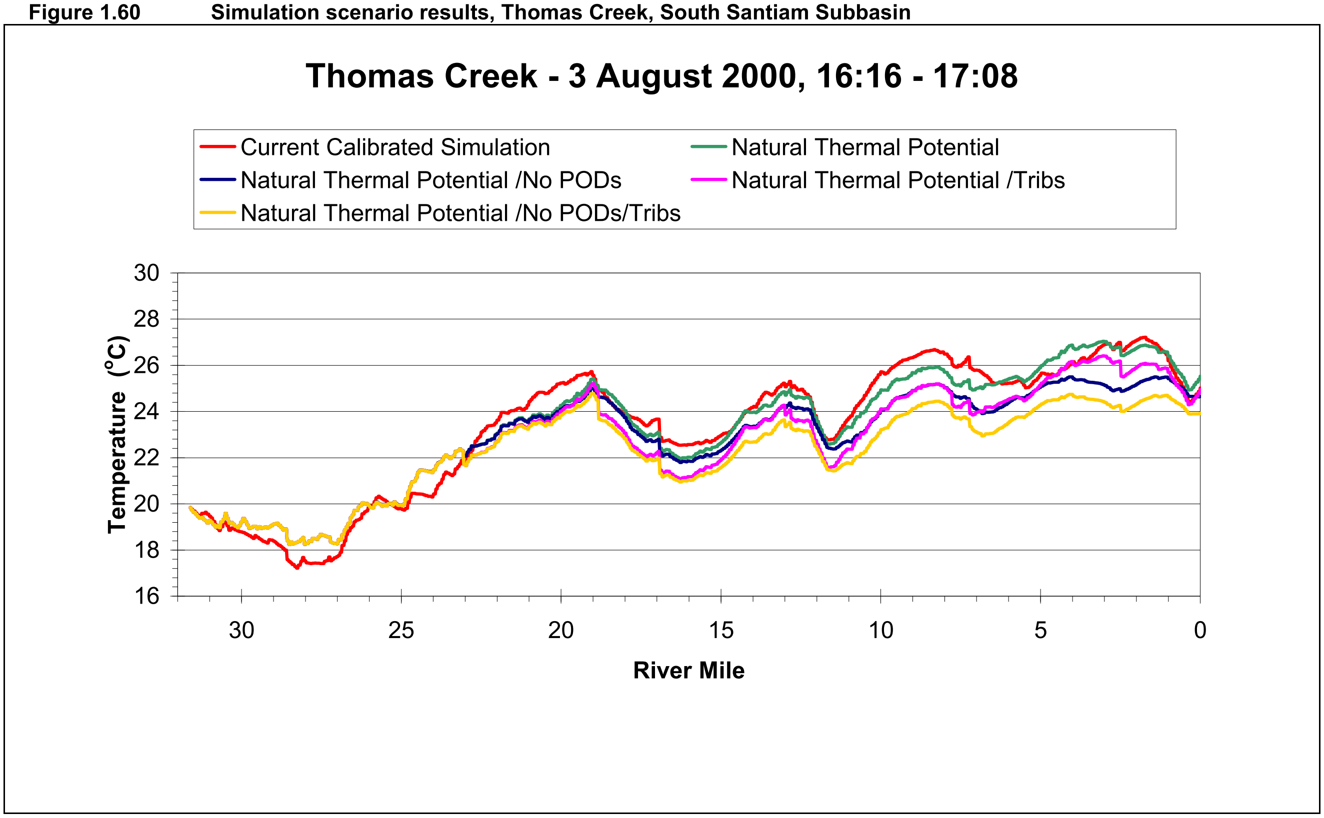


Figure 1.61 Simulation scenario results, Coyote Creek, Upper Willamette Subbasin

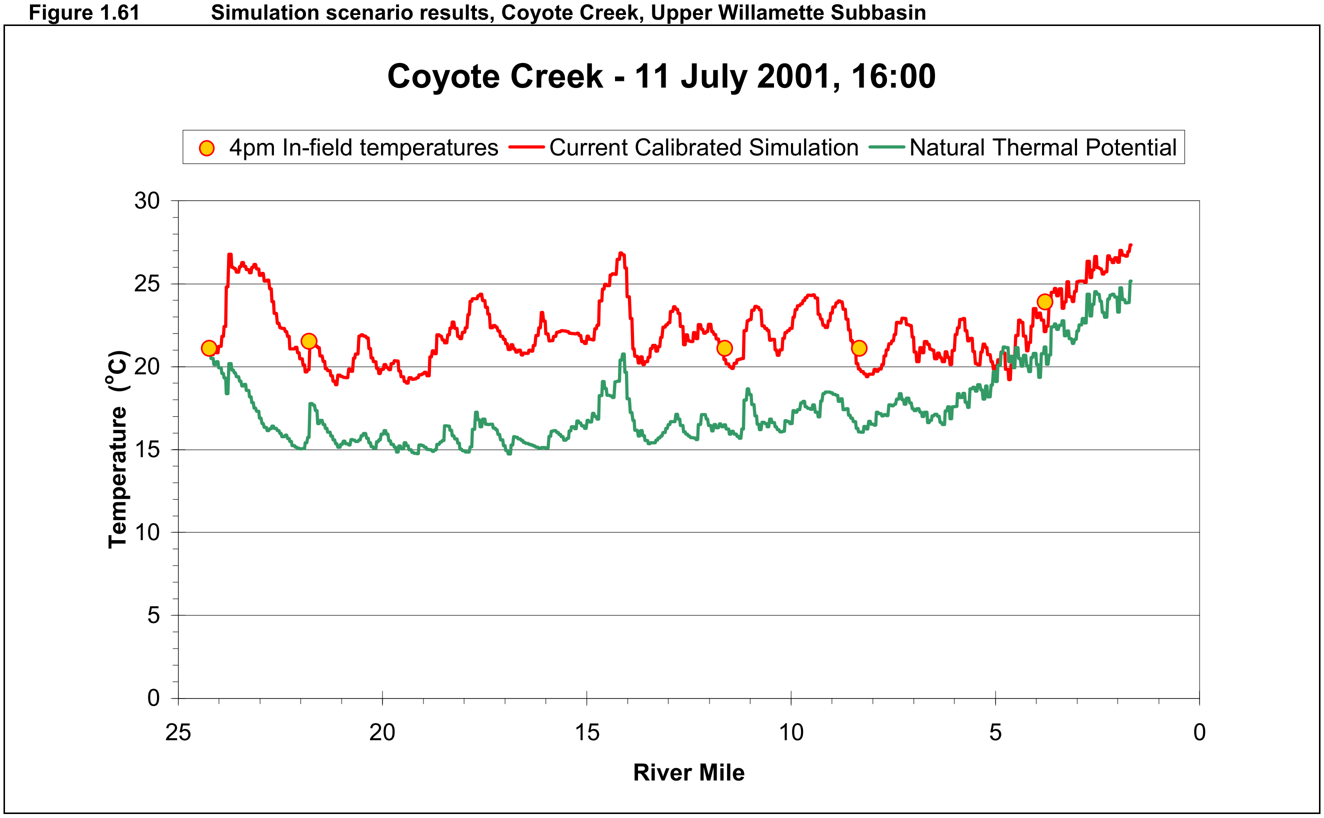
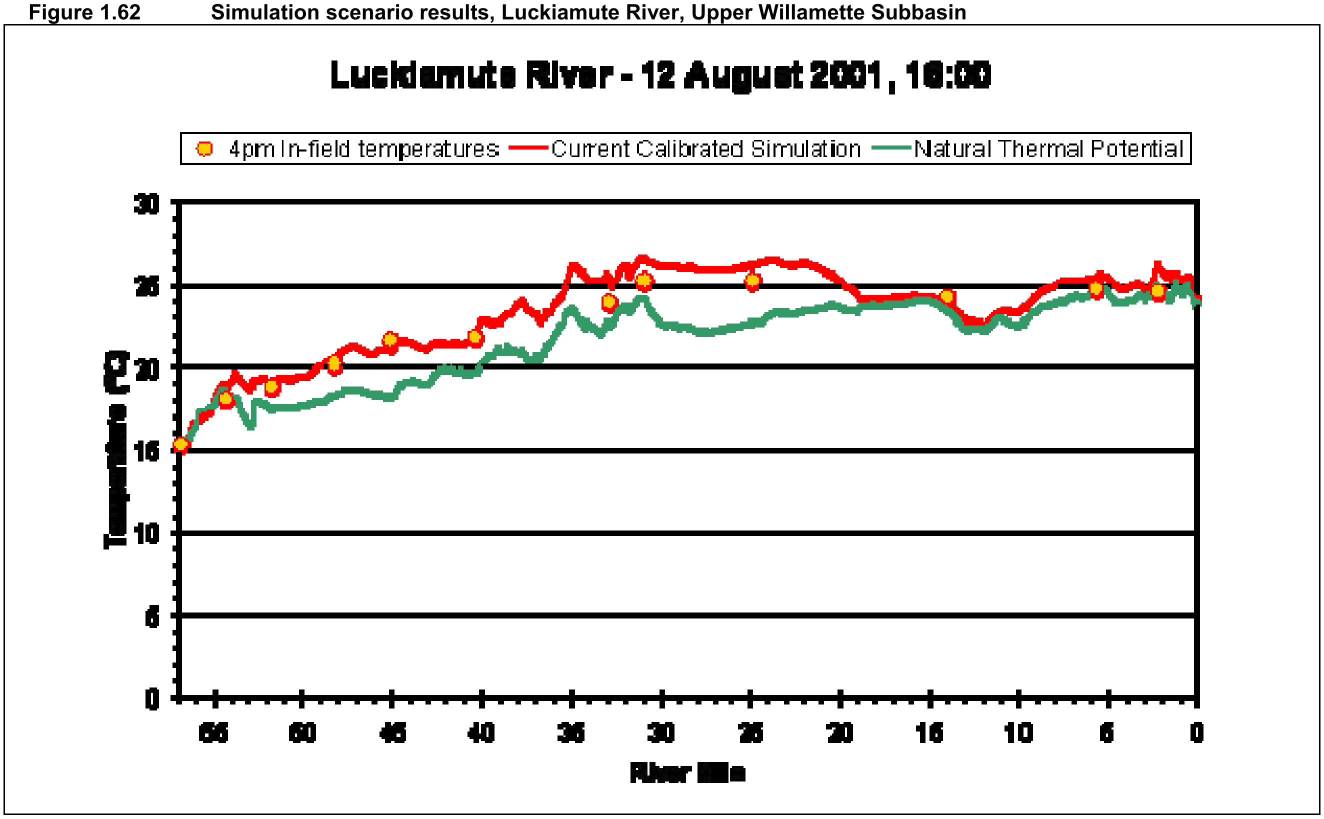


Figure 1.62 Simulation scenario results, Luckiamute River, Upper Willamette Subbasin



4.3.3 Validation

For the purposes of this analytical effort, validation refers to the statistical comparison of measured field data and the Heat Source model simulated current condition. Standard error statistics are calculated for TIR derived spatial temperature data sets and instream measured temporal temperature data sets. Each measurement of temperature is discrete and is used to assess model accuracy. Simulation outputs are only accurate to levels that exceed the validation statistics.

Stream temperatures derived from TIR data offer an extremely robust validation data set for spatial stream temperature simulation tools. Since the TIR temperature data are continuous, the number of simulated temperatures available for model validation is limited to model resolution. With TIR temperature data, the spatial scalability for any given methodology is unlimited by validation data. For streams where TIR was not available, validation is limited to temperatures monitoring locations, and stream survey sites.

Spatial and temporal data are stratified in the validation to test for biases in the simulation methodology. Since TIR temperature data sets are robust spatially, there is a possibility that the simulation could be calibrated to the specific time when TIR data was obtained, yet perform poorly for other periods of the day. Streams where TIR was unavailable may also perform poorly in reaches where no monitoring data was collected. Validation statistics are presented in **Table 1.30** and **1.32**

Mean Error (ME) – A mean error of zero indicates a perfect fit. A positive value indicates on average the model predicted values are less than the observed data. A negative value indicates on average the model predicted values are greater than the observed data. The mean error statistic may give a false ideal value of zero (or near zero) if the average of the positive deviations between predictions and observations is about equal to the average of the negative deviations in a data set. Because of this, the mean absolute error statistic should be used in conjunction with mean error to measure model performance.

$$ME = \frac{\sum (y - x)}{n}$$

Mean Absolute Error (MAE) - A mean absolute error of zero indicates a perfect fit. The magnitude of the mean absolute error indicates the average deviation between model predicted values and observed data. The mean absolute error cannot give a false zero.

$$MAE = \frac{\sum |(y - x)|}{n}$$

Root Mean Square Error (RMS) – A root mean square error of zero indicates a perfect fit. Root mean square error is a measure of the magnitude of the differenvce between model predicted values and observed data.

$$RMS = \sqrt{\frac{\sum (y - x)^2}{n}}$$

R Squared – An r squared of one indicates a perfect fit. R squared measures how well a regression line fits observed data.

$$R^2 = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{\sqrt{\left[n\sum x^2 - \left(\sum x\right)^2\right]\left[n\sum y^2 - \left(\sum y\right)^2\right]}}$$

y = A single predicted or modeled data value
x = A single corresponding field or observed data value
n = Total number of data points or observations

Table 1.30 Validation statistics for current condition simulations and TIR data

TIR STREAMS	ME	MAE	RMS	R SQUARED	N
Johnson Creek TIR	0.78	1.09	1.34	0.50	366
Little North Santiam River TIR	0.71	0.73	0.90	0.60	815
McKenzie River TIR	-0.23	0.33	0.39	0.93	1418
Mosby Creek TIR	-0.72	1.22	1.50	0.62	1136
Thomas Creek TIR	-0.21	0.55	0.68	0.92	1670

Table 1.31 Validation statistics for current condition simulations and measured field data

CONTINUOUS TEMPERATURE MONITORING LOCATIONS	ME	MAE	RMS	R SQUARED	N
Coyote Creek @ Gillespie (RM 24.2) Lasar # 25627	0.01	0.01	0.02	1.00	24
Coyote Creek @ Powell Rd (RM 21.8) Lasar# 25626	-0.23	1.61	1.86	0.15	24
Coyote Creek @ Crow Rd (RM 11.6) Lasar# 11148	-1.54	1.54	1.96	0.86	24
Coyote Creek @ Petzold Rd (RM 8.3) Lasar# 10151	-1.54	1.54	1.96	0.86	24
Coyote Creek @ Centrell Rd (RM 3.8) Lasar# 10150	-1.22	1.22	1.33	0.83	24
Crabtree Creek @ RM 34.5 Lasar #25608	0.01	0.01	0.02	1.00	24
Crabtree Creek @ RM 31.5 Lasar# 25607	0.36	1.84	2.08	0.68	24
Crabtree Creek @ RM 29.4 Lasar # 22651	-0.30	1.15	1.41	0.76	24
Crabtree Creek @ RM 25.3 Lasar# 25502	0.44	0.65	0.74	0.95	24
Crabtree Creek @ RM 23.0 Lasar# 22654	-0.41	0.80	0.88	0.99	24
Crabtree Creek @ RM 18.4 Lasar# 25498	-0.92	1.00	1.52	0.83	24
Crabtree Creek @ RM 12.7 Lasar# 25496	0.07	0.86	1.02	0.76	24
Crabtree Creek @ RM 5.9 Lasar# 10663	-0.35	0.47	0.57	0.92	24
Crabtree Creek @ RM 2.4	-0.74	0.91	1.08	0.96	24
Johnson Creek @ Revenue Rd Lasar# 28729	0.00	0.00	0.00	1.00	24
Johnson Creek @ Short Road Lasar# 28730	0.02	1.12	1.22	0.89	24
Johnson Creek @ Palmblad Road Lasar# 11626	0.09	0.42	0.54	0.93	24
Johnson Creek @ Regner Gage Lasar# 11327	-0.30	1.05	1.17	0.82	24
Johnson Creek @ Pleasantview/ 190th Ave. Lasar# 11326	-0.42	0.78	0.85	0.84	24
Johnson Creek @ SE Circle Avenue Lasar# 28731	-0.55	1.08	1.20	0.98	24
Johnson Creek @ 122nd and Leach Lasar# 10856	0.05	0.86	1.04	0.67	24
Johnson Creek @ 92nd Avenear Flavel Lasar# 10853	-1.16	1.78	2.06	0.98	24
Johnson Creek @ Bell Road and JC Blvd Lasar# 28732	-0.35	0.91	1.08	0.93	24
Johnson Creek @ 45th Ave Footbridge Lasar# 11323	1.33	1.33	1.45	0.82	24
Johnson Creek @ Milwaukie Gage	-0.57	0.63	0.79	0.97	24
Johnson Creek @ 17th Avenue Lasar# 11321	-0.36	0.51	0.60	0.97	24
Little N. Santiam @ RM 15.4	0.01	0.02	0.02	1.00	24
Little N. Santiam @ Elk Horn Park	-0.24	0.38	0.46	0.98	24
Little N. Santiam @ RM 8.5	-0.28	0.81	0.93	0.76	24
Little N. Santiam @ RM 4.7	-0.99	1.02	1.16	0.96	24
Little N. Santiam @ North Fork County Park	-0.83	0.85	0.98	0.94	24
Little N. Santiam @ USGS site 14182500	-0.78	0.78	0.87	0.95	24

Table 1.32 Validation statistics for current condition simulations and measured field data (contd.)

CONTINUOUS TEMPERATURE MONITORING LOCATIONS	ME	MAE	RMS	R SQUARED	N
Lukiamute @ RM 56.8 Lasar# 25494	0.01	0.01	0.02	1.00	24
Lukiamute @ RM 54.3 Lasar# 25493	-1.99	2.24	2.46	0.88	24
Lukiamute @ RM 51.8 Lasar# 25490	-0.77	0.92	1.21	0.95	24
Lukiamute @ RM 48.3 Lasar# 25488	-0.30	0.50	0.72	0.94	24
Lukiamute @ RM 45.1 Lasar# 25486	-0.54	0.54	0.73	0.95	24
Lukiamute @ RM 40.1 Lasar# 11111	-1.01	1.01	1.17	0.97	24
Lukiamute @ RM 32.9 Lasar# 25483	-0.95	1.43	1.65	0.96	24
Lukiamute @ RM 31.0 Lasar# 25480	-0.58	1.05	1.20	1.00	24
Lukiamute @ RM 24.9 Lasar# 25477	-2.25	2.52	2.96	0.93	24
Lukiamute @ RM 14.0 Lasar# 10659	-1.28	1.30	1.66	0.70	24
Lukiamute @ RM 5.7 Lasar# 25475	-1.15	1.48	1.77	0.92	24
Lukiamute @ RM 2.2 Lasar# 10658	-0.72	1.21	1.35	0.86	24
McKenzie River @ RM 75.4 Ollalie	0.00	0.00	0.00	1.00	24
McKenzie River @ Belknap Springs Resort	-0.99	0.99	1.11	0.91	24
McKenzie River @ McKenzie Bridge	-0.19	0.38	0.54	0.67	24
McKenzie River @ Quartz Cr. Bridge	0.02	0.39	0.50	0.82	24
Mohawk River @ RM 24.7 Lasar# 25608	0.00	0.01	0.01	1.00	24
Mohawk River @ RM 22.9 Lasar# 25607	-0.43	0.50	0.64	0.97	24
Mohawk River @ RM 21.5 Lasar# 22651	-0.66	0.69	0.87	0.96	24
Mohawk River @ RM 14.7 Lasar# 25502	-0.38	0.44	0.55	0.95	24
Mohawk River @ RM 12.1 Lasar# 22654	-0.24	0.59	0.68	0.83	24
Mohawk River @ RM 8.1 Lasar# 25498	-0.78	0.78	0.95	0.92	24
Mohawk River @ RM 3.4 Lasar# 25496	-1.30	1.30	1.43	0.96	24
Mohawk River @ RM 1.5 Lasar# 10663	-1.35	1.35	1.54	0.97	24
Mosby Creek @ RM 21.5 Lasar# 30165	0.00	0.00	0.01	1.00	24
Mosby Creek @ RM 13.0 Lasar# 28101	0.14	0.86	1.06	0.80	24
Mosby Creek @ RM 5.1 Lasar# 28799	-0.25	0.81	1.15	0.79	24
Mosby Creek @ RM 0.7 Lasar# 30368	0.44	0.67	0.89	0.82	24
Mosby Creek @ RM 0.5 Lasar# 28103	0.55	0.89	1.08	0.84	24
Thomas Creek @ RM 31.6 BLM Site U/S	0.00	0.01	0.01	1.00	24
Thomas Creek @ RM 26.8 BLM Site D/S	-0.74	0.88	1.02	0.76	24
Thomas Creek @ RM 24.0 Willamette Industries Gate	-1.45	1.45	1.56	0.96	24
Thomas Creek @ RM 18.6 D/S Jordon Creek	-1.04	1.04	1.13	0.97	24
Thomas Creek @ RM 17.1 Hannah Covered Bridge	-0.48	0.85	1.03	0.93	24
Thomas Creek @ RM 14.4 Old USGS Gage	-0.62	0.82	1.17	0.89	24
Thomas Creek @ RM 11.9 Shimanek Bridge	-1.19	1.30	1.49	0.80	24
Thomas Creek @ RM 8.0 West of Scio	-0.15	0.62	0.70	0.90	24
Thomas Creek @ RM 2.5 Kelly Road	-0.22	0.80	0.90	0.91	24

4.4 Total Daily Heat Load from Point Sources, Nonpoint Sources, and Background

4.4.1 Total Daily Heat From Point Sources

There are no NPDES permitted point sources discharging into streams modeled for temperature with heat source in the Willamette subbasins. There are however many NPDES point sources discharging to waterbodies modeled for effective shade. Accounting for these heat loads is described in the subbasin chapters of this TMDL document. Some NPDES point source heat load values were derived from CE-QUAL W2 modeling for the major tributaries. Accounting for these heat loads is described in the temperature **Chapter 4** of the main TMDL document.

4.4.2 Total Daily Solar Heat From Nonpoint Sources and Background

Solar heating is established as a primary pollutant in stream heating processes. The calculation of the overall heat load received by the stream system from solar radiation yields the nonpoint sources of solar heat for the total stream system as well as for each stream/river. The total daily solar heat load is the cumulative solar heat received by a stream over one day during the critical period (i.e., July/August period). For the purposes of this analytical effort, the total solar heat load is the sum of the products of the daily solar heat flux and surface area of exposure for each stream reach (i.e., for each stream data node every 100 feet).

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

Background levels of solar heat estimate the portion of the total daily solar heat load that occurs when nonpoint sources of heat are minimized. The background condition is the system potential total daily solar heat load (i.e., where anthropogenic nonpoint sources are minimized) and is calculated by substituting the system potential daily solar flux and the potential wetted width into the equation above. In this fashion, the total daily solar load is calculated for both the current condition (H_{solar}) and the system potential condition ($H_{solar}^{Background}$). With the background portion of the total daily solar load accounted for, the remaining portion can be attributed to anthropogenic nonpoint sources. Therefore, the anthropogenic nonpoint source total daily solar load is the difference between the total daily solar load and the background total daily solar load. Derived total daily loads for background sources and anthropogenic nonpoint and point sources are presented in **Table 1.33**.

$$H_{solar}^{NPS} = H_{solar} - H_{solar}^{Background}$$

where,

A_y: Stream surface area unique to each stream segment (cm^2)
dx: Stream segment length and distance step in the methodology (cm)
Φ_{solar}: Solar heat flux unique to each stream segment (kcal cm^{-2} day^{-1})
H_{solar}: Total daily solar heat load delivered to the stream (kcal day^{-1})
H_{solar}^{NPS}: Portion of the total daily solar heat load delivered to the stream that originates from nonpoint sources of pollution (kcal day^{-1})
$H_{solar}^{Background}$: Portion of the total daily solar heat load delivered to the stream that originates from background sources of pollution that are not affected by human activities (kcal day^{-1})
W_{wetted}: Wetted width unique to each stream segment (cm)

For the purposes of this analysis the total heat load is calculated from the simulated current condition. The background condition is calculated from the system potential land cover condition simulation. The nonpoint source load is the difference between the current total daily solar heat load and the background total daily solar heat load.

4.4.3 Total Daily Heat Load

87 percent of the total solar loading that occurs in the Willamette subbasins, including major tributaries, is from background sources, while the remaining 13 percent originates from anthropogenic nonpoint sources. (see **Figure 1.63)**. At least half of the streams modeled receive 25 percent or more of their solar heat from anthropogenic nonpoint sources. Quantified solar loading values are presented in **Table 1.33**.

Figure 1.63 Distribution of total non point source heat load for modeled streams

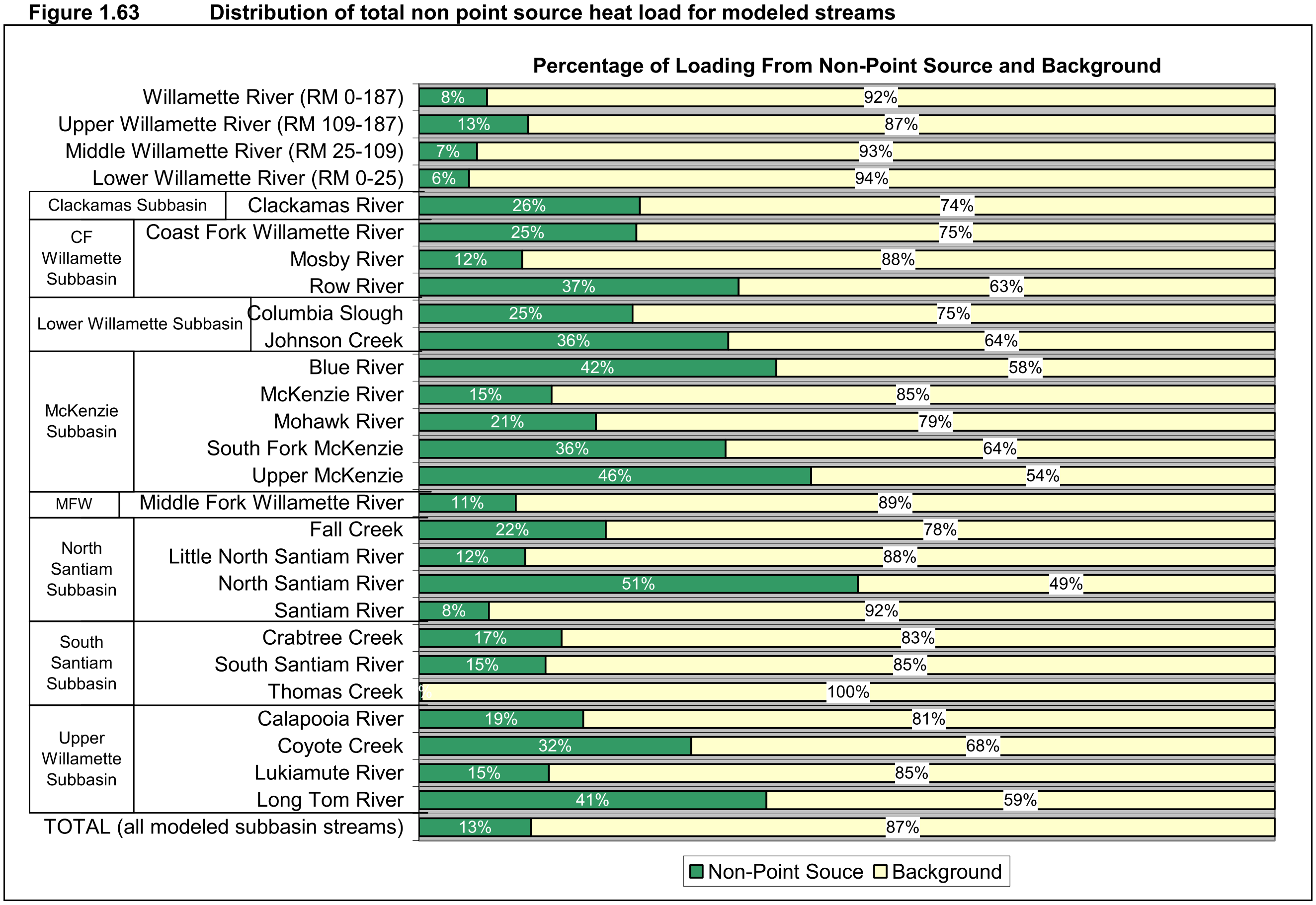


Table 1.33 Solar loading contribution from anthropogenic nonpoint sources, and background

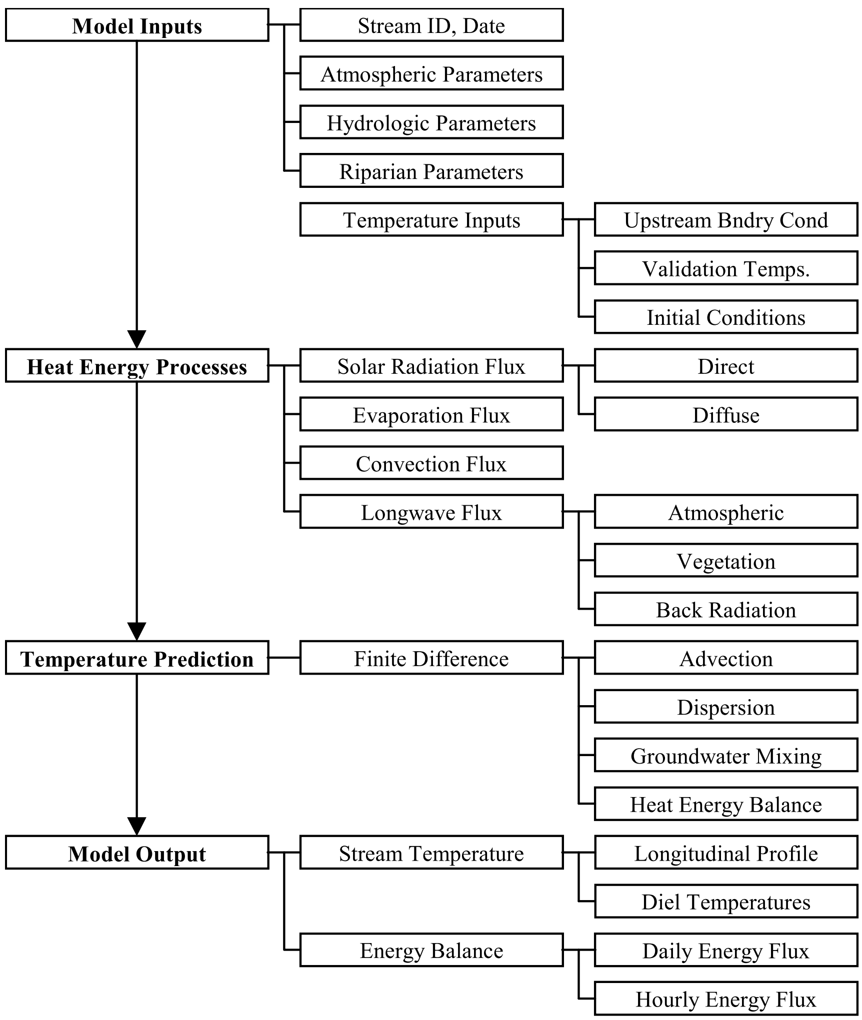
Subbasin	River Mile Reach	August **Current Condition** Solar Loading (Billion Kcal/day)	August **Potential (Background)** Solar Loading (Billion Kcal/day)	August **Anthropogenic** Solar Loading (Billion Kcal/day)	August **Portion from Anthropogenic Non-Point Sources**
Willamette River	**Willamette River (RM 0-187)**	287.93	265.01	22.92	8.0%
	187-171.8 (Upper Willamette)	13.52	11.37	2.15	15.9%
	171.8-161.2 (Upper Willamette)	9.11	7.59	1.52	16.7%
	161.2-149 (Upper Willamette)	11.25	9.81	1.44	12.8%
	149-132.1 (Upper Willamette)	14.52	12.41	2.11	14.5%
	132.1-119.4 (Upper Willamette)	12.04	11.07	0.98	8.1%
	119.4-109 (Upper Willamette)	10.45	9.60	0.84	8.1%
	109-84.1 (Middle Willamette)	32.99	30.48	2.51	7.6%
	84.1-54.9 (Middle Willamette)	40.35	36.96	3.39	8.4%
	54.9-35.7 (Middle Willamette)	30.68	29.61	1.06	3.5%
	35.7-24.8 (Middle Willamette)	23.93	22.22	1.71	7.2%
	24.8-13.1 (Lower Willamette)	30.40	27.88	2.51	8.3%
	13.1-3.4 (Lower Willamette)	43.56	41.50	2.05	4.7%
	3.4-0 (Lower Willamette)	15.14	14.50	0.64	4.2%
Clackamas Subbasin	**Clackamas**	11.99	8.89	3.09	25.8%
	23.4-5.1	9.53	7.14	2.40	25.1%
	5.1-0	2.45	1.76	0.70	28.3%
Coast Fork Willamette Subbasin	**Coast Fork**	5.78	4.31	1.47	25.4%
	29.4-20.8	0.64	0.39	0.25	39.4%
	20.8-0	5.14	3.92	1.22	23.7%
	Mosby River	0.32	0.28	0.04	12.1%
	Row River	1.78	1.12	0.66	37.4%
	7.5-0	1.78	1.12	0.66	37.4%
Lower Willamette Subbasin	**Columbia Slough**	3.54	2.66	0.89	25.0%
	Lower Slough	2.12	1.97	0.14	6.8%
	Middle Slough	1.07	0.42	0.65	60.7%
	Upper Slough	0.36	0.27	0.09	25.8%
	Johnson Creek	0.58	0.37	0.21	36.1%
Mckenzie Subbasin	**Blue River**	0.16	0.09	0.07	41.8%
	McKenzie	52.60	44.46	8.14	15.5%
	59.8-41.3	7.70	6.46	1.23	16.0%
	41.3-13.7	17.10	14.17	2.92	17.1%
	13.7-0	27.80	23.82	3.98	14.3%
	Mohawk River	0.77	0.61	0.16	20.7%
	South Fork Mckenzie	0.68	0.44	0.24	35.8%
	Upper McKenzie	1.78	0.96	0.81	45.8%
Middle Fork Willamette Subbasin	**Middle Fork**	9.98	8.85	1.13	11.3%
	11.2-16.8	2.84	2.44	0.39	13.8%
	11.2-0	7.15	6.41	0.74	10.3%
	Fall Creek	1.18	0.92	0.26	21.8%
	7.1-0	1.18	0.92	0.26	21.8%
North Santiam Subbasin	**Little North Santiam**	0.68	0.60	0.08	12.4%
	North Santiam	11.19	10.63	0.56	5.0%
	27-0	11.19	10.63	0.56	5.0%
	Santiam	9.19	8.44	0.75	8.2%
	11.7-0	9.19	8.44	0.75	8.2%
South Santiam Subbasin	**Crabtree**	1.58	1.32	0.26	16.7%
	South Santiam	21.51	18.33	3.18	14.8%
	37.7-0	21.51	18.33	3.18	14.8%
	Thomas Creek	1.01	1.01	0.00	0.3%
Upper Willamette Subbasin	**Calapooia River**	2.40	1.94	0.46	19.2%
	Coyote Creek	0.27	0.19	0.09	31.8%
	Lukiamute River	1.32	1.12	0.20	15.2%
	Long Tom	3.80	2.25	1.54	40.6%
	25.7-0	3.80	2.25	1.54	40.6%

Chapter 5 – Heat Source Model Analytical Framework

5.1 Conceptual Model

At any particular instant of time, a defined stream reach is capable of sustaining a particular water column temperature. Stream temperature change that results within a defined reach is explained rather simply. The temperature of a parcel of water traversing a stream/river reach enters the reach with a given temperature. If that temperature is greater than the energy balance is capable of supporting, the temperature will decrease. If that temperature is less than energy balance is capable of supporting, the temperature will increase. Stream temperature change within a defined reach, is induced by the energy balance between the parcel of water and the surrounding environment and transport of the parcel through the reach. The temperature model utilized by ODEQ to estimate stream network thermodynamics and hydrology is Heat Source (Boyd, 1996). It was developed in 1996 as a Masters Thesis at Oregon State University in the Departments of Bioresource Engineering and Civil Engineering. The general progression of the model is outlined in **Figure 1.64**,

Figure 1.64 Heat source temperature model flow chart



It takes time for the water parcel to traverse the longitudinal distance of the defined reach, during which the energy processes drive stream temperature change. At any particular instant of time, water that enters the upstream portion of the reach is never exactly the temperature that is supported by the defined reach. And, as the water is transferred downstream, heat energy and hydraulic processes that are variable with time and space interact with the water parcel and induce water temperature change. The described modeling scenario is a simplification; however, understanding the basic processes in which stream temperatures change occurs over the course of a defined reach and period of time is essential.

5.2 Governing Equations

5.2.1 Heat Energy Processes

Water temperature change is a function of the total heat energy transfer in a discrete volume and may be described in terms of energy per unit volume. It follows that large volume streams are less responsive to temperature change, and conversely, low flow streams will exhibit greater temperature sensitivity.

Equation 1. Heat Energy per Unit Volume,

$$\Delta T_w = \frac{\Delta Heat \quad Energy}{Volume}$$

Water has a relatively high heat capacity ($c_w = 10^3$ cal kg^{-1} K^{-1}) (Satterlund and Adams 1992). Conceptually, water is a heat sink. Heat energy that is gained by the stream is retained and only slowly released back to the surrounding environment, represented by the cooling flux ($\Phi_{cooling}$). Heating periods occur when the net energy flux (Φ_{total}) is positive: ($\Phi_{heating} > \Phi_{cooling}$).

Equation 2. Heat Energy Continuity,

$$\Phi_{total} = \Phi_{heating} - \Phi_{cooling}$$

In general, the net energy flux experienced by all stream/river systems follows two cycles: a seasonal cycle and a diurnal cycle. In the Pacific Northwest, the seasonal net energy cycle experiences a maximum positive flux during summer months (July and August), while the minimum seasonal flux occurs in winter months (December and January). The diurnal net energy cycle experiences a daily maximum flux that occurs at or near the sun's zenith angle, while the daily minimum flux often occurs during the late night or the early morning. It should be noted, however, that meteorological conditions are variable. Cloud cover and precipitation significantly alter the energy relationship between the stream and its environment.

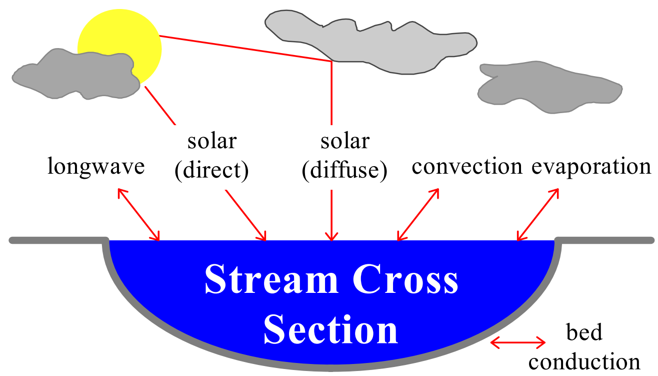
The net heat energy flux (Φ_{total}) consists of several individual thermodynamic energy flux components, namely: solar radiation (Φ_{solar}), long-wave radiation ($\Phi_{longwave}$), conduction ($\Phi_{conduction}$), groundwater exchange ($\Phi_{groundwater}$) and evaporation ($\Phi_{evaporation}$).

Equation 3. Net Heat Energy Continuity,

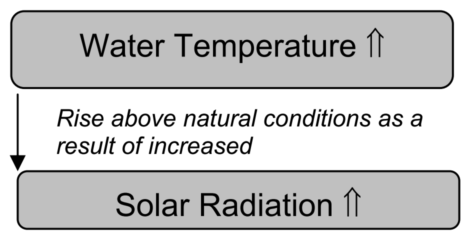
$$\Phi_{total} = \Phi_{solar} + \Phi_{longwave} + \Phi_{convection} + \Phi_{evaporation} + \Phi_{streambed} + \Phi_{groundwater}$$

Stream temperature is an expression of heat energy per unit volume, which in turn is an indication of the rate of heat exchange between a stream and its environment. The heat transfer processes that control stream temperature include solar radiation, longwave radiation, convection, evaporation and bed conduction (Wunderlich, 1972; Jobson and Keefer, 1979; Beschta and Weatherred, 1984; Sinokrot and Stefan, 1993; Boyd, 1996). With the exception of solar radiation, which only delivers heat energy, these processes are capable of both introducing and removing heat from a stream. **Figure 1.65** displays heat energy processes that solely control heat energy transfer to and from a stream.

Figure 1.65 Heat Energy Processes



When a stream surface is exposed to midday solar radiation, large quantities of heat will be delivered to the stream system (Brown 1969, Beschta et al. 1987). Some of the incoming solar radiation will reflect off the stream surface, depending on the elevation of the sun. All solar radiation outside the visible spectrum (0.36µ to 0.76µ) is absorbed in the first meter below the stream surface and only visible light penetrates to greater depths (Wunderlich, 1972). Sellers (1965) reported that 50% of solar energy passing through the stream surface is absorbed in the first 10 cm of the water column. Removal of riparian vegetation, and the shade it provides, contributes to elevated stream temperatures (Rishel et al., 1982; Brown, 1983; Beschta et al., 1987). The principal source of heat energy delivered to the water column is solar energy striking the stream surface directly (Brown 1970). Exposure to direct solar radiation will often cause a dramatic increase in stream temperatures. The ability of riparian vegetation to shade the stream throughout the day depends on vegetation height, width, density, position relative to the stream, and stream aspect.



Both the atmosphere and vegetation along stream banks emit longwave radiation that can heat the stream surface. Water is nearly opaque to longwave radiation and complete absorption of all wavelengths greater than 1.2µ occurs in the first 5 cm below the surface (Wunderlich, 1972). Longwave radiation has a cooling influence when emitted from the stream surface. The net transfer of heat via longwave radiation usually balances so that the amount of heat entering is similar to the rate of heat leaving the stream (Beschta and Weatherred, 1984; Boyd, 1996).

Evaporation occurs in response to internal energy of the stream (molecular motion) that randomly expels water molecules into the overlying air mass. Evaporation is the most effective method of dissipating heat from water (Parker and Krenkel, 1969). As stream temperatures increase, so does the rate of evaporation. Air movement (wind) and low vapor pressures increase the rate of evaporation and accelerate stream cooling (Harbeck and Meyers, 1970).

Convection transfers heat between the stream and the air via molecular and turbulent conduction (Beschta and Weatherred, 1984). Heat is transferred in the direction of warmer to cooler. Air can have a warming influence on the stream when the stream is cooler. The opposite is also true. The amount of convective heat transfer between the stream and air is low (Parker and Krenkel, 1969; Brown, 1983). Nevertheless, this should not be interpreted to mean that air temperatures do not affect stream temperature.

Depending on streambed composition, shallow streams (less than 20 cm) may allow solar radiation to warm the streambed (Brown, 1969). Large cobble (> 25 cm diameter) dominated streambeds in shallow streams may store and conduct heat as long as the bed is warmer than the stream. Bed conduction may cause maximum stream temperatures to occur later in the day, possibly into the evening hours. Conduction may also occur between groundwater, tributary, or point source inputs and the stream. The rate of conduction between two volumes of water depends upon 1) their relative volumes and 2) the temperatures of each water volume.

The instantaneous heat transfer rate experienced by the stream is the summation of the individual processes:

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

Solar Radiation (Φ_{Solar}) is a function of the solar angle, solar azimuth, atmosphere, topography, location and riparian vegetation. Simulation is based on methodologies developed by Ibqal (1983) and Beschta and Weatherred (1984). *Longwave Radiation* ($\Phi_{Longwave}$) is derived by the Stefan-Boltzmann Law and is a function of the emissivity of the body, the Stefan-Boltzmann constant and the temperature of the body (Wunderlich, 1972). *Evaporation* ($\Phi_{Evaporation}$) relies on a Dalton-type equation that utilizes an exchange coefficient, the latent heat of vaporization, wind speed, saturation vapor pressure and vapor pressure (Wunderlich, 1972). *Convection* ($\Phi_{Convection}$) is a function of the Bowen Ratio and terms include atmospheric pressure, and water and air temperatures. *Bed Conduction* ($\Phi_{Conduction}$) simulates the theoretical relationship ($\Phi_{Conduction} = K \cdot dT_b / dz$), where calculations are a function of thermal conductivity of the bed (K) and the temperature gradient of the bed (dT_b/dz) (Sinokrot and Stefan, 1993). Bed conduction is solved with empirical equations developed by Beschta and Weatherred (1984).

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

5.2.2 Non-Uniform Heat Energy Transfer Equation

The rate change in stream temperature is driven by the heat energy flux (Φ_i). A defined volume of water will attain a predictable rate change in temperature, providing an accurate prediction of the heat energy flux. The rate change in stream temperature (T) is calculated as shown in **Equation 4**.

Equation 4. Rate Change in Temperature Caused by Heat Energy Thermodynamics,

$$\frac{\partial T}{\partial t} = \left(\frac{Ax_i \cdot \Phi_i}{\rho \cdot c_p \cdot V_i} \right),$$

Which reduces to,

$$\frac{\partial T}{\partial t} = \left(\frac{\Phi_i}{\rho \cdot c_p \cdot D_i} \right).$$

Where,

Ax_i:	cross-sectional wetted area (m^2)
C_p:	specific heat of water (cal $kg^{-1} \cdot {}^oC^{-1}$)
D_i:	average stream depth (m)
t:	time (s)
T:	Temperature (^oC)
V_i:	volume (m^3)
Φ_i:	total heat energy flux (cal $m^{-2} \cdot s^{-1}$)
ρ:	density of water (kg/m^3)

Advection (U_x) redistributes heat energy in the positive longitudinal direction. No heat energy is lost or gained by the system during advection, and instead, heat energy is transferred downstream as a function of flow velocity. In the case where flow is uniform, the rate change in temperature due to advection is expressed in the first order partial differential equation below.

Equation 5. Rate Change in Temperature Caused by Advection,

$$\frac{\partial T}{\partial t} = -U_x \cdot \frac{\partial T}{\partial x}$$

Dispersion processes occur in both the upstream and downstream direction along the longitudinal axis. Heat energy contained in the system is conserved throughout dispersion, and similar to advection, heat energy is simply moved throughout the system. The rate change in temperature due to dispersion is expressed in the second order partial differential equation below.

Equation 6. Rate Change in Temperature Caused by Dispersion,

$$\frac{\partial T}{\partial t} = D_L \cdot \frac{\partial^2 T}{\partial x^2}$$

The dispersion coefficient (D_L) may be calculated by stream dimensions, roughness and flow. In streams that exhibit high flow velocities and low longitudinal temperature gradients, it may be assumed that the system is advection dominated and the dispersion coefficient may be set to zero (Sinokrot and Stefan 1993). In the event that dispersion effects are considered significant, the appropriate value for the dispersion coefficient can be estimated with a practical approach developed and employed in the QUAL 2e model (Brown and Barnwell 1987). An advantage to this approach is that each parameter is easily measured, or in the case of Manning's coefficient (n) and the dispersion constant (K_d), estimated.

Equation 7. Physical Dispersion Coefficient,

$$D_L = C \cdot K_d \cdot n \cdot U_x \cdot D^{\frac{5}{6}}$$

Where,

C:	Unit conversion C = 3.82 for English units C = 1.00 for Metric units
D:	Average stream depth (m)
D_L:	Dispersion coefficient (m^2/s)
K_d:	Dispersion constant
n:	Manning's coefficient
U_x:	Average flow velocity (m/s)

The simultaneous non-uniform one-dimensional transfer of heat energy is the summation of the rate change in temperature due to heat energy thermodynamics, advection and dispersion. Given that the stream is subject to steady flow conditions and is well mixed, transverse temperature gradients are negligible (Sinokrot and Stefan 1993). An assumption of non-uniform flow implies that cross-sectional area and flow velocity vary with respect to longitudinal position. The following second ordered parabolic partial differential equation describes the rate change in temperature for non-uniform flow.

Equation 8. Non-Uniform One-dimensional Heat Energy Transfer,

$$\frac{\partial T}{\partial t} = -U_x \cdot \frac{\partial T}{\partial x} + D_L \cdot \frac{\partial^2 T}{\partial x^2} + \frac{\Phi}{c_p \cdot \rho \cdot D_i}$$

$$\text{Steady Flow: } \frac{\partial U_x}{\partial t} = 0$$

$$\text{Non-Uniform Flow: } \frac{\partial U_x}{\partial x} \neq 0$$

The solution to the *one-dimensional heat energy transfer equation* is essentially the summation of thermodynamic heat energy exchange between the stream system and the surrounding environment and physical processes that redistribute heat energy within the stream system. It is important to note that all heat energy introduced into the stream is conserved, with the net heat energy value reflected as stream temperature magnitude. Further, heat energy is transient within the stream system, due to longitudinal transfer of heat energy (i.e., advection and dispersion). The net heat energy flux (Φ) is calculated at every distance step and time step based on physical and empirical formulations developed for each significant energy component. The dispersion coefficient (D_L) is assumed to equal zero.

5.2.3 Boundary Conditions and Initial Values

The temperatures at the upstream boundary (i_o) for all time steps (t_o ,t_1,..., t_{M-1}, t_M) are supplied by the upstream temperature inputs. The downstream boundary temperature at longitudinal position i_{n+1} is assumed to equal that of i_n with respect to time t. Initial values of the temperatures at each distance node (i_o ,i_1,..., i_{N-1}, i_N) occurring at the starting time (t_o) can be input by the model user or assumed to equal the boundary condition at time t_o.

5.2.4 Spatial and Temporal Scale

The lengths of the defined reaches are 100 feet. The temperature model is designed to analyze and predict stream temperature for one day and is primarily concerned with daily prediction of the diurnal energy flux and resulting temperatures in July or August. Prediction time steps are limited by stability considerations for the finite difference solution method.

5.3 Input Parameters

Data collected during this TMDL effort has allowed the development of temperature simulation methodology that is both spatially continuous and spans a full days length (diurnal). Detailed spatial data sets have been developed for the following parameters:

- ✓ River and Tributary Digital Mapping at 1:5,000 scale
- ✓ Riparian Vegetation Species, Size and Density Digital Mapping at 1:5,000 scale
- ✓ West, East and South Topographic Shade Angles calculations at 1:5,000 scale
- ✓ Stream Elevation and Gradient at 1:5,000 scale,
- ✓ Hydrology Developed from Field Data - Spatially Continuous Flow, Wetted Width, Velocity and Depth Profiles.

All input data are longitudinally referenced in the model allowing spatial and/or continuous inputs to apply to certain zones or specific river segments.

5.3.1 Spatial Input Parameters

Longitudinal Distance (meters): Defines the modeled reaches for which spatial input parameters reference. Model reaches are 100 feet each, are derived from DOQ 1:5000 river layer digitized from Digital Orthophoto Quarter Quads (DOQs) and geo-referenced color aerial photographs, and are measured in the downstream direction.

Elevation (meters): Sampled for each model reach either from Digital Raster Graphic (DRG) or Digital Elevation Model (DEM).

Gradient (%): Is the difference between the upstream and downstream elevations divided by the reach length.

Bedrock (%): The percent of streambed material that has a diameter of 25 cm or greater. Values are derived from stream survey data or assumed where data are limited.

Aspect (decimal degrees from North): Calculated for each reach break and represents the direction of stream flow.

Flow Volume (cubic meters per second): Measured by ODEQ with standard USGS protocols with interpolation between flow measurement sites, while taking into account known water withdrawals and inputs.

Flow Velocity (meters per second): Derived from Manning's equation and Leopold power functions calibrated to measured flow velocity data.

Wetted Width (meters): Derived from Manning's equation and Leopold power functions calibrated to measured wetted width data.

Average Depth (meters): Derived from Manning's equation and Leopold power functions calibrated to measured average depth data. Calculated based on assuming rectangular channel.

Near-Stream Disturbance Zone Width (meters): Commonly referred to as bankfull width or channel width. Based upon ODEQ field measurements and aerial photograph interpretation.

Channel Incision (meters): Depth of the active channel below riparian terrace or floodplain. Based on ODEQ field measurements.

Riparian Height (meters): Determined from the professional expertise of foresters with ODF and the USFS and from ODEQ field observations.

Canopy Density (%): Determined from the professional expertise of foresters with ODF, the USFS, and from ODEQ field observations and aerial photograph interpretation.

Riparian Overhang (meters): Distance of riparian vegetation intrusion over the bankfull channel width. Based on ODEQ field observations.

Topographic Shade Angle (decimal degrees): The angle made between the stream surface and the highest topographic features to the west, east and south as calculated from DEM at each stream reach.

5.3.2 Continuous Input Parameters

Wind Speed (meters per second): Hourly values measured by NOAA, municipal airports, or the Oregon Climate Service.

Relative Humidity (%): Hourly values measured by NOAA, municipal airports, or the Oregon Climate Service.

Air Temperature (^{o}C): Hourly values measured by NOAA, municipal airports, or the Oregon Climate Service.

Stream Temperature (^{o}C): Hourly values measured by ODEQ and other agencies as stated in each subbasin TMDL.

Tributary Temperature (^{o}C): Hourly values measured by ODEQ, and other agencies as stated in each subbasin TMDL.

Tributary/Flow Volume (cubic meters per second): Measured flow volumes for all major tributaries by ODEQ and other agencies as stated in each subbasin TMDL.

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IV. WILLAMETTE RIVER MAINSTEM MODEL CALIBRATION

Description of model

The Willamette River Mainstem River model consists of 9 sub-models that cover the Willamette River, 91 miles of the Columbia River, and a number of major tributaries to the Willamette River, including the Coast and Middle Forks of the Willamette River, the McKenzie River, the Santiam River and the Clackamas River (Figure 1). A total of 576 river miles are modeled.

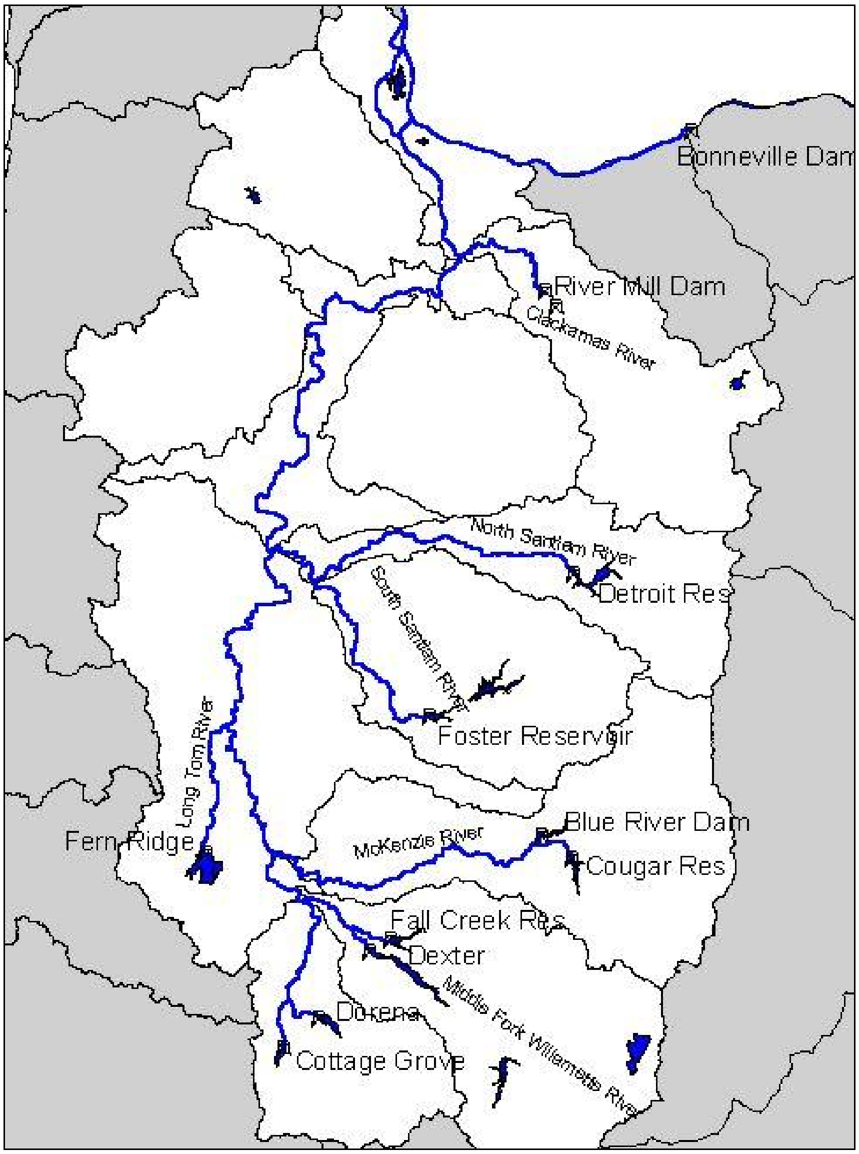

Figure 1. Willamette Mainstem W2 Model

The Willamette River can be divided into distinct reaches based on physical characteristics (Laenen and Risley 1997). The upper reach from Eugene to Albany (RM 187 to 119) is characterized by a meandering and braided channel with many islands and sloughs. This reach is shallow and the bed composed almost entirely of cobbles and gravels which, during the summer, are covered with biological growth. The middle reach from Albany to the Yamhill River (RM 119 to 56) is characterized by a meandering channel deeply incised into the valley. This reach is deeper and has fewer gravel bars exposed in the summer than the upper reach. The Newberg Pool extends from RM 56 to the Willamette Falls at Oregon City (RM 26.5), a 50 ft. high water fall. The Newberg Pool is a deep, slow-moving reservoir like reach that is a depositional area for silt to small gravel sized material.

Below the Willamette Falls the river is a tidally influenced freshwater estuary that is significantly influenced by Columbia River tidal fluctuations. When the water surface level of the Columbia exceeds the water surface level in the Willamette, Columbia River water enters the Willamette and the net flow direction of the Willamette is negative (upstream). At such times, Columbia water enters as a distinct bottom wedge. As the tidal elevation in the Columbia recedes, flow direction reverses and the mixture of Columbia River and Willamette waters leaves the system. Due to the influence of the Columbia River on the lower Willamette, a portion of the Columbia River has been included in the model.

In the Columbia, the limit of tidal influence is the Bonneville Dam (RM 144.5). Reversing flow has been observed in the Columbia as far upstream as RM 98, located between the confluences of the Multnomah Channel (RM 87) and the Willamette Channel (RM 101) (Wilson and Paulson, 2000).

In order to optimize model efficiency, the Willamette Mainstem model is divided into 9 sub-models, as follows:

1. **Lower Willamette** – Includes tidal reaches of the Willamette up to the Willamette Falls (RM 26.5) and a portion of the Columbia River from Beaver Army Terminal (Columbia River Mile 53.8) to Bonneville Dam (RM 144.5). Included are the Willamette River main channel, which enters the Columbia at RM 101, and the Multnomah Channel, which enters the Columbia at RM 87;
2. **Mid-Willamette** – The Willamette River from Willamette Falls to RM 85.4 (City of Salem). Includes the Newberg Pool, which extends from the Falls to about RM 56 (City of Newberg);
3. **Upper Willamette** – Willamette River from RM 85.4 to RM 185.2 (Springfield);
4. **Coast and Middle Fork Willamette** – Includes the Willamette River from RM 185.2 to the confluence of Coast and Middle Forks (RM 186.8), the Coast Fork Willamette and Row River, and the Middle Fork Willamette and Fall Creek;
5. **Clackamas River** – The Clackamas River up to River Mill Dam/Faraday Reservoir (RM 26).
6. **Santiam and North Santiam River** – Includes the Santiam River (all 12 miles) and the North Santiam River up to Big Cliff Dam (RM 46.4), below Detroit Dam (RM 49);
7. **South Santiam River** – The South Santiam River to Foster Dam (RM 38);
8. **Long Tom River** – The Long Tom River to Fern Ridge Dam (RM 26);
9. **McKenzie River** – Includes the McKenzie River to RM 60, the Blue River to Blue River Dam (RM 1.5), and the South Fork McKenzie River to Cougar Dam (RM 4).

Model development was under the direction of the Willamette River Modeling Coordination Team (MCT), which consists of representatives with experience in water quality modeling or related fields from the U.S. Army Corps of Engineers (USACE), U.S. Geological Survey (USGS), Portland State University, the Oregon Association of Clean Water Agencies (ACWA), the Oregon DEQ, industry, and others. The MCT was formed in 2001 and, following review of available options, recommended that dynamic, two-dimensional models of the Willamette River and major tributaries from the mouth to major reservoirs be developed that are capable of modeling temperature, algae, dissolved oxygen and pH (DEQ, 2001a and DEQ, 2001b). In addition, the MCT recommended that dynamic models be developed of major reservoirs. Such river and reservoir models would allow: (1) temperature, algae, dissolved oxygen and pH to be modeled dynamically in the Willamette River and major tributaries; (2) model calculations to be compared to all applicable standards for temperature, algae, dissolved oxygen and pH, including daily maximum temperature, maximum pH, and minimum dissolved oxygen; and (3) allow all potentially stratified reaches, such as the Newberg Pool and the tidal Willamette, to be modeled with vertical layers. In addition, reservoir models would allow the impact of reservoir operations on the quality of water in reservoirs and leaving reservoirs to be evaluated.

The modeling framework used for the model is CE-QUAL-W2 (W2), a two-dimensional, laterally averaged, hydrodynamic and water quality model. It is best suited for relatively long and narrow rivers, lakes, reservoirs and estuaries exhibiting longitudinal and vertical water quality gradients (Cole and Buchak 1994, Cole and Wells 2000). Considerable flexibility is provided for modeling hydraulic structures such as culverts, spillways, weirs, and selective withdrawal structures. 34 water quality constituents may be modeled including temperature, dissolved oxygen, labile and refractory dissolved and particulate organic matter, dissolved and suspended solids, bacteria, phosphorus, nitrogen, phytoplankton, inorganic carbon, alkalinity, and pH. The latest version of the model includes a shade routine that allows shade and temperature to modeled in a method similar to the DEQ temperature model Heat Source (Boyd and Kasper, 2004), which provides a significant advantage over other models considered. As a dynamic model, CE-QUAL-W2 can calculate the full diel cycle and, therefore, calculate daily maximum temperature, daily minimum dissolved oxygen, and daily maximum and minimum pH. This allows direct comparisons of model calculations to water quality standards. Simulations can also be performed for long time periods and non-steady state flow conditions. Therefore, critical salmonid spawning periods may be evaluated in addition to critical summer low flow periods. CE-QUAL-W2 is supported by the U.S. Army Corps of Engineers (USACE) Waterways Experiment Station.

Due to resource constraints, model development has been phased. Phase I focused on data collection and W2 river model construction and calibration to address 1998 303(d) listings for temperature and bacteria. This phase was completed in 2003. Phase II is focused on river model calibration for other water quality parameters, including dissolved oxygen, pH, and algae. Clackamas County and Portland General Electric funded development and calibration of the model for temperature, dissolved oxygen, and algae for the lower and mid Willamette up to the City of Salem. The remainder of the model is fully calibrated for temperature, however, additional data collection is needed to calibrate the Upper Willamette for DO and algae.

Model development and calibration was divided between Portland State University (PSU) Department of Civil and Environmental Engineering, the USGS, and DEQ. PSU developed and calibrated all models except the Santiam, North Santiam and South Santiam. PSU model development was under the direction of Scott Wells, with model development and calibration performed by Robert Annear, Chris Berger, Mike McKillip, and Sher Jarmal Khan. Agencies which provided support to PSU for this effort included USACE (via Planning Assistance to States support), Clackamas County Tri-City Service District, Portland General Electric, and DEQ. Santiam and North Santiam River model development and calibration was performed by USGS, with modeling performed by Stewart Rounds and Annette Sullivan of the Portland Office (Sullivan and Rounds, 2004). Support for this effort was provided by municipal members of the Oregon Association of Clean Water Agencies (ACWA). South Santiam River model development was performed by DEQ, with modeling performed by James Bloom and Wang Xiaoyan. In addition, vegetative shade assessments and preliminary channel digitization for all reaches was performed by DEQ staff including Agnes Lut, Steve Mrazik, Pamela Wright, and Tracy Harrison using TTools developed by Matt Boyd (Watershed Sciences, Inc.) and Brian Kasper (DEQ) (Boyd and Kasper, 2002).

Models of many smaller tributaries were also developed. These were used to estimate the effects that load allocations for these streams will have on temperature in the Mainstem. Many tributaries were modeled by DEQ using the one-dimensional stream temperature model Heat Source (Boyd and Kasper, 2004). Heat Source is steady-state for flow and fully dynamic for thermodynamics. Streams for which Heat Source models were developed or are proposed include:

- Calapooia River (Upper Willamette),
- Luckiamute River (Upper Willamette),
- McKenzie River upstream from the South Fork McKenzie confluence (downstream the McKenzie is modeled using W2 as part of the Mainstem model),
- Mohawk River (McKenzie Subbasin),
- Little North Santiam River (North Santiam),
- Mosby Creek (Coast Fork Willamette)
- Thomas Creek (South Santiam),
- Crabtree Creek (South Santiam),
- Molalla and Pudding Rivers,
- Yamhill River.

The Tualatin River, a tributary to the lower Willamette, was modeled by USGS using CE-QUAL-W2 (Rounds and Wood, 2001). 303(d) Listings for temperature for the Tualatin Subbasin are addressed in an earlier TMDL.

The Molalla-Pudding and Yamhill subbasins have later deadlines for TMDL development than the rest of the Willamette Basin. Therefore, models of these streams will be developed at a later date.

Data used for model calibration

To calibrate the model, data was assembled and additional data collected for bathymetry, time-of-travel, stage height, stream discharge, temperature, meteorology and streamside vegetation.

Bathymetry data

Channel bathymetry from the 1960's was extracted from existing HEC-2 models of the Willamette and tributaries provided by the USACE. Detailed bathymetry data from the HEC-2 models is available for about 50% of the Willamette River, 50% of the Santiam reaches modeled, 35% of North Santiam reaches modeled, and nearly 100% of South Santiam reaches modeled (see).

To supplement and fill gaps in the HEC-2 data and to verify that the HEC-2 data are still representative, the USGS collected bathymetric data from the main stem Willamette River in March, 2002. Support for this effort was provided by ACWA. Detailed cross-sectional and longitudinal depth-profile data was collected in the mainstem Willamette River from Harrisburg (RM 161) to Willamette Falls (RM 26.5). Particular focus was placed on reaches where HEC-2 cross-sectional data were not available (RMs 175-121, 114-89, 77-74, 42-28). Stream cross-sectional data was collected approximately every mile along the profile of the river. In addition, detailed stream discharge was measured every 3 to 5 miles. (Rounds, web page report)

In order to provide data on modeled mainstem tributary wetted widths, USGS performed width surveys on the Clackamas, Santiam, North Santiam, South Santiam, McKenzie, Blue, South Fork McKenzie, Middle Fork Willamette, Coast Fork Willamette, and Row Rivers, and Fall Creek. Widths were measured approximately every mile, depending on accessibility. A total of 129 sites were visited. Each site was visited three times – in April, June, and August of 2002 – so that a range of flow conditions were encountered. Surveys were restricted to the reaches from the river mouth upstream to the first major dam. For example, the survey on the North Santiam ended at Big Cliff Dam, just below Detroit Dam (Rounds, web page report).

Table 1. Reaches with HEC-2 bathymetry data

River	Upper End of Reach	Lower End of Reach
Willamette River	187.0	175.0
Willamette River	120.99	114.36
Willamette River	89.61	77
Willamette River	73.94	42.1
Willamette River	28.3	0
Santiam River	11.7	6.0
North Santiam R	52.45	45.7
North Santiam R	28.09	24.9
North Santiam R	19.4	14.1
North Santiam R	2.9	0.0
South Santiam R	35.8	0.0
Tualatin R	66.92	0.0
Yamhill R	11.1	0.0

Detailed information on USGS Willamette Study data collection efforts, along with the data, is available at the USGS web page: http://or.water.usgs.gov/projs_dir/will_tmdl/main_stem_bth.html

Time-of-travel data

Time-of-travel data from dye studies was used to calibrate the models and ensure that stream velocities are accurately calculated. Time-of-travel data for the Willamette River and tributaries was available from dye studies performed in the late 1950s and early 1960s by the USGS (Harris, 1968). Data was also available from later dye studies performed by USGS on the Clackamas River and other small streams in the Willamette River Basin (Laenen and Bencala, 2001; Lee, 1995). Fernald and others (2001) also carried out a dye study over a 16-mile reach in the Willamette River near Harrisburg (RM 161) (S.A. Rounds USGS web page: http://or.water.usgs.gov/projs_dir/will_tmdl/main_stem_bth.html).

To supplement this data and verify its accuracy, USGS performed dye tracer studies on both the Long Tom River and a 25-mile reach of the Willamette River. Dye studies were carried out for two flow conditions, once in May/June, 2002 and again in August/September, 2002. (Rounds, web page report)

Stage and discharge data

Accurate steam flow rate gauging is essential for accurate stream modeling. Approximately 78 gages that relate directly to modeled mainstem reaches were active during the 2001 and 2002 model calibration periods (Figure 2). Most gages are operated by USGS, with support from a variety of cooperating agencies including USACE; the utilities Portland General Electric (PGE) and Eugene Water and Electric Board (EWEB); municipalities including Portland, Woodburn, Clackamas County, Newberg, and Salem; and others. Several gages are operated by the Oregon Water Resources Department and the U.S. National Weather Service. 58 stream gages recorded both stage and discharge. Lake gages and several tidally influenced Columbia and Lower Willamette River gages, where reversing flows occur, only recorded stage. Recording intervals for the gages is generally 30 minutes, with data from most gages available in real-time. 30 of these gages also recorded stream temperature.

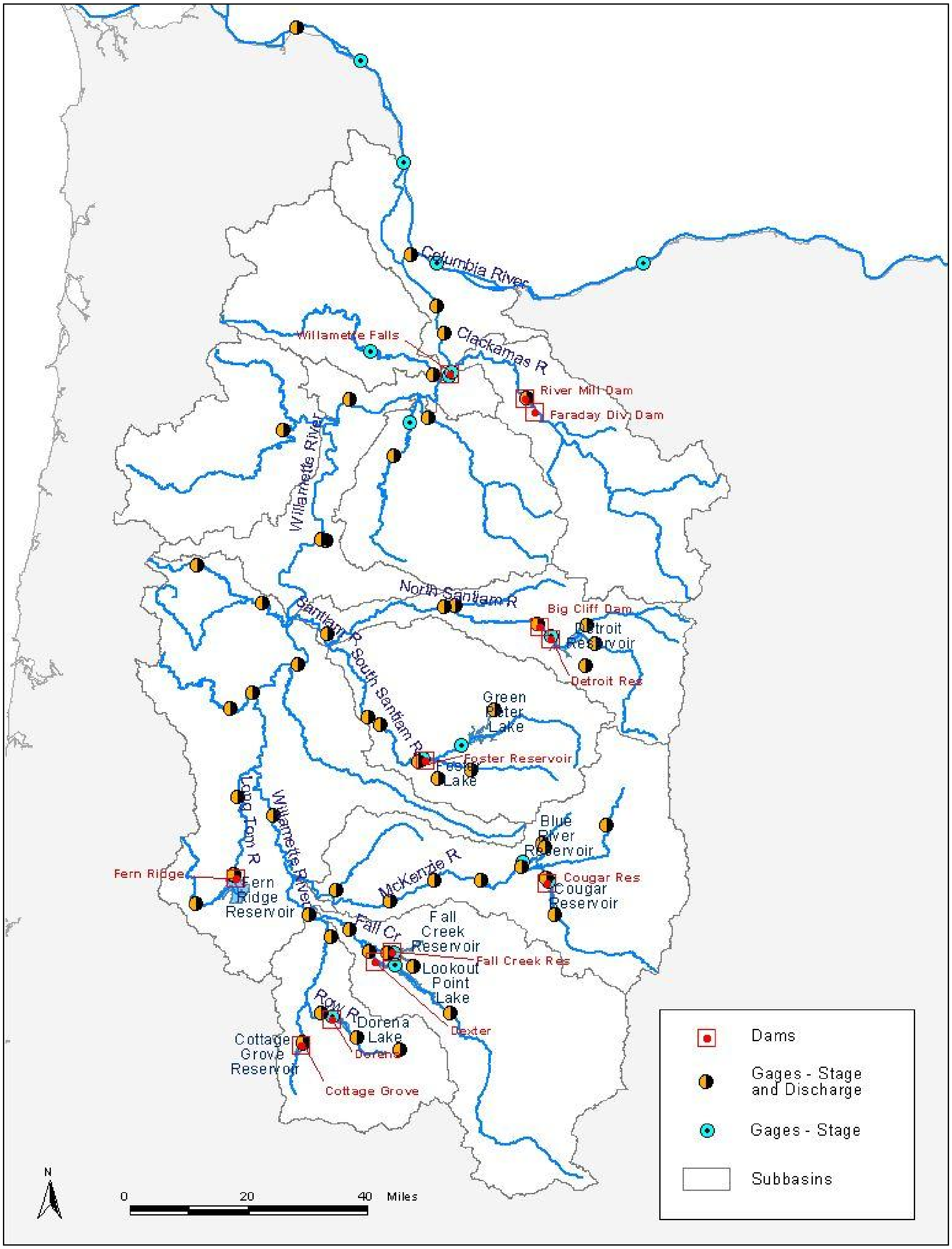

Figure 2. Stage and discharge gages during 2001-2002 studies

Effluent flow data

Effluent flow rates are measured by all significant point sources that discharge process wastewater or cooling water to modeled reaches. This self monitoring data was submitted to ODEQ by the facilities. Point sources included in the model are presented in Table 2.

Table 2. Point Sources

Site Name	Town	RM	Permitted Discharge MGD	Model Seg	Sub Model
WEYERHAEUSER COMPANY	Springfield	1.0	17.0	321	McKenzie
City of Cottage Grove WWTP	Cottage Grove	22.0	2.0	52	Coast Fork
City of Stayton WWTP	Stayton	14.9	1.9		North Santaim
City of Sweet Home WWTP	Sweet Home	31.5	1.38		South Santiam
City of Lebanon WWTP	Lebanon	15.9	3.0		South Santiam
City of Eugene MWMC POTW	Eugene	178.0	49.0	46	Upper Willamette
Fort James Operating Company	Halsey	148.4	4.5	252	Upper Willamette
Pope & Talbot, Inc. Halsey Pulp Mill	Halsey	148.3	17.0	252	Upper Willamette
Evanite Fiber Corporation	Corvallis	132.2	1.7	347	Upper Willamette
City of Corvallis WWTP	Corvallis	130.8	9.7	358	Upper Willamette
City of Albany WWTP	Albany	119.0	8.7	444	Upper Willamette
Weyerhaeuser Company, Albany Paper Mill	Albany	116.5	15.0	454	Upper Willamette
City of Salem WWTP	Salem	78.0	35.0	42	Mid Willamette
City of Newberg WWTP	Newberg	50.3	4.0	246	Mid Willamette
SP Newsprint Company	Newberg	49.7	17.0	245	Mid Willamette
City of Wilsonville WWTP	Wilsonville	39.0	2.7	318	Mid Willamette
City of Canby WWTP	Canby	33.0	2.0	353	Mid Willamette
Evergreen Mill – West Linn Company	West Linn	27.7	6.0	396	Mid Willamette
Blue Heron Paper Company	Oregon City	27.5	10.5	2	Lower Willamette
Tri-City WPCP	Oregon City	25.5	8.4	6	Lower Willamette
City of Portland, WWTP	Lake Oswego	20.2	8.3	35	Lower Willamette
Oak Lodge STP	Milwaukie	20.1	4.0	36	Lower Willamette
Clackamas County Service District #1	Milwaukie	18.7	10.0	47	Lower Willamette
Oregon Museum Of Science And Industry	Portland	13.5	2.38	62	Lower Willamette
Wacker Siltronic Corporation	Portland	6.3	2.7	93	Lower Willamette
Oregon Steel Mills, Inc.	Portland	2.7	5.70	93	Lower Willamette

Continuous stream and tributary temperature data

Continuous temperature monitoring data recorded on an hourly or more frequent basis was used to provide data to calibrate the models. Monitoring was performed at upstream boundaries, mouths of major tributaries, point sources, and at appropriate intervals in-stream (Figure 3).

Temperature monitoring stations fall into two categories:

1. Permanent monitoring at existing gages operated by USGS and others. Such stations provide secure, year-round monitoring, generally on a half-hourly basis. Frequently the data are available in real-time.
2. Seasonal (spring through fall) monitoring via temporary seasonal deployments. Such stations provide additional data to supplement the stream gage data.

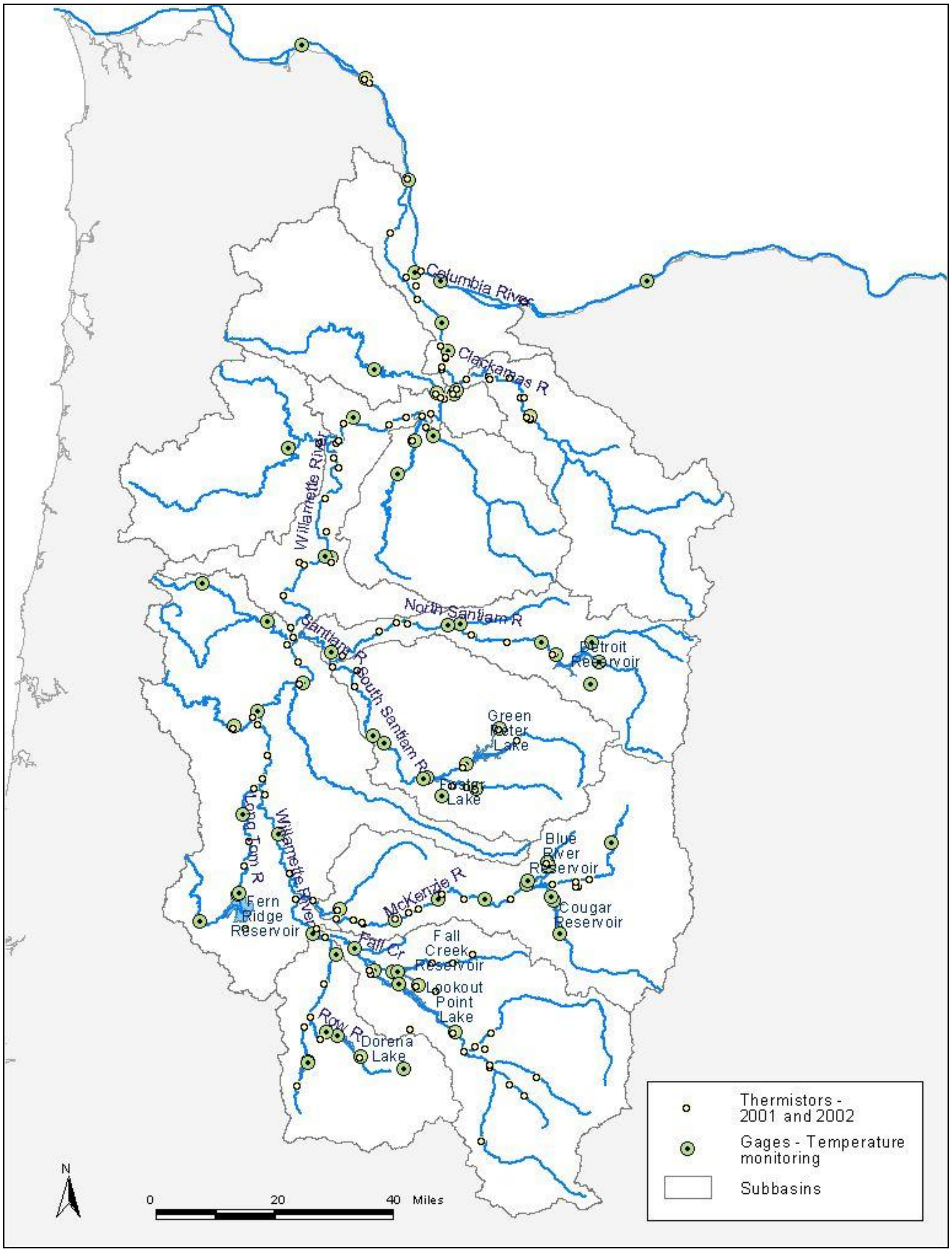

Figure 3. Stations with continuous temperature monitoring in 2001 and/or 2002

Stage and discharge gages upgrades

The U.S. Geological Survey (USGS) and others continuously monitor river stage and discharge at a number of gages in the Willamette Basin. Prior to the 2001 and 2002 model calibration studies, temperature was being monitored at about 15 gages that are significant to the mainstem (Table 3 and Figure 3).

In order to provide a baseline data set for temperature model calibration, approximately 15 additional flow gages were upgraded to year-round temperature monitoring (Table 4).

In general, temperature monitoring commenced at these sites in early August, 2001 and continued through the duration of the 2001 and 2002 study. Funding to upgrade the gages was provided by USACE and ACWA.

Table 3. Gages performing year-round temperature monitoring prior to study

Site ID	Station Name	Lat	Long	Agency	Coop Agency	Near Real-time
14180300	BLOWOUT CREEK NEAR DETROIT, OR	44.653056	-122.129170	USGS	SALEM	yes
14179000	BREITENBUSH R ABV FRENCH CR NR DETROIT, OR.	44.752778	-122.127780	USGS	SALEM	yes
14246900	COLUMBIA R AT BEAVER ARMY TERM	46.181944	-123.180556	USGS	USGS	yes
14211550	JOHNSON CREEK AT MILWAUKIE,OR	45.453056	-122.641940	USGS	PRTLND	yes
14182500	LITTLE NORTH SANTIAM RIVER NEAR MEHAMA, OR	44.791667	-122.577780	USGS	USACE	yes
14162500	MCKENZIE R NR VIDA OR	44.125000	-122.469440	USGS	EWEB	yes
14152000	MIDDLE FORK WILLAMETTE R AT JASPER, OR	43.998333	-122.904720	USGS	USACE	yes
14178000	NORTH SANTIAM R BL BOULDER CR NR DETROIT,OR	44.706944	-122.100000	USGS	USACE	yes
14183000	NORTH SANTIAM RIVER AT MEHAMA, OR	44.788889	-122.616670	USGS	USACE	yes
14181500	NORTH SANTIAM RIVER AT NIAGARA,OR	44.752778	-122.297220	USGS	USACE	yes
14189000	SANTIAM RIVER AT JEFFERSON, OR	44.715278	-123.011110	USGS	USACE	yes
14159200	SF MCKENZIE R ABV COUGAR LK NR RAINBOW	44.047222	-122.216667	USGS	USACE	yes
14159500	SOUTH FORK MCKENZIE RIVER NR RAINBOW,OR	44.136111	-122.247220	USGS	USACE	yes
14166000	WILLAMETTE R AT HARRISBURG OR	44.270556	-123.172500	USGS	USACE	yes
14191000	WILLAMETTE RIVER AT SALEM,OR	44.944444	-123.041670	USGS	USGS	yes

Table 4. Gages upgraded to year-round continuous temperature monitoring

Site ID	Station Name	Lat	Long	Agency	Coop Agency	Near Real-time
14162200	BLUE R AT BLUE RIVER OR	44.162500	-122.331940	USGS	USACE	no
14153500	COAST FORK WILLAMETTE R BL COTTAGE GR DAM,OR	43.720833	-123.048610	USGS	USACE	no
14151000	FALL CREEK BL WINBERRY CR NR FALL CR,OR	43.944444	-122.773610	USGS	USACE	yes
1421155	JOHNSON CREEK AT MILWAUKIE,OR	45.45305	-	USGS	PRTLND	yes
14169000	LONG TOM RIVER NEAR ALVADORE,OR	44.123611	-123.298610	USGS	USACE	no
14150000	MIDDLE FORK WILLAMETTE RIVER NEAR DEXTER, OR	43.945833	-122.836110	USGS	USACE	no
14155500	ROW RIVER NEAR COTTAGE GROVE, OR	43.793056	-122.990280	USGS	USACE	no
14187200	SOUTH SANTIAM RIVER NEAR FOSTER,OR	44.412500	-122.687500	USGS	USACE	yes
1418750	SOUTH SANTIAM RIVER AT WATERLOO,	44.49861	-	USGS	USACE	yes
14170000	LONG TOM RIVER AT MONROE, OR	44.313056	-123.295280	USGS	USACE	yes
1416900	LONG TOM RIVER NEAR ALVADORE,OR	44.12361	-	USGS	USACE	No
14163900	MCKENZIE RIVER NEAR WALTERVILLE, OR	44.070000	-122.770000	USGS	EWEB	Yes
14192015	WILLAMETTE RIVER AT KEIZER (temperature)			USGS	USACE	
14197900	WILLAMETTE RIVER AT NEWBERG,OR	45.284400	-122.960600	USGS	NWBRG	Yes
14207740	WILLAMETTE R AB FLS AT OREGON CITY,OR	45.348611	-122.618890	USGS	USGS	yes

Primary seasonal thermistor deployments

Thermistors, small submersible electronic thermometers that record temperature on a continuous basis, were deployed at approximately 95 mainstem related locations in 2001 and 2002. Most deployments were performed for both years (Figure 3).

Multiple organizations collaborated with ODEQ to place thermistors. Most Mainstem thermistors were deployed by organizations other than ODEQ, although ODEQ did perform extensive thermistor deployments in 2000, 2001 and 2002 on smaller tributaries to the Willamette and other streams in the Willamette Basin. Agencies which placed thermistors in 2001 and 2002 included the Northwest Pulp & Paper Association (NWPPA) via its contractor SECOR; ACWA member municipalities including Eugene, Corvallis, Salem, and Portland; the utilities PGE and EWEB; and federal agencies USACE and USFS.

Thermistors were deployed at locations which represented well mixed conditions. In potentially stratified reaches, such as the tidal Willamette and Columbia, deployment of units at multiple depths was encouraged

Thermistors were generally deployed from spring through fall. Agencies which deployed thermistors were asked to place units in the spring before in-stream temperatures began to exceed 12.8^{o}C and leave them in place until temperatures dropped below 12.8^{o}C, although in practice dates of deployment and retrieval were controlled by flow related stream access issues more than by temperature.

For data quality assurance purposes, organizations which deployed thermistors received training from ODEQ and adopted ODEQ quality assurance methodologies. Consequently, most of the data collected received ODEQ's highest quality assurance grade.

Effluent temperature

Significant point source effluent dischargers were encouraged to monitor effluent temperature. Temperature data was collected by all significant point sources that discharge process wastewater or cooling water to modeled reaches (Table 2).

Meteorological data

The model requires hourly inputs for air temperature, solar radiation, wind speed, and humidity. While numerous meteorological stations collect weather data, such of precipitation data, only a handful collect continuous meteorological data. Sources of meteorological data for model calibration include:

1. U.S. Bureau of Reclamation AgriMet stations
2. NOAA/NWS/FAA Surface Airways METAR stations
3. RAWS weather stations
4. University of Oregon Solar Radiation Monitoring Laboratory (SRML) stations
5. H. J. Andrews Experimental Forest station
6. Natural Resources Conservation Service (NRCS) SNOTEL stations
7. City of Portland HYDRA Rainfall Network stations
8. Horizons Network air quality and meteorological data stations.

Available meteorological data stations are shown in Figure 4.

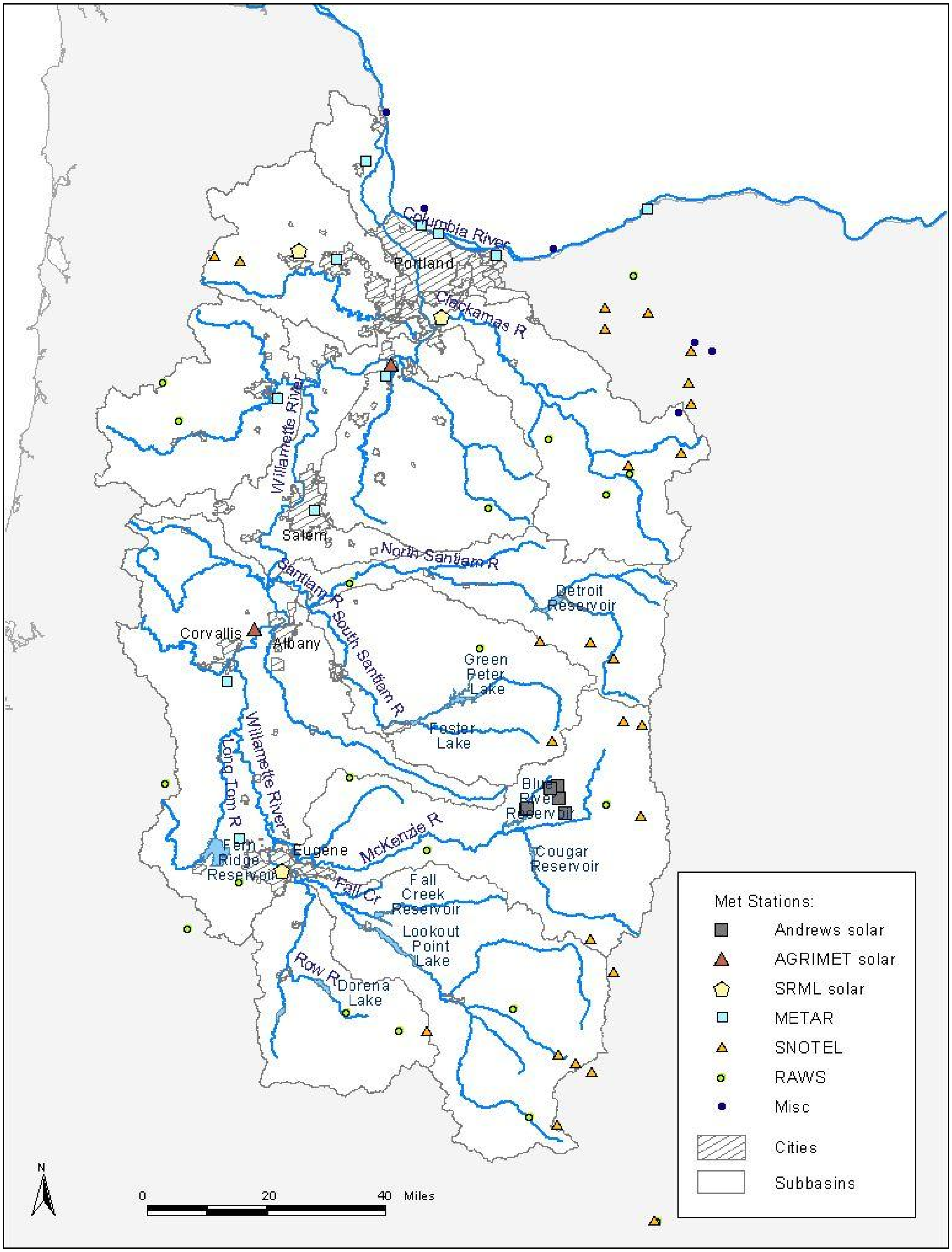

Figure 4. Meteorological Stations

Information on specific meteorological stations used for model calibration is presented in the model calibrations reports. The following is additional information on the principle stations used for model calibration:

AgriMet

The U.S. Bureau of Reclamation monitors air temperature, solar radiation, wind speed and humidity at AgriMet stations located at Corvallis, Forest Grove and Aurora. AgriMet is a satellite-based network of automated agricultural weather stations which upload data in near real-time. Monitoring is performed on hourly or more frequent intervals and the data are available via the Web. Agrimet stations provide hourly measurements of:

- Air temperature
- Precipitation
- Solar radiation
- Soil temperature
- Dew point
- Relative humidity
- Wind travel
- Wind direction
- Peak wind gust

http://mac1.pn.usbr.gov/agrimet/index.html

NOAA/NWS/FAA Surface Airways (METAR) network

METAR stations are aviation weather report stations are operated by the National Oceanic and Atmospheric Administration, the National Weather Service, and the Federal Aviation Administration. Stations are located at airports including: Aurora, Corvallis, Eugene, Hillsboro, McMinnville, Portland, Salem, and Troutdale. METAR stations provide hourly measurements of:

- Wind speed and direction
- Wind gusts
- Precipitation
- Air temperature
- Relative humidity
- Dewpoint
- Barometric pressure

http://nimbo.wrh.noaa.gov/Portland/current.html

RAWS

Remote Automated Weather Stations (RAWS) are weather stations which collect, store, and upload data hourly via satellite to the National Interagency Fire Center, Boise, Idaho. Data are used by fire managers to predict fire behavior and monitor fuels. RAWS sensors provide hourly measurements of:

- Wind speed and direction
- Wind gusts
- Precipitation
- Air temperature
- Relative humidity
- Fuel moisture.

http://www.fire.blm.gov/FactSheets/raws.htm

SRML

The University of Oregon Solar Radiation Monitoring Laboratory operates monitoring stations that provide data for solar energy resource evaluation and long-term climate studies. Funding is provided by Bonneville Power Administration, Eugene Water and Electric Board, Portland General Electric, Northwest Power Planning Council, and others. Solar radiation data collected includes direct (beam) and diffuse radiation. Currently operating SRML stations in the Willamette Basin are located in Portland (Gladstone), Forest Grove, and Eugene.

The Eugene station at the University of Oregon collects a large variety of solar radiation data types including global, direct normal, diffuse, ground reflected, and a variety of tilt angles. Spectral types include beam, multifilter (total, diffuse, and direct), and ultraviolet. The Portland (Gladstone) station is part of the

Clackamas Community College Environmental Learning Center program. Data are shared via an agreement with Portland General Electric. Data types include global, direct normal, diffuse and tilted south 30°. All data are collected at frequent intervals. The Forest Grove station collects global solar radiation, temperature, rainfall, wind speed and direction and relative humidity.
http://solardat.uoregon.edu/SolarData.html

H. J. Andrews Experimental Forest

Considerable meteorological data are collected at H. J. Andrews Experimental Forest Long Term Ecological Research (LTER) stations, located in the western Cascade Range of Oregon in the drainage basin of Lookout Creek, a tributary of Blue River and the McKenzie River. Support for the measurement program is provided by the Pacific Northwest Research Station and the National Science Foundation.

Solar radiation and other meteorological data including temperature, dew point, relative humidity, wind speed, and precipitation is collected at the Primary Met Station (PRIMET). This station is located in a maintained clearing at 1410 ft. elevation on Lookout Creek just upstream from Blue River Reservoir. Data are recorded at least hourly.
http://lternet.edu/documents/data-informationmanagement/DIMES/html/henshaw1.fv2.htm
http://www.fsl.orst.edu/lter/

Shade data

Vegetation assessments were performed by ODEQ to determine model inputs for vegetative shade. The assessments used a combination of satellite imagery, aerial photography (digital ortho quads or DOQs), and field data.

Steps in vegetation assessments include:

1. Obtain recent multispectral imagery (aerial photographs and satellite imagery),
2. Digitize stream thalwegs and banks,
3. Digitize riparian vegetation polygon layer,
4. Perform field surveys to collect ground-level riparian vegetation data,
5. Assign appropriate species composition, stand height, and stand density to vegetation polygons,
6. Process data using TTools to generate model inputs.

Vegetation assessments were performed for the Willamette River and all modeled tributaries. Vegetation assessments were not performed for the Columbia River, since modeled reaches are relatively insensitive to shade. See Chapter 4: Willamette Mainstem Temperature TMDL and Appendix C Chapter 3 – Willamette Subbasins Stream Temperature Analysis for additional detail on vegetation assessments and derivation of shade input files.

Model Calibration

Model calibration statistical summaries

All modeled reaches were calibrated on year 2001 and 2002 data. In addition, the South Santiam was calibrated on year 2000 data.

Model calibration adequacy was estimated using calibration statistics (equations 1-3).

$$\text{Mean Error (ME)} = \frac{\sum_{1}^{n}(\text{model} - \text{data})}{n} \qquad \text{(eq. 1)}$$

$$\text{Absolute Mean Error (AME)} = \frac{\sum_{1}^{n} abs(\text{model} - \text{data})}{n} \quad \text{(eq. 2)}$$

$$\text{Root Mean Square Error (RMS)} = \sqrt{\frac{\sum_{1}^{n} abs(\text{model} - \text{data})^2}{\text{n}}} \quad \text{(eq. 3)}$$

where:

model = model calculated temperature
data = observed temperature

Model developers attempted to achieve RMS errors of less than 1.0^{o}C for all stations. Model calibration RMS error statistics for hourly values are summarized in Table 5. As shown, RMS errors are generally less than 1.0^{0}C, which indicates that the models meet the goal of calculating temperature with an accuracy of +/- 1.0^{o}C.

Table 5. Root Mean Square Error (RMS) statistics for hourly data

	2001			2002		
	Min	Avg	Max	Min	Avg	Max
Lower Willamette (excluding Columbia River)	0.27	0.52	0.74	0.30	0.44	0.53
Mid-Willamette	0.07	0.55	0.81	0.48	0.62	0.85
Upper Willamette	0.04	0.48	0.64	0.03	0.45	0.61
Coast and Middle Fork Willamette	0.10	0.79	1.87	0.17	0.93	2.23
Clackamas	0.03	0.67	0.86	0.03	0.43	0.68
Santiam and North Santiam	0.50	0.83	1.16	0.43	0.69	0.84
South Santiam	0.25	0.68	0.88	0.72	0.83	0.94
Long Tom River	0.04	0.69	1.07	0.05	0.74	1.16
McKenzie River	0.16	0.73	0.99	0.16	0.48	0.76

Maximum errors in the Coast and Middle Fork Willamette model (which includes Fall Creek, Row River, and the first 2 miles of the Willamette River) are greater than average due to greater than average error in Coast Fork Willamette, which has an average RMS error of 1.2^{o}C in both 2001 and 2002. With Coast Fork Willamette excluded, RMS error in the Coast and Middle Fork Willamette model averages 0.50^{o}C and 0.71^{o}C for 2001 and 2002, respectively.

Mean Error (ME) is presented in Table 6. ME provides insight into potential model bias. A negative ME indicates the model underpredicts and a positive ME indicates it overpredicts, while an ME of zero indicates zero bias. Average Mean Errors are generally in the range -0.5^{o}C to 0.5^{o}C, which indicates that the model shows minimal bias.

Table 6. Mean Error (ME) statistics for hourly data

	2001			2002		
	Min	**Avg**	**Max**	**Min**	**Avg**	**Max**
Lower Willamette	-0.42	-0.11	0.47	-0.14	0.10	0.33
Mid-Willamette	-0.92	-0.30	0.12	-0.42	-0.19	0.14
Upper Willamette	-0.22	0.11	0.49	-0.57	-0.36	0.01
Coast and Middle Fork Willamette	-1.49	-0.32	0.25	-1.24	-0.41	0.47
Clackamas	-0.14	-0.02	0.15	-0.42	-0.21	0.11
Santiam and North Santiam	NA	NA	NA	NA	NA	NA
South Santiam	-0.56	-0.25	0.00	0.13	0.16	0.19
Long Tom River	-.13	0.03	0.36	-0.40	-0.19	0.13
McKenzie River	-0.59	-0.35	0.06	-0.13	0.14	0.40

As with RMS, ME statistics for the Coast and Middle Fork Willamette model are greater than other models due to the Coast Fork Willamette. With the Coast Fork Willamette excluded, ME error in the Coast and Middle Fork Willamette model averages 0.02°C and 0.10°C in 2001 and 2002, respectively.

For the South Santiam, calibration was also performed using 2000 data. For 2000, RMS averaged 0.67°C and ME 0.10°C.

Overall, the statistics show that the Willamette River models have an accuracy of +/-0.5°C. For the Lower, Middle and Upper Willamette River, average RMS error statistics for 2001 were 0.52, 0.55 and 0.48 °C, respectively, and for 2002 were 0.44, 0.62 and 0.45 °C, respectively. For the Lower, Middle and Upper Willamette, average ME statistics for 2001 were -0.11, -0.30, and -0.22 °C, respectively, and for 2002 were 0.10, -0.19, and -0.36 °C, respectively. These statistics show that model calculated Willamette River temperatures are generally within +/-0.5°C of observed temperatures.

Model calibration plots

Model calibration plots for water level, flow, and temperature for all stations, along with calibration statistics, are presented for 2001 and 2002 in extensive model calibration reports (described below). Typical calibration plots for hydrodynamics and temperature for the Willamette River are presented below. Plots are presented for stations at Portland and at Salem/Keizer (Salem temperature monitoring performed at nearby Keizer station) (Figure 5 through Figure 10, all from Berger, et al 2004). 2002 is presented since data are available for more of the season in 2002 than in 2001. Calibrations statistics for these stations are presented in Table 7.

Table 7. Summary statistics for example Willamette River stations, 2002

Parameter and station	ME	RMS
Water level at Portland (14211720), m	-0.13	0.21
Continuous temperature at Portland, °C	0.10	0.43
Daily maximum temperature at Portland, °C	0.26	0.51
Discharge at Salem (14191000), m^3/s	0.14	0.87
Continuous temperature at Keizer (14192015), °C	-0.37	0.55
Daily maximum temperature at Keizer, °C	-0.37	0.57

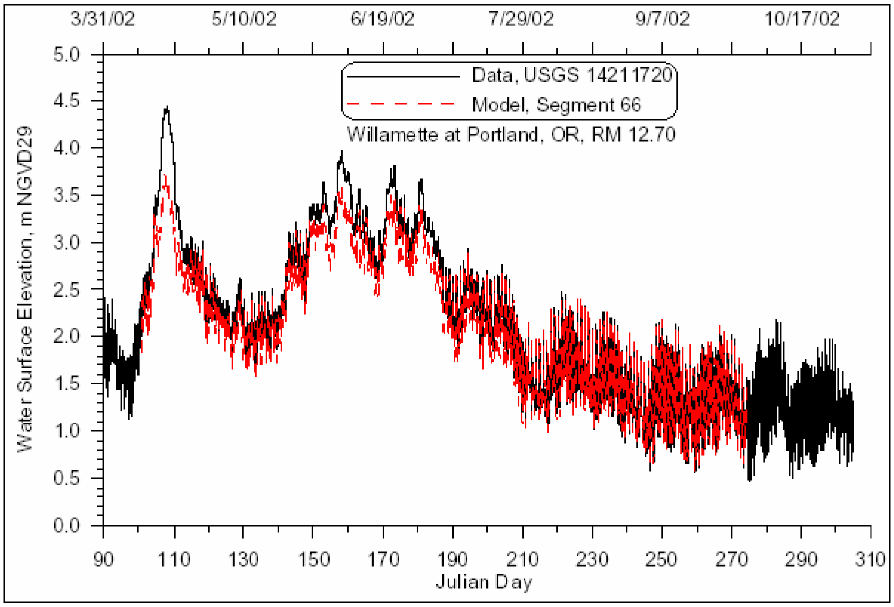

Figure 5. Willamette River at Portland model-data water level comparison, 2002

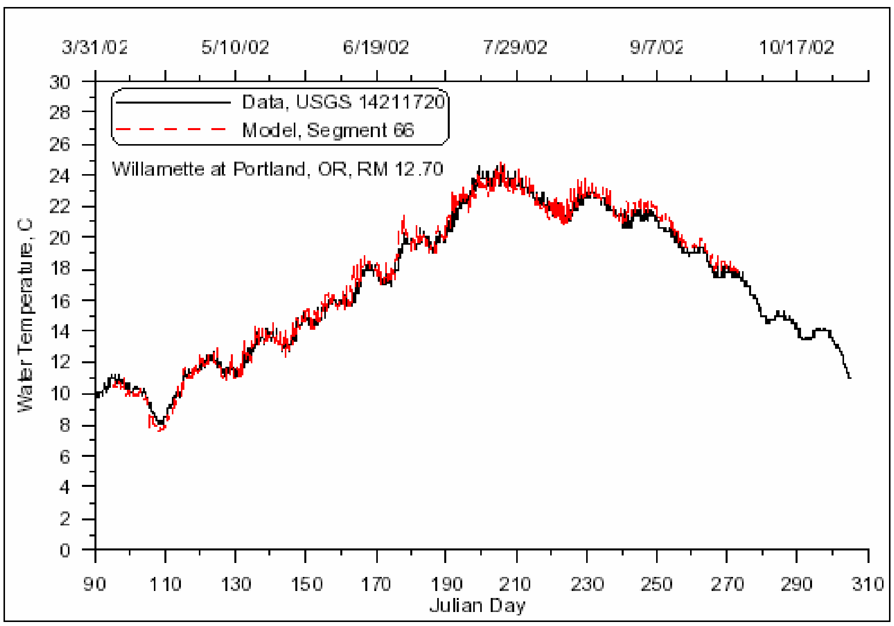

Figure 6. Willamette River at Portland model-data continuous temperature comparison, 2002

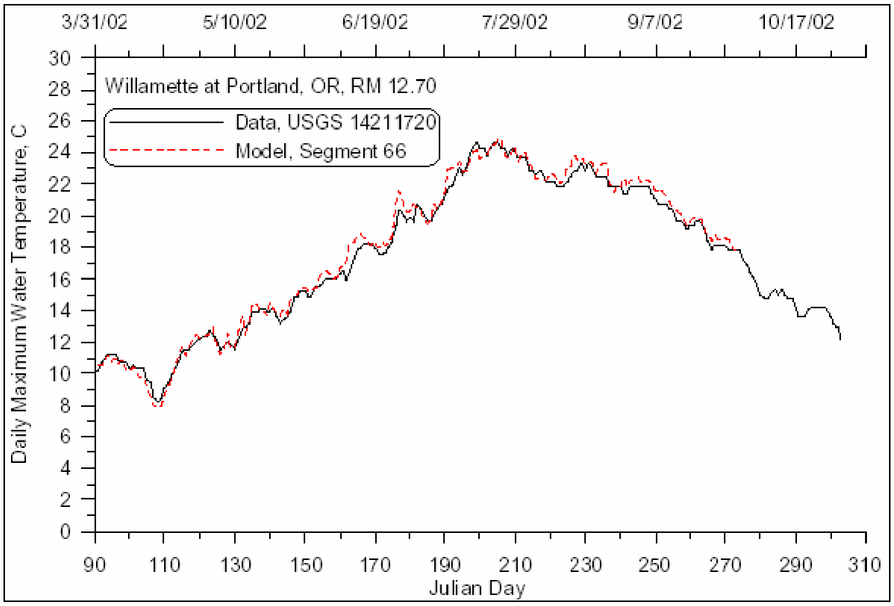

Figure 7. Willamette River at Portland model-data daily maximum temperature comparison, 2002

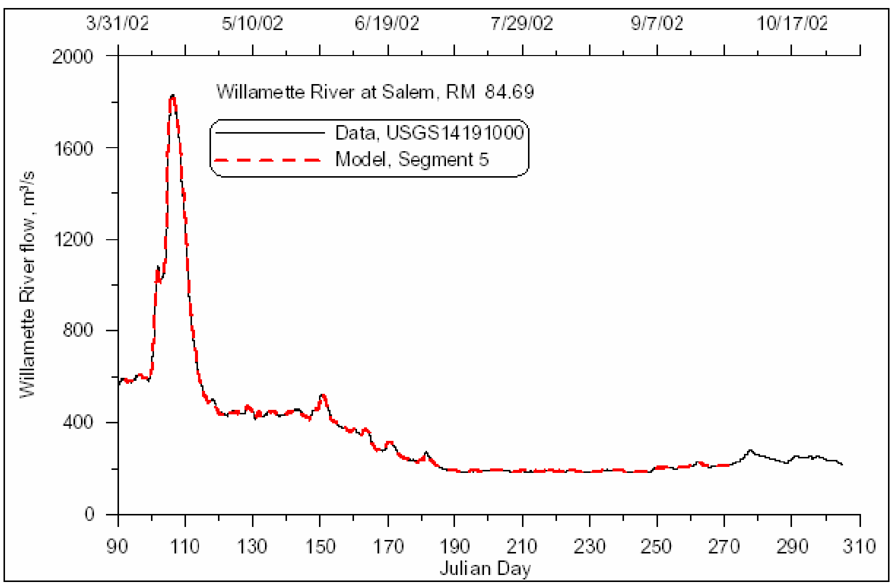

Figure 8. Willamette River at Salem model-data flow comparison, 2002

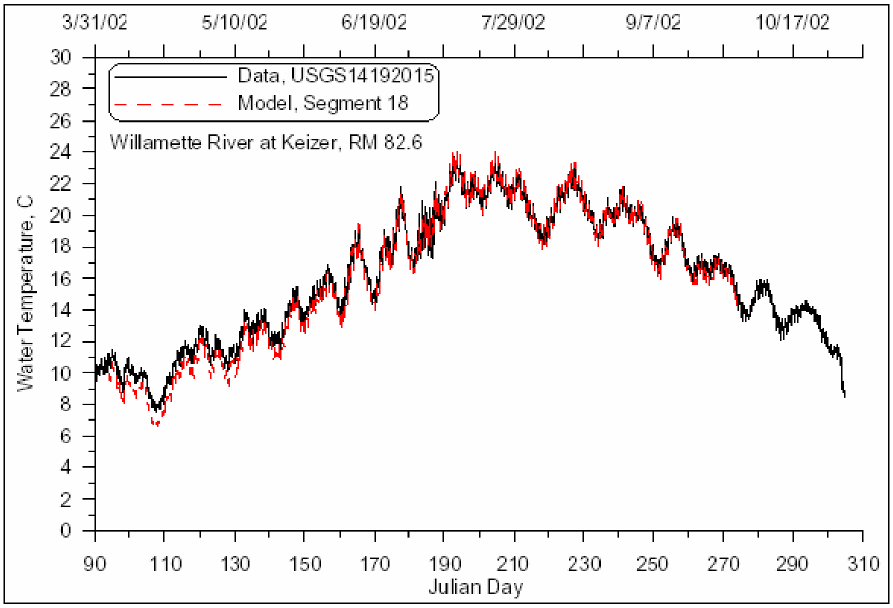

Figure 9. Willamette River at Keizer model-data continuous temperature comparison, 2002

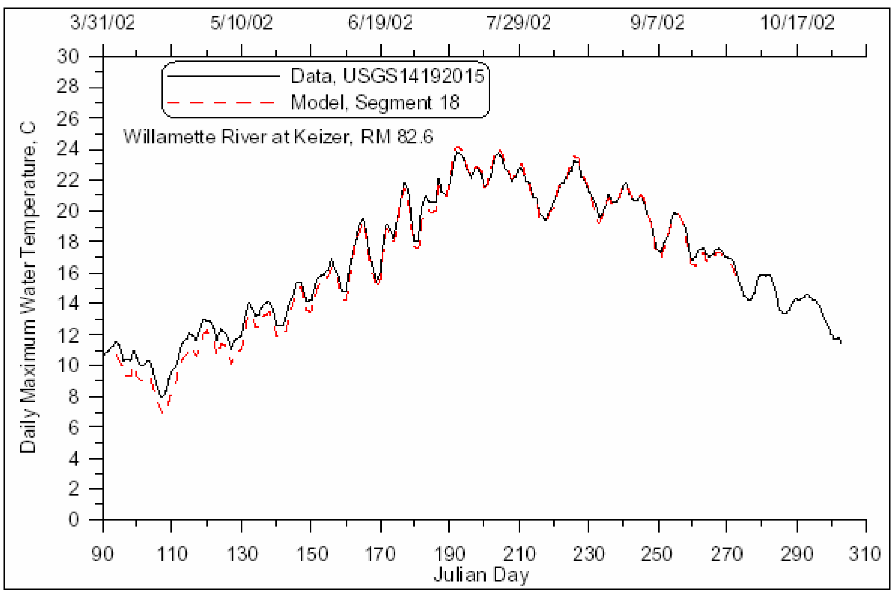

Figure 10. Willamette River at Keizer model-data daily maximum temperature comparison, 2002

Detailed calibration reports

Detailed information on model construction and calibration is available via the Portland State University Department of Civil and Environmental Engineering web page: http://www.ce.pdx.edu/w2/Willamette/

Reports under development by PSU and available via their web page include:

- Model Boundary Conditions and Setup for 2001 and 2002
- Model Calibration for 2001 and 2002
- Model Scenarios for 2001 and 2002

The North Santiam and Santiam models were developed by the Portland office of the U.S. Geological Survey. Information on the U.S. Geological Survey study on the North Santiam and Santiam River can be obtained via the USGS web page:
http://oregon.usgs.gov/projs_dir/will_tmdl/model.html

Details of the North Santiam and Santiam River models are provided in USGS Scientific Investigations Report 2004-5001 (Sullivan and Rounds, 2004). The report describes the objectives and results of the modeling work, including a quantification of model performance, a discussion of those processes that influence temperature in these rivers, and the results of sensitivity tests and hypothetical scenarios run with the model.
http://water.usgs.gov/pubs/sir/2004/5001/

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V. NATURAL THERMAL POTENTIAL RIVER TEMPERATURE GRAPHS

Contour plots in Figure 1 and 2 show 2001-2002 seven day average maximum natural thermal potential Willamette River temperatures. The contour break at approximately model river mile 175 is the confluence of the Willamette and McKenzie Rivers. The contour break at approximately model river mile 108 is the confluence of the Willamette and Santiam Rivers. The contour break at approximately model river mile 25 is at Willamette Falls.

2001 natural thermal potential river temperatures represent model sim 31 data. 2002 natural thermal potential temperatures represents model sim 32 data.

Figure 1. 2001 Willamette River seven-day average maximum natural thermal potential temperatures.

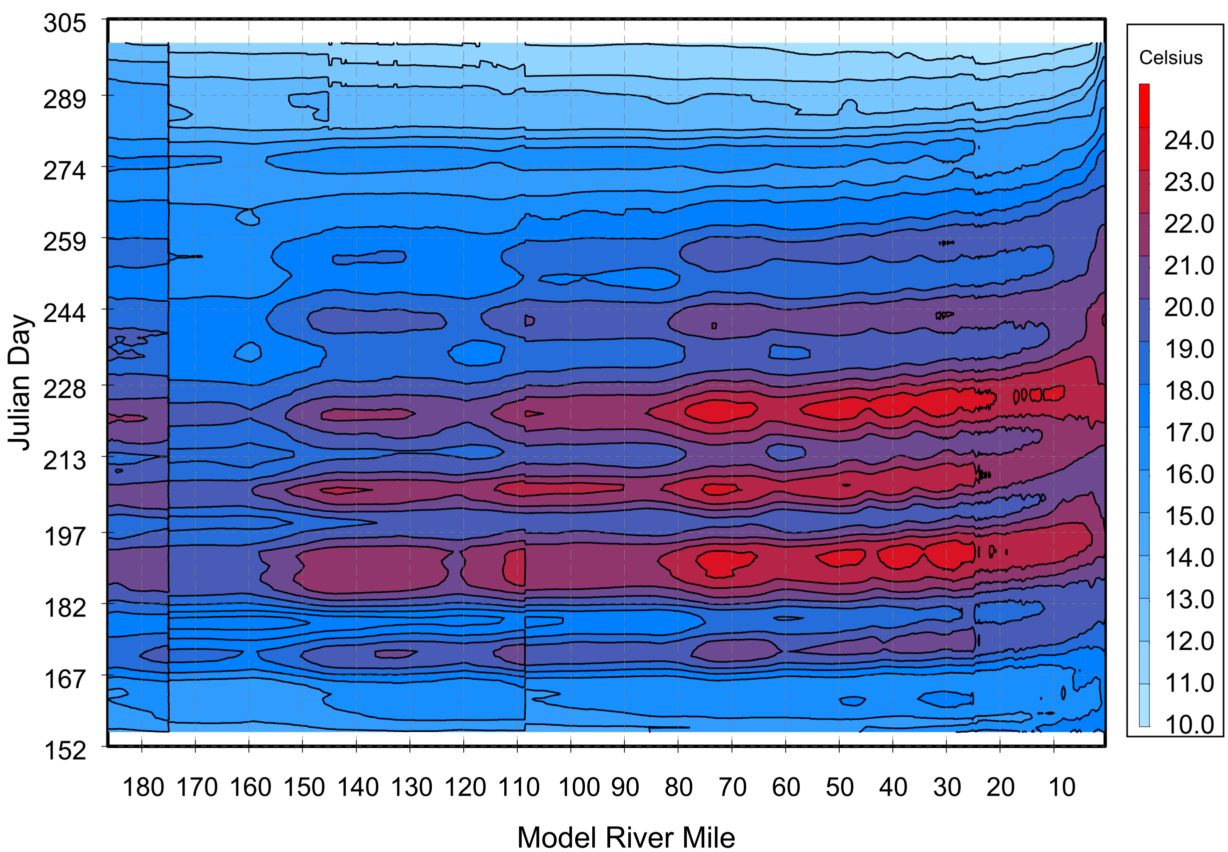
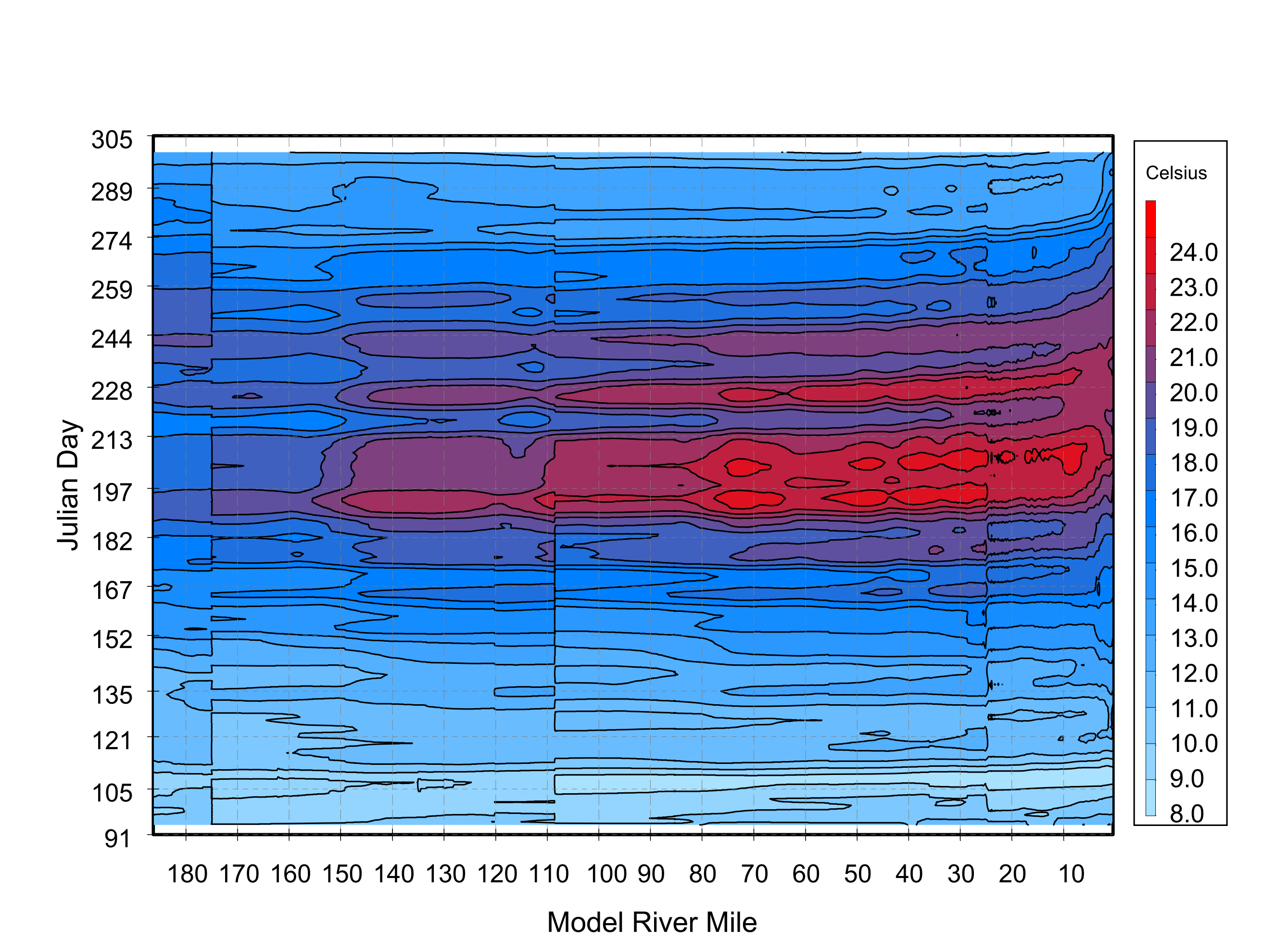


Figure 2. **2002 Willamette River seven-day average maximum natural thermal potential temperatures.**



Figures 3 though 14 illustrate the 2001-2002 modeled seven day average maximum natural thermal potential Willamette River temperature longitudinally by calendar month. Each line represents the longitudinal temperature profile for one day within the month. The top of the white area reflects the maximum seven day average maximum for the month. The bottom of the white area reflects the minimum seven day average maximum for the month.

Figure 3. **June 2001 Willamette River natural thermal potential and biological criteria temperatures.**

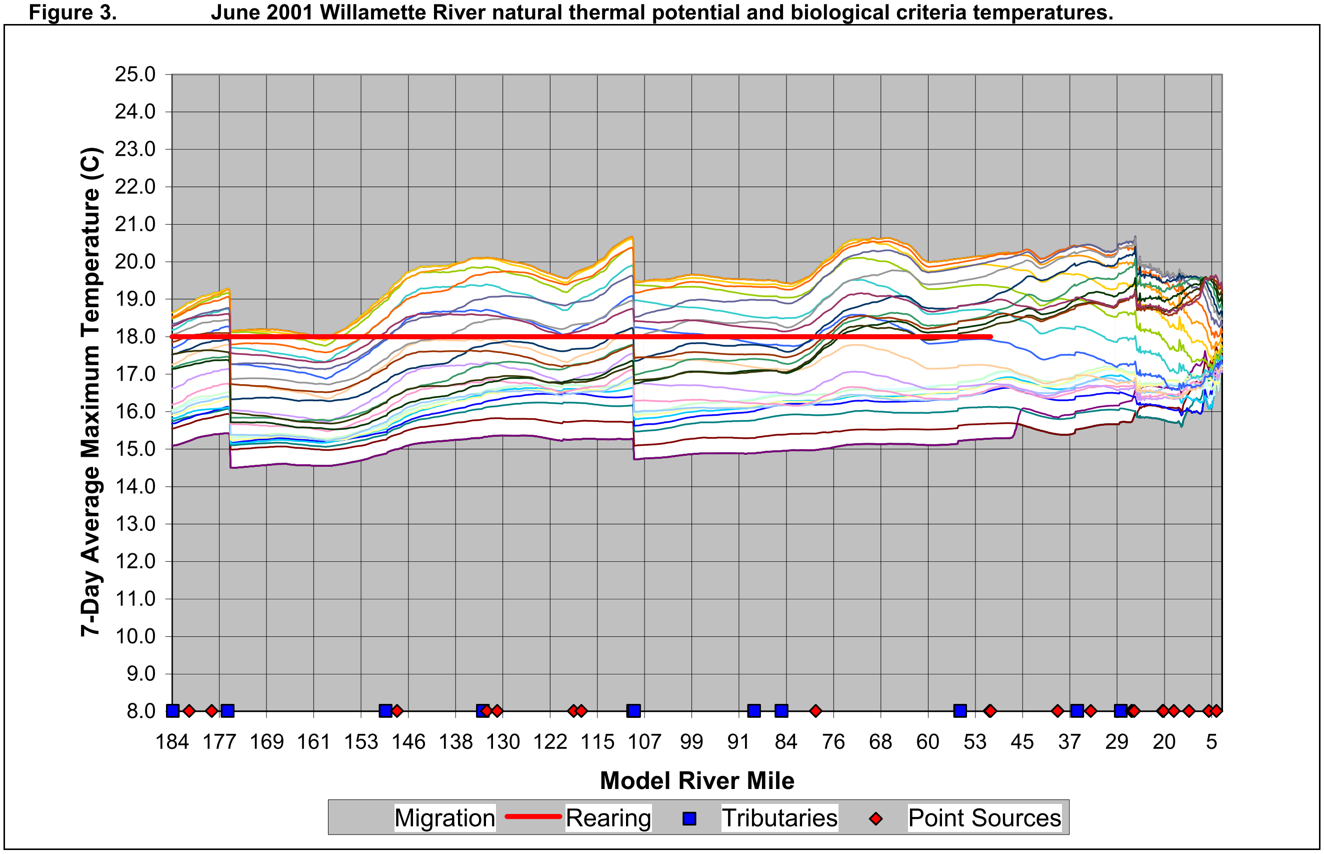


Figure 4. **July 2001 Willamette River natural thermal potential and biological criteria temperatures.**

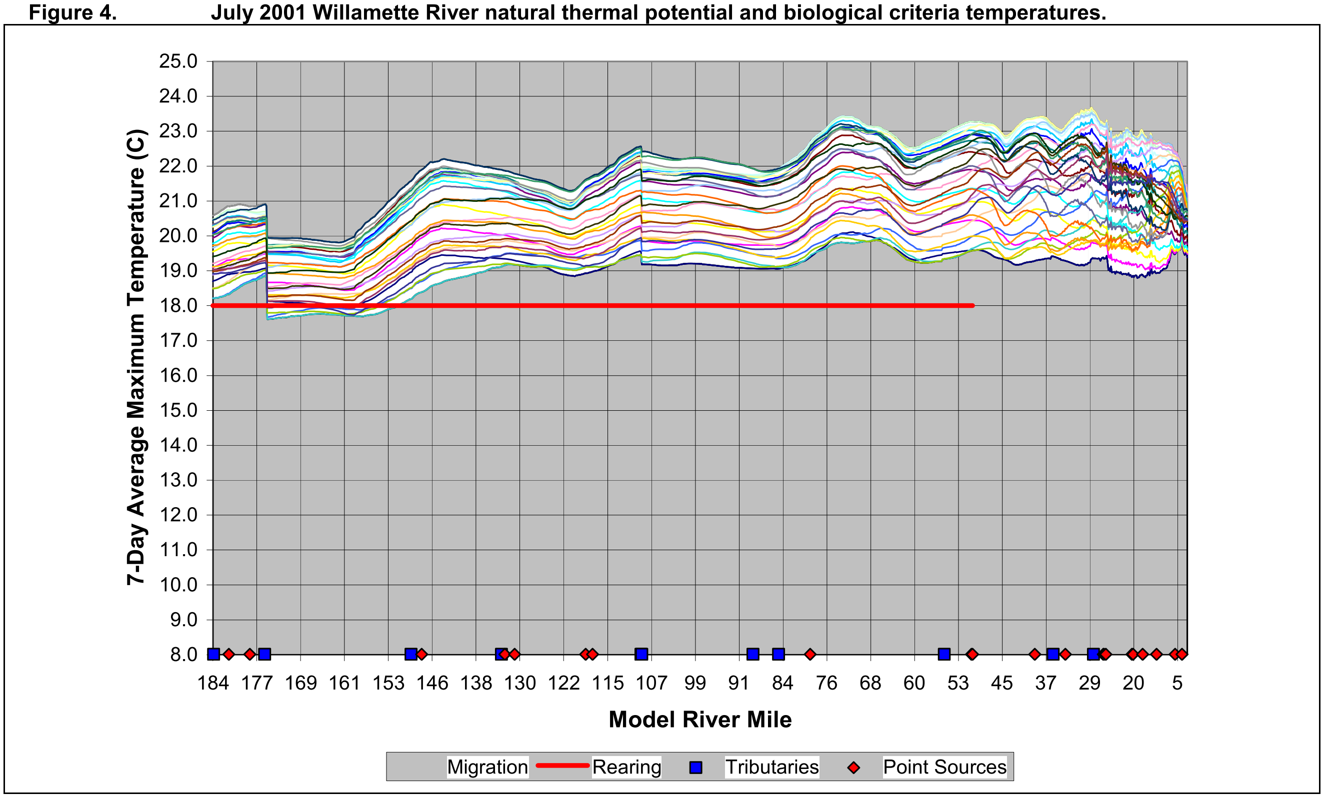


Figure 5. **August 2001 Willamette River natural thermal potential and biological criteria temperatures.**

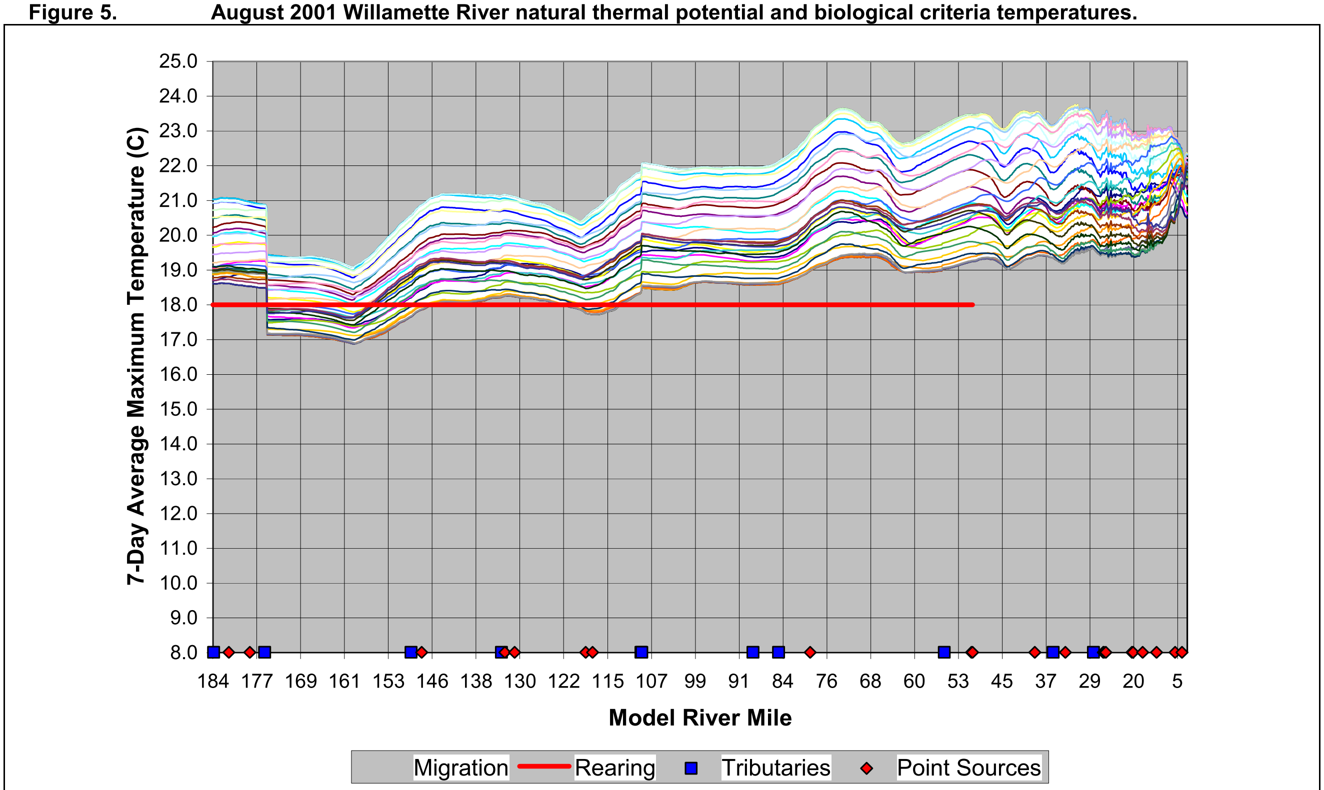


Figure 6. **September 2001 Willamette River natural thermal potential and biological criteria temperatures.**

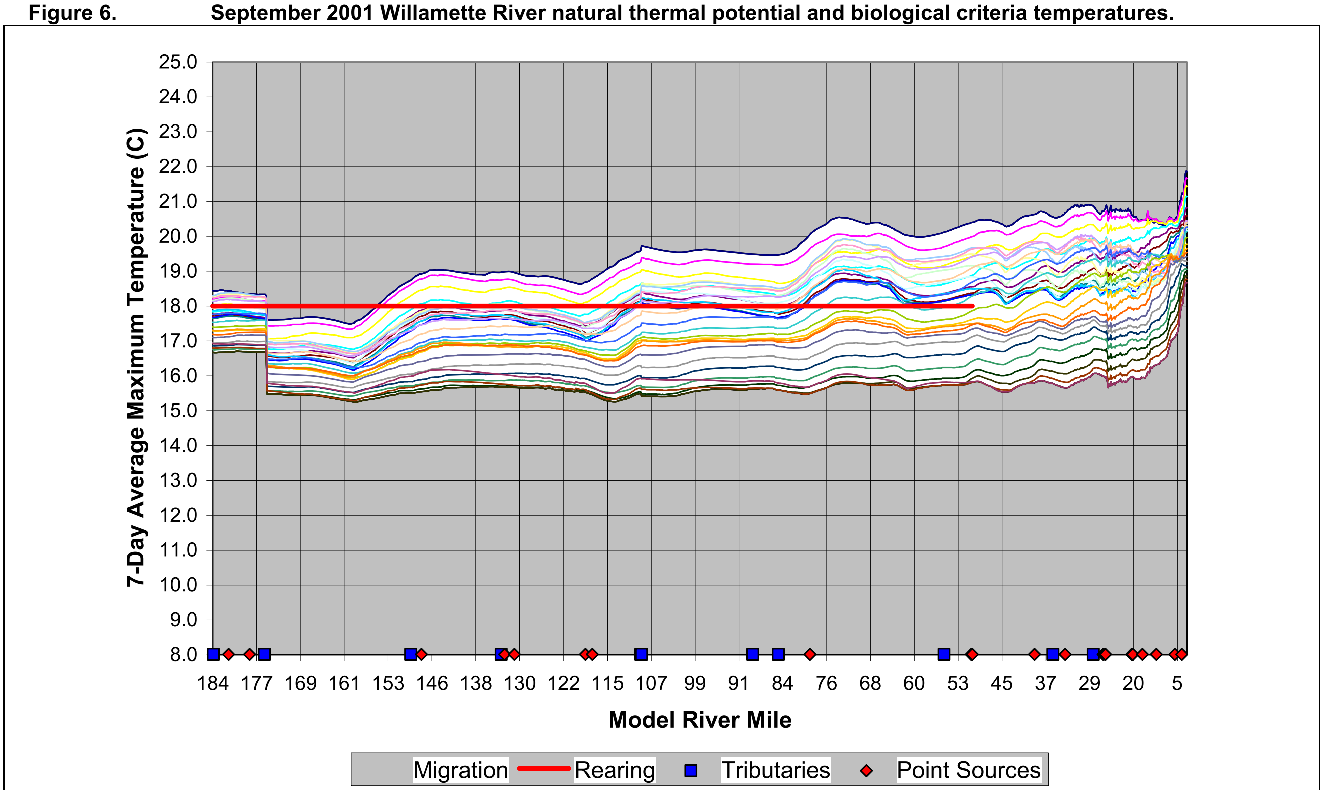


Figure 7. **October 2001 Willamette River natural thermal potential and biological criteria temperatures.**

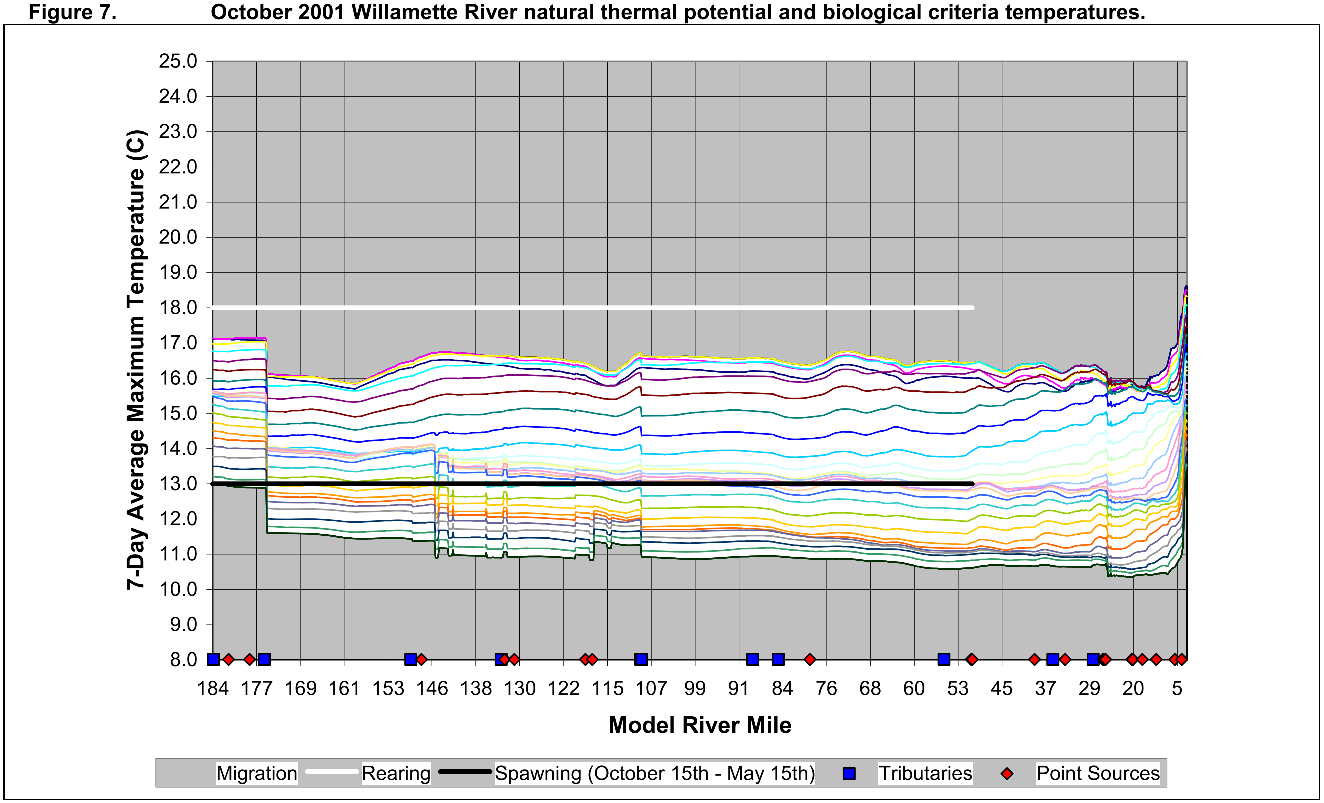


Figure 8. **April 2002 Willamette River natural thermal potential and biological criteria temperatures.**

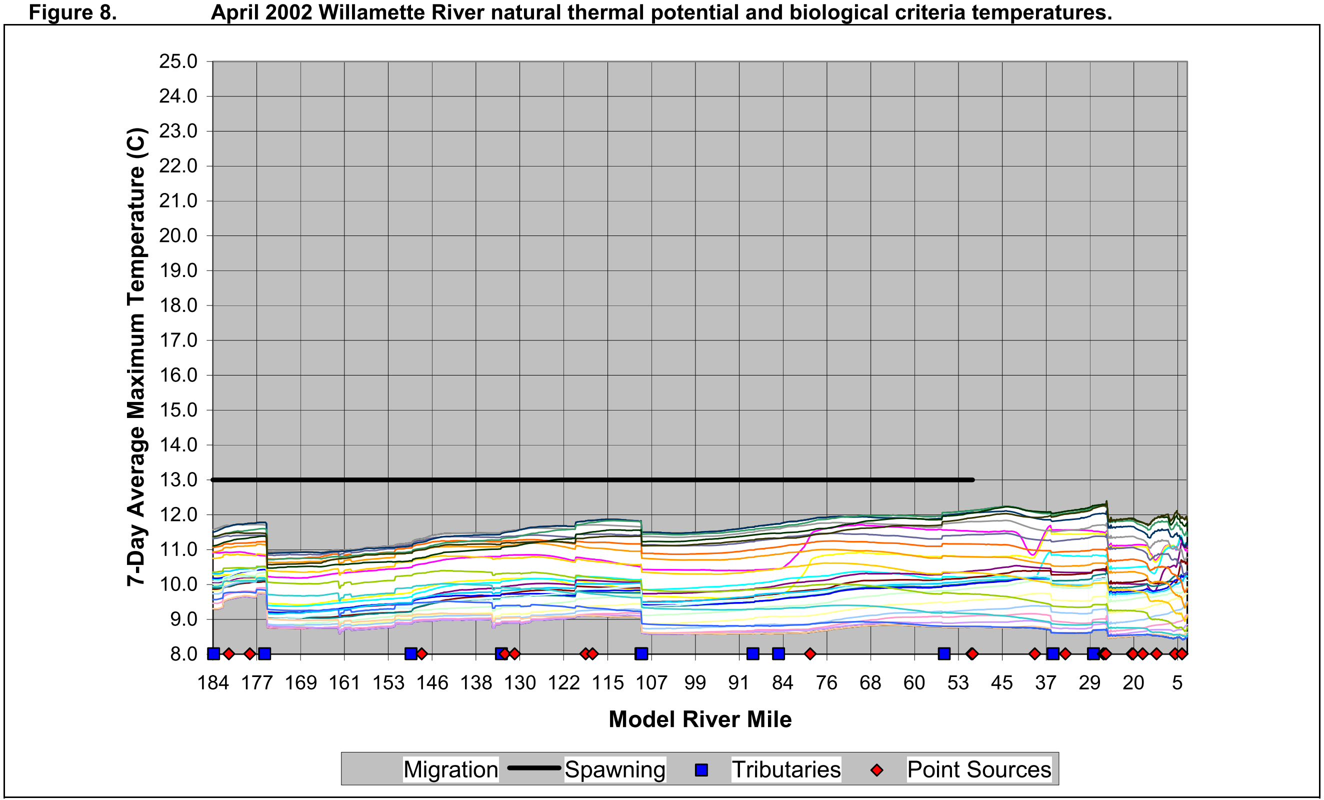


Figure 9. **May 2002 Willamette River natural thermal potential and biological criteria temperatures.**

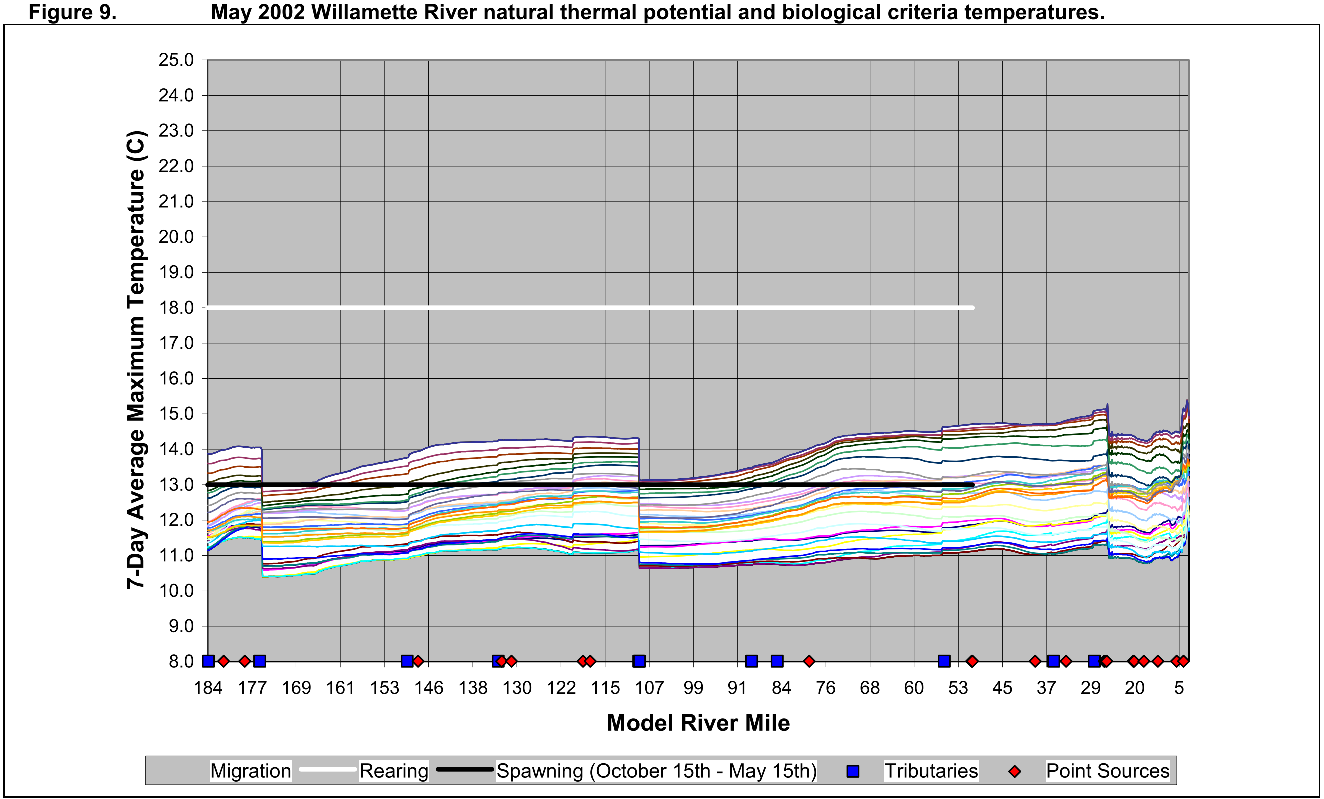


Figure 10. **June 2002 Willamette River natural thermal potential and biological criteria temperatures.**

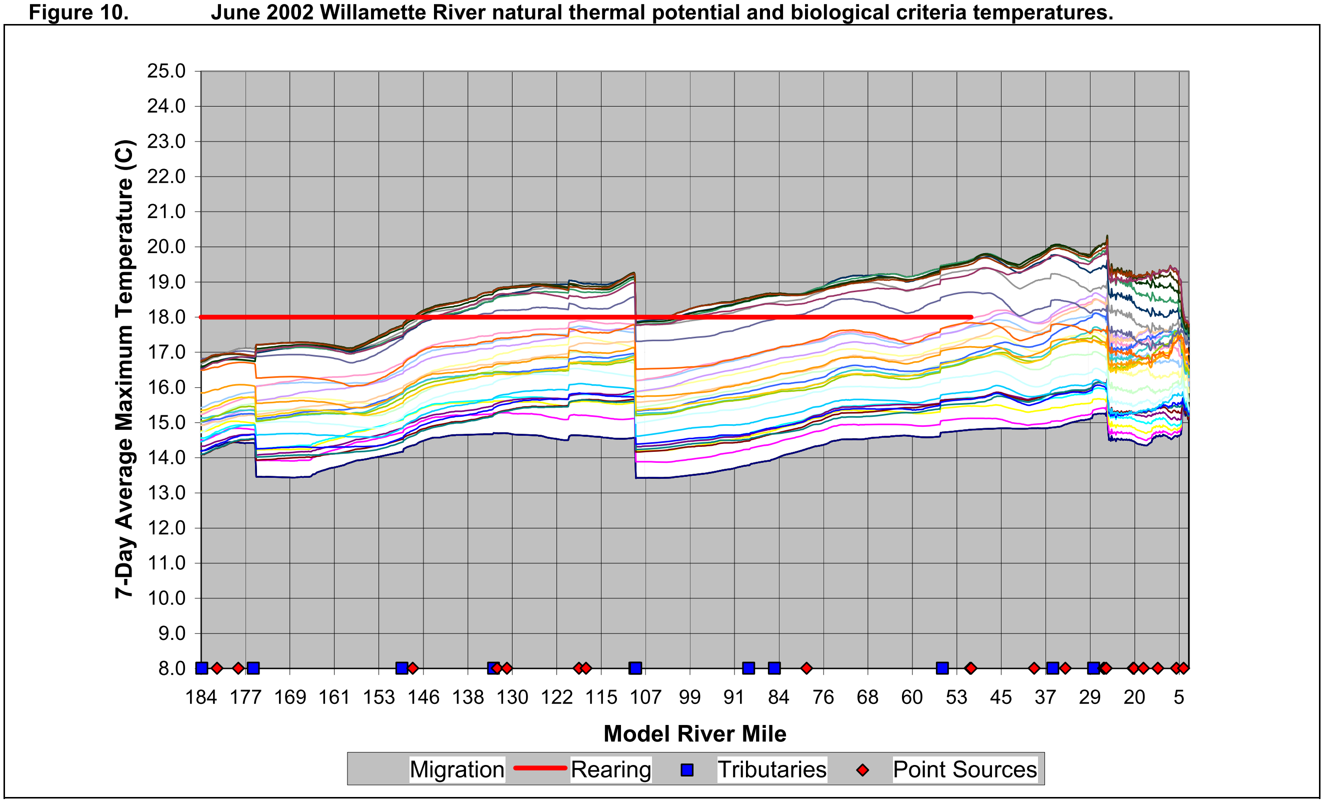


Figure 11. July 2002 Willamette River natural thermal potential and biological criteria temperatures.

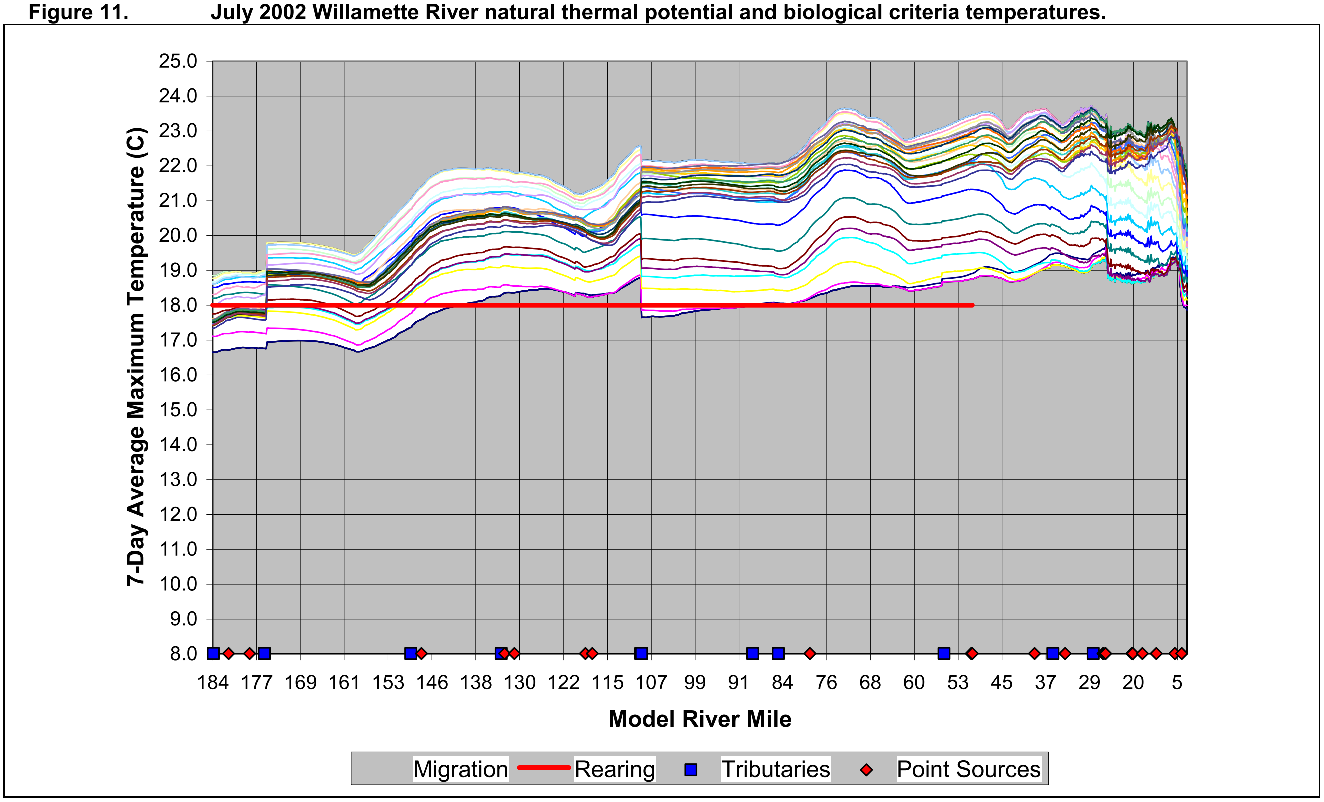


Figure 12. August 2002 Willamette River natural thermal potential and biological criteria temperatures.

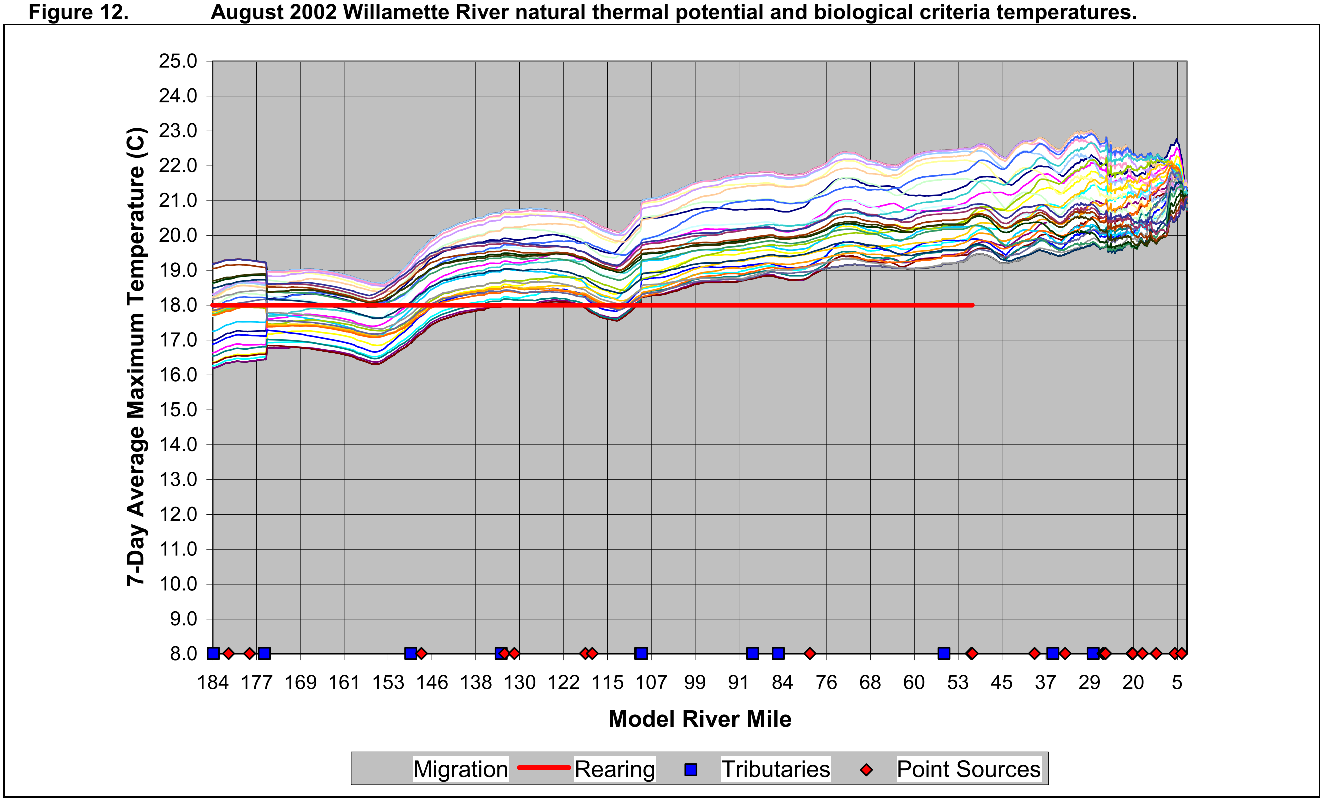


Figure 13. **September 2002 Willamette River natural thermal potential and biological criteria temperatures.**

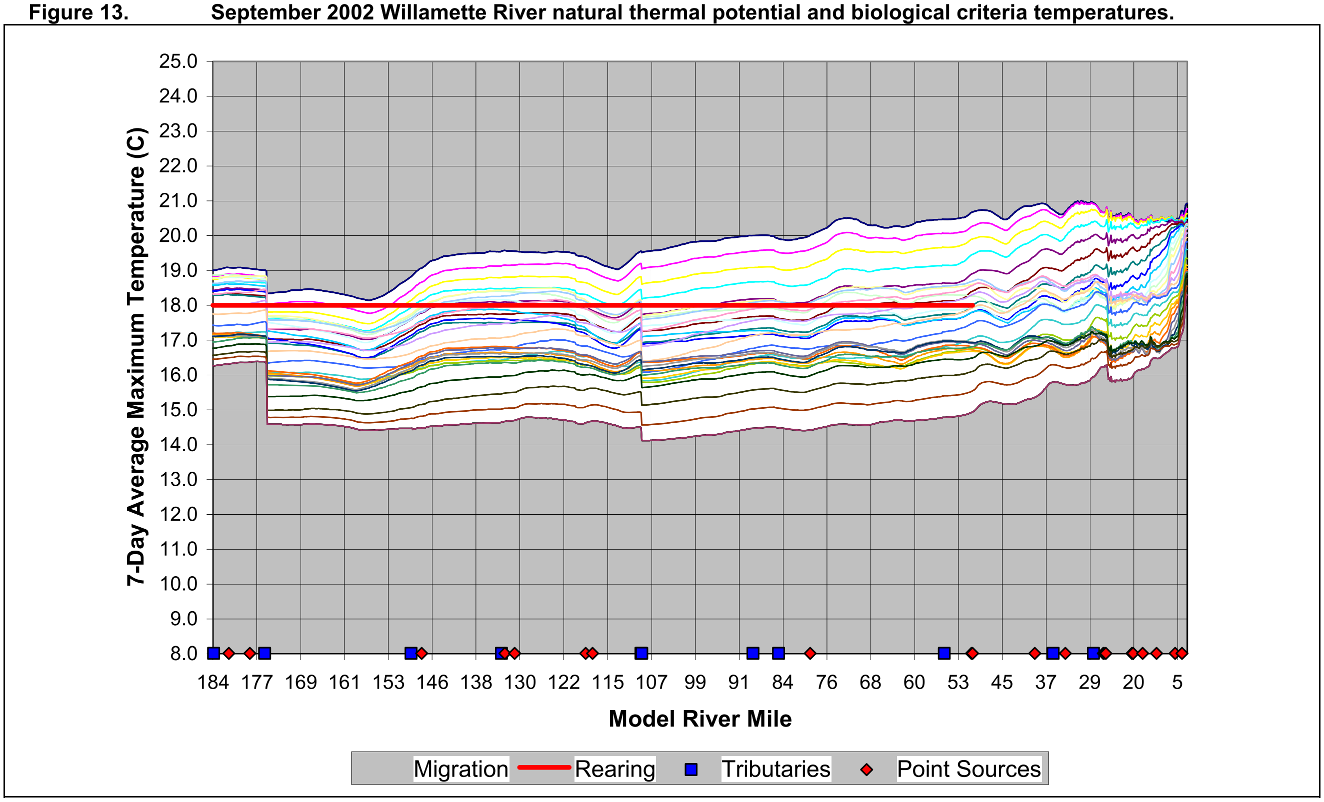
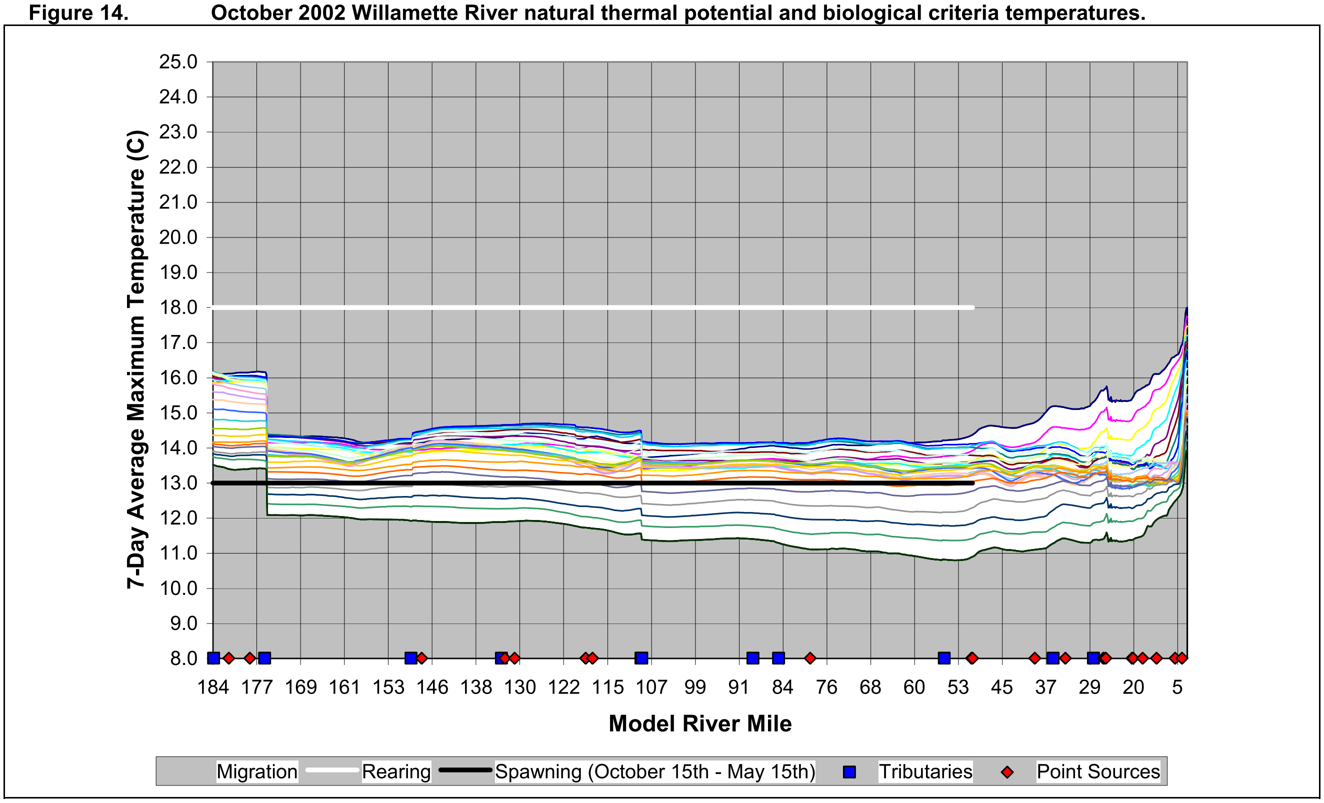


Figure 14. **October 2002 Willamette River natural thermal potential and biological criteria temperatures.**



VI. RESERVOIR NATURAL THERMAL POTENTIAL ANALYSIS

Estimated targets for stream temperature below U.S. Army Corps of Engineers Willamette River Basin Project dams to meet "natural thermal potential" (NTP) temperatures

Purpose and Methodology

This paper describes methodology used to establish load allocations for the U.S. Army Corps of Engineers (USACE) Willamette Project reservoirs. Load allocations were based on no project impact to natural stream temperatures and no portion of the human use allowance was allocated individually or collectively to project reservoirs. Natural thermal potential temperatures were estimated for each stream affected by a project reservoir. These estimates were based on seven-day rolling average water temperature data from streams tributary to each reservoir. NTP estimates were based on flow-weighted temperatures when data from more than one tributary were available. NTP estimates are presented as monthly median values for each reservoir and serve as target temperatures and surrogates for load allocations until further data collection and analysis support their revision.

Recent tributary temperature and flow data were used to develop target temperatures for the discharge point or tail race of USACE reservoirs. This simple approach does not have the accuracy or utililty of TMDL modeling methods used to identify NTP temperature targets and heat allocations lower in the mainstem Willamette River, but it does identify natural seasonal temperature patterns and their differences with current thermal regimes.

Daily average tributary temperatures were used to calculate NTP target temperatures rather than daily maximum upstream temperatures values. Reservoirs dampen diel water temperature fluctuations and results in seven day average daily maximum (7dADM) tailrace temperatures that are similar to seven day average (7dAvg) and minimum temperatures. To address this effect and ensure that downstream temperatures target NTP, reservoir tailrace target temperatures are based on daily average upstream tributary temperatures. Downstream of the tailrace, discharged water will be subjected to normal meteorological processes and some diel temperature fluctuation and separation of daily minimums and maximums will be realized. Reservoir effects on tail water temperatures and downstream heating effects are discussed in greater detail in Chapter Four, the Willamette Temperature TMDL and its appendices which detail hydroelectric project load allocations.

Moving seven day average temperatures for two to three years of data were compiled and median values for each month calculated for each USACE reservoir. This median value is the tailrace target temperature and serves as the NTP and load allocation surrogate until revised. Reservoir load allocation target temperatures are generally warmer in summer than currently observed but cooler in late summer and early autumn. Salmon migration, spawning, egg and fry development are closely tied to seasonal temperatures and water quality standards require restoration of a natural thermal regime. Implementation of the surrogate measures or revised NTP targets will restore much of the natural seasonal thermal regime of downstream river reaches, but full restoration of the temporal and spatial thermal diversity is unlikely in river reaches downstream from each reservoir as the reservoirs will continue to dampen diel fluctuation in temperature and modify spatial thermal patterns.

ODEQ anticipates these target temperatures will be revised. Targets were based on thermistor data from locations often well upstream of slack water of each reservoir and do not account for heating that naturally occurs as waters flow downstream from tributary monitoring points to the tailrace location. USACE has demonstrated that historical temperature data collected near the current location of Cougar Dam are warmer than load allocation targets developed by ODEQ. Median seven day average temperature targets developed with thermistors data from locations above the reservoir are at or below the range of historical average monthly temperatures.

Nonpoint sources of heat included in the current load allocations will also be addressed when load allocations are revised. USACE reservoirs are located in landscapes historically managed for timber production, mining and recreation and these activities may influence the reservoir tributary temperatures used to calculate target temperatures. Reductions in temperature may occur in streams above reservoirs as system potential vegetation targets are met.

Calculated Stream Temperature Targets

Calculated stream temperature targets are presented in Table 1. All USACE load allocations are applicable April through October because this is the period when stream temperatures in the Willamette may exceed biologically-based criteria. Load allocations are also necessary for the month of November for those reservoirs that release water with temperatures in excess of the 13°C spawning criterion. Included on this list are the Middle Fork Willamette Projects, the McKenzie Projects, and the Santiam Projects. Insufficient data were available to calculate these November targets but it is anticipated that attainment of October load allocations will also result in attainment of November allocations

The load allocation temperature targets shown in bold in Table 1 were based on median seven day average tributary temperatures for each month. When insufficient data were available to calculate this statistic, load allocation temperature limits were based on average month-to-month changes in temperature for stations for which data were available. Average month-to-month observed changes in monthly median seven day average are shown in Table 2.

Table 1. Estimated seven day average stream temperatures targets (°C) that meet the "Natural Thermal Potential" load allocation for USACE reservoirs.

Subbasin:	Coast Fork Willamette	Coast Fork Willamette	Middle Fork Willamette	Middle Fork Willamette	Middle Fork Willamette	McKenzie	McKenzie	South Santiam	North Santiam	Upper Willamette
Reservoirs:	**Cottage Grove**	**Dorena**	**Hills Creek**	**Dexter/ Lookout Pt.**	**Fall Creek**	**Cougar**	**Blue**	**Foster/ Green Peter**	**Big Cliff/ Detroit**	**Fern Ridge**
Jan										
Feb										
Mar										
Apr	*9.4*	*8.8*	*5.8*	6.5	*6.5*	**5.5**	**5.5**	*6.1*	**5.4**	*9.0*
May	**11.4**	**10.8**	**7.8**	8.6	*8.6*	**7.7**	**7.6**	**8.2**	**7.3**	*10.8*
Jun	**15.5.0**	**16.5**	**11.0**	13.2	*12.2*	**10.0**	**9.9**	**12.4**	**9.7**	**14.6**
Jul	**19.9**	**22.3**	**14.2**	17.4	**15.9**	**11.7**	**11.2**	**18.4**	**12.8**	**16.7**
Aug	**18.3**	**20.4**	**13.6**	16.5	**15.8**	**10.9**	**10.6**	**18.0**	**12.8**	**16.0**
Sep	**16.4**	**18.2**	**12.5**	13.9	**13.5**	**9.5**	**9.5**	**15.5**	**10.9**	**14.0**
Oct	*13.5*	*15.3*	*9.6*	10.2	*10.6*	**7.2**	**7.2**	*12.6*	**7.7**	**8.0**
Nov			*9.6*	10	*10*	**7.2**	**7.2**	*10*	**7.7**	
Dec										

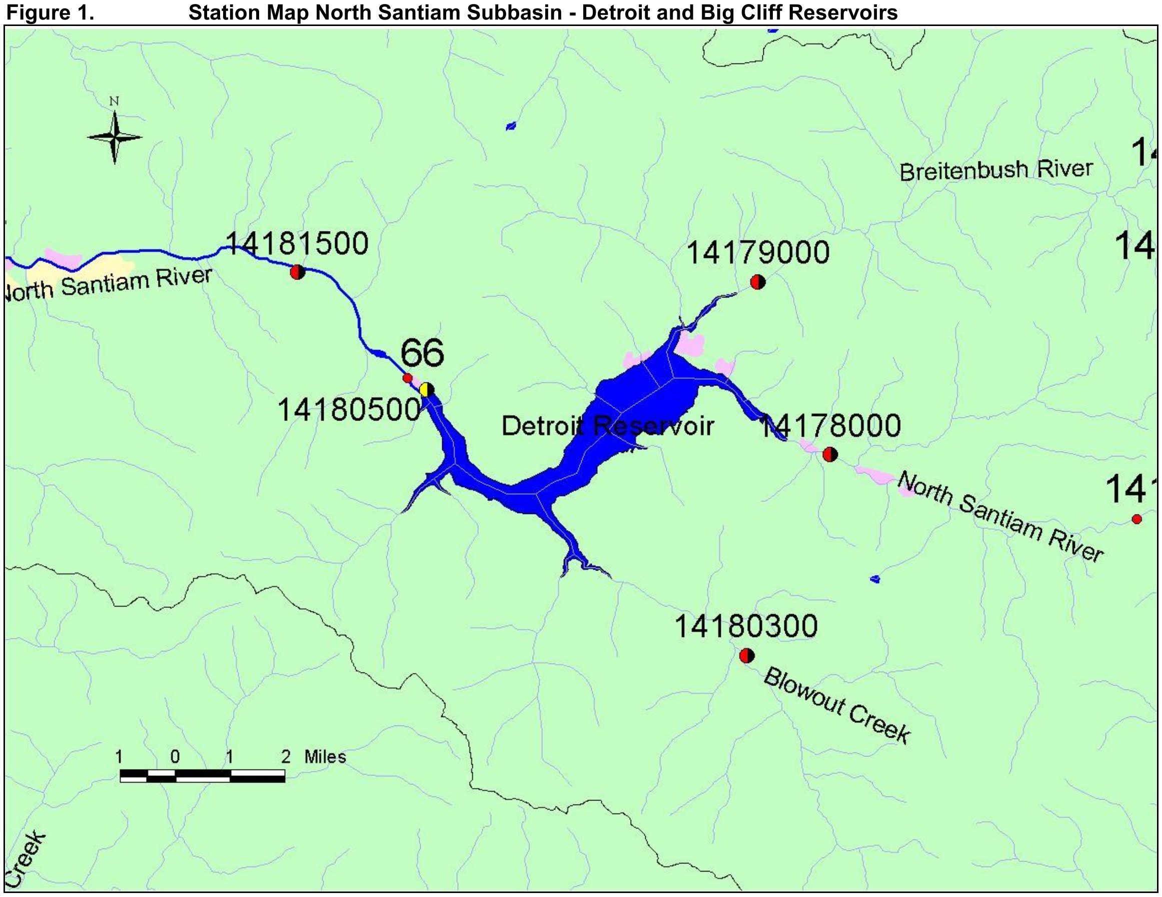
Table 2. Month to month change in stream temperatures above USACE Reservoirs

Months	Average Observed Change in Median 7dAvg
April to May	2.1
May to June	3.6
June to July	3.7
July to August	-0.8
August to September	-1.9
September to October	-2.0

North Santiam Subbasin

Natural thermal potential temperature targets for the North Santiam River were based on flow-weighted average temperatures of major streams that discharge to Detroit Reservoir reservoirs. Most of the flow to Detroit Reservoir is provided by the upper North Santiam River, Breitenbush River, and Blowout Creek (Figure 1).

Figure 1. Station Map North Santiam Subbasin - Detroit and Big Cliff Reservoirs



USGS gages on the three tributary streams and on the North Santiam River downstream from Detroit Reservoir continuously monitor stream flow and temperature. Flow-weighted average temperatures for streams above the reservoir (U/S T-C), as well as temperatures for the gage below the reservoir (D/S T-C), are shown in Figure 2,3, and 4 (flow-weighted average temperature calculated by USGS). Seven day rolling average for tributary temperatures for 2000, 2001 and 2002 are shown in Figure 5. Biologically-based numeric criteria for salmon and steelhead trout spawning and rearing are also shown. Observed downstream temperatures are compared to upstream target temperatures and biological criteria in Figure 2. As shown in Figure 4, temperatures downstream from Detroit Reservoir were considerably cooler than upstream temperatures in the summer and considerably warmer than upstream temperatures in the fall. This is typical of large storage reservoirs with deep outlets. Upstream and downstream temperature data for three years are averaged in Figure 7. The averaged upstream temperatures serve as a surrogate load allocation for Detroit Reservoir. Temperature targets were met in the summer of 2000 and 2002 but exceeded in 2001. Temperatures in all three years exceeded fall spawning criteria and surrogate load allocation targets.

Figure 2. **Temperature upstream (flow-weighted mix) and downstream of Detroit Reservoir – 2000**

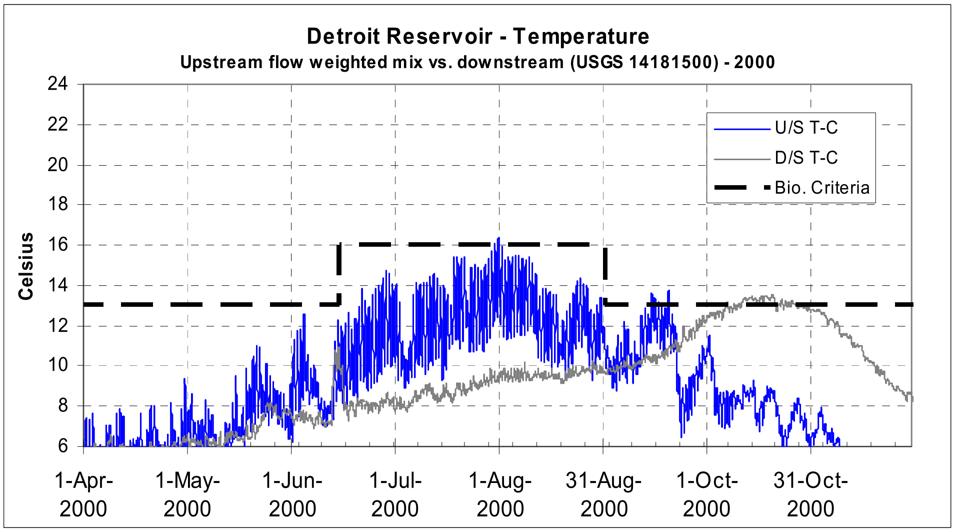


Figure 3. **Temperature upstream (flow-weighted mix) and downstream of Detroit Reservoir - 2001**

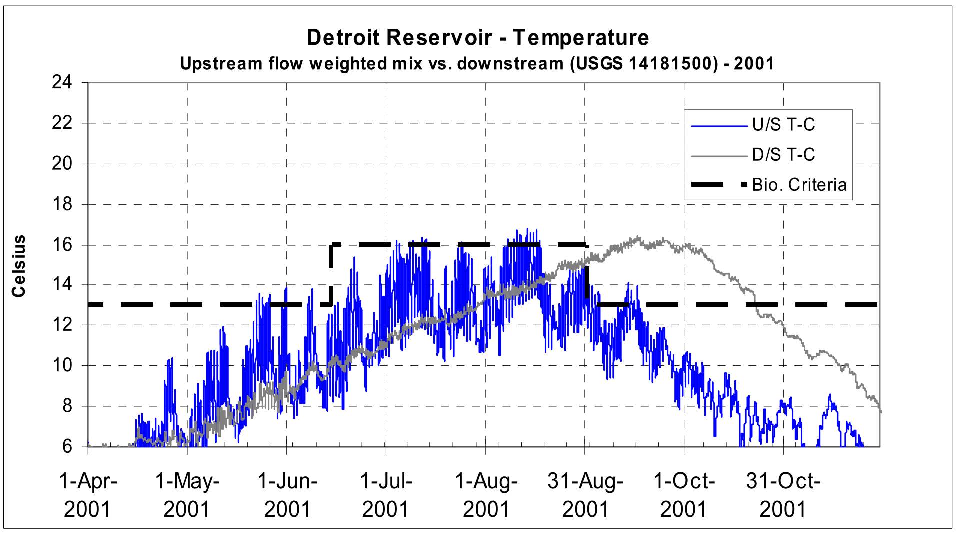


Figure 4. **Temperature upstream (flow-weighted mix) and downstream of Detroit Reservoir – 2002**

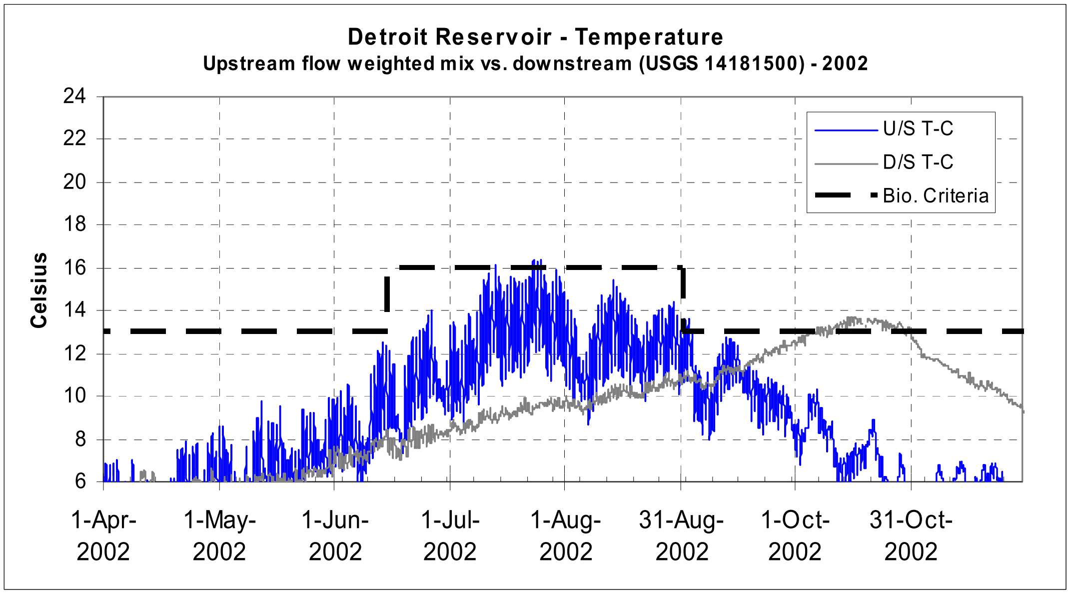


Figure 5. **Detroit Reservoir –Seven day average of upstream daily average temperatures 2000, 2001 and 2002.**

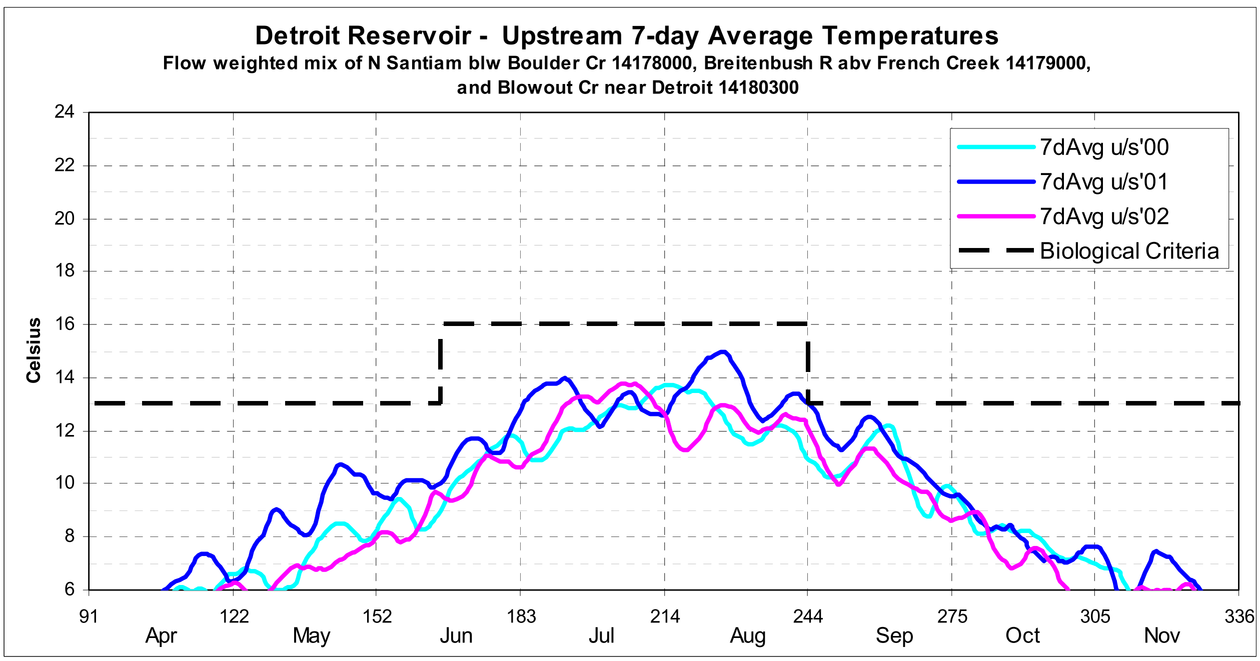


Figure 6. **Detroit Reservoir - Target "natural thermal potential" temperatures vs. current downstream temperatures.**

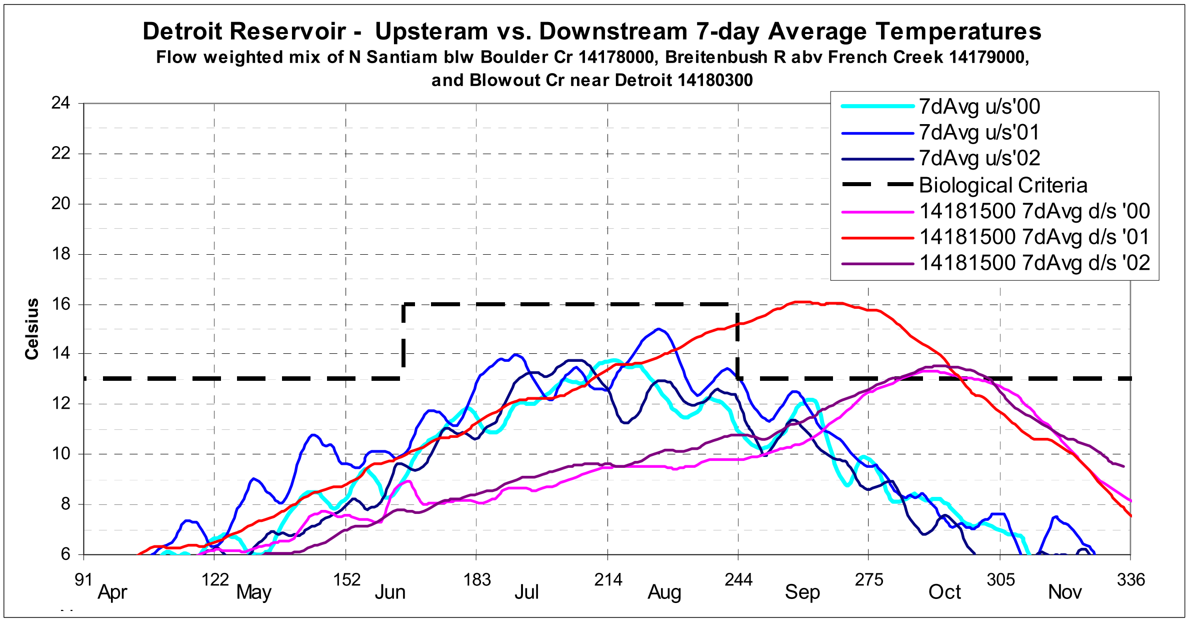
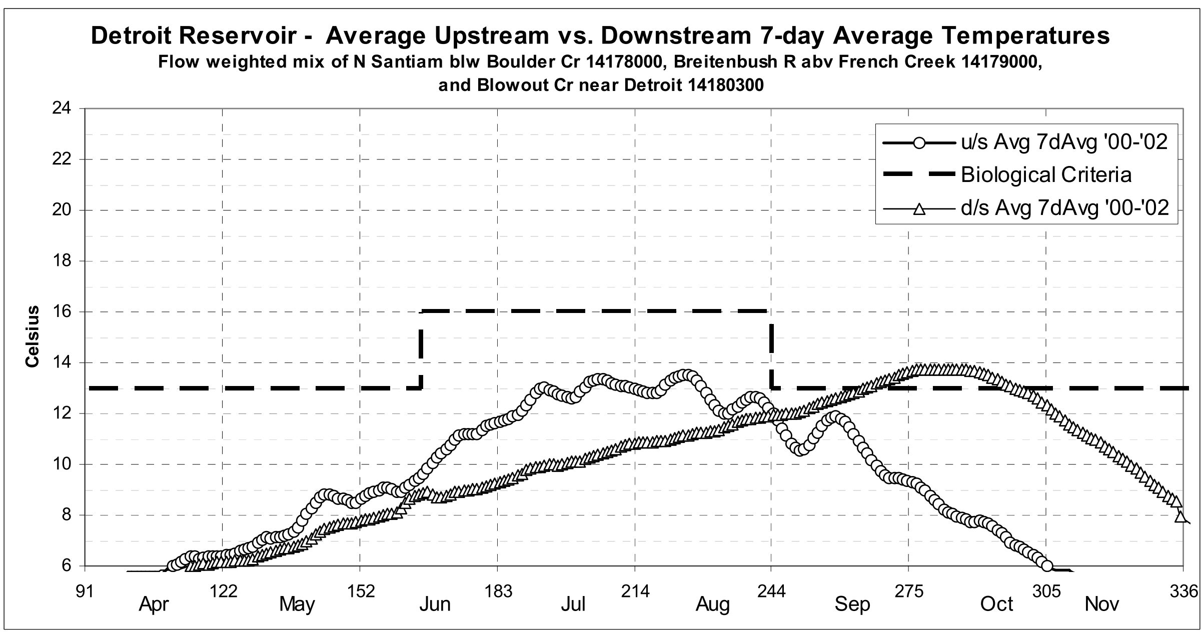


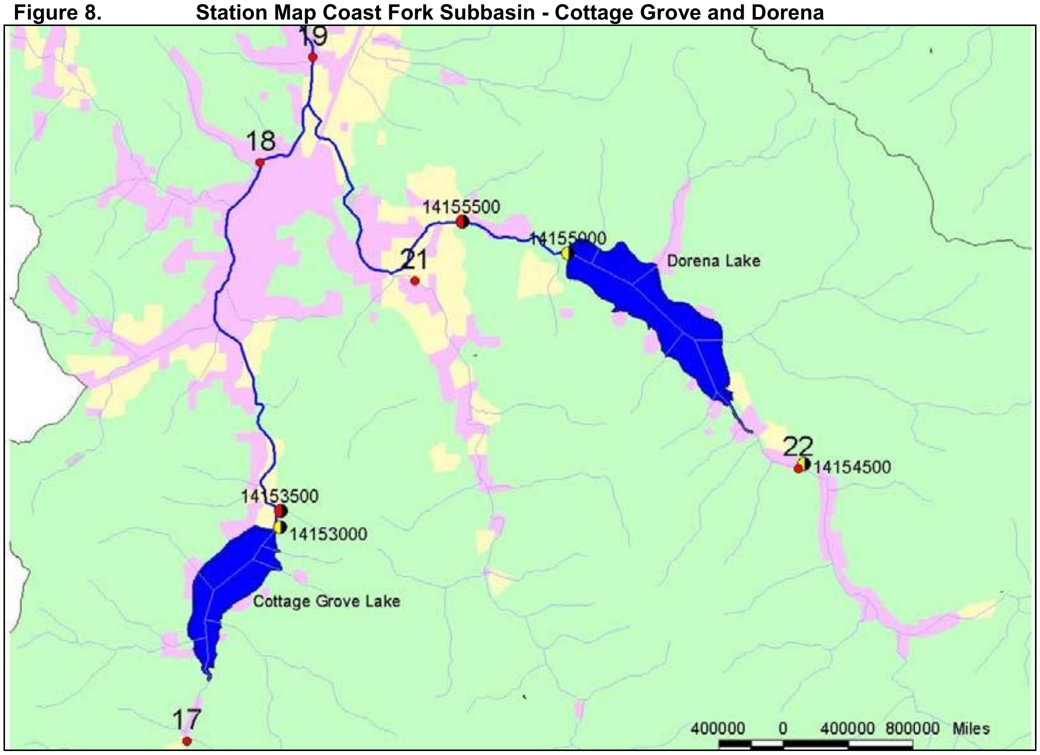
Figure 7. **Average of 2000, 2001 and 2002 data above and below Detroit Reservoir.**



Coast Fork Willamette Subbasin

Two major USACE reservoirs are present in the Coast Fork Willamette Subbasin. Cottage Grove Lake is located on the Coast Fork Willamette River and Dorena Lake on the Row River. Thermistors were deployed seasonally above Cottage Grove and Dorena Reservoirs, while year-round flow and temperature monitoring was performed at USGS gages downstream from the reservoir (Figure 8).

Figure 8. Station Map Coast Fork Subbasin - Cottage Grove and Dorena



Cottage Grove Lake

Figures 9 and 10 compare 2001 and 2002 temperatures upstream of Cottage Grove Lake to downstream temperatures (USGS gage no. 14153500). As shown, downstream temperatures are cooler than upstream temperatures in June through mid to late August, and warmer in late August and September. Figure 11 shows upstream and downstream seven day average temperatures for 2001 and 2002.

Figure 9. Temperature upstream and downstream of Cottage Grove Reservoir - 2001

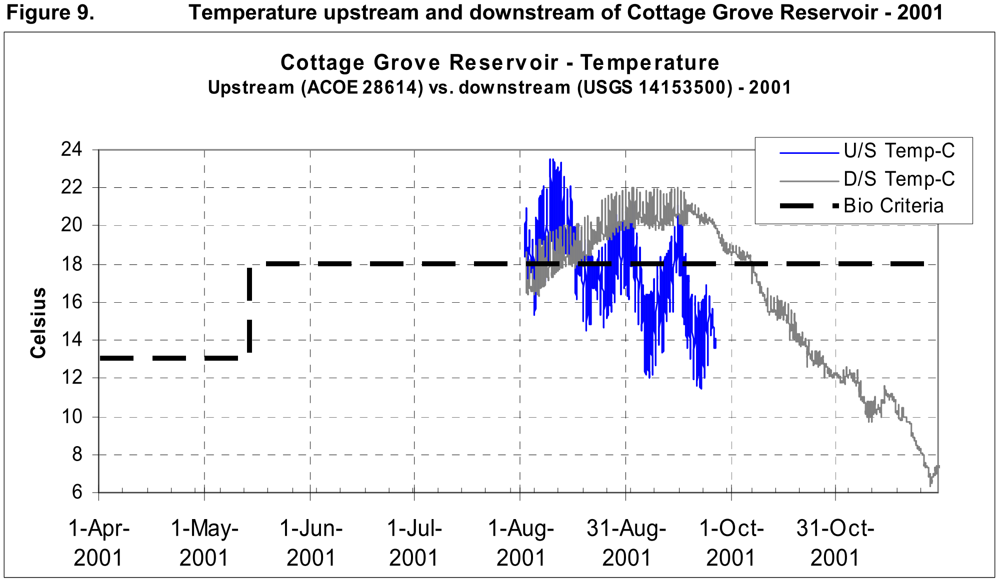


Figure 10. **Temperature upstream and downstream of Cottage Grove Reservoir – 2002**

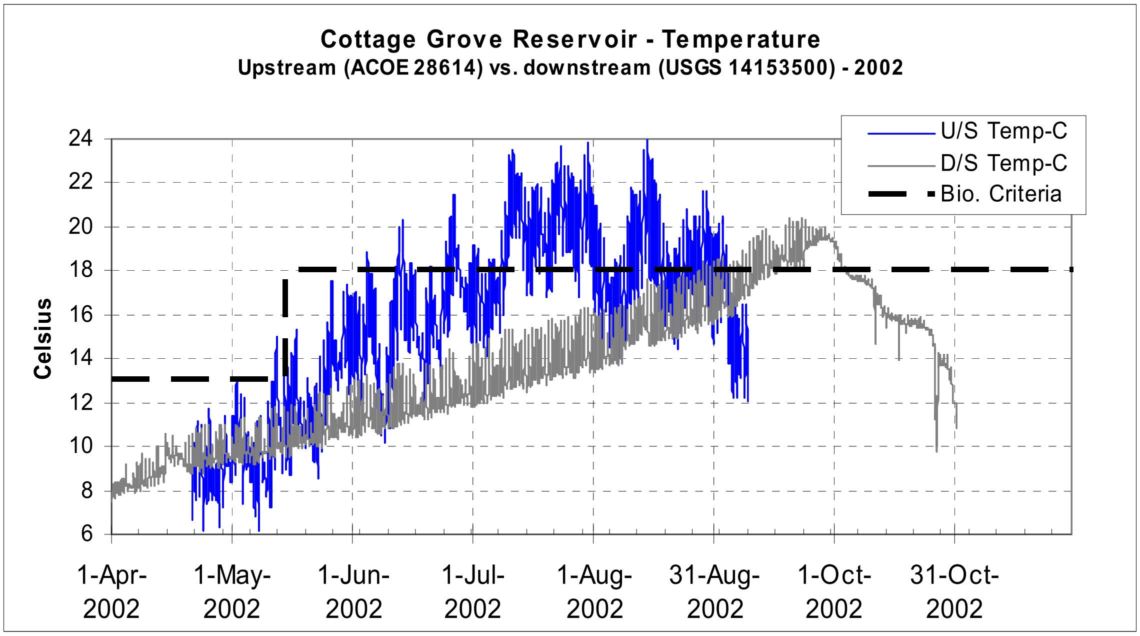
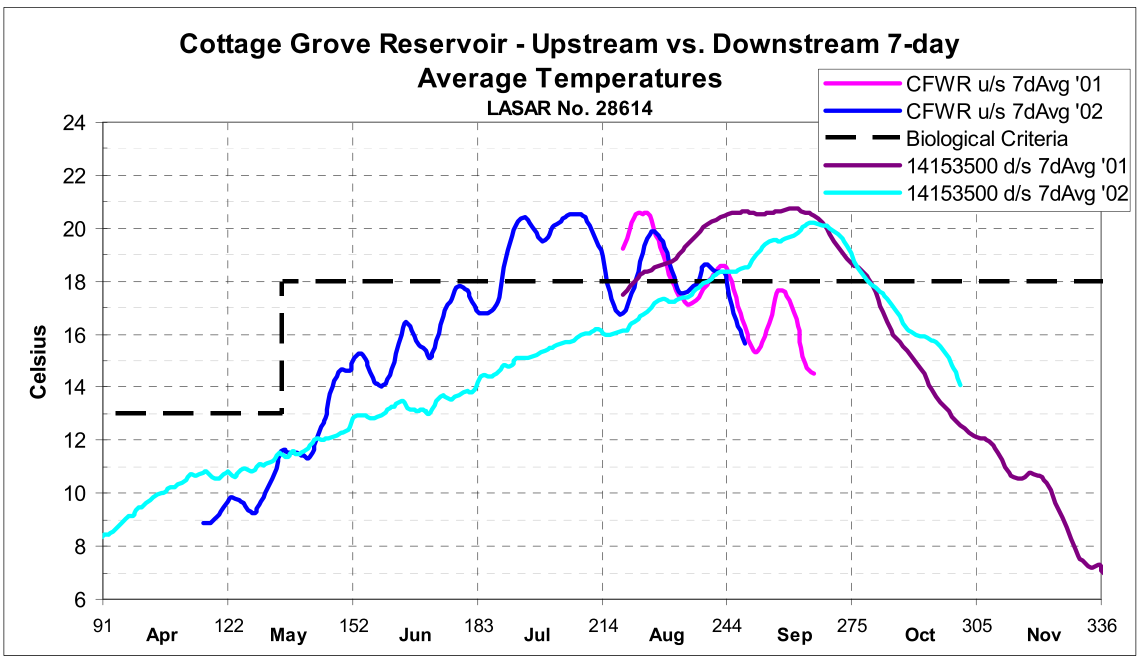


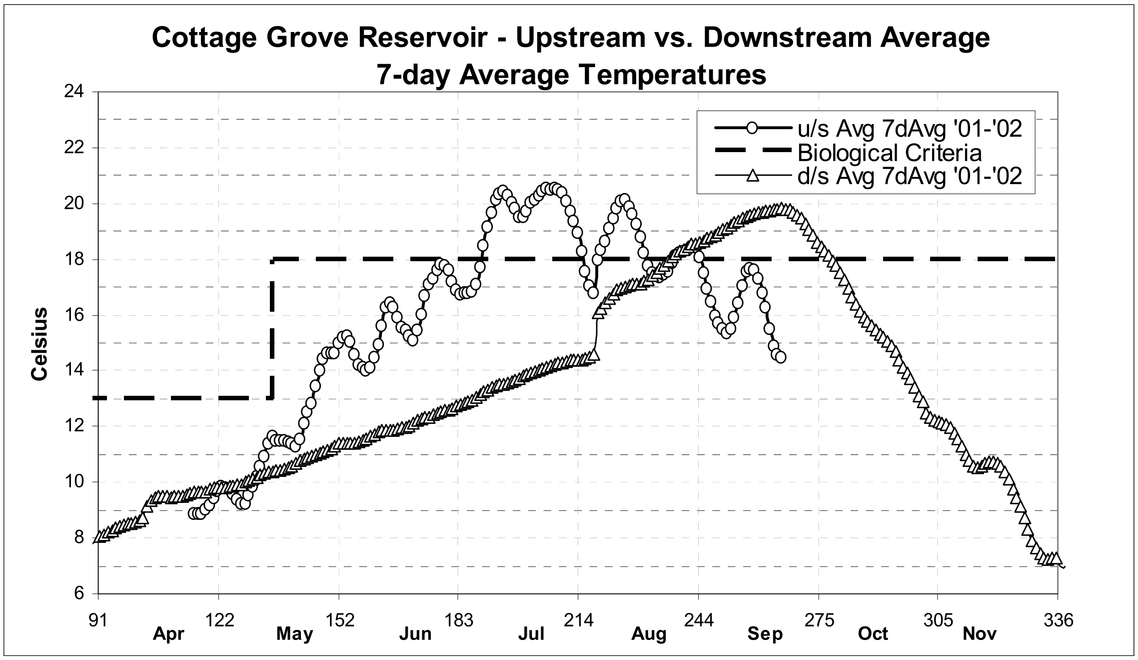
Figure 11. **Cottage Grove Reservoir - upstream and downstream seven day average temperatures**



The medians are used as the estimated target tailrace temperatures that would meet natural thermal potential temperature in the reaches downstream from the reservoir. Insufficient upstream data was available to directly calculate targets for April, October, and November. For these months targets are based on average month-to-month changes in temperature for stations for which data was available.

Figure 12 compares downstream temperatures to target temperautres. As shown, the targets tend to be met in June and July and are exceeded in August through October. The targets are also exceeded in May.

Figure 12. Cottage Grove Reservoir - Target "natural thermal potential" temperatures vs. current downstream temperatures



Dorena Lake

Figure 13 and 14 compare 2001 and 2002 Row River temperatures upstream of Dorena Lake reservoir (Figure 18) to temperatures downstream (USGS gage no. 14155500). Figure 15 shows upstream and downstream seven day average temperatures for 2001 and 2002.

Figure 13. Temperature upstream and downstream of Dorena Lake - 2001

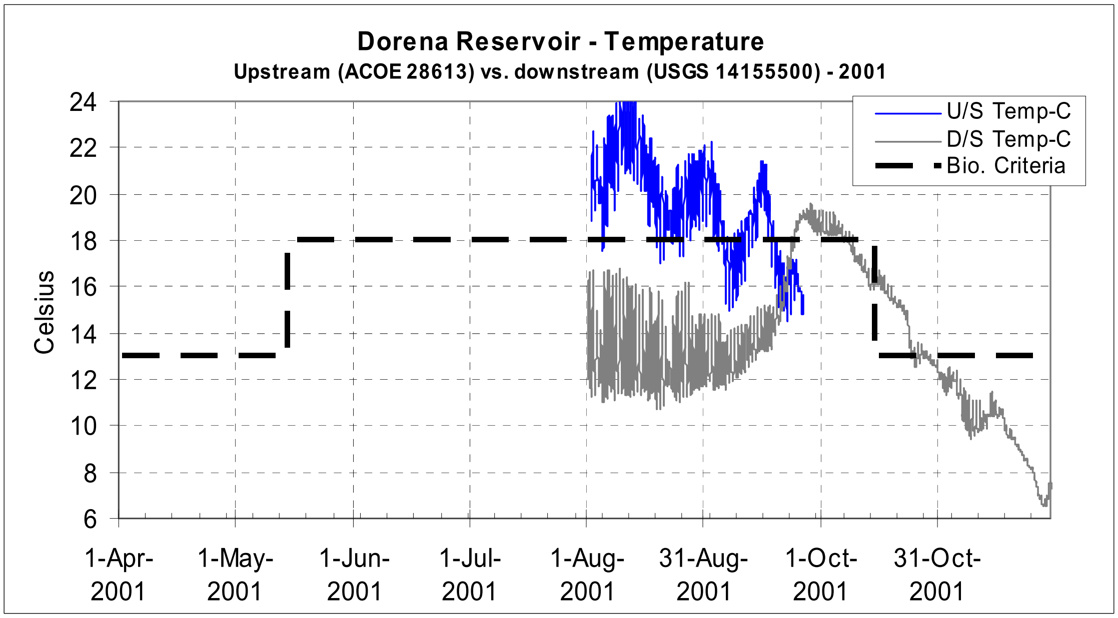


Figure 14. Temperature upstream and downstream of Dorena Lake - 2002

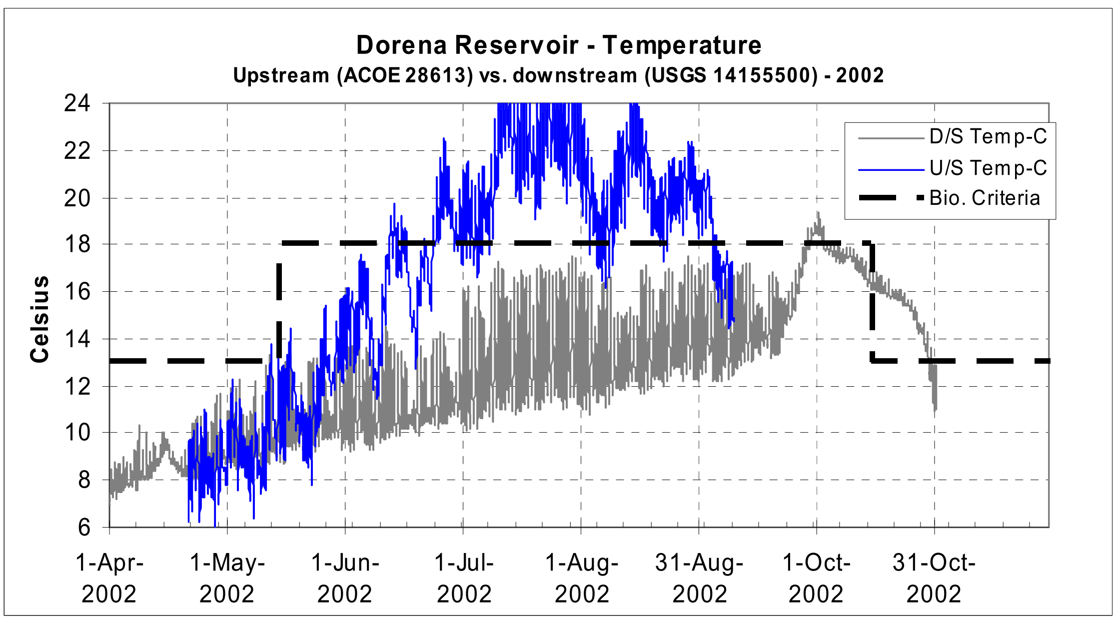


Figure 15. **Dorena Lake - upstream and downstream seven day average temperatures**

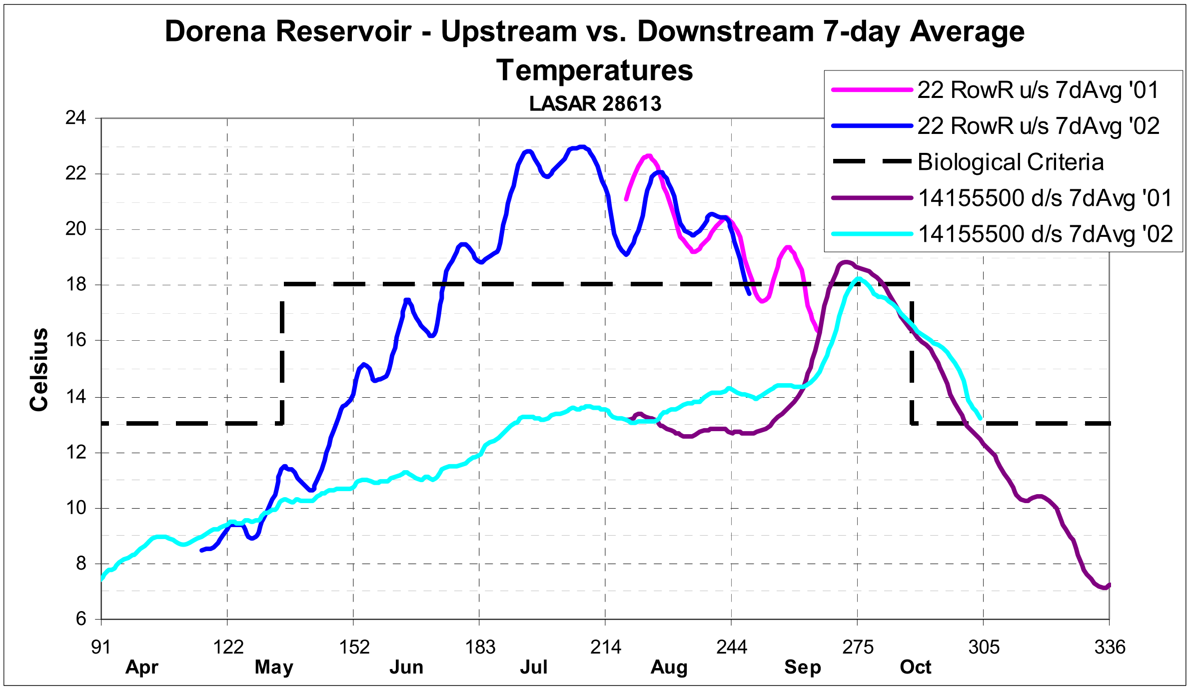
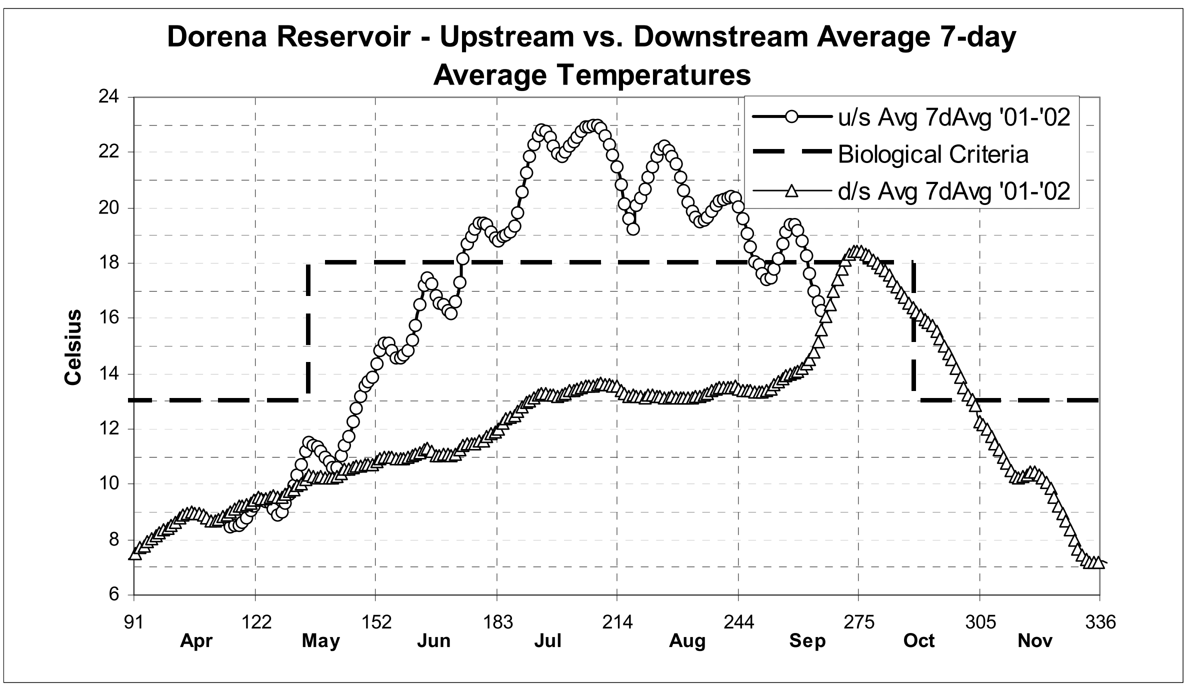


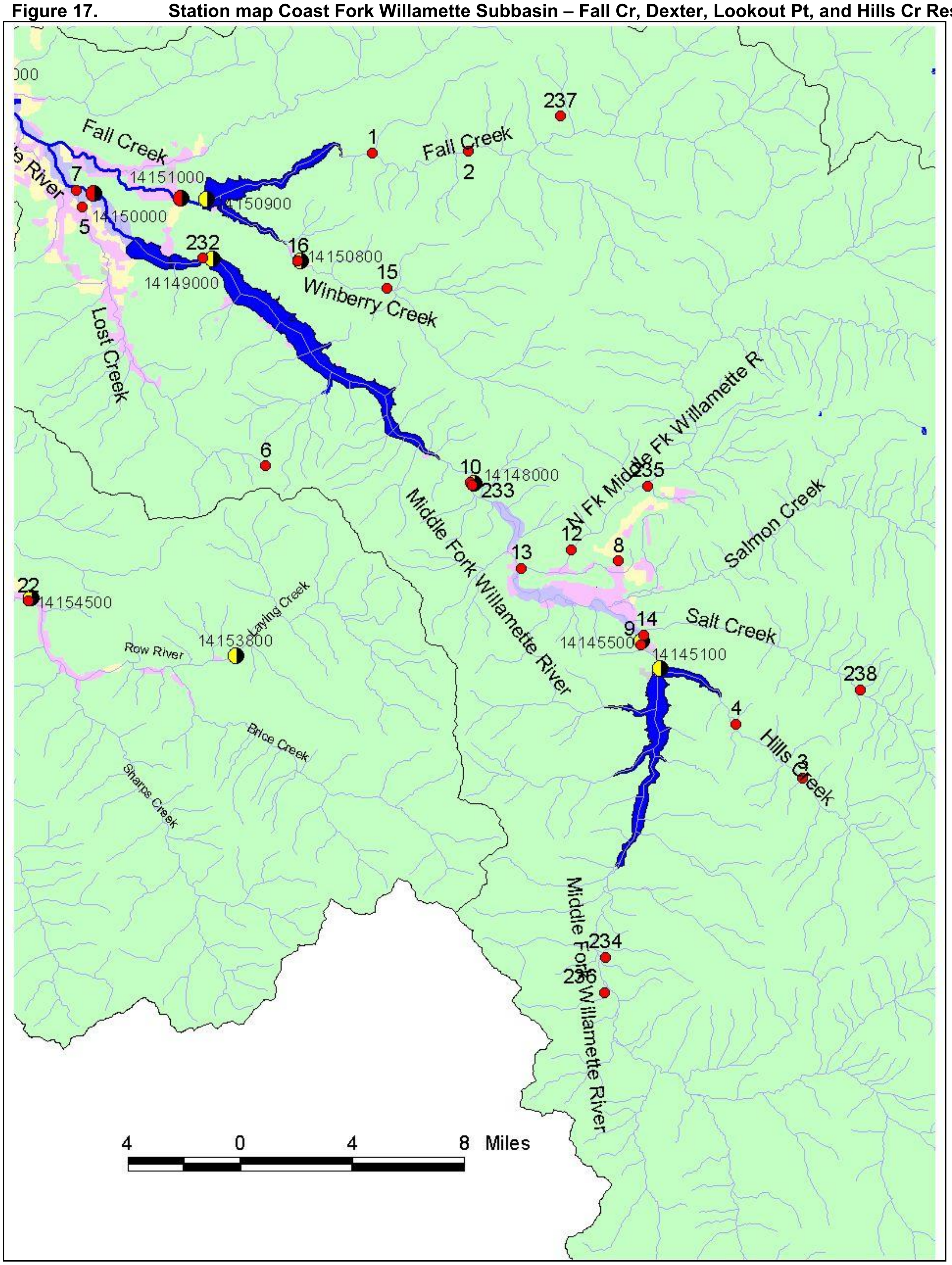
Figure 16 compares average seven day average temperatures downstream of Dorena reservoir upstream target temperatures. As shown, the targets tend to be met through late September and exceeded in early autumn.

Figure 16. **Dorena Lake - Target "natural thermal potential" temperatures vs. downstream temperatures**



Middle Fork Willamette Subbasin

Figure 17. Station map Coast Fork Willamette Subbasin – Fall Cr, Dexter, Lookout Pt, and Hills Cr Reservoirs



Fall Creek Reservoir

Continuous temperature data at stations above and below Fall Creek Reservoir are presented below. Seven day average and seven day average of daily maximum flow-weighted upstream temperatures are presented in Figure 18. Seven day average temperatures above and below the reservoir are presented in Figure 19. Averaged seven day average of daily temperatures immediately downstream from the reservoir are compared to the target temperatures in Figure 20

Figure 18. **Fall Creek Reservoir – 2001 upstream temperatures and biological criteria**

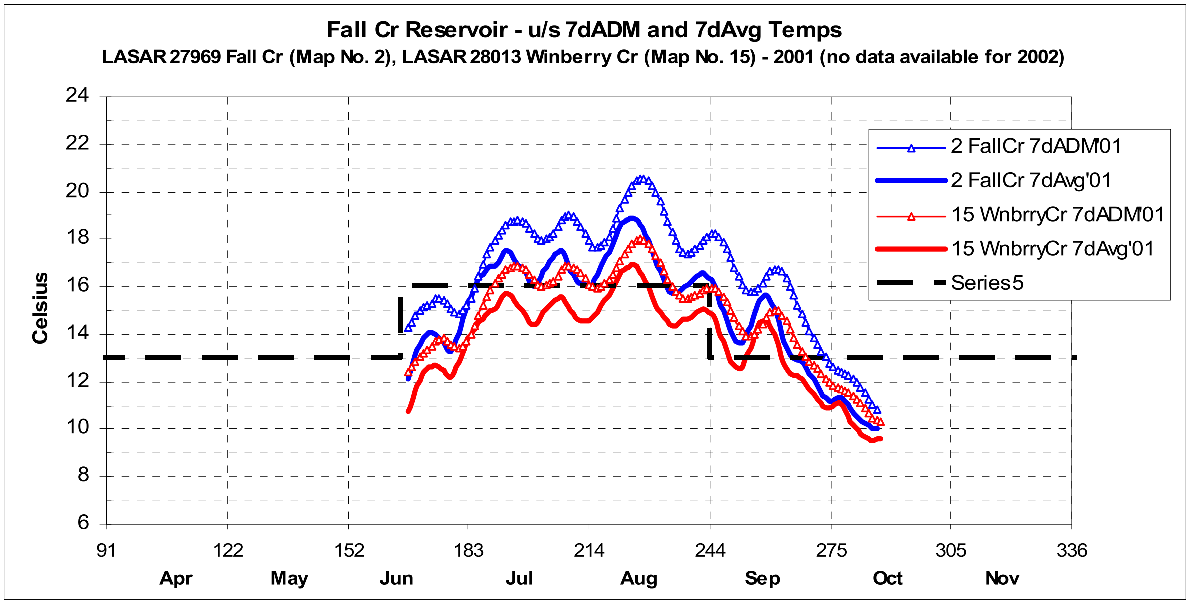


Figure 19. **Fall Creek Reservoir – 2001 upstream and 2001 and 2002 downstream temperatures.**

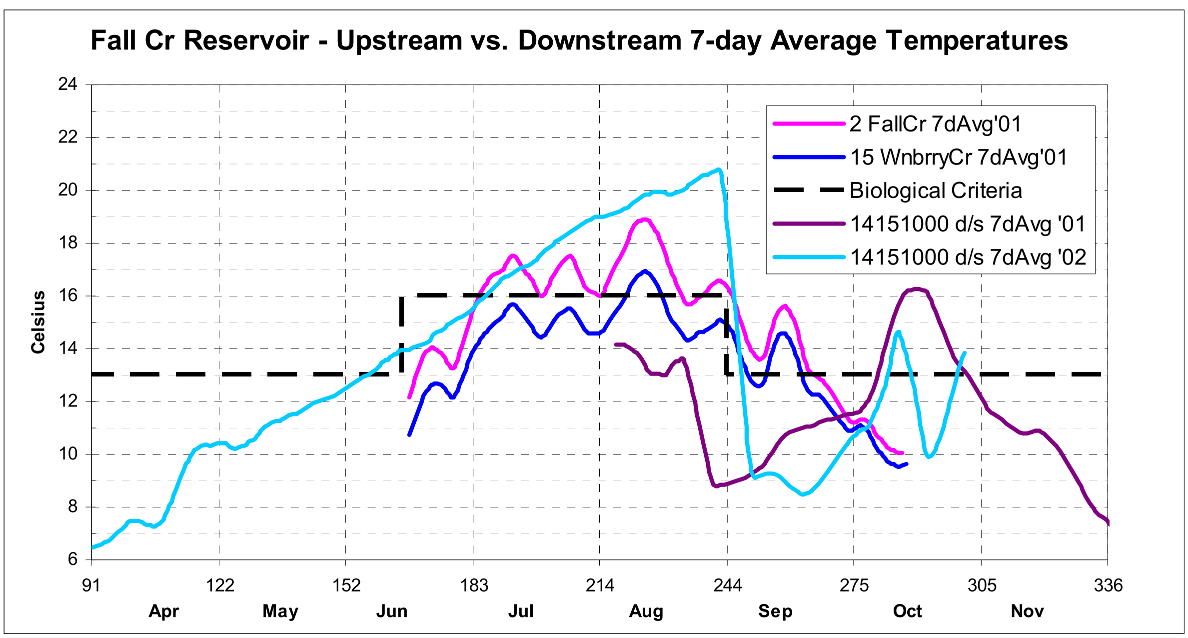
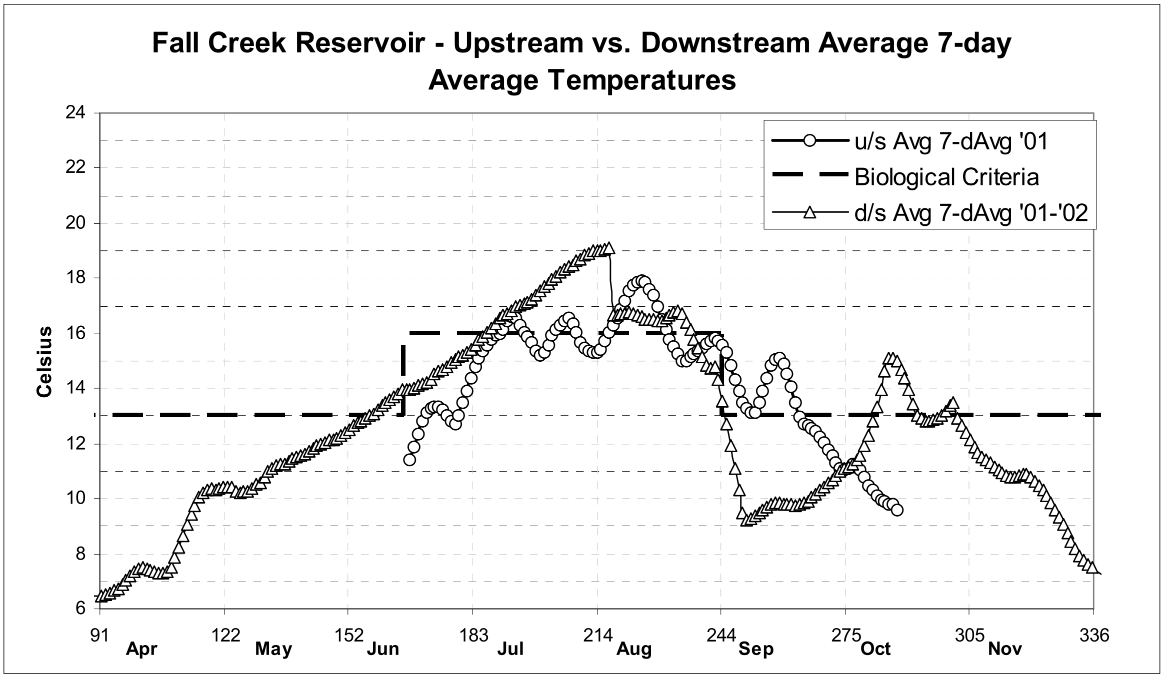


Figure 20. Fall Creek Reservoir – Target "natural thermal potential" temperatures vs. current downstream temperatures



Hills Creek Reservoir

Continuous temperature data at stations above and below Hills Creek Reservoir are presented below. Seven day average and seven day average of daily maximum upstream temperatures are presented in Figure 21. Seven day average temperatures patterns are illustrated in Figure 22 and Figure 23.

Figure 21. Hills Creek Reservoir – upstream seven day average of daily maximum and seven day average temperatures

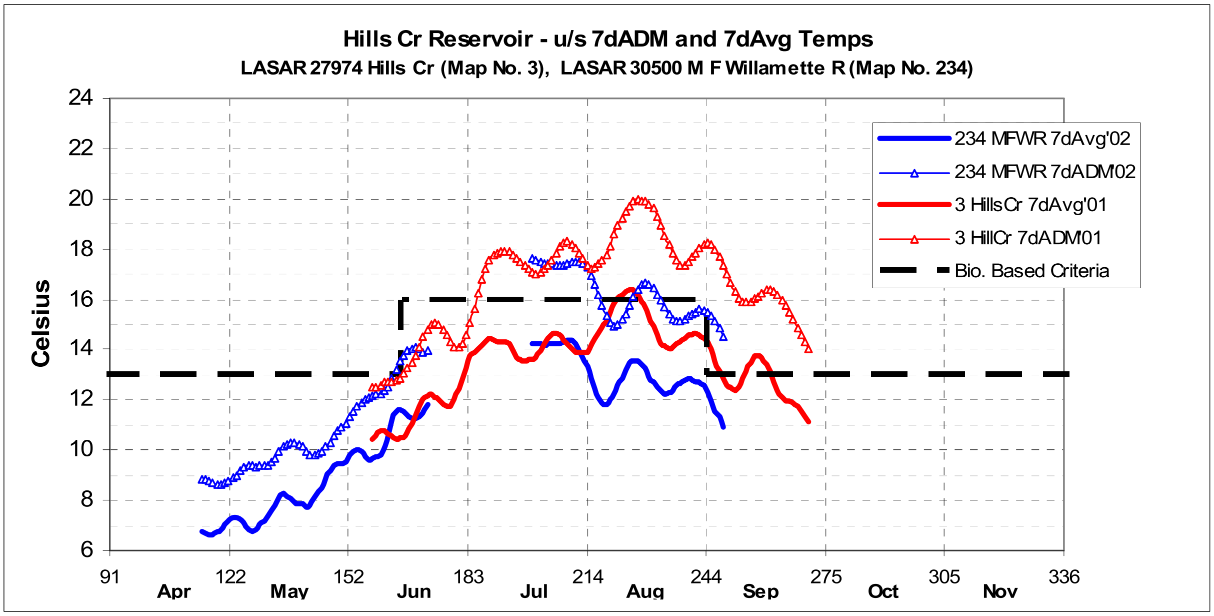


Figure 22. **Hills Creek Reservoir – 2001 and 2002 upstream and downstream temperatures**

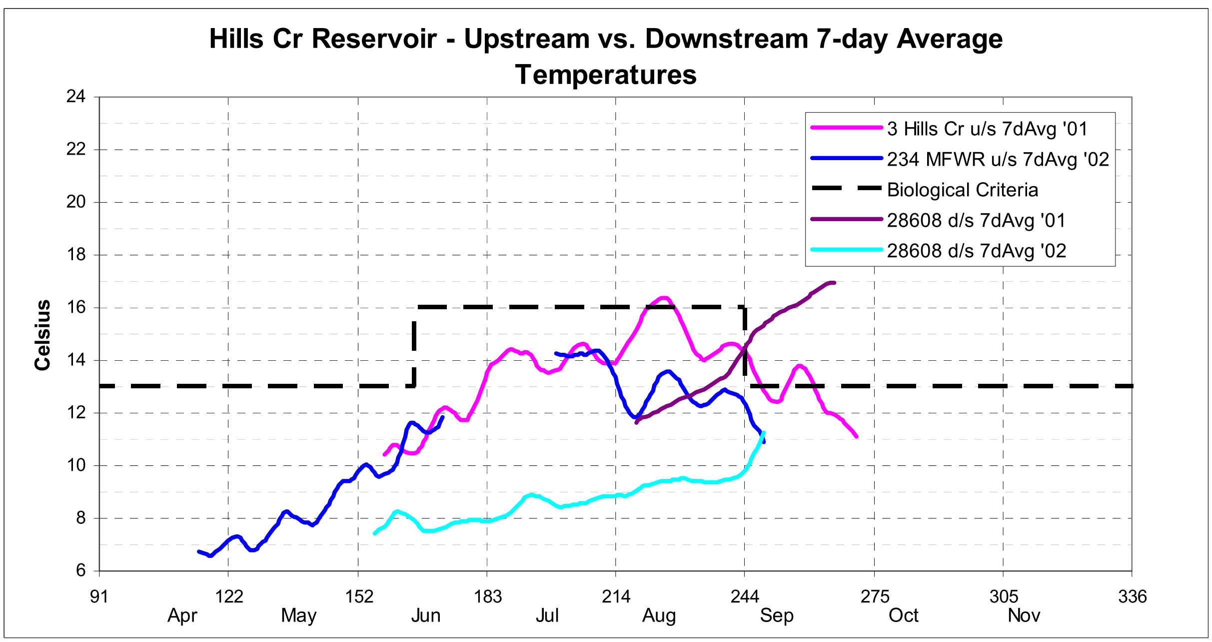
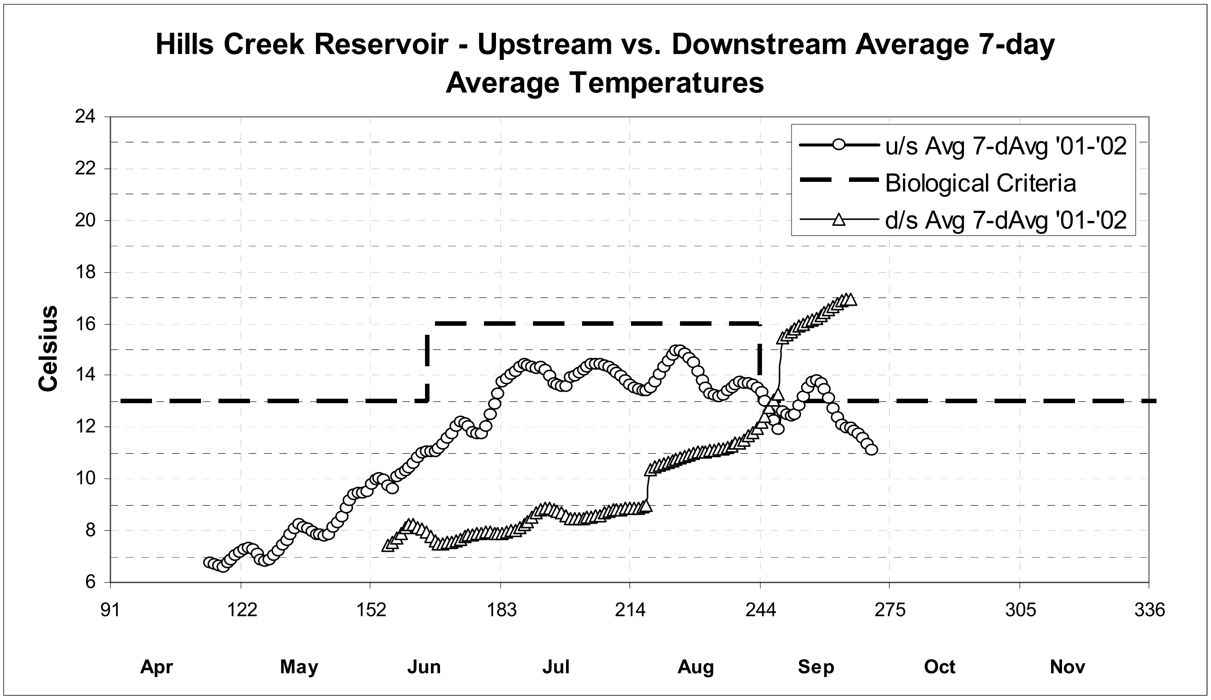


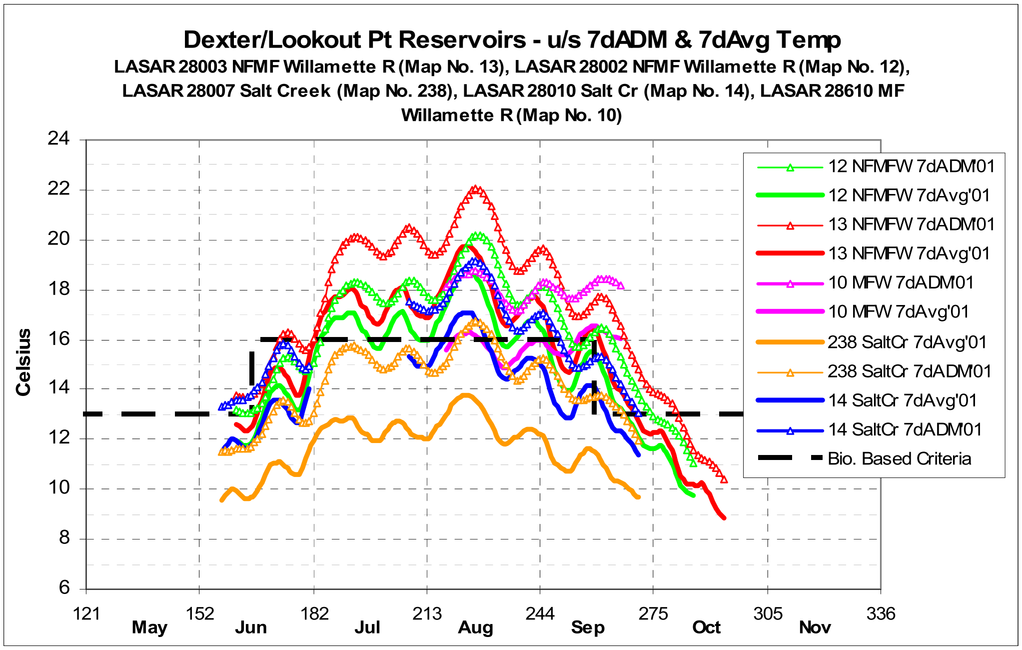
Figure 23. **Hills Creek Reservoir - Target "natural thermal potential" temperatures vs. current downstream temperatures**


Hills Creek Reservoir - Upstream vs. Downstream Average 7-day Average Temperatures
Celsius
24
22
20
18
16
14
12
10
8
6
91
122
152
183
214
244
275
305
336
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
u/s Avg 7-dAvg '01-'02
Biological Criteria
d/s Avg 7-dAvg '01-'02

Dexter and Lookout Point Reservoirs

Continuous temperature data at stations above and below Dexter and Lookout Point Reservoirs are presented in Figure 24.

Figure 24. Dexter/Lookout Point Reservoirs – upstream seven day average of daily maximum and seven day average temperatures

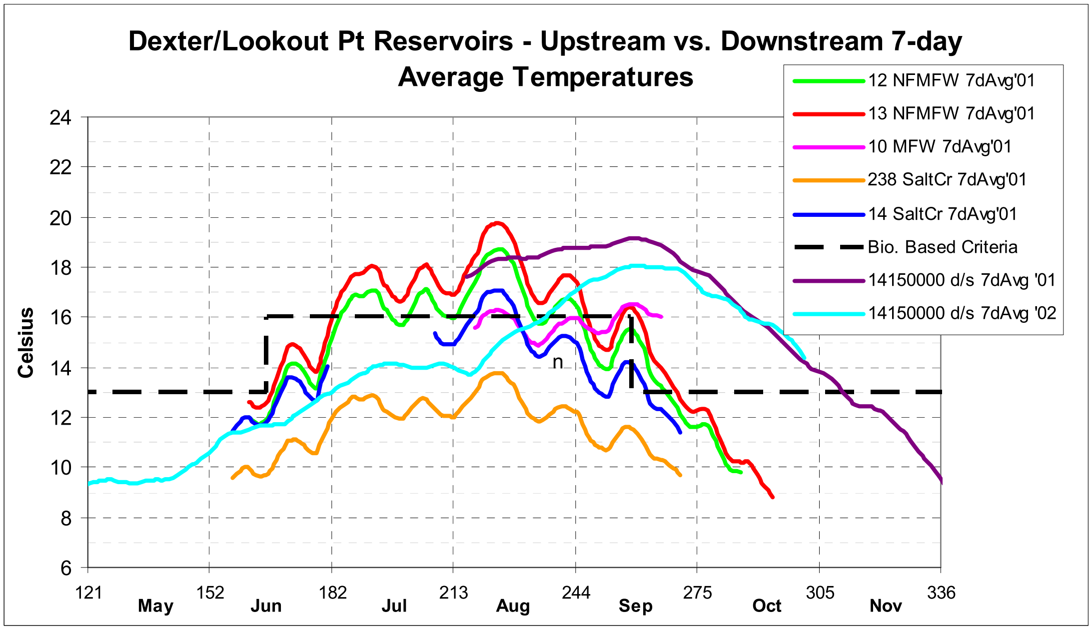


Temperature in the Middle Fork Willamette River immediate above Lookout Point Reservoir is influenced by releases from Hills Creek Reservoir and from major tributaries which enter below Hills Creek Reservoir including the North Fork Middle Fork Willamette River, Salt Creek, and Salmon Creek. As shown in Table 3, in winter and spring tributary flow dominates while in late summer and early fall Hills Creek Reservoir discharges dominate. The temperatures of the tributaries are shown in Figure 25.

Table 3. Middle Fork Willamette River flow rates in reach between Lookout Point and Hills Creek Reservoirs

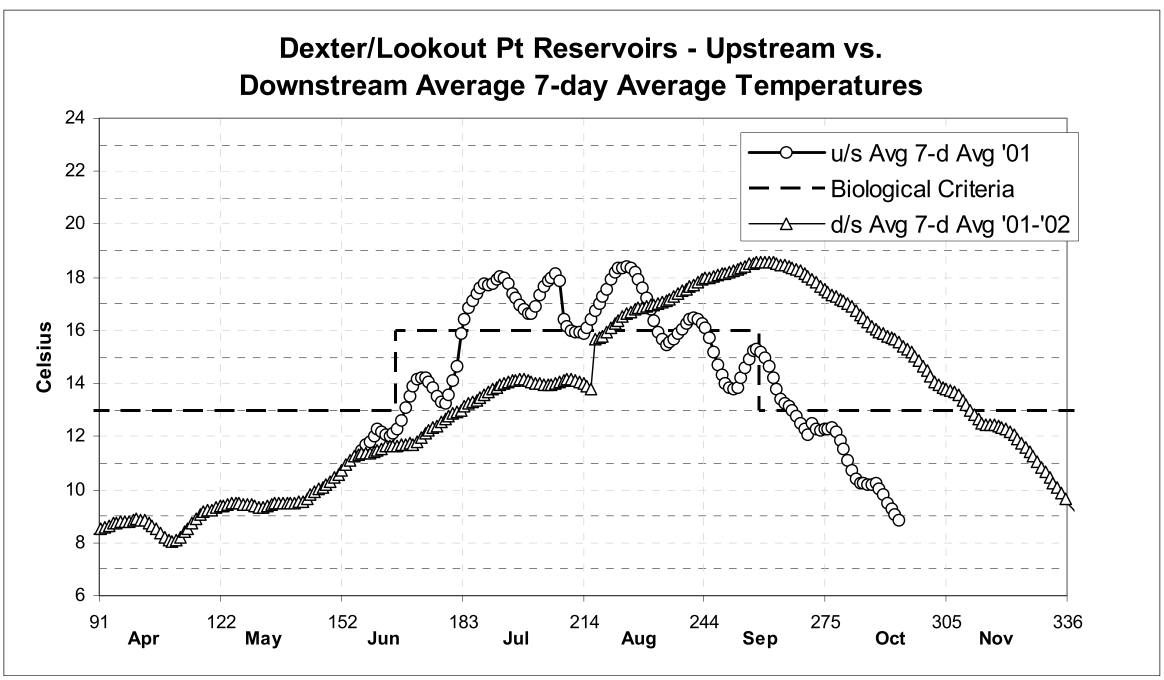
	MFW AB SALT CR	MFW BLW N FORK	Trib Flow Rates	% of Q due to tribs below Hills Cr Res
	14145500	14148000	Delta Q	% tribs
Jan	1,743	4,087	2,344	57.4%
Feb	1,254	4,031	2,777	68.9%
Mar	1,059	3,633	2,574	70.9%
Apr	1,138	3,822	2,684	70.2%
May	1,268	3,673	2,405	65.5%
Jun	1,016	2,637	1,621	61.5%
Jul	540	1,211	671	55.4%
Aug	547	829	282	34.0%
Sep	854	978	124	12.7%
Oct	960	1,313	353	26.9%
Nov	1,477	2,915	1,438	49.3%
Dec	1,889	3,980	2,091	52.5%

Figure 25. **Seven day average temperatures of tributaries entering reach between Hills Creek and Lookout Point Reservoirs**



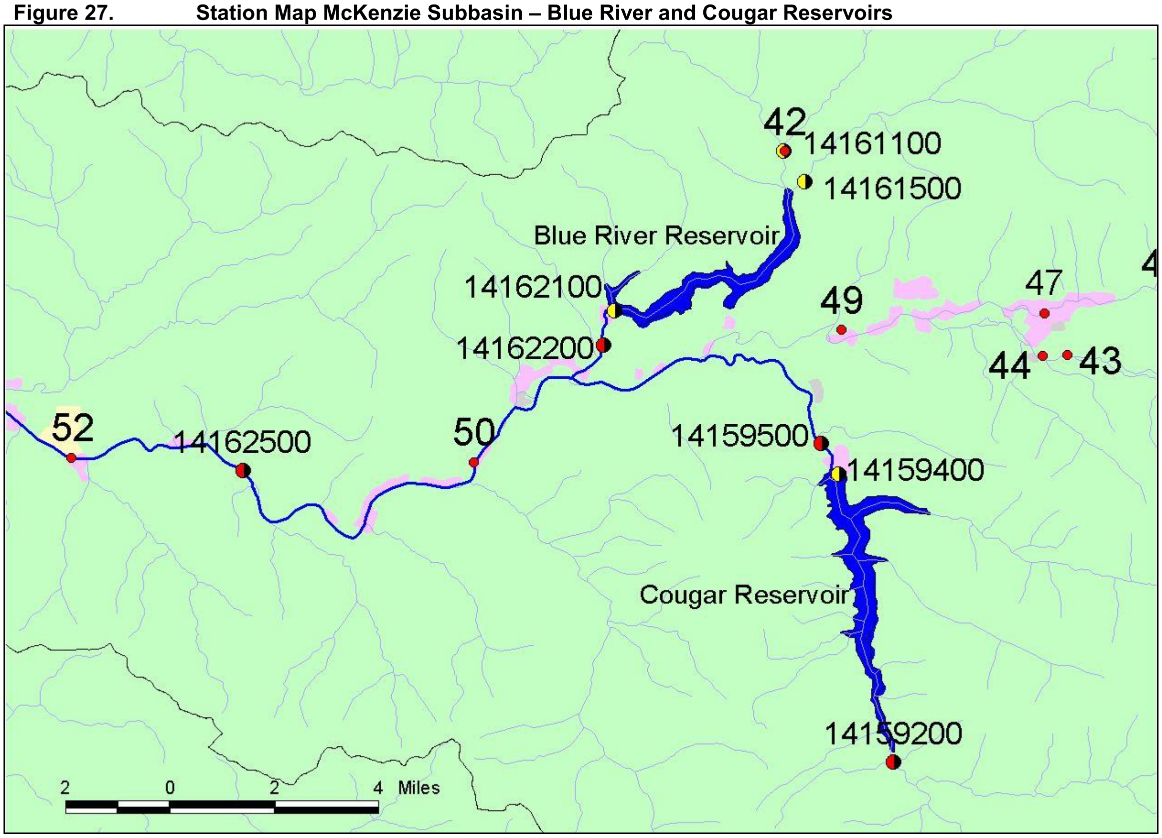
Because Middle Fork Willamette River temperatures are influenced by both Hills Creek Reservoir tailrace temperatures and tributary temperatures, temperatures above Lookout Point Reservoir are calculated as a flow-weighted mix of the two. Numeric target temperatures for Dexter Reservoir tailrace have been set to the flow-weighted mix of the Hills Creek Reservoir target temperatures and the tributary temperatures (using median average tributary seven day average temperatures). These targets are shown in Figure 26.

Figure 26. **Dexter Reservoir - Target "natural thermal potential" temperatures vs. current downstream temperatures**



McKenzie Subbasin

Figure 27. Station Map McKenzie Subbasin – Blue River and Cougar Reservoirs



Cougar Reservoir

Continuous temperature data at stations above and below Cougar Reservoir are presented in Figure 28 and Figure 29. illustrates 2001 and 2002 upstream seven day average of daily maximum and seven day average temperatures. Observed seven day average of daily temperatures immediately downstream from the reservoir are compared to the targets in Figure 31. As shown, downstream temperatures in 2001 were considerably less than the targets in the summer and considerably greater than the targets in the fall. In 2002, reservoir water levels were lowered to allow construction of selective withdrawal towers and, consequently, temperatures exceeded targets in both summer and fall.

Figure 28. Temperature upstream and downstream of Cougar Reservoir - 2001

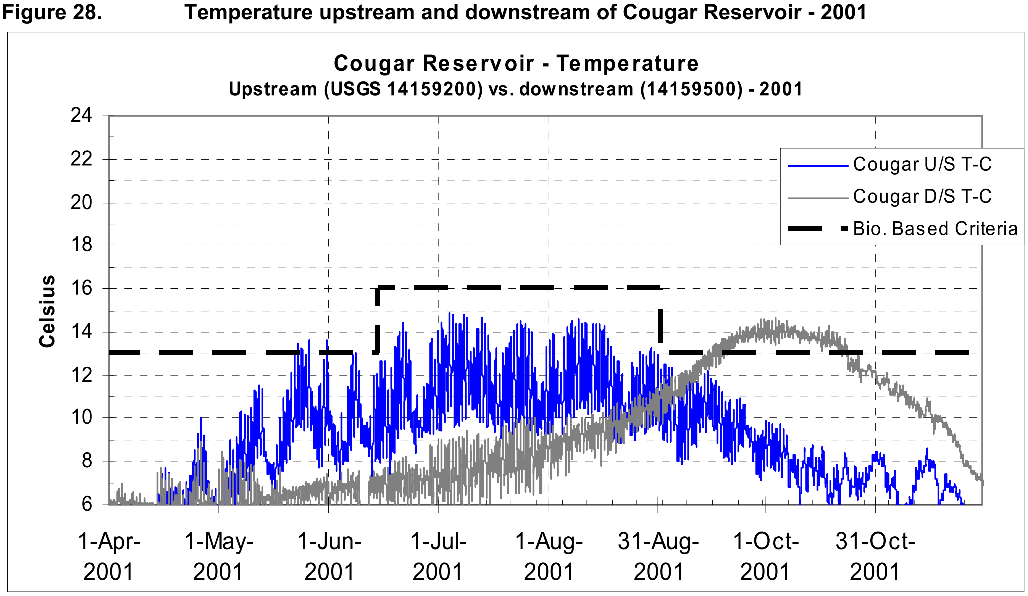


Figure 29. Temperature upstream and downstream of Cougar Reservoir - 2002

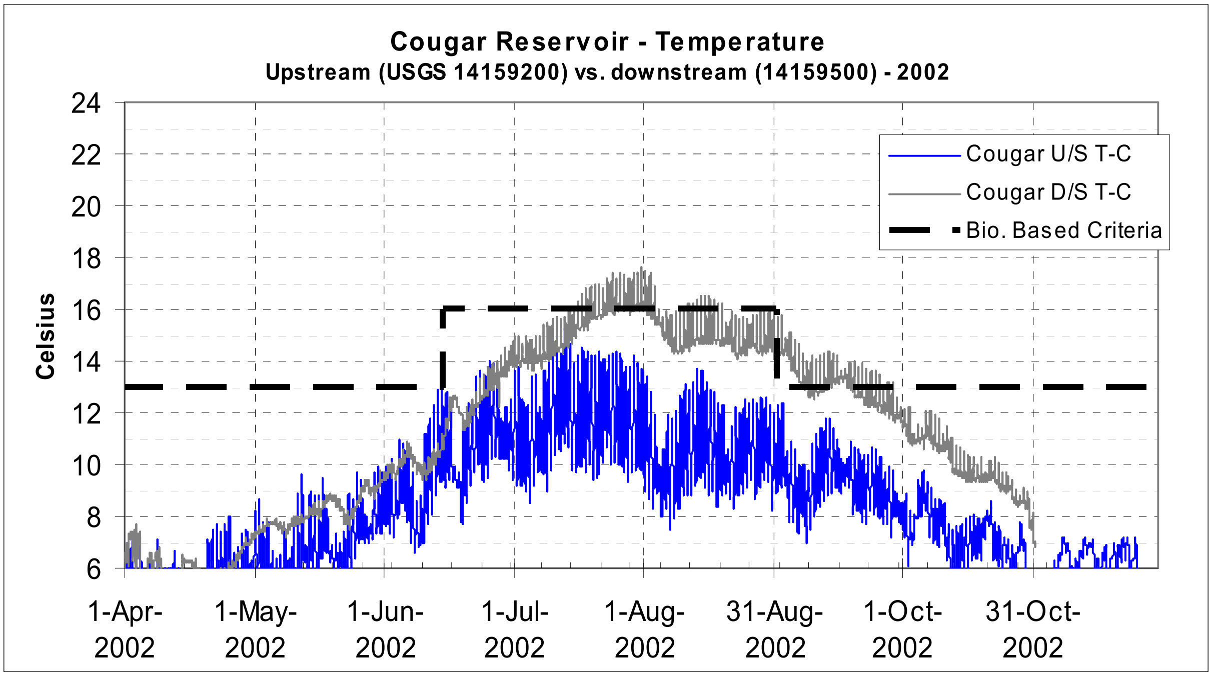


Figure 30. Cougar Reservoir – 2001 and 2002 upstream seven day average of daily maximum and seven day average temperatures

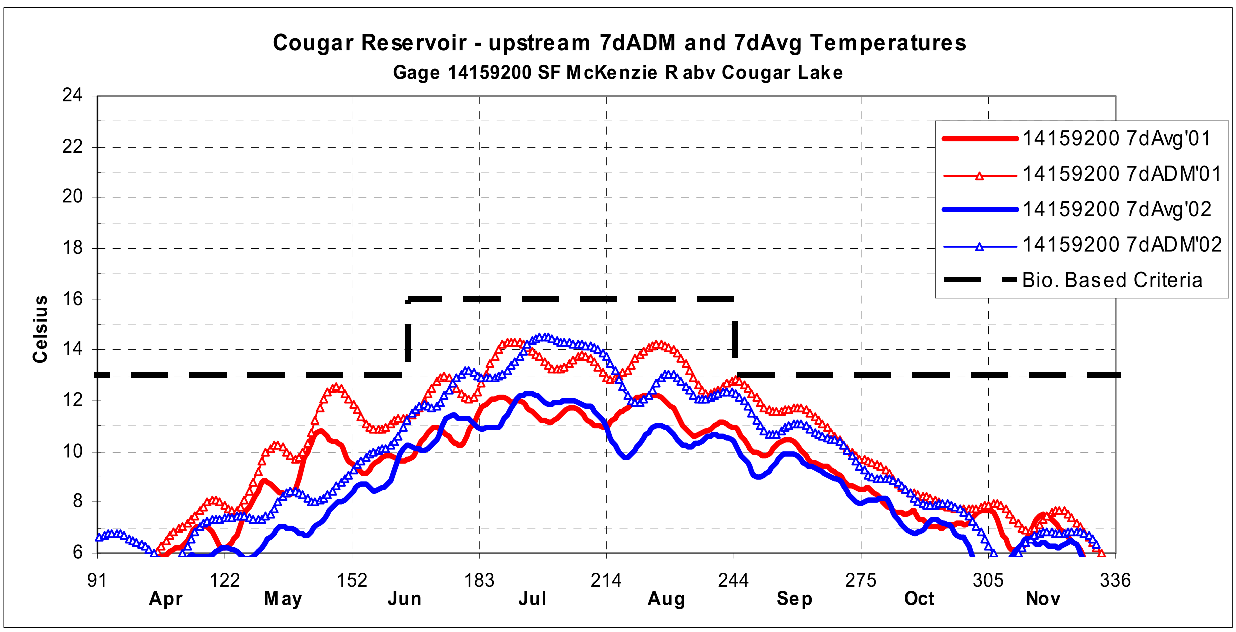
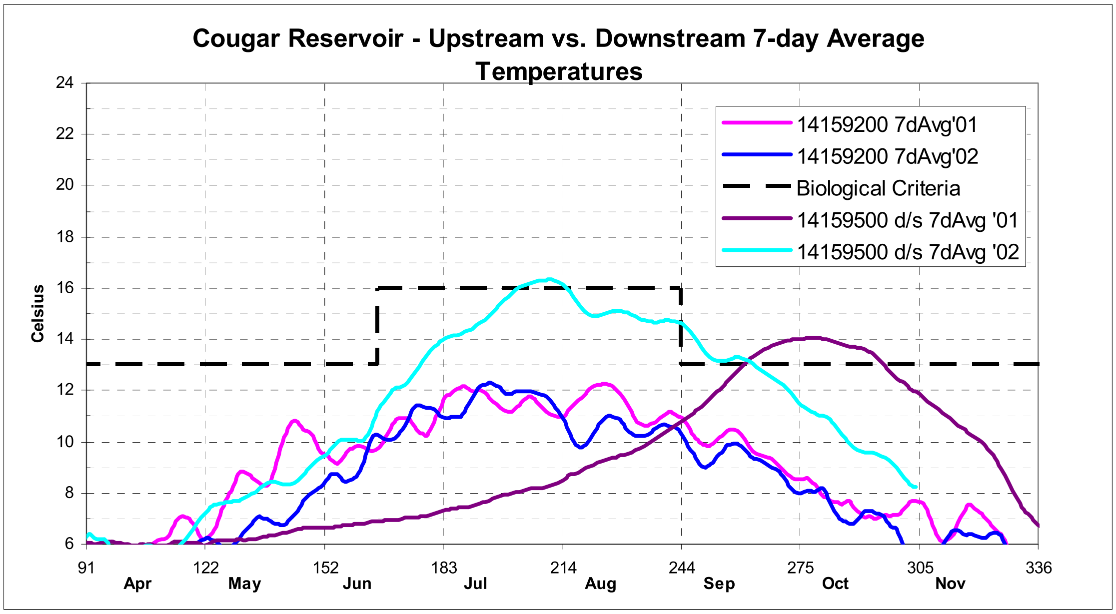


Figure 31. Cougar Reservoir - Target "natural thermal potential" temperatures vs. current downstream seven day average of temperatures



Blue River Reservoir

No data are available for Blue River above the reservoir. Available data for other representative upstream streams is presented in Figure 32 and Figure 33. These streams are the upper McKenzie River above South Fork McKenzie River and the South Fork McKenzie River above Cougar Reservoir. Seven day average and seven day average of daily maximum upstream temperatures are presented in Figure 34 and Figure 35. Observed seven day average of daily average temperatures at the downstream from the reservoir are compared to the target temperatures in Figure 36.

Figure 32. Blue River Reservoir – 2001 Reference stream temperatures and Blue River temperatures downstream of reservoir.

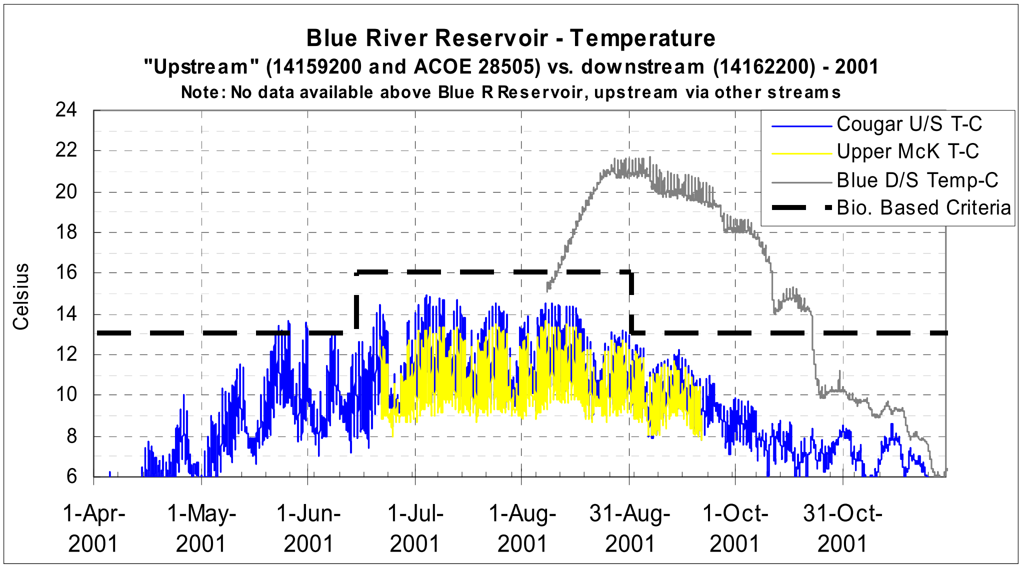


Figure 33. Blue River Reservoir – 2002 Reference stream temperatures and Blue River temperatures downstream of reservoir.

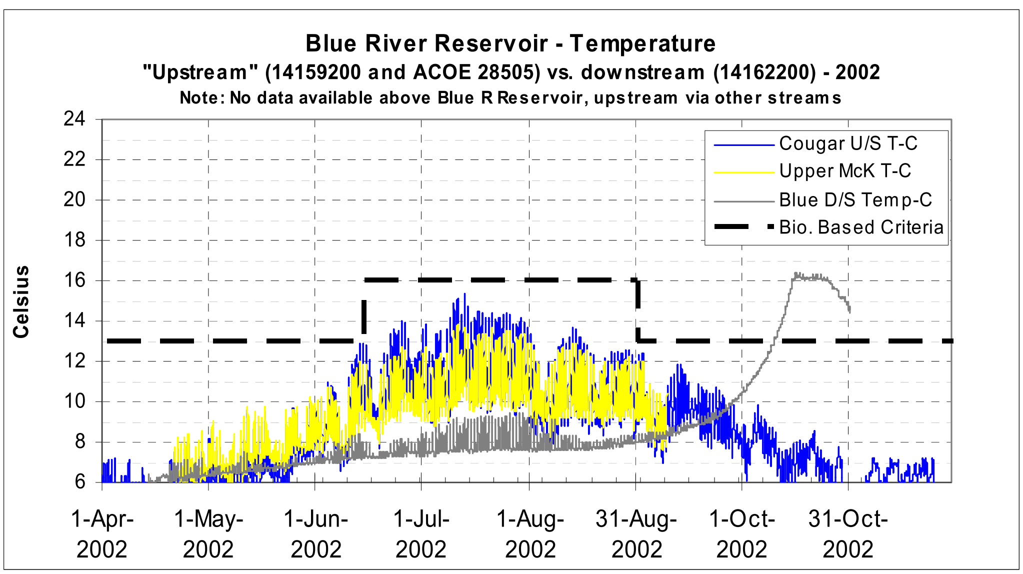


Figure 34. Blue River Reservoir – Reference stream seven day average of daily maximum and seven day average temperatures.

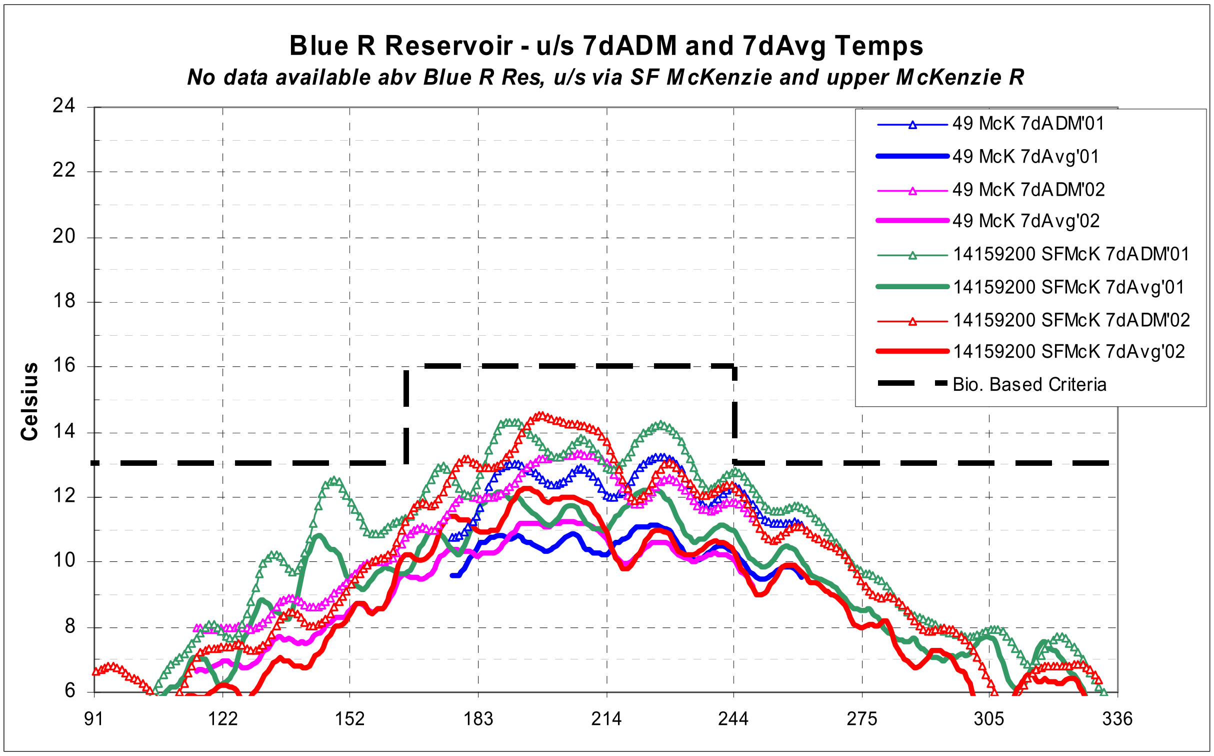


Figure 35. Blue River Reservoir – Reference stream seven day average of daily maximum and seven day average temperatures.

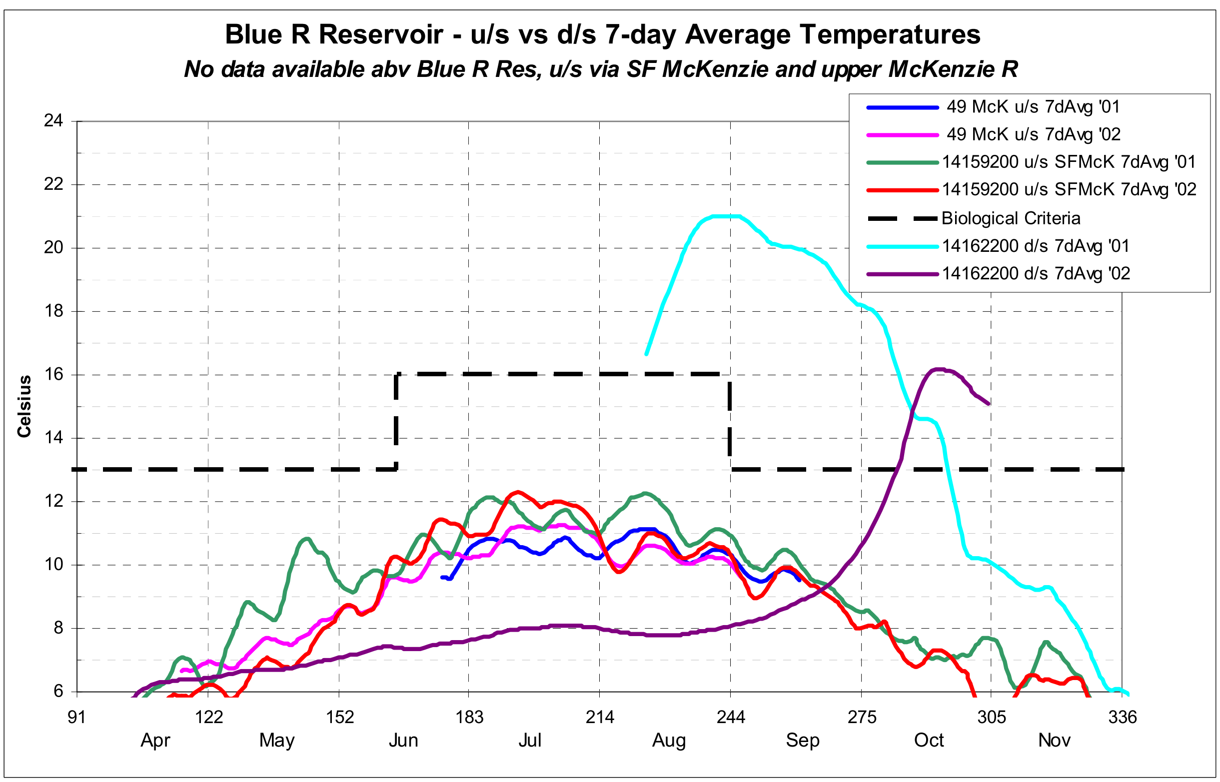
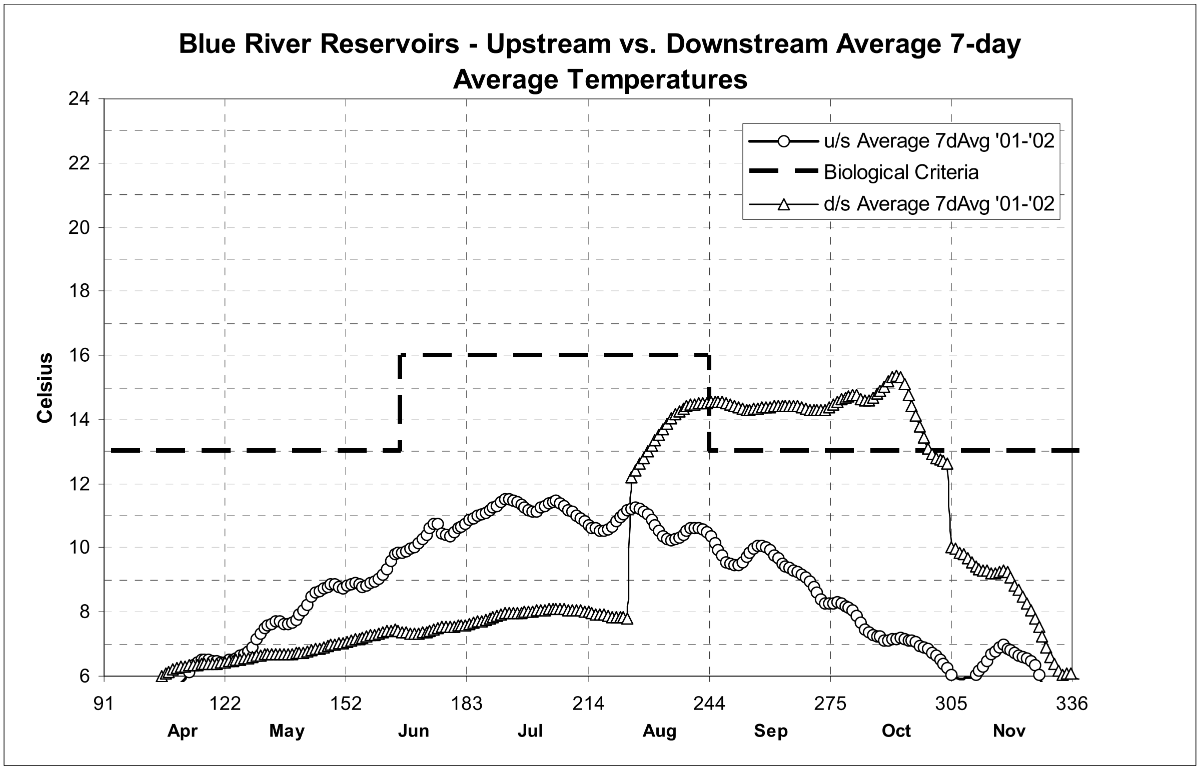
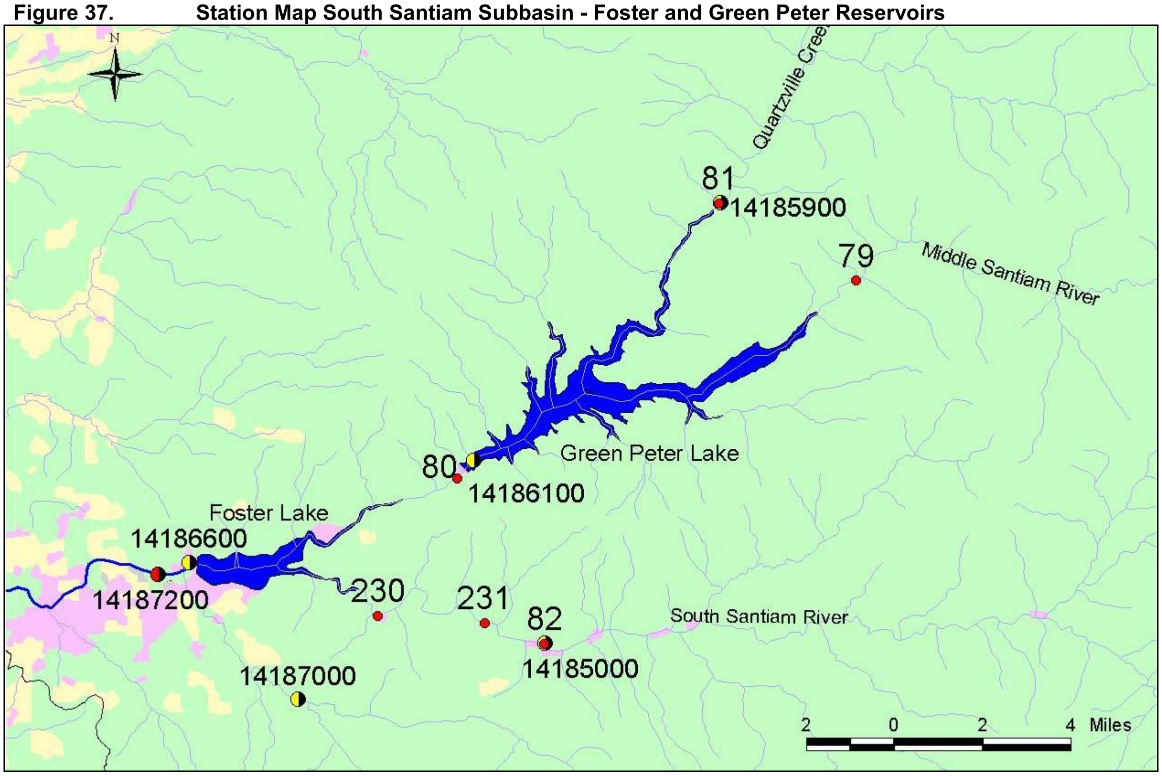


Figure 36. Blue River Reservoir - Target "natural thermal potential" temperatures vs. current downstream seven day average of daily maximum temperatures.



South Santiam Subbasin

Figure 37. Station Map South Santiam Subbasin - Foster and Green Peter Reservoirs



Foster and Green Peter Reservoirs

Foster and Green Peter Reservoirs are large reservoirs that significantly influence temperatures in the South Santiam River. Continuous temperature data at stations above and below the reservoir are presented in Figre 38 and Figure 39. Seven day averages of daily maximum upstream temperatures are presented in Figure 40 and seven day average temperatures are presented in Figure 41. Observed seven day average of daily average temperatures immediately downstream from the reservoir are compared to the NTP targets in Figure 42.

Figure 38. Temperature upstream and downstream of Foster and Green Peter Reservoir - 2000

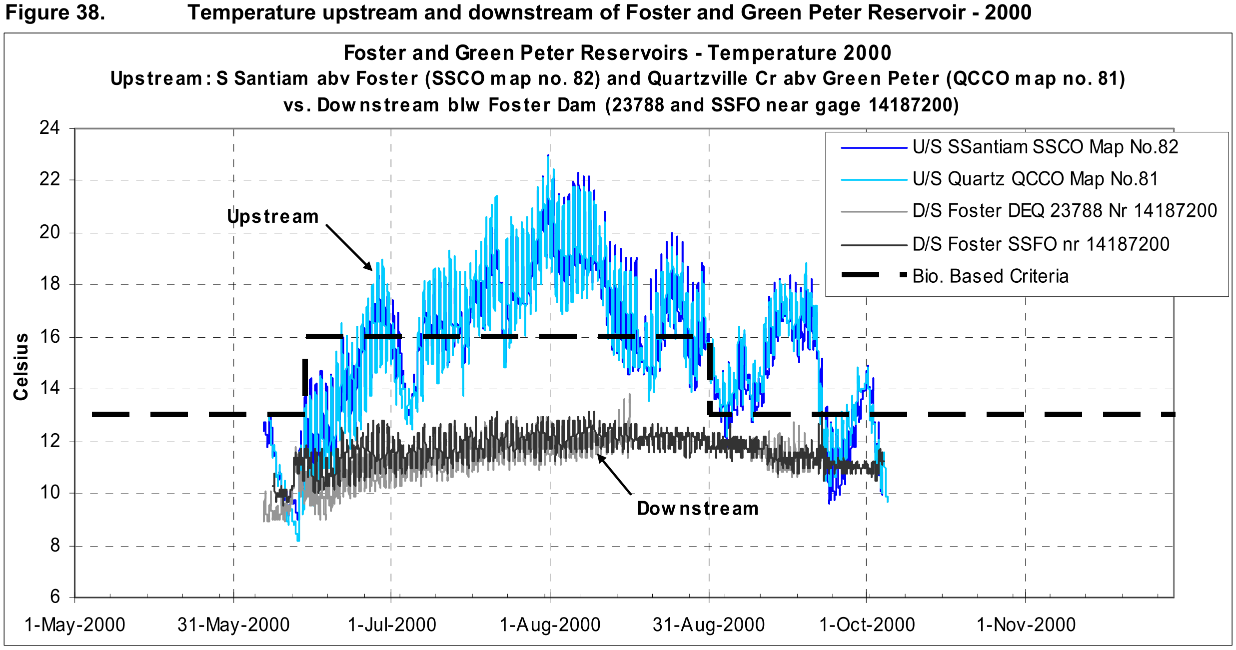


Figure 39. Temperature upstream and downstream of Foster and Green Peter Reservoir - 2001

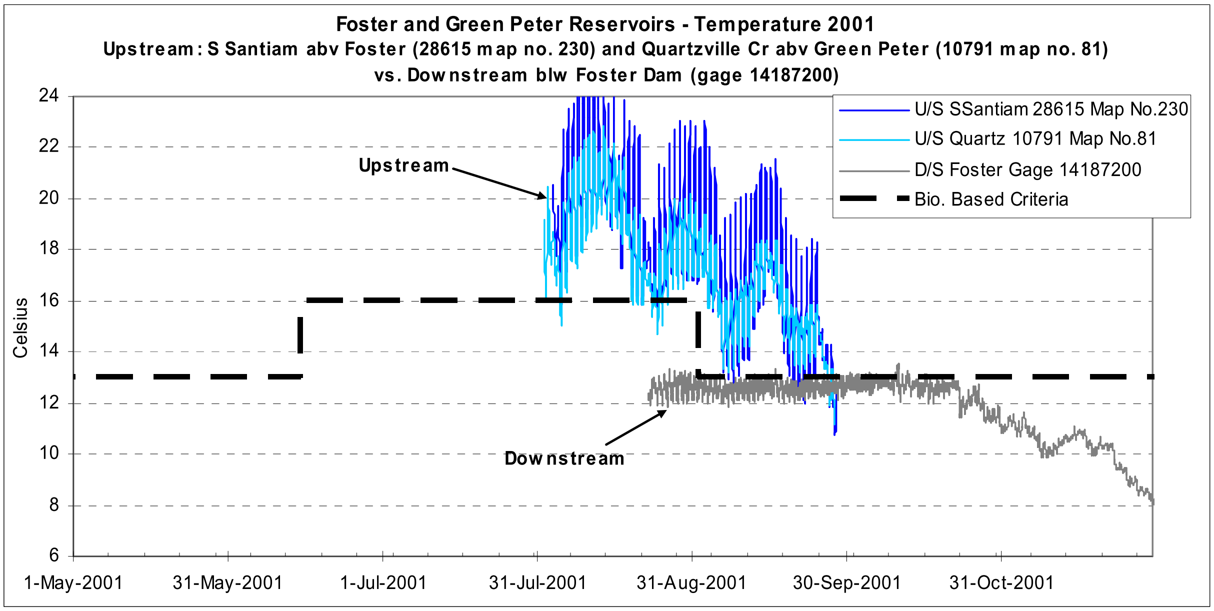


Figure 40. Foster/Green Peter Reservoirs - upstream seven day average of daily maximum temperatures

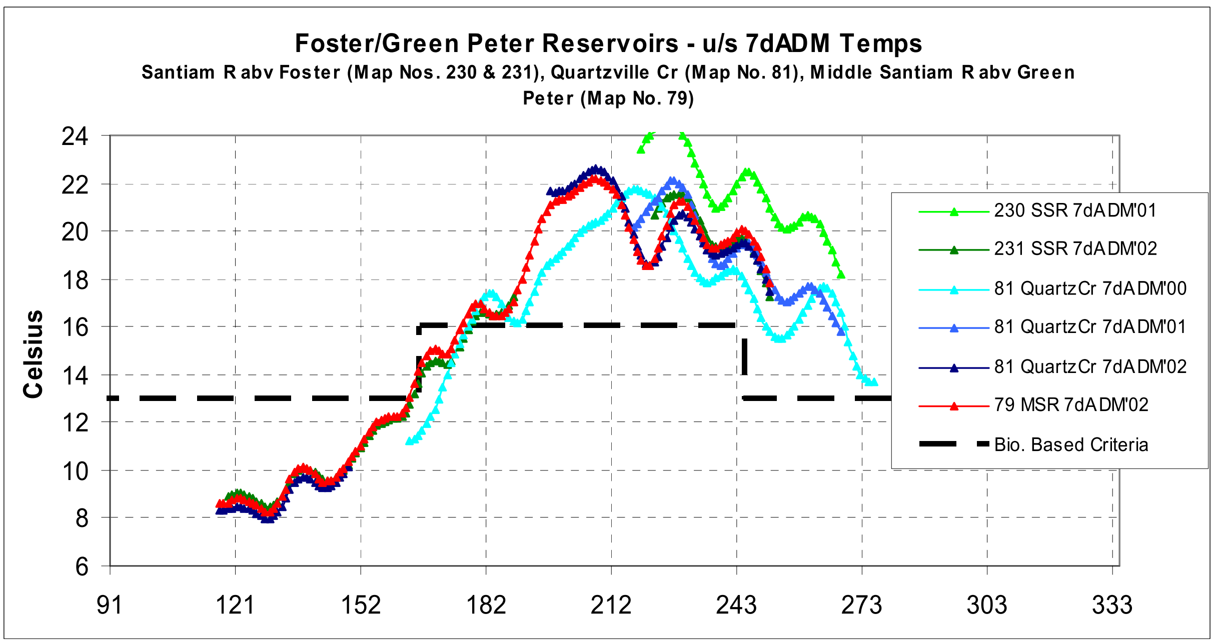


Figure 41. Foster/Green Peter Reservoirs – 2000, 2001 and 2002 seven day average temperatures.

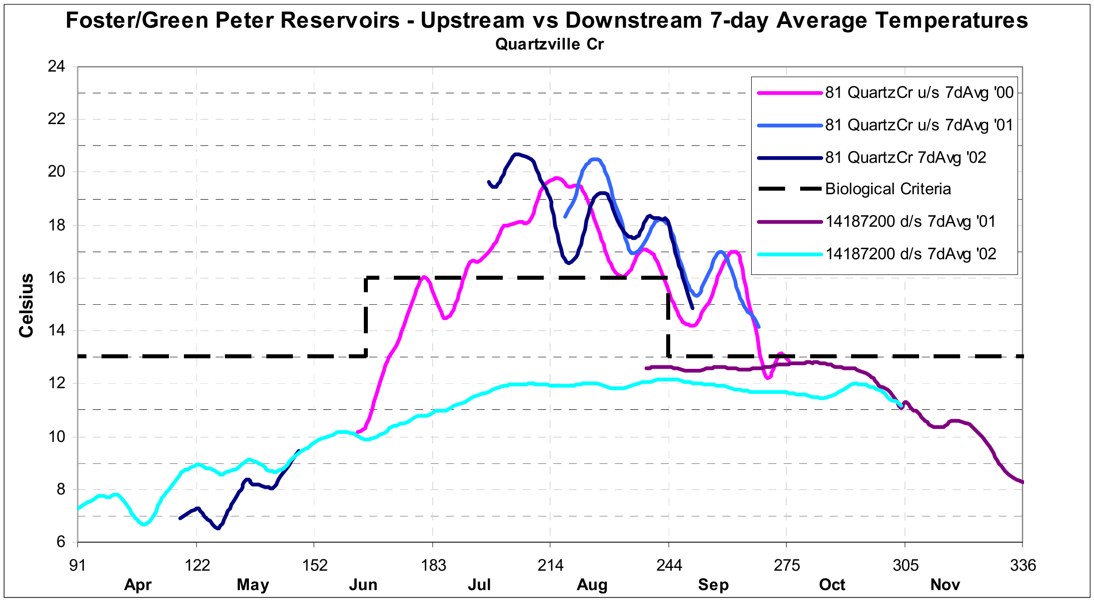
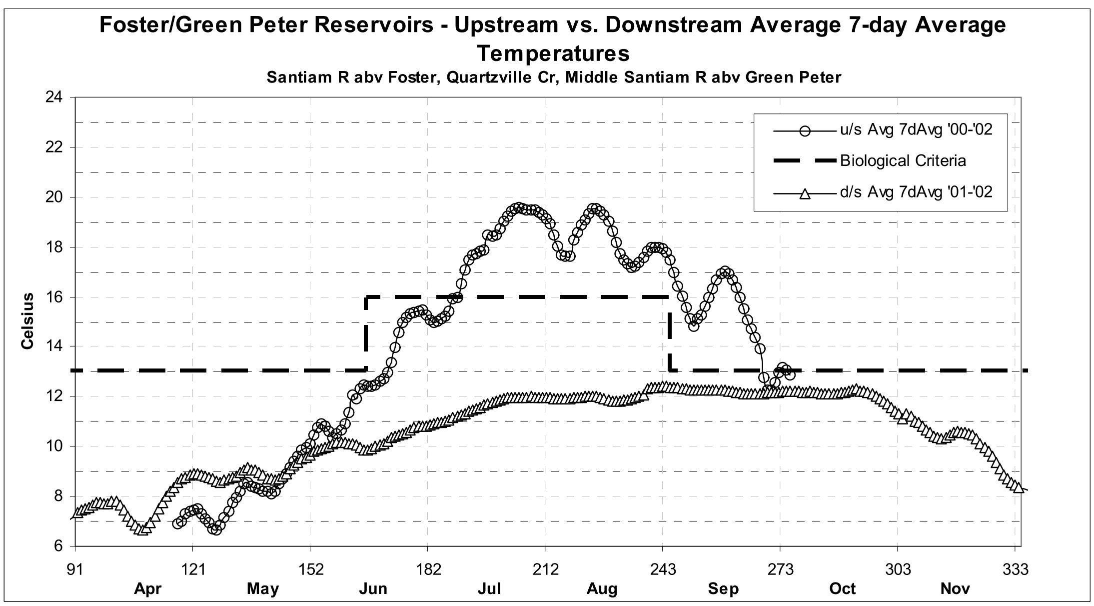


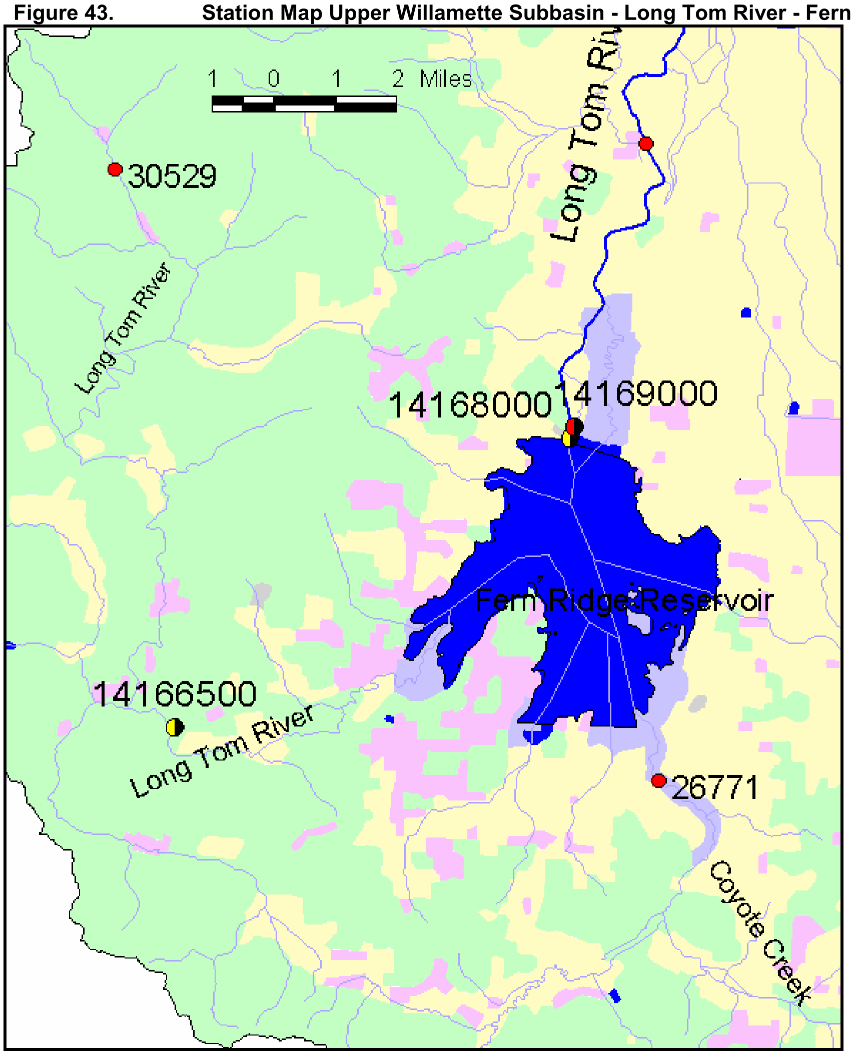
Figure 42. Foster Reservoir - Target "natural thermal potential" temperatures vs. current downstream seven day average temperatures



Upper Willamette Subbasin – Fern Ridge Lake
Insufficient data are currently available to accurately calculate natural thermal potential temperature targets for Fern Ridge Lake. Most of the flow entering the reservoir during the summer is from Long Tom River. The only station with continuous temperature monitoring data on Long Tom River above the reservoir is Long Tom River at RM 53.8 (LASAR No. 30529). This station is located too far upstream from the reservoir to accurately reflect potential NTP (Figure 43). However, in the absence of a better station, the data were used along with Coyote Creek data to develop the NTP targets for the reservoir.

Long Tom River is the main source of summer flow to Fern Ridge Lake, while during the rest of the year significant flow is contributed by Coyote Creek. Continuous temperature monitoring data just above the confluence of Coyote Creek with Fern Ridge Lake is available for 2001 and 2002. (Coyote Creek at Cantrell Road above Fern Ridge Reservoir, LASAR No. 26771). These data were averaged on a flow-weighted basis with the Long Tom River data to estimate the target NTP temperatures for the reservoir. The Long Tom River flow rate was from the gage at Noti (14166500), while the Coyote Creek flow rate was an estimate based on correlations between historic Coyote Creek flow and Long Tom River flow. A Coyote Creek discharge gage is no longer active.

Figure 43. Station Map Upper Willamette Subbasin - Long Tom River - Fern Ridge Lake



Fern Ridge Reservoir

Continuous temperature data at stations above and below the reservoir are presented in Figure 44 and Figure 45. Seven day average and seven day average of daily maximum upstream temperatures are presented in Figure 46. Upstream and downstream seven day average temperatures are presented in Figure 47. Seven day average od the daily average temperatures downstream from the reservoir (USGS Gage 14169000 at Alvadore) are compared to the targets in Figure 48.

Figure 44. Temperature upstream and downstream of Fern Ridge Reservoir - 2001

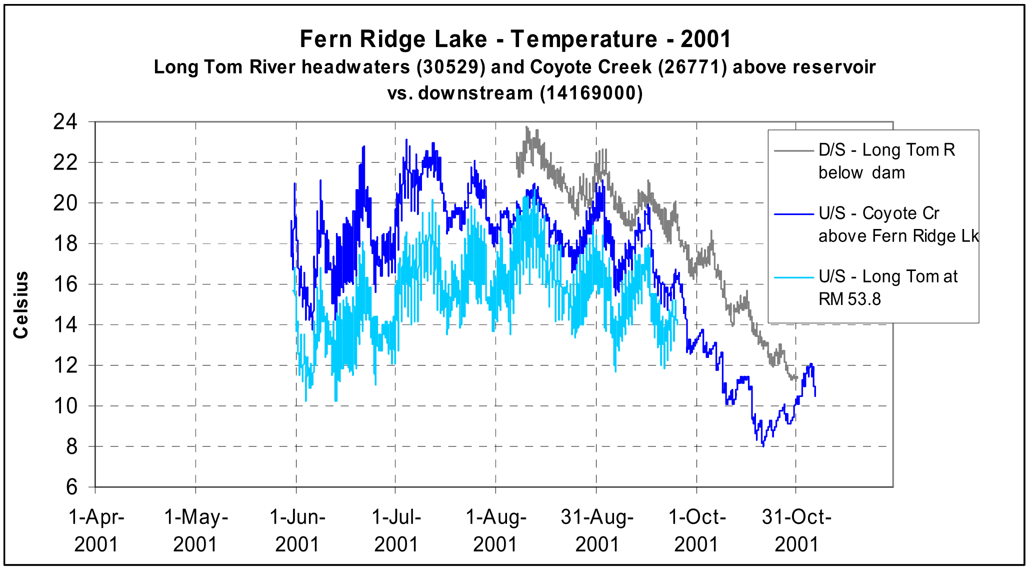


Figure 45. Temperature upstream and downstream of Fern Ridge Reservoir - 2002

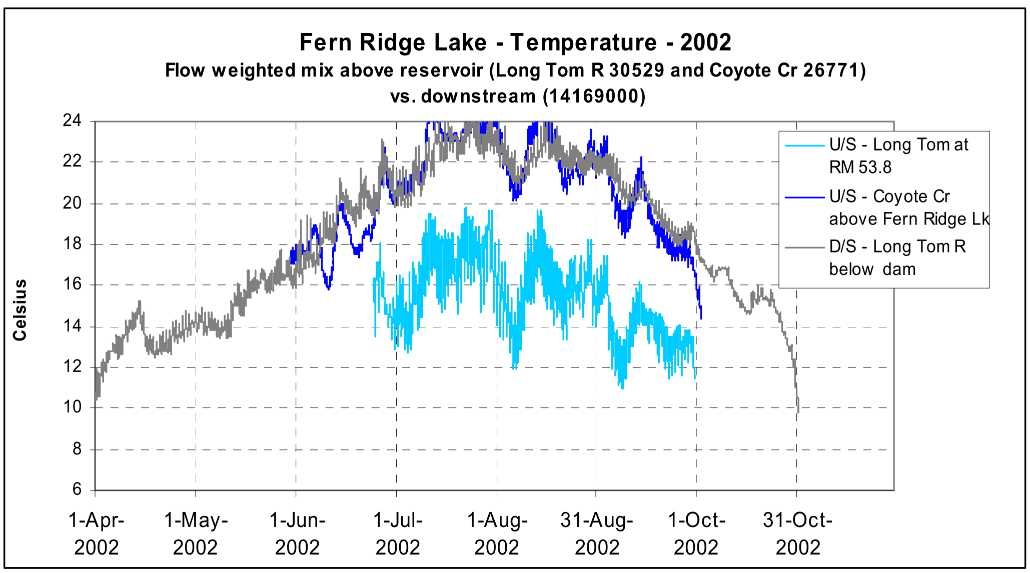


Figure 46. **Fern Ridge Reservoir - upstream seven day average of daily maximum and seven day average temperatures**

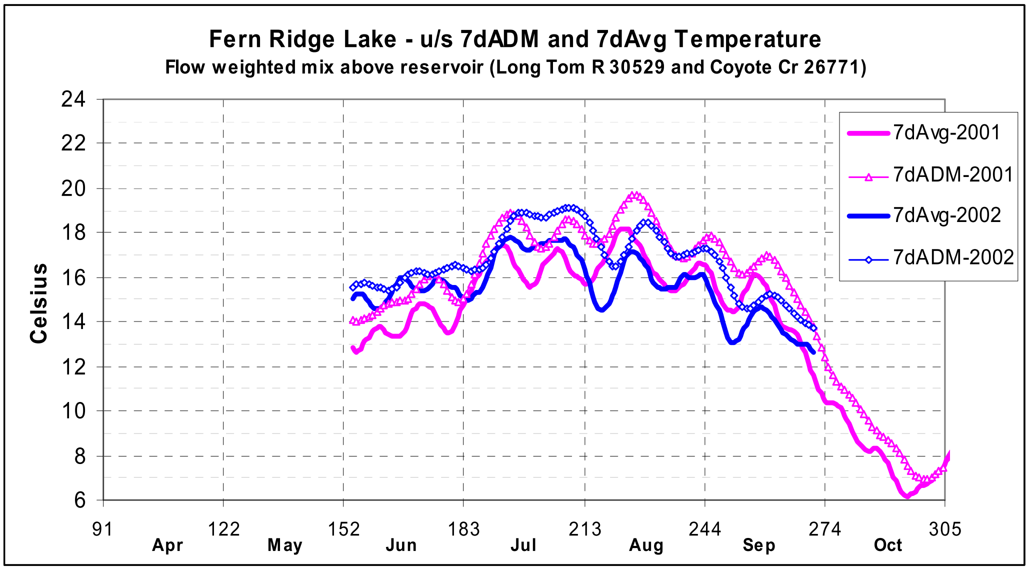


Figure 47. **Fern Ridge Reservoir – 2001 and 2002 seven day average temperatures.**

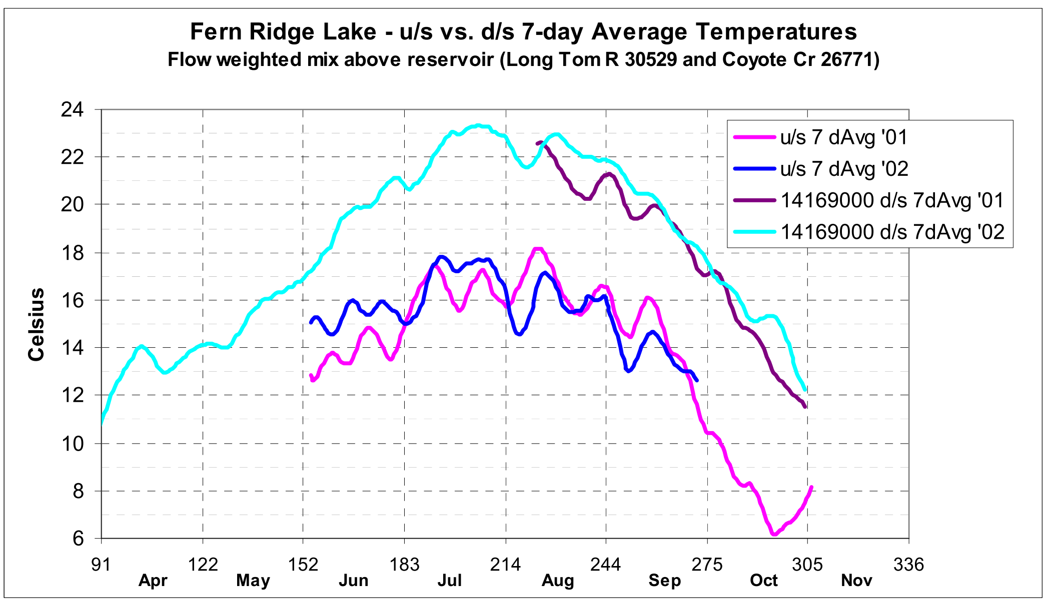


Figure 48. Fern Ridge Reservoir - Target "natural thermal potential" temperatures vs. current downstream seven day average temperatures