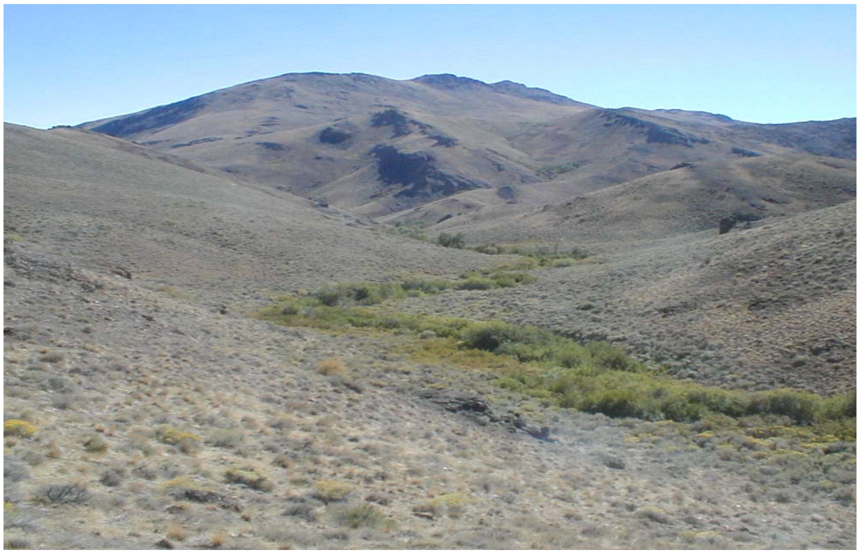
Alvord Lake Subbasin
Total Maximum Daily Load (TMDL)
&
Water Quality Management Plan (WQMP)



Prepared by:

State of Oregon
Department of Environmental Quality

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Primary authors are:
Bruce Hammon, Bonnie Lamb, Dick Nichols, Brian Kasper, Matt Boyd

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For more information contact:

Greg Aldrich, Manager of Watershed Management Section
Department of Environmental Quality
811 Southwest 6th Avenue
Portland, Oregon 97204
aldrich.greg@deq.state.or.us

Dick Nichols, Manager of Eastern Region
Department of Environmental Quality
2146 Northeast 4th Street
Bend, Oregon 97701
nichols.dick@deq.state.or.us

ALVORD LAKE SUBBASIN TOTAL MAXIMUM DAILY LOAD (TMDL)

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WATER QUALITY SUMMARY

Section 303(d) of the Federal Clean Water Act (CWA) requires that a list be developed of all impaired or threatened waters within each state. The Oregon Department of Environmental Quality (ODEQ) is responsible for assessing data, compiling the 303(d) list and submitting the 303(d) list to the Environmental Protection Agency (EPA) for federal approval. Section 303(d) also requires that the state establish a Total Maximum Daily Load (TMDL) for any waterbody designated as water quality limited (with a few exceptions, such as in cases where violations are due to natural causes or pollutants cannot be defined). TMDLs are written plans with analysis that establishes that waterbodies will attain and maintain water quality levels specified in water quality standards. The Alvord Lake Subbasin is comprised of eight 5th-field watersheds and has stream segments listed on the 2002 Oregon 303(d)[1] List for temperature, and dissolved oxygen.

TMDL SUMMARIES

Following are brief descriptions of the TMDLs included in this document.

Alvord Lake Subbasin Stream Temperature TMDL (Chapter II)

The Alvord Lake Subbasin is a closed basin which means that its streams are not connected to the Pacific Ocean and anadromous fish are blocked from accessing the basin. In addition, many streams are disconnected from each other. There are no large streams that serve as immigration conduits for fish, and connect stream networks and fish populations. As a result, the majority of streams in this subbasin do not support salmonid fishes (salmon and trout) due to natural limitations. Because of the discontinuous nature of the stream network in the Alvord Lake Subbasin, this TMDL is not established for all streams in the subbasin. Instead, the TMDL is established for streams in the Alvord Lake Subbasin that either contain salmonid fish or that are tributaries to streams that contain salmonid fish. Salmonid fish distribution was determined by ODFW. Federally threatened salmonids do reside in the subbasin.

The stream temperature standard uses numeric and qualitative triggers to invoke a condition that requires "no measurable surface water increase resulting from anthropogenic activities" if any of the triggers are exceeded. The Alvord Lake Subbasin temperature TMDL targets human caused sources of heat from one primary source: increased solar radiation loading. The loading capacity presented in the TMDL is the total allowable daily heat loading. Load allocations are developed for human caused and background nonpoint sources of heat. An implicit margin of safety is provided in the conservative assumptions made in development of the load allocations.

Percent effective shade targets are used as surrogate measures for nonpoint source pollutant loading since they offer a straightforward parameter to monitor and measure. They are also easily translated into quantifiable water management objectives. Site specific effective shade surrogates can be used to assess TMDL nonpoint source allocation attainment. Attainment of surrogate measures ensures attainment of the nonpoint source allocations.

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[1] The 303(d) list is a list of stream segments that do not meet water quality standards

Willow Creek (Trout Creek Mountains) Temperature TMDL (Chapter III)

The Willow Creek TMDL was drafted by ODEQ in 1999. The types of data and modeling analysis used to produce this TMDL are different from the methods applied in other streams in the Alvord Lake Subbasin (**Chapter II**). Therefore, the Willow Creek TMDL drafted in 1999 is provided in this chapter separate from other streams within the subbasin. This TMDL also targets human caused sources of heat from increased solar radiation loading and uses percent effective shade targets as surrogate measures for nonpoint source pollutant loading.

Willow Creek (Trout Creek Mountains) Dissolved Oxygen TMDL (Chapter IV)

The primary benefit of maintaining adequate dissolved oxygen (DO) concentrations is to support a healthy and balanced distribution of fish, invertebrates, and other aquatic life. In the Alvord Lake Subbasin, the dissolved oxygen standard is designed to protect cool-water fish as the most sensitive beneficial use. Based on data collected by ODEQ in 1998, Willow Creek in the Trout Creek Mountains was added to the 303(d) list in 2002 for not meeting the state's dissolved oxygen standard.

Dissolved oxygen in water bodies may fall below healthy levels for a number of reasons including carbonaceous biochemical oxygen demand (CBOD) within the water column, nitrogenous biochemical oxygen demand (NBOD, also known as nitrification), algal respiration, zooplankton respiration, sediment oxygen demand (SOD) and increased temperatures. While many chemical and physical processes can affect dissolved oxygen levels, stream temperature is a significant contributing factor to water quality standards violations for dissolved oxygen. Increased solar heating of the water column and warm stream temperatures contribute to excessive periphyton growth, which in turn depletes instream dissolved oxygen levels. A regression model was developed in this TMDL to investigate the association between temperature and dissolved oxygen. The model predicts that the dissolved oxygen standard will be achieved through the implementation of the *system potential* temperature TMDL allocations.

WATER QUALITY MANAGEMENT PLAN SUMMARY

To address these TMDLs, a Water Quality Management Plan (WQMP) has been developed focusing on the following area:

- Establishing and protecting riparian area vegetation

Implementation of TMDLs is critical to the attainment of water quality standards. The support of Designated Management Agencies (DMAs) in implementing TMDLs is essential. A DMA is any agency or entity responsible for affecting water quality through its management of land and/or water. In instances where ODEQ has no direct authority for implementation, ODEQ works with DMAs on implementation to ensure attainment of water quality standards. The DMAs in the Alvord Lake Subbasin include: Bureau of Land Management, Oregon Department of Agriculture, Oregon Department of Forestry, and Oregon Department of Transportation. These agencies will develop water quality implementation plans to comply with the TMDL and Water Quality Management Plan.

CHAPTER I: OVERVIEW AND BACKGROUND

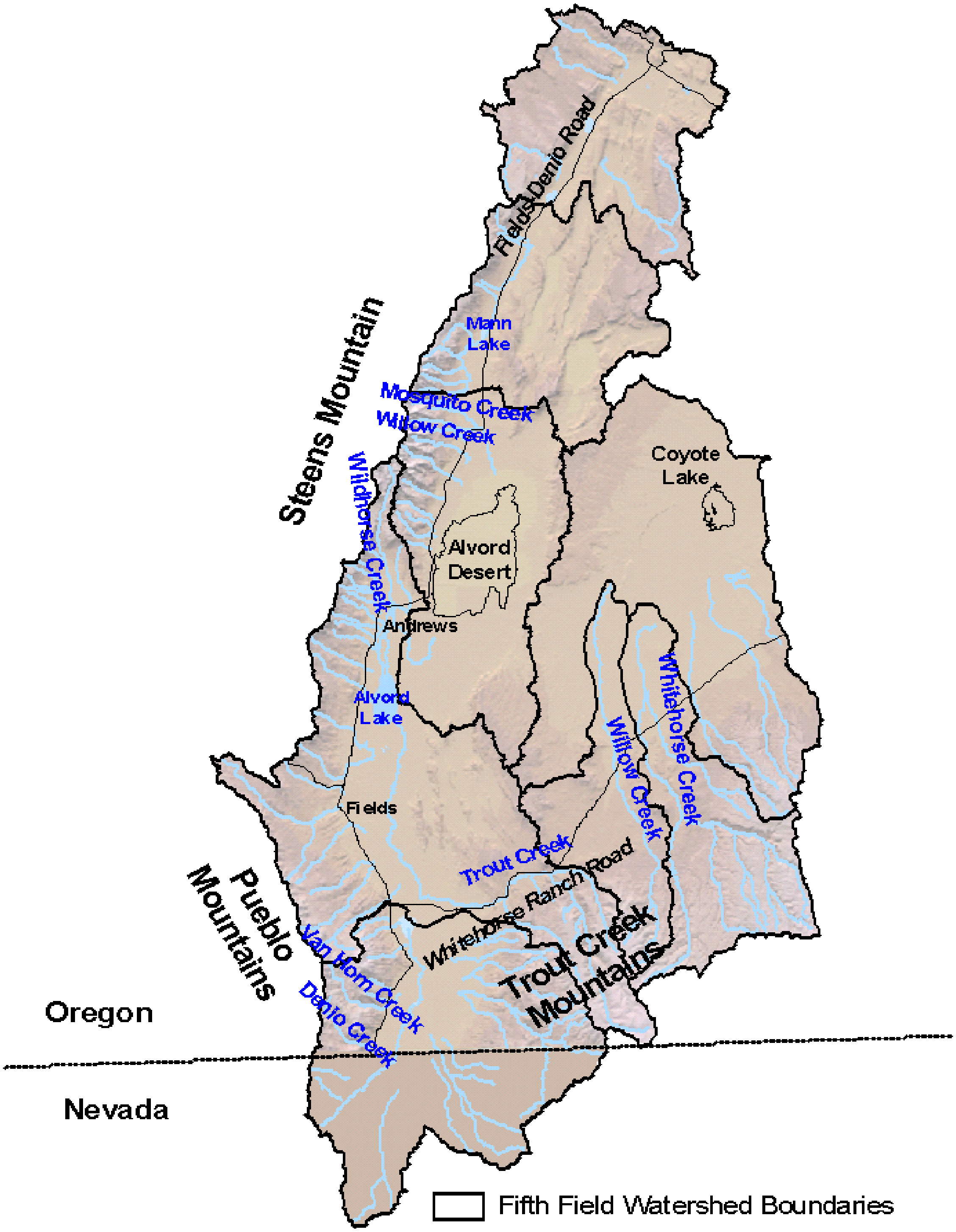


Figure 1-1. The Alvord Lake Subbasin includes eight 5th field watersheds.

1.1 INTRODUCTION

The following summary introduces the Alvord Lake Subbasin, discusses the purpose of this document and describes the goals and plans established within.

The Alvord Lake Subbasin (Hydrologic Unit Code 17120009) is comprised of eight 5th-field watersheds (**Figure 1-1**). The majority of the subbasin is located in Harney County; however, the Willow Creek and Whitehorse watersheds reside within the extreme southwest corner of Malheur County. The subbasin encompasses an area of approximately 2,150 square miles. The diverse terrain within the subbasin ranges from the rugged, steep mountainous headwaters at 9400 feet elevation to the playa in the desert floor at 4000 feet.

The Alvord Lake Subbasin TMDL establishes water quality goals for 303(d) listed and salmonid-bearing streams and their tributaries located in the subbasin. It also lays out steps toward meeting these goals. Water quality programs that lead to TMDL attainment will advance Oregon's commitment to complying with State and Federal Law. To accomplish this, the State has promoted a path that progresses towards water quality standard compliance, with protection of the beneficial uses of waters of the State the primary goal. The data review and analysis contained in this document summarizes the varied data collection efforts and studies that have occurred in the Alvord Lake Subbasin since 1998. It is expected that water quality programs will utilize this TMDL to develop and/or alter water quality management efforts. In addition, this TMDL should be used to track water quality, instream physical parameters and landscape conditions that currently exist. In the future, it will be important to determine the adequacy of planned water quality improvement efforts.

Numerous streams do not meet Oregon water quality standards. Observation, history and research clearly indicate that near stream areas of the watershed have been modified through land cover disturbance and over use, stream straightening, levee construction, land re-surfacing and constriction due to management and diversion structures. Each TMDL contained in this document evaluates impairments and establishes TMDL numeric goals based on attainment of water quality standards.

The report is organized as follows:
- Chapter I describes an overview of the TMDLs and the geographic area of the Alvord Lake Subbasin.
- Chapter II summarizes the other seven elements for the temperature TMDLs for the Subbasin.
- Chapter III summarizes the other seven elements for the temperature TMDL for Willow Creek (Trout Creek Mountains).
- Chapter IV summarizes the other seven elements for the dissolved oxygen TMDL in Willow Creek (Trout Creek Mountains).
- Chapter V describes the analytical methodology used in the Heat Source models.
- Appendix A describes the reasonable assurance of implementation and provides an overview of the Water Quality Management Plan.

The Alvord Lake Subbasin has noteworthy distinctions:
- More than 84 percent of the Subbasin is publicly owned.
- The dominant land use is agriculture (livestock and wild horse grazing, hay crop production).
- This is an extremely remote region of Oregon. There are no point sources of pollution; therefore, nonpoint sources are the only water quality concern.
- The geothermal waters of Borax Lake in the Alvord Desert are the home of the endangered Borax Lake chub which is the only native warm water species of fish in Oregon.
- The threatened Lahontan cutthroat trout, which is the most sensitive beneficial use, represents the northern most distribution of these fish with the majority of the population in Nevada and California.

1.2 OVERVIEW OF TOTAL MAXIMUM DAILY LOADS

1.2.1 Elements of a TMDL

The quality of Oregon's streams, lakes, estuaries and groundwater is monitored by the Oregon Department of Environmental Quality (ODEQ). This information is used to determine whether water quality standards are being violated and, consequently, whether the beneficial uses of the waters are impaired. Beneficial uses include fisheries, aquatic life, drinking water, recreation and irrigation. Specific State and Federal plans and regulations are used to determine if violations have occurred: these regulations include the *Federal Clean Water Act of 1972* and its amendments *40 Code of Federal Regulations 131*, and *Oregon's Administrative Rules (OAR Chapter 340)* and *Oregon's Revised Statutes (ORS Chapter 468)*.

The term water quality limited is applied to streams, lakes and estuaries where required treatment processes are being used, but violations of State water quality standards occur. With a few exceptions, such as in cases where violations are due to natural causes, the State must establish a Total Maximum Daily Load or TMDL for any waterbody designated as water quality limited. A TMDL is the total amount of a pollutant (from all sources) that can enter a specific waterbody without violating the water quality standards.

The loading capacity is the total permissible pollutant load allocated to point, nonpoint, background, and future sources of pollution. Load Allocations are portions of the loading capacity that are attributed to either natural background sources, such as soils, or from non-point sources, such as urban, agriculture or forestry activities. Allocations can also be reserved for future uses. Simply stated, allocations are quantified measures that assure water quality standard compliance while distributing the allowable pollutant loads between sources. The TMDL is the integration of all these developed allocations.

The U. S. Environmental Protection Agency (EPA) has the authority under the Clean Water Act to approve or disapprove TMDLs that states submit. When a TMDL is officially submitted by a state to EPA, the Agency has 30 days to take action on the TMDL. In the case where EPA disapproves a TMDL, EPA would need to establish the TMDL within 30 days.

The required elements of a TMDL that must be submitted to EPA include:

1. A description of the geographic area to which the TMDL applies;
2. Specification of the applicable water quality standards;
3. An assessment of the problem, including the extent of deviation of ambient conditions from water quality standards;
4. Evaluation of seasonal variations
5. Identification of point sources and nonpoint sources;
6. Development of a loading capacity including those based on surrogate measures and including flow assumptions used in developing the TMDL;
7. Development of Waste Load Allocations for point sources and Load Allocations for nonpoint sources;
8. Development of a margin of safety.

1.2.3 TMDL Implementation via the Water Quality Management Plan

Implementation of TMDLs is critical to the attainment of water quality standards. The support of Designated Management Agencies (DMAs) in implementing TMDLs is essential. A DMA is any agency or entity responsible for affecting water quality through its management of land and/or water. In instances where ODEQ has no direct authority for implementation, ODEQ works with DMAs on implementation to ensure attainment of water quality standards. The DMAs in the Alvord Lake Subbasin include: Bureau of Land Management, Oregon Department of Agriculture, Oregon Department of Forestry, and Oregon

Department of Transportation. These agencies will develop water quality plans to comply with the TMDL and Water Quality Management Plan (WQMP).

ODEQ intends to submit a TMDL WQMP to EPA concurrently with submission of TMDLs. Both the TMDLs and their associated WQMP will be submitted by ODEQ to EPA as updates to the State's Water Quality Management Plan pursuant to 40 CFR 130.6. Such submissions will be a continuing update of the Continuing Planning Process (CPP).

The following are elements of the WQMP that will be submitted to EPA:

- Condition assessment and problem description
- Goals and objectives
- Proposed management strategies
- Timeline for implementing management strategies
- Relationship of management strategies to attainment of water quality standards
- Timeline for attainment of water quality standards
- Identification of responsible participants or DMAs
- Identification of sector-specific implementation plans
- Schedule for preparation and submission of implementation plans
- Reasonable assurance
- Monitoring and evaluation
- Public involvement
- Planned efforts to maintain management strategies over time
- Costs and funding
- Citation to legal authorities
- Identification of voluntary programs/incentives to implement management strategies

Appendix A contains the WQMP for the Alvord Lake Subbasin. This document explains the roles of various land management agencies, federal, state, and local governments, as well as private landowners in implementing the actions necessary to meet the allocations in the TMDLs. It also includes directly or by reference the statutes, rules, ordinances, local plans, and all other known mechanisms for implementation. The WQMP for the Alvord Lake Subbasin focuses specifically on:

- State Forest Lands (Forest Practices Act)
- Private Forest Lands (Forest Practices Act)
- Bureau of Land Management (Water Quality Restoration Plans)
- Private Agricultural Lands (Greater Harney Basin Agricultural Water Quality Management Area Plan)

These documents and several public summary documents are: available upon request, at locations within the Alvord Lake Subbasin and can be found on the ODEQ website: http://waterquality.ODEQ.state.or.us/wq/. The TMDL and WQMP build upon the following land management programs in the Alvord Lake Subbasin:

- Oregon's Forest Practices Act (State and private forestlands)
- Senate Bill 1010 (agricultural lands)
- Oregon Plan (all lands)
- Many other programs (ODOT, Cities & County, etc.)

Appendix A includes (1) schedules for evaluating and producing programs, rules or policy to implement TMDLs, (2) recommendations of best management practices to improve water quality, (3) discussion of costs, areas and impairments of emphasis, long-term monitoring, public involvement and maintenance of effort over time.

ODEQ relied heavily on input from local stakeholders while developing the TMDLs for the Alvord Lake Subbasin. ODEQ worked closely with BLM, ODFW and private landowners in the collection of the data described in these TMDLs. Draft TMDL modeling results and strategies were presented at local meetings with BLM and ODFW, and at meetings of the Local Advisory Committee for the Greater Harney Basin Agricultural Water Quality Management Area. These meetings were all open to the public. In addition, drafts of TMDL modeling results and strategies were presented to owners of the large ranches affected by the TMDL. Valuable contributions from all these forums included review and comment concerning method development, data collection, data evaluation and study of the interaction between land use and water quality. The knowledge derived from these data collection efforts and discussions, some of which is presented in this document, has been used to design the enclosed protective and enhancement strategies that address water quality issues.

1.2.4 Implementation and Adaptive Management Issues

The goal of the Clean Water Act and associated Oregon Administrative Rules is that water quality standards shall be met or that all feasible steps will be taken towards achieving the highest quality water attainable. This is a long-term goal in many watersheds, particularly where nonpoint sources are the main concern. To achieve this goal, implementation must commence as soon as possible.

Total Maximum Daily Loads (TMDLs) are numerical loadings that are set to limit pollutant levels such that in-stream water quality standards are met. ODEQ recognizes that TMDLs are values calculated from mathematical models and other analytical techniques designed to simulate and/or predict very complex physical, chemical and biological processes. Models and techniques are simplifications of these complex processes and, as such, are unlikely to produce an exact prediction of how streams and other waterbodies will respond to the application of various management measures. It is also recognized that there is a varying level of uncertainty in the TMDLs depending on factors such as amount of data that is available and how well the processes listed above are understood. It is for this reason that the TMDLs have been established with a margin of safety. Subject to available resources, ODEQ will review and, if necessary, modify TMDLs established for a subbasin on a five-year basis or possibly sooner if ODEQ determines that new scientific information is available that indicates significant changes to the TMDL are needed.

Water Quality Management Plans (WQMPs) are plans designed to reduce pollutant loads to meet TMDLs. ODEQ recognizes that it may take some period of time—from several years to several decades-- after full implementation before management practices identified in a WQMP become fully effective in reducing and controlling certain forms of pollution such as heat loads from lack of riparian vegetation. In addition, ODEQ recognizes that the technology for controlling some nonpoint sources of pollution is still in the development stages and it will likely take one or more iterations before effectiveness can be adequately be evaluated. It is possible that after application of all reasonable best management practices, some TMDLs or their associated surrogates cannot be achieved as originally established.

ODEQ also recognizes that, despite the best and most sincere efforts, natural events beyond the control of humans may interfere with or delay attainment of the TMDL and/or its associated surrogates. Such events could be, but are not limited to, floods, fire, insect infestations, and drought.

In these TMDLs, the surrogate of effective shade has been defined as an alternative target for meeting the TMDLs. The purpose of the surrogate is not to bar or eliminate human access or activity in the subbasin or its riparian areas. It is the expectation, however, that this WQMP and the associated DMA-specific Implementation Plans will address how human activities will be managed to achieve the surrogates. It is also recognized that full attainment of pollutant surrogates (*system potential* shade, for example) at all locations may not be feasible due to physical, legal or other regulatory constraints. To the extent possible, the Implementation Plans should identify potential constraints, but should also provide the ability to mitigate those constraints should the opportunity arise. For instance, at this time, the existing location of a road or highway may preclude attainment of *system potential* shade due to safety considerations. In the future, however, should the road be expanded or upgraded, consideration should be given to designs that support TMDL load allocations and pollutant surrogates such as *system potential* shade.

ODEQ will work with DMAs in developing Implementation Plans that are consistent in meeting the assumptions and requirements of the load allocations. These plans will be developed/modified within 1-2 years following the development/modification of a TMDL and will include but not be limited to the following:

- Management measures tied to attainment of the TMDL,
- Timeline for implementation (including appropriate incremental measurable water quality targets and milestones for implementing control actions),
- Timeline for attainment of water quality standards including an explanation of how implementation is expected to result in the attainment of water quality standards,
- Monitoring and evaluation

If a source that is covered by this TMDL complies with its Implementation Plan (for example SB1010 plan or WQRP) or applicable forest practice rules, it will be considered in compliance with the TMDL.

ODEQ intends to regularly review progress of this WQMP and the associated Implementation Plans to achieve TMDLs. If and when ODEQ determines that WQMP has been fully implemented, that all feasible management practices have reached maximum expected effectiveness and a TMDL or its interim targets have not been achieved, ODEQ shall reopen the TMDL and adjust it or its interim targets and its associated water quality standard(s) as necessary. The determination that all feasible steps have been taken will be based on, but not limited to, a site-specific balance of the following criteria: protection of beneficial uses; appropriateness to local conditions; use of best treatment technologies or management practices or measures; and cost of compliance (OAR 340-41-026(3)(a)(D)(ii)).

The implementation of TMDLs and the associated plans is generally enforceable by ODEQ, other State agencies and local government. However, it is envisioned that sufficient initiative exists to achieve water quality goals with minimal enforcement. Should the need for additional effort emerge, it is expected that the responsible agency will work with land managers to overcome impediments to progress through education, technical support or enforcement. Enforcement may be necessary in instances of insufficient action towards progress. In the case of nonpoint sources, this could occur first through direct intervention from land management agencies (e.g. ODF, ODA, counties and cities), and secondarily through ODEQ. The latter may be based in departmental orders to implement management goals leading to water quality standards.

In employing an adaptive management approach to this TMDL and WQMP, ODEQ has the following expectations and intentions:

- Subject to available resources, ODEQ will review and, if necessary, modify TMDLs and WQMPs established for the Alvord Lake Subbasin on a five-year basis or possibly sooner if ODEQ determines that new scientific information is available that indicates significant changes to the TMDL are needed. In conducting this review, ODEQ will evaluate the progress towards achieving the TMDL (and water quality standards) and the success of implementing the WQMP.
- ODEQ expects that each management agency will also monitor and document its progress in implementing the provisions of its component of the WQMP. This information will be provided to ODEQ for its use in reviewing the TMDL.
- As implementation of the WQMP proceeds, ODEQ expects that management agencies will develop benchmarks for attainment of TMDL surrogates, which can then be used to measure progress.
- Where implementation of the WQMP or effectiveness of management techniques is found to be inadequate, ODEQ expects management agencies to revise the components of the WQMP to address these deficiencies.
- When ODEQ, in consultation with the management agencies, concludes that all feasible steps have been taken to meet the TMDL and its associated surrogates and attainment of water quality standards,

the TMDL, or the associated surrogates is not practicable, it will reopen the TMDL and adjust it or its interim targets and its associated water quality standard(s) as necessary. The determination that all feasible steps have been taken will be based on, but not limited to, a site-specific balance of the following criteria: protection of beneficial uses; appropriateness to local conditions; use of best management practices or measures; and cost of compliance (OAR 340-41-026(3)(a)(D)(ii)).

1.4 ALVORD LAKE SUBBASIN OVERVIEW

1.4.1 Geology

The Alvord Lake Subbasin is located in the Great Basin, a geographic unit of the Basin and Range Physiographic Province. The Basin and Range Province is an immense region of alternating, north-south and northwest-southeast-trending, faulted mountains and flat valley floors. The north-south faults move vertically to form mountains on one side and valleys on the other side which forms the Basin and Range topography. The region was created about 20 million years ago as the earth's crust stretched, thinned, and then broke into some 400 mountain blocks that partly rotated from their originally horizontal positions. These mountains of late Precambrian and Paleozoic rock continue to erode and fill the intervening valleys with fresh sediment (USGS 2000). The Steens Mountain fault scarp is the most prominent feature on the landscape extending approximately 20 miles with a peak elevation of over 9700 feet.

The fault block geology of the subbasin has a major influence in shaping the streams and life history of the floral communities of the region. Streams are relatively short ranging from 2 to 20 miles in length. The area has a diverse range of plant communities (cottonwood, aspen, and willow dominated communities) that for the purpose of this TMDL are informally subdivided in four ecologically distinct sub-provinces: East Steens Mountain, Pueblo Mountains, Trout Creek Mountains, and the Willow-Whitehorse region. The geomorphology of the of the creeks across the subbasin possess similar attributes in channel type and dimension with widths averaging approximately 12 feet at lower elevations. Many of the streams are ephemeral, intermittent, or display loose/gain phenomenon (certain portions may flow subsurface at times).

1.4.2 Climate

The topography of the subbasin varies from the rugged, steep mountainous headwaters at 9700 feet elevation to the playa in the desert floor at 4000 feet (**Figure 1-2**). The terrain along with the absence of the moderating influence of the Pacific Ocean results in arid conditions. The dry air retains less heat than moist air; therefore, the region experiences extreme fluctuations in daily and seasonal temperatures. Summer air temperatures can range from the 30° Fahrenheit during the evening to over 90° during the day. The rain shadow effect of the Cascades reduces the amount of available moisture from storms over the Pacific Ocean causing a decrease in precipitation in an easterly direction. The influence of the fault scarp formation of the Steens Mountain is to create a local rain shadow effect with annual precipitation as high as 49”-55”. The valley 4.5 miles below will receive 7”-9” of annual moisture (**Figure 1-3**). The greater part of precipitation comes in the form of snowfall during the winter months. Where the terrain is steep (as much as 30% slope or greater), precipitation runs off rapidly during the late spring resulting in exceptionally low base flow conditions during late summer.

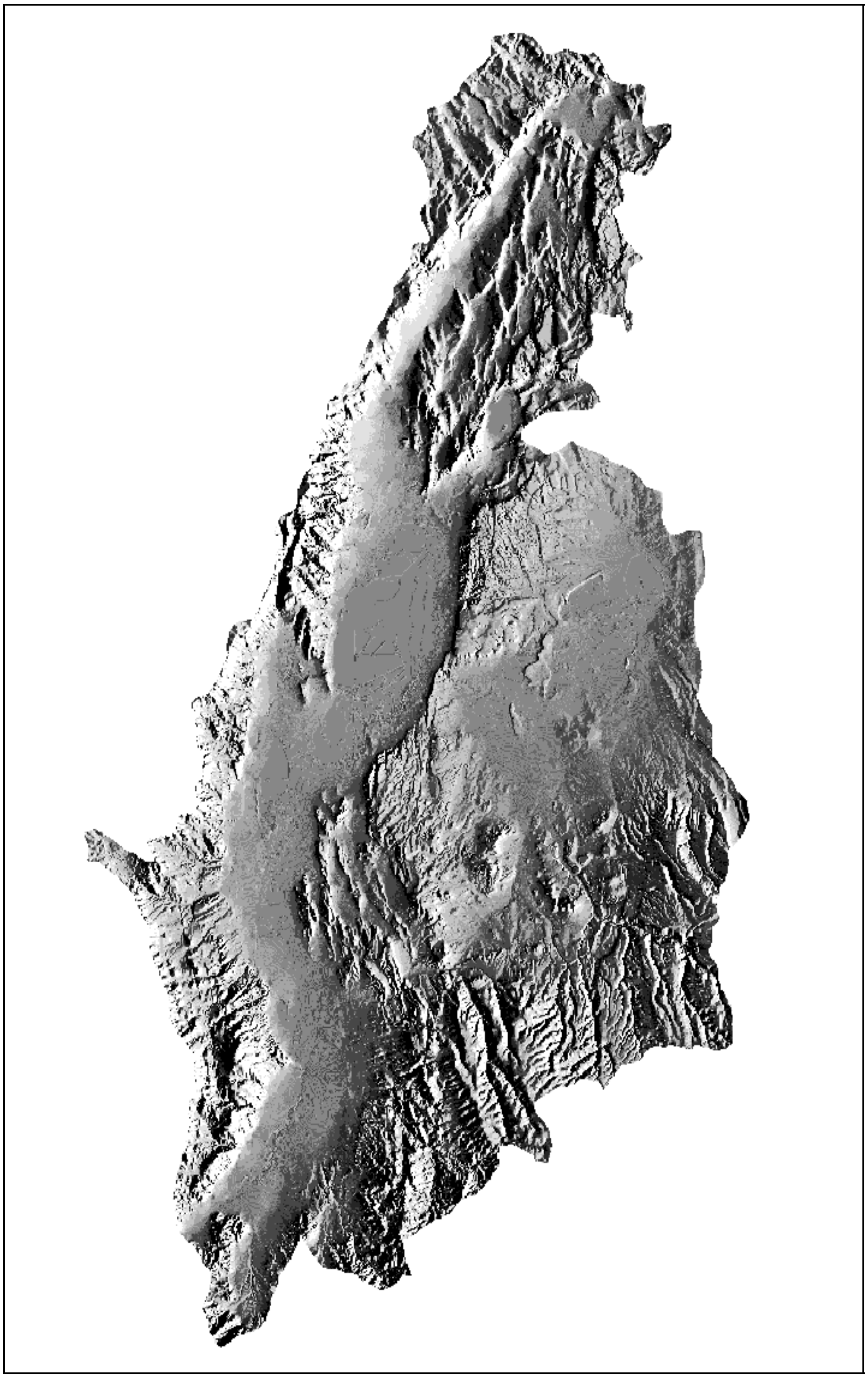


Figure 1-2 . Topographic Relief of the Alvord Lakes Subbasin

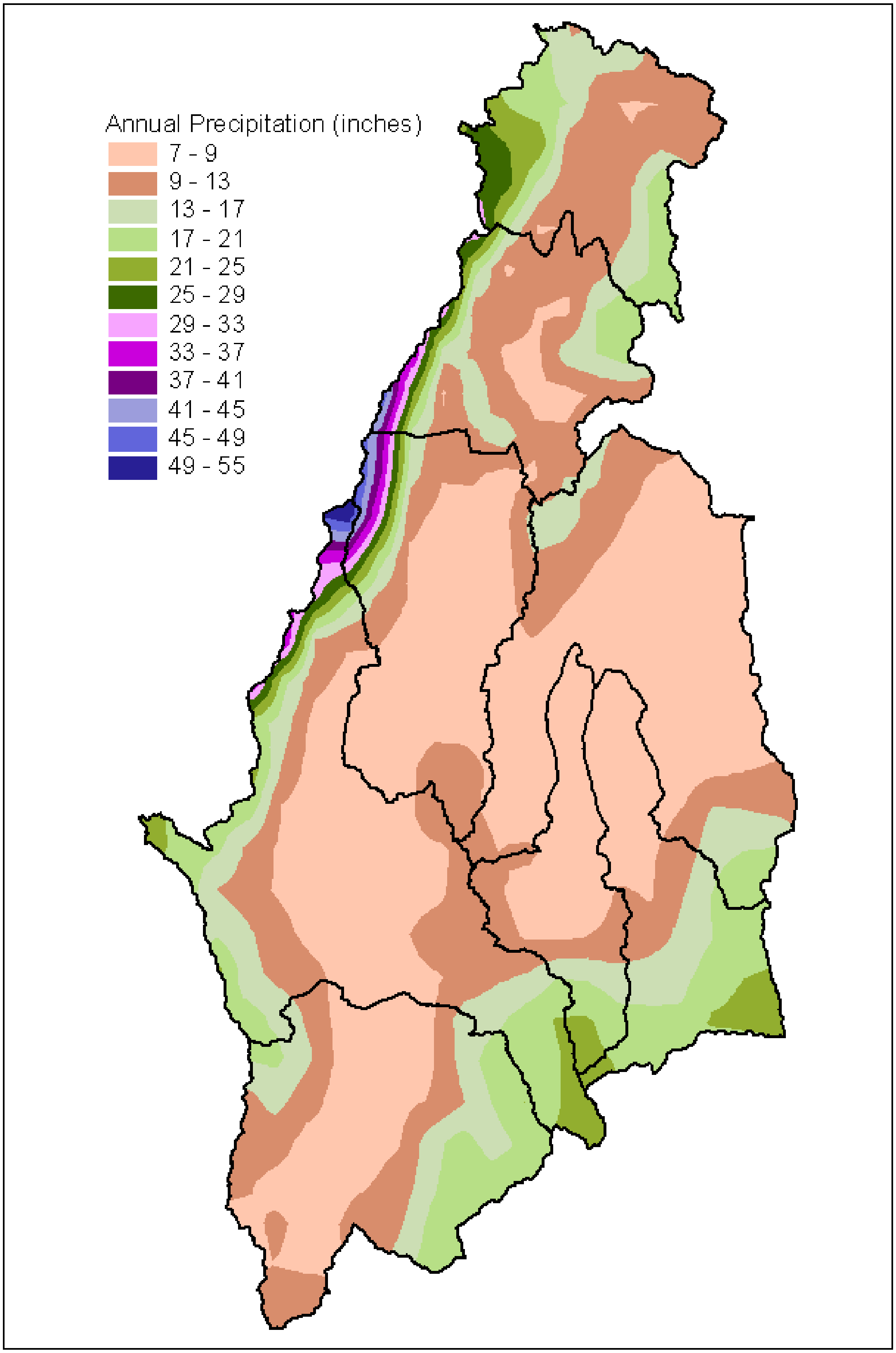


Figure 1-3 . Annual Precipitation of the Alvord Lakes Subbasin

(*digital data from Oregon Geospatial Data Clearinghouse*)

1.4.3 Stream Flow

Low flows generally occur during the mid-to-late summer months starting in July and extending into the early winter months due to minimal precipitation, post runoff season and in some instances increased agriculture water withdrawals for irrigation. Historic stream flow data for the Alvord Lake Subbasin is extremely limited. There are only two USGS/OWRD gages: Wild Horse Creek near Andrews, Oregon with a period of record ending 1953; and Trout Creek near Fields, Oregon with the period of record ending in 1997. The low flows were measured as part of the subbasin assessment. The flows during 2001 were recorded for all of the streams surveyed. The volume of low flow, or base flow, for most streams is generally less than 1.0 cubic foot per second (cfs). The exception was Trout Creek which was measured at 1.76 cfs during low flow.

1.4.4 Land Use and Ownership

The majority of land within the Alvord Lake Subbasin (84%) is owned by the federal government and is managed by the Bureau of Land Management (BLM) (**Table 1-1** and **Figure 1-4)**. The remainder of land is held privately, generally by large ranches.

Land cover in the Alvord Lake Subbasin is predominantly shrubland (77.9%). The remainder of coverage is divided into other uses as depicted in **Table 1-2** and **Figure 1-5**. Wetlands and water cover 0.4% of the entire subbasin.

Table 1-1. Alvord Lake Subbasin Ownership Covered by TMDL

Ownership	Alvord Lake Subbasin Square Miles	Percent of Total Ownership
Bureau of Land Management	1,756	81.7 %
State of Oregon Lands	37	1.7%
Private	357	16.6%
Totals	2,150	100%

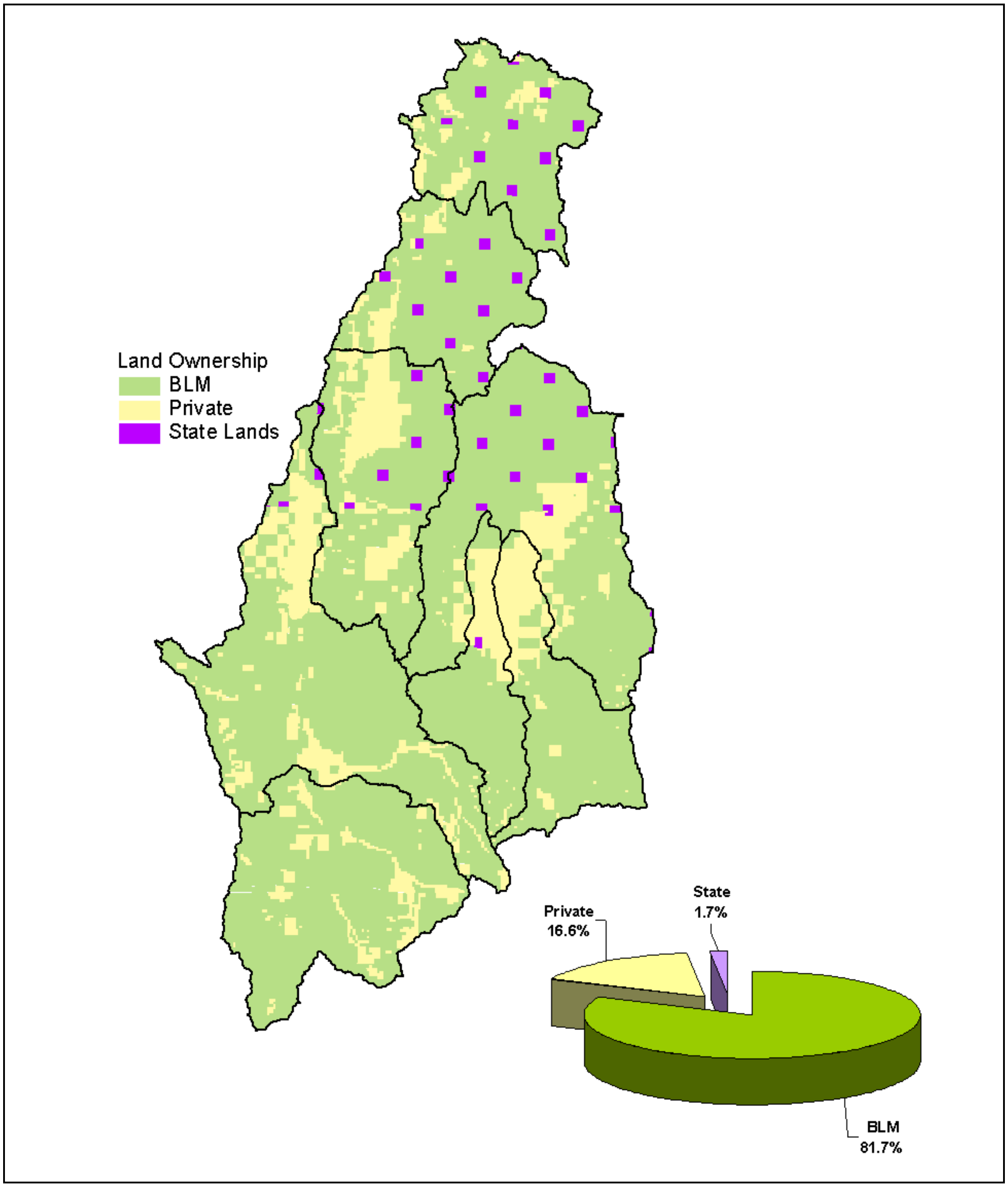


Figure 1-4. Land Ownership in the Alvord Lake Subbasin

(*digital data from BLM Burns andVale District Offices and BLM Nevada*)

Table 1-2. Alvord Lake Subbasin Land Covered by the TMDL

Land Cover in the Alvord Lakes Subbasin	Percent of Total
Shrubland	77.9%
Forested upland	1.3%
Barren land	7.7%
Grasslands	10.3%
Planted/cultivated crops	2.4%
Developed land	<1%.
Wetlands	0.3%
Water	0.1%

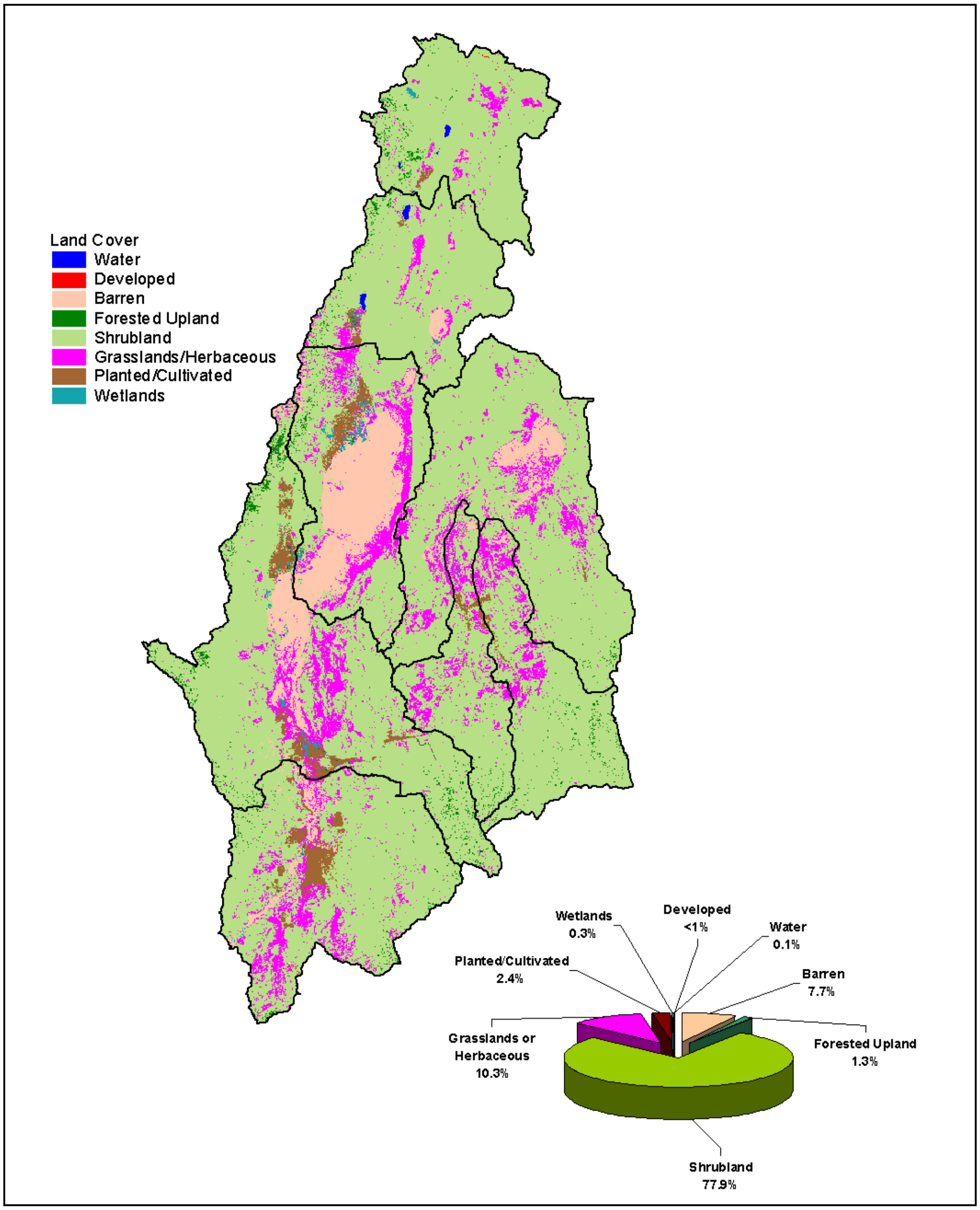


Figure 1-5. Land Use Spatial Distributions

(*digital data from USGS National Land Cover Dataset*)

1.4.5 Fisheries

A variety of fish species are present in the Alvord Lake Subbasin including those listed in **Table 1-3** and **Figure 1-6**.

Table 1-3. Fish Species of the Alvord Lake Subbasin

Common Name	Species	Listing Status
Lahontan cutthroat trout	*Oncorhynchus clarki henshawi*	Threatened (USFWS) (ODFW)
Lahontan cutthroat trout	*Oncorhynchus clarki ssp.*	None (hatchery variety)
Rainbow trout	*Oncorhynchus mykiss ssp.*	none
Alvord cutthroat trout	*O. clarki unclassified*	extinct
Brown trout	*Salmo trutta*	none
Borax Lake chub	*Gila boraxobius*	Endangered (USFWS) (ODFW)
Alvord chub	*Gila alvordensis*	Sensitive, Vulnerable (ODFW)

Key species of interest to this TMDL include the Lahontan cutthroat trout and rainbow trout. Life stage periodicities for these key species are listed in **Table 1-4**. Life stage periodicity was determined by consensus of fisheries biologists from ODFW, BLM, and U.S. Fish & Wildlife Service with representatives from Bend, Burns, Ontario, and Vale Offices. It is important to note that the timing of spawning, egg incubation, and fry emergence varies annually depending on environmental conditions including water availability from snow pack and climatic cycles.

Table 1-4. Life Stage Periodicity

Species	*Life Stage*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Lahontan cutthroat trout	**Adult**	X	X	X	X	X	X	X	X	X	X	X	X
	Spawning				X	X	X						
	Incubation				X	X	X	X*					
	Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
	Migration			X	X	X							
Rainbow trout-hybridized	**Adult**	X	X	X	X	X	X	X	X	X	X	X	X
	Spawning				X	X	X						
	Incubation				X	X	X	X*					
	Juvenile	X	X	X	X	X	X	X	X	X	X	X	X
	Migration			X	X	X							

*headwaters and upper elevation egg incubation and fry emergence

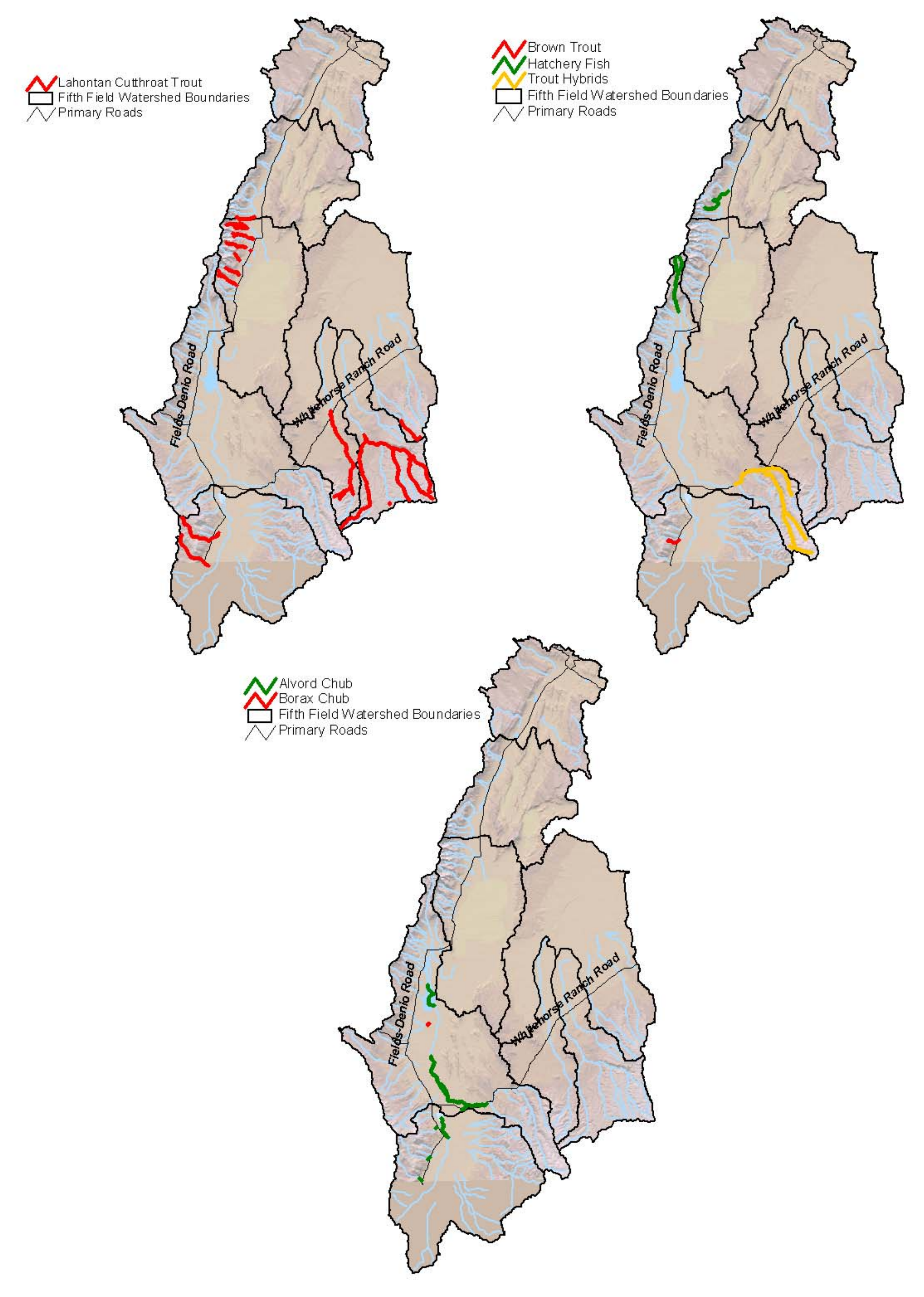


Figure 1-6. Fish Distribution in Alvord Lake Subbasin

(*data from BLM Burns and Vale District Offices and ODFW*)

1.4.5.1 Life History of Fishes in the Alvord Lake Subbasin

The zoogeography of the present day's fishes is poorly documented. The native chub species likely have origins from the Lahontan basin (Smith 1978) to the south in Nevada. The Alvord cutthroat trout which is the native trout that occupied some streams in the region is now extinct according to Behnke (1992). The Lahontan cutthroat trout originated from the Lahontan basin; however, the mechanism by which they arrived is unclear. Lahontan cutthroat trout found in streams originating on the east side of the Steens Mountain and the Pueblo Mountains are the descendents of fish transplanted from Whitehorse and Willow Creeks in the Trout Creek Mountains by the Oregon Department of Fish & Wildlife (Wayne Bowers, personal communication). Given the absence of natural mechanisms, like big rivers, to distribute and connect fish populations, the fish species within the Alvord Lake Subbasin are dispersed randomly among suitable habitats. These habitats include, in some cases, the major portions of creeks but for the most part only include segments where water is available and suitable habitat conditions exist. Some streams were never stocked due to natural limitations, some were stocked and the fish did not survive, or they supported cool and warm water fishes.

1.4.5.2 Lahontan Cutthroat Trout

The Alvord Lake Subbasin is recognized as a high priority for protection and restoration due to the presence of the Lahontan cutthroat trout in many streams. This trout was originally listed as endangered by the U.S. Fish and Wildlife Service (USFWS) in 1970. The listing status was later reclassified as threatened in 1975. The Recovery Plan was developed by the USFWS in 1995 (USFWS 1995).

The Lahontan cutthroat trout in the Willow and Whitehorse drainages, which are a source of stock for other streams in the subbasin, were originally described by Hubbs and Miller (1948) and later by Behnke (1992) as the Whitehorse cutthroat trout. Since that time, genetic delineation has determined these fish are Lahontan cutthroat trout (Williams 1991; Williams et al. 1992). ODEQ contracted with Dr. Jason Dunham to evaluate the life history needs of these fish. The following is an excerpt from his 1999 report to ODEQ:

> "The Lahontan cutthroat trout is a threatened subspecies of cutthroat trout endemic to the Great Basin of southeast Oregon, northern Nevada, and northeastern California (Coffin and Cowan 1995). In the State of Oregon, the natural range for Lahontan cutthroat trout includes the Coyote Lake or Willow/Whitehorse basin, including Willow and Whitehorse Creeks; and the northwest Lahontan basin, which is drained by the upper Quinn River basin, including McDermitt and Sage Creeks (see Hanson et al. 1993; Coffin and Cowan 1995; Jones et al. 1998).
>
> Cutthroat trout colonized the Lahontan basin by at least 30,000 years ago (Trotter 1987), and perhaps as early as the Pliocene (Taylor and Smith 1981). Through this long history in the basin, cutthroat trout had access to a variety of stream and lacustrine habitats. The high stand of Lake Lahontan occurred about 14,000 years ago, when the lake itself covered approximately 22,100 km^2 in a drainage basin of about 117,000 km^2 (LaRivers 1962, Thompson et al. 1986). Following its high stand, Lake Lahontan rapidly desiccated to contemporary levels by about 8,000 years ago, isolating cutthroat trout populations in the eastern (Quinn and Humboldt River) basins from those in the western (Truckee, Carson and Walker River) Lahontan basins.
>
> The Coyote Lake basin in southeast Oregon is an isolated endorheic basin with no direct connection to the Lahontan basin to the south. Little is known of the history of colonization by cutthroat trout in the Coyote Lake basin, but Behnke (1992) believed the most plausible explanation was a headwater stream transfer of cutthroat trout from the neighboring Quinn River basin. Recent genetic analysis using mitochondrial restriction site markers indicated Lahontan cutthroat trout in the Coyote Lake basin and Quinn River basin are genetically distinctive (Williams et al. 1998). Lahontan cutthroat trout in the Coyote Lake basin also are ecologically distinctive, since they are the only fish species in the basin (Jones et al. 1998).
>
> It is evident that populations of Lahontan cutthroat trout have experienced dramatic changes in climatic and hydrologic conditions over time. Spatial variability in these conditions is also evident. Before population declines dramatically reduced the range of Lahontan cutthroat trout, it was found in a remarkable diversity of habitats and thermal environments, including small desert streams (e.g. Willow and Whitehorse Creeks), larger rivers draining the eastern Sierra-Nevada range (e.g. the Walker, Carson, and Truckee Rivers), high-elevation oligotrophic lakes (e.g. Lake Tahoe and Independence

> Lake), and lower-elevation eutrophic lakes (e.g. Pyramid and Walker Lakes). Therefore, it seems reasonable to assume different populations have experienced a variety of different selective pressures. This diverse ecological context may have provided a selective arena favoring local adaptation of some populations (e.g. Hendry et al. 1998).
>
> In Oregon, it seems likely in recent history that all populations of Lahontan cutthroat trout were restricted to living in stream habitats, though fish may have inhabited Coyote Lake in pluvial times (Behnke 1992). In these stream habitats, the opportunity for expression of different migratory life histories was available. Cutthroat trout in streams may adopt a "resident" life history, defined here as fish that spend their entire lives within a restricted zone of a stream very near, or entirely within spawning and rearing areas. Alternatively, some individuals may adopt a "fluvial" life history, where adults make extensive annual or seasonal migrations to feed in downstream habitats, returning to natal streams to reproduce (e.g. Northcote 1997).
>
> It is believed that many Lahontan cutthroat trout populations historically interacted as metapopulations (Coffin and Cowan 1995). The term "metapopulation" refers to a collection of discrete local breeding populations. In the case of Lahontan cutthroat trout, metapopulation dynamics may result when local breeding populations in tributary streams are interconnected by larger downstream habitats. Interaction among tributary populations may have occurred through "straying" or dispersal of resident and/or fluvial fish (see Rieman and Dunham 1999). This was more likely historically, as fragmentation of habitats in the past 150 years has isolated local populations in many tributary habitats (Dunham et al. 1999). Loss of connectivity among local populations has been linked to increased risk of local extinction (Dunham et al. 1997).
>
> In Oregon, it is unclear whether or not Lahontan cutthroat trout populations in Willow and Whitehorse Creeks functioned as a metapopulation, but metapopulation dynamics were much more likely historically in the Quinn River basin, including McDermitt Creek. Today, the potential for metapopulations in this basin is compromised by nonnative salmonids and widespread habitat degradation (Coffin and Cowan 1995).
>
> Human impacts on aquatic habitats are evident everywhere in the Lahontan basin. Changes in aquatic habitats related to human developments over the past 200 years were reviewed by Minshall et al. (1989). They point out that while very little information is available on historic habitat condition, a variety of lines of evidence strongly demonstrate that contemporary and historical land uses have dramatically degraded aquatic habitats in the region.
>
> Degradation and loss of habitat are risk factors identified by U.S. Fish and Wildlife Service (USFWS), which estimates that Lahontan cutthroat trout inhabit only about 15% of historically occupied habitat in the eastern Lahontan basin (Coffin and Cowan 1995). Lahontan cutthroat trout initially were listed as endangered by USFWS in 1970, and subsequently reclassified as threatened in 1975 to facilitate management and allow regulated angling (Coffin and Cowan 1995).
>
> It was not until the early 1990s that basin-wide habitat restoration efforts to benefit Lahontan cutthroat trout were initiated on the ground. Two positive examples of restoration efforts include Willow and Whitehorse Creeks in southeast Oregon (Dufferena 1996), and Marys River in northeast Nevada (Gutzwiller et al. 1997)".

The Alvord Lake Subbasin also contains a hatchery variety of Lahontan cutthroat trout that is maintained to provide sport fishing in the region (called Hatchery Fish in **Figure 1-6**). These fish are not protected by the Endangered Species Act because of their hatchery origin. Their distribution is limited to Mann Lake, Mann Creek, House Creek, and Little Wildhorse Creek.

1.4.5.3 Rainbow Trout

The fishes that currently inhabit the Trout Creeks (Trout Creek, Big Trout Creek, and Little Trout Creek) are a highly hybridized mixture of rainbow and cutthroat trout (called Trout Hybrids in **Figure 1-6**). For the purposes of this TMDL, it is assumed the dominant characteristics of these fish are those of an exotic rainbow trout. The stocking of rainbow trout in the Trout Creeks started in the late 1920s and persisted for many years which increased competition for food and habitat, and caused genetic introgression of the endemic Alvord cutthroat trout. The Alvord cutthroat trout which originally occupied this system is presumed extinct (Behnke 1992). There are no life history studies of the current hybrid form of rainbow trout although it is assumed this sub specific species has similar life history attributes as the Lahontan cutthroat trout given phenotypic adaptation to the desert environment.

1.4.5.4 Brown Trout

Brown trout *(Salmo trutta)* are native to Europe. They are piscivorous (eat other fish) and efficiently compete with other trout species in altered, warm water habitats. Although they are not currently stocked in any streams of the subbasin, brown trout are found in the lower portion of Van Horn Creek. They were first observed there by fish biologists in 1983, the result of an illegal introduction (Hanson 1993). They were observed again in Van Horn Creek in 1991. The abundance of brown trout in Van Horn Creek has not been estimated nor has the life history been studied. The length-frequency distribution of brown trout in Van Horn Creek is shown in **Table 1-5** (Hanson 1993). Van Horn Creek is the only known location of brown trout in the subbasin.

Table 1-5. Length Frequency Distribution of Brown Trout in Van Horn Creek

Inches	% Distribution
4	5
5	5
6	40
7	10
8	30
9	5
10	5

1.4.5.5 Borax Lake Chub

The Borax Lake chub is the sole fish species in Borax Lake, located in the Alvord desert. The Borax Lake chub is an endemic species which exists nowhere else (Williams and Bond 1980). It is listed by the U.S. Fish and Wildlife Service as endangered. This chub species is relatively small ranging from 1.3-2.0 inches with a maximum length of 3.5 inches (Williams, J.E 1995). These fish are capable of spawning year around but generally reproduce in the spring (Williams and Bond 1980). The Borax Lake chub is a warm water species that thrives primarily in the geothermal springs of the lake but also exists in related waters.

The Borax Lake system consists of about 105 total acres of lakes, ponds and marshes. Water flows from the lake to surrounding marshes, pools and lower Borax Lake. This area serves as the extent of critical habitat for the chub. The lake is elevated above the valley floor by over 30 feet as a result of sodium-borate salt deposits from spring flows creating a fragile salt crust shoreline. Several different studies of Borax Lake have found that water temperature in the lake can vary considerably in both space and time. In one study, temperatures measured in the lake ranged from 18^{o}C (64.4^{o}F) at the lake's edge to more than 93^{o}C (199.4^{o}F) where the geothermal waters enter the bottom of the vent area (Schneider and McFarland 1995). In another study, water temperatures in the lake were shown to be prone to unusually large fluctuations over short periods of time. The daily mean temperature at a given site sometimes fluctuated 10^{o}C within a single week (Perkins et al. 1996). The lake is currently controlled by the Nature Conservancy with management cooperation from the BLM.

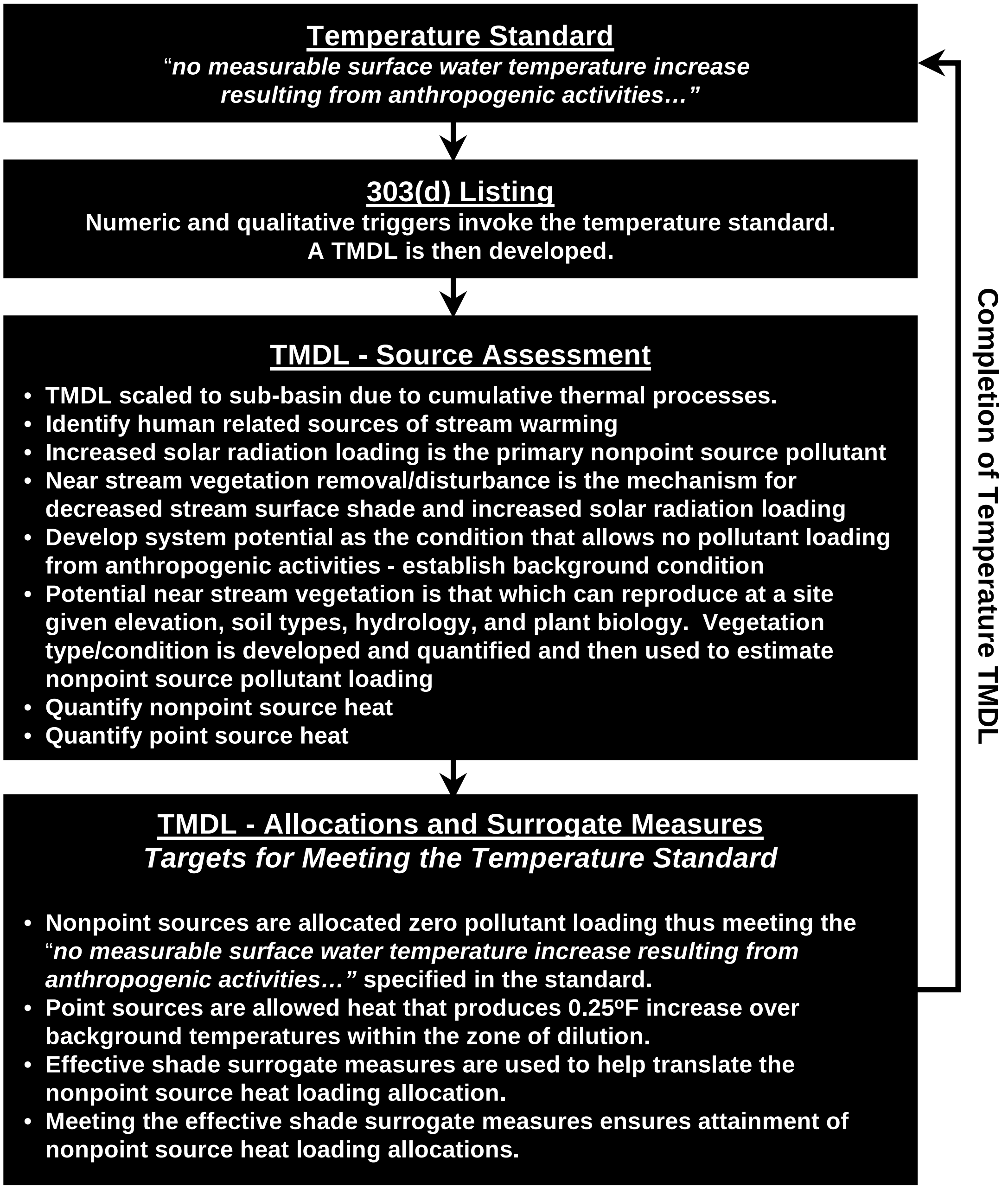
1.4.5.6 Alvord Chub

The Alvord chub is an endemic species closely related to the Borax Lake chub. It is a moderately sized minnow that can grow to over 4" (ODFW 1996). This species is not federally listed but is considered by the Oregon Department of Fish and Wildlife (ODFW) as a sensitive vulnerable species. It inhabits marshes, creeks and springs with variable bottom types where the current is absent or moderate (ODFW 1996). The fish are narrowly distributed with populations occupying varies ponds and the lower reaches of the Trout Creek system.

CHAPTER II: STREAM TEMPERATURE TMDL

2.1 OVERVIEW

2.1.1 Summary of Temperature TMDL Development and Approach



Temperature Standard

"no measurable surface water temperature increase resulting from anthropogenic activities…"

303(d) Listing

Numeric and qualitative triggers invoke the temperature standard. A TMDL is then developed.

TMDL - Source Assessment

- TMDL scaled to sub-basin due to cumulative thermal processes.
- Identify human related sources of stream warming
- Increased solar radiation loading is the primary nonpoint source pollutant
- Near stream vegetation removal/disturbance is the mechanism for decreased stream surface shade and increased solar radiation loading
- Develop system potential as the condition that allows no pollutant loading from anthropogenic activities - establish background condition
- Potential near stream vegetation is that which can reproduce at a site given elevation, soil types, hydrology, and plant biology. Vegetation type/condition is developed and quantified and then used to estimate nonpoint source pollutant loading
- Quantify nonpoint source heat
- Quantify point source heat

TMDL - Allocations and Surrogate Measures

Targets for Meeting the Temperature Standard

- Nonpoint sources are allocated zero pollutant loading thus meeting the "*no measurable surface water temperature increase resulting from anthropogenic activities…*" specified in the standard.
- Point sources are allowed heat that produces 0.25ºF increase over background temperatures within the zone of dilution.
- Effective shade surrogate measures are used to help translate the nonpoint source heat loading allocation.
- Meeting the effective shade surrogate measures ensures attainment of nonpoint source heat loading allocations.

ODEQ Temperature Standard, 303(d) Listing and TMDL Development Process

2.1.1.1 Summary of Stream Temperature Standard

Human activities and aquatic species that are to be protected by water quality standards are deemed beneficial uses. Water quality standards are developed to protect the most sensitive beneficial use within a water body of the State. The stream temperature standard is designed to protect cold water fish (Salmonids) rearing and spawning as the most sensitive beneficial use.

Several numeric and qualitative trigger conditions invoke the temperature standard. Numeric triggers are based on temperatures that protect various salmonid life stages. Qualitative triggers specify conditions that deserve special attention, such as the presence of threatened and endangered cold water species, and dissolved oxygen violations. The occurrence of one or more of the stream temperature triggers will invoke the temperature standard (**Table 2-1**).

Once invoked, a water body is designated water quality limited. For such water quality limited water bodies, the temperature standard specifically states that "***no measurable surface water temperature increase resulting from anthropogenic activities is allowed"*** (OAR 340-41-0882(2)(b)(A)). Thermally impaired water bodies in the Alvord Lake Subbasin are subject to the temperature standard that mandates a condition of no allowable anthropogenic (human caused) related temperature increases.

2.1.1.2 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. For example, Willow Creek is water quality limited for temperature. To address this listing in the TMDL, Willow Creek and its 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.

The temperature standard specifies that "***no measurable surface water temperature increase resulting from anthropogenic activities is allowed***". An important step in the TMDL is to examine the human caused contributions to stream heating. The pollutant is heat. The TMDL establishes that the human caused contributions of nonpoint source solar radiation heat loading result from varying levels of decreased stream surface shade throughout the subbasin. Decreased levels of stream shade are caused by near stream land cover disturbance/removal and channel morphology changes. Other human caused sources of stream warming include stream flow reductions and warm surface water return flows.

System potential as defined in the TMDL 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. *System potential*, as developed in this TMDL, also does not consider potential channel morphology. **In essence, *system potential* is the design condition used for TMDL analysis that meets the temperature standard by requiring that human caused activities create no measurable increase in surface water temperatures.**

- *System potential* is an estimate of the condition where human caused activities that cause stream warming are modified to the extent that they create no measurable increase in surface water temperatures.
- *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. Nonpoint sources are expected to reduce the human caused portion of solar radiation heat loading to the point where it can not be measured. Allocated conditions are expressed as heat per unit time (BTU per day). The nonpoint source heat allocation is translated to effective shade surrogate measures that correspond to the nonpoint source solar radiation allocation. Effective shade surrogate measures provide site-specific targets for land managers. And, attainment of the surrogate measures ensures compliance with the nonpoint source allocations.

Table 2-1. Alvord Lake Subbasin Temperature TMDL Components

Waterbodies	Perennial or fish bearing (as identified by ODFW, or USFWS) streams within the 4th field HUC (hydrologic unit code) 17120009.
Pollutant Identification	<u>*Pollutants*</u>*:* Human caused heat from solar radiation loading from nonpoint sources
Target Identification (Applicable Water Quality Standards) *CWA §303(d)(1)*	OAR 340-41-0882(2)(b)(A) To accomplish the goals identified in OAR 340-041-0120(11), unless specifically allowed under a Department-approved surface water temperature management plan as required under OAR 340-041-0026(3)(a)(D), no measurable surface water temperature increase resulting from anthropogenic activities is allowed: (i) In a basin for which salmonid fish rearing is a designated beneficial use, and in which surface water temperatures exceed 64.0°F (17.8°C); (ii) In waters and periods of the year determined by the Department to support native salmonid spawning, egg incubation, and fry emergence from the egg and from the gravels in a basin which exceeds 55.0°F (12.8°C); (iii) In waters determined by the Department to support or to be necessary to maintain the viability of native Oregon bull trout, when surface water temperatures exceed 50.0°F (10.0°C); (iv) In waters determined by the Department to be ecologically significant cold-water refugia; (v) In stream segments containing federally listed Threatened and Endangered species if the increase would impair the biological integrity of the Threatened and Endangered population; (vi) In Oregon waters when the dissolved oxygen (DO) levels are within 0.5 mg/l or 10 percent saturation of the water column or intergravel DO criterion for a given stream reach or subbasin; (vii) In natural lakes.
Existing Sources *CWA §303(d)(1)*	Forestry, Agriculture, Transportation, Rural Residential
Seasonal Variation *CWA §303(d)(1)*	Peak temperatures occur throughout June, July, August, September, and October. Spawning occurs in the drainage.
TMDL Loading Capacity and Allocations *40 CFR 130.2(f)* *40 CFR 130.2(g)* *40 CFR 130.2(h)*	<u>*Loading Capacity:*</u> The water quality standard specifies a loading capacity based on the condition that meets the *no measurable surface water temperature increase resulting from anthropogenic activities.* This condition is termed *System Potential* and is achieved when nonpoint source solar radiation loading reflects that produced by riparian vegetation without human disturbance. <u>*Load Allocations (Non-Point Sources):*</u> *System Potential* solar radiation loading. <u>*Waste Load Allocations (Point Sources)*</u>: none; no point sources in the subbasin
Surrogate Measures *40 CFR 130.2(i)*	<u>Translates Nonpoint Source Load Allocations</u> • Effective Shade targets translate the nonpoint source solar radiation loading capacity.
Margins of Safety *CWA §303(d)(1)*	<u>*Margins of Safety*</u> are demonstrated in critical condition assumptions and are inherent to methodology. No numeric margin of safety is developed.
Water Quality Standard Attainment Analysis *CWA §303(d)(1)*	• Attainment of the water quality standard achieved through mandating "***no measurable surface water temperature increase resulting from anthropogenic activities***"*;* nonpoint sources to target *system potential* conditions • The Water Quality Management Plan will consist of Implementation Plans that contain measures to attain load allocations.

2.1.1.3 Applicability of the Temperature TMDL, Load Allocations and TMDL Surrogates (Effective Shade)

The Alvord Lake Subbasin is a closed basin which means that its streams are not connected to the Pacific Ocean and anadromous fish are blocked from accessing the basin. In addition, many streams are disconnected from each other. Streams develop high in the surrounding mountains and drain to the desert floor to lakes or depressions. During the post-glacial era Alvord Lake served as a reservoir that linked stream networks. As Alvord Lake dried up over geologic time the lake level diminished, losing the connectivity between streams. Today, most of these streams are isolated from each other. There are no large streams that serve as immigration conduits for fish, and connect stream networks and fish populations. As a result, the majority of streams in this subbasin do not support salmonid fishes (salmon and trout) due to natural limitations. **Table 2-2** contains a list of streams in the basin that have been determined by Oregon Department of Fish and Wildlife (ODFW) to support salmonid fisheries. Streams not listed in **Table 2-2** do not currently contain salmonids, and ODFW does not intend to establish salmonid fisheries in these streams.

Pursuant to the federal Clean Water Act, a TMDL is required for any waterbody that is listed pursuant to Section 303d of the Act. The TMDL is expected to establish the maximum pollutant load that can be allowed to meet the water quality standard. Therefore this TMDL is established for streams in the Alvord Lake Subbasin that are either listed on the 2002 303(d) list (http://www.ODEQ.state.or.us/) or are tributaries to streams identified on the 303(d) list. To ensure protection of salmonid fish that reside in streams that are not listed on the 303d list, it is also established for those unlisted streams that contain salmonid fish or that are tributaries to streams that contain salmonid fish. **Table 2-2** and **Figure 2-1** identify those streams or tributaries where the temperature TMDL applies based on these criteria.

Many streams in the Alvord Lake Subbasin also have a lose-gain phenomenon as the result of site-specific geology and hydrology. As an example, Willow Creek is located on the east side of the Steens Mountain and originates high in the Steens in a very short steep (slopes of 30%+) upper watershed. The stream flows to the valley transition where, during bank-full or greater events, it loses stream power and deposits large coarse-grained materials (boulder/cobble class). At the point of sediment deposition (roughly mid-elevation) two phenomena occur:

- sediment disequilibrium resulting in avulsion or channel anastomosation (multiple thread channels); and,
- creation of a coarse grained fluvial deposit which allows surface water to drain sub-surface to ground water or acts as hyporheic underflow.

As a result, the perennial portion of Willow Creek is about 50% of the stream length. The remainder of the downstream channel is dry most of the year starting in July. ODEQ’s work on desert streams and Blue Mountain streams indicate this spatially intermittent pattern is not uncommon, particularly on the east side of the Steens Mountain where the elevation changes are dramatic. These types of events have been occurring over geologic time as evidenced by massive alluvial fans of large particle sized materials at the base of the Steens Mountain, and relic channels (versus short term human caused impacts) causing channels to shift/redistribute.

Compounding this situation is the issue of water availability from snow pack. The average annual rainfall for the subbasin is about 8”. Desert streams depend on snow pack as a water source for base flow during the late summer period. Consensus among researchers and biologists is that streams within the Alvord Lake Subbasin experience “shrink-swell “ phenomenon based on the amount of water that is available from snow pack during any given year. This corresponds to patterns of fish distribution that expand or contract commensurate with available water. During good water years of high precipitation fish will pioneer new areas, but then retract to suitable habitats during the lesser years of low precipitation. Further, plant communities respond similarly to the annual cycles but on a reduced adaptive scale due to the lack of mobility.

Because of the lose-gain phenomena associated with the streams in the Alvord Lake Subbasin, a team of biologists with ODEQ, BLM and ODFW and several private landowners visited most of the streams identified in **Table 2-2** in May, 2003 to determine the “bottom” of each stream. This determination was made by looking at the types of vegetation and channel morphology present in the lower reaches of the streams to assess the portion of the stream that had enough water in it most years to support the establishment of riparian vegetation and salmonid fisheries. For Trout Creek, the “bottom” of the stream occurred on private land where the team was not given permission to access the area to make the necessary determination. In this instance, the bottom of the stream was determined largely from aerial photographs and local knowledge of the systems. In this TMDL, the surrogate measure of *system potential* shade will only be applied to those portions of the streams determined to have enough water for enough of the year to support the establishment of riparian vegetation (**Table 2-2**, **Figure 2-1**).

As was described in the **Executive Summary** (pages i-ii), there are two separate chapters describing TMDLs for temperature in the Alvord Lake Subbasin. This chapter, Chapter II, describes the temperature TMDL developed for the salmonid-bearing streams (and their tributaries) in the Alvord Lake Subbasin. Willow Creek in the Trout Creek Mountains is included as a salmonid-bearing stream, however a separate TMDL for Willow Creek was drafted by ODEQ in 1999 (included as Chapter III in this document). The types of data and modeling analysis used to produce this TMDL are different than the methods presented here in Chapter II. Although the TMDLs were developed differently, both target human caused sources of heat from increased solar radiation loading and use percent effective shade targets as surrogate measures for nonpoint source pollutant loading.

Table 2-2. Applicable TMDL Streams or Stream Segments in the Alvord Lake Subbasin

Stream	Basis for TMDL	"Bottom" of Stream
East Steens Mountain		
Big Alvord Creek	Salmonid bearing*	Fields-Denio Highway
Buena Vista Creek	Salmonid bearing	Confluence with Mosquito Creek
Cottonwood Creek	Salmonid bearing	~200 yards above old county road (42.715278/-118.49194)
Little Alvord Creek	Salmonid bearing	Fields-Denio Highway
Little McCoy Creek	Salmonid bearing	End of USGS perennial delineation on Quad map (42.71214/-118.472881)
Little Wildhorse Creek	Salmonid bearing, 303(d) list	Confluence with Wildhorse Creek
Mann Creek	Salmonid bearing	42.73365/118.4838
Mosquito Creek	Salmonid bearing	Fields-Denio Highway (new road alignment constructed in 2003)
Pike Creek	Salmonid bearing	Fields-Denio Highway
Wildhorse Creek	Salmonid bearing, connected to 303(d) listed stream	42.51917/-118.59523
Willow Creek	Salmonid bearing, 303(d) list	Lower BLM Boundary
Pueblo Mountains		
Denio Creek	Salmonid bearing, 303(d) list	Fields-Denio Highway
Van Horn Creek	Salmonid bearing, 303(d) list	Fields-Denio Highway
Trout Creek Mountains		
Big Trout Creek	Salmonid bearing, 303(d) list	Confluence with Little Trout Creek
East Fork Big Trout Creek	Salmonid bearing, connected to 303(d) listed stream	Confluence with Big Trout Creek
Little Trout Creek	Salmonid bearing, connected to 303(d) listed stream	Confluence with Big Trout Creek
Trout Creek	Salmonid bearing, connected to 303(d) listed stream	3.4 miles below Whitehorse Ranch Rd, confluence with South Branch (42.1565/-118.4987)
Unnamed tributary to Big Trout Creek at RM 13.8	Salmonid bearing	Confluence with Big Trout Creek
Willow/Whitehorse		
Antelope Creek	Salmonid bearing	End of USGS perennial delineation on Quad map (42.36516/-118.15150)
Cottonwood Creek	Salmonid bearing	Confluence with Whitehorse Creek
Doolittle Creek	Salmonid bearing	Confluence with Whitehorse Creek
Fifteenmile Creek	Salmonid bearing	Confluence with Whitehorse Creek
Little Whitehorse Creek	Salmonid bearing	Confluence with Whitehorse Creek
Whitehorse Creek	Salmonid bearing	End of USGS perennial delineation on Quad map (42.283656/-118.201586)
Sheepline Creek	Salmonid bearing	Confluence with Whitehorse Creek
Willow Creek	Salmonid bearing, 303(d) list	End of USGS perennial delineation on Quad map (42.32626/-118.26991)
Jawbone Creek	Salmonid bearing, connected to 303(d) listed stream (called unnamed creek on the list)	Confluence with Willow Creek
Unnamed tributary to Little Whitehorse Creek near headwaters	Salmonid bearing	Confluence with Little Whitehorse Creek
Unnamed tributary to Jawbone Creek	Salmonid bearing	Confluence with Jawbone Creek

*Note: Salmonid bearing streams determined by ODFW; Hanson, M., W. Bowers, and R. Perkins. 1993. Lahontan Subbasins Fish Management Plan. Oregon Department of Fish and Wildlife, Portland.

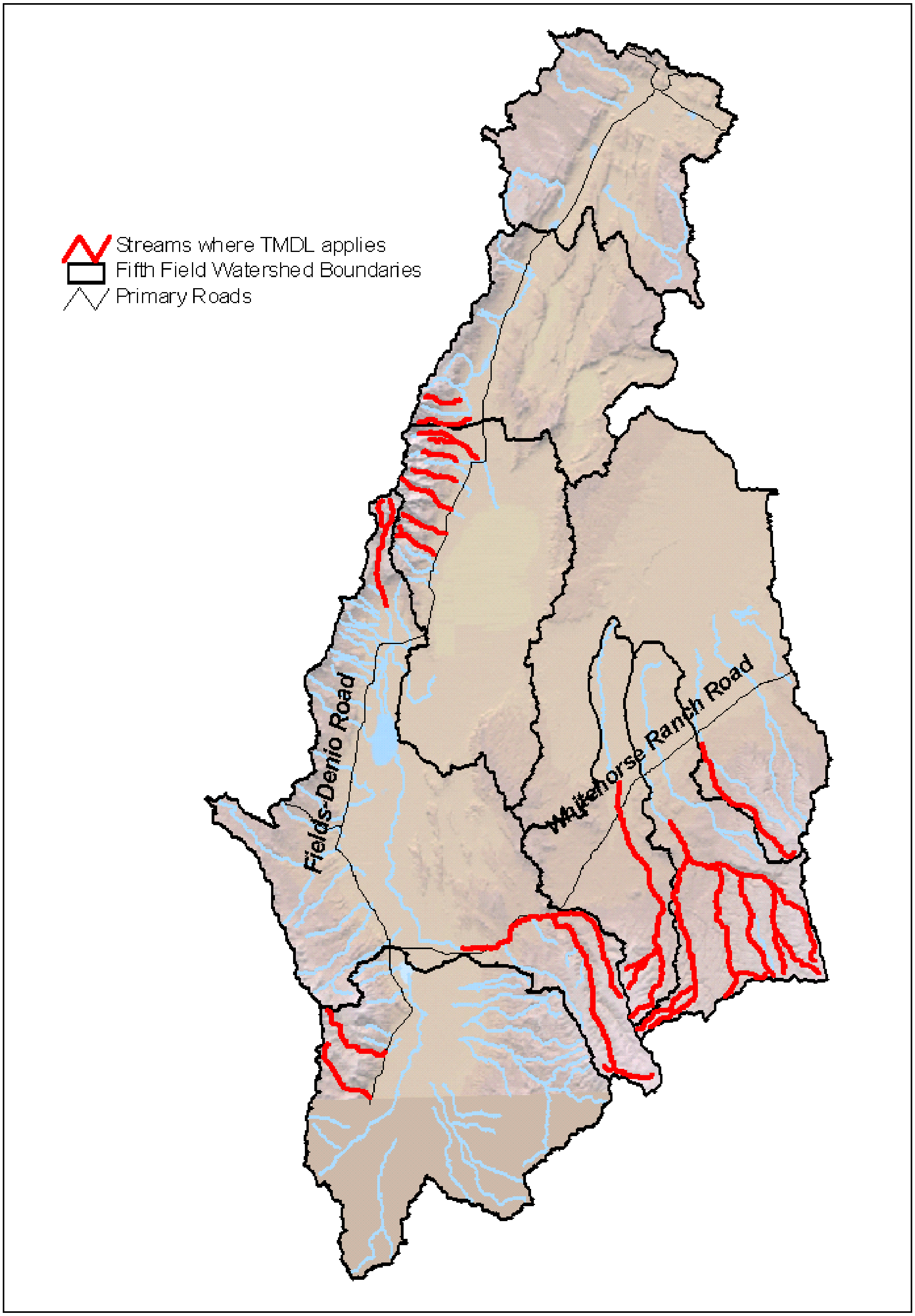


Figure 2-1. Streams Where Alvord Lake Subbasin Temperature TMDL Applies

2.1.1.4 Limitations of Stream Temperature TMDL Approach

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

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

The state of scientific understanding of stream temperature is evolving; however, there are still areas of analytical uncertainty that introduce errors into the analysis. The following 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 is 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.
- Small desert streams present significant challenges when attempting to characterize existing and *system potential* vegetation conditions due to the narrow channel widths (3-4 meters) and the absence of wide riparian corridors (as little as 7-8 meters in some places). The Heat Source model used by ODEQ in TMDL development is generally applied in situations where the width of the stream and riparian area are much greater (typically greater than 20 meters) and upland conditions, such as forests, are vastly different than in the Alvord. Using this model in the Alvord results in a TMDL that meets the nominal requirement of the Clean Water Act to provide an analysis of thermal loading for the modeled streams. The analysis of the surrogate shade values associated with the thermal loads provides helpful direction to understand the overall trend in existing and *system potential* vegetative conditions.
- In some cases, like the Trout Creeks, there is not scientific consensus related to riparian and hydrologic potential conditions because there was insufficient time to complete the field studies. In this instance ODEQ used the best available information including recent vegetative surveys and applied best professional judgment when determining *system 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).
- ODEQ has documented natural lose-gain phenomena which must be considered in the application of this temperature TMDL's surrogate measure of *system potential* vegetation. There are certain sections on the lower end of many streams where there is insufficient water to support riparian vegetation because of naturally occurring conditions. This phenomenon is recognized in this TMDL through *system potential* calculations where site specific data are available. Also, when measuring attainment of *system potentia*l vegetation and channel morphology this phenomenon must be recognized.

2.1.2 Salmonid Thermal Requirements

The emphasis of this TMDL is focused on the protection of cold water salmonids, specifically trout in the Alvord Lake Subbasin. If stream temperatures become too hot, fish die almost instantly due to denaturing of critical enzyme systems in their bodies (Hogan, 1970). The ultimate *instantaneous lethal limit* occurs in high temperature ranges (upper-90°F). Such warm temperature extremes are rare in the Alvord Lake Subbasin.

The stream temperatures observed within the Alvord Lake Subbasin are more commonly in the mid-70°F range (mid- to high-20°C range). These temperatures cause stress of cold-water fish species during exposure times lasting a few hours to one day. The exact temperature at which a cold water fish succumbs to such a thermal stress depends on the temperature that the fish is acclimated and on particular development life-stages. This cause of death from high temperatures, termed the *incipient lethal limit*, is from breakdown of physiological regulation of vital processes such as respiration and circulation (Heath and Hughes, 1973).

The most common and widespread cause of thermally induced fish mortality is attributed to interactive effects of decreased or lack of metabolic energy for feeding, growth or reproductive behavior, increased exposure to pathogens (viruses, bacteria and fungus), decreased food supply (impaired macroinvertebrate populations) and increased competition from warm water tolerant species. This mode of thermally induced mortality, termed indirect or *sub-lethal*, is more delayed, and occurs weeks to months after the onset of elevated temperatures (for most cold water species, mid-60°F to low-70°F).

While the above data provide a general idea of the effects of thermal stress on salmonids, the Department contracted with Dr. Jason Dunham, University of Nevada-Reno, to review the scientific literature to identify the specific thermal needs of the Lahontan cutthroat trout. The following is an excerpt from his report to ODEQ (Dunham, 1999).

> "The best available data indicate Lahontan cutthroat trout begin to show signs of physiological stress under chronic exposure to temperatures above 22° C (Vigg and Koch 1980; Dickerson and Vinyard 1999). This applies only to fish held under relatively optimal (e.g. high food availability, dissolved oxygen, low ammonia) laboratory conditions. Heat shock proteins are induced at detectable levels almost immediately when fish are exposed to chronic temperatures of 26° C, and within 24 hours at 24° C (L. Weber, personal communication).
>
> While induction of heat shock proteins was not immediately detectable at 24° C, this does not mean that fish exposed to temperatures equal to or greater than 24° C were not immediately stressed (L. Weber, personal communication). There may be a time lag between occurrence of physiological stress (e.g. cell damage caused by high temperature) and the stress response (e.g. induction of detectable levels of heat shock proteins). Here it is critical to distinguish between occurrence of stress and the expression of detectable symptoms.
>
> Nothing is known of response times of Lahontan cutthroat trout to potentially stressful temperatures, so it is impossible to define a critical short-term exposure time (e.g. number of seconds, minutes, or hours over a critical temperature). Until such data are available, I conservatively assume that stress occurs immediately at 24° C. Another source of uncertainty is that heat-shock protein experiments were conducted at 2° C intervals, so resolution of the temperature threshold for stress response is limited accordingly.
>
> In summary, the evidence suggests Lahontan cutthroat trout *may* experience stress when exposed either chronically or intermittently on a short-term basis to maximum daily temperatures equal to or greater than 23-24° C."

2.2 TARGET IDENTIFICATION – CWA §303(D)(1)

2.2.1 Sensitive Beneficial Use Identification

Salmonid fish spawning, incubation, fry emergence and rearing are deemed the most temperature-sensitive beneficial uses within the Alvord Lake Subbasin.

Beneficial uses and the associated water quality standards are generally applicable basin-wide (i.e., the Malheur Lake Basin, which includes the Alvord Lake Subbasin). Some uses require further delineation. At a minimum, uses are considered attainable wherever feasible or wherever attained historically. In applying standards and restoration, it is important to know where existing salmonid spawning locations are and where they are potentially attainable. Salmonid spawning and the quality of the spawning grounds are particularly sensitive to water quality and streambed conditions. Other sensitive uses (such as drinking water and water contact recreation) are applicable throughout the drainage. Oregon Administrative Rules (OAR Chapter 340, Division 41, Section 882, Table 18) lists the “Beneficial Uses” occurring within the Malheur Lake Basin (**Table 2-3**). Numeric and narrative water quality standards are designed to protect the most sensitive beneficial uses. Salmonid spawning and rearing are the most sensitive beneficial uses in the Alvord Lake Subbasin.

Table 2-3. Beneficial uses occurring in the Malheur Lake Basin, including the Alvord Lake Subbasin

(OAR 340 – 41 – 882)
Temperature-Sensitive Beneficial uses are marked in Grey

Beneficial Use	***Occurring***	***Beneficial Use***	***Occurring***
Public Domestic Water Supply	✓	Salmonid Fish Spawning (Trout)	✓
Private Domestic Water Supply	✓	Salmonid Fish Rearing (Trout)	✓
Industrial Water Supply	✓	Resident Fish and Aquatic Life	✓
Irrigation	✓	Aesthetic Quality	✓
Livestock Watering	✓	Wildlife and Hunting	✓
Boating	✓	Fishing	✓
Hydro Power		Water Contact Recreation	✓

The Alvord Lake Subbasin is recognized as a high priority for protection and restoration due to the presence of the Lahontan cutthroat trout in many streams. This trout was originally listed as endangered by the U.S. Fish and Wildlife Service (USFWS) in 1970 (Federal Register 35:16047). The listing status was later reclassified as threatened in 1975 (Federal Register 40:29864). The Recovery Plan was developed by the USFWS in 1995 (USFWS 1995). The Lahontan cutthroat trout in the Alvord Lake Subbasin are in the northern extreme of their distribution with the majority of the population in Nevada and northern California (see **Figure 1-6** for distribution in the Alvord Lake Subbasin). These are resident trout that do not travel to the ocean because the basin is physically closed to migration (endorheic basin). Many of the streams bearing the Lahontan cutthroat trout are considered disjunct from each other resulting in genetic isolation from a larger connected metapopulation. The Coyote Lake population may have a limited potential for genetic exchange during extreme years of high precipitation.

Other fish species found in the Alvord Lake Subbasin include the Alvord chub, genetically introgressed Alvord cutthroat trout or ‘cutbow’ in the Trout Creeks, a small population of brown trout stocked in Van Horn Creek, and the endangered (USFWS) Borax Lake chub. The Borax Lake chub is an endemic warm water species and sole occupant of the geothermal waters of Borax Lake. (See **Section 1.4.5** for a further discussion of fish species found in the Alvord Lake Subbasin).

For the purposes of the Alvord Lake Subbasin TMDL the Lahontan cutthroat trout is considered the most sensitive beneficial use. However, the TMDL applies to all streams containing salmonid fisheries (**Table 2-2** and **Figure 2-1**).

2.2.2 Water Quality Standard Identification

2.2.2.1 Stream Temperature Standard

A seven-day moving average of daily maximums (7-day statistic) was adopted as the statistical measure of the stream temperature standard. Absolute numeric criteria are deemed action levels and indicators of water quality standard compliance. Unless specifically allowed under an ODEQ-approved surface water temperature management plan as required under OAR 340-041-0026(3)(a)(D), no measurable surface water temperature increase resulting from human caused activities is allowed in State of Oregon waters determined out of compliance with the temperature standard. A much more extensive analysis of water temperature related to aquatic life and supporting documentation for the temperature standard can be found in the *1992-1994 Water Quality Standards Review Final Issue Papers (ODEQ, 1995)*.

The temperature standard applicable in the Alvord Lake Subbasin specifies that "no measurable surface water temperature increase resulting from anthropogenic (human induced) activities is allowed".

Malheur Lake Basin Temperature Standard

OAR 340-41-0885(2)(b)(A) To accomplish the goals identified in OAR 340-041-0120(11), unless specifically allowed under a Department-approved surface water temperature management plan as required under OAR 340-041-0026(3)(a)(D), no measurable surface water temperature increase resulting from anthropogenic activities is allowed:

(i) In a basin for which Salmonid fishes rearing is a designated beneficial use, and in which surface water temperatures exceed 64.0°F (17.8°C);

(ii) In waters and periods of the year determined by the Department to support native salmonid spawning, egg incubation, and fry emergence from the egg and from the gravels in a basin which exceeds 55.0°F (12.8°C);

(iii) In waters determined by the Department to support or to be necessary to maintain the viability of native Oregon bull trout, when surface water temperatures exceed 50.0°F (10.0°C);

(iv) In waters determined by the Department to be ecologically significant cold-water refugia;

(v) In stream segments containing federally listed Threatened and Endangered species if the increase would impair the biological integrity of the Threatened and Endangered population;

(vi) In Oregon waters when the dissolved oxygen (DO) levels are within 0.5 mg/l or 10 percent saturation of the water column or intergravel DO criterion for a given stream reach or subbasin;

(vii) In natural lakes.

At the time of development of this TMDL, ODEQ is considering revisions to the temperature standard. One of the issues under consideration is whether to include specific temperature criteria for both Lahontan cutthroat trout and redband trout. Because specific criteria for these two trout are not established at this time, ODEQ must use the current criterion for protection of salmonids in the development of this TMDL. To the extent that resources are available, ODEQ will reopen this TMDL in the future, however, if:

1) New criteria is established for Lahontan and redband that is less stringent than the general salmonid criterion, and

2) It is demonstrated that application of the general salmonid criterion imposes overly burdensome and unreasonable restrictions that would not otherwise be required had the TMDL been developed with the Lahontan and redband trout criteria.

2.2.2.2 Deviation from Water Quality Standard

Section 303(d) of the Federal Clean Water Act (1972) requires that water bodies that violate water quality standards, thereby failing to fully protect *beneficial uses*, be identified and placed on a 303(d) list. The Alvord Lake Subbasin has 6 stream segments on the 2002 303(d) list for water temperature violations (**Table 2-4** and **Figure 2-2**). All segments were listed based upon the 64°F rearing criterion. In addition, there are 8 stream segments in the Alvord Lake Subbasin that have been classified as being of “potential concern” for temperature. These are reaches where the rearing and/or spawning criteria were exceeded, but the data used for the assessment was collected solely from a drought year (1991, 1992, 1994 or 2001). Spawning typically occurs in the Alvord Lake Subbasin from April 1-June 30. For specific information regarding Oregon’s 303(d) listing procedures, and to obtain more information regarding the Alvord Lake Subbasin’s 303(d) listed streams, visit ODEQ’s web page at **http://www.deq.state.or.us/**.

It should be noted that the analysis for 303(d) listed streams in this TMDL document applies to the entire length of the stream and, when this TMDL is approved by EPA, the streams will be removed from the 303(d) list. This TMDL analysis also applies to the 8 stream segments classified as being of “potential concern” in Table 2-4. It should also be noted that this TMDL uses *system potential* shade as a surrogate for heat load (**Section 2.7**). While the TMDL applies to the entire length of the stream, this TMDL recognizes that, because the lower ends of the streams are dry much of the year, riparian vegetation is not viable.

The observed maximum 7-day temperature statistics from data collected during 2001 are also illustrated in **Figure 2-2**. Generally, stream temperatures follow a longitudinal (downstream) heating pattern and are above the rearing standard of 64°F (17.8°C) for most reaches, typically during portions of July and/or August. A notable exception to this is Van Horn Creek, which did not exceed the rearing standard in 2001. Data collected in 2000-2002 by BLM and ODEQ on Van Horn Creek indicate that the numeric spawning criterion of 55°F (12.8°C) was exceeded during the month of June, however. Van Horn was originally included on the 303(d) list based on data collected in 1995-1997.

2.2.3 Pollutant Identification

With a few exceptions, such as in cases where violations are due to natural causes, the State must establish *a Total Maximum Daily Load* or *TMDL* for any waterbody designated on the 303(d) list as violating water quality standards. A *TMDL* is the total amount of a pollutant (from all sources) that can enter a specific waterbody without violating the water quality standards.

Water temperature change is an expression of heat energy exchange per unit volume:

$$\Delta Temperature \propto \frac{\Delta Heat \quad Energy}{Volume}$$

Human caused heat sources are derived from solar radiation as increased levels of sunlight reach the stream surface, effluent discharges to surface waters and flow augmentation. The pollutant targeted in this TMDL is heat from human caused increases in solar radiation loading to the stream network. Warm water effluent discharges are not targeted in this TMDL because there are no point source discharges in the Alvord Lake Subbasin.

The pollutants identified for stream temperature pollution are human caused increases in solar radiation loading at the stream surface and warm water discharge to surface waters.

Table 2-4. Alvord Lake Subbasin 303(d) Listed Segments, 2002

Stream Segment	Listed Parameter	Listing Status	Miles Affected
Big Trout Creek	Temperature (rearing)	**303(d) Listed**	RM 0-16.6
	Temperature (spawning)	Potential Concern	RM 0-16.6
Denio Creek	Temperature (rearing)	**303(d) Listed**	RM 0-6.1
East Fork Big Trout Creek	Temperature (rearing)	Potential Concern	RM 0-6.6
	Temperature (spawning)	Potential Concern	RM 0-6.6
Little Trout Creek	Temperature (rearing)	Potential Concern	RM 0-9.3
Little Wildhorse Creek	Temperature (rearing)	**303(d) Listed**	RM 0-2.5
Mosquito Creek	Temperature (rearing)	Potential Concern	RM 0-7.4
Trout Creek	Temperature (rearing)	Potential Concern	RM 0-30
Unnamed Waterbody (Jawbone Creek)	Temperature (spawning)	Potential Concern	RM 0-4
Van Horn Creek	Temperature (rearing)	**303(d) Listed**	RM 0-8.2
Willow Creek (East Steens)	Temperature (rearing)	**303(d) Listed**	RM 0-5.3
Willow Creek	Temperature (rearing)	**303(d) Listed**	RM 0-33.5
	Temperature (spawning)	Potential Concern	RM 0-33.5
Total Stream Miles included on 303(d) list for Temperature (rearing)			**72.2**
Total Stream Miles listed as “Potential Concern” for Temperature (rearing)			**53.3**
Total Stream Miles listed as “Potential Concern” for Temperature (spawning)			**60.7**

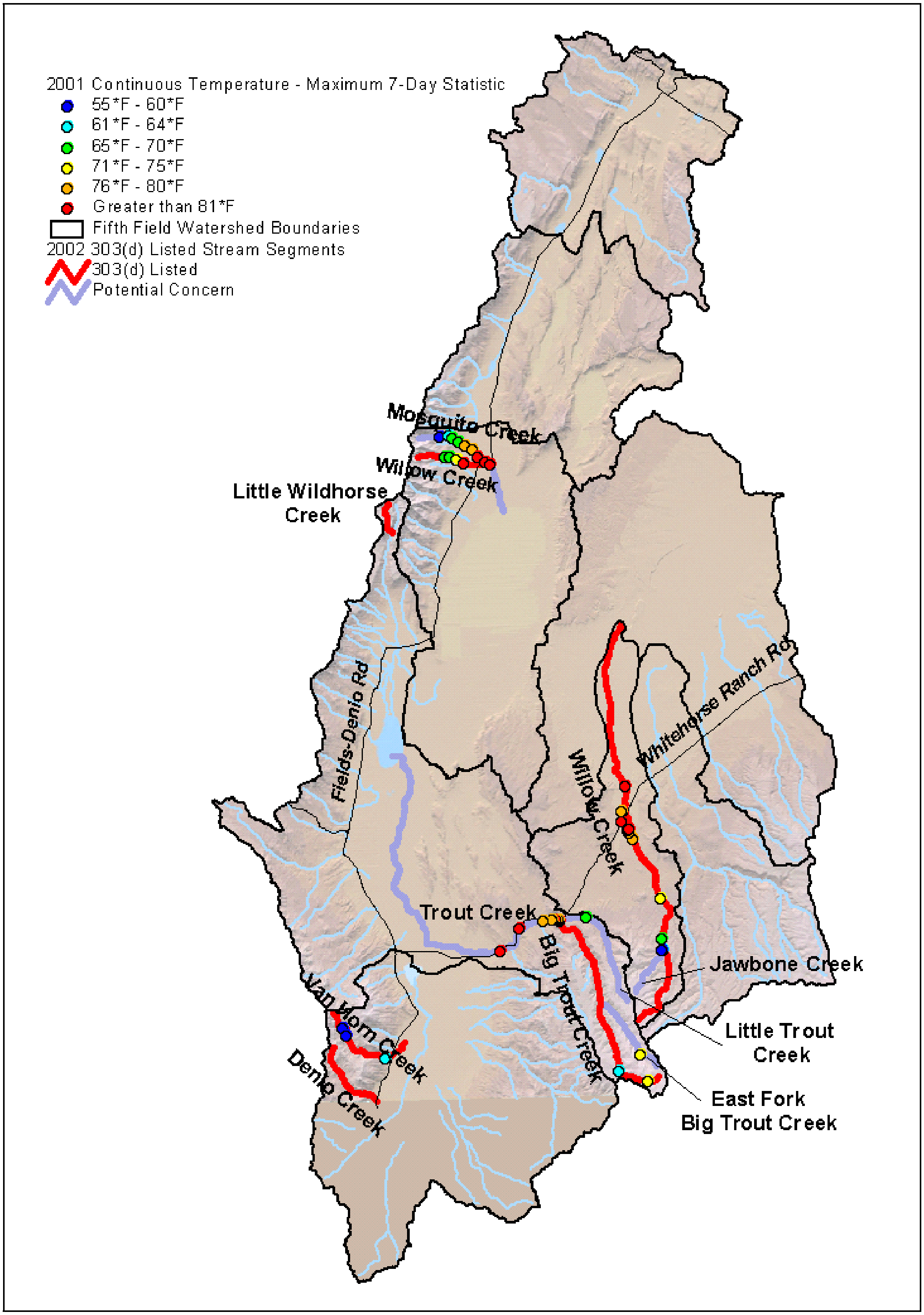


Figure 2-2. 2002 303(d) List for Temperature and 7-Day Temperature Statistic Data for 2001

2.3 SEASONAL VARIATION - CWA §303(D)(1)

Maximum temperatures typically occur in July and August, with temperatures starting to drop off in early September. Exceedance of the 64°F numeric criterion differs at different sites, but typically occurs in portions of July and/or August. It should also be noted that some streams may be above the 55°F numeric spawning criterion during the periods when spawning is likely to occur (April 1-June 30). **Figures 2-3** through **2-5** show the location of all TMDL-related continuous temperature monitoring locations in the East Steens, Pueblo Mountains and the Trout Creeks and the daily maximum and diurnal stream temperatures in 2001 for each site named on the maps.

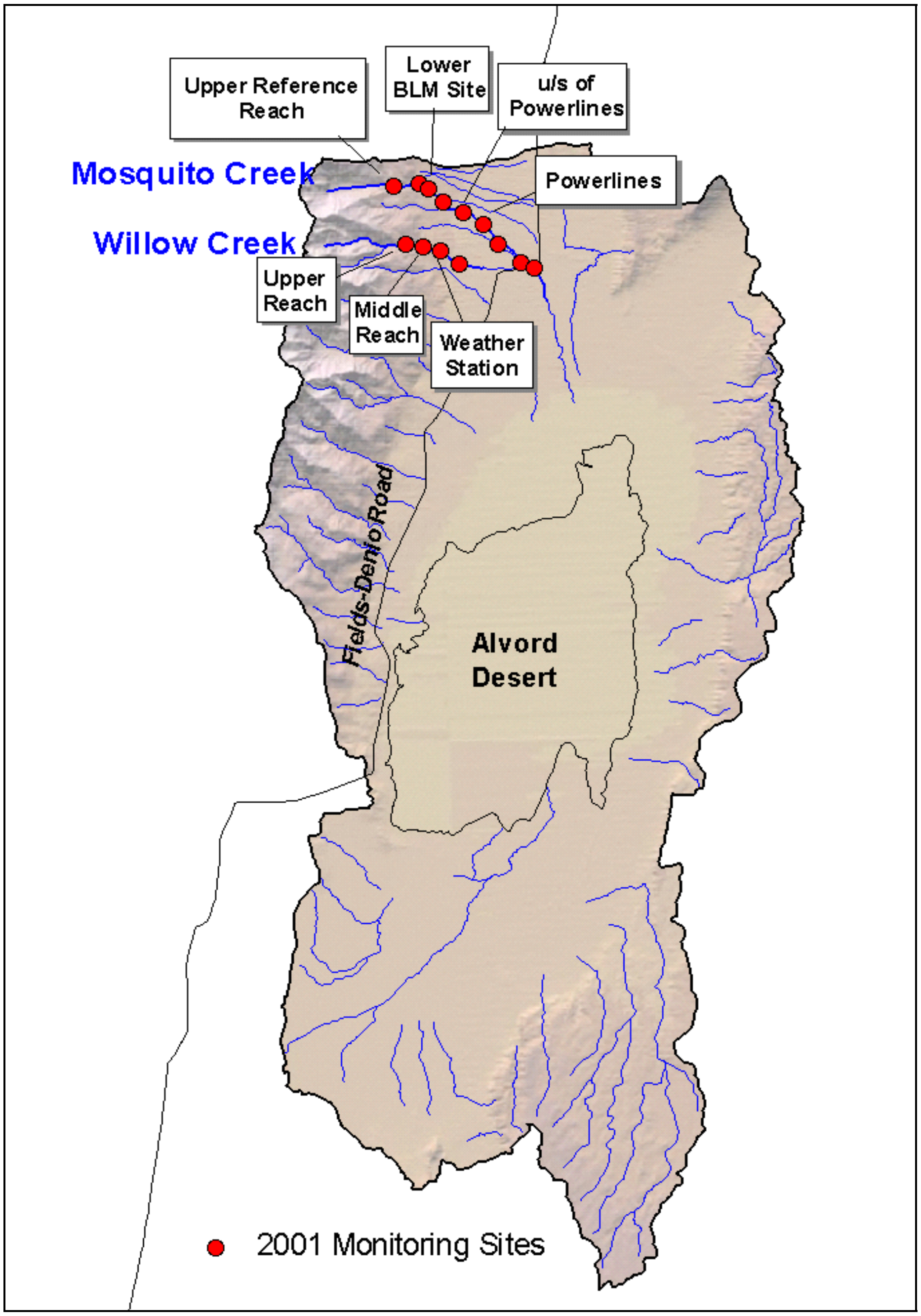
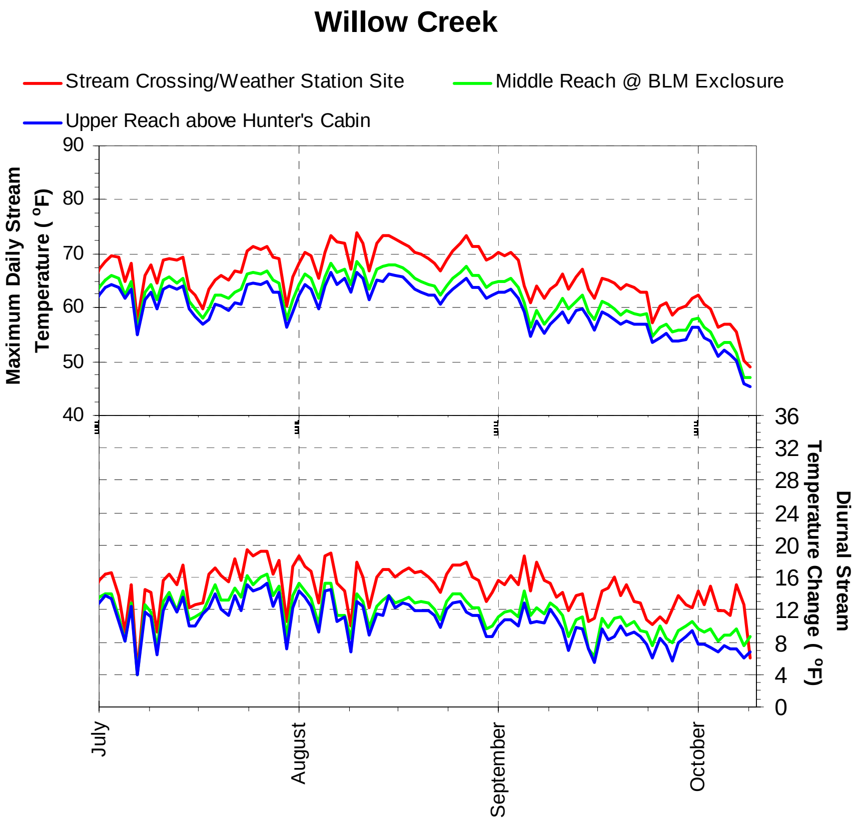


Figure 2-3. 2001 StreamTemperatures – Willow Creek and Mosquito Creek (East Steens Ecological Province)



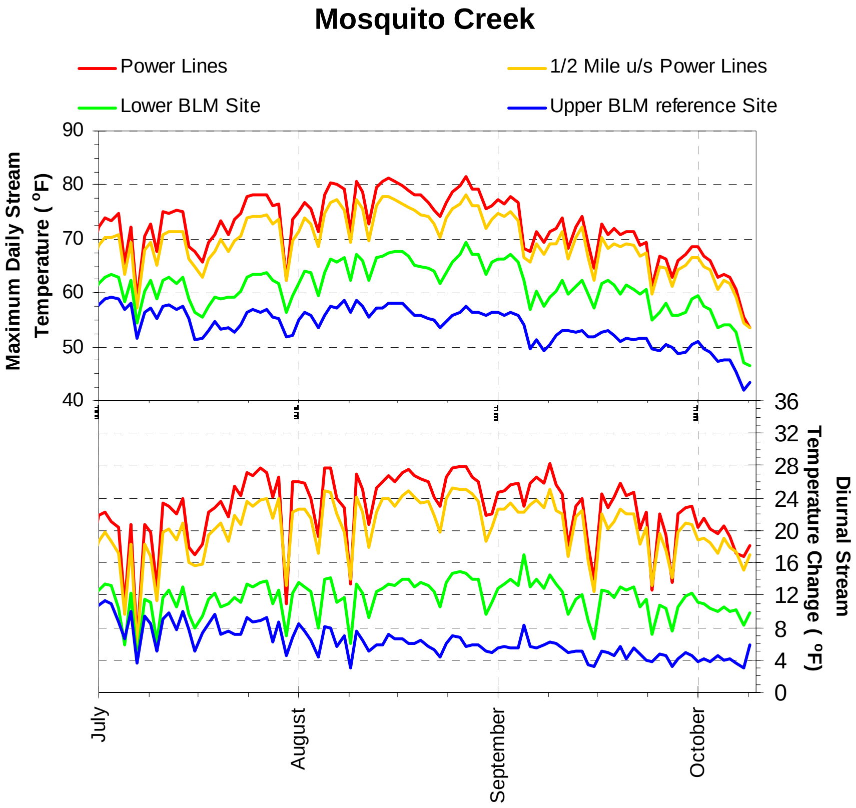


Figure 2-3 (continued). 2001 StreamTemperatures – Willow Creek and Mosquito Creek (East Steens Ecological Province)

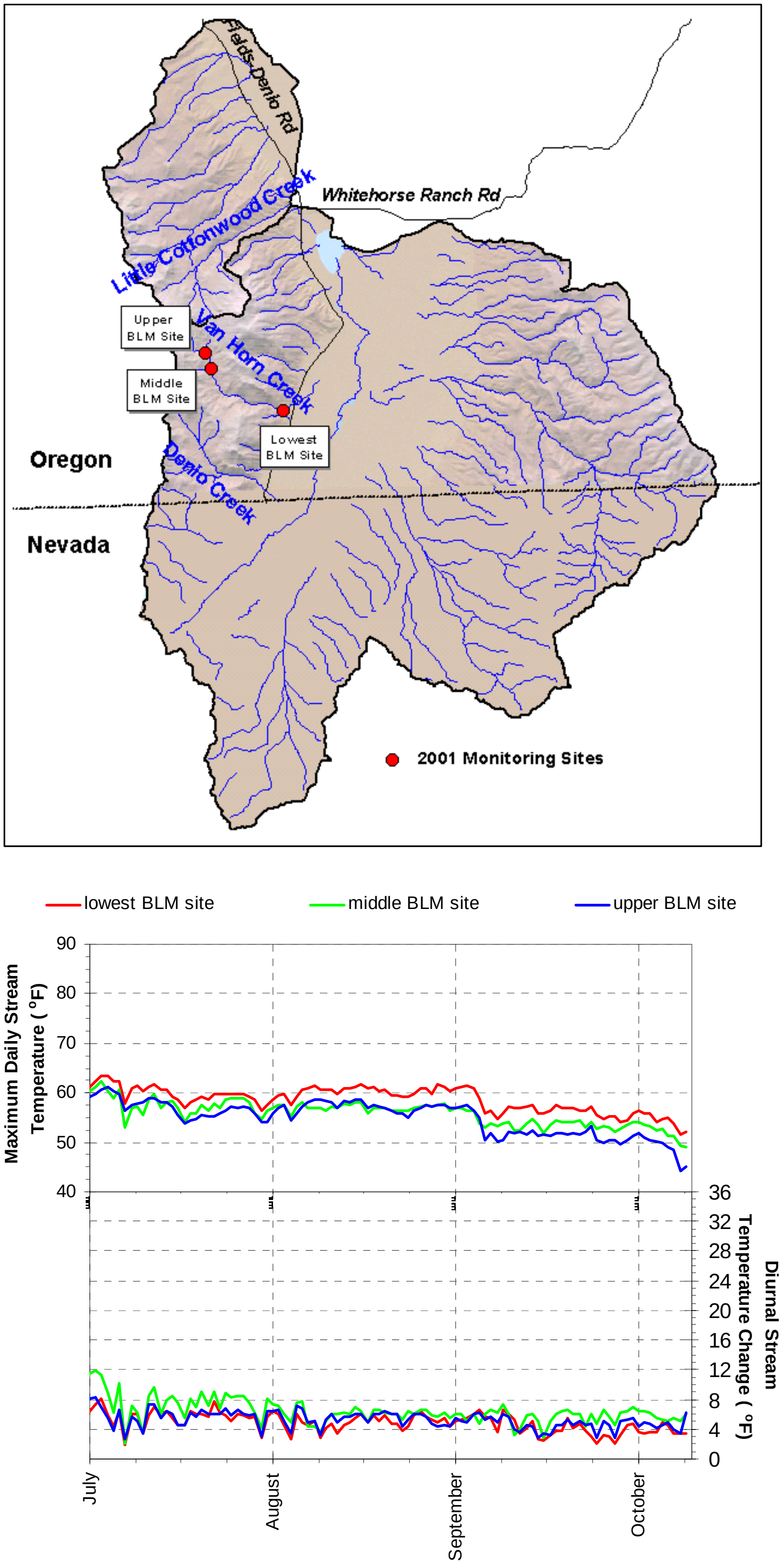


Figure 2-4. 2001 Stream Temperatures – Van Horn Creek (Pueblo Mountains Ecological Province)

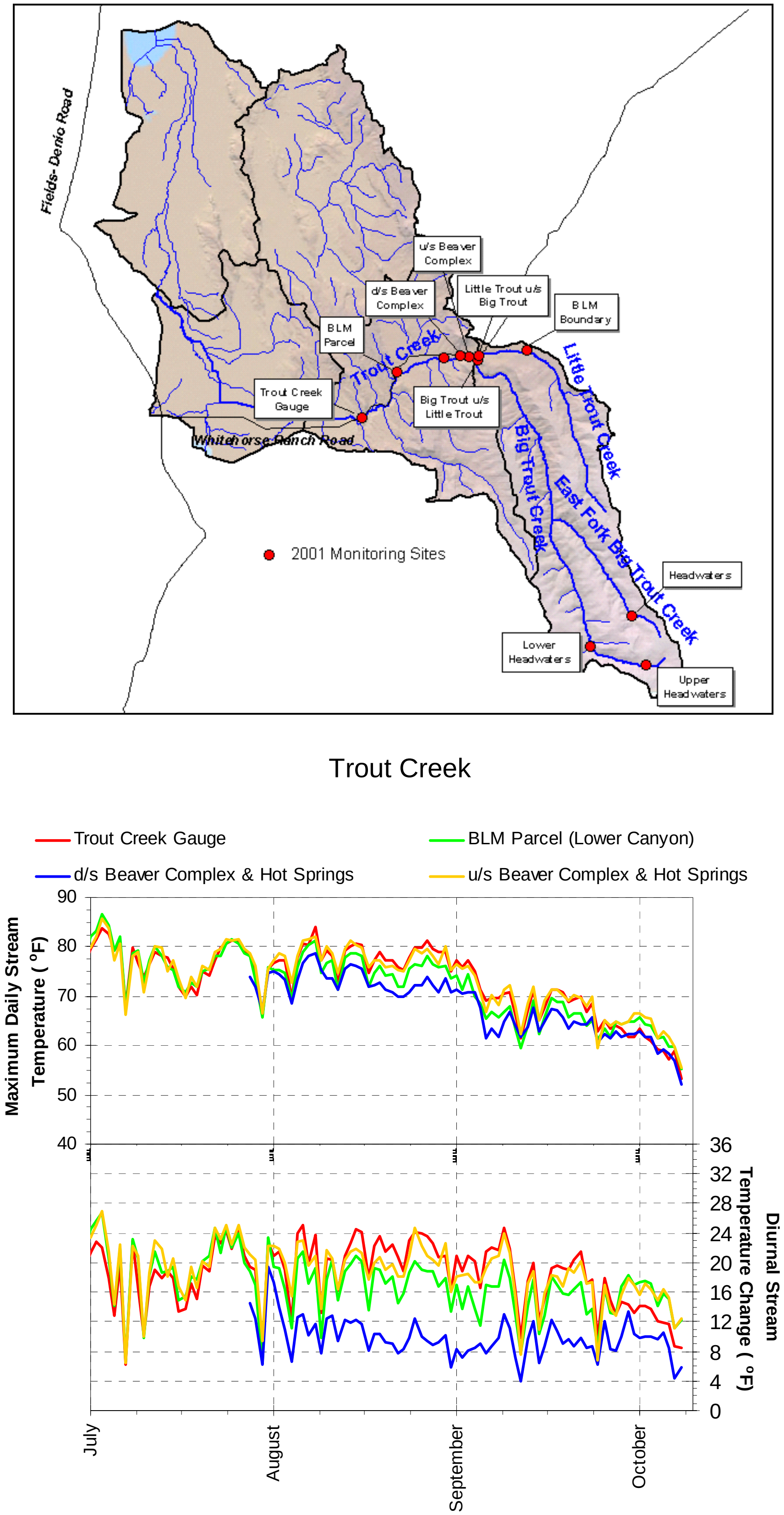
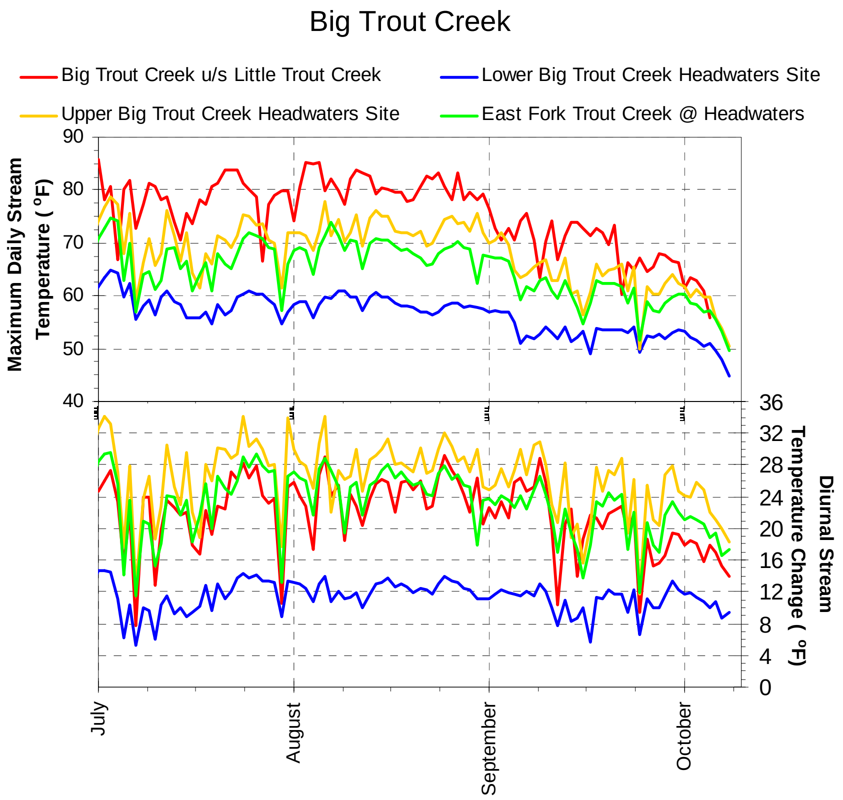


Figure 2-5. 2001 Stream Temperatures – Trout Creek, Little Trout Creek, East Fork Big Trout Creek (Trout Creek Mountains Ecological Province)



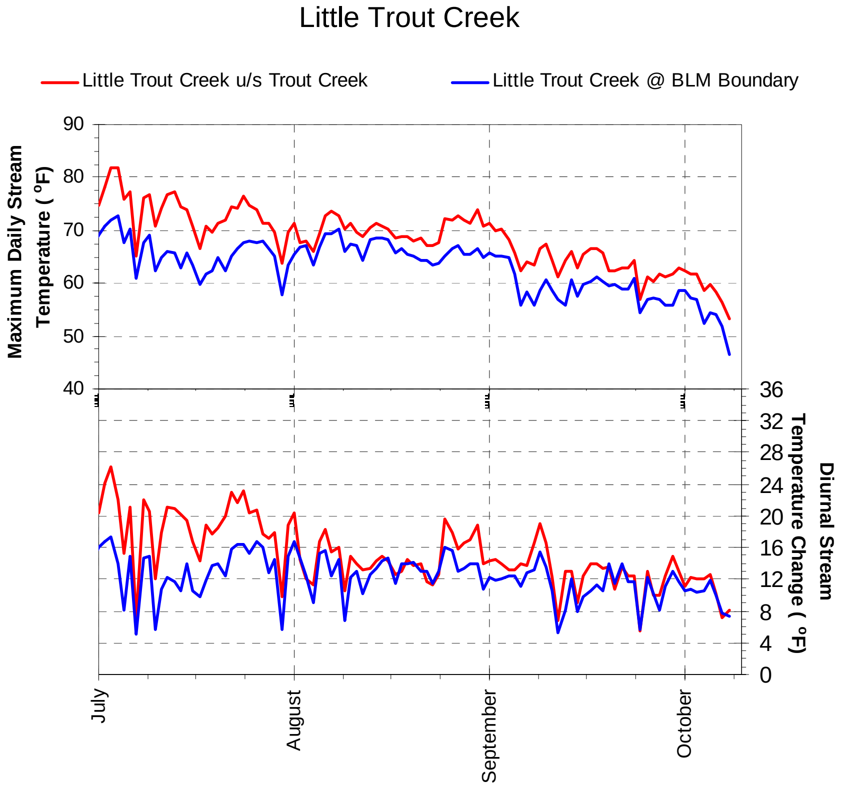


Figure 2-5 (continued). 2001 Stream Temperatures – Trout Creek, Little Trout Creek, East Fork Big Trout Creek (Trout Creek Mountains Ecological Province)

2.4 EXISTING HEAT SOURCES - CWA *§303(D)(1)*

2.4.1 Stream Heating Processes – Background Information

Riparian vegetation, stream morphology, hydrology, climate, and geographic location influence stream temperature. While climate and geographic location are outside of human control, riparian condition, channel morphology and hydrology are affected by land use activities. Specifically, the elevated summertime stream temperatures attributed to human caused sources in the Alvord Lake Subbasin result from the following:

- ✓ Riparian vegetation disturbance which reduces stream surface shading via decreased riparian vegetation height, width and/or density, thus increasing the amount of solar radiation reaching the stream surface;
- ✓ Riparian vegetation disturbance which reduces connection of the stream to the floodplain, thus decreasing the release of cooler subsurface (hyporheic) flows during warmer summer months.

In addition, the following conditions can affect stream temperatures in the Alvord Lake Subbasin:

- ✓ Reduced summertime base flows from instream withdrawals;
- ✓ Localized channel widening (increased wetted width to depth ratios) which increases the stream surface area exposed to energy processes, namely solar radiation.
- ✓ Improper management of upland vegetation which decreases the ability of the uplands to safely capture and store precipitation and augment the volume of late season stream flows.

Human activities that can contribute to degraded water quality conditions in the Alvord Lake Subbasin include agriculture activities (including grazing), road location, timber harvest, and rural residential development related to riparian disturbances. The relationships between percent effective shade, channel morphology, hydrology and stream temperature are illustrated in **Figure 2.6**. A more detailed discussion of stream heating processes is provided in **Chapter V**.

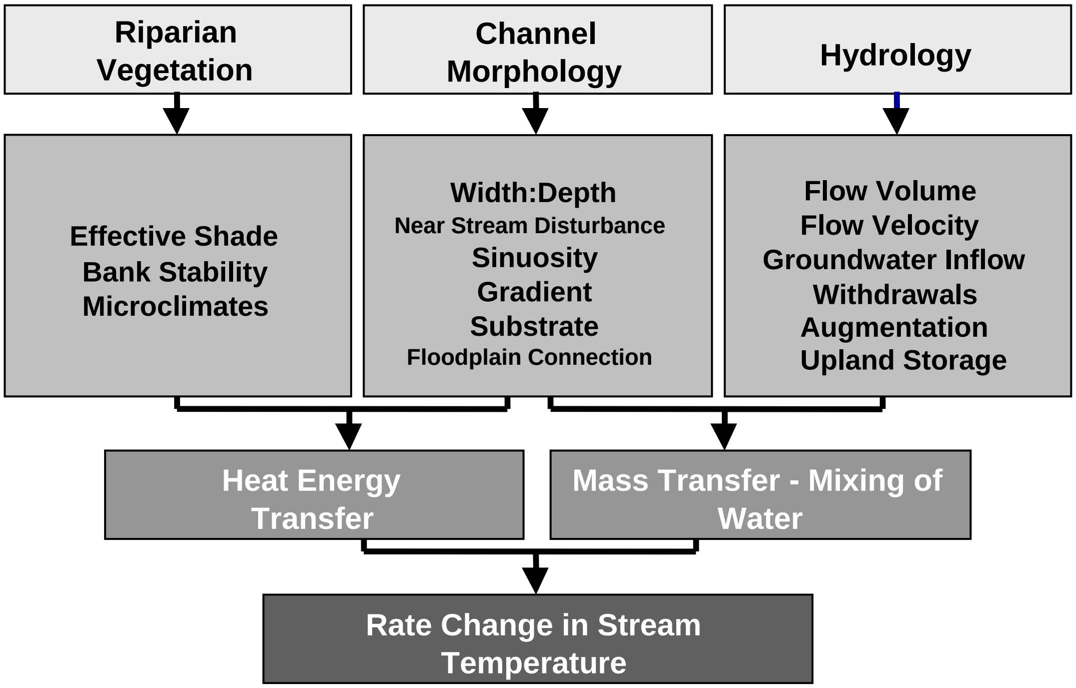


Figure 2-6. Stream Heating Processes in the Alvord Lake Subbasin

2.4.2 Analytical Methodology

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 and has been regularly upgraded through 2003. The model has been peer reviewed and comments are available on the ODEQ website at: http://www.ODEQ.state.or.us/wq/HeatSource/HeatSource.htm. ODEQ currently supports the Heat Source methodology and computer programming (a more extensive discussion of the analytical framework for the model is provided in **Chapter V**).

The Heat Source model (version 6.0) is comprised of modules that can simulate dynamic open channel hydraulics, flow routing, heat transfer, effective shade and stream temperature. In order to accurately simulate the thermal response of the stream to changes in near stream vegetation, channel morphology, and/or in-stream flow, detailed instream temperature and flow measurements are required. Summertime flows in modeled streams typically need to be greater than 2 cfs in order to calibrate the current condition scenarios. In the Alvord Lake Subbasin, there are few continuous flow gauges in the Subbasin and summertime flows in all streams are less than 2 cfs (see **Section 2.4.3.2** for a further discussion of flows). Because of this limitation, the open channel hydraulics, flow routing, heat transfer processes and water column temperature modules could not be utilized in developing the Alvord Lake Subbasin TMDL.

Instead, the load allocations for the Alvord Lake Subbasin TMDL were developed using the module in Heat Source (version 6.0) that calculates the potential and received solar radiation flux at the stream surface and also provides effective shade output data. This portion of the model is called “Shade-a-lator”. Stream surface solar exposure and effective shade were simulated for **58.7 miles** of Mosquito Creek, Willow Creek (East Steens), Van Horn Creek, Trout Creek, Big Trout Creek, Little Trout Creek and East Fork Big Trout Creek (**Figure 2-7**). Simulations were performed to assess the solar load received at the stream under current and *system potential* vegetation and the shade provided by these two vegetative conditions. The results from the simulations are provided under **Sections 2.4.3.1** and **2.5.1** below**.**

The temperature TMDL results for Willow Creek (Trout Creek Mountains) are presented in **Chapter III**. This TMDL was drafted by ODEQ in 1999 using an earlier version of Heat Source (version 5.5). The types of data and modeling analysis used to produce the Willow Creek TMDL are different from the methods described here and will be further described in **Chapter III** and **Chapter V**.

2.4.3 Nonpoint Sources of Heat

Settlement of the Alvord Lake Subbasin in the mid-1800s brought about changes in the near stream vegetation and hydrologic characteristics of the streams. Historically, human activities including agricultural practices have altered the stream morphology and hydrology and decreased the amount of riparian vegetation in the drainage. The subbasin includes primarily agricultural lands. Channel straightening, while providing relief from local flooding, increases flooding downstream, and may result in the destruction of riparian vegetation and increased channel erosion. Irrigation diversions in the lower elevations of the Alvord Lake Subbasin have reduced stream flow levels.

Elevated summertime stream temperatures attributed to nonpoint sources result from riparian vegetation disturbance (reduced stream-surface shade) and reduced base flow

Riparian vegetation, stream morphology, hydrology, climate (water availability from snow pack) and geographic location influence stream temperature. While climate (water availability) and geographic location are outside of human control, riparian condition, channel morphology and hydrology are affected by land use activities.

Low summertime flows decrease the thermal assimilative capacity of streams. Pollutant (solar radiation) loading causes larger temperature increases in stream segments where flows are reduced. The lower reaches of some streams in the Alvord Lake Subbasin are extensively utilized for crop irrigation during the summer months when water is available.

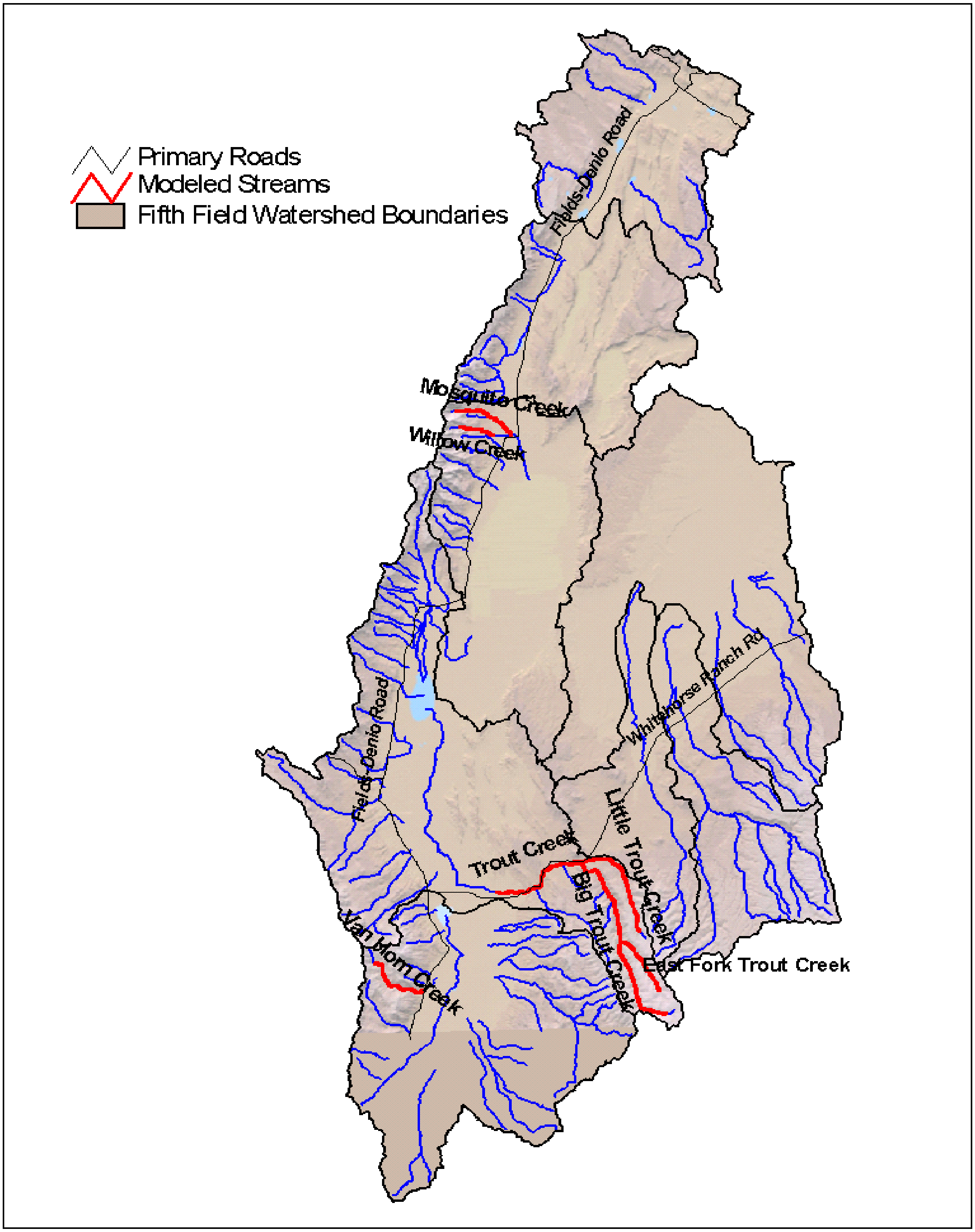


Figure 2-7. Streams Modeled for TMDL Temperature Analysis

Land use activities in the Alvord Lake Subbasin are managed either by the BLM (who manage 84% of the land in the subbasin) or by private landowners. Although Oregon counties have authority to regulate land use activities through local comprehensive plans, it is unlikely that either Harney or Malheur County would have regulatory responsibilities over activities that would influence stream temperature. Given the extremely rural character of the Alvord Lake Subbasin, riparian activities on private land would either be managed under an Agricultural Water Quality Management Area Plan or under the Forest Practices Act.

Specifically, the elevated summertime stream temperatures attributed to human caused nonpoint sources result from the following:

1. ***Near stream vegetation disturbance or removal*** *reduces stream surface shading via decreased riparian vegetation height, width and/or density, thus increasing the amount of solar radiation reaching the stream surface (shade is commonly measured as percent effective shade or open sky percentage). Riparian vegetation also plays an important role in shaping the channel morphology, resisting erosive high flows, maintaining floodplain roughness, and maintaining connection with the floodplain for increased water storage and hyporheic flows.*
2. ***Channel modifications and widening*** *(increased width to depth ratios) increases the stream surface area exposed to energy processes, namely solar radiation. Channel widening decreases potential shading effectiveness of shade-producing near-stream vegetation.*
3. ***Reduction of summertime flows*** *decrease the thermal assimilative capacity of streams, causing larger temperature increases in stream segments where flows are reduced.*

2.4.3.1 Riparian Vegetation

Riparian vegetation plays an important role in controlling stream temperature change. Near stream vegetation height, width and density combine to produce shadows that when cast across the stream reduce solar radiant loading. Bank stability is largely a function of riparian vegetation. Riparian corridors often produce a microclimate that surrounds the stream where cooler air temperatures, higher relative humidity and lower wind speeds are characteristic.

2.4.3.1.1 Current Condition Vegetation

Current condition riparian vegetation was characterized using digital orthophoto quads (DOQs) and confirmed where field data were available. DOQs taken in either 1989 or 1994 were available for the entire subbasin area. Vegetation polygons were digitized in the near stream area (300 feet on either side of the stream channel) and classified by vegetation type (**Tables 2-5** through **2-8**). All classifications included an average riparian vegetation height and canopy density. The *system potential* vegetation associated with each current condition land cover type was developed by ODEQ staff in conjunction with staff from the Burns and Vale Districts of the BLM and using the vegetative field studies conducted by Angela Evenden in the Trout Creek Mountains (Evenden, 1989) (see **Section 2.4.3.1.2** below for a further discussion of *system potential* vegetation). **Figure 2-8** displays an example of vegetation and land cover polygons derived from orthophotos at approximately 1:4,000 on Mosquito Creek.

Ground level vegetation measurements were collected by ODEQ and BLM during the summers of 2001 and 2002 throughout the Alvord Lake Subbasin to assist in current condition vegetation classifications. ODEQ collected field data relative to riparian conditions including: vegetative community type, canopy height, canopy density, effective shade, and channel characteristics (morphology, flood prone area, etc.)

Stream reaches were also digitized from DOQs at less than 1:5,000. These stream data layers were then segmented into data points spaced at 100-foot intervals. All river mile designations were calculated using this highly accurate stream delineation and, therefore, may not match historical river mile designations from other sources such as Oregon Water Resources Department (OWRD) or USGS maps. The “bottom” of each stream presented in the modeling analysis (river mile “0”) was determined as described in **Section 2.1.1.3** above.

The stream data point layers form the basis for automated sampling performed using Ttools[2]. At every distance node (i.e. every 100 feet) along the stream, vegetation was sampled out to 80 feet from the channel edge at 10-foot intervals for both stream banks. A total of 18 vegetation samples were taken at each stream distance node. This automated near stream vegetation sampling was completed for 58.7 rivermiles in the Alvord Lake Subbasin (**Figure 2-7**) including Mosquito Creek (5.9 miles), Willow Creek (East Steens) (3.1 miles), Van Horn Creek (6.1 miles), Trout Creek (11.4 miles), Little Trout Creek (9.2 miles), Big Trout Creek (17.5 miles) and East Fork Big Trout Creek (5.5 miles).

Table 2-5. Current Condition and System Potential Land Cover Vegetation for Mosquito Creek

Land Cover Code	Current Condition Land Cover	Potential Condition Land Cover	Land Cover Height (feet)	Land Cover Density (%)	Land Cover Overhang (feet)
305	Barren-Embankment (steep)	No change	0.0	0%	0.0
400	Barren-Road	No change	0.0	0%	0.0
500	Juniper-Sage-Native Grasses	No change	6.9	75%	0.7
501	Juniper-Grasses (< 25% CC)	No change	34.8	25%	3.5
5011	Juniper (>75% CC)	No change	29.9	75%	3.0
5012	Juniper-Sage-Grasses (<50% CC)	No change	18.0	50%	1.8
502	Mountain big sage-Native Grasses	No change	4.9	100%	0.5
503	Wyoming big sage-Nonnative Plants	No change	4.9	100%	0.5
504	Grasses	No change	1.0	75%	0.0
505	Bitterbrush-Grasses	No change	6.6	50%	0.7
508	Ephemeral drainage	No change	4.9	25%	0.5
509	Relic channel/Irrigation channel	No change	6.9	25%	0.7
600	Coyote Willow-flats	No change	5.9	65%	0.6
601	Springs-Mesic Graminoid	No change	1.0	100%	0.0
602	Cottonwood/Pacific willow (mature)	No change	40.0	80%	4.0
607	Cottonwood/Aspen/Pacific willow	8012	22.6	68%	2.3
8012		Cottonwood/Pacific willow/ Aspen	29.9	75%	3.0
802	Pacific willow/Cottonwood	8022	13.8	25%	1.4
8022		Pacific willow/ Cottonwood	20.0	50%	2.0
803	Pacific willow/Coyote willow	8032	12.1	50%	1.2
8032		Pacific willow/Coyote willow/Cottonwood	20.0	50%	2.0
804	Coyote willow/Pacific willow/ Cottonwood	8042	8.9	50%	0.9
8042		Coyote willow/Pacific willow/Cottonwood	15.1	50%	1.5
805	Coyote willow flats	No change	7.9	75%	0.8

---

[2] Ttools is an automated computer sampling tool that was developed by ODEQ to sample the following spatial data using the ArcView Geographic Information System: stream aspect, channel width, near stream vegetation and topographic shade angles. Sampling resolution is user defined and, for the Alvord Lake Subbasin TMDL, was set at 100 foot intervals longitudinally (i.e. along the stream) and 10 foot intervals in the transverse direction (i.e. perpendicular to the stream).

Table 2-6. Current Condition and *System Potential* Land Cover Vegetation for Willow Creek (East Steens)

Land Cover Code	Current Condition Land Cover	Potential Condition Land Cover	Land Cover Height (feet)	Land Cover Density (%)	Land Cover Overhang (feet)
304	Barren Rock	No change	0.0	0%	0.0
306	Barren	No change	0.0	0%	0.0
500	Juniper-Sage-Native Grasses	No change	6.9	75%	0.7
5012	Juniper-Sage-Grasses (<50% CC)	No change	18.0	50%	1.8
501	Juniper-Grasses (< 25% CC)	No change	34.8	25%	3.4
502	Mountain big sage-Native Grasses	No change	4.9	100%	0.5
504	Grasses	No change	1.0	75%	0.0
507	Mahogany-Grasses	No change	14.1	50%	1.4
600	Coyote Willow-flats	No change	5.9	65%	0.6
601	Springs-Mesic Graminoid	No change	1.0	100%	0.0
800	Cottonwood/Pacific willow (mature)	No change	40.0	80%	4.0
806	Cottonwood/Pacific willow (<25%CC)	8061	19.0	25%	1.9
807	Cottonwood/Pacific willow (50%CC)	8061	27.9	50%	2.8
8061		Pacific willow/Cottonwood	24.9	65%	2.5
808	Cottonwood/willow (DRY)	No change	2.6	10%	0.0

Table 2-7. Current Condition and *System Potential* Land Cover Vegetation for Van Horn Creek

Land Cover Code	Current Condition Land Cover	Potential Condition Land Cover	Land Cover Height (feet)	Land Cover Density (%)	Land Cover Overhang (feet)
301	Bare mineral soil	502	0.0	0%	0.0
302	Pasture	503	0.0	0%	0.0
304	Barren Rock	No change	0.0	0%	0.0
305	Barren-Embankment (steep)	No change	0.0	0%	0.0
400	Barren-Paved Road	503	0.0	0%	0.0
403	Barren-Ag. Road	503	0.0	0%	0
500	Juniper-Sage-Native Grasses	No change	6.9	75%	0.7
5012	Juniper-Sage-Grasses (<50% CC)	No change	18.0	50%	1.8
502	Mountain big sage-Native Grasses	No change	4.9	100%	0.5
5021	Mountain big sage-Native Grasses (arid)	No change	3.3	100%	0.3
503		Wyoming big sage-Nonnative Plants	4.9	100%	0.5
504	Grasses	No change	1.0	75%	0.1
507	Mahogany-Grasses	No change	14.1	50%	1.4
508	Ephemeral drainage	No change	4.9	25%	0.5
700	Aspen/Scoulers willow/Alder	703	20.0	50%	2.0
701	Aspen/Scoulers willow	No change	29.9	85%	3.0
702	Alder/Willow (<25% CC)	706	8.9	25%	0.9
703	Mixed deciduous/willow (>75% CC)	706	20.0	75%	2.0
704	Alder/Willow	706	19.0	75%	1.9
705	Alder/Willow (>50% CC)	706	13.8	50%	1.4
706		Cottonwood/alder/willow (>75% CC)	26.2	75%	2.6
707	Coyote willow (<25% CC)	7072	7.9	25%	0.8
7072		Willow mix potential	12.1	50%	1.2
801	Cottonwood/Aspen/Pacific willow	No change	22.6	75%	2.3
805	Coyote willow-sub	No change	7.9	75%	0.8

Table 2-8. Current Condition and *System Potential* Land Cover Vegetation for the Trout Creeks

Land Cover Code	Current Condition Land Cover	Potential Condition Land Cover	Land Cover Height (feet)	Land Cover Density (%)	Land Cover Overhang (feet)
302	Pasture	503	0.0	0%	0.0
304	Barren Rock	No change	0.0	0%	0.0
305	Barren-Embankment (steep)	No change	0.0	0%	0.0
3248	Building	503	14.8	100%	0.0
400	Barren-Road	503	0.0	0%	0.0
403	Barren-Ag. Road	503	0.0	0%	0.0
500	Juniper-Sage-Native Grasses	No change	6.9	75%	0.7
5012	Juniper-Sage-Grasses (<50% CC)	No change	18.0	50%	1.6
5011	Juniper (>75% CC)	No change	29.9	75%	3.0
502	Mountain big sage-Native Grasses	No change	4.9	100%	0.5
503	Wyoming big sage-Nonnative Plants	No change	4.9	100%	0.5
5041	Grass Floodplain	803T	1.0	50%	0.0
5042	Grass Upland	No change	1.0	50%	0.0
505	Bitterbrush-Grasses	No change	6.6	50%	0.7
507T[3]	Mahogany/grasses	No change	14.1	50%	1.6
509	Relic channel/Irrigation channel	No change	6.9	25%	0.7
600	Coyote Willow-flats	No change	5.9	65%	0.7
601	Springs-Mesic Graminoid	No change	1.0	100%	0.0
803T	Pacific willow/coyote willow	907	9.5	50%	1.0
805	Coyote willow-sub	No change	7.9	75%	0.8
704T	Willow/alder	900	19.0	90%	2.0
705T	Willow/alder	704T	13.8	50%	1.3
706T	Willow/alder	No change	26.2	75%	2.6
900	Willow/alder	No change	27.9	85%	3.3
901	Willow/alder/aspen	No change	29.9	85%	3.3
902	Willow/alder/aspen	900	18.0	75%	2.0
903	Willow/aspen	No change	27.9	85%	3.0
904	Aspen (upland association)	903	18.0	75%	2.0
905	Mixed deciduous	No change	14.1	50%	1.6
906	Scouler willow/aspen	908	18.0	75%	2.0
907		Willow/alder	22.0	75%	2.3
908		Willow/aspen	24.0	75%	2.5

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[3] "T" indicates that some Trout Creek Land Cover Codes were amended to reflect a separate and distinct data set of vegetative characteristics.

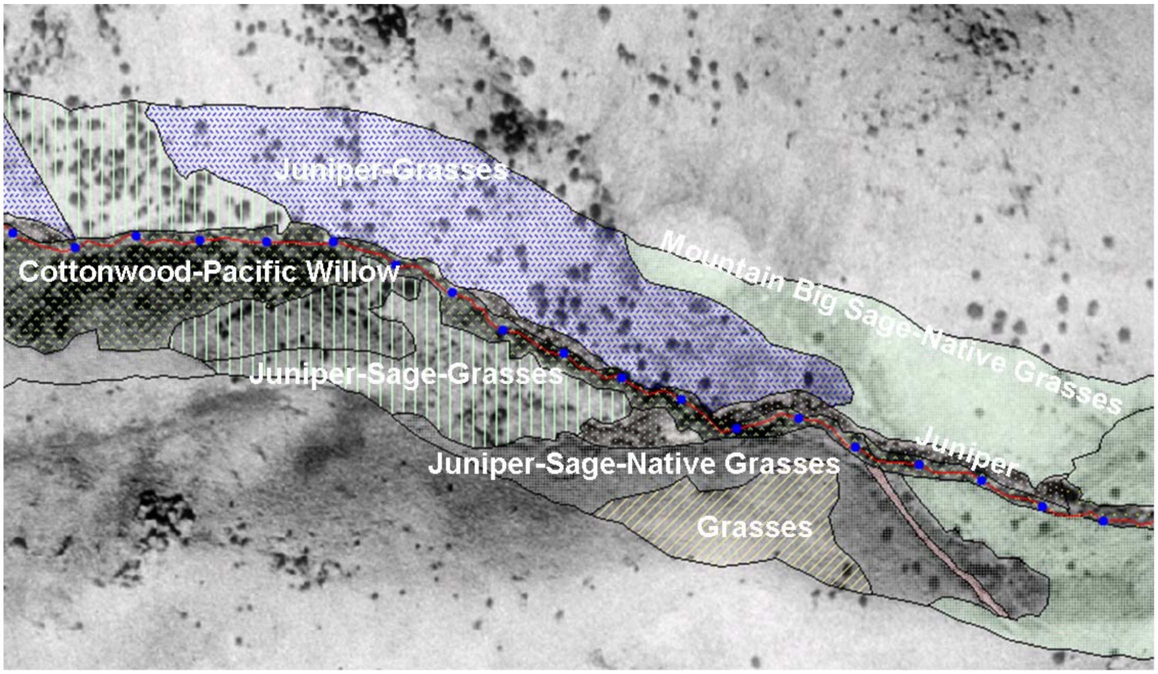

Figure 2-8. Mosquito Creek Vegetation Mapping from Digital Orthophoto Quad

2.4.3.1.2 Current Condition Effective Shade

Effective shade is a measurement of the portion of direct solar radiation that is attentuated and scattered before reaching the stream surface. A complete definition of effective shade is presented in **Chapter V**. Ground level effective shade measurements were collected by ODEQ and BLM staff during the summer of 2001 and 2002 using a solar pathfinder[4]. Multiple measurements were collected longitudinally and then averaged along the survey reach. Effective shade can be highly variable when vegetation and channel morphology conditions are variable. Therefore, when possible, multiple measurements were collected along each reach and then the shade values averaged.

Once the automated near stream vegetation sampling was completed, the Shade-a-lator module of the Heat Source model was used to simulate effective shade conditions under current vegetative conditions along the streams surveyed. The results of these simulations are presented in **Figures 2.9-2.15**. The measured shade values were used to validate the effective shade data simulated by the model. As can be seen in the figures, the model simulated the measured shade values better in some streams or portion of streams, than in others. ODEQ believes that one of the reasons the model did not perform well in some reaches was due to the narrow extent of the riparian zone. As described above, the vegetation sampling was done in 10 foot increments moving out from the channel edge. This 10 foot increment was the smallest increment that could accurately be sampled by the model. In some instances, the riparian zone was so narrow, that the first point of vegetation sampling (10 feet from channel edge) was already sampling the upland sagebrush community (such as near the Powerlines site on Mosquito Creek, **Figure 2-9**) rather than the riparian area. In situations such as this, the model underestimated the effective shade produced by the current condition vegetation.

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[4] A Solar Pathfinder is used to measure effective shade. It can estimate solar radiation for any site throughout the year. An image of the surrounding shade producing features (i.e. vegetation and topography) is projected on to a disk that can then be read to give solar radiation levels.

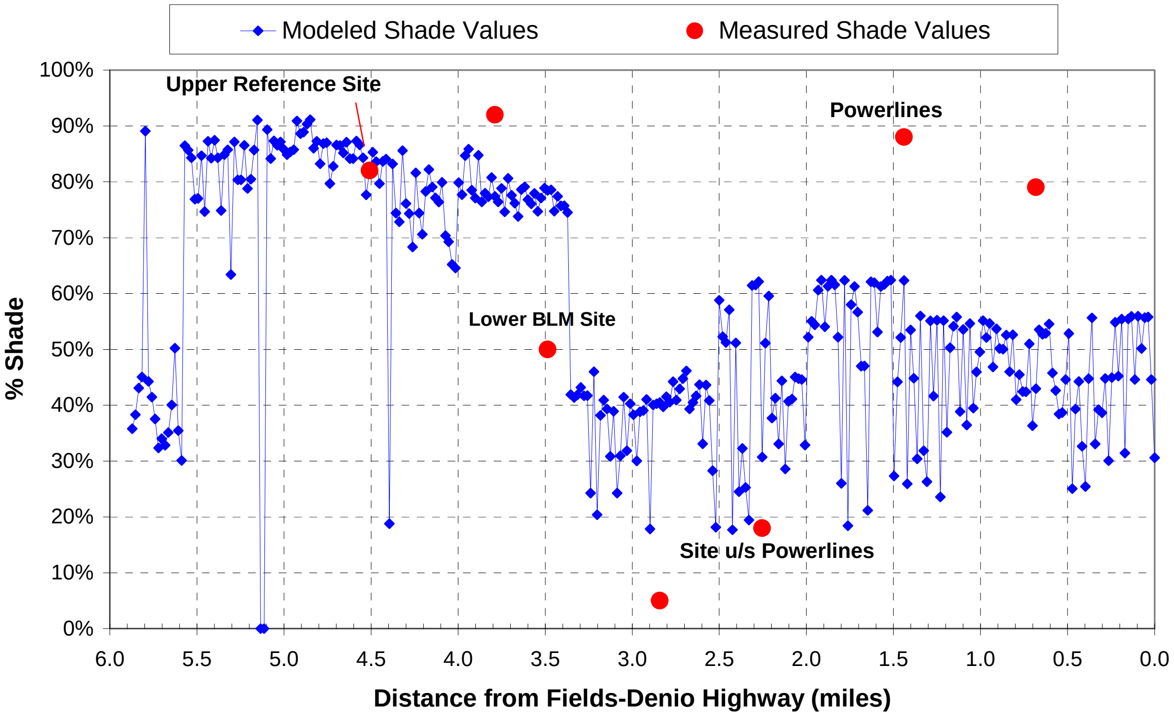


Figure 2-9. Measured and Modeled Current Condition Shade Values for Mosquito Creek

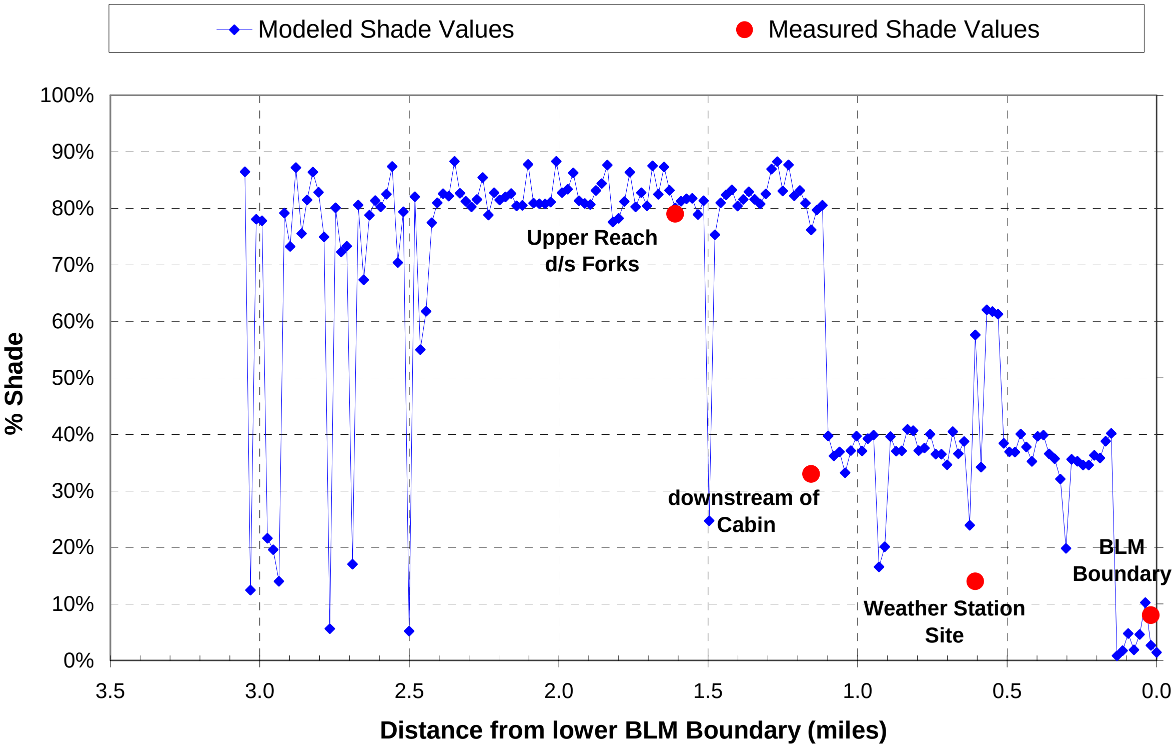


Figure 2-10. Measured and Modeled Current Condition Shade Values for Willow Creek (East Steens)

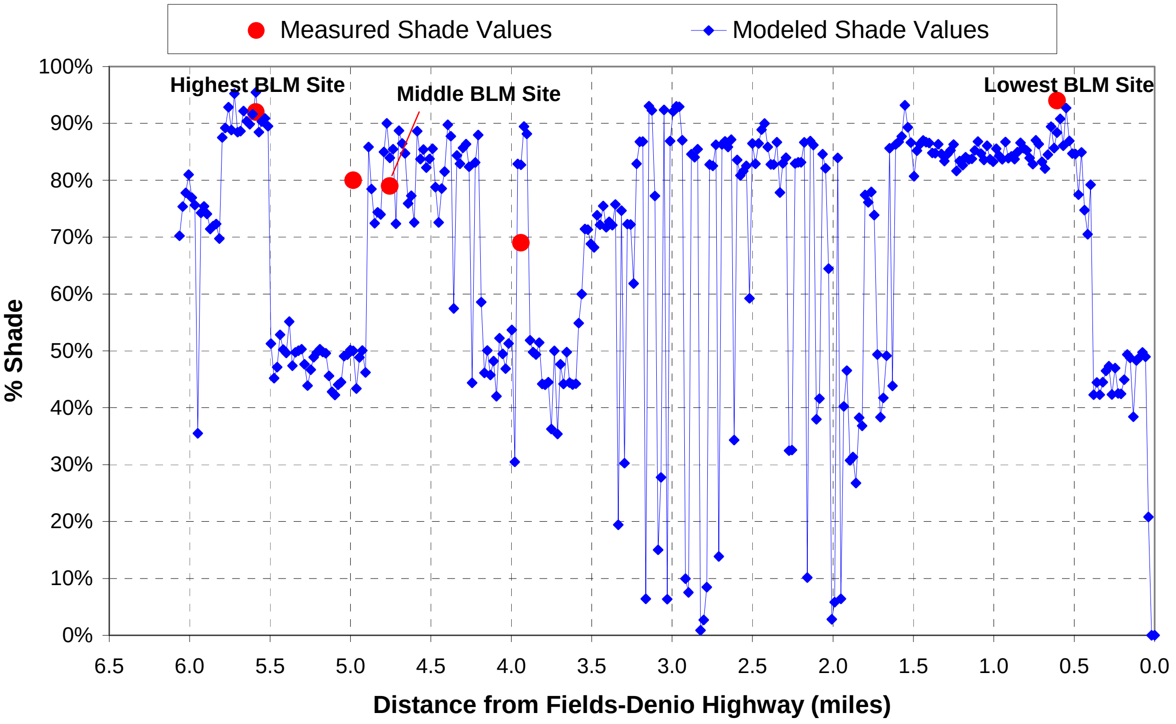


Figure 2-11. Measured and Modeled Current Condition Shade Values for Van Horn Creek

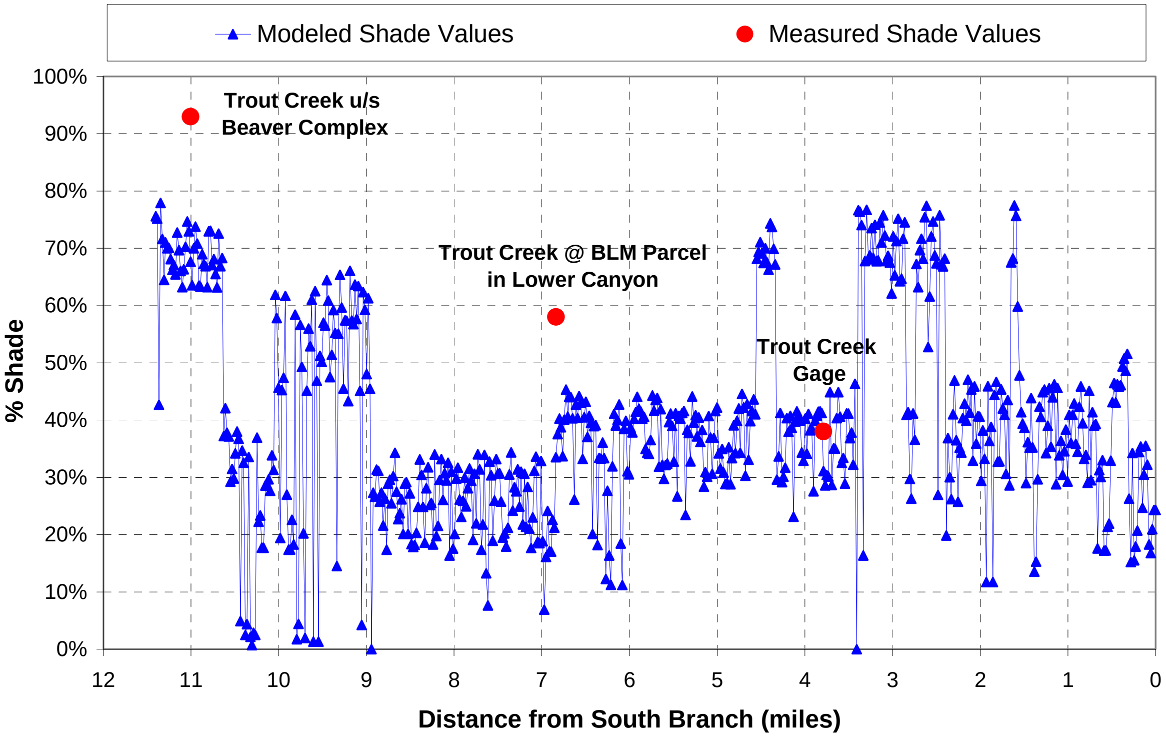


Figure 2-12. Measured and Modeled Current Condition Shade Values for Trout Creek

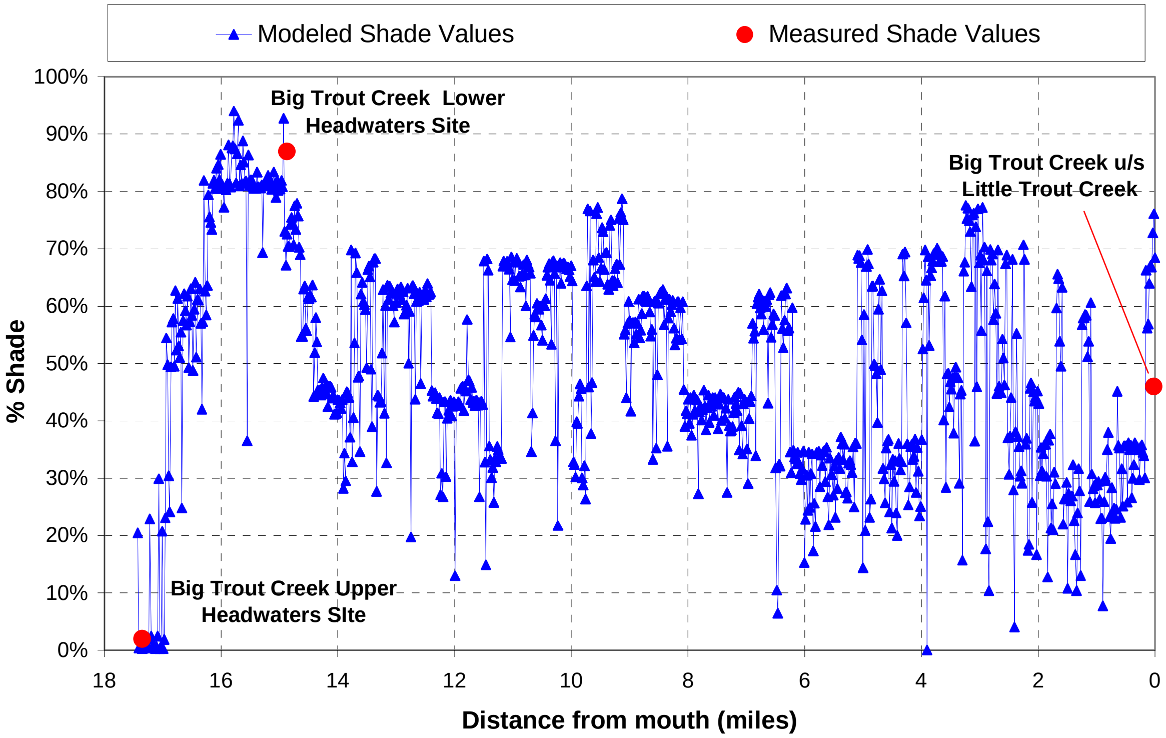


Figure 2-13. Measured and Modeled Current Condition Shade Values for Big Trout Creek

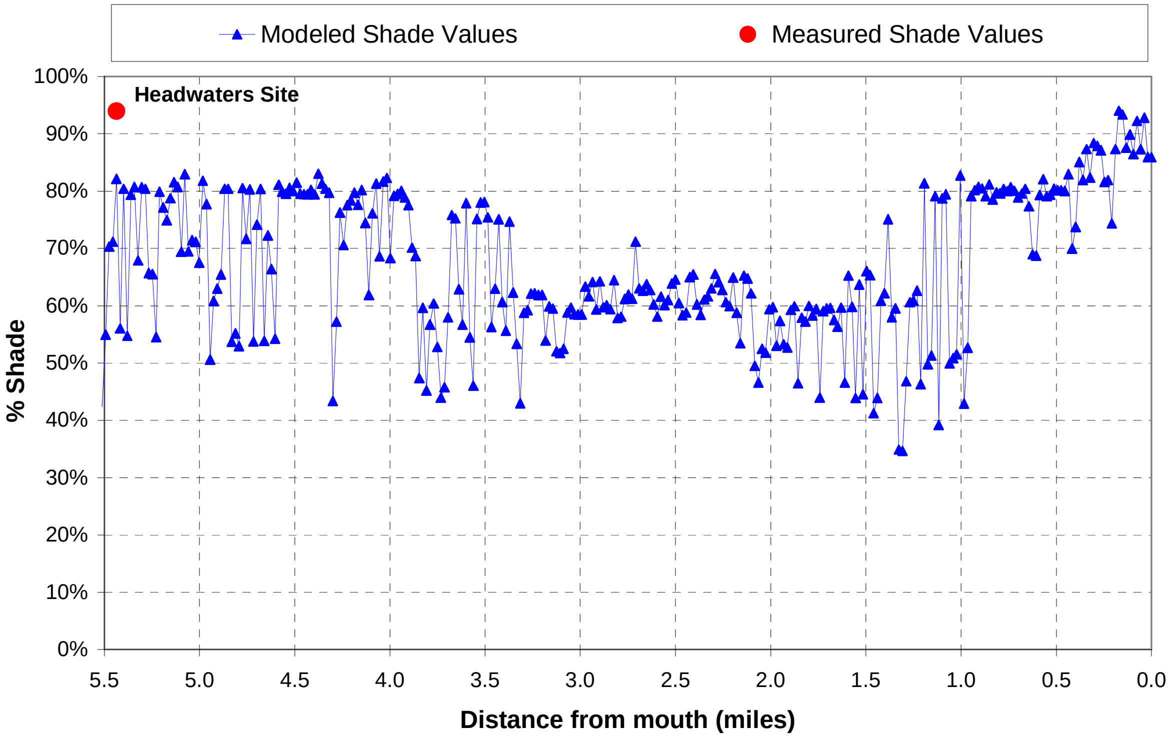


Figure 2-14. Measured and Modeled Current Condition Shade Values for East Fork Big Trout Creek

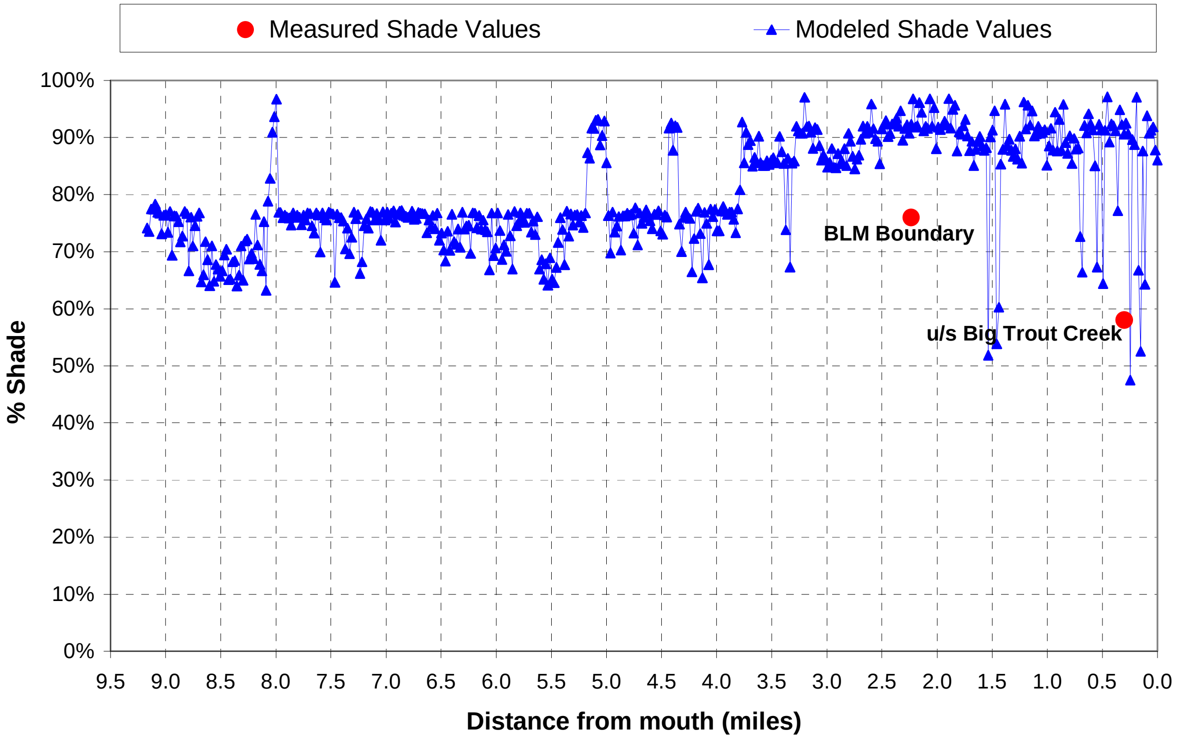


Figure 2-15. Measured and Modeled Current Condition Shade Values for Little Trout Creek

2.4.3.1.3 System Potential Condition

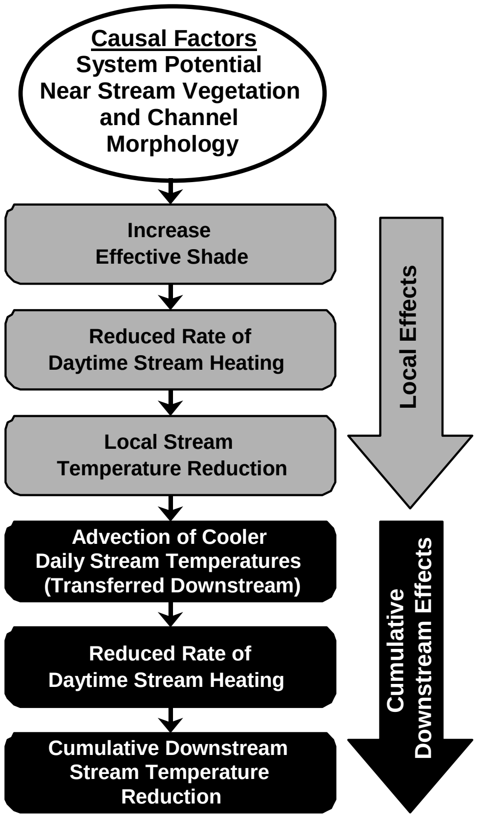
System potential effective shade occurs when near stream vegetation is at a climax life stage. A climax life stage is represented by the following conditions:

- Vegetation is mature and undisturbed;
- Vegetation height and density is at or near the potential expected for the given plant community;
- Vegetation is sufficiently wide to maximize solar attenuation; and
- Vegetation width accommodates channel migrations.

System potential vegetation for each of the modeled stream reaches was developed by ODEQ staff in conjunction with staff from the Burns and Vale Districts of the BLM. The Trout Creek Mountains *system potential* was developed using ODEQ data and vegetative field studies conducted by Angela G. Evenden as part of her PhD thesis (Evenden 1989).

Automated computerized near stream vegetation sampling was repeated to determine the *system potential* condition for each stream reach described in **Section 2.4.3.1.1** above, replacing the current condition land cover with potential condition land cover as indicated in **Tables 2-5** through **2-8**. It should be noted from these tables, that many of the current condition land cover categories were determined to already be at *system potential* conditions.

Thermal Response to System Potential Conditions



Current near stream vegetation distribution and height and *system potential* riparian vegetation height are displayed in **Figures 2-16** through **2-22** for the seven streams analyzed. The vegetation distribution is shown for both the right and left stream banks. Note that the river miles presented in these figures were derived from a 1:5000 stream coverage used for ODEQ simulation purposes and may differ slightly from other sources (such as OWRD or USGS river miles).

Ecological Provinces. In order to determine *system potential* conditions for streams throughout the entire subbasin, including those not modeled, the subbasin was divided into four Ecological Provinces: East Steens, Pueblo Mountains, Trout Creek Mountains, and Willow-Whitehorse (**Figure 2-23**). Natural resource specialists with ODEQ and with the Burns District Office of the BLM conducted extensive surveys of vegetative communities to determine existing and *system potential* vegetative conditions on public lands during 2002 for the East Steens and Pueblo Mountains provinces. *System potential* was determined through consensus and best professional judgment. The Trout Creek Mountains *system potential* was developed using ODEQ data and vegetative field studies conducted by Angela G. Evenden as part of her PhD thesis in 1989. *System potential* vegetative conditions for the Willow-Whitehorse province were developed in cooperation with the Vale District Office of the BLM in 1998. *System potential* vegetation for private lands was developed by ODEQ.

A fluvial geomorphology assessment of representative streams within each of the provinces was also conducted. The survey of fluvial geomorphology of subbasin streams involved collecting field data along the longitudinal extent of representative streams within each province. The purpose of these surveys was to assess stream stability using Rosgen's level II field methods and characterize riparian conditions (community type, vegetation height, canopy density, etc.) including effective shade. Additionally, the ODEQ and BLM conducted comprehensive shade surveys in the Pueblo Mountains and East Steens Mountain Ecological Provinces using a solar path finder to arrive at averages for effective shade by stream reach. The bankfull width, flood prone area, and effective shade data gathered during these surveys were used in the calculation of the regional shade curves described in **Section 2.7.2**.

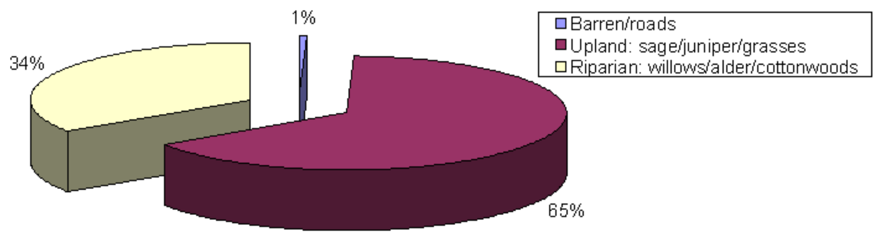
Based on the field data collected and summarized in **Tables 2-5** through **2-8**, *system potential* conditions were developed for three to four different elevation zones within each ecological province (**Tables 2-9** through **2-12**). These elevation zones are used to determine appropriate effective shade surrogate measures for the Alvord Lake Subbasin in **Section 2.7.2** . The *system potential* conditions for the Willow-Whitehorse Ecological Province were determined from the earlier TMDL work done for Willow Creek in 1999. More details are provided in **Chapter III**.

2.4.3.2 Stream Flow

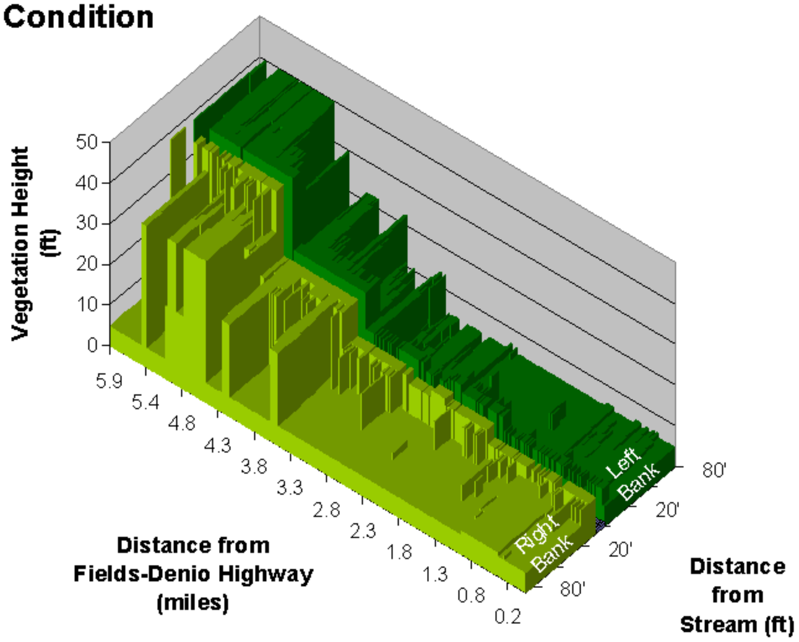
Stream temperature change is generally inversely related to flow volume. As flows decrease, stream temperature tends to increase if energy processes remain unchanged (Boyd, 1996). Runoff in the Alvord Lake subasin is primarily derived from snow melt, with peak runoff typically occurring in the spring. Late summer low flows are common for many streams in the watershed due to low summer precipitation and water withdrawals. Low flows were measured as part of the subbasin assessment in 2001. The flows during 2001 were recorded for all of the streams surveyed. The volume of low flow, or base flow, for most streams was generally less than <1.0 cubic foot per second (cfs). The exception was Trout Creek which was measured at 1.76 cfs during low flow.

Summer base flows in the lower reaches of Alvord Lake Subbasin streams are reduced by water withdrawals for irrigation and lose-gain phenomenon in some streams. The out-of-stream beneficial uses of the water from these streams are primarily irrigation and domestic uses. The subbasin has dedicated water rights for irrigation and other uses. There are in-stream water rights appropriated to ODFW for the protection of fish in the Alvord Lake Subbasin in Trout Creek, Little Trout Creek, and East Fork of Big Trout Creek. Although water withdrawal affects stream temperature, this TMDL recognizes irrigation withdrawals as a legitimate use. Therefore, **stream flow was not targeted directly in this TMDL**.

Mosquito Creek Remotely Sensed Vegetation



Current Condition



System Potential

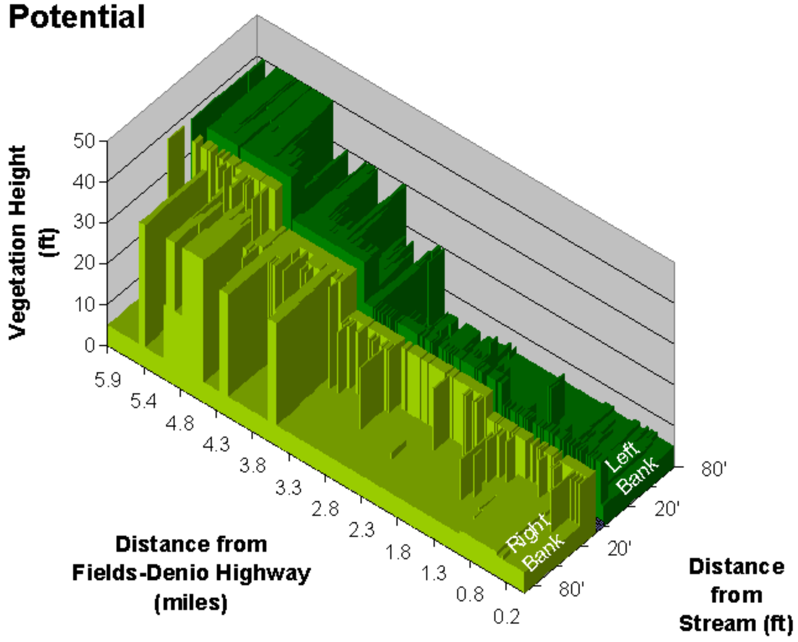
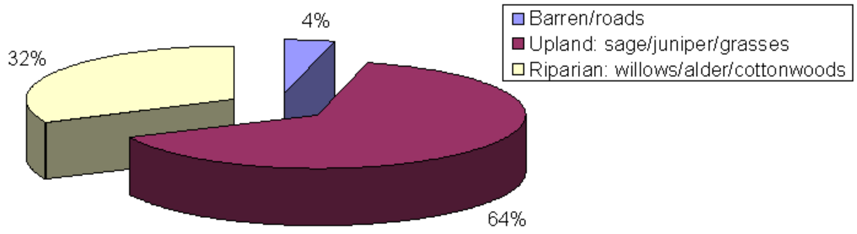
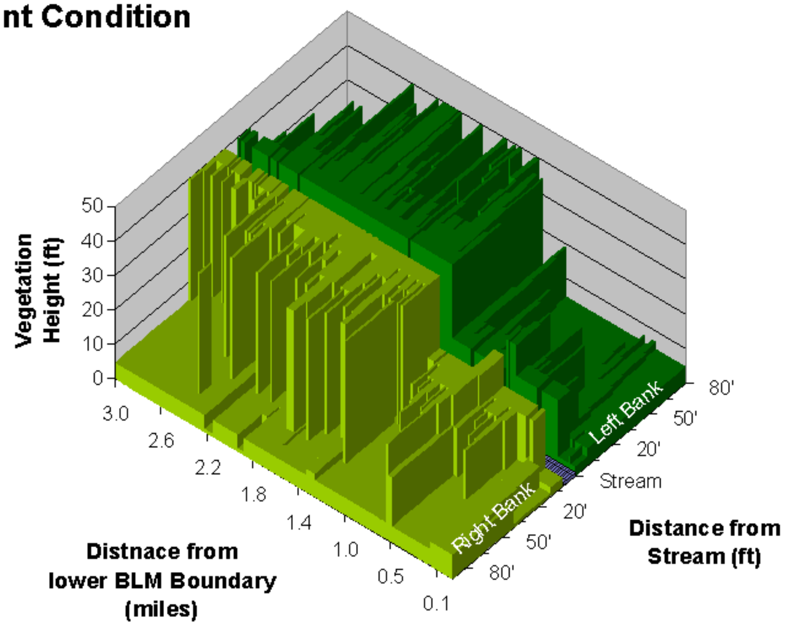


Figure 2-16. Mosquito Creek Near Stream Vegetation Distribution

Willow Creek Remotely Sensed Vegetation



Current Condition



System Potential

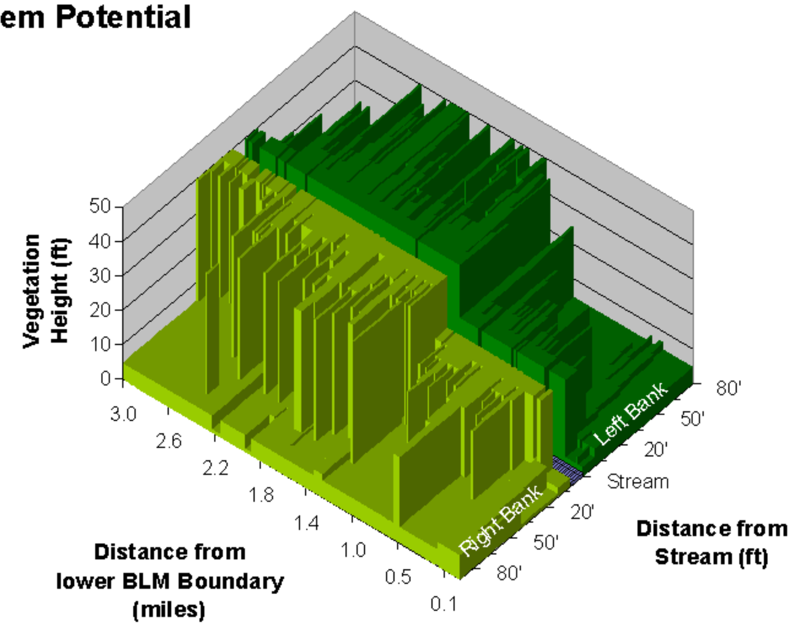
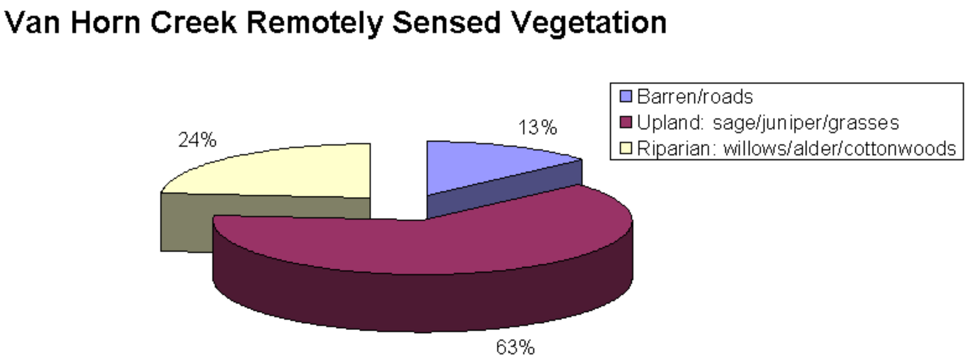
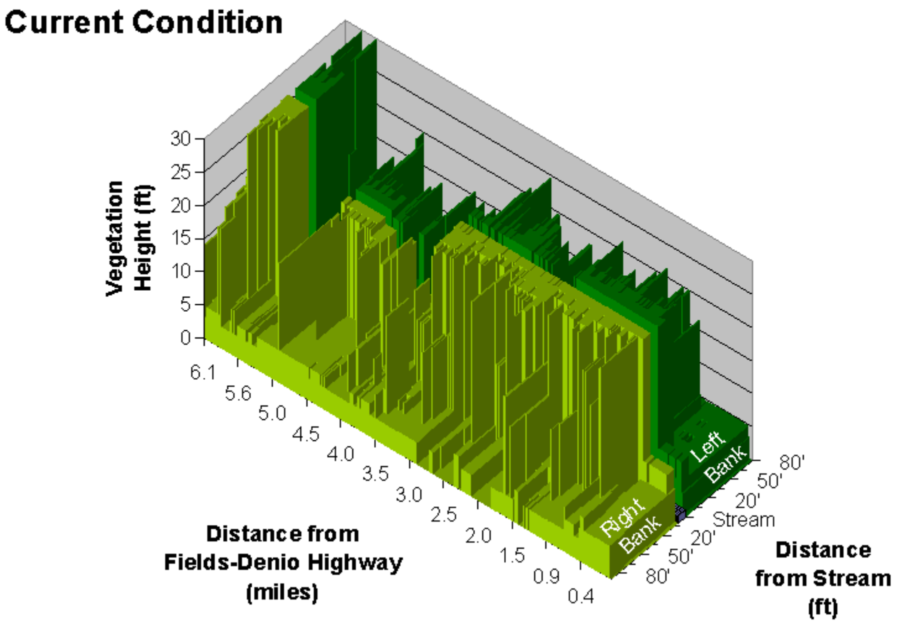


Figure 2-17. Willow Creek Near Stream Vegetation Distribution


Van Horn Creek Remotely Sensed Vegetation


Current Condition

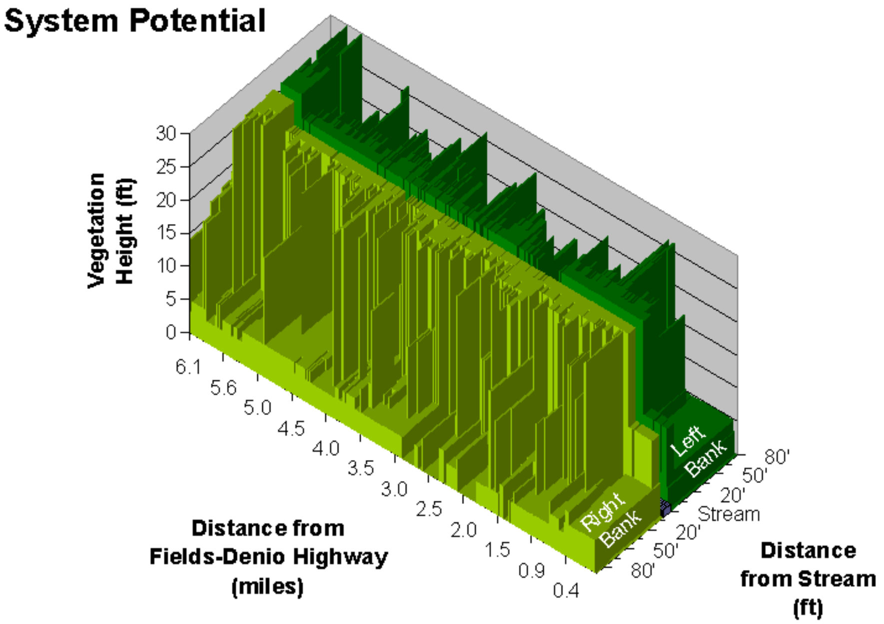

System Potential

Figure 2-18. Van Horn Creek Near Stream Vegetation Distribution

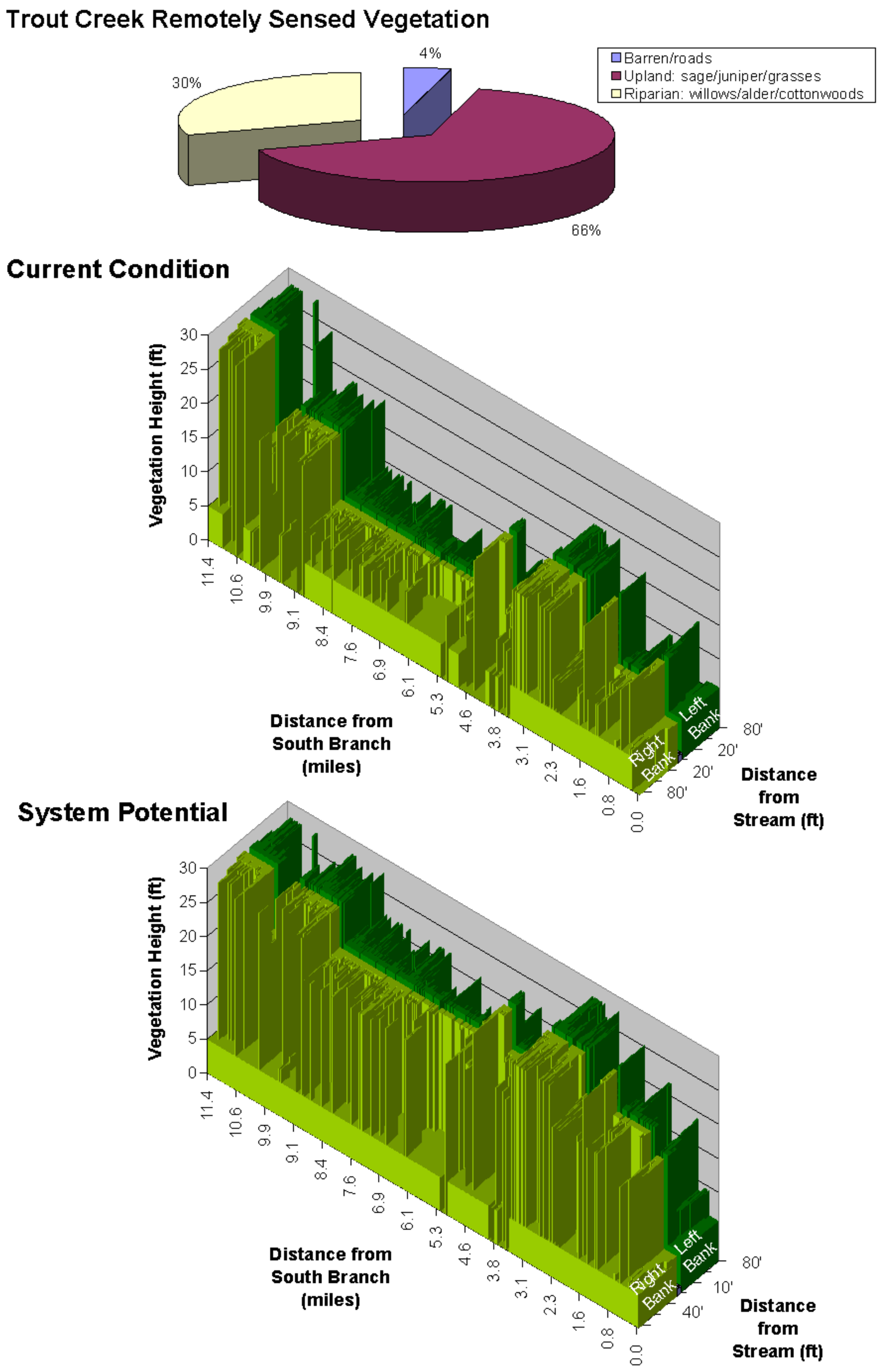


Figure 2-19. Trout Creek Near Stream Vegetation Distribution

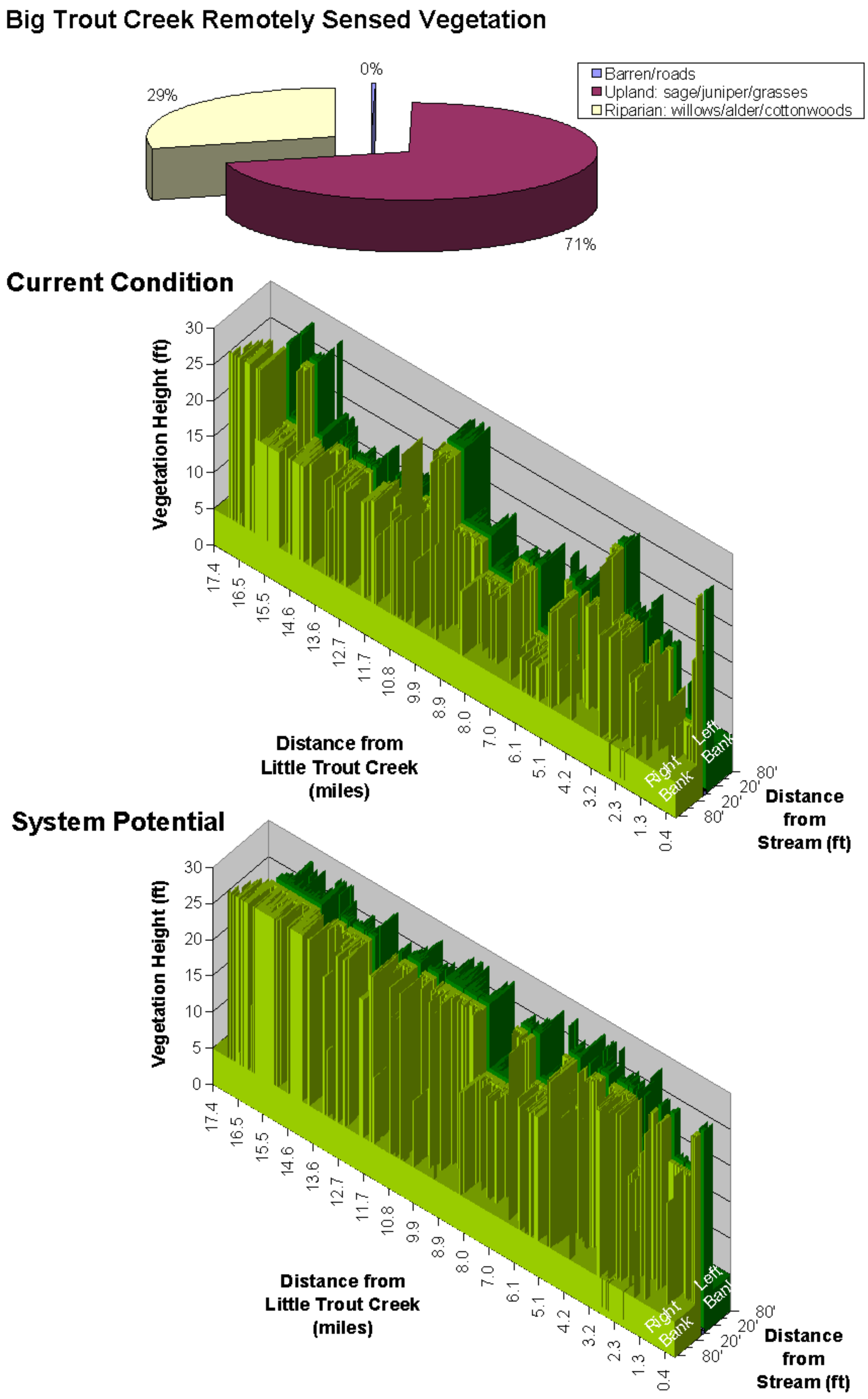
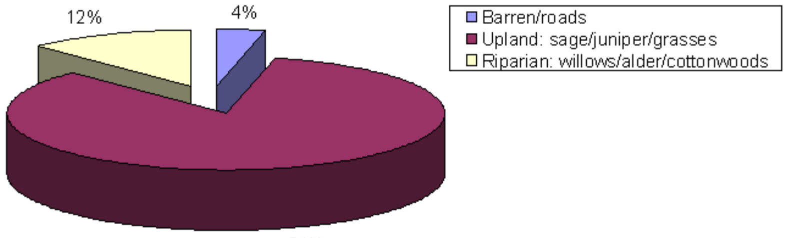
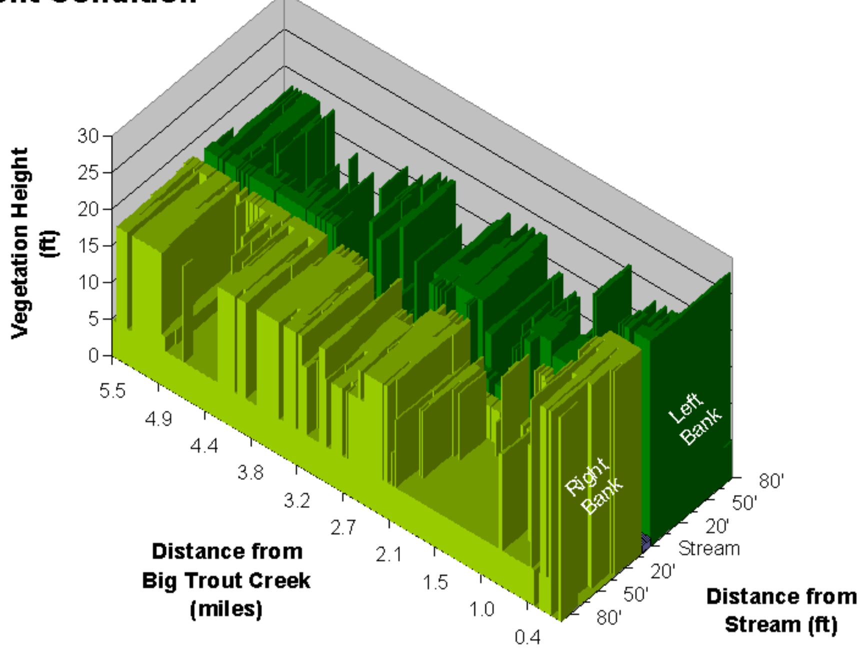


Figure 2-20 Big Trout Creek Near Stream Vegetation Distribution

East Fork Big Trout Creek Remotely Sensed Vegetation



Current Condition



System Potential

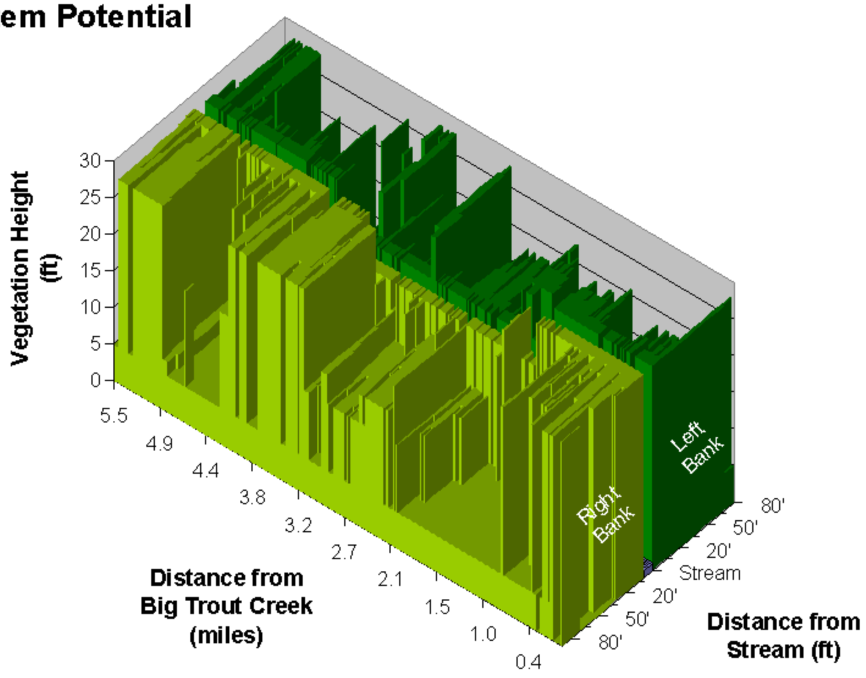


Figure 2-21. East Fork Big Trout Creek Near Stream Vegetation Distribution

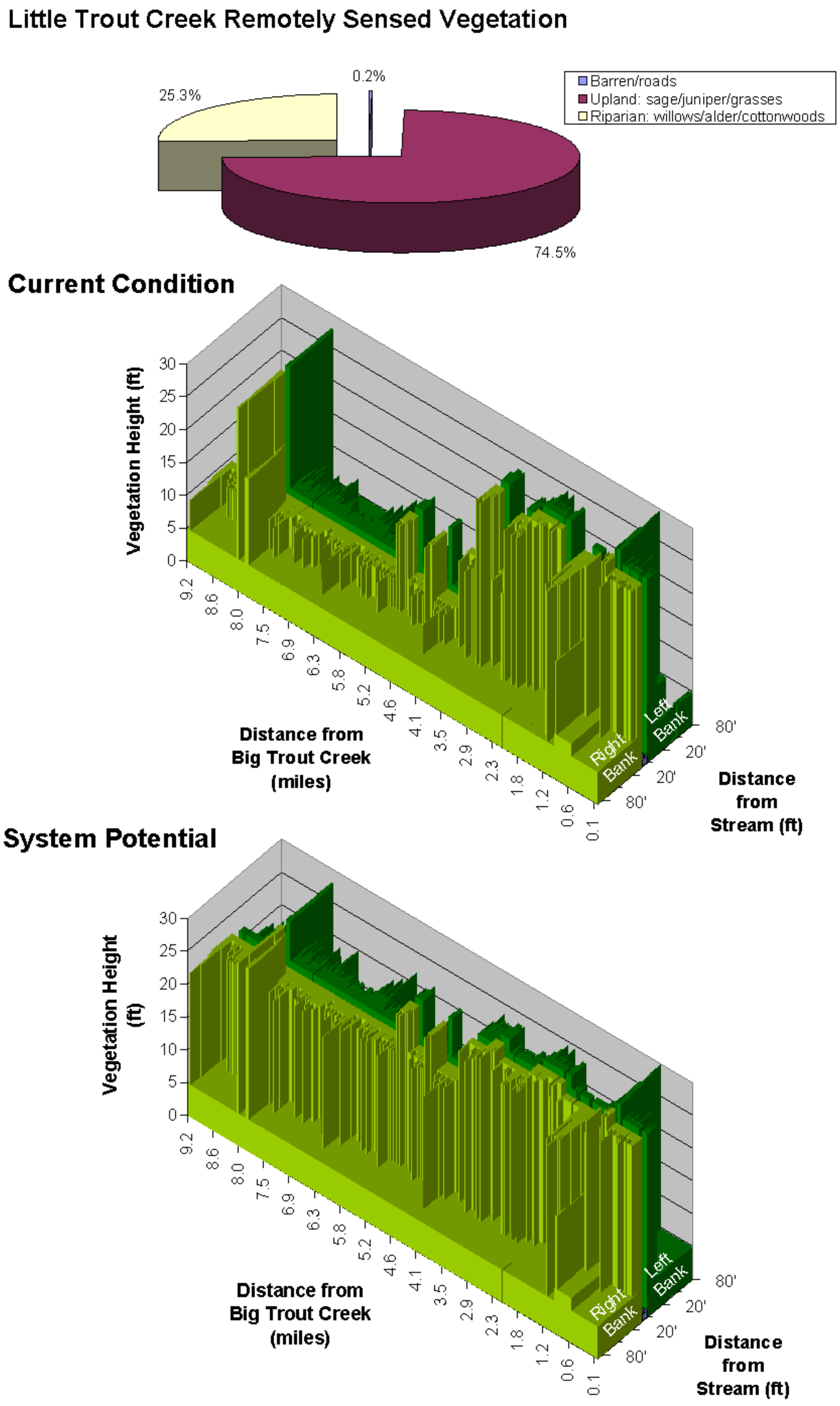


Figure 2-22. Little Trout Creek Near Stream Vegetation Distribution

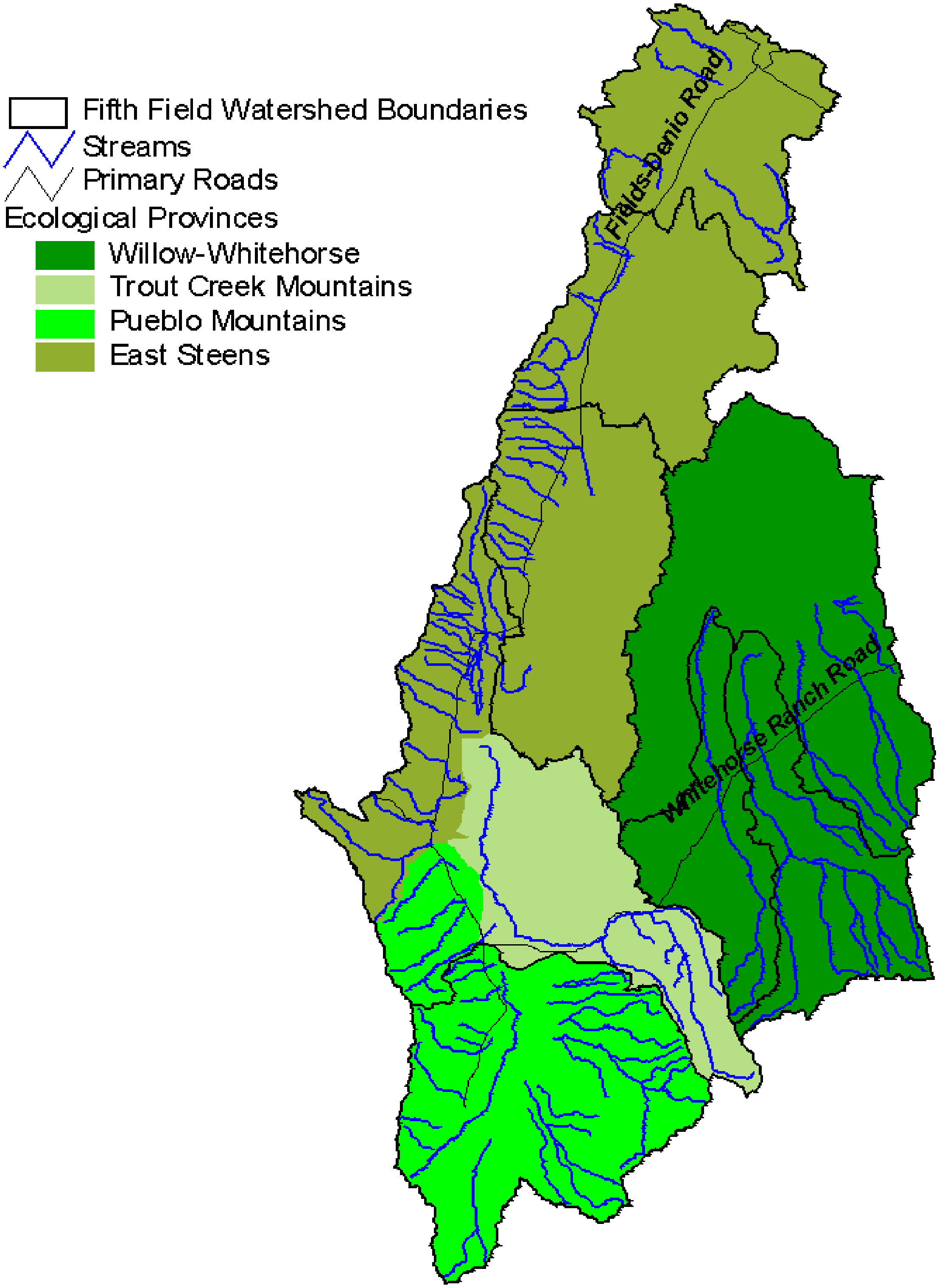


Figure 2-23. Ecological Provinces in the Alvord Lake Subbasin

Table 2-9. *System Potential* Conditions for the East Steens Ecological Province

East Steens Mountain Region		Potential Near Stream Conditions		
Vegetation Zone	**Stream Reach**	**Vegetation Community *System Potential*** **Channel Morphology *System Potential***	**Overstory Vegetation Height (feet)**	**Average Canopy Density**
Black Cottonwood-Pacific Willow	Headwaters 6800’-5200’	**Community Type**: Co-dominant cottonwood-willow community w/ minor aspen **Individual Plant types**: Black Cottonwood Pacific Willow Quaking Aspen Salix ssp. Scouler willow Common Snowberry	40’ average canopy height 48’ 24’ 40’ 18’ 22’ 6’	80%
		Dominant Channel Type: Rosgen A-B channel types with variable flood prone width within structurally controlled valley		
Pacific Willow-Black Cottonwood - Aspen	Mid-Elevation 5200’-4260’	**Community Type**: Co-dominant willow-cottonwood community w/ minor aspen **Individual Plant types**: Pacific Willow Black Cottonwood Salix ssp. Quaking Aspen	25’ average canopy height 24’ 28’ 18’ 30’	65%
		Dominant Channel Type: Rosgen B channel type Flood prone width: 30’		
Willow Mix	Low- Elevation 4260’-4100’	**Community Type**: Dominant Pacific Willow-Coyote Willow mix **Individual Plant types**: Pacific Willow Coyote Willow Salix ssp. Black Cottonwood	20’ average canopy height 24’ 16’ 18’ 15’	50%
		Dominant Channel Type: Rosgen B-C channel type Flood prone width within entrenched section 43’ (C within relic F between 4500’-4300’ elevation), otherwise 33’ flood prone area		

Table 2-10. *System Potential* Conditions for the Pueblo Mountains Ecological Province

Pueblo Mountains Region		**Potential Near Stream Conditions**		
Vegetation Zone	**Stream Reach**	**Vegetation Community *System Potential*** **Channel Morphology *System Potential***	**Overstory Vegetation Height (feet)**	**Average Canopy Density**
Aspen-Alder-Willow	Headwaters 6400’-6100’	**Community Type**: Co-dominant Quaking Aspen-Alder-Scouler Willow	33’ average canopy height	85%
		Individual Plant types:		
		Quaking Aspen	40’	
		Alder	28’	
		Scouler willow	22’	
		Salix ssp.	18’	
		Dominant Channel Type: Rosgen A-B channel types with variable flood prone width within structurally controlled valley		
Alder-Cottonwood-Willow	Mid-Low Elevation 6100’-4300’	**Community Type**: Co-dominant Alder-Black Cottonwood-Salix ssp.	28’ average canopy height	75%
		Individual Plant types:		
		Alder	28’	
		Black Cottonwood	40’	
		Salix ssp.	18’	
		Scouler Willow	22’	
		Lemon Willow	16’	
		Cherry	22’	
		Red Osier Dogwood	12’	
		Dominant Channel Type: Rosgen A-B channel type Flood prone width: 13-20’		
Willow mix	Lowest-Elevation 4300’-4248	**Community Type**: Salix ssp. Mix	14’ average canopy height	50%
		Individual Plant types:		
		Salix ssp. mix	12’	
		Coyote Willow	16’	
		Dominant Channel Type: Rosgen B-C channel type Flood prone width: 20’		

Table 2-11. *System Potential* Conditions for the Trout Creek Mountains Ecological Province

Trout Creek Mountains Region		Potential Near Stream Conditions		
Vegetation Zone	**Stream Reach**	**Vegetation Community *System Potential*** / **Channel Morphology *System Potential***	**Overstory Vegetation Height (feet)**	**Average Canopy Density**
Mesic Graminoid-Willow	Headwaters >7218’	**Community Type**: Co-dominant mesic graminoid-willow **Individual Plant types**: Lemon Willow Graminoid **Dominant Channel Type**: Rosgen B-E channel types with variable flood prone width. Mesic community 36’ flood prone area	8.5’ average canopy height 16’ 1’	10%
Aspen-Willow	High Elevation 7218’-6562’	**Community Type**: Co-dominant aspen-willow **Individual Plant types**: Quaking Aspen Pacific Willow Geyer Willow Lemon Willow **Dominant Channel Type**: Rosgen B channel type Flood prone width: 25’	29’ average canopy height 40’ 24’ 15’ 16’	90%
Willow-Alder	Mid Elevation 6562’-4500’	**Community Type**: Co-dominant willow-alder (1:1) **Individual Plant types**: Mountain Alder Pacific Willow Lemon Willow Scouler Willow **Dominant Channel Type**: Rosgen B-C channel type Flood prone width: 55’	24’ average canopy height 28’ 24’ 16’ 22’	75%
Willow	Low Elevation 4500’-4240’	**Community Type**: Dominant willow **Individual Plant types**: Coyote Willow Yellow Willow Pacific Willow **Dominant Channel Type**: Rosgen C dominant (B canyon) channel type Flood prone width: 70’ average	18’ average canopy height 16’ 18’ 24’	60%

Table 2-12. *System Potential* Conditions for the Willow-Whitehorse Ecological Province*

Willow-Whitehorse Region		Potential Near Stream Conditions		
Vegetation Zone	**Stream Reach**	**Average Height (feet)**	**Average Canopy Density**	**Riparian Buffer Width (feet)**
Aspen	7000’-5800’	30	30%	20
Mountain Alder	5800’-5000’	25	30%	30
Willow	5000’-4780’	18	30%	40
Willow	4780’-4460’	18	30%	55
Willow	4460’-4360’	18	30%	60

* Note: The *system potential* conditions for the Willow-Whitehorse Ecological Province were determined from the earlier TMDL work done for Willow Creek in 1999. More details are provided in Chapter III. The width of the potential riparian buffer was determined by Rosgen’s protocols for calculating and measuring the flood prone area for each stream reach (Rosgen 1994). The flood prone area represents the maximum potential area in which riparian plant species can be established and maintained. Available moisture and annual disturbance within the flood prone area are key components of plant succession, from early colonization to late seral stages.

2.4.3.3 Channel Morphology

Changes in channel morphology, namely channel widening, impact stream temperatures. Channel morphology is a broad term which encompasses hydraulic geometry (shape of the cross section of a stream’s channel), distance of vegetation from the stream, sinuosity, gradient, substrate, and other physical characteristics of a stream. The characteristics of a channel can significantly influence stream heating. For example, a stream with a large width to depth ratio will receive more solar radiation on a unit volume basis than one with a narrow, deep channel, resulting in greater diel fluctuations in temperature. The distance of vegetation from the stream is very important, since vegetation too far from the stream to provide shade will do little to prevent heating. An additional benefit inherent to narrower/deeper channel morphology is a higher frequency of pools that contribute to aquatic habitat or cold water refugia. In addition, the removal of streamside vegetation can reduce bank stability leading to increased sediment loads and a wider stream channel and can reduce connection with the floodplain leading to decreased water storage and hyporheic flow of cooler water during the summer months.

The shade surrogate measures developed in the temperature TMDL provide for the establishment of *system potential* riparian communities. The s*ystem potential* riparian communities will not only provide shade but will also stabilize stream banks, resulting in: (1) the reduction of sediment inputs and subsequent decreases in channel width and, (2) the reconnection of the stream with the floodplain restoring water storage functions. Therefore the surrogate measures established for temperature will benefit channel width, sediments and bank storage as well.

Although **channel morphology was not targeted directly in this TMDL**, ODEQ does feel that it is important to acknowledge the important role that channel morphology can play in regulating stream temperatures. For this reason, a brief discussion of channel morphology in the Alvord Lake Subbasin is presented here.

An assessment of channel stability was performed on representative streams within the Alvord Lake Subbasin using Rosgen's Level II & III Departure Analysis. The objective of these surveys was to determine if the stream channels were stable and capable of delivering sediment at bankfull or greater flows. The parameters used to determine morphological characteristics include valley type, bankfull width and depths, width/depth ratio, flood prone width, entrenchment, sinuosity and others. If a particular stream or segment indicated an unstable channel form such as type 'A3', 'G' or 'F', additional surveys were performed on that stream to complete the Level III stability analysis (Pfankuch, Channel Stability Evaluation and Stream Classification Summary).

The majority of streams surveyed in the subbasin are considered morphologically stable. That is, the channel types are a stable form ('B', 'C', 'E'), stream characteristics (dimension, pattern, and profile) are consistent with valley types, the streams are not aggrading or degrading beyond normal channel adjustments, and sensitive indicators like width/depth ratios are relatively low (mean w/d ratios 12). There are exceptions, however, namely Willow Creek in the East Steens and Willow Creek in the Trout Creek Mountains (see **Section 3.4.3.3** for a further discussion of Willow Creek in the Trout Creek Mountains).

Willow Creek and other streams located in the East Steens Mountain region experience deposition of boulder-to-cobble size material in the mid-to-lower reaches as a result of hydraulic disturbance. Willow Creek originates high in the Steens Mountain at a peak elevation of approximately 9500 feet. The elevation change from the peak of the rim to the valley floor is a 5000 feet drop over 4.6 miles (21% average slope). This energy gradient provides a high capacity for sediment transport (stream power) during runoff events. Peak flows transport large particles of alluvial materials downstream to the point where transport power diminishes and deposition occurs as a function of gradient (roughly mid-elevation). Two phenomena take place where sediment is deposited: sediment disequilibrium resulting in avulsion (channel shift or redistribution), or anastomosation (multiple thread channels); and, the creation of a porous coarse-grained alluvial fan that allows surface water to drain sub-surface to ground water or as hyporheic underflow. As a result, the perennial flows in Willow Creek reach only about 50% of its total channel length. The stream below the deposition feature is dry most of the year starting in July. ODEQ considers this natural event that has been occurring over geologic time and unrelated to human caused activities.

2.4.4 Point Sources of Heat

There are no point sources located within the Alvord Lake Subbasin.

2.5 LOADING CAPACITY – 40 CFR 130.2(F)

The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards. EPA's current regulation defines loading capacity as "*the greatest amount of loading that a water can receive without violating water quality standards*." (40 CFR § 130.2(f)). The water quality standard states that ***no measurable surface water temperature increase resulting from anthropogenic activities*** is allowed in the Alvord Lake Subbasin when surface water temperature criteria are exceeded. The primary pollutant is human influenced increases in solar radiation loading (nonpoint sources).

*The Water Quality Standard mandates a **Loading Capacity** based on the condition that meets the **no measurable surface water temperature increase resulting from human caused activities when surface water temperature criteria are exceeded.***

In this document, the loading capacity is expressed in terms of British thermal units per day (BTU/ft^2/day). This represents the amount of energy that can be added to a waterbody and still obtain water quality standards.

2.5.1 Nonpoint Sources

The loading capacity is dependent on the available assimilative capacity of the receiving water. For nonpoint sources, the loading capacity is the amount of background solar radiation that reaches the stream when the stream is at *system potential* conditions in terms of riparian vegetation and channel morphology. For streams whose *system potential* temperatures are at or above the temperature criteria for a given period, there is no available assimilative capacity; the loading capacity is consumed by natural sources.

Current solar radiation loading was calculated by simulating current stream and vegetation conditions for Mosquito Creek, Willow Creek (East Steens), Van Horn Creek, Trout Creek, Big Trout Creek, East Fork Big Trout Creek and Little Trout Creek. Background loading was calculated by simulating the solar radiation heat loading that resulted with *system potential* near stream vegetation. This background condition, based on *system potential*, reflects an estimate of nonpoint source heat load that would occur while meeting the temperature standard (i.e., ***no measurable surface water increase resulting from anthropogenic activities is allowed***).

Figures 2-24 to **2-30** contrast the longitudinal profile of the current solar radiation heat loading with the solar radiation heat loading that occurs with *system potential* land cover for each modeled creek. Notice that solar radiation loading at *system potential* (loading capacity) is generally less than at levels currently observed, although the difference varies by stream and stream reach. Notice also, that in almost all the streams modeled, a portion of each stream is already at *system potential* vegetation. Because the TMDL targets achieving *system potential* vegetation, the TMDL applies year-round for nonpoint sources.

2.5.2 Point Sources

There are no point sources located within the Alvord Lakes Subbasin, therefore no loading capacity was developed.

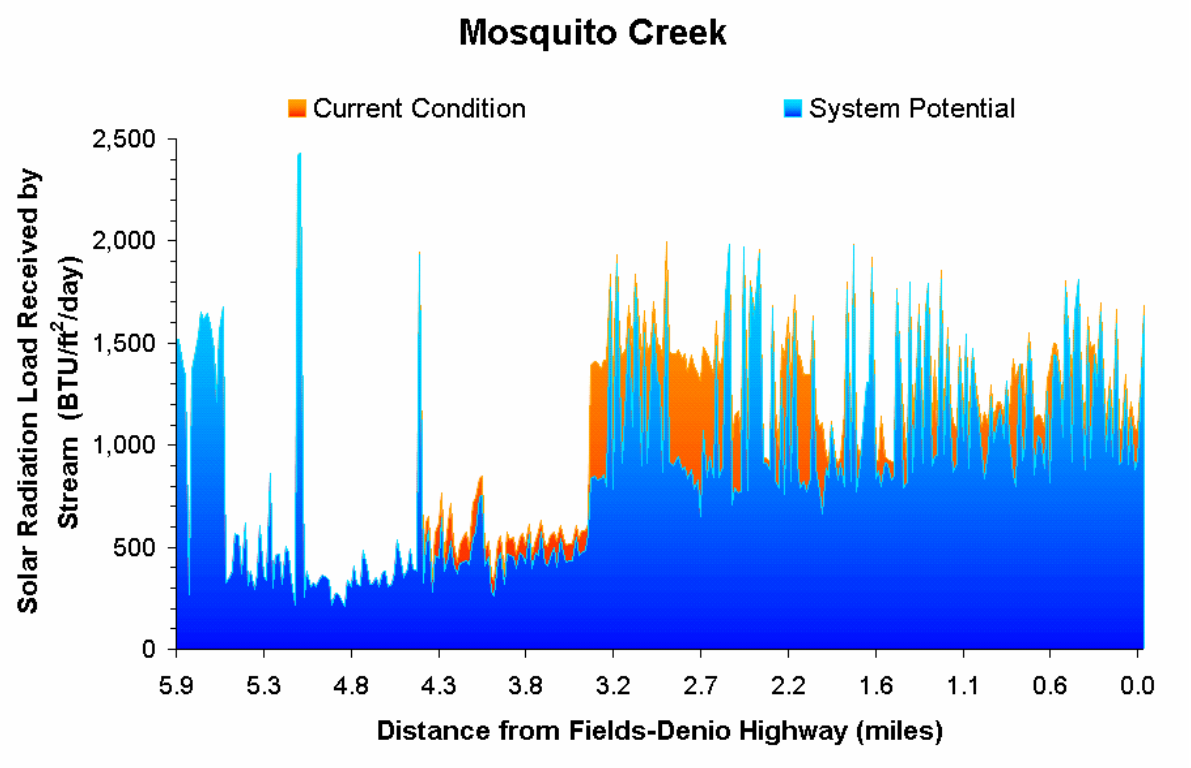


Figure 2-24. Solar Radiation Loading in Mosquito Creek – Current and *System Potential* Conditions

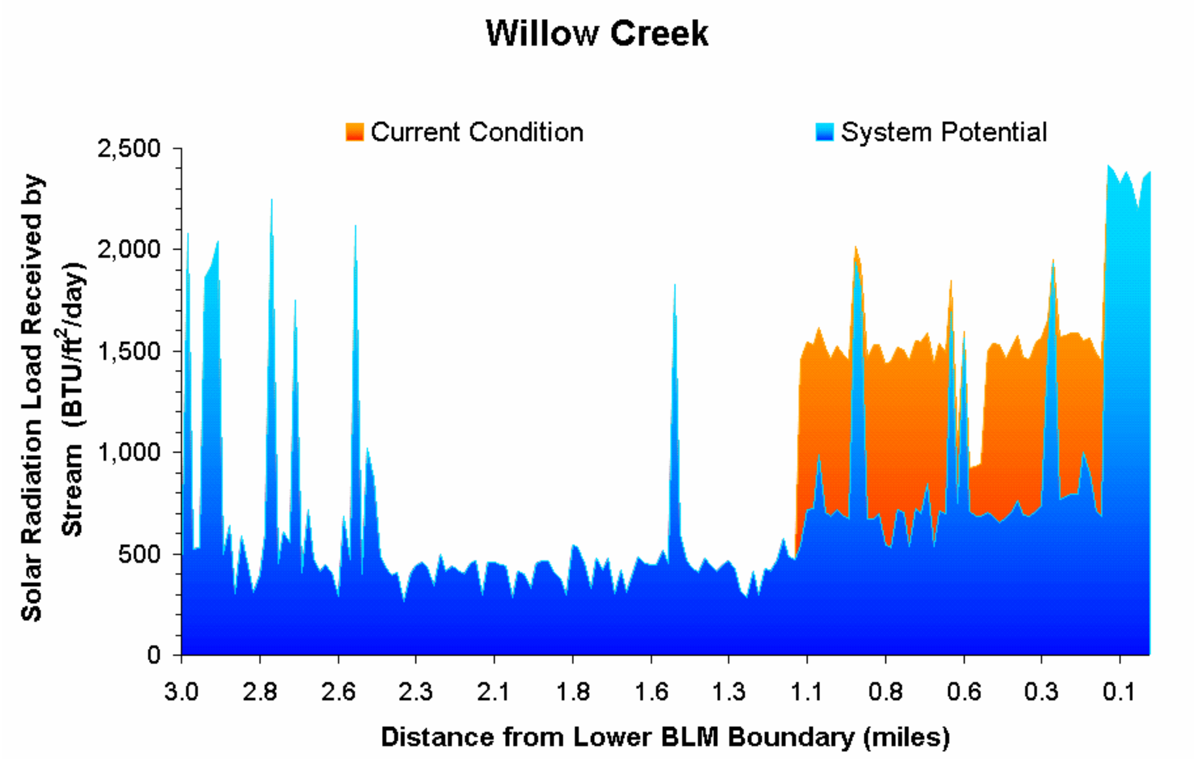


Figure 2-25. Solar Radiation Loading in Willow Creek – Current and *System Potential* Conditions

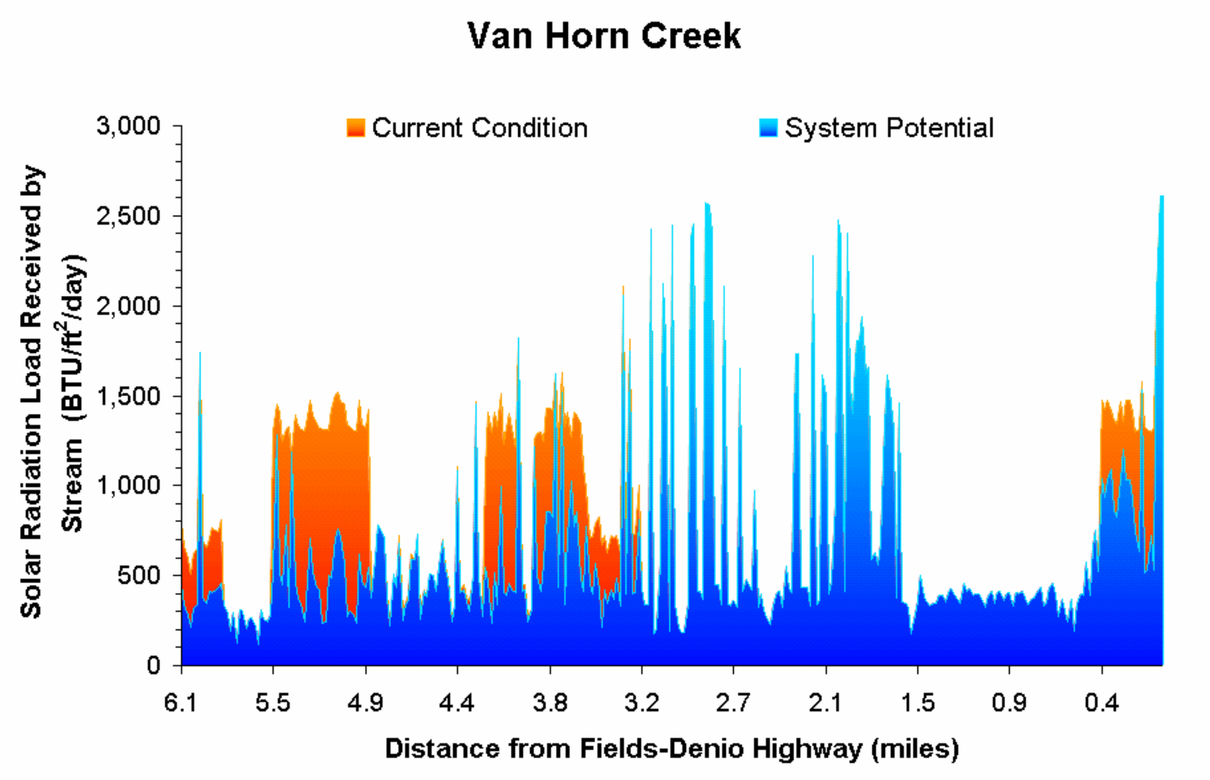


Figure 2-26. Solar Radiation Loading in Van Horn Creek – Current and *System Potential* Conditions

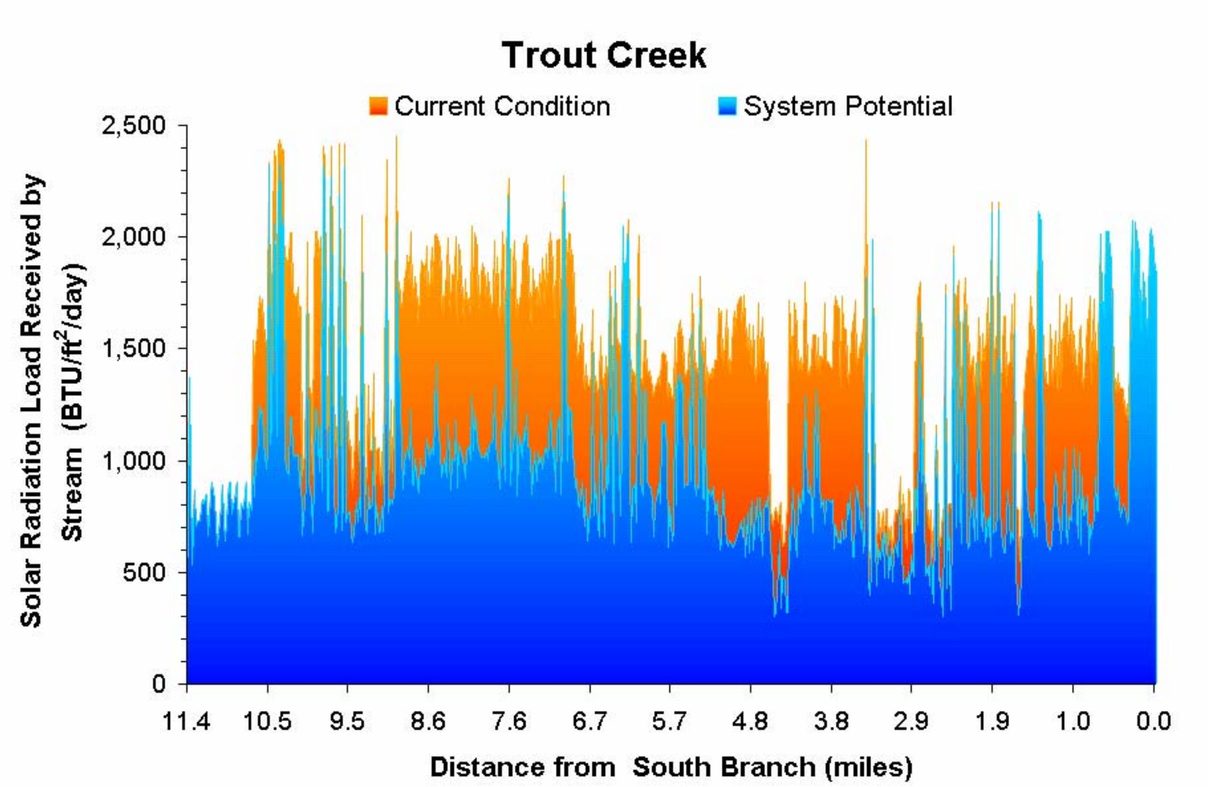


Figure 2-27. Solar Radiation Loading in Trout Creek – Current and *System Potential* Conditions

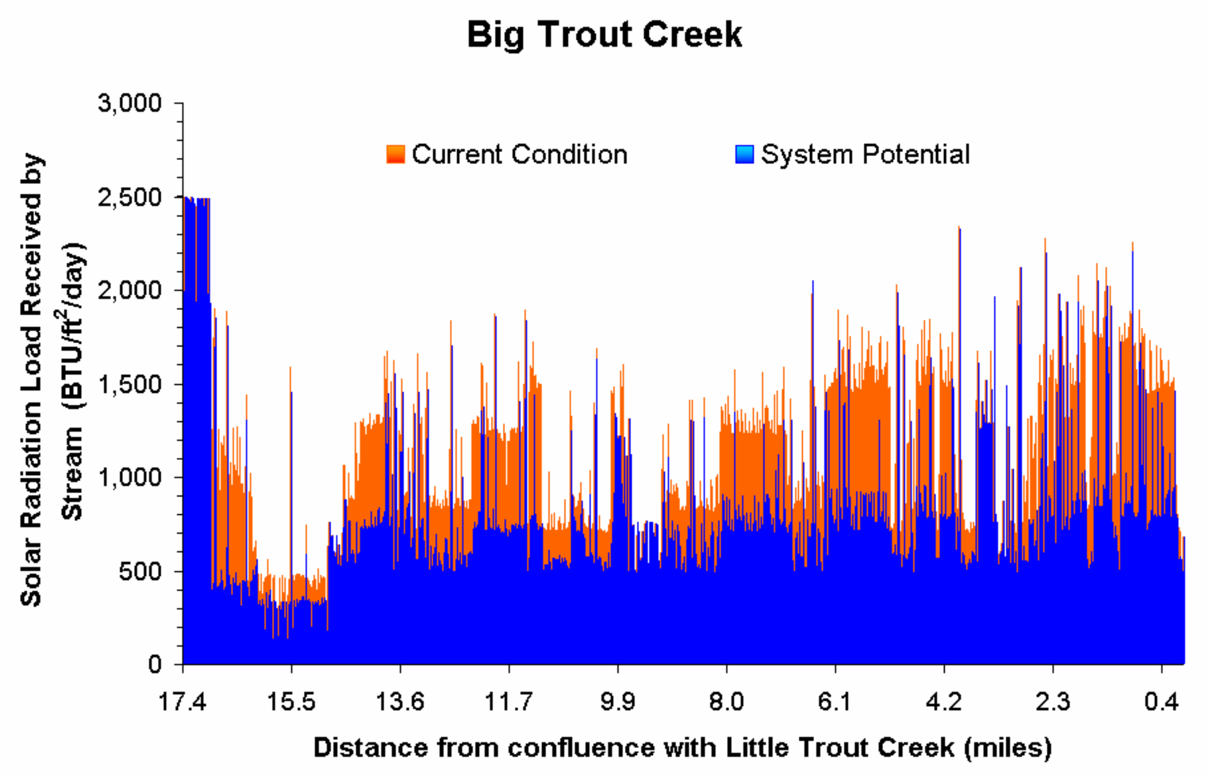


Figure 2-28. Solar Radiation Loading in Big Trout Creek – Current and *System Potential* Conditions

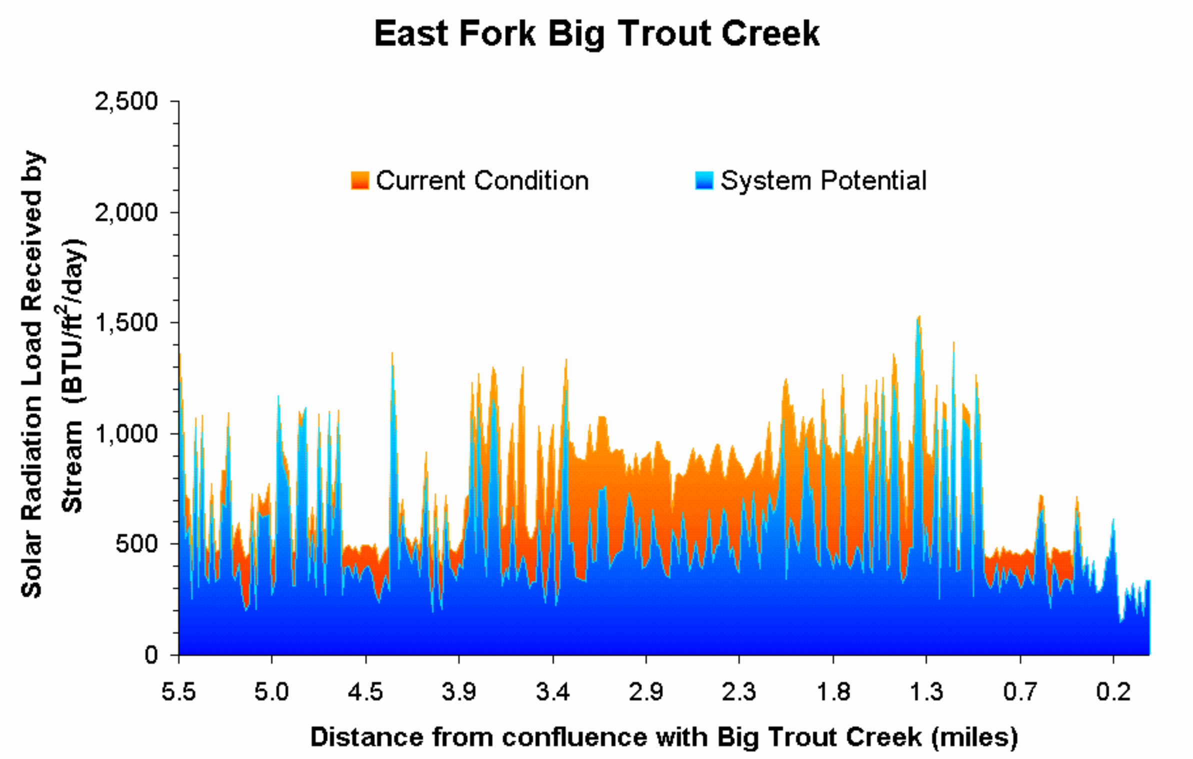


Figure 2-29. Solar Radiation Loading in East Fork Big Trout Creek – Current and *System Potential* Conditions

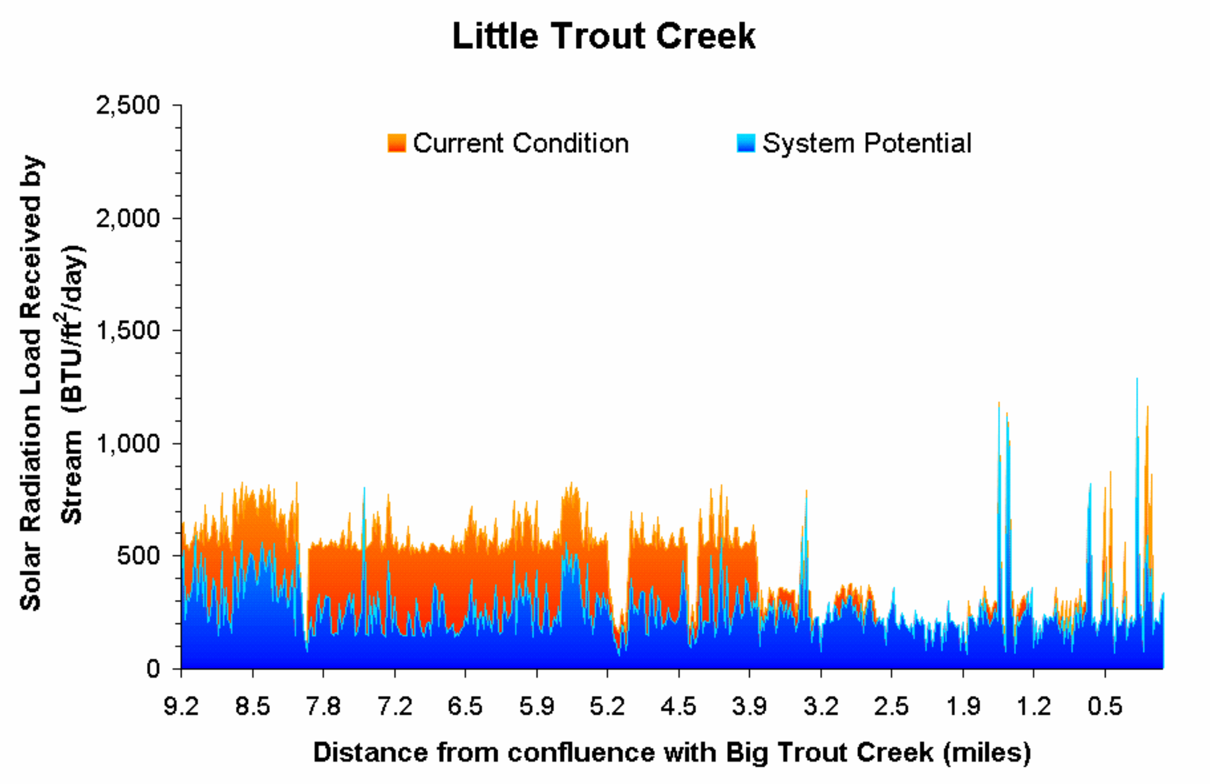


Figure 2-30. Solar Radiation Loading in Little Trout Creek – Current and *System Potential* Conditions

2.6 ALLOCATIONS – 40 CFR 130.2(G) AND (H)

Loading capacity is available for allocation where surface water temperatures throughout a given stream and all reaches downstream decrease below the standard by an amount sufficient to accommodate either point source or nonpoint source influences.

Load Allocations are portions of the loading capacity divided between natural, human and future nonpoint pollutant sources. **Table 2-13** lists load allocations (i.e. distributions of the loading capacity) according to land-use. Each DMA's portion of the WQMP (**Appendix A**) will address only the lands and activities within each identified stream segment to the extent of the DMA's authority. A *Waste Load Allocation* (WLA) is the amount of pollutant that a point source can contribute to the stream without violating water quality criteria. Because there are no point sources in the Alvord Lake Subbasin, no waste load allocation was derived.

Table 2-13. Temperature Load Allocation Summary

Source	**Loading Allocation**
Natural	100%
Agriculture	0%
Forestry	0%
Future Sources	0%

Because it was not possible to simulate *system potential* temperatures in the Alvord Lake Subbasin, ODEQ has taken a conservative approach. Based on available data (**Figures 2-3** through **2-5**), ODEQ believes that it is likely that *system potential* temperatures in the subbasin will still be above either the spawning or rearing criteria for some portion of the year, even after *system potential* vegetation is reached. This assumption is based on the fact that with current temperatures in excess of 70^{o}F in early July, it is unlikely that the numeric spawning criterion of 55^{o}F would be met at the end of June, even with *system potential* vegetation. As such, the loading capacity for the Alvord Lake Subbasin has been completely allocated to natural sources; no assimilative capacity exists for nonpoint sources. This approach was deemed to be the most protective of the beneficial uses. This approach requires that nonpoint sources manage riparian areas to achieve *system potential* conditions. The means of achieving these conditions will be through restoring and protecting riparian vegetation and, where appropriate, increasing stream flows and narrowing of stream channel widths. If and when *system potential* conditions are achieved in the future in the Alvord Lake Subbasin, if it is determined that there is, in fact, some thermal load available to allocate to human caused sources, ODEQ may reevaluate this TMDL and redistribute the available load.

Thermal modeling that was conducted for the Willow Creek watershed in the Trout Creek Mountains in 1999 (presented in **Chapter III**) also supports this approach to determining load allocations. Thermal simulations done using *system potential* conditions on Willow Creek indicated that even under *system potential* conditions, the 17.8^{o}C (64^{o}F) rearing criterion would still be exceeded.

A zero load allocation does not necessarily mean that nonpoint sources are prohibited from using the land for grazing or other purposes. If the activity is addressed in an approved management or restoration plan it is allowed providing it will not have a significant impact on water quality over that achieved by a zero allocation.

2.7 SURROGATE MEASURES – 40 CFR 130.2(I)

The Alvord Lake Subbasin Temperature TMDL incorporates measures other than "*daily loads*" to fulfill requirements of §303(d). Although a loading capacity for heat energy is derived (e.g. BTU/ft^{2}/ day), it is of limited value in guiding management activities needed to solve identified water quality problems. In addition to heat energy loads, this TMDL allocates "*other appropriate measures*" (or surrogates measures) as provided under EPA regulations (40 CFR 130.2(i)).

The *Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program* (U.S. EPA 1998) offers a discussion on the use of surrogate measures for TMDL development. The Report indicates:

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

Water temperature warms as a result of increased solar radiation loads. A loading capacity for radiant heat energy (i.e., incoming solar radiation) can be used to define a reduction target that forms the basis for identifying a surrogate. The specific surrogate used is percent effective shade (expressed as the percent reduction in potential solar radiation load delivered to the water surface). The solar radiation loading capacity is translated directly (linearly) by effective solar loading. The definition of effective shade allows direct measurement of the solar radiation loading capacity.

Over the years, the term shade has been used in several contexts, including its components such as shade angle or shade density. For purposes of this TMDL, shade is defined as the percent reduction of potential solar radiation load delivered to the water surface. Thus, the role of effective shade in this TMDL is to prevent or reduce heating by solar radiation and serve as a linear translator to the solar loading capacities.

Effective shade screens the water's surface from direct rays of the sun. Highly shaded streams often experience cooler stream temperatures due to reduced input of solar energy (Brown 1969, Beschta et al. 1987, Holaday 1992, Li et al. 1994). The surrogate measure of effective shade targets the establishment of a *system potential* riparian community to provide the instream temperatures that will result from a riparian system which is minimally impacted by human caused activities. The *system potential* riparian community provides thermal buffering in the form of shade as well as providing: (1) stream bank stabilization which results in a reduction in sediment inputs and subsequent decreases in channel width; and, (2) reconnection of the floodplain which restores function, channel stability, and water storage and release as hyporheic, or subsurface flows, during the warmer summer months. Although the TMDL focuses on the surrogate measure of effective shade, ODEQ recognizes there are factors other than shade that contribute to the rate at which streams warm.

2.7.1 Site Specific Effective Shade Surrogate Measures

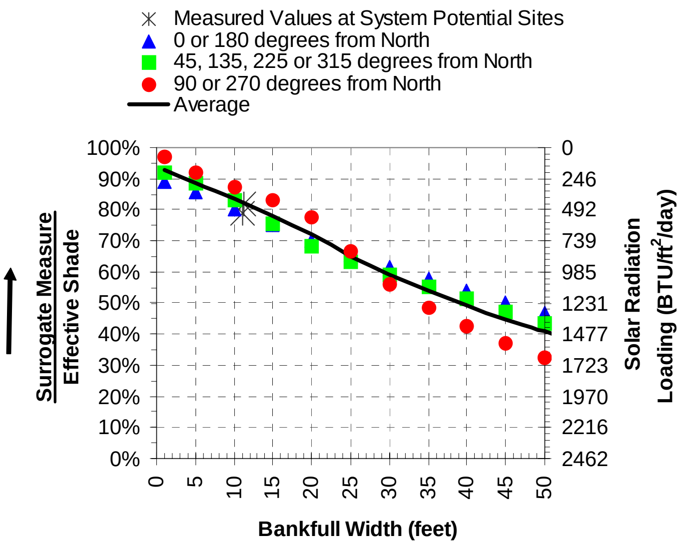
Because the model did not accurately portray current conditions in all creeks and/or portions of creeks (**Section 2.4.3.1.2**), ODEQ did not develop site specific shade curves for the modeled streams. Instead, the Ecological Province shade curves (**Section 2.7.2** below) should be used for developing the surrogate measures for these streams.

2.7.2 Effective Shade Curves for Ecological Provinces

Percent effective shade is perhaps the most straightforward stream parameter to monitor/calculate and is easily translated into quantifiable water quality management and recovery objectives. Effective shade curves were developed for each of the Ecological Provinces (described in **Section 2.4.3.1.3**) in elevation zones (**Figures 2-31** to **2-41**). These curves represent general relationships between *system potential* effective shade and stream bankfull width. The curves can be applied to determine effective shade allocations. They are developed using trigonometric equations estimating the shade underneath tree canopies. The particular curve that applies to a given reach depends on the expected *system potential* vegetation for the reach and its expected height, density, and channel overhang at maturity. Effective shade field measurements are included on several of the figures (**Figures 2-31**, **2-32**, **2-34**, **2-35**, **2-38 and 2-39**) where the vegetation conditions at the monitoring sites were determined to already be at *system potential* conditions.

While the descriptions of the vegetation communities in the Ecological Provinces generally describe the stream conditions observed during TMDL field assessments, ODEQ recognizes that there may be instances where the Ecological Province communities do not adequately describe *system potential* conditions for a given stream or stream reach. For example, based on preliminary information provided by the BLM, the upper reaches of Denio Creek in the Pueblo Mountain Ecological Province may in fact have a *system potential* community more similar to the mesic graminoid community described for the headwaters areas in the Trout Creek Mountains. As further field inventory information becomes available for streams not surveyed during the TMDL data collection efforts, ODEQ will work with local natural resources managers to determine stream-specific *system potential* target communities, as time and resources allow.

Effective shade curves can be applied to all streams in the Alvord Lake Subbasin for which a shade target is desirable. After applicable curves are developed for each *system potential* vegetation type, this method is easy to apply to streams with correlative characteristics. While the method provides no information on existing shade conditions or the expected *system potential* stream temperature, it does provide quick and accurate estimates of the amount of shade needed to ensure that there is no measurable increase in in-stream temperatures.



Black Cottonwood-Pacific Willow Community

Average Canopy Height: 40 feet
Average Canopy Density: 80%

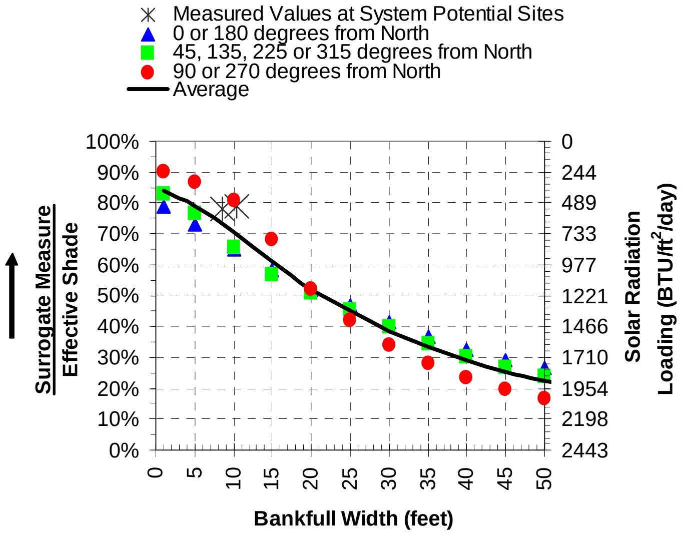
Dominant Plant Species

- Black Cottonwood
- Pacific Willow
- Quaking Aspen
- Salix ssp.
- Scoulers Willow
- Common Snowberry

Dominant Channel Type

- Rosgen A-B channel types
- Variable flood prone width within structurally controlled valley

Figure 2-31. Shade Curves–East Steens Headwaters Ecological Province (6800' – 5200')



Pacific Willow-Black Cottonwood-Aspen Community

Average Canopy Height: 25 feet
Average Canopy Density: 65%

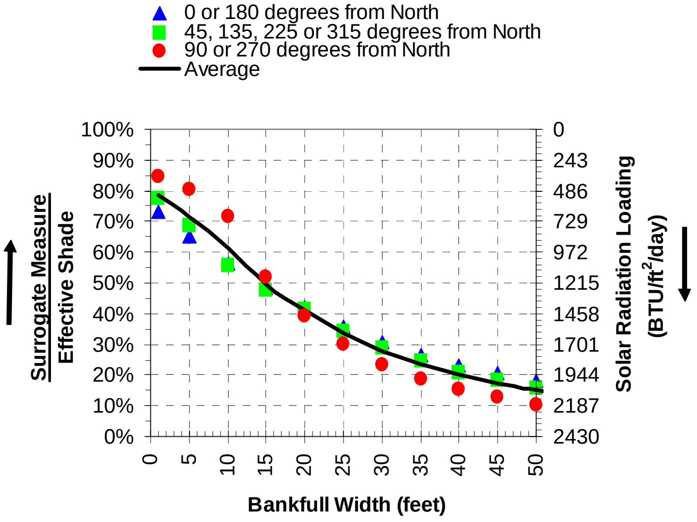
Dominant Plant Species

- Pacific Willow
- Black Cottonwood
- Salix ssp.
- Quaking Aspen

Dominant Channel Type

- Rosgen B channel type
- Flood prone width: 30 feet

Figure 2-32. Shade Curves–East Steens Mid Elevation Ecological Province (5200' – 4260')



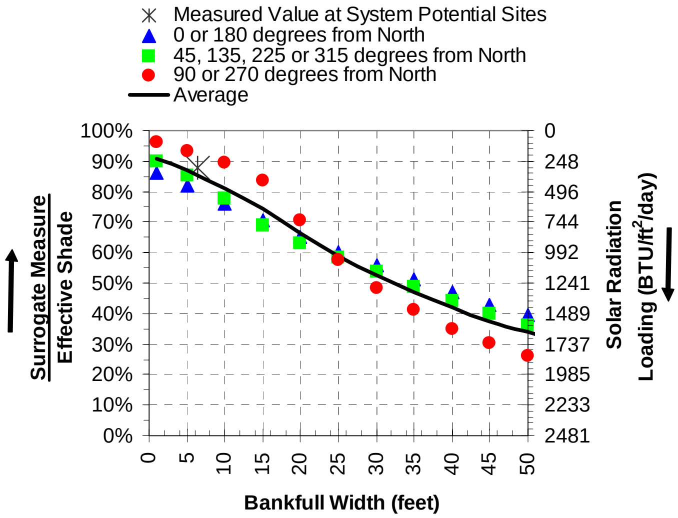
Willow Mix Community

Average Canopy Height: 20 feet
Average Canopy Density: 50%

Dominant Plant Species
- Pacific Willow
- Coyote Willow
- Salix ssp.

Dominant Channel Type
- Rosgen B-C channel types
- Flood prone width: 33 feet
- Within entrenched section, (Channel Type C within relic Channel Type F) flood prone width: 43 feet

Figure 2-33. Shade Curves–East Steens Low Elevation Ecological Province (4260' – 4100')



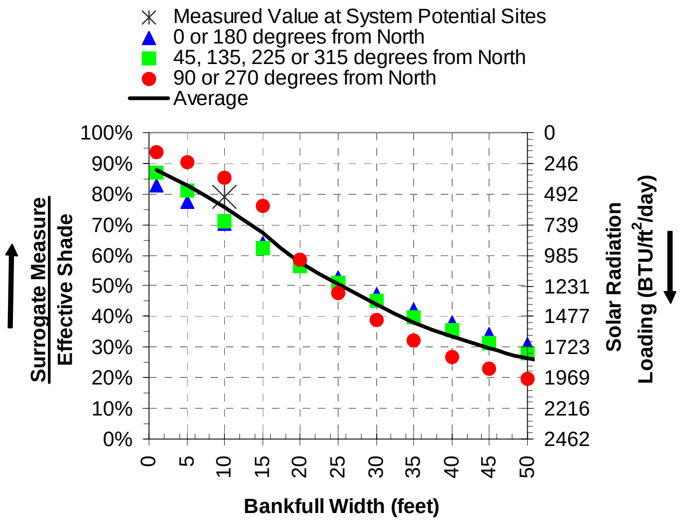
**Quaking Aspen–Alder–
Scouler Willow Community**

Average Canopy Height: 33 feet
Average Canopy Density: 85%

Dominant Plant Species
- Quaking Aspen
- Alder
- Scouler Willow
- Salix ssp.

Dominant Channel Type
- Rosgen A-B channel types
- Variable flood prone width within structurally controlled valley

Figure 2-34. Shade Curves–Pueblo Mountains Headwaters Ecological Province (6400'-6100')



Alder-Black Cottonwood-Willow Mix Community

Average Canopy Height: 28 feet
Average Canopy Density: 75%

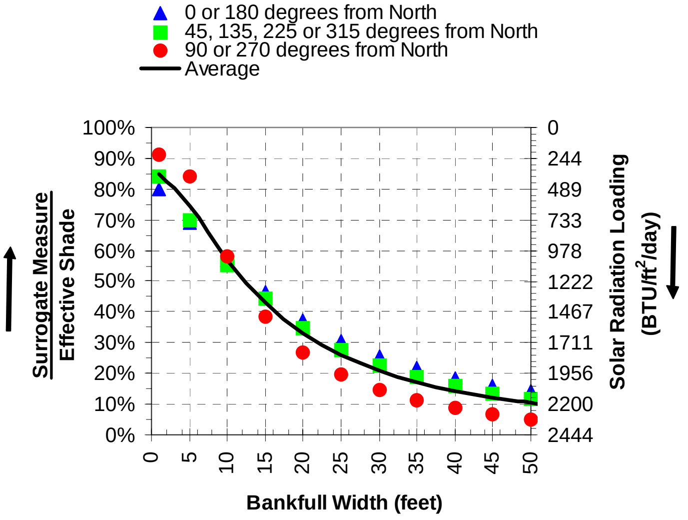
Dominant Plant Species

- Alder
- Black Cottonwood
- Salix ssp.
- Scouler Willow
- Lemon Willow
- Cherry
- Quaking Aspen

Dominant Channel Type

- Rosgen A-B channel type
- Flood prone width: 13-20 feet

Figure 2-35. Shade Curves–Pueblo Mts Mid-Low Elevation Ecological Province (6100'-4300')



Willow Mix Community

Average Canopy Height: 14 feet
Average Canopy Density: 50%

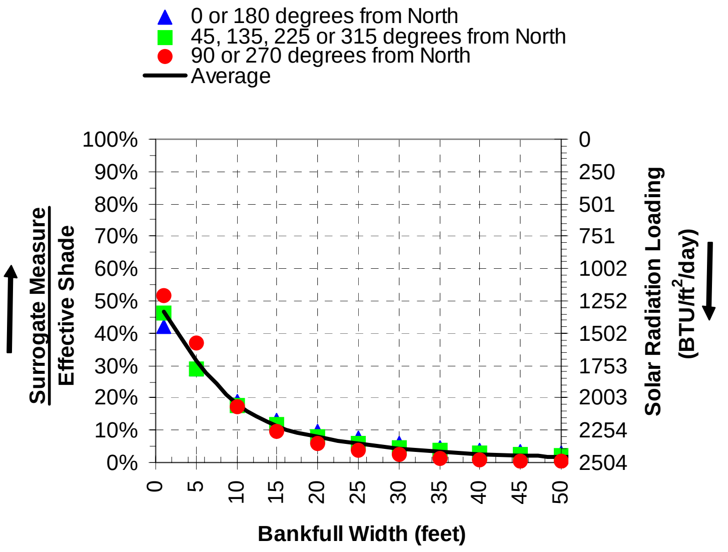
Dominant Plant Species

- Salix ssp.
- Coyote Willow

Dominant Channel Type

- Rosgen B-C channel types
- Flood prone width: 20 feet

Figure 2-36. Shade Curves–Pueblo Mts Lowest Elevation Ecological Province (4300'-4248')



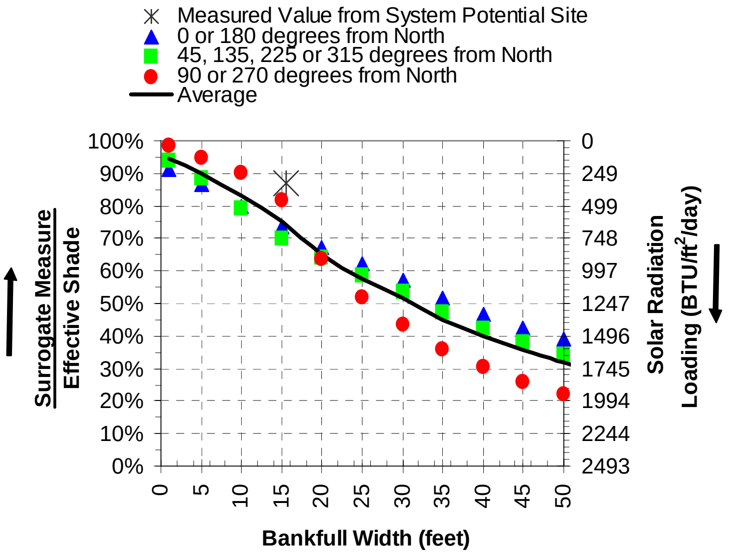
Co-dominant Mesic Graminoid-Willow Community

Average Canopy Height: 8.5 feet
Average Canopy Density: 10%

Dominant Plant Species
- Lemon Willow
- Graminoid

Dominant Channel Type
- Rosgen B-E channel types
- Variable flood prone width with 36 foot average

Figure 2-37. Shade Curves–Trout Creek Mts Headwaters Ecological Province (>7218')



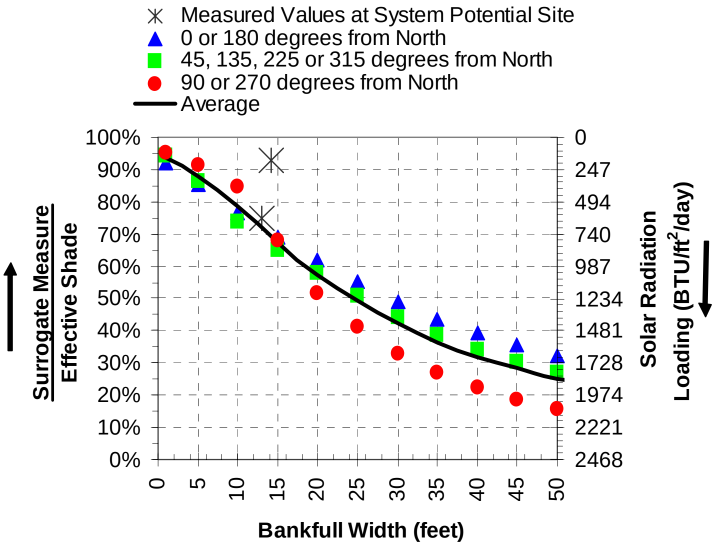
Co-dominant Aspen-Willow Community

Average Canopy Height: 29 feet
Average Canopy Density: 90%

Dominant Plant Species
- Quaking Aspen
- Pacific Willow
- Geyer Willow
- Lemon Willow

Dominant Channel Type
- Rosgen B channel type
- Flood prone width: 25 feet

Figure 2-38. Shade Curves–Trout Creek Mts High Elevation Ecological Province (7218'-6562')



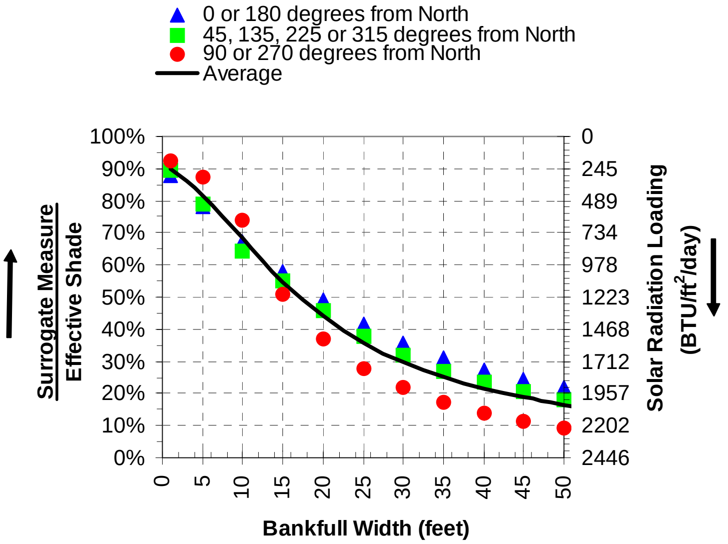
Co-dominant Willow-Alder Community

Average Canopy Height: 24 feet
Average Canopy Density: 75%

Dominant Plant Species
- Mountain Alder
- Pacific Willow
- Lemon Willow
- Scouler Willow

Dominant Channel Type
- Rosgen B-C channel type
- Flood prone width: 55 feet

Figure 2-39. Shade Curves–Trout Creek Mts Mid Elevation Ecological Province (6562'-4500')



Willow Community

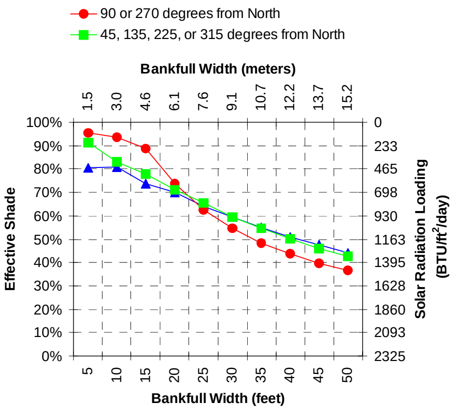
Average Canopy Height: 18 feet
Average Canopy Density: 60%

Dominant Plant Species
- Coyote Willow
- Yellow Willow
- Pacific Willow

Dominant Channel Type
- Rosgen C dominant channel type (B channel type in canyon)
- Flood prone width: 70 feet average in valley, 25 feet in canyon

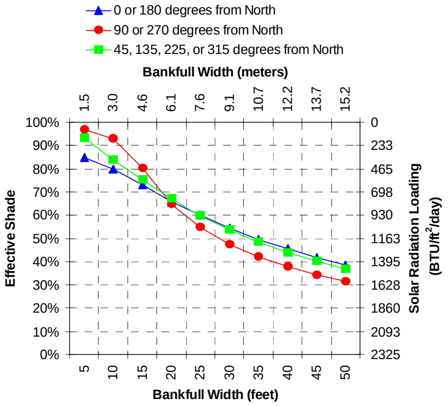
Figure 2-40. Shade Curves–Trout Creek Mts Low Elevation Ecological Province (4500'-4240')

Aspen Community
Elevation 7000' – 5800'



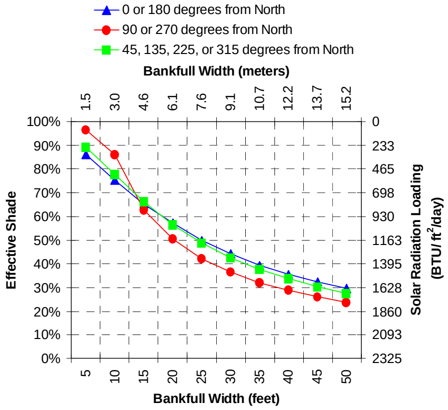
Average Canopy Height: 30 feet
Average Canopy Density: 30%
Average Riparian Buffer Width: 20 feet
Dominant Rosgen Channel Type: Type A

Mountain Alder Community
Elevation 5800' – 5000'



Average Canopy Height: 25 feet
Average Canopy Density: 30%
Average Riparian Buffer Width: 30 feet
Dominant Rosgen Channel Type: Type B

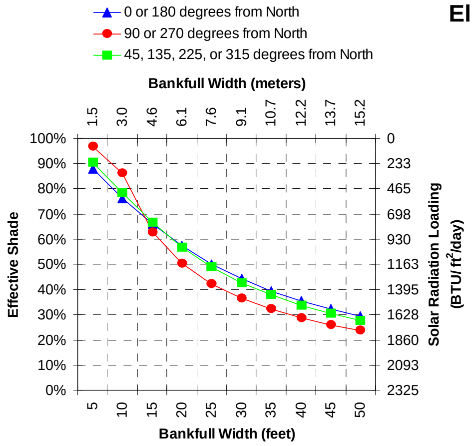
Willow Community
Elevation 5000' – 4780'



Average Canopy Height: 18 feet
Average Canopy Density: 30%
Average Riparian Buffer Width: 40 feet
Dominant Rosgen Channel Type: Type E

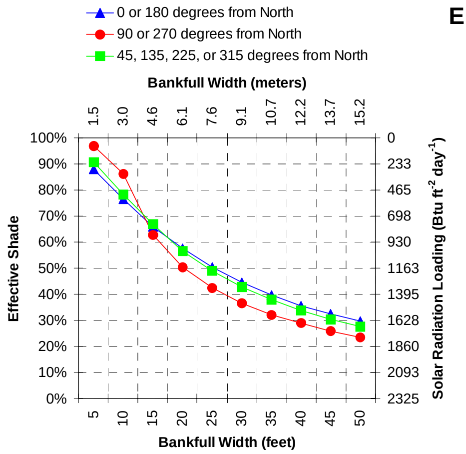
Figure 2-41. Shade Curves–Willow-Whitehorse Ecological Province

Willow Community
Elevation 4780’ – 4460’



Average Canopy Height: 18 feet
Average Canopy Density: 30%
Average Riparian Buffer Width: 55 feet
Dominant Rosgen Channel Type: Type E

Willow Community
Elevation 4460’ – 4360’



Average Canopy Height: 18 feet
Average Canopy Density: 30%
Average Riparian Buffer Width: 60 feet
Dominant Rosgen Channel Type: Type C

Figure 2-41 (continued). Shade Curves–Willow-Whitehorse Ecological Province

2.8 MARGINS OF SAFETY – CWA §303(D)(1)

The Clean Water Act requires that each TMDL be established with a margin of safety (MOS). The statutory requirement that TMDLs incorporate a MOS is intended to account for uncertainty in available data or in the actual effect controls will have on loading reductions and receiving water quality. A MOS is expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDL (e.g., derivation of numeric targets, modeling assumptions or effectiveness of proposed management actions).

The MOS may be implicit, as in conservative assumptions used in calculating the loading capacity, Waste Load Allocation, and Load Allocations. The MOS may also be explicitly stated as an added, separate quantity in the TMDL calculation. In any case, assumptions should be stated and the basis behind the MOS documented. The MOS is not meant to compensate for a failure to consider known sources. **Table 2-14** presents six approaches for incorporating a MOS into TMDLs.

The following factors may be considered in evaluating and deriving an appropriate MOS:

- ✓ *The analysis and techniques used in evaluating the components of the TMDL process and deriving an allocation scheme.*
- ✓ *Characterization and estimates of source loading (e.g., confidence regarding data limitation, analysis limitation or assumptions).*
- ✓ *Analysis of relationships between the source loading and instream impact.*
- ✓ *Prediction of response of receiving waters under various allocation scenarios (e.g., the predictive capability of the analysis, simplifications in the selected techniques).*
- ✓ *The implications of the MOS on the overall load reductions identified in terms of reduction feasibility and implementation time frames.*

A TMDL and associated MOS, which results in an overall allocation, represent the best estimate of how standards can be achieved. The selection of the MOS should clarify the implications for monitoring and implementation planning in refining the estimate if necessary (adaptive management). The TMDL process accommodates the ability to track and ultimately refine assumptions within the TMDL implementation-planning component.

Table 2-14. Approaches for Incorporating a Margin of Safety into a TMDL

Type of Margin of Safety	***Available Approaches***
Explicit	1. Set numeric targets at more conservative levels than analytical results indicate. 2. Add a safety factor to pollutant loading estimates. 3. Do not allocate a portion of available loading capacity; reserve for MOS.
Implicit	1. Conservative assumptions in derivation of numeric targets. 2. Conservative assumptions when developing numeric model applications. 3. Conservative assumptions when analyzing prospective feasibility of practices and restoration activities.

2.8.1 Implicit Margins of Safety

Calculating a numeric MOS is not easily performed with the methodology presented in this document. In fact, the basis for the loading capacities and allocations is the definition of *system potential* conditions. It is illogical to presume that anything more than *system potential* riparian conditions are possible, feasible or reasonable. Additionally, in the Alvord Lake Subbasin TMDL, ODEQ has allocated 100% of the load to natural sources. This is because ODEQ believes that, even when *system potential* vegetation is achieved, stream temperatures in the Alvord Lake Subbasin would still be above either the spawning or rearing numeric criteria. If it is determined in the future that both the spawning and rearing criteria can be met in the Alvord Subbasin, ODEQ may revisit this TMDL and reallocate loads.

2.9 WATER QUALITY STANDARD ATTAINMENT ANALYSIS – CWA §303(D)(1)

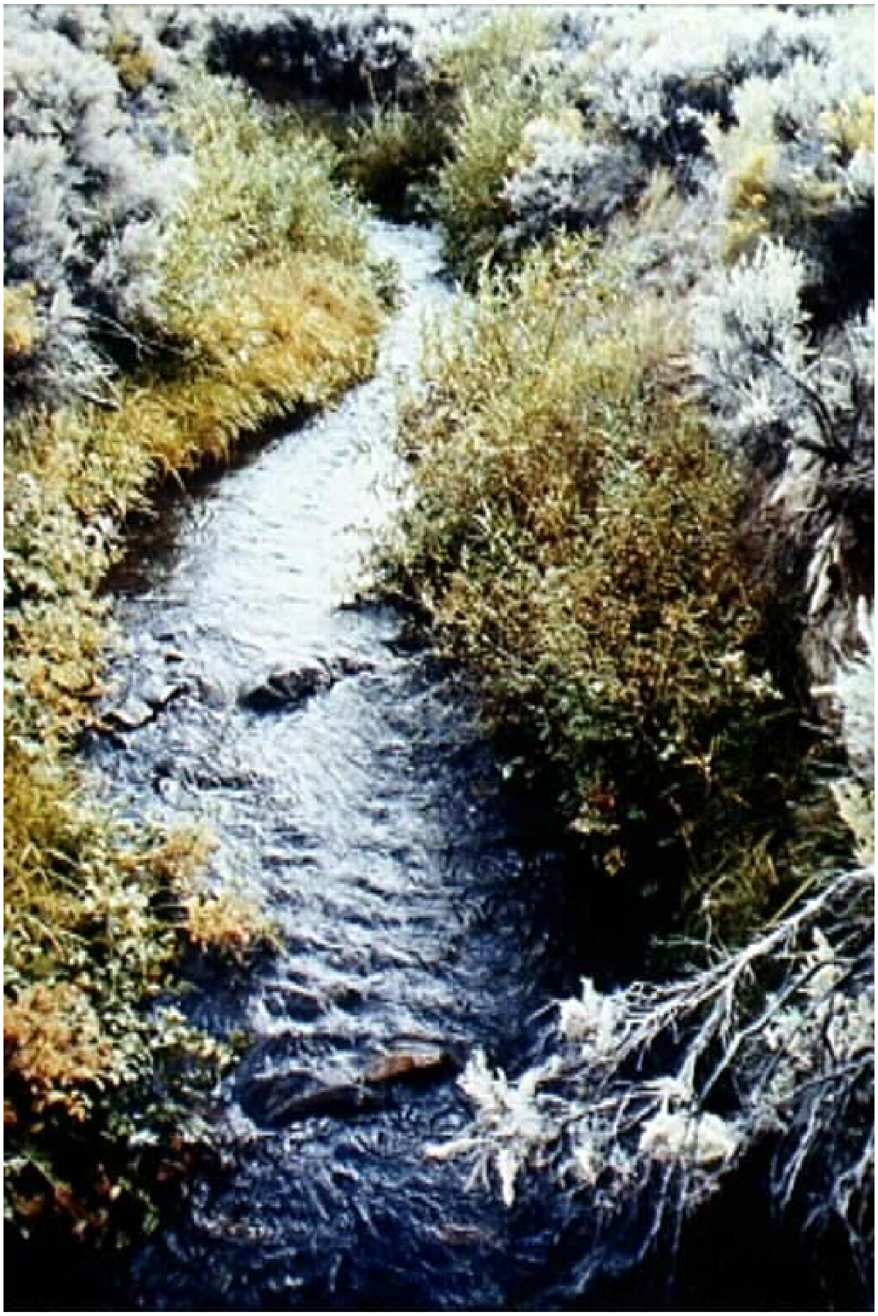
The temperature TMDL and the temperature water quality standards are achieved when nonpoint source solar radiation loading is representative of a riparian vegetation condition without human disturbance.

*Stream temperatures that result from the system potential conditions represent attainment of the temperature standard (**no measurable surface water temperature increase resulting from anthropogenic activities).***

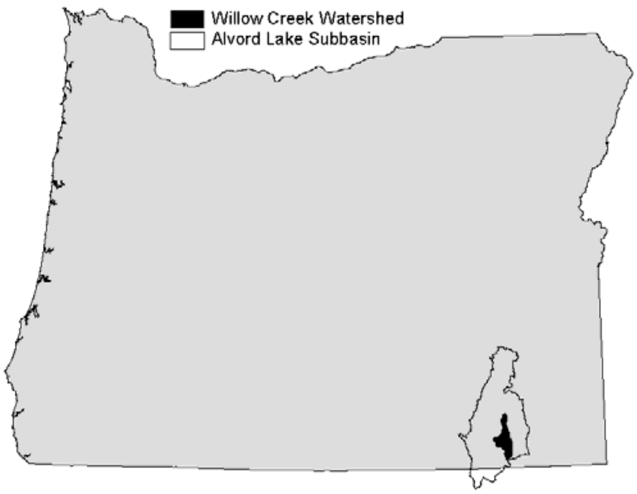
Because it was not possible to simulate the stream temperatures that would result from *system potential* conditions along creeks in the Alvord Lake Subbasin, ODEQ has taken a conservative approach by allocating the entire load to natural sources. This approach requires that nonpoint sources reduce temperature inputs to reach *system potential* conditions. This approach represents attainment of the water quality standard in that it mandates “***no measurable surface water temperature increase resulting from anthropogenic activities”.***

An overriding emphasis of the temperature TMDL is the focus on spatial distributions of stream temperatures in the Alvord Lake Subbasin. With the advent of new sampling technologies and analytical tools that include landscape scaled data and computational methodologies, an improved understanding of stream temperature dynamics is emerging (Boyd, 1996, Torgersen et al., 1999, Torgersen et al., 2001, ODEQ 2000, ODEQ 2001a, ODEQ2001b, ODEQ 2001c). Simple conceptual models that focus on a single stream, landscape or atmospheric parameter will fail to capture the interactions of a multitude of parameters that are interrelated. These parameters combine to have complex thermal effects. As an example, temperature simulations demonstrate at a network scale that stream temperature is relatively insensitive to potential land cover conditions. However, when coupled with potential channel width, stream temperatures are highly sensitive to potential land cover. When flow volume is increased to potential, the temperature reductions created by potential land cover and channel width are further increased. The results of this analytical effort clearly demonstrate that a comprehensive restoration approach should be developed that focuses on the protection and recovery of land cover and channel morphology, and increases instream flow volume.

CHAPTER III: WILLOW CREEK TEMPERATURE TMDL



3.1 OVERVIEW



The Willow Creek TMDL was drafted by ODEQ in 1999. The types of data and modeling analysis used to produce this TMDL are different from the methods applied in other streams in the Alvord Lake Subbasin (**Chapter II**). Therefore, the Willow Creek TMDL drafted in 1999 is provided in this chapter separate from other streams within the subbasin. This TMDL applies to all streams in the Willow Creek watershed which are indicated in Table 2-2 and Figure 2-1. This includes Willow Creek, Jawbone Creek and an unnamed tributary to Jawbone Creek.

The Willow Creek Watershed is located in southeastern Oregon between the Oregon Canyon Mountains to the east and the Trout Creek Mountains to the west. The watershed is located within the Mallheur Lake Basin and the Alvord Lake Subbasin. Willow Creek flows in a northerly direction and drains into the Coyote Lake basin. The Coyote Lake basin has been dry in recent history. The area covered by the Willow Creek Watershed includes 50.2 square miles (130 km^2), managed primarily by private landowners and the Bureau of Land Management (BLM). Elevations vary from about 4,200 feet (above mean sea level) at the desert floor to a little over 8,000 feet in the mountains . The lowest elevations contain irrigated hay fields and are predominantly private lands. The areas above the basin floor are predominantly BLM lands and are used for cattle grazing and recreation. Cattle, wild horse, and sheep grazing have occurred in the basin since the late 1800s. Land ownership is displayed in **Figure 3-1**.

Willow Creek is home to the rare Lahontan cutthroat trout *Oncorhynchus clarki henshawi*. The United States Fish and Wildlife Service listed this trout as a threatened species in 1975. Several agencies are mandated to take proactive roles to develop management strategies for rivers located within the Malheur Lake Basin. It is imperative that future water quality management plans (WQMPs) developed during these efforts will consider the relatively robust data that describe water quality, instream physical parameters, and landscape features. The impending management efforts demand that stakeholders, land managers, public servants and the general public become knowledgeable with water quality issues in the Willow Creek Watershed.

The data review contained in this document summarizes the varied data collection and study efforts that have recently occurred in the Willow Creek Watershed. The University of Nevada Reno (UNR), Oregon Department of Fish and Wildlife, the Fish and Wildlife Department of Oregon State University (OSU), and ODEQ have recently conducted and extensive data collection effort and study of the interaction between land use and water quality within the Willow Creek Watershed. Knowledge derived from these efforts, some of which is presented in this document, should be used to design protective enhancement strategies that address water quality issues.

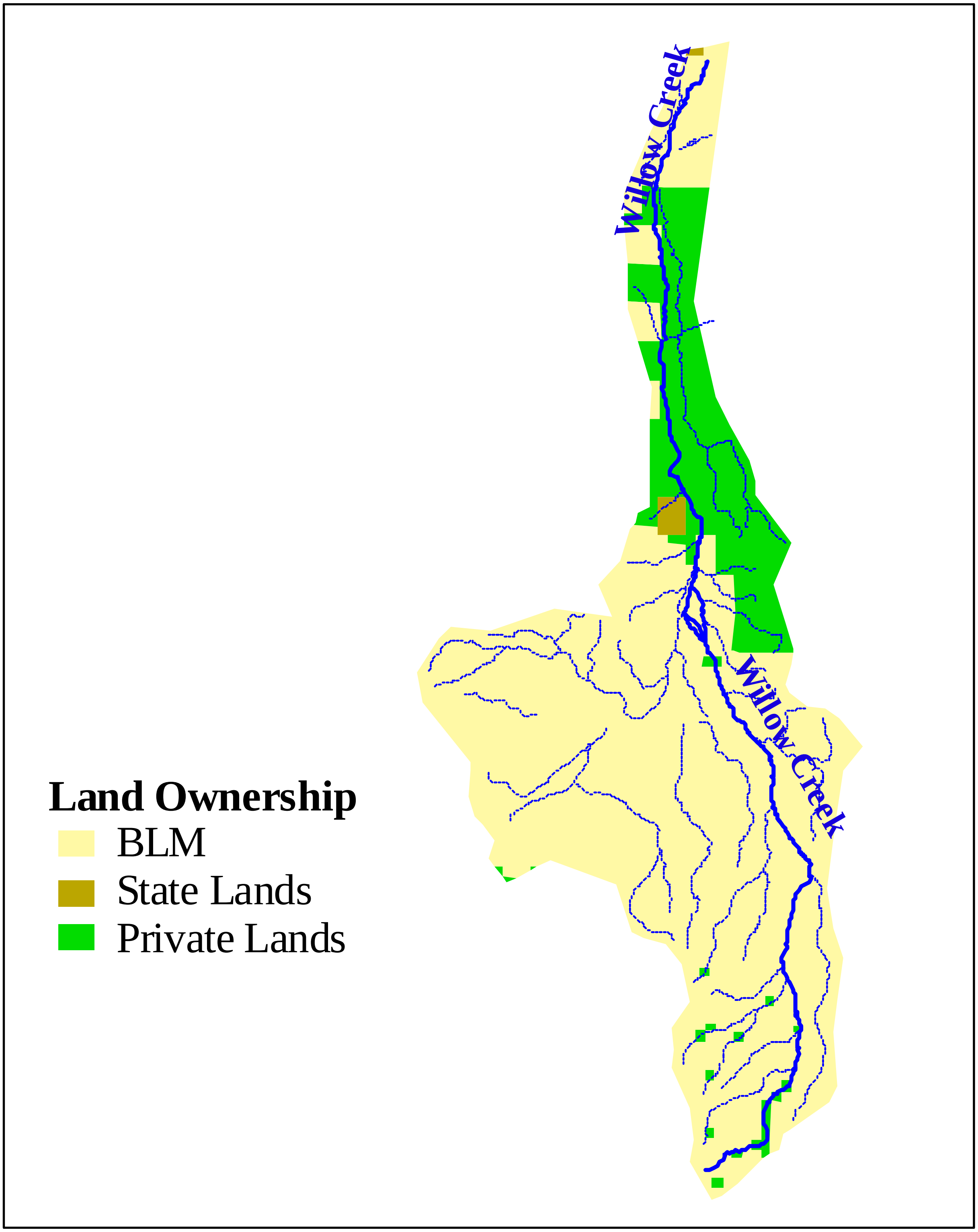


Figure 3-1. Land Ownership in the Willow Creek Watershed

3.2 TARGET IDENTIFICATION – CWA §303(D)(1)

3.2.1 Sensitive Beneficial Uses

Oregon Administration Rules (**OAR Chapter 340, Division 41, Table 18**) lists designated "*Beneficial Uses*" occurring in the Willow Creek Watershed (**Table 3-1**). The numeric and narrative water quality standards are designed to protect the most sensitive beneficial uses. Spawning and rearing use by the Lahontan cutthroat trout are the most sensitive beneficial uses in Willow Creek. This resident trout is the only fish species that resides in Willow Creek. For a further discussion of beneficial uses in the Willow Creek watershed, refer to **Section 2.2.1**.

Table 3-1. Beneficial uses occurring in the Malheur Lake Basin including Willow Creek Watershed *(OAR 340 – 41 – 882)*

Temperature-Sensitive Beneficial uses are marked in Grey

Beneficial Use	***Occurring***	***Beneficial Use***	***Occurring***
Public Domestic Water Supply	✓	Salmonid Fish Spawning (Trout)	✓
Private Domestic Water Supply	✓	Salmonid FisheRearing (Trout)	✓
Industrial Water Supply	✓	Resident Fish and Aquatic Life	✓
Irrigation	✓	Aesthetic Quality	✓
Livestock Watering	✓	Wildlife and Hunting	✓
Boating	✓	Fishing	✓
Hydro Power		Water Contact Recreation	✓

3.2.2 Water Quality Standard Identification

3.2.2.1 Temperature Standard

For a discussion of the stream temperature standard, see **Section 2.2.2.1** where this information is presented for the whole Alvord Lake Subbasin.

3.2.2.2 Deviation from Water Quality Standard

ODEQ, UNR, and OSU collected continuous temperature data on Willow Creek during the summer of 1998 (**Figure 3-2**). The distance between the lower and upper site is 20 kilometers (12.4 miles). The approximate location of the upper and lower beaver dams, as well as the "Willow Creek Hot Springs" are also illustrated on **Figure 3-2**. It is important to note that the upper and lower portions of Willow Creek are not shown in **Figure 3-2** in order to increase the visual resolution of the image.

Observed maximum 7-day temperature statistics measured in Willow Creek during the summer of 1998 are also illustrated in **Figure 3-2**. Generally, stream temperatures follow a longitudinal (downstream) heating pattern and are above the associated standard (see **Section 2.2.2.2**). Specifically, daily maximum temperatures commonly exceed 27^{o}C (80.6^{o}F) in lower reaches of Willow Creek during July and August. This temperature regime exceeds the incipient lethal limit and approaches the instantaneous lethal limit for Lahontan Cutthroat trout . Water temperatures observed at all sites exceeded the rearing criterion of 17.8^{o}C (64^{o}F). Willow Creek is included in its entirety on the 2002 303(d) list for exceeding the rearing criterion (see **Section 2.2.2.2**). The observed water temperature variability between sites in Willow Creek decreases dramatically during the winter period.

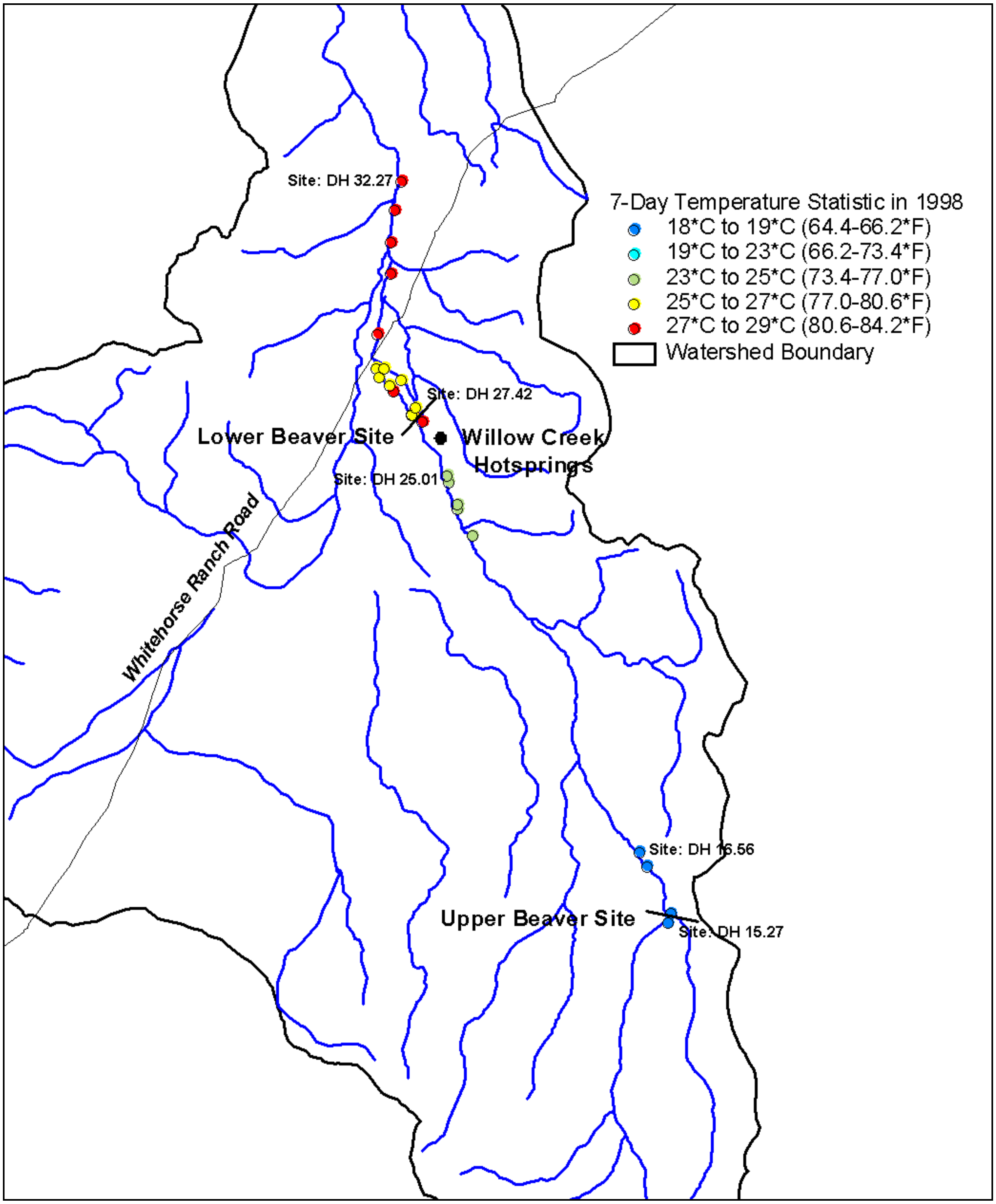


Figure 3-2. 1998 Continuous Temperature Monitoring Sites and Observed 7-Day Statistic

[DH is the distance from headwaters and is expressed in kilometers)

Figure 3-3 displays stream heating as a function of measured perennial stream distance from headwaters. Willow Creek stream temperatures increased by approximately 10^{o}C in an 18-km distance. This translates into a 0.6^{o}C increase per river kilometer, indicating that dramatic stream heating processes are currently occurring within Willow Creek.

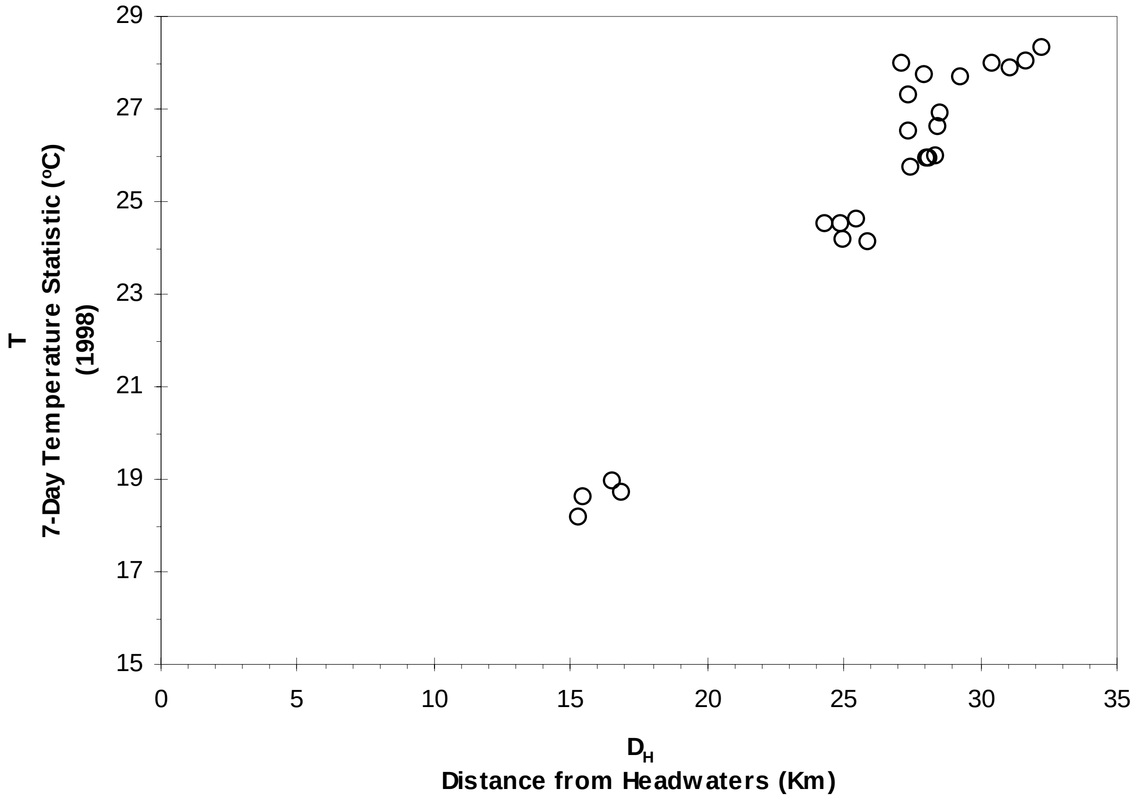


Figure 3-3. Longitudinal Stream Heating Curve observed in Willow Creek (1998)

7-Day Statistic Values Related to Distance from Headwaters

3.2.3 Pollutant Identification

With a few exceptions, such as in cases where violations are due to natural causes, the State must establish *a Total Maximum Daily Load* or *TMDL* for any waterbody designated on the 303(d) list as violating water quality standards. A *TMDL* is the total amount of a pollutant (from all sources) that can enter a specific waterbody without violating the water quality standards. For a further discussion of stream temperature as a pollutant, see **Section 2.2.3** where this information is presented for the whole Alvord Lake Subbasin.

3.3 SEASONAL VARIATION - CWA §303(D)(1)

Section 303(d)(1) of the Clean Water Act requires this TMDL to be "established at a level necessary to implement the applicable water quality standard with seasonal variations." Both stream temperature and flow vary seasonally. Water temperatures are coolest in winter and early spring months. Stream temperatures exceed State water quality standards in summer and early fall months (June, July, August and September). Warmest stream temperatures correspond to prolonged solar radiation exposure, warm air temperature, low flow conditions and decreased groundwater contribution. These conditions occur during late summer and early fall and promote the warmest seasonal instream temperatures. The analysis presented in this TMDL is performed during summertime periods in which controlling factors for stream temperature are most critical. The critical period for this TMDL is June 1 through September 30 each year. **Figure 3-4** illustrates the seasonal variation at five points along Willow Creek (refer to **Figure 3-2** for site locations).

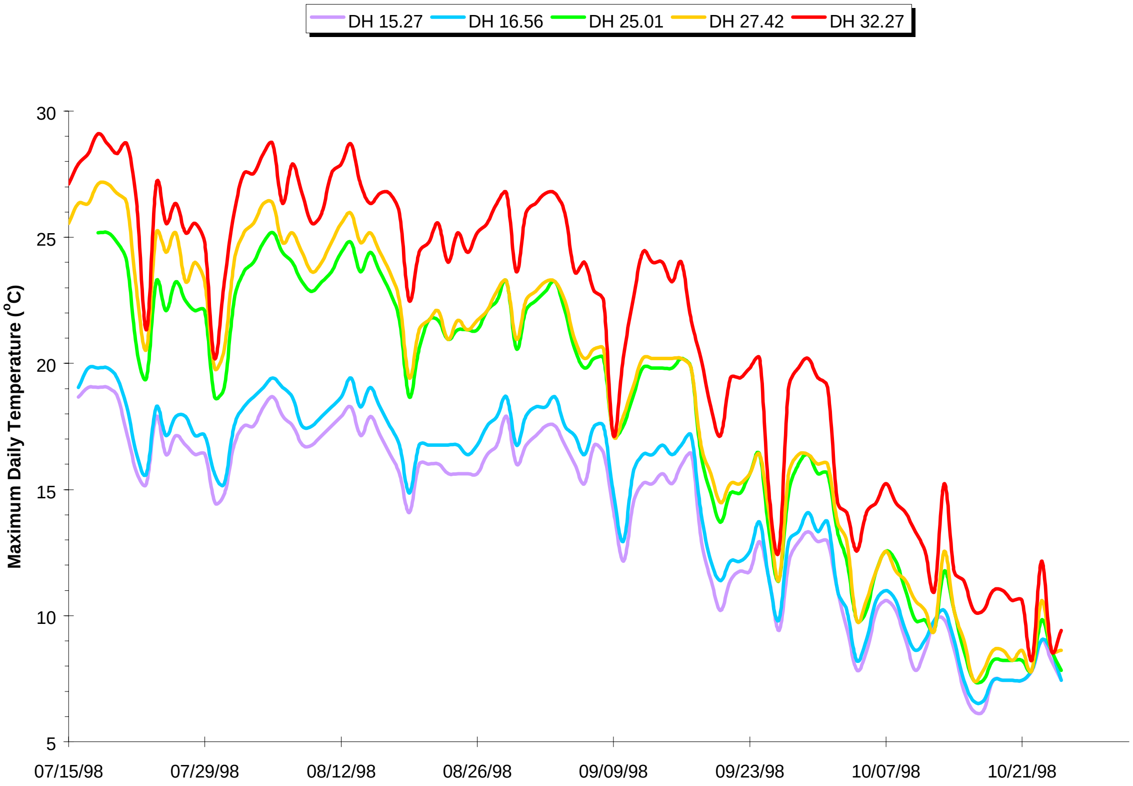


Figure 3-4. Seasonal Variation in Willow Creek temperatures (1998)

[DH is the distance from headwaters and is expressed in kilometers)

3.4 EXISTING HEAT SOURCES - CWA *§303(D)(1)*

3.4.1 Stream Heating Processes – Background Information

Riparian vegetation, stream morphology, hydrology, climate, and geographic location influence stream temperature. While climate and geographic location are outside of human control, riparian condition, channel morphology and hydrology are affected by land use activities. Human activities that can contribute to degraded water quality conditions in the Willow Creek Watershed include agricultural activities (including grazing), road location, timber harvest, and rural residential development related riparian disturbances. For a general discussion of stream heating processes, please refer to **Section 2.4.1** and **Chapter V**.

3.4.2 Analytical Methodology

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 and has been regularly upgraded through 2003. The model has been peer reviewed and comments are available on the ODEQ website at: http://www.ODEQ.state.or.us/wq/HeatSource/HeatSource.htm. ODEQ currently supports the Heat Source methodology and computer programming. The modeling done for the Willow Creek temperature TMDL was done in 1999 using Version 5.5 of the Heat Source model.

The temperature model is designed to analyze and predict diurnal energy flux and the resulting stream temperature for the warmest time of the year, typically July-August. The model was validated using hydrologic, thermal and landscape data describing the current condition using data collected in 1998. Once the modeled reach output was validated for current conditions, stream temperatures and energy conditions were predicted for *system potential* riparian condition. All other model inputs were assumed to remain unchanged.

Stream temperature was simulated for five reaches along Willow Creek (**Figure 3-5** and **Table 3-2**), covering 12.4 miles (20 kilometers). The reaches were determined by breaks in elevation and differences in vegetation (see **Section 3.4.3.1** for further discussion of the reach breaks). The results from the simulations are provided under **Sections 3.4.3.4 and 3.5.1** below**.** A more extensive discussion of the analytical framework and methodology for this version of the model is provided in **Chapter V.**

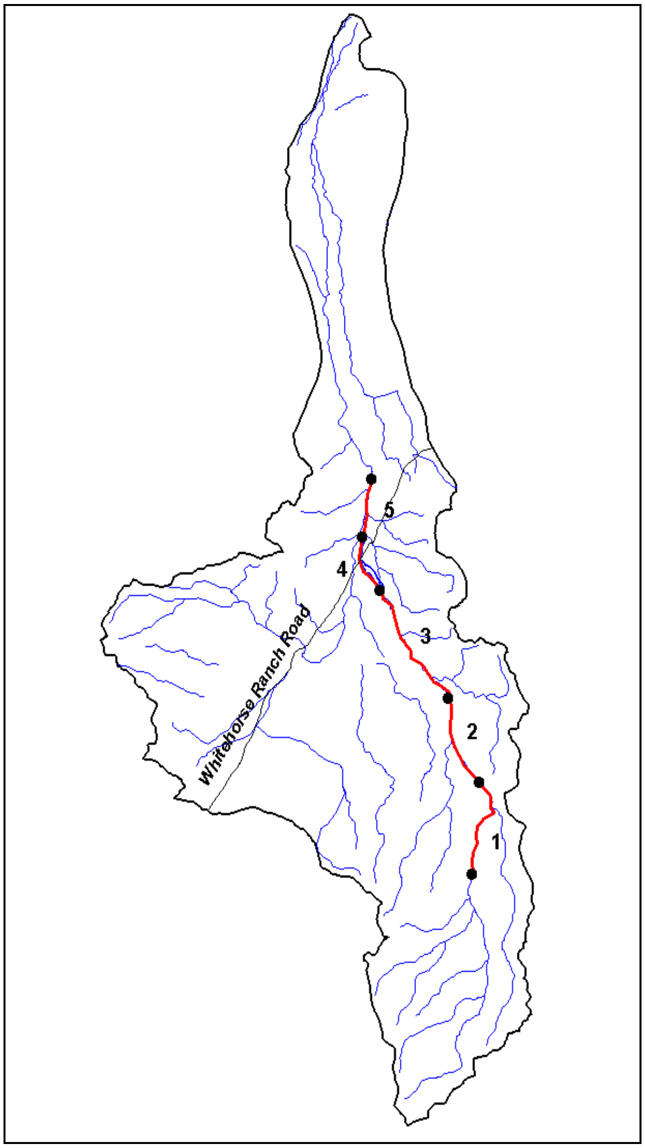


Figure 3-5. Stream Temperature Simulation Extent – Red Indicates Simulation Reaches

Table 3-2. Willow Creek Simulation Reaches (*DH is Distance from Headwaters in Kilometers*)

Simulation Reach	Upper Extent	Lower Extent
1	DH 12.29	DH 16.56
2	DH 16.56	DH 20.81
3	DH 20.81	DH 27.11
4	DH 27.11	DH 29.87
5	DH 29.87	DH 32.27

3.4.3 Nonpoint Sources of Heat

Settlement of the Alvord Lake Subbasin in the mid-1800s brought about changes in the near stream vegetation and hydrologic characteristics of the streams. Historically, human activities including agricultural practices have altered the stream morphology and hydrology and decreased the amount of riparian vegetation in the drainage. The drainage includes primarily agricultural lands. Channel straightening, while providing relief from local flooding, increases flooding downstream, and may result in the destruction of riparian vegetation and increased channel erosion. Irrigation diversions in the lower elevations of the Alvord Lake Subbasin have reduced stream flow levels.

The Willow Creek Watershed has also been subjected to grazing impacts for over 100 years. Habitat degradation has occurred during this time. During the summer of 1992 and 1993, ODFW personnel conducted stream habitat surveys on seven streams in the Willow and Whitehorse Creek watersheds in southeast Oregon using the ODFW Aquatic Inventory Project Stream Survey Methods (ODFW 1994). Grazing was the dominant land use associated with the reaches. Heavy grazing pressure on the riparian area of many areas along the creeks has resulted in high proportions of silt substrates, actively eroding stream banks, and reduced stream shading.

Specifically, the elevated summertime stream temperatures attributed to human caused nonpoint sources result from:

1. ***Near stream vegetation disturbance or removal** reduces stream surface shading via decreased riparian vegetation height, width and/or density, thus increasing the amount of solar radiation reaching the stream surface (shade is commonly measured as percent effective shade or open sky percentage). Riparian vegetation also plays an important role in shaping the channel morphology, resisting erosive high flows and maintaining floodplain roughness.*
2. ***Channel modifications and widening** (increased width to depth ratios) increases the stream surface area exposed to energy processes, namely solar radiation. Channel widening decreases potential shading effectiveness of shade-producing near-stream vegetation.*
3. ***Reduction of summertime flows** decrease the thermal assimilative capacity of streams, causing larger temperature increases in stream segments where flows are reduced.*

3.4.3.1 Riparian Vegetation

Riparian vegetation plays an important role in controlling stream temperature change. Near stream vegetation height, width and density combine to produce shadows that when, cast across the stream, reduce solar radiant loading. Bank stability is largely a function of riparian vegetation. Riparian corridors often produce a microclimate that surrounds the stream where cooler air temperatures, higher relative humidity and lower wind speeds are characteristic.

3.4.3.1.1 Current Condition Vegetation

Common riparian plant species within the Trout Creek Mountains of southeastern Oregon are presented in **Table 3-3**. The Willow Creek Watershed is located within this mountain range. Current riparian vegetation conditions in Willow Creek were also observed during a Rosgen Level III analysis of Willow Creek coordinated by ODEQ in the summer and fall of 1998. Observed riparian vegetation species, along with measured reach averaged stream surface shading, are presented in **Table 3-4**. As can be seen in **Table 3-4**, very little riparian shade is currently available in lower reaches of Willow Creek (i.e., no shade at the downstream reach).

Table 3-3. Common Riparian Species of the Trout Creek Mountains (Evenden, 1989)

Tree Species	• Aspen - *Populus tremuloides*
Shrub Species	• Mountain Alder - *Alnus incana* • Willow spp - Pacific (*Salix lasiandra*), Geyer's (*S. geyeriana*), Lemmon's (*S. lemmonii*), Yellow (*S. lutea*), Coyote (*S. exigua*) • Currant – *Ribes spp.* • Wild rose - *Rosa woodsii*, • Big sagebrush - *Artemisia tridentata* • Rabbitbrush – *Chrysothamnus spp*.
Herbaceous Species	• Sedges - *Carex spp*. • Rushes - *Juncus spp*. • Bluegrass - *Poa spp*., • Small fruit bulrush - *Scirpus microcarpos*, Macoun's buttercup - *Ranunculus macounii*, • Foxtail - *Alopecurus aequalis*

Table 3-4. Observed Current Riparian Vegetation on Willow Creek (1998 survey)

Reach (elevation)	Dominant Riparian Vegetation Type (Dominant Canopy Types/Understory)	% Shade
7000 - 5800 ft	Aspen-Willow/Graminoids, Forbs	Not Measured
5800 - 5000 ft	Alder-Willow/Shrub, Graminoids	75
5000 - 4780 ft	Willow-Alder/Graminoids (sedge, rush, grass)	Not Measured
4780 - 4460 ft	Willow-Graminoids (sedge, rush, grasses)	9
4460 - 4360 ft	No riparian vegetation	Zero

3.4.3.1.2 System Potential Riparian Vegetation Conditions

BLM staff from the Vale District Office provided potential vegetation height values for riparian species within the Willow Creek Watershed. Values presented in **Table 3-5** represent the potential height to which riparian vegetation will grow, based on species potential and local climatic influences.

The width of the potential riparian buffer was determined by Rosgen's protocols for calculating and measuring the flood prone area for each stream reach (Rosgen, 1994). The flood prone area represents the maximum potential area in which riparian plant species can be established and maintained. Available moisture and annual disturbance within the flood prone area are key components of plant succession, from early colonization to late seral stages. **Table 3-6** summarizes the potential riparian geometry based on elevation.

Table 3-5. Potential Canopy Height by Species

Species	Maximum Height (meters)
Aspen	10+ (33+ feet)
Mountain Alder	8 (26 feet)
Tree Like Willow Pacific Willow (*S. lasiandra*)	10 (33 feet)
Medium Stature Willows Geyer's (*S. geyerania*) Lemon's (*S. lemmonii*) Yellow (*S. lutea*)	5 to 6 (16 to 20 feet)
Short Stature Willow Coyote (*S. exigua*)	2 to 3 (6 to 10 feet)

Table 3-6. Potential Riparian Vegetation Condition by Elevation

Reach (elevation) (feet)	Riparian Vegetation Site Potential (late seral stage maturity)	Buffer Height	Buffer Width	Buffer Density
7000 – 5800	Aspen	30 ft.	20 ft.	30%
5800 – 5000	Mountain Alder	25 ft.	30 ft.	30%
5000 – 4780	Willow	18 ft.	40 ft.	30%
4780 – 4460	Willow	18 ft.	55 ft.	30%
4460 – 4360	Willow	18 ft.	60 ft.	30%

3.4.3.2 Stream Flow

Stream temperature change is generally inversely related to flow volume. As flows decrease, stream temperature tends to increase if energy processes remain unchanged (Boyd 1996). Runoff in the Willow Creek Watershed is primarily derived from snow melt, with peak runoff typically occurring in the spring. Late summer low flows are common due to low summer precipitation and water withdrawals. Flows were measured (August 11-13, 1998) between 5.7 and 1 cubic foot per second in Willow Creek, with the higher flows occurring closer to the headwaters. There are no flow gauging stations located on Willow Creek.

Although water withdrawal affects stream temperature, this TMDL recognizes irrigation as an out of stream beneficial use. Therefore, the TMDL does not attempt to control or limit legitimate water rights to improve water quality. **Stream flow was not targeted directly in this TMDL**.

3.4.3.3 Channel Morphology

Changes in channel morphology, namely channel widening, can impact stream temperatures. As a stream widens, the surface area exposed to radiant sources and ambient air temperatures increases, resulting in increased energy exchange between the stream and its environment (Boyd 1996). Further, wide channels are likely to have decreased levels of shade due to simple geometric relationships between riparian height and channel width. Conversely, narrow channels are more likely to experience higher levels of shade. An additional benefit inherent to narrower/deeper channel morphology is a higher frequency of pools that contribute to aquatic habitat. Narrower/deeper channels reduce the surface area for aquatic algae growth, which is directly related to other water quality parameters (i.e., pH and dissolved oxygen). In addition, the removal of streamside vegetation can reduce bank stability leading to increased sediment loads and a wider stream channel.

Although **channel morphology was not targeted directly in this TMDL**, ODEQ does feel that it is important to acknowledge the important role that channel morphology can play in regulating stream temperatures. A brief general discussion of channel morphology in the Alvord Lake Subbasin is presented in **Section 2.4.3.3**. In addition, a specific discussion of Willow Creek channel morphology data collected in 1992, 1993 and 1998 presented below.

3.4.3.3.1 Channel Width to Depth Ratios

The width to depth ratio is a fundamental measure of channel morphology. High width to depth ratios (greater than 10.0) imply wide shallow channels, while low width to depth ratios (less than 10.0) suggest that the channel is narrow and deep. The PACFISH target for width to depth ratio is 10.0 (USFS, 1995b). In terms of reducing stream surface exposure to radiant energy sources, it is generally favorable for stream channels to be narrow and deep (low width to depth ratios). ODFW measured width to depth ratios for Willow Creek during the summers of 1992 and 1993. The survey reach began at the Whitehorse Ranch road crossing (i.e., Reach 1) and extended 27,390 meters upstream (**Table 3-7).** Note that these reach breaks do not correspond to the same reach breaks used for Heat Source modeling and determination of vegetation communities.

Table 3-7. Observed Width to Depth Ratios in Willow Creek (ODFW, 1994)

Reach	Reach Distance (m)	Width to Depth Ratio
1	14,752	16.8
2	4,053	14.2
3	5,096	17.5
4	3,785	19.9

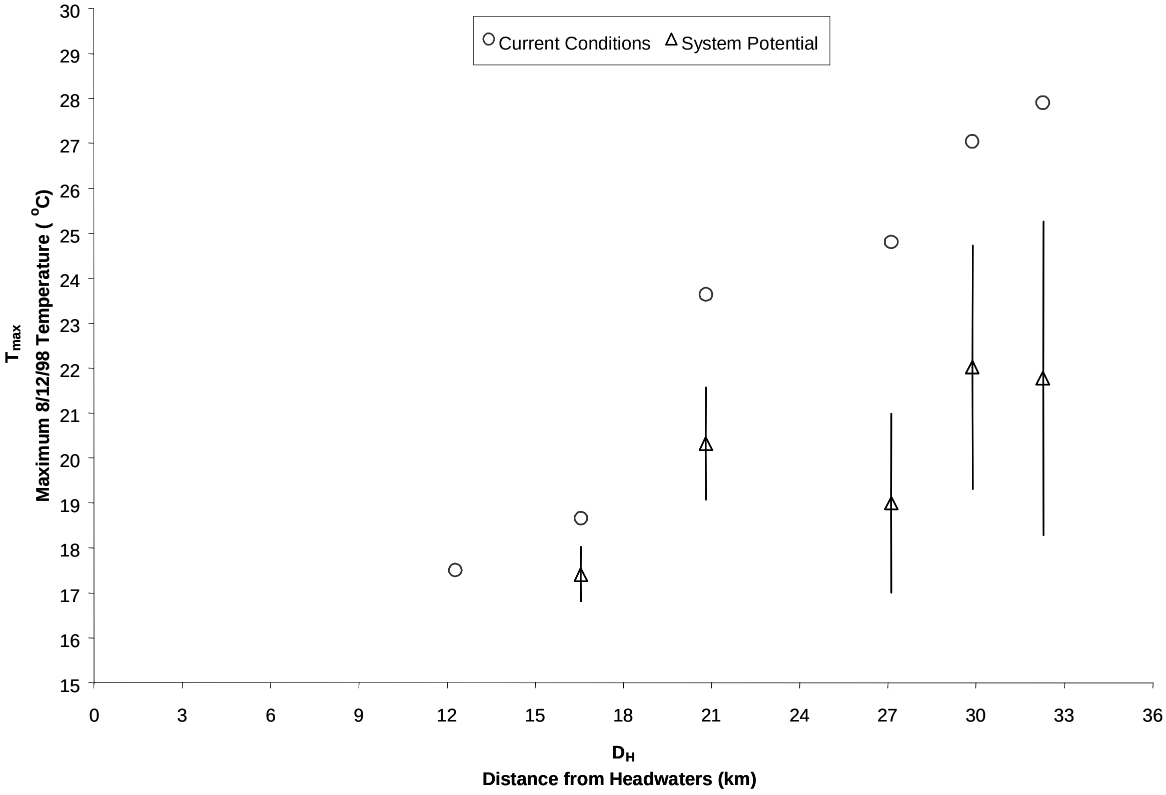
3.4.3.3.2 1998 Fluvial Geomorphology Survey

The 1998 Rosgen Level III fluvial geomorphology survey of Willow Creek revealed a 12.6' headcut or 'G' channel type, and an unstable channel condition in the lowest reach below the Whitehorse Ranch Road. The headcut or head ward advance has terminated at a basalt formation where it is considered stable from further migration. Unfortunately, the headcut serves as a permanent fish passage barrier for fish migrating upstream. The source of the headcut is unknown. The unstable channel conditions below the Whitehorse Ranch Road are directly attributed to the current management of livestock and wild horses. A 2001 survey of Willow Creek by ODEQ indicates the headcut remains stable but the disequilibrium associated with the lower reach continues as evidenced by aggradation or deposition of fine sediment (D50 1.7 mm) and highly unstable banks. The removal of streamside vegetation has reduced bank stability leading to increased sediment loads and a wider stream channel. This issue needs to be addressed in the Water Quality Restoration Plan as a management concern.

3.4.3.4 Willow Creek Thermal Response Simulations

To assess the thermal response of stream temperature to changes in vegetation, simulations were performed for portions of Willow Creek (**Figure 3-5**) with the Heat Source model using current vegetation conditions and *system potential* vegetation conditions. August 12, 1998 was chosen as the day to use in running model simulations to represent critical summer temperature conditions.

All simulated stream reaches demonstrated that the solar radiation under *system potential* conditions induces significant stream temperature reductions from current conditions; however, predicted water temperatures still exceed 64.0^{o}F (17.8^{o}C). **Figure 3-6** displays simulation results.



Simulated Willow Creek Reach	Distance from Headwaters (Km)	Current Condition Measured Daily Maximum Stream Temperature (°C)	System Potential Simulated Daily Maximum Stream Temperature (°C)
1	16.6	**18.7 (65.7°F)**	**17.4 (63.3°F)**
2	20.8	**23.6 (74.5°F)**	**20.3 (68.5°F)**
3	27.1	**24.8 (76.6°F)**	**19 (66.2°F)**
4	29.9	**27.0 (80.6°F)**	**22 (71.6°F)**
5	32.3	**27.9 (82.2°F)**	**21.8 (71.2°F)**

Figure 3-6. Effect of Solar Radiation Loads on Daily Maximum Stream Temperature

Error bars represent cumulative standard error (SE)

3.4.4 Point Sources of Heat

There are no point sources located within the Willow Creek Watershed.

3.4.5 Beaver Dams and Hotsprings

In addition to the human caused sources of heat described in **Sections 3.4.3** and **3.4.4**, two possible natural sources of heat were identified along Willow Creek: (1) two complexes of beaver dams and (2) the Willow Creek Hot Springs. A thermal assessment was done to determine the possible impact of these sources on stream temperatures in Willow Creek.

Longitudinal heating occurs at a relatively constant rate along the length of Willow Creek (**Figure 3-7**). Observed water temperatures in Willow Creek upstream, within, and below two beaver complexes, as well as the Willow Creek Hot Springs, were not outside the 95% prediction interval. The approximate locations of these structures are also highlighted on **Figure 3-2**.

These results indicate that water temperatures were not significantly affected by these potential thermal sources under current stream conditions. That is, pooled water behind the beaver dams and “Hot Spring” thermal loading do not appear to be heating (or cooling) at a rate any different than that of the mainstem (i.e., downstream water temperatures are within the 95% prediction interval of the trend line). Accordingly, managing for *system potential* effective shade is an appropriate step to address water temperature problems within the Willow Creek watershed.

In addition, ODEQ performed a study of the hot springs on August 13, 1998. The mixing zone was 12 feet for conductivity and temperature. The flow rate of the hot springs was 4.1 liters per minute.

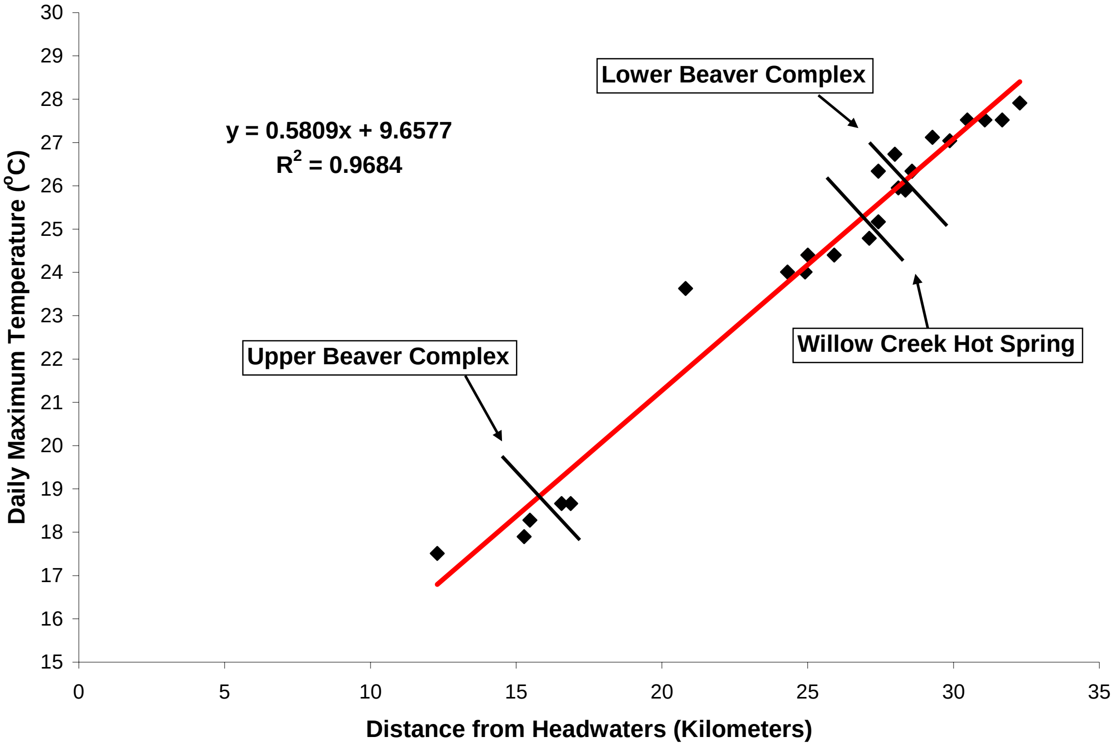


Figure 3-7. Observed Daily Maximum Temperatures in Willow Creek (Augsut 12, 1998)

3.5 LOADING CAPACITY - 40 CFR 130.2(F)

The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards. EPA’s current regulation defines loading capacity as “*the greatest amount of loading that a waterbody can receive without violating water quality standards*.” (40 CFR § 130.2(f)). The water quality standard states that ***no measurable surface water temperature increase resulting from anthropogenic activities*** is allowed in the Alvord Lake Subbasin when surface water temperature criteria are exceeded. The primary pollutant is human influenced increases in solar radiation loading (nonpoint sources).

In this document, the loading capacity is expressed in terms of British thermal units per day (BTU/ft^2/day). This represents the amount of energy that can be added to a waterbody and still obtain water quality standards.

3.5.1 Nonpoint Sources

The loading capacity is dependent on the available assimilative capacity of the receiving water. For nonpoint sources, the loading capacity is the amount of background solar radiation that reaches the stream when the stream is at *system potential* conditions in terms of riparian vegetation and channel morphology. For streams whose *system potential* temperatures are at or above the temperature criteria for a given period, there is no available assimilative capacity; the loading capacity is consumed by natural sources.

System potential solar radiation loading for Willow Creek is based on bankfull width and stream orientation during late July and early August. Riparian vegetation *system potential* is utilized to capture optimal and realistic heat energy reductions. Stream segments in which solar loading has been determined to correspond to late ecological stage riparian vegetation are allocated *system potential* solar loading capacities. **Table 3-8** lists the *system potential* loading capacities for Willow Creek by simulation reach.

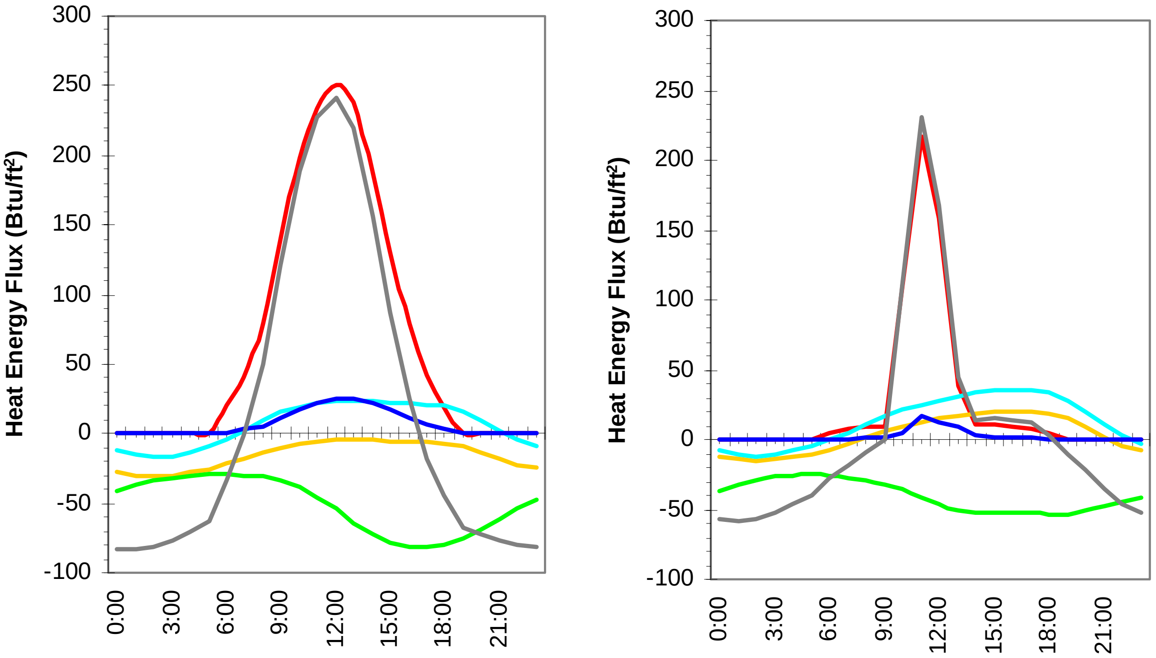
Table 3-8. Loading Capacity - (Daily Solar Radiation Loading)

Simulation Reach	Upper Boundary	Lower Boundary	Solar Radiation Loading Capacity *(BTU/ft^2/day)*
1	DH 12.3	DH 16.6	556
2	DH 16.6	DH 20.8	1084
3	DH 20.8	DH 27.1	598
4	DH 27.1	DH 29.9	767
5	DH 29.9	DH 32.3	798

3.5.1.1 Justification/Logic for Solar Radiation Loading Capacities

Loading capacities for Willow Creek are heat energy from incoming solar radiation expressed as BTU per ft^2 per day. Analysis/Simulation of heat transfer processes indicate that water temperatures increase above natural daily fluctuations when the heat load from solar radiation is above those allowed by *system potential* riparian vegetation conditions (see **Chapter V**).

In terms of water temperature increases, the principle source of heat energy is solar radiation directly striking the stream surface. **Figure 3-8** illustrates the total energy budget for the third simulation reach of Willow Creek as an example. Simple inspection of **Figure 3-8** confirms that solar radiation is the predominant heat energy process in the “Current Condition” simulation. The simulated “*System Potential* Condition” is also displayed in **Figure 3-8**, where a significant reduction in the diurnal (daily) solar radiation load is apparent. The total energy budgets for the other simulated reaches are provided in **Chapter V**.



(ODEQ Simulation)

Reach 3 - Current Condition

Total Reach Averaged Solar Loading
(Current Solar Loading = 1658 BTU/ft^2/day)

Reach 3 - Load Capacity – Targeted System Potential Condition

Reach Averaged Solar Loading
(Targeted Solar Loading = 598 BTU/ft^{-2}/day)

Total Flux ***Solar*** ***Longwave*** ***Evaporation*** ***Convection*** ***Conduction***

Figure 3-8. Simulated Daily Heat Energy Balance Based on Reach 3 Average Current Conditions and *System Potential* Conditions

3.5.2 Point Sources

There are no point sources located within the Willow Creek Watershed, therefore no waste load allocation was derived.

3.6 ALLOCATIONS - 40 CFR 130.2(G) AND (H)

Loading capacity will be available for allocation where surface water temperatures throughout a given stream and all reaches downstream decrease below the standard by an amount sufficient to accommodate either point source or nonpoint source influences.

Load Allocations are portions of the loading capacity divided between natural, human and future nonpoint pollutant sources. **Table 3-9** lists load allocations (i.e. distributions of the loading capacity) according to land-use. Each DMA's portion of the WQMP (**Appendix A**) will address only the lands and activities within each identified stream segment to the extent of the DMA's authority. A *Waste Load Allocation* (WLA) is the amount of pollutant that a point source can contribute to the stream without violating water quality criteria. Because there are no point sources in the Alvord Lake Subbasin, no waste load allocation was derived.

The loading capacity of the Willow Creek Watershed is all allocated to natural sources since, even at *system potential* conditions, temperatures in the watershed will still exceed the 64°F standard (see **Section 3.4.3.4**). No assimilative capacity exists for nonpoint sources. This requires that nonpoint sources reduce heat inputs to reach *system potential* conditions. The means of achieving these conditions is through restoring and protecting riparian vegetation, narrowing of stream channel widths and, where appropriate, increasing instream flows.

If and when *system potential* conditions are achieved in the future in Willow Creek, if it is determined that there is, in fact, some thermal load available to allocate to human caused sources, ODEQ may reevaluate this TMDL and redistribute the available load.

Table 3-9. Temperature Load Allocation Summary

Source	Loading Allocation
Natural	100%
Agriculture	0%
Forestry	0%
Future Sources	0%

3.7 SURROGATE MEASURES – 40 CFR 130.2(I)

The Willow Creek Temperature TMDL incorporates measures other than "*daily loads*" to fulfill requirements of §303(d). Although a loading capacity for heat energy is derived (e.g. BTU/ft^2/ day), it is of limited value in guiding management activities needed to solve identified water quality problems. In addition to heat energy loads, this TMDL allocates "*other appropriate measures*" (or surrogates measures) as provided under EPA regulations (40 CFR 130.2(i)). The specific surrogate used in this TMDL is percent effective shade (expressed as the percent reduction in potential solar radiation load delivered to the water surface). The solar radiation loading capacity is translated directly (linearly) by effective solar loading. The definition of effective shade allows direct measurement of the solar radiation loading capacity. Percent effective shade is perhaps the most straightforward stream parameter to monitor/calculate and is easily translated into quantifiable water quality management and recovery objectives. See **Section 2.7** for a further discussion of the use of surrogate measures for temperature.

3.7.1 Site Specific Effective Shade Surrogate Measures

Effective shade allocations in the Willow Creek Temperature TMDL are derived using heat loads. Percent effective shade (surrogate measure) can be linked to specific areas and, thus, to management actions needed to ameliorate water temperature increases. Further, effective shade allocations serve as direct translators to the solar radiation loading capacities.

System potential effective shade is based on bankfull width and stream orientation for late July and early August. Riparian *system potential* is utilized to capture optimal and realistic effective shade allocations. **Table 3-10 and Figure 3-9** list the *system potential* effective shade allocations (i.e. surrogate measure) for the simulated Willow Creek reaches. It is logical to assume the rate of tree growth is the limiting factor in attaining *system potential* effective shade levels.

Table 3-10. Surrogate Measures – Allocations (Effective Shade)

[DH is the distance from headwaters and is expressed in kilometers)

Simulation Reach	Upper Boundary	Lower Boundary	Solar Radiation Loading Capacity *(BTU/ft^2 per day)*	Surrogate Measure Allocated Effective Shade
1	DH 12.3	DH 16.6	556	67.4%
2	DH 16.6	DH 20.8	1084	40.7%
3	DH 20.8	DH 27.1	598	68.7%
4	DH 27.1	DH 29.9	767	61.0%
5	DH 29.9	DH 32.3	798	59.4%

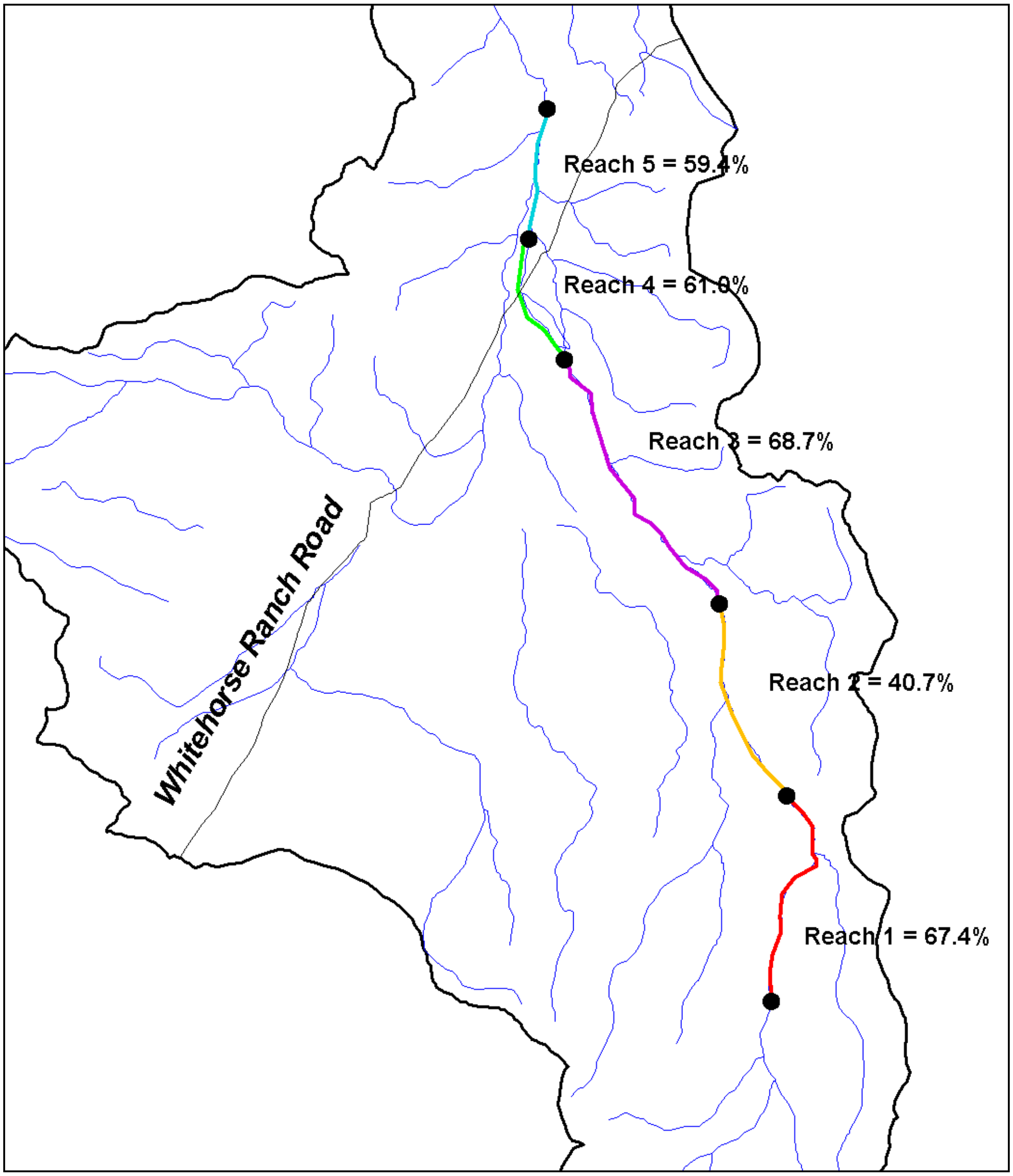


Figure 3-9. ***System Potential*** **Effective Shade Derived from Late Stage/Late Seral Buffers**

3.7.2 Regional Effective Shade Curves

Regional effective shade curves were also developed for the Willow Creek Watershed. Effective shade curves represent general relationships between *system potential* effective shade and stream bankfull width. The curves can be applied to determine effective shade allocations for stream reaches that were not simulated as described above. The curves are developed using trigonometric equations estimating the shade underneath tree canopies. The particular curve that applies to a given reach depends on the expected *system potential* vegetation for the reach and its expected height, density, and channel overhang at maturity.

System potential effective shade and solar radiation loading were simulated for various bankfull widths. *System potential* vegetation was assumed to correlate to the late seral stage indigenous riparian vegetation community detailed in **Table 3-6**. Using riparian vegetation height, width, and density estimates, it is possible to estimate the *potential effective* shade and daily solar radiation loading for all active channel width and stream orientation combinations in late July and early August. **Figures 3-10** through **3-14** provide potential effective shade and potential daily solar loading for the riparian vegetation types along Willow Creek by elevation zone (see **Table 3-6**). Each shade curve is based upon the *system potential* riparian conditions as described by biologists with the BLM Vale District Office in March of 1999. Future site specific effective shade allocations can be derived from these curves as a function of *system potential* riparian vegetation, bankfull width, stream aspect, and elevation.

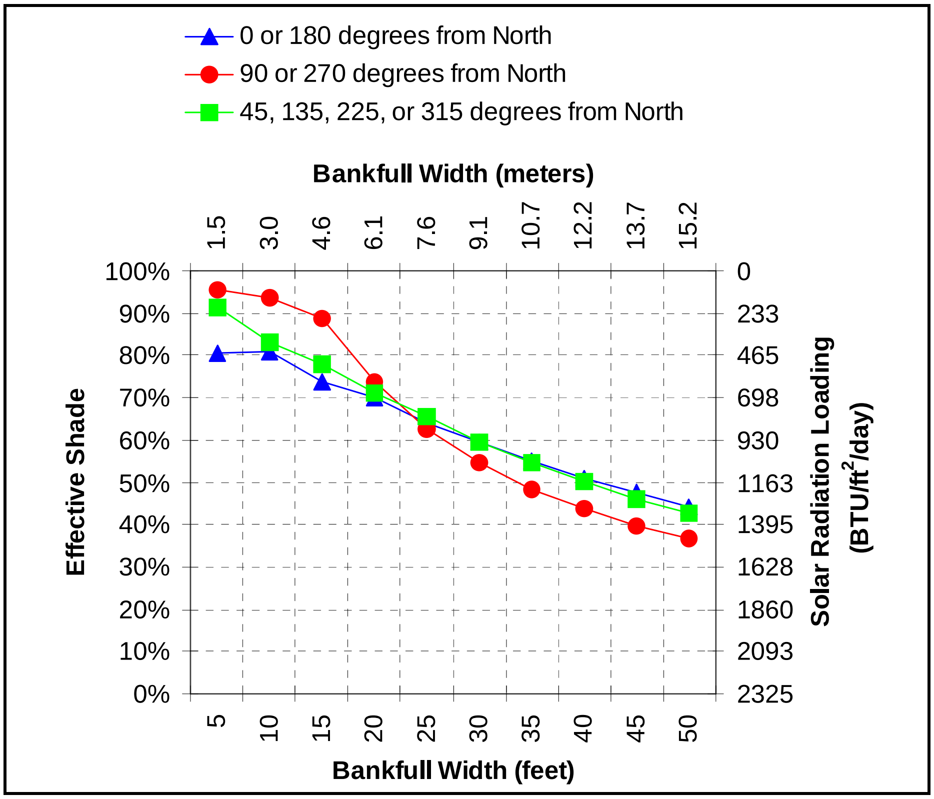


Figure 3-10. Aspen – Elevation 7000 to 5800 feet

Buffer Height = 30 ft, Buffer Width = 20 ft and Buffer Density = 30%

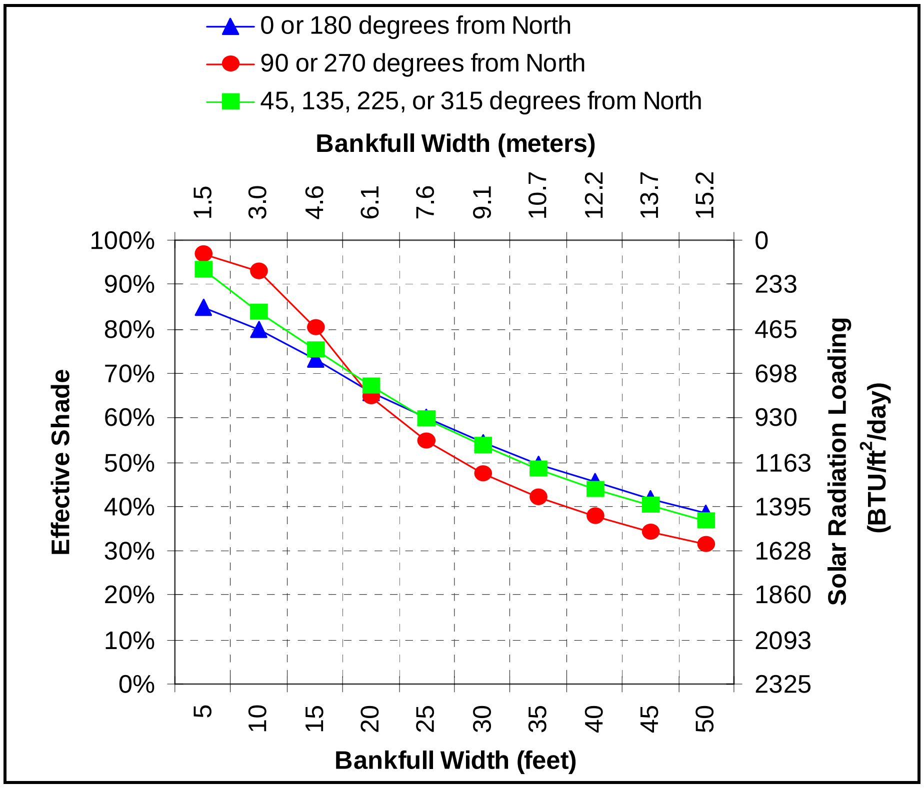


Figure 3-11. Mountain Alder – Elevation 5800 to 5000 feet

Buffer Height = 25 ft, Buffer Width = 30 ft and Buffer Density = 30%

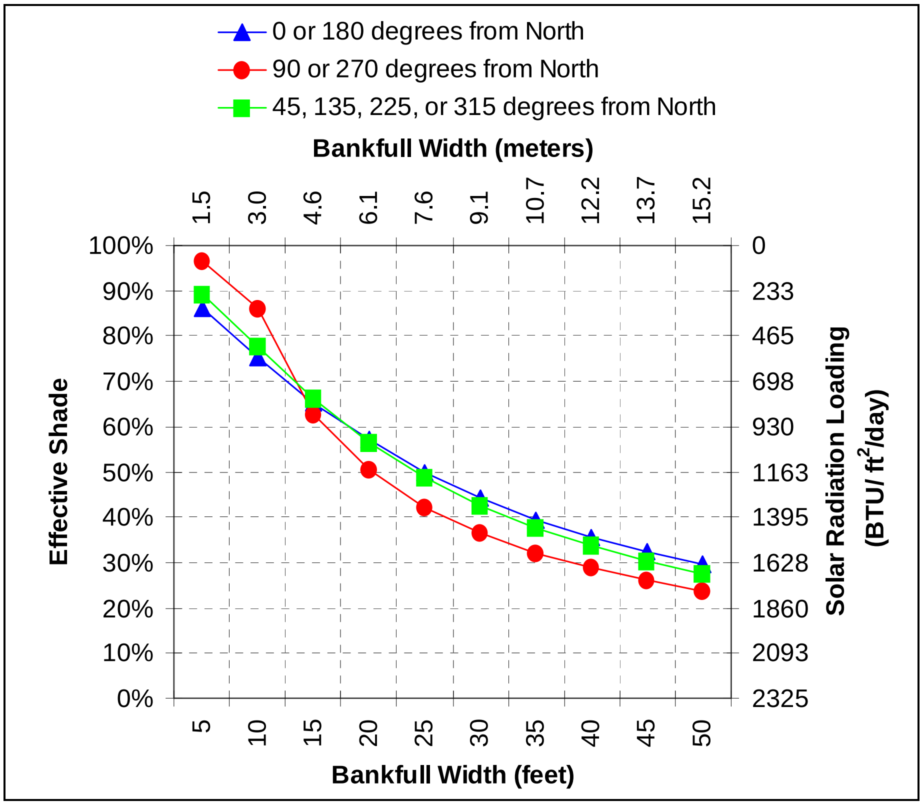


Figure 3-12. Willow – Elevation 5000 to 4780 feet

Buffer Height = 18 ft, Buffer Width = 40 ft and Buffer Density = 30%

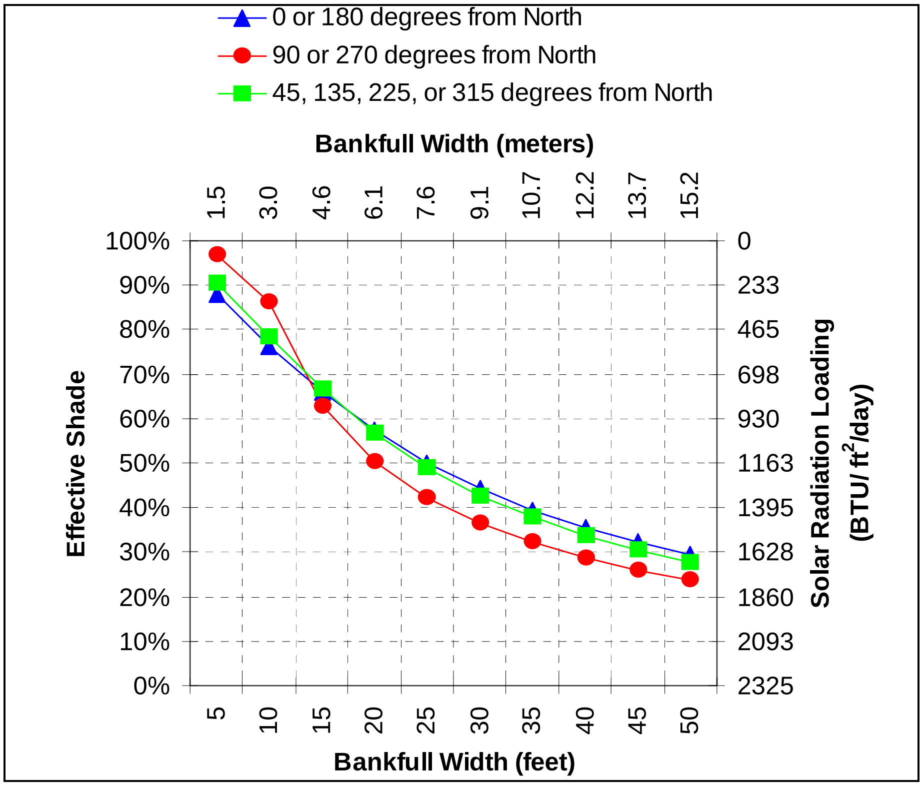


Figure 3-13. Willow – Elevation 4780 to 4460 feet

Buffer Height = 18 ft, Buffer Width = 55 ft, Buffer Density = 30%

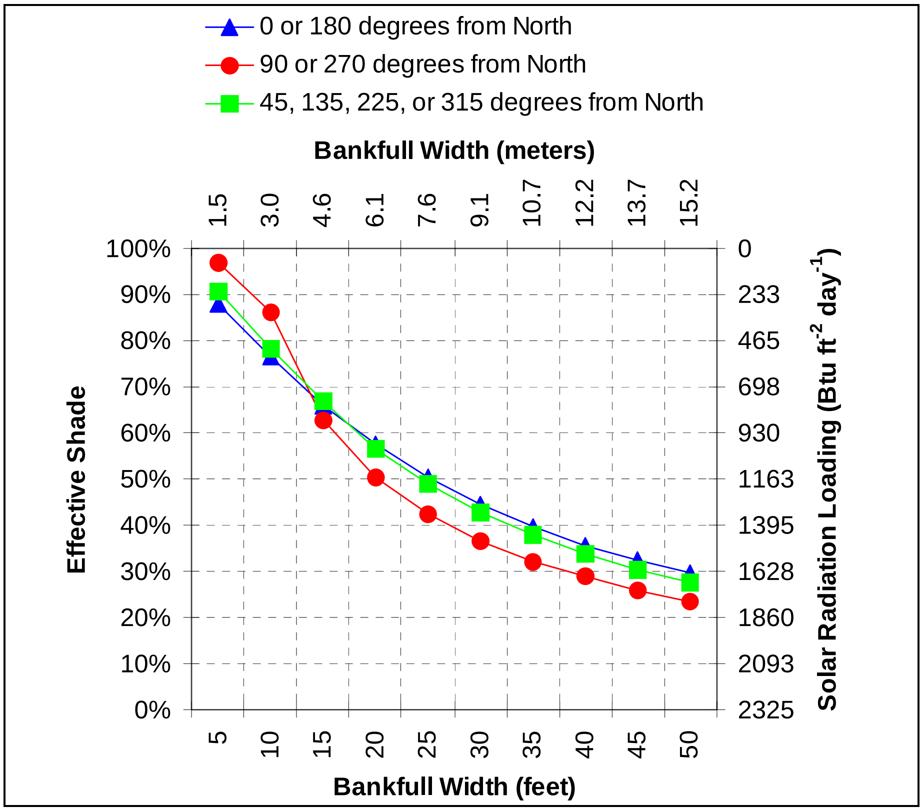


Figure 3-14. Willow – Elevation 4460 to 4360 feet

Buffer Height = 18 ft, Buffer Width = 60 ft, Buffer Density = 30%

3.8 MARGINS OF SAFETY – CWA §303(D)(1)

See **Section 2.8** for a more detailed general discussion of Margins of Safety.

3.8.1 Implicit Margins of Safety

Description of the MOS for the Alvord Lake Subbasin TMDL nonpoint source load allocations begins with a statement of assumptions. A MOS has been incorporated into the temperature assessment methodology. Conservative estimates for groundwater inflow and wind speed were used in the stream temperature simulations. Specifically, unless measured, groundwater inflow was assumed to be zero. In addition, wind speed was also assumed to be at the lower end of recorded levels for the day of sampling. Recall that groundwater directly cools stream temperatures via mass transfer/mixing. Wind speed is a controlling factor for evaporation, a cooling heat energy process. Further, cooler microclimates and channel morphology changes associated with late seral conifer riparian zones were not accounted for in the simulation methodology.

Calculating a numeric MOS is not easily performed with the methodology presented in this document. In fact, the basis for the loading capacities and load allocations is the definition of *system potential* conditions. It is illogical to presume that anything more than *system potential* riparian conditions are possible, feasible or reasonable for load allocations.

3.9 WATER QUALITY STANDARD ATTAINMENT ANALYSIS – CWA §303(D)(1)

Stream temperature simulation results, presented in **Figure 3-6**, clearly demonstrate that *system potential* effective shade levels can drastically reduce the amount of heat entering the stream, which results in cooler stream temperatures. However, predicted water temperatures still exceed 64.0°F (17.8°C). Simulation results suggest that stream thermal conditions in Willow Creek can have vastly different temperature regimes if adequate riparian protection measures are implemented to promote *system potential* riparian conditions. This conclusion is consistent with *all* temperature modeling efforts for other waterbodies in the Pacific Northwest (Brown 1969; Beschta and Weatherred 1984; Boyd 1996). Stream temperatures (**Figure 3-6**) that result from *system potential* conditions represent attainment of the temperature standard (***no measurable surface water temperature increase resulting from human caused activities***).

It should be noted that this modeling exercise solely focused on solar radiation as a function of riparian vegetation and the shade it provides the stream. In essence, excluding flow changes, channel morphology changes and cooler microclimates as they relate to riparian vegetation condition, almost certainly underestimates the cooling attributed to allocated riparian restoration scenarios. It is also likely that the simulation results, presented in **Figure 3-6,** underestimate potential cooling induced by the loading capacities because the simulation reaches do not extend to headwaters. In effect, these modeling results do not represent the true stream networks as they exist, and instead, are selected stream reaches simulated in a series.

CHAPTER IV: WILLOW CREEK DISSOLVED OXYGEN TMDL

Table 4-1. Willow Creek Dissolved Oxygen TMDL Components

Waterbodies	Willow Creek - HUC CODE 171200090803
Pollutant Identification	_Pollutant:_ increased oxygen demand due to human caused activities, such as near stream vegetation disturbance/removal, that results in increased periphyton growth
Target Identification (Applicable Water Quality Standards) *CWA §303(d)(1)*	**OAR 340-041-0885(2)(a)** (in part) *(A) For waterbodies identified by DEQ as providing salmonid spawning, during the periods from spawning until fry emergence from the gravels, the following criteria apply:* *(i) The dissolved oxygen shall not be less than 11.0 mg/L. However, if the minimum intergravel dissolved oxygen, measured as a spatial median, is 8.0 mg/L or greater, then the DO criterion is 9.0 mg/L;* (ii) *Where conditions of barometric pressure, altitude, and temperature preclude attainment of the 11.0 mg/L or 9.0 mg/L criteria, dissolved oxygen levels shall not be less than 95 percent of saturation;* *(E) For waterbodies identified by ODEQ as providing cool-water aquatic life, the dissolved oxygen shall not be less than 6.5 mg/l as an absolute minimum. At the discretion of ODEQ, when it is determined that adequate information exists, the dissolved oxygen shall not fall below 6.5 mg/l as a 30-day mean minimum, 5.0 mg/l as a seven-day minimum mean, and shall not fall below 4.0 mg/l as an absolute minimum;*
Existing Sources *CWA §303(d)(1)*	Forestry, Agriculture, Transportation, Rural Residential
Seasonal Variation *CWA §303(d)(1)*	Critical DO levels on Willow Creek generally occur in mid-late summer.
TMDL Loading Capacity and Allocations *40 CFR 130.2(f)* *40 CFR 130.2(g)* *40 CFR 130.2(h)*	_Loading Capacity:_ The LC for the mainstem is the cool water-aquatic life dissolved oxygen criteria: *The dissolved oxygen shall not fall below 6.5 mg/L as an absolute minimum.* _Wasteload Allocations (Point Sources)_: There are no point sources in the Willow Creek Watershed that adversely affect dissolved oxygen levels. _Load Allocations (Non-Point Sources)_: The LAs for instream DO are presented in **Table 4-7** and target *system potential* radiation loading.
Surrogate Measures *40 CFR 130.2(i)*	Translates Nonpoint Source Load Allocations Effective Shade targets translate the nonpoint source solar radiation loading capacity.
Margins of Safety *CWA §303(d)(1)*	Margin of Safety demonstrated in critical condition assumptions and is inherent to methodology. Explicit margin of safety of 0.6 mg/L DO. (Detailed in section)
Water Quality Standard Attainment Analysis *CWA §303(d)(1)*	• Regression modeling of TMDL loading capacities demonstrates attainment water quality standards • Attainment of the water quality standard achieved through mandating "***no measurable surface water temperature increase resulting from anthropogenic activities****";* nonpoint sources to target *system potential* conditions. • The Water Quality Management Plan will consist of Implementation Plans that contain measures to attain load allocations.

4.1 OVERVIEW

The primary benefit of maintaining adequate dissolved oxygen (DO) concentrations is to support a healthy and balanced distribution of fish, invertebrates, and other aquatic life. In the Alvord Lake Subbasin, the dissolved oxygen standard is designed to protect cool-water fish as the most sensitive beneficial use. Based on data collected by ODEQ in 1999, Willow Creek in the Trout Creek Mountains was added to the 303(d) list in 2002 for not meeting the state's dissolved oxygen standard.

While many chemical and physical processes can affect dissolved oxygen levels, stream temperature is a significant contributing factor to water quality standards violations for dissolved oxygen. Increased solar heating of the water column and warm stream temperatures are factors that contribute to excessive periphyton growth, which in turn depletes instream dissolved oxygen levels. A regression model was developed in this TMDL to investigate the association between temperature and dissolved oxygen. The model predicts that the dissolved oxygen standard will be achieved through the implementation of the *system potential* temperature TMDL allocations (**Sections 3.6** and **3.7**).

The rest of the overview information for Willow Creek can be found in **Section 3.1**.

4.2 TARGET IDENTIFICATION – CWA §303(D)(1)

4.2.1 Sensitive Beneficial Uses

Oregon Administration Rules (**OAR Chapter 340, Division 41, Table 18**) lists designated "*Beneficial Uses*" occurring in the Willow Creek Watershed (**Table 4-2**). The numeric and narrative water quality standards are designed to protect the most sensitive beneficial uses. High concentrations of dissolved oxygen in the water column are essential to support healthy aquatic communities of fish and invertebrates. Spawning and rearing use by the Lahontan cutthroat trout are the most sensitive beneficial uses in Willow Creek for dissolved oxygen. This resident trout is the only fish species that resides in Willow Creek. During their early life stages as eggs and fry, these trout are especially sensitive to reduced dissolved oxygen concentrations. For a further discussion of beneficial uses in the Willow Creek Watershed, refer to **Section 2.2.1.**

Table 4-2. Beneficial uses occurring in the Malheur Lake Basin including Willow Creek Watershed *(OAR 340 – 41 – 882)*

Temperature-Sensitive Beneficial uses are marked in Grey

Beneficial Use	***Occurring***	***Beneficial Use***	***Occurring***
Public Domestic Water Supply	✓	Salmonid Fish Spawning (Trout)	✓
Private Domestic Water Supply	✓	Salmonid FisheRearing (Trout)	✓
Industrial Water Supply	✓	Resident Fish and Aquatic Life	✓
Irrigation	✓	Aesthetic Quality	✓
Livestock Watering	✓	Wildlife and Hunting	✓
Boating	✓	Fishing	✓
Hydro Power		Water Contact Recreation	✓

4.2.2 Water Quality Standard Identification

4.2.2.1 Dissolved Oxygen Standard

The dissolved oxygen water quality criteria applicable to the Malheur Lake Basin (including the Willow Creek Watershed) are delineated in the Oregon Administrative Rules (**Figure 4.1**).

Oregon Administrative Rule 340-041-0885 (2)(a)

(a) Dissolved oxygen (DO): The changes adopted by the Commission on January 11, 1996, became effective July 1, 1996. Until that time, the requirements of this rule that were in effect on January 10, 1996, apply:

(A) For waterbodies identified by ODEQ as providing salmonid spawning, during the periods from spawning until fry emergence from the gravels, the following criteria apply:

(i) The dissolved oxygen shall not be less than 11.0 mg/L. However, if the minimum intergravel dissolved oxygen, measured as a spatial median, is 8.0 mg/L or greater, then the DO criterion is 9.0 mg/L;

(ii) Where conditions of barometric pressure, altitude, and temperature preclude attainment of the 11.0 mg/L or 9.0 mg/L criteria, dissolved oxygen levels shall not be less than 95 percent of saturation.

(B) For waterbodies identified by ODEQ as providing salmonid spawning during the period from spawning until fry emergence from the gravels, the spatial median intergravel dissolved oxygen concentration shall not fall below 6.0 mg/l;

(C) A spatial median of 8.0 mg/l intergravel dissolved oxygen level shall be used to identify areas where the recognized beneficial use of salmonid spawning, egg incubation and fry emergence from the egg and from the gravels may be impaired and therefore require action by ODEQ. Upon determination that the spatial median intergravel dissolved oxygen concentration is below 8.0 mg/l,ODEQ may, in accordance with priorities established ODEQ for evaluating water quality impaired waterbodies, determine whether to list the waterbody as water quality limited under the Section 303(d) of the Clean Water Act, initiate pollution control strategies as warranted, and where needed cooperate with appropriate designated management agencies to evaluate and implement necessary best management practices for nonpoint source pollution control;

(D) For waterbodies identified by ODEQ as providing cold-water aquatic life, the dissolved oxygen shall not be less than 8.0 mg/l as an absolute minimum. Where conditions of barometric pressure, altitude, and temperature preclude attainment of the 8.0 mg/l, dissolved oxygen shall not be less than 90 percent of saturation. At the discretion of DEQ, when it is determined that adequate information exists, the dissolved oxygen shall not fall below 8.0 mg/l as a 30-day mean minimum, 6.5 mg/l as a seven-day minimum mean, and shall not fall below 6.0 mg/l as an absolute minimum;

(E) ***For waterbodies identified by ODEQ as providing cool-water aquatic life, the dissolved oxygen shall not be less than 6.5 mg/l as an absolute minimum****. At the discretion of ODEQ, when it is determined that adequate information exists, the dissolved oxygen shall not fall below 6.5 mg/l as a 30-day mean minimum, 5.0 mg/l as a seven-day minimum mean, and shall not fall below 4.0 mg/l as an absolute minimum;*

(F) For waterbodies identified by ODEQ as providing warm-water aquatic life, the dissolved oxygen shall not be less than 5.5 mg/l as an absolute minimum. At the discretion of ODEQ, when it is determined that adequate information exists, the dissolved oxygen shall not fall below 5.5 mg/l as a 30-day mean minimum, and shall not fall below 4.0 mg/l as an absolute minimum.

Figure 4-1. Malheur Lake Basin Dissolved Oxygen Standard

As can be noted in the standard, different dissolved oxygen requirements have been identified for different types of aquatic life: cold-, cool-, and warm water. Cold-, cool-, and warm-water aquatic life are defined in Oregon Administrative Rule **(OAR) 340-041-0006** as follows:

> *(51) "Cold-Water Aquatic Life" – The aquatic communities that are physiologically restricted to cold water, composed of one or more species sensitive to reduced oxygen levels. Including but not limited to Salmonidae and cold-water invertebrates.*
> *(52) "Cool-Water Aquatic Life" – The aquatic communities that are physiologically restricted to cool waters, composed of one or more species having dissolved oxygen requirements believed similar to the cold-water communities. Including but not limited to Cottidae, Osmeridae, Acipenseridae, and sensitive Centrarchidae such as the small-mouth bass.*
> *(53) "Warm-Water Aquatic Life" – The aquatic communities that are adapted to warm-water conditions and do not contain either cold- or cool-water species.*

For the 2002 303(d) list a memo written by ODEQ to EPA in June of 1998 was used to determine where to apply the different dissolved oxygen criteria. In this memo, ODEQ stated that the application of the criteria depends on which Ecoregion (Omernik and Gallant 1986) a given water body occupies. The Alvord Lake Subbasin is in the Snake River Basin/High Desert Ecoregion. According to the 1998 memo, the cool water dissolved oxygen criterion will be applied to waters in that Ecoregion. While the cool-water aquatic life definition does not typically include the family Salmonidae, ODEQ has decided to apply the cool-water definition to the Willow Creek system for several reasons: (1) the Ecoregion in which Willow Creek is located; and (2) the documented thermal tolerance of Lahontan cutthroat trout (Dunham 1999).

Based on the application of the dissolved oxygen standard to protect cool-water aquatic life in a system that contains Salmonidae, the important numeric criteria which would apply are: 11.0 mg/l or 95% saturation or intergravel dissolved oxygen of greater than 6.0 mg/L during times of the year when salmonid spawning through fry emergence is occurring and 6.5 mg/l during the rest of the year. Spawning in the Malheur Lake Basin is designated as occurring from March 1-June 30.

4.2.2.2 Deviation from Water Quality Standard

ODEQ sampled dissolved oxygen concentrations, dissolved oxygen saturation, pH, nutrients and BOD at eight locations within Willow Creek during the summer (August) and fall (November) of 1998 (**Figure 4-2**). Samples collected during August correspond to a condition of high stress on Lahonton cutthroat trout resulting from elevated water temperatures. Sample locations were situated in order to allow for the evaluation of the longitudinal change of these water quality parameters as well as seasonal changes. During each sampling session, data was collected continuously at three of the sites in order to determine diurnal changes of these parameters. Grab samples were collected at all eight locations.

Observed values for both the grab sample and continuous monitoring sites (**Figure 4-3)** indicate that daily minimum dissolved oxygen concentrations were below the 6.5 mg/l cool water criteria at the one monitoring site located in the East Channel below the Lower Beaver Complex during the August sampling event. The flow of Willow Creek is split into multiple channels below the beaver complex, with the East Channel receiving a much reduced volume of flow as a result of the beaver activity.

When comparing data from the three continuous monitoring stations, observed summer dissolved oxygen levels decrease, moving downstream while the diurnal variability increases. Diurnal variability increases dramatically at the downstream sampling location (i.e., Dh 29.87) which indicates that photosynthesis and respiration rates were higher at this location. Observed summer dissolved oxygen saturation levels also indicate that biological activity increases in Willow Creek at the downstream location, with super-saturation and under-saturation conditions occurring during the daytime and nighttime, respectively (**Figure 4-4**).

Observed winter dissolved oxygen concentrations were much higher than under summer conditions (**Figure 4-3**). None of the sites violated the dissolved oxygen criteria during November, although the site with the lowest dissolved oxygen concentrations was still the site located in the East Channel below the Lower Beaver Complex, based on one grab sample. Again, this site had reduced flow due to the channel split below the beaver complex.

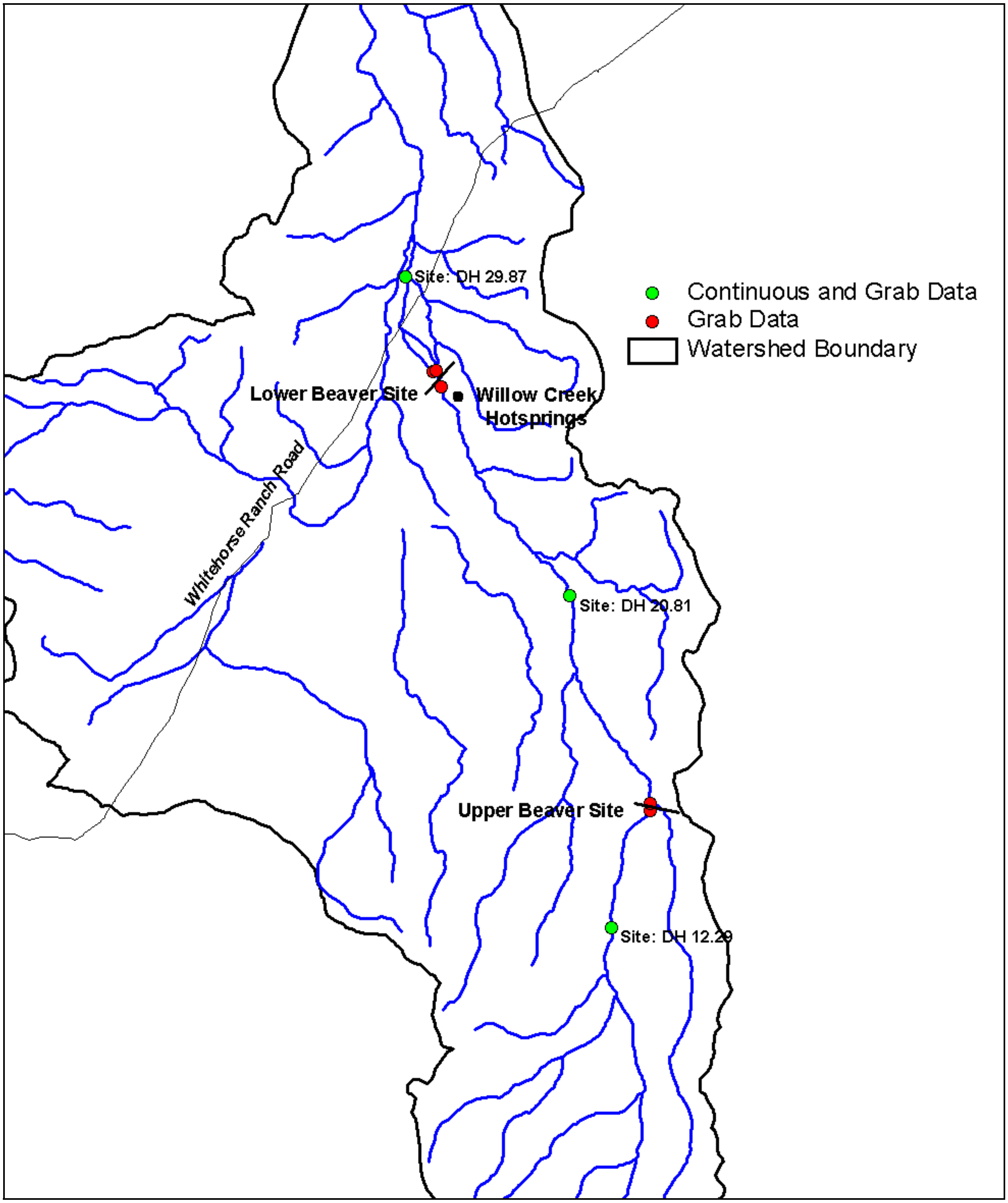


Figure 4-2. Monitoring Locations, 1998

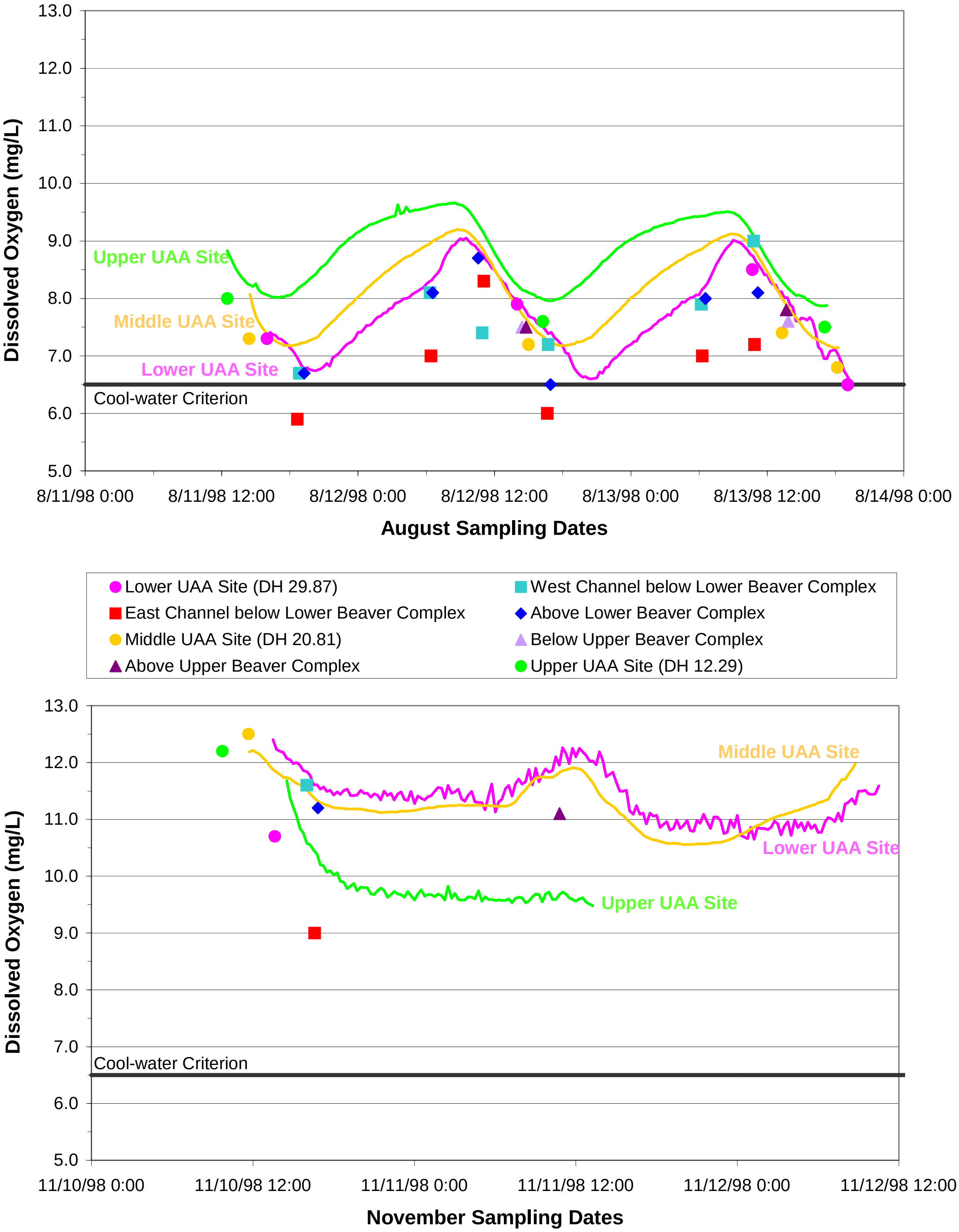


Figure 4-3. Seasonal and Diurnal Variation in Willow Creek Dissolved Oxygen Concentrations: Grab Sample and Continuous Data (1998)

[DH is the distance from headwaters and is expressed in kilometers)

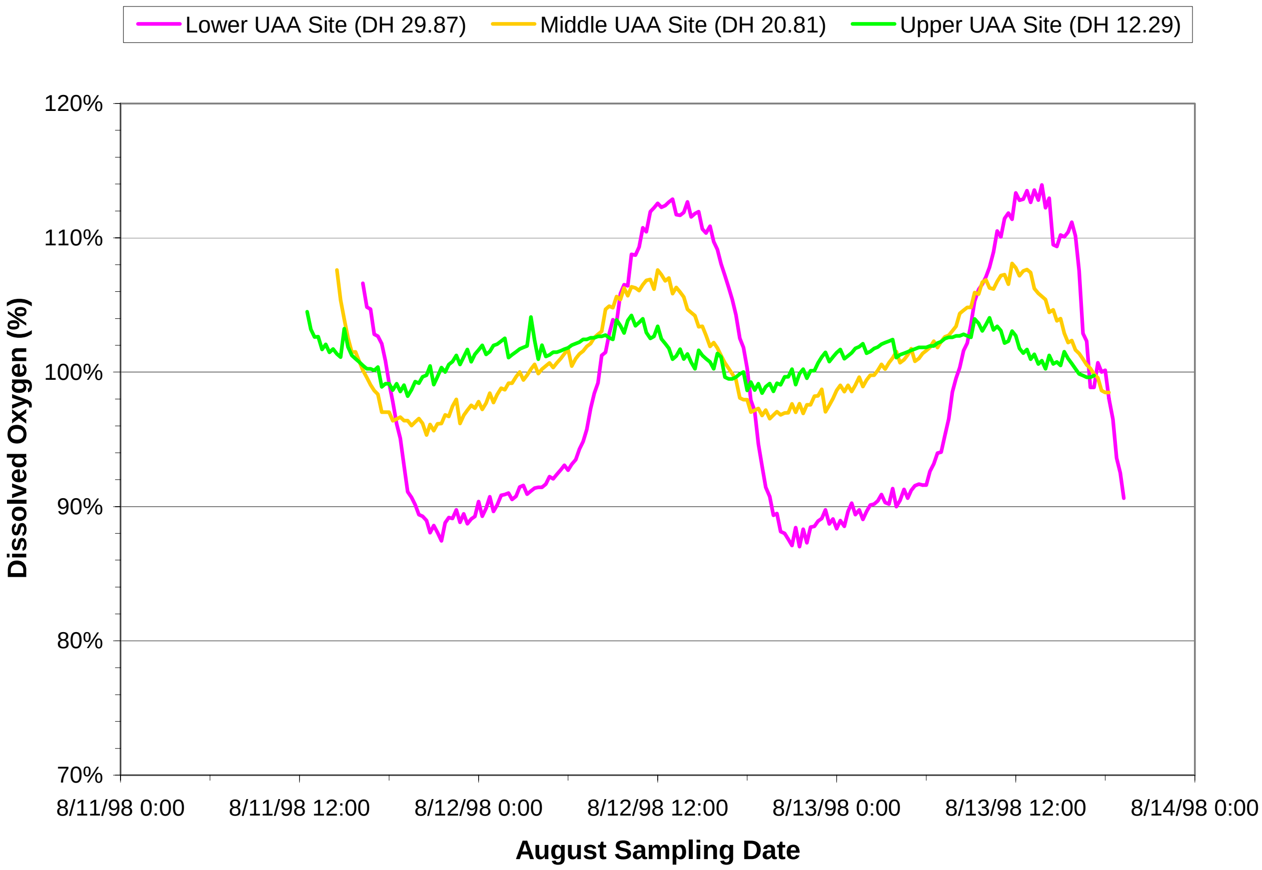


Figure 4-4. Diurnal Variation in Willow Creek Dissolved Oxygen Saturation: Continuous Data (1998)

[DH is the distance from headwaters and is expressed in kilometers)

Section 303(d) of the Federal Clean Water Act (1972) requires that water bodies that do not meet water quality standards, thereby failing to fully protect *beneficial uses*, be identified and placed on a 303(d) list. Willow Creek is included on the 2002 303(d) list for dissolved oxygen violations for the period June 1-September 30 based on the violations observed at the one site in the East Channel below the Lower Beaver Complex in August, 1998. The time period in which this violation is listed as occurring is incorrect on the 2002 303(d) list. Because the data used to list Willow Creek was collected in August, the listing should only apply to summer rearing conditions, which occur from July 1-February 28. The listing should not apply during the spawning season (which includes the month of June) since no data was collected during the spawning season. If more data becomes available indicating that there are dissolved oxygen problems in Willow Creek during the spawning period, then this TMDL can be refined at that point. Until then, ODEQ will revise the 303(d) list to reflect that the listing only occurs during summer rearing conditions.

For specific information regarding Oregon's 303(d) listing procedures, and to obtain more information regarding the Alvord Lake Subbasin's 303(d) listed streams, visit the Department of Environmental Quality's web page at **http://www.deq.state.or.us/**.

4.2.3 Pollutant Identification

ODEQ is required by the CWA to establish *a Total Maximum Daily Load* or *TMDL* for any waterbody designated on the 303(d) list as violating water quality standards unless the standards exceedences are due to natural causes. A *TMDL* is the total amount of a pollutant (from all sources) that can enter a specific waterbody without violating the water quality standards.

While many chemical and physical processes can affect dissolved oxygen levels, this analysis determines that water quality standards can be achieved simply by implementing the surrogate measures developed for stream temperature. Increased solar heating of the water column and warm stream temperatures are factors that contribute to excessive periphyton growth. *Increased oxygen demand due to anthropogenic activities that result in increased periphyton mass is defined as the pollutant.* The reduction of periphyton mass is targeted to meet water quality standards in this TMDL.

4.3 SEASONAL VARIATION - CWA §303(D)(1)

Section 303(d)(1) of the Clean Water Act requires this TMDL to be "established at a level necessary to implement the applicable water quality standard with seasonal variations." Stream temperature and dissolved oxygen vary both seasonally and diurnally.

There has been limited dissolved oxygen data collected on Willow Creek. Most of the data has been collected during the summer months when maximum dissolved oxygen deficits occur as a result of conditions conducive to excessive periphyton growth. Such conditions include increased steam temperature. As was discussed in **Sections 2.4** and **3.4**, stream temperature can be influenced by a number of factors, including the condition of riparian vegetation and stream flow.

Temperature has a significant impact on the dissolved oxygen in a stream in two ways. With increasing temperatures, the amount of oxygen that can remain dissolved in water decreases. Also, in general, dissolved oxygen sinks increase their oxygen consumption as temperature increases. Therefore, *the critical condition for dissolved oxygen is during summer conditions* when stream temperatures are highest and stream flows are lowest. During cooler, higher flow conditions, dissolved oxygen concentrations will generally be much higher than during summer low flow.

4.4 EXISTING SOURCES - CWA *§303(D)(1)*

4.4.1 Source Descriptions

Dissolved oxygen in water bodies may fall below healthy levels for a number of reasons including carbonaceous biochemical oxygen demand (CBOD) within the water column, nitrogenous biochemical oxygen demand (NBOD, also known as nitrification), sediment oxygen demand (SOD), and algal growth. Increased water temperatures will also reduce the amount of oxygen in water by decreasing its solubility and increasing the rates of both nitrification and the decay of organic matter. For example, at 10°C, 100% DO saturation is 11.3 mg/L; at 30°C the same water sample would contain only 7.6 mg/L of dissolved oxygen.

ODEQ assessed the magnitude of the oxygen demand associated with these processes and/or whether they were likely to have any impact at all. A brief description of these oxygen-demanding processes and an analysis of their potential to impact dissolved oxygen concentrations in Willow Creek is listed below (excerpted from ODEQ 2002).

4.4.1.1 NBOD and CBOD

When nitrogen in the form of ammonia is introduced to natural waters, the ammonia may "consume" dissolved oxygen as nitrifying bacteria convert the ammonia into nitrate and nitrite. The process of ammonia being transformed into nitrate and nitrite is called nitrification. The consumption of oxygen during this process is called nitrogenous biochemical oxygen demand, NBOD. To what extent this process occurs, and how much oxygen is consumed, is related to several factors, including residence time, water temperature, ammonia concentration in the water and the presence of nitrifying bacteria.

Water column carbonaceous biochemical oxygen demand is the oxygen consumed by the decomposition of organic matter in water. The sources of the organic matter can be varied, either resulting from natural sources such as direct deposition of leaf litter or from human caused sources such as polluted runoff. The most likely sources of organic matter in the Willow Creek Watershed are leaf litter and bovine or wild horse manure.

Water quality data was collected from August 11 through 14, 1998. Median nutrient concentrations are presented in **Table 4-3**. Ammonia concentrations were very low at all sites. Nitrate plus nitrite concentrations were elevated at the upper elevation sites, decreasing with distance down the creek. A further discussion of this nutrient data is provided below in **Section 4.4.1.3.2**. Although not presented in **Table 4-3**, BOD_5 levels during the same time period averaged only 0.3 mg/l (with a maximum concentration of 1.2 mg/L at the Lower UAA site), thus discounting the likelihood of any significant pollution sources impacting NBOD or CBOD oxygen demand.

Table 4-3. Median Summer Nutrient Concentrations observed in Willow Creek.

Distance from Headwaters (km) (# samples)	Site Name	TP (mg/L)	d-Ortho-P (mg/L)	TKN (mg/L)	NH_4-N (mg/L)	NO_3+NO_2-N (mg/L)
12.290 (3)	Upper UAA	0.08	0.059	0.2	0.02	0.34
15.273 (1)	Above Upper Beaver Complex	0.08	0.055	0.2	0.02	0.31
15.473 (1)	Below Upper Beaver Complex	0.09	0.054	0.2	0.02	0.30
20.810 (3)	Middle UAA	0.09	0.061	0.2	0.03	0.21
27.110 (2)	Above Lower Beaver Complex	0.10	0.066	0.3	0.04	0.13
27.987 (2)	West Channel below Lower Beaver Complex	0.10	0.061	0.3	0.03	0.09
28.069 (2)	East Channel below Lower Beaver Complex	0.09	0.072	0.3	0.02	0.09
29.871 (3)	Lower UAA	0.12	0.075	0.2	0.02	0.02

[TP is Total Phosphorus; d-ortho-P is dissolved ortho phosphorus; TKN is Total Kjeldahl Nitrogren, NH_4-N is Ammonia as Nitrogen; NO_3+NO_2-N is nitrate plus nitrite as nitrogen]

4.4.1.2 Sediment Oxygen Demand (SOD)

Sediments in waterbodies are important to riverine systems. However, too much sediment can increase levels of other pollutant parameters. When solids that contain organics settle to the bottom of a stream they may decompose anaerobically or aerobically, depending on conditions. The oxygen consumed in aerobic decomposition of these sediments is called sediment oxygen demand (SOD) and represents another dissolved oxygen sink for a stream. The SOD may differ from both water column CBOD and nitrification in that SOD will remain a DO sink for a much longer period after the pollution discharge ceases (e.g., organic-containing sediment deposited as a result of rain-driven runoff may remain a problem long after the rain event has passed).

ODEQ is not aware of any SOD data that has been collected from Willow Creek. However, SOD data would be very useful for any future DO modeling and potential TMDL refinement. It should be noted that in stream survey work done on Willow Creek in both 1998 and 2001, the lower reach below the Whitehorse

Ranch Road was the only reach characterized by the deposition of fine sediment (D50 1.7 mm). This deposition was associated with highly unstable stream banks.

4.4.1.3 Algal Growth

Algae living in streams (either free floating or attached as benthic algae or periphyton) use light energy for growth during daylight conditions. This process, called photosynthesis, produces oxygen (O_2) as a byproduct, and consumes carbon dioxide (CO_2):

$$6\,CO_2 + 6H_2O \xrightarrow{\text{Photosynthesis}} C_6H_{12}O_6 + 6\,O_2$$

(**Equation 4-1**)

Instream dissolved oxygen concentration increases as a result of this process. Maximum daily dissolved oxygen levels occur in late afternoon, following a full day of oxygen production. Alternatively, dissolved oxygen is consumed and carbon dioxide is produced during the night when respiration replaces photosynthesis as the primary biological process or activity:

$$6\,O_2 + C_6H_{12}0_6 \xrightarrow{\text{Respiration}} 6\,H_2O + 6\,CO_2$$

(**Equation 4-2**)

Thus, minimum daily dissolved oxygen conditions occur just before sunrise, following a full night period of respiration. Dissolved oxygen can fluctuate widely in systems dominated by algae (i.e., free floating and attached (periphyton)).

Photosynthesis can also result in instream oxygen concentrations greater than saturation (super-saturation). Saturation is defined as the maximum oxygen concentration anticipated at observed pressure (elevation) and water temperature. Super-saturation conditions can occur when oxygen produced during photosynthesis is at a rate greater than the gas transfer rate across the air/water interface. Similarly, under-saturation conditions can occur when oxygen consumed in the water column from respiration is at a rate greater than the gas transfer rate across the air/water interface.

The consumption of carbon dioxide (CO_2) during photosynthesis (**Equation 4-1**) and the production of CO_2 during respiration (**Equation 4-2**) also directly affect river pH levels. That is, water pH levels increase at decreasing aqueous CO_2 concentrations, and therefore photosynthesis can increase river pH levels. Alternatively at night, when photosynthesis is not occurring but plants and animals continue to respire, there is a net production of carbon dioxide entering the water and subsequently water pH levels decrease.

In some waterbodies, dissolved oxygen standards may be violated because of the presence of algae. Excessive algal concentrations can cause large diurnal fluctuations in both dissolved oxygen and pH. Such streams generally exhibit supersaturated dissolved oxygen concentrations during the day and low dissolved oxygen concentrations at night. Conversely, pH concentrations tend to peak in the late afternoon in systems with a high level of biological activity.

Both dissolved oxygen (**Figures 4-3** and **4-4**) and pH data (**Figure 4-5**) collected in Willow Creek indicate that biological activity (photosynthesis and respiration) is elevated at the downstream location (DH 29.87). It should be noted that the pH standard was not violated in any of the samples collected from Willow Creek in 1998.

The State of Oregon has designated an action level of 15 µg/L concentration of chlorophyll a (a measure of algal content) to indicate when algal growth may be a problem. Chlorophyll a levels measured at all of the monitoring locations during August, 1998 were well below Oregon's 15 µg/l action level, with an average concentration for the creek of 0.6 ug/L and a maximum concentration of 1.3 ug/L. The maximum value was observed at the Middle UAA Site (DH 20.81).

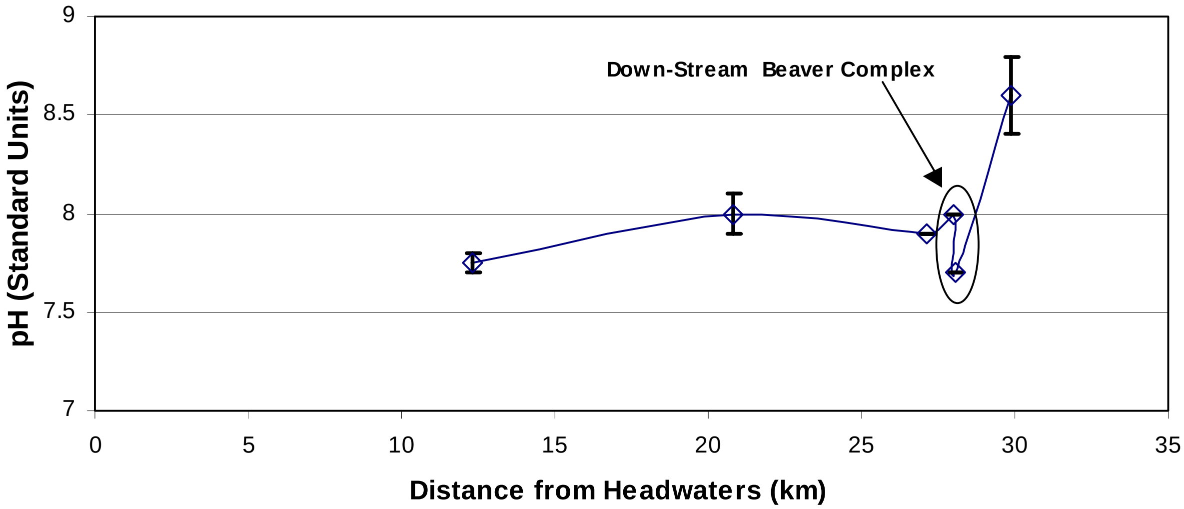


Figure 4-5. Late afternoon pH levels observed in Willow Creek, August 11-13,1998.

[Late afternoon was defined as between 3 and 7 PM; bars represent the range of observed values at each station]

However, periphyton growth (attached algae) is a potential concern, particularly in the lower reaches of Willow Creek where filamentous green algae was present. ODEQ collected four samples of aquatic vegetation and periphyton in the lower reaches of Willow Creek during the summer of 1998 (**Table 4-4**). Specifically, sites were located within recently created channels within the downstream beaver complex on Willow Creek. The rate of periphyton growth is governed by the availability of 1) **light** (solar radiation), 2) **nutrients** and 3) **water temperature** (Thomann and Mueller 1987). If all of these are available in excess, then dense mats of periphyton will grow and the algae biomass will then be regulated by macro-invertebrate grazing, substrate characteristics, and hydraulic sloughing. The role of each of these factors in Willow Creek is discussed below.

Table 4-4. Observed Willow Creek Macrophyte and Algae species composition, August 1998.

Sample #	Identified Primary Species	Additional Species Information
1	*Cladophora* sp. (a filamentous green alga)	Variety of attached algae, mostly diatoms
2	*Cladophora* sp., *Spirogyra* sp., and *Oedogonium* sp. (a filamentous green alga)	Variety of attached algae, mostly diatoms
3	*Potamogeton sp*., (pond weed)	Variety of macroinvertebrates including Simulidae (black flies) and Hydropsychidae (caddisflies)
4	*Cladophora* sp. (a filamentous green alga)	Variety of attached algae, mostly diatoms

4.4.1.3.1 Solar Radiation

Increased solar radiation has been shown to increase dissolved oxygen by encouraging photosynthetic chemical reactions associated with primary production (DeNicola et al. 1992). It has been shown that periphyton communities achieve maximum photosynthesis rates even at low light intensities (Gregory et al. 1987; and Powell 1996). Therefore, it is difficult to manage periphyton growth through light attenuation.

Solar radiation levels were measured within Willow Creek during the late summer and early fall 1998 at several locations. (It is important to note that the instruments [UniData Loggers] used to measure solar radiation were not calibrated, and therefore should only be considered as an indication of general solar radiation patterns at the river surface). Observed solar loading increased dramatically during "day-light" hours, indicating that very little shade is currently available to reduce incoming light (**Figure 4-6**). Similar results were measured at a site located approximately 14 km downstream ((DH = 26.707 km). These results indicate that sufficient light (solar radiation) is available for periphyton growth in the river.

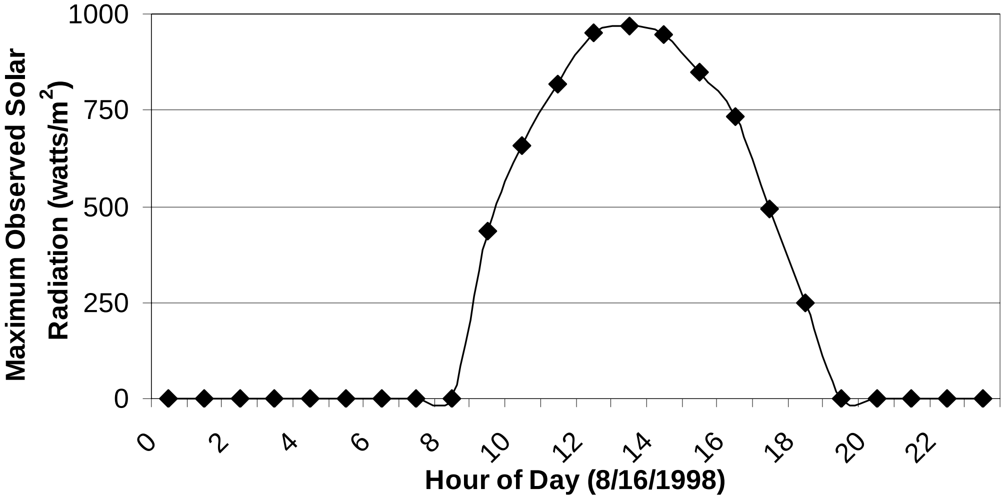


Figure 4-6. Maximum Solar Radiation Measured at the Water Surface of Willow Creek on August 16, 1998 at the Upper UAA Site (DH = 12.290 km)

4.4.1.3.2 Nutrients

Phosphorus and nitrogen are essential nutrients for algal growth, although not all forms are readily available for algal uptake. Phosphorus in the form of dissolved ortho-phosphate (d-ortho-P) and nitrogen in the form of ammonia, nitrate, and nitrite (NH_4-N and NO_3+NO_2-N) are readily available for algal uptake. Welch (1996) reported that long strands of attached filamentous green algae (periphyton) can develop within streams enriched with inorganic nutrients (nitrogen and phosphorus), especially when water velocity is relatively low. Filamentous green algae (periphyton) communities were observed in lower sections of Willow Creek during the summer of 1998 (**see Table 4-4**).

ODEQ sampled Willow Creek for water column nutrients between August 11 through 14, 1998. Median nutrient concentrations are presented in **Table 4-3**. Little variability in concentration was observed at a specific site during the course of the study, however variability was observed between sites for ortho-phosphorus and nitrate+nitrite nitrogen. The observed concentrations were sufficient to satisfy metabolic growth demands of periphyton (Welch 1996). There are no point source nutrient discharges present within the Willow Creek watershed, nor are there any known significant nonpoint sources. During ODEQ's field investigations of Willow Creek, no tangible evidence of human caused activities that could provide a nutrient source to the creek, such as livestock grazing, were observed. Therefore, it is suspected that the nutrient concentrations observed in Willow Creek are from "natural" geologic sources

Although ODEQ does not currently have numeric nutrient water quality standards, the U.S. EPA has recently published Ambient Water Quality Criteria Recommendations for Nutrients on an Ecoregion basis (U.S. EPA 2000). The recommendations are based on the 25th percentiles of all nutrient data collected within a given Ecoregion to estimate "reference" conditions without human caused impacts. For the Northern Basin and Range Ecoregion where Willow Creek is located, the 25th percentile data for NO_2+NO_3-N is 0.025 mg/L, for TKN is 0.23 mg/L and for total phosphorus is 0.055 mg/L.

Phosphorus. Summer phosphorus concentrations in Willow Creek are shown in **Figure 4-7**. Dissolved phosphorus concentrations changed very little, indicating that biological activity (e.g., attached and/or free floating algae) does not appear to effect instream phosphorus concentrations in Willow Creek. The beaver ponds also did not appear to dramatically affect phosphorus concentrations in the creek. Water quality samples were collected at both the upstream and downstream beaver pond locations (see **Figure 4-2** for approximate location of the ponds).

Total phosphorus concentrations observed along the whole length of Willow Creek were elevated above the Ecoregion “reference” condition of 0.055 mg/L total phsophorus (U.S. EPA 2000). A sample collected on August 14, 1998 in the “Hot Spring” located near the Willow Creek mainstem (DH 26.6, **Figure 4-2**) had similar phosphorus concentrations as those observed in the nearby creek (**Table 4-5**). This suggests that the relatively high phosphorus levels in the creek may be the result of groundwater recharge from natural sources. Total phosphorus concentrations did increase in the impacted downstream reach.

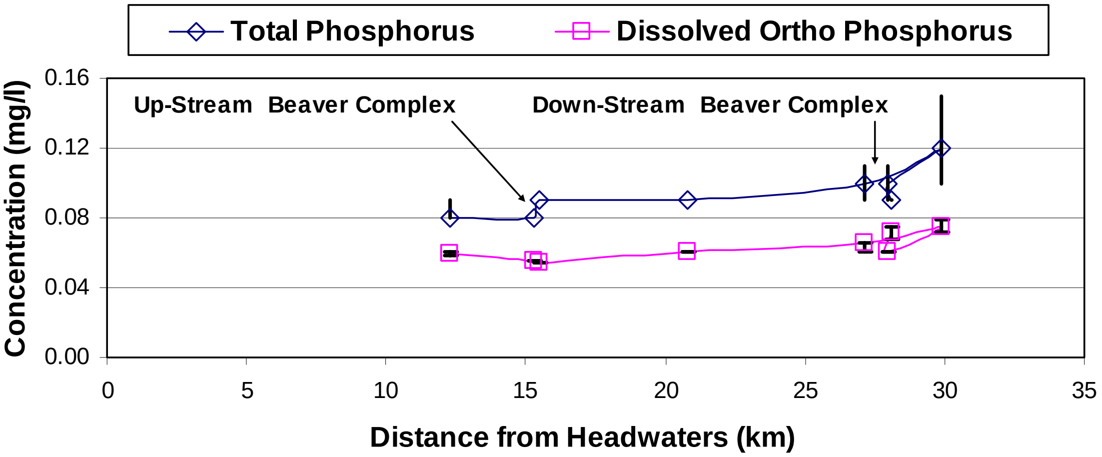


Figure 4-7. Obseved Summer Phosphorus Concentrations in Willow Creek during August, 1998.

[Bars represent the range of observed values at each station.]

Table 4-5. Observed nutrient concentrations in a Hot Spring that was located near the Willow Creek mainstem at approximately Dh 26.6 km on August 14, 1998

TP (mg/L)	d-Ortho-P (mg/L)	TKN (mg/L)	NH_4-N (mg/L)	NO_3+NO_2-N (mg/L)
0.09	0.046	0.2	0.03	0.03

Nitrogen. Observed TKN and ammonia nitrogen concentrations did not change much in Willow Creek (**Table 4-3**, **Figure 4-8**). However, observed nitrate+nitrite nitrogen concentrations were elevated in upstream sites. Concentrations at the upper sites were in excess of 0.30 mg/L in comparison with the Ecoregion “reference” concentration of 0.025 mg/L. Nitrate+nitrite nitrogen concentration decreased steadily with distance down the creek, with concentrations of 0.02 mg/L at the lowest monitoring site. Nitrate+nitrite nitrogen concentrations in the hot spring were 0.03 mg/L, suggesting that nitrate+nitrite nitrogen levels in the groundwater may also be 0.03 mg/L. It appears that, over the length of the creek, instream nitrate+nitrite nitrogen concentrations are being 1) consumed by the periphyton, 2) denitrified, and/or 3) diluted with groundwater with low nitrate+nitrite-nitrogen concentrations (see **Table 4-5**). It is not possible to determine, with available information, which of the above mentioned factor(s) are responsible for this decreasing nitrogen concentration trend in Willow Creek, or what is causing the elevated nitrate+nitirite nitrogen concentrations at higher elevations.

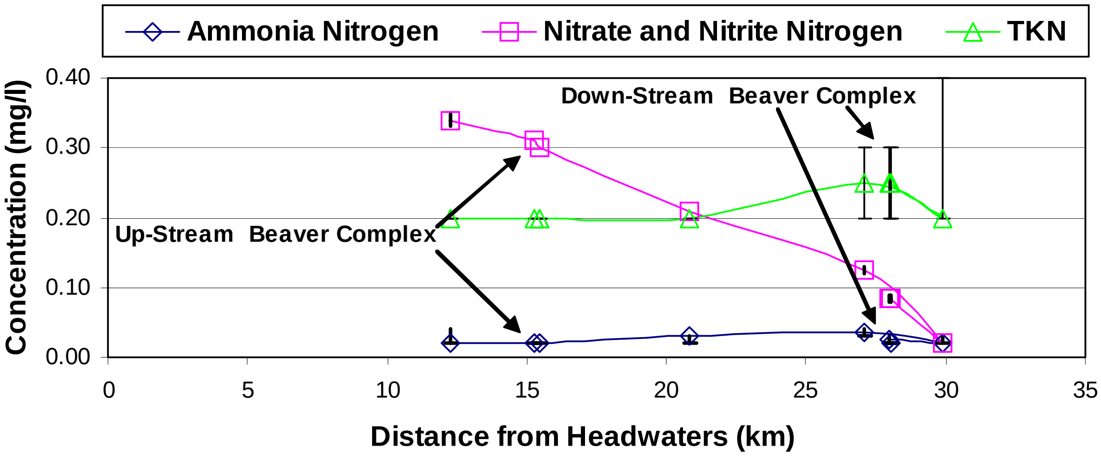


Figure 4-8. Obseved Summer Nitrogen Concentrations in Willow Creek during August, 1998.

[Bars represent the range of observed values at each station.]

4.4.1.3.3 Water Temperature

Numerous researchers have determined that algae (periphyton) growth rates are positively correlated with water temperature (McIntire and Phinney 1965; Eppley 1972) (**Figure 4-9**). Welch (1996) concluded that the long-term consequence of a water temperature increase was a gradual change of the algal community composition towards a dominance by nuisance species (i.e., filamentous blue-green algae) resulting in greater net production in the river. See **Section 4.4.1.4** below for a further discussion of the effects of temperature on dissolved oxygen concentrations in Willow Creek.

4.4.1.4 Temperature

Temperature has a significant impact on the dissolved oxygen in a stream in two ways. The first is that with increasing temperatures the amount of oxygen that can remain dissolved in water decreases. The second is that, in general, all of the dissolved oxygen sinks listed above increase their oxygen consumption as temperature increases. Increased temperature increases the metabolic rate of microflora which results in higher productivity and respiration rates of oxygen which in turn results in decreased dissolved oxygen in the stream.

Water temperatures have been measured extensively in the Willow Creek watershed during the past several years by several agencies. A detailed description of the water temperature conditions in Willow Creek is provided in **Chapter III – Willow Creek Temperature TMDL**.

Water temperature trends within Willow Creek follow observed pH and dissolved oxygen trends. Areas with high observed daily maximum pH levels and low observed dissolved oxygen concentrations are associated with river reaches where water temperatures are the highest (**Figures 4-3, 4-5** and **4-10**). Conditions leading to elevated water temperatures in lower Willow Creek (i.e., little or no riparian shade - see **Section 3.4.3.1.1)** also result in elevated pH levels and low dissolved oxygen concentrations in Lower Willow Creek.

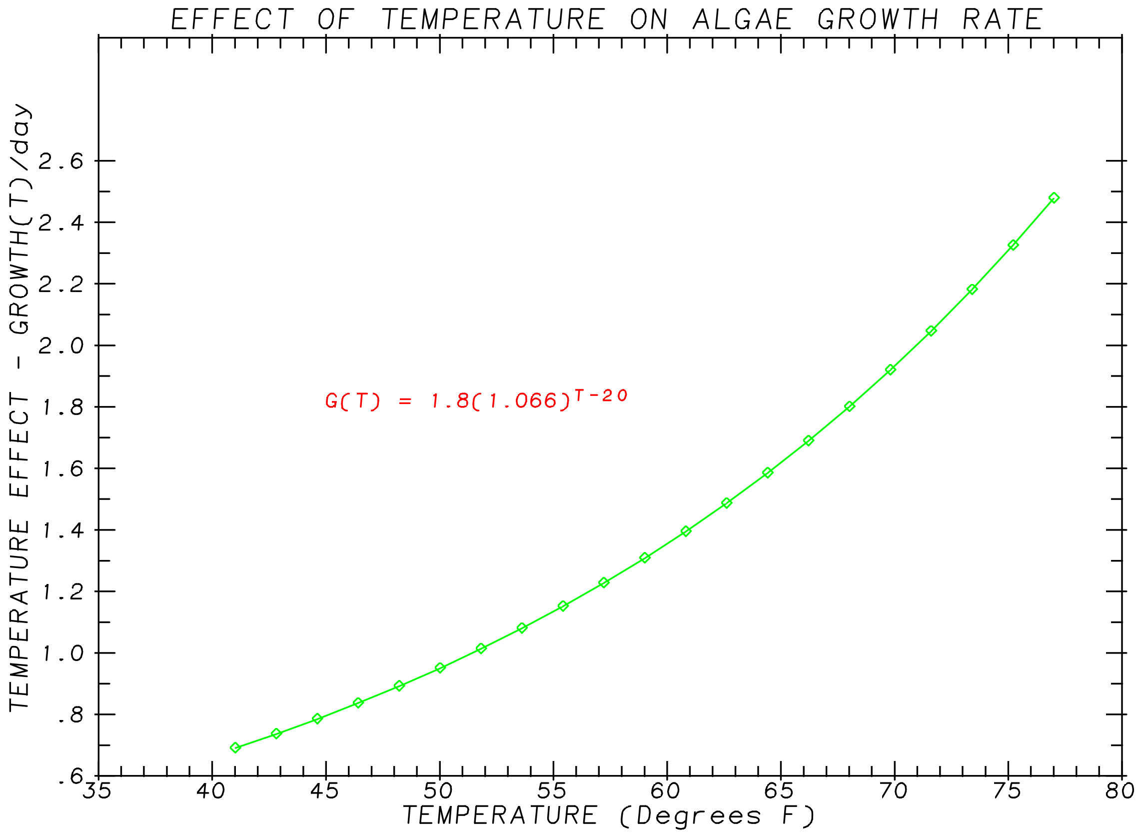


Figure 4-9. The Theoretical Relationship between Instream Temperature and Algal Growth

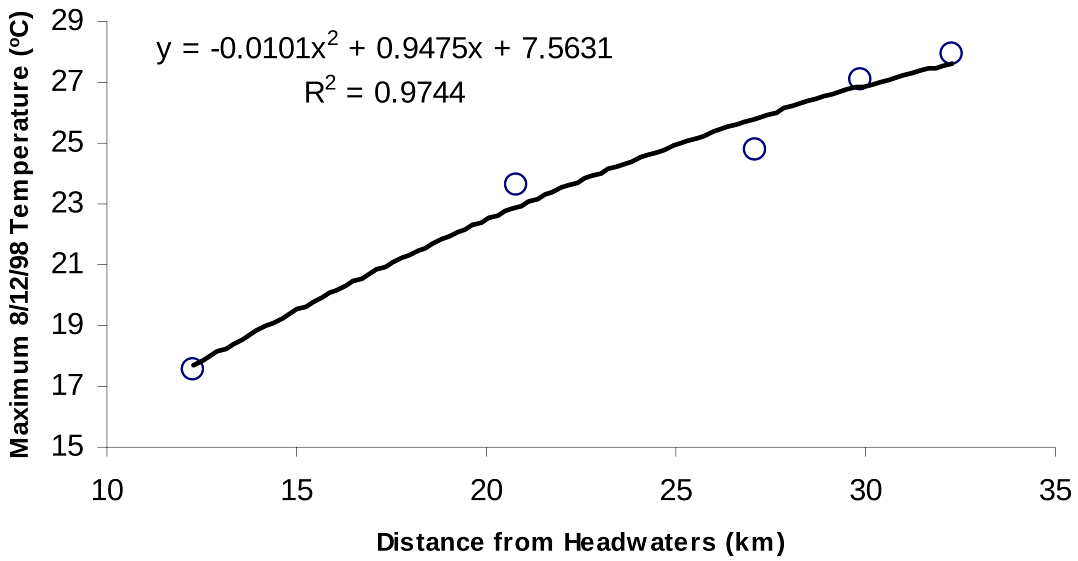


Figure 4-10. Water Temperature Profile in Willow Creek on August 12, 1998.

4.4.1.5 Other

While there are other factors such as stream flow that may influence the dissolved oxygen in Willow Creek, these are not considered pollutants (or the result of pollutants) and therefore are not analyzed within the TMDL context for allocations. It should be mentioned, however, that flow does play an important role in regulating stream temperature (see **Section 3.4.3.2**). Stream temperature change is generally inversely related to flow volume. As flows decrease, stream temperature tends to increase if energy processes remain unchanged (Boyd 1996).

The monitoring site in the East Channel below the Lower Beaver Complex had very reduced flows when channel morphology data was collected in August, 2001. On August 29, 2001, flows in Willow Creek above the Lower Beaver Complex were 1.6 cfs. Flows were measured in the East and West Channels below the beaver complex (two of multiple channels below the beaver complex) on the same day. Flow in the West Channel was 0.9 cfs and in the East Channel was 0.3 cfs.

4.4.2 Analysis – Regression Model

In the source assessment provided above in **Section 4.4.1**, the primary adverse impact to dissolved oxygen concentrations in Willow Creek is the removal of riparian vegetation and its associated shade. The lower portions of Willow Creek have little or no shade, which in turn results in an increased rate of stream warming, increased periphyton growth and decreased dissolved oxygen due to periphyton respiration (**Figure 4-11**). No other significant potential human caused sources were identified, either through an examination of water quality indicators or a review of potential human caused sources in the basin. For this reason, ODEQ decided to focus the analysis on the improvement in instream dissolved oxygen concentrations that would result from implementing the temperature TMDL *system potential* vegetation allocations (**Section 3.4.3.4**).

As presented in **Section 3.4.3.4**, the measured daily maximum stream temperature in Reach 5 (the most downstream reach modeled) in 1998 was 27.9°C (82.2°F). With *system potential* riparian vegetation in this reach, the simulated maximum stream temperature in this reach was 21.8°C (71.2°F). **Figure 4-12** shows the association between dissolved oxygen and temperature in Willow Creek observed from the grab sample data collected by ODEQ in 1998. The regression analysis ignores other factors, such as the effect that nutrients and light have on algal growth, and subsequently dissolved oxygen. Nonetheless, it illustrates an association between dissolved oxygen and instream temperature.

Using the regression equation (R^2=0.77) presented in **Figure 4-12**, the dissolved oxygen concentrations corresponding to 27.9°C and 21.8°C were compared. Under 1998 conditions, the dissolved concentration using this equation was predicted to be 5.9 mg/L. This is similar to the concentration observed at the East Channel sampling site below the Beaver Complex (the site where the dissolved oxygen standard was exceeded based on 1998 data). Under *system potential* thermal conditions (21.8°C), the predicted dissolved oxygen concentration was 7.1 mg/L., an increase of 1.2 mg/L, and well above the cool-water dissolved oxygen criterion of 6.5 mg/L.

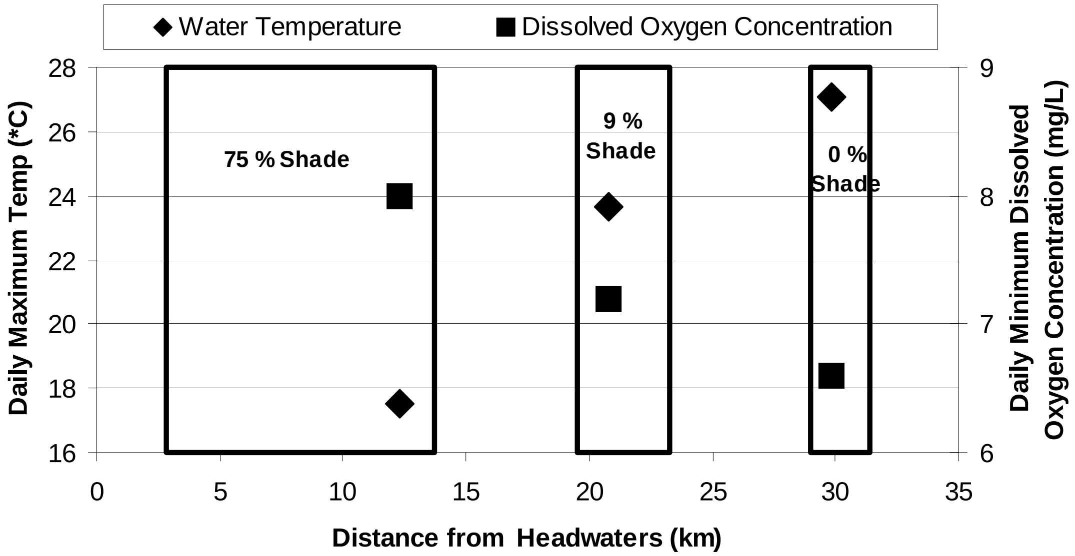


Figure 4-11. Summary of Observed Daily Minimum Dissolved Oxygen Concentration and Daily Maximum Water Temperatures in Willow Creek on 8/12/1998.

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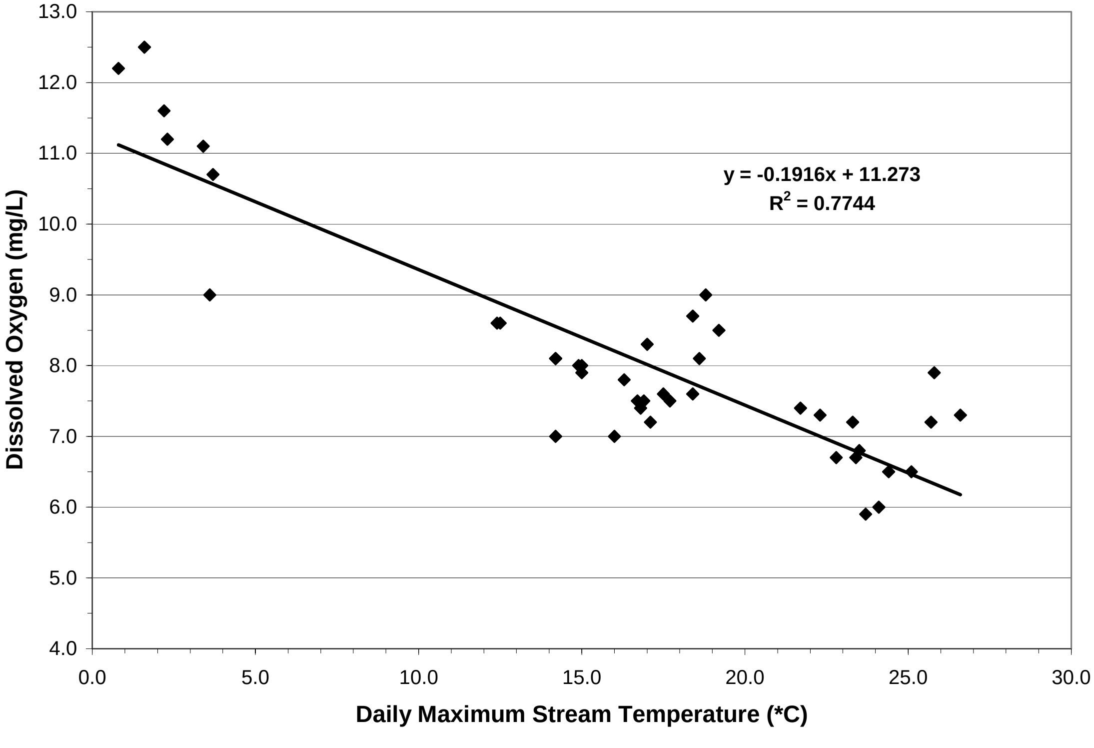


Figure 4-12. Correlation between Daily Maximum Water Temperature and Dissolved Oxygen Concentration in Willow Creek – August 11-13, 1998

4.5 LOADING CAPACITY - 40 CFR 130.2(F)

As discussed in the source assessment, a water quality concern in the lower reaches of Willow Creek is that dissolved oxygen concentrations violate the State of Oregon water quality criterion for cool-water aquatic life of 6.5 mg/L. The presence of attached algae (periphyton) can have a profound effect on the variability of dissolved oxygen throughout a day and from day to day.

Nutrients, light availability, and instream temperature are all parameters necessary for supporting periphyton growth. The data review indicates that the best opportunity to reduce dissolved oxygen to below the water quality standard is through the implementation of the Willow Creek Temperature TMDL (**Chapter III**).

The rate of periphyton growth is limited by the availability of light, nutrients, and water temperature. *In a situation where the available light for periphyton growth is at an optimum level and nutrients are plentiful, then the growth of periphyton will be dependent on the temperature effect* (Thomann and Mueller, 1987). The algal growth rate increases significantly as the instream temperature increases (**Figure 4-9**).

The data review also indicates that the decrease in dissolved oxygen is associated with the increase in instream temperature. The regression analysis of dissolved oxygen versus temperature (**Figure 4-12**) predicts that instream dissolved oxygen concentrations will be maintained above the cool-water criterion (6.5 mg/L) when *system potential* temperature TMDL allocations and the resulting instream cooling are achieved. The temperature model of Willow Creek (**Section 3.4.3.4**) predicts *system potential* temperatures as shown in **Table 4-6** (recall of table in **Figure 3-6**). The dissolved oxygen vs. temperature regression predicts the instream dissolved oxygen associated with these *system potential* temperatures (last column in **Table 4-6**). In all reaches, the dissolved oxygen standard is achieved when the creek achieves *system potential* temperatures. ***The loading capacities for this TMDL are therefore the system potential instream temperatures as predicted in Section 3.9 Water Quality Standard Attainment Analysis – CWA §303(d)(1).***

Table 4-6. Effect of Solar Radiation Loads on Daily Maximum Stream Temperature and Minimum Dissolved Oxygen Concentration

Simulated Willow Creek Reach	Distance from Headwaters (Km)	Current Condition Measured Daily Maximum Stream Temperature (°C)	Current Condition Measured Daily Minimum Stream D.O. (mg/L)	System Potential Simulated Daily Maximum Stream Temperature (°C)	System Potential Simulated Daily Minimum Stream D.O. (mg/L)
1	16.6	**18.7 (65.7°F)**	**--**	**17.4 (63.3°F)**	**7.9**
2	20.8	**23.6 (74.5°F)**	**6.8 mg/L**	**20.3 (68.5°F)**	**7.4**
3	27.1	**24.8 (76.6°F)**	**6.5 mg/L**	**19 (66.2°F)**	**7.6**
4	29.9	**27.0 (80.6°F)**	**6.5 mg/L**	**22 (71.6°F)**	**7.1**
5	32.3	**27.9 (82.2°F)**	**--**	**21.8 (71.2°F)**	**7.1**

4.6 ALLOCATIONS - 40 CFR 130.2(G) AND (H)

Load Allocations are portions of the loading capacity divided between natural, human and future nonpoint pollutant sources. **Table 4-7** lists load allocations (i.e. distributions of the loading capacity) according to land-use. Each DMA's portion of the WQMP (**Appendix A**) will address only the lands and activities within each identified stream segment to the extent of the DMA's authority. A *Waste Load Allocation* (WLA) is the amount of pollutant that a point source can contribute to the stream without violating water quality criteria. Because there are no point sources in the Alvord Lake Subbasin, no waste load allocation was derived. The dissolved oxygen regression analysis of Willow Creek determined that achieving the load allocations established for temperature will reduce periphyton growth and lead to the attainment of the water quality standards for dissolved oxygen. Therefore, the loading capacity of the Willow Creek Watershed for dissolved oxygen is all allocated to natural sources since, even at *system potential* conditions, temperatures in the watershed will still exceed the 64°F standard (see **Section 3.4.3.4**). No assimilative capacity exists for nonpoint sources. This requires that nonpoint sources reduce heat inputs to reach *system potential* conditions. These conditions will be achieved through restoring and protecting riparian vegetation, narrowing of stream channel widths and, where appropriate, increasing instream flows.

This load allocation also assumes that there will be no additional dissolved oxygen demands placed on the system by other human caused activities. If and when *system potential* conditions are achieved in the future in the Alvord Lake Subbasin, and it is determined that there is, in fact, some dissolved oxygen load available to allocate to human caused sources, then ODEQ may reevaluate this TMDL and redistribute the available load.

Table 4-7. Oxygen Demand Load Allocation Summary

Source	Loading Allocation
Natural	100%
Agriculture	0%
Forestry	0%
Future Sources	0%

4.7 MARGINS OF SAFETY – CWA §303(D)(1)

A MOS has been incorporated into the temperature assessment methodology (see **Section 3.8** for more details). It should also be noted that this modeling exercise solely focused on solar radiation as a function of riparian vegetation and the shade it provides the stream. In essence, excluding flow changes, channel morphology changes and cooler microclimates as they relate to riparian vegetation condition, almost certainly underestimates the cooling attributed to allocated riparian restoration scenarios. It is also likely that the simulation results underestimate potential cooling induced by the loading capacities because the simulation reaches do not extend to headwaters. In effect, these modeling results do not represent the true stream networks as they exist, and instead, are selected stream reaches simulated in a series.

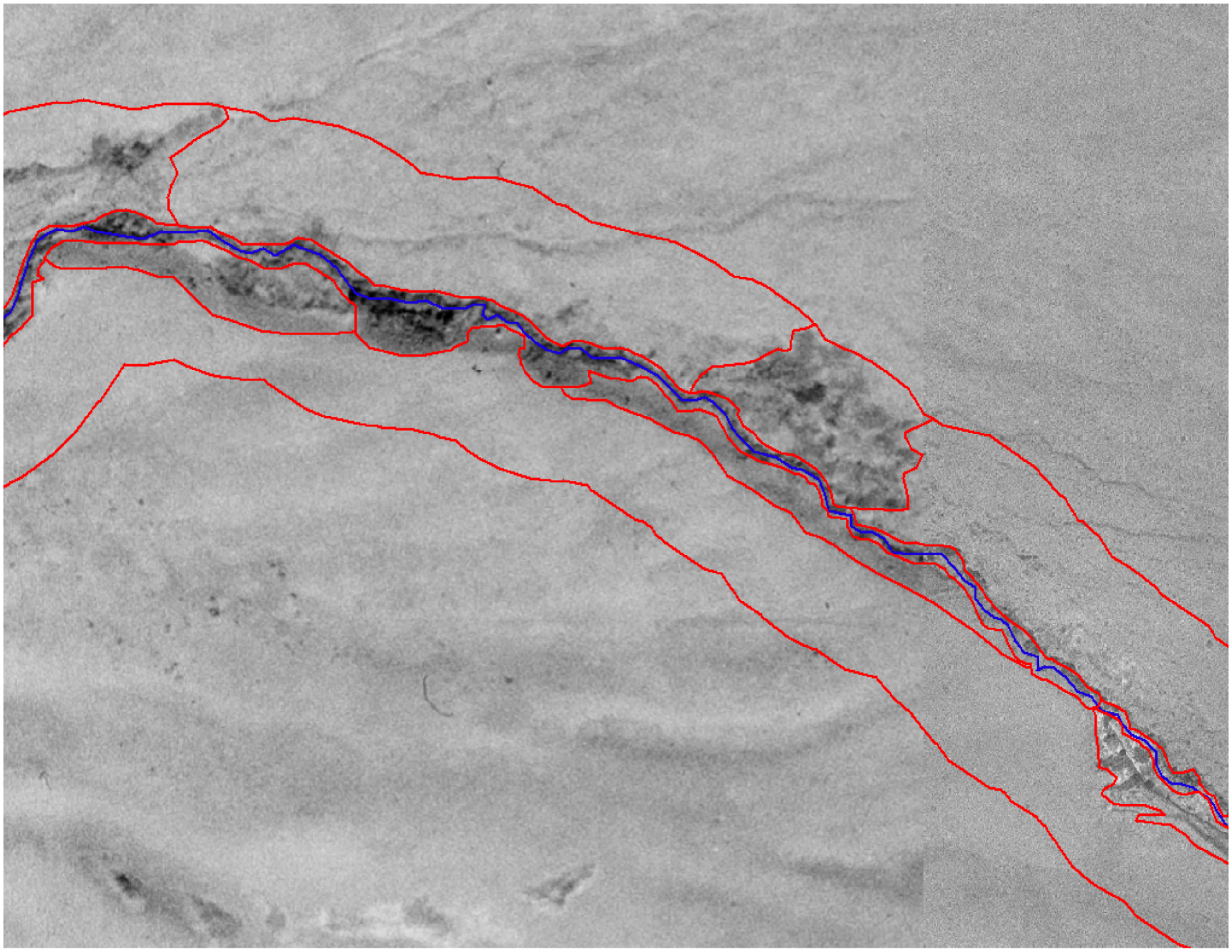
The following explicit margin of safety also applies in determination of the Dissolved Oxygen TMDL for Willow Creek:

- The dissolved oxygen criterion applicable to this TMDL is an absolute minimum dissolved oxygen concentration of 6.5 mg/L. The regression model predicted that during summer low flow (critical) conditions in the lower reaches of Willow Creek, the absolute minimum dissolved oxygen will be 7.1 mg/L. Targeting 7.1 mg/L dissolved oxygen provides an explicit margin of safety of 0.6 mg/L.

4.8 WATER QUALITY STANDARD ATTAINMENT ANALYSIS – CWA §303(D)(1)

Stream temperature simulation results, presented in **Figure 3-15** clearly demonstrate that *system potential* effective shade levels can drastically reduce the amount of heat entering the stream, which results in cooler stream temperatures. And the regression analysis presented in **Figure 4-12** and **Table 4-5** clearly demonstrates that with these cooler *system potential* temperatures, the absolute minimum dissolved oxygen concentration criterion of 6.5 mg/L will be achieved. Since this is the first iteration of this TMDL, it can be refined at a later date when and if additional data are available.

CHAPTER V: TEMPERATURE TMDL ANALYTICAL FRAMEWORK



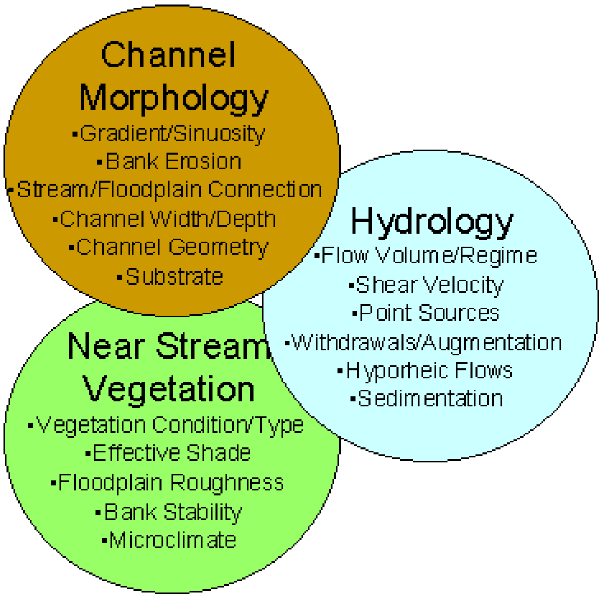
Digital orthoquad photo with digitized stream position (blue) and near stream vegetation (red) to 300 feet from channel edge on both banks (Mosquito Creek).

5.1 SCOPE

Parameters that affect stream temperature can be grouped as near stream 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 the Alvord Lake Subbasin Temperature TMDLs are designed to include all of the parameters that affect stream temperature provided that available data and methodologies allow accurate quantification.

Stream temperature dynamics are complicated when these three parameters (i.e. near stream land cover, channel morphology and hydrology) 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 consider all of these parameters and rely on ground level and remotely sensed spatial data. To understand temperature on a landscape scale is a difficult and often resource intensive task. General analytical techniques employed in this effort are statistical and deterministic modeling of hydrologic and thermal processes.

Factors That Affect Stream Temperature Dynamics



(Many of these parameters are interrelated)

Stated Purpose:

The overriding intent of this analytical effort is to improve the understanding of the Alvord Lake Subbasin 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.

- 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. Current analytical methods fail to capture some upland, atmospheric and hydrologic processes. At a landscape scale can these exclusions can lead to errors in analytical outputs. For example, quantification techniques for microclimates that occur in near stream areas are not developed and available to this effort.
- 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.
- Current analysis is focused on a defined critical condition. This critical condition 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 is less explicit. For example, spawning periods have not received such a robust consideration.
- Small desert streams present significant challenges when attempting to characterize existing and *system potential* vegetation conditions due to the narrow channel widths (3-4 meters) and the absence of wide riparian corridors (as little as 7-8 meters in some places). The Heat Source model used by ODEQ in TMDL development is generally applied in situations where the width of the stream and riparian area are much greater (typically greater than 20 meters) and upland conditions, such as forests, are vastly different than in the Alvord Lake Subbasin.
- 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.
- In some cases, like the Trout Creeks, there is not scientific consensus related to riparian and hydrologic potential conditions because there was insufficient time to complete the field studies. In this instance ODEQ used the best available information including recent vegetative surveys and applied best professional judgment when determining *system 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).
- ODEQ has documented natural lose-gain phenomena which must be considered in the application of this temperature TMDL's surrogate measure: *system potential* vegetation. There are certain sections on the lower end of many streams where there is insufficient water to support riparian vegetation because of these naturally occurring conditions. This phenomenon is recognized in this TMDL through *system potential* calculations where site specific data are available. Also, when measuring attainment of *system potential* vegetation and channel morphology this phenomenon must be recognized.

While these assumptions outline potential areas of weakness in the methodology used in the stream temperature analysis, ODEQ has undertaken a comprehensive approach. All of the important stream parameters that could be accurately quantified are included in this analysis. In the context of understanding of stream temperature dynamics in the Alvord Lake Subbasin, these areas of limitations should be the focus for future study. ODEQ acknowledges the limitations stated above in accordance with the scientific method and it also recognizes that this analytical effort provides a rigorous, complete, statistically valid and advanced treatment of stream temperature dynamics.

The remainder of this section describes stream heating processes. It is then followed by two sections, one describing the analytical methodology used in **Chapter II** and one describing the methodology used in **Chapter III**. Because these two TMDLs were done at different times using different versions of Heat Source, the methodologies are somewhat different. The outcomes are different as well. In **Chapter II**, data limitations precluded simulations of instream temperatures. Instead, load allocations were developed based on the potential and received solar radiation flux at the stream surface and on effective shade surrogate measures. Most of the actual model results have already been presented in **Chapter II**. In **Chapter III**, in-stream temperatures under *system potential* conditions were calculated, in addition to solar flux and effective shade. Because of the more involved model calculations used in determining in-stream temperatures, more model validation data is provided in **Section 5.4**.

5.2 OVERVIEW OF STREAM HEATING PROCESSES

Stream temperature dynamics are complex. Changes in rates of heat transfer can vary considerably across relatively small spatial and temporal scales. In quantifying and understanding stream heat and mass transfer processes, the challenge is not represented in theoretical conceptions of thermodynamics and relations to flowing water. Thermodynamics is a well-established academic discipline that offers a scientifically tested methodology for understanding stream temperature. In fact, the methodology used to evaluate stream temperature is quite simple when compared to other thermodynamic applications that have become common technological necessities to the American way of life (i.e. a car radiators, cooling towers, solar thermal panels, insulation, etc.). Instead, the true challenge in understanding stream temperature materializes with the recognition that thermally significant heat and mass transfer processes occur in very fine spatial and temporal scales. Tremendous spatial variability occurs across a watershed, and is compounded by adding a temporal component. At any stream reach, thermal processes constantly change throughout the day, month and year. Stream temperatures are a result of a multitude of heat transfer and mass transfer process. The conceptual and analytical challenge is to develop a framework that captures these forms of variability to the best possible extent.

Water temperature change (ΔT_w) is a function of the heat transfer in a discrete volume and may be described in terms of changes in heat per unit volume. It is then possible to discuss stream temperature change as a function of two variables: heat and mass transfer.

Water Temperature Change as a Function of Heat Exchange per Unit Volume:

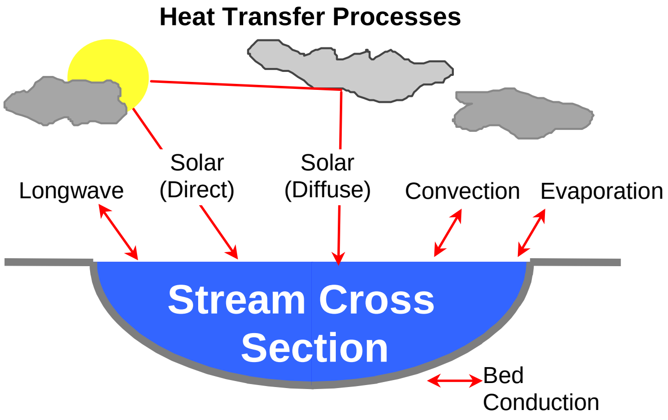
$$\Delta T_w \propto \frac{\Delta \text{Heat}}{\text{Volume}}$$

1. **Heat transfer** relates to processes that change heat in a defined water volume. There are several thermodynamic pathways that can introduce or remove heat from a stream. For any given stream reach, heat exchange is closely related to the season, time of day and the surrounding environment and the stream characteristics. Heat transfer processes can be dynamic and change over relatively small distances and time periods. Several heat transfer processes can be affected by human activities. These pathways are discussed below in **Section 5.2.1 Heat Transfer Processes**.

2. **Mass transfer** relates to transport of flow volume downstream, instream mixing and the introduction or removal of water from a stream. For instance, flow from a tributary will cause a temperature change if the temperature is different from the receiving water. Mass transfer occurs commonly in stream systems as a result of advection, dispersion, groundwater exchange, hyporheic flows, surface water exchange and other human related activities that alter stream flow volume. Mass transfer processes are discussed in **Section 5.2.2 Mass Transfer Processes**.

5.2.1 Heat Transfer Processes

Stream heating processes follow two cycles: a seasonal cycle and a diurnal cycle. In the Pacific Northwest, the seasonal stream heating cycle experiences a maximum positive flux during summer months (July and August) while the minimum seasonal stream heating periods occur in the winter months (December and January). The diurnal net heating cycle experiences a daily maximum at or near midday. This maximum usually corresponds to the solar zenith. The daily minimum rate of stream heating usually occurs during the late night or the early morning. It should be noted, however, that meteorological conditions are variable. Cloud cover and precipitation, humidity and wind seriously alter the heat transfer pathways between the stream and its environment.



The heat transfer processes that control stream temperature include solar radiation, longwave radiation, convection, evaporation, and bed conduction. All other processes are capable of both introducing and removing heat from a stream, with the exception of solar radiation, which only delivers heat energy. These thermal processes occur simultaneously and result in an overall rate of heat exchange with a stream.

When a stream surface is exposed to midday solar radiation, large quantities of heat will be delivered to the stream system (Brown 1969, Beschta et al. 1987). Low levels of stream shade allows solar radiation to become a dominant stream heating transfer process. This holds true even when accounting for surface reflection and the absorption properties of water outside the visible spectrum. As would be expected maximum heat transfer rates occur when a stream is exposed to midday solar radiation.

Longwave radiation, also referred to as thermal radiation, is a source of both heating and cooling. Longwave radiation heat is derived from the atmosphere and vegetation along stream banks and is a source of heat when received by the stream surface. Water readily absorbs the thermal spectral wavelength. Longwave radiation is also emitted from the stream surface, and thus, has a cooling influence. Thermal radiation emitted from the stream is called back radiation and can be accurately measured from aerial remote sensing equipment. 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). The overall net heat transfer rate from longwave radiation (i.e. the sum from the atmosphere, surrounding land cover and back radiation from the stream) is small relative to other thermal processes.

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. This is the preferred cooling mechanism employed by the human body via perspiration. As stream temperatures increase, so does the rate of evaporation. Air movement (wind) and low vapor pressures and relative humidity increase the rate of evaporation and accelerate stream cooling. Evaporation is the primary mechanism for stream cooling.

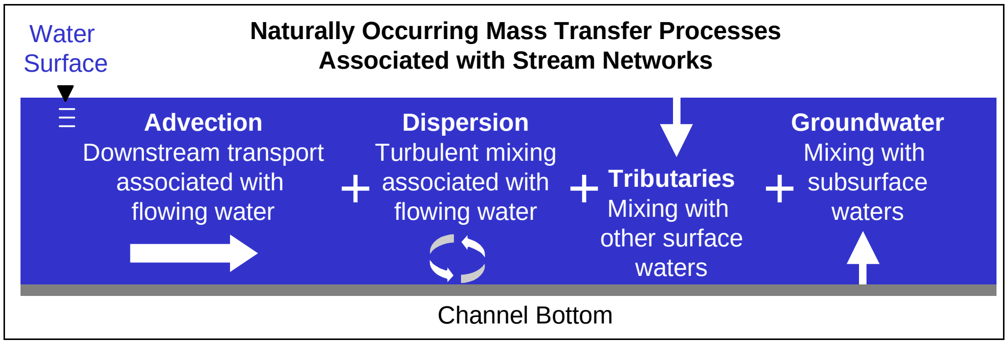
Condensation is the opposite of evaporation. When the air temperature reaches the dew point, the air mass at the stream surface interface becomes saturated and triggers a phase change of water vapor into liquid. Condensation represents a heating process, but occurs during limited portions of the day if at all (usually during early morning periods when nighttime temperatures are cool). Condensation is a minor component relative to other the heat transfer processes.

Convection transfers heat between the stream and the air via molecular and turbulent conduction. 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. Air has a low conductance relative to water and simply cannot conduct heat efficiently. An easy way to conceptualize the conductance between water and air is to compare the body's perception of temperature when both water and air are at the same temperature. Human exposure to air at 60°F is possible for long periods, while exposure to 60°F water is fatal in a matter of two hours. Air is a poor conductor of heat. Nevertheless, this should not be interpreted to mean that air temperatures do not affect stream temperature. Air temperatures play a complex role in stream heating processes affecting vapor pressure gradients, relative humidity and atmospheric thermal radiation levels. However, air temperatures can only impart heat to a stream very slowly via conduction.

Depending on streambed composition, solar radiation may warm the streambed. Larger substrate dominated streambeds and/or shallow streams may allow the bed to differentially heat and then conduct heat to the stream as long as the bed is warmer than the stream. Bed conduction of heat to the water column may cause maximum stream temperatures to occur later in the day, possibly into the evening hours. Heat associated with physical processes such as friction and compression is a negligible source and is not included in this analysis.

5.2.2 Mass Transfer Processes

Mass transfer processes refer to the downstream transport and mixing of water throughout a stream system. The downstream transport of dissolved/suspended substances and heat associated with flowing water is called advection. Dispersion results from turbulent diffusion that mixes the water column. Due to dispersion, flowing water is usually well mixed vertically. Stream water mixing with inflows from surface tributaries and subsurface groundwater sources also redistribute heat within the stream system. These processes (advection, dispersion and mixing of surface and subsurface waters) redistribute the heat of a stream system via mass transfer.

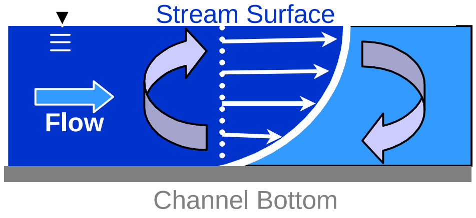


Heat that is transported by river flow is referred to as advected heat. It follows that advection can only occur in the downstream direction. No heat energy is lost or gained by the system during advection, assuming the heat from mechanical processes such as friction and compression is negligible. Advection is simply the rate at which water and heat is transferred downstream.

Dispersion refers to the mixing caused by turbulent diffusion. In natural stream systems flows are often vertically mixed due to turbulent diffusion of water molecules. Turbulent flows result from a variable flow velocity profile, with lower velocities occurring near the boundaries of the channel (i.e. channel bottom and stream banks). Higher velocities occur farthest away from channel boundaries, commonly at the top of the water column. The velocity profile results from the friction between the flowing water and the rough surfaces of the channel. Since water is flowing at different rates through the channel cross-section, turbulence is created, and vertical mixing results. Dispersion mixes water molecules at a much higher rate than molecular diffusion. Turbulent diffusion can be calculated as a function of stream dimensions, channel roughness and average flow velocity. Dispersion occurs in both the upstream and downstream directions.

Dispersion refers to mixing from turbulent flow.

Dispersion results from a vertical velocity profile. Velocity varies as a function of channel depth. Slower velocities occur at the bottom of the water column. Faster velocities occur at the top of the water column. The vertical gradient in flow velocity causes a tumbling motion of water.

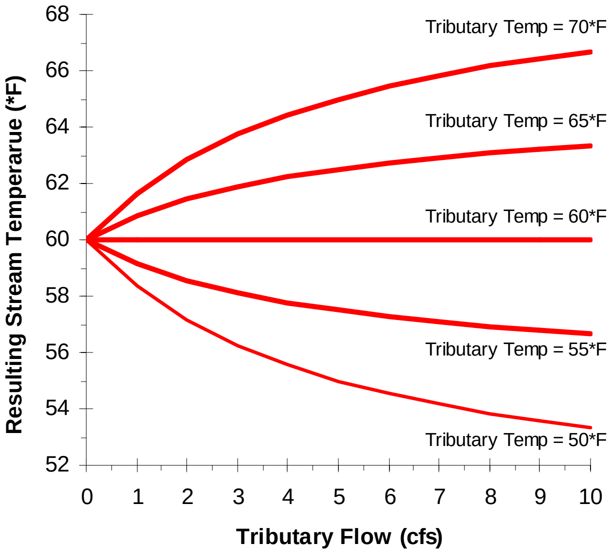


Tributaries and groundwater mixing change the heat of a stream segment when the stream temperature is different from the receiving water. Mixing simply changes the heat as a function of stream and inflow volumes and temperatures. Remote sensing using forward looking infrared radiometry can easily identify areas where heat change occurs due to mixing with surface and subsurface waters.

Example of Resulting Stream Temperatures After Stream Mixing With Variable Tributary Flows and Temperatures

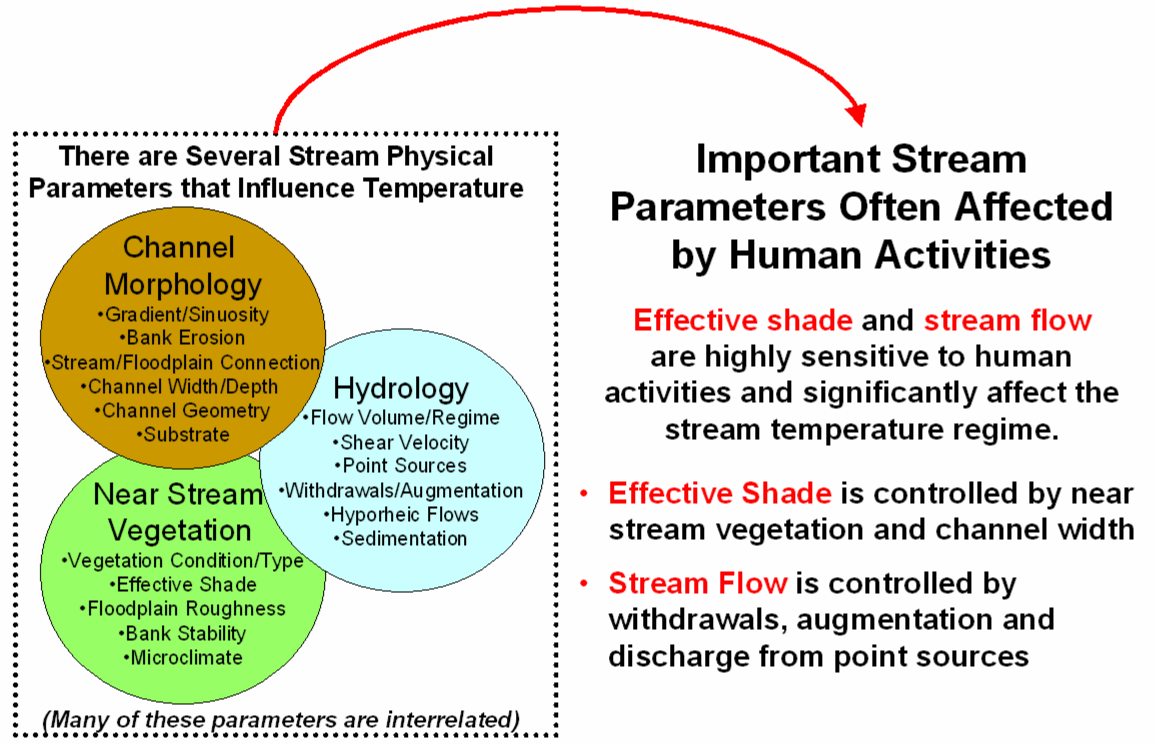
Stream Flow = 5 cfs

Stream Temperature = 60ºF



5.2.3 Human Sources of Stream Warming

The overriding intent of the Oregon stream temperature standard is to reduce human related stream warming to the point where it is not measurable. Brown (1969) identified temperature change as a function of heat and stream volume. Using this simple relationship, it becomes apparent that stream temperature change is a function of the heat transfer processes and mass transfer processes. To isolate the human influence on this expression, it is important to associate the human influence on the heat transfer processes and/or mass transfer processes.



Important Stream Parameters Often Affected by Human Activities

Effective shade and stream flow are highly sensitive to human activities and significantly affect the stream temperature regime.

- **Effective Shade is controlled by near stream vegetation and channel width**
- **Stream Flow is controlled by withdrawals, augmentation and discharge from point sources**

5.2.3.1 Solar Radiation and Effective Shade

The solar radiation heat process considered in the stream thermal budget is often the most significant heat transfer process and can be highly influenced by human related activity. Decreased levels of stream shade increase solar radiation loading to a stream. The primary factors that determine of stream surface shade are near stream vegetation physical characteristics and channel width. Near stream vegetation height controls the shadow length cast across the stream surface and the timing of the shadow. Channel width determines the shadow length necessary to shade the stream surface. Near stream vegetation and channel width are sometimes interrelated in that stream bank erosion rates can be a function of near stream vegetation condition. *Human activities that change the type or condition of near stream land cover and/or alter stream channels by widening beyond appropriate channel equilibrium dimensions to levels that result in decreased stream surface shading will like have a warming effect on stream temperature.* Such human activities include grazing of riparian vegetation by livestock, logging or clear-cutting of riparian vegetation, and straightening or armoring of stream channels.

5.2.3.2 Stream Flow Modifications

Recall the simple relationship presented by Brown (1969):

$$\Delta T_w \propto \frac{\Delta \text{Heat}}{\text{Volume}}.$$

It follows that large volume streams are less responsive to temperature change, and conversely, low flow streams will exhibit greater temperature sensitivity. Specifically, stream flow volume will affect the wetted channel dimensions (width and depth), flow velocity (and travel time) and the stream assimilative capacity. *Human related reductions in flow volume can have a significant influence of stream temperature dynamics, most likely increasing diurnal variability in stream temperature.*

Beyond the simple conception of reduced flow and corresponding reduced assimilative capacity, flow modifications can be highly complex in nature. Diversions can reroute surface waters through irrigation systems of various efficiencies. Often a portion of it irrigated water returns to the stream system at some lower gradient location.

5.2.4 Natural Sources and Stream Warming

Natural sources that may elevate stream temperature include hot springs, drought, fires, insect damage to near stream land cover, diseased near stream land cover and windthrow and blowdown in riparian areas. The processes in which natural sources affect stream temperatures include increased stream surface exposure to solar radiation and decreased summertime flows. Legacy conditions (increased width to depth ratios and decreased levels of stream surface shading) that currently exist are, in part, due to natural disturbances. The extent of natural disturbances on near stream vegetation, channel morphology and hydrology in not well documented.

5.3 SIMULATIONS:ALVORD LAKE SUBBASIN TMDL (CHAPTER II)

5.3.1 Overview of Modeling Purpose, Valid Applications & Limitations

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 and has been regularly upgraded through 2003. The model has been peer reviewed and comments are available on the ODEQ website at: http://www.ODEQ.state.or.us/wq/HeatSource/HeatSource.htm. ODEQ currently supports the Heat Source methodology and computer programming.

The version of the Heat Source model used in this TMDL is comprised of modules that can simulate dynamic open channel hydraulics, flow routing, heat transfer, effective shade and stream temperature. In order to accurately simulate the thermal response of the stream to changes in near stream vegetation, channel morphology, and/or in-stream flow, detailed in-stream temperature and flow measurements are required. Summertime flows in modeled streams typically need to be greater than 2 cfs in order to calibrate the current condition scenarios. In the Alvord Lake Subbasin, there are few continuous flow gauges in the Subbasin and summertime flows in all streams are less than 2 cfs. Because of this limitation, the open channel hydraulics, flow routing, heat transfer processes and water column temperature modules could not be utilized in developing the Alvord Lake Subbasin TMDL.

Instead, the load allocations for the Alvord Lake Subbasin TMDL were developed using the module in Version 6.0 of Heat Source that calculates the potential and received solar radiation flux at the stream surface and also provides effective shade output data. This portion of the model is called “Shade-a-lator”. Near stream land cover and effective shade analyses were utilized in this portion of the model.

5.3.1.1 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.
- Many areas within the Alvord Lake Subbasin were not analyzed. This analytical effort provides site specific near stream land cover targets for 58.7 river miles on seven streams. This represents approximately 24% (7 of 29) of the total number of streams where the TMDL applies (**Table 2-2**).

5.3.1.2 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. channel morphology and near stream land cover type and physical attributes).
- The period of simulation is valid for effective shade values that occur in late July and early August.
- Many areas within the Alvord Lake Subbasin were not analyzed. This analytical effort provides site-specific effective shade targets for 58.7 river miles on seven streams. This represents approximately 24% (7 of 29) of the total number of streams where the TMDL applies (**Table 2-2**).

5.3.2 Effective Shade

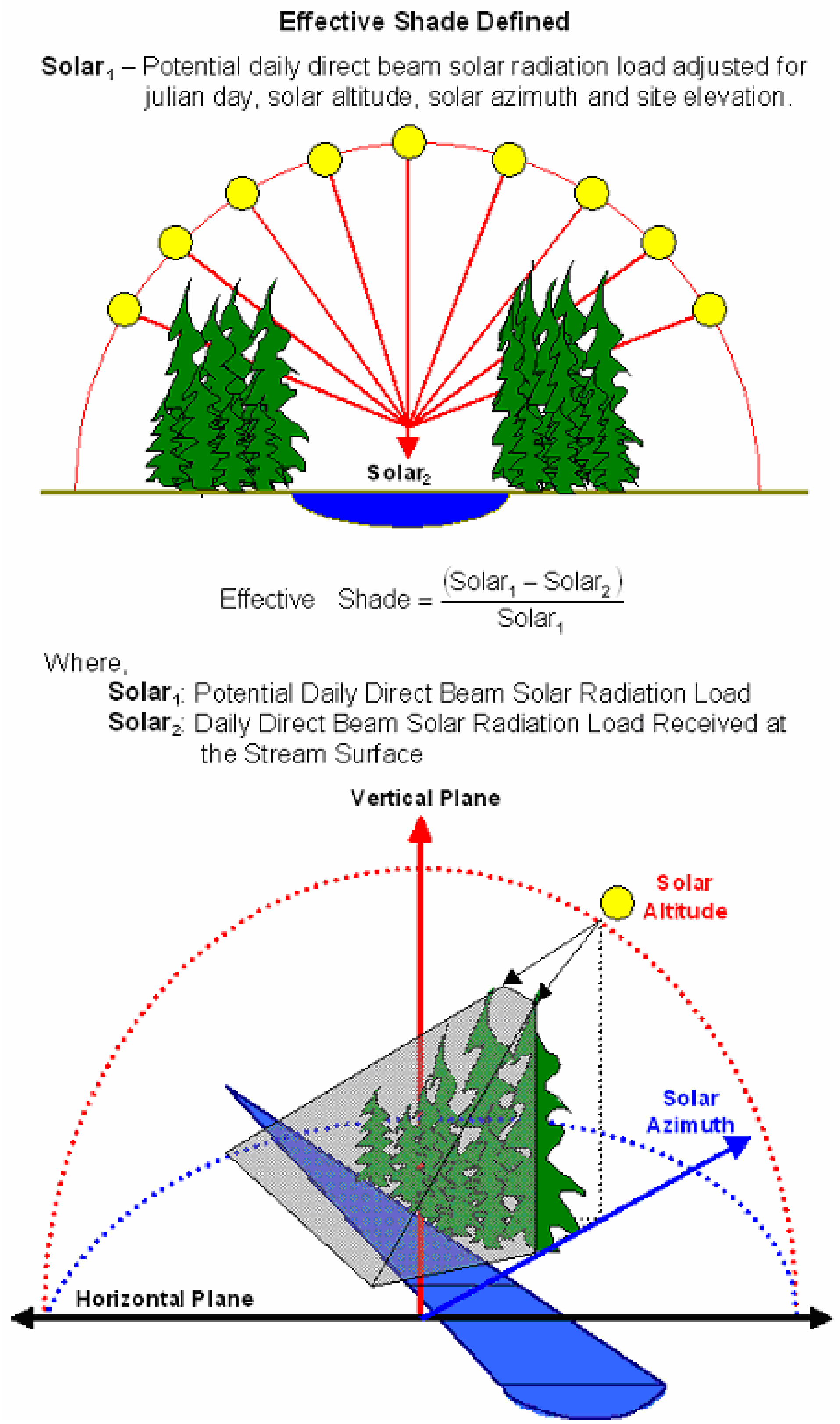
5.3.2.1 Overview - Description of Shading Processes

Stream surface shade is an important parameter that controls the stream heating derived from solar radiation. Recall that 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 (**Table 5-1**). It follows that 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 focus of this analytical effort.

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 (i.e., produce shade). The solar position has a vertical component (i.e., solar altitude) and a horizontal component (i.e., solar azimuth) 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) (**Figure 5-1**). 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). Effective shade is a ratio of the received solar load to the total potential solar load (**Figure 5-1**)

Table 5.1. Factors that Influence Stream Surface Shade

Description	***Blue – Not Influenced by Human Activities*** ***Red - Influenced by Human Activities*** ***Parameter***
Season/Time	Date/Time
Stream Characteristics	Aspect, Channel Width
Geographic Position	Latitude, Longitude
Vegetative Characteristics	Near Stream Land cover Height, Width, Density
Solar Position	Solar Altitude, Solar Azimuth



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

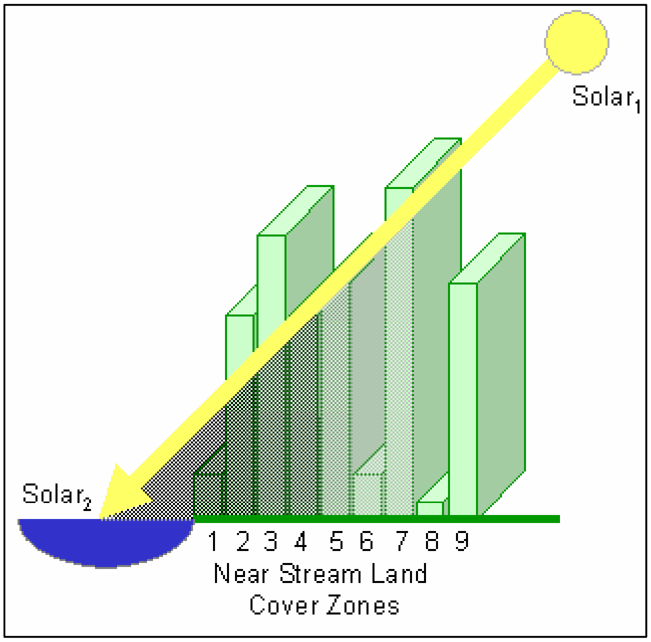
Solar$_2$: Daily Direct Beam Solar Radiation Load Received at the Stream Surface

Figure 5-1. Shade Geometric Relationships and Effective Shade Definition

6.3.2.2 Effective Shade Simulation Methodology

Using computer software developed by ODEQ[5], stream surface shade can be simulated at a landscape scale. Topographic shade angle, channel morphology and land cover derived spatial data sets serve as high resolution input data. Stream surface shade production is a function of geometric relationships between the sun's position and topography, near stream land cover and channel features. For any given location, the sun's position is a function of time (i.e. season and time of day). Provided an accurate location description (i.e. latitude and longitude), the exact position of the sun for any given time can be easily simulated.

A vector between the sun and the stream can then be calculated. Topographic, land cover and/or stream channel features that obstruct the sun → stream vector create shade. Shade produced by topographic features and/or channel banks completely attenuates direct beam solar radiation. The shading algorithms mimic the travel direction of a photon from the sun to the stream. The first potential barrier to a photon is a topographic feature. If the sun angle is greater than that of topographic features, then the stream is not shaded from surrounding topography. The direct beam is then routed to the top of the land cover boundaries.



Land cover is broken into nine consecutive zones, each is ten feet in width, and located in the transverse direction. The direct beam is routed through the vegetation zones, starting at the outer zone 9. Each land cover height is checked to see if it intersects the sun → stream vector. If it does, then the attenuation of direct beam solar radiation caused by the land cover zone occurs as a function of a light extinction coefficient and the path length through the land cover zone. Path length through the land cover zone is a function of zone width, stream aspect, solar altitude and solar azimuth. Attenuation is calculated using Beer's Law (Oke, 1978). Direct beam radiant energy that passes through a land cover zone is then routed to the next inner land cover zone and the process is repeated. Once through all nine land cover zones, remaining direct beam solar radiation is routed to the stream surface. Diffuse solar radiation filters through the canopy and is attenuated as a function of canopy opening. If only the portion of the stream surface is shaded, while the remaining portion is exposed to direct beam solar radiation, the land cover attenuated solar flux is used for the shaded portion, and an unattenuated solar flux is used for the non-shaded portion. At the stream surface, the remaining direct beam and the received diffuse solar radiation are summed and become the solar load received at the top of the stream surface (Solar$_2$).

A portion of solar radiation is reflected off the stream surface as a function of the solar angle, while the remaining portion enters the water column. The water column solar path length is a function of the solar angle and water depth. The portion of the received direct beam solar radiation absorbed by the water column is a function of water column path length and the transmissivity of the water column. The remaining solar radiation is received at the stream bed, where a portion is absorbed as a function of solar angle and literature values for reflectivity properties of quartz (Beschta and Weatherred, 1984). Heat absorbed by the streambed will cause differential heating and start conducting back to the water column. The remaining portion of solar direct beam radiation is reflected off the stream bed and travels towards the surface of the stream, where again there is absorption of remain solar radiation in the water column as a function of path length and stream transmissivity.

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[5] ODEQ has developed and maintains a computer application called Shade-a-lator that can predict stream surface shade at a user defined spatial scales.

Below are the steps used for calculating effective shade. Effective shade is a ratio of the received solar load to the total potential solar load. Both total potential and received solar radiation is calculated for any given day at a 10-minute time step for each stream data node.

1. Calculate solar position as a function of time and in relation to a defined location. Variables calculated are:
   - solar altitude
   - solar zenith
   - solar declination
   - solar azimuth

2. Calculate direct beam and diffuse beam solar radiation received at the top of the land cover boundary. Variables calculated are:
   - air mass thickness
   - air mass transmissivity
   - topographic shade angle
   - solar load received at edge of atmosphere
   - direct beam solar radiation received at top of land cover boundary
   - diffuse solar radiation received at top of land cover boundary
   - potential solar load

3. Calculate direct beam and diffuse beam solar radiation received at the top of the stream surface. Direct beam solar radiation is routed through all land cover zones (i.e. 9 zones every 10 feet starting at the furthest from the stream channel). Diffuse solar radiation is proportional to the canopy opening. Variables calculated are:
   - percent canopy opening
   - land cover transmissivity
   - path length through land cover
   - direct beam solar radiation received at top of stream
   - diffuse solar radiation received at top of stream
   - shadow extension into the stream channel
   - portion of the stream channel shaded (0 to 1)
   - total solar load received at top of stream

4. Calculate solar radiation absorbed in the water column and streambed. Variables calculated are:
   - water surface reflectivity
   - water column transmissivity
   - streambed reflectivity
   - path length through water column
   - total solar load received by water column

5. Calculate effective shade. Variables calculated are:
   - $Solar_1$ = daily sum of potential solar load
   - $Solar_2$ = daily sum of total solar load received at top of water column
   - Effective Shade = $(Solar_1 - Solar_2) / Solar_1$

5.4 SIMULATIONS: WILLOW CREEK TMDL (CHAPTER III)

The purpose of this stream temperature simulation effort is to quantify stream temperatures (and the corresponding energy processes) that result when estimated *system potential* riparian vegetation exists. The model is validated using hydrologic, thermal and landscape data describing the current condition. Only 1998 data were used. Once the modeled reach output has been validated, stream temperatures and energy conditions are predicted for a *system potential* riparian condition. All other model inputs are assumed to remain unchanged.

Model results should be used with caution. Associated prediction errors and goodness of fit estimates are provided with all model output. The authors are aware of possible sources of error in the predictions. However, the methodology is sound and based on the most recent understanding of stream thermodynamics and hydraulics. As is generally the case in simulating non-linear water quality, model results are best suited for relative comparisons, rather than determinations of water quality parameter magnitude. Ultimate stream temperature magnitude is estimated in the report and is presented with upper and lower error boundaries. Discussions of the model results should include considerations for these boundaries of error.

Using a stream temperature prediction model (Heat Source v.5.5), a large extent of Willow Creek was simulated for temperature. The basic steps involved in stream temperature simulation are presented in the following section.

5.4.1 Methodology

5.4.1.1 Selection of Temperature Simulation Reaches

Willow Creek was split into five reaches for temperature simulation (**Table 5-2** and **Figure 5-3**).

Table 5-2. Willow Creek Simulation Reaches (DH is Distance from Headwaters in Kilometers)

Simulation Reach	Upper Extent	Lower Extent
1	DH 12.29	DH 16.56
2	DH 16.56	DH 20.81
3	DH 20.81	DH 27.11
4	DH 27.11	DH 29.87
5	DH 29.87	DH 32.27

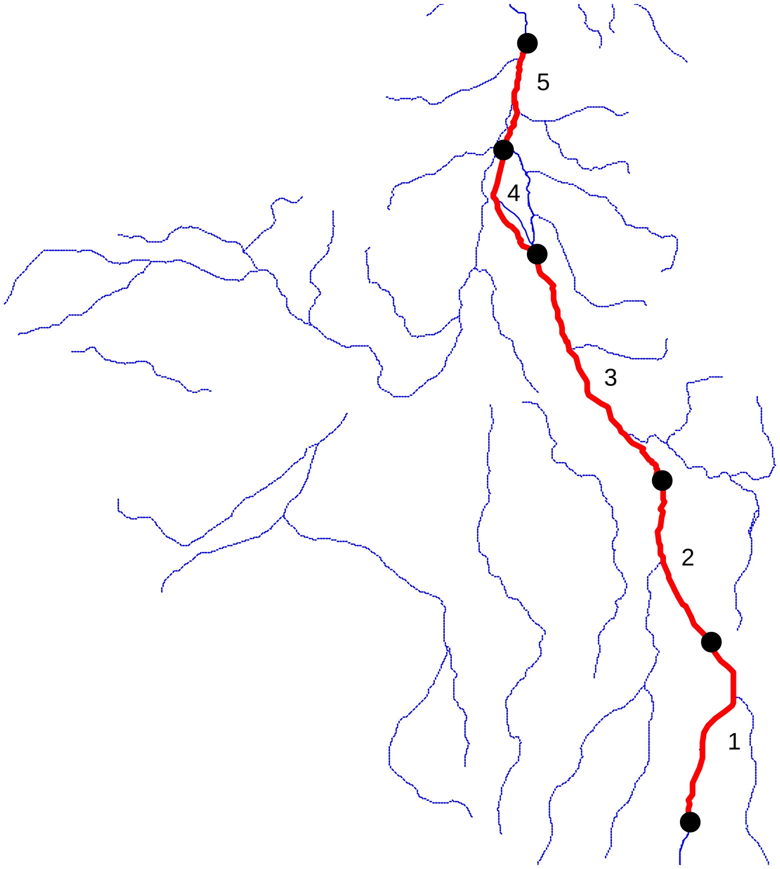


Figure 5-3. Stream Temperature Simulation Extent – Red Indicates Simulation Reaches

5.4.1.2 Model Input: Site Specific Data

The model required the collection and input of the parameters identified in **Table 6-3**.

Table 6-3. Heat Source v. 5.5 Model Input Parameters

• Date	• Buffer Height
• Stream Aspect	• Buffer Width
• Latitude	• Buffer Density
• Longitude	• Topographic Shade Angle (West)
• Reach Length	• Topographic Shade Angle (East)
• Channel Width	• Min. Air Temperature
• Flow Volume	• Max. Air Temperature
• Flow Velocity	• Relative Humidity
• Percent Bedrock	• Buffer Distance to Stream
• Groundwater Inflow	• Elevation
• Groundwater Temperature	• Wind Speed
• Dispersion Coefficient	• Upstream Hourly Temperature Data

5.4.1.3 Prediction of Current Condition (Downstream Temperature Profile)

Current instream temperatures were simulated (see **Section 5.4.3** for results)

5.4.1.4 Model Validation: Statistical Analysis of Model Output

The model was validated using the following three statistical methods:

- Pearson's Product Moment (R^2)
- Standard Error (S.E.)
- WSTAT

See **Section 5.4.2** for a further discussion of model validation.

5.4.1.5 Prediction of Stream Reach System Potential Conditions

System potential conditions were predicted for the same five reaches (**Table 5-4**) based on the knowledge provided by the BLM staff from the Vale District Office. A further discussion of determination of *system potential* riparian conditions is provided in **Section 3.4.3.1.2**.

Table 5-4. *System Potential* Vegetation Conditions for Simulation Reaches

Simulation Reach	Riparian Vegetation Type(s)*	Buffer Height (meters)	Buffer Width (meters)	Buffer Density	Percent Overhang
1	Mountain Alder and Willow	7.01	6.95	30%	15%
2	Willow	5.49	12.19	30%	15%
3	Willow	5.49	16.76	30%	15%
4	Willow	5.49	16.76	30%	15%
5	Willow	5.49	18.29	30%	15%

*Willow height is an average of the tree like species and medium stature willow species that both occupy these riparian systems under equilibrium or climax conditions (refer to **Section 3.4.3.1** in **Chapter III**).

5.4.1.6 Prediction of Stream Reach Based on Cumulative Upstream *System Potential* Conditions (Downstream Temperature Profile)

The instream thermal conditions under *system potential* conditions were predicted using the calibrated model. A few key points for model prediction are summarized below:

- Utilized upstream reach *system potential* stream temperature for upstream model input in downstream reach simulation (i.e. downstream *system potential* temperature profile or Reach #1 becomes input temperature profile for Reach #2).
- Assumed that current condition standard error (S.E.) applies to *system potential* simulations.
- Standard error (S.E.) of upstream predictions accumulates in the downstream direction.

5.4.2 Model Validation

5.4.2.1 Temperature Validation

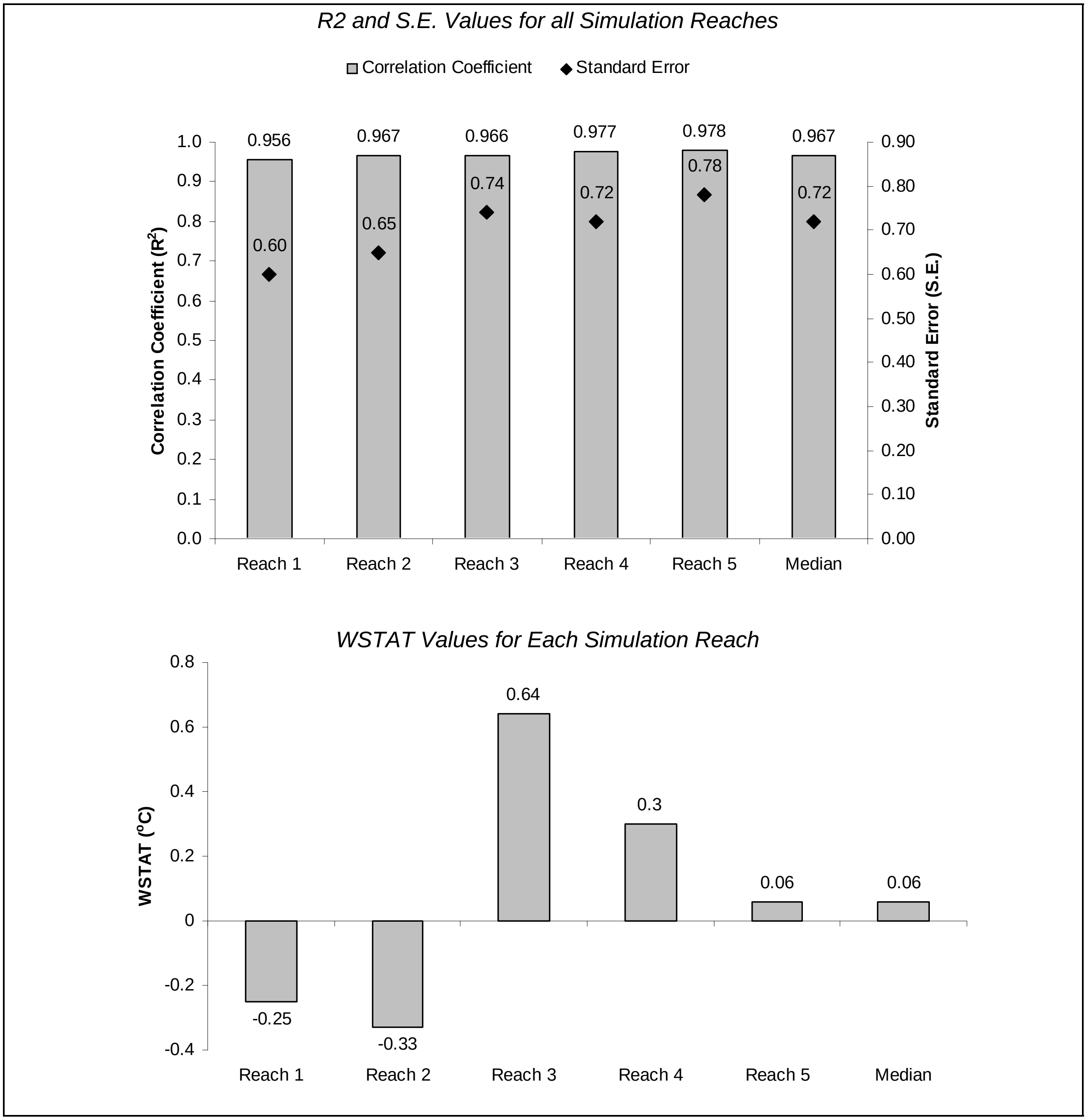
Three statistical measurements were used to assess the accuracy of stream temperature simulations. Comparisons between simulated and actual (measured) stream temperature profiles were used to generate the square of the Pearson product moment correlation coefficient (R^2) and the standard error

(S.E.) for each simulation reach. The WSTAT was also calculated for each simulation reach (see equation below). **Figure 5-4** graphically summarizes the errors and correlation coefficients associated with this simulation.

$$\text{WSTAT} = \frac{\Sigma(\text{Predicted} - \text{Observed Hourly Temperature})}{\text{n (\# of Observations)}}$$

Median values for all eight simulation reaches were:

- Correlation Coefficient (R^2): **0.967**
- Standard Error (S.E.): **0.72°C**
- WSTAT: **0.06°C**



R2 and S.E. Values for all Simulation Reaches

WSTAT Values for Each Simulation Reach

Figure 5.4. Temperature Profile Simulation Accuracy

5.4.3 Summary of Model Results

5.4.3.1 Temperature Output

Predicted maximum daily stream temperatures are cooler when *system potential* riparian conditions persist (Buffer 4). Longitudinal stream heating is drastically reduced in the simulated *system potential* riparian condition. **Figure 5-5** shows the measured (actual) longitudinal stream heating pattern compared to those induced by simulated *system potential* riparian vegetation geometry (Buffer 4). *System potential* simulations demonstrate that stream temperature change occurs more gradually.

Vertical bars indicate the standard error associated with each simulation. Recall that all simulation errors of upstream prediction reaches were assumed to accumulate in the downstream direction. The result is an increasing margin of error for simulations in the downstream direction. Perhaps this method for accounting prediction error overstates the margin of error; however, it is important to recognize the limitations inherent to this methodology.

Current condition and *system potential* (Buffer 4) diurnal temperatures are plotted for all eight simulation reaches in **Figure 5-6**. Daily maximum stream temperatures for current conditions and all buffer scenarios (Buffers 1 through 4) are displayed in **Figure 5-7**.

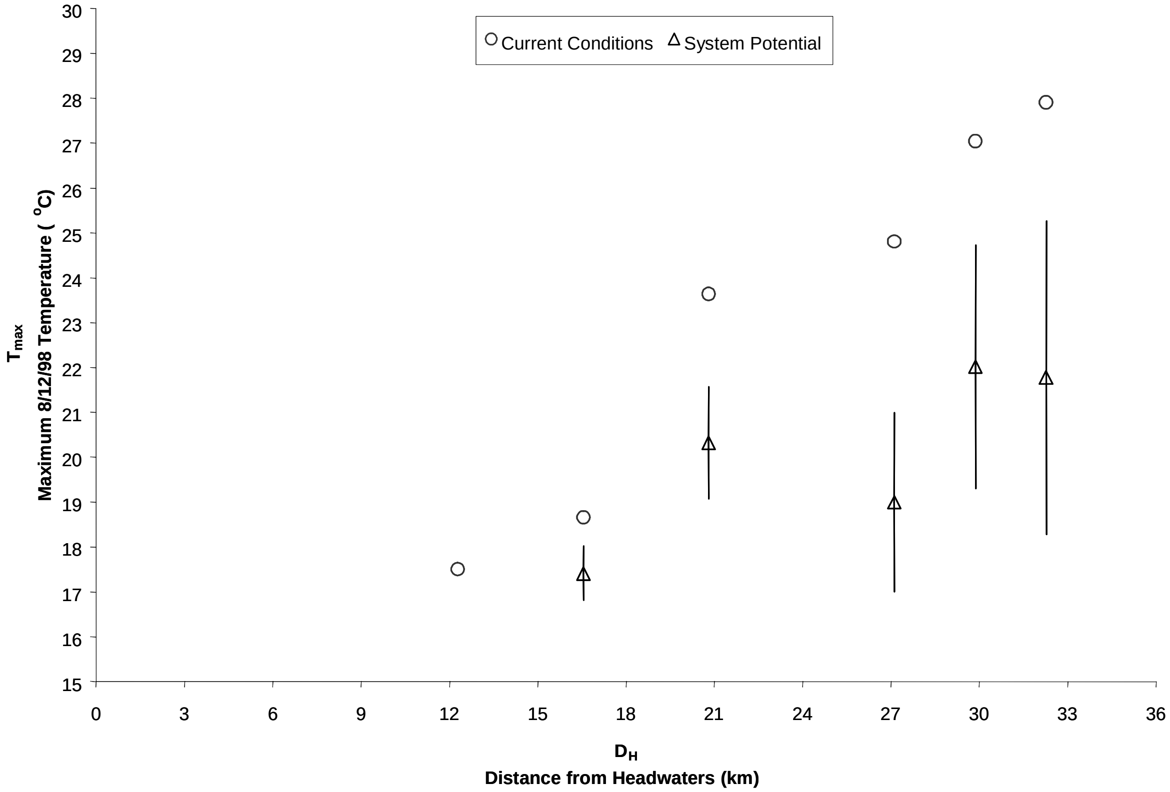
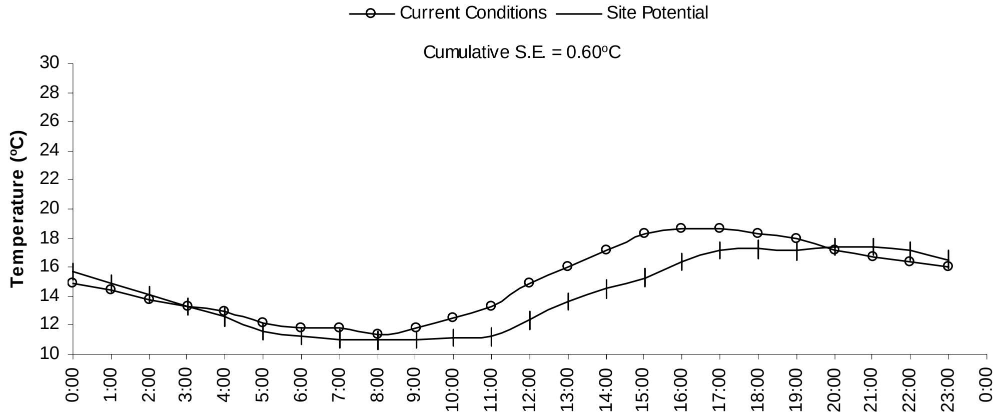
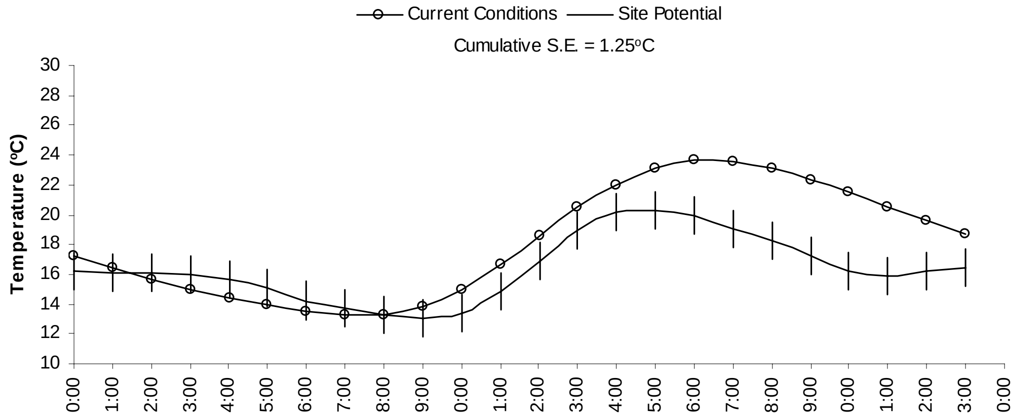


Figure 5-5. Actual Stream Heating Curve and Predicted *System Potential* Daily Maximum Temperatures with Associated Error Bars *(August 12, 1998)*

Reach #1



Reach #2



Reach #3

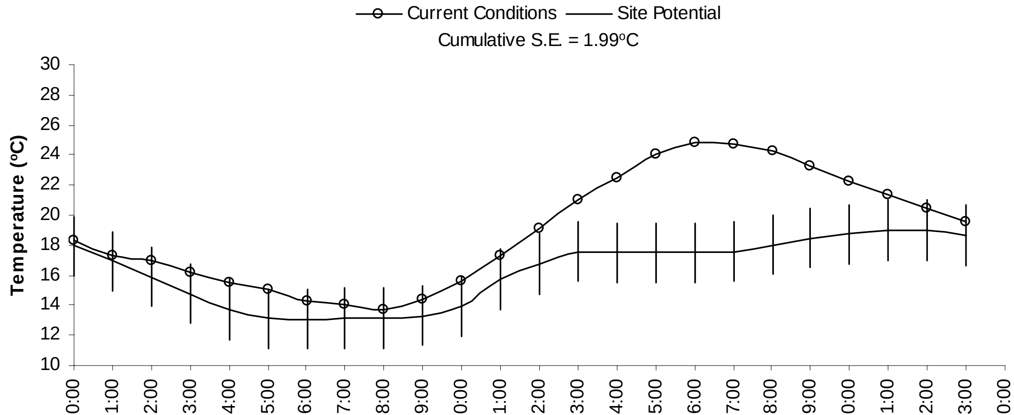
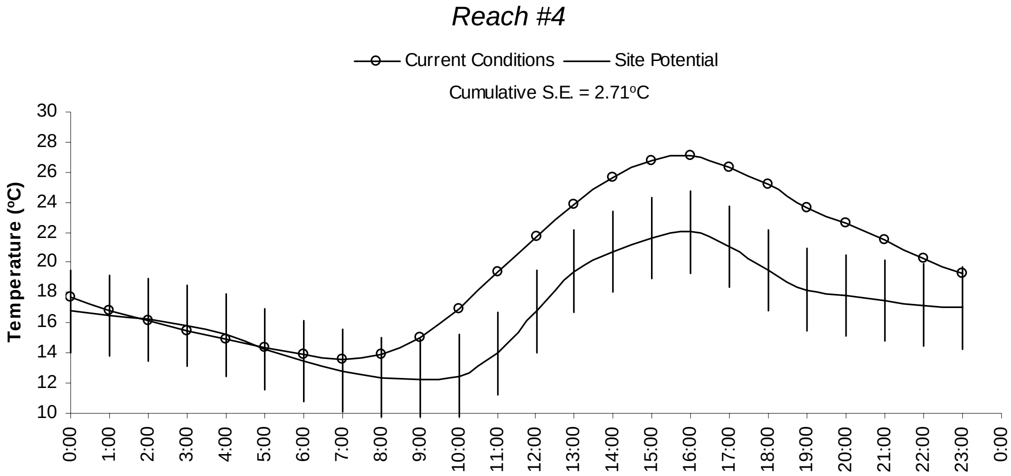


Figure 5-6. Current Condition and *System Potential* Diurnal Temperature Profiles *(August 12, 1998)*



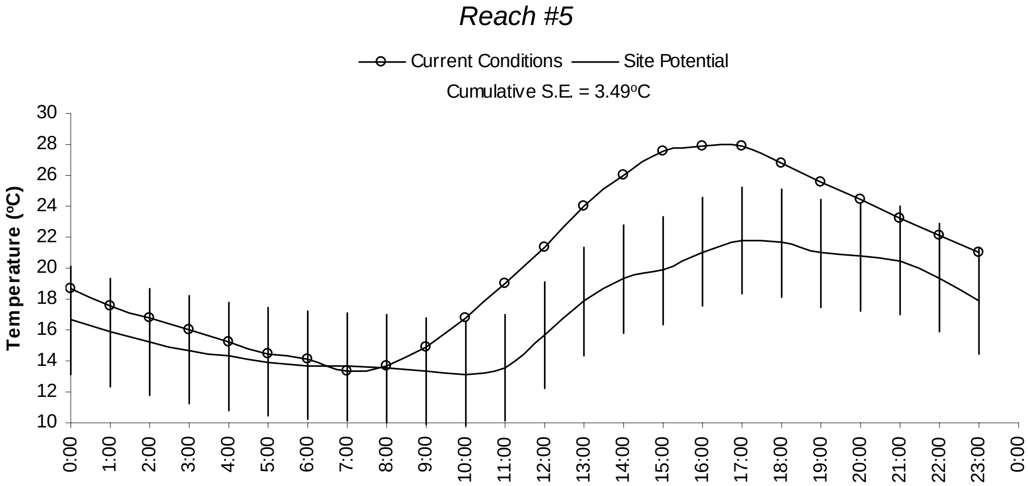
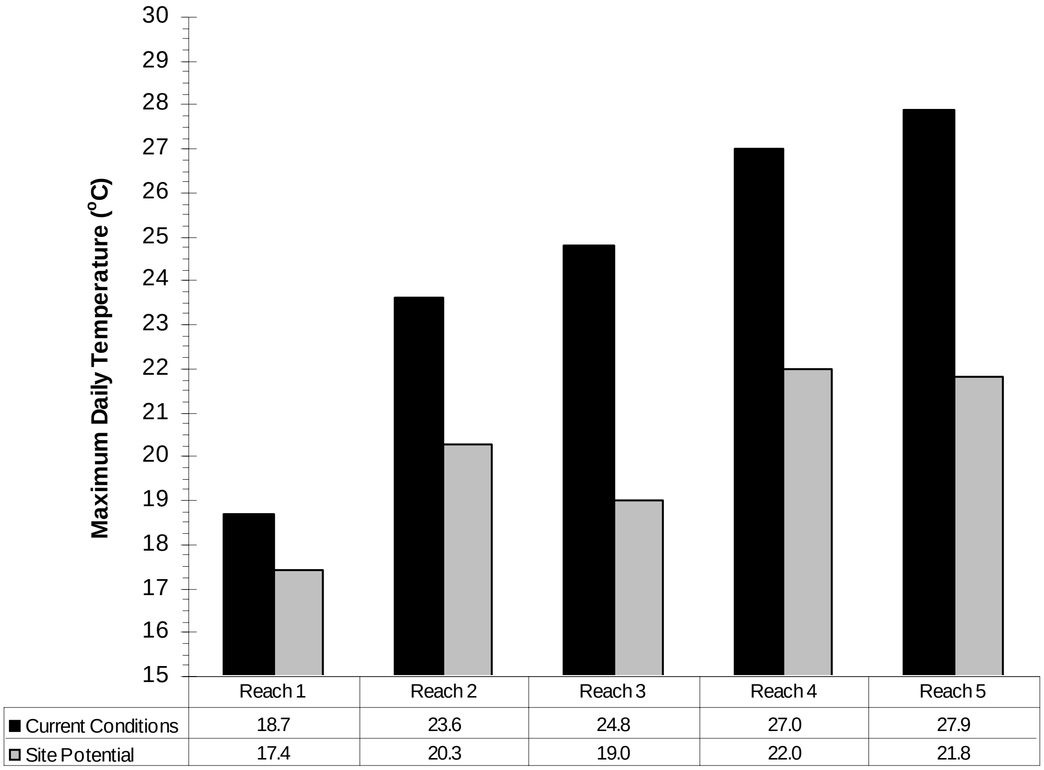


Figure 5-6 (continued). Current Condition and *System Potential* Diurnal Temperature Profiles *(August 12, 1998)*



	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
■ Current Conditions	18.7	23.6	24.8	27.0	27.9
▨ Site Potential	17.4	20.3	19.0	22.0	21.8

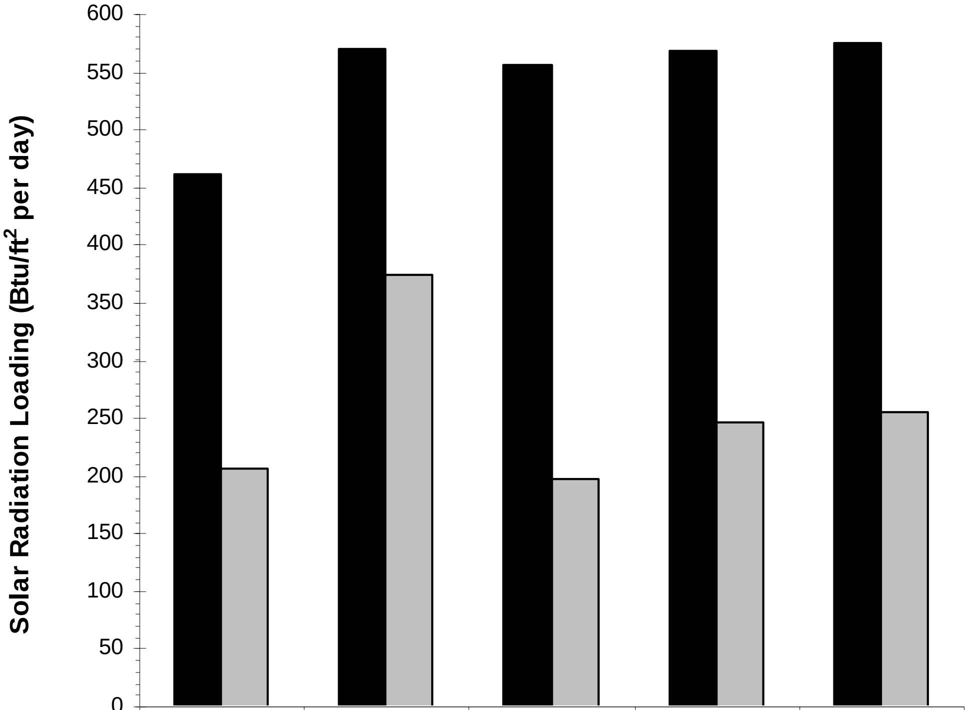
Figure 5-7. Maximum Daily Stream Temperatures for Varying Buffer (*August 12, 1998)*

5.4.3.2 Solar Radiation Output

Figure 5-8 represents the solar loading calculated for current conditions and *system potential* conditions. Those solar loading values were calculated directly from the simulated percent effective shade conditions shown in **Figure 5-9**.

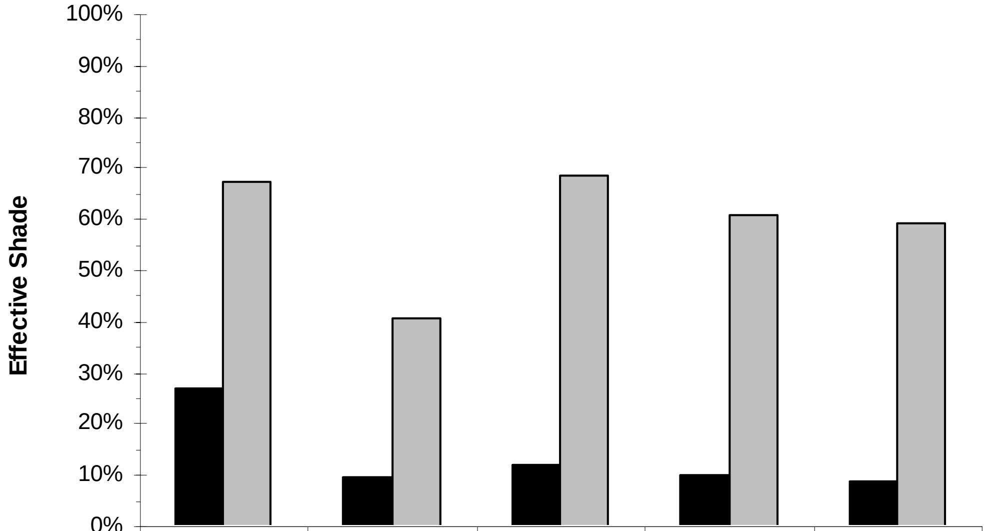
5.4.3.3 Individual Simulation Reach Outputs:

The remainder of the section contains the simulation results for each of the five simulation reaches. The input parameters are first summarized in table form. Below that is a graphical representation of the model calibration, which compares the predicted stream temperatures to the actual stream temperatures. The next figure presented for each simulation reach compares the heat energy profiles of the current condition and the *system potential* condition. Finally, the daily heat energy totals for the current condition and the *system potential* are shown in bar graph format.



	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
■ Current Conditions	461.0	570.7	555.6	568.2	575.1
□ Site Potential	205.6	374.0	197.4	246.0	256.0

Figure 5-8. Daily Solar Radiation Loading at Stream Surface (BTU/ft^2/day) - Calculations for Current Conditions and *System Potential* Riparian Vegetation (August 12, 1998)



	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
■ Current Conditions	26.9%	9.5%	11.9%	9.9%	8.8%
□ Site Potential	67.4%	40.7%	68.7%	61.0%	59.4%

Figure 5-9. Effective Shade - Calculations for Current Conditions and *System Potential* Riparian Vegetation

5.4.3.3.1 Simulation Reach #1

Input Parameters

Run Name	Willow Creek – Reach 1	
Date	August 12, 1998	
Julian Day	223	
Latitude	42.31	*(deg N)*
Longitude	-118.22	*(deg W)*
Stream Aspect	20	*(deg)*
Percent Bedrock	75%	
Reach Length	4270	*(meters)*
Channel Width	1.5	*(meters)*
Flow Volume	0.161	*(cms)*
Flow Velocity	0.21	*(m/s)*
Groundwater Inflow	0.00	*(cms)*
Groundwater Temp.	10.00	*(*C)*
Ave. Stream Depth	0.51	*(meters)*
Dispersion	0.00	*(m2/s)*
Buffer Height	3.00	*(meters)*
Buffer Width	3.00	*(meters)*
Buffer Density	20%	
Distance to Stream	1.23	*(meters)*
Bank Slope	0.25	*(rise/run)*
% Tree Overhang	15%	
Topographic (West)	0.0	*(deg)*
Topographic (East)	0.0	*(deg)*
Overhanging Distance	0.09	*(meters)*
Shade Angle	57.8	*(deg)*
View to Sky	36%	
Effective Shade	27%	
Elevation	1585	*(meters)*
Wind Speed	0.30	*(m/s)*

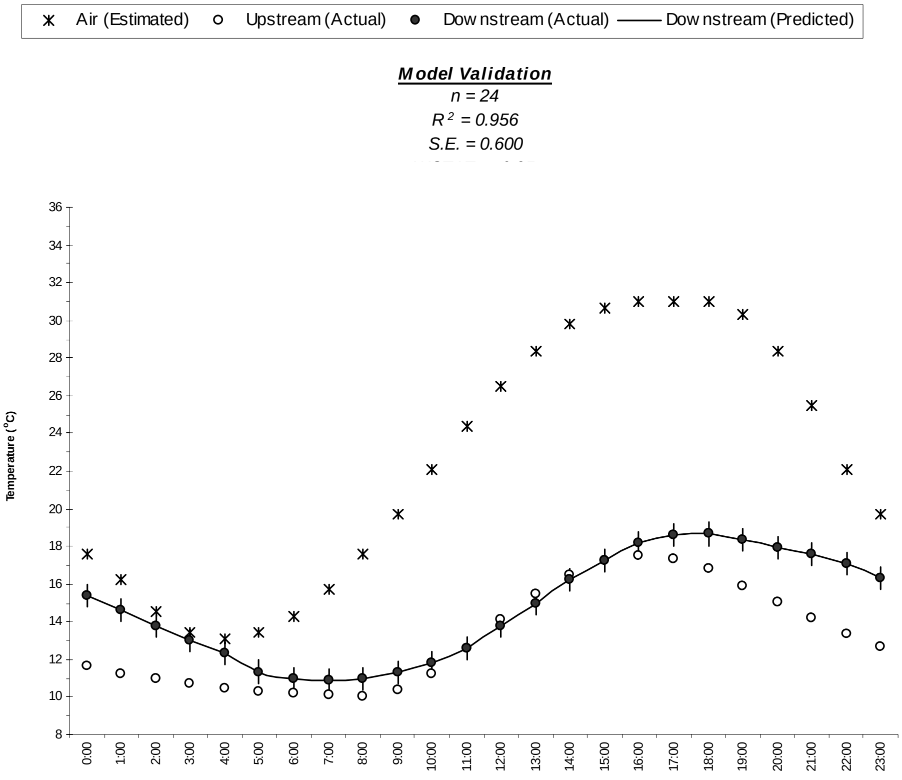


Figure 5-10. Willow Creek Reach 1 Model Calibration *(August 12, 1998)*

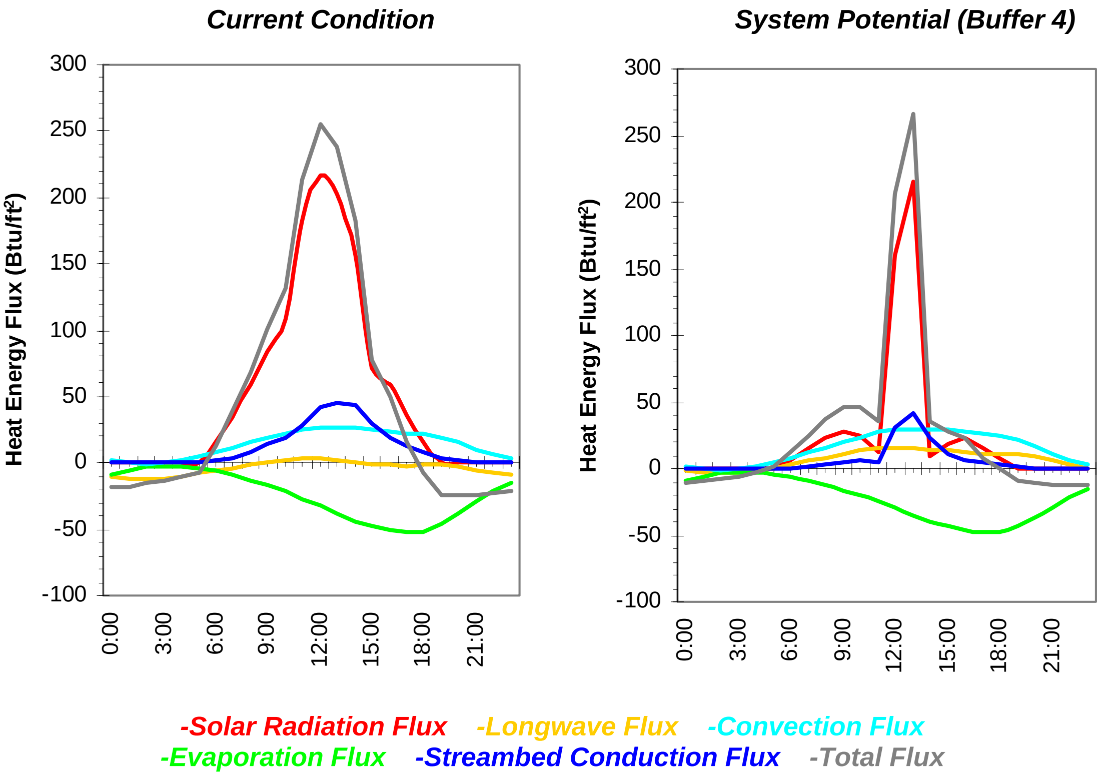


Figure 5-11. Willow Creek Reach 1 Heat Energy Profiles *(August 12, 1998)*

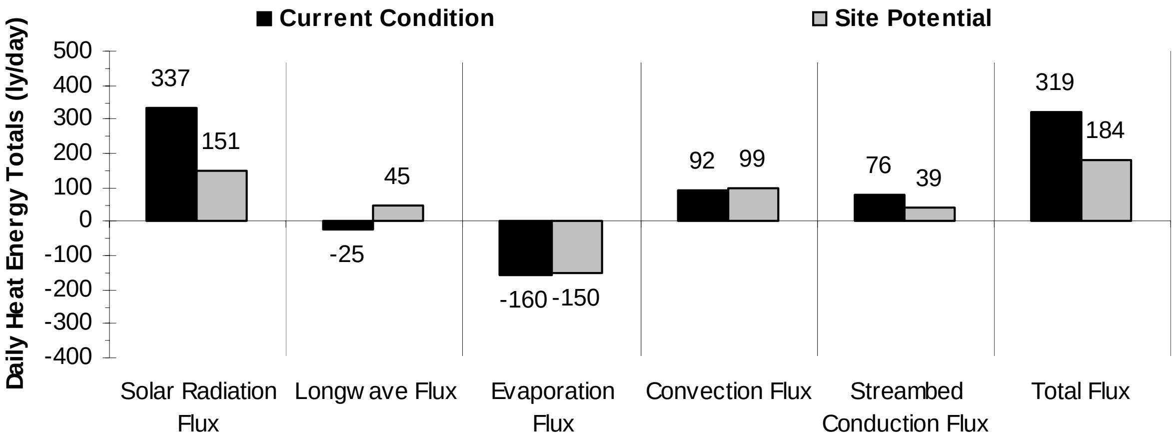


Figure 5-12. Willow Creek Reach 1 Daily Heat Energy Totals *(August 12, 1998)*

5.4.3.3.2 Simulation Reach #2

Input Parameters

Run Name	Willow Creek – Reach 2	
Date	August 12, 1998	
Julian Day	223	
Latitude	42.21	*(deg N)*
Longitude	-118.23	*(deg W)*
Stream Aspect	345	*(deg)*
Percent Bedrock	50%	
Reach Length	4250	*(meters)*
Channel Width	2.95	*(meters)*
Flow Volume	0.161	*(cms)*
Flow Velocity	0.18	*(m/s)*
Groundwater Inflow	0.00	*(cms)*
Groundwater Temp.	10.00	*(*C)*
Ave. Stream Depth	0.30	*(meters)*
Dispersion	0.00	*(m2/s)*
Buffer Height	2.50	*(meters)*
Buffer Width	2.50	*(meters)*
Buffer Density	20%	
Distance to Stream	3.10	*(meters)*
Bank Slope	0.25	*(rise/run)*
% Tree Overhang	15%	
Topographic (West)	0.0	*(deg)*
Topographic (East)	0.0	*(deg)*
Overhanging Distance	0.08	*(meters)*
Shade Angle	29.1	*(deg)*
View to Sky	68%	
Effective Shade	9%	
Elevation	1510	*(meters)*
Wind Speed	0.30	*(m/s)*

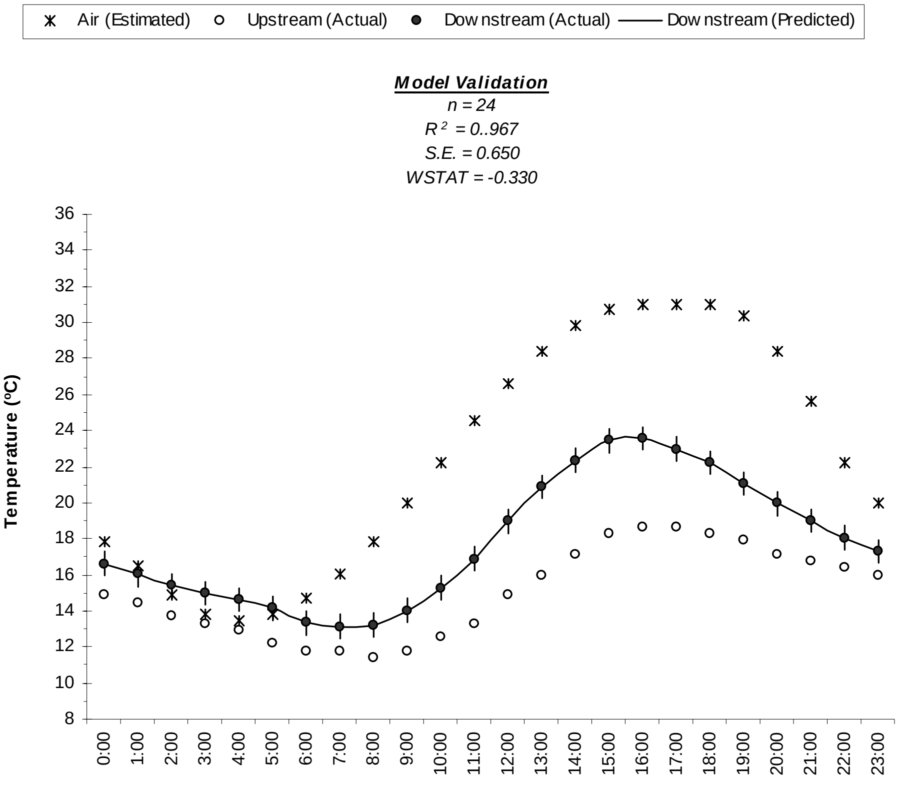


Figure 5-13. Willow Creek Reach 2 Model Calibration *(August 12, 1998)*

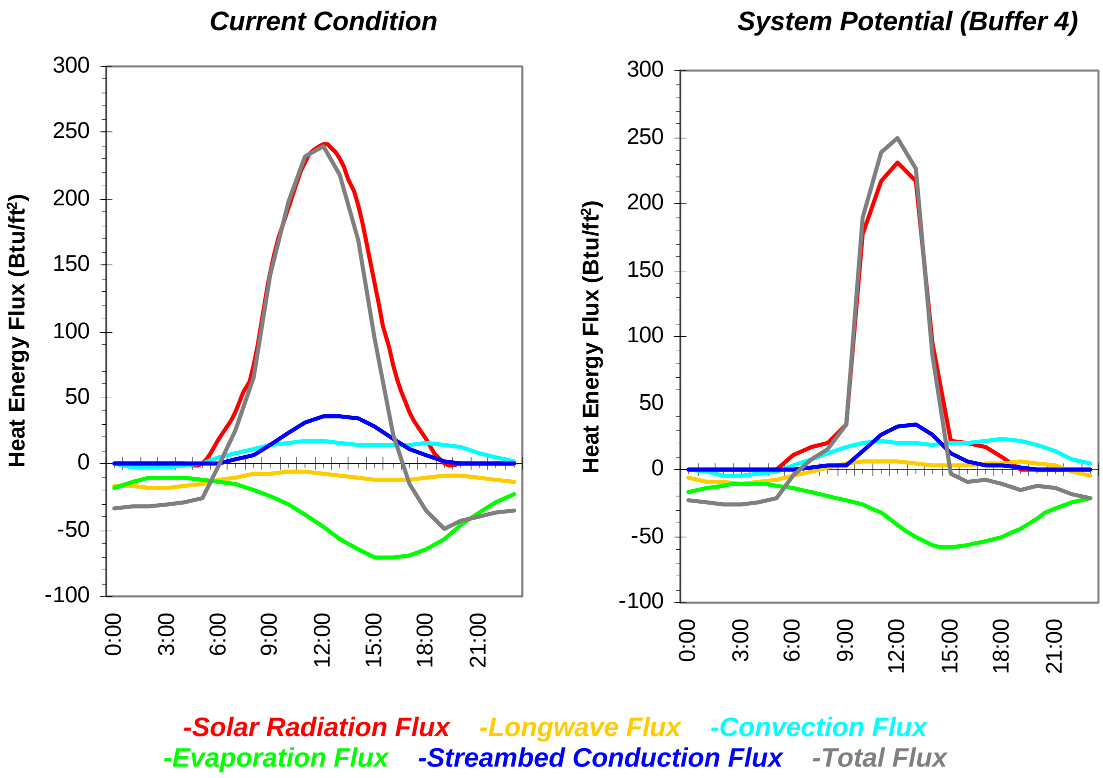


Figure 5-14. Willow Creek Reach 2 Heat Energy Profiles *(August 12, 1998)*

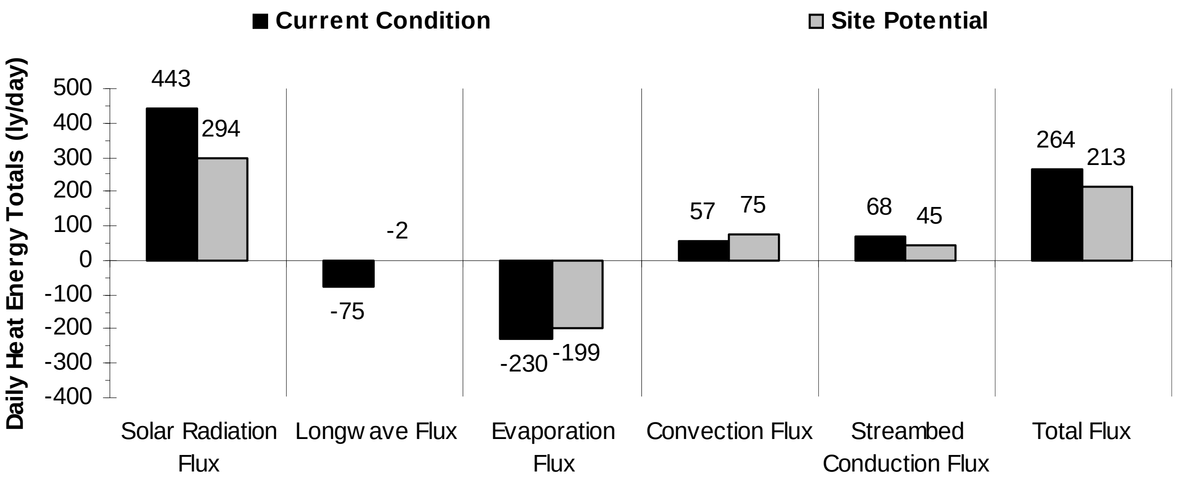


Figure 5-15. Willow Creek Reach 2 Daily Heat Energy Totals *(August 12, 1998)*

5.4.3.3.3 Simulation Reach #3

Input Parameters

Run Name	Willow Creek – Reach 3	
Date	August 12, 1998	
Julian Day	223	
Latitude	42.25	*(deg N)*
Longitude	-118.25	*(deg W)*
Stream Aspect	330	*(deg)*
Percent Bedrock	35%	
Reach Length	6300	*(meters)*
Channel Width	2.6	*(meters)*
Flow Volume	0.164	*(cms)*
Flow Velocity	0.2	*(m/s)*
Groundwater Inflow	0.00	*(cms)*
Groundwater Temp.	10.00	*(*C)*
Ave. Stream Depth	0.32	*(meters)*
Dispersion	0.00	*(m2/s)*
Buffer Height	1.60	*(meters)*
Buffer Width	1.60	*(meters)*
Buffer Density	20%	
Distance to Stream	0.84	*(meters)*
Bank Slope	0.20	*(rise/run)*
% Tree Overhang	0%	
Topographic (West)	0.0	*(deg)*
Topographic (East)	0.0	*(deg)*
Overhanging Distance	0.00	*(meters)*
Shade Angle	36.8	*(deg)*
View to Sky	59%	
Effective Shade	12%	
Elevation	1390	*(meters)*
Wind Speed	0.50	*(m/s)*

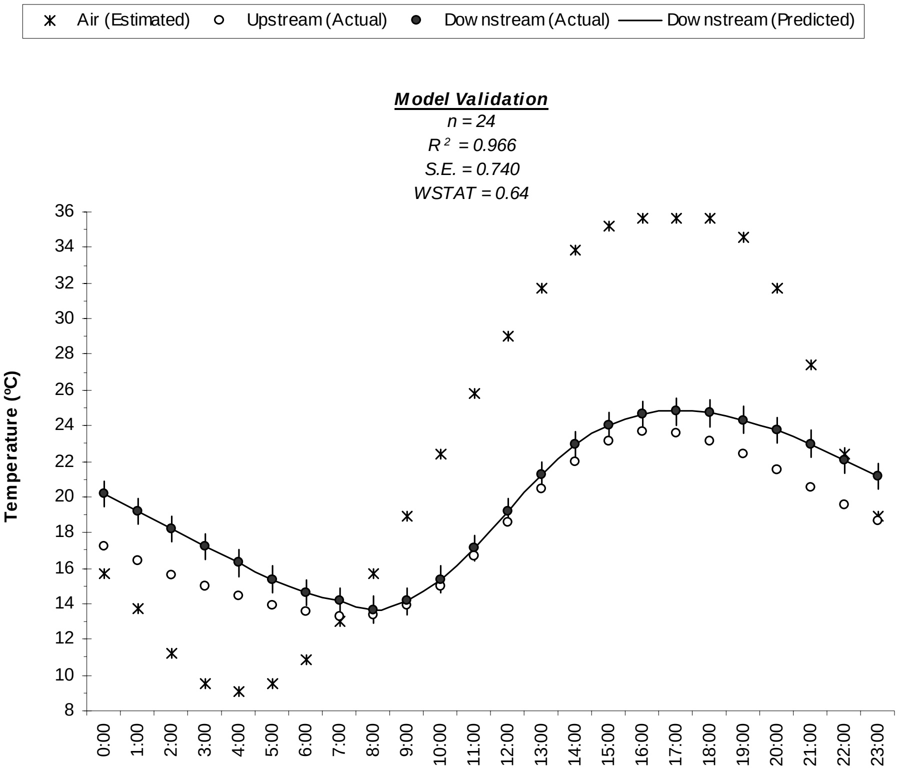


Figure 5-16. Willow Creek Reach 3 Model Calibration *(August 12, 1998)*

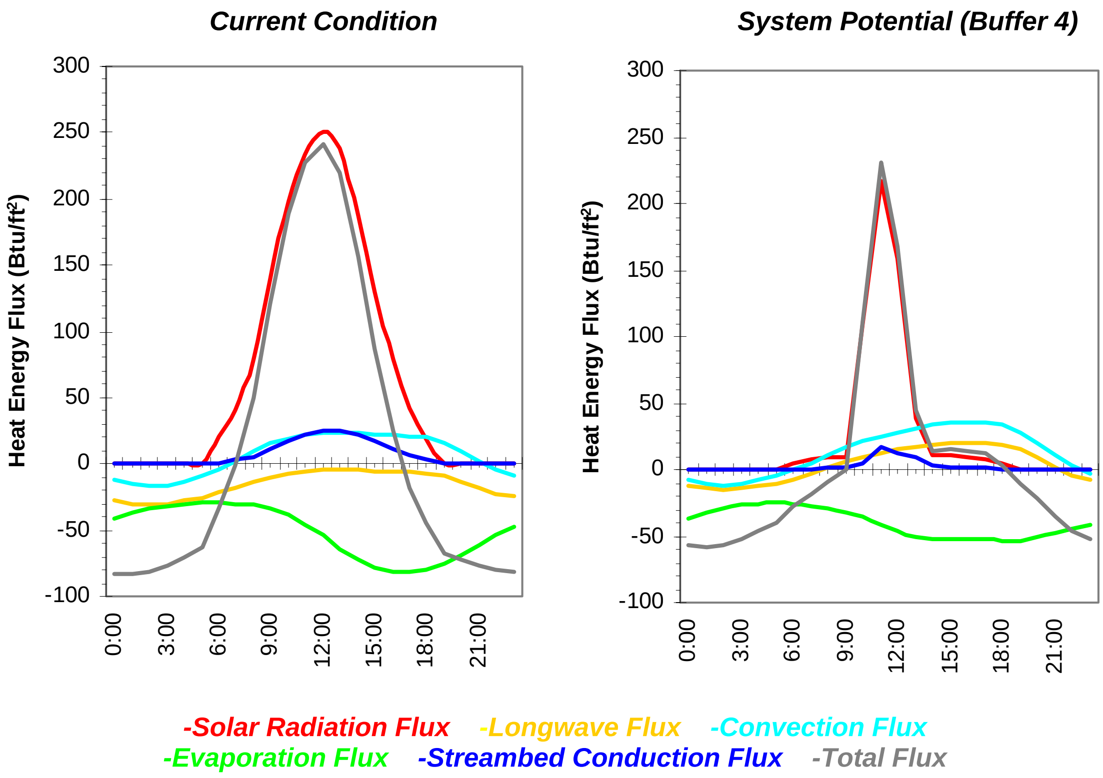


Figure 5-17. Willow Creek Reach 3 Heat Energy Profiles *(August 12, 1998)*

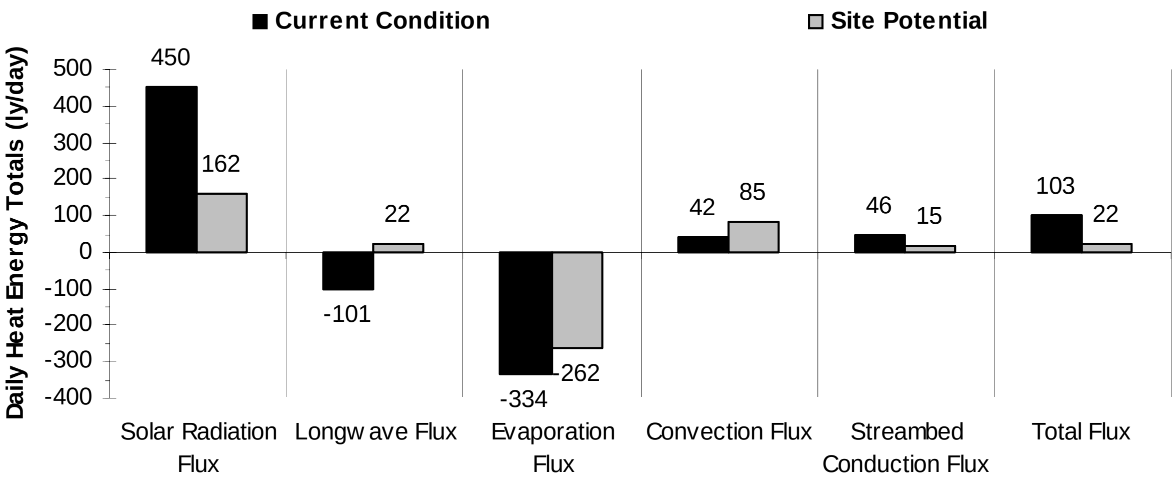


Figure 5-18. Willow Creek Reach 3 Daily Heat Energy Totals *(August 12, 1998)*

5.4.3.3.4 Simulation Reach #4

Input Parameters

Run Name	Willow Creek – Reach 4	
Date	August 12, 1998	
Julian Day	223	
Latitude	42.29	*(deg N)*
Longitude	-118.28	*(deg W)*
Stream Aspect	0	*(deg)*
Percent Bedrock	25%	
Reach Length	2761	*(meters)*
Channel Width	2	*(meters)*
Flow Volume	0.076	*(cms)*
Flow Velocity	0.145	*(m/s)*
Groundwater Inflow	0.00	*(cms)*
Groundwater Temp.	10.00	*(*C)*
Ave. Stream Depth	0.26	*(meters)*
Dispersion	0.00	*(m2/s)*
Buffer Height	1.70	*(meters)*
Buffer Width	1.70	*(meters)*
Buffer Density	25%	
Distance to Stream	1.74	*(meters)*
Bank Slope	0.20	*(rise/run)*
% Tree Overhang	0%	
Topographic (West)	0.0	*(deg)*
Topographic (East)	0.0	*(deg)*
Overhanging Distance	0.00	*(meters)*
Shade Angle	31.8	*(deg)*
View to Sky	65%	
Effective Shade	10%	
Elevation	1355	*(meters)*
Wind Speed	0.50	*(m/s)*

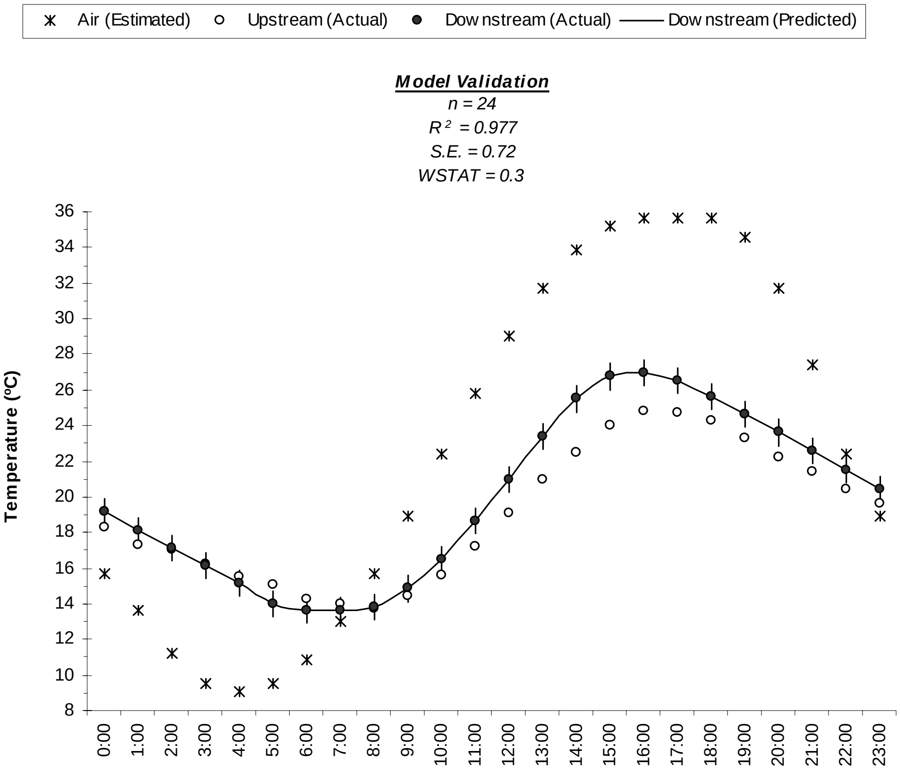


Figure 5-19. Willow Creek Reach 4 Model Calibration *(August 12, 1998)*

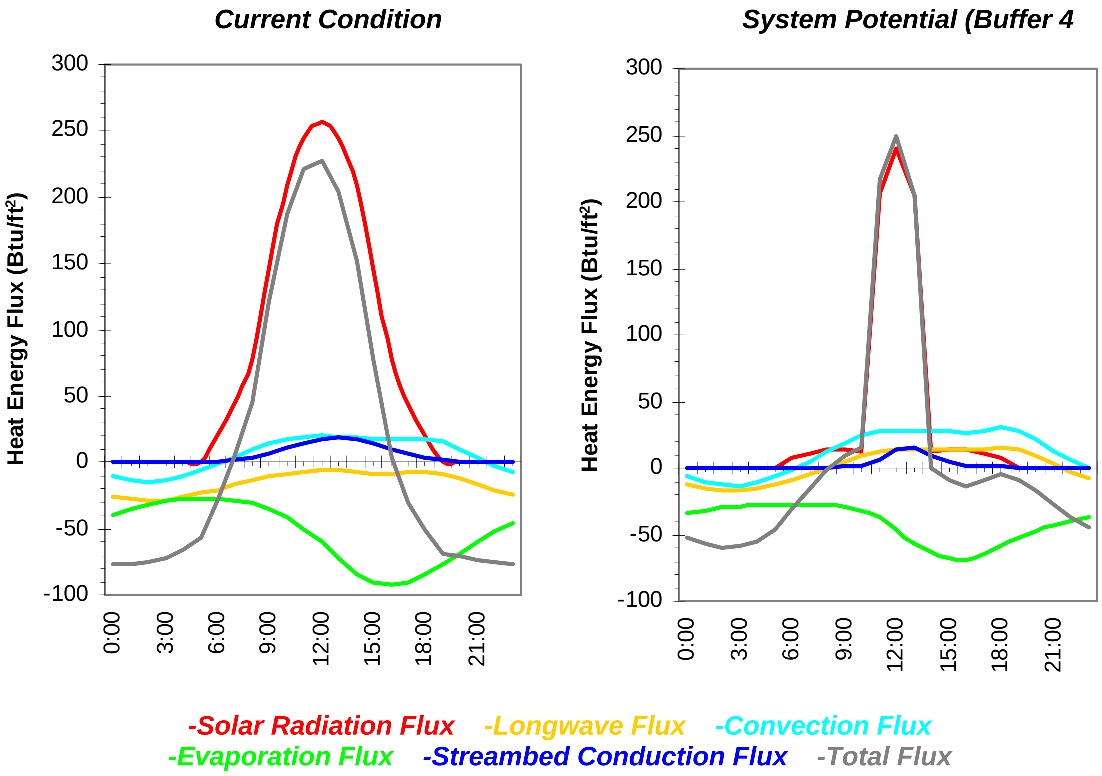


Figure 5-20. Willow Creek Reach 4 Heat Energy Profiles *(August 12, 1998)*

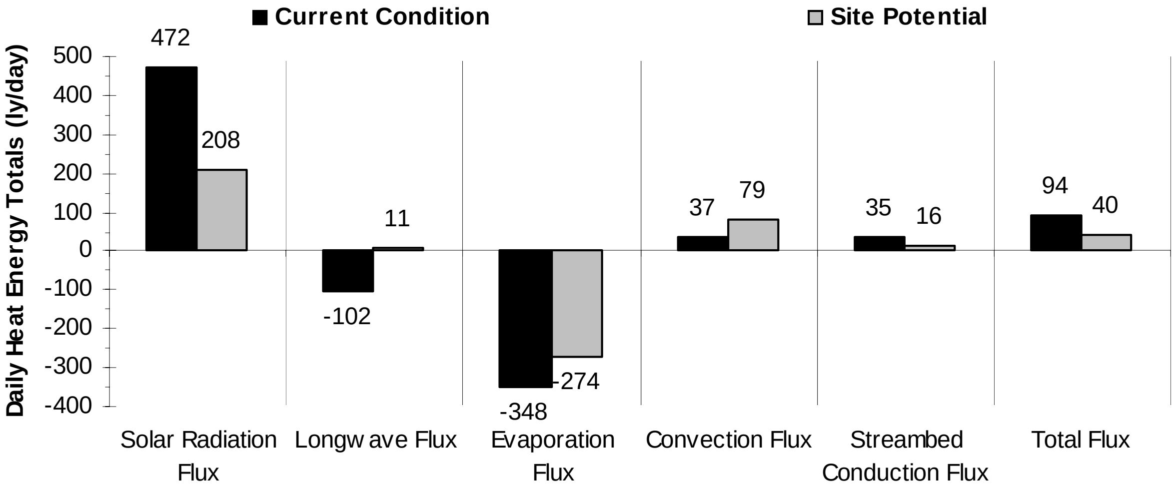


Figure 5-21. Willow Creek Reach 4 Daily Heat Energy Totals *(August 12, 1998)*

5.4.3.3.5 Simulation Reach #5

Input Parameters

Run Name	Willow Creek – Reach 5	
Date	August 12, 1998	
Julian Day	223	
Latitude	42.31	*(deg N)*
Longitude	-118.27	*(deg W)*
Stream Aspect	10	*(deg)*
Percent Bedrock	25%	
Reach Length	2400	*(meters)*
Channel Width	2.2	*(meters)*
Flow Volume	0.076	*(cms)*
Flow Velocity	0.12	*(m/s)*
Groundwater Inflow	0.00	*(cms)*
Groundwater Temp.	10.00	*(*C)*
Ave. Stream Depth	0.29	*(meters)*
Dispersion	0.00	*(m2/s)*
Buffer Height	1.70	*(meters)*
Buffer Width	1.70	*(meters)*
Buffer Density	20%	
Distance to Stream	1.64	*(meters)*
Bank Slope	0.20	*(rise/run)*
% Tree Overhang	0%	
Topographic (West)	0.0	*(deg)*
Topographic (East)	0.0	*(deg)*
Overhanging Distance	0.00	*(meters)*
Shade Angle	31.8	*(deg)*
View to Sky	65%	
Effective Shade	9%	
Elevation	1330	*(meters)*
Wind Speed	0.00	*(m/s)*

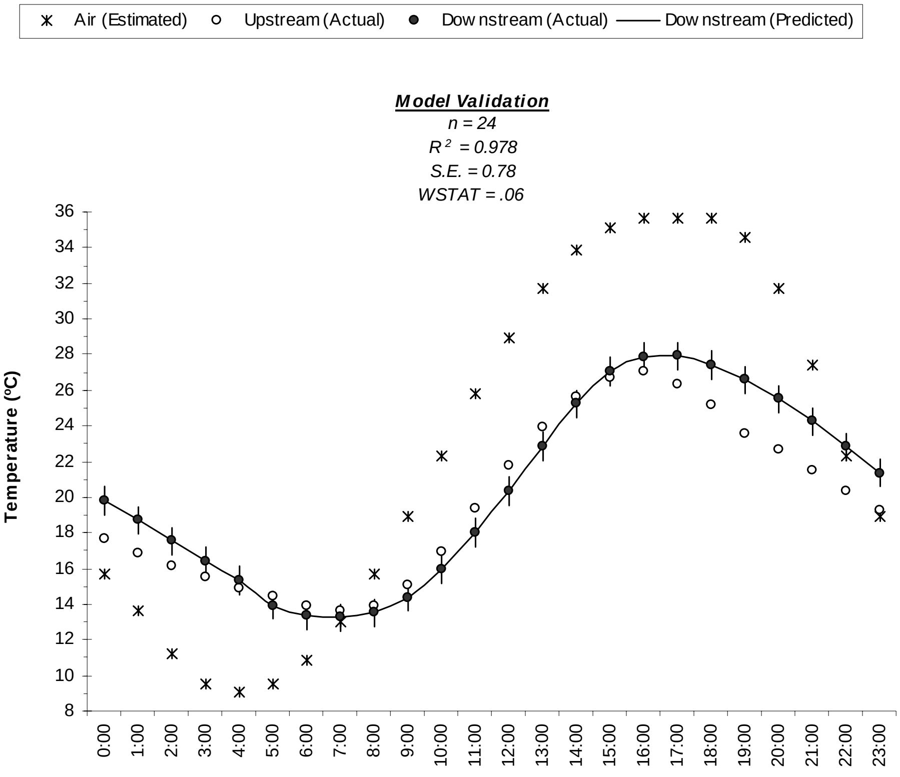


Figure 5-22. Willow Creek Reach 5 Model Calibration *(August 12, 1998)*

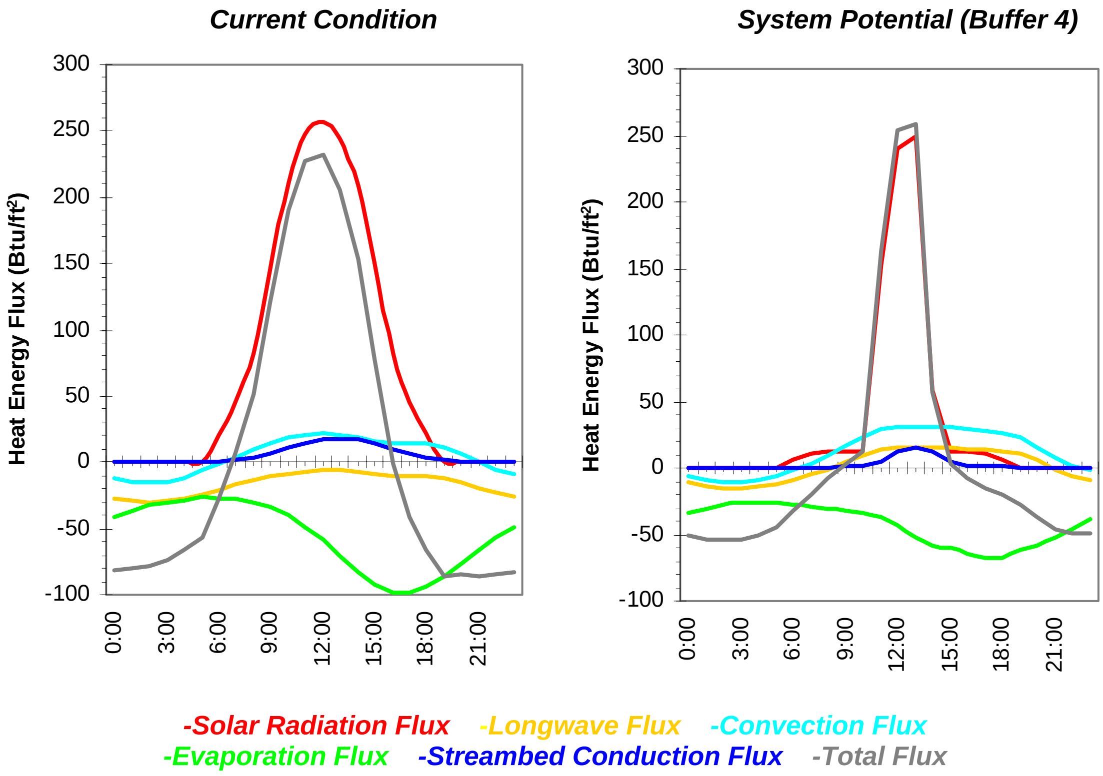


Figure 5-23. Willow Creek Reach 5 Heat Energy Profiles *(August 12, 1998)*

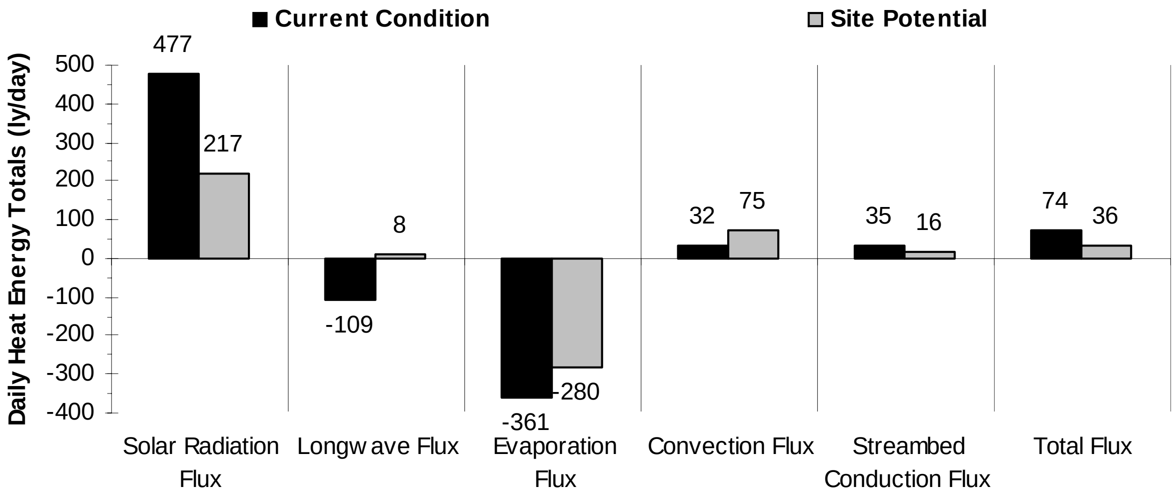


Figure 5-24. Willow Creek Reach 5 Daily Heat Energy Totals *(August 12, 1998)*

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ACRONYM LIST

AWQMA – Agricultural Water Quality Management Area

BLM – Bureau of Land Management

BMP – Best Management Practice

BOF – Board of Forestry

BTU – British Thermal Unit

CAFO – Confined Animal Feeding Operation

CBOD – Carbonaceous Biochemical Oxygen Demand

CC – Canopy Cover

CFR - Code of Federal Regulations

cfs - cubic feet per second

CWA - Clean Water Act

d/s - downstream

DEM - Digital Elevation Model

DH – Distance from Headwaters

DMA – Designated Management Agency

DO – Dissolved Oxygen

DOQ - Digital Orthophoto Quad

EPA - (United States) Environmental Protection Agency

EQC – Environmental Quality Commission

FPA – Forest Practices Act

HUC - Hydrologic Unit Code

INFISH – Inland Native Fish Strategy

LA - Load Allocation

LC - Loading Capacity

MOA – Memorandum of Agreement

MOS – Margin of Safety

MOU – Memorandum of Understanding

NBOD – Nitrogenous Biochemical Oxygen Demand

NPDES – National Pollutant Discharge Elimination System

OAR - Oregon Administrative Rules

ODA - Oregon Department of Agriculture

ODEQ - Oregon Department of Environmental Quality

ODF - Oregon Department of Forestry

ODFW - Oregon Department of Fish and Wildlife

ODOT – Oregon Department of Transportation

OSU – Oregon State University

OWRD - Oregon Water Resources Department

RM - River Mile

SE - Standard Error

SOD – Sediment Oxygen Demand

TKN – Total Kjeldahl Nitrogen

TMDL - Total Maximum Daily Load

UNR – University of Nevada Reno

u/s - upstream

USGS - United States Geological Survey

USFWS – United States Fish & Wildlife Service

W:D - Width to Depth (ratio)

WPCF – Water Pollution Control Facilities

WQ – Water Quality

WQMP – Water Quality Management Plan

WQRP – Water Quality Restoration Plan