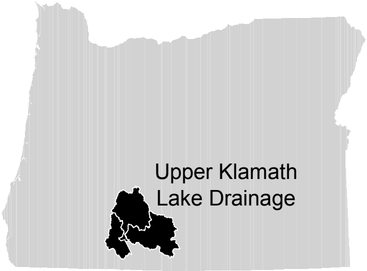
Upper Klamath Lake Drainage Total Maximum Daily Load (TMDL) and Water Quality Management Plan (WQMP)



Prepared by,

State of Oregon
Department of Environmental Quality

May 2002

Printed by the Oregon Department of Environmental Quality

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May, 2002

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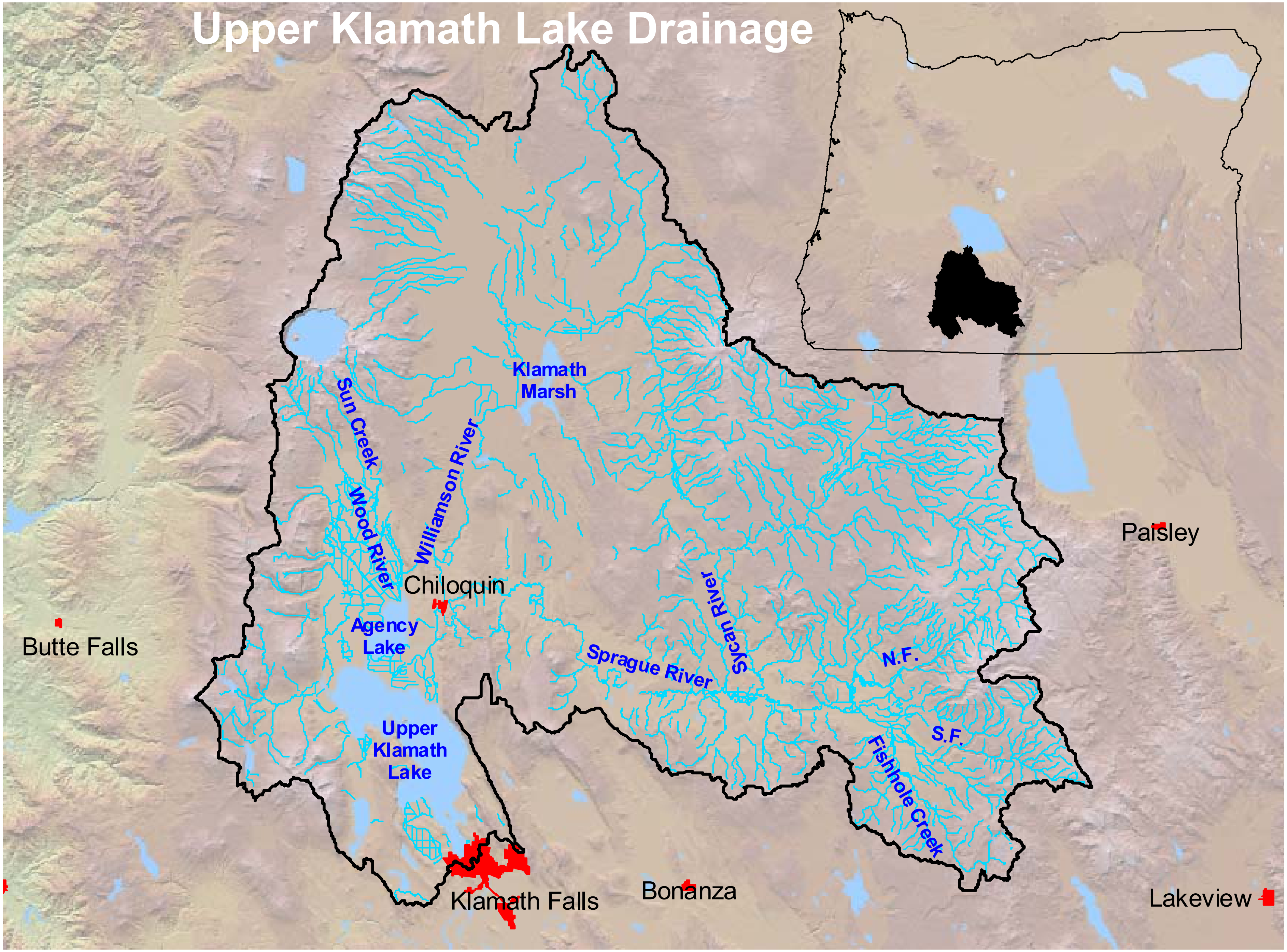
Upper Klamath Lake Drainage



UPPER KLAMATH LAKE DRAINAGE TOTAL MAXIMUM DAILY LOAD (TMDL) AND WATER QUALITY MANAGEMENT PLAN (WQMP)

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EXECUTIVE SUMMARY

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 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 an analysis that establishes that waterbodies will attain and maintain water quality levels specified in water quality standards.

The Upper Klamath Lake drainage is comprised of three 4th field hydrologic units (i.e. the Upper Klamath Lake subbasin, the Williamson River subbasin, and the Sprague River subbasin) and has stream segments listed on the 1998 Oregon 303(d)[1] list for: temperature, dissolved oxygen (DO), chlorophyll-a, pH, and habitat modification. The TMDL developed in this document for each of the 303(d) water quality parameters identifies pollutants and establishes loading limits designed to comply with water quality standards.

Habitat and flow modification concerns are identified under biological criteria[2] standard exceedance and will be addressed in management plans to be developed by designated management agencies (DMAs). As they are not pollutants, TMDLs will not be developed for habitat and flow modification. Chlorophyll-a is listed in the Oregon Administrative Rules (OAR) as a “nuisance criteria” and will be addressed in the Water Quality Management Plan (WQMP).

TMDL SUMMARIES

Following are brief descriptions of the TMDLs included in this document. A summary of the allocations and waste load allocations developed in this TMDLs are listed on **page iii** and listed in table form at the beginning of each TMDL chapter.

Upper Klamath Lake and Agency Lake TMDL (Chapter II)

Upper Klamath Lake and Agency Lake are hypereutrophic. High nutrient loading promotes correspondingly high production of algae, which, in turn, modifies physical and chemical water quality characteristics that can directly diminish the survival and production of fish populations. Year to year variations in the timing and development of algal blooms during late spring and early summer are strongly water temperature dependent. The Upper Klamath Lake and Agency Lake TMDL examines total phosphorous loading targets as the primary method of improving lake water quality. Statistical analysis and deterministic modeling demonstrates that pH levels are reduced to levels that benefit aquatic life when total phosphorus loading rates are reduced.

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

[2] Biological criteria 303(d) listings do not have a pollutant identified, and thus, cannot have a TMDL pollutant loading limit. Instead, biological criteria listing (i.e. flow and habitat modifications) will be addressed in water quality management plans (Chapter VI).

Stream Temperature TMDL (Chapter III)

The Federally threatened salmonids that reside in the subbasin are highly sensitive to warm stream temperatures. Oregon’s stream temperature standard uses numeric and narrative triggers to invoke a condition that requires "no measurable surface water increase resulting from anthropogenic activities." Rather than target specific stream temperature levels, this TMDL targets a condition where human related stream warming is minimized. While this method may seem complex, it allows site specific targets that are more appropriate and variable than application of any one stream temperature level throughout the watershed.

The stream temperature TMDL targets the defined thermal pollutant: heat from human sources. There are two sources of pollutants: increased solar radiation heat loading and heat from point source warm water discharge. Other factors considered in the analysis of stream heating are land cover type and condition, channel morphology and instream flows. The loading capacity is the total allowable daily heat loading. Load allocations are developed for anthropogenic and background nonpoint sources of heat. Waste load allocations are developed for all point sources. There is no explicit numeric margin of safety provided in the temperature TMDL. Effective shade and channel morphology targets are used as a surrogate measure for nonpoint source pollutant loading offering straightforward parameters to monitor and measure. Attainment of TMDL surrogate measures (i.e. effective shade and channel morphology targeted conditions) ensures attainment of the nonpoint source allocations.

Sprague River Dissolved Oxygen TMDL (Chapter IV)

The Sprague River is listed as impaired due to insufficient concentrations of dissolved oxygen (DO). 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 and sediment oxygen demand (SOD). Increased water temperatures will also reduce the amount of oxygen in water by decreasing its solubility and increasing the rates of nitrification, respiration rates and the decay of organic matter. Depth of streambed, sediments, algal populations, phosphorus, and turbidity can impact levels of DO. DO fluctuation is directly related to the changes in any of these parameters, either individually or in combination.

It was determined by the DO modeling of the Sprague River that achieving the load allocations and temperature reductions established in the stream temperature TMDL will reduce periphyton growth and lead to the attainment of the water quality standards.

Sprague River PH TMDL (Chapter V)

Algae production is the principle cause of wide pH fluctuations in the Sprague River. The algae of concern is periphyton. As periphyton obtains carbon dioxide for cell growth the bicarbonate present in the water is decreased. Removal of the bicarbonate from the water will generally increase the pH. High pH is stressful to fish. This daily increase in pH is associated with algal photosynthesis, which is maximized by mid-day light and warmth. The pH standard has been exceeded during the warmest part of the day from about rivermile 50.1 to the mouth. It was determined by pH modeling of the Sprague River that achieving the load allocations established for stream temperature will reduce periphyton growth and lead to the attainment of the water quality standards for pH.

Summary of Load Allocations and Waste Load Allocations

Water Quality Limitation	Load Allocations				Waste Load Allocations		
	Quantity	**Geographic Areas**	**Season**	**Responsibility**	**Quantity**	**Point of Compliance**	**Season**
Temperature	Allowable solar heat based on land cover type/condition and channel morphology	Perennial Streams of the Upper Klamath Lake Drainage	July to September annual peak temperatures	Land uses: Agriculture Forestry Urban Transportation	Allowable heat input during critical period	End of pipe	April 15 to November 1
Dissolved Oxygen	% Phosphorus reduction	Perennial Streams of the Upper Klamath Lake Drainage, Agency, Klamath Lakes	July to October annual minimal DO levels	Land uses: Agriculture Forestry Urban Transportation	percent reduction in DO during critical period late summer, fall	Measurement of DO In UKL Tributaries Sprague	Late Summer, Fall, Spring
pH	% Phosphorus reduction	Perennial Streams of the Upper Klamath Lake Drainage, Agency, Klamath Lakes	June to October annual peak pH levels	Land uses: Agriculture Forestry Urban Transportation	percent reduction in discharge phosphorus all seasons	Measurement of pH in UKL, Sprague River	Spring to Fall
Chlorophyll -a	% Phosphorus reduction	Upper Klamath and Agency Lakes.		Land uses: Agriculture Forestry Urban Transportation	Nuisance Criteria; reduction in levels all seasons.		Late Summer

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CHAPTER I

OVERVIEW AND BACKGROUND

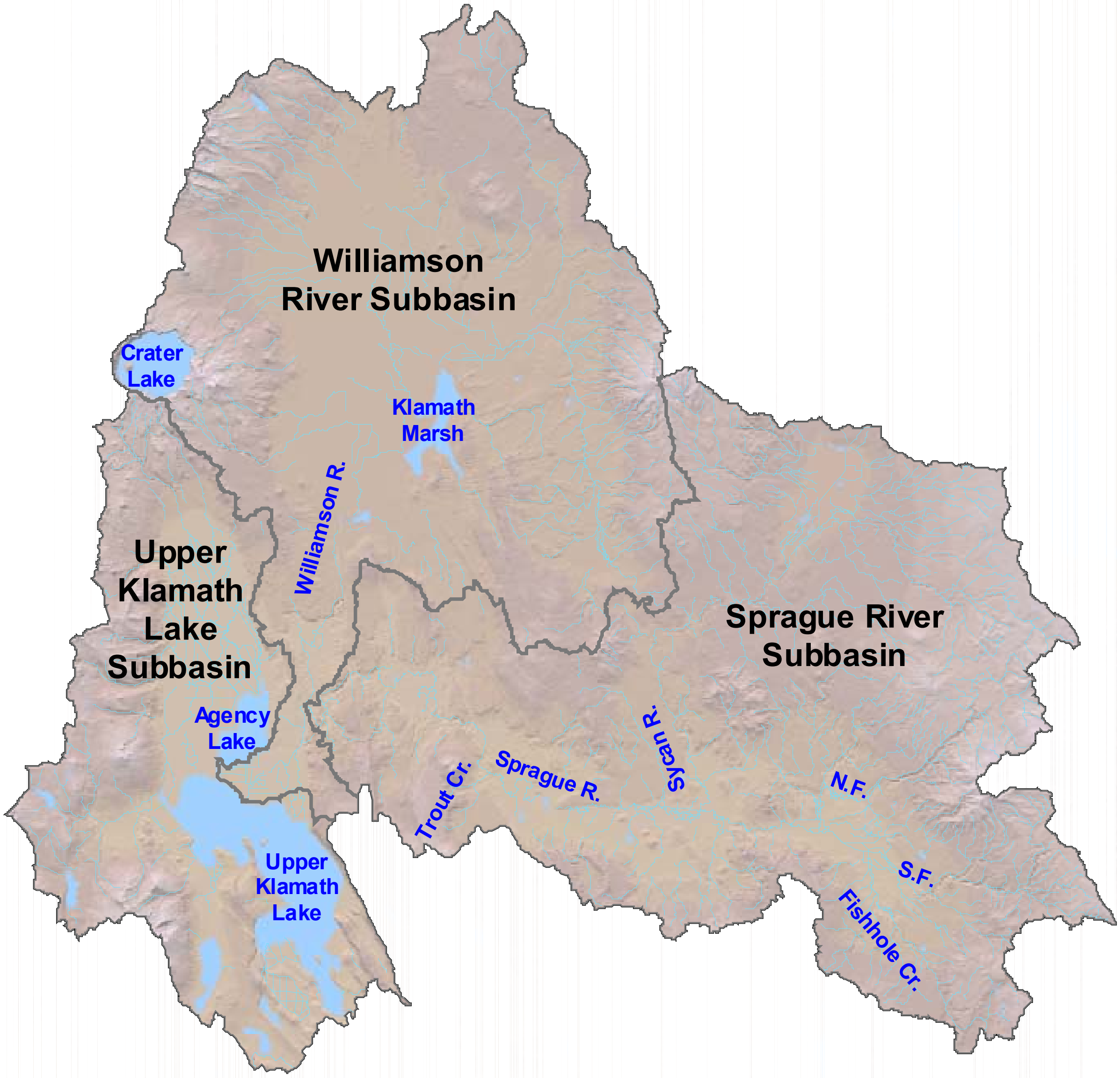


Figure 1-1. The Upper Klamath and Agency Lake drainage includes three 4th field hydrologic units: Williamson River, Sprague River and Upper Klamath Lake Subbasins.

1.1 INTRODUCTION

The following summary serves to introduce the Upper Klamath Lake drainage (**Figure 1-1**), discuss the purpose of this document and describe the goals and plans established within.

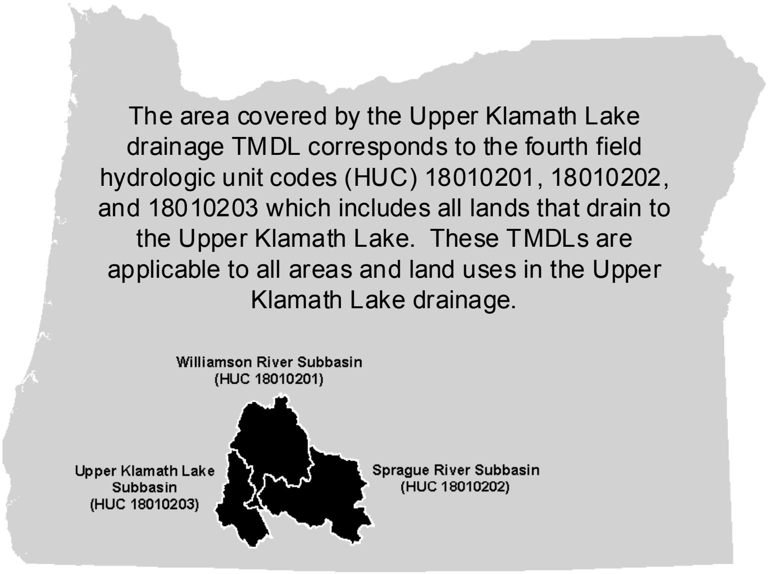
The Upper Klamath Lake drainage has an area of 3,774 square miles and is located in southern Oregon. Three fourth field hydrologic units comprise the Upper Klamath Lake drainage: 1) the Sprague River Subbasin, 2) the Williamson River Subbasin, and 3) the Upper Klamath Lake Subbasin. The Upper Klamath Lake drainage lies almost entirely within Klamath County, with some overlap into Lake County to the east, and a very small portion in Jackson County to the west. The headwaters of the Sprague River are located in the Fremont National Forest. A major tributary to the Sprague River is the Sycan River, which also originates in the Fremont National Forest, flows through the Sycan Marsh, and joins the Sprague River in the valley floor. The Sprague River generally flows westward until its confluence with the Williamson River. The Williamson River also originates in the Fremont National Forest, then it flows through the Klamath Marsh, and continues southward to Upper Klamath Lake.

Numerous streams do not meet Oregon water quality standards. Each TMDL contained in this document evaluates water quality impairments, establishes TMDL numeric goals based on attainment of water quality standards, and then outlines the steps required to meet 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 and study that has recently occurred in the Upper Klamath Lake, Sprague, and Williamson subbasins. It is hoped that water quality programs will utilize this TMDL to develop and/or improve existing 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.

The report is organized as follows:
- The main text summarizes the eight TMDL elements (listed on page 4) for each of the TMDL parameters: temperature, dissolved oxygen, pH, and chlorophyll-a.
- Appendices and attachments contain a more detailed description of the data, studies, computer modeling, references, and data analyses that were done to develop TMDLs or to address other parameters of concern.
- A Water Quality Management Plan is also presented in **Chapter VI**.

The Klamath Basin has several noteworthy distinctions:
- More than 34 percent of the basin is in private ownership.
- The Klamath Tribes are located within the drainage.
- Federal and state agencies have been working with stakeholders for over twenty years to answer questions regarding fish kills in Upper Klamath Lake.
- The largest area of land use is private and public forest.
- The water quality concerns are predominately distributed nonpoint sources of pollution instead of discrete point source pollution.
- The entire Klamath Basin (including the Upper Klamath Lake drainage) is 7th largest of Oregon’s basins.
- Upper Klamath Lake is the largest, natural body of fresh water in the Pacific Northwest.
- The Upper Klamath Lake drainage is home to productive agricultural and forestlands and contains streams with historically viable trout and anadromous salmonids. Redband trout (a type of rainbow) are present in Klamath and Agency Lakes, and Williamson and Sprague Rivers.

1.2 OVERVIEW OF TOTAL MAXIMUM DAILY LOADS



The area covered by the Upper Klamath Lake drainage TMDL corresponds to the fourth field hydrologic unit codes (HUC) 18010201, 18010202, and 18010203 which includes all lands that drain to the Upper Klamath Lake. These TMDLs are applicable to all areas and land uses in the Upper Klamath Lake drainage.

Figure 1-2. The Klamath and Agency Lake drainage includes three 4th field hydrologic units: Williamson, Sprague and Upper Klamath Lake Subbasins.

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 (DEQ). 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 Title 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 that is allocated to point, non-point, background, and future sources of pollution. Wasteload Allocations are portions of the total load that are allotted to point sources of pollution, such as sewage treatment plants or industries. The Wasteload Allocations are used to establish effluent limits in discharge permits. 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 nonpoint and point sources. The TMDL is the integration of all these developed wasteload and load 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, EPA 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 non-point 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 non-point sources;
8. Development of a margin of safety.

1.2.2 Parameters not being addressed by a TMDL

The 303(d) List is intended to identify all waters not meeting water quality standards. EPA has interpreted that Total Maximum Daily Loads (TMDLs) are to be established only where a water body is water quality limited by a "pollutant."[3] In the case where the listings are for parameters such as for Habitat Modification or Flow Modification which are not pollutants[4], TMDLs would not need to be established and other approaches to address these concerns, such as through Management Plans, could be used to address these impairments. In the case of a Biological Criteria listing which could be due to either a pollutant (e.g. excessive temperature, low dissolved oxygen or sedimentation) or some form of pollution (flow or habitat modification), the likely cause for the Biological Criteria exceedance needs to be determined. If pollutants were the likely cause, a TMDL would need to be established. If some other form of pollution was involved, other appropriate measures could be used.

The 1998 303(d) list contains listings for waters in the Upper Klamath Lake drainage for habitat modification, for which ODEQ is not submitting a TMDL. Detailed discussions regarding this parameter is provided in the Appendices. A summary of the rationale for not developing TMDLs for this parameter follows:

Habitat Modification: Factors that were identified which affect fish assemblages include water quality, flow and habitat modification. TMDLs are being developed for temperature and dissolved oxygen throughout the subbasin which should address the water quality pollutants of concern and improve the water quality for the fish assemblages. Other factors such as habitat and flow improvements are not pollutants and a TMDL will not be developed. However, these factors will need to be addressed in management plans in order to have substantial improvements in the fish assemblages.

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[3] Section 303(d)(1)(C) states that "each State shall establish for the waters identified in paragraph (1)(A) of this subsection, and in accordance with the priority ranking, the total maximum daily load, for those pollutants which the Administrator identifies under section 304(a)(2) as suitable for such calculation.

[4] The term pollutant is defined in section 502(6) of the CWA and in the proposed 40 CFR 130.2(d) as follows: "The term "pollutant" means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water."

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 DEQ has no direct authority for implementation, DEQ works with DMAs on implementation to ensure attainment of water quality standards. The DMAs in the Upper Klamath Lake drainage include: US Forest Service, US Bureau of Reclamation, US Fish and Wildlife Service, Crater Lake Park Service, Oregon Department of Agriculture and the Oregon Department of Forestry, Klamath County, and the City of Klamath Falls. These agencies have developed water quality management plans (WQMP) to load allocations identified in the 1988 TMDLs and/or are operating under NPDES permits.

DEQ intends to submit a TMDL WQMP to EPA concurrently with submission of TMDLs. Both the TMDLs and their associated WQMP will be submitted by DEQ 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 WQMPs that will be submitted to EPA:

- Condition assessment and problem description
- Goals and objectives
- Identification of responsible participants
- Proposed management measures
- Timeline for implementation
- Reasonable assurance
- Monitoring and evaluation
- Public involvement
- Costs and funding
- Citation to legal authorities

***Chapter VI** contains the above elements for DMAs and contains schedules for when permits and management plans will be updated.*

A Water Quality Management Plan (WQMP) is included as a companion document to the TMDLs. 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 Upper Klamath Lake drainage focuses specifically on:

- State Forest Lands (Forest Practices Act)
- Private Forest Lands (Forest Practices Act)
- US Bureau of Reclamation Lands (Water Quality Management Plan)
- US Fish and Wildlife Services Lands (Water Quality Management Plan)
- Federal Forest Lands (Northwest Forest Plan)
- Private Agricultural Lands (SB1010 Plan)
- Klamath County Lands (County Ordinances)

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

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

Chapter VI 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. The primary authors were workgroups appointed to represent the specific land uses, providing stakeholder representation as well as technical and policy expertise.

The Upper Klamath Basin TMDL Citizens Advisory Committee was formed to assist the Department in developing TMDLs for the Upper Klamath Lake drainage. The committee includes representatives of various land uses and resources. Valuable contributions by the committee include 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 discussion, some of which is presented in this document, has been used to design the enclosed protective and enhancement strategies that address water quality issues. Citizen Advisory Committee meetings were open to the public and public participation at the meetings was encouraged.

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 non-point 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 technology for controlling some pollution sources such as nonpoint sources and stormwater is, in many cases, in the development stages and will likely take one or more iterations to develop effective techniques. 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 this TMDL, pollutant surrogates have been defined as alternative targets for meeting the TMDL for some parameters. The purpose of the surrogates is not to bar or eliminate human access or activity in the subbasin or its riparian areas. It is the expectation, however, that WQMPs will address how human activities will be managed to achieve the surrogates. It is also recognized that full attainment of pollutant surrogates (system potential vegetation, for example) at all locations may not be feasible due to physical, legal or other regulatory constraints. To the extent possible, WQMPs 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 vegetation 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 vegetation.

When developing water quality-based effluent limits for NPDES permits, ODEQ will ensure that effluent limits developed are consistent with the assumptions and requirements of the wasteload allocation (CFR 122.44(d)(1)(vii)(B)). Similarly, the Department will work with nonpoint sources in developing management plans that are consistent in meeting the assumptions and requirements of the load allocations. These permits and plans will be developed/modified within 1-2 years following the develop/modification of a TMDL and include but not be limited to the following (February 2000 MOA between ODEQ and EPA):

- 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, and
- Monitoring and evaluation.

If a source that is covered by this TMDL complies with its permit, WQMP or applicable forest practice rules, it will be considered in compliance with the TMDL. ODEQ intends to regularly review progress of WQMPs to achieve TMDLs. If and when ODEQ determines that WQMP have been fully implemented, that all feasible management practices have reached maximum expected effectiveness and a TMDL or its interim targets have not been achieved, the Department 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 management 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 and permit holders 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.

A zero waste load allocation does not necessarily mean that a point source is prohibited from discharging any wastes. A source may be permitted to discharge by ODEQ if the holder can adequately demonstrate that the discharge will not have a significant impact on water quality over that achieved by a zero allocation. For instance, a permit applicant may be able to demonstrate that a proposed thermal discharge would not have a measurable detrimental impact on projected stream temperatures when system temperature is achieved. Or, in the case where a TMDL is set based upon attainment of a specific pollutant concentration, a source could be permitted to discharge at that concentration and still be considered as meeting a zero allocation.

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 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.
- When developing water quality-based effluent limits for NPDES permits, ODEQ will ensure that effluent limits developed are consistent with the assumptions and requirements of the wasteload allocation (CFR 122.44(d)(1)(vii)(B)).
- 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 are 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 treatment technologies or management practices or measures; and cost of compliance (OAR 340-41-026(3)(a)(D)(ii)).

1.3 UPPER KLAMATH LAKE DRAINAGE OVERVIEW

1.3.1 Geology

The Upper Klamath Lake drainage headwaters predominately occur in the coniferous forests of the Fremont and Winema National Forests, and at over 5,000 feet elevation (the highest point in the subbasin is 9,490 feet in elevation). The Williamson River enters Upper Klamath Lake at 4,140 feet above sea level. Shaded relief topography is depicted in **Figure 1-4**. The Upper Klamath Lake drainage is surrounded by relatively steep mountains. There are several high elevation meadows and marshes that the stream network flows through (i.e., Klamath Marsh in the Williamson River Subbasin and Sycan Marsh, Teddy Powers Meadow, and Lee Thomas Meadow in the Sprague River Subbasin).

Upper Klamath Lake is in a large, flat valley adjacent to the eastern slopes of the Cascade Range in south-central Oregon. It is the largest lake (by area) wholly within Oregon, having a surface area of about 140 square miles at maximum lake surface elevation, a length of about 25 miles, and a width ranging from 2.5 to 12.5 miles. Despite its large size, the lake is shallow and has a mean summer depth of about 8 feet and a maximum depth of about 58 feet (U.S. Army Corp of Engineers, 1979, 1982).

The north-northwest trending Klamath Basin corresponds, in part, to a down-faulted crustal block, which is 6-9 mile wide. It is known as the Klamath Graben and extends north toward Crater Lake in the Cascade range and is bounded by high, steep escarpments, especially along the eastern rim. As much as 6,600 feet of unconsolidated sediment fills the graben. Rocks in the area are predominately volcanic origin, consisting of unconsolidated or consolidated volcanic materials or unconsolidated sediments largely derived from volcanic rocks.

Parts of Upper Klamath Lake drainage were heavily glaciated during the Plistocene. During this time a large pluvial lake, Lake Modoc, covered much of the basin floor. Large quantities of ash and pumice as well as accumulations of diatoms and peat were deposited in the basin. At the end of the Pliestocene, about 10,000 years ago, Lake Modoc began to shrink, forming Upper and Lower Klamath Lakes.

About 6,900 years ago, a massive eruption occurred from what is now referred to as Mount Mazama at the northern end of Upper Klamath Lake Drainage. Mount Mazama collapsed during this eruption forming Crater lake and generated pumice and ash deposits over much of the Upper Klamath Lake Drainage. Volcanic materials resulting from the deposition of ash from Mount Mazama have been observed to a depth 10.5 feet in sediment cores (Snyder and Morace, 1997)

The drainage area for Upper Klamath Lake is about 3,800 square miles. The principal tributaries to the lake are the Williamson and Wood Rivers. The Williamson River is the largest, with much of its flow derived from the Sprague River. The Williamson River subbasin and the Sprague River subbasin has a drainage area of approximately 3,000 square miles and constitutes 79 percent of the total drainage area that contributes to Upper Klamath Lake. The Sprague River has a drainage area of 1,580 square miles 53 percent of the Williamson River subbasin. Together, the Williamson and Sprague Rivers supply about one-half of the inflow to Upper Klamath Lake.

In addition to streams, spring flow and groundwater seepage provide continuous inflow to the lake throughout the year (Illian, 1970). Upper Klamath Lake is drained at the southern end by the Link River, which flows through a short reach and enters Lake Ewauna at Klamath Falls. The headwaters of the Klamath River proper are about one mile south of Klamath Falls where Lake Ewauna flows into the Klamath River. Link River Dam on the Link River regulates the flow from Upper Klamath Lake. Since 1919, the operation of Link River Dam has facilitated the control of lake level elevations. Upper Klamath

Lake, Sprague River, and Williamson River subbasins are home to productive forested and agriculture lands and has the distinction of containing extensive waterbodies with expansive marshes teeming with waterfowl, blue-ribbon trout streams, and large ranches. Valuable contributions from agriculture, forestry, fisheries, the Klamath Tribes and federal agencies in these watersheds have prompted extensive data collection and study of the interaction between land use and water quality.

1.3.2 Climate

The climate of the Upper Klamath Lake drainage is generally characterized dry summers with high temperatures and wet winters with moderately low temperatures. Due to its location approximately 120 miles east of the Cascade Mountain Range, it is in the path of storms originating in the north Pacific Ocean. Winter precipitation is derived from these storms traversing in an easterly direction. The Cascade Range creates a rain shadow that affects the distribution of precipitation throughout the Upper Klamath Lake drainage. Annual precipitation (**Figure 1-5**) in the basin ranges from lows of 15 inches at Upper Klamath Lake and along the Sprague River to highs reaching 90 inches at Crater Lake (Daly et al, 1994, 1997). The mean annual precipitation (**Table 1-1**) for the Upper Klamath Lake subbasin is 27 inches. The mean annual precipitation is 23 inches in the Williamson River subbasin upstream from the confluence with the Sprague River and 20 inches in the Sprague River subbasin. Mean annual snow accumulation ranges from 15 inches in the valleys to more than 160 inches in the mountainous areas of the basin. Snowfall represents 30 percent of the annual precipitation in the valleys and more than 50 percent of the total at higher elevations.

Table 1-1. Average Monthly Climate Data for Chiloquin, Oregon

Parameter	Jan	Feb	Mar	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Year
Air Temperature (°F)													
Mean	27.2	30.1	37.4	43.5	48.5	55.9	61.0	61.1	53.8	45.8	34.8	27.5	44.1
Maximum	36.4	40.4	48.5	57.7	64.3	72.7	79.8	80.5	71.9	62.1	44.8	36.2	58.2
Minimum	17.9	19.8	26.3	29.3	32.6	39.1	42.3	41.8	35.7	29.6	24.8	18.7	30.1
Precipitation (inches)													
Mean	2.4	2.83	2.47	1.30	1.29	.65	.61	.57	.82	1.23	3.18	3.59	21.8

1.3.3 Stream Flow

Low flows generally occur during the end of the summer months (July to October) due to decreased precipitation and increased agriculture water withdrawals. It is extremely likely that 7Q10 low flows[5] in the lower portions of the drainage are impacted (i.e., lowered) by upstream diversions. Relatively little historical flow data exists for the Upper Klamath Lake drainage. Six USGS gages on the Sycan, Sprague, and Williamson Rivers have recorded enough historical daily values to calculate Log Pearson Type III 7Q10 low flows. **Figure 1-3** displays those calculated 7Q10 low flows for each USGS gage, while **Table 1-2** summarizes the gage locations and periods of record.

1.3.4 Land Use and Ownership

Land ownership is predominantly private and United States Forest Service in the Upper Klamath Lake drainage, accounting for 42.3% and 53.4% of the land area, respectively. Crater Lake National Park

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[5] 7Q10 refers to a seven day averaged low flow condition that occurs on a ten-year return period. Mathematically, this low flow condition has a 10% probability of occurring every year. A Log Pearson Type III distribution was used to calculate the return period.

makes up 3% of the land area. Nearly 1% of the area is National Wildlife Refuge. Spatial distributions of land ownership are displayed in **Figure 1-6**.

Land use in the Upper Klamath Lake drainage is predominantly forested (69.4%) and shrubland/grassland (13.7%). Agriculture (farming and grazing occur on 5.5% of the drainage. Wetlands and water make up 6% and 3.7% of the surface area, respectively. **Figure 1-7** shows the spatial distribution of major land use types.

Table 1-2. Log Pearson Type III 7Q10 Low Flow

Low Flow Averaged over 7 days with a Return Period of 10 Years				
Stream	**Location**	**Period**	**River Mile**	**7Q10 Low Flows (cfs)**
Sycan River	Below Snake Creek	1978-1991	3.0	8.4
Sprague River	Near Beatty, OR	1953-1991	75.1	76.2
Sprague River	Near Chiloquin, OR	1921-1999	5.4	120.2
Williamson River	Below Sheep Creek	1978-1991	67.8	37.6
Williamson River	Near Klamath Agency, OR	1954-1995	27.0	0
Williamson River	Below Sprague River	1923-1999	11.0	390.4

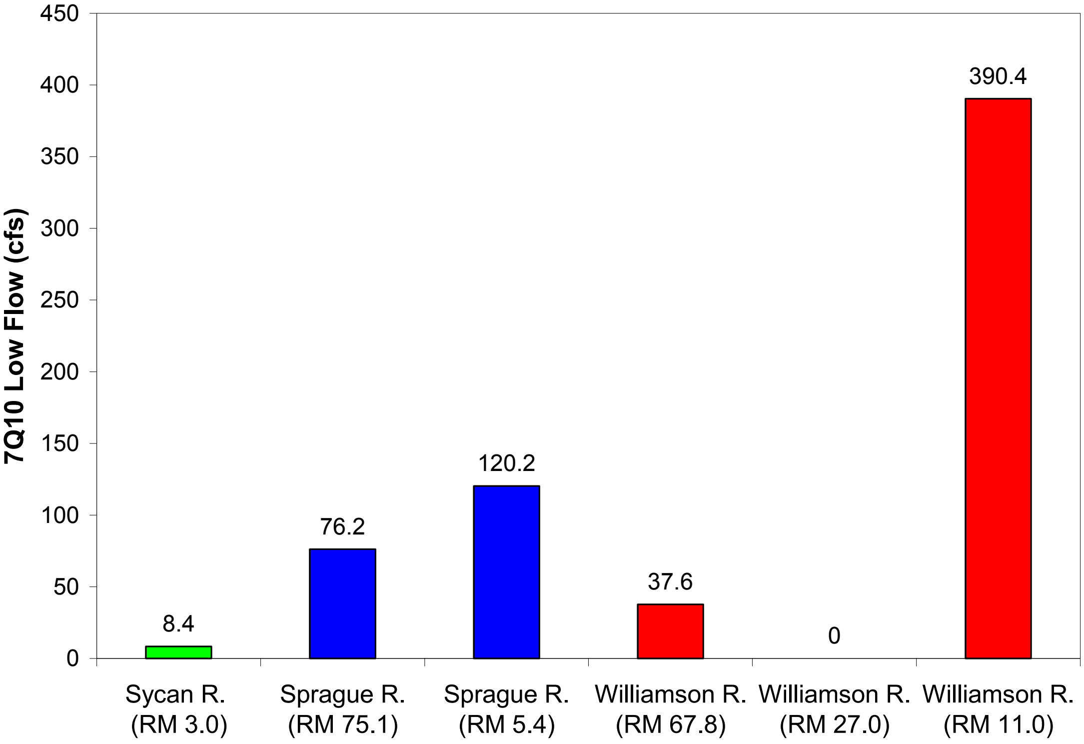


Figure 1-3. Upper Klamath Lake drainage 7Q10 Low Flows (cfs)

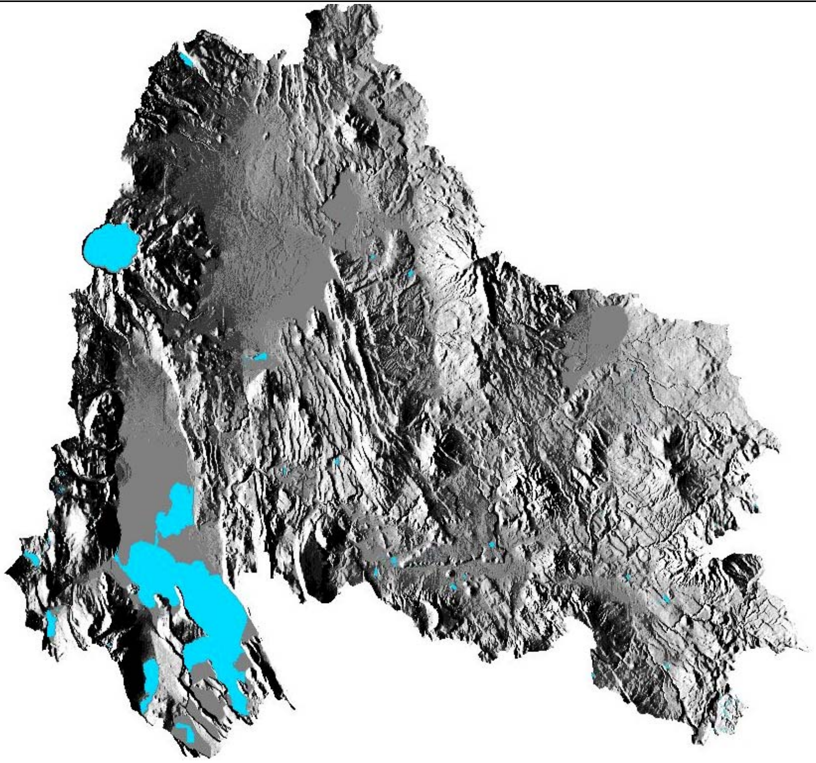


Figure 1-4. Illustration of the Upper Klamath Lake drainage Shaded Relief Topography

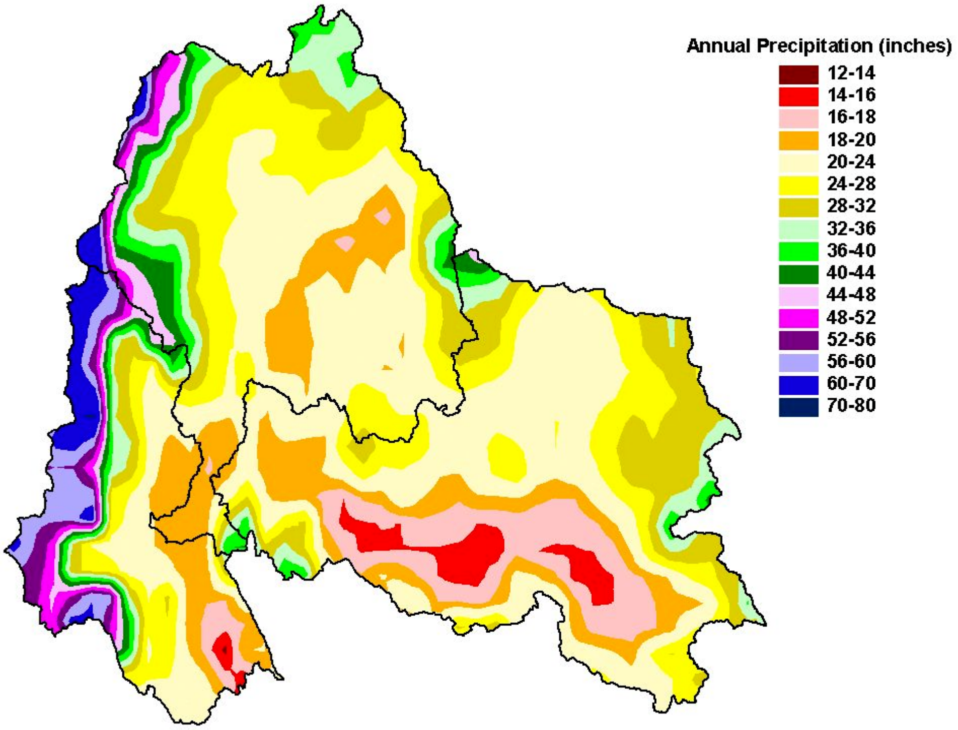


Figure 1-5. Upper Klamath Lake drainage Precipitation (Oregon SSCGIS)

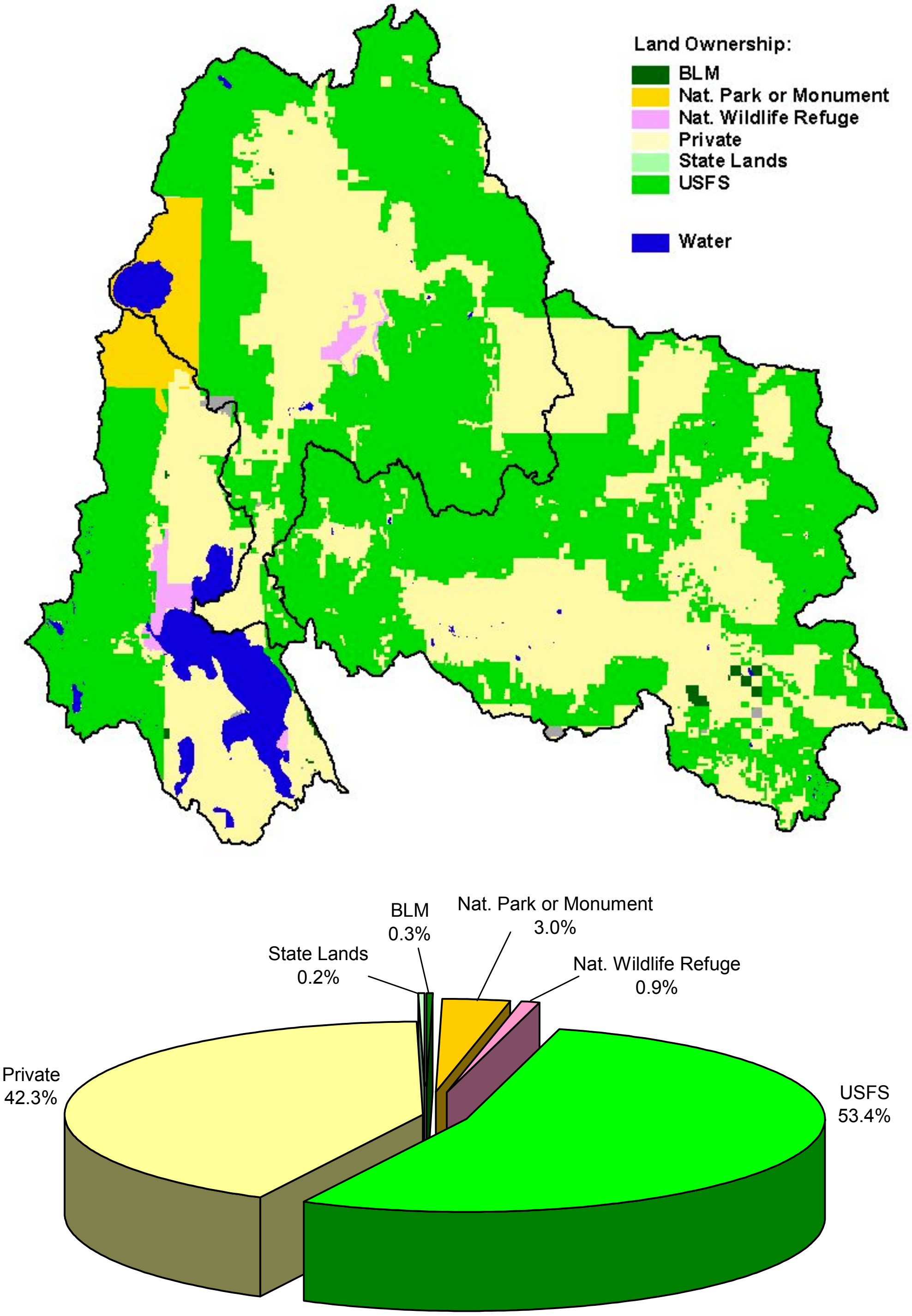


Figure 1-6. Land Ownership/Management Spatial Distributions

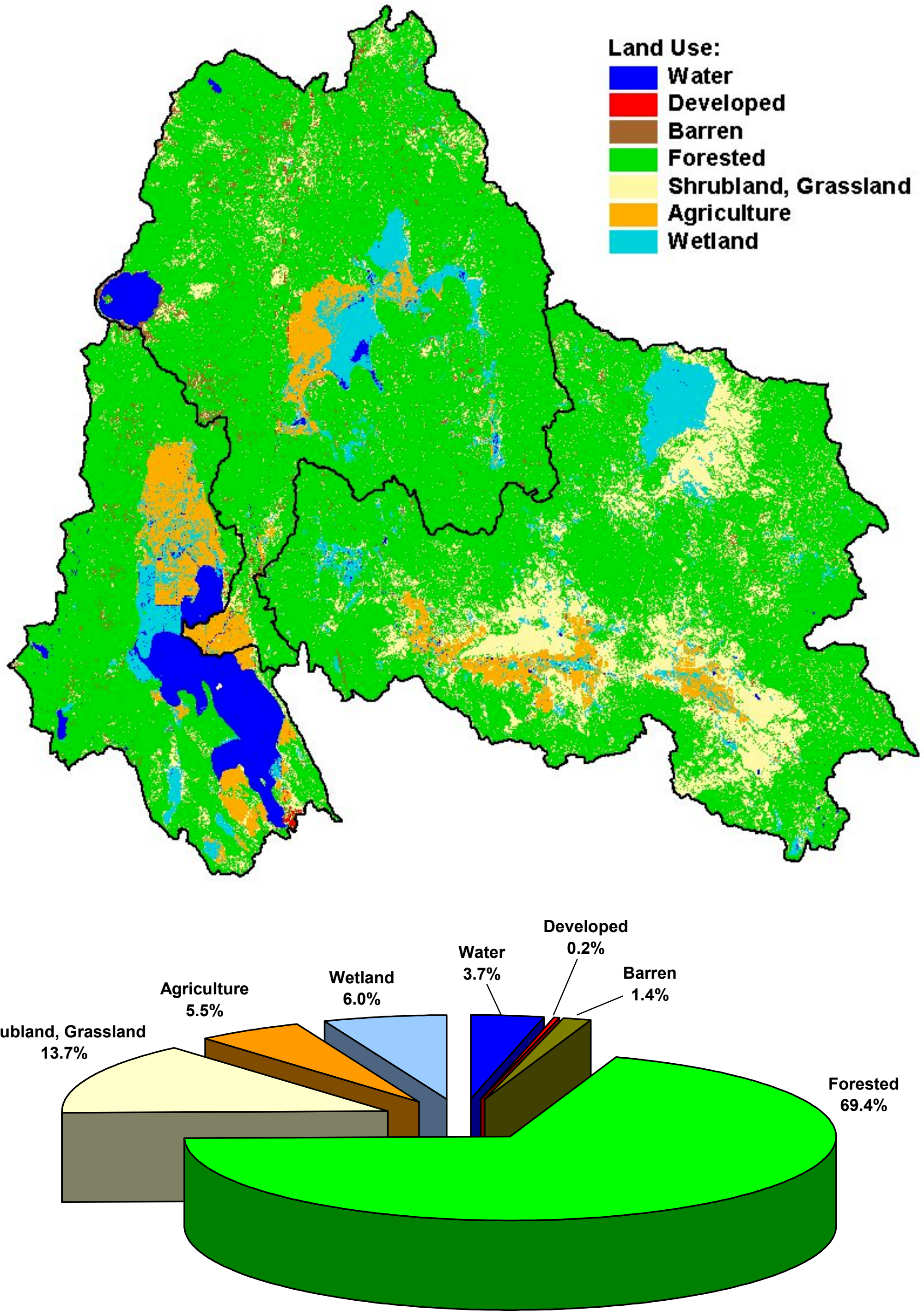


Figure 1-7. Land Use Spatial Distributions

1.3.5 Fisheries

A wide variety of fish species are present in the UKLDB. Fish species presently found in the Upper Klamath Lake drainage include:

Interior redband trout (*Oncorhynchus mykiss*)
Eastern brook trout (*Salvelinus frontinalis*)
Brown trout (*Salmo trutta*)
Bull Trout (*Salvelinus confluent)*

Blue chub (*Gila coerula*)
Fathead minnow (*Pimephales promelas*)
Speckled dace (*Rhinichthys osculus*)
Tui chub (*Gila bicolor*)

Klamath largescale sucker (*Catostomaus snyderi*)
Lost River sucker (*Deltistes luxatus*)
Shortnose sucker (*Chasmistes brevirostris*)

Brown bullhead (*Ameiurus nebulosus*)
Largemouth bass (*Micropterus salmoides*)
Pumpkinseed (*Lepomis gibbosus*)
Yellow perch (*Perca flavescens*)

Klamath Lake sculpin (*Cottus princeps*)
Marbled sculpin (*Cottus klamathensis*)
Slender sculpin (*Cottus tenuis*)

Klamath Lamprey (*Lampetra similis*)
Pacific lamprey (*Lampetra tridentata*)

Key species of interest to this TMDL include the Interior redband trout (*Oncorhynchus mykiss*), Bull Trout (*Salvelinus confluent),* Lost River sucker (*Deltistes luxatus*) and Shortnose sucker (*Chasmistes brevirostris).* Life stages periodicities for these key species are listed in **Table 1-3**.

Table 1-3. Life Stage Periodicity

Species	*Life Stage*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Redband trout	**Adult**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
	Spawning	**X**	**X**	**X**	**X**	**X**	**X**						
	Incubation	**X**	**X**	**X**	**X**	**X**	**X**						
	Fry		**X**	**X**	**X**	**X**	**X**	**X**					
	Juvenile	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
	Migration												
Bull trout	**Adult**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
	Spawning	**X**	**X**	**X**	**X**	**X**	**X**						
	Incubation	**X**	**X**	**X**	**X**	**X**	**X**						
	Fry		**X**	**X**	**X**	**X**	**X**	**X**					
	Juvenile	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
	Migration												
Lost River sucker	**Adult**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
	Spawning		**X**	**X**	**X**	**X**	**X**						
	Incubation		**X**	**X**	**X**	**X**	**X**						
	Larval		**X**	**X**	**X**	**X**	**X**	**X**					
	Juvenile	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
	Migration	**X**	**X**	**X**	**X**	**X**	**X**						
Short nose sucker	**Adult**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
	Spawning				**X**	**X**	**X**	**X**					
	Larval				**X**	**X**	**X**	**X**					
	Fry				**X**	**X**	**X**	**X**	**X**				
	Juvenile	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
	Migration												

Bull Trout

A native of the Upper Klamath Lake drainage, Bull Trout (*Salvelinus confluentus*) was listed in 1998 by the U.S. Fish and Wildlife Service as threatened within the Klamath Basin (**Figure 1-8**). Due to anthropogenic changes in their habitat, the trout are now restricted to the headwaters of nine sub-drainages and fragmentation has caused resident inbreeding. There is currently an active Bull Trout recovery group headed by ODFW with representatives from USFWS, USFS, Klamath Tribes, forest products industry, TNC and agricultural groups.

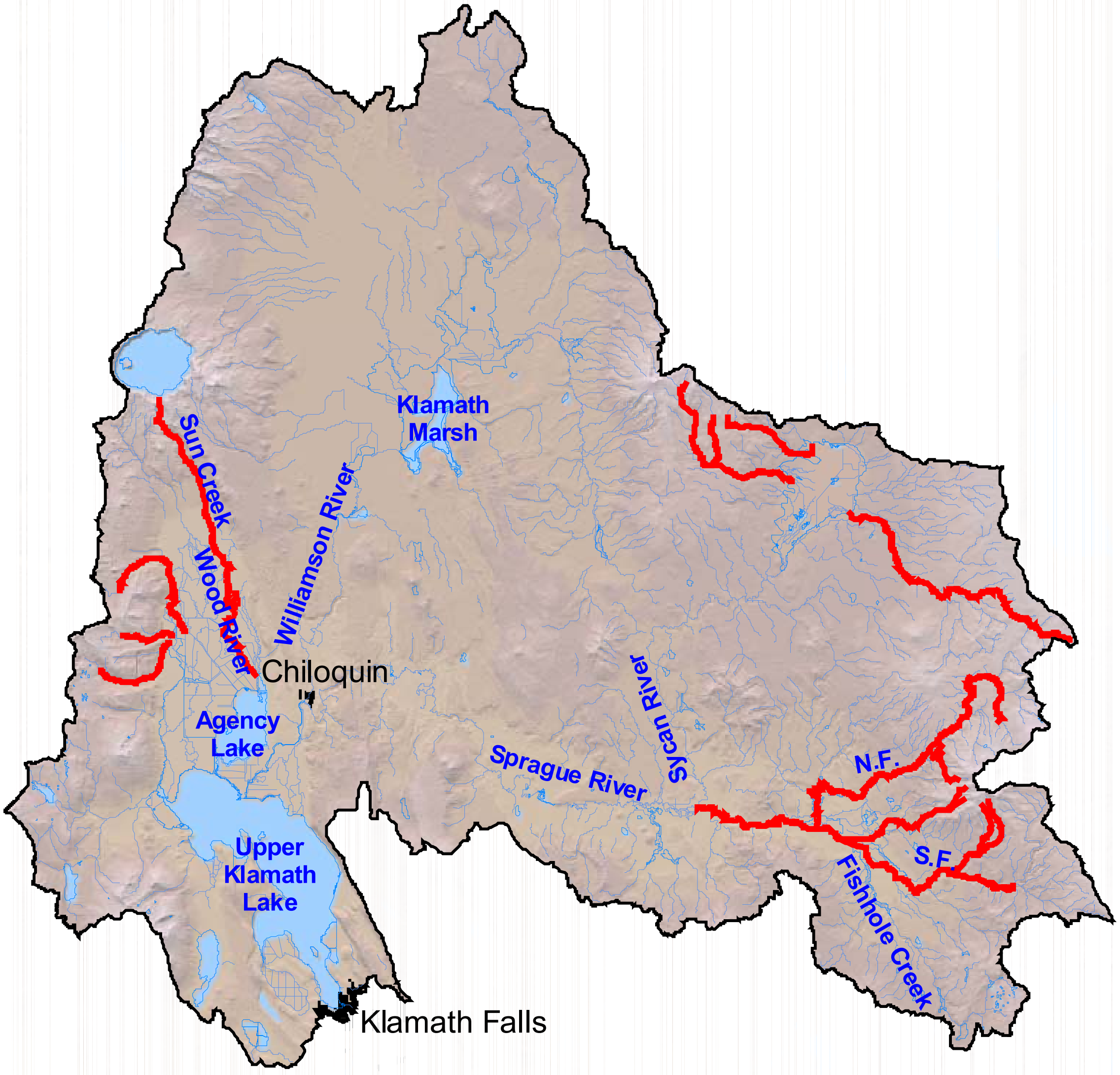


Figure 1-8. Bull Trout Distribution

Lost River and Shortnose Sucker

Drying sucker fish at the Lost River. Tribal fishing for suckers was stopped in the mid-1980's (OWRD, 2001).

The Lost River sucker *(Deltistes luxatu*s) and shortnose sucker *(Chasmistes brevirostri*s) were federally listed as endangered on July 18, 1988, because they were at risk of extinction owing to significant population declines with continued downward trends, a lack of recent recruitment, range reduction, habitat loss/degradation and fragmentation, potential hybridization, competition and predation by exotic fishes, and other factors (USFWS 1988). These fish were once very abundant and were important seasonal foods of native Americans and white settlers in the upper Klamath River basin (Cope 1879, Gilbert 1898, Howe 1968). Spawning migrations occurred in the spring at a critical time when winter food stores had been exhausted. The Klamath and Modoc Indians dried suckers for later use. It was estimated that the aboriginal harvest at one site on the Lost River may have been 50 tons annually (Stern 1966). In 1959, suckers were made a game species under Oregon State law; however, the game fishery was terminated in 1987, just prior to federal listing. Lost River suckers and Shortnose suckers are called "lake suckers" because they primarily occur in lake (lacustrine) habitats. This contrasts with the majority of sucker species, which are riverine. **Figure 1-9** indicates the distribution of suckers in the Upper Klamath Lake drainage.

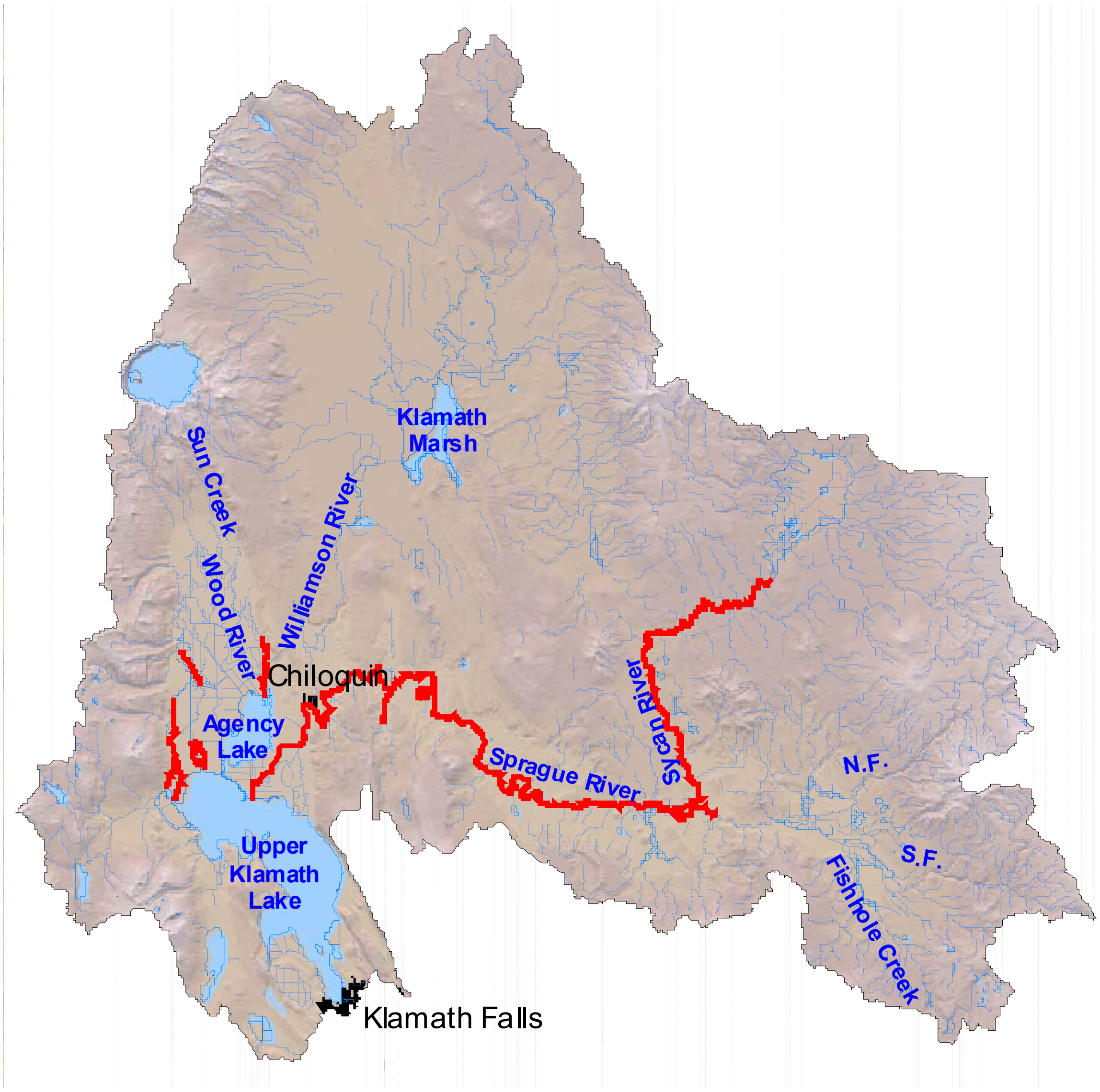


Figure 1-9. Lost River and Shortnose Sucker Distribution

Redband Trout

"We thought nothing of catching a five- or six-pound trout," recalls Basin resident Ivan Bold, remembering days of better fishing. Fishing guides are also noting declining catches as the Basin's waterways struggle to support the demands placed on them (OWRD, 2001).

Redband trout are most likely a separate species within the salmon family (*Oncorhynchus mykiss)* and this necessitated the change in species name of rainbow trout from *S. gairdneri* to *O. mykiss,* of the Southern Oregon region. The species is one of the most taxonomically complicated trout groups in Oregon. The species probably consists of multiple subspecies, of which Klamath redband is one. None of these have been formally recognized. The most recently published data on the species is in Behnke (1992), where three subspecies with ranges extending into Oregon are proposed: *O.m. irideus*, or coastal rainbow and steelhead trout; *O.m. gairdneri,* or inland Columbia Basin redband and steelhead trout; and *O.m. newberrii*, or Oregon Basin redband trout. In general, the group Behnke calls *O.m. irideus* is undisputed.

Isolated trout in Jenny Creek, above a waterfall, and in the upper Williamson and upper Sprague rivers have meristic characteristics and biochemical characters that suggest a common origin, but are quite distinctive from all other trout. These "ancient redband" trout in the Klamath may each be a separate subspecies founded from an ancient redband ancestor that occupied Oregon prior to *O.m. gairdneri*. Each has been isolated from all other forms of trout since the physical isolation of their basins thousands of years ago. Their unique nature is the result of physiological changes during the long period of isolation. Redband are common in most areas of the lake in fall, winter, and spring. In summer months lake-resident redband trout move to tributary mouths and springs to avoid adverse water quality. In addition to the native redband trout, hatchery rainbow trout have been stocked in the Upper Klamath Lake drainage since 1922 (Logan and Markle 1993).

Redband were found in the largest fish die-off in the summer of 1997 at Pelican Bay, Harriman Creek and Williamson River. The species has not been listed under the Endangered Species Act, but is a native trout resistant to the summer bacteria *Ceratomyxa shasta* that occurs in Klamath Lake. Survival of native trout is of major concern to both tribes and natural resource agencies.

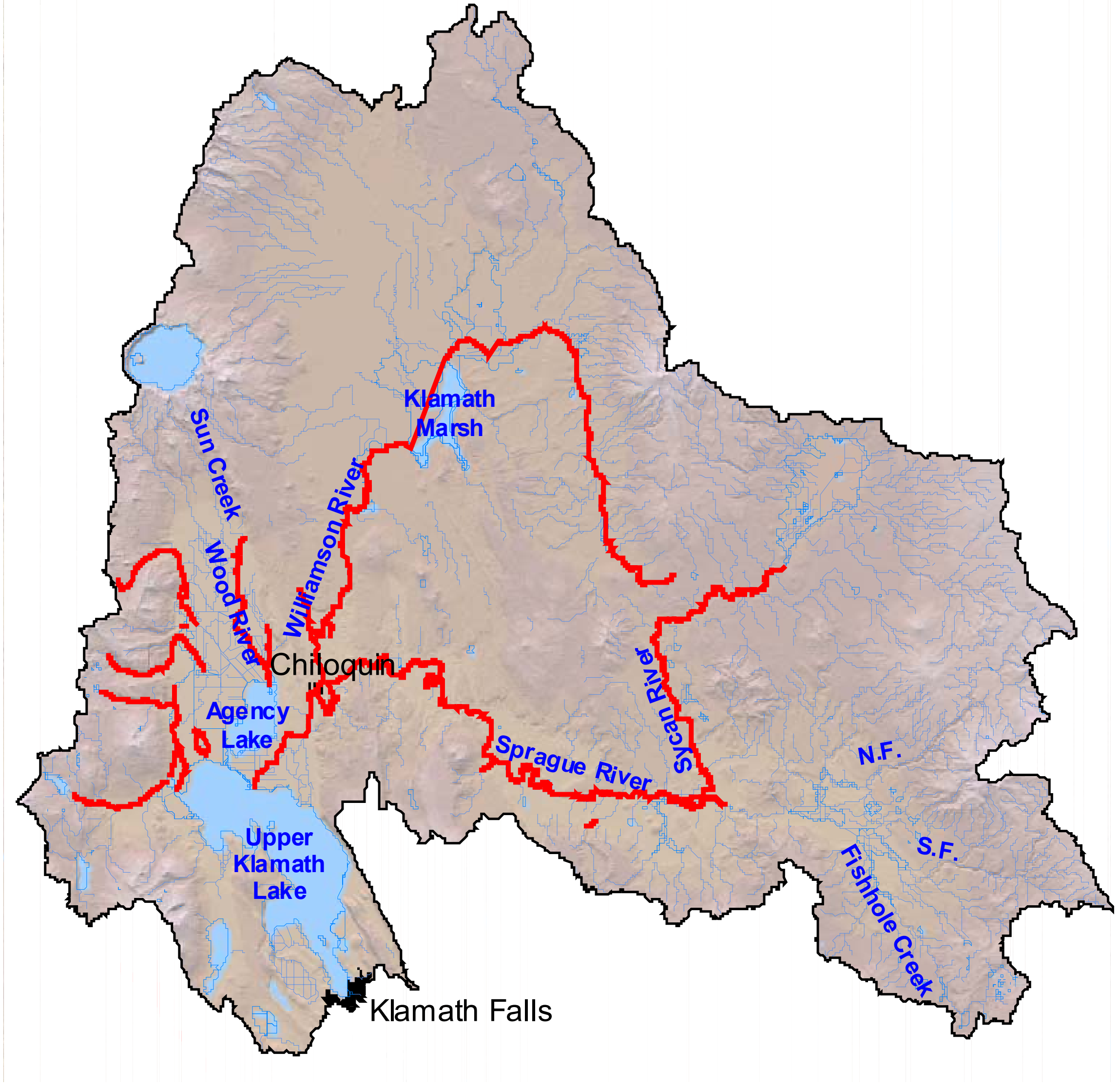


Figure 1-10. Redband Trout Distribution.

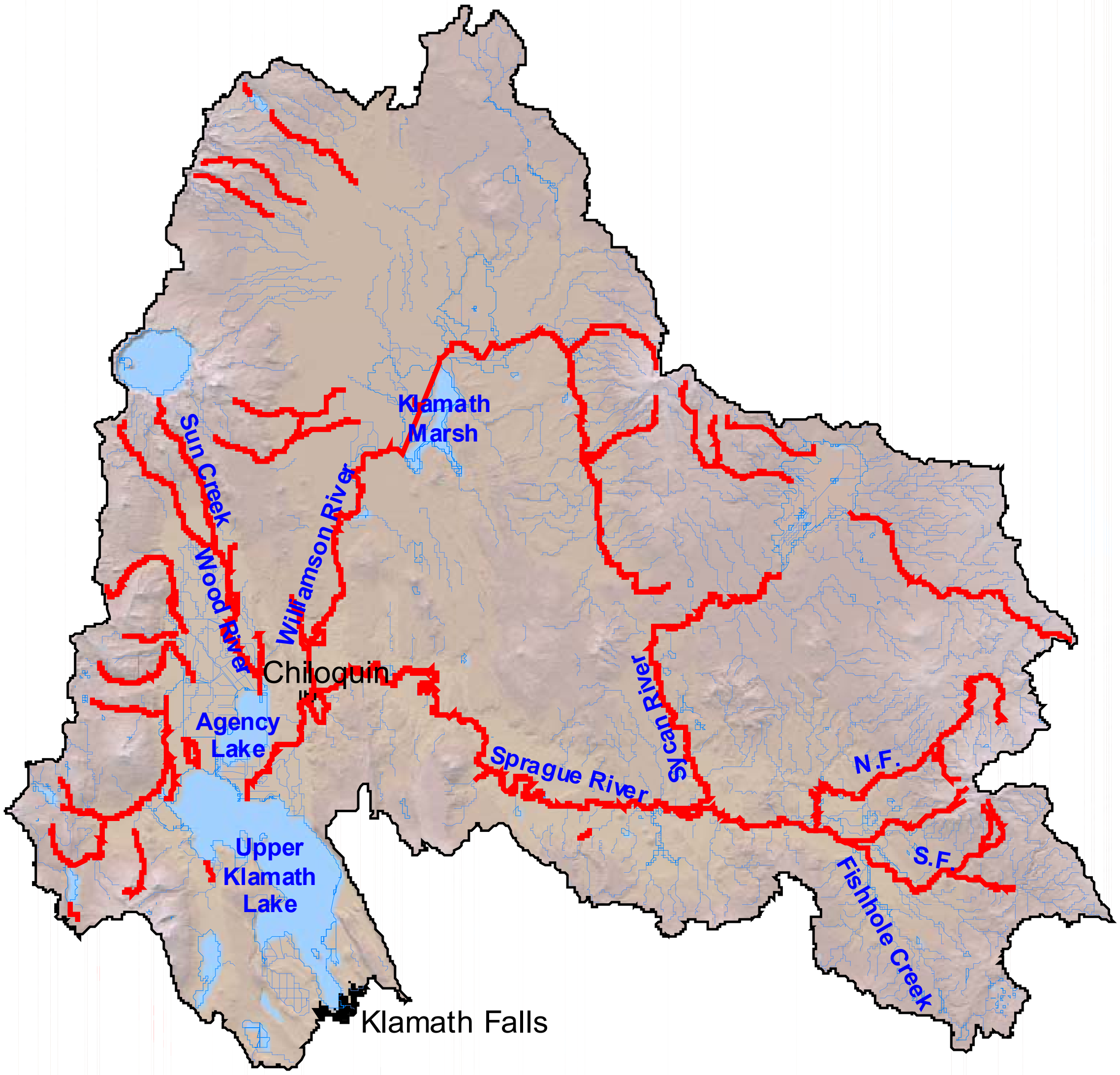


Figure 1-11. All Temperature Sensitive Beneficial Uses

1.4 EXISTING WATER QUALITY PROGRAMS

1.4.1 Oregon Forest Practices Act

The Oregon Forest Practices Act (FPA, 1994) contains regulatory provisions that include the objectives to classify and protect water resources, reduce the impacts of clearcut harvesting, maintain soil and site productivity, ensure successful reforestation, reduce forest management impacts to anadromous fish, conserve and protect water quality and maintain fish and wildlife habitat, develop cooperative monitoring agreements, foster public participation, identify stream restoration projects, recognize the value of bio-diversity and monitor/regulate the application of chemicals. Oregon's Department of Forestry (ODF) has adopted Forest Practice Administrative Rules (1997) that define allowable actions on State, County and private forestlands. Forest Practice Administrative Rules allow revisions and adjustments to the regulatory parameters it contains. Several revisions have been made in previous years and it is expected that the ODF, in conjunction with ODEQ, will continue to monitor the success of the Forest Practice Administrative Rules and make appropriate revisions when necessary to address water quality concerns.

1.4.2 Senate Bill 1010

Senate Bill 1010 allows the Oregon Department of Agriculture (ODA) to develop Water Quality Management Plans for agricultural lands where such actions are required by State or Federal Law, such as TMDL requirements. The Water Quality Management Plan should be crafted in such a way that landowners in the local area can prevent and control water pollution resulting from agricultural activities. Local stakeholders will be asked to take corrective action against identified problems such as soil erosion, nutrient transport to waterways and degraded riparian areas. It is ODA's intent to establish Water Quality Management Plans on a voluntary basis. However, Senate Bill 1010 allows ODA to use civil penalties when necessary to enforce against agriculture activity that is found to transgress parameters of an approved Water Quality Management Plan. ODA has expressed a desire to work with the local stakeholders and other State and Federal agencies to formulate and enforce approved Water Quality Management Plans.

1.4.3 Oregon Plan

The State of Oregon has formed a partnership between Federal and State agencies, local groups and grassroots organizations, that recognizes the attributes of aquatic health and their connection to the health of salmon populations. The Oregon Plan considers the condition of salmon as a critical indicator of ecosystems (CSRI, 1997). The decline of salmon populations has been linked to impoverished ecosystem form and function. Clearly stated, the Oregon Plan has committed the State of Oregon to the following obligations: an ecosystem approach that requires consideration of the full range of attributes of aquatic health, focuses on reversing factors decline by meeting objectives that address these factors, develops adaptive management and a comprehensive monitoring strategy, and relies on citizens and constituent groups in all parts of the restoration process.

The intent of the Oregon Plan is to conserve and restore functional elements of the ecosystem that supports fish, wildlife and people. In essence, the Oregon Plan is different from the traditional agency approach, and instead, depends on sustaining a local-state-federal partnership. Specifically, the Oregon Plan is designed to build on existing State and Federal water quality programs, namely: Coastal Zone Non-point Pollution Control Programs, the Northwest Forest Plan, Oregon's Forest Practices Act, Oregon's Senate Bill 1010 and Oregon's Total Maximum Daily Load Program.

1.4.4 Northwest Forest Plan

In response to environmental concerns and litigation related to timber harvest and other operations on Federal Lands, the United States Forest Service (USFS) and the Bureau of Land Management (BLM) commissioned the Forest Ecosystem Management Assessment Team (FEMAT) to formulate and assess the consequences of management options. The assessment emphasizes producing management alternatives that comply with existing laws and maintaining the highest contribution of economic and social well being. The "backbone" of ecosystem management is recognized as constructing a network of late-succession forests and an interim and long-term scheme that protects aquatic and associated riparian habitats adequate to provide for threatened species and at risk species. Biological objectives of the Northwest Forest Plan include assuring adequate habitat on Federal lands to aid the "recovery" of late-succession forest habitat-associated species listed as threatened under the Endangered Species Act and preventing species from being listed under the Endangered Species Act.

1.5 PUBLIC INVOLVEMENT

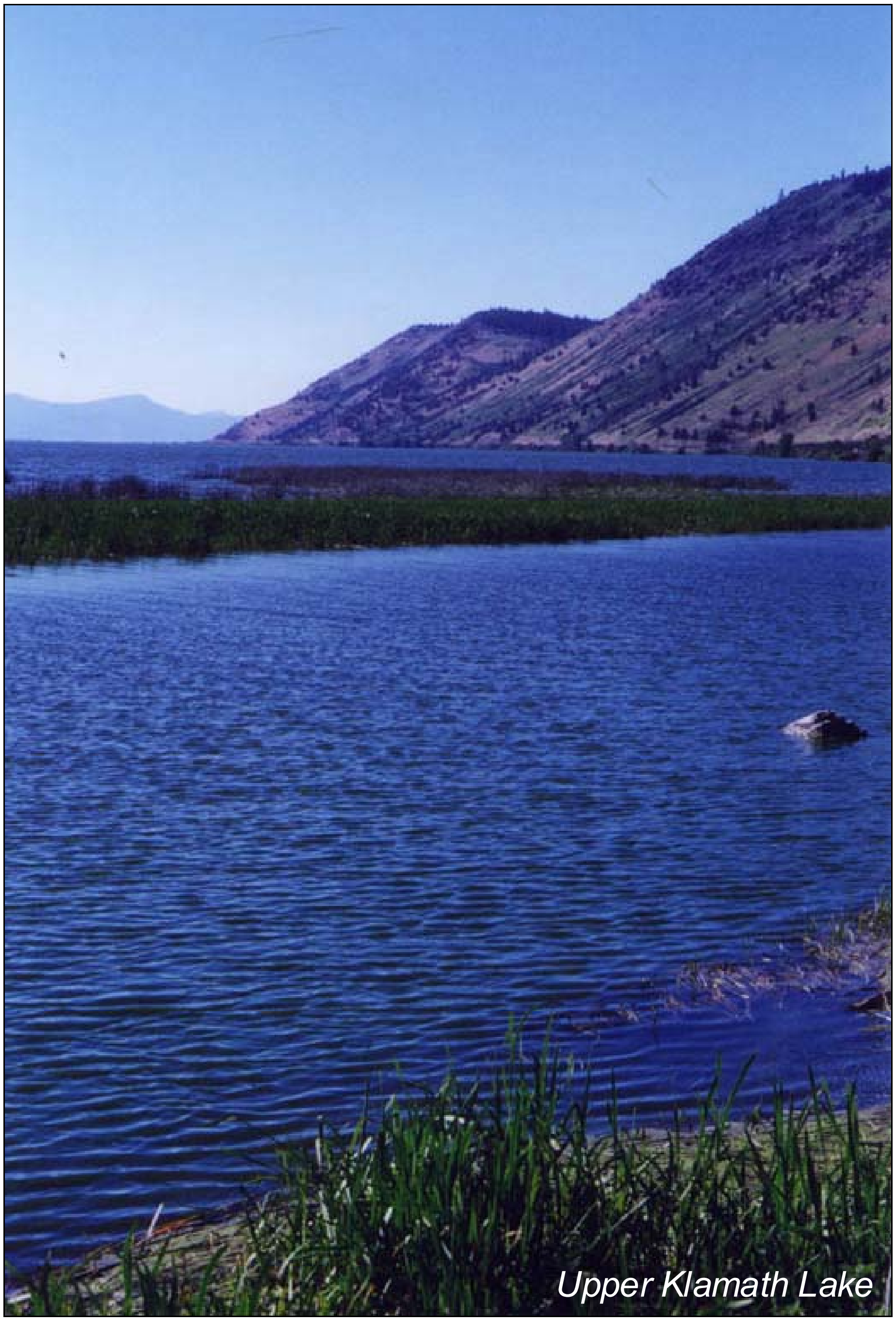
Technical and citizens advisory committees were formed to review and comment on the approach used for developing the TMDLs and WQMP. Committees were composed of local scientists and stake holders representing DMAs and representatives of various land uses. The technical advisory committee was first convened in October 1998. The citizen's advisory committee was first convened in February 1999. The advisory committees were convened periodically during the TMDL development process to gain feedback from local scientists and stakeholders. Valuable contributions from the committees include comments concerning method development, data collection, data analyses and TMDLs documentation. Public attendance and participation at committee meetings during committee meetings was encouraged.

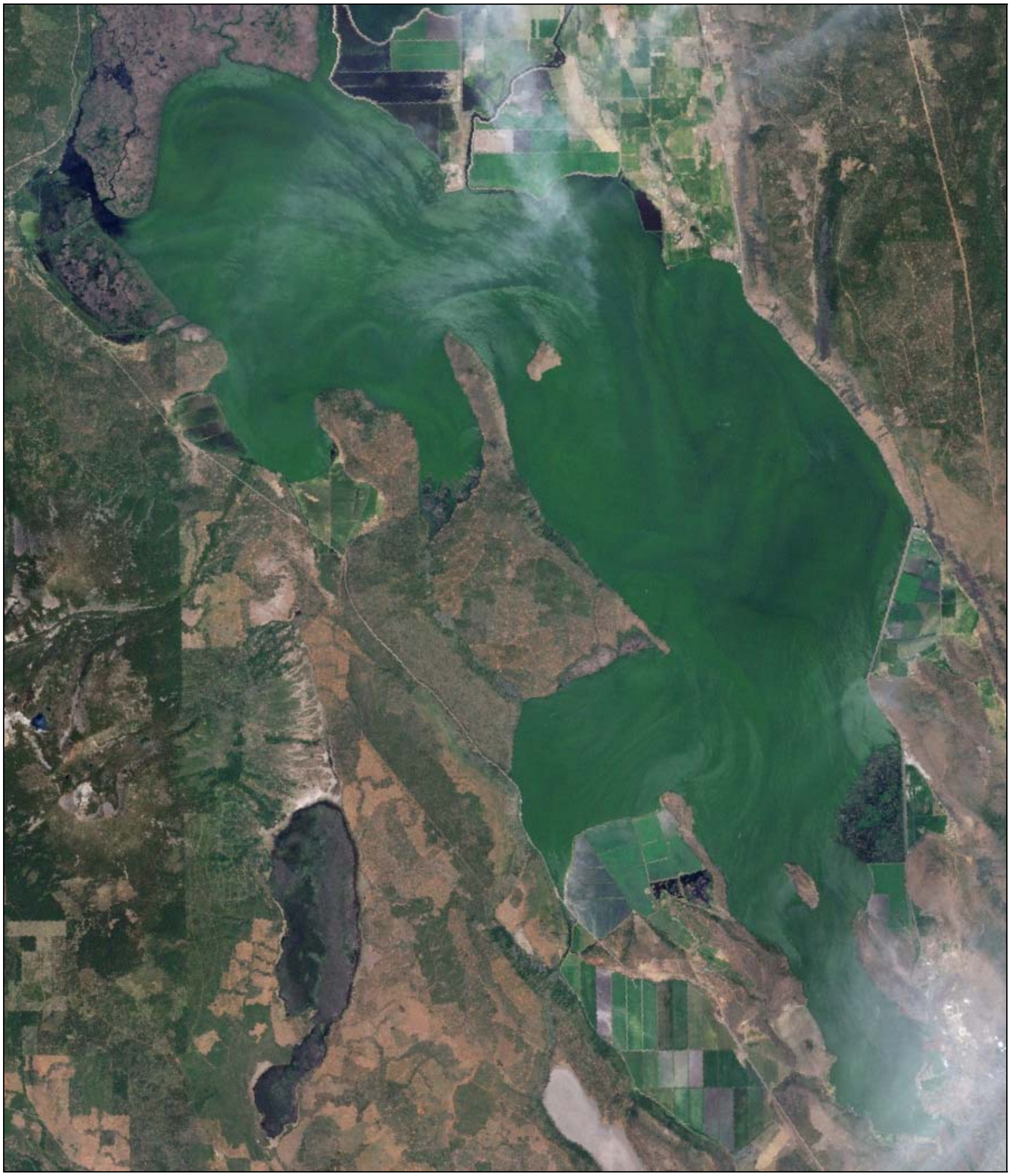
1.6 DATA SOURCES

Data utilized for the development of the TMDLs was drawn from a variety of sources. **Attachment 2** provides a complete list of data received for consideration in the development of TMDLs for Upper Klamath and Agency Lakes. **Figure 2-2** depicts the locations of data collection sites listed in **Attachment 2**. It is important to note that some of the data collected cannot be used for calculation of nutrient loads to Upper Klamath and Agency Lakes because flow data was not collected in conjunction with nutrient data. A large portion of the data collected for lake nutrient TMDL development was provided by others, including: US Bureau of Reclamation, US Forest Service, Oregon Water Resources Department, US Geological Survey and Oregon State University Extension Service.

CHAPTER II

UPPER KLAMATH AND AGENCY LAKES TMDL





Upper Klamath Lake sampled June 17, 2001 - Extensive blooms of the cyanobacterium *Aphanizomenon flos-aqaue* (AFA) are apparent. Image courtesy USGS EROS Data Center and the Landsat 7 Science Team (http://visibleearth.nasa.gov/cgi-bin/viewrecord?9863) and consists of high-resolution (i.e. 15 meter) multispectral data.

2.1 INTRODUCTION

> *"The term eutrophic is often associated with adverse water quality condition (pollution), whereas in reality, a body of water may be both ecologically "healthy" and eutrophic. Historically UKL [Upper Klamath Lake] was a productive (eutrophic) and diverse ecosystem. It is presently a hypereutrophic system that frequently experiences such poor water quality as to be lethal to its native species (Saiki and Monda 1993). Thus statements such as UKL [Upper Klamath Lake] has always been a eutrophic system" should not be used as an excuse for inaction nor construed to mean that the system was polluted or unhealthy… The argument that it is useless to reduce nutrient loading because the lake will still be eutrophic indicates a misunderstanding of trophic level classifications."*
>
> -Gearheart et al. 1995

Upper Klamath and Agency Lakes are large (235.4 and 35.6 km^2, respectively), shallow (mean depth approximately 2 meters), hypereutrophic lake system located in south-central Oregon just east of the Cascades. Low dissolved oxygen and pH water quality violations have led to the 1998 303(d) listing of both Upper Klamath and Agency Lakes. This TMDL will cover both lake systems for dissolved oxygen and pH.

Low dissolved oxygen and high pH levels have been linked to high algal productivity in both lakes (Kann and Walker, 2001 and Walker 2001). Chlorophyll-*a* concentrations exceeding 200 μg/l are frequently observed in the summer months (Kann and Smith, 1999). Algal blooms are accompanied or followed by excursions from Oregon's water quality standards for pH, dissolved oxygen and free ammonia. Water quality standards are established to protect the beneficial uses of Upper Klamath and Agency Lakes. The most sensitive beneficial uses are protected aquatic resources, including the endangered species (shortnose sucker, Lost River sucker), and interior redband trout. Based upon monitored levels of dissolved oxygen, pH and chlorophyll-a, both Agency Lake and Upper Klamath Lake have been designated as water quality limited for resident fish and aquatic life (ODEQ 303(d) List 1998). The remaining portion of this TMDL identifies the pollutant, analyzes the sources, develops pollutant loads designed to meet water quality standards and relates these TMDL targets to water quality compliance.

Historical accounts indicate that Upper Klamath and Agency Lakes were considered eutrophic 100 years ago. However, over that time period there have been numerous land and water use changes that have impacted watershed hydrologic regimes and nutrient export characteristics of the drainage. Land use practices have also affected nutrient cycling and leaching through the loss of wetlands. The hydrology of the lake has been changed by increases in upland water yields, by extensive diking and draining of seasonal wetland/marsh areas, by water diversions from tributaries entering the lake, by diversion of water out of the lake, and by the construction of a dam at the lake's outlet in 1921 that allows the lake to be operated as a storage reservoir. As a result, both the timing and quantity of the lake flushing flows and nutrient retention dynamics have been altered, and lake surface elevation and volume are seasonally reduced below historic levels.

There have also been major changes in management of the watershed resulting in degradation of riparian corridors, and the conversion of 35,000 acres of wetlands to pasture and agriculture on the lake periphery itself (Gearheart et al. 1995; Risley and Laenen 1999). The Environmental Protection Agency Index of Watershed Indicators (EPA 1998) indicates that at least 110,000 acres of the watershed have been converted to irrigated pasture or other agricultural activities. Risley and Laenen (1999) show an eleven-fold increase in permitted irrigated land acreage between 1900 and the present. Most of these 110,000 acres occur in riparian and flood plain areas, with the majority being flood-irrigated. These watershed land use changes are consistent with the types of activities that would cause altered hydraulic regimes (Poff et al. 1997) and increased nutrient loading to tributaries and Upper Klamath and Agency Lakes (Carpenter and Cottingham 1997).

Human related changes to Upper Klamath Lake Drainage

The Upper Klamath Lake TMDL is developed using a large database of lake and upland information that has been, and continues to be, collected by multiple academic efforts, government agencies and the Klamath Tribes (see **Attachment 2**). Both statistical and deterministic analytical methods are used to correlate parameters and simulate water quality. Specifically, a statistical correlation between lake mean total phosphorus, chlorophyll-a and pH is used to justify the use of total phosphorus as a controlling parameter in dealing with adverse pH and dissolved oxygen levels in Upper Klamath Lake. Both internal (i.e. lake generated) and external (i.e. watershed generated) sources of total phosphorus are considered in the loading analysis. Internal loading of phosphorus from the lake sediments is a large source, producing roughly two thirds of the yearly average total load to the lake water column. External sources represent the remaining one third of loading to the lake, largely coming from near lake reclaimed wetlands and traditional upland sources of nutrients such as erosion, increased water yields, riparian/wetland disturbance and natural sources such as springs. A model has been developed that can simulate lake mean pH values based on total phosphorus loading to the lake and other secondary factors that affect pH such as available light, lake temperature, mean lake depth, season/date, sedimentation and burial processes, and other processes that control nutrient dynamics in the lake. This model is used to demonstrate that reductions in total phosphorus loading to the lake will improve water quality to levels that comply with water quality standards.

Table 2-1. Upper Klamath Lake pH, Dissolved Oxygen and Chlorophyll-a TMDL Components

Waterbodies	Upper Klamath and Agency Lakes are 303(d) listed. This TMDL applies to both Upper Klamath and Agency Lake and all rivers, streams, springs, pumped and drained discharges that covey pollutants to these lakes or surface waters that eventually drain pollutants into these lakes.
Pollutant Identification	*Pollutants:* Total phosphorus from external sources
Target Identification (Applicable Water Quality Standards) *CWA §303(d)(1)*	**pH** OAR 340-41-962(2)(d): pH (hydrogen ion concentration) values shall not fall outside the ranges identified in paragraphs (A) and (B) of this subsection. The following exception applies: *Waters impounded by dams existing on January 1, 1996, which have pHs that exceed the criteria shall not be considered in violation of the standard if the Department determines that the exceedance would not occur without the impoundment and that all practicable measures have been taken to bring the pH in the impounded waters into compliance with the criteria: (A) Fresh waters except Cascade lakes: pH values shall not fall outside the range of 6.5 – 9.0. When greater than 25 percent of ambient measurements taken between June and September are greater than pH 8.7, and as resources are available according to priorities set by the Department, the Department shall determine whether the values higher than 8.7.* **Dissolved Oxygen** OAR 340-41-962 (2)(E): For waterbodies identified by the Department 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 the Department, when the Department determines 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. **Chlorophyll-a** OAR 340-041-150: The following values and implementation program shall be applied to lakes, reservoirs, estuaries and streams, except for ponds and reservoirs less than ten acres in surface area, marshes and saline lakes: (1) (b) Nuisance Phytoplankton Growth: Natural lakes that do not stratify, reservoirs, rivers and estuaries: 0.015 mg/L.
Existing Sources *CWA §303(d)(1)*	Nutrient leaching from reclaimed wetlands and upland sources such as agriculture, forestry and urban runoff and transport to the streams that drain to Upper Klamath Lake.
Seasonal Variation *CWA §303(d)(1)*	Critical pH, dissolved oxygen and chlorophyll-*a* conditions occur from June through October. Total phosphorus loading from various pathways occurs year round. Therefore, pollutant loading allocations apply to all seasons.
TMDL Loading Capacity and Allocations *40 CFR 130.2(f)* *40 CFR 130.2(g)* *40 CFR 130.2(h)*	***Loading Limits - External Total Phosphorus Delivered to Upper Klamath Lake*** *Loading Capacity: 109,130 kg external total phosphorus per year* *Waste Load Allocations (Point Sources)*: 1,620 *kg external total phosphorus per year* *Load Allocations (Non-Point Sources): 107,510 kg external total phosphorus per year*
Surrogate Measures *40 CFR 130.2(i)*	Compliance Monitoring Targets • *110 µg/l annual lake mean total phosphorus concentration* • *30 µg/l springtime (March – May) mean total phosphorus concentration* • *66 µg/l annual mean total phosphorus concentration fro all inflows to the lake*
Margins of Safety *CWA §303(d)(1)*	*Margins of Safety* 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)*	• Analytical modeling of TMDL loading capacities demonstrates attainment water quality standards

2.2 POLLUTANT IDENTIFICATION

The pollutant targeted in the Upper Klamath and Agency Lake TMDL is total phosphorus*.* *A total phosphorus load reduction is the primary and most practical mechanism to reduce algal biomass and attain water quality standards for pH and dissolved oxygen.*

- *Seasonal maximum algal growth rates are controlled primarily by phosphorus, and secondarily by light and temperature.*
- *High phosphorus loading promotes production of algae, which, then modifies physical and chemical water quality characteristics that diminish the survival and production of fish populations.*

In Upper Klamath Lake and Agency Lake total phosphorus is the identified pollutant that causes pH, dissolved oxygen and chlorophyll-*a* water quality standard violations. Lake total phosphorus is derived from internal (in lake) and external (upslope) sources that vary seasonally. Measured water quality standard violations are typically associated with excessive algal production. Extensive blooms of the cyanobacterium *Aphanizomenon flos-aqaue* (AFA) cause significant water quality deterioration due to photosynthetically elevated pH (Kann and Smith 1993) and to both supersaturated and low dissolved oxygen (DO) concentrations (Kann 1993a, 1993b). Adverse effects that detract from native fish survival and viability occur during periods of both high pH and low DO reach. These blooms are seasonally and spatially variable throughout the lake systems.

Upper Klamath Lake during a cyanobacterium *Aphanizomenon flos-aqaue* (AFA) bloom

A total phosphorus load reduction is the primary mechanism to attain water quality standards for pH, dissolved oxygen and algal biomass in Upper Klamath Lake and Agency Lake (Kann and Walker, 2001 and Walker, 2001). Seasonal maximum algal growth rates in Upper Klamath and Agency Lakes, and its subsequent impact on elevated pH and low DO levels, are controlled primarily by phosphorus availability, and secondarily by light and temperature. High lake water nutrient concentrations result from nutrient loading to the lake and nutrients derived from lake sediments and promote correspondingly high production of algae, which, in turn, modifies physical and chemical water quality characteristics that can directly diminish the survival and production of fish populations. Year to year variations in the timing and development of algal blooms during late spring and early summer are largely temperature dependent.

Under conditions of high nutrient input and adequate light, algae growth rates increase, resulting in an accumulation of biomass. Ultimately a combination of factors (i.e. light penetration and transmittance through the water column, nutrient availability, water temperature, and other factors) limits further growth. As biomass increases and nutrients are accumulated in biomass, the available soluble forms of nitrogen (N) and phosphorus (P) in the lake water column decrease. Nutrients accumulate seasonally in the biomass and become unavailable for further biomass increase. Lake primary productivity follows a seasonal lifespan, and eventually biomass dies in the fall and deposits in the lake sediments, where decomposition and benthic biochemical processes store (in lake sediments) and liberate (recycle) portions of the nutrients back to the water column and become available for algal uptake.

Although nitrogen is an important structuring component of the algal communities and often determines biomass types, phosphorus reduction has been shown to be the most effective and practical long-term nutrient management option to control algal biomass (Sas et al., 1989). This is especially true of nitrogen fixing species such as *Aphanizomenon*, which can augment their nitrogen needs in what may otherwise be a nitrogen limiting system. While nitrogen limitations may be a factor later in the growing season, there is no evidence that the energy requirement for nitrogen fixation is actually limiting algal densities during the critical months of June and July, when energy supply (solar radiation), algal growth rates, and pH excursion frequencies are highest.

The chlorophyll-a v. phosphorus and lake mean pH v. chlorophyll-a relationships described by Kann (1993; 1998) and Walker (1995) support total phosphorus load reduction as the management goal for Upper Klamath and Agency Lakes. Empirical relationships developed from lake monitoring data reveal:

- There is a statistical relationship between lake total phosphorus concentration and chlorophyll-a concentrations;
- There is a statistical relationship between lake mean pH and chlorophyll-a concentrations;

A lake-mean total phosphorus concentration of approximately100 μg/l corresponds to a mean chlorophyll-*a* concentration of approximately 66 μg/l and a mean pH of 9.0 in June-July (**Figure 2-1**).

Violations of water quality standards for dissolved oxygen are directly related to algal productivity which in turn, is a function of phosphorous loading to Upper Klamath and Agency Lakes. The technical analysis of the water quality data demonstrates that the reduction of phosphorous loads, while concentrating on anthropogenic sources associated with external nutrient loading to the Upper Klamath Lake, is addressed to the maximum extent possible through the phosphorous loading capacity. Consequently, development of a TMDL for dissolved oxygen is performed in conjunction with pH in this chapter.

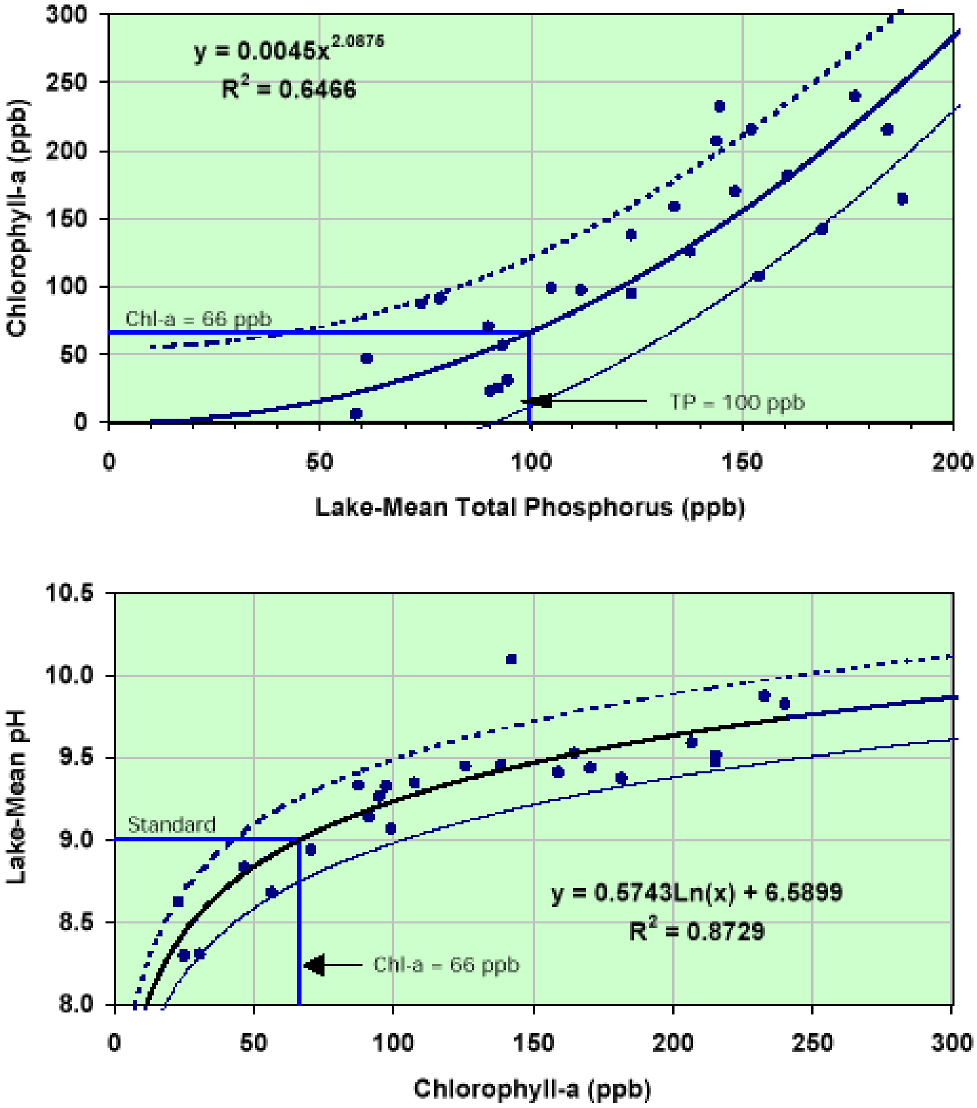


Figure 2-1. Empirical Relationship Relating Total Phosphorus, Chlorophyll-a and pH *(Walker 2001)*

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

2.3.1 Sensitive Beneficial Uses

Oregon Administrative Rules (OAR Chapter 340, Division 41, Section 0962, Table 19) lists the "Beneficial Uses" occurring within the Klamath basin (see **Table 2-2**). 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 Upper Klamath Lake drainage. Other sensitive uses (such as drinking water and water contact recreation) are also applicable.

Table 2-2. Beneficial uses occurring in the UKLDB *(OAR 350 – 41 – 0962)*

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	✓	Wildlife and Hunting	✓
Livestock Watering	✓	Fishing	✓
Boating	✓	Water Contact Recreation	✓
Hydro Power	✓	Aesthetic Quality	✓

Water quality problems are of great concern because of their potential impact on native fish populations in the lake, including the Shortnose sucker (*Chasmistes brevirostris*), Lost River sucker (*Deltistes luxatus*), and interior redband trout (*Oncorhynchus mykiss* ssp.). Both sucker species were listed as endangered under the Endangered Species Act in 1988, and water quality degradation resulting from algal blooms had been identified as a probable major factor in their declines (Williams 1988). All three of the these fish species, as well as native blue and tui chubs, were found in substantial numbers during fish kills occurring in 1995, 1996, 1997 (BRD 1996, Perkins et al. 2000).

Accordingly, the degraded water quality that results from these blooms is a significant threat to the long-term viability of the endangered suckers and other aquatic life, not only because of catastrophic mortality events, but also because of reduced fitness and survival as result of chronic stress. Hence, reduction of algal biomass is a critical element of any management program designed to allow recovery of fish populations.

2.3.2 pH Standard

OAR 340-41-962(2)(d): pH (hydrogen ion concentration) values shall not fall outside the ranges identified in paragraphs (A) and (B) of this subsection. The following exception applies:

Waters impounded by dams existing on January 1, 1996, which have pHs that exceed the criteria shall not be considered in violation of the standard if the Department determines that the exceedance would not occur without the impoundment and that all practicable measures have been taken to bring the pH in the impounded waters into compliance with the criteria: (A) Fresh waters except Cascade lakes: pH values shall not fall outside the range of 6.5 – 9.0. When greater than 25 percent of ambient measurements taken between June and September are greater than pH 8.7, and as resources are available according to priorities set by the Department, the Department shall determine whether the values higher than 8.7.

2.3.3 Dissolved Oxygen Standard

OAR 340-41-962 (2)(E): For waterbodies identified by the Department 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 the Department, when the Department determines 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.

2.3.4 Chlorophyll-a Standard

OAR 340-041-150: The following values and implementation program shall be applied to lakes, reservoirs, estuaries and streams, except for ponds and reservoirs less than ten acres in surface area, marshes and saline lakes:

(2) (b) Nuisance Phytoplankton Growth: Natural lakes that do not stratify, reservoirs, rivers and estuaries: 0.015 mg/L.

2.3.5 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. Upper Klamath and Agency Lakes have been put on the 1998 303(d) list for pH, dissolved oxygen and chlorophyll-*a* violations. For specific information regarding Oregon's 303(d) listing procedures, and to obtain more information regarding the Upper Klamath and Agency Lakes 303(d) listed streams, visit the Department's web page at http://www.deq.state.or.us/.

AFA is the dominant primary producer in Upper Klamath and Agency Lakes, comprising greater than 90% of the primary producer biomass during blooms. During AFA bloom conditions, particularly when coupled with high rates of respiration that dominate at night, DO can vary considerably. Also during blooms, available carbon dioxide is used and pH rises to levels greater than 10.0, which is lethal to fish. Such pH and DO events can occur throughout the summer in shallow hypereutrophic water bodies like Upper Klamath and Agency Lakes where growth conditions are optimal. Following these blooms when high levels of AFA biomass die-off, the microbial degradation of this biomass and additional DO demand by sediment can deplete DO and increase ammonia concentrations to levels that restrict growth, are stressful, and are lethal to fish.

Accordingly, a clear link is established between high algal biomass (blooms) and harmful water quality in Upper Klamath and Agency Lakes. Algal blooms, dominated by AFA now occur annually from June through October (Kann 1998). Increases in algal biomass are most often caused by increase nutrient enrichment by nitrogen (N) and phosphorus (P) (Carpenter et al 1998, Cooke et al. 1993).

The pH criteria (6.5 to 9.0) was exceeded in 41% of historical (1992-1999) samples and in 89% of samples collected in July, the month with peak algal densities. Excursions from dissolved oxygen criteria occurred less frequently (13% on an annual basis). Oxygen excursions occur most frequently (35%) in August, the period of declining algal blooms, when fish kills have also been observed (Perkins et al., 2000). Accordingly, Upper Klamath and Agency Lake DO, pH, and chlorophyll (algal biomass) have been designated as water quality limited on Oregon's 1998 303(d) list for exceeding DO, pH, and chlorophyll (algal biomass) water quality standards (**Table 2-3**).

Table 2-3. Agency and Klamath Lake parameters listed on the 1998 303d list.

Waterbody Name	Parameter	Period
Agency Lake	Chlorophyll a	Summer
Agency Lake	pH	Summer
Agency Lake	Dissolved Oxygen (DO)	Summer
Upper Klamath Lake	Chlorophyll a	Summer
Upper Klamath Lake	pH	Summer
Upper Klamath Lake	Dissolved Oxygen (DO)	Summer

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

Critical pH, dissolved oxygen and chlorophyll-*a* conditions occur from June through October. The total phosphorus loading from various pathways occurs year round. Therefore, pollutant loading analysis and allocations applies to all seasons.

Water quality data collection for Upper Klamath Lake and Agency Lake has been extensive, dating back to the early 1990's. Contributors include the Klamath Tribes, U.S. Department of the Interior, the U.S. Geological Survey (USBR and USGS), U.S. Forest Service and Oregon State University Agriculture Extension Researchers. When comparing water quality samples reported by other researchers, there is no evidence that suggests errors (Rykbost and Charlton, 2001).

Total phosphorus data is summarized by monitoring site and data source and is presented in **Attachment 2**. The available data for the Upper Klamath Lake system reflects the comprehensive analytical efforts that have been conducted in the area over the past decade. Water quality sampling locations for Upper Klamath and Agency Lakes and the drainage are shown in **Figure 2-2.** Summaries of seasonal pH, total phosphorus and chlorophyll-*a* data collected at these locations is presented in **Figure 2-3**.

Overview of Nutrient and Flow Data

Data Collection Sites:	162
Date Sources:	11
Total Phosphorus Samples (since 1991):	3,189
Corresponding Flow Measurements (since 1991):	510
Upland Total Phosphorus Measurements	1,889
Lake Total Phosphorus Measurements	1,275
Well Total Phosphorus Measurements	26

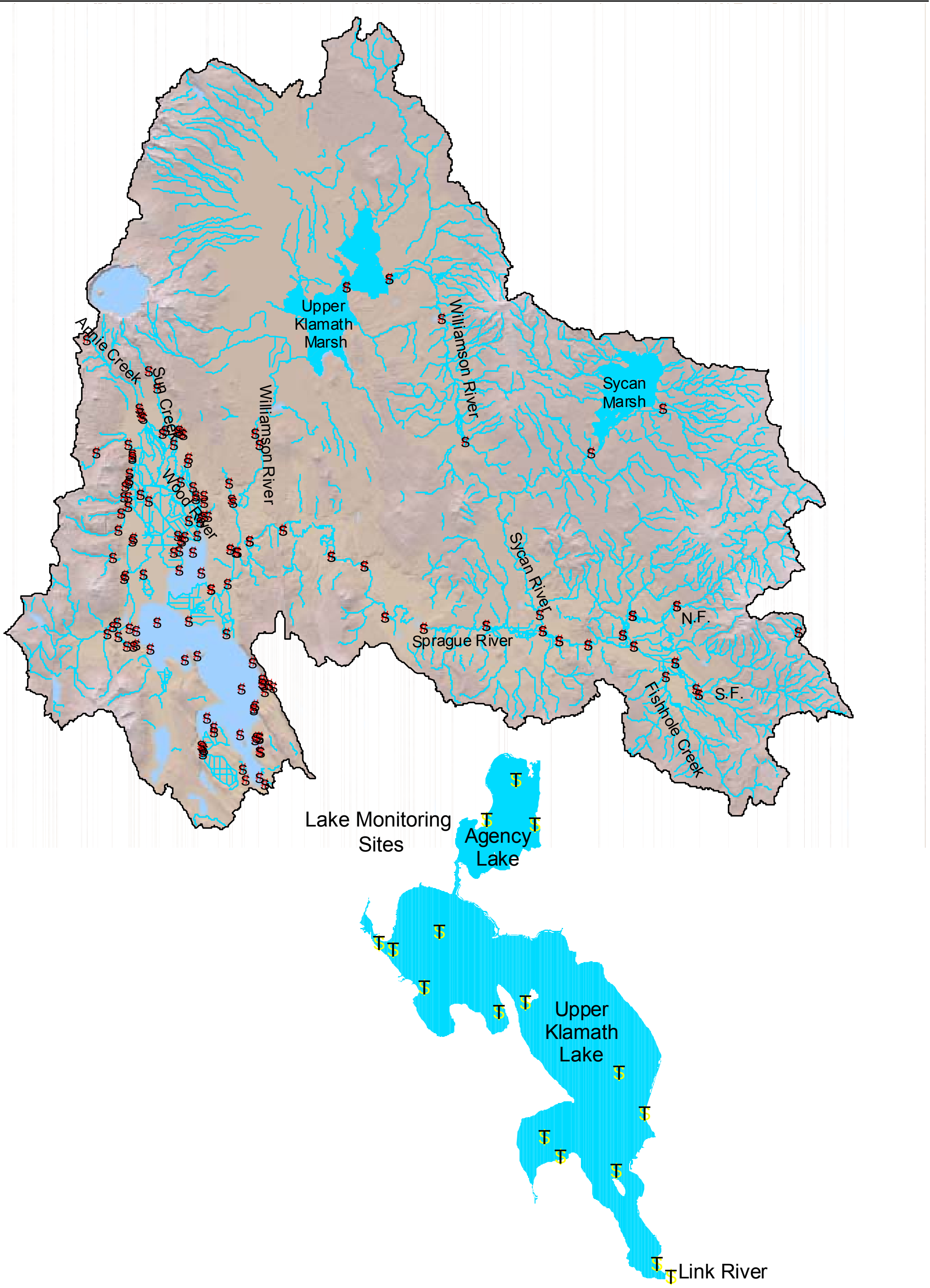


Figure 2-2. Water Quality Sampling Sites Used in the Lake TMDL (see **Attachment 2 – Total Phosphorus and Flow Data**)

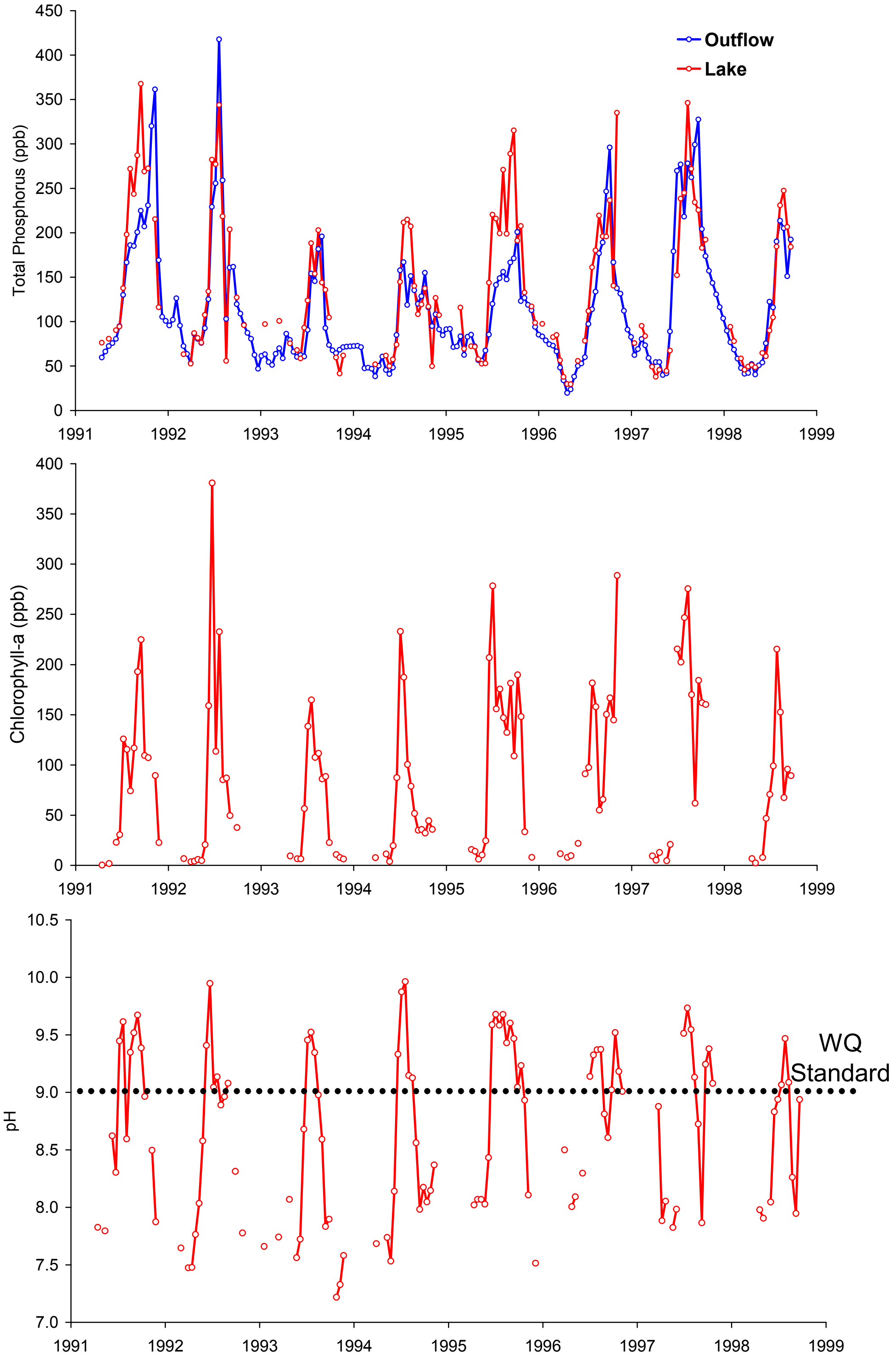


Figure 2-3. Observed Total Phosphorus, Chlorophyll-a and pH Values (data from Kann 2000)

Critical Condition

Although the mass-balance model simulates lake-mean phosphorus concentrations and the TMDL represents a long-term-average load to the entire system, the derivation considers seasonal and spatial variations in lake water quality. Seasonal variations are considered by simulation of the entire calendar year and extracting compliance statistics for June and July, historically the period of peak algal growth and pH excursion frequency. Spatial variations (vertical and horizontal) are considered by modeling them as stochastic variations around the lake-mean value on a given sampling date. The approach therefore incorporates the "critical condition" concept required for consideration in TMDL development (USEPA 1999).

Nutrient data indicate that Upper Klamath Lake is highly eutrophic (hypereutrophic). Total phosphorus concentrations in the lake can exceed 300 µg/l. Algal productivity is quite high, with chlorophyll-a concentrations exceeding 200 µg/l frequently observed in summer months (Kann and Smith, 1993). Algal blooms usually correspond or precede departures from pH and dissolved oxygen water quality standards. Water quality violations for pH and dissolved oxygen generally occur from May to November as shown in **Figure 2-4**.

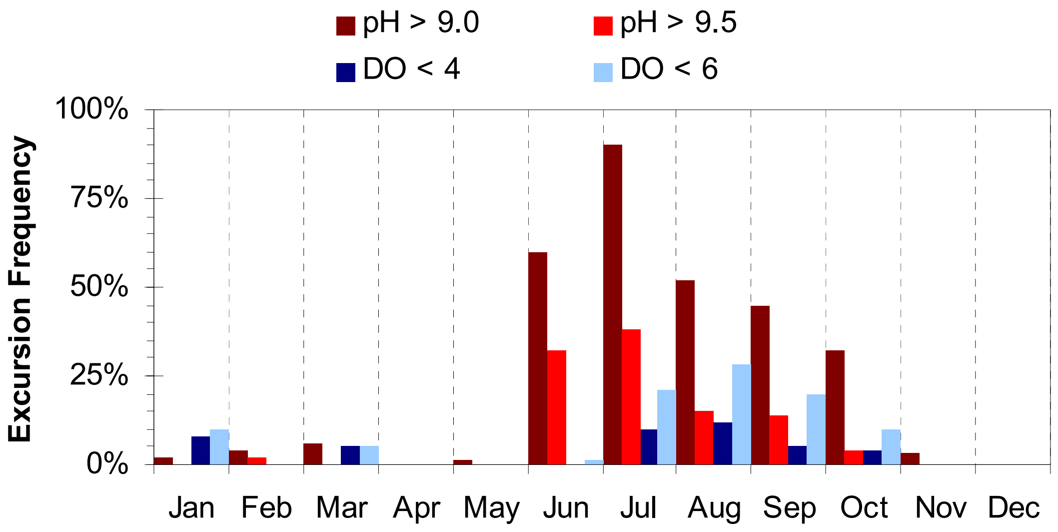


Figure 2-4. Seasonal Excursions Frequencies above Water Quality Standards

2.5 SOURCE ASSESMENT - CWA *§303(D)(1)*

2.5.1 Overview of Phosphorus Sources

Sources of phosphorous in the Upper Klamath Lake drainage are distributed across the landscape from springs in the headwaters to sediments in Upper Klamath and Agency Lakes. Mobilization of phosphorous from agriculture and other nonpoint sources, however, appears to have pushed the lake into an exaggerated state of eutrophication (NAS, February 2002). This section characterizes the following sources of phosphorous in UKLD:

- External sources from uplands
- External sources from reclaimed wetlands
- Internal sources from lake sediments

Between 1992 and 1998, detailed in-lake and external nutrient loading data were collected by multiple parties[6] as part of a long-term water quality monitoring program in the Upper Klamath Basin. Utilizing this data, it is possible to develop a time series mass balance for phosphorus and nitrogen at a bi-weekly interval. Results are presented for annual and seasonal time scales. On an annual average, internal phosphorus loading was approximately 61% of the total loading to the lake, while external loading comprised 39% of the total phosphorus sources, with each having a standard deviation of 9%.(see **Table 2-4**).

Table 2-4. Estimated Average Annual Total Phosphorus Internal and External Load for Upper Klamath and Agency Lakes (1992 – 1998)
(Kann and Walker, 2001)

Water Year	Internal Load[7] (mtons/yr)	External Load[8] (mtons/yr)	Total Load (mtons/yr)	Percent Internal Load	Percent External Load
1992	294	113	407	72%	28%
1993	265	208	473	56%	44%
1994	195	112	307	64%	36%
1995	394	169	563	70%	30%
1996	212	241	453	47%	53%
1997	376	220	596	63%	37%
1998	257	208	465	55%	45%
Average	**285**	**182**	**466**	**61%**	**39%**
Stand. Dev.	**76**	**52**	**96**	**9%**	**9%**

External total phosphorus loading (i.e. processes that directly load the lake as well as source areas that contribute flow and nutrients to the lake) is the sum of loading from precipitation, 7-mile Canal, Wood River, agricultural pumping, springs/ungaged tributaries, and Williamson River (Kann and Walker, 2001). These external load breakouts are largely due to data collection design, with sites selected where data could be collected at or near the source before contributing to the lake.

Lake outflow total phosphorus loads tended to increase during high runoff events in the spring. High outflow rates of phosphorus continue into the summer period when external load into the lake is low, indicating that phosphorus is internally loaded to the lake from the nutrient rich sediments. Rykbost and Charlton (2001) and Kann and Walker (2001) document elevated lake mean total phosphorus concentrations in June, July, August, September and October. These seasonal increases in lake mean total phosphorus concentrations are the result of internal loading during this period. Large net internal loading events are generally followed by a substantial decline, indicating a sedimentation event. Such events coincide with algal bloom crashes where the cause is simply dead algae falling out of the water column and onto the lake sediment (Kann 1998). The increased levels of phosphorus in Upper Klamath and Agency Lakes during summer months are attributed to increases from internal loading via lake sediments during the summer period (Barbiero and Kann 1994; Laenen and LeTourneau 1996; Kann 1998).

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[6] Nutrient data has been collected by the Klamath Tribes, US Bureau of Reclamation, Oregon State University Extension Staff, US Geological Survey, Oregon Water Resources Department, Natural Resource Scientists, Inc., Winema National Forest and Oregon Department of Environmental Quality. This data is presented in **Attachment 2** of this document.

[7] Internal loading refers to total phosphorus derived from sediments in the lake. A detailed description of external loading of nutrients to Upper Klamath Lake is presented in **Section 2.5.4**.

[8] External loading refers to total phosphorus derived from sources other than the water and sediments in the lake. A detailed description of external loading of nutrients to Upper Klamath Lake is presented in **Section 2.5.3**.

Figure 2-5 demonstrates the seasonal (i.e. June through October) increase in lake water phosphorus concentration that results from increases in internal loading.

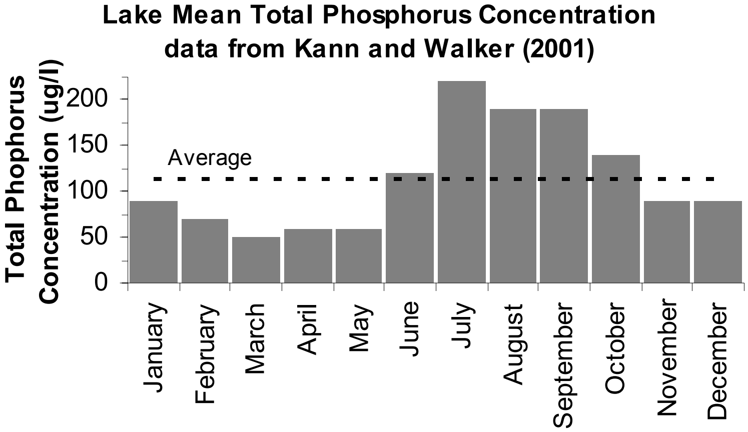


Figure 2-5. Lake Mean Total Phosphorus Concentrations

2.5.2 Lake Response (Sediment Core Analysis)

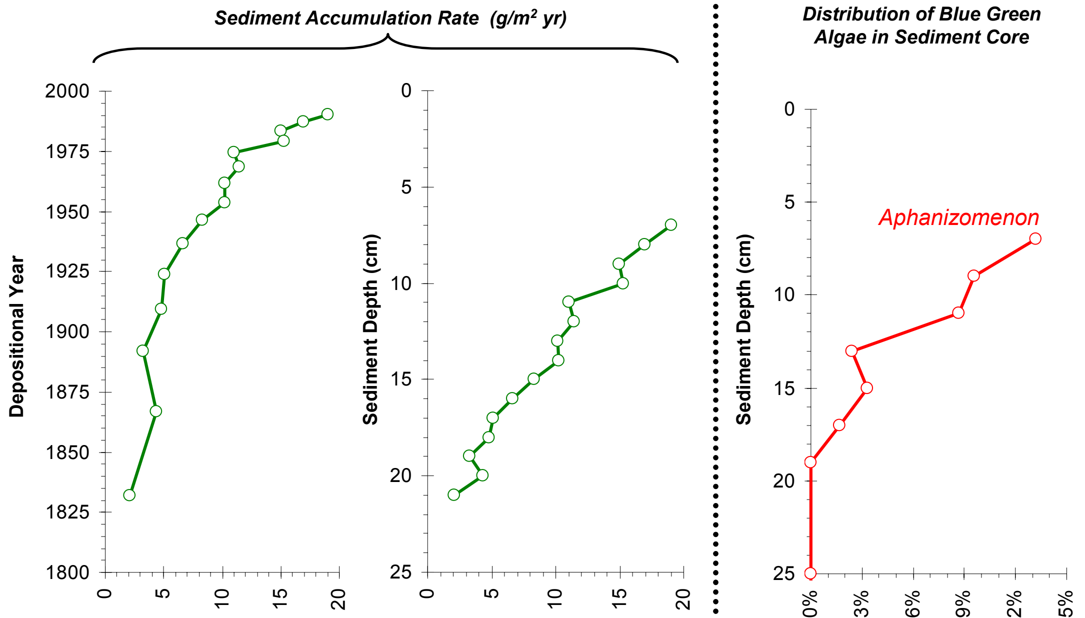
In October 1998, the United States Bureau of Reclamation collected sediment cores from Upper Klamath Lake in order to determine historic sedimentation rates and algal compositions deposited over the last 150 years (Eilers et al, 2001). Results obtained from this investigation indicate that water quality conditions within the lake have changed dramatically as development of the surrounding watershed progressed. Specifically, this study showed that the sediment accumulation rates (SAR) have substantially increased in the 20th century. In addition, the modern sediments (20th century) are enriched in both nitrogen (N) and phosphorus (P) compared to pre-settlement sediment. The authors speculate that the increases in nutrient concentrations may be affected to various degrees by geochemical reactions within the sediments. However, the study revealed that the changes in concentration were also marked by changes in the N:P ratio and in a qualitative change in the source of nitrogen. Results indicate that changes are due, in part, to anthropogenic influence.

Nitrogen and phosphorus accumulation rates were observed to vary between strata with a significant decrease in the nitrogen to phosphorous ratio (N:P) in the upper (“newer”) sediments. The authors of this study conclude that this N:P ratio shift may be the result of either increased phosphorus loading or a decline of nitrogen fixation from lake biomass. However, the authors point out that given the abundance of nitrogen fixing algae currently present in the lake, it appears more likely that the phosphorus loading has increased relative to nitrogen loading to the lake.

The authors (Eilers, Kann, Cornett, Moser, Amand, and Gubala) also looked at the proportion of a particular stable isotope of nitrogen (^{15}N) in the sediment cores, which are found at high levels (compared with ^{14}N). The ^{15}N results from Upper Klamath Lake indicate a significant increase in the later part of the 20th century following the construction of the dam on the outlet of the lake in 1921. This event is generally contemporaneous with an increase in watershed loading from nonpoint sources of nitrogen. These results indicate large inputs of nonpoint source pollution from watershed sources (Fry 1999). The authors point out several other factors, such as changing water temperatures, that may also influence the sediment ^{15}N levels. Like many of the findings related to studying the sediment core data, an increase in the detection of ^{15}N during the 20th century results from complex chemical and hydrological process, but is generally interpreted as an indication that sources of nutrient loading had increased during this period.

Indication of Lake Water Quality Changes

(Eilers et al., 2001)



Sediment core analysis demonstrates that sediment accumulation rates have increased over that past 120 years

Nitrogen fixing blue-green algae are now more abundant indicating an increase in phosphorus availability

Figure 2-6. Upper Klamath Lake Sediment Core Analysis (Eilers et al. 2001).

The study utilized stable tracers (titanium and aluminum) because they are not readily altered and concentrations can be measured within sediment cores to indicate the history and magnitude of watershed disturbance. Both of these metals show major increases in the upper sediment layer confirming an increase in post-settlement external sediment inputs to the lake. An alternative explanation for these observed distributions is a rapid decrease in the deposition of plankton in the 20th century that would cause the external inputs to be proportionally greater than the internal inputs. This latter explanation is considered unlikely give the history of the watershed and the current high levels of primary production within the lake system. The authors conclude that the increase in titanium and aluminum provide strong evidence of increased sediment inputs to the lake associated with erosion and land use disturbance occurring within the watershed during the 20th century.

Finally, the authors of this study investigated algal species composition within layered sediment strata. Although mixing in the upper sediments prevents temporal periods less than 10 years to be compared in the analysis of the history of the Upper Klamath Lake, the results demonstrated a measurable shift in the phytoplankton assemblages in the lake. Specifically, *Pediastrum*, a green alga, was well-preserved in the sediments and exhibited a sharp decline in the relative abundance in the upper sediments. However, *Aphanizomenon*, a cyanobacteria, has increased dramatically since the 1900s. It is important to note again that a clear link between high algal biomass (blooms) and harmful water quality in Upper Klamath and Agency Lake, and such algal blooms, dominated by the blue-green alga *Aphanizomenon flos-aqaue* (AFA) now occur annually from June through October (Kann 1998).

Results obtained from this sediment core analysis highlight the impact of watershed development over the past century and its direct impact on water quality conditions within Klamath Lake. Additionally, the reported findings and interpretations provide a strong linkage between external anthropogenic sources of nutrients and sediments with the observed increase in abundance of AFA . Sediment core data (i.e. sediment accumulation rates and distributions of AFA) can be found in **Figure 2-6**.

2.5.3 External Sources of Phosphorus

External loading refers to total phosphorus derived from sources other than the water and sediments in the lake. Based on information presented in this section, humans have increased the external nutrient loading to the lake largely, but not exclusively, via:

1. Reclaiming and draining near lake wetlands for agricultural uses. Wetland reclamation and use may account for 29% of the external total phosphorus loading to the lake.

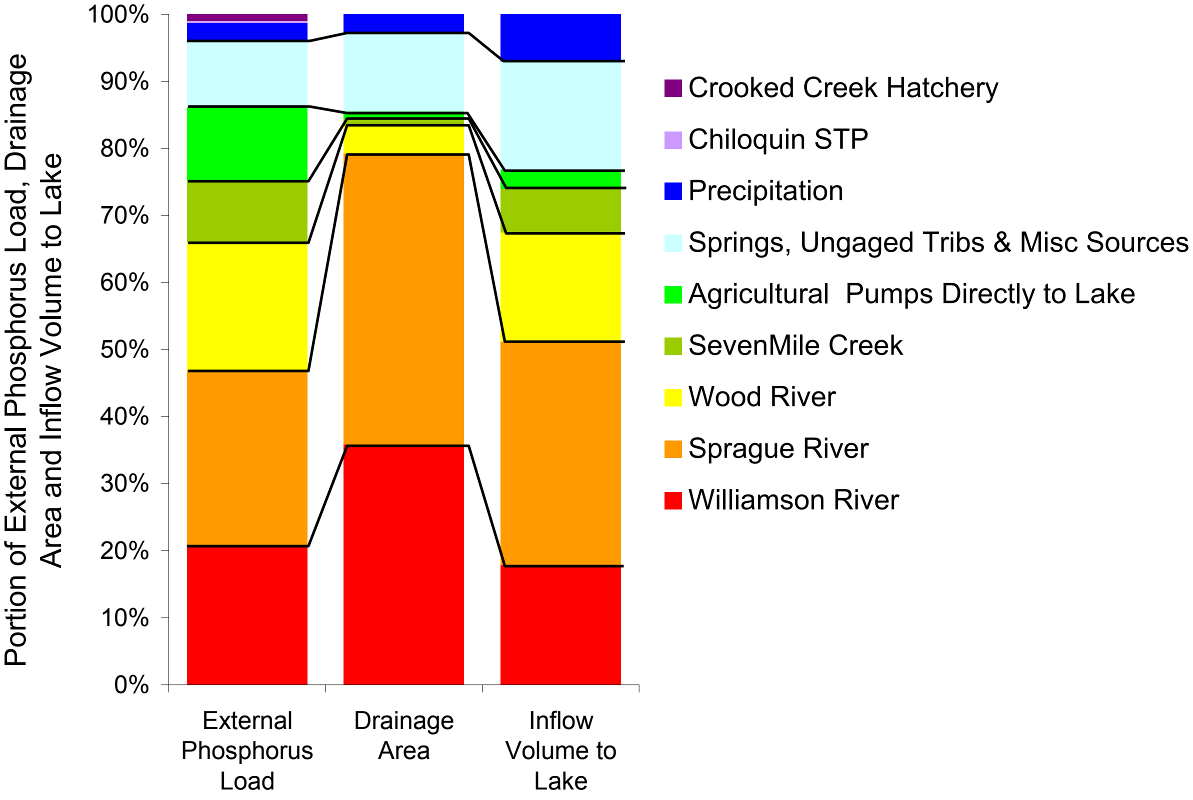
And,

2. Increased water yields and runoff rates in the Williamson and Sprague subbasins have been documented in the 1951-1996 period that are independent of climatic conditions. These increase water yields are likely the result of land use and may account for 18% of the external total phosphorus loading to the lake.

Despite high background phosphorus levels in Upper Klamath Lake drainage tributaries, data exists from numerous studies to indicate that external phosphorus loading and concentration in Upper Klamath Lake are elevated substantially above these background levels (Miller and Tash 1967; USACE 1982; Campbell et al. 1993; USGS Water Resources Data 1992-1997; EPA Storet Data 1959-1997). One of the earliest nutrient loading studies (Miller and Tash 1967; updates by USACE 1982) indicates that even though direct agricultural input from pumps and canals accounting for only 12.4% of the water inflow, these sources account for 31% of the annual external total phosphorus (TP) budget. Snyder and Morace (1997) demonstrate that nitrogen and phosphorus are liberated from drained wetland areas, leach into adjacent ditches, and are subsequently pumped to the lake or its tributaries. Gearheart et al. (1995) estimated that over 50% of the annual total phosphorus load from the watershed could be reduced with improved agricultural management practices. Anderson (1998) likewise estimates that in-lake total phosphorus concentration can be reduced utilizing watershed management strategies. Rykbost and Charlton (2001) state that “nutrient loading in Klamath Lake is unquestionably enhanced by the drainage of irrigation water from agricultural properties adjacent to the lake.”

Sources of phosphorus are distributed throughout the Upper Klamath Lake drainage. For simplicity, these sources are broken into source areas that contribute directly to the lake phosphorus levels (Kann and Walker, 2001). ODEQ has added point sources (i.e. Chiloquin STP and Crooked Creek Hatchery) of phosphorus that are not considered in the Kann and Walker (2001) loading analysis. The source areas considered in phosphorus load analysis are listed in **Figure 2-7** along with the distributions of the contributing drainage area, flow inputs to the lake and the annual total phosphorus loading received by the lake. Water and nutrient budget components for Upper Klamath and Agency Lakes were broken into seven major source categories: Williamson River, Sprague River, Wood River, Seven-Mile Canal, agricultural pumps, ungaged springs and tributaries and precipitation received by the lake system.

Phosphorous loading from the two point sources (Chiloquin STP and Crooked Creek Fish Hatchery) were estimated and are small when compared to the other sources of external phosphorus loading. Average flow from the hatchery is approximately 10.3 mgd with a corresponding total phosphorous concentration of 0.13 mg/L. Estimated flow and concentration from the Chiloquin STP is 0.1 mgd and 4 mg/L, respectively. **Figure 2-7** depicts the relatively small contribution the point sources make to the total phosphorous load to Upper Klamath and Agency Lakes.



Source Area/Type	Portion of Total Phosphorus Load	Portion of External Phosphorus Load	Portion of Drainage Area	Portion of Inflow Volume to Lake
Williamson River	8.0%	20.5%	35.9%	17.9%
Sprague River	10.3%	26.5%	43.4%	33.2%
Wood River	7.4%	19.1%	4.0%	16.4%
SevenMile Creek	3.5%	9.0%	1.1%	6.5%
Ag. Pumps Directly to Lake	4.4%	11.2%	1.1%	2.9%
Miscellaneous Sources	3.8%	9.8%	11.7%	16.1%
Precipitation	1.1%	2.7%	2.8%	7.0%
Chiloquin STP	0.1%	0.3%	n/a	~0.0%
Crooked Creek Hatchery	0.4%	1.0%	n/a	~0.0%
Internal Loading	61.0%	n/a	n/a	n/a

Figure 2-7. Distributions – External Phosphorus Loading, Drainage Area and Flow Input to Upper Klamath and Agency Lakes (Kann and Walker, 2001)

Using the mass balance developed by Kann and Walker (2001), the Williamson River and Sprague River subbasins contribute 51% of the annual flow input to Upper Klamath Lake. The Wood River and Seven Mile Creek accounts for 16% and 7% of the flow inputs, respectively. Other flow inputs to the lake include agricultural pumps (3%), springs and ungage tributaries (16%) and precipitation received by the lake (7%).

Roughly half of the external phosphorus loading to Upper Klamath Lake is derived from the Williamson River and Sprague River subbasins. The Wood River contributes 19% of the external total phosphorus load. Other external total phosphorus sources include Seven-Mile Canal (9%), springs and ungaged tributaries (10%), agricultural pumps (11%) and precipitation (3%). Point sources account for a very small portion of the external total phosphorus loading to Upper Klamath Lake.

The total external phosphorus load delivered to Upper Klamath Lake and Agency Lake is estimated to be 181.6 metric tons[9] per year (Kann and Walker, 2001). **Figure 2-8** presents annual external loading to the lake as both an external phosphorus load and a unit area phosphorus load. Relative contributions of phosphorus from each distributed source area should be made comparing unit area external phosphorus loads. For example, the Williamson River subbasin delivers a large external phosphorus load to Upper Klamath Lake (86.4 metric tons per year) when compared to that contributed from Seven-Mile Creek (16.5 metric tons per year). The drainage area of the Williamson River subbasin is large (3501 km^2), while the drainage area of Seven Mile Creek is comparatively small (106 km^2). When the production of annual external phosphorus loading is considered as a unit area load, the Williamson River subbasin contributes considerably less phosphorus per square kilometer (11 kg/ km^2 per year), while the Seven Mile Creek drainage contributes a high rate of loading per unit area (156 kg/ km^2 per year).

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[9] 1 metric ton = 1000 kg

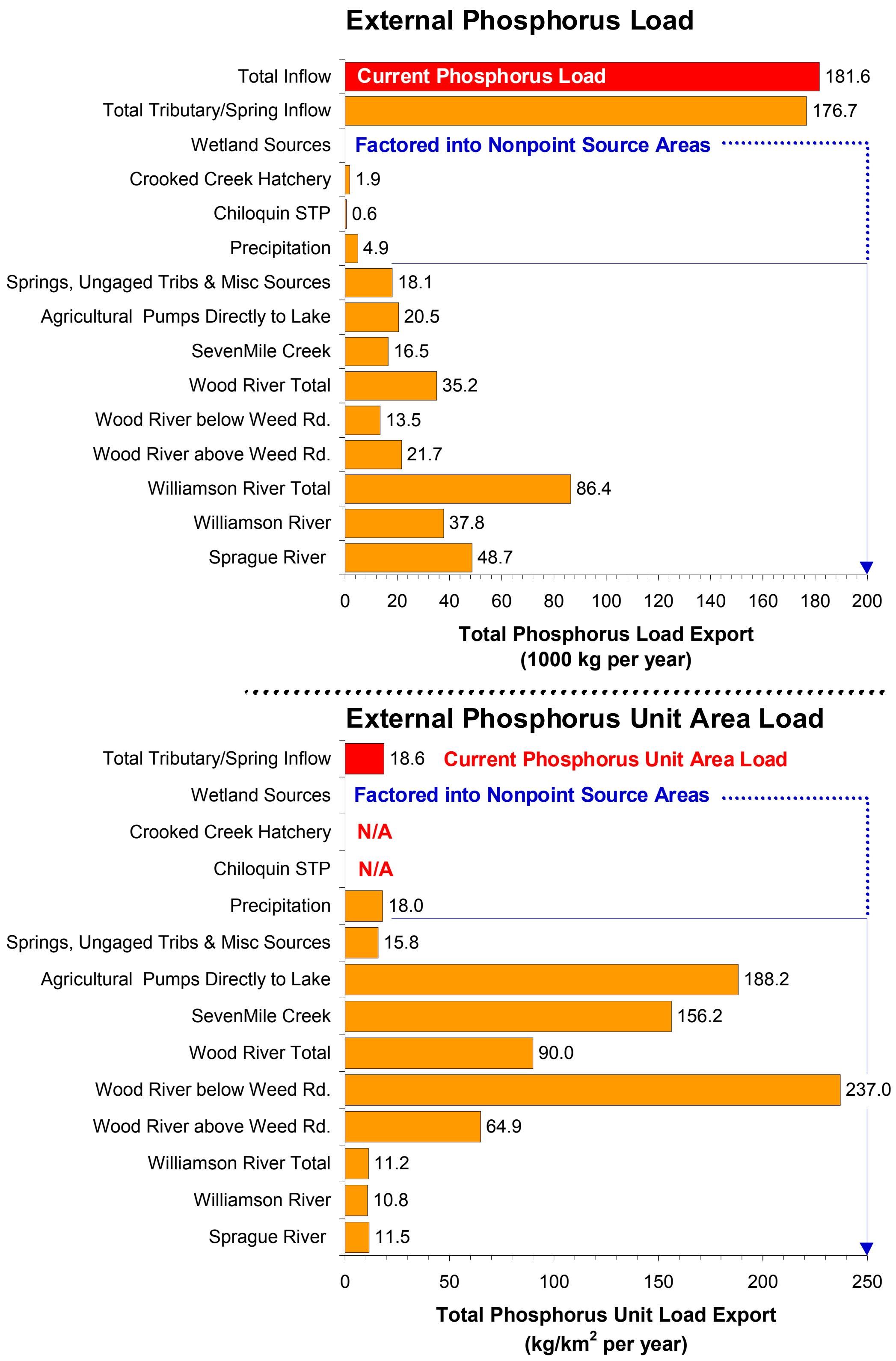
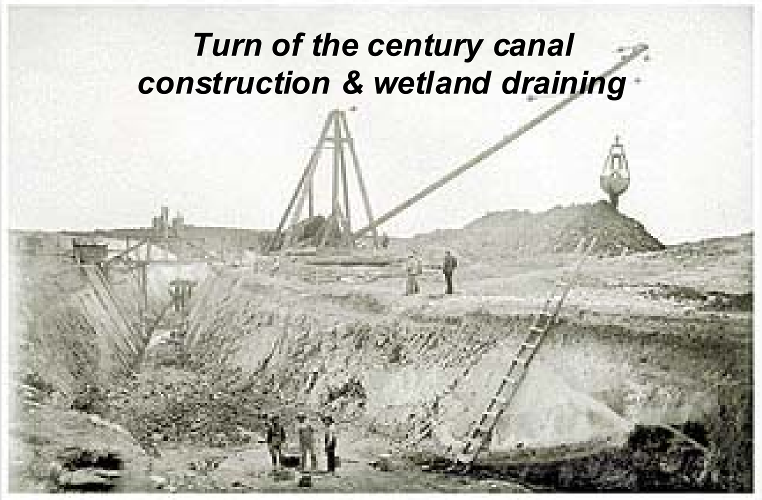


Figure 2-8. Annual External Total Phosphorus Loads (Kann and Walker, 2001)

2.5.3.1 Reclaimed Wetlands as an External Source of Phosphorus

> "Nutrient loading in Klamath Lake is unquestionably enhanced by the drainage of irrigation water from agricultural properties adjacent to the lake. Prior to reclamation, all of these properties were either permanent or seasonal wetlands. Following construction of dikes and drainage systems, the properties were managed for pastures and/or crop production. Soils are high in organic matter content and native fertility; therefore pastures and hay crops on these lands are generally not fertilized. Natural processes associated with mineralization of these soils release nutrients subject to transport in drainage water."
>
> -Rykbost and Charlton, 2001

Wetlands adjacent to Upper Klamath Lake have been drained for the cultivation of crops and cattle grazing. An extensive effort to reclaim wetlands started in 1889 and continued through 1971. Recent scientific efforts demonstrate that reclaimed wetlands can become a source of phosphorus (Snyder and Morace, 1997) and eventually result in nutrient loading to the Upper Klamath Lake (Bortleson and Fretwell, 1993). In light of these studies, targeted wetland restoration is taking place resulting in large reclaimed land areas in various stages of restoration. **Figure 2-9** displays the reclaimed wetland acreage for each reclamation project and **Figure 2-12** displays the cumulative total acreage reclaimed by year. **Figure 2-13** displays Upper Klamath and Agency Lake and the associated wetlands.



Snyder and Morace (1997) quantified the load of total phosphorus from reclaimed wetlands to Upper Klamath Lake by accounting for pumped volumes from drained wetlands and nutrient concentrations of pumped water. The same study also measured and modeled the nutrient loss due to peat decomposition associated with each reclaimed wetland presented in **Figure 2-12**. Little variation between sites or water years existed in the data. The median phosphorus unit area load from drained wetlands received by Upper Klamath Lake is ~2 lbs/acre per year (i.e. 220 kg/km^2 per year in metric units). Such high rates of annual loading are not directly comparable to other source areas in the Upper Klamath Lake Drainage presented in Kann and Walker (2001) because values include both lands that drain reclaimed wetlands and those that do not. However, source areas that drain large areas of reclaimed wetlands do have a high rate of phosphorus loading (**Table 2-5**). This information, along with other studies, indicates that reclaimed wetlands are a large source of phosphorus when considered as a unit area and as the total phosphorus loss from reclaimed wetlands.

Wetland areas were commonly reclaimed by building dikes to disassociate lake flow, constructing a network of drainage ditches and pumping surface and shallow groundwater to help drain the water from the wetland area and lower the water table (Snyder and Morace, 1997). One consequence of lowering the water tables in reclaimed wetlands is an increase in aerobic decomposition of peat soils that liberates and introduces nutrients, namely nitrogen and phosphorus, into surface waters and shallow groundwater. The transport of this nutrient rich water occurs rapidly via drainage ditches and pumping to the lake or tributaries to the lake. The period of time since drainage coupled with the agricultural use of the reclaimed wetland likely have a combined effect on the rate of peat decomposition. Activities that introduce air and oxygenated water into the soils will increase peat decomposition rates and increase nutrient introduction into water (Snyder and Morace, 1997). Therefore, activities such as disking and furrowing likely increase peat decomposition. Cattle grazing can cause soil compaction, which can slow rates of peat decomposition. Further, simply eliminating mechanical pumping and/or gravity drainage of wetlands slows the decomposition of peat soils and the subsequent transport of nutrients to Upper Klamath Lake.

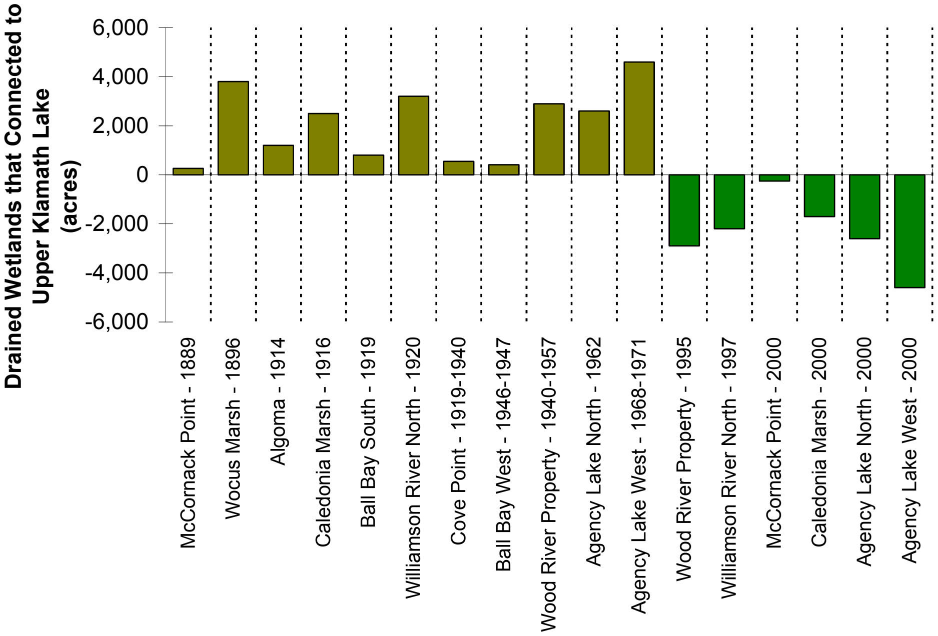


Figure 2-9. Reclaimed wetland acreage by wetland unit. Negative values indicate restored wetlands *(Snyder and Morace, 1997, Snyder, 2001)*

Table 2-5. Derived loading rates of phosphorus for areas that drain reclaimed wetlands

Source Areas that Drain Reclaimed Wetlands[10] *Data from Kann and Walker (2001)*	**Median Reclaimed Wetland Load** *Data from Snyder and Morace (1997)*
Wood River below Weed Road ~ 237 kg/km^2 per year	~ 220 kg/km^2 per year
Agricultural Pumps ~ 188 kg/km^2 per year	

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[10] These source areas also drain other lands. Therefore, a direct comparison to between Kann and Walker (1999) loading rates cannot be made with Snyder and Morace (1997) measured values for loading rates from reclaimed wetlands.

Geiger (2001) suggests that nutrient loads from restored wetlands previously reclaimed for agricultural production is influenced by the relative lake-wetland hydraulic connection. Geiger (2001) hypothesizes that isolation of former wetlands around Upper Klamath and Agency Lakes by diking and draining has degraded the water quality of the lakes by the resultant deprivation of wetland function, rather than by the subsequent agricultural discharges related to use of the reclaimed wetland. Further, Geiger (2001) has suggested that dissolved organic substances derived from the decomposition of marsh plants suppress the growth of AFA and that water quality improvements may result from these decreases in primary productivity. However, limited data has been collected to support these hypotheses. Future studies are needed to quantify the significance of these processes compared to the well documented phosphorous loading from peat soil decomposition and leaching that accompanies wetland reclamation.

Physical and chemical parameters reveal the decomposition rates of peat in soils associated with reclaimed wetlands and soils associated with undrained wetlands. Snyder and Morace (1997) found that reclaimed wetlands have lower total nitrogen relative to undrained wetland soils (see **Figure 2-11**). Drained and undrained wetlands experience similar median total phosphorus content, however drained wetlands have a larger range measured values. Snyder and Morace (1997) suggest that measured values are "indicative of the occurrence of both phosphorus loss[es] due to drainage and phosphorus accumulation due to adsorption or exchange with adjacent soil layers or ground water, or from agricultural sources such as cattle urine and feces or fertilizer for crops." Annual losses of phosphorus from peat soils in reclaimed wetlands are estimated with a first-order decay function:

$$A_t = Ae^{-kt}$$

-Snyder and Morace, 1997

where,

A_t: Mass of phosphorus stored in soils of reclaimed wetland at time t (tons)
A^*: Initial mass of phosphorus stored in soils of reclaimed wetland (tons)
K^*: Rate constant (year^{-1})
t: Time since drainage (year)

*Values for A and k can be found in ***Table 2-5***

Annual phosphorus losses from reclaimed wetlands estimated with the first-order decay function, wetland reclamation acreage and wetland acreage that is currently undergoing restoration is presented in **Figure 2-12**. Phosphorus losses from reclaimed wetlands peaked in 1963 at 68,200 kg per year. Year 2001 estimates are greatly reduced to ≈11,000 kg per year due to wetland restoration that is in progress. This represents a best-case scenario where restored wetlands no longer contribute to peat soil decomposition.[11] Calculations that estimate a condition in which no restoration is occurring substantially increase the losses in phosphorus to ≈52,000 kg per year. It is important to note that the average total external phosphorus load to Upper Klamath Lake is 181,600 kg per year. Therefore, total phosphorus derived from reclaimed wetlands potentially account for 29% of the total load. Assuming that wetlands currently under restoration will regain the ability to prevent phosphorus losses, an estimated reduction of ≈41,000 kg/year in phosphorus losses from reclaimed wetlands results (ODEQ calculation for 2001), representing a ≈80% reduction loading from near lake reclaimed wetlands and a 23% reduction in the average total phosphorus external load to the lake. It should be noted that phosphorus losses from reclaimed wetlands are not specifically demonstrated to relate to phosphorus delivery to Upper Klamath Lake since the pathways for delivery are variable for each reclaimed wetland. Adsorption to soils and suspended sediments, ground water sinks, and bio-uptake may reduce dissolved phosphorus before reaching the lake system. However, it is a valid assumption that ongoing and future wetland restoration are mechanisms that reduce phosphorus losses from wetland sources, and in turn, reduce phosphorus loading to Upper Klamath and Agency Lakes.

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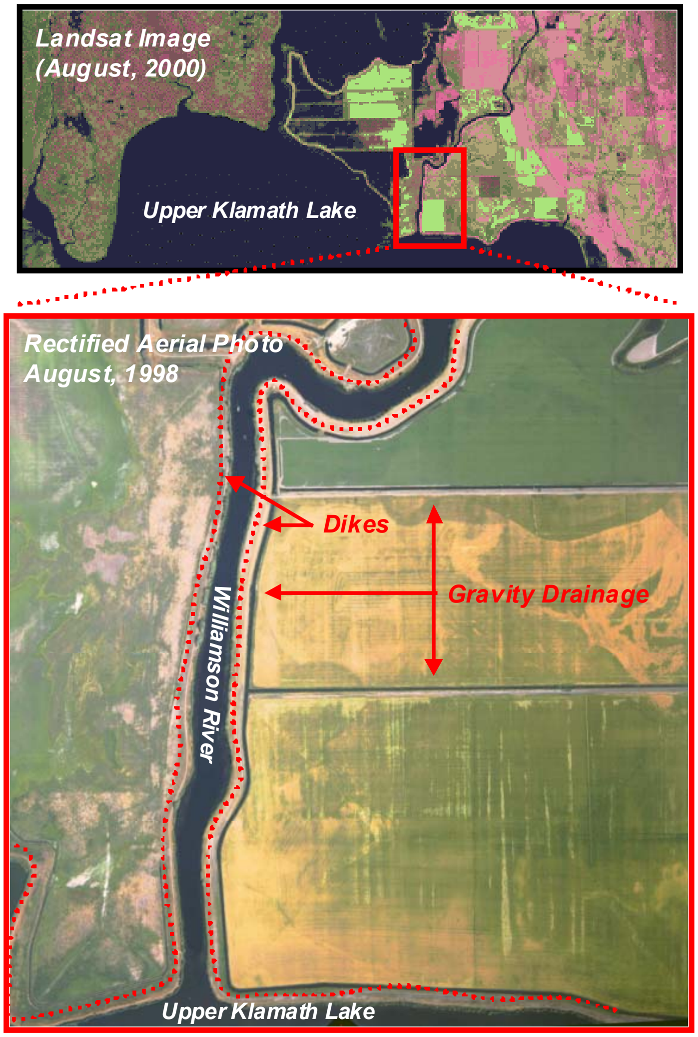
[11] Snyder, personal communication

When peat soils are inundated for the majority of the year (i.e. water tables are above peat soils) a significant reduction in the decomposition rate and release of nutrients is hypothesized by Snyder and Morace (1997). Maximal nutrient load reductions from drained wetland areas occur when:

- Inundation of wetlands decreases aerobic peat decomposition,
- Mechanical pumping and gravity drainage that artificially circulates water volumes from drained wetlands is minimized, and
- Wetland function reinitiates long-term storage of nutrients within the peat soils.

Results of wetland studies suggest that a strategy for nutrient loading reductions to Upper Klamath Lake should include land use considerations, wetland restoration, re-inundation and reconnection to the lake. A 29% reduction in external total phosphorus external loading to the lake is the theoretical maximum attainable reduction that would result from the restoration of the wetlands listed in **Table 2-6**.



Example of an Upper Klamath Lake Reclaimed Wetland

Williamson River Delta

Dikes are constructed to disassociate the wetland from the river and lake waters. Gravity drainage and agricultural pumps maintain lower water surface elevations below the dikes. The difference between lake water surface elevation and the reclaimed wetland can reach 7-8 feet. Subsidence is commonly experienced in these areas due to soil loss, decomposition and loss of buoyancy (Snyder, personal communication). Maximum subsidence in this area is reported as 9-10 feet (TNC, personal communication).

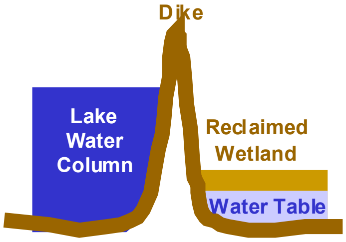


Figure 2-10. Aerial views of a reclaimed wetland – Williamson River Delta

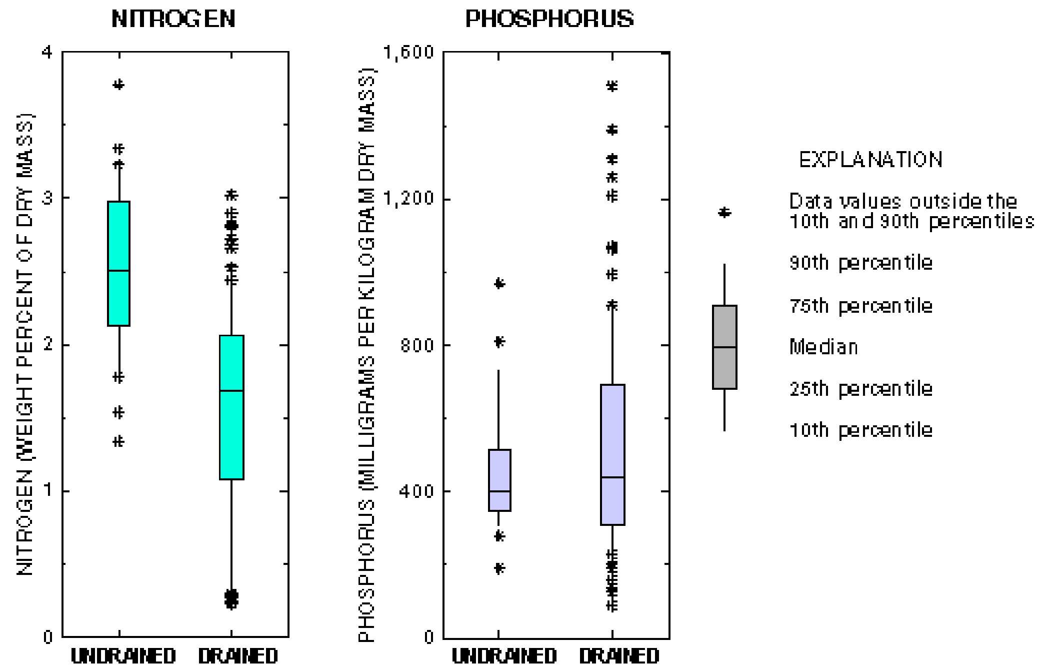


Figure 2-11. Nutrient content in drained and undrained wetland soils adjacent to Upper Klamath Lake *(taken directly from Snyder, 2001)*

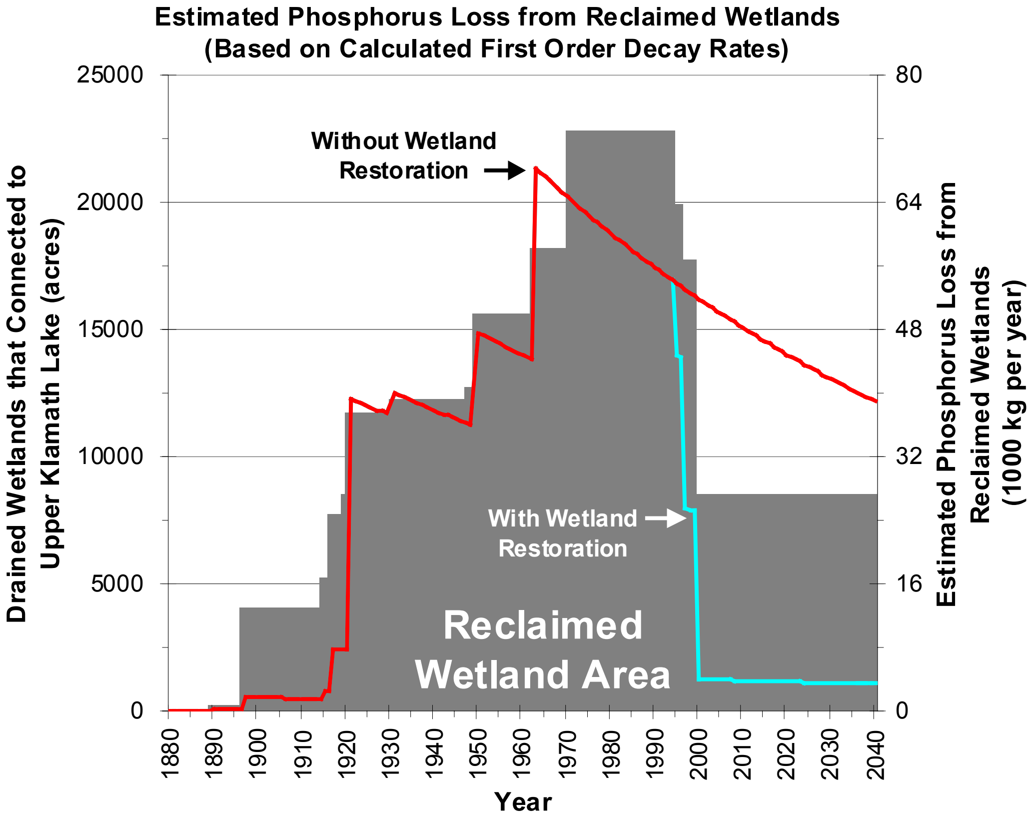


Figure 2-12. Estimated phosphorus loss from reclaimed wetlands and reclaimed wetland surface area *(data from Snyder, 2001).*

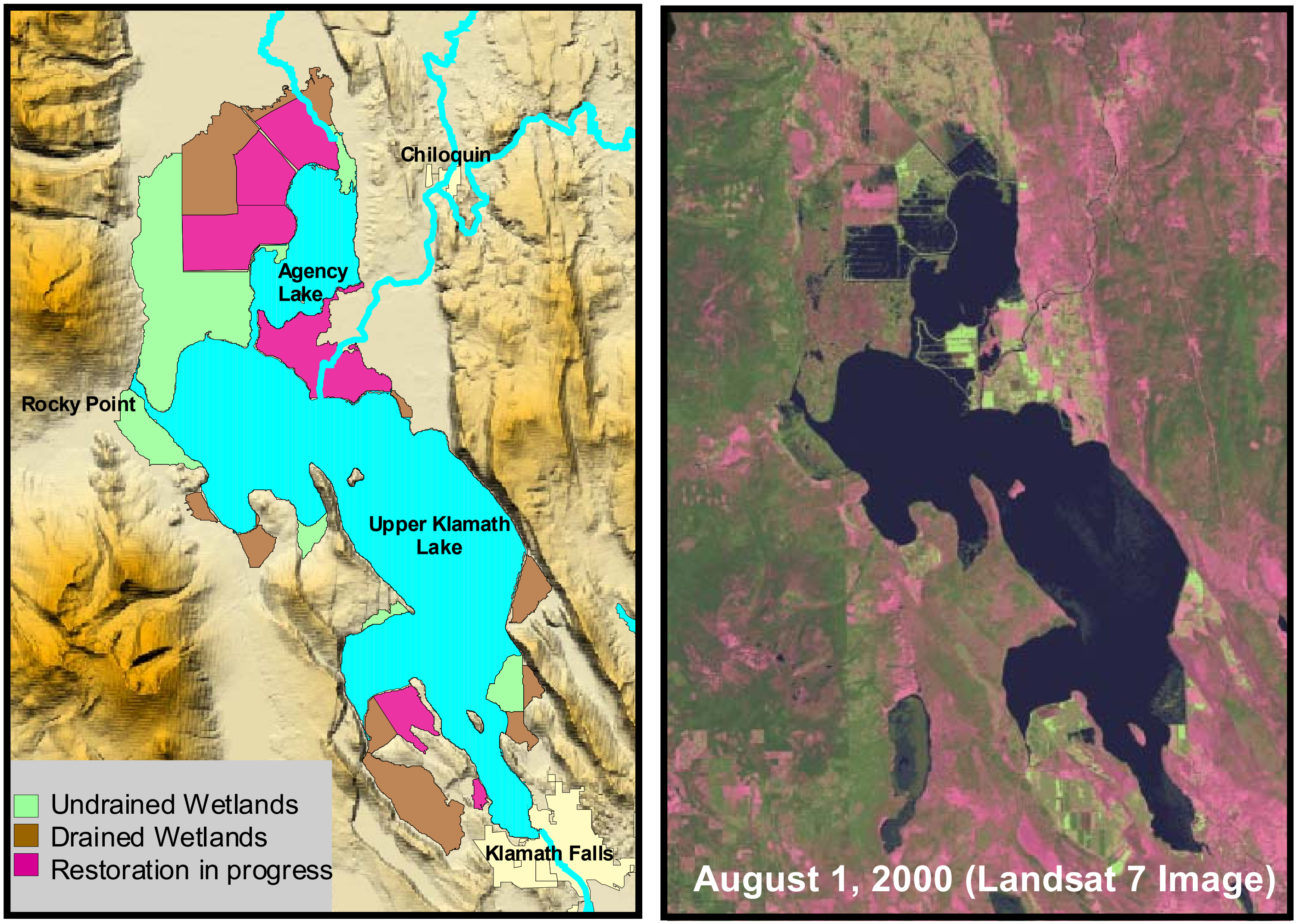


Figure 2-13. Current Wetland Status Identified by Landsat 7 Data
(taken directly from Snyder, 2001)

Table 2-6. Reclaimed Wetland Data and Derived Phosphorus First-Order Decay Functions (Snyder and Morace, 1997)

USGS Code	Common Name & Construction Date	Area (acres)	Cumulative Wetland Area (acres)	Land Use	Annual Loss of Total Phosphorus 1965-1966 (Tons)	Annual Loss of Total Phosphorus 1994-1995 (Tons)	Decay Coefficient k (Year^{-1})	Initial Phosphorus Mass A (Tons)
				Reclaimed Wetlands				
MCC	McCornack Point - 1889	260	260	Crop Cultivation	0.22	0.17	0.0095	50
WOC	Wocus Marsh - 1896	3,800	4060	Mixed Agriculture	1.40	1.40	0.0005	2700
ALG	Algoma (1914)	1,200	5260	Crop Cultivation	0.93	0.89	0.0017	610
CAM	Caledonia Marsh (1916)	2,500	7760	Crop Cultivation	5.00	4.60	0.0029	2000
BBS	Ball Bay South (1919)	800	8560	Cattle Grazing	NC*	NC*	NC*	NC*
WRN	Williamson River North (1920)	3,200	11760	Crop Cultivation	25.00	21.00	0.0070	5000
COV	Cove Point (1919-1940)	550	12310	Crop Cultivation	2.60	2.00	0.0080	430
BBW	Ball Bay West (1946-1947)	410	12720	Cattle Grazing	0.09	0.08	0.0006	160
WRR	Wood River Property (1940-1957)	2,900	15620	Cattle Grazing	12.00	10.00	0.0064	2100
ALN	Agency Lake North (1962)	2,600	18220	Cattle Grazing	26.00	20.00	0.0098	2700
ALW	Agency Lake West (1968-1971)	4,600	22820	Cattle Grazing	NC*	0.00	0.0000	3400
				Wetlands Being Restored				
WRR	Wood River Property - 1995	-2,900	19,920	Wetland				
WRN	Williamson River North - 1997	-2,200**	17,720	Wetland				
MCC	McCornack Point - 2000	-260	17,460	Wetland				
CAM	Caledonia Marsh - 2000	-1,700**	15,760	Wetland				
ALN	Agency Lake North - 2000	-2,600	13,160	Wetland				
ALW	Agency Lake West - 2000	-4,600	8,560	Wetland				

* NC - Not Calculated
** Only partially restored - Actual restoration extent is currently less than total wetland area

2.5.3.2 Upland Sources of External Phosphorus

> *"The view of the lake as a naturally hypereutrophic system (Johnson et al. 1985) is consistent with its shallow morphology, deep organic-rich sediments, and a large watershed with phosphorus-enriched soils. However, watershed development, beginning in the late-1800's and accelerated through the 1900's, is strongly implicated as the cause of its current hypereutrophic character (Bortleson and Fretwell 1993)."*
>
> -Eilers et al., 2001

Gearheart et al. (1995) concludes that considerable changes have occurred in the upstream watershed as large areas of land surrounding the major lake tributaries have been converted to agricultural and grazing land. Euro-American settlers took great efforts to utilize natural resources within the Upper Klamath Lake drainage. Much of the historical and current impacts that affect the uplands that drain to Upper Klamath Lake are cultivated agricultural, rangeland livestock grazing and forestry related. These three sources account for nearly 90% of the external phosphorus loading to Upper Klamath Lake (Gearheart et al. 1995).

Many of the numerous streams and rivers supplied by snow-melt and groundwater are used for irrigation water for livestock and cultivated crops. Extensive wetlands, both adjacent to Upper Klamath Lake and Agency Lake and other vast wetland/riparian areas in the upland areas, have been drained to provide rich farmlands to support livestock and to create cropland. Cattle production in Klamath County peaked in the 1960's with 140,000 head of livestock and is currently near 100,000 head (Gearheart et al. 1995). The Environmental Protection Agency (EPA Index of Watershed Indicators 1998) has estimated that at least 110,000 acres (172 mi^2) of the watershed have been converted to irrigated pasture or other agricultural activities. Risley and Laenen (1999) estimate an eleven-fold increase in permitted irrigated land acreage between 1900 and the present.

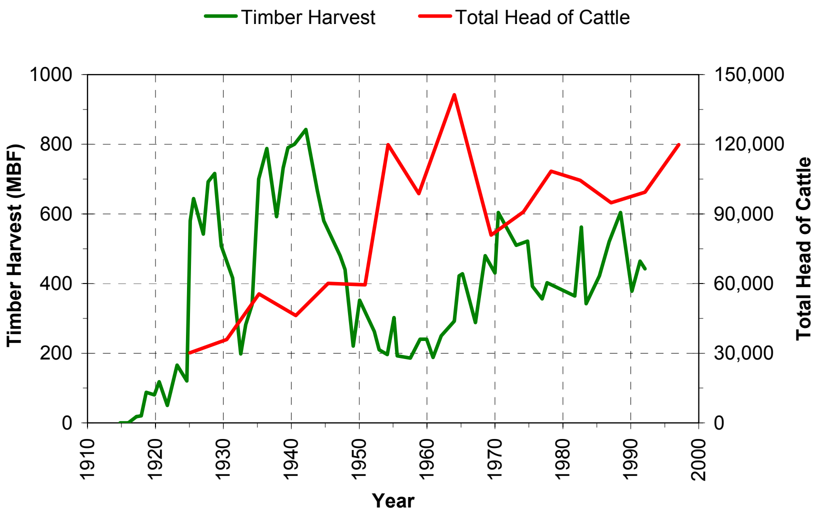


Figure 2-14. Historical timber harvest and total head of cattle for Klamath County[12] (data from Gearheart et al. 1995)

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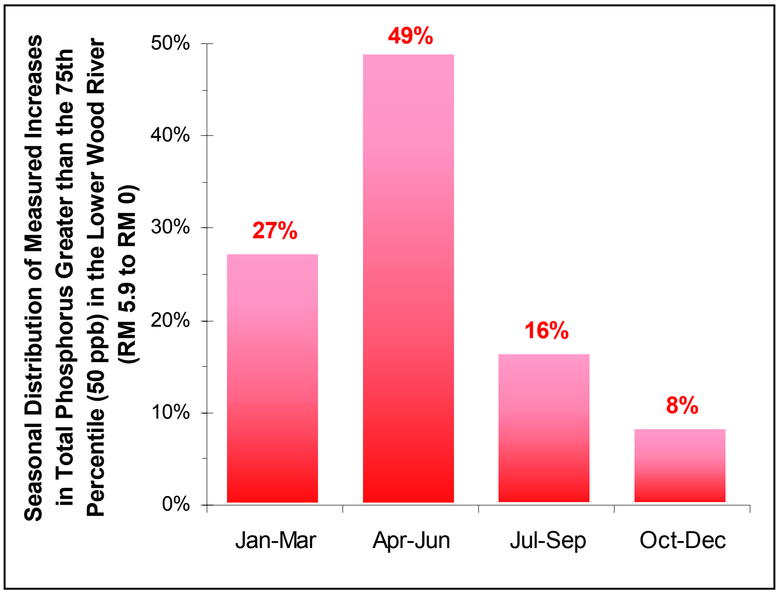
[12] The Upper Klamath Lake drainage comprises 55% of Klamath County.

The extensive forests in the surrounding mountains historically provided abundant supplies of timber to local mills. Timber harvest in the area was most active from 1925 to 1945, reaching a maximum production in excess of 800 MBF (million board feet) per year, and is now currently stabilized near 400 MBF per year (Eilers et al. 2001).

A strong signal of watershed disturbance is provided in sediment core values for titanium (Ti) and aluminum (Al), both of which indicate major increases in erosion inputs to Upper Klamath Lake in the last century (Eilers et al. 2001). Increases in Ti and Al provide strong evidence of erosion inputs associated with disturbance of the watershed. Gearheart et al. (1995) report that the total phosphorus (TP) concentrations in many of the UKL tributaries can be correlated to both runoff events and suspended solids concentrations. Approximately 50% of the total phosphorus loading occurs during a four month runoff period from February through May (Gearheart et al. 1995). Erosion is the major process in transporting phosphorus from the watershed into the lake. Exceptions to this trend are spring systems such as Spring Creek, a major tributary to the Williamson River that comprises the majority of base flow downstream of Upper Klamath Marsh.

It is important to note (once again) that historical accounts indicate that Upper Klamath and Agency Lakes would have been considered eutrophic, even 100 years ago. These accounts are supported by measured elevated concentrations of total phosphorus within springs throughout the basin (Kann and Walker 2001, Rykbost and Charlton 2001). However, in many locations throughout the watershed the observed total phosphorus concentrations measured in tributaries and rivers are elevated significantly above these background conditions. For example, water quality data collected longitudinally along Wood River over a five-year period showed that nutrient concentrations increased as the river traveled through six miles of reclaimed wetlands and pasturelands in the lower watershed (i.e. downstream from Weed Road Bridge) (Kann and Walker, 2001). **Figure 2-15** displays the total phosphorus concentrations for the Wood River at two locations (river mile 0.0 and river mile 5.9) relative to the average spring and lake concentrations for the period of 1992 to 1998. Large increases in total phosphorus concentrations in the lower Wood River generally occur in the winter and spring months. Approximately 76% of the 130 paired total phosphorus measurements experience increases greater than the 75th percentile (i.e. increases of 50 µg/l or greater) in the period spanning January to June. This timing corresponds to pumping schedules, drainage of the surrounding inundated lands for grazing and agricultural uses and peak seasonal runoff. It should be noted that major restoration projects have recently been completed in this area that are, in part, designed to reduce the sources of total phosphorus in the lower Wood River reach.



Water quality samples from fourteen springs are summarized in **Attachment 2** and presented in **Figure 2-16**. Summary statistics were calculated for springs in Upper Klamath Lake drainage having at least seven samples. For comparison purposes, the average, median, geomean and standard deviation about the mean were calculated for each spring. Results indicate that for the 118 spring samples the average concentration of total phosphorus is 77 µg/L with a standard deviation of 22 µg/L from the mean.

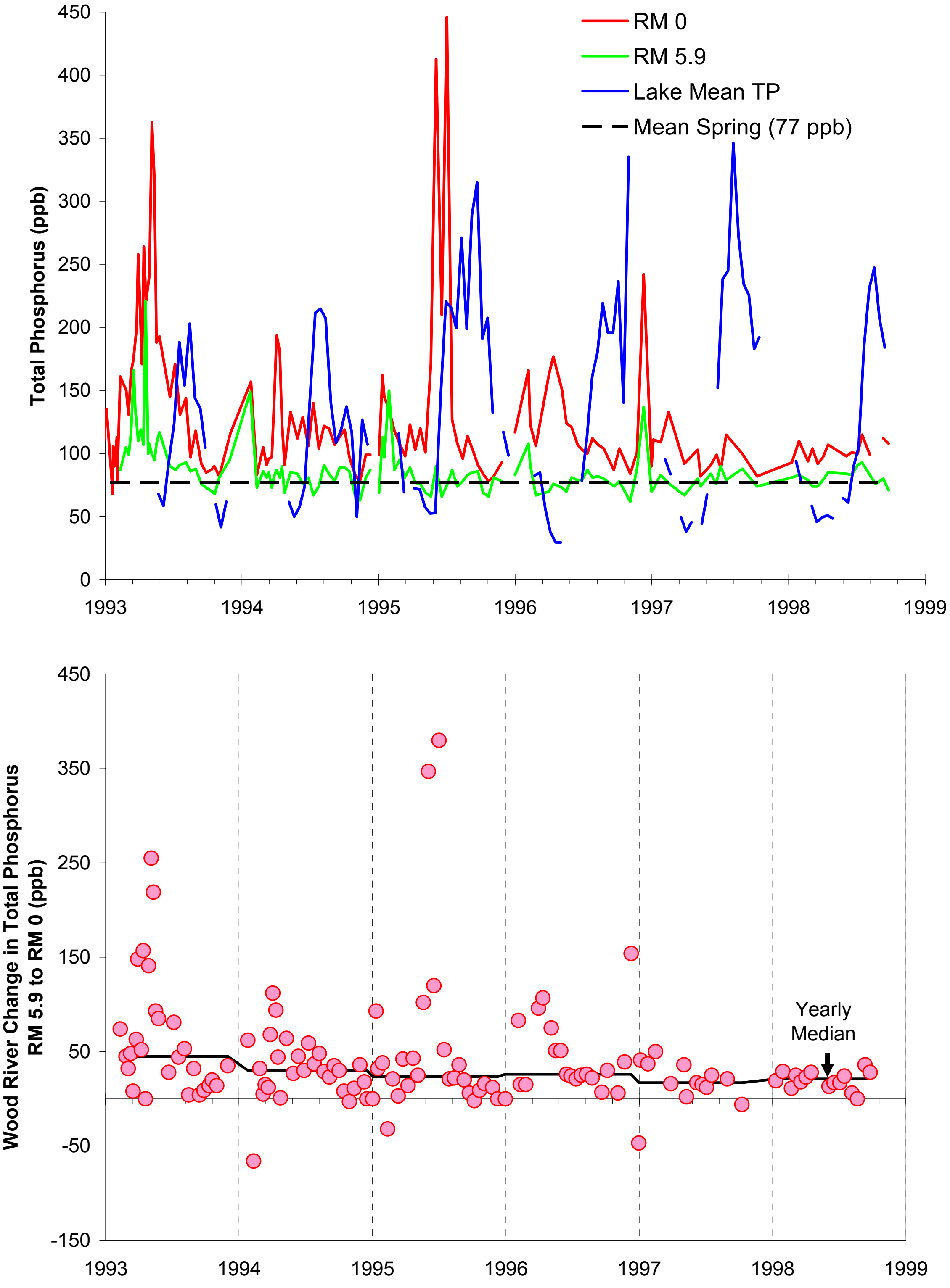


Figure 2-15. Total Phosphorus Concentrations in Wood River, Klamath Lake and median spring values – A consistent pattern of increasing total phosphorus concentrations is apparent in the monitoring data between Weed Road (RM 5.9) and Dike Road (RM 0).

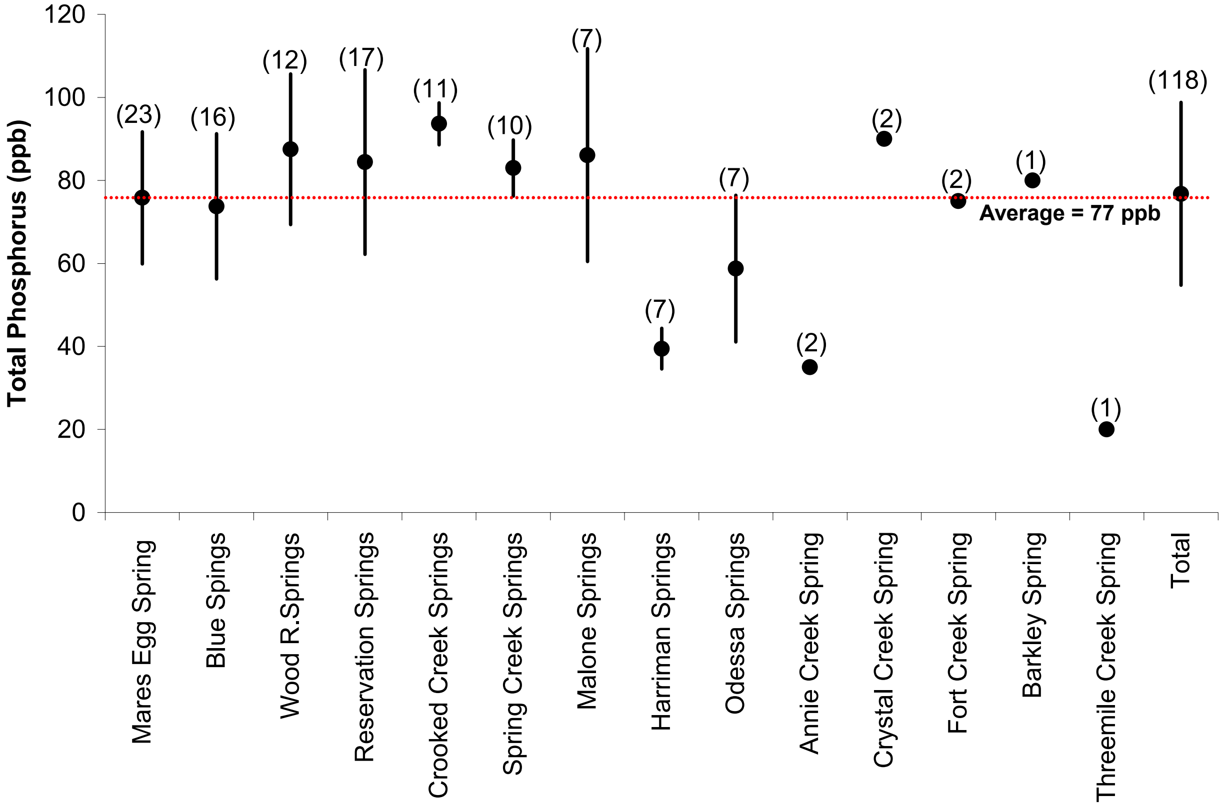
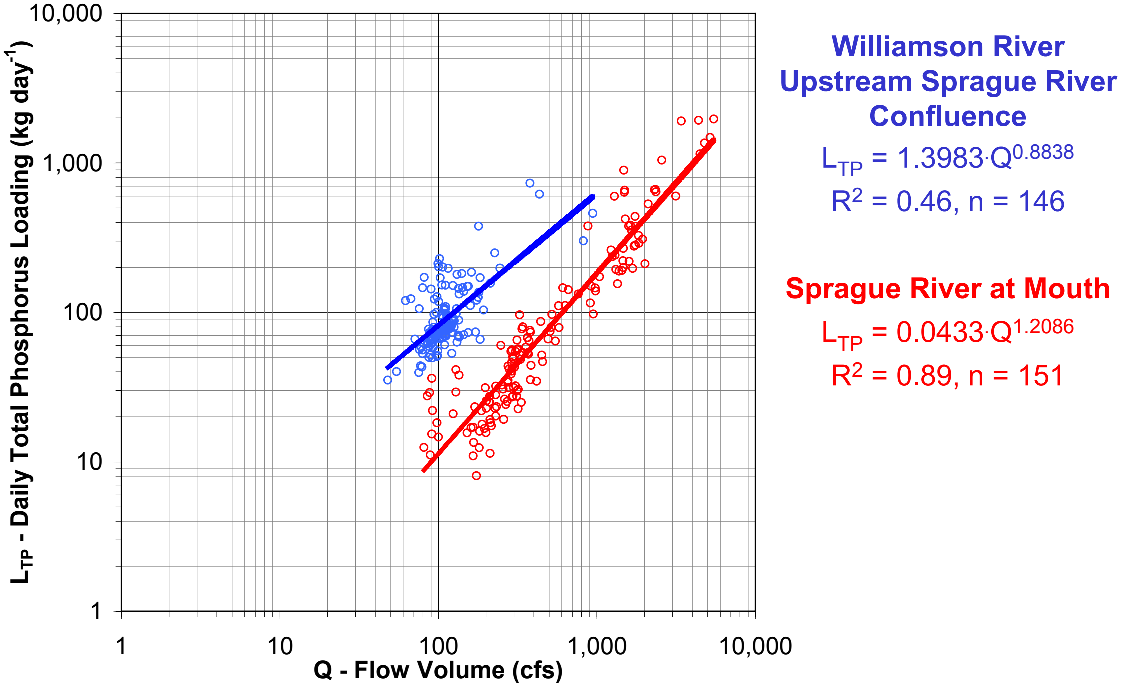


Figure 2-16. Total Phosphorus Concentrations of springs in the Upper Klamath Lake Drainage - mean spring values with one standard deviation about the mean along with sample size (n).

The Sprague River delivers a significant portion of the bound phosphorus load to the lake, primarily during peak runoff events when erosion rates are highest (Gearheart et al. 1995). When compared to the Williamson River, the Sprague River has a high correlation (Sprague River - R^2 = 0.89, Williamson River - R^2 = 0.46) between flow rate and total phosphorus loading (see **Figure 2-17**). To some degree, the Williamson River phosphorus loading upstream of the Sprague River confluence is independent of flow rate below the 2-year high flow. The Sprague River phosphorus loading is highly dependent on flow rate for all return periods, indicating that runoff inputs during peak flows is a significant phosphorus source. This relationship between flow rate and phosphorus loading for the Sprague River is observed throughout the range of flow values, suggesting that surface runoff inputs may occur at flow rates well below statistical peak flows listed in **Figure 2-17**.

A strong correlation between water yield and loading rates indicates that the Sprague River is a primary source of particulate and surface flow transported phosphorus. When summarized by monthly values, the Sprague River phosphorus loading is a function of season and high flow timing. The Williamson River upstream of the Sprague River confluence is relatively independent of season and high flow timing (see **Figure 2-18**). When compared to the Williamson River (upstream of the Sprague River Confluence), the Sprague River is a large seasonal source of phosphorus loading. Recall that Eilers et al. (2001) report that Al and Ti lake sediment core results indicate high rates of upland erosion. Further, Gearheart et al. (1995) reports that upland total phosphorus loading occurs primarily as bound phosphorus and is highly correlated to peak runoff and total suspended solids (TSS). Erosion is a source of bound phosphorus generated during seasonal runoff events. In the context of these results, the disparity in loading rates of phosphorus (displayed in **Figure 2-18**) suggests higher (and more variable) rates of runoff and erosion in the Sprague River drainage than that occurring in the Williamson River drainage.



High Flow Return Periods for Sprague and Williamson Rivers *(gage data from 1990 to 2000)*

Return Period	Log Peason III High Flow (cfs)	
	Sprague River at Mouth	Williamson River Upstream Sprague River Confluence
2 Years	2,761	558
5 Years	6,207	1,064
10 Years	8,750	1,989
25 Years	11,850	8,123

Figure 2-17. Daily Total Phosphorus Loading v. Flow Rate

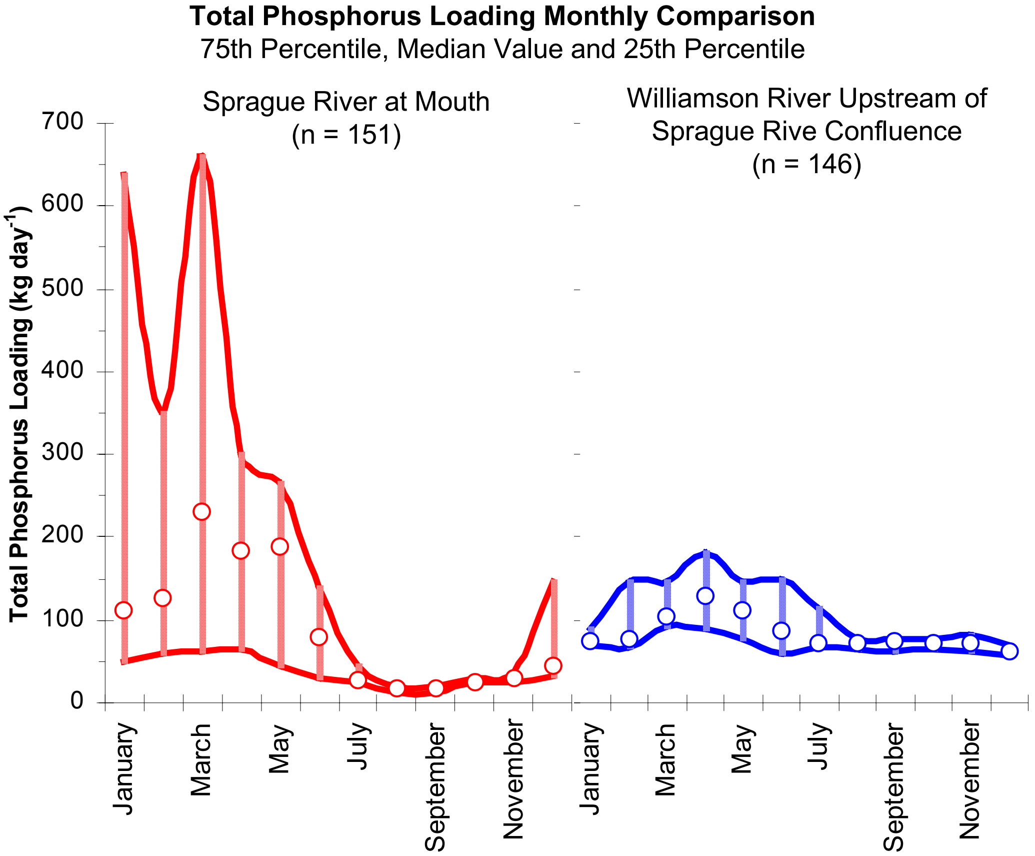


Figure 2-18. Daily Total Phosphorus Loading by Month for the Sprague River and Williamson River Upstream of the Sprague River Confluence.

Some researchers and local stakeholders have speculated that water diverted out of streams for cultivated agriculture, irrigating crops and use by livestock result in reduction of phosphorus loads to surface waters that drain to Upper Klamath Lake (Rykbost and Charleton, 2001; Shapiro and Associates, 2001; Hathaway and Todd, 1993). However, agricultural land uses generally are greater sources of nutrients, especially nitrogen and phosphorus, than forest and pasture land uses (Correll et al. 1992). Hydrologic modifications, channelization and degradation of wetland/riparian areas can detract from the ability of an area to process transported nutrients and organic matter, resulting in increased nutrient export from a site (Lowrance et al. 1983, 1984, 1985). Human related nutrients produced from a site results from the combination of nutrient load produced by human land use and the ability of the environment to remove nutrients via adsorption, chemical binding and/or bio-uptake. Omernick (1977) found a nationwide averaged 900% increase in nitrogen and phosphorus concentrations in streams draining agricultural areas when compared to streams draining forested areas. Phosphorus loading has traditionally been associated with overland flow and surface flows.

Historical flow data from the Williamson River and Sprague River drainages suggest that runoff patterns have changed as a result of human land use patterns (Riseley and Laenen 1998). Long-term climate data (precipitation and air temperature) were included in the analysis to account for the influence of climate on historical runoff data. Annual runoff in the Williamson River has been measured below the confluence and at the mouth of the Sprague River near Chiloquin. As depicted in **Figure 2-19,** the average yearly water yields have increased by 34% in the Williamson River subbasin and 42% in the Sprague River subbasin (Riseley and Laenen 1999).

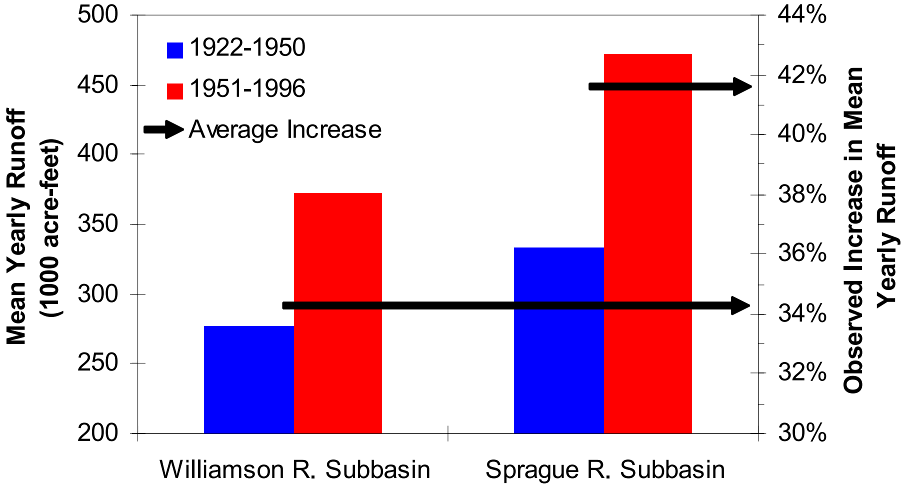


Figure 2-19. Two Sample Tests for Differences in Williamson and Sprague River Annual Runoff for Two Periods: 1922-1950 and 1951-1996 (Risley and Laenen, 1999)

Riseley and Laenen (1999) suggest that the statistically significant shifts in annual runoff are caused by human development and land use. The bulk of the irrigated acreage in the Williamson and Sprague drainages were developed between 1950 and 1980. While irrigated acreage cannot explain the increase in water yields, other associated landscape modifications that accompany irrigated crop cultivation and livestock grazing may offer an explanation: decreased summertime evapotranspiration, increased runoff rates, reduced infiltration and reduced riparian, floodplain and wetland water storage. Timber harvest can accelerate the snow melt and decrease evapotranspiration, causing increased water yields (Rothacher, 1970). However, **Figure 2-14** indicates a decrease in timber harvests in the post-1950's period. Therefore, it is more likely that the combined effects of hydrologic disturbance that have increased water yields in the Williamson and Sprague River subbasins are related to agricultural activities in the drainage.

Total external phosphorus loading is simply the product of concentration and flow volume. Therefore, assuming that total phosphorus concentrations have not decreased in the 1951-1996 period, relative to the 1922-1950 period, the Sprague and Williamson River subbasins generate a proportionally larger total phosphorus load simply by virtue of increased water yields. External loading rates of total phosphorus derived from the increased water yield in the Williamson and Sprague River subbasins may account for 18% (327,000 kg/year) of the total external load to the lake. **Table 2-7** lists the water yields and associated total phosphorus loading rates for the Williamson and Sprague River subbasins.

Table 2-7. Williamson River and Sprague River Subbasin Water Yields and Associated Total Phosphorus Loading Rates.

	Increase in Water Yield from 1922-1950 Period to 1951-1996 Period	**Current External Total Phosphorus Load (1000 kg/year)**	**External Phosphorus Load Associated with Increased Water Yield (1000 kg/year)**	**Potential Total Phosphorus Load Reduction as a Percent of the Total External Load (181,600 kg/year)**
Williamson River Subbasin	34.2%	37.8	12.9	7.1%
Sprague River Subbasin	41.6%	48.7	20.2	11.1%
Total	37.8%	86.5	32.7	18.0%

2.5.4 Internal Lake Sources of Phosphorus

Internal phosphorus loading (sediment regenerated phosphorus delivered to the lake water column) is a large source of phosphorus in Upper Klamath Lake (Barbiero and Kann 1994; Laenen and LeTourneau 1996; Kann 1998). An important mechanism for the release of phosphorus in shallow productive polymictic (continuously mixed) lakes is photosynthetically elevated pH (Welch 1992; Sondergaard 1988; Jacoby et al. 1982). Elevated pH increases phosphorus flux to the water column by solubilizing iron-bound phosphorus in both bottom and resuspended sediments as high pH causes increased competition between hydoxyl ions and phosphate ions decreasing the sorption of phosphate on iron. Evidence for this exists in Upper Klamath Lake where it was shown that the phosphorus associated with hydrated iron oxides in the sediment was the principle source of phosphorus to the overlying water, and that iron-phosphorus reaction decrease from May to June and July (Wildung et al. 1997). In addition, the probability of achieving increased internal loading rate increases with pH, and it appears that a pH of approximately 9.3 is the level at which the probability of internal loading sharply increases (Kann 1998). Empirical evidence from Upper Klamath Lake, along with supportive evidence from other lakes, indicates that as the *AFA* bloom progresses that pH increases. A flux of phosphorus to the water column from lake sediments increases the water column phosphorus concentration and further elevates AFA biomass and pH, setting up a positive feedback loop (Kann 1998). Internal load was calculated for the 1992 to 1998 period and is included in this analysis. Internal phosphorus loading to the lake averaged 285 mtons/year with a standard deviation of 76 mtons/year. **Figure 2-20** displays the annual average internal and external phosphorus loads and **Figure 2-21** displays the observed and predicted internal recycling rates developed by Walker (2001).

It should be noted that other sediment/water column processes are likely occurring to an unknown degree, in addition to solubilizing iron-bound phosphorus in both bottom and resuspended sediments. Mechanical mixing and entrainment of sediments by wave/wind energy can resuspend sediments into the water column. Other chemical and biological processes may alter the phosphorus gradient and rates of transfer from sediment to the water column.

2.5.5 Phosphorus Budget

Total phosphorus loads average 466 mtons/year: external loading accounts for 182 mtons/year and internal loading accounts for 285 mtons/year. Phosphorus sources to the lake water column result from inflow (including precipitation) and recycling from lake sediments. Phosphorus losses from the lake result from outflow and gross sedimentation. Biweekly phosphorus fluxes (i.e. loading and removal rates: inflows, outflows, gross sedimentation and recycling) between 1992 and 1999 for a combined effect that results in the total available phosphorus concentration in the lake at any given time. Biweekly and yearly average phosphorus mass balance pathway values are presented in **Figure 2-21.**

Nutrient contributions into Upper Klamath and Agency Lakes from various source classes (i.e. external sources and internal loading from sediments) are summarized in **Table 2-4**. These values were calculated from water quality data collected within these lakes and their tributaries from 1992 through 1998 (Kann and Walker, 2001). On an annual basis there tends to be a net retention of total phosphorus in the lake due to the significant sedimentation events from algal crashes and the likely settling of particulate phosphorus during high runoff. However, it is evident from the negative retention (positive internal loading) during the May through September period that internal loading is a significant source of phosphorus to the lake. Although there is a high contribution of internal total phosphorus loading to the lake during the algal growing season, it has been noted that the mobilization of phosphorus from iron has the potential to respond rapidly when primary productivity and pH maxima are reduced (Marsden 1989). The rapid response may be due to a reversal of the positive feedback mechanism described earlier in **Section 2.5.4 Internal Lake Sources of Phosphorus**.

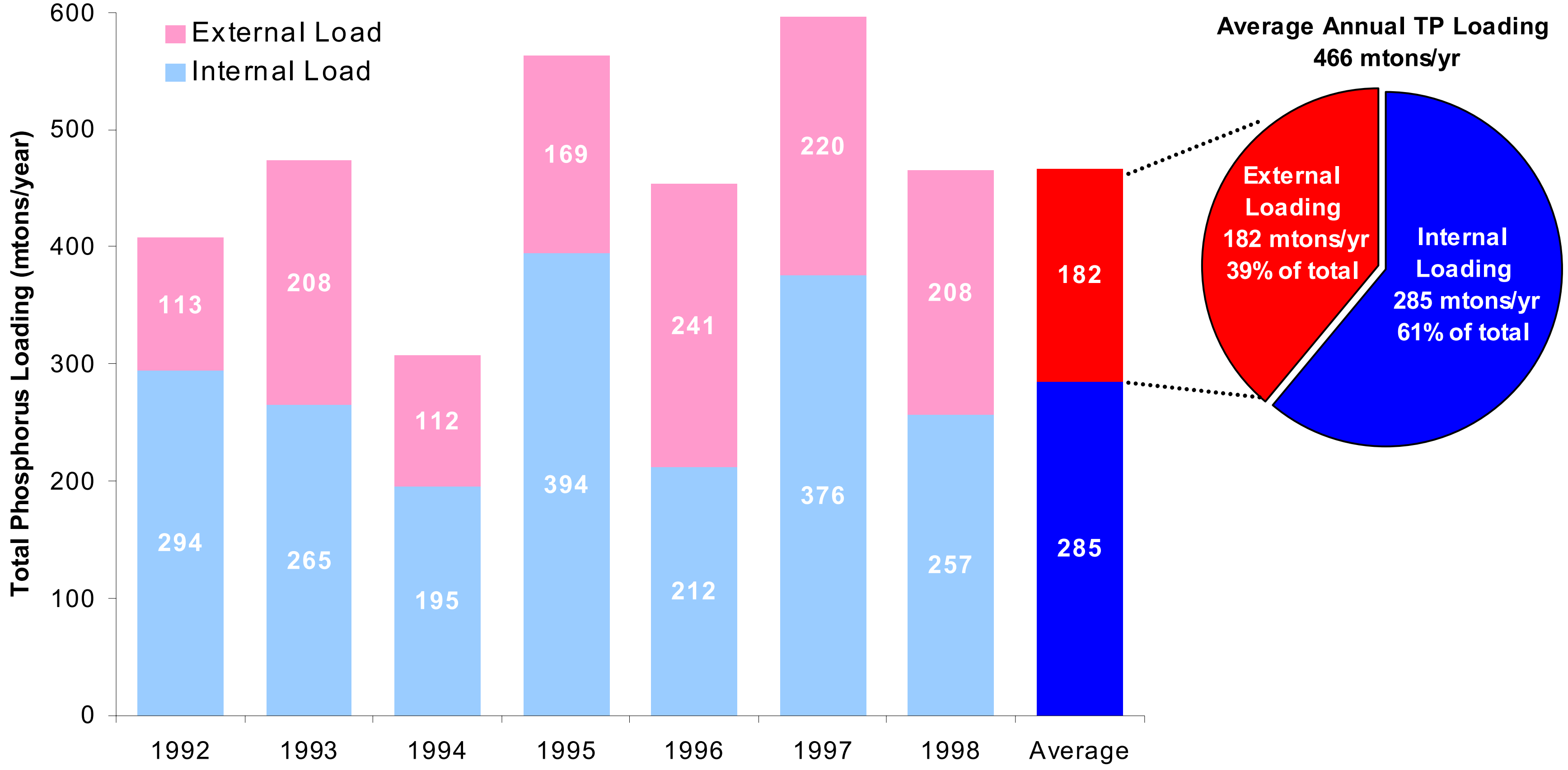
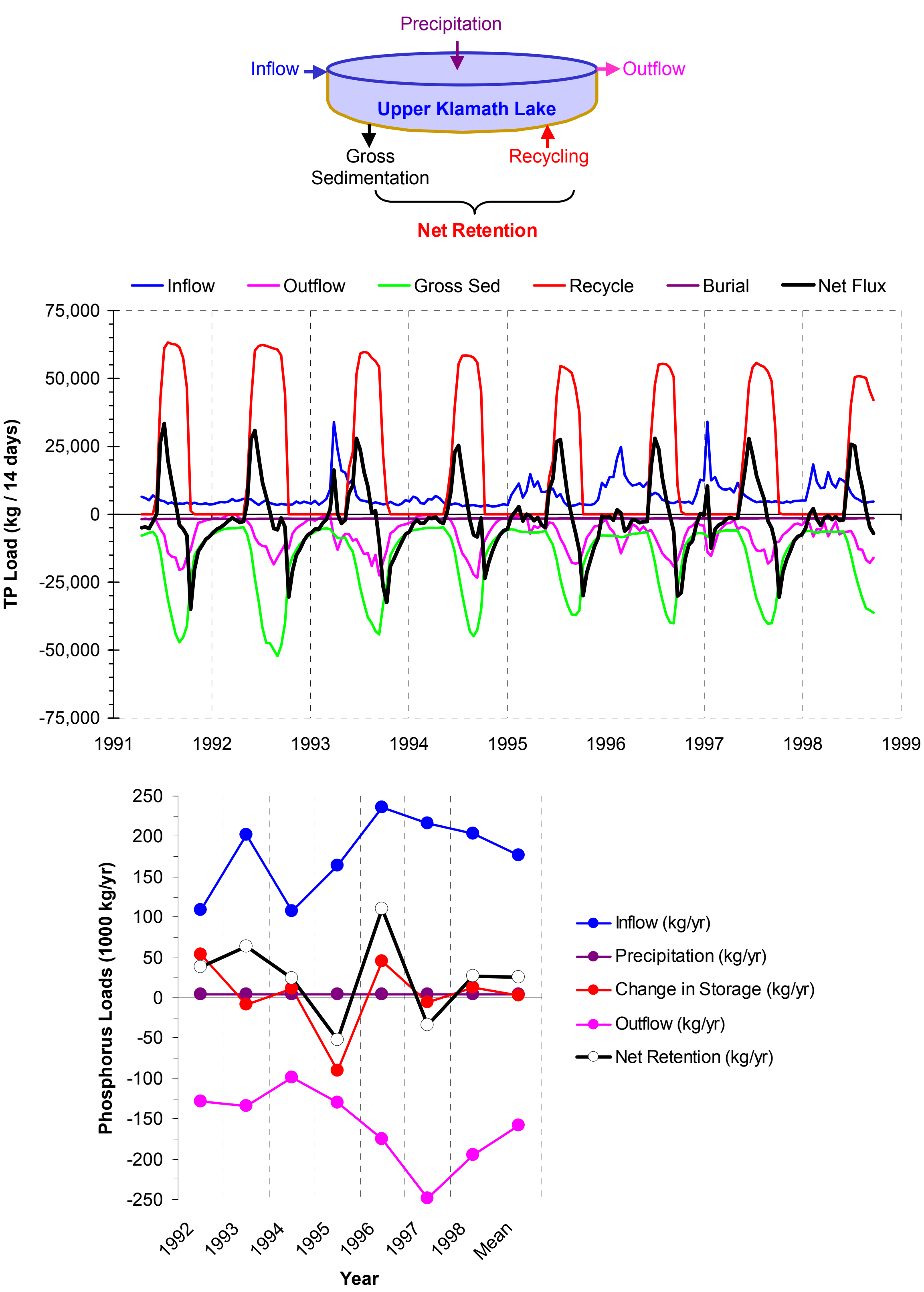


Figure 2-20. Total Phosphorus Load as a Function of External and Internal Loads (Walker 2001)



Phosphorus Sources, Losses and Sinks

Figure 2-21. Time Series Total Phosphorus Flux Mass Balance Pathways - Inflow, Outflow, Gross Sedimentation and Recycling (Walker, 2001)

2.5.6 Nitrogen Budget

The total nitrogen balance indicates that Upper Klamath Lake is a seasonally significant source of nitrogen (Kann and Walker, 2001). The primary source for this increase in internal nitrogen loading is from nitrogen fixation by the blue-green alga *Aphanizomenon flos-aqaue* (Kann 1998). As a consequence of algal nitrogen fixation, the average outflow total nitrogen load was 3.5 times the inflow load in 1992-1999. Another potential source is the mobilization of inorganic nitrogen from lake sediments during anaerobic bacterial decomposition.

2.6 PHOSPHORUS REDUCTIONS NECESSARY TO MEET WATER QUALITY STANDARDS

2.6.1 Water Quality Standard Attainment Analysis - CWA §303(d)(1)

As mentioned earlier in this document, although nitrogen concentrations can be a controlling mechanism for algal growth in lake systems, phosphorus reduction has been shown to be the most effective long-term nutrient management option to control algal biomass in Klamath and Agency Lakes (Kann, 1993; 1998, and Walker, 1995).

The pollutant load analysis draws primarily from the “Development of a Phosphorus TMDL for Upper Klamath Lake, Oregon” (Walker, 2001). The response of pH levels at various phosphorus loading levels for Upper Klamath and Agency Lakes was developed using a dynamic mass-balance model that simulates phosphorus, chlorophyll-a and pH variation as function of external phosphorus loads and other controlling factors (Walker 2001). The model is calibrated with extensive monitoring data collected for the Lake and its tributaries between 1990 and 1999. A flow chart of the pH model developed by Walker (2001) is presented in **Figure 2-22** and documentation of the model is available on DEQ’s website at: http://www.deq.state.or.us/wq/TMDLs/UprKlamath/Walker_Report.pdf.

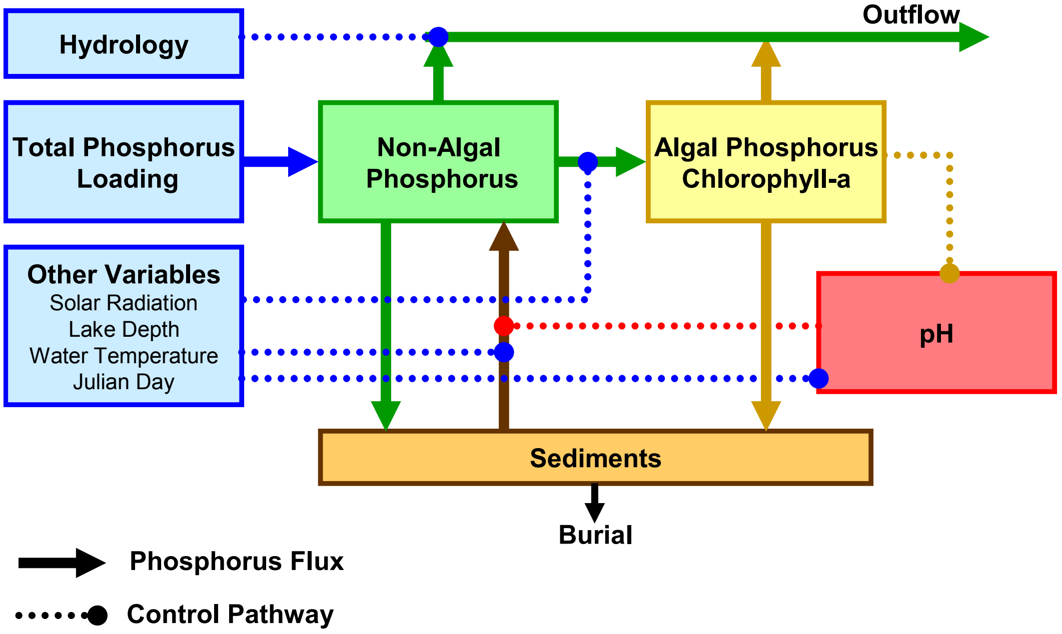


Figure 2-22. Conceptual Flow Chart of the pH Model (Walker, 2001)

A direct simulation of pH excursion frequency as a function of total phosphorus load and other controlling factors utilize the calibrated dynamic pH model (Walker 2001). Simulation results are expressed as relationships between percent reductions in total phosphorus loads and pH excursion frequencies, computed using various spatial and temporal averaging methods. Total phosphorus reduction simulation results are presented in **Table 2-8** and **Figure 2-23** where total external phosphorus loading is reduced incrementally 0% to 55%. Analytical outputs suggest that excursion frequencies for the pH standard can theoretically be reduced to ~0%, if the load for total phosphorous is reduced by 50% (Walker 2001). However, there is evidence that such a load reduction is not possible/feasible (see **Section 2.5.3 External Sources of Phosphorus**). General "compliance" with water quality standards does not necessarily require that all measurements are below a specific number value at all locations (and depths) throughout all times of a year. A recognized reality is that water quality conditions are driven by variables (i.e. climate, hydrology, biochemical reactions, biological processes, etc.) that vary via human manipulations and natural forces over a space and time to the extent that 100% compliance is theoretically unattainable under any loading regime. Walker (2001) advocates a quantitative definition of compliance of water quality standards that acknowledges spatial and temporal variability in the lake and upland systems, as well as the uncertainties with measurements, monitoring programs and analytical techniques.

Figure 2-23. Lake-Mean pH Frequency as a Function of External Phosphorus Load Reduction *(Walker, 2001)*

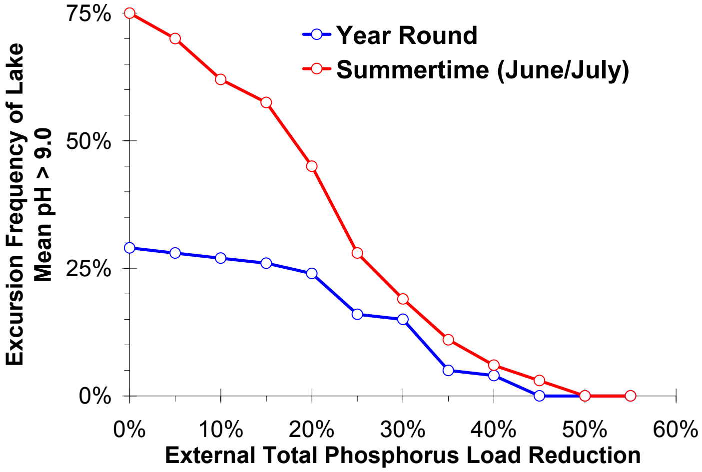


Table 2-8. Lake pH Response at Various External Total Phosphorus Load Reduction

	Frequency of pH Values > 9.0	
Reduction in External Loading	Year Round Mean	Summertime Mean June-July
0%	29%	75%
25%	16%	28%
30%	15%	19%
35%	5%	11%
40%	4%	6%
45%	0%	3%
50%	0%	0%
55%	0%	0%

TP Load Reduction

Improvement in pH

In light of these monitoring and analytical limitations and the complexity of the lake and drainages, the selection of a TMDL targeted loading condition and compliance frequency ultimately becomes a professional judgment. As is the case in any such professional judgment, there are varying perspectives on an appropriate targeted condition. Regardless, **a 40% reduction in total phosphorus loading to Upper Klamath Lake represents the targeted condition for this TMDL.** This target acknowledges external load reductions that range from 33% to 47% that are documented in the literature (from Kann and Walker, 2001). Further, other potential external loading reductions highlighted in **Section 2.5.3 External Sources of Phosphorus** that demonstrates a potential 47% reduction in external total phosphorus loading to the lake:

- 29% reduction in external total phosphorus loading from near-lake wetland restoration, and

- 18% reduction in external total phosphorus loading resulting from upland hydrology and land cover restoration.

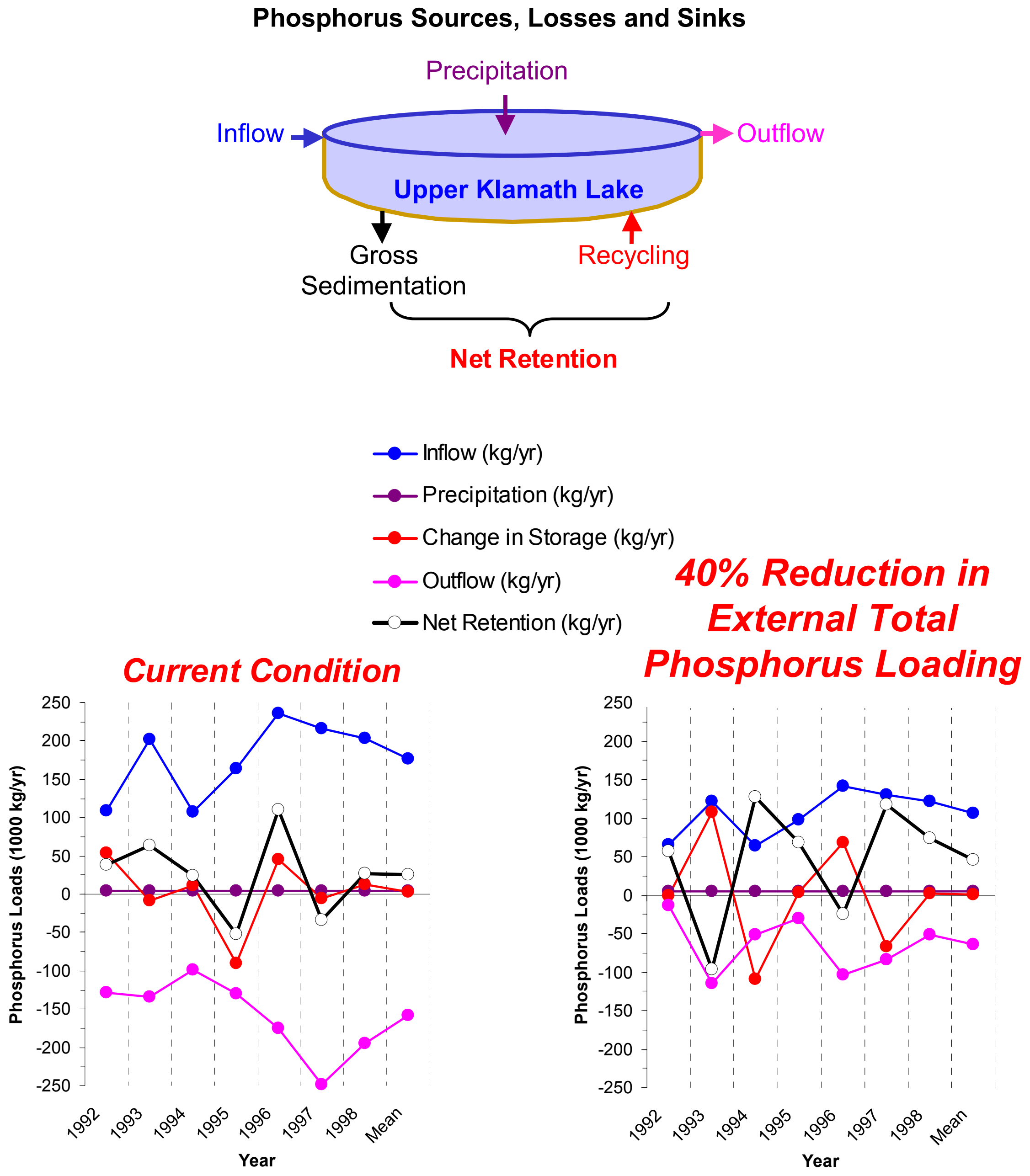
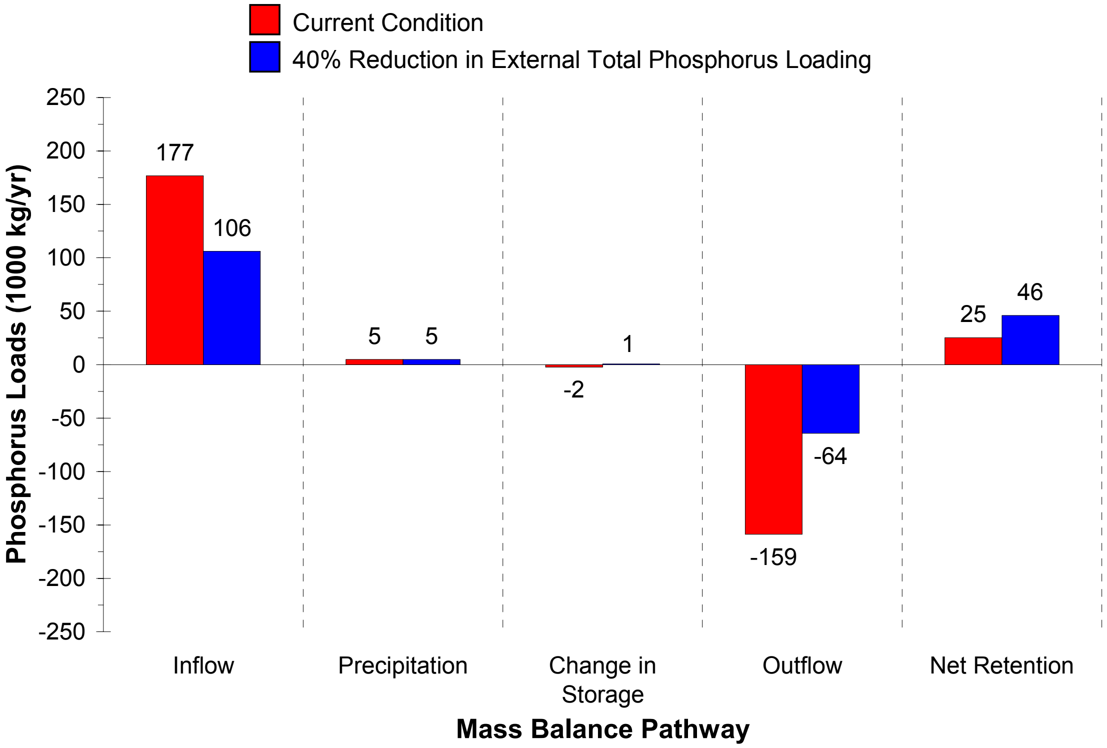


Figure 2-24. Current Condition and 40% Reduction to External Total Phosphorus - Yearly Average Phosphorus Mass Balance Pathways - Inflow, Precipitation, Outflow, Change in Storage and Net Retention in Sediments (Walker, 2001)



A net retention of total phosphorus in the lake results from significant sedimentation of biomass from algal crashes and settling of particulate phosphorus during high runoff. The mobilization of phosphorus from iron has the potential to respond rapidly when primary productivity and pH maxima are reduced (Marsden 1989). Therefore, a reversal of this positive feedback mechanism increases the net retention of phosphorus as lower pH values result from the 40% reduction in external total phosphorus loading to the lake. These lower pH values decrease the rate of recycling associated with internal phosphorous sources.

Figure 2-25. Current Condition and 40% Reduction in External Total Phosphorus - Average Phosphorus Mass Balance Pathways over Period of Data/Analysis Record (1992 – 1998) - Inflow, Precipitation, Outflow, Change in Storage and Net Retention in Sediments (Walker, 2001)

2.6.2 Measured Water Quality Trends

The Seasonal Kendall test performed on observed UKL mean total phosphorus collected during March through May, 1991 to 2000, indicates that there is a statistically significant decreasing trend (see **Attachment 2** - **Figure 3**). The purpose of reducing phosphorus in Upper Klamath Lake is to reduce algal biomass, indicated by chlorophyll a, and subsequently pH. Lowering pH to the water quality standard (9.0) should significantly reduce or eliminate toxic conditions in the lake.

2.7 LOADING CAPACITY - 40 CFR 130.2(F)

The loading capacity (see **Figure 2-26**) provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with water quality 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 load capacity is estimated for purposes of this TMDL as the external total phosphorus loading into Upper Klamath and Agency Lakes that corresponds to a reduction of approximately 40% from current conditions. At this total phosphorus loading level it is expected that the pH criteria of 9.0 will largely be achieved, with limited excursions. Further, any progress towards the load capacity will be accompanied by improvements in water quality (see **Table 2-7** – blue shaded Region in **Section 2.6.1 Water Quality Standard Attainment Analysis - CWA §303(d)(1)**).

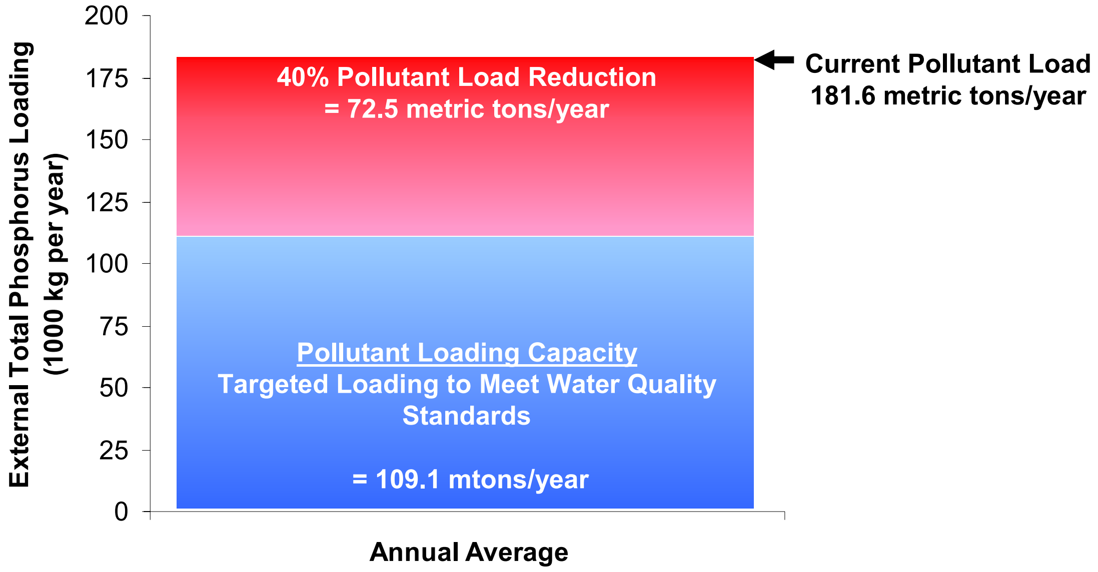


Figure 2-26. Loading Capacity for Upper Klamath and Agency Lakes

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

Load Allocations *are developed for nonpoint source phosphorus loading. These allocations include background sources such as precipitation, springs, soil contributions, etc., and anthropogenic distributed sources such as wetland reclamation, upland sources, pumps, canals, etc. Further these allocations are flexible. Large load reductions from one source area may allow smaller reductions in other source areas.*

Waste Load Allocations *for point sources specify phosphorus loading rates that will be achieved through regulatory permits.*

Table 2-9 *lists the distribution of external total phosphorus loading to Upper Klamath and Agency Lakes allocated to the various sources.*

2.8.1 Point Sources

There are two point sources of phosphorus that discharge to waters that drain to Upper Klamath Lake: the Chiloquin Sewage Treatment Plant and the Crooked Creek Fish Hatchery. The phosphorus loads that result from discharge are calculated by multiplying the year discharge volume by the yearly discharge phosphorus concentration. **The waste load allocation targets a 40% loading rate reduction, which matches the 40% reduction in external loading a specified in Section 2.6 Phosphorus Reductions Necessary to Meet Water Quality Standards. In the event that background condition concentrations prevent attainment of a 40% loading reduction, the background condition becomes the target.** The allowable phosphorus loads that result from discharge are calculated by multiplying the year discharge volume by the yearly targeted phosphorus concentration. Equations used in this analysis are presented below. Terms are defined in **Table 2-8**, where flow volume data, phosphorus concentrations and calculated loading rates are presented.

$$\text{Load} = Q \cdot P_{\text{current}} \cdot \frac{l \cdot \text{Kg}}{10^9 \cdot m^3 \cdot \mu g} \qquad \text{WLA} = Q \cdot P_{\text{WLA}} \cdot \frac{l \cdot \text{Kg}}{10^9 \cdot m^3 \cdot \mu g}$$

Estimated background loading rates for phosphorus are developed to match background receiving water concentrations of phosphorus. Background concentrations of phosphorus at the Crooked Creek hatchery are estimated by using the measured concentration of the spring flowing into the hatchery (90 μg/L). Background levels of total phosphorous for the Chiloquin STP was estimated as the calculated background concentration of nearby springs (80 μg/L) (see **Attachment 2- Table 3** for spring nutrient concentration summaries).

Point Source	Associated Spring	Samples n	Median[13] Total Phosphorus (ppb)
Chiloquin STP	Spring Creek Springs	11	80
Crooked Creek Hatchery	Crooked Creek Springs	10	90

Table 2-8. Point Source Flow Discharge Data, Estimated Phosphorus Concentrations and Calculated Loading Rates

		Phosphorus Concentration (μg/l)		Total Phosphorus Load (mton/year)		Total Phosphorus Load Reduction
	Discharge Q (cms)	Current ($P_{current}$)	Background & Allowable (P_{WLA})	Current (Load)	Allowable (WLA)	
Chiloquin Sewage Treatment Plant*	$1.38 \cdot 10^5$	4000	80 2,400	0.55	0.33	40%
Crooked Creek Hatchery	$1.43 \cdot 10^7$	130	90 90	1.86	1.29	31%

*A 40% reduction in load is targeted for the Chiloquin Sewage Treatment Plant. Background concentration is not targeted.

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[13] The median total phosphorus concentration of nearby springs is used to estimate local background levels (P_{WLA}) that serve as the lower bound for reductions.

2.8.2 Allocation Summary

Determination of the load capacity is a required element of a TMDL. The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards. By definition, TMDLs are the sum of the allocations [40 CFR 130.2(i)]. Allocations are defined as the portion of a receiving water loading capacity that is allocated to point or non-point sources and natural background. A *Load Allocation* (LA) is the amount of pollutant that non-point sources can contribute to the stream without exceeding state water quality standards. Each DMA's portion of the WQMP (see **Chapter VI**) will address only the lands and activities within each identified stream segment to the extent of the DMA's authority. The *Waste Load Allocation* (WLA) is the amount of pollutant that point sources can contribute to the waterbody without violating water quality standards.

107.5 metric tons – Nonpoint Source Load Allocation
Waste Load Allocations { 0.3 metric tons - Chiloquin Waste Water Treatment Plant
1.3 metric tons - Crooked Creek Fish Hatchery
0.0 metric tons - Margin of Safety
\+ 0.0 metric tons - Reserve Capacity

Loading Capacity = 109.1 metric tons per year - Total Phosphorus

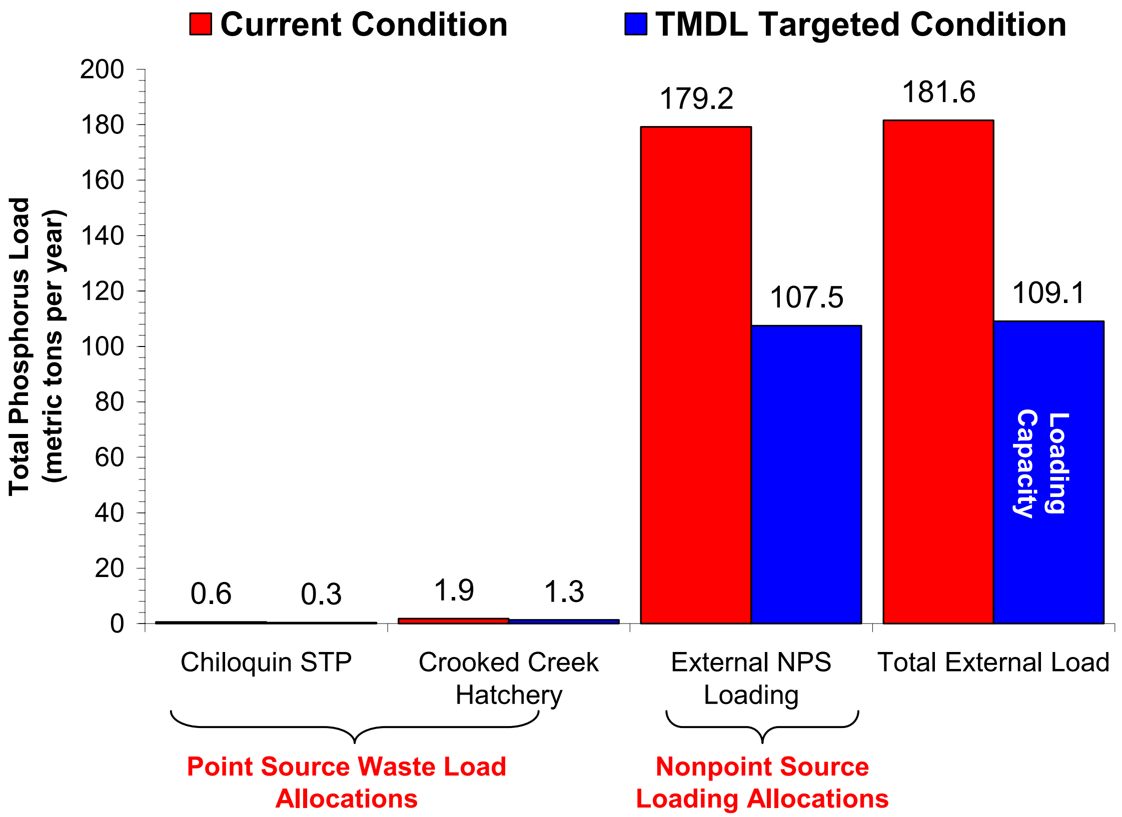


Figure 2-27. Phosphorus Loading - Current Condition and Allocated Condition

Table 2-9. Allocation Summary

Nonpoint Sources		
Source		**Loading Allocation** **Allowable Nonpoint Source Total phosphorous Load (metric tons/year)**
Nonpoint Source External Sources		107.5
Point Sources		
Facility Name	**Receiving Water**	**Waste Load Allocation** **Allowable Point Source Total phosphorous Load (metric tons/year)**
Chiloquin Sewage Treatment Plant	Williamson River	0.3
Crooked Creek Fish Hatchery	Crooked Creek	1.3
All Point Sources		1.6
Reserve Capacity and Margins of Safety		
Reserve Capacity		0.00
Margin of Safety		0.0
Total Allowable External Phosphorus Loading		**109.1**

2.9 DERIVED WATER QUALITY TARGETS – SURROGATE MEASURES

The Upper Klamath Lake TMDL incorporates measures in addition to the daily loads presented in **Section 2.8 Allocations** to fulfill requirements of 303(d). While it is important to quantify and analyze the total phosphorus pollutant load reductions in the TMDL, it is also helpful to identify target concentrations that help guide management activities and compliance monitoring and tracking. Phosphorus target concentrations are presented below for the lake and tributaries that correlate with the TMDL targeted 40% external total phosphorus loading reduction to Upper Klamath and Agency Lakes (Walker 2001).

Lake and Inflow Total Phosphorus Concentration Targets

~110 µg/l annual lake mean total phosphorus concentration
~30 µg/l spring (March - May) lake mean total phosphorus concentration
~66 µg/l annual mean total phosphorus concentration from all inflows to the lake

Total Phosphorus Loading Reduction

~40% external loading reduction of total phosphorus where possible

2.10 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 2-10** 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, represents 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 2-10. 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.

Implicit Margins of Safety

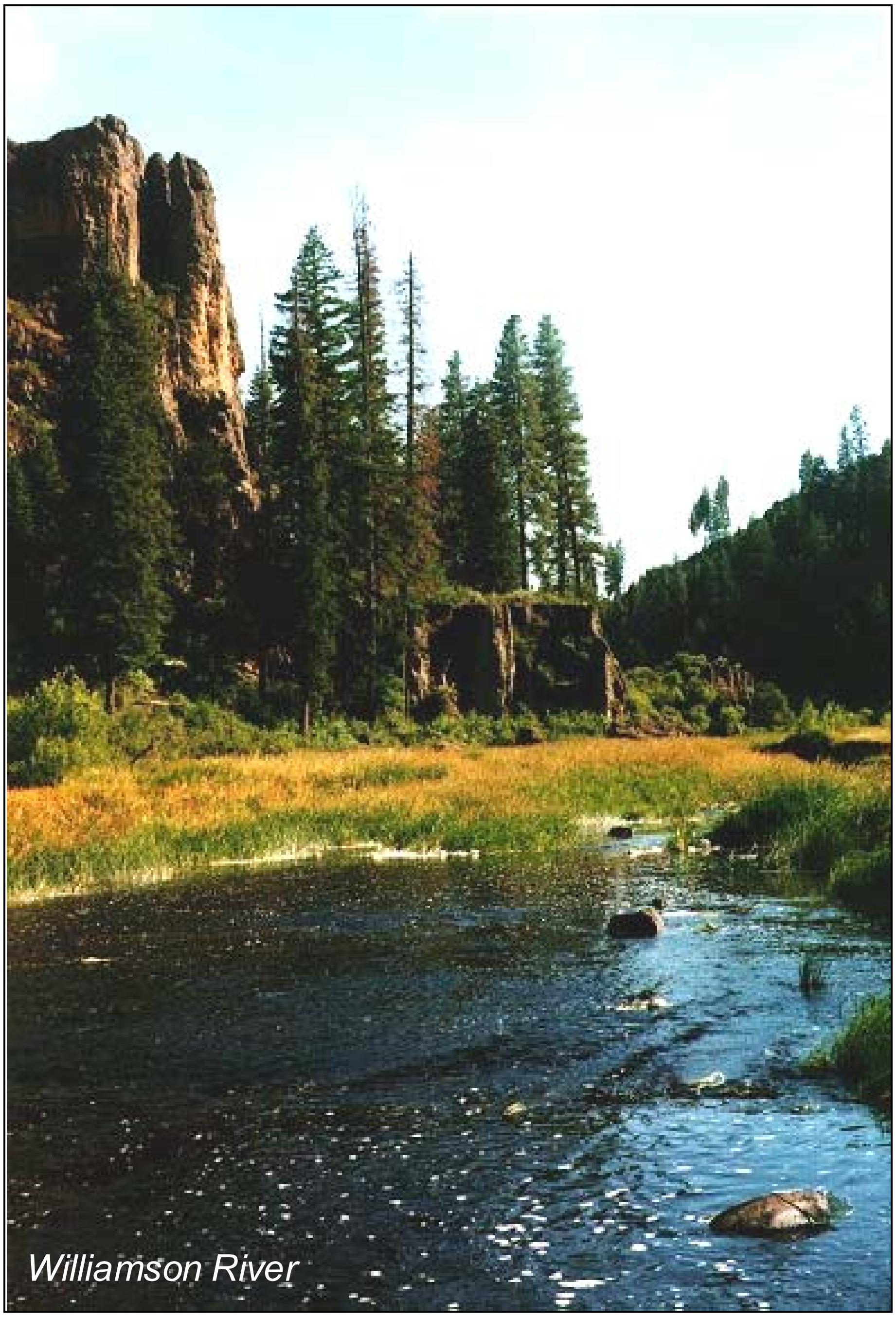
A MOS has been incorporated into the calculation of waste load and load allocations. Specifically, conservative assumptions are used in derivation of numeric targets and conservative assumptions are used when developing numeric model applications.

Reserve Capacity

There is no allocated pollutant load for future sources of heat in the Upper Klamath Lake drainage.

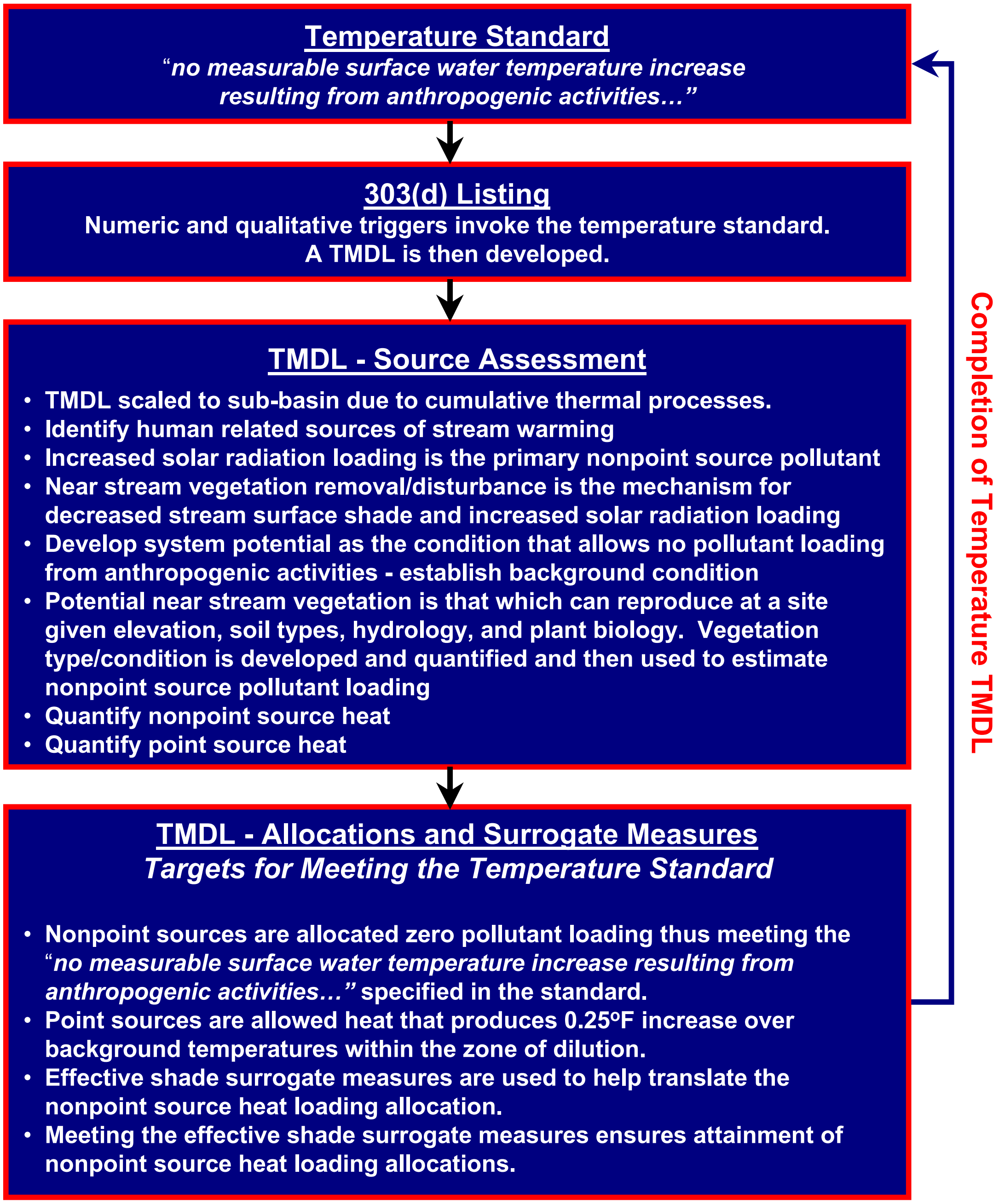
CHAPTER III

STREAM TEMPERATURE TMDL



3.1 OVERVIEW

3.1.1 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 0.25°F 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.**

Figure 3-1. Oregon DEQ Temperature Standard, 303(d) Listing and TMDL Development Process

3.1.1.1 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, dissolved oxygen violations and/or discharge into natural lake systems. The occurrence of one or more of the stream temperature trigger will invoke the temperature standard.

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 340-41-0962(2)(b)(A)). Thermally impaired water bodies in the Upper Klamath Lake drainage are subject to the temperature standard that mandates a condition of no allowable anthropogenic related temperature increases.

3.1.1.2 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, the Williamson River is water quality limited for temperature. To address this listing in the TMDL, the Williamson River and all major tributaries are included in the TMDL analysis and TMDL targets apply throughout the entire stream network. This broad approach is necessary to address the cumulative nature of stream temperature dynamics.

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

As defined in this TMDL, system potential is the combination of potential near stream land cover condition and potential channel morphology conditions. 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. Potential channel morphology is developed using an estimate of width to depth ratios appropriate for the Rosgen channel type regressed from regional curves. System potential does not consider management or land use as limiting factors. **In essence, system potential is the design condition used for TMDL analysis that meets the temperature standard by minimizing human related warming.**

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

Heat is the identified pollutant. Nonpoint sources are expected to eliminate the anthropogenic portion of solar radiation heat loading. Point sources are allowed heating that results in less than 0.25°F increase in a defined mixing zone. Allocated conditions are expressed as heat per unit time (kcal per day). The nonpoint source heat allocation is translated to effective shade surrogate measures that linearly translates the nonpoint source solar radiation allocation. Effective shade surrogate measures provide site-specific targets for land managers. And, attainment of the surrogate measures ensures compliance with the nonpoint source allocations.

3.1.1.3 Limitations of Stream Temperature TMDL Approach

It is important to acknowledge limitations to analytical outputs and 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. Three major limitations should be recognized:

- Current analysis is focused on a defined critical condition. This usually occurs in late July or early August when stream flows are low, radiant heating rates are high and ambient conditions are warm. However, there are several other important time periods where fewer data are available and the analysis is less explicit. For example, spawning periods have not received comparable treatment as the period of seasonal maximum stream temperature.
- Current analytical methods fail to capture some upland, atmospheric and hydrologic processes. At a landscape scale these exclusions can lead to errors in analytical outputs. For example, methods do not currently exist to simulate riparian microclimates at a landscape scale.
- In some cases, there is not scientific consensus related to riparian, channel morphology and hydrologic potential conditions. This is especially true when confronted with highly disturbed sites, meadows and marshes and potential hyporheic/subsurface flows.

Table 3-1. Upper Klamath Lake drainage Temperature TMDL Components

Waterbodies	Perennial or fish bearing (as identified by ODFW, USFW or NFMS) streams within the 4th field HUCs (hydrologic unit codes) 18010201, 18010202, and 18010203.
Pollutant Identification	*Pollutants:* Anthropogenic heat from (1) solar radiation loading from nonpoint sources and (2) warm water discharge to surface waters.
Target Identification (Applicable Water Quality Standards) *CWA §303(d)(1)*	OAR 340-41-0965(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, Urban, Industrial Discharge, Waste Water Treatment Facilities
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)*	*Loading Capacity:* 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*. Loading capacities in the Upper Klamath Lake drainage are the sum of (1) background solar radiation heat loading profiles for the mainstem rivers and major tributaries (expressed as kcal per day) based on potential near stream vegetation characteristics without anthropogenic disturbance and (2) allowable heat loads for NPDES permitted point sources based on the 0.25°F allowable temperature increase in the mixing zone. Loading Capacity = 49,376,613,753 kcal/day *Waste Load Allocations (Point Sources)* [14]: Maximum allowable heat loading based on system potential stream temperatures and facility design flow is 928,062 kcal per day for all permitted point sources discharging to temperature impaired waterbodies. *Load Allocations (Non-Point Sources)*: Maximum allowable heat loading associated with background solar radiation loading is 49,375,685,691 kcal per day.
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)*	*Margins of Safety* 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)*	• Analytical modeling of TMDL loading capacities demonstrates attainment water quality standards • The Temperature Management Plan will consist of Implementation Plans, Water Quality Management Plan (WQMP) and Facility Operation Plans that contain measures to attain load / waste load allocations.

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[14] These effluent temperatures and WLAs were based on calculating no measurable increase above system potential using the flows, temperatures and equations in Table 9 which shows loadings and effluent temperatures under one set of conditions. However as the permits are renewed, WLAs may be recalculated using the equations if flow rates or effluent temperatures differ. Also, a maximum allowable discharge temperature will be included that will ensure incipient lethal temperatures are not exceeded. Therefore, the maximum temperature allowed in the permit may be different from the values expressed here and will be determined at the time of permit renewal to determine no measurable increase above system potential using the equations in **Table 3-6**.

3.1.2 Salmonid Thermal Requirements

Salmonids and some amphibians are highly sensitive to temperature. In particular, bull trout (*Salvelinus confluentus*) are among the most temperature sensitive of the cold water fish species. Oregon's water temperature standard employs logic that relies on using *indicator species,* which are the most sensitive. If temperatures are protective of *indicator species*, other species will share in this level of protection.

If stream temperatures become too hot, fish die almost instantaneously 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 Upper Klamath Lake drainage.

More common and widespread within the Upper Klamath Lake drainage are summertime stream temperatures in the mid-70°F range (mid- to high-20°C range). These temperatures cause death 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, as well as, particular development life-stages. This cause of mortality, termed the *incipient lethal limit*, results 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 (mid-60°F to low-70°F). **Table 3-2** summarizes the modes of cold water fish mortality.

Table 3-2. Modes of Thermally Induced Cold Water Fish Mortality
(Brett, 1952; Bell, 1986, Hokanson et al., 1977)

Modes of Thermally Induced Fish Mortality	Temperature Range	Time to Death
Instantaneous Lethal Limit – Denaturing of bodily enzyme systems	> 90°F > 32°C	Instantaneous
Incipient Lethal Limit – Breakdown of physiological regulation of vital bodily processes, namely: respiration and circulation	70°F - 77°F 21°C - 25°C	Hours to Days
Sub-Lethal Limit – Conditions that cause decreased or lack of metabolic energy for feeding, growth or reproductive behavior, encourage increased exposure to pathogens, decreased food supply and increased competition from warm water tolerant species	64°F - 74°F 17.8°C - 23°C	Weeks to Months

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

3.2.1 Sensitive Beneficial Use Identification

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

Beneficial uses and the associated water quality standards are generally applicable drainage-wide (i.e., the Upper Klamath Lake drainage). 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 962, Table 19) lists the "Beneficial Uses" occurring within the Klamath Basin (**Table 3-3**). 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 Upper Klamath Lake drainage.

Table 3-3. Beneficial uses occurring in the Upper Klamath Lake drainage
(OAR 340 – 41 – 962)
Temperature-Sensitive Beneficial uses are marked in ***Red***

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	✓	Anadromous Fish Passage	✓
Livestock Watering	✓	Wildlife and Hunting	✓
Boating	✓	Fishing	✓
Hydro Power		Water Contact Recreation	✓
Aesthetic Quality	✓	Commercial Nav./Transport.	

The Lost River sucker (*Deltistes luxatus*), and the shortnose sucker (*Chasmistes brevirostris*) were placed on the endangered species list in 1988. The Lost River sucker and the shortnose sucker are native to Upper Klamath Lake and its tributaries (see **Figure 1-9, page 18**). Both species are primarily lake residents that spawn in the lake's tributaries (i.e., streams, rivers, and springs). Construction of dams, instream diversion structures, irrigation canals, wetland draining, and the dredging of Upper Klamath Lake have fragmented their historical habitat range. Water quality degradation in the Upper Klamath Lake drainage has led to large-scale fish kills related to algal bloom cycles. Elevated water temperatures stimulate algal growth, which in turn depletes dissolved oxygen levels and increases the pH. Reducing stream temperatures will help preserve endangered Lost River sucker and shortnose sucker populations.

Bull trout (*Salvelinus confluentus*) were listed as threatened without critical habitat in 1998. Isolated remnant populations remain in the headwaters of rivers and in spring water dominated streams in the Upper Klamath Lake drainage (see **Figure 1-8, page 16**). Stream habitat alterations that have affected bull trout populations include obstructions to migration, degradation of water quality, especially increasing temperatures and increased amounts of fine sediments, alteration of natural stream flow patterns, and structural modification of stream habitat (such as removal of cover or channelization). Bull trout are habitat specialists, meaning that there are preferred conditions for reproduction. A small fraction of available stream habitat in a subbasin is used for spawning, while a much more extensive area is used as foraging habitat, or seasonally as migration corridors to other water bodies. Redband Trout also occur throughout the Upper Klamath Lake drainage and are protected as a sensitive beneficial use under the stream temperature water quality standard. Distributions of Redband Trout are presented in **Figure 1-10, page 20**.

3.2.2 Water Quality Standard Identification

*The temperature standard applicable to the Upper Klamath Lake drainage mandates that **no measurable surface water increase resulting from anthropogenic activities is allowed**.*

3.2.2.1 Stream Temperature Standard

OAR 340-41-0965(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.

3.2.2.2 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 Upper Klamath Lake drainage has 457 stream segments on the 1998 303(d) list for water temperature violations (**Table 3-4** and **Figure 3-2**). All segments were listed based upon the 64°F rearing criteria. For specific information regarding Oregon's 303(d) listing procedures, and to obtain more information regarding the Upper Klamath Lake drainage's 303(d) listed streams, visit the Department of Environmental Quality's web page at http://www.deq.state.or.us/.

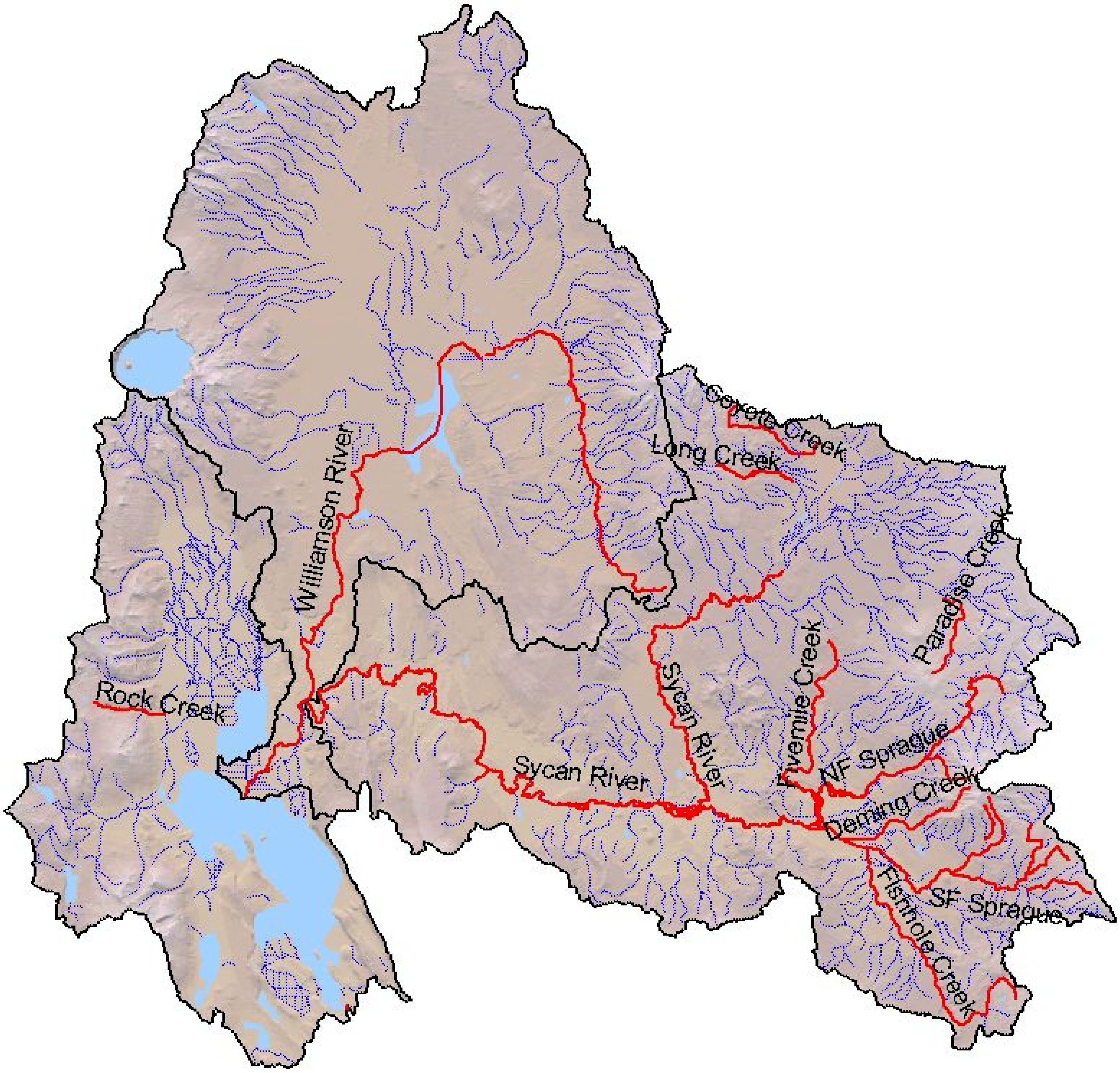

Figure 3-2. 1998 303(d) List for Temperature (Bolded **Red** Lines)

Table 3-4. Upper Klamath Lake drainage Stream Segments on the 1998 303(d) List for Temperature

Subbasin Name	Stream Name	Segment Listed
Sprague	Boulder Creek	Mouth to Headwaters
Sprague	Brownsworth Creek	Mouth to Hammond Creek
Sprague	Brownsworth Creek	Hammond Creek to Headwaters
Sprague	Buckboard Creek	Mouth to Headwaters
Sprague	Calahan Creek	Mouth to Hammond Creek
Sprague	Coyote Creek	Mouth to Headwaters
Sprague	Deming Creek	Mouth to Campbell Reservoir Diversion
Sprague	Deming Creek	Campbell Reservoir Diversion to Headwaters
Sprague	Fishhole Creek	Mouth to Headwaters
Sprague	Fivemile Creek	Mouth to Headwaters
Sprague	Leonard Creek	Mouth to Headwaters
Sprague	Long Creek (Sycan Marsh)	Sycan Marsh to Calahan Creek
Sprague	Paradise Creek	Mouth to Headwaters
Sprague	Pothole Creek	Mouth to Headwaters
Sprague	Sprague River	Mouth to North/South Fork
Sprague	Sprague River, North Fork	Mouth to Dead Cow Creek
Sprague	Sprague River, South Fork	Mouth to Camp Creek
Sprague	Sycan River	Mouth to Rock Creek
Sprague	Trout Creek	Mouth to Headwaters
Williamson	Williamson River	Mouth to Sprague River
Williamson	Williamson River	Sprague River to Klamath Marsh
Williamson	Williamson River	Klamath Marsh to Headwaters
Upper Klamath Lake	Fourmile Creek	Mouth to RM 1
Upper Klamath Lake	Rock Creek	Mouth to Headwaters

3.2.3 Pollutant Identification

Heat originating from human increases in solar radiation loading and warm water discharge to surface waters.

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:

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

Anthropogenic heat sources are derived from solar radiation as increased levels of sunlight reach the stream surface and effluent discharges to surface waters. Therefore, the pollutants targeted in this TMDL are (1) heat from human caused increases in solar radiation loading to the stream network and (2) heat from warm water discharges of human origin.

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

Anthropogenic nonpoint source heat loading accounts for approximately one quarter of the total solar heat load. The remaining portion of the solar heat load is attributed to background.

Heat loading was calculated for both nonpoint and point sources. Of the total heat loading that occurs during the summertime critical condition, 76.1% is attributed to natural background and 23.9% is from anthropogenic nonpoint sources (**Figure 3-3**). Point sources contribute a very small portion of the total heat loading in the Upper Klamath Lake drainage relative to nonpoint source heat loading (i.e. point source contribution is not shown in **Figure 3-3**).

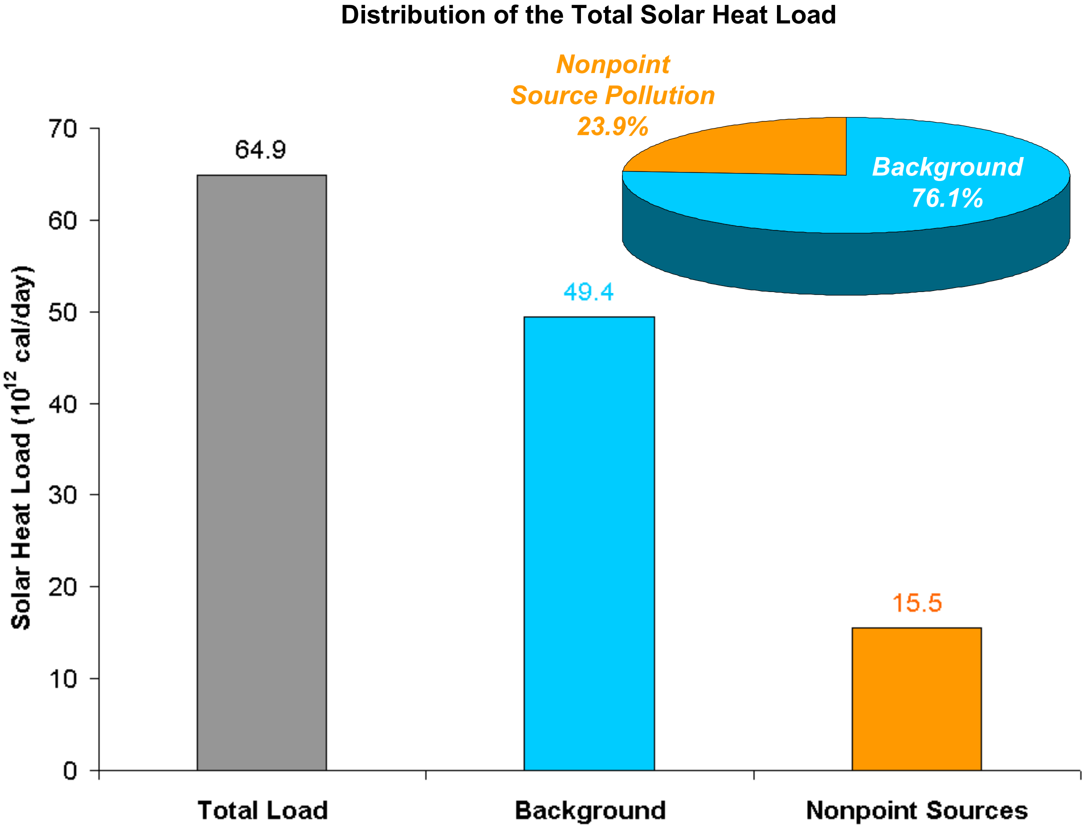

Figure 3-3. Distribution of Current Condition Heat Loading. Total daily solar heat load derived as the sum of the products of the daily solar heat flux and wetted surface area. For the purposes of this analysis the total heat load is calculated from the simulated current condition. The background condition is calculated from the system potential channel width and land cover condition simulations. Potential land cover has a high and low range. Solar heat flux output data is averaged for these two conditions to obtain an average potential heat load. The nonpoint source load is the difference between the current total daily solar load and the background total daily solar heat load.

3.3.1 Nonpoint Sources of Heat

Elevated summertime stream temperatures attributed to nonpoint sources result from increased solar radiation heat loading. Near stream vegetation disturbance/removal and channel morphology disturbances have reduced levels of stream shading and exposed streams to higher levels of solar radiation (i.e., reduction in stream surface shading via decreased riparian vegetation height, width and/or density increases the amount of solar radiation reaching the stream surface). Anthropogenic nonpoint source contributions account for 23.9% of the total heat loading. The heat loading analysis is discussed in detail within ***the Upper Klamath Lake Drainage Stream Temperature Analysis (Attachment 1)***

Settlement of the Upper Klamath Lake drainage in the mid-1800s brought about changes in the near stream vegetation and hydrologic characteristics of the streams. Historically, agricultural and logging practices have altered the stream morphology and hydrology and decreased the amount of riparian vegetation in the drainage. The drainage includes urban, agricultural, and forested lands. Due to agricultural practices, many streams in the lower watershed have undergone extensive channelization for drainage and flood control. Channel straightening, while providing relief from local flooding, increases flooding downstream and may result in the destruction of riparian vegetation and increased channel erosion. Additionally, major diversions and multiple points of diversion in the Upper Klamath Lake drainage have lowered stream flow levels.

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.

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 by human uses. Many streams in the Upper Klamath Lake drainage are extensively utilized for crop irrigation during the summer months.

Site specific total nonpoint source solar radiation heat load was derived for the Williamson River, Sprague River, North Fork Sprague River, South Fork Sprague River, Sycan River, Fishhole Creek, and Trout Creek (**Table 3-5**). Current condition solar radiation loading was calculated by simulating current stream and vegetation conditions (the methodology is presented in detail in the **Upper Klamath Lake Drainage Stream Temperature Analysis - Attachment 1**). Background loading was calculated by simulating the solar radiation heat loading that resulted with system potential near stream vegetation and channel morphology. 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***).

Figure 3-4 contrasts the longitudinal profile of the current solar radiation heat loading with the solar radiation heat loading that occurs with system potential land cover and channel morphology. **The solar radiation heat load calculated for system potential near stream vegetation and channel morphology is considered the background condition with anthropogenic sources removed.** The anthropogenic portion of the total current condition solar radiation heat load for the modeled streams is given in **Figure 3-5**.

Total Solar Radiation Heat Load from <u>All Nonpoint Sources,</u>

$$H_{\text{Total NPS}} = H_{\text{SP NPS}} + H_{\text{Anthro NPS}} = \Phi_{\text{Total Solar}} \cdot A$$

Solar Radiation Heat Load from <u>Background Nonpoint Sources (System Potential),</u>

$$H_{\text{SP NPS}} = \Phi_{\text{SP Solar}} \cdot A$$

Solar Radiation Heat Load from <u>Anthropogenic Nonpoint Sources,</u>

$$H_{\text{Anthro NPS}} = H_{\text{Total NPS}} - H_{\text{SP NPS}}$$

**All solar radiation loads are the clear sky received loads that account for Julian time, elevation, atmospheric attenuation and scattering, stream aspect, topographic shading, near stream vegetation stream surface reflection, water column absorption and stream bed absorption.*

where,

$H_{\text{Total NPS}}$: Total Nonpoint Source Heat Load (kcal/day)
$H_{\text{SP NPS}}$: Background Nonpoint Source Heat Load based on System Potential (kcal/day)
$H_{\text{Anthro NPS}}$: Anthropogenic Nonpoint Source Heat Load (kcal/day)
$\Phi_{\text{Total Solar}}$: Total Daily Solar Radiation Load (ly/day)
$\Phi_{\text{SP Solar}}$: Background Daily Solar Radiation Load based on System Potential (ly/day)
$\Phi_{\text{Anthro Solar}}$: Anthropogenic Daily Solar Radiation Load (ly/day)
A: Stream Surface Area - calculated at each 100 foot stream segment node (cm^2)

Table 3-5. Nonpoint Source Solar Radiation Heat Loading - Current Condition with Background (Loading Capacity) and Anthropogenic Contributions

	$H_{\text{Total NPS}}$	$H_{\text{SP NPS}}$	$H_{\text{Anthro NPS}}$	
Stream	**Current Condition** Solar Radiation Heat Loading (10^{12} cal/day)	**Background** System Potential Solar Radiation Heat Loading[15] (10^{12} cal/day)	**Anthropogenic** Nonpoint Source Solar Radiation Heat Loading (10^{12} cal/day)	Portion of Current Solar Radiation Load from Anthropogenic Nonpoint Sources
Williamson River	19.1	14.7	4.4	29.4%
Sprague River	27.6	20.8	6.8	42.5%
N.F. Sprague River	3.7	2.4	1.3	5.7%
S.F. Sprague River	2.7	2.2	0.6	4.2%
Sycan River	10.2	8.0	2.2	15.7%
Fishhole Cr.	1.3	1.0	0.3	2.0%
Trout Cr./SF Trout Cr.[16]	0.3	0.3	0.0	0.5%
Totals	64.9	49.4	15.5	100.0%

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[15] Background solar radiation heat loading is based on effective shade resulting from system potential near stream vegetation.

[16] The modeling exercise covered the Trout Creek mainstem and South Fork Trout Creek. In Figure 13, river miles 0 to 1.6 are Trout Creek, and river miles 1.6 to 8.0 are South Fork Trout Creek.

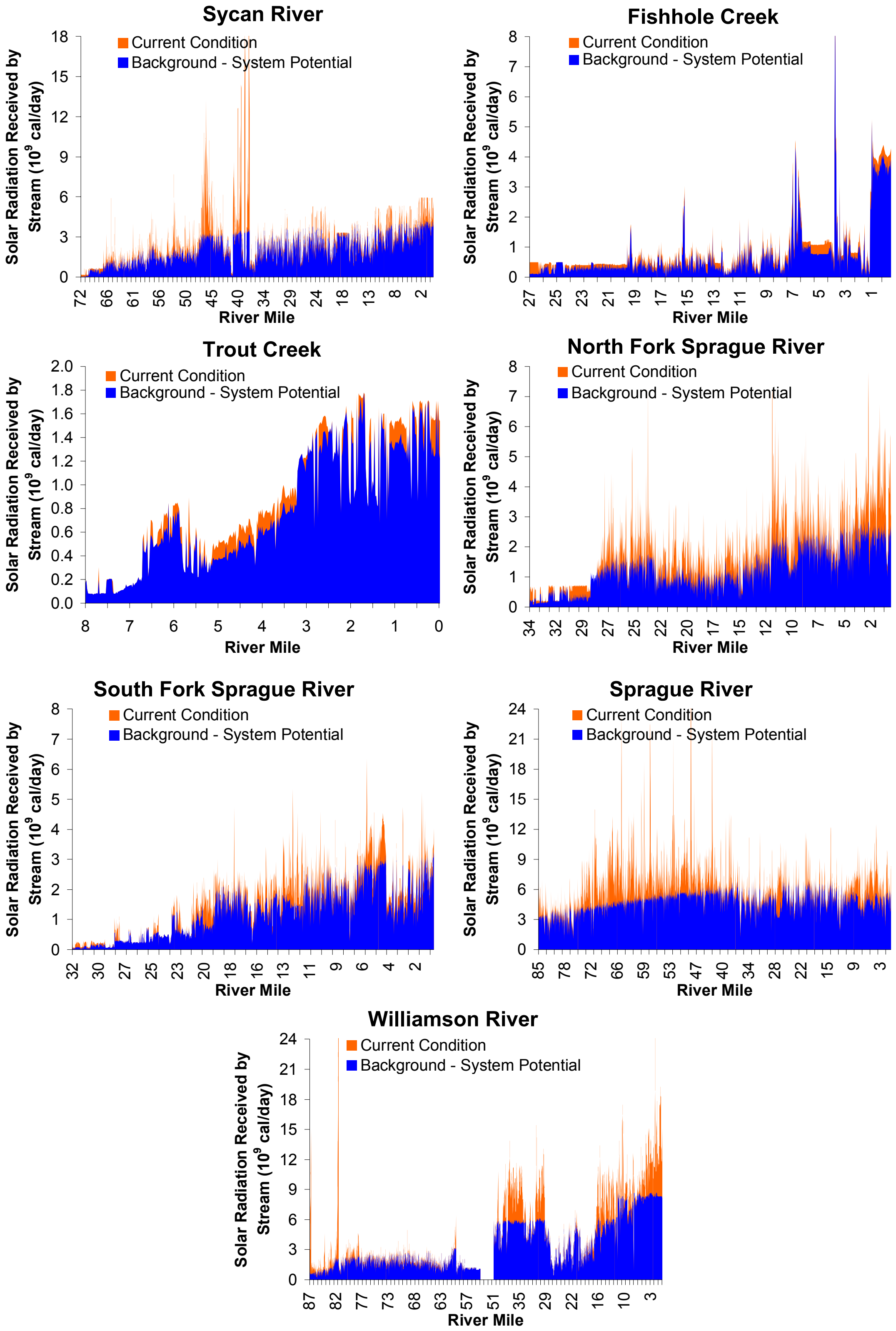

Figure 3-4. Solar Radiation Loading - Current Condition and Background - System Potential[17]

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[17] On the Trout Creek chart, river miles 0 to 1.6 are Trout Creek and river miles 1.6 to 8.0 are South Fork Trout Creek.

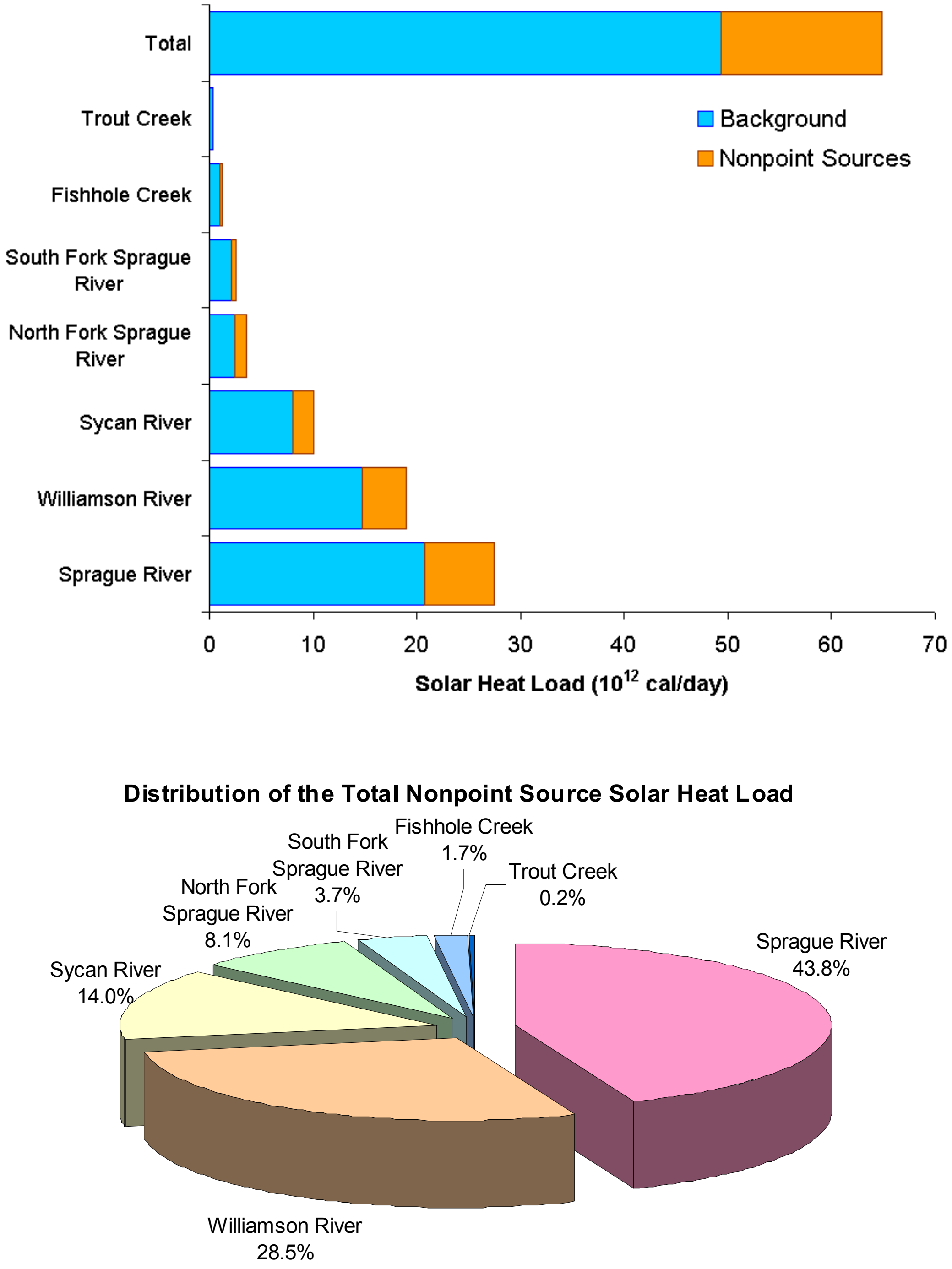


Figure 3-5. Anthropogenic Nonpoint Source and Background Solar Heat Loading

3.3.2 Point Sources of Heat

The Oregon Department of Environmental Quality maintains a database for point source information. This data was used to place point sources within the Upper Klamath Lake drainage. Five point sources discharge to waters within the Upper Klamath Lake drainage:

Crooked Creek Hatchery discharges into Crooked Creek at RM 5.6
Chiloquin Sewage Treatment Plant discharges to Williamson River at RM 11.8
Specialty Fiber Products discharges non-contact cooling water and sormwater into a pond.
Klamath Veneer discharges non-contact cooling water and stormwater into Upper Klamath Lake.
Jeld-Wen also discharges into Upper Klamath Lake.

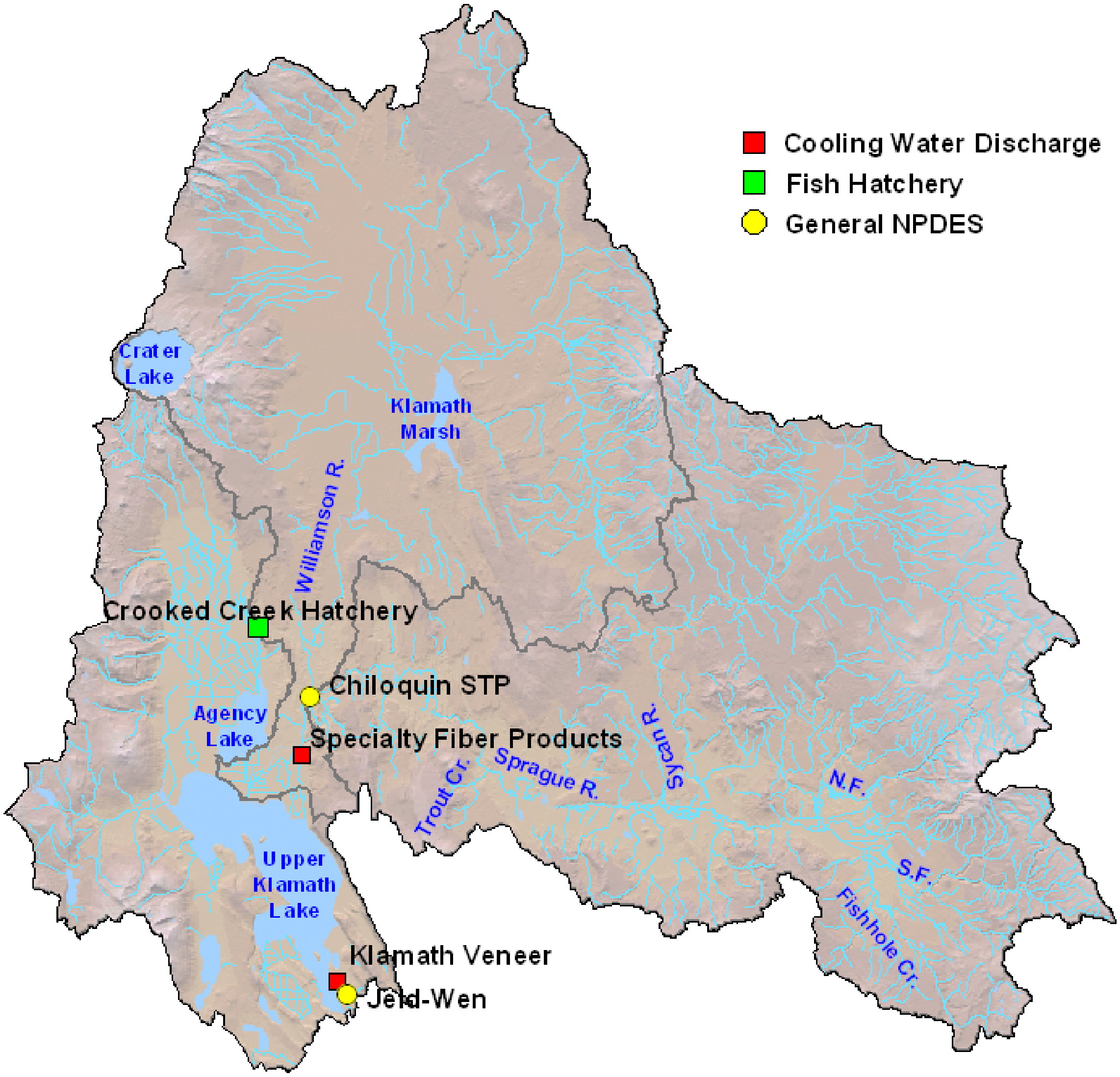


Figure 3-6. Point sources of heat

Waste load allocations are developed for point sources that discharge to temperature impaired waterbodies or discharge into waterbodies that drain to temperature impaired waterbodies. Chiloquin waster water treatment plant is the only point source where effluent is discharged into temperature impaired waterbodies. Simulated system potential stream temperatures during the critical condition in August are estimated by removing anthropogenic sources of heat throughout the Upper Klamath Lake drainage. These system potential temperatures are developed using computer modeling (see the **Upper Klamath Lake Drainage Stream Temperature Analysis - Attachment 1**) and used to assign the wasteload allocations to the point sources. Often, there are a number of point sources in a subbasin, some on segments that would be below the numeric criteria at system potential and some for which system potential would be above the numeric criteria. On some small streams, there would likely be complete mix of effluent and the stream within the mixing zone. On larger streams, the mixing zone would be a portion of the river (e.g. 25% or as described through a mixing zone study). The assumptions that should be used in evaluating the "no measurable increase as measured by 0.25°F at the edge of the mixing zone" relates to both the interpretation of the standard and mixing zone policy.

Heat loading from point sources occurs when waters with differing temperatures are mixed. The temperature standard specifies that point sources cannot produce a temperature increase of greater than 0.25°F at the edge of the mixing zone. For computational purposes, ODEQ has defined the zone of dilution as 1/4 of the 7Q10 low flow. The design condition for point source is the heat from effluent that produces a 0.25°F increase (or less) in the zone of dilution. The equations for calculating the heat load from point sources are provided below. **Table 3-6** displays the calculated parameters for point source heat loading analysis**. Figure 3-7** displays the heat loading limits as they apply to the Chiloquin WWTP. The current condition is well below heat limits for standard compliance. There is no reasonable potential that this facility will violate stream temperature standards.

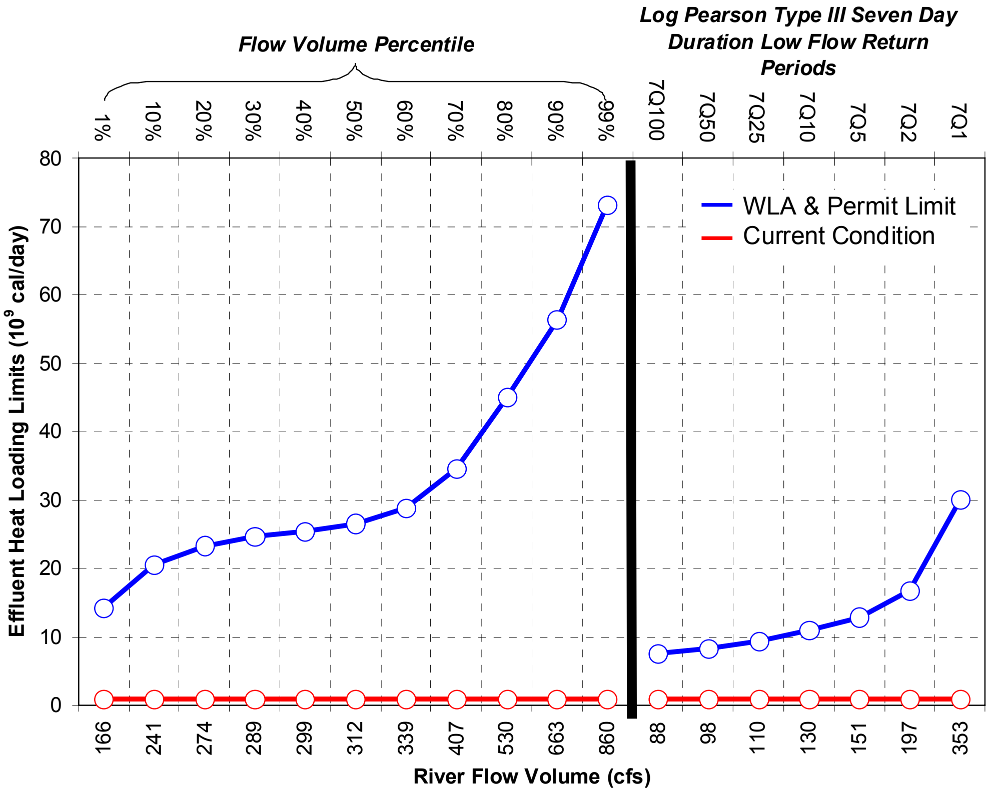
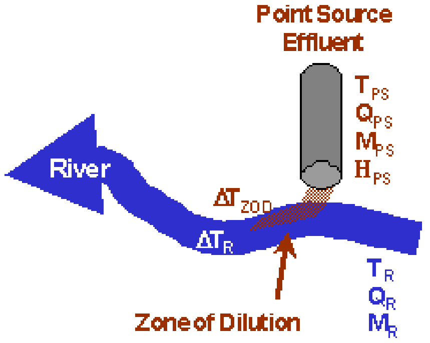


Figure 3-7. Chiloquin WWTP Effluent Heat Limits – Current condition is well below heat limits for standard compliance. There is no reasonable potential that this facility will violate stream temperature standards.

Heat Loading Parameters Calculated for Each Point Source



Point Source Parameter	Equation
Change in river temperature	$\Delta T_R = \frac{(Q_{PS}\cdot T_{PS})+(Q_R\cdot T_R)}{(Q_{PS}+Q_R)} - T_R$
Mass of river flow	$M_R = Q_R \cdot \frac{1\cdot m^3}{35.3\cdot ft^3}\cdot\frac{1000\cdot kg}{1\cdot m^3}\cdot\frac{86400\cdot sec}{1\cdot day} = \frac{kg}{day}$
Mass of river flow at zone of dilution	$M_{ZOD} = Q_{ZOD} \cdot \frac{1\cdot m^3}{35.3\cdot ft^3}\cdot\frac{1000\cdot kg}{1\cdot m^3}\cdot\frac{86400\cdot sec}{1\cdot day} = \frac{kg}{day}$
Current point source heat loading on river	$H_{PS} = M_R \cdot c \cdot \Delta T_R \cdot \left(\frac{5^\circ F}{9^\circ C}\right)$
Change in river temperature at zone of dilution	$\Delta T_{ZOD} = \frac{H_{WLA}}{M_{ZOD}\cdot c}\cdot\left(\frac{9^\circ F}{5^\circ C}\right)$ $\Delta T_{ZOD} = \frac{(Q_{PS}\cdot T_{PS})+(Q_{ZOD}\cdot T_R)}{(Q_{PS}+Q_{ZOD})} - T_R$
Allowable Temperature Change in Zone of Dilution	If $\Delta T_{ZOD} > 0.25^\circ F$ then Max $\Delta T_{ZOD} = 0.25^\circ F$ If $\Delta T_{ZOD} \leq 0.25^\circ F$ then Max $\Delta T_{ZOD} = \Delta T_{ZOD}$
Allowable Point Source Heat Loading in Zone of Dilution	$H_{WLA} = M_{ZOD} \cdot c \cdot Max\Delta T_{ZOD} \cdot \left(\frac{5^\circ F}{9^\circ C}\right)$
Allowable Effluent Temperature	$T_{WLA} = \frac{[(Q_{PS}+Q_{ZOD})\cdot(T_R + Max\Delta T_{ZOD})]-(Q_{ZOD}\cdot T_R)}{Q_{PS}}$ $T_{WLA} = \frac{\left[(Q_{PS}+Q_{ZOD})\cdot\left(T_R + \frac{H_{WLA}}{M_{ZOD}\cdot c}\cdot\left(\frac{9^\circ F}{5^\circ C}\right)\right)\right]-(Q_{ZOD}\cdot T_R)}{Q_{PS}}$

where,

T_R: Upstream potential river temperature (^oF)
T_{PS}: Point source effluent temperature (^oF)
T_{WLA}: Maximum allowable point source effluent temperature (^oF)
ΔT_R: Change in river temperature (^oF)
ΔT_{ZOD}: Change in river temperature at edge of zone of dilution - 0.25^oF allowable (^oF)
Max ΔT_{ZOD}: Maximum Allowable Change in river temperature at edge of zone of dilution (^oF)

- If zone of dilution temperature change is greater than 0.25^oF then maximum allowable zone of dilution temperature change is 0.25^oF, or
- If zone of dilution temperature change is less than 0.25^oF then maximum allowable zone of dilution temperature change is the current zone of dilution temperature change.

Q_R: Upstream river flow - Calculated as 7Q10 low flow statistic (cfs)
Q_{ZOD}: Upstream river flow through zone of dilution - Calculated as 1/4 7Q10 low flow statistic (cfs)
Q_{PS}: Point source effluent discharge (cfs)
M_R: Daily mass of river flow (kg/day)
M_{ZOD}: Daily mass of river flow through zone of dilution (kg/day)
M_{PS}: Daily mass of effluent (kg/day)
H_{PS}: Heat from point source effluent received by river (kcal/day)
H_{WLA}: Allowable heat from point source effluent received by river (kcal/day)
c: Specific heat of water (1 kcal/kg ^oC)

Table 3-6. Point Source Heat Loading Data[18]

		Q_R	Q_{PS}	T_{PS}	Max T_P	Ave ΔT_R	ΔT_{ZOD}	M_R	M_{ZOD}	H_{PS}	H_{WLA}		T_{WLA}
Facility Name	Receiving Water	Receiving Water 7Q10 Low Flow (cfs)	Facility Design Flow (cfs)	Point Source Effluent Temp. (°F)	Max Daily Site Potential River Temp. (°F)	Ave River Temp Increase During Diurnal Cycle (°F)	Allowable Temperature Increase in Zone of Dilution (°F)	River Volume Daily Mass (kg/day)	Zone of Dilution Daily Mass (kg/day)	Current Point Source Heat Loading on River (10^9 cal /day)	Allowable Point Source Heat Loading in Zone of Dilution (10^9 cal/day)	Percent Reduction in Point Source Heat Load	Allowable Effluent Temp. (°F)
Chiloquin STP	Williamson R. RM 11.8	130	0.16	72[19]	55.0	0.01	0.25	$3.18 \cdot 10^8$	$0.80 \cdot 10^8$	0.06	11.1	NRP*	Existing Condition
									Totals	$2.37 \cdot 10^6$	$2.37 \cdot 10^6$		

*NRP – No Reasonable Potential

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[18] These effluent temperatures and WLAs were based on calculating no measurable increase above system potential using the flows, temperatures and equations. However as the permits are renewed, WLAs may be recalculated using the equations if flow rates or effluent temperatures differ. Also, a maximum allowable discharge temperature will be included that will ensure incipient lethal temperatures are not exceeded. Therefore, the maximum temperature allowed in the permit may be different from the values expressed here and will be determined at the time of permit renewal to determine no measurable increase above system potential.

[19] This effluent temperature is estimated by ODEQ. The WLA may be re-calculated during the permitting process if effluent temperature data differs from this TMDL.

3.4 SEASONAL VARIATION & CRITICAL CONDITION - CWA §303(D)(1)

Maximum temperatures typically occur in July and August (**Figure 3-8).** The TMDL focuses the analysis during the August period as a critical condition as identified by 1999 temperature data.

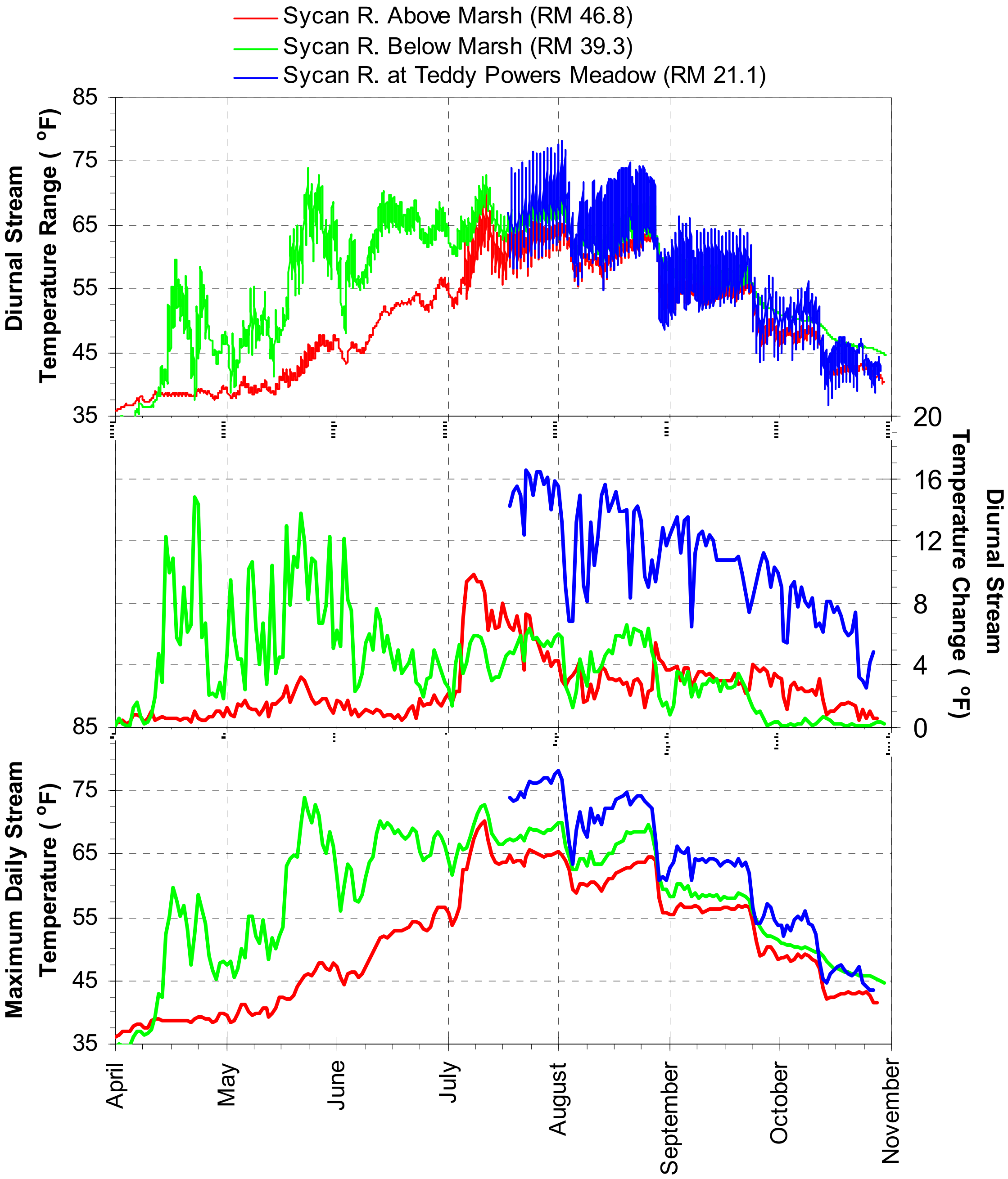

Figure 3-8. 1999 Observed Daily Maximum Temperatures – Sycan River

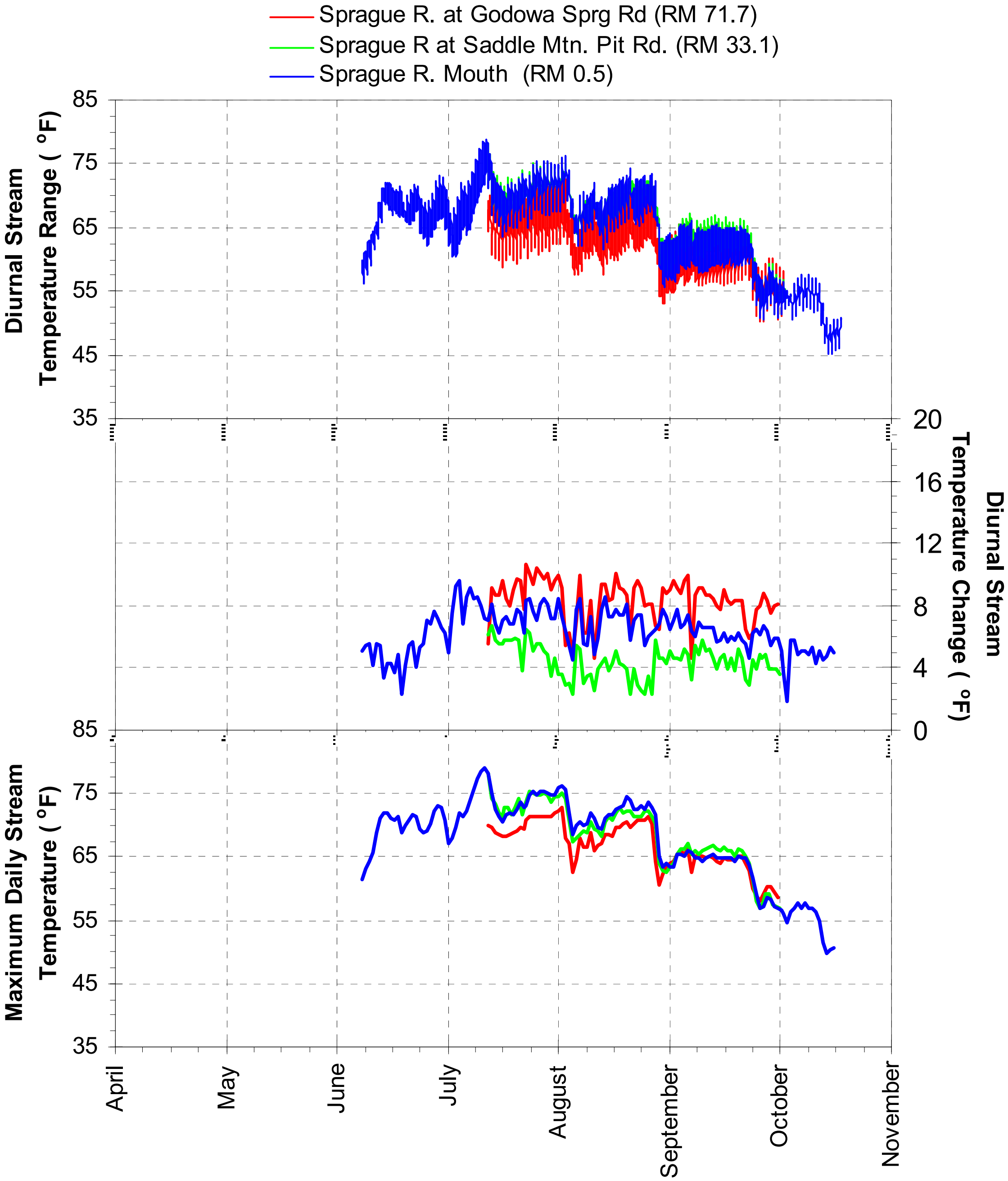

Figure 3-8 (continued). 1999 Observed Daily Maximum Temperatures – Sprague River

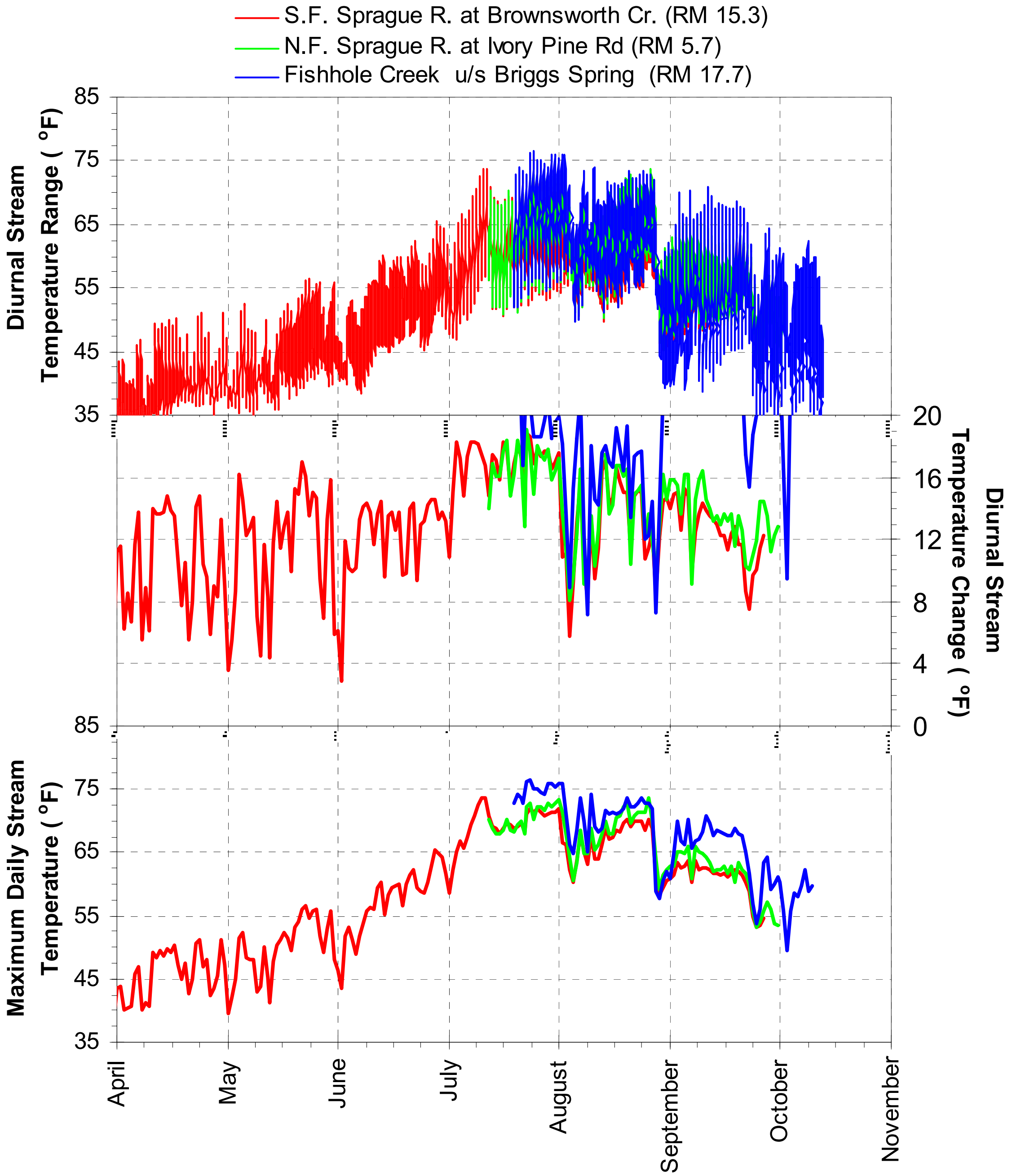

Figure 3-8 (continued). 1999 Observed Daily Maximum Temperatures – Sprague River Tributaries

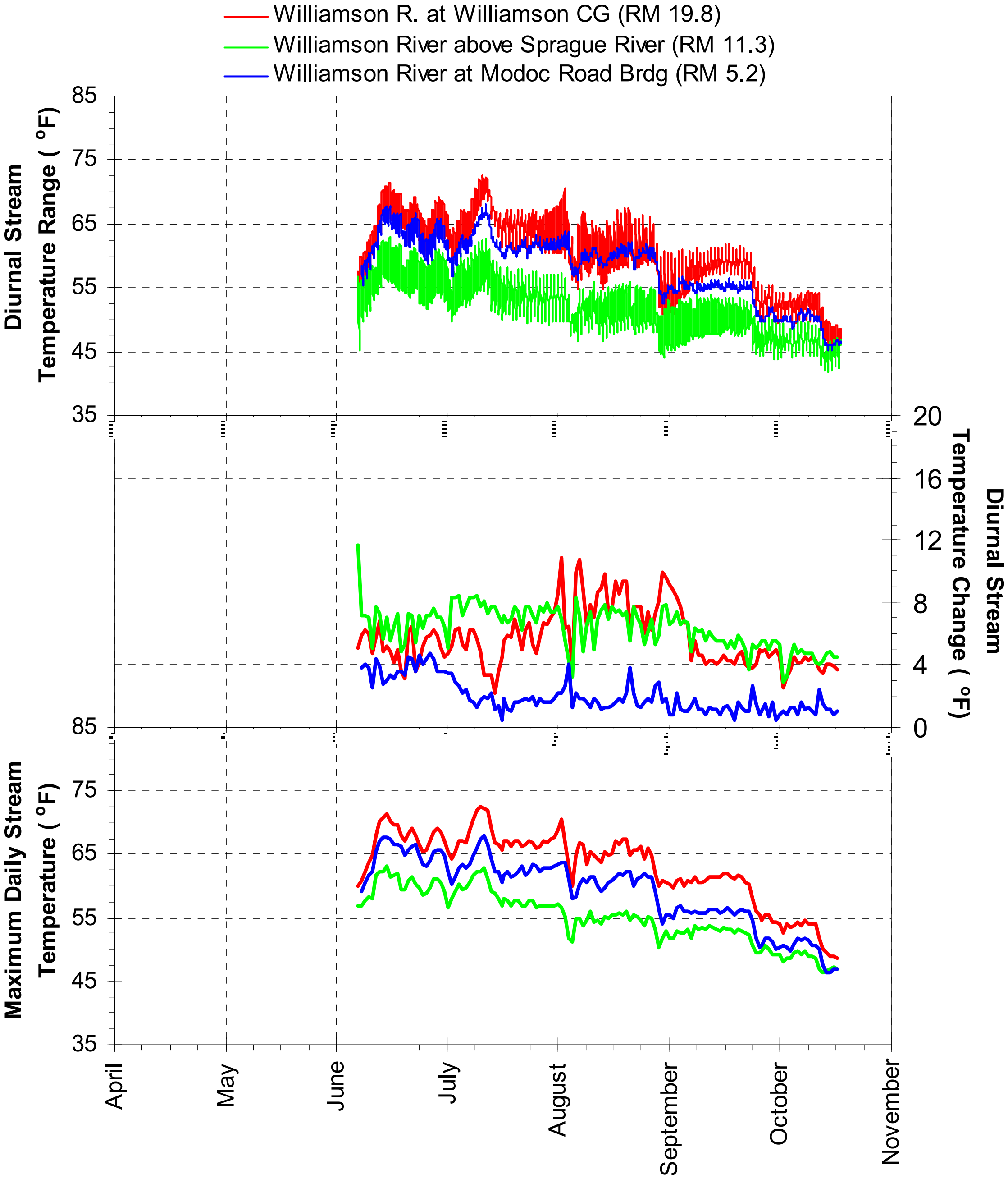

Figure 3-8 (continued). 1999 Observed Daily Maximum Temperatures – Williamson River

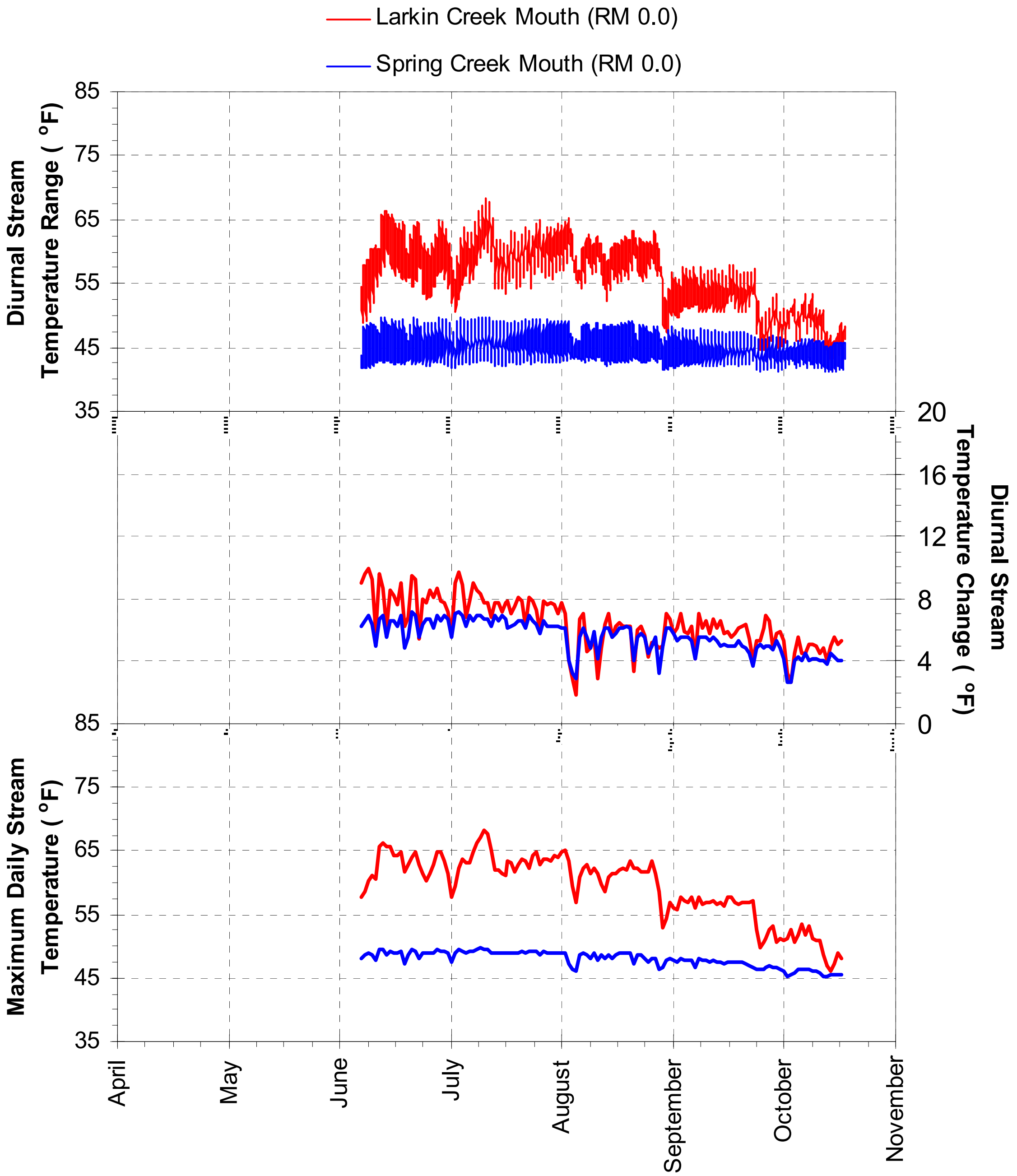

Figure 3-8 (continued). 1999 Observed Daily Maximum Temperatures – Williamson River Tributaries

3.5 LOADING CAPACITY – 40 CFR 130.2(F)

*The water quality standard (listed in Section 3.2.2) mandates a **loading capacity** based on the condition that meets the **no measurable surface water temperature increase resulting from anthropogenic activities.** This loading condition is developed as the sum of nonpoint source background solar radiation heat loading and the allowable point source heat load.*

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 Klamath River Basin (OAR 340-41-0965(2)(b)(A)).
- The pollutants are human increases in solar radiation loading (nonpoint sources) and heat loading from warm water discharge (point sources).
- **Loading capacities** in the Upper Klamath Lake drainage are the sum of (1) background solar radiation heat loading profiles (expressed as kcal per day) based on potential land cover characteristics and channel morphology and (2) allowable heat loads for NPDES permitted point sources based on the 0.25°F allowable temperature increase in the zone of dilution.
- The calculations used to determine the loading capacity are presented in section **3.3 Existing Heat Sources - CWA *§303(d)(1)***
- The Upper Klamath Lake Drainage Stream Temperature Analysis (**Attachment 1**) describes the modeling results that lead to the development of system potential river temperatures.

The Heat Loading Capacity (H_{LC} = 49,376,613,753 kcal/day) is the sum of nonpoint source background based on system potential (H_{LA} = 49,375,685,691 kcal/day), allowable point source heat (H_{WLA} = 928,062 kcal/day), heat included in a margin of safety (H_{MOS} = 0 kcal/day) and heat held as a reserve capacity (H_{RC} = 0 kcal/day).

$$
\begin{array}{rcl}
H_{LA} & \rightarrow & 49{,}375{,}685{,}691 \text{ kcal/day} \\
H_{WLA} & \rightarrow & 928{,}062 \text{ kcal/day} \\
H_{MOS} & \rightarrow & 0 \text{ kcal/day} \\
H_{RC} & \rightarrow & + \ 0 \text{ kcal/day} \\
\hline
H_{LC} & \rightarrow & 49{,}376{,}613{,}753 \text{ kcal/day}
\end{array}
$$

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

Load Allocations (Nonpoint Sources) - *Load Allocations* are portions of the loading capacity reserved for natural, human and future nonpoint pollutant sources. *The **temperature standard** targets system potential (i.e., no measurable temperature increases from anthropogenic sources). To meet this requirement the system potential solar radiation heat load (*46,025,933,728 *kcal/day) is allocated to background nonpoint sources.*

Wasteload Allocations (Point Sources) - A *Waste Load Allocation* (WLA) is the amount of pollutant that a point source can contribute to the stream without violating water quality criteria. *Surface water discharges into Upper Klamath Lake drainage receiving waters have been given a heat load based on the 0.25°F allowable increase in the zone of dilution as specified in the temperature standard. Heat loads have been converted to allowable effluent temperatures as well. It should be noted that the wasteload allocation is the point source heat load (2,367,258 kcal/day) and not the calculated maximum effluent temperatures. There are several options for meeting the allocated heat loads (i.e. passive effluent temperature reductions, changes in facility discharge operation, purchasing instream flows, pollutant trading, etc.).*

Table 3-7. Heat Allocation Summary - Distributions of the Loading Capacity

<table>
<tr><th colspan="4">Nonpoint Sources</th></tr>
<tr><th colspan="3">Source</th><th><u>Loading Allocation</u>
Allowable Nonpoint Source Solar Radiation Heat Load (kcal/day)</th></tr>
<tr><td colspan="3">All Nonpoint Sources</td><td>49,375,685,691</td></tr>
<tr><th colspan="4">Point Sources</th></tr>
<tr><th>Facility Name</th><th>Receiving Water</th><th>Maximum Effluent Temperature (°F)</th><th><u>Waste Load Allocation</u>
Allowable Point Source Heat Load (kcal/day)</th></tr>
<tr><td>Chiloquin WWTP</td><td>Williamson R.
RM - 11.5</td><td>72</td><td>928,062
(Current Condition)</td></tr>
<tr><th colspan="4">Reserve Capacity and Margins of Safety</th></tr>
<tr><th colspan="3">Source</th><th><u>Loading Allocation</u>
Allowable Nonpoint Source Solar Radiation Heat Load (kcal/day)</th></tr>
<tr><td colspan="3">Reserve Capacity</td><td>0</td></tr>
<tr><td colspan="3">Margin of Safety</td><td>0</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="3">Total Allowable Heat Loading (Loading Capacity)</td><td>49,376,613,753</td></tr>
</table>

3.7 SURROGATE MEASURES – 40 CFR 130.2(I)

The Upper Klamath Lake drainage 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. Langleys per 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 Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program"* (FACA Report, July 1998) offers a discussion on the use of surrogate measures for TMDL development. The FACA 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. 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). 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, effective 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.

3.7.1 Site Specific Effective Shade Surrogate Measures

Site specific effective shade surrogates are developed to help translate the nonpoint source solar radiation heat loading allocations. Attainment of the effective shade surrogate measures is equivalent to attainment of the nonpoint source load allocations.

Percent effective shade is a surrogate measure that can be calculated directly from the loading capacity. Additionally, percent effective shade is simple to quantify in the field or through mathematical calculations and is useful in guiding nonpoint source management practices. **Figures 3-9** to **3-15** display the percent effective shade values that correspond to the loading capacities throughout the Upper Klamath Lake drainage. It is important to note that the percent effective shade surrogate measures rely upon both the system potential land cover (near stream vegetation) and potential channel morphology (near stream disturbance zone widths). The **Upper Klamath Lake Drainage Stream Temperature Analysis - Attachment 1** contains detailed descriptions of the methodology used to develop the temperature TMDL.

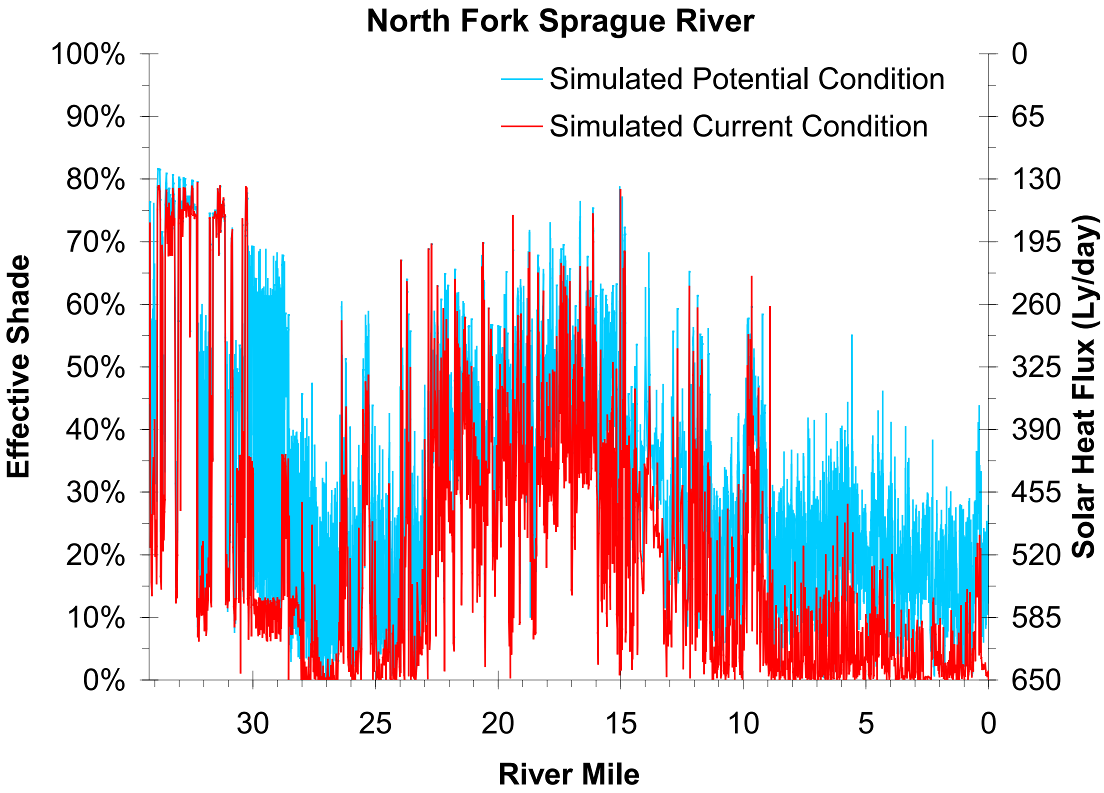

Figure 3-9. Percent Effective Shade Surrogate Measures – North Fork Sprague River

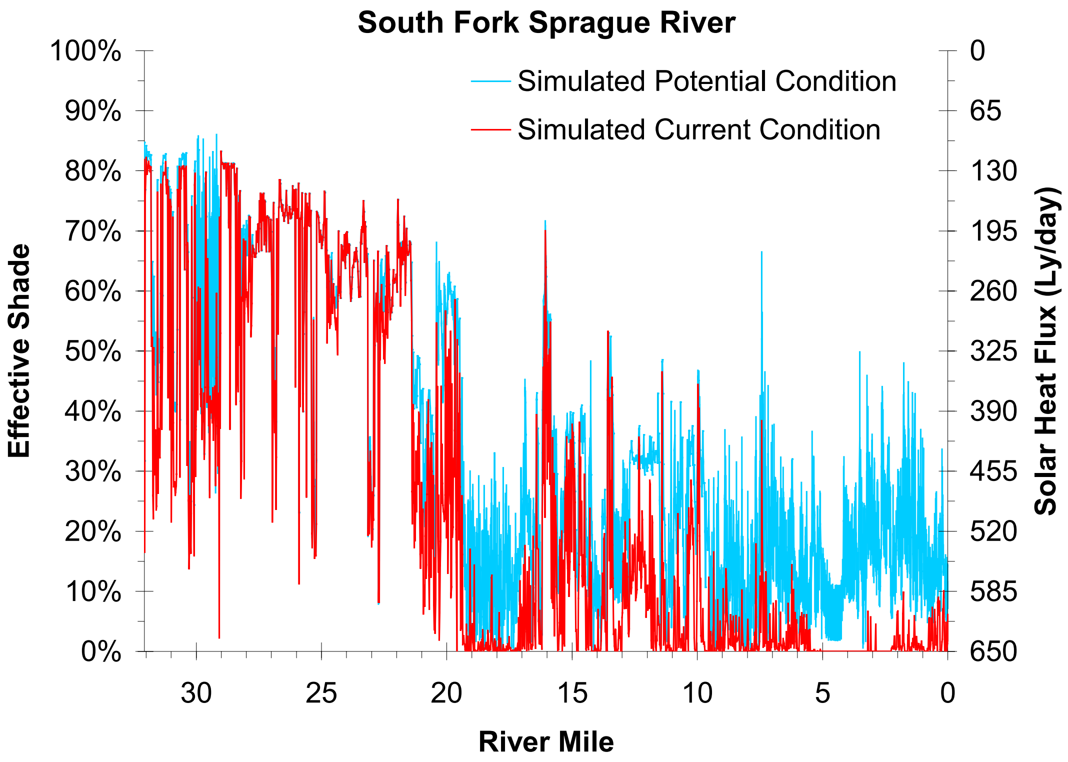

Figure 3-10. Percent Effective Shade Surrogate Measures – South Fork Sprague River

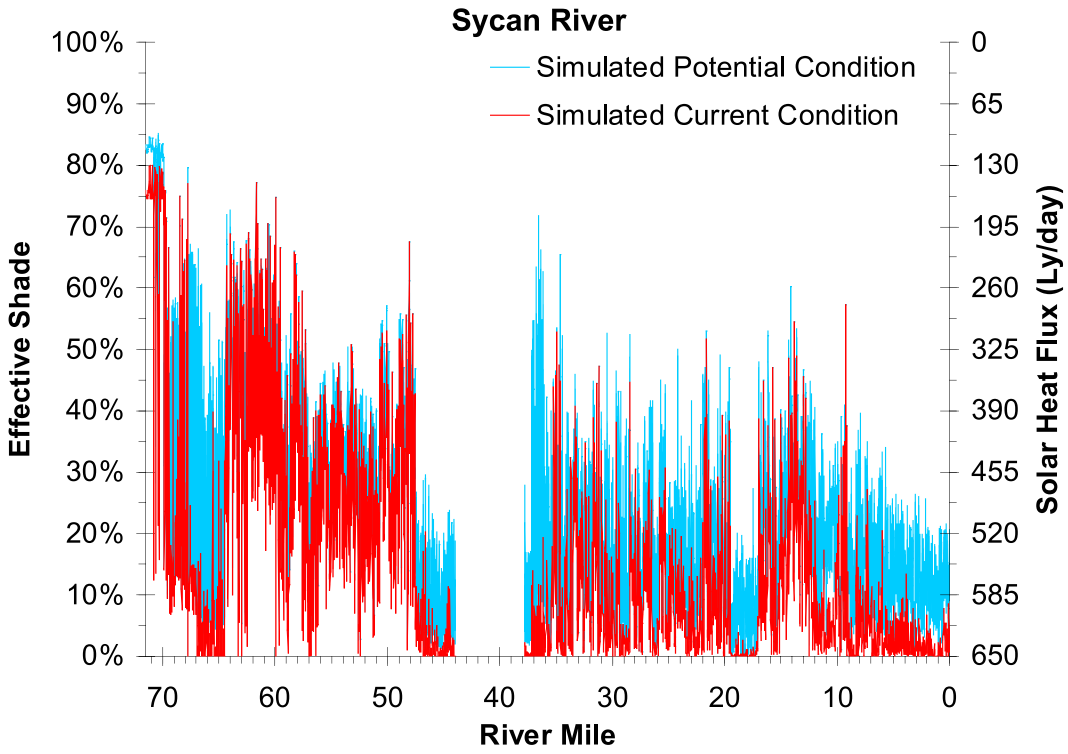

Figure 3-11. Percent Effective Shade Surrogate Measures – Sycan River

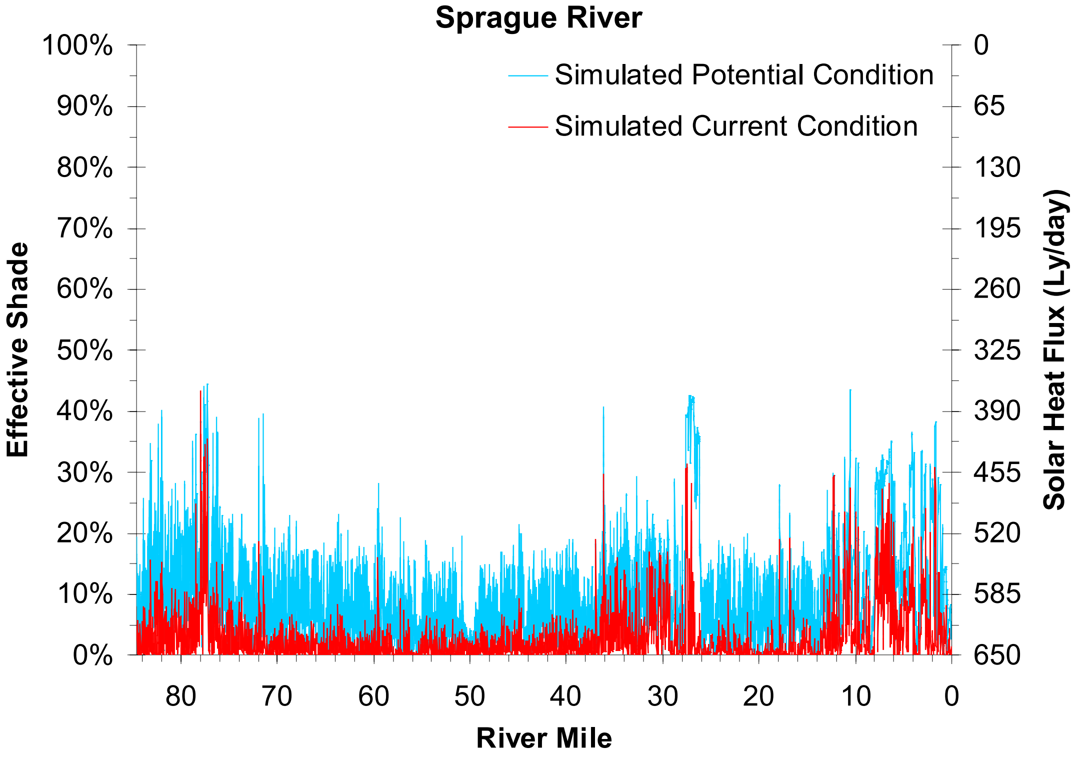

Figure 3-12. Percent Effective Shade Surrogate Measures – Sprague River

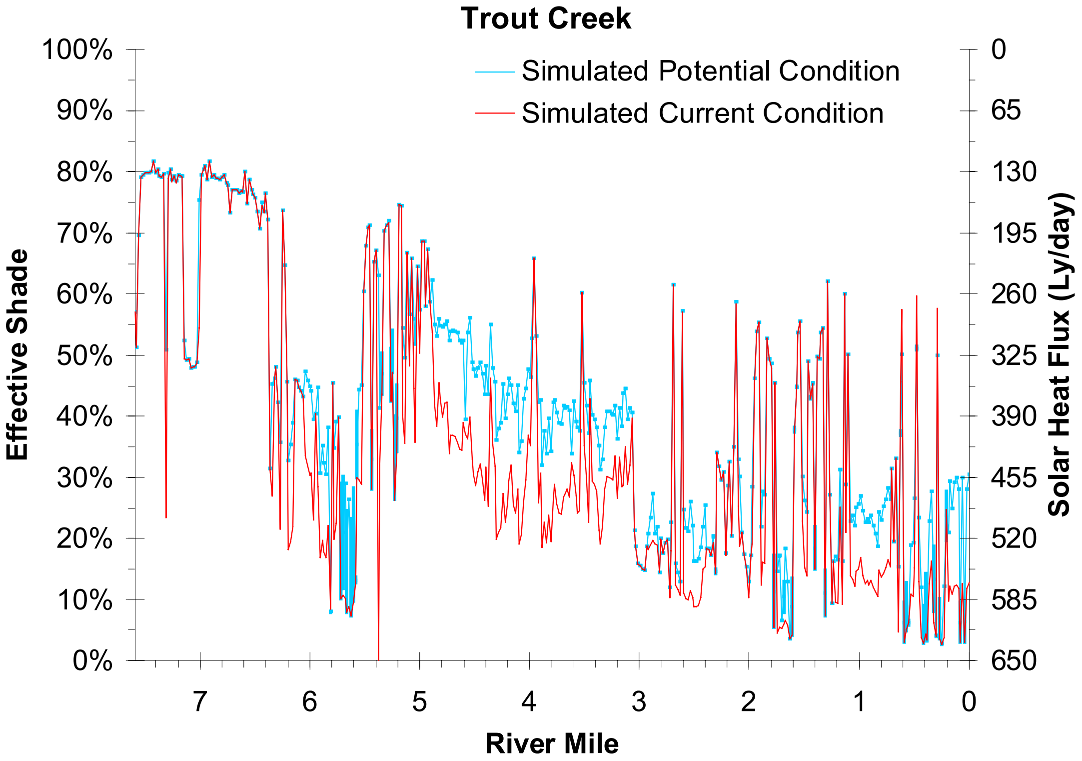

Figure 3-13. Percent Effective Shade Surrogate Measures – Trout Creek[20]

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[20] River miles 0 to 1.6 are Trout Creek and river miles 1.6 to 8.0 are South Fork Trout Creek.

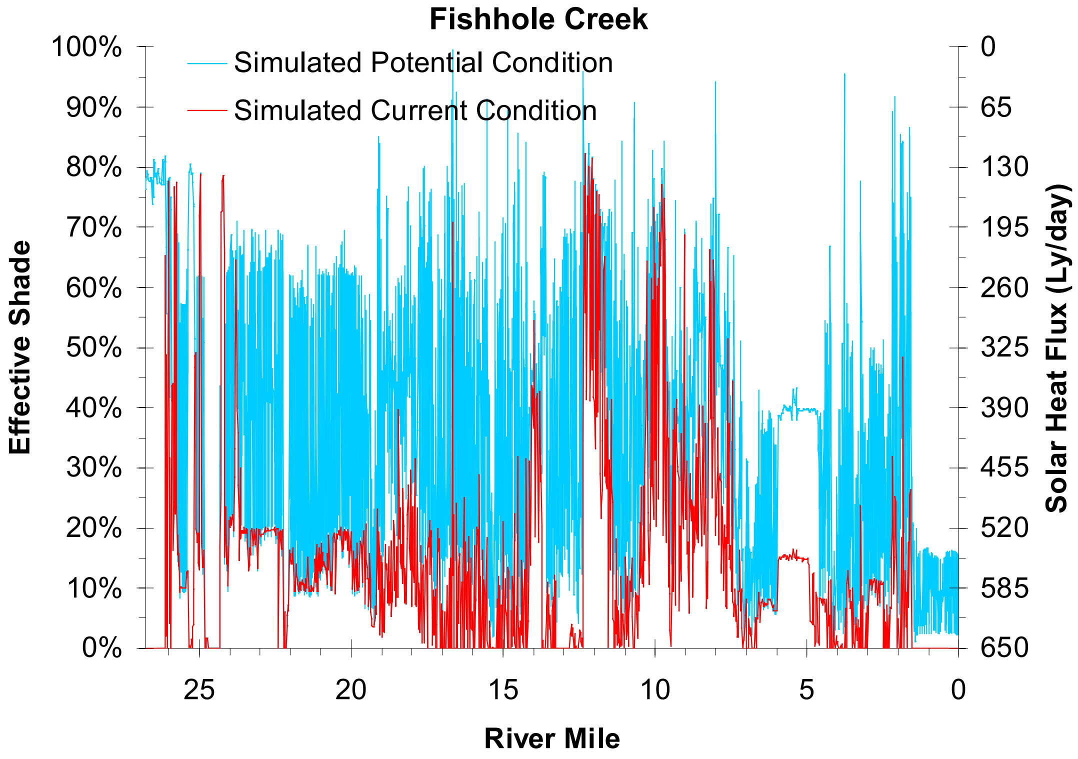


Figure 3-14. Percent Effective Shade Surrogate Measures – Fishhole Creek

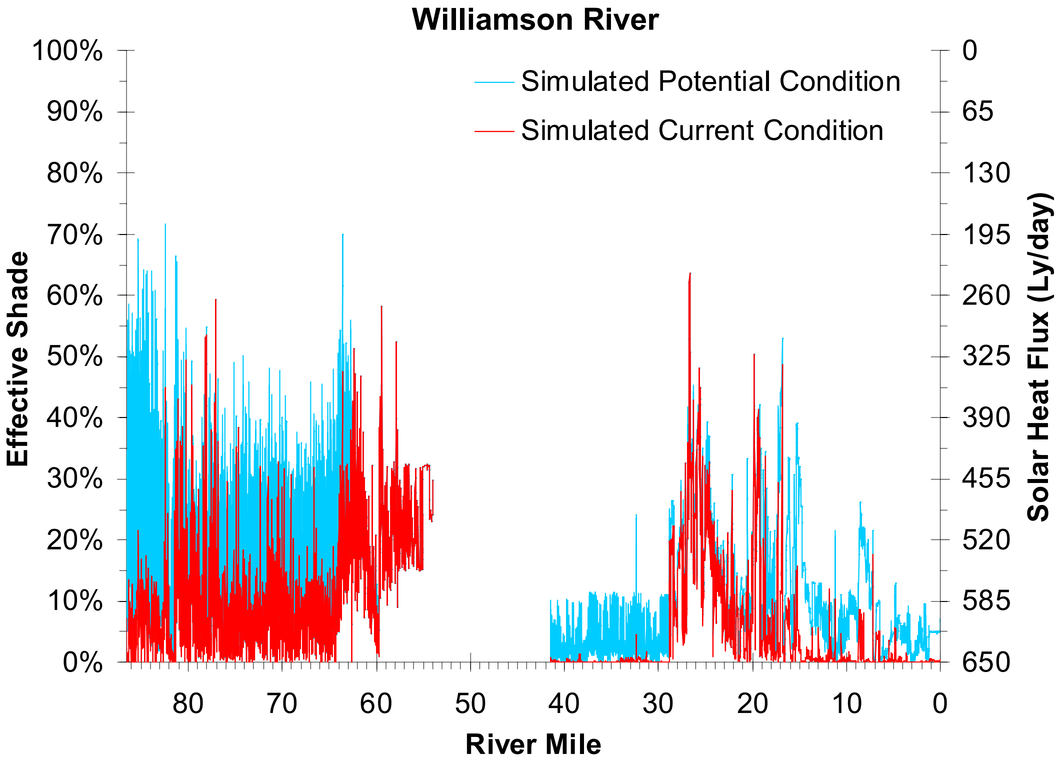


Figure 3-15. Percent Effective Shade Surrogate Measures – Williamson River

3.7.2 Effective Shade Curves - Surrogate Measures

Where specific effective shade levels are not specified in **Figures 3-9** to **3-15**, effective shade for the appropriate potential land cover type (described in detail within the Upper Klamath Lake Drainage Stream Temperature Analysis - **Attachment 1** and near stream disturbance zone width are provided in **Figures 3-17** to **3-21.**

Part of the effective shade curve methodology relies of channel width estimates (i.e. near stream disturbance zone width). The near stream disturbance zone (NSDZ) width is defined for purposes of the TMDL, as the width between shade-producing near-stream vegetation. This dimension was measured from georeferenced aerial photographs. Where near-stream vegetation was absent, the near-stream boundary was used, as defined as armored stream banks or where the near-stream zone is unsuitable for vegetation growth due to external factors (i.e., roads, railways, buildings, etc.). **Figure 3-16** illustrate the near stream disturbance zone.

In general, the NSDZ width serves as an accurate estimate of bankfull widths. When compared to ground level data, NSDZ width samples have a correlation coefficient of 0.94, a standard error or 5.2 feet and an average absolute deviation of 4.3 feet. NSDZ width samples can be used to estimate bankfull width provided that statistical accuracy limitations are acknowledged. The methodology used may over estimate bankfull widths for narrow stream channels and under estimate bankfull channel width for wider stream channels. Sources of error include scale limitations from aerial photo resolution, plan view line of sight to the stream channel boundaries and the clarity of the channel edge (i.e. there must be a visibly defined channel boundary). There is an obvious bias to the methodology towards features visible in plan view. Vertical features (i.e. channel incisions, cut banks, flood plain relief, etc.) can be difficult to distinguish from aerial photos.

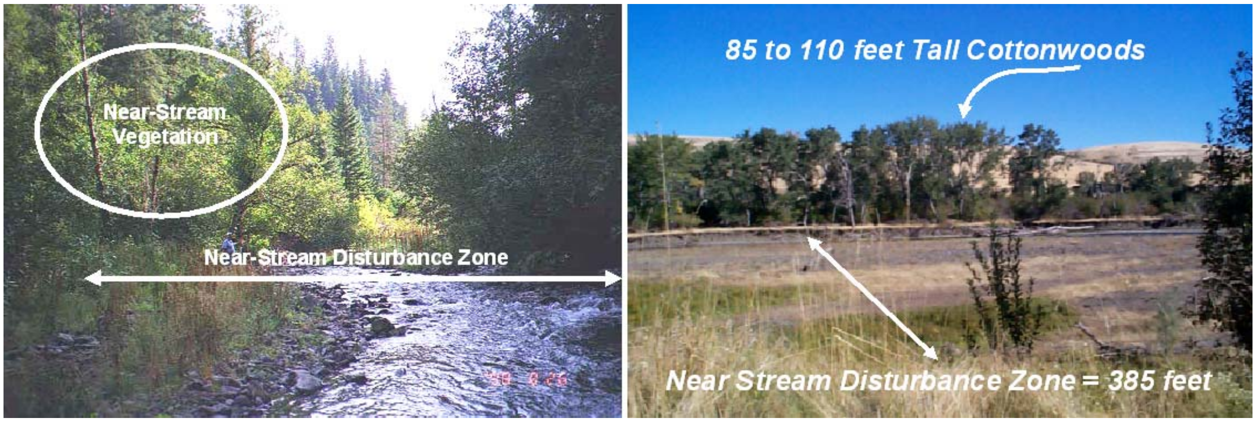
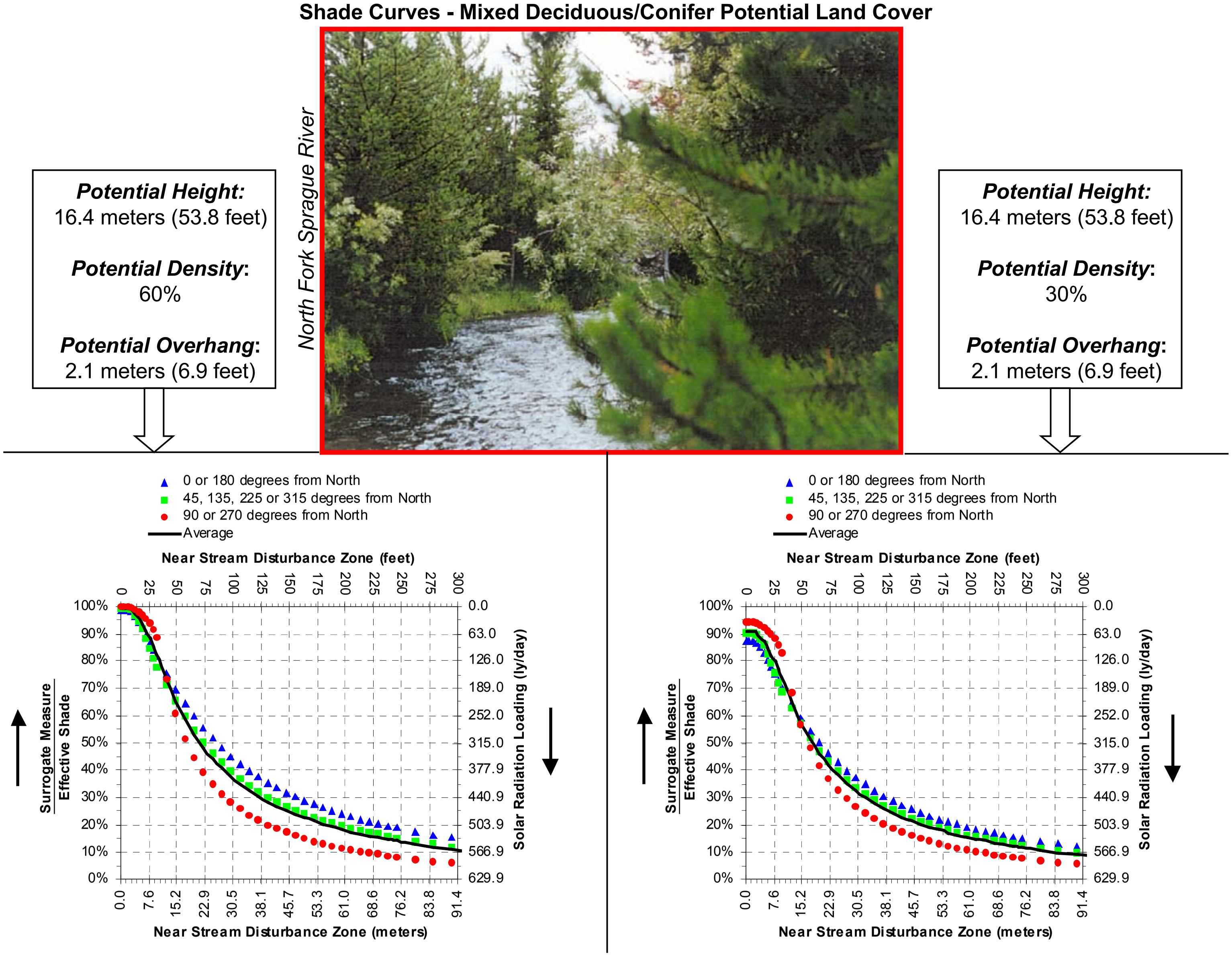


Figure 3-16. Near stream disturbance zone width



Potential Height: 16.4 meters (53.8 feet)

Potential Density: 60%

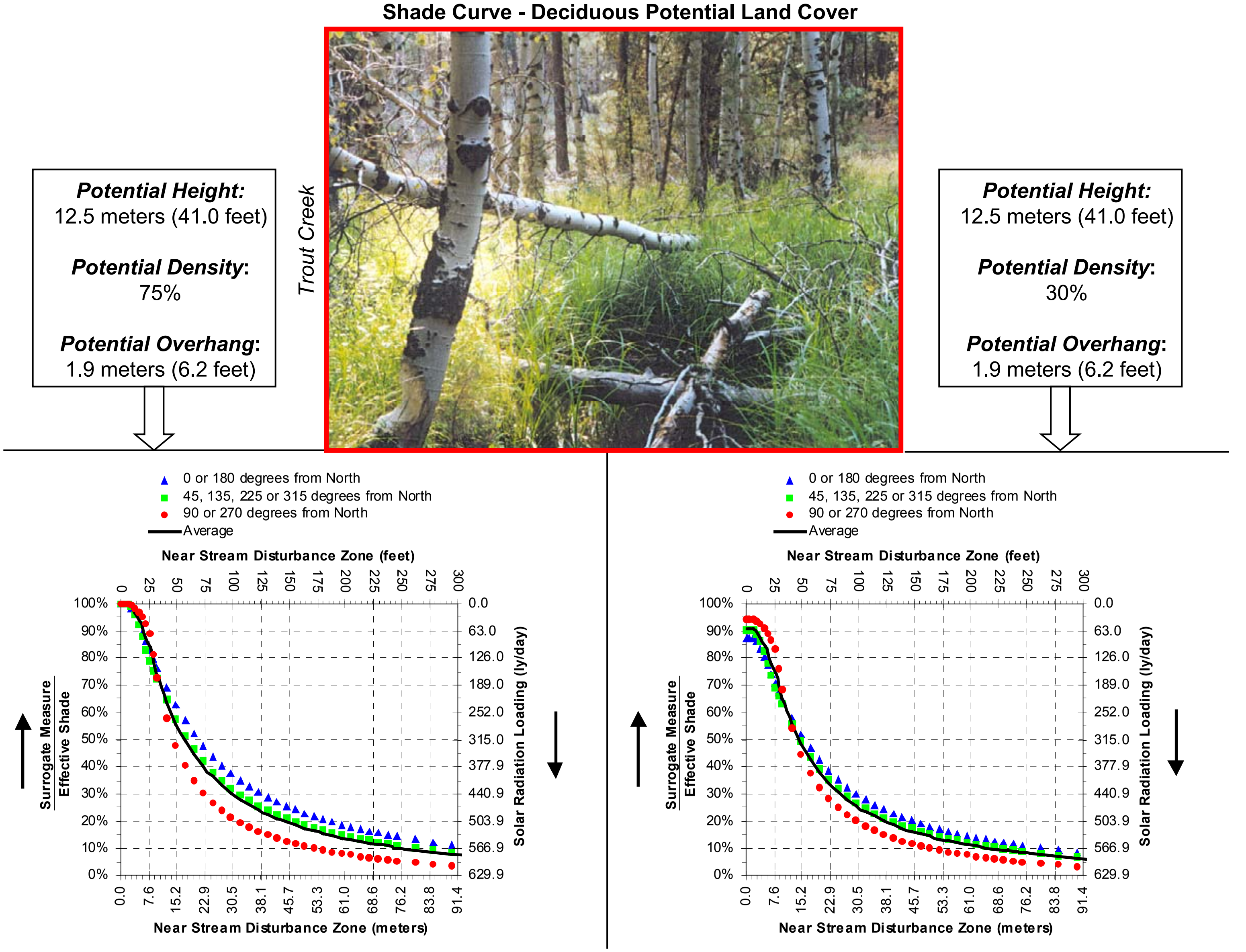
Potential Overhang: 2.1 meters (6.9 feet)

Potential Height: 16.4 meters (53.8 feet)

Potential Density: 30%

Potential Overhang: 2.1 meters (6.9 feet)

Figure 3-17. Shade Curves – Mixed Deciduous and Conifer Potential Land Cover



Shade Curve - Deciduous Potential Land Cover

Potential Height:
12.5 meters (41.0 feet)

Potential Density:
75%

Potential Overhang:
1.9 meters (6.2 feet)

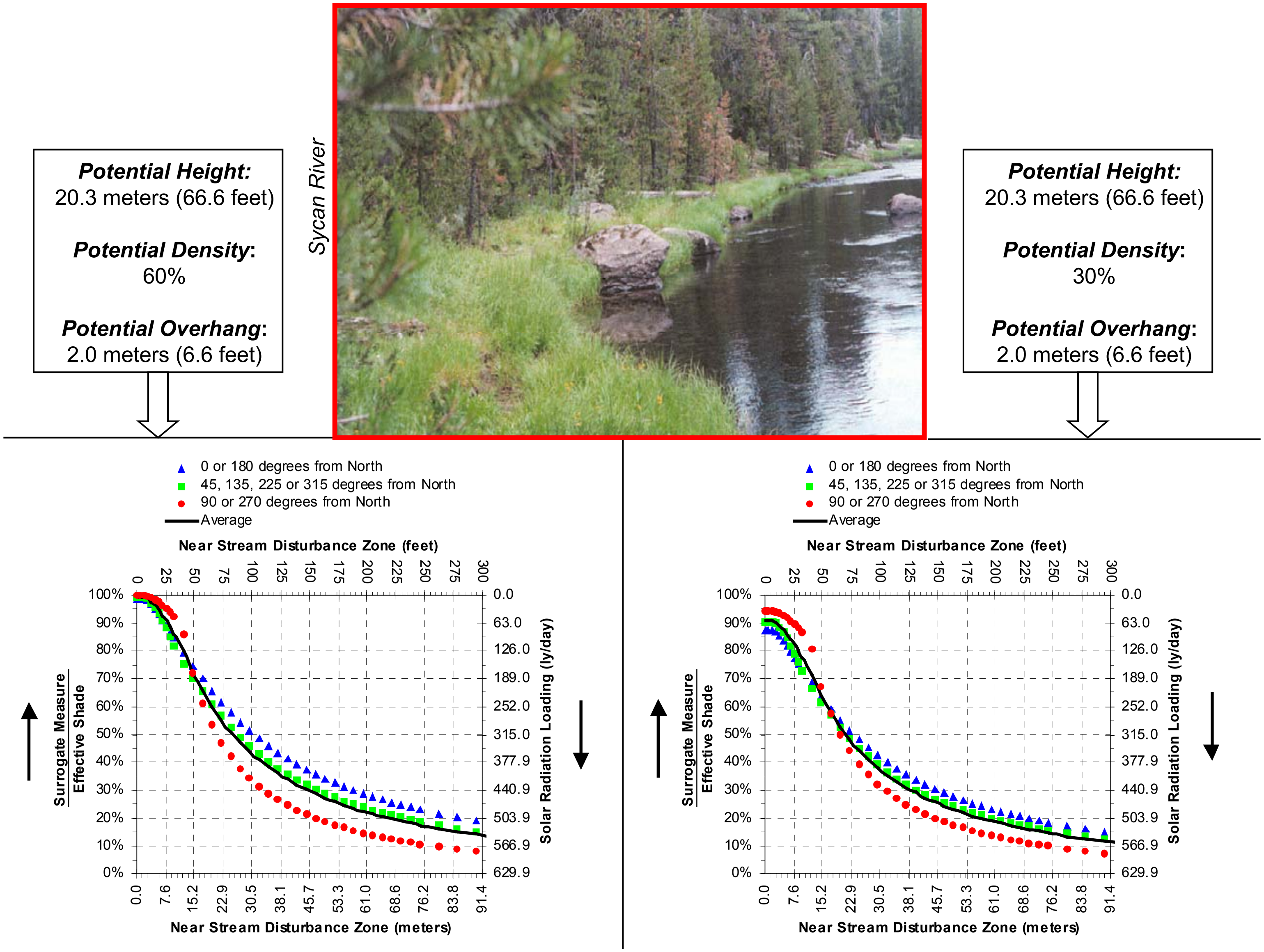
Potential Height:
12.5 meters (41.0 feet)

Potential Density:
30%

Potential Overhang:
1.9 meters (6.2 feet)

Figure 3-18. Shade Curves – Deciduous Potential Land Cover

Shade Curve - Conifer Potential Land Cover



Potential Height:
20.3 meters (66.6 feet)

Potential Density:
60%

Potential Overhang:
2.0 meters (6.6 feet)

Potential Height:
20.3 meters (66.6 feet)

Potential Density:
30%

Potential Overhang:
2.0 meters (6.6 feet)

Figure 3-19. Shade Curves – Conifer Potential Land Cover

Shade Curve - Wetland Shrub Potential Land Cover

North Fork Sprague River

Potential Height:
3.2 meters (10.5 feet)

Potential Density:
90%

Potential Overhang:
0.5 meters (1.6 feet)

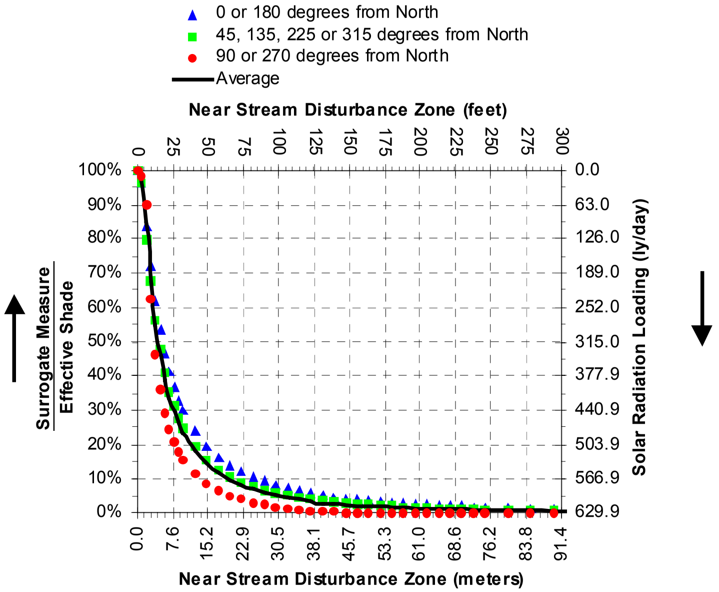


Figure 3-20. Shade Curve – Wetland Shrub Potential Land Cover

Shade Curve - Graminoid/Forb Potential Land Cover

South Fork Sprague River

Potential Height:
0.55 meters (1.8 feet)

Potential Density:
90%

Potential Overhang:
0.27 meters (0.9 feet)

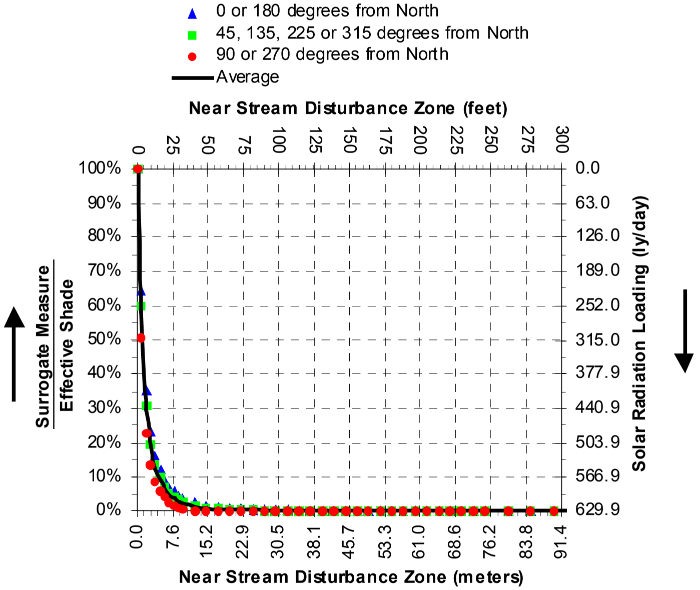


Figure 3-21. Shade Curve – Graminoid/Forb Potential Land Cover

3.7.3 Channel Morphology - Surrogate Measures

Channel width is an important component in stream heat transfer and mass transfer processes. Effective shade, stream surface area, wetted perimeter, stream depth and stream hydraulics are all highly sensitive to channel width. Accurate measurement of channel width across the stream network, coupled with other derived data, allows a comprehensive analytical methodology for assessing channel morphology (see **Attachment 1** for more information regarding the analysis of channel width). Potential bankfull width is estimated as a function of width to depth ratio and drainage area. Relating targeted width to depth ratios to Rosgen stream types, bankfull width can also be assessed as a function of drainage area and Rosgen stream type. **Table 3-8** lists channel morphology surrogate measures.

Table 3-8. Channel Morphology Surrogate Measure - Potential Level I Rosgen Stream Types and Targeted Width to Depth Ratios

<table>
<tr><th>Current Level I Rosgen Stream Type</th><th colspan="6">Surrogate Measure
Potential Level I Rosgen Stream Type &
Targeted Width to Depth Ratio</th></tr>
<tr><td>A</td><td colspan="6">A
W:D = 7.9</td></tr>
<tr><td>B</td><td colspan="6">B
W:D = 18.6</td></tr>
<tr><td>C</td><td colspan="3">C
W:D = 29.8</td><td colspan="3">E
W:D = 7.1</td></tr>
<tr><td>D</td><td colspan="2">C
W:D = 29.8</td><td colspan="2">D
W:D = N/A</td><td colspan="2">E
W:D = 7.1</td></tr>
<tr><td>E</td><td colspan="6">E
W:D = 7.1</td></tr>
<tr><td>F</td><td colspan="3">C
W:D = 29.8</td><td colspan="3">E
W:D = 7.1</td></tr>
<tr><td>G</td><td colspan="3">C
W:D = 29.8</td><td colspan="3">E
W:D = 7.1</td></tr>
</table>

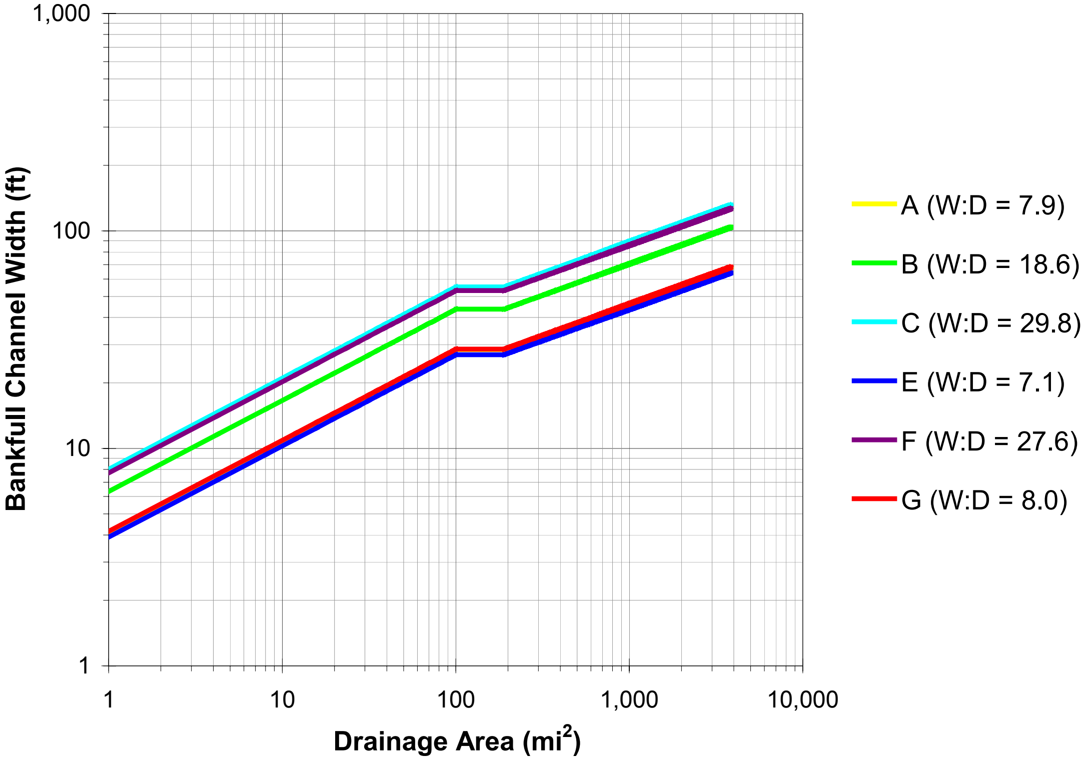


Figure 3-22. Potential Bankfull Width as a Function of Width to Depth Ratio and Drainage Area

3.8 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

A TMDL and associated MOS, which results in an overall allocation, represents 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 3-9. 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.

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.*

Implicit Margins of Safety

Description of the MOS for the Upper Klamath Lake drainage Temperature TMDL 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 mature and healthy near stream land cover 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 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.

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

The temperature TMDL and the temperature water quality standards are achieved when (1) nonpoint source solar radiation loading is representative of a condition without human disturbance and (2) point source discharges cause no measurable temperature increases (as defined in the temperature standard) in surface waters.

Stream temperatures (displayed in ***Figures 3-23*** *to* ***3-27****) that result from the system potential conditions represent attainment of the temperature standard* ***(no measurable surface water temperature increase resulting from anthropogenic activities)****.*

Simulations were performed to calculate the temperatures that result under the allocated conditions and surrogate measures (i.e. potential channel morphology and land cover) that represent the system potential condition with ***no measurable surface water temperature increase resulting from anthropogenic activities***. The resulting simulated stream temperatures represent attainment of system potential, and therefore, attainment of the temperature standard.

Figures 3-23 through **3-27** display the stream temperatures that result from system potential conditions. Analysis of potential flow conditions indicate that irrigation practices are a contributing factor to stream heating, and that improving flow conditions could further improve aquatic habitat. Although flow is not allocated in this TMDL, stream temperatures that result from system potential flow conditions are included in the charts for informational purposes. The stream temperatures that result from the potential channel width and land cover are the allocated condition.

A total of 250.6 river miles in the Williamson River, Sycan River, Sprague River, North Fork Sprague River, and South Fork Sprague River were analyzed and simulated during the critical period (August 4 to August 16, 1999). **Figures 3-23** to **3-27** compares the current stream temperatures with the potential conditions for each stream modeled.

Maximum daily stream temperature distributions are presented in **Figure 3-28**. Currently 61% of the sampled stream segments in the Upper Klamath Lake Drainage exceed 68°F[21]. Under potential land cover and channel width, 17% of the simulated stream segments exceed 68.5°F resulting in an additional 117 river miles that remain below this temperature threshold when compared to the current condition. When potential flow volume is added to potential land cover and channel width, 10% of the simulated stream segments exceed 68°F, resulting in an additional 26 river miles below this threshold condition when compared to the potential land cover and channel width. Results indicate that 83% of the stream length can achieve maximum daily stream temperatures less than 68°F under system potential conditions. With this result comes a reality that 17% of the stream system (roughly 45 river miles) will remain above 68°F.

An overriding emphasis of the temperature TMDL is the focus on spatial distributions of stream temperatures in the Upper Klamath Lake drainage. Comparisons of stream temperature distributions capture the variability that naturally exists in stream thermodynamics. Spatial variability is observed in all of the stream segments sampled and analyzed. With the advent of new sampling technologies and analytical tools that include landscape scaled data and

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[21] The EPA proposed redband trout sub-lethal thermal limit is 68°F

computational methodologies, an improved understanding of stream temperature dynamics is emerging (Boyd, 1996, Faux et al. 2001, Torgersen et al., 1999, Torgersen et al., 2001, ODEQ 2000, ODEQ 2001a, ODEQ2001b, ODEQ 2001c). This understanding accommodates spatial and temporal variability that includes departures from biologically derived temperature threshold conditions.

Further, 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, at a network scale modeling demonstrates 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 during low flow periods.**

Summary of Conclusions Developed in this Stream Temperature Analysis (see Attachment 1 for more information)

Conclusion #1 - Modest Increases in Effective Shade Produce Thermally Significant Cooling

Conclusion #2 - Spatial and temporal thermal variability includes departures from biologically derived temperature threshold conditions (i.e. EPA proposed Redband Trout sub-lethal thermal limit of 68°F). This holds true even in the defined "potential conditions"

Conclusion #3 - The shift in stream temperature distribution is favorable to fish. An additional 117 stream miles are expected to become optimal, making sub-optimal thermal exposure very limited in the potential condition.

Conclusion #4 - 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.

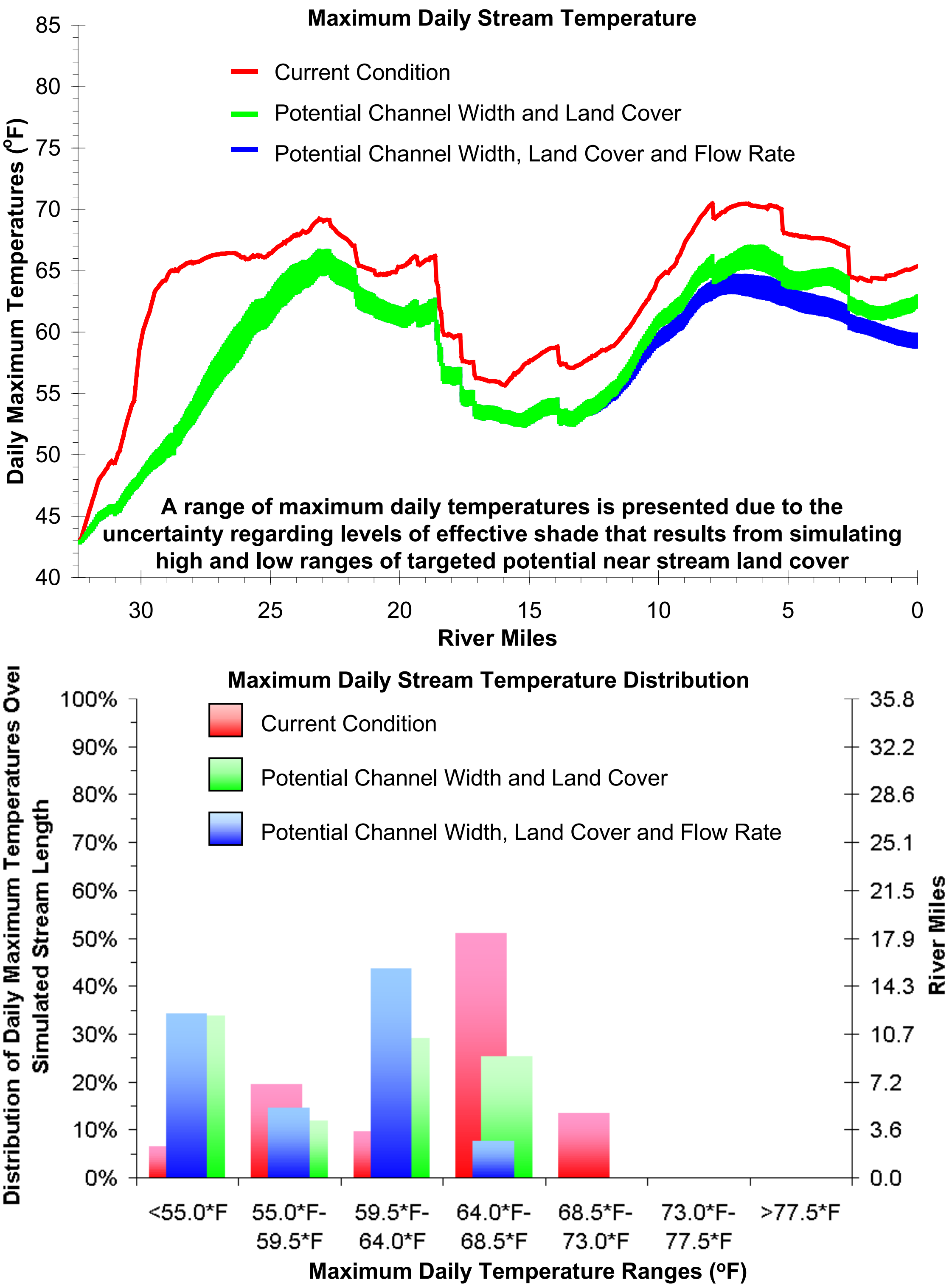
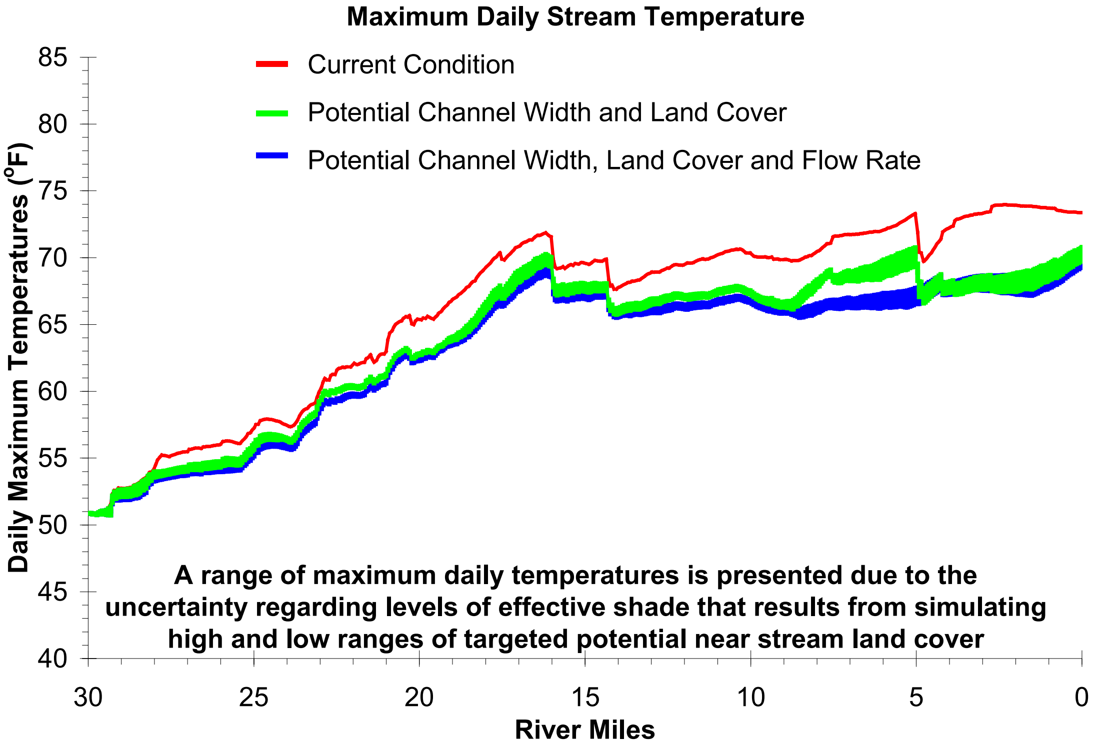


Figure 3-23. North Fork Sprague River Daily Maximum Temperature Distribution
(Current Condition and Allocated Condition)
(August 16, 1999)



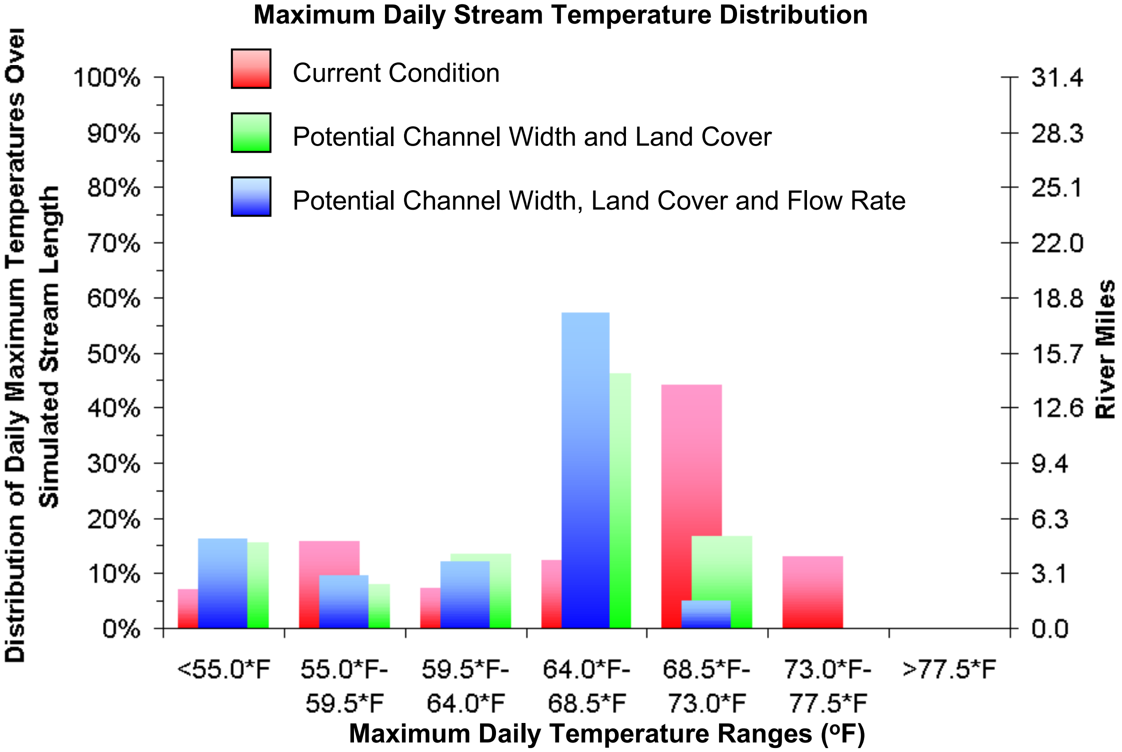


Figure 3-24. South Fork Sprague River Daily Maximum Temperature Distribution (Current Condition and Allocated Condition) *(August 12, 1999)*

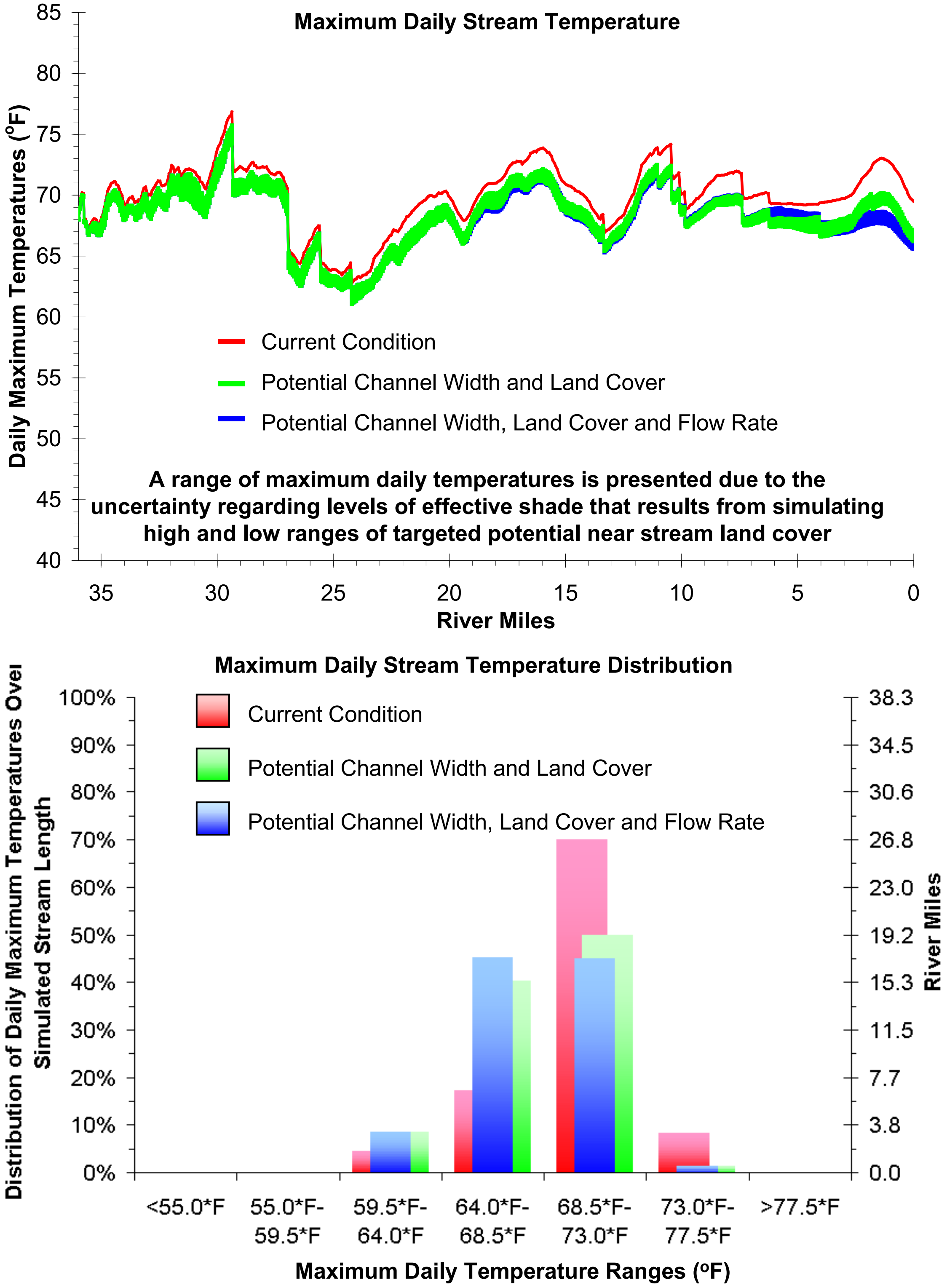
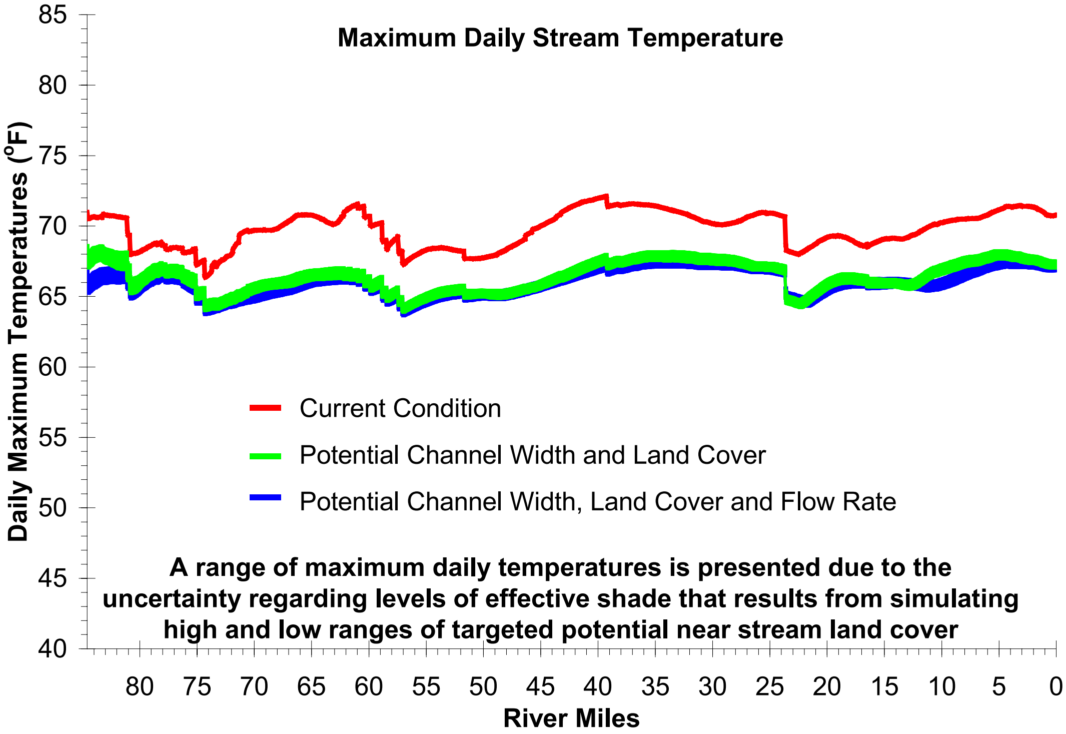


Figure 3-25. Sycan River Daily Maximum Temperature Distribution
(Current Condition and Allocated Condition)
(August 16, 1999)



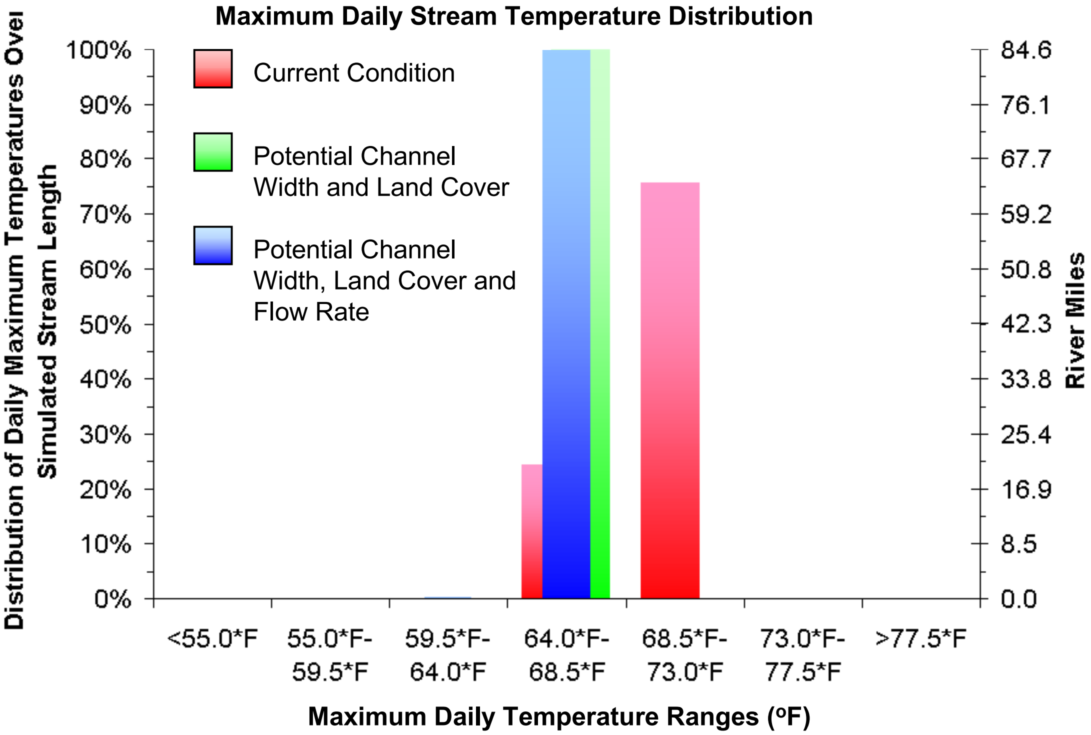
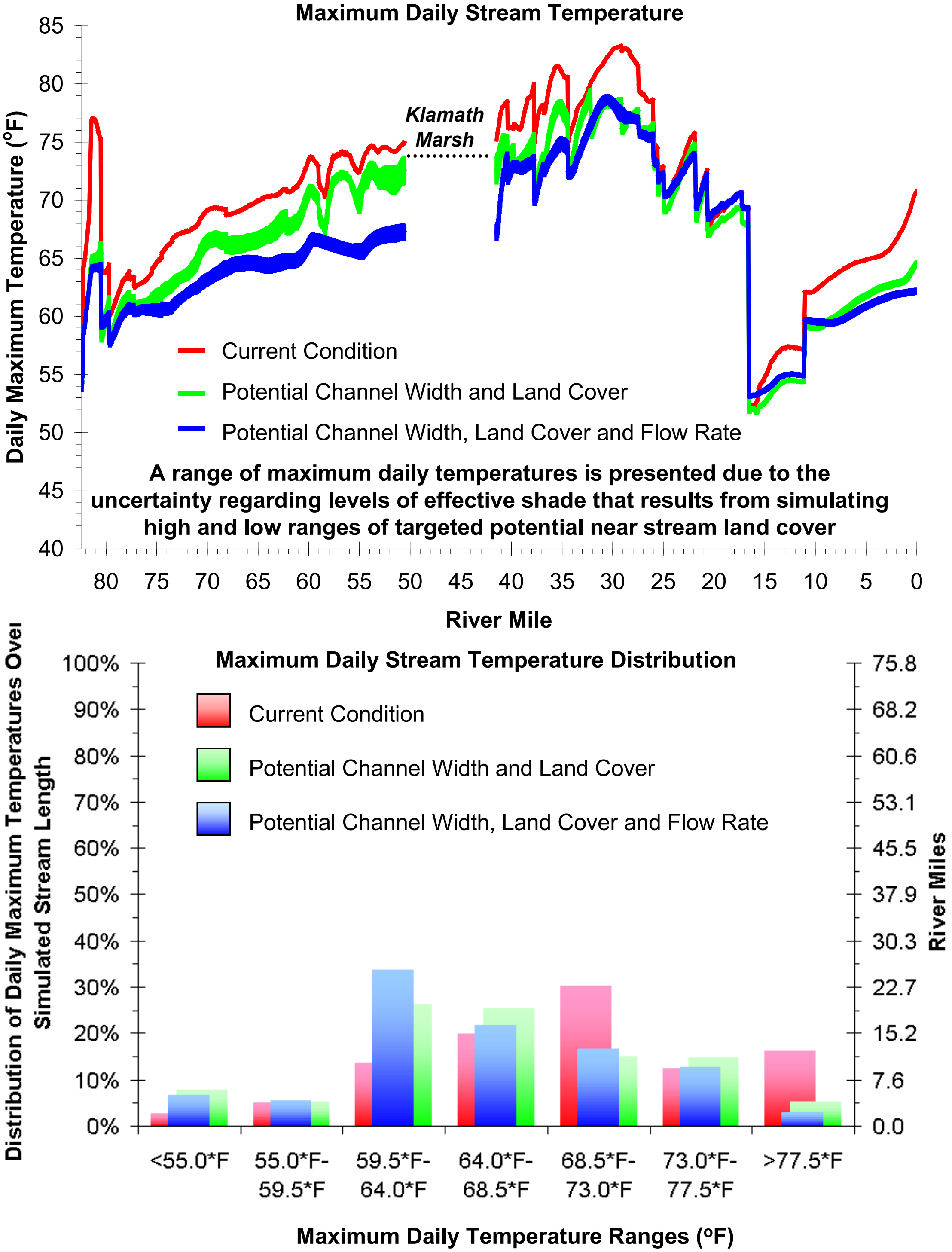
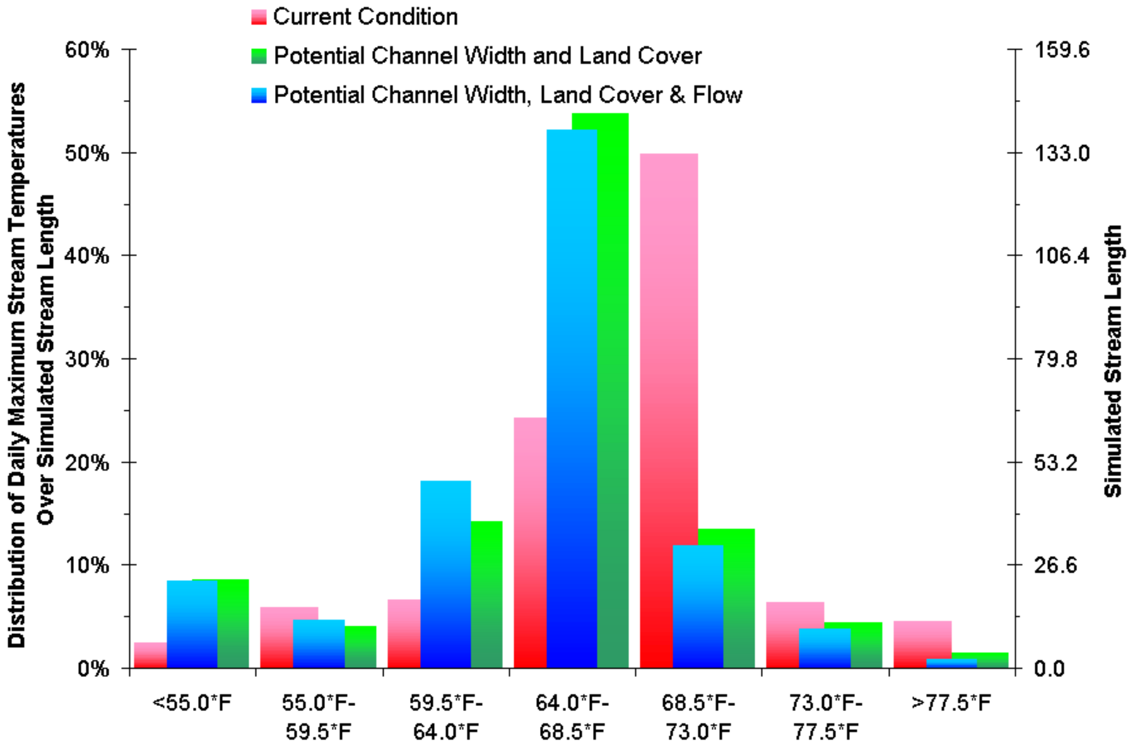


Figure 3-26. Sprague River Daily Maximum Temperature Distribution
(Current Condition and Allocated Condition)
(August 12, 1999)



A range of maximum daily temperatures is presented due to the uncertainty regarding levels of effective shade that results from simulating high and low ranges of targeted potential near stream land cover

Figure 3-27. Williamson River Daily Maximum Temperature Distribution
(Current Condition and Allocated Condition)
(August 4, 1999)



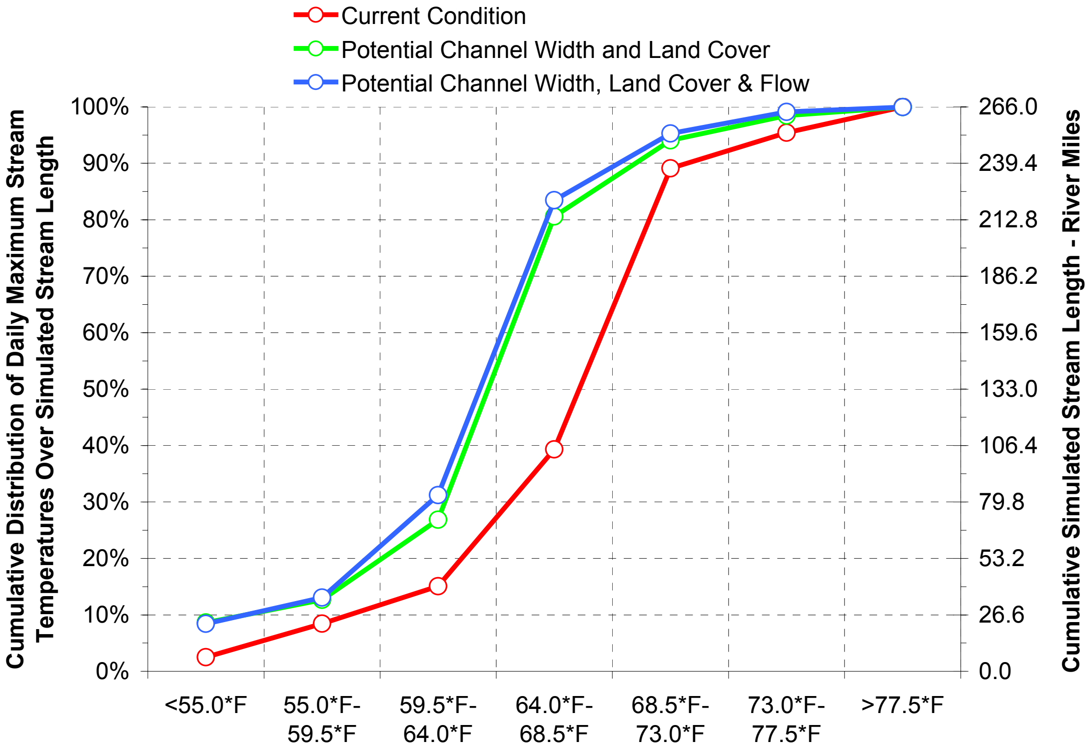
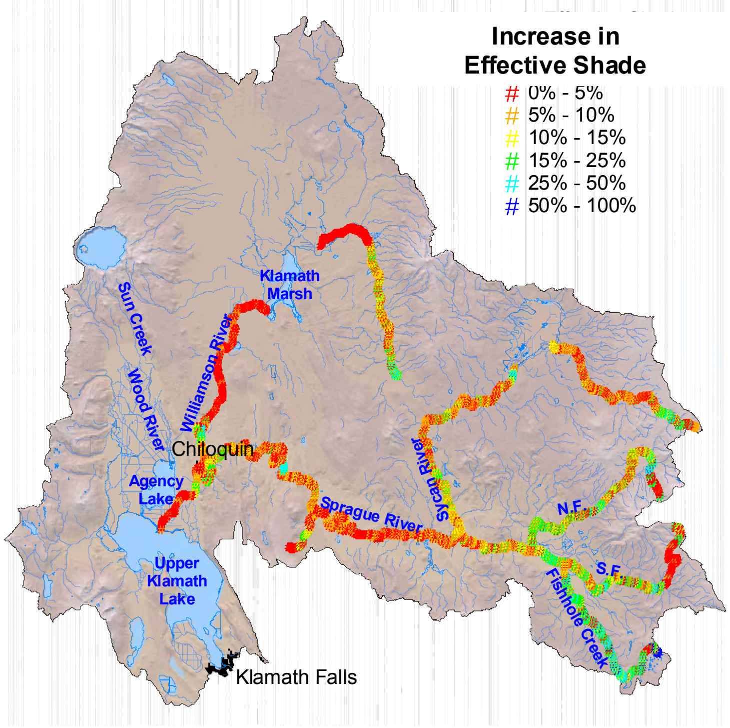
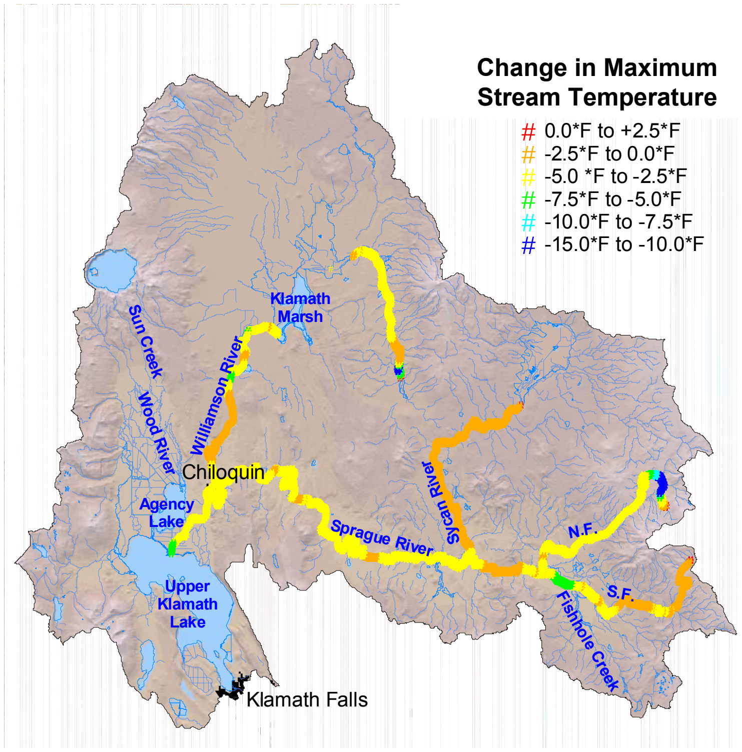


Figure 3-28. Distributions of maximum daily maximum stream temperatures in the Williamson River and Sprague River stream network (266 river miles) for current and potential conditions (*August, 1999)*

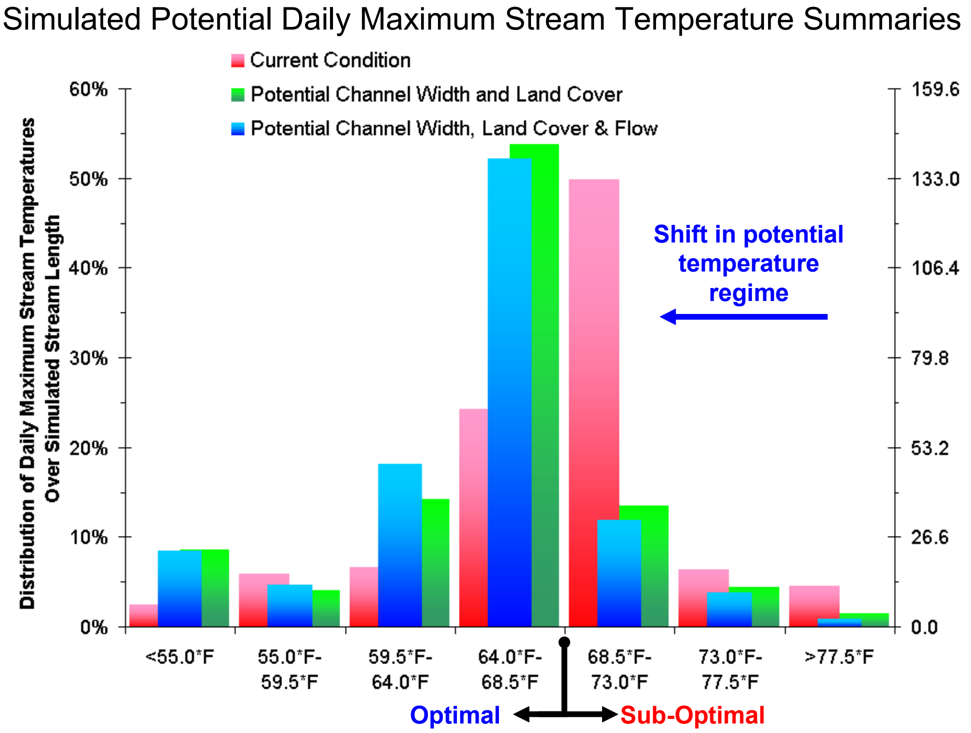
Increase in Effective Shade Resulting from Potential Channel Width & Land Cover



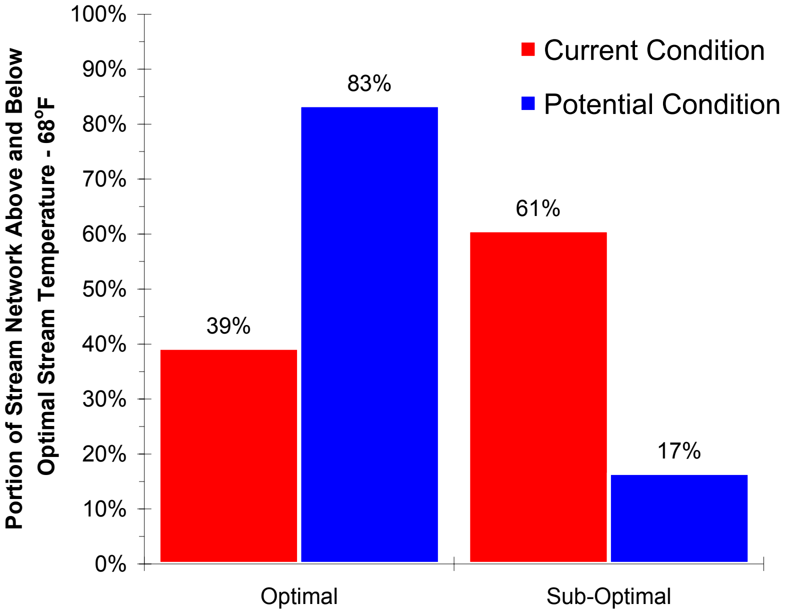
Temperature Difference Resulting from Potential Channel Width & Land Cover



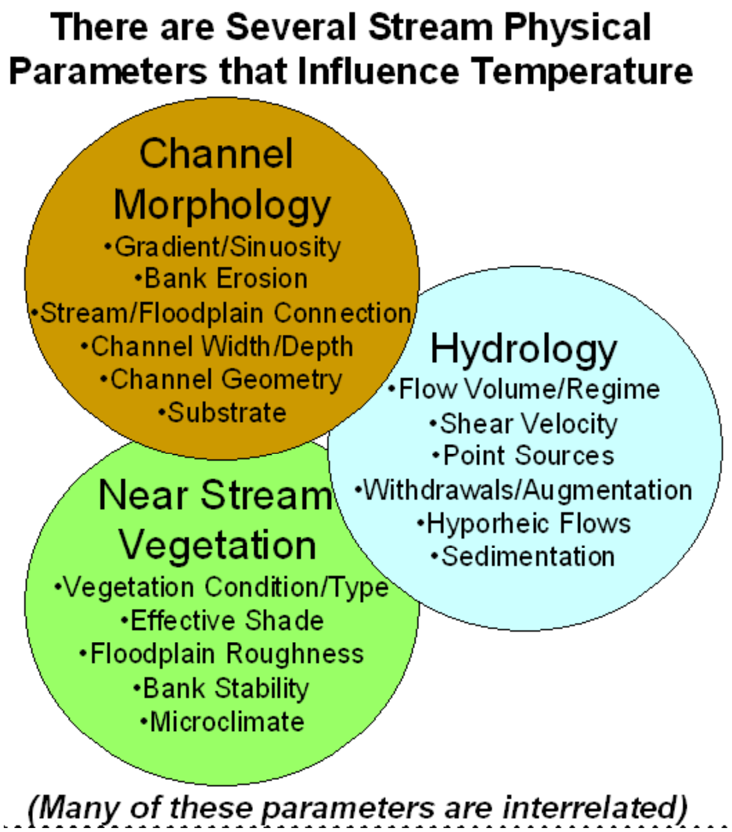
Conclusion #1 - Modest Increases in Effective Shade Produce Thermally Significant Cooling



Conclusion #2 - Spatial and temporal thermal variability includes departures from biologically derived temperature threshold conditions (i.e. EPA proposed Redband Trout limit of 68°F). This holds true even in the defined "potential conditions"



Conclusion #3 - The shift in stream temperature distribution is favorable to fish. An additional 117 stream miles are expected to become optimal, making sub-optimal thermal exposure very limited in the potential condition.



Conclusion #4 - 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.

CHAPTER IV

SPRAGUE RIVER DISSOLVED OXYGEN TMDL

Algal Mass in the North Fork Sprague River

Table 4-1. Upper Klamath Lake drainage Dissolved Oxygen TMDL Components

Waterbodies	SPRAGUE RIVER - HUC CODE 18010202.
Pollutant Identification	*Pollutants:* increased algal biomass resulting from human caused increases in stream temperatures, channel modifications and near stream vegetation disturbance/removal.
Target Identification (Applicable Water Quality Standards) *CWA §303(d)(1)*	**OAR 340-041-0965(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.* *(D) For waterbodies identified by DEQ 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 DEQ 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 DEQ, 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 DEQ 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 DEQ, 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 ;*
Existing Sources *CWA §303(d)(1)*	Forestry, Agriculture, Transportation, Rural Residential, Urban
Seasonal Variation *CWA §303(d)(1)*	Critical DO levels on the Sprague River generally occur in 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 cold water-aquatic life dissolved oxygen criteria: *The dissolved oxygen shall not fall below 6.0 mg/L as an absolute minimum.* *Waste Wasteload Allocations (Point Sources)*: There are no point sources in the Sprague subbasin that adversely affect dissolved oxygen. *Load Allocations (Non-Point Sources)*: The LAs for instream temperature are presented in **Table 3-7** and surrogate measures listed in **Section 3.7 Surrogate Measures – 40 CFR 130.2(i)**).
Surrogate Measures *40 CFR 130.2(i)*	Margins of Safety demonstrated in critical condition assumptions and is inherent to methodology. (Detailed in section)
Margins of Safety *CWA §303(d)(1)*	• Analytical modeling of TMDL loading capacities demonstrates attainment water quality standards
Water Quality Standard Attainment Analysis *CWA §303(d)(1)*	To be conducted by Oregon Department of Environmental Quality

4.1 OVERVIEW

Data was collected on the Sprague River during two synoptic surveys in 1999 and 2000. Grab data and continuous monitoring data were collected during these efforts. Computer simulations (i.e. Qual2E) were developed using this data and data developed in the temperature TMDL for hydrology, channel morphology and near stream vegetation. Dissolved oxygen was calibrated in a steady state hydraulic simulation with dynamic algal growth simulations. Producing an equivalent algal biomass at critical portions of the finite difference grid simulated periphyton. Calibration focused on dissolved oxygen during early morning and late evening periods.

Conditions developed in the temperature TMDL listed as surrogate measures (see **Section 3.7 Surrogate Measures – 40 CFR 130.2(i)**) that relate to channel morphology, near stream land cover and resulting solar loading and stream temperature were demonstrated to improve dissolved oxygen levels that meet water quality standards.

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

Loss of DO has detrimental effects on aquatic species, especially salmonids. Minimum levels of oxygen are required to maintain all healthy populations. A minimum level of 4.0 mg/L DO concentration is needed to avoid acute mortality of non-salmonid fish in early life Stages (U.S. EPA, 1986), a minimum of 4.0 mg/L for cool water species, and a minimum of 6.0 mg/L for cold water species (OAR 340-041-0965(2)(a)).

4.2.1 Sensitive Beneficial Use Identification

The primary benefit to maintaining adequate dissolved oxygen (DO) concentrations is to support a healthy and balanced distribution of aquatic life. **Table 4-2** lists the beneficial uses that occur in the Sprague River highlights those that are related to DO.

Table 4-2. Beneficial uses occurring in the Upper Klamath Lake Subbasin
(OAR 340 – 41 – 965)
*Beneficial uses related to Dissolved Oxygen are marked in **RED***

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	✓	Anadromous Fish Passage	✓
Livestock Watering	✓	Wildlife and Hunting	✓
Boating	✓	Fishing	✓
Hydro Power		Water Contact Recreation	✓
Aesthetic Quality	✓	Commercial Navigation & Transportation	

The applicable section(s) of the dissolved oxygen rule (OAR 340-041-0965) are determined by the presence of cool or cold-water aquatic life, and the life stages of any salmonids present (i.e., spawning, rearing, etc.). Redband trout are the most sensitive beneficial use in the Sprague River Subbasin. A map showing where redband trout are a beneficial use is included in **Figure 1-10, page 21**. 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.

Based on available fish survey information, habitat assessments and professional judgement, DEQ, with input from the USFWS, ODF&W and Klamath Tribes staff, the stream segments denoted in **Figure 1-10** are designated as providing cold water aquatic life. The dynamic water quality modeling done to determine the TMDL predicts the daily diel range of dissolved oxygen during "worst case" conditions. The Department, with input from local fisheries biologists, has determined that sufficient data and analyses provide the basis for targeting the 6.0 mg/L absolute minimum cold water criteria. The 6.0 mg/L minimum dissolved oxygen, with the 0.4 mg/L margin of safety included in this TMDL, will be protective of beneficial uses (redband trout).

4.2.2 Water Quality Standard Identification

4.2.2.1 Dissolved Oxygen Water Quality Standard

Oregon Administrative Rule 340-041-0965

(3) No wastes shall be discharged and no activities shall be conducted which either alone or in combination with other wastes or activities will cause violation of the following standards in the waters of the Klamath Basin:
   (a) Dissolved oxygen (DO): The changes adopted by the Commission on January 11, 1996, become 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 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.
      (B) For waterbodies identified by DEQ 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 DEQ. Upon determination that the spatial median intergravel dissolved oxygen concentration is below 8.0 mg/l, DEQ may, in accordance with priorities established DEQ 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 DEQ 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 DEQ 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 DEQ, 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 DEQ 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 DEQ, 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;

4.2.2.2 Deviation from Water Quality Standard

Dissolved Oxygen concentrations and other related data has been collected in the Sprague Subbasin. Data has been collected at stations by DEQ, USGS, Klamath Tribes, OSU.

Monitoring of DO levels on the mainstem of the Sprague River is carried out at several locations. Samples are collected at approximately one-week intervals during the May through November season. DEQ has collected water chemistry samples at RM 74.0, 48.5, 40.6, 32.8,28.4, 9.8, 7.2, and 0.71. The USGS also operates continuous monitoring stations at the headwaters of the North and South Fork, and along the mainstem at RM 49.6, 5.2, 4.1, at 0.19 at Chiloquin. **Figure 4-1** shows the monitoring sites along the Sprague River.

Figure 4-2 illustrates dissolved oxygen data collected by DEQ. Critical dissolved oxugen conditions occur at the Sprague River near River Crest Road (RM 50.1) where slower velocities and elevated temperatures encourage excessive periphyton growth.

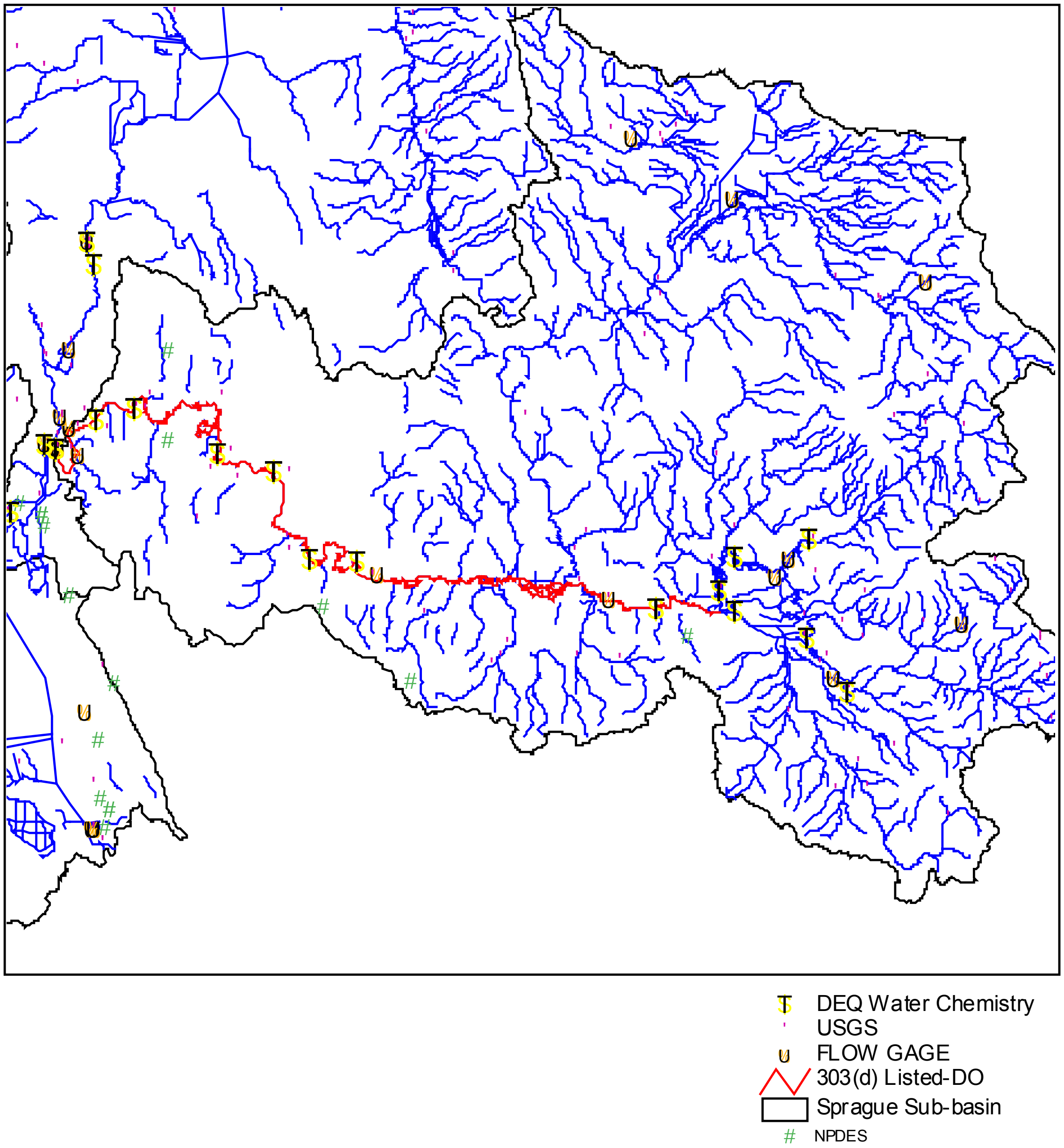
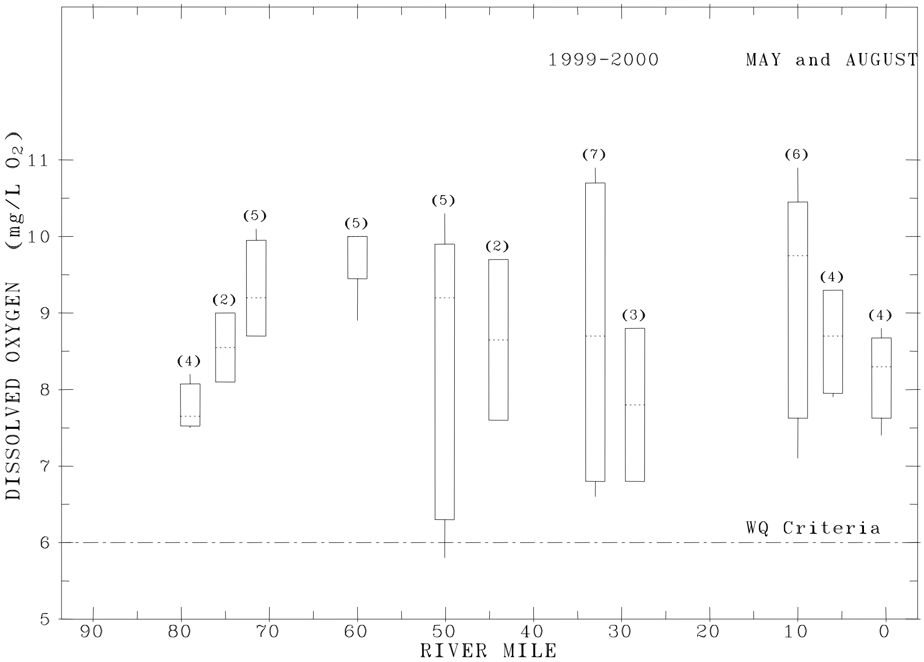


Figure 4-1. Monitoring Sites on Sprague River

Sprague River near River Crest Road dissolved oxygen (longitudinal box and whisker plot)



Sprague River near River Crest Road diurnal DO (diurnal continuous data)

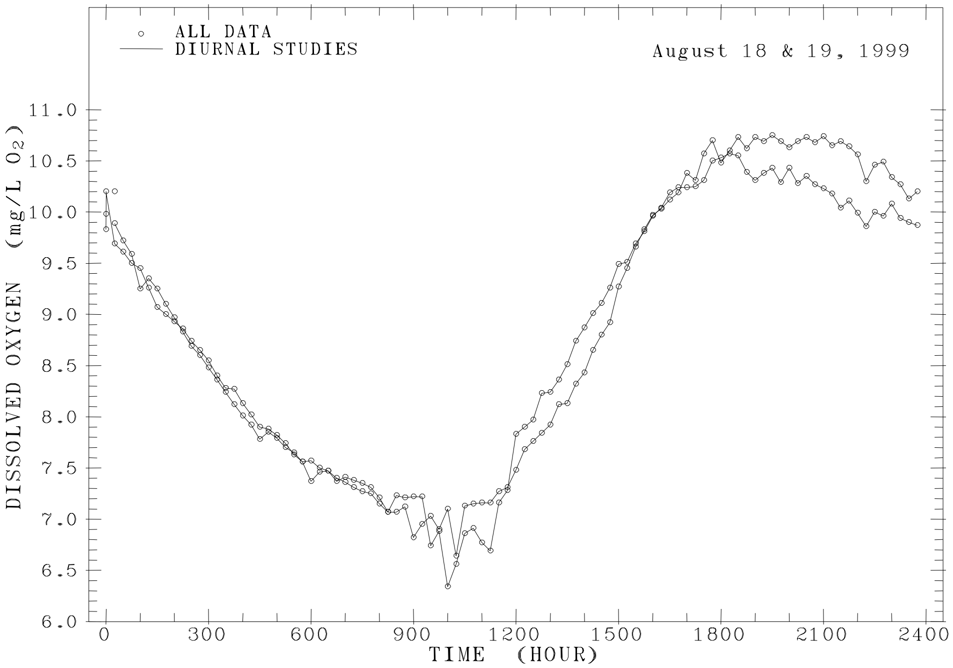


Figure 4-2. Sprague River near River Crest Road dissolved oxygen

Section 303(d) of the Federal Clean Water Act (1972) requires that waterbodies that violate water quality standards, thereby failing to fully protect beneficial uses, be identified and placed on the state's 303(d) list. The Sprague River, from mouth to North/South Fork (RM 0.0-79.1) has been placed on the Oregon Department of Environmental Quality's (DEQ) 1998 303(d) list for dissolved oxygen.

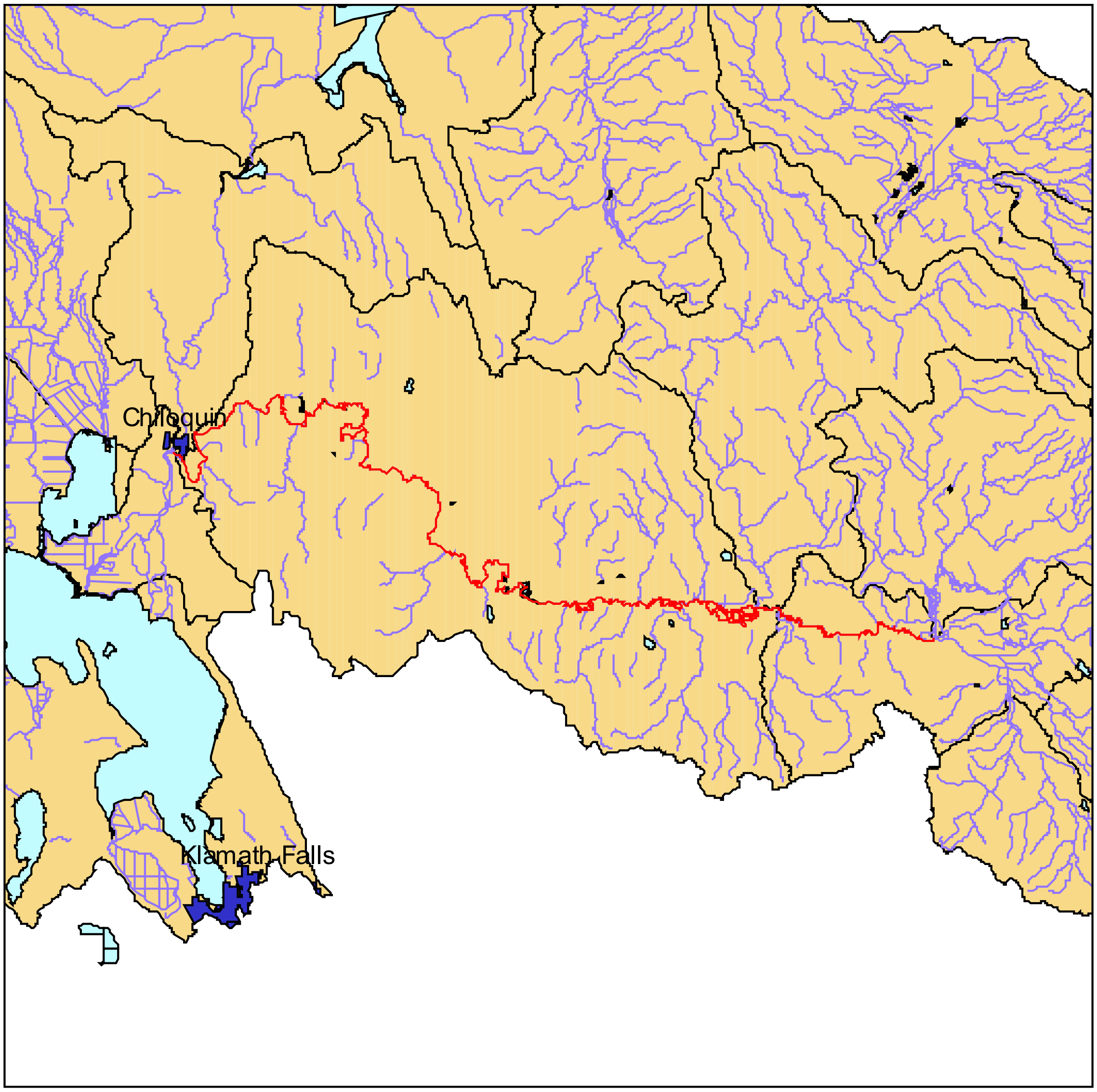


Figure 4-3. Sprague River 303(d) listing (dissolved oxygen)
Mouth to North/South Fork
May 1 - Oct. 31

4.2.3 Pollutant Identification

While many chemical and physical processes can affect dissolved oxygen levels, this analysis determines that water quality standards can be achieved simply by targeting pollutant loading and surrogate measures developed for stream temperature. Specifically, increased solar heating of the water column, poor channel morphology conditions and warm stream temperatures cause excessive periphyton growth. **Periphyton (algal growth) mass is targeted as a pollutant**. The reduction of periphyton mass is targeted in the dissolved oxygen TMDL to meet water quality standards.

4.3 EXISTING SOURCES - CWA §303(D)(1)

4.3.1 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), algal respiration, zooplankton respiration and sediment oxygen demand (SOD). 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. More detailed discussions of the relationships between dissolved oxygen and pollutants are included in the discussion below.

Causes of DO depletion in streams and lakes are many and depend widely on the local ecosystem, background history and climate. Depth of streambed, sediments, algal populations, and phosphorus, and turbidity can impact levels of DO. DO fluctuation is directly related to the changes in either one of these parameters, either individually or in combination.

4.3.1.1 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).

Sediment oxygen demand (SOD) is the oxygen demand exerted by the aerobic decomposition of sediments on the stream bottom. The Department is not aware of any SOD data being collected from the Sprague River. SOD is not considered to be a significant contributor to oxygen depletion in the Sprague River. This assumption is based on model calibration. However, SOD data would be very useful for any future DO modeling and potential TMDL refinement.

4.3.1.2 Ammonia

When nitrogen in the form of ammonia is introduced to natural waters, the ammonia may “consume” dissolved oxygen as nitrifying bacteria converts the ammonia into nitrite and nitrate.

The process of ammonia being transformed into nitrite and nitrate 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. It is because of this somewhat complex relationship that a computer model was used to determine the amount of ammonia that can be attenuated by the river and still meet the DO standards.

4.3.1.3 CBOD

Water column carbonaceous biochemical oxygen demand (CBOD) 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 anthropogenic sources such as polluted runoff.

4.3.1.4 Algal Growth

In many waterbodies, dissolved oxygen concentrations may be violated because of excessive algal growth. Excessive algae concentrations can cause large diurnal fluctuations in DO. Such streams generally exhibit supersaturated dissolved oxygen concentrations during the day and low DO concentrations at night. The State of Oregon has designated an action level of 15 ug/L concentration of chlorophyll a (a measure of suspended algal content) to indicate when algal growth may be a problem. Chlorophyll a action level concentrations are not exceeded in the Sprague River. However, periphyton growth (attached algae) is a concern due to the diurnal DO fluctuations resulting from photosynthesis and respiration.

4.3.1.5 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.

4.3.1.6 Other

While there are other factors such as stream flow that may influence the dissolved oxygen in the tributaries, these are not considered pollutants (or the result of pollutants) and therefore are not analyzed within the TMDL context for allocations.

4.3.2 Analysis - Water Quality Modeling

A dynamic water quality model (dynamic biological component, steady state hydraulics) was developed for the Sprague River in order to evaluate the sensitivity of diurnal dissolved oxygen concentrations to temperature. The model was developed using the modeling framework QUAL2E (USEPA 1987). QUAL2E is supported by the U.S. Environmental Protection Agency and has been extensively applied throughout North America. Channel geometry, velocity, flow and temperature inputs to the model were extracted from a Heat Source temperature model of the Sprague River developed by DEQ.

4.3.2.1 Model Limitations/Assumptions

Qual2e models phytoplankton (suspended algae) rather than periphyton (attached algae). Periphyton is the algae of concern in the Sprague River. The assumption was made that the biological processes (photosynthesis and respiration) in Qual2e could simulate the effect of periphyton growth, provided that during the dynamic simulation the algal concentrations in the critical reach were similar during the early morning and late afternoon time periods. Therefore, boundary and inflow algal concentrations were adjusted during model calibration to result in morning and afternoon algal biomass being roughly equivalent.

Qual2e can dynamically simulate temperature and the biological component; the model, however, is limited to steady-state hydraulics. Inflow into the reaches resulting from springs and tributaries was accounted for in the model, utilizing information from the Heat Source model.

4.3.2.2 Model Calibration

The model was calibrated to daily minimum and maximum dissolved oxygen data, as well as instream temperature, biochemical oxygen demand, and organic phosphorus. The following plot demonstrates the DO calibration. Descriptive statistics for model calibration parameters are presented in **Table 4-3**.

Table 4-3. DO Model Calibration Parameter Statistics

August, 1999-2000	Orthophosphorus (mg/l)	Inorganic Nitrogen (mg/l)	Biochemical Oxygen Demand (mg/l)
Number of data	48	49	49
Mean (95% Confidence Limit)	0.0429	0.0266	0.8224
Upper Confidence Limit	0.0517	0.0296	0.9800
Lower Confidence Limit	0.0341	0.0236	0.6649
Standard Error Mean	0.0044	0.0015	0.0784
Standard Deviation	0.0302	0.0105	0.5486
Coefficient of Variation	0.7043	0.3935	0.6670
Coefficient of Skewness	6.1225	1.7011	2.0860
n-Kurtosis	40.6239	5.1785	5.0595
Geometric Mean	0.0392	0.0249	0.6956
Maximum	0.2400	0.0704	2.9000
Median	0.0390	0.0250	0.7000
Minimum	0.0190	0.0150	0.2000
75th Percentile	0.0440	0.0350	0.9500
25th Percentile	0.0350	0.0202	0.5000

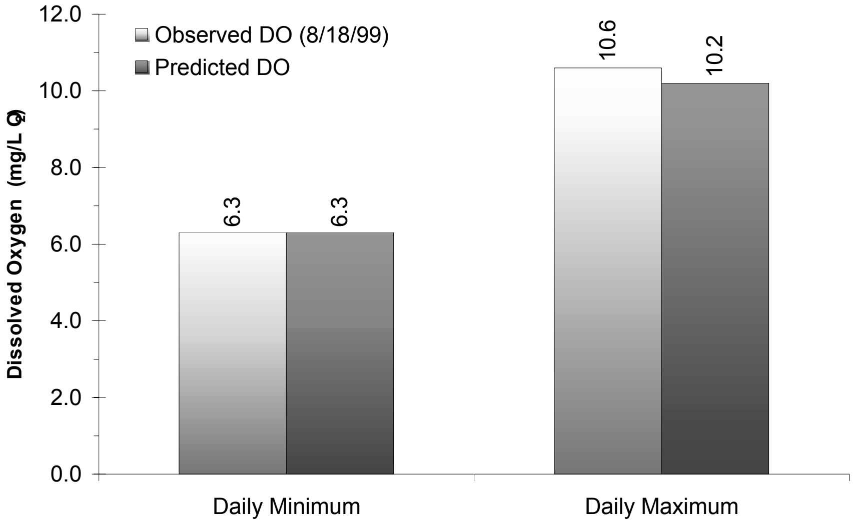


Figure 4-4. Sprague River diurnal dissolved oxygen (measured vs. modeled)

4.3.2.4 Model Simulation – Sensitivity to Temperature Reduction

Nutrients to support periphyton growth are relatively low in the Sprague River, and should be reduced further as a result implementation of the lake nutrient TMDL. Biochemical oxygen demand is also relatively low. Therefore, the emphasis on achieving and maintaining the dissolved oxygen standard is on the benefits from reducing the temperature effect on periphyton growth through instream temperature reduction. Following are descriptive statistics of Sprague River orthophosphorus, total inorganic nitrogen, and biochemical oxygen demand data collected by DEQ:

A simulation was performed to evaluate the impact on DO of the temperature reductions expected from the temperature TMDL system potential shade scenario. The results of the DO model simulation with system potential stream temperatures, potential solar heat loading and improvements in channel morphology are presented in **Figure 4.5**.

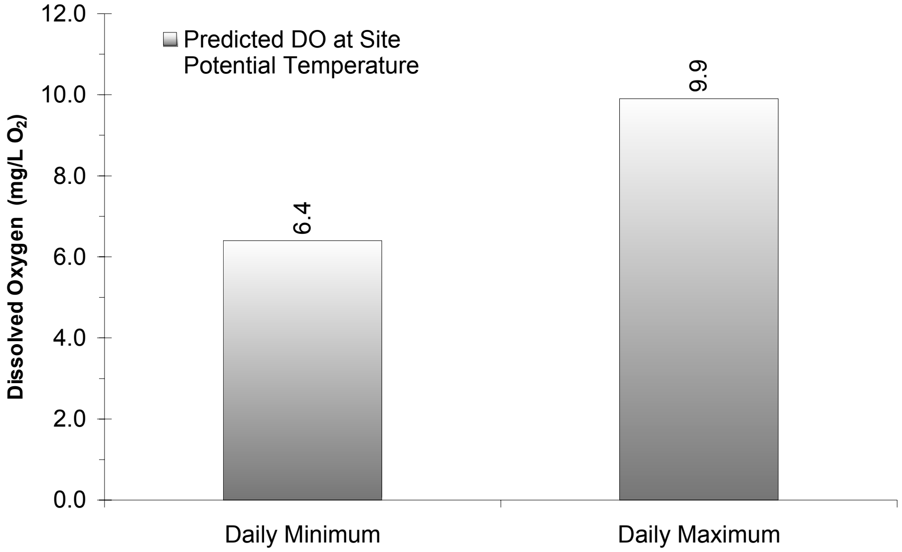


Figure 4-5. DO model simulation output with site potential temperature

4.4 LOAD ALLOCATIONS – 40 CFR 130.2(G) & (H)

It was determined by the DO modeling of the Sprague River that achieving the load allocations established for temperature will reduce periphyton growth and lead to the attainment of the water quality standards for DO.

Allocations for Dissolve Oxygen are the same as those for stream temperature:

- **Section 3.6 Allocations - 40 CFR 130.2(g) and (h)**
- **Section 3.7 Surrogate Measure - 40 CFR 130.2(I)**

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

The following are margins of safety are explicit and implicit in the determination of the DO TMDL:

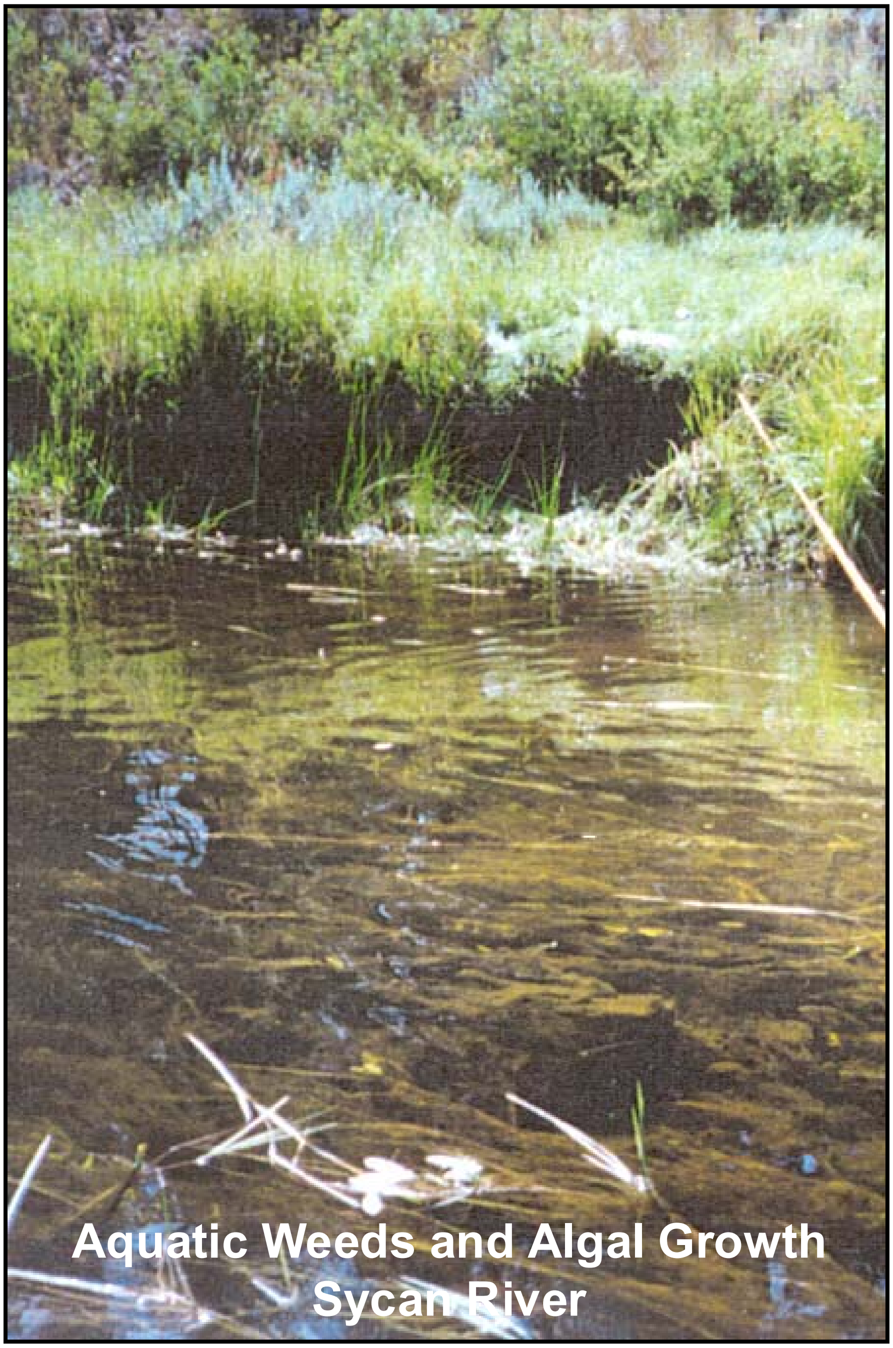
- The DO criteria applicable to this TMDL is an absolute minimum dissolved oxygen concentration of 6.0 mg/L. The dynamic model predicted that during summer low flow (critical) conditions the absolute minimum DO will be 6.4 mg/L. Targeting 6.4 mg/L DO provides an explicit 0.4 mg/L margin of safety.

4.6 SEASONAL VARIATION – CWA §303(D)(1)

There has been limited DO data collected on the Sprague River. Most of the data has been collected during the summer months when maximum DO deficits occur as a result of conditions conducive to excessive periphyton growth. Such conditions include the increased steam temperature. As stated earlier, 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. The second is that, in general, dissolved oxygen sinks increase their oxygen consumption as temperature increases. Therefore, the critical condition for DO is during summer conditions. During cooler, higher flow conditions, DO concentrations will generally be much higher than during summer low flow, which is the critical condition addressed in this TMDL.

CHAPTER V

SPRAGUE RIVER PH TMDL



Aquatic Weeds and Algal Growth
Sycan River

Table 5-1. Upper Klamath Lake drainage Dissolved Oxygen TMDL Components

Waterbodies	SPRAGUE RIVER - HUC CODE 18010202.
Pollutant Identification	Pollutants: increased algal biomass resulting from human caused increases in stream temperatures, channel modifications and near stream vegetation disturbance/removal.
Target Identification (Applicable Water Quality Standards) *CWA §303(d)(1)*	**OAR 340-041-0965(2)(D)** *Fresh waters (except Cascade lakes): pH values shall not fall outside the range of 6.5 to 9.0.*
Existing Sources *CWA §303(d)(1)*	Forestry, Agriculture, Transportation, Rural Residential, Urban
Seasonal Variation *CWA §303(d)(1)*	Critical DO levels on the Sprague River generally occur in 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 cold water-aquatic life dissolved oxygen criteria: *The pH shall not fall below 6.0 mg/L as an absolute minimum.* Waste Wasteload Allocations (Point Sources): There are no point sources in the Sprague subbasin that adversely affect pH. Load Allocations (Non-Point Sources): The LAs for instream temperature are presented in **Table 3-7** and surrogate measures listed in **Section 3.7 Surrogate Measures – 40 CFR 130.2(i)**).
Surrogate Measures *40 CFR 130.2(i)*	Margins of Safety demonstrated in critical condition assumptions and is inherent to methodology. (Detailed in section)
Margins of Safety *CWA §303(d)(1)*	• Analytical modeling of TMDL loading capacities demonstrates attainment water quality standards
Water Quality Standard Attainment Analysis *CWA §303(d)(1)*	To be conducted by Oregon Department of Environmental Quality

5.1 OVERVIEW

Algae production is the principle cause of wide pH fluctuations in the Sprague River. The algae of concern is periphyton. As periphyton obtains carbon dioxide for cell growth the bicarbonate present in the water is decreased. Removal of the bicarbonate from the water will generally increase the pH. High pH is stressful to fish. This daily increase in pH is associated with algal photosynthesis, which is maximized by mid-day light and warmth. The pH standard has been exceeded during the warmest part of the day from about rivermile 50.1 to the mouth.

A carbon balance model was used by ODEQ to assess pH in relation to hydrology, channel morphology, soluble orthophophorus and other nutrients, and stream temperature. Continuous and grab samples collected in 2000 were used for model development. Calibrations were made targeting measured pH levels. Through modeling it was determined that stream temperature surrogate measures presented in the **Section 3.7 Surrogate Measures – 40 CFR 130.2(i)**) that relate to channel morphology, near stream land cover and resulting solar loading and stream temperatures were demonstrated to reduce pH to levels that meet water quality standards.

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

5.2.1 Sensitive Beneficial Use Identification

Beneficial uses affected by aquatic weeds, algae and pH include water contact recreation, aesthetics, and fish-related uses. Excessive algal growth can increase pH in the river to levels that are stressful to fish. The Sprague River provides habitat for redband trout. Redband trout are the most sensitive beneficial use in the Sprague River Subbasin. Discussion of the distribution of redband trout can be found in **Section 1.3.5 Fisheries, Figure 1-10.**

5.2.2 Water Quality Standard Identification

5.2.2.1 pH Water Quality Standard

The following is the State of Oregon standard that is applicable to pH, in the Klamath Basin (OAR 340-41-965(2)(d):

- *Fresh waters (except Cascade lakes): pH values shall not fall outside the range of 6.5 to 9.0.*

5.2.2.2 Deviation from Water Quality Standard and Critical Condition

The Sprague River is listed on the 1998 §303(d) list for pH from the mouth to thye North/South Fork confluence for the summer period. Oregon's §303(d) list and its supporting data references can be publicly accessed through the Oregon Department of Environmental Quality web page at the following URL: http://www.deq.state.or.us.

Observed total phosphorus, pH, and temperature data, all factors that influence periphyton growth, are reviewed below. Much of the reviewed data were used as input to a pH (carbon balance) model used to determine the TMDL.

Phosphorus

An intensive survey was conducted by DEQ on August 16 – 20, 1999. Orthophosphorus (soluble phosphorus), the most readily available form for periphyton growth, was collected at several sites on the Sprague River. **Table 5-2** lists the data collected during the survey that was used as pH model input:

Table 5-2. Sprague River Orthophosphorus (August 16-20, 1999)

MONITORING LOCATION		**Orthophosphorus (mg/L)**
N. Fork Sprague @ Cambell Rd.	(RM 1.5)	0.049
S. Fork Sprague @ Ivory Pine	(RM 1.0)	0.035
Sprague R. near River Crest Rd.	(RM 50.1)	0.040
Sprague R. nr. Williamson Rd.	(RM 10.0)	0.038
Sprague R. @ Chiloquin Ridge Rd.	(RM 6.0)	0.033

As can be seen in **Table 5-2**, the orthophosphorus (OP) steadily decreases from the forks to the mouth. This is evidence that there is periphyton uptake of OP which is decreasing the concentration as the periphyton grow. In order to limit the growth of periphyton, it is recommended in the literature that one of the nutrients be limited to the half-saturation constants.

Literature values for phosphorus half-saturation constants range from 0.001 to 0.005 mg/L (Thomann and Mueller, 1987). This will result in a periphyton productivity rate that is no greater than 50 percent of the maximum rate. It would be highly unlikely for there to be any algal growth limitation for OP because concentrations observed in the North and South forks of the Sprague River are 7 to 10 times higher than the high end of this range, or 0.035 to 0.049 mg/L. There is apparently sufficient instream OP in the forks to support periphyton growth downstream to the Sprague River at rivermile 50.1 where pH violations occur.

Figure 5-1 presents pH data collected by DEQ during May and August, 1999-2000. The longitudinal boxes represent minimum, maximum, upper and lower quartiles, and median observed pH values. The observed pH begins to exceed the 9.0 SU criteria at rivermile 50.1. The increase in pH coincides with the increase in stream temperature from the confluence of the forks to rivermile 50.1.

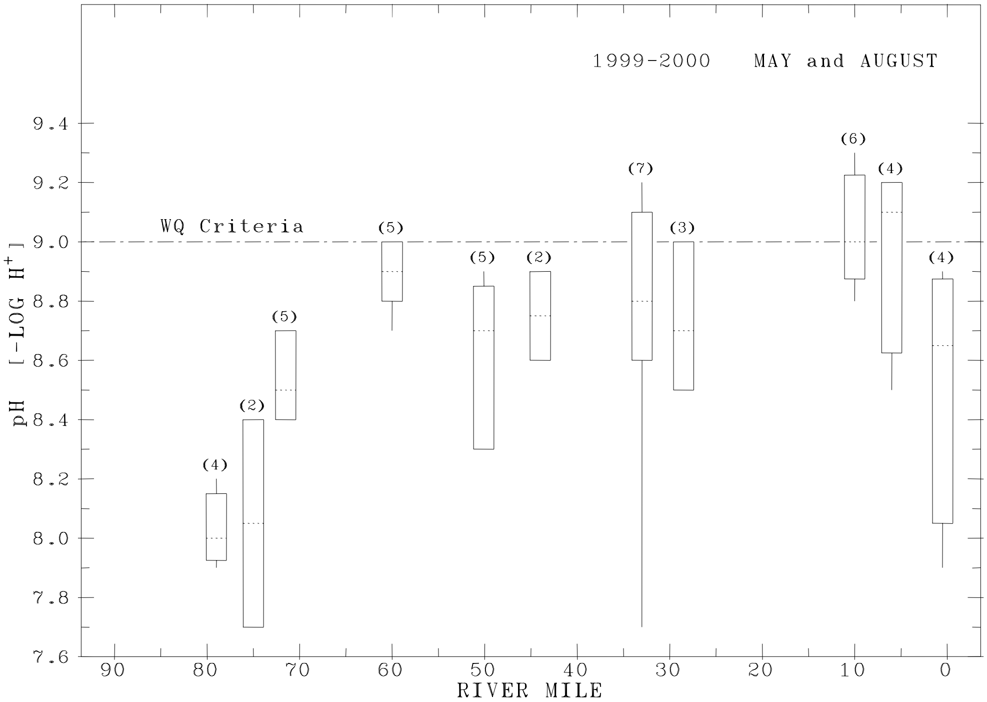


Figure 5-1. Sprague River Longitudinal pH (Box and Whiskers Plot)

5.2.3 Pollutant Identification

Instream temperature is the pollutant that is the focus of this pH TMDL. Nutrients, pH and temperature data indicate that reducing instream temperature is the key to reducing excessive periphyton growth and pH fluctuations in the river. Since phosphorus concentrations are above what could be considered limiting in the upper reaches of the Sprague River, there does not appear to be adequate opportunity to reduce phosphorus loads to have a significant impact on either periphyton growth or pH.

A model (discussed below) was developed to further investigate the relationship between temperature and pH. The model corroborates the association seen in the pH and temperature data collected at rivermile 50.1. The model predicts that the pH standard will be achieved through the implementation of the system potential temperature TMDL allocations.

5.3 EXISTING SOURCES - CWA §303(D)(1)

5.3.1 Data Review

A relationship between pH and stream temperature can be developed. **Figure 5-2** is a regression analysis that illustrates the relationship between pH and temperature at rivermile 50.1. Data plotted were collected by DEQ using a continuous (every 15 minutes) pH, DO and temperature instrument.

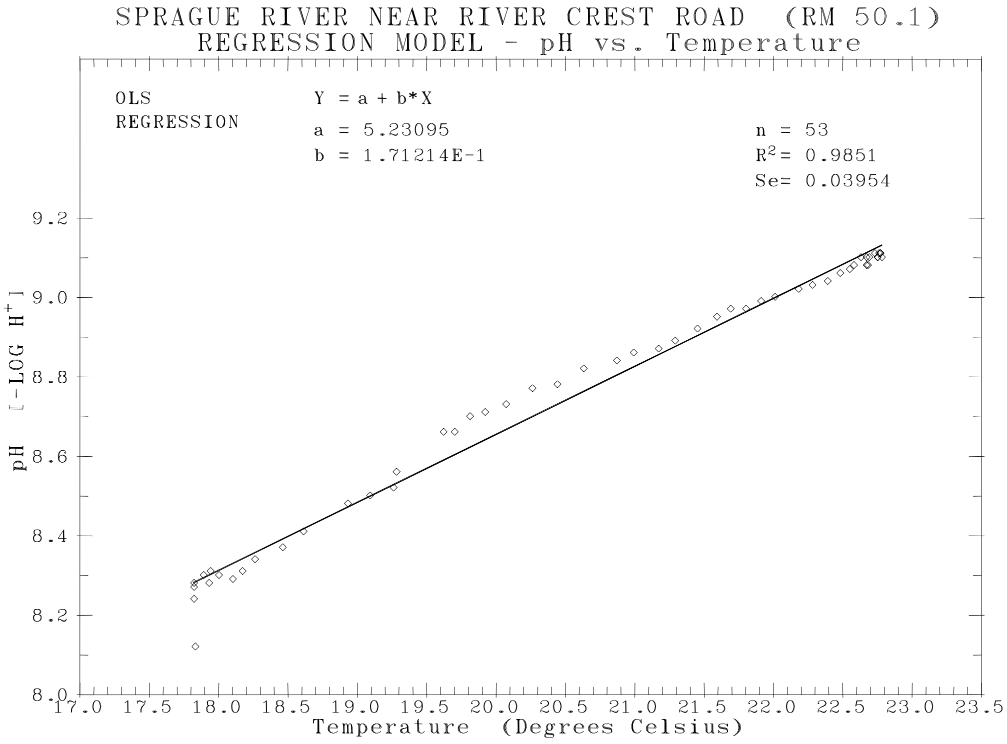


Figure 5-2. Regression Analysis, pH vs. Temperature at RM 50.1

The above plot represents data collected from dawn to dusk for a single day. The pH is relatively low during the early morning hours when stream temperature is at its lowest; the pH increases to above the 9.0 SU pH standard in the afternoon when water temperature warms. The regression analysis ignores other factors, such as the effect that nutrients and light have on algal growth, and subsequently pH. Nonetheless, it illustrates an association between pH and instream temperature.

The increase in Sprague River temperature coincides with the increase in periphyton growth and pH. It appears from this data review that the key to reducing periphyton growth and meeting the goal of instream pH below 9.0 SU is to reduce instream temperature.

Figure 5-3 represents the theoretical relationship between instream temperature and algal growth. The algal growth rate increases significantly as the instream temperature increases.

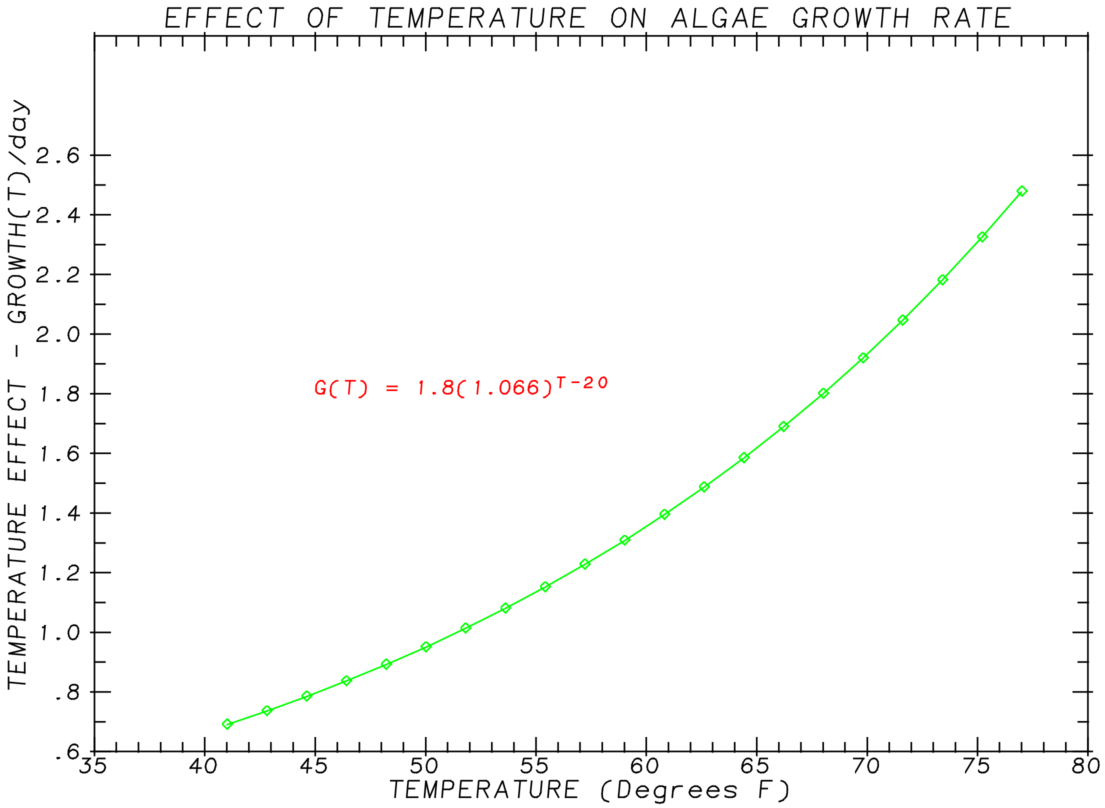


Figure 5-3. The Theoretical Relationship between Instream Temperature and Algal Growth

5.3.2 Photosynthesis and the Carbonate Buffering System

The following sections discuss the theory and application of the pH model used to determine the periphyton loading capacities.

Periphyton is important because of its ability to photosynthesize. The essence of the photosynthetic process centers about chlorophyll containing plants that can utilize radiant energy from the sun, convert water and carbon dioxide into glucose, and release oxygen. The photosynthesis reaction can be written as (Thomann and Mueller, 1987):

$$6\,CO_2 + 6H_2 0 \xrightarrow{\text{photosynthesis}} C_6H_{12}O_6 + 6\,O_2$$

(Equation 5-1)

Periphyton obtains energy from the sun for this daytime process. Instream dissolved oxygen is produced by the removal of hydrogen atoms from the water. The photosynthesis process consumes dissolved forms of carbon during the production of plant cells. Periphyton requires oxygen for respiration, which can be considered to proceed throughout the day and night

(Thomann and Mueller, 1987). Carbon dioxide (CO_2) is produced during the respiration process as represented by the following equation:

$$6\,CO_2 + 6H_20 \xleftarrow{\text{Respiration}} C_6H_{12}O_6 + 6\,O_2$$

(Equation 5-2)

The consumption of CO_2 during photosynthesis and CO_2 production during respiration has no direct influence on alkalinity. Since alkalinity is associated with a charge balance, changes in CO_2 concentrations result in a shift of the carbon equilibrium proton balance and the pH of the solution. (The pH of a solution is defined as an expression of hydrogen-ion concentration in terms of its negative logarithm (Sawyer and McCarty, 1978.)) However, it can be shown that photosynthesis would result in limited alkalinity changes through the uptake of charge ions, such as ortho-phosphorus ($PO4^-$), nitrate (NO_3^-), and ammonia ($NH3^+$).

Carbon dioxide is very soluble in water, some 200 times greater than oxygen, and obeys normal solubility laws within the conditions of temperatures and pressures encountered in fresh water ecosystems (Wetzel, 1983). Dissolved CO_2 hydrates to yield carbonic acid ($CO_2 + H_20 \Leftrightarrow H_2CO_3$). The concentration of hydrated carbon dioxide ($CO_{2(aq)}$) predominates over carbonic acid in natural waters and it is assumed that carbonic acid is largely equivalent to hydrated carbon dioxide (e.g. $[H_2CO_3^*] \cong [CO_{2(aq)}]$) (Snoeyink and Jenkins, 1980).

Carbonic acid dissociates rapidly relative to the hydration reaction to form bicarbonate ($H_2CO_3^* \Leftrightarrow H^+ + HCO_3^-$). In addition, bicarbonate dissociates to form carbonate ions ($HCO_3^- \Leftrightarrow H^+ + CO_3^{2-}$). The various components of the carbonate equilibria are interrelated by temperature dependent constants (i.e. pK_{a1} and pK_{a2}, respectively) which establishes an equilibrium between $H_2CO_3^*$, HCO_3^-, and CO_3^{2-}:

$$\begin{gathered} HCO_3^- + H_20 \Leftrightarrow H_2CO_3^* + OH^- \\ CO_3^{2-} + H_20 \Leftrightarrow HCO_3^- + OH^- \\ H_2CO_3^* \Leftrightarrow H_20 + CO_2 \end{gathered}$$

(Equation 5-3)

From these dissociation relationships, the proportions of $H_2CO_3^*$, HCO_3^-, and CO_3^{2-} at various pH values indicate that $H_2CO_3^*$ dominates in waters at pH 5 and below. Above pH of 9.5 CO_3^{2-} is quantitatively significant. Between a pH of 7 and 9.5 HCO_3^- predominates (Wetzel, 1983).

Alkalinity is defined as a measure of the capacity of a water solution to neutralize a strong acid (Snoeyink and Jenkins, 1980). In natural water this capacity is attributable to bases associated with the carbonate buffering system (HCO_3^-, CO_3^{2-} and OH^-). The carbonate equilibria reactions given above result in solution buffering. Any solution will resist change in pH as long as these equilibria are operational.

Photosynthesis and respiration are the two major biologically mediated processes that influence the amount of available $CO_{2(aq)}$ in fresh water systems. Accordingly, the pH of the solution will fluctuate diurnally and seasonally in accordance with a change of charge balance resulting from the production and/or consumption of $CO_{2(aq)}$ during these respective processes. Thus, an estimation of $CO_{2(aq)}$ will provide a method to determine pH levels in relation to the carbonate equilibrium proton balance within the solution. The concentration of $CO_{2(aq)}$ (e.g. $H_2CO_3^*$) in solution can be determined as:

$$[H_2CO_3^*] = \alpha_0 C_{tCO3}$$

(Equation 5-4)

where $\propto_0$ is mathematically defined as (Chapra, 1997):

$$\alpha_0 = \frac{[H^+]^2}{[H^+]^2 + [H^+]Ka1 + Ka1Ka2}$$

(Equation 5-5)

where K_{a1} and K_{a2} are equilibrium constants for carbonic acid and bicarbonate ions, respectively, and where the amount of total inorganic carbon (C_{tCO3}) in natural waters is defined as:

$$C_{tCO3} = \frac{Alkalinity - \frac{Kw}{[H^+]} + [H^+]}{(\alpha 1 + 2\alpha 2)}$$

(Equation 5-6)

The “Alkalinity” component of Equation 6 is expressed in milliequivalents (meq). The “Kw” term is a temperature dependent equilibrium constant for water and can be defined as:

$$K_w = [H^+][OH^-]$$

(Equation 5-7)

The“$\propto_1$” and “$\propto_2$” terms in Equation 6 are mathematical definitions of ionization fractions (Chapra, 1997):

$$\alpha_1 = \frac{[H^+]k_{a1}}{[H^+]^2 + [H^+]K_{a1} + K_{a1}K_{a2}}$$

(Equation 5-8)

$$\alpha_2 = \frac{K_{a1}K_{a2}}{[H^+]^2 + [H^+]K_{a1} + K_{a1}K_{a2}}$$

(Equation 5-9)

An increase in instream CO_2 results in a lower pH. Conversely, a decrease in CO_2 results in a higher pH. The consumption of CO_2 during periphyton photosynthesis causes elevated pH levels between the Sprague River at rivermile 71.5, 50.1 and 6.0 monitoring sites.

5.3.3 pH Model

The impact of algal production on pH can be determined by a mass balance of the carbonate species. Assuming that the consumption of carbon is consistent along the river bottom, the change in total carbonate species can be estimated as the amount of $CO_{2\ (aq)}$ plus the amount brought in by aeration and production, minus the amount of carbon dioxide consumed over time:

$$C_{CO2(aq)T} = C_{CO2(aq)E} - (\{[C_{CO2(aq)E} - C_{CO2(aq)T}]e^{-ka_{CO2}T}\} + \{[1 - e^{-ka_{CO2}T}][\frac{P_{aCO2}}{K_{aCO2}}]\})$$

(Equation 5-10)

where:

$C_{CO2(aq)}$ = Dissolved CO_2 (e.g. $[CO_{2(aq)}] \approx [H_2CO_3^*]$) (mmoles/l); and
E = Equilibrium Condition @ Time = 0;
T = Time (day);
K_{aCO2} = Inorganic carbon gas transfer rate from the atmosphere (day^{-1});
P_{aCO2} = Periphyton consumption of CO_2 (mmoles CO_2/mg O_2/l * day).

Periphyton oxygen production is developed through an analytical formula developed by Di Torro (1981) that relates the observed range of diurnal dissolved oxygen (Δ_{DO}), depth (H), and aeration coefficient (Ka_{O2}) to a measure of maximum potential benthic oxygen production (P_{aO2}):

$$P_{aO2} = \left(\frac{0.5Ka_{O2}[1 - e^{-KaO2}]}{[1 - e^{(-0.5Ka_{O2})}]^2}\right)(\Delta_{DO})(H)$$

(Equation 5-11)

Equation 11 is a method to calculate the amount of oxygen produced by periphyton per bottom area normalized by depth (mg/l-day). The stoichiometric equivalent of carbon consumed during the photosynthetic process was determined by a simple mass balance relationship which defines the amount of oxygen produced during photosynthesis to the amount of carbon consumed (Equation 1). Specifically, P_{aO2} (Equation 11) was converted to carbon consumed during the photosynthetic process (Chapra, 1997) and incorporated into the model:

$$\text{Oxygen to Carbon Coversion} = \frac{6 \text{ mmole } CO_2}{6 \text{ x } 32 \text{ mg}O_2} = 0.03125 \frac{\text{mmole } CO_2}{\text{mg}O_2}$$

(Equation 5-12)

Equation 10 is analogous to classical dissolved oxygen balances, with the exception that only the free carbon ($[CO_{2(aq)}] \approx [H_2CO_3^*]$) portion of the total carbonate concentration is involved in the aeration equilibrium calculations. Neglecting the influence of buffers other than the carbonate system, and assuming that total alkalinity does not change, the pH can then be estimated from the application of these equations. Changes in free carbon (e.g. $[CO_{2(aq)}] \approx [H_2CO_3^*]$) and total carbonate species (e.g. $[C_tCO_3]$) due to photosynthesis and respiration were calculated through the application of Equation 10. At the range of pH found in the Sprague River (approximately 6.5-9.2), it can be assumed that most of the carbonate buffers are in the form of bicarbonate HCO_3^- (e.g. $C_tCO_3 \approx HCO_3^-$). The temperature dependent equilibrium constant for bicarbonate (K_{a1}) is defined as:

$$K_{a1} = \frac{[H^+][HCO_3^-]}{[H_2CO_3^*]}$$

(Equation 5-13)

Through substitution and rearrangement, pH can be defined as the negative logarithm of $[H^+]$:

$$[H^+] = \frac{K_{A1}[CO_{2(aq)}]}{[C_tCO_3]}$$

(Equation 5-14)

where $[C_tCO_3]$ and $[CO_{2(aq)}]$ are determined through the application of Equation 10.

The carbon balance presented in Equation 10 is expressed in terms of a deficit, and is defined as the difference between saturation and existing concentrations. The carbon deficit will increase due to carbon uptake from periphyton and decrease from gas exchange (Chapra, 1997). The carbon equilibrium level in water is defined as saturation, at which point no net diffusion exchange of carbon between air and the water will occur. The carbon exchange rate between air and water depends on both the differences between existing carbon concentrations and saturation, as well as water turbulence. For example, carbon diffusion rates will increase at a greater carbon deficit and water turbulence levels. This process is similar to re-aeration in streams.

It is assumed that the dominant carbon balance processes are photosynthetic uptake (i.e. periphyton uptake) and carbon re-areation (i.e. gas exchange). By assuming that the uptake of carbon and equilibrium reactions occur at a greater rate than replacement of carbon through aeration, the response of pH to reduced carbon concentration can be modeled. Accordingly, the carbon balance accounts for the current deficit, the amount of carbon brought in through aeration due to that deficit, the amount of carbon lost due to photosynthesis and the amount of carbon brought in through aeration due to the increase deficit resulting from photosynthesis.

The impact of algal production on pH was determined by solving the inorganic carbon mass balance up to a pH of 9.5. Above 9.5, the solution was assumed to be simply greater than 9.5 in order to simplify the calculations (e.g. available inorganic carbon is significantly curtailed at pH values equal or above 9.5.).

5.3.4 Application of the pH Model

5.3.4.1 Model Time Step

A simple steady state analysis does not provide information on how effective nutrient control may be downstream of the nutrient source because uptake from benthic algae reduces the available nutrient supply. Accordingly, a time dependent solution of the inorganic carbon balance was used to assess the potential influence of diurnal pattern of photosynthetic activity. A time dependent determination of total carbonate (C_tCO_3) and hydrated carbon dioxide ($CO_{2(aq)}$) provided a method to estimate in-stream pH levels resulting from increased periphyton production rates downstream of a source of pollution. The time step was modeled at a ten-minute interval.

5.3.4.2 CO_2 and O_2 Aeration Rate

The carbon mass balance equations in this model are extremely sensitive to the estimated, or assumed, ratios between aeration (Ka_{O2}) and production (P_a) rates. It can be shown that a decreased gas transfer or increased benthic consumption rate would increase the rate which the $CO_{2(aq)}$ deficit develops, and therefore result in an increase in-stream pH. In addition, increased depths would decrease the relative impact from periphyton production rates (P_a). The distance or the time required to exceed water quality standards is dependent on the availability of inorganic carbon concentrations of the water entering the section of the river, or from other sources such as tributaries, groundwater, or atmospheric aeration of CO_2.

Aeration rates (K_{aO2}) were estimated through the use of the Tsivoglou and Wallace (1972) formula. The formula was developed using a database of direct measurement of re-aeration:

$$K_{aO2} = 0.88US$$

(Equation 5-15)

Where K_{aO2} is in day^{-1} at 20*C, *S* is the slope in feet/mile, and *U* is the velocity in feet per second. More recent comparisons by Grant and Skavroneck (1980) indicated that this expression is most accurate for small shallow streams (Thomann and Mueller, 1987).

There is little literature describing aeration rates for inorganic carbon (Ka_{CO2}). Tsivoglou (1967) found during a series of laboratory tests that the mean ratio for dissolved oxygen (Ka_{O2}) and inorganic carbon aeration rates (Ka_{CO2}) to be 0.894 with a range of 0.845 to 0.940 and a standard deviation of 0.034. Simonsen and Harremoest (1978) determined aeration rates in a river using a twin curve method for both carbon and oxygen and found that the Ka_{CO2} averaged

0.57 Ka_{O2}. It was assumed that the aeration rates for inorganic carbon followed the relationship presented by Simonsen and Harremoest (1978).

5.3.4.3 Periphyton Growth

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). If all of these are available in excess (i.e. non limiting condition), then dense mats of periphyton will grow and the algal mass will then be regulated by grazing by macro-invertebrates, grazer predation, substrate characteristics, and hydraulic sloughing.

Potential periphyton growth was assumed to occur proportional to the calculated growth rate from light availability (G_L) and the calculated growth rate from nutrient (G_N) concentration, whichever rate is lowest. It was assumed that the calculated production rate of oxygen (P_{AO2}) (see Equation 11) was proportionately reduced by these periphyton growth rate functions:

$$\text{Potential Periphyton Growth} = \text{Minimum}\,(G_N \text{ or } G_L) * P_{AO2}$$

(Equation 5-16)

In addition, a component to estimate periphyton growth response to changes in stream temperature (G_T) was used to estimate the instream pH in the Sprague River from rivermile 84.6 to the mouth given instream temperatures ranging from 18 to 22 degrees Celsius.

5.3.4.4 Algal Growth Factor - Availability of Light (G_L)

Increased Solar Radiation has been shown to increase pH by encouraging photosynthetic chemical reactions associated with primary production (DeNicola et al., 1992). Increased algal productivity in response to increased solar exposure has been well documented (Gregory et al., 1987; DeNicola et al, 1992). In addition, it has been shown that photosynthesis of benthic algal communities in streams reaches a maximum at low light intensities (Gregory et al., 1987; Powell, 1996).

The effect of solar radiation on periphyton productivity (G_L) was added to model calculations, and was assumed to follow a sinusoidal curve described by Simonsen and Harremoest (1978):

$$G_L = \cos\frac{2\pi}{\alpha}t$$

(Equation 5-17)

where alpha is the length of day (assumed 16 hours/day) and t is the time of day and is represented in **Figure 5-3**.

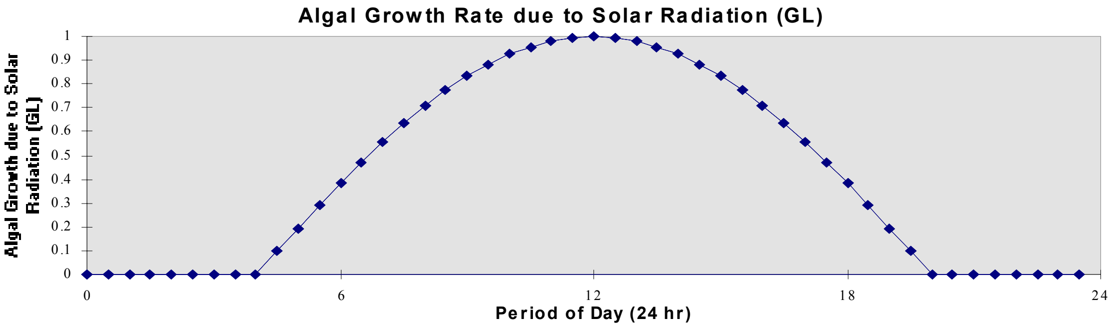


Figure 5-3. Algal Growth Rate due to Solar Radiation (G_L)

5.3.4.5 Algal Growth Factor - Nutrients (G_N)

Algae (periphyton) production due to phosphorus concentrations, as well as periphyton nutrient uptake, was assumed to follow the Michaelis-Menton model of enzyme kinetics: Algae production and nutrient uptake due to available nutrients (G_N) was assumed to be relative to the availability of in-stream dissolved orthophosphorus (**Figure 5-4**).

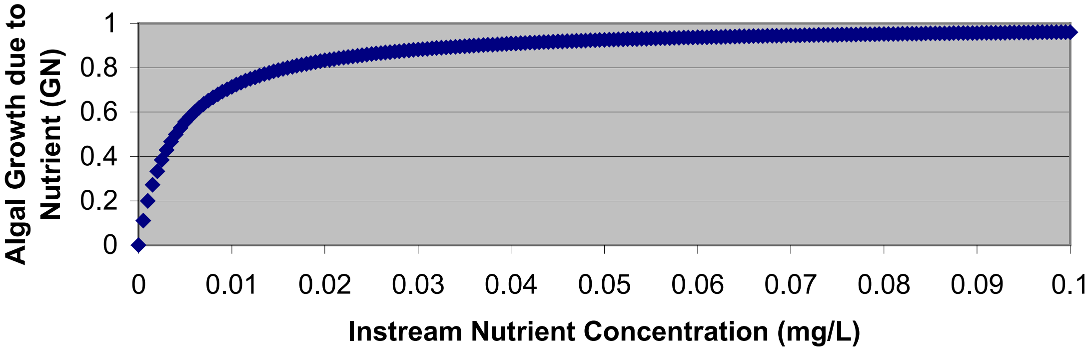


Figure 5-4. Algal Growth rate due to instream nutrient concentration (G_N)

A conservative 0.004 mg/l Michaelis-Menton half saturation constant (K_S) was used in the model to calculate G_N. This value corresponds to an algal growth rate which is one half (0.5) the maximum rate. Typical phosphorus half saturation constants found in literature for benthic algae range from 0.004 to 0.008 mg/l.

If a nutrient control program is initiated, but the reduction in input load only reduces the nutrient concentration to a level of about two to three times the Michaelis constant, then there will be no effect on the algal growth rate. This is equivalent to the notion of the limiting nutrient. Removing a nutrient that is in excess will not have any effect on growth rate until lower concentrations are reached. The treatment program may then be ineffective. The nutrient effect on algal growth, therefore, is a marked contrast to other types of water quality problems where reductions in input load (as in biochemical oxygen demand reduction) can generally be considered as being advantageous (Thomann and Meuller, 1987).

Horner et al. (1990), conducting research in laboratory streams, observed that nutrient uptake by filamentous algae increased most dramatically as Soluble Reactive Phosphorus (SRP) concentrations increased up to 0.015 mg/l, and decreased beyond 0.025 mg/l. The author noted that this information corroborates results presented in Horner et al. (1983): Working with the attached filamentous green algae *Mougeotia* sp., Horner et al. (1983) reported that algal accrual increased in proportion to increased SRP up to about 0.025 mg/l, but further increases were not as pronounced above that concentration, presumably due to a saturation of uptake rates.

Bothwell (1989) reported that maximum algal growth occurred at ortho-phosphorus concentration of 0.028 mg/l. However, this author reported that there appears to be differences between saturation growth rates and biomass accrual rates, with algal cellular requirements saturated at ambient phosphorus levels between 0.003 - 0.004 mg/l (Bothwell, 1992). However, many researchers have found that much higher levels of phosphorus are required to produce algal bloom problems in streams and rivers (Horner et al., 1990; Horner et al., 1983; Welch et al., 1989). Discrepancies may arise because of species differences, differing physical factors, the influences of algal mat thickness and community nutrient requirements, and the dynamics of nutrient spiraling. Accordingly, it was assumed that the algal growth, and subsequently the phosphorus uptake rate, was saturated at in-stream concentrations greater than 0.025 mg/l.

It is important to note that Bothwell (1985) observed that additions of multiple nutrients have a greater stimulatory effect on periphyton than estimated from single nutrients as assumed in this modeling work. Accordingly, pH modeling simulations may underestimate the actual production rates resulting from nutrient additions (G_N) that would be observed in the river.

5.3.4.6 Algal Growth Factor - Temperature (G_T)

The assimilative capacity of a water body is often proportional to temperature because of its influence on equilibrium conditions and several biological and chemical reaction rates. In a review of laboratory studies, field studies and mathematical models, O'Connor (1998) demonstrated that the gas transfer rate between the water surface and overlying atmosphere, rather than the carbonate equilibrium reaction rate, was the controlling mechanism for pH change resulting from temperature changes. Therefore the analysis of assimilative capacity at different temperatures focuses on factors influencing CO_2 exchange and not the carbonate equilibrium reaction.

Specific temperature dependent functions affecting CO_2 exchange include in this model are: 1) CO_2 saturation; 2) maximum algal growth rate (expressed as the photosynthetic demand of carbon); and 3) CO_2 aeration. Temperature influences were estimated by multiplying the ratio between the estimated rate at predicted temperatures and the calculated rate at initial conditions, which was calibrated using observed field temperature data.

The saturation level of carbon dioxide is related to temperature through Henry's law and is calculated as a function of temperature and altitude according to USEPA (1986); and as expressed by Caupp et al. (1997):

$$\mathrm{CO_2\ Saturation} = 10^{-\left(\frac{-2385.73}{\mathrm{Temp}} + 14.01884 - 0.0152642 * \mathrm{Temp}\right)} * 3.162 * 10^{-4} * e^{\frac{(-0.03418\ *\ \mathrm{Elivation})}{(288.0\ -\ 0.006496\ *\ \mathrm{Elivation})}} * 44000$$

(Equation 5-18)

where Temp is water temperature in Kelvin, and Elevation is elevation in meters.

The influence of temperature on the CO_2 aeration rate is modified using the Arrhenius relationship with a standard reference to 20 ^{O}C. The USEPA Document (1985) identified a typical range of theta values between 1.022 and 1.024, with a reported range of 1.008 to 1.047. This range was developed for the simulation of dissolved oxygen. A theta value of 1.02 identified by O'Connor (1998) for CO_2 was used:

$$\mathrm{K_t} = \mathrm{K_{20}}\ \theta^{(Temperate\ (^{o}C)\ -\ 20\ ^{o}C)}$$

(Equation 5-19)

where K_t is the CO_2 aeration rate at temperature (t), and K_{20} is the CO_2 aeration rate at 20 ^{O}C.

Temperature effects on the algal growth rate were related directly to maximum production rate (P_{AO2}) (Equation 11). Algal growth rate, expressed as photosynthetic demand of carbon, was adjusted for temperature using the equations presented by the USEPA (1986):

$$\text{Algal Growth}_{\text{(Temperature)}} = \theta^{\text{(Temperature (C) - 20 (C))}}$$

(Equation 5-20)

Typical theta values were reported by USEPA to range between 1.01 and 1.2. Eppley (1972) reported a theta of 1.066. This value was used in the model.

5.3.5 Initial Buffering Capacity

Initial alkalinity, pH and temperature of the Sprague River were included in the carbon balance calculations in the model.

5.3.5.1 Algal Biomass Accrual

Results obtained from the application of this model do not simulate algal biomass accrual, but it provides a method to calculate an assumed diel production (≈ growth) pattern. A simple procedure proposed by Horner et al. (1983) and discussed by Welch et al. (1989) provides a steady state kinetic prediction of the potential periphyton biomass accrual based on physical and chemical characteristics of the river and their influence on algae growth rates and accumulation. The model was originally calibrated against the growth of filamentous green algae in artificial channels over a range of velocities and phosphorus concentrations. Application of the model with site specific data from the Spokane River, Washington (Welch et al., 1989) and the Coast Fork Willamette River, Oregon (DEQ 1995-b) indicated that the rate of biomass accumulation reduced proportionally to that of in-stream limiting nutrient concentrations, and that the rate of bioaccumulation was expected to decrease downstream as uptake removed the limiting nutrient. In addition, it was also hypothesized that periphyton biomass will eventually approach maximum levels even at low in-stream nutrient concentrations following a sufficiently long growing season.

5.3.5.2 Invertebrate Grazing

The pH model described above does not estimate the potential effects of grazing by macroinvertebrate on the standing crops and net production of the periphyton community. Grazing may influence not only standing crop, but also nutrient uptake and recycle rates, as well as species distribution within the benthic algal mat. Grazing generally results in lower periphyton biomass (Lamberti et al., 1987 and; Welch et al., 1989), a simplified algal community, lower rates of carbon production, and a constraint nutrient cycling (Mulholland et al., 1991). Reduced production rates anticipated under a nutrient control strategy would likely increase the relative influence of grazing as a controlling mechanism on periphyton. Hence, periphyton biomass accrual rates in The Sprague River may be lower than predicted by the model as a result of a relative increased invertebrate grazing pressure at the anticipated reduced periphyton growth rates.

5.3.6 Model Calibration

The model was calibrated using the streamflow and continuous pH data collected during August, 1999. As can be seen in **Figures 5-5** and **5-6** the model calculated pH matched the observed pH.

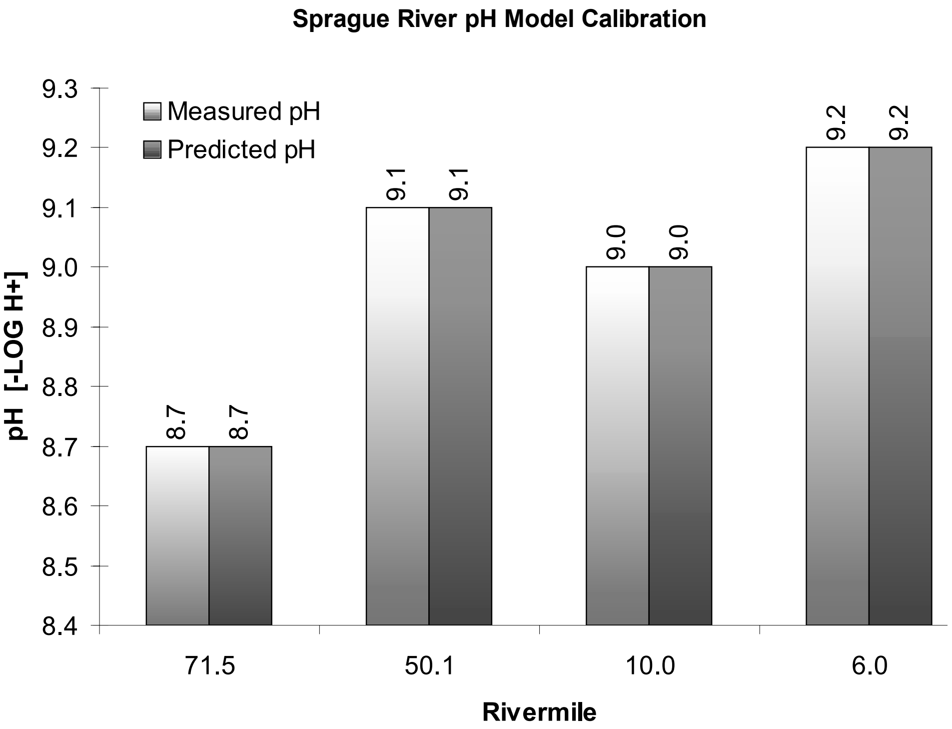


Figure 5-5. Sprague River pH Model Calibration

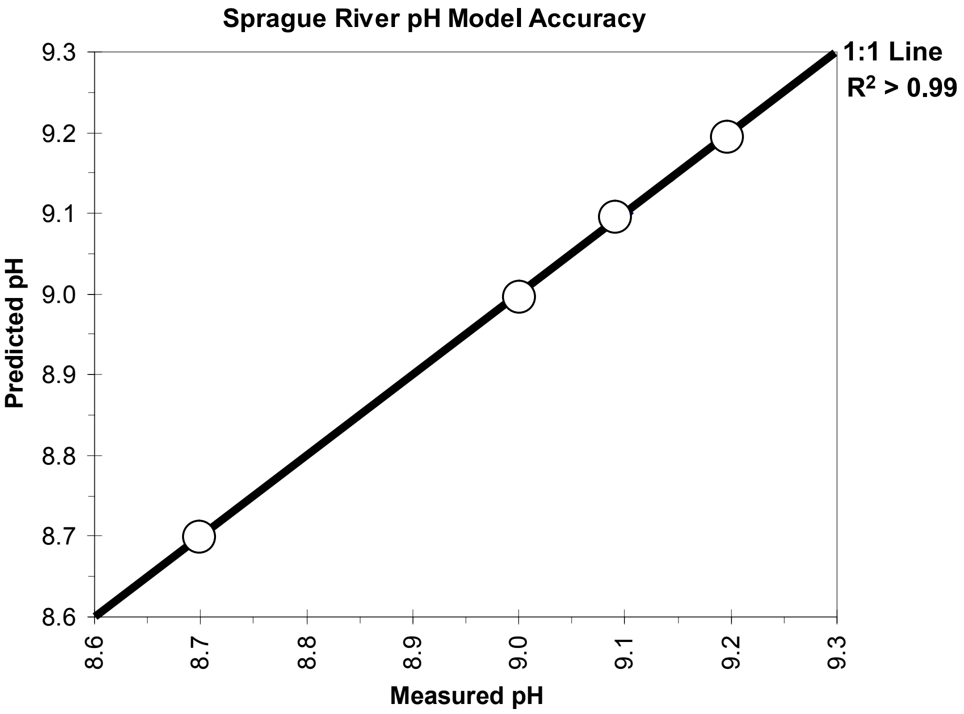


Figure 5-6. Sprague River pH Model Accuracy

5.3.7 pH Standard Attainment Analysis

The temperature model of the Sprague River predicts system potential maximum temperatures at rivermiles 71.5, 50.1 and 6.0 of 18.3, 18.9, and 19.4 degrees Celsius, respectively. The pH model predicts that the maximum instream pH at rivermile 50.1 will be 8.6 SU with the river achieving site potential temperatures (**see model output in Figure 5-7**). The pH predicted at site potential temperature near the mouth of the Sprague River is 8.5 SU. **The loading capacities for pH are the system potential instream temperatures discussed above.**

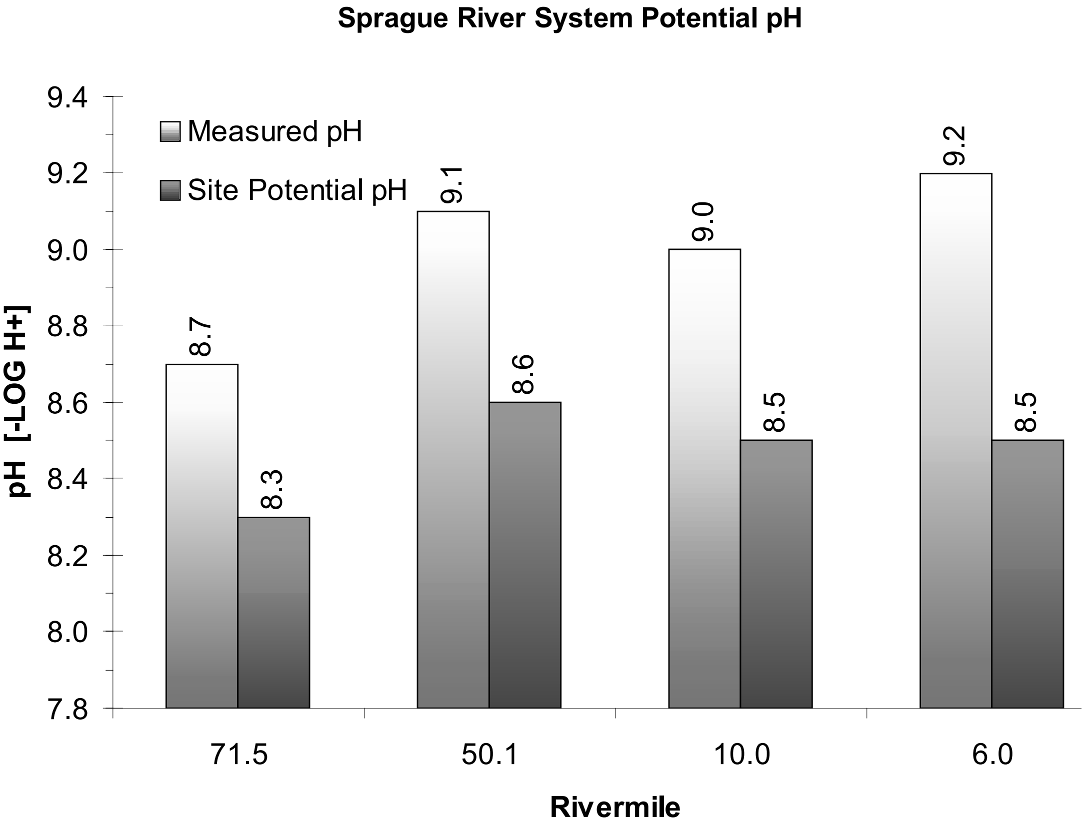


Figure 5-7. pH Model Output at System Potential Temperatures

5.4 LOADING CAPACITY – 40 CFR 130.2 (F)

As discussed in the data review, a water quality concern in the Sprague River from approximately rivermile 50.1 to the mouth is pH exceeding the State of Oregon water quality standard (greater than 9.0 standard pH units (SU)). The presence of instream aquatic plants can have a profound effect on the variability of pH throughout a day and from day to day. In the Sprague River, the emphasis is on attached algae (periphyton) which clings to rocks and other surfaces.

Nutrients, light availability, and instream temperature are all parameters necessary for supporting periphyton growth. The data review indicates that the best opportunity to reduce pH to below the water quality standard is through the implementation of the temperature TMDL.

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 data review also indicates that the increase in pH is correlated with the increase in instream temperature at rivermile 50.1. Both the regression analysis of pH versus temperature and a pH model of the Sprague River (rivermile 84.6 to the mouth) predict that the instream pH will be maintained below the standard (9.0 SU) when system potential temperature TMDL allocations and the resulting instream cooling are achieved.

The temperature model of The Sprague River (Section 4.1.7) predicts system potential temperatures of 18.3, 18.9 and 19.4 degrees Celsius at rivermiles 71.5, 50.1, and 6.0, respectively. The pH/temperature regression and the pH model predict that the maximum instream pH at rivermiles 71.5, 50.1 and 6.0 will be 8.6 SU and thus achieving the pH standard, when the river achieves system potential temperatures. **The loading capacities for this TMDL are the system potential instream temperatures as predicted in Section 3.9 Water Quality Standard Attainment Analysis – CWA §303(d)(1).**

5.5 LOAD ALLOCATIONS – 40 CFR 130.2(G) & (H)

It was determined by the above pH modeling of the Sprague River that achieving the load allocations established for temperature will reduce periphyton growth and lead to the attainment of the water quality standards for pH. Refer to 3.6 Allocations – 40 CFR 130.2(g) and (h) of the temperature TMDL for allocations. **The temperature TMDL allocations are the allocations for this TMDL.**

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

The following are margins of safety implicit in the determination of the periphyton/pH TMDL:

- A conservative half-saturation constant was used in the model (0.004) which is at the lower end of the range in the literature for algae (EPA, 1985).

- The pH model does not estimate the potential effects of grazing by macroinvertebrates on the periphyton crop. Grazing may influence not only the standing crop, but also nutrient uptake and recycle rates, as well as species distribution within the benthic algal mat. Grazing generally results in lower periphyton biomass (Lamberti, et al., 1987 and Welch, et al., 1989), a simplified algal community, lower rates of carbon production, and constrained nutrient cycling (Mulholland, et al., 1991). Reduced algal production rates under the temperature management strategy will likely increase the relative influence of grazing as a controlling mechanism on periphyton.

- Because photosynthesis responds quantitatively to changes in light, environmental variation in its quantity and quality potentially accounts for much of the variation in the physiology, population growth, and community structure of benthic algae (Stevenson et al. 1996). In addition to reducing periphyton growth through cooling the river, the additional shading of the river resulting from the implementation of the temperature TMDL will help reduce light availability, which may help the river shift from a dominance of nuisance filamentous green algae species (i.e. *Cladophora*) to single cell species (i.e., diatoms).

CHAPTER VI

WATER QUALITY MANAGEMENT PLAN

6.1 INTRODUCTION

This document is intended to describe strategies for how the Upper Klamath Lake Drainage Basin (UKLDB) Total Maximum Daily Load (TMDL) will be implemented and, ultimately, achieved. The main body of the Water Quality Management Plan (WQMP) has been prepared by the Oregon Department of Environmental Quality (ODEQ) and includes a description of activities, programs, legal authorities, and other measures for which ODEQ and the designated management agencies (DMAs) have regulatory responsibilities. This WQMP is the overall framework describing the management efforts to implement TMDLs in the UKLDB. DMA-specific Implementation Plans which describe each DMA's existing or planned efforts to implement their portion of the TMDLs will be submitted to DEQ for approval within one year of finalizing the TMDL. The relationship between DMAs and the TMDL/WQMP is presented schematically in **Figure 6-1**, below.

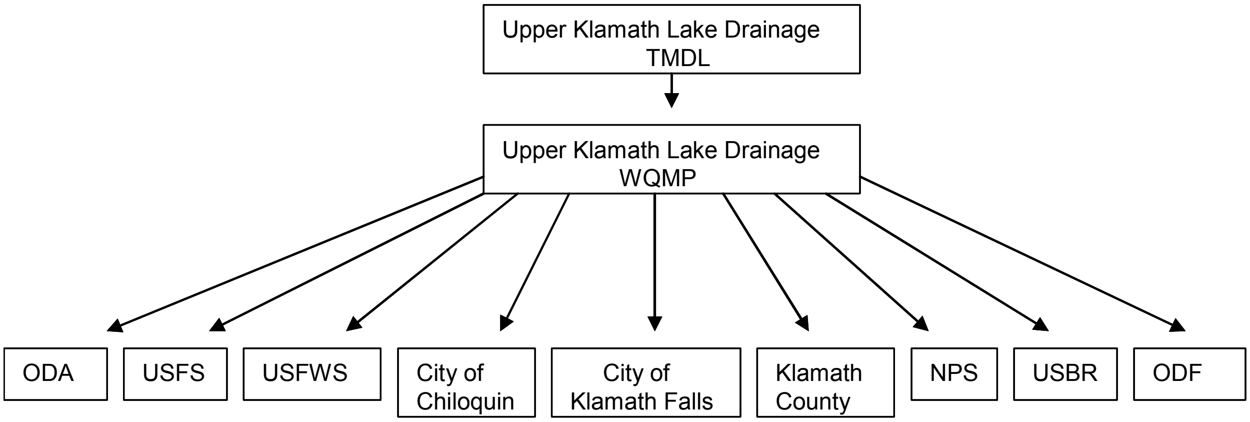


Figure 6-1. TMDL/WQMP DMA Implementation Plan Schematic

These Implementation Plans, when complete, are expected to fully describe DMA efforts to achieve their appropriate allocations, and ultimately, water quality standards. Since the DMAs will require some time to fully develop these Implementation Plans once the TMDLs are finalized, the first iteration of the Implementation Plans are not expected to completely describe management efforts. While the listed DMAs comprise the majority of agencies and organizations responsible for affecting water quality, the Department may find that there other DMAs responsible for water quality improvement. The list of DMAs will be expanded at that time.

ODEQ recognizes that TMDL implementation is critical to the attainment of water quality standards. Additionally, the support of DMAs in TMDL implementation is essential. In instances where ODEQ has no direct authority for implementation, it will work with DMAs on implementation to ensure attainment of the TMDL allocations and, ultimately, water quality standards. Where ODEQ has direct authority, it will use that authority to ensure attainment of the TMDL allocations (and water quality standards).

This document is the first iteration of the Water Quality Management Plan (WQMP) for the new and revised UKLDB TMDLs. As explained in "Element 6" of this document, DMA-specific Implementation Plans will be more fully developed once the current TMDLs are finalized. This WQMP will establish proposed timelines (following final TMDL approval) to develop full Implementation Plans. ODEQ and the DMAs will work cooperatively in the development of the TMDL Implementation Plans and ODEQ will assure that the plans adequately address the elements described below under "TMDL Water Quality Management Plan Guidance". In short, this document is a starting point and foundation for the WQMP elements being developed by ODEQ and UKLDB DMAs.

6.2 ADAPTIVE MANAGEMENT

The goal of the Clean Water Act and associated Oregon Administrative Rules (OARs) 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 non-point sources are the main concern. To achieve this goal, implementation must commence as soon as possible.

Upper Klamath Lake TMDLs are numerical loadings that are set to limit pollutant levels such that in-lake 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. TMDLs for Upper Klamath Lake were developed using the available data and associated pollutant loading estimates available at the time. Models and techniques are simplifications of these complex processes and, as such, are unlikely to produce an exact prediction of how Upper Klamath and Agency Lakes will respond to the application of various management measures.

WQMPs are plans designed to reduce pollutant loads to meet TMDLs. ODEQ recognizes that it may take several decades - after full implementation before management practices identified in a WQMP become fully effective in reducing and controlling pollution. In addition, ODEQ recognizes that technology for controlling nonpoint source pollution is, in many cases, in the development stages and will likely take one or more iterations to develop effective techniques. It is possible that after application of all reasonable best management practices, some TMDLs or their associated surrogates cannot be achieved as originally established. **Figure 6-2** is a graphical representation of this adaptive management concept.

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 the UKL TMDLs, pollutant surrogate (total phosphorus) has been defined as alternative targets for meeting the TMDLs for pH and dissolved oxygen. The purpose of a surrogate is not to bar or eliminate human activity in the basin. 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 surrogate. It is also recognized that full attainment of pollutant surrogate (target load reduction) 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.

If a non-point source that is covered by the TMDLs complies with its finalized Implementation Plan or applicable forest practice rules, it will be considered in compliance with the TMDL.

If and when ODEQ determines that the 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, the Department shall reopen the TMDL and adjust it or its interim targets and the associated water quality standard(s) as necessary.

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. 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 on departmental orders to implement management goals leading to water quality standards.

If a source is not given a load allocation, it does not necessarily mean that the source is prohibited from discharging any wastes. A source may be permitted to discharge by ODEQ if the holder can adequately demonstrate that the discharge will not have a significant impact on water quality over that achieved by a zero allocation. For instance, a permit applicant may be able to demonstrate that a proposed thermal discharge would not have a measurable detrimental impact on projected stream temperatures when site temperature is achieved. Alternatively, in the case where a TMDL is set based upon attainment of a specific pollutant concentration, a source may be permitted to discharge at that concentration and still be considered as meeting a zero allocation.

As part of the adaptive management process, the Department is committed toward ensuring that there is a process to evaluate new data and technical analyses into the TMDL as this information is made available. In response to this need, the Department will be actively involved after the TMDL is approved by EPA and will assign a staff person to oversee implementation of the TMDL and this WQMP. Activities assigned to this staff person include:

I. With the assistance of local stake holders, establishing a science review team comprised of qualified scientists to accomplish the following objectives:

  A. Provide a forum to review water quality data.
  B. Provide technical review of research reports related to water quality of UKLD.
  C. Assist the Department in coordinating water quality monitoring in the UKLD.
  D. Provide a forum to discuss the effectiveness of activities to reduce and control pollution.
  E. Provide recommendations concerning adjustments to the TMDL and/or allocations.
  F. Convene a meeting of the science review team quarterly to assess progress.

II. At least annually, and more frequently if deemed necessary, hold a public meeting to provide updates on new data and progress toward implementing the TMDL and WQMP.

III. Within two years (and every two years thereafter), convene a special meeting of the science review team and local stakeholders to consider and/or propose modifications to the TMDL and/or WQMP. The Department will seriously consider any and all recommendations proposed by stakeholders to revise the TMDL/WQMP. However, the Department will make the final decision on revising the TMDL because a revision of the TMDL will require significant resources.

IV. DEQ staff will actively assist researchers in acquiring funding for research projects in, but not limited to, the following list:

A. **Investigate and model phosphorus internal loading as a function of wind-induced mixing of suspended sediments**. The role of wind in the cycling of nutrients from the sediments is not considered in this TMDL. Previous research by USGS studied the mechanisms for wind-induced resuspension of sediments. Further studies should quantify the loading of phosphorus to the water column from wind-induced resuspended sediments.

B. **Investigate and model cycling and storage of phosphorus in sediments**. Data collection and analysis should focus on both long-term changes in nutrient storage in sediments and lake management effects of storage processes.

C. **Quantify loading capacity and load allocations as a function of lake levels**. This TMDL is developed for average loading, hydrologic and reservoir/lake management conditions from 1991 to 1998. Additional analysis is needed to evaluate pH responses for alternative reservoir/lake management (Walker 2001).

D. **Quantify sedimentation and phosphorus loading as a function of sediment loads from tributaries**. It is widely acknowledged that both human and natural upland sources of sedimentation contribute bound phopsphorus to the streams and rivers that drain to Upper Klamath Lake (Gearheart et al. 1995, Eilers et al. 2001 and Kann and Walker, 2001). Sediment sources should be monitored from the source (i.e. active erosion, stream bank retreat and downcutting) and the downstream effects (i.e. stream and lake sedimentation and sediment accumulation rates) should be more accurately quantified. Overland erosion, stream bank erosion and overall stream condition is an important component for each of the TMDL parameters in this document. While there has been significant effort in quantifying and analyzing causes and effects of sedimentation, improved understanding and documentation of source areas, associated impacts and restoration processes will serve to benefit and compliment the overall goals of this TMDL.

E. **Quantify phosphorus loads reductions associated with reconnected wetlands**. Snyder and Morace (1997) provide compelling information regarding the role of wetlands in Upper Klamath Lake nutrient loading. Further research should consider the quantification of loading reductions associate with wetland functions: reduction of peat decomposition, removal of pumps and gravity drains from reclaimed areas, wetland reconnection to the lake systems and wetland macrophyte nutrient uptake dynamics.

F. **Investigate the role of dissolved humic substances in the suppression of *AFA* blooms**. Geiger (2001) speculates that dissolved organic material can affect the growth rates of *Aphanizonmenon* via: the effect on light availability, interactions among dissolved iron, dissolved organic matter and nutrients and/or the complexation of toxic metals by dissolved organic matter.

G. **Install continuous flow gages at the mouth of Sevenmile Canal and Wood River at Dike Road**. Gaps in flow data occur in the lower Wood River and Sevenmile Canal monitoring sites during the 1991 to 1998 period of record. While it is recognized that these are difficult sampling environments, the installation and operation of Doppler gages will allow accurate quantification of flows and nutrient loading. These sites justify the monitoring expense due to their high rates of nutrient loading, the increased accuracy will translate to more accurate loading calculations, and due to the current and future restoration efforts there is a need for measurement of the potential loading reductions.

H. **Identify hot-spots of external (upland, wetland and lake biota) phosphorus loading**. Geiger (personal communication) suggests that nutrient loading from malfunctioning septic systems should be quantified. Rykbost (personal communication) suggests that future investigations should quantify rates of phosphorus loading from waterfowl and introduced fish species.

I. **Quantify phosphorus loads from ungaged springs and artesian wells**.

J. **Investigate the potential composition near stream land cover composition at highly disturbed near stream sites**.

K. **Where appropriate, refine channel morphology targets based upon hydrologic conditions and riparian function**.

L. **Develop a coordinated water quality sampling and quality assurance plan to integrate sampling activities by the Klamath Tribes, state and federal agencies**.

In addition to the implementation activities stated above, ODEQ also has the following expectations and intentions:

- ODEQ expects that each DMA will also monitor and document its progress in implementing the provisions of its Implementation Plan. This information will be provided to ODEQ for its use in reviewing the TMDL.
- As implementation of the WQMP and the associated Implementation Plans proceeds, ODEQ expects that DMAs will develop benchmarks for attainment of TMDL surrogates, which can then be used to measure progress.
- Where implementation of the Implementation Plans or effectiveness of management techniques are found to be inadequate, ODEQ expects management agencies to revise the components of their Implementation Plan to address these deficiencies.
- When ODEQ, in consultation with the DMAs, 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 revise it as appropriate. ODEQ would also consider reopening the TMDL should new information become available indicating that the TMDL or its associated surrogates should be modified.

6.3 TMDL WATER QUALITY MANAGEMENT PLAN GUIDANCE

In February 2000, ODEQ entered into a Memorandum of Agreement (MOA) with the U.S. Environmental Protection Agency (EPA) that describes the basic elements needed in a TMDL Water Quality Management Plan (WQMP). That MOA was endorsed by the Courts in a Consent Order signed by United States District Judge Michael R. Hogan in July 2000. These elements, as outlined below, will serve as the framework for this WQMP.

WQMP Elements

1. Condition assessment and problem description
2. Goals and objectives
3. Identification of responsible participants
4. Proposed management measures
5. Timeline for implementation
6. Reasonable assurance
7. Monitoring and evaluation
8. Public involvement
9. Costs and funding
10. Citation to legal authorities
11. This UKLDB WQMP is organized around these plan elements and is intended to fulfill the requirement for a management plan contained in OAR 340-041-0745.

6.3.1 Condition Assessment and Problem Description

The 1998 303(d) Upper Klamath Lake Drainage listings are summarized below (for more information refer to the DEQ website containing Oregon's 303(d) list at http://waterquality.deq.state.or.us/wq/. In the following text, values other than State water quality standards are referenced. This is because some standards are narrative rather than numeric, necessitating additional numeric targets to fulfill or evaluate attainment of water quality standards.

- Temperature: Williamson River, Sprague River Drainage, Agency Lake, Upper Klamath Lake, and tributaries based on exceedance of the numeric temperature criteria of the Oregon water quality standard.

- pH: Sprague River, mouth to North/South Fork, Agency, Upper Klamath lakes based on exceedance of numeric pH criteria of the Oregon water quality standard.

- DO: Agency, Upper Klamath Lakes, Sprague River, mouth to North/South Fork based on the toxicity absolute minimum criteria of 4.0 mg/l an Oregon water quality standard; also based on listing specifications for ‘cold’ or ‘cool’ water.

- Chlorophyll-a : Klamath and Agency Lakes. Listed as a nuisance criteria.

- Habitat*:* Threemile Creek, mouth to headwaters based on low pool frequency and minimal large woody debris occurrence, relative to ODFW benchmarks.

6.3.2 Existing Sources of Water Pollution

6.3.2.1 Eutrophication

Upper Klamath and Agency Lakes exhibits many water quality problems typically associated with excessive algal production. Extensive blooms of the cyanobacterium *Aphanizomenon flos-aqaue* (AFA) cause significant water quality deterioration due to photosynthetically elevated pH (Kann and Smith 1993) and to both supersaturated and low dissolved oxygen (DO) concentrations (Kann 1993a, 1993b). AFA is the dominant primary producer in Upper Klamath and Agency Lakes (UKL), comprising >90% of the primary producer biomass during blooms. Both high pH and low DO reach levels that are considered lethal levels in UKL, and as such are important parameters affecting survival and viability of native fishes.

Total phosphorus load reduction is the primary mechanism to attain water quality standards for pH, dissolved oxygen and algal biomass in Upper Klamath Lake and Agency Lake. Seasonal maximum algal growth rates in Klamath and Agency Lakes, and its subsequent impact on elevated pH and low dissolved oxygen levels, are controlled primarily by phosphorus and secondarily by light and temperature. High nutrient loading promotes correspondingly high production of algae, which, in turn, modifies physical and chemical water quality characteristics that can directly diminish the survival and production of fish populations. However, year to year variations in the timing and development of algal blooms during late spring and early summer are strongly temperature dependent.

Under conditions of high nutrient input and adequate light, algae growth rates increase, resulting in an accumulation of biomass, until some factor, either light, nutrients, or other factors, limits further growth. As biomass increases, the available soluble forms of nitrogen (N) and phosphorus (P) decrease, because the nutrients are accumulated in the biomass, and are therefore unavailable for further biomass increase.

The primary anthropogenic sources of total phosphorus in the UKLDB are the following (this listing is not meant to be comprehensive, but it does contain probable sources in UKDB):

1. Wastewater Treatment Plants and Sanitary Sewer Systems
One municipal waste water treatment plant at Chiloquin discharges into the Williamson River. Wasteload allocations have been assigned to this plant.
2. Permitted Sites other than POTWs
Crooked Creek fish hatchery is the only other permitted point source. Wasteload allocations have been assigned to this facility.
3. Agricultural Runoff
Some of the potential sources of phosphorus in agricultural runoff are fertilizers, animal waste, and erosion.
4. Urban Runoff
Urban runoff can be quite high in total phosphorus concentrations. The ultimate sources could include fertilizers, erosion, cross-connections, etc.
5. Rural Runoff
Rural runoff may contain phosphorus from the same sources as urban runoff, with the possible exception of sanitary sewers. Additional potential sources are ranches, farms, and horse pastures. These sites are often stocked very densely.
6. Forestry Runoff
Since surface runoff in forested areas during the TMDL season is expected to be minimal, phosphorus loads from forestry operations during are most likely predominately associated with roads and culverts.
7. Failing Septic Systems
Effluent from failing septic systems will contain phosphorus, along with bacteria, BOD and other pollutants.
8. Instream and Near-stream Erosion
Phosphorus contained in soils may be transported to Upper Klamath and Agency Lakes through instream and near-stream erosion. While a certain amount of this erosion is natural, some erosion (especially during the summer), is not natural.

6.3.2.2 Temperature

Surface water temperatures in UKDB are heavily influenced by human activities. These activities are diverse and may have either a detrimental or a beneficial impact on river temperature. Some of these activities have readily observable and direct impact on water temperature, such as cool water releases from reservoirs, while other activities may have a less observable impact, such as the loss of riparian vegetation (shading), water withdrawal and the disconnection of floodplains to rivers.

Riparian vegetation, stream morphology, hydrology, climate, and geographic location influence stream temperature. While climate and geographic location are outside of human control, the condition of the riparian area, channel morphology and hydrology can be affected by land use activities. Specifically, elevated summertime stream temperatures attributed to anthropogenic sources may result from the following conditions within the UKLDB:

1. Riparian vegetation disturbance that reduces stream surface shading, riparian vegetation height, and riparian vegetation density (shade is commonly measured as percent effective shade),
2. Channel widening (increased width to depth ratios) due to factors such as loss of riparian vegetation that increases the stream surface area exposed to energy processes, namely solar radiation,
3. Reduced flow volumes (from irrigation, industrial, and municipal withdrawals) or increased high temperature discharges, and
4. Disconnected floodplains which prevent/reduce groundwater discharge into the river.

6.3.3 Goals and Objectives

The overall goal of the TMDL Water Quality Management Plan (WQMP) is to achieve compliance with water quality standards for each of the 303(d) listed parameters and streams in the UKLDB. Specifically the WQMP combines a description of all Designated Responsible Participants (or Designated Management Agencies (DMA)) plans that are or will be in place to address the load and wasteload allocations in the TMDL. The specific goal of this WQMP is to describe a strategy for reducing discharges from nonpoint sources to the level of the load allocations and for reducing discharges from point sources to the level of the waste load allocations described in the TMDL. As discussed above, this plan is preliminary in nature and is designed to be adaptive as more information is gained regarding the pollutants, allocations, management measures, and other related areas.

The expectation of all DMAs are to:

1. Develop Best Management Practices (BMPs) to achieve Load Allocations and Waste Load Allocations.
2. Give reasonable assurance that management measures will meet load allocations through both quantitative and qualitative analysis of management measures.
3. Adhere to measurable milestones for progress.
4. Develop a timeline for implementation, with reference to costs and funding.
5. Develop a monitoring plan to determine if:

- BMPs are being implemented
- Individual BMPs are effective
- Load and wasteload allocations are being met
- Water quality standards are being met

6.3.4 Identification of responsible participants

The purpose of this element is to identify the organizations responsible for the implementation of the plan and to list the major responsibilities of each organization. What follows is a simple list of those organizations and responsibilities. This is not intended to be an exhaustive list of every participant that bears some responsibility for improving water quality in the UKDB. Because this is a community wide effort, a complete listing would have to include every business, every industry, every farm, and ultimately every citizen living or working within UKLDB. We are all contributors to the existing quality of the waters in the UKLDB and we all must be participants in the efforts to improve water quality.

Oregon Department of Environmental Quality
- NPDES Permitting and Enforcement
- WPCF Permitting and Enforcement
- Technical Assistance
- Financial Assistance

Oregon Department of Agriculture
- Agricultural Water Quality Management Plan Development, Implementation & Enforcement.
- CAFO Permitting and Enforcement
- Technical Assistance
- Revise Agricultural WQMAP
- Rules under Senate Bill (SB) 1010 to clearly address TMDL and Load Allocations as necessary.Riparian area management

Oregon Department of Forestry
- Forest Practices Act (FPA) Implementation

- Conservation Reserved Enhancement Program
- Revise statewide FPA rules and/or adopt subbasin specific rules as necessary.
- Riparian area management

Oregon Department of Transportation
- Routine Road Maintenance, Water Quality and Habitat Guide Best Management Practices
- Pollution Control Plan and Erosion Control Plan
- Design and Construction

Federal Land Management Agencies (Forest Service, USFWS Refuges, BLM, National Park Service)
- Implementation of Northwest Forest Plan
- Following standards and Guidance listed in PACFISH
- Development of Restoration Management Plans

City of Chiloquin
- Construction, operation and maintenance of a wastewater treatment plant and sanitary sewer system
- Construction, operation and maintenance of most of the municipal separate storm sewer system

City of Klamath Falls
- Construction, operation, and maintenance of the municipal separate storm sewer system within the city limits.
- Land use planning/permitting
- Maintenance, construction and operation of parks and other city owned facilities and infrastructure
- Riparian area management

Klamath County
- Construction, operation and maintenance of County roads and county storm sewer system.
- Land use planning/permitting
- Maintenance, construction and operation of parks and other county owned facilities and infrastructure
- Inspection and permitting of septic systems
- Riparian area management

Oregon Dept. of Fish and Wildlife
- Operation and maintenance of Crooked Creek fish hatchery.

US Bureau of Reclamation
- Management of water levels in Upper Klamath Lake

Table 6-1. Geographic Coverage of Designated Management Agencies deveped as the 303d listed stream segments along with the responsible Designated Management Agencies

Stream	Segment	TMDL Parameters	Designated Management Agencies
Williamson River	Mouth to Klamath Marsh	Temperature	USFS, ODA, CC, ODOT
Williamson River	Klamath Marsh to Headwaters	Temperature	USFS, ODA, USFWS
Sprague River	Mouth to N-S Fork Sprague River	Temperature	USFS, ODA
N. Fork Sprague River	Mouth to Dead Cow Creek	Temperature	USFS, ODA
S. Fork Sprague River	Mouth to Camp Creek	Temperature	USFS, ODA
Sycan River	Mouth to Sycan Marsh	Temperature	USFS, ODA
Sycan River	Sycan Marsh to headwaters	Temperature	USFS, ODA
Fishole Creek	Mouth to headwaters	Temperature	USFS, ODA, ODF
Four Mile Creek	Mouth to RM 4.0	Temperature	ODA
Rock Creek	Mouth to headwaters	Temperature	USFS, ODA

Denio Creek	Mouth to headwaters	Temperature	USFS
Corral Creek	Mouth to headwaters	Temperature	USFS
Pothole Creek	Mouth to headwaters	Temperature	USFS
Paradise Creek	Mouth to headwaters	Temperature	ODF, USFS
Leonard Creek	Mouth to headwaters	Temperature	ODF, USFS
Long Creek	Mouth to headwaters	Temperature	ODF, USFS
Upper Klamath and Agency Lakes		pH, DO, chlorophyll-a	USFS, ODA, BLM, USFWS, ODOT, CLNP, KC, USBR

*Notes: DO = Dissolved Oxygen, DO is listed for May – Oct. unless otherwise noted, Temperature and Chlorophyll-a are listed for Summer unless otherwise noted.

CC = City of Chiloquin
ODA= Oregon Dept. of Agriculture
ODF = Oregon Dept. of Forestry
USFWS = US Fish and Wildlife Service
CLNP= Crater Lake National Park
KC = Klamath County
USBR = US Bureau of Reclamation
ODFW = Oregon department of Fish and Wildlife

6.3.5 Proposed Management Measures

This section of the plan outlines the proposed management measures that are designed to meet the wasteload allocations and load allocations of each TMDL. The timelines for addressing these measures are given in the following section.

The management measures to meet the load and wasteload allocations may differ depending on the source of the pollutant. Given below is a categorization of the sources and a description of the management measures being proposed for each source category.

Wastewater Treatment Plants
The wasteload allocations given to the one wastewater treatment plants (WWTPs), will be implemented through modifications to their National Pollutant Discharge Elimination System (NPDES) permit. The permits will either include numeric effluent limits or provisions to develop and implement management plans, whichever is appropriate.

General and Minor Individual NPDES Permitted Sources
All general NPDES permits and minor individual NPDES permits will be reviewed and, if necessary, modified to ensure compliance with allocations. Either numeric effluent limits will be incorporated into the permits or specific management measures and plans will be developed.

Other Sources
For discharges from sources other than the WWTPs and those permitted under general or minor NPDES permits, ODEQ has assembled an initial listing of management categories. This listing, given in **Table 6-2** below, is designed to be used by the designated management agencies (DMAs) as guidance for selecting management measures to be included in their Implementation Plans. Each DMA will be responsible for examining the categories in **Table 6-2** to determine if the source and/or management measure is applicable within their jurisdiction. This listing is not comprehensive and other sources and management measures will most likely be added by the DMAs where appropriate. For each source or measures deemed applicable a listing of the frequency and extent of application should also be provided. In addition, the DMAs are responsible for source assessment and identification, which may result in additional categories. It is crucial that management measures be directly linked with their effectiveness at reducing pollutant loading contributions.

Table 6-2. Management categories sorted by pollutant source and/or management measures

Management Measure	Source Category	Standard/Parameter	
		Temperature	Total Phosphorus
Public Awareness and Outreach	General Outreach	X	X
	Targeted Outreach		X
New Development and Construction	Planning Procedures	X	X
	Permitting/design	X	X
	Education and Outreach	X	X
	Construction Control Activities	X	X
	Procedures/Measures		
	Inspection/Enforcement		
	Post-Construction Control Activities	X	X
	Procedures/Measures		
	Inspection/Enforcement		
	Storm Drain System Construction		X
Existing Development	Storm Drain System - O&M		
	Retrofit		X
	Inlet		X
	Lines (Daylighting)		X
	Water Quality Facilities		X
	Drainage Ditches		X
	Other		X
	Streets and Roads		
	Street Sweepers		X
	Maintenance activities		X
	Septic Systems		
	Procedures/Measures		X
	Inspection/Enforcement		X
	Parking Lots		X
	Commercial and Industrial Facilities		X
	Source Control (Fertilizers)		X
	Residential		
	Illegal Dumping		X
	Illicit Discharges and Cross Connections		X
	Commercial and Industrial		
	Illegal Dumping		X
	Illicit Discharges and Cross Connections		X
Wetland Management	Restoration		X
	Contruct wetlands for water quality treatment		X
Riparian Area Management	Re-vegetation	X	X
	Streambank Stabilization		X
Public and Governmental Facilities	Parks		X
	Public Waterbodies (Ponds, etc.)		
	Municipal Corporation Yard O&M	X	X
	Other Public Buildings and Facilities	X	X
Forest Practices	Riparian Area Management	X	X
	Roads/Culverts		X
Agricultural Practices	Riparian Area Management	X	X
	Erosion Control		X
	Animal Waste		X
	CAFOs		
	Other		
	Nutrient Management		X
Planning and Assessment	Source Assessment/Identification	X	X
	Source Control Planning	X	X
Monitoring and Evaluation	BMP Monitoring and Evaluation	X	X
	Instream Monitoring	X	X
	BMP Implementation Monitoring	X	X
Transportation	Road Construction/ Maintenance/Repair	X	X

6.3.6 Timeline for Implementation

The purpose of this element of the WQMP is to demonstrate a strategy for implementing and maintaining the plan and the resulting water quality improvements over the long term. Included in this section are timelines for the implementation of ODEQ activities. Each DMA-specific Implementation Plan will also include timelines for the implementation of the milestones described earlier. Timelines should be as specific as possible and should include a schedule for BMP installation and/or evaluation, monitoring schedules, reporting dates and milestones for evaluating progress.

The DMA-specific Implementation Plans are designed to reduce pollutant loads from sources to meet TMDLs, associated loads and water quality standards. **Individual Implementation Plans, where they exist, are referenced in this document and are not attached as appendices**. The Department recognizes that where implementation involves significant habitat restoration or reforestation, water quality standards may not be met for decades. In addition, the Department recognizes that technology for controlling nonpoint source pollution is, in some cases, in the development stages and will likely take one or more iterations to develop effective techniques.

For UKLD TMDLs, pollutant surrogates have been defined as alternative targets for meeting the TMDL for some parameters. The purpose of the surrogates is not to bar or eliminate human access or activity in the subbasin or its riparian areas. It is the expectation, however, that the 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 vegetation, 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 vegetation 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 vegetation.

The Department intends to regularly review progress of the Implementation Plans. The plans, this overall WQMP, and the TMDLs are part of an adaptive management process. Modifications to the WQMP and the Implementation Plans are expected to occur on an annual or more frequent basis. Review of the TMDLs are expected to occur approximately five years after the final approval of the TMDLs, or whenever deemed necessary by ODEQ. **Table 6-3** below, gives the timeline for activities related to the WQMP and associated DMA Implementation Plans.

Table 6-3. Water Quality Management Plan Timeline

Activity	**2002**		**2003**		**2004**		**2005**		**2006**	
ODEQ Establishes MAOs with NPDES Sources	■	■								
ODEQ Incorporate WLAs into Permits					■	■				
DMA Development and Submittal of Implementation and Monitoring Plans	■	■	■	■						
DMA Implementation of Plans			■	■	■	■	■	■	■	■
ODEQ/DMA/Public Review of TMDL and WQMP										■
DMA Submittal of Annual Reports	Sept. 30 of Each Year									

6.3.7 Reasonable Assurance

This section of the WQMP is intended to provide reasonable assurance that the WQMP (along with the associated DMA-specific Implementation Plans) will be implemented and that the TMDL and associated allocations will be met.

There are several programs that are either already in place or will be put in place to help assure that this WQMP will be implemented. Some of these are traditional regulatory programs such as specific requirements under NPDES discharge permits. Other programs address nonpoint sources under the auspices of state law (for forested and agricultural lands) and voluntary efforts.

6.3.7.1 Point Sources - NPDES and WPCF Permit Programs

Reasonable assurance that implementation of the point source wasteload allocations will occur will be addressed through the revision, issuance or revision of NPDES and WPCF permits. The ODEQ administers two different types of wastewater permits in implementing Oregon Revised Statute (ORS) 468B.050. These are: the National Pollutant Discharge Elimination System (NPDES) permits for surface water discharge; and Water Pollution Control Facilities (WPCF) permits for onsite (land) disposal. The NPDES permit is also a Federal permit, which is required under the Clean Water act for discharge of waste into waters of the United States. ODEQ has been delegated authority to issue NPDES permits by the EPA. The WPCF permit is unique to the State of Oregon. As the permits are renewed, they will be revised to insure that all 303(d) related issues are addressed in the permit. These permit activities assure that elements of the TMDL WQMP involving urban and industrial pollution problems will be implemented.

For point sources, provisions to address the appropriate waste load allocations (WLAs) will be incorporated into NPDES permits when permits are renewed by ODEQ, typically within 1 year after the EPA approves the TMDL. It is likely each point source will be given a reasonable time to upgrade, if necessary, to meet its new permit limits. A schedule developing information to meet waste load allocations will be established in a Mutual Agreement Order (MAO). Adherence to permit conditions is required by State and Federal Law and ODEQ has the responsibility to ensure compliance.

The NPDES permits for the single wastewater treatment plant (City of Chiloquin) with wasteload allocations, will be revised to address the WLAs. The general NPDES permits within the subbasin will also be revised to address the appropriate WLAs.

6.3.7.2 Nonpoint Sources

State Forestry

The Oregon Department of Forestry (ODF) is the designated management agency for regulation of water quality on non-federal forest lands. The Board of Forestry has adopted water protection rules, including but not limited to OAR Chapter 629, Divisions 635-660, which describe BMPs for forest operations. These rules are implemented and enforced by ODF and monitored to assure their effectiveness. The Environmental Quality Commission, Board of Forestry, ODEQ, and ODF have agreed that these pollution control measurers will be relied upon to result in achievement of state water quality standards. ODF provides on the ground field administration of the Forest Practices Act (FPA). For each administrative rule, guidance is provided to field administrators to insure proper, uniform and consistent application of the Statutes and Rules. The FPA requires penalties, both civil and criminal, for violation of Statutes and Rules. Additionally, whenever a violation occurs, the responsible party is obligated to repair the damage. For more information, refer to the Management Measures element of this Plan.

ODF and ODEQ are involved in several statewide efforts to analyze the existing FPA measures and to better define the relationship between the TMDL load allocations and the FPA measures designed to protect water quality. Although the analysis and modeling in the TMDL demonstrate that increased levels of shade on many of the forested stream reaches in the subbasin would decrease solar loading and potentially lower maximum daily stream temperatures, insufficient information exists to determine if specific FPA revisions will be necessary to meet the TMDL load allocations. The information in the TMDL, as well as other monitoring data, will be an important part of the body of information used in determining the adequacy of the FPA.

As the DMA for water quality management on nonfederal forestlands, the ODF is also working with the ODEQ through a memorandum of understanding (MOU) signed in June of 1998. This MOU was designed to improve the coordination between the ODF and the ODEQ in evaluating and proposing possible changes to the forest practice rules as part of the Total Maximum Daily Load process. The purpose of the MOU is also to guide coordination between the ODF and ODEQ regarding water quality limited streams on the 303d list. An evaluation of rule adequacy will be conducted (also referred to as a “sufficiency analysis”) through a water quality parameter by parameter analysis. This statewide demonstration of forest practices rule effectiveness in the protection of water quality will address the following specific parameters and will be conducted in the following order:

1) Temperature
2) Sediment and turbidity
3) Aquatic habitat modification
4) Bio-criteria
5) Other parameters

These sufficiency analyses will be reviewed by peers and other interested parties prior to final release. The analyses will be designed to provide background information and assessments of BMP effectiveness in meeting water quality standards. Once the sufficiency analyses are completed, they will be used as a coarse screen for common elements applicable to each individual TMDL to determine if forest practices are contributing to water quality impairment within a given watershed and to support the adaptive management process.

Currently ODF and DEQ do not have adequate data to make a collective determination on the sufficiency of the current FPA BMPs in meeting water quality standards within the UKLDB. This situation most closely resembles the scenario described under condition c of the ODF/ODEQ MOU. Therefore, the current BMPs will remain as the forestry component of the TMDL. The draft versions of the statewide FPA sufficiency analyses for the various water quality parameters will be completed as noted above. The proposed UKLDB TMDLs will be completed in 2002. Data from an ODF/ODEQ shade study was collected over the summer of 1999 and a final report will be completed in the summer of 2001, and information from the forest practices ad hoc committee advisory process is currently available. Information from these efforts, along with other relevant information provided by the ODEQ, will be considered in reaching a determination on whether the existing FPA BMPs meet water quality standards within the UKLDB.

Agriculture

It is the Oregon Department of Agriculture’s (ODA) statutory responsibility to develop agricultural water quality management (AWQM) plans and enforce rules that address water quality issues on agricultural lands. The AWQM Act directs ODA to work with local farmers and ranchers to develop water quality management area plans for specific watersheds that have been identified as violating water quality standards and having agriculture water pollution contributions. The agriculture water quality management area plans are expected to identify problems in the watershed that need to be addressed and outline ways to correct those problems. These water quality management plans are developed at a local level, reviewed by the State Board of Agriculture, and then adopted into the Oregon Administrative Rules. It is the intent that these plans focus on education, technical assistance, and flexibility in addressing agriculture water quality issues. These plans and rules will be developed or modified to achieve water quality standards and will address the load allocations identified in the TMDL. In those cases when an operator refuses to take action, the law allows ODA to take enforcement action. ODEQ will work with ODA to ensure that rules and plans meet load allocations.

Recognizing the adopted rules need to be quantitatively evaluated in terms of load allocations in the TMDL and pursuant to the June 1998 Memorandum of Agreement between ODA and ODEQ, the agencies will conduct a technical evaluation commencing in late 2000. The agencies will establish the relationship between the plan and its implementing rules and the load allocations in the TMDL to determine if the rules provide reasonable assurance that the TMDLs will be achieved. The AWQMA Local Advisory Committee (LAC) will be apprised and consulted during this evaluation. This adaptive management process provides for review of the AWQMA plan to determine if any changes are needed to the current AWQMA rules specific to the UKLDB.

Oregon Department of Transportation

The Oregon Department of Transportation (ODOT) has been issued an NPDES MS4 waste discharge permit. Included with ODOT's application for the permit was a surface water management plan which has been approved by ODEQ and which addresses the requirements of a Total Maximum Daily Load (TMDL) allocation for pollutants associated with the ODOT system. Both ODOT and ODEQ agree that the provisions of the permit and the surface water management plan will apply to ODOT's statewide system. This statewide approach for an ODOT TMDL watershed management plan addresses specific pollutants, but not specific watersheds. Instead, this plan demonstrates how ODOT will incorporate water quality protection into project development, construction, and operations and maintenance of the state and federal transportation system that is managed by ODOT, thereby meeting the elements of the National Pollutant Discharge Elimination System (NPDES) program, and the TMDL requirements.

The MS4 permit and the plan:

- Streamlines the evaluation and approval process for the watershed management plans
- Provides consistency to the ODOT highway management practices in all TMDL watersheds.
- Eliminates duplicative paperwork and staff time developing and participating in the numerous TMDL management plans.

Temperature and sediment are the primary concerns for pollutants associated with ODOT systems that impair the waters of the state. ODEQ is still in the process of developing the TMDL water bodies and determining pollutant levels that limit their beneficial uses. As TMDL allocations are established by watershed, rather than by pollutants, ODOT is aware that individual watersheds may have pollutants that may require additional consideration as part of the ODOT watershed management plan. When these circumstances arise, ODOT will work with DEQ to incorporate these concerns into the statewide plan.

Federal Forest Lands

All management activities on federal lands managed by the U.S. Forest Service (USFS) and the Bureau of Land Management must follow standards and guidelines (S&Gs) as listed in the respective Land Use and Management Plans (LRMPs), as amended, for the specific land management units. The WQMPs for USFS and BLM are anticipated to outline BMPs to achieve water quality standards and address the nonpoint Load Allocations.

In response to environmental concerns and litigation related to timber harvest and other operations on Federal Lands, the United States Forest Service (USFS) and the Bureau of Land Management (BLM) commissioned the Forest Ecosystem Management Assessment Team (FEMAT) to formulate and assess the consequences of management options. The assessment emphasizes producing management alternatives that comply with existing laws and maintaining the highest contribution of economic and social well being. The "backbone" of ecosystem management is recognized as constructing a network of late-successional forests and an interim and long-term scheme that protects aquatic and associated riparian habitats adequate to provide for *threatened species* and *at risk species*. Biological objectives of the Northwest Forest Plan include assuring adequate habitat on Federal lands to aid the "recovery" of late-successional forest habitat-associated species listed as threatened under the Endangered Species Act and preventing species from being listed under the Endangered Species Act.

Urban and Rural Sources

Responsible participants for implementing DMA specific water quality management plans for urban and rural sources were identified in Chapter 5 of this Water Quality Management Plan. Upon approval of the UKLD TMDLs, it is ODEQ's expectation that identified, responsible participants will develop, submit to DEQ, and implement individual water quality management plans that will achieve the load allocations established by the TMDLs. These activities will be accomplished by the responsible participants in accordance with the Schedule in Chapter 7 of this Water Quality Management Plan. The DMA specific water quality implementation plans must address the following items:

1) Proposed management measures tied to attainment of the load allocations and/or established surrogates of the TMDLs, such as vegetative site potential for example.
2) Timeline for implementation.
3) Timeline for attainment of load allocations.
4) Identification of responsible participants demonstrating who is responsible for implementing the various measures.
5) Reasonable assurance of implementation.
6) Monitoring and evaluation, including identification of participants responsible for implementation of monitoring, and a plan and schedule for revision of implementation plan.
7) Public involvement.
8) Maintenance effort over time.
9) Discussion of cost and funding.
10) Citation of legal authority under which the implementation will be conducted.

Should any responsible participant fail to comply with their obligations under this WQMP, the Department will take all necessary action to seek compliance. Such action will first include negotiation, but could evolve to issuance of Department or Commission Orders and other enforcement mechanisms.

The Oregon Plan

The Oregon Plan for Salmon and Watersheds represents a major effort, unique to Oregon, to improve watersheds and restore endangered fish species. The Oregon Plan is a major component of the demonstration of " reasonable assurance " that this TMDL WQMP will be implemented.

The Plan consists of four essential elements:

Coordinated Agency Programs:
Many state and federal agencies administer laws, policies, and management programs that have an impact on salmon and water quality. These agencies are responsible for fishery harvest management, production of hatchery fish, water quality, water quantity, and a wide variety of habitat protection, alteration, and restoration activities. Previously, agencies conducted business independently. Water quality and salmon suffered because they were affected by the actions of all the agencies, but no single agency was responsible for comprehensive, life-cycle management. Under the Oregon Plan, all government agencies that impact salmon are accountable for coordinated programs in a manner that is consistent with conservation and restoration efforts.

Community-Based Action:
Government, alone, cannot conserve and restore salmon across the landscape. The Oregon Plan recognizes that actions to conserve and restore salmon must be worked out by communities and

landowners, with local knowledge of problems and ownership in solutions. Watershed councils, soil and water conservation districts, and other grassroots efforts are vehicles for getting the work done. Government programs will provide regulatory and technical support to these efforts, but local people will do the bulk of the work to conserve and restore watersheds. Education is a fundamental part of the community based action. People must understand the needs of salmon in order to make informed decisions about how to make changes to their way of life that will accommodate clean water and the needs of fish.

Monitoring:
The monitoring program combines an annual appraisal of work accomplished and results achieved. Work plans will be used to determine whether agencies meet their goals as promised. Biological and physical sampling will be conducted to determine whether water quality and salmon habitats and populations respond as expected to conservation and restoration efforts.

Appropriate Corrective Measures:
The Oregon Plan includes an explicit process for learning from experience, discussing alternative approaches, and making changes to current programs. The Plan emphasizes improving compliance with existing laws rather than arbitrarily establishing new protective laws. Compliance will be achieved through a combination of education and prioritized enforcement of laws that are expected to yield the greatest benefits for salmon.

Voluntary Measures

There are many voluntary, non-regulatory, watershed improvement programs (Actions) that are in place and are addressing water quality concerns in the UKLDB. Both technical expertise and partial funding are provided through these programs. Examples of activities promoted and accomplished through these programs include: planting of conifers, hardwoods, shrubs, grasses and forbs along streams; relocating legacy roads that may be detrimental to water quality; replacing problem culverts with adequately sized structures, and improvement/ maintenance of legacy roads known to cause water quality problems. These activities have been and are being implemented to improve watersheds and enhance water quality. Many of these efforts are helping resolve water quality related legacy issues.

Landowner Assistance Programs

A variety of grants and incentive programs are available to landowners in the UKDB. These incentive programs are aimed at improving the health of the watershed, particularly on private lands. They include technical and financial assistance, provided through a mix of state and federal funding. Local natural resource agencies administer this assistance, including the Oregon Department of Forestry, the Oregon Department of Fish and Wildlife, ODEQ, Klamath Basin Ecosystem Restoration Office, the National Resources Conservation Service, Bureau of Reclamation, National Wildlife Foundation, Small Business Administration, Oregon Watershed Enhancement Board, Oregon State University Agriculture Extension Service, Klamath Watershed Council, Klamath County Soil and Water Conservation District, and the Klamath Basin Ecosystem Foundation.

Field staff from the administrative agencies provide technical assistance and advice to individual landowners, watershed councils, local governments, and organizations interested in enhancing the UKDB. These services include on-site evaluations, technical project design, stewardship/conservation plans, and referrals for funding as appropriate. This assistance and funding is further assurance of implementation of the TMDL WQMP.

Financial assistance is provided through a mix of cost-share, tax credit, and grant funded incentive programs designed to improve on-the-ground watershed conditions. Some of these programs, due to source of funds, have specific qualifying factors and priorities. Cost share programs include the Forestry Incentive Program (FIP), Stewardship Incentive Program (SIP), Environmental Quality Incentives Program (EQIP), and the Wildlife Habitat Incentive Program (WHIP).

6.3.8 Monitoring and Evaluation

Monitoring and evaluation has two basic components: 1. implementation of DMA specific water quality management plans identified in this document and 2. Physical, chemical and biological parameters for water quality and specific management measures. This information will provide information on progress being made toward achieving TMDL allocations and achieving water quality standards and to use as we evaluate progress as described under Adaptive Management in Chapter 1: Introduction.

The information generated by each of the agencies/entities gathering data in the UKLDB will be pooled and used to determine whether management actions are having the desired effects or if changes in management actions and/or TMDLs are needed. This detailed evaluation will typically occur on a 5 year cycle. If progress is not occurring then the appropriate management agency will be contacted with a request for action.

The objectives of this monitoring effort are to demonstrate long-term recovery, better understand natural variability, track implementation of projects and BMPs, and track effectiveness of TMDL implementation. This monitoring and feedback mechanism is a major component of the "reasonable assurance of implementation" for the UKDBTMDL-WQMP

This WQMP will be tracked by accounting for the numbers, types, and locations of projects, BMPs, educational activities, or other actions taken to improve or protect water quality. The mechanism for tracking DMA implementation efforts will be annual reports to be submitted to ODEQ.

6.3.9 Public Involvement

To be successful at improving water quality a TMDL WQMP must include a process to involve interested and affected stakeholders in both the development and the implementation of the plan. In addition to the ODEQ public notice policy and public comment periods associated with TMDLs and permit applications, future UKLDB TMDL public involvement efforts will focus specifically on urban, agricultural and forestry activities. DMA-specific public involvement efforts will be detailed within the Implementation Plans included in the appendices.

6.3.10 Costs and Funding

Designated Management Agencies will be expected to provide a fiscal analysis of the resources needed to develop, execute and maintain the programs described in their Implementation Plans.

The purpose of this element is to describe estimated costs and demonstrate there is sufficient funding available to begin implementation of the WQMP. Another purpose is to identify potential future funding sources for project implementation. There are many natural resource enhancement efforts and projects occurring in the subbasin which are relevant to the goals of the plan. These efforts, in addition to proposed future actions are described in the Management Measurers element of this Plan.

6.3.11 Potential Sources of Project Funding

Funding is essential to implementing projects associated with this WQMP. There are many sources of local, state, and federal funds. The following is a partial list of assistance programs available in the UKLDB.

Program	**Agency/Source**
Oregon Plan for Salmon and Watersheds	OWEB
Environmental Quality Incentives Program	USDA-NRCS
Wetland Reserve Program	USDA-NRCS
Conservation Reserve Enhancement Program	USDA-NRCS
Stewardship Incentive Program	ODF
Access and Habitat Program	ODFW
Partners for Wildlife Program	USDI-FSA
Conservation Implementation Grants	ODA
Water Projects	WRD
Nonpoint Source Water Quality Control (EPA 319)	ODEQ-EPA
Riparian Protection/Enhancement	COE
Oregon Community Foundation	OCF
Klamath Basin Ecosystem Restoration	UFWS
Bureau of Reclamation	USBR
Water Resources Program	BIA
National Wildlife Foundation	NWF
Small grants program	KSWCD
Jobs-in-the-Wods	KERO
Partners for Fish and Wildlife	KERO
Hatfield Funds	KERO

Grant funds are available for improvement projects on a competitive basis. Field agency personnel assist landowners in identifying, designing, and submitting eligible projects for these grant funds. For private landowners, the recipient and administrator of these grants is generally the local Soil and Water Conservation District. Grant fund sources include:

Oregon Watershed Enhancement Board (OWEB) which funds watershed improvement projects with state money. This is an important piece in the implementation of Oregon's Salmon Plan. Current and past projects have included road relocation/closure/improvement projects, in-stream structure work, riparian fencing and revegetation, off stream water developments, and other management practices.
USFWS Klamath Basin Ecosystem Restoration Office funds are federal funds for fish habitat and water quality improvement projects. These have also included projects addressing road conditions, grazing management, aquatic habitiat restoration, water quality retoration, and wetland restoration .
Individual grant sources for special projects have included Forest Health money available through the State and Private arm of the USDA Forest Service.

6.3.12 Citation to Legal Authorities

6.3.12.1 Clean Water Act Section 303(d)

Section 303(d) of the 1972 federal Clean Water Act as amended requires states to develop a list of rivers, streams and lakes that cannot meet water quality standards without application of additional pollution controls beyond the existing requirements on industrial sources and sewage treatment plants. Waters that need this additional help are referred to as “water quality limited” (WQL). Water quality limited waterbodies must be identified by the Environmental Protection Agency (EPA) or by a state agency which has been delegated this responsibility by EPA. In Oregon, this responsibility rests with the ODEQ. The ODEQ updates the list of water quality limited waters every two years. The list is referred to as the 303(d) list. Section 303 of the Clean Water Act further requires that Total Maximum Daily Loads (TMDLs) be developed for all waters on the 303(d) list. A TMDL defines the amount of pollution that can be present in the waterbody without causing water quality standards to be violated. An WQMP is developed to describe a strategy for reducing water pollution to the level of the load allocations and waste load allocations prescribed in the TMDL, which is designed to restore the water quality and result in compliance with the water quality standards. In this way, the designated beneficial uses of the water will be protected for all citizens.

The Oregon Department of Environmental Quality is authorized by law to prevent and abate water pollution within the State of Oregon pursuant to the following statute:

ORS 468B.020 **Prevention of pollution** (1) Pollution of any of the waters of the state is declared to be not a reasonable or natural use of such waters and to be contrary to the public policy of the State or Oregon, as set forth in ORS 468B.015.

(2) In order to carry out the public policy set forth in ORS 468B.015, the department shall take such action as is necessary for the prevention of new pollution and the abatement of existing pollution by:

  (a) Fostering and encouraging the cooperation of the people, industry, cities and counties, in order to prevent, control and reduce pollution of the waters of the state; and
  (b) Requiring the use of all available and reasonable methods necessary to achieve the purposes of ORS 468B.015 and to conform to the standards of water quality and purity established under ORS 468B.048.

6.3.12.2 NPDES and WPCF Permit Programs

The ODEQ administers two different types of wastewater permits in implementing Oregon Revised Statute (ORS) 468B.050. These are: the National Pollution Discharge Elimination System (NPDES) permits for waste discharge; and Water Pollution Control Facilities (WPCF) permits for waste disposal. The NPDES permit is also a Federal permit and is required under the Clean Water Act. The WPCF permit is a state program. As permits are renewed they will be revised to insure that all 303(d) related issues are addressed in the permit.

6.3.12.3 Oregon Administrative Rules

The following Oregon Administrative Rules provide numeric and narrative criteria for parameters of concern in the UKLDB:

Standard/Criteria of Concern: Nuisance Phytoplankton Growth
Applicable Rules: OAR 340-41-150

TMDL Parameter: pH
Applicable Rules: OAR 340-41-965 (1) (d)

TMDL Parameter: Temperature
Applicable Rules: OAR 340-41-026(3)(a)(D)
OAR 340-41-006(54) and (55)
OAR 340-41-965 (1) (b)

TMDL Parameter: Dissolved Oxygen
Applicable Rules: OAR 340-041-965 (1) (a)

6.3.12.4 Oregon Forest Practices Act

The Oregon Department of Forestry (ODF) is the designated management agency for regulation of water quality on non-federal forest lands. The Board of Forestry has adopted water protection rules, including but not limited to OAR Chapter 629, Divisions 635-660, which describes BMPs for forest operations. The Environmental Quality Commission (EQC), Board of Forestry, ODEQ and ODF have agreed that these pollution control measurers will be relied upon to result in achievement of state water quality standards.

ODF and ODEQ statutes and rules also include provisions for adaptive management that provide for revisions to FPA practices where necessary to meet water quality standards. These provisions are described in ORS 527.710, ORS 527.765, ORS 183.310, OAR 340-041-0026, OAR 629-635-110, and OAR 340-041-0120.

6.3.12.5 Senate Bill 1010

The Oregon Department of Agriculture has primary responsibility for control of pollution from agriculture sources. This is accomplished through the Agriculture Water Quality Management (AWQM) program authorities granted ODA under Senate Bill 1010 Adopted by the Oregon State Legislature in 1993. The AWQM Act directs the ODA to work with local farmers and ranchers to develop water quality management plans for specific watersheds that have been identified as violating water quality standards and have agriculture water pollution contributions. The agriculture water quality management plans are expected to identify problems in the watershed that need to be addressed and outline ways to correct the problems.

6.3.12.6 Oregon Department of Transportation

The Oregon Department of Transportation (ODOT) plan addresses the requirements of a Total Maximum Daily Load (TMDL) allocation for pollutants associated with the ODOT system. This statewide approach for an ODOT TMDL watershed management plan would address specific pollutants, but not specific watersheds. Instead, this plan would demonstrate how ODOT incorporates water quality into project development, construction, and operations and maintenance of the state and federal transportation system, thereby meeting the elements of the National Pollutant Discharge Elimination System (NPDES) program, and the TMDL requirements.

ODOT has partnered with ODEQ in the development of several watershed management plans. By presenting a single, statewide, management plan, ODOT:

- Streamlines the evaluation and approval process for the watershed management plans
- Provides consistency to the ODOT highway management practices in all TMDL watersheds.
- Eliminates duplicative paperwork and staff time developing and participating in the numerous TMDL management plans.

Temperature and sediment are the primary concerns for pollutants associated with ODOT systems that impair the waters of the state. ODEQ is still in the process of developing the TMDL water bodies and determining pollutant levels that limit their beneficial uses. As TMDL allocations are established by watershed, rather than by pollutants, ODOT is aware that individual watersheds may have pollutants that may require additional consideration as part of the ODOT watershed management plan. When these circumstances arise, ODOT will work with ODEQ to incorporate these concerns into the statewide plan

6.3.12.7 Local Ordinances

Within the Implementation Plans in the appendices, the DMAs are expected to describe their specific legal authorities to carry out the management measures they choose to meet the TMDL allocations. Legal authority to enforce the provisions of a City’s NPDES permit would be a specific example of legal authority to carry out management measures.

ACRONYM LIST

BLM – Bureau of Land Management

CFR - Code of Federal Regulations

cfs - cubic feet per second

CWA - Clean Water Act

DEM - Digital Elevation Model

DEQ - Department of Environmental Quality (Oregon)

DOQ - Digital Orthophoto Quad

DOQQ - Digital Orthophoto Quarter Quad

EPA - (United States) Environmental Protection Agency

FLIR - Forward Looking Infrared Radiometry

HUC - Hydrologic Unit Code

LA - Load Allocation

LC - Loading Capacity

NSDZ - Near-Stream Disturbance Zone

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

OWRD - Oregon Water Resources Department

R^2 – Correlation coefficient

RM - River Mile

SE - Standard Error

TMDL - Total Maximum Daily Load

USBR (US BOR) - United States Bureau of Reclamation

US COE - United States Army Corps of Engineers

USDA - United States Department of Agriculture

USFS - United States Forest Service

USGS - United States Geological Survey

W:D - Width to Depth (ratio)

WLA - Waste Load Allocation

WQS - Water Quality Standard

WWTP - Waste Water Treatment Plant

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