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Characterization of Select Water Quality Parameters within the Upper Deschutes and Little Deschutes Subbasins

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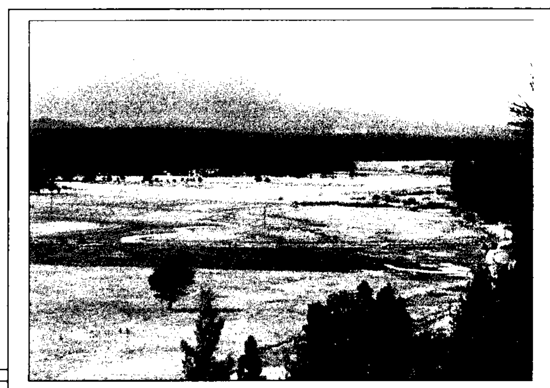

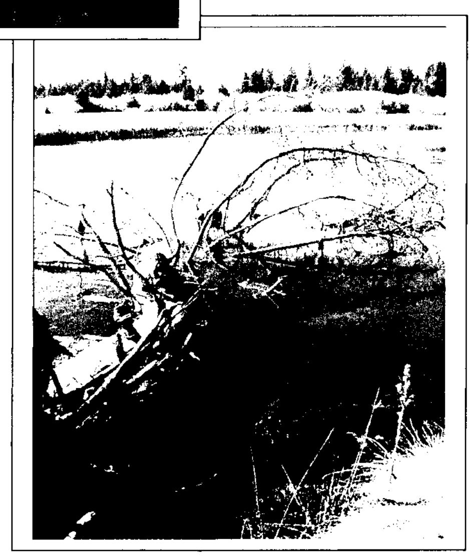

Enhancing and protecting the Upper Deschutes River watershed through collaborative projects in watershed stewardship, habitat enhancement, and community awareness.

Characterization of Select Water Quality Parameters within the Upper Deschutes and Little Deschutes Subbasins

By Lesley Jones

Upper Deschutes Watershed Council
Bend, Oregon: 2003

PHOTOGRAPHS

Top: Indian Ford Creek and Black Butte, Oregon (UDWC archive photo)
Left: Upper Deschutes River downstream Wickiup Reservoir, Oregon (UDWC archive photo)
Right: Upper Deschutes River upstream of the City of Bend, Oregon (UDWC archive photo)

ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

The *Characterization of Select Water Quality Parameters within the Upper Deschutes and Little Deschutes Subbasins* report (Technical Report) is the result of the Upper Deschutes Watershed Council (UDWC) Water Quality Specialist analyses of interagency water quality data gathered from monitoring efforts throughout the Upper Deschutes and Little Deschutes Subbasins. Data collected from multiple sources between 1990 and 2002 are graded for quality control and quality assurance and compiled into a comprehensive, regional database housed under the UDWC Water Quality Monitoring Program.

The Technical Report presents the analyses of datasets within the regional database. The Technical report describes select water quality parameters, presents and discusses analyses, summarizes key findings, and suggests recommendations for future actions. The water quality parameters selected for the Technical Report include pH, dissolved oxygen, percent saturation, biochemical oxygen demand, turbidity, sedimentation, chlorophyll-*a*, nutrients, and bacteria. The water quality data are analyzed to address critical questions:

1. *How does the parameter change along the longitudinal extent of the aquatic system?*
2. *What is the daily and seasonal variability of the parameter within the aquatic system?*
3. *What is the long-term trend of the parameter within the aquatic system?*
4. *Is the parameter compliant with regulatory criteria for the aquatic system?*

In addition, the data are analyzed to address the status of pollution, primary production growth limiting nutrient, and chlorophyll-*a* within the subbasins.

Key Findings

Regional data

A function of the UDWC Water Quality Monitoring Program is to compile existing water quality data and provide a technical report of the water quality within the region. Regional water quality data is currently compiled into a regional database by the UDWC program. The regional database is used to characterize the region and utilizes trends for regional analyses. The analyses in the Technical Report can be applied towards addressing regional priority issues that may require further investigation.

Some water quality parameters within the regional database have insufficient data for analyses, while other water quality parameters have a surplus of data that requires further analyses. The UDWC program provides additional monitoring in order to supplement the regional database and is making efforts to provide further analyses of surplus data. A goal of the UDWC Water Quality Monitoring Program is to provide regional analyses that are statistically and practically significant and the Technical Report is a preliminary step towards obtaining this goal.

pH

As indicated by pH levels, there may be regional impacts from flow modifications, nonpoint source pollution, and water diversions. Nonpoint source pollution carried by uncharacterized urban runoff may be impacting water quality. Areas of sediment deposition near and within the City of Bend may have the tendency to accumulate nonpoint source pollution carried by uncharacterized urban runoff into deposited sediments, while water diversions lowering summer water flows within the middle Deschutes reach may exacerbate any impacts of nonpoint source pollution from uncharacterized urban runoff and rural land use. Conditions of the middle Deschutes reach at the Lower Bridge site may illustrate the accumulative nature of upstream and long-term impacts from nonpoint source pollution. A water quality limited status exists for the Lower Bridge site and this site is on the state 2002 303(d) listing within the segment from RM 126.4 (Steelhead Falls) to RM 168.2 (upstream of the City of Bend).

Dissolved oxygen, percent saturation, and biochemical oxygen demand

Throughout the subbasins, dissolved oxygen concentrations may reflect a maximization of percent saturation during light hours except for the Little Deschutes River during May possible due to the combination of waters that are not well aerated and low primary production within the water column. Areas of sediment deposition near and within the City of Bend may have the tendency to accumulate nonpoint source pollution carried by uncharacterized urban runoff into deposited sediments, while supersaturated waters within the middle Deschutes reach may be due to high primary productivity. The middle Deschutes reach may be more eutrophic than the upper Deschutes Reach and may exhibit increases in decomposition processes possibly due to decreases in flow, increases in primary producer die offs, and increases in organic and inorganic inputs from uncharacterized urban runoff, rural land use, and agriculture. Conditions of the upper Deschutes River at the Lower Bridge site may illustrate the accumulative nature of upstream and long-term impacts.

Turbidity and sedimentation

Anthropogenic impacts of water regulation may be increasing bank instability and contributing to a seasonal regime of sediment load transport along the upper Deschutes reach into depositional areas upstream and within the City of Bend. The subbasins may have a naturally high fine sediment component that makes evaluation of sedimentation via fine sediments more difficult due to a lack of knowledge regarding regional background levels for fine sediments. Turbidity levels are well below the recommended guidelines set by OWEB, yet compliance to these guidelines does not indicate protection of beneficial uses within an aquatic system that may have naturally low turbidity levels. Continuous monitoring of turbidity can provide information regarding spatial and temporal turbidity fluctuations and indicate reaches that are vital to salmonid escape and survival. Evaluation of the biological integrity of the region via analyses of existing macroinvertebrate data can indicate any impacts from sedimentation, because these evaluations are based on biological criteria, are not affected by the suspected naturally high fine sediment component, and have a quality historical dataset that can be used in the regional multivariate index that is currently underdevelopment.

Chlorophyll-*a*

The Wickiup/Crane Prairie Reservoir complex may be contributing to increased mean chlorophyll-*a* concentrations as each spring storage release may cause phytoplankton to transport from the complex to the upper Deschutes River. The chlorophyll-*a* dataset is limited by monitoring efforts conducted only during summer months. A nonpoint source pollution issue may exist at the State Recreation Road site near La Pine State Park. The anthropogenic influence of water regulation may be contributing to the optimization of periphyton growth within the upper Deschutes River and may be contributing to a shift in the balance of the upper Deschutes River. There are no benthic chlorophyll-*a* data to evaluate periphyton growth within the rivers of the subbasins. The lack of chlorophyll-*a* data prevents complete analyses of the trophic status of the upper Deschutes River and Little Deschutes River.

Nutrients

There appears to be a greater ability of the upper Deschutes reach to process the nutrient load compared to the middle Deschutes reach, which may be due to undocumented increases in periphyton primary production within the upper Deschutes reach in combination with nutrient loads and flow modification. The water storage release from Wickiup Reservoir may affect TN concentrations within the upper Deschutes River. TN concentrations of the middle Deschutes reach may be affected by uncharacterized urban runoff, rural land use, and agriculture, while water diversions may exacerbate conditions and possibly increase the impacts from nutrient loading. A nonpoint source issue at State Recreation Road may exist. The waters of the Upper Deschutes and Little Deschutes Subbasins are nitrogen limited and exhibit a mesotrophic to eutrophic state contributed by high TP concentrations.

Bacteria

E. coli in the aquatic system indicate the presence of fecal contamination that may contain pathogenic bacteria, protozoa, and viral particles; aggressive pathogens that cause human illness. The detection of higher than normal concentrations of *E. coli* in recreational waters may indicate the presence of other water borne diseases and is a reason for further evaluation. Within the subbasins, a low concentration under 10 *E. coli* CFU/100 mL appears to be the result of natural inputs of *E. coli* from wildlife and can be considered normal. All sites that report levels of bacteria greater than 10 *E. coli* CFU/100 mL are easily accessed and have urban and rural land use influences. Sediment depositional areas may be conducive to accumulation of bacterial inputs from uncharacterized urban runoff, rural land use, and recreational use, while the Lower Bridge site may be representative of consistent, long-term, and upstream impacts from uncharacterized urban runoff, rural land use and flow modifications. There are no state 303(d) listed waterbodies or segments within the upper Deschutes and Little Deschutes Subbasins. The state criteria for bacteria is evaluated according to a single sample maximum of 406 *E. coli* CFU/100mL or a 30 day log mean value no to exceed 126 *E. coli* CFU/100 mL. Single samples have not exceeded the maximum of 406 *E. coli* CFU/100 mL, and the 30 day log mean of bacterial concentrations of the subbasins has not been evaluated. It is recommended that sites with high water contact recreation are evaluated according to the 30 day log mean concentrations in order to protect the beneficial use of recreational waters.

Summary of Priority Issues

Regional Water Quality Impairment
The continued investigations into water quality impairments within the subbasins are recommended due to 303(d) listings, nonpoint source pollution, and flow modifications. The subbasins include over 1,800 miles of streams, and many segments are listed as impaired under Section 303(d) of the Clean Water Act. The water quality impairments affect the beneficial uses. Many segments have insufficient data for trends and status analyses or surplus data that needs preliminary analyses. Compliance to water quality criteria remains a significant challenge in the region as evident by the increase in listed stream miles between 1998 and 2002.

Human Health
Investigations of human health indicators are recommended due to possible regional anthropogenic impacts on beneficial uses. The City of Bend is experiencing rapid population growth as evident by the city reports of population increases from 12,000 to over 60,000 people in less than 20 years. The area of Bend is partially served by a piped stormwater system that contributes uncharacterized point source discharges into the upper Deschutes River and contributes uncharacterized nonpoint source overland flow of stormwater discharging into the river. Flow modifications likely result in increases in sediment loads within the upper Deschutes River between Wickiup Reservoir and the City of Bend and increases in sediment deposition within the City of Bend. Urban runoff may transport compounds that partition into the deposited sediments, accumulate, and may cause human health risks and water borne illnesses upon exposure during recreation and water contact.

Environmental Health
Investigations of environmental health indicators are recommended due to possible regional anthropogenic impacts on beneficial uses. Above the City of Bend, the quality of waters within the Wickiup/Crane Prairie Reservoirs are largely uncharacterized and need to be evaluated, and the quantities of reservoir waters released may have impacts including decreasing bank stability, altering nutrient concentrations, and possibly optimizing periphyton populations. In addition, the City of Bend urban runoff transports uncharacterized compounds into the upper Deschutes River and below the City of Bend water diversions for agriculture may exasperate conditions. The flow fluctuations and the uncharacterized urban runoff may be contributing to the anthropogenic eutrophication of the upper Deschutes River. Increasing eutrophication impacts the health of biological communities of the upper Deschutes River.

ABBREVIATIONS AND ACRONYMS

BLM	Bureau of Land Management
BOD-5	Biochemical oxygen demand
BOR	Bureau of Reclamation
C	Celsius
cfs	Cubic feet per second
CFU	Colony Forming Unit
CRNG	Crooked River National Grasslands, Ochoco National Forest
DNF	Deschutes National Forest
DO	Dissolved oxygen
EPA	Environmental Protection Agency
FLIR	Forward Looking Infrared Radiometry
FWS	Fall, winter, and spring
IGDO	Intergravel dissolved oxygen
μg/L	Micrograms per liter
mg/L	Milligrams per liter
LDR	Little Deschutes River
MDR	Middle Deschutes reach
NIST	National Institute of Standards and Technology
NTU	Nephelometric turbidity units
OAR	Oregon Administrative Rules
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
OWEB	Oregon Watershed Enhancement Board
OWRD	Oregon Water Resources Department
PGE	Portland General Electric
QA/QC	Quality assurance and quality control
REMAP	Regional Environmental Mapping and Assessment Program
RM	River mile
S	Summer
TMDL	Total maximum daily load
TN	Total nitrogen
TP	Total phosphorous
UDWC	Upper Deschutes Watershed Council
USFS	Deschutes National Forest and Ranger Districts
USGS	United States Geological Survey
UDR	Upper Deschutes reach
WQL	Water quality limited

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1.0 INTRODUCTION

Water quality monitoring in the Upper Deschutes and Little Deschutes Subbasins is conducted by a variety of federal, state, and local organizations. These organizations have collected water quality data over several years and for a variety of purposes. Historically, the lack of coordinated, regional monitoring activities resulted in data gaps, duplication of efforts, inconsistent protocols, and a lack of communication and data sharing. To improve the efficacy of existing monitoring programs, the United States Geological Survey (USGS) was contracted to develop the *Framework for Regional. Coordinated Monitoring in the Middle and Upper Deschutes River Basin. Oregon USGS Report 00-386* published in 2000. The *Characterization of Select Water Quality Parameters within the Upper Deschutes and Little Deschutes Subbasins* report (Technical Report) is the result of the implementation of the USGS report by the Upper Deschutes Watershed Council (UDWC) Water Quality Specialist. Analyses of interagency water quality data gathered from monitoring efforts throughout the Upper Deschutes and Little Deschutes Subbasins are presented.

1.1 Framework for Regional Coordinated Monitoring

In 1998, a group of local natural resource management agencies formed a committee to address water quality issues in the Upper Deschutes and Little Deschutes Subbasins. The purpose of this committee was to identify issues, provide information on previous and current monitoring programs, develop and agree on monitoring actions, and work on an interagency monitoring plan. The UDWC, collaborating closely with the committee, was awarded a grant by the Oregon Watershed Enhancement Board to develop a water quality monitoring strategy.

The UDWC contracted with the USGS, an impartial scientific body, and developed the *Framework for Regional, Coordinated Monitoring in the Middle and Upper Deschutes River Basin, Oregon (USGS Report 00-386)*, published in 2000 (Regional Framework). The Regional Framework describes water quality issues in the Upper Deschutes and Little Deschutes Subbasins and the existing monitoring programs to address water quality issues within the subbasins. The primary issues of concern identified in the Regional Framework are water quantity, water temperature, turbidity and sediment transport, eutrophication, bacteria, aquatic macroinvertebrates, and the physical status of channel configuration and habitat for aquatic inhabitants. The Regional Framework provides specific suggestions and recommendations for a phased approach to improve future long-term water quality monitoring.

The UDWC is committed to implementing the recommendations outlined in the Regional Framework. The UDWC has entered into a memorandum of understanding with ODEQ, Oregon Water Resources Department (OWRD), Oregon Department of Fish and Wildlife (ODFW), United States Forest Service (USFS), Bureau of Land Management (BLM), and Bureau of Reclamation (BOR) to collaborate on water quality monitoring activities of the Upper Deschutes and Little Deschutes Subbasins. The Technical Report is being developed by the UDWC as part of the Regional Framework implementation process.

1.2 Purpose

The Regional Framework provides specific suggestions and recommendations for a phased approach to improve future and long-term regional activities via the implementation of coordinated status, trends, and compliance monitoring. The purpose of the Technical Report is to present the compilation and analyses of existing, regional water quality monitoring data. The Technical Report describes select water quality parameters monitored within the subbasins and provides and discusses analyses regarding status, trends, and compliance.

1.3 Study Area

The Upper Deschutes and Little Deschutes Subbasins are approximately 1.2 million acres and include over 1,800 miles of rivers and tributaries. The Upper Deschutes Subbasin is divided into two segments; the upper Deschutes reach and middle Deschutes reach. The upper Deschutes reach includes the

Deschutes River from Wickiup Reservoir to the Swalley Canal; the lowest of a series of diversion points in the City of Bend. The middle Deschutes reach includes the Deschutes River from the Swalley Canal to the inflow at Lake Billy Chinook. The Little Deschutes River subbasin includes the Little Deschutes River from its headwaters to the confluence with the upper Deschutes River. Although part of the Upper Deschutes and Little Deschutes Subbasins, the Metolius River watershed, Tumalo Creek watershed, Squaw Creek watershed, tributaries, lake waterbodies, and reservoir waterbodies are not analyzed within the Technical Report.

1.4 Beneficial Uses and Water Quality Standards

The beneficial uses of water within the Upper Deschutes and Little Deschutes Subbasins are regulated by water quality standards developed by the Oregon Department of Environmental Quality (ODEQ). **Table 1.1** lists the beneficial uses identified by ODEQ within the Upper Deschutes and Little Deschutes Subbasins. Aquatic life beneficial uses, particularly salmonid spawning and rearing, are considered one of the most sensitive beneficial uses of water in the subbasins.

Table 1.1 Beneficial uses within the Upper Deschutes and Little Deschutes Subbasins

Public Domestic Water Supply	Anadromous Fish Passage	Water Contact Recreation
Private Domestic Water Supply	Resident Fish and Aquatic Life	Wildlife and Hunting
Industrial Water Supply	Salmonid Fish Spawning	Fishing
Irrigation	Salmonid Fish Rearing	Boating
Livestock Watering		Aesthetics

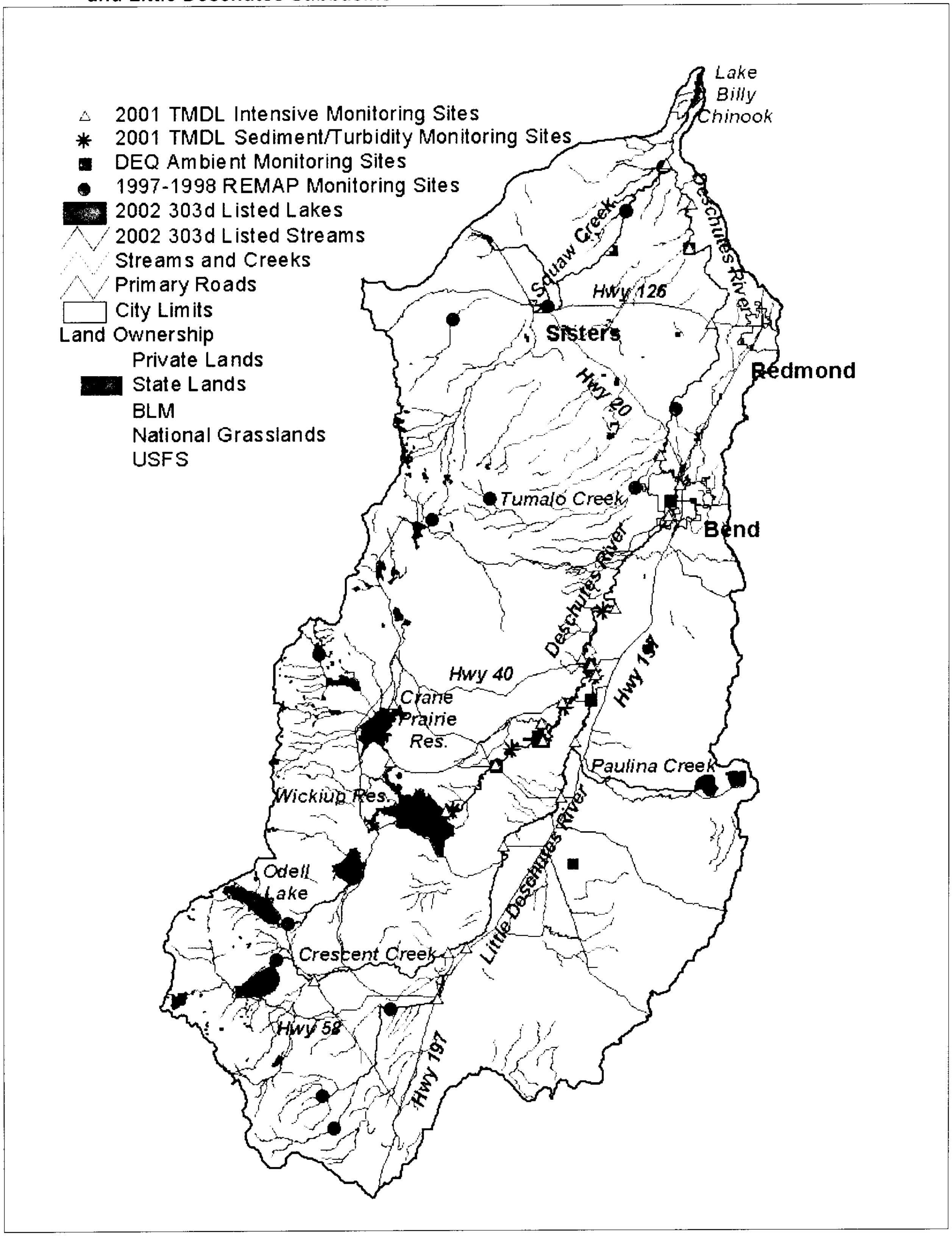
(ODEQ, 2001)

1.5 Upper Deschutes and Little Deschutes Subbasins 303(d) List and Total Maximum Daily Loads

In 2002, several Upper Deschutes and Little Deschutes Subbasins stream reaches and lakes were included on the state 303(d) list for not meeting water quality standards for temperature, pH, dissolved oxygen, chlorophyll-*a*, turbidity, and sedimentation (**Map 1.1**). Several waterbodies and segments are listed as impaired due to non-compliance with Oregon water quality standards and under the federal Clean Water Act 22 USC Section 1313 for more than one water quality parameter. For a detailed description of the specific listed waterbodies within the subbasin see the ODEQ 2002 303(d) list (**Appendix A**). The water quality data used to support the listings can be found on the ODEQ website http://www.deq.state.or.us/wq/303dlist/303dpage.htm. The specific water quality standards can be found at http://www.deq.state.or.us/wq/wqrules/wqrules.htm.

The waterbodies and segments that do not comply with state standards are shown in red on **Map 1.1**. Total Maximum Daily Loads (TMDLs) need to be developed for waterbodies and segments on the 303(d) list and will apply on all listed waterbodies and on any waterbodies flowing into the listed waterbodies. The development of TMDLs are expected to be completed in 2005 by ODEQ.

Map 1.1 Monitoring sites and 303(d) listed waterbodies and segments within the Upper Deschutes and Little Deschutes Subbasins



2.0 METHODS

A comprehensive, regional database is used for analyses. Data for each parameter are analyzed according to critical questions developed to address status, trends, and compliance of the upper Deschutes River and Little Deschutes River.

2.1 Quality Assurance and Quality Control

Water quality monitoring efforts are conducted by various agencies that are encouraged to follow appropriate quality assurance and quality control (QA/QC) methodologies. Technical assistance is made available through the Upper Deschutes Watershed Council Water Quality Monitoring Program. This program promotes QA/QC methodologies outlined in the *Water Quality Monitoring Technical Guide Book* (Oregon, 1999), *DEQ Laboratory Field Sampling Reference Guide* (ODEQ, 1998), and *Standard Methods for the Examination of Water and Wastewater 20th edition* (APHA, 1998). QA/QC protocols that are promoted are as defined in the *Water Quality Monitoring Technical Guide Book:*

QA: the overall management system of a project including the organization, planning, data collection, quality control, documentation, evaluation and reporting activities. QA provides the information needed to determine the data quality and whether it meets the project requirements.

QC: the routine technical activities intended primarily to control errors. Since errors can occur in either the field, the laboratory, or in the office, QC must be a part of each of these activities.

The ODEQ data quality matrix for common water quality measuring protocols and the required precision and accuracy of the method or instrumentation needed to achieve the highest data quality level possible are promoted. Water quality data ranked level A or B are used for ODEQ 303(d) listing and de-listing purposes. Water quality data from several natural resource agencies and organizations are graded for quality and presented in the Technical Report. Data ranked level A or B are loaded into a comprehensive, regional database and are used for analyses.

2.2 Data

A function of the UDWC Water Quality Monitoring Program is to compile existing data and provide a characterization of the region, which is the purpose of the Technical Report.

Regional water quality data is currently compiled into a regional database by the UDWC program. This data has been collected by various water quality monitoring efforts of different agencies. Agencies have decided where and when samples are to be taken according to the needs of agency studies, and as a result data is collected via a variety of sampling designs that include authoritative and probability sampling designs.

- Authoritative sampling investigations collect samples to answer questions regarding a site or a disturbance rather than for statistical inference regarding the population. The authoritative samples are not randomly or independently drawn from the population therefore they draw conclusions that only apply to the original sample and not the entire population.

- Probability sampling investigations collect samples to answer questions regarding the population. The probability samples are randomly and independently drawn from the population therefore they draw conclusions estimating population conditions.

The regional database is used to characterize the region yet consists of data that was gathered for some other purpose prior to the establishment of the UDWC Water Quality Monitoring Program. The UDWC program utilizes historic and current data in order to increase knowledge of regional water quality. Although it is possible to perform statistical analyses on datasets that are compiled from authoritative and probabilistic sampling designs, these analyses are complicated and are beyond the scope of the Technical Report.

For the Technical Report, the regional trends are estimated by using the slope of a linear regression line. The Technical Report utilizes linear regression for informal, quick, and easy screening of regional trends. The insights drawn from the Technical Report should be kept in context of sites that are sampled for some reason of the authoritative agencies such as TMDL development and sites that utilize probabilistic designs for intra-site trends analyses and water quality indexing studies.

Due to the variety of monitoring sources for regional data, some water quality parameters within the regional database have insufficient data for analyses while other water quality parameters have a surplus of data that requires further analyses. The UDWC program provides additional monitoring in order to supplement the regional database and is making efforts to provide further analyses of surplus data.

The analyses in the Technical Report can be applied towards identifying regional priority issues that may require further investigation. The Technical Report provides preliminary regional analyses, or characterizations, that provide the background required for the future design of regional probability sampling. Regional probability sampling can utilize available historic information to stratify the region and set appropriate probabilities of selection. The result is the ability to do regional analyses that have that can be used by conservation, restoration, and agency efforts to address regional priority issues. A goal of the UDWC Water Quality Monitoring Program is to provide regional analyses that are statistically and practically significant and the Technical Report is a preliminary step towards obtaining this goal.

A summary of regional water quality monitoring surveys and parameters is provided in **Appendix B**. Monitoring site by river mile and corresponding parameters used in the Technical Report are listed in **Appendix C**, which also provides easy reference for graphs depicting data by river mile. For each parameter analyses, the data source used to build the parameter dataset is narrated.

2.3 Water Quality Parameters

The water quality parameters selected for the Technical Report include pH, dissolved oxygen, percent saturation, biochemical oxygen demand, turbidity, sedimentation, chlorophyll-*a*, nutrients, and bacteria. **Table 2.1** shows the water quality parameters and the corresponding beneficial uses that may be affected by criteria violations.

Water quality is affected by many factors including natural and anthropogenic impacts. Natural factors that affect water quality include soil types, hydrology, and geomorphology. Anthropogenic impacts on water quality include point and nonpoint sources of pollution and past and present forest, agricultural, and urban land use practices. The impacts have resulted in the listing of many segments on the state water quality impaired list.

Table 2.1 Water quality parameters and associated beneficial uses

Water Quality Parameter	Associated Beneficial Use
pH	Resident Fish and Aquatic Life Water Contact Recreation
Dissolved Oxygen	Resident Fish and Aquatic Life Salmonid Fish Spawning and Rearing
Percent saturation	Resident Fish and Aquatic Life Salmonid Fish Spawning and Rearing
Turbidity	Resident Fish and Aquatic Life Water Supply Aesthetics
Sedimentation	Resident Fish and Aquatic Life Salmonid Fish Spawning and Rearing
Chlorophyll-*a*	Water Contact Recreation Aesthetics Fishing Water Supply Livestock Watering
Nutrients	Aesthetics Resident Fish and Aquatic Life Water Contact Recreation Salmonid Fish Spawning and Rearing
Bacteria (*Escherichia coli*)	Water Contact Recreation

(ODEQ, 2001)

2.4 Critical Questions

Critical questions are addressed in the Technical Report. How the data are sorted to answer the critical questions is described by narrative. The critical questions are:

1. How does the parameter change along the longitudinal extent of the aquatic system?

For analyses, data are sorted by site, year, month, and a.m./p.m. The a.m./p.m. mean for each day is calculated, daily means are established, and a month mean is derived from all sampled days. The month means are used to establish a year mean. The year means for each site are displayed in graphical format within each parameter section.

2. What are the daily and seasonal variability of the parameter within the aquatic system?

For seasonal analyses, data are sorted by year, month, site, and am./p.m. The a.m./p.m. mean for each day is calculated, daily means are established, and a site mean is derived from all sampled days. The site means are used to establish the month mean. The month means are used to establish a long-term seasonal mean over the entire time period and are represented in graphical format within each parameter section.

3. *What is the long-term trend of the parameter within the aquatic system?*

For analyses, data are sorted by year, month, site, and am./p.m. The a.m./p.m. mean for each day is calculated, daily means are established, and a site mean is derived from all sampled days. The site means are used to establish the month mean. The month means for each year are displayed in graphical format within each parameter section.

4. *Is the parameter compliant with regulatory criteria for the aquatic system?*

The protocol for obtaining the sample minimum is the same as that used for ODEQ 303(d) listing and de-listing purposes and follows guidelines set by the EPA (ODEQ, 2003b. EPA, 1998). One modification to the protocol is made; the EPA and ODEQ methodologies for listing and de-listing purposes attain the minimal number of samples by including all data from multiple years within a given season , while the Technical Report methodologies attain the minimal number of samples by including data from a single season. The difference in methodologies provides a seasonal compliance analyses profile for sites and information regarding regional conditions that is in addition to the information provided by the 303(d) listings. By applying the recommended guidelines for parameters, compliance analyses are extended to parameters that do not have regulatory criteria set by the state. The results of both the Technical Report analyses and the 303(d) analyses are provided for each parameter.

For analyses, datasets consist of sample data from different days. Datasets are evaluated to determine if the sample minimum is available for compliance analyses according to the Technical Report methodology described above. Unless stated otherwise within the parameter section for compliance analyses, the dataset is categorized:

- Water quality limited (WQL) - Datasets with at least 5 samples per time period and 10% of the samples and a minimum of two exceedences are needed to exceed the applicable criterion for the waterbody.

- Attaining criteria - Datasets with at least 5 samples per time period and at least 90% of the samples in the dataset must be in compliance with the applicable criterion.

- Insufficient data - Datasets that have less than 5 samples per time period.

Unless stated otherwise within the parameter section for compliance analyses, time periods are designated:

Summer (S): June 1 through September 30
Fall-Winter-Spring (FWS): October 1 to May 31

3.0 pH

3.1 Introduction

pH is a measure of the hydrogen ion concentration of a solution using a logarithmic scale of 0.0 to 14.0. Low pH less than 7.0 is considered acidic while high pH greater than 7.0 is alkaline. Water pH can have both direct and indirect effects on the aquatic ecosystem. In general, aquatic organisms do best in a water pH range of 6.5 to 8.5. Water pH can impact both aquatic insect populations and salmonids by affecting egg development, egg hatching, and embryo development. Extreme pH levels can affect the availability and toxicity of certain pollutants such as heavy metals and ammonia, which can negatively affect fish.

Like temperature, pH naturally varies both daily and seasonally. Daily fluctuations in pH are usually the result of the photosynthetic activity of aquatic plants. During daylight hours when aquatic plants uptake carbon dioxide and release oxygen, the water becomes more alkaline; pH values increase. Conversely, during the night when plants are not actively photosynthesizing yet other aquatic organisms are producing carbon dioxide via respiration, the water becomes more acidic; pH values decrease. The daily peak in pH values occurs around mid to late afternoon while the lowest values occur just before sunrise (Oregon Plan, 1999). Seasonal fluctuations in pH are also due to the differences in the photosynthetic activity of aquatic plants, and fluctuations are affected by increased primary production during the summer and decreased primary production during the winter.

pH values can be altered by increased primary production due to increased nutrient loading into the aquatic system predominately driven by anthropogenic impacts. Anthropogenic impacts include nutrient loading from failing septic systems, agricultural runoff, urban runoff, and sewage spills. Acid rain deposition is another anthropogenic impact that alters pH values. A natural source that affects pH values includes the chemistry of the local substrate.

3.2 Analyses

Throughout the entire Upper Deschutes and Little Deschutes Subbasins, ODEQ has set general numeric criteria for pH to protect the beneficial uses of water including resident fish, aquatic life, and water contact recreation. The ODEQ pH criteria state that pH shall not fall outside the range of 6.5 to 8.5, and for waterbodies specific to the Cascade Lakes the pH range is 6.0 to 8.5. For the Technical Report, the following scale is applied in order to rate pH values and describe conditions:

Extremely acidic	pH 0.0 – 4.9
Moderately acidic	pH 5.0 – 5.9
Slightly acidic	pH 6.0 – 6.9
Neutral	pH 7.0
Slightly alkaline	pH 7.1 – 8.0
Moderately alkaline	pH 8.1 – 9.0
Extremely alkaline	pH 9.1 – 14.0

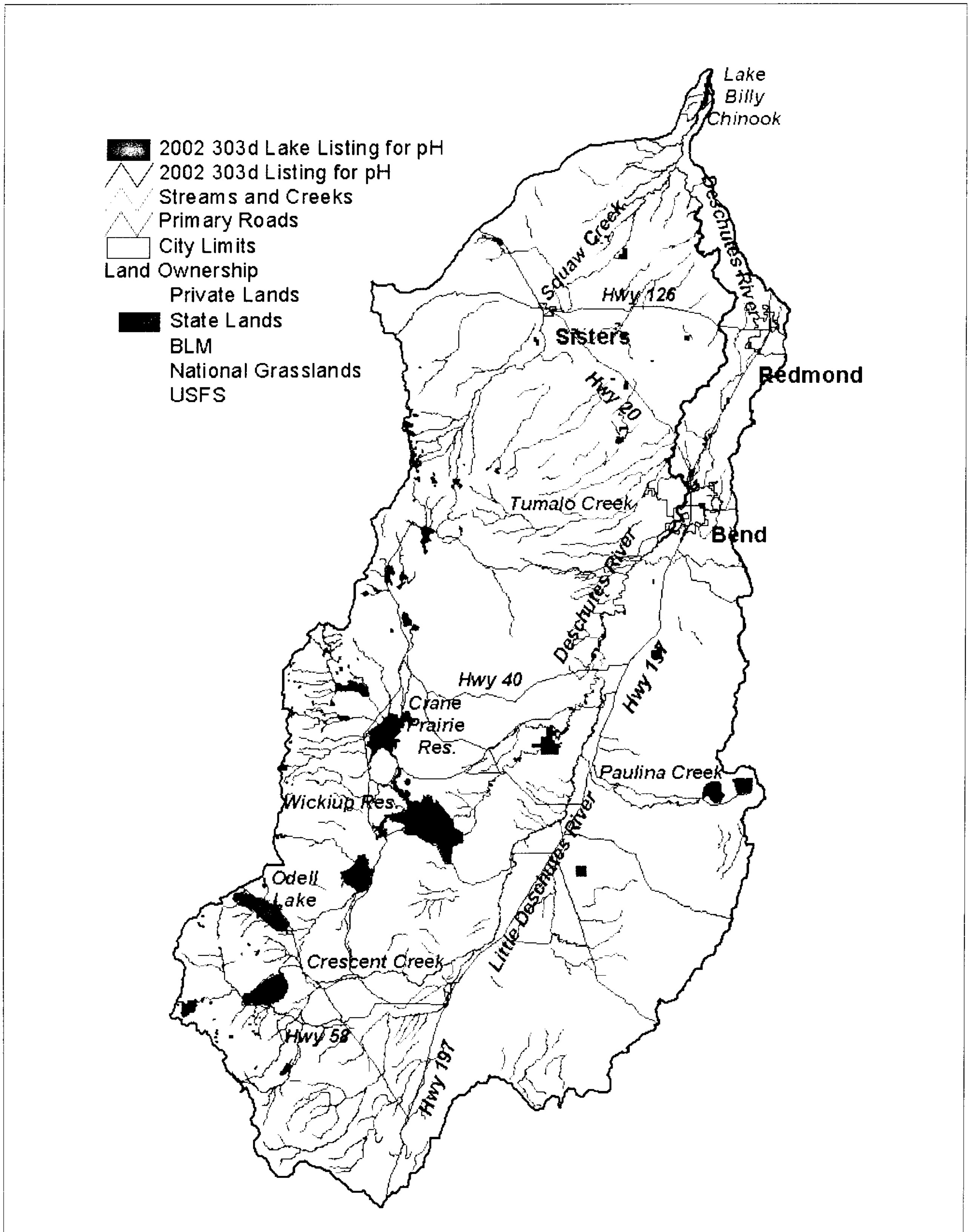
Slight fluctuation	pH change <1.0
Moderate fluctuation	pH change $1.1 < x < 1.9$
Extreme fluctuation	pH change > 2.0

The Deschutes River is included on the State 303(d) list for exceeding the pH criterion from RM 126.4 (Steelhead Falls) to RM 168.2 (upstream of the City of Bend). **Map 3.1** shows the waterbodies and segments that exceed the pH criterion within the Upper Deschutes and Little Deschutes Subbasins.

To address the critical questions, data collected from 1993 to 2002 by ODEQ ambient monitoring and intensive water quality monitoring studies for TMDL development are used to illustrate trends along the longitudinal extent of the upper Deschutes reach and Middle Deschutes reach. Data collected from 1995 to 2002 by ODEQ ambient monitoring, ODEQ intensive water quality monitoring studies for TMDL development, and REMAP studies are used to illustrate trends along the longitudinal extent of the Little Deschutes River.

ODEQ ambient monitoring and intensive water quality monitoring data are predominately collected during the odd numbered months of January, March, May, July, September, and November. Some months and years have relatively small datasets compared to other months and years that have relatively large datasets. The year 2001 has the largest dataset due to the 2001 TMDL monitoring efforts. The relatively small amount of data collected on even months are incorporated into odd month data. This is accomplished by consolidating data collected between the first and fifteenth of the month into the previous month dataset, and data collected between the sixteenth and last day of the month into the post month dataset.

Map 3.1 pH 303(d) listed waterbodies and segments within the Upper Deschutes and Little Deschutes Subbasins



3.2.1 How does pH change along the longitudinal extent of the aquatic system?

Changes along the longitudinal extent of reaches within the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 3.1** and **Figure 3.2.** A solid grey line represents a longitudinal grand mean. A dashed black line represents the applicable criterion. A solid black line represents a linear regression and is provided for insight regarding the trend over the longitudinal extent during the time period.

The upper Deschutes River has a longitudinal grand mean pH value of 8.0, appears to have an upward trend in mean pH values with decreasing river mile, and ranges from slightly to moderately alkaline.

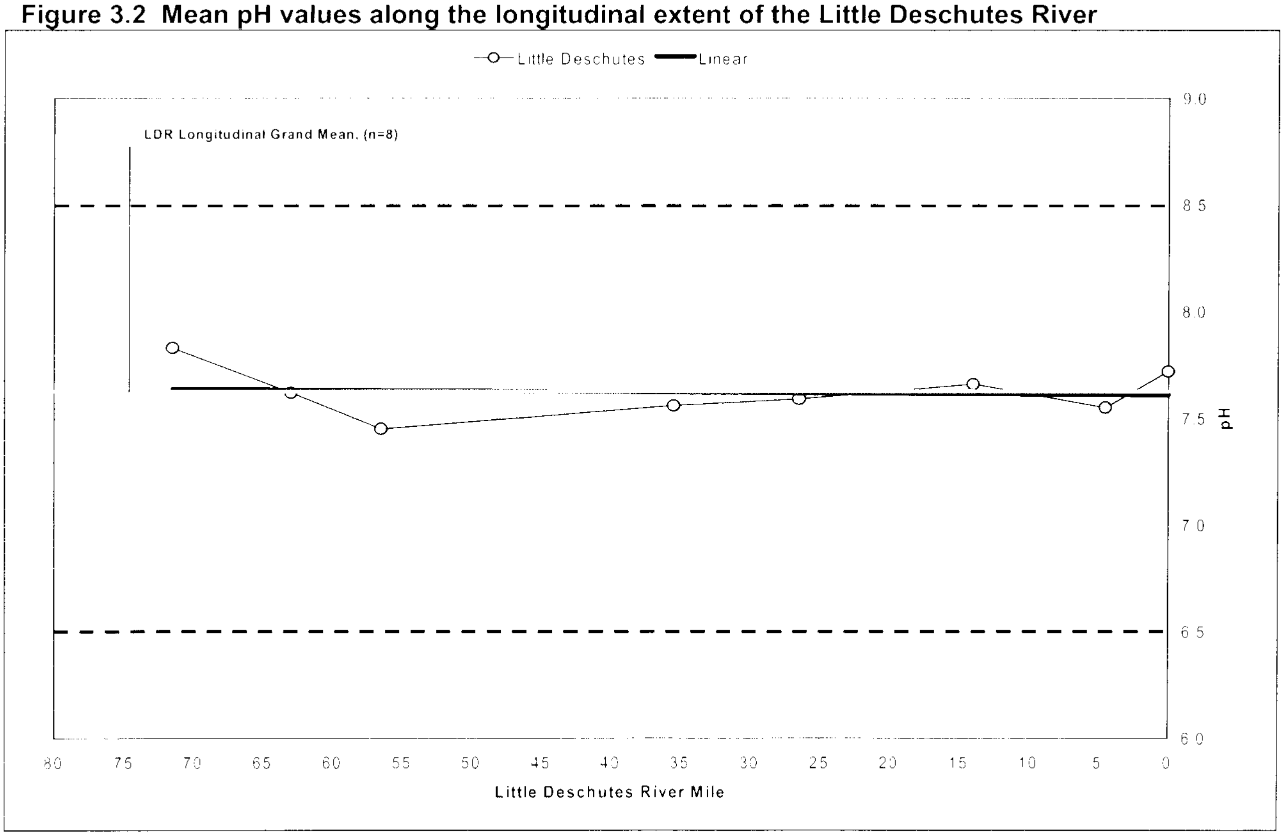
The upper Deschutes reach has a longitudinal grand mean pH value of 7.8 and is slightly alkaline. A linear regression results in a positive slope. This indicates a downstream upward trend in mean pH values.

The middle Deschutes reach has a longitudinal grand mean pH value of 8.2 and is moderately alkaline. A linear regression results in a positive slope. This indicates a downstream upward trend in mean pH values.

The Little Deschutes River has a longitudinal grand mean pH value of 7.6 and is slightly alkaline. A linear regression results in a slope that is not increasing or decreasing. This indicates a downstream trend of constant mean pH values.

Figure 3.1 Mean pH values along the longitudinal extent of the upper Deschutes River

Figure 3.2 Mean pH values along the longitudinal extent of the Little Deschutes River



3.2.2 *What are the daily and seasonal variability of pH?*

Daily fluctuations in pH

The measurements from continuously monitored sites during the summer of 2001 are used to show daily changes in pH. These sites were monitored on July 17, July 18, and July 19 with multi-parameter data loggers set to take pH readings every 15 minutes. This three day monitoring session enables a comparison of daily changes at each site and between the sites. pH data from seven continuous monitoring sites within the subbasins are presented (**Figure 3.3**). Five sites are along the upper Deschutes River and include downstream of Crane Prairie Reservoir, downstream of Wickiup Reservoir, Harper Bridge, Riverhouse Hotel in the City of Bend, and Lower Bridge. Two sites are on the Little Deschutes River and include the Little Deschutes River at Crescent Creek and the Little Deschutes River at Crosswater Golf Course upstream from the confluence with the upper Deschutes River. A dashed black line represents the applicable criterion.

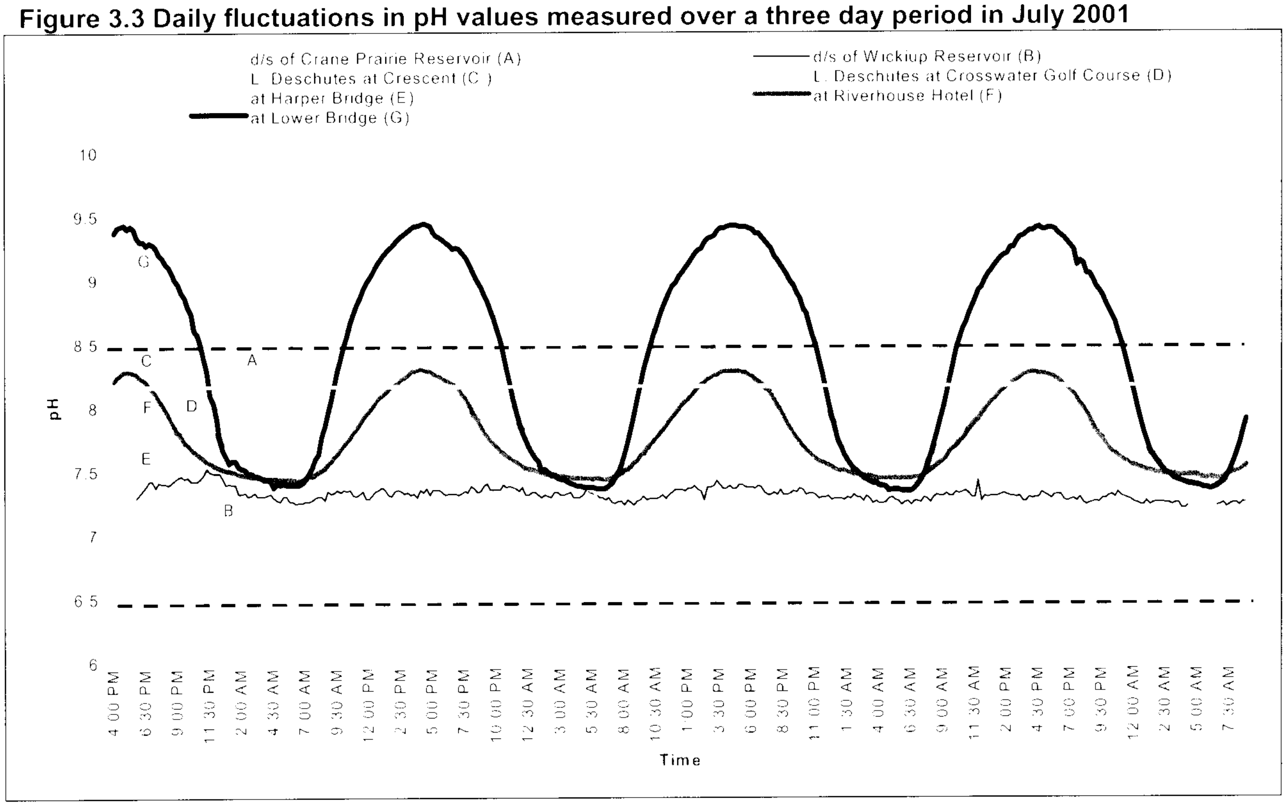
The upper Deschutes River downstream Crane Prairie Reservoir expresses a slight fluctuation in daily pH values ranging from approximately 8.4 – 8.8 and a moderate alkaline aquatic system. The upper Deschutes River downstream Wickiup Reservoir expresses a slight fluctuation in daily pH values ranging from 7.2 to 7.5 and a slight alkaline aquatic system.

Sites between downstream Wickiup Reservoir and upstream Lower Bridge express a moderate fluctuation in daily pH values ranging from approximately 7.2 – 8.7 and a slight to moderate alkaline aquatic system.

The upper Deschutes River at Lower Bridge expresses an extreme fluctuation in daily pH values ranging from approximately 7.4 to 9.4 and a slight alkaline to extreme alkaline aquatic system.

The Little Deschutes River expresses a moderate fluctuation in daily pH values ranging from approximately 7.2 – 8.7 and a slight to moderate alkaline aquatic system.

Figure 3.3 Daily fluctuations in pH values measured over a three day period in July 2001



Seasonal fluctuations in pH

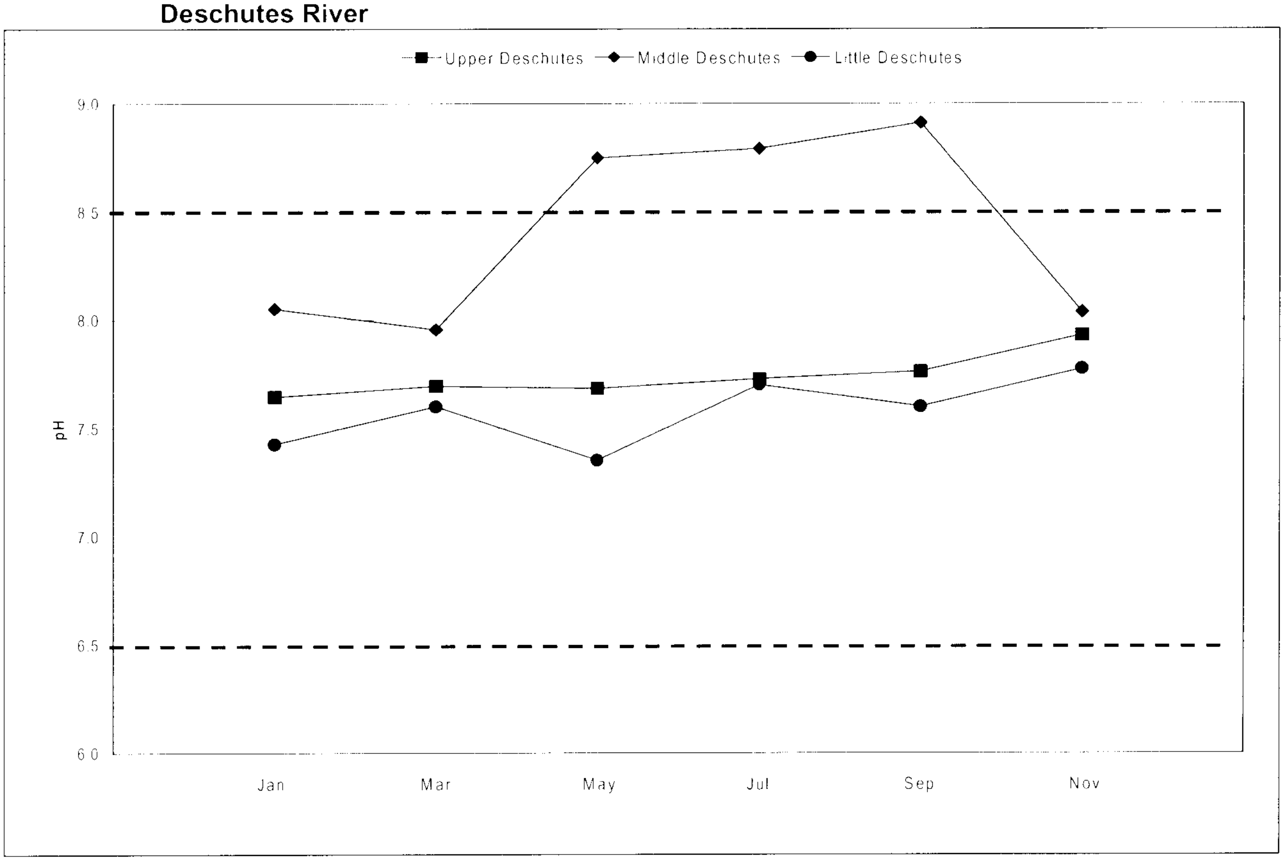
Seasonal fluctuations within reaches of the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 3.4**. A dashed black line represents the applicable criterion.

The upper Deschutes reach has a seasonal grand mean pH value of 7.7 and is a slight alkaline aquatic system. There is a slight fluctuation in mean seasonal pH values ranging from 7.7 to 7.9 and a slight alkaline fluctuation within the aquatic system.

The middle Deschutes reach has a seasonal grand mean pH value of 8.4 and is moderate alkaline aquatic system. There is a moderate fluctuation in mean seasonal pH values ranging from 7.9 – 8.8 and a moderate to extreme alkaline fluctuation within the aquatic system.

The Little Deschutes River has a seasonal grand mean pH value of 7.6 and is a slight alkaline aquatic system. There is a slight fluctuation in mean seasonal pH values ranging from 7.4 – 7.8 and a slight alkaline fluctuation within the aquatic system.

Figure 3.4 Seasonal fluctuations in mean pH values within the upper Deschutes River and Little Deschutes River



3.2.3 What is the long-term trend in pH?

The long-term trends for reaches within the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 3.5, Figure 3.6, and Figure 3.7**. A solid grey line represents a long-term grand mean. A dashed black line represents the applicable criterion. A solid black line represents a linear regression and is provided for insight regarding the trend over the time period.

The upper Deschutes reach has a long-term grand mean pH value of 7.7 and is a slight alkaline aquatic system. A linear regression results in a positive slope. This indicates a temporal upward trend of mean pH values.

The middle Deschutes reach has a long-term grand mean pH value of 8.4 and is a moderate alkaline aquatic system. A linear regression results in a positive slope. This indicates a temporal upward trend of mean pH values.

The Little Deschutes River has a long-term grand mean pH value of 7.6 and is a slight alkaline aquatic system. A linear regression results in a positive slope. This indicates a temporal upward trend of mean pH values.

Figure 3.5 Long-term trend in mean pH values within the upper Deschutes reach

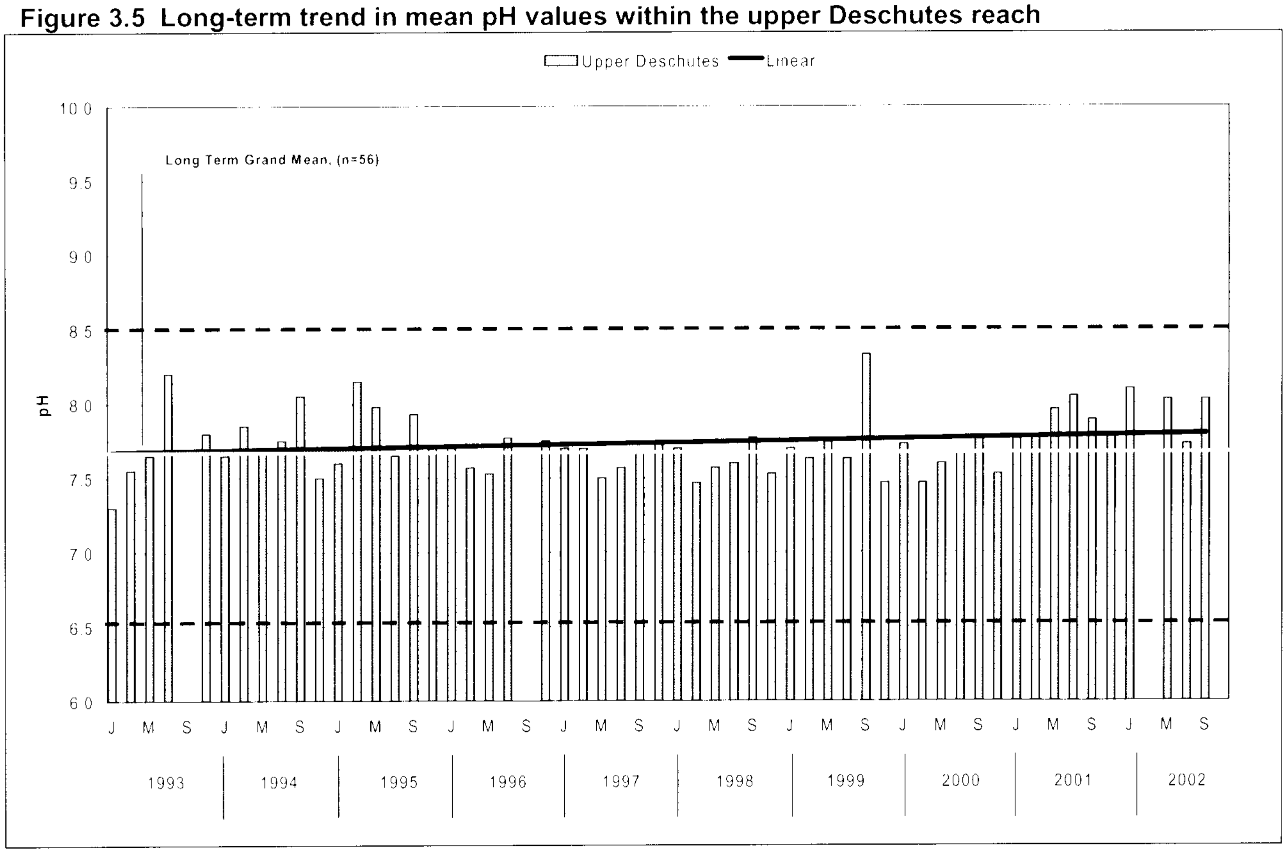


Figure 3.6 Long-term trend in mean pH values within the middle Deschutes reach

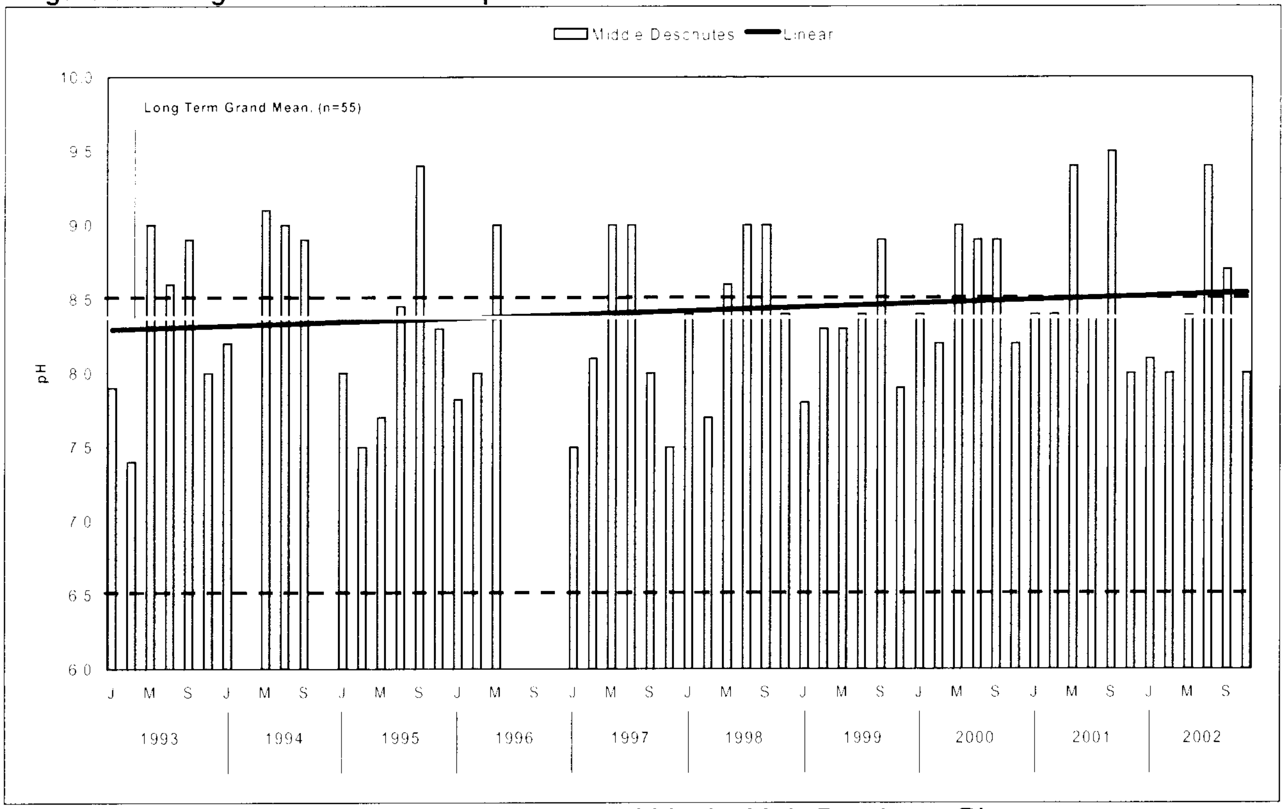
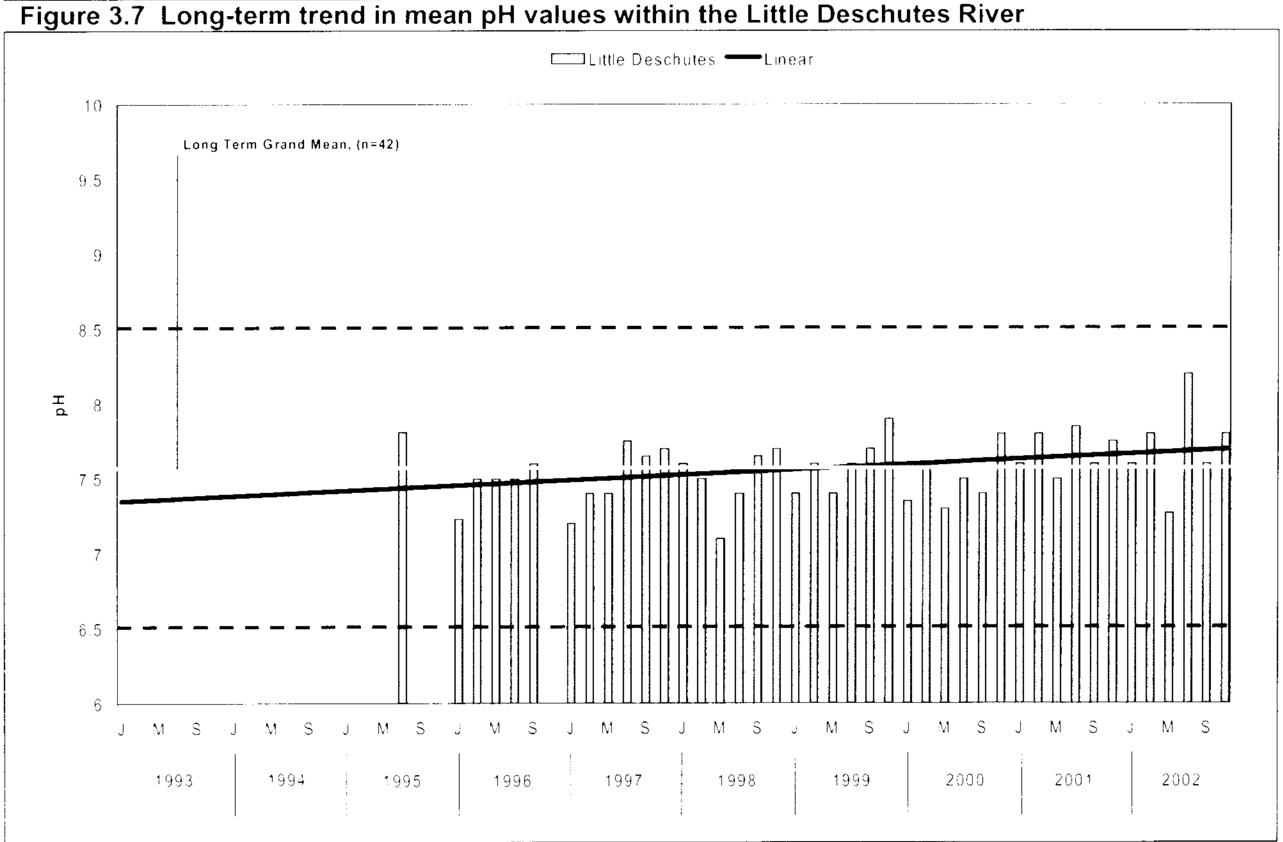


Figure 3.7 Long-term trend in mean pH values within the Little Deschutes River



3.2.4. Are pH values compliant with regulatory criteria?

Data are evaluated by site and season. The sites and the season applicable for analyses are displayed in **Table 3.1**. Three upper Deschutes reach sites and one middle Deschutes reach site satisfy the minimal sample number required by the EPA and ODEQ for analyses of compliance with the regulatory criteria. There are no Little Deschutes River sites that satisfy the minimal sample number required for analyses of compliance with the regulatory criteria when data is evaluated by season.

Site analyses are displayed by quantiles in **Figure 3.8**. The data are presented in quantiles depicting the minimum, 10%, 25%, median, 75%, 90% and maximum boundaries. The number of samples at a particular site is stated within parentheses. A solid black line represents the data mean. The dashed black line represents the applicable criteria.

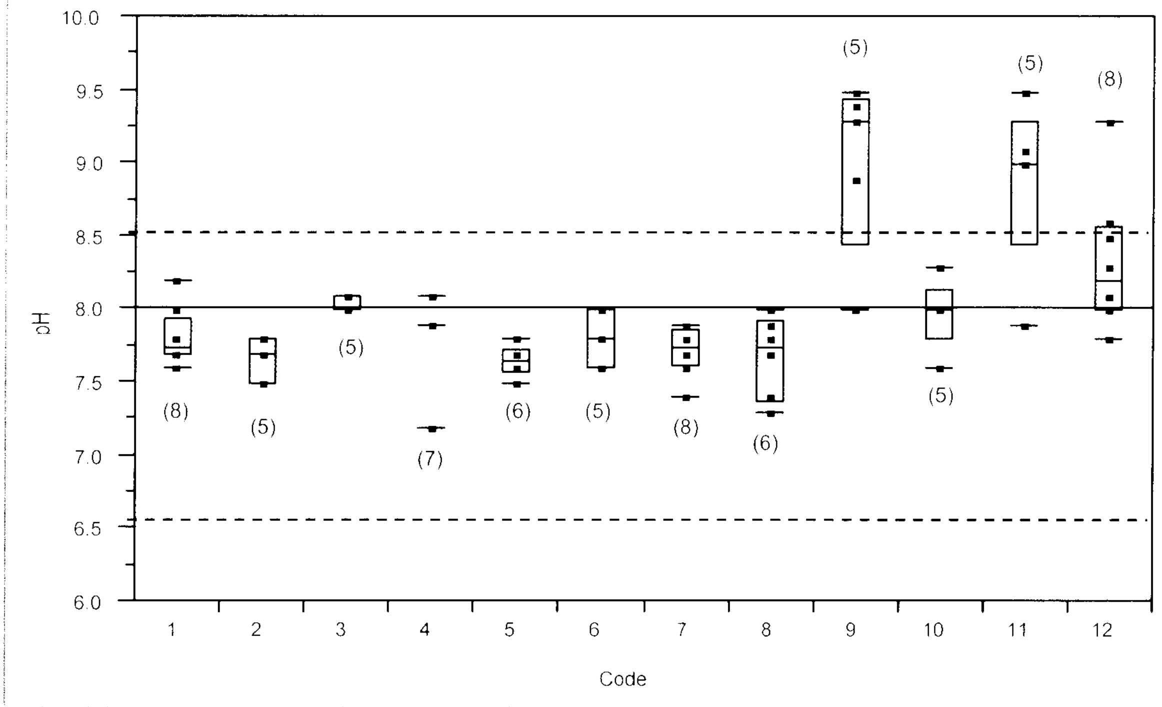
Table 3.1 pH datasets that meet the minimal sample number required for compliance analyses

Code	Season	RM	Site	Segment	Compliance analyses
1	FWS 1995/1996	217	Pringle Falls	UDR	Attaining criteria
2	FWS 1998/1999	217	Pringle Falls	UDR	Attaining criteria
3	S 2001	217	Pringle Falls	UDR	Attaining criteria
4	FWS 2001/2002	217	Pringle Falls	UDR	Attaining criteria
5	FWS 1995/1996	191.5	Harper Bridge	UDR	Attaining criteria
6	S 2001	191.5	Harper Bridge	UDR	Attaining criteria
7	FWS 2001/2002	191.5	Harper Bridge	UDR	Attaining criteria
8	FWS 1995/1996	166.5	Mirror Pond	UDR	Attaining criteria
9	S 1995	133.5	Lower Bridge	MDR	**WQL**
10	FWS 1995/1996	133.5	Lower Bridge	MDR	Attaining criteria
11	S 2001	133.5	Lower Bridge	MDR	**WQL**
12	FWS 2001/2002	133.5	Lower Bridge	MDR	**WQL**

S= June 1 through September 30 FWS: October 1 to May 31 WQL = water quality limited

The Little Deschutes River dataset is categorized as having insufficient data for compliance analyses.

Figure 3.8 Detail of pH values within the upper Deschutes River



Quantiles

Code	minimum	10.0%	25.0%	median	75.0%	90.0%	maximum
1	7.6	7.6	7.7	7.8	8.0	8.2	8.2
2	7.5	7.5	7.5	7.7	7.8	7.8	7.8
3	8.0	8.0	8.0	8.0	8.1	8.1	8.1
4	7.2	7.2	7.9	7.9	7.9	8.1	8.1
5	7.5	7.5	7.6	7.7	7.7	7.8	7.8
6	7.6	7.6	7.6	7.8	8.0	8.0	8.0
7	7.4	7.4	7.6	7.8	7.9	7.9	7.9
8	7.3	7.3	7.4	7.8	7.9	8.0	8.0
9	8.0	8.0	8.5	9.3	9.5	9.5	9.5
10	7.6	7.6	7.8	8.0	8.2	8.3	8.3
11	7.9	7.9	8.5	9.0	9.3	9.5	9.5
12	7.8	7.8	8.0	8.2	8.6	9.3	9.3

The ODEQ pH criteria state that pH shall not fall outside the range of 6.5 to 8.5.

The upper Deschutes reach sites and seasons code 1 – 8 are categorized as attaining criteria, because 90% of the dataset are within the applicable criteria.

The middle Deschutes reach sites and seasons code 9, 11, and 12 are categorized as water quality limited, because 10% of the dataset and a minimum of two exceedences are not compliant with the applicable criteria. Sites and seasons code 10 are categorized as attaining criteria, because 90% of the dataset are within the applicable criteria.

3.3 Discussion and Key Findings

As indicated by pH levels, there may be regional impacts from flow modifications, nonpoint source pollution, and water diversions. Nonpoint source pollution carried by uncharacterized urban runoff may be impacting water quality. Areas of sediment deposition near and within the City of Bend may have the tendency to accumulate nonpoint source pollution carried by uncharacterized urban runoff into deposited sediments, while water diversions lowering summer water flows within the middle Deschutes reach may exacerbate any impacts of nonpoint source pollution from uncharacterized urban runoff and rural land use. Conditions of the middle Deschutes reach at the Lower Bridge site may illustrate the accumulative nature of upstream and long-term impacts from nonpoint source pollution. A water quality limited status exists for the Lower Bridge site and this site is on the state 2002 303(d) listing within the segment from RM 126.4 (Steelhead Falls) to RM 168.2 (upstream of the City of Bend).

The upper Deschutes River appears to be slightly to moderately alkaline and exhibits an upward trend in pH values along the longitudinal extent of the river and with time. The upper Deschutes reach and middle Deschutes reach exhibit a downstream upward trend in mean pH values along the longitudinal extent of the upper Deschutes River, while the upper Deschutes reach, middle Deschutes reach, and Little Deschutes River all exhibit a downstream upward trend in mean pH values with time (**Figure 3.1, Figure 3.5, Figure 3.6,** and **Figure 3.7**). Downstream upward trends in mean pH values along the longitudinal extent and with time may be indicative of nonpoint source pollution within areas of the subbasins. Pollutants entering a system can increase pH via increasing nutrients leading to increases in primary production and consequently increases in oxygen production. Pollutants entering a system can also decrease pH by the addition of acidic compounds, which upon degradation commonly result in more acidic compounds. The direction that pH is driven depends on the type of pollutants and site specific characteristics. Conditions at the Mirror Pond site, the middle Deschutes reach, and the Lower Bridge site may be demonstrating the tendency of nonpoint source pollution to affect pH values.

Longitudinal extent mean ph at the Mirror Pond site is categorized as being slightly alkaline while all other sites within the City of Bend are categorized as being moderately alkaline (**Figure 3.1**). The discrepancy in categorization may be due to the possible sedimentation at this site in combination with uncharacterized urban runoff. Sediments accumulate compounds commonly found in urban runoff. Urban runoff compounds are commonly acidic and contribute to more acidic conditions. In addition, byproducts of urban runoff compound degradation are commonly acidic. Possible changes in the system due to the combination of uncharacterized urban runoff and sediment deposition is supported by the BOD-5 results for the City of Bend illustrating the highest BOD-5 at the Mirror Pond site; elevated BOD-5 indicates compound degradation (**Figure 4.5**).

At sites within the middle Deschutes reach, longitudinal extent mean pH values approach the upper limits of the state criterion of 8.5 pH and reflect moderate alkaline conditions (**Figure 3.1**). Seasonal mean pH values are also moderately alkaline and warm month conditions are not compliant with the state criteria of 8.5 pH (**Figure 3.4**). In addition, many long-term mean pH values are not compliant with the state criteria of 8.5 pH and several long-term mean pH values are above 9.0 pH therefore are of serious concern for aquatic life (**Figure 3.6**). Influences on pH in the middle Deschutes reach may include the uncharacterized urban runoff, agriculture, and water diversions.

Uncharacterized urban runoff, agriculture, and water diversions may influence mean pH values within the middle Deschutes reach. pH levels within the middle Deschutes reach seasonally reflect slight to moderate alkaline conditions that are greater than conditions reflected by the upper Deschutes reach and the Little Deschutes River during the same time periods (**Figure 3.4**). Although May, July, and September mean pH values are not compliant with state criteria of 8.5 pH, mean pH values during January, March, and November do not violate state criteria but are still relatively elevated within the middle Deschutes reach. Uncharacterized compounds from urban and rural runoff that enter the water may be transported with increasing flows from Wickiup storage releases to the middle Deschutes reach where lower summer flows due to water diversions may exacerbate any nonpoint source pollution. Uncharacterized compounds that are carried into the upper Deschutes River upstream of the middle

Deschutes reach may indirectly cause pH levels to be elevated via possible increases in primary production within the middle Deschutes reach.

Water diversions may influence mean pH values within the middle Deschutes reach via decreasing water flows. During the warmer summer months when water diversions are decreasing the flow within the middle Deschutes reach, there are increases in nutrient concentrations (**Figure 7.1**). Generally, decreased flows and warmer air temperatures result in warmer water temperatures and less water to dilute compounds entering the river. The warmer water temperature and increased nutrients also generally increase primary production. Although many polluting compounds from urban runoff are acidic, increased primary production results in more photosynthesis activity producing oxygen and increasing mean pH values. This process may be apparent in the middle Deschutes reach and is supported by the relatively higher dissolved oxygen and percent saturation exhibited by the middle Deschutes reach compared to the upper Deschutes reach (**Figure 4.1** and **Figure 4.3**), the extreme daily fluctuations in dissolved oxygen and percent saturation at the middle Deschutes reach sites above Riverhouse Hotel and Lower Bridge (**Figure 4.11** and **Figure 4.12**).

The upward trend in mean pH values along the longitudinal extent of the rivers and with time may have an accumulative impact on the health of the Upper Deschutes Subbasin. The impact may be evident upon analyses of daily fluctuations in pH during July 2001 along several sites of the upper Deschutes River (**Figure 3.3**). Downstream of the Wickiup/Crane Prairie Reservoir complex, a slightly alkaline aquatic system and slight fluctuations in pH exist. Sites between downstream Wickiup Reservoir and upstream Lower Bridge express a slightly to moderately alkaline aquatic system and moderate fluctuation in daily pH values. The Lower Bridge exhibits a slightly to extreme alkaline aquatic system and extreme fluctuations in daily pH values. The downstream change in daily pH behavior appears to be on a continuum and may illustrate the effects of upstream and long-term pollution impacts along the longitudinal extent of the upper Deschutes River and on the lower end of the Upper Deschutes Subbasin.

The pH datasets that meet the minimal sample number required for compliance analyses illustrate that the Lower Bridge is categorized as water quality limited three out of the four season/years that had qualifying datasets (**Table 3.1**). The water quality limited status at the Lower Bridge site is within the state 2002 303(d) listing of the segment from RM 126.4 (Steelhead Falls) to RM 168.2 (upstream of the City of Bend).

Key Findings

- As indicated by pH, possible nonpoint source pollution carried by uncharacterized urban runoff, agriculture and water diversions may be impacting water quality within the upper Deschutes River.

- As indicated by pH, areas of sediment deposition near and within the City of Bend may have the tendency to accumulate nonpoint source pollution carried by uncharacterized urban runoff into deposited sediments.

- Water diversions lowering summer water flows within the middle Deschutes reach may exacerbate the impacts of possible nonpoint source pollution from uncharacterized urban runoff and rural land use.

- Conditions of the upper Deschutes River at the Lower Bridge site may illustrate the accumulative nature of upstream and long-term impacts from possible nonpoint source pollution.

- A water quality limited status exists for the Lower Bridge site and is within the state 2002 303(d) listing of the segment from RM 126.4 (Steelhead Falls) to RM 168.2 (upstream of the City of Bend).

4.0 DISSOLVED OXYGEN, PERCENT SATURATION, & BIOCHEMICAL OXYGEN DEMAND

4.1 Introduction

A natural stream system both produces and consumes oxygen. Oxygen is produced within the aquatic system via two processes; primary production photosynthesis that results in energy production and passive atmospheric aeration. Oxygen is consumed within the aquatic system via aquatic organisms utilizing respiration and redox reactions resulting in energy production. In a healthy aquatic system, a balance between consumers and producers exists.

Three factors illustrate the balance of oxygen in the waters of an aquatic system; concentration, saturation, and demand. Dissolved oxygen is the concentration of oxygen in the water. Percent saturation is the amount of oxygen that can be held within the water. Biochemical oxygen demand (BOD-5) is measured over a five day incubation period and reflects the rate of oxygen consumption due to microbial degradation of organic matter and the chemical oxidation of inorganic matter (EPA, 1997). BOD-5 is a reflection of oxygen consumption and the extent of organic pollution within the water.

The concentration of dissolved oxygen within the water undergoes daily fluctuations. Primary producers utilize photosynthesis and aquatic aerobic organisms utilize respiration and redox reactions to gain energy. During the daylight hours, aquatic plants utilize photosynthesis resulting in oxygen production. Concurrently, respiration and aerobic redox reactions that decompose organic and inorganic matter consume oxygen. At night photosynthesis is inactive and oxygen is not produced within the system except by atmospheric aeration, while respiration and decomposition continues to consume oxygen. The balance between photosynthesis that produces oxygen and respiration and decomposition that consume oxygen affects the amount of dissolved oxygen levels in the water.

The concentration of dissolved oxygen within the water undergoes seasonal fluctuations. Warmer temperatures during summer months increases the rates of photosynthesis and decomposition. As plants die at the end of the season, decomposers consume oxygen to break down the organic plant compounds.

The percent saturation within the water is affected by temperature and altitude. Cold water holds more dissolved oxygen than warm water. Water at higher altitudes holds less dissolved oxygen than water at lower altitudes, because the degree of atmospheric pressure is less at higher altitudes. In general, when the total dissolved gas that includes oxygen, carbon dioxide, and other gases in water exceeds 110% it can have negative impacts on aquatic species (ODEQ, 2003b). Supersaturation of water by oxygen may occur due to rapidly aerated water and high primary production and is also considered harmful to aquatic species. High percent saturation levels negatively affect the ability of aquatic species to uptake the correct amount of oxygen due to osmotic gradients that govern oxygen diffusion in aquatic species; oxygen passing through fish gills.

The BOD-5 within the aquatic system is affected by the amount of microorganisms utilizing aerobic redox reactions. As organic compounds enter the system, the rate of aerobic redox reactions utilizing oxygen increases as decomposition of the organic and inorganic compounds occurs and energy is harnessed. A high BOD-5 reflects a high oxygen consumption rate. A high oxygen consumption rate indicates that dissolved oxygen concentrations are in demand and possibly decreasing, which negatively impacts the biodiversity of the aquatic system because respiring aquatic organisms, such as fish, also utilize oxygen to harness energy.

Anthropogenic activities impact dissolved oxygen levels. Changes in flow affect the aeration of the water. Sewage seepage, urban runoff, and nutrient loading increases the amount of organic and inorganic compounds within the water, therefore increasing the BOD-5 within the aquatic system.

Aquatic organisms are affected by the fluctuations in dissolved oxygen within the aquatic system. If oxygen is consumed at a faster rate than it is produced, dissolved oxygen levels decrease and aquatic organisms can be negatively affected. Salmon and trout, especially in their early life stages as eggs and alevins, are very susceptible to low dissolved oxygen concentrations.

4.2 Analyses

ODEQ has set a minimum level of dissolved oxygen and percent saturation to protect the most sensitive beneficial uses of resident fish, aquatic life, and salmonid fish rearing and spawning within the entire Deschutes Basin. The cold water criterion is applied to the data during the non-spawning time period (ODEQ, 2003b). During salmonid spawning until fry emergence in the Deschutes River and east and west side tributaries from October 1 – June 30 the salmonid spawning until fry emergence criteria apply (ODEQ, 2003b). The criteria are as follows:

Cold water
Not less than 8.0 mg/L absolute minimum or 90% saturation

Salmonid Spawning until fry emergence
Not less than 11.0 mg/L or 95% saturation
Not less than 9.0 mg/L or 95% saturation if intergravel dissolved oxygen (IGDO) is 8.0 mg/L or greater

Additional analyses of the maximum levels of percent saturation of oxygen are provided. Waters supersaturated with oxygen indicate conditions that may be a problem for organisms in that blood oxygen levels can increase resulting in gas bubbles in the blood. Factors that affect the ability of aquatic species to cope with supersaturated oxygen levels include the ability to escape conditions and the duration of exposure. For Oregon waters, there are no criteria or guidelines set to evaluate waters supersaturated with oxygen. In general, it is recommended that percent saturation of oxygen in water not exceed 110% due to negative impacts on aquatic species. For evaluation in the Technical Report, the following guidelines are applied for cold water and salmonid spawning seasons:

>110% supersaturated

BOD-5 criteria are set by ODEQ to regulate effluents but not for in-situ evaluation purposes. The BOD-5 are evaluated by applying the EPA narrative; the greater the BOD-5, the more rapidly oxygen is depleted in the stream (EPA. 1997).

Dissolved oxygen levels fluctuate seasonally and over a 24-hour period, therefore continuous dissolved oxygen data gathered during April 2002, July 2001, and November 2001 at four sites are evaluated. Two sites are within the upper Deschutes reach and two sites are within the Little Deschutes River. These for sites include below Wickiup Reservoir, Harper Bridge, Little Deschutes at Crescent Creek, and Little Deschutes at Crosswater Golf Course. Both dissolved oxygen and percent saturation daily fluctuations are presented.

In addition to addressing the critical questions, BOD-5 is evaluated according to a modified qualitative index. In general, polluted waters result in BOD-5 greater than 10 mg/L while clean waters result in only a few mg/L (Dojlido, 1993). For the Technical Report, adaptations of the Oregon Water Quality Index (WQI) (Cude, 1996) and the Upper Deschutes River Basin WQI (Hubler, 1999) are used to evaluate the BOD-5 levels:

Qualitative Index for BOD-5

0.0 - 0.9 mg/L	excellent - fair
1.0 – 2.9 mg/L	poor
>3.0 mg/L	very poor
>10.0 mg/L	polluted

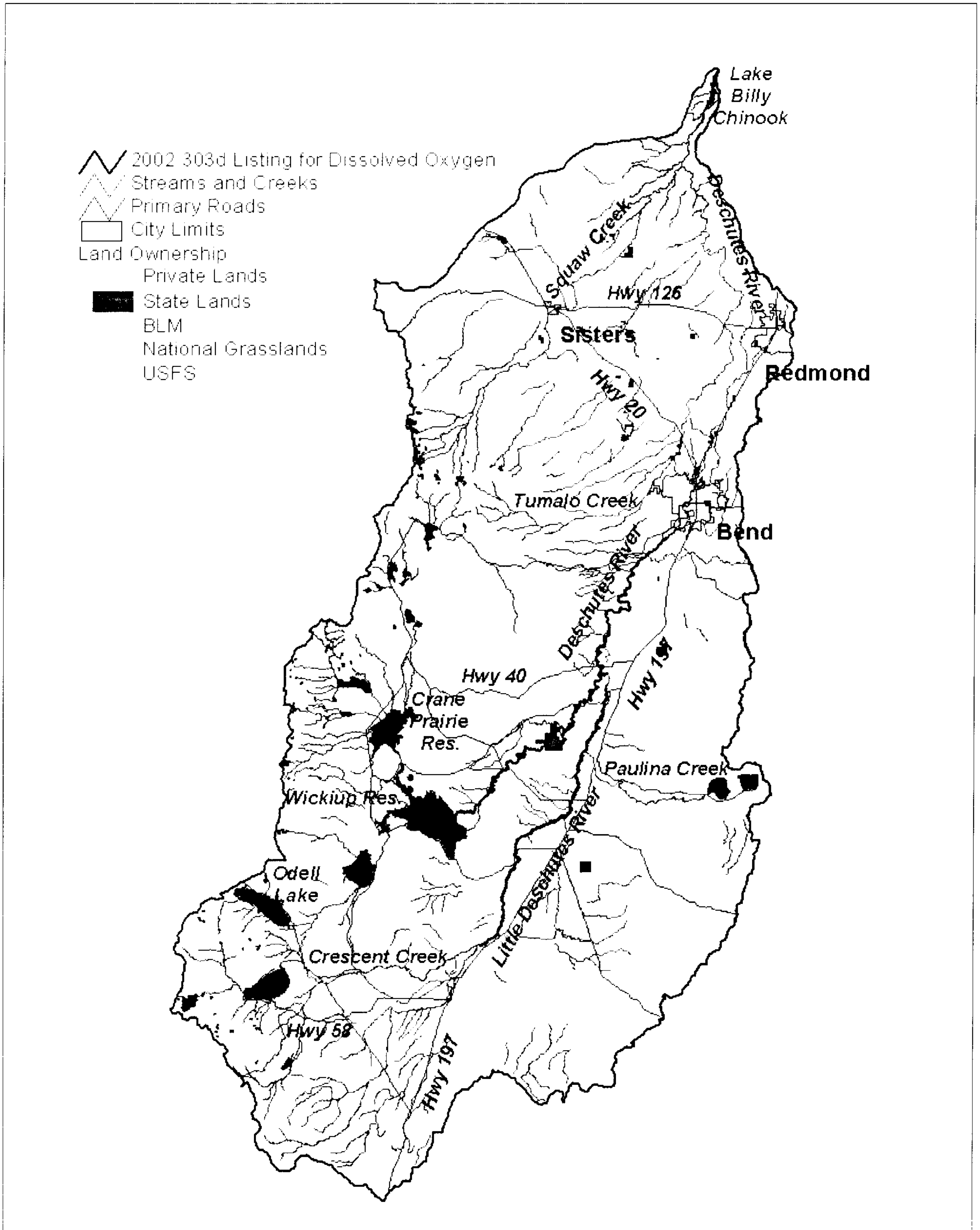
The Deschutes River is listed on the 2002 303(d) list for exceeding the dissolved oxygen criterion for spawning from RM 168.2 (upstream of the City of Bend) to RM 222.2 (downstream Wickiup Reservoir). The Deschutes River is also listed for exceeding the cold water dissolved oxygen criterion from RM 168.2 (upstream of the City of Bend) to RM 189.4 (downstream Sunriver). Lava Lake, the headwaters of the Deschutes River, is listed for exceeding the cool water dissolved oxygen criterion. The Little Deschutes River is listed from its mouth at RM 0 upstream to RM 54.1 for exceeding the dissolved oxygen criterion for spawning. **Map 4.1** illustrates waterbodies and segments that exceed the dissolved oxygen criteria.

Data collected from 1993 to 2002 by ODEQ ambient monitoring and intensive water quality monitoring studies for TMDL development are used to illustrate trends along the longitudinal extent of the upper Deschutes reach and middle Deschutes reach. Data collected from 1995 to 2002 by ODEQ ambient monitoring, ODEQ intensive water quality monitoring studies for TMDL development, and REMAP studies are used to illustrate trends along the longitudinal extent of the Little Deschutes River.

Data are predominately collected during the odd numbered months of January, March, May, July, September, and November. Some months and years have relatively small datasets compared to other months and years that have relatively large datasets. The year 2001 has the largest dataset due to the 2001 TMDL monitoring efforts. The relatively small amount of data collected on even months is incorporated into odd month data. This is accomplished by consolidating data collected between the first and fifteenth of the month into the previous month dataset, and data collected between the sixteenth and last day of the month into the post month dataset.

There are limitations to the BOD-5 data set. These limitations are evident in examination of the long-term trend analyses in **Figure 4.16**, **Figure 4.17**, and **Figure 4.18**. The upper Deschutes reach has the most complete dataset with multiple sites contributing to each bar. The middle Deschutes reach has the most limited dataset with all months only having one site sampled usually once except for the following months and years that had multiple sites contributing to the bar mean: July 1995, January 1996, July 2001, November 2001, and May 2002. The Little Deschutes River also has a limited dataset with all month only having one to two sites sampled usually once except for the following months and years that had multiple sites contributing to the bar mean: July 1995, January 1996, July 2001, November 2001, and March 2002.

Map 4.1 Dissolved oxygen 303(d) listed waterbodies and segments within the Upper Deschutes and Little Deschutes Subbasins



4.2.1 How do dissolved oxygen, percent saturated oxygen, and biochemical oxygen demand change along the longitudinal extent of the aquatic system?

Changes along the longitudinal extent of reaches within the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 4.1** and **Figure 4.2** for dissolved oxygen, **Figure 4.3** and **Figure 4.4** for percent saturation, and **Figure 4.5** and **Figure 4.6** for BOD-5. A solid grey line represents a longitudinal grand mean. A solid black line represents a linear regression and is provided for insight regarding the trend over the longitudinal extent during the time period.

The upper Deschutes River expresses a longitudinal grand mean DO concentration of 10.4 mg/L, oxygen saturation of 101%, and a BOD-5 of 1.0 mg/L.

Dissolved oxygen

The upper Deschutes reach expresses a longitudinal grand mean DO concentration of 10.0 mg/L. A linear regression results in a negative slope. This indicates a downstream downward trend of mean DO concentrations.

The middle Deschutes reach expresses a longitudinal grand mean DO concentration of 10.8 mg/L. A linear regression results in a positive slope. This indicates a downstream upward trend of mean DO concentrations.

The Little Deschutes River expresses a longitudinal grand mean DO concentration of 9.3 mg/L. A linear regression results in a negative slope. This indicates a downstream downward trend of mean DO concentrations.

Percent saturation

The upper Deschutes reach expresses a longitudinal grand mean oxygen saturation of 98%. A linear regression results in a negative slope. This indicates a downstream downward trend of mean percent saturation values.

The middle Deschutes River expresses a longitudinal grand mean oxygen saturation of 104%. A linear regression results in a positive slope. This indicates a downstream upward trend of mean percent saturation values.

The Little Deschutes River expresses a longitudinal grand mean oxygen saturation of 96%. A linear regression results in a negative slope. This indicates a downstream downward trend of mean percent saturation values.

BOD-5

The upper Deschutes reach expresses a longitudinal grand mean BOD-5 of 0.9 mg/L. A linear regression results in a negative slope. This indicates a downstream downward trend of mean BOD-5.

The middle Deschutes reach expresses a longitudinal grand mean BOD-5 rate of 1.0 mg/L. A linear regression results in a slope that is not increasing or decreasing. This indicates a downstream trend of constant mean BOD-5.

The Little Deschutes River expresses a longitudinal grand mean BOD-5 of 0.6 mg/L. A linear regression results in a positive slope. This indicates a downstream upward trend of mean BOD-5.

Figure 4.1 Mean dissolved oxygen concentrations along the longitudinal extent of the upper Deschutes River

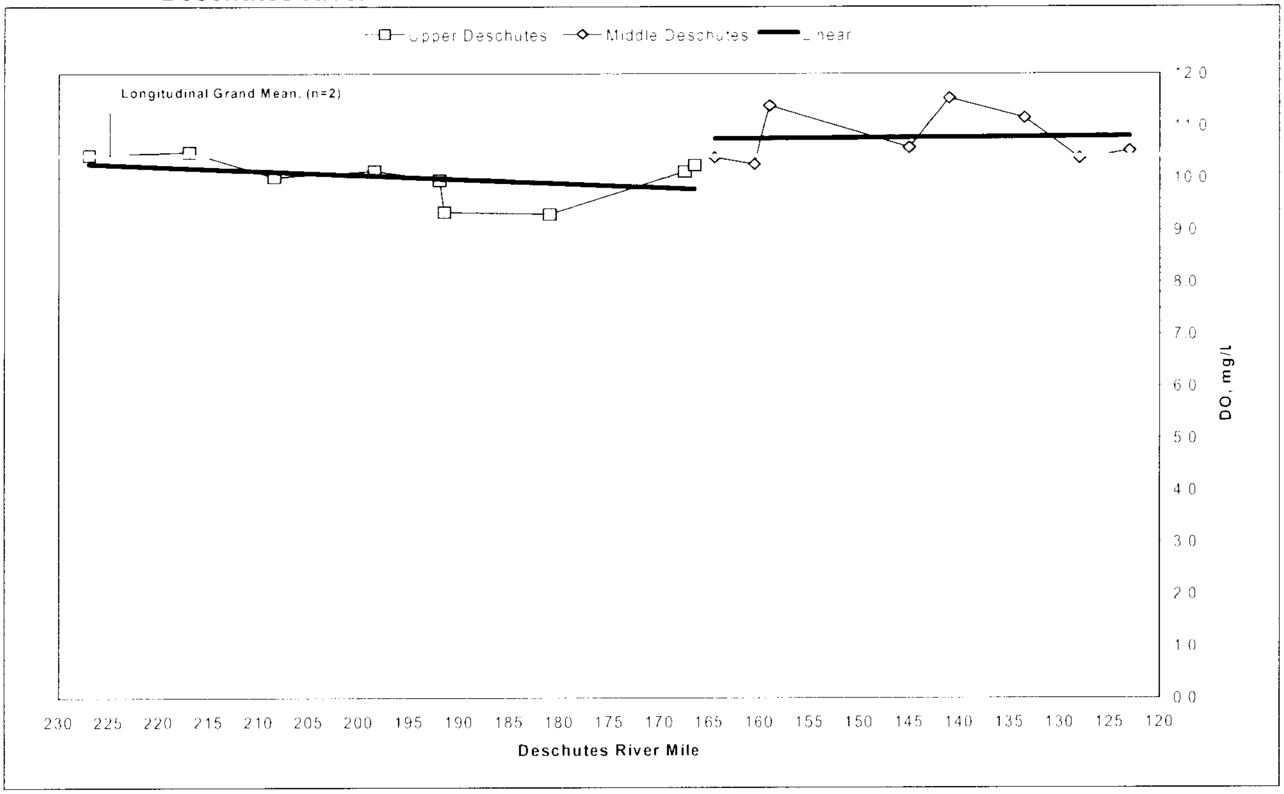


Figure 4.2 Mean dissolved oxygen concentrations along the longitudinal extent of the Little Deschutes River

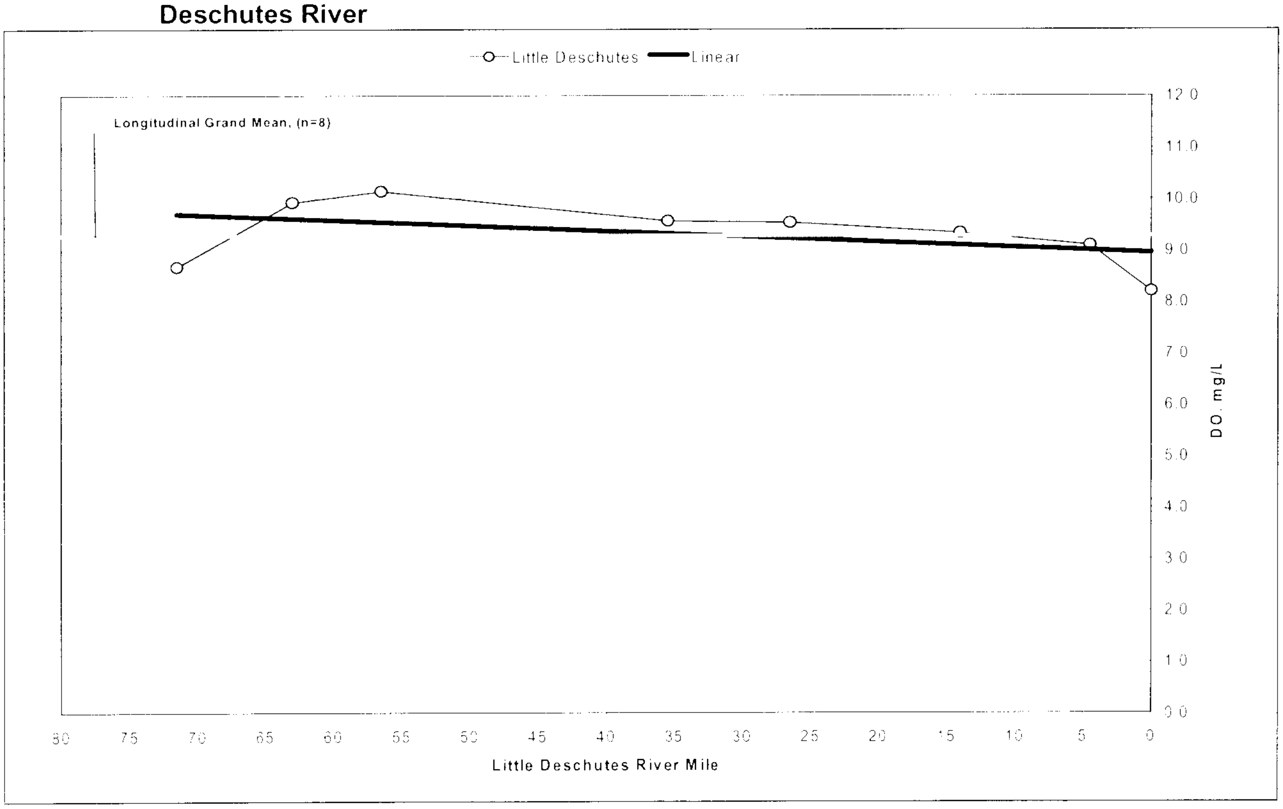


Figure 4.3 Mean percent saturation along the longitudinal extent of the upper Deschutes River

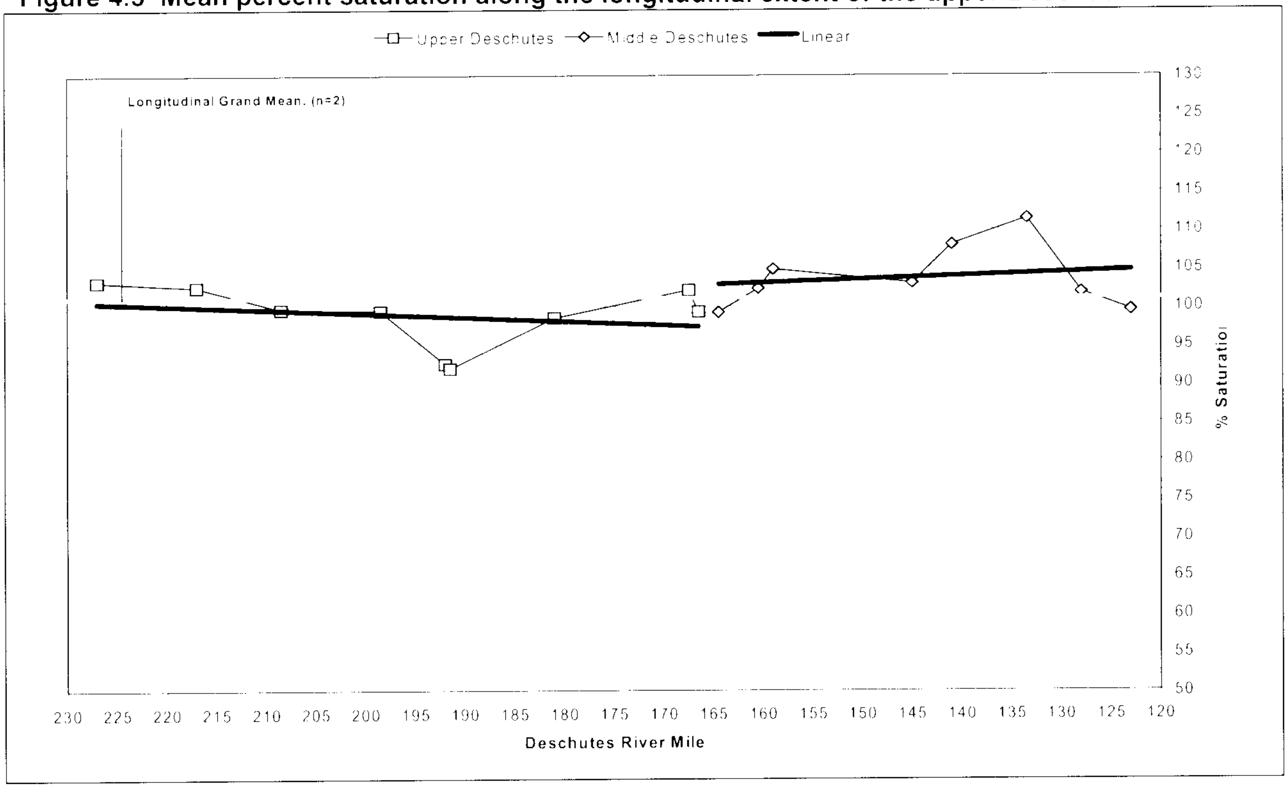


Figure 4.4 Mean percent saturation along the longitudinal extent of the Little Deschutes River

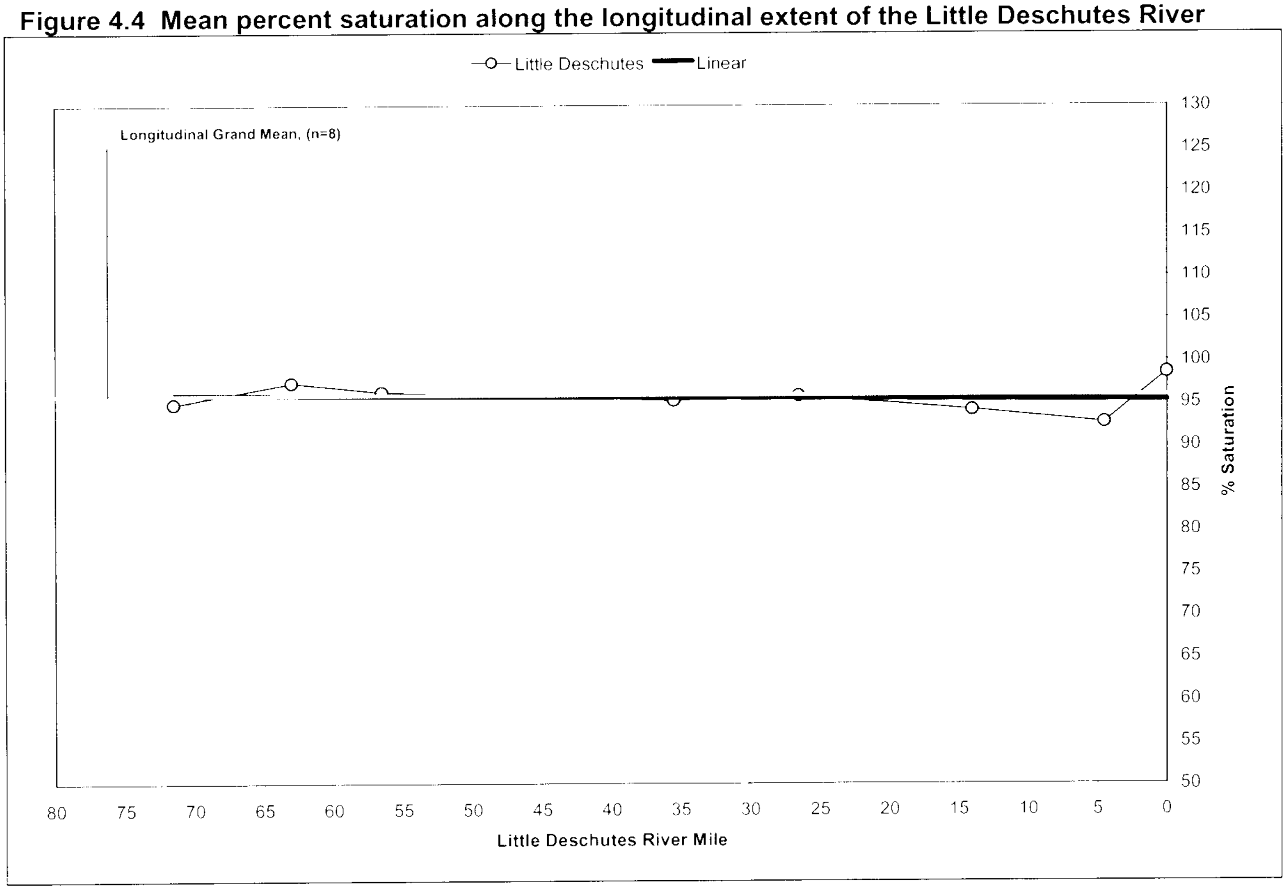


Figure 4.5 Mean BOD-5 along the longitudinal extent of the upper Deschutes River

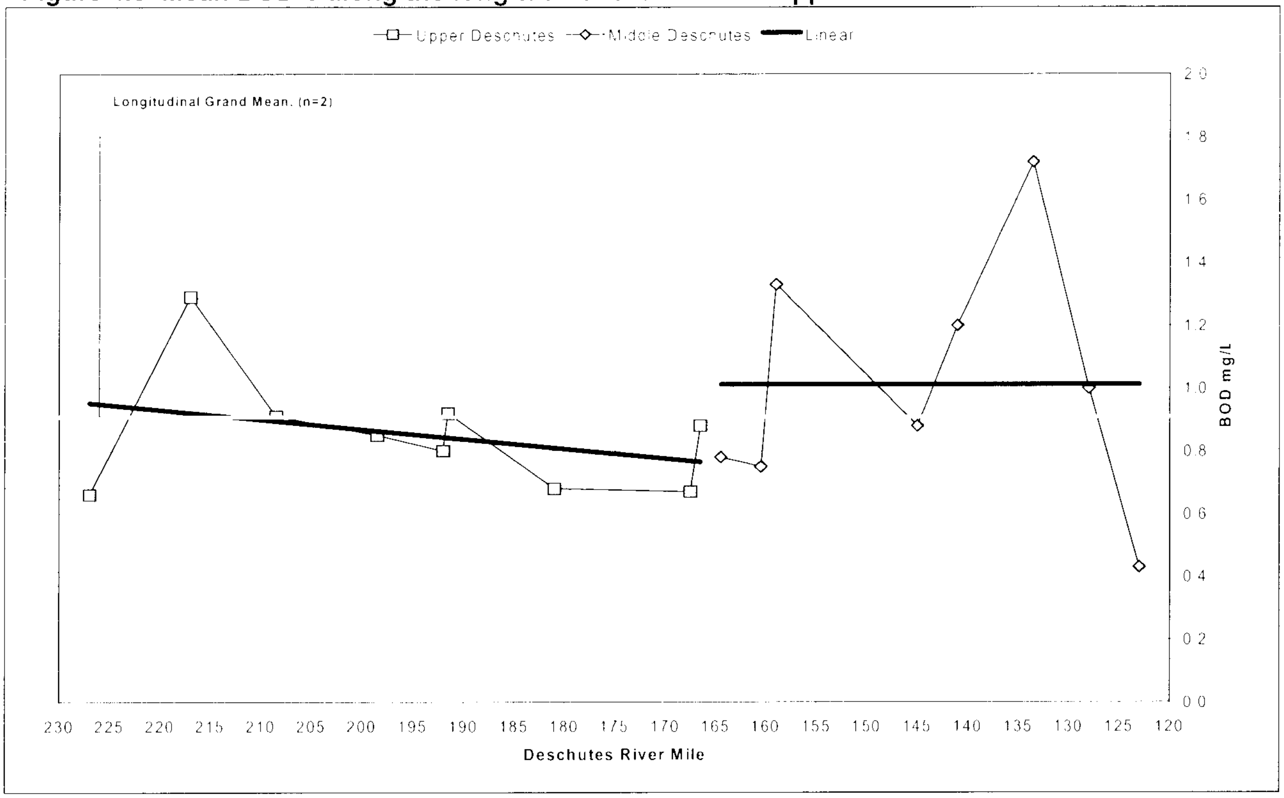
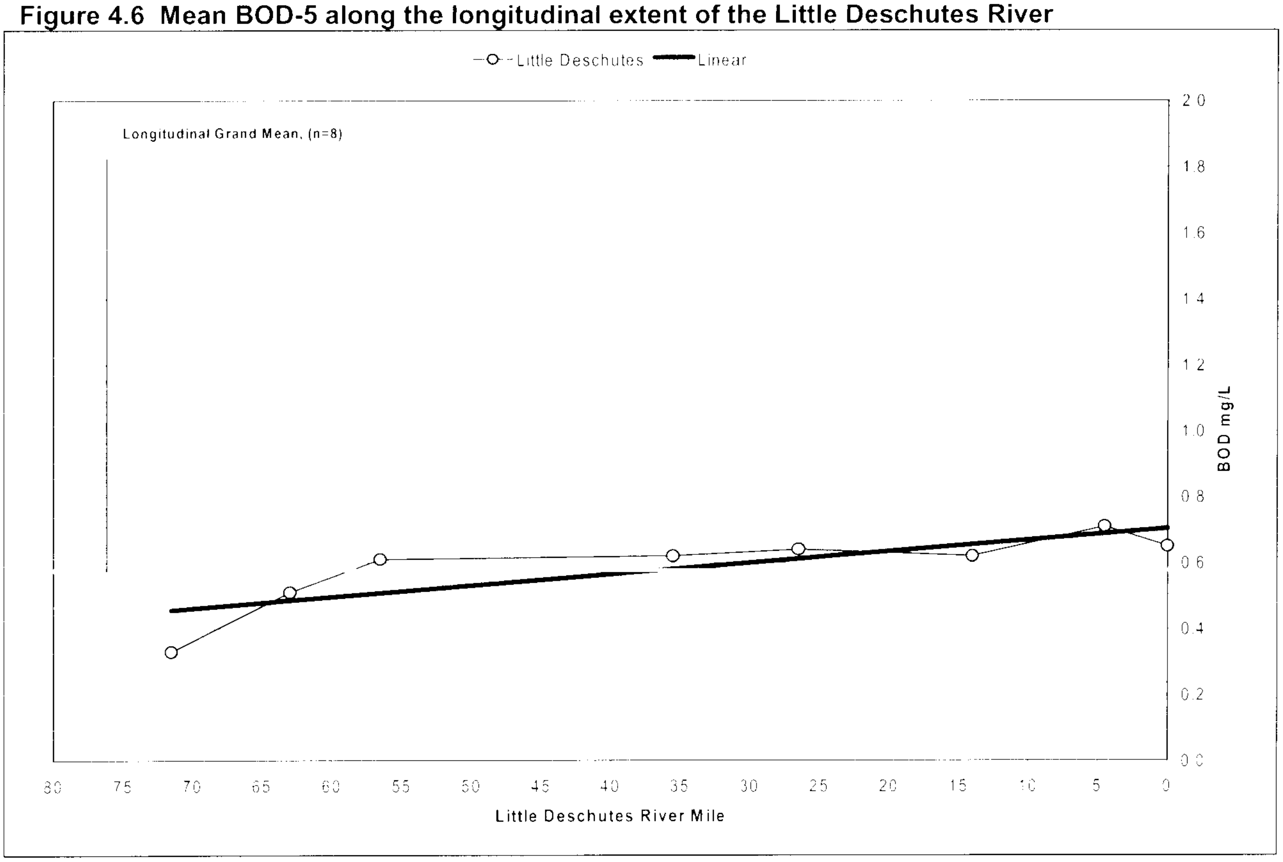


Figure 4.6 Mean BOD-5 along the longitudinal extent of the Little Deschutes River



4.2.2 What are the daily and seasonal variability of dissolved oxygen, percent saturated oxygen, and biochemical oxygen demand?

Daily fluctuations in dissolved oxygen and percent saturation

The measurements from continuously monitored sites during July 2001, November 2001, and April 2002 are used to show daily changes in dissolved oxygen and percent saturation. Sites are monitored with multiparameter dataloggers set to record measurements every 15 min. Four sites are depicted during July 2001 and November 2001 and include below Wickiup Reservoir, Harper Bridge, Little Deschutes at Crescent Creek, and Little Deschutes at Crosswater Golf Course (**Figure 4.7**, **Figure 4.8**, **Figure 4.9**, and **Figure 4.10**). During April 2002, two more sites are depicted in addition to the four sites previously listed and include above Riverhouse Hotel and Lower Bridge sites (**Figure 4.11** and **Figure 4.12**). A dashed black line represents the applicable criterion.

During July 2001, all sites but one reflect daily fluctuations ranging from 6.7 – 9.9 mg/L dissolved oxygen and 82 - 119 percent saturation (**Figure 4.7** and **Figure 4.8**). A different profile is exhibited by the site below Wickiup Reservoir that reflects a narrow daily fluctuation between 9.1 – 10.2mg/L dissolved oxygen and approximately 101 – 114 percent saturation.

During November 2001, dissolved oxygen at all sites reflects daily fluctuations with different ranges (**Figure 4.9**). Below Wickiup Reservoir and the Little Deschutes at Crosswater Golf Course sites reflect daily fluctuations ranging from 9.5 -11.0 mg/L. The Harper Bridge site reflects daily fluctuations ranging from 10.2 – 11.9 mg/L dissolved oxygen. The Little Deschutes at Crescent Creek site reflects daily fluctuations ranging from 10.8 – 12.7 mg/L dissolved oxygen.

During November 2001, percent saturation at all sites reflects daily fluctuations with different ranges (**Figure 4.10**). Below Wickiup Reservoir reflects daily fluctuations ranging from approximately 82 – 94 percent saturation. The Little Deschutes at Crosswater Golf Course reflects daily fluctuations ranging from 83 – 98 percent saturation. The Harper Bridge site reflects daily fluctuations ranging from 91 – 102 percent saturation. The Little Deschutes at Crescent Creek site reflects daily fluctuations ranging from 96 – 106 percent saturation.

During April 2002, all sites but three reflect daily fluctuations ranging from 8.3 – 9.8 mg/L dissolved oxygen and 89 – 103 percent saturation (**Figure 4.11** and **Figure 4.12**). A different profile is exhibited by the site below Wickiup Reservoir that reflects a narrow daily fluctuation between 10.7 – 11.2 mg/L dissolved oxygen and 113 - 114 percent saturation. A different profile is exhibited by the site above Riverhouse Hotel that reflects a daily fluctuation ranging from 7.5 – 10.8 mg/L dissolved oxygen and 76 – 113 percent saturation. A different profile is exhibited by the site at Lower Bridge that reflects a daily fluctuation ranging from 7.7 – 11.4 mg/L dissolved oxygen and 83 – 125 percent saturation.

Figure 4.7 Daily fluctuations in dissolved oxygen concentrations measured over a three day period in July 2001.

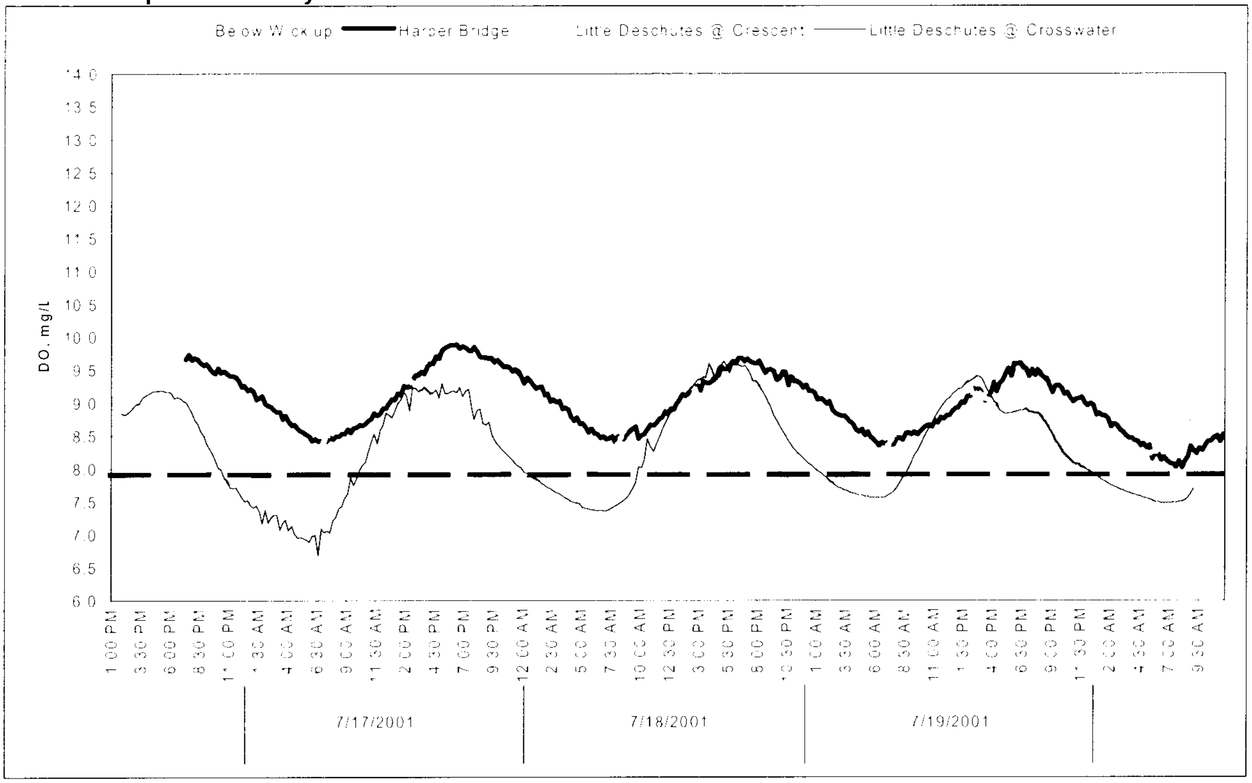


Figure 4.8 Daily fluctuations in percent saturation concentrations measured over a three day period in July 2001.

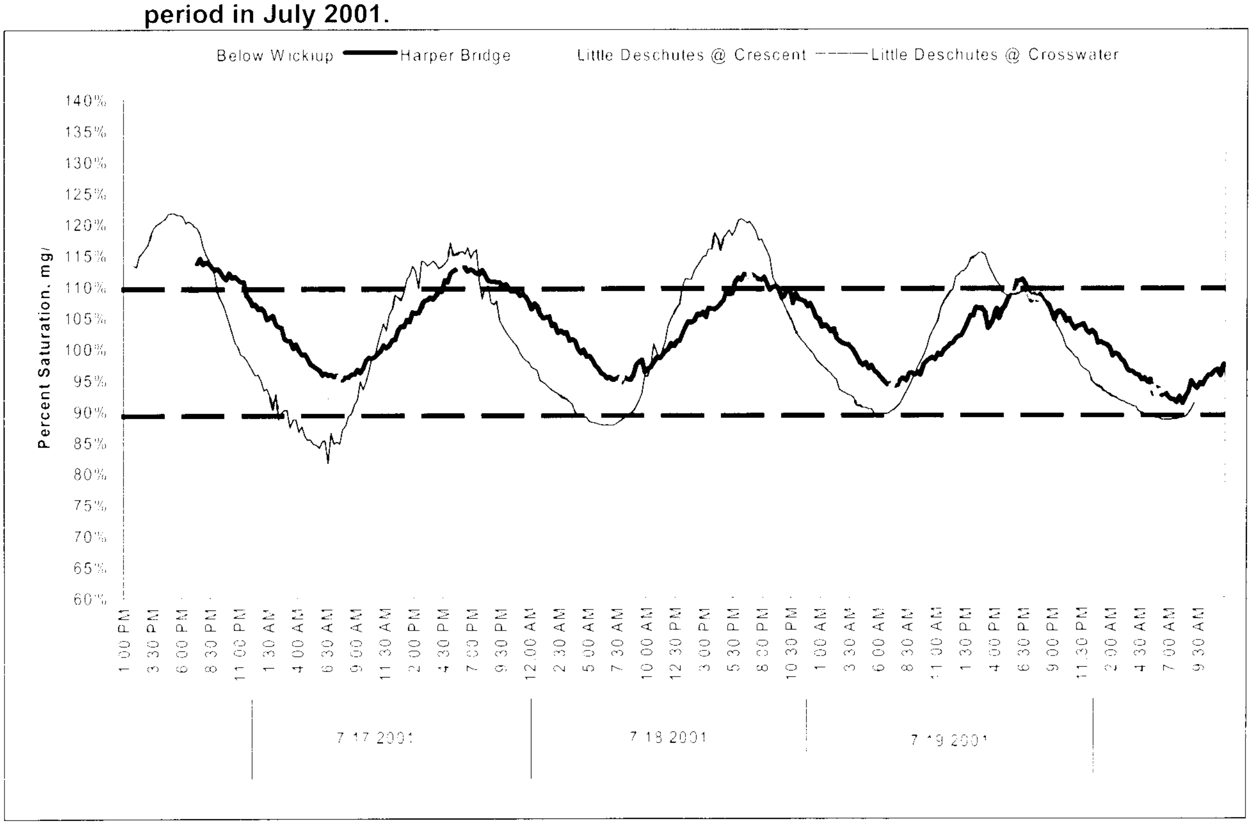


Figure 4.9 Daily fluctuations in dissolved oxygen concentrations measured over a two day period in November 2001.

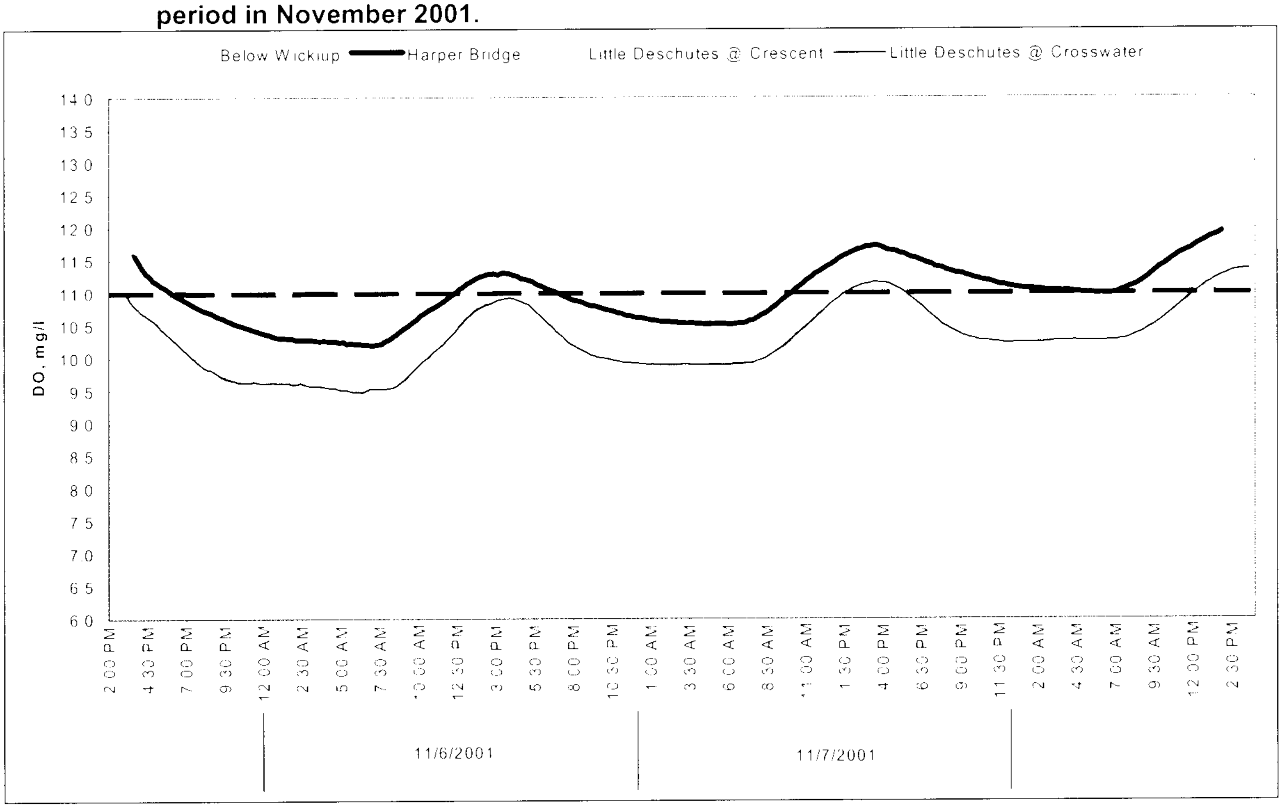


Figure 4.10 Daily fluctuations in percent saturation concentrations measured over a two day period in November 2001.

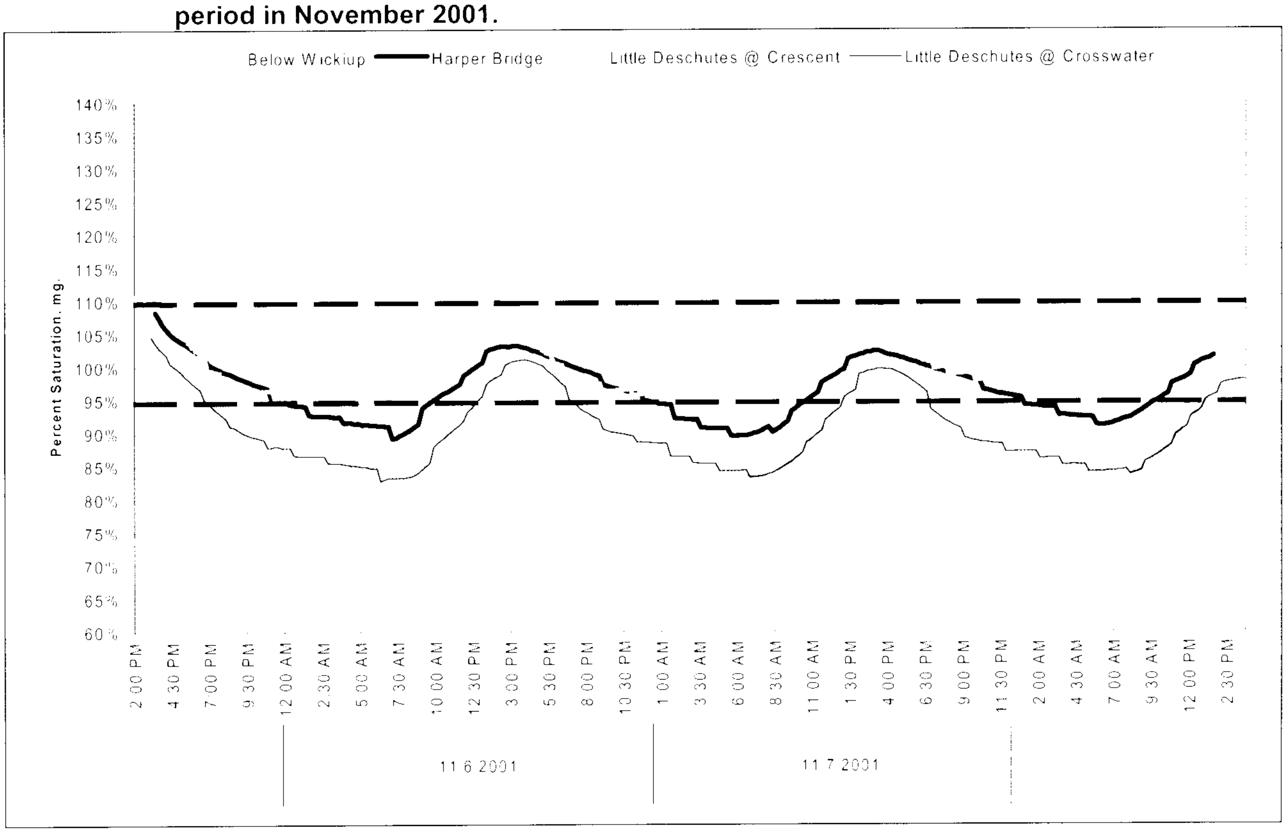


Figure 4.11 Daily fluctuations in dissolved oxygen concentrations measured over a three day period in April and May 2001.

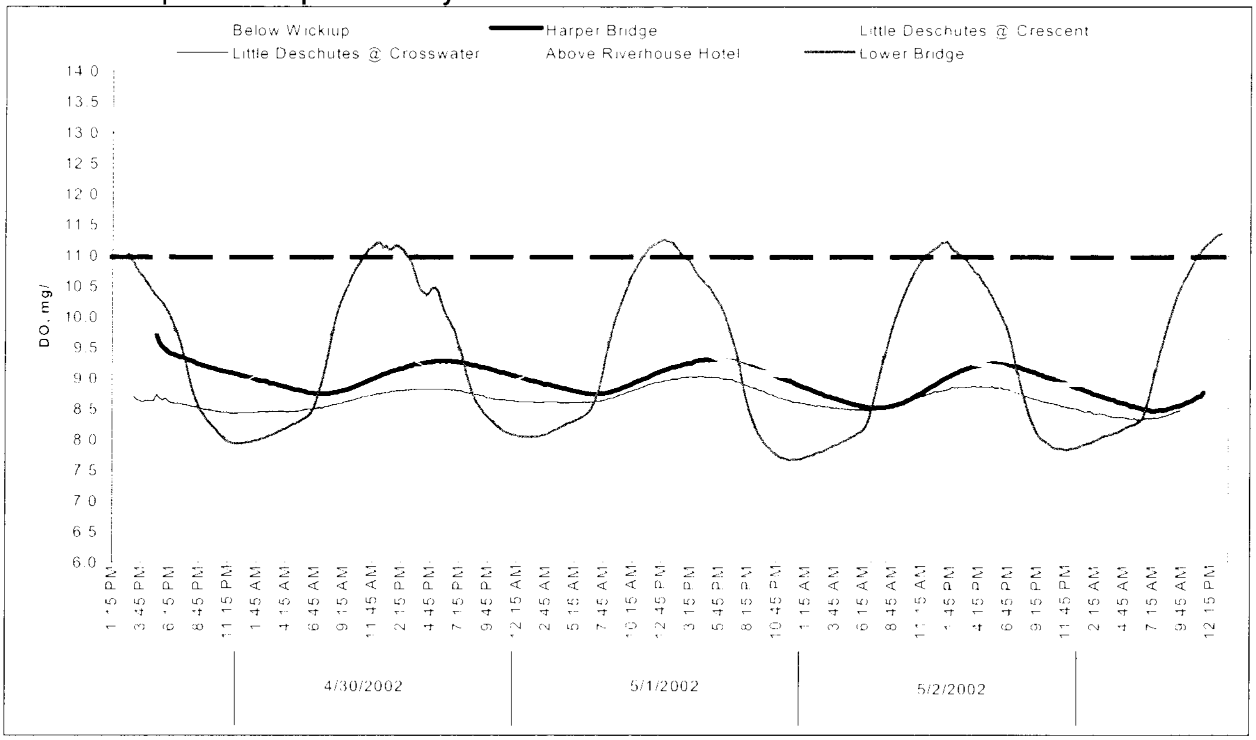
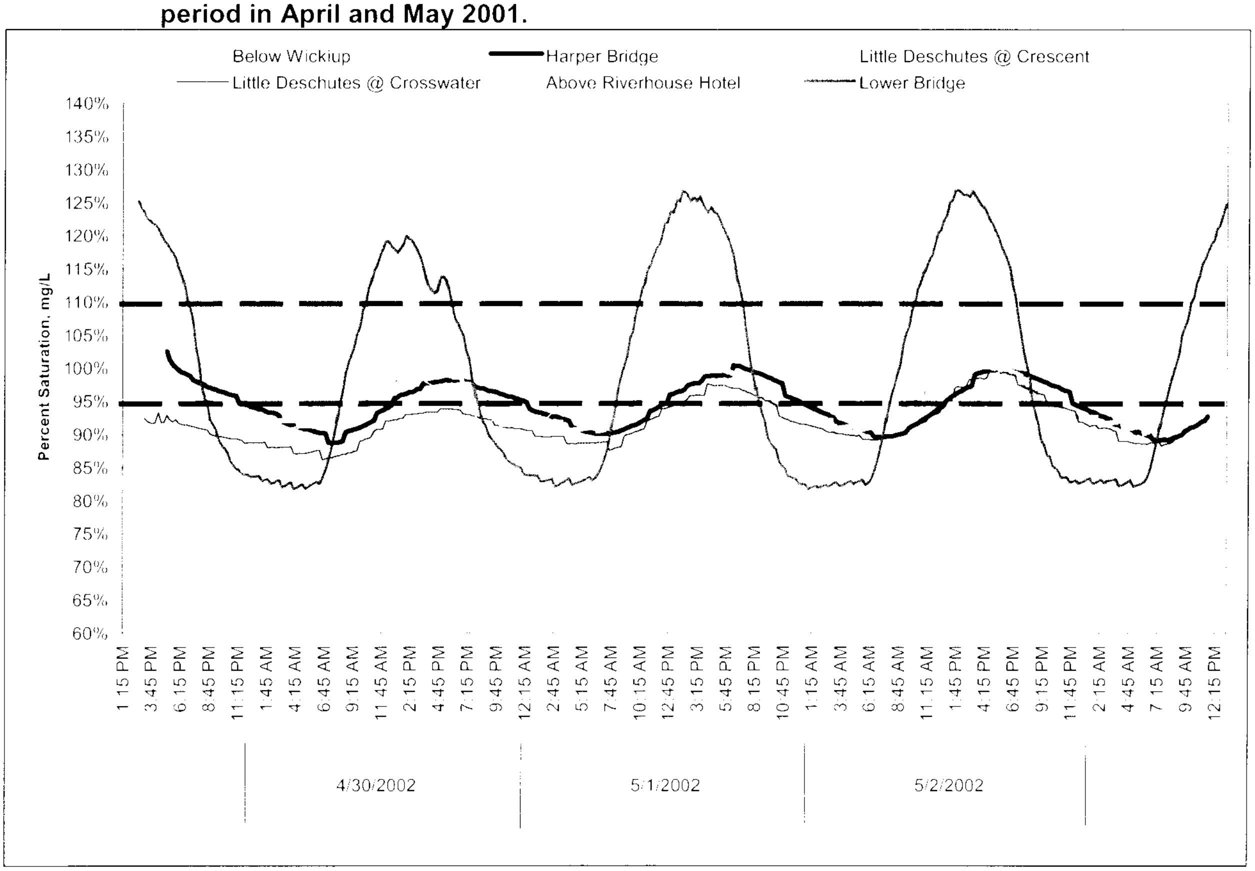


Figure 4.12 Daily fluctuations in percent saturation concentrations measured over a three day period in April and May 2001.



Seasonal fluctuations in dissolved oxygen, percent saturation, and BOD-5

Seasonal fluctuations within reaches of the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 4.13** for dissolved oxygen, **Figure 4.14** for percent saturation, and **Figure 4.15** for BOD-5.

The upper Deschutes River expresses a seasonal mean DO concentration of 10.6 mg/L, saturated oxygen of 105%, and BOD-5 of 1.4 mg/L.

Dissolved oxygen

The upper Deschutes reach has a seasonal grand mean DO concentration of 10.1 mg/L and a fluctuation in mean seasonal DO concentrations ranging from 8.8 - 11.6 mg/L.

The middle Deschutes reach has a seasonal grand mean DO concentration of 11.2 mg/L and a fluctuation in mean seasonal DO concentration ranging from 9.5 – 12.7 mg/L.

The Little Deschutes River expresses a seasonal grand mean DO concentration of 9.4 mg/L and a fluctuation in mean seasonal DO concentrations ranging from 7.6 – 11.3 mg/L.

Percent saturation

The upper Deschutes reach expresses a seasonal grand mean oxygen saturation of 98% and a fluctuation in mean seasonal oxygen saturation of 96 – 100%.

The middle Deschutes reach expresses a seasonal grand mean oxygen saturation of 111% and a fluctuation in mean seasonal oxygen saturation of 102 – 123%.

The Little Deschutes River expresses a seasonal grand mean oxygen saturation of 93% and a fluctuation in mean seasonal oxygen saturation of 92 - 98%.

BOD-5

The upper Deschutes reach expresses a seasonal grand mean BOD-5 of 1.0 mg/L and a fluctuation in mean seasonal BOD-5 ranging from 0.8 – 1.1 mg/L.

The middle Deschutes reach expresses a seasonal grand mean BOD-5 of 1.8 mg/L and a fluctuation in mean seasonal BOD-5 ranging from 0.8 – 3.4 mg/L.

The Little Deschutes River expresses a seasonal grand mean BOD-5 of 0.8 mg/L and a fluctuation in mean seasonal BOD-5 ranging from 0.4 – 1.2 mg/L.

Figure 4.13 Seasonal fluctuations in mean dissolved oxygen concentrations within the upper Deschutes River and Little Deschutes River

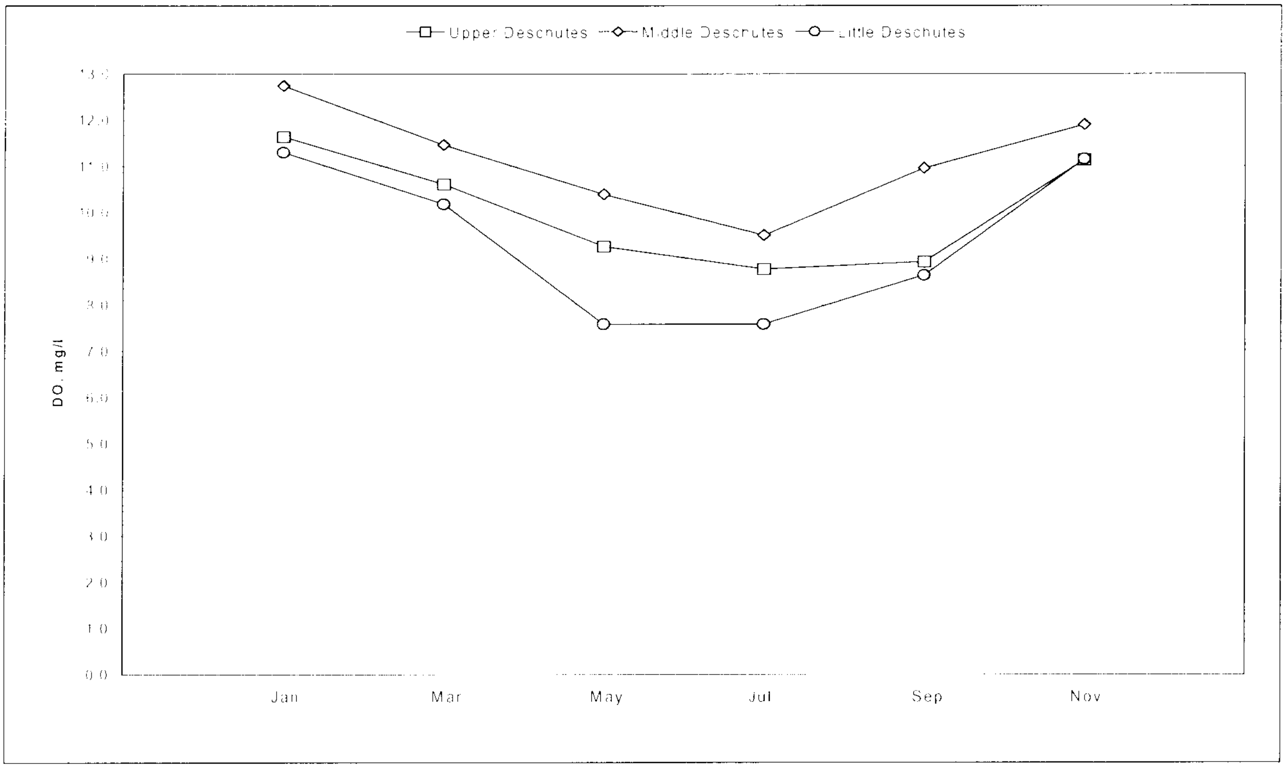


Figure 4.14 Seasonal fluctuations in mean percent saturation values within the upper Deschutes River and Little Deschutes River

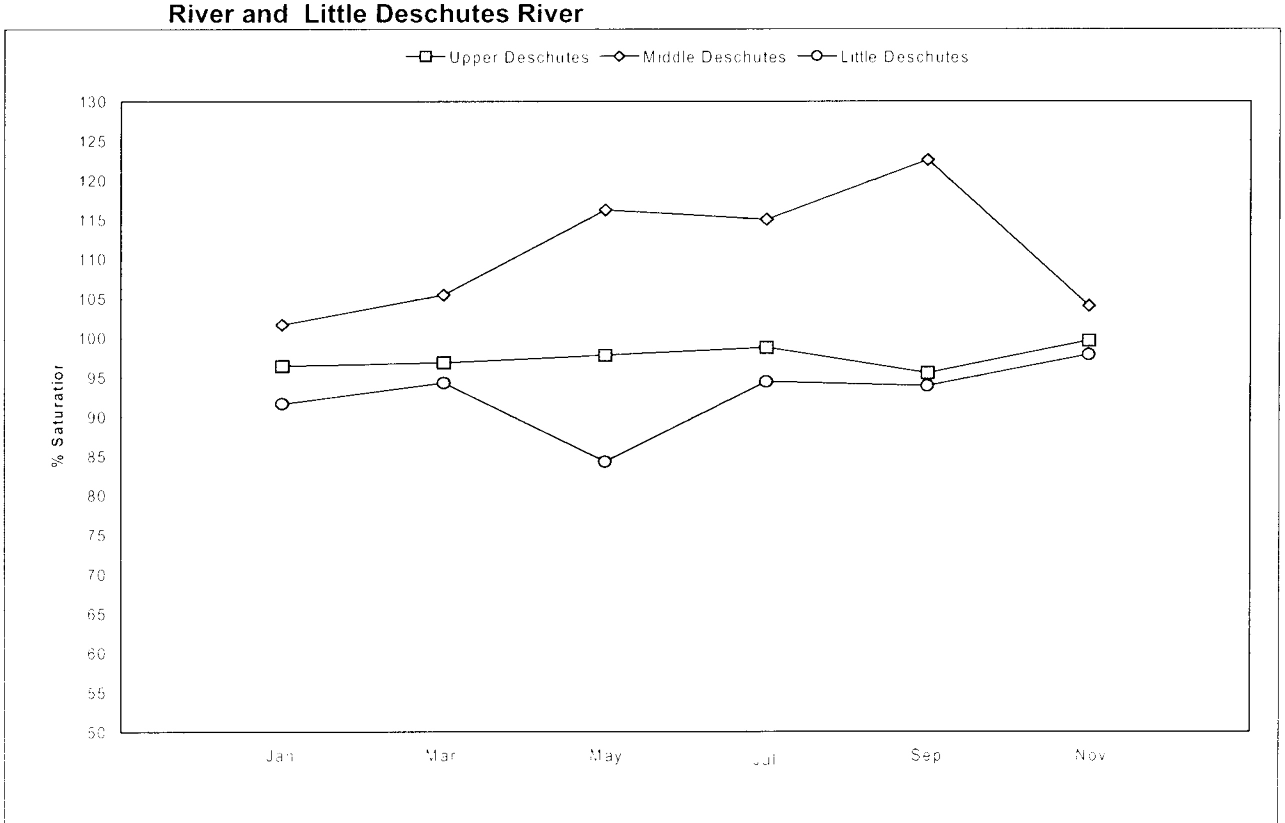
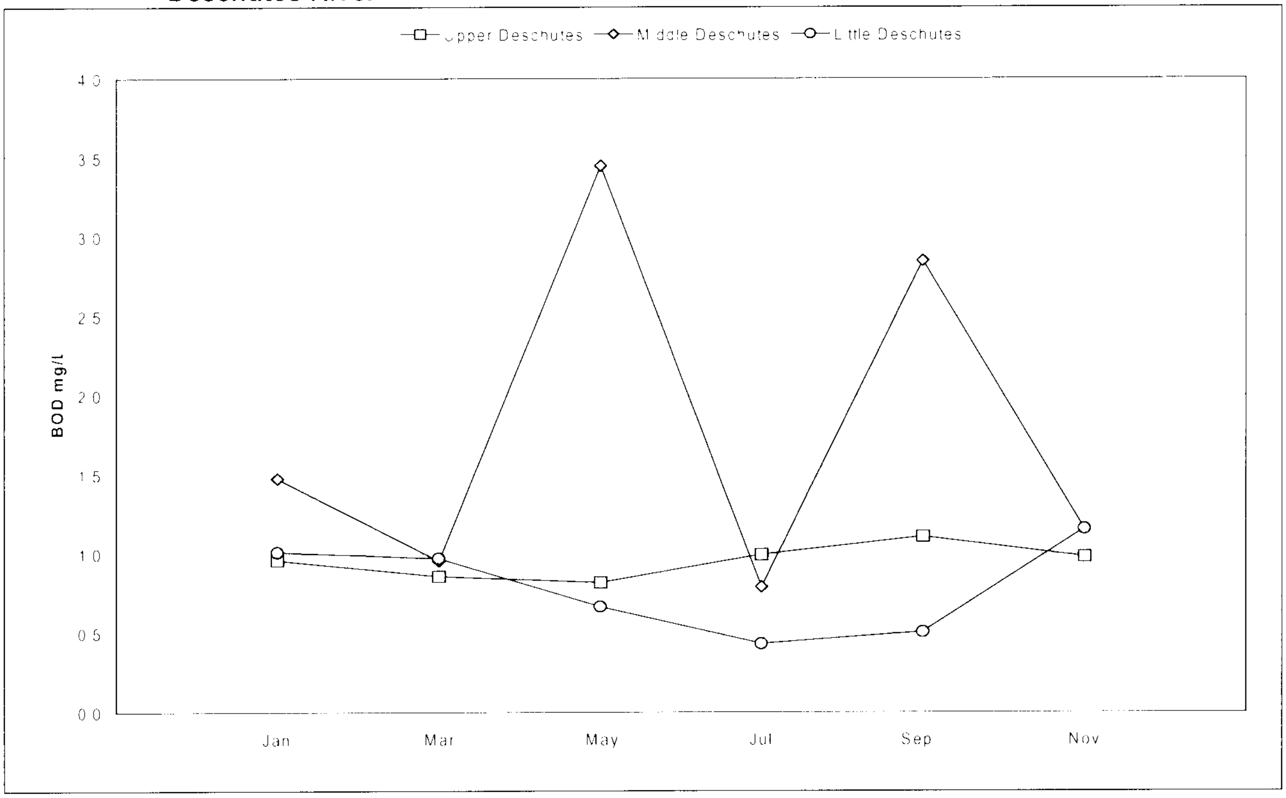


Figure 4.15 Seasonal fluctuations in mean BOD-5 within the upper Deschutes River and Little Deschutes River



4.2.3 What are the long-term trends in dissolved oxygen, percent saturation, and biochemical oxygen demand?

The long-term trend within reaches of the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 4.16**, **Figure 4.17**, and **Figure 4.18** for dissolved oxygen concentrations, **Figure 4.19**, **Figure 4.20**, and **Figure 4.21** for percent saturation, and **Figure 4.22**, **Figure 4.23**, and **Figure 4.24** for BOD-5. A solid grey line represents a long-term grand mean. A solid black line represents a linear regression and is provided for insight regarding the trend over the time period.

The upper Deschutes River expresses a long-term mean in DO of 10.6 mg/L, saturated oxygen of 105%, and BOD-5 of 1.4 mg/L.

Figure 4.16 Long-term trend in mean dissolved oxygen concentrations within the upper Deschutes reach

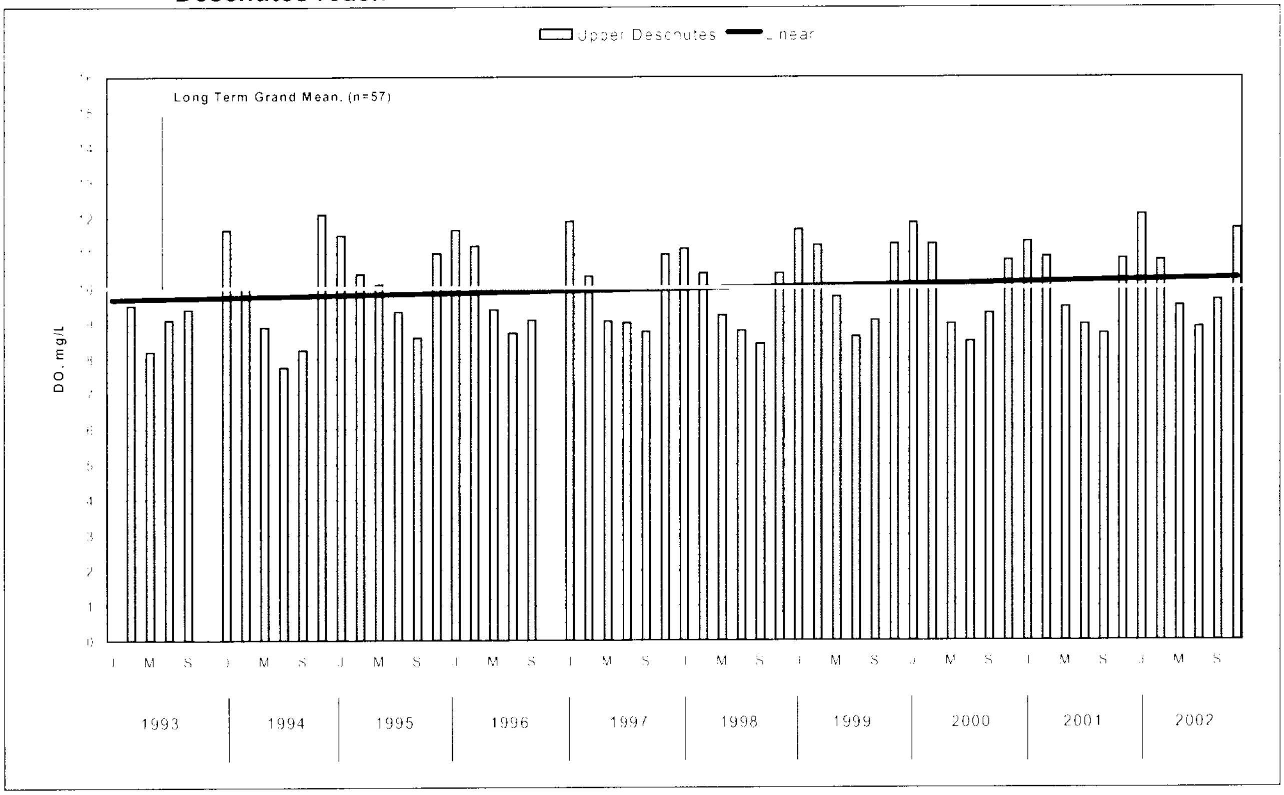


Figure 4.17 Long-term trend in mean dissolved oxygen concentrations within the middle Deschutes reach

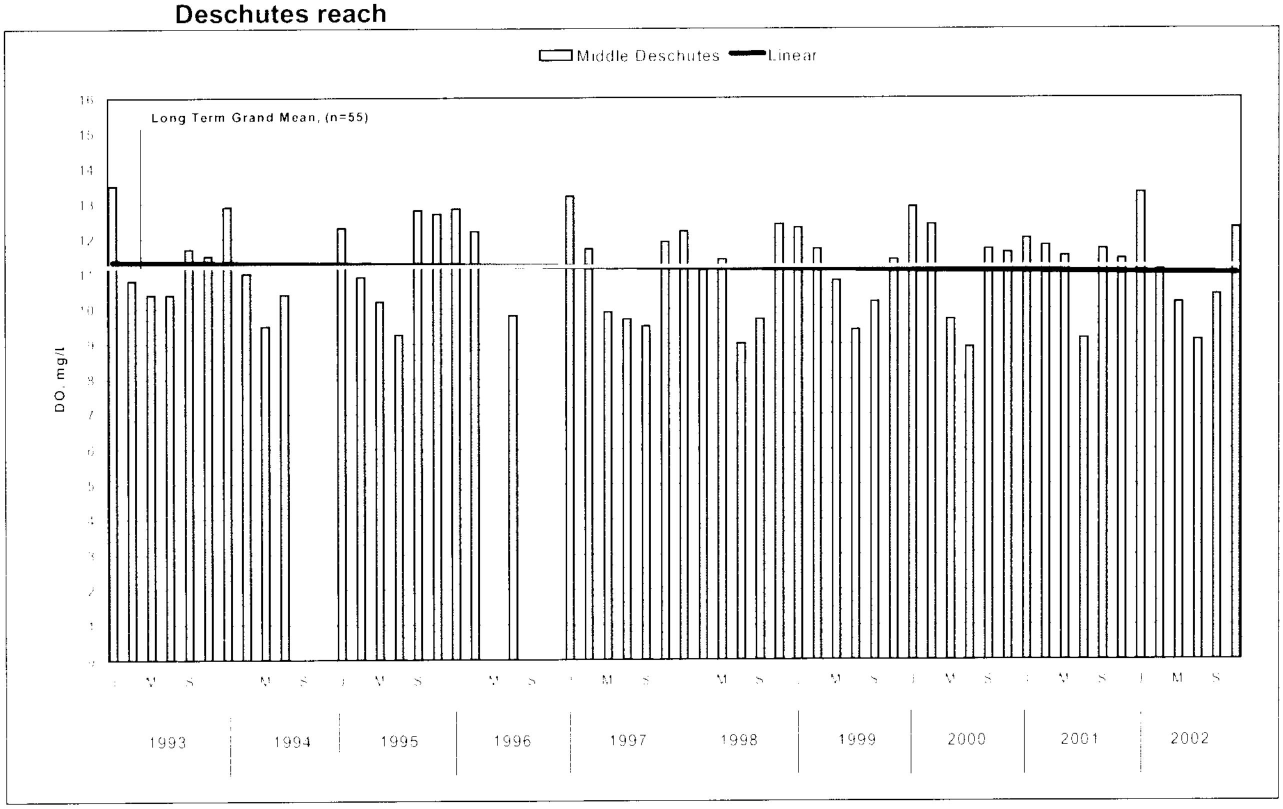
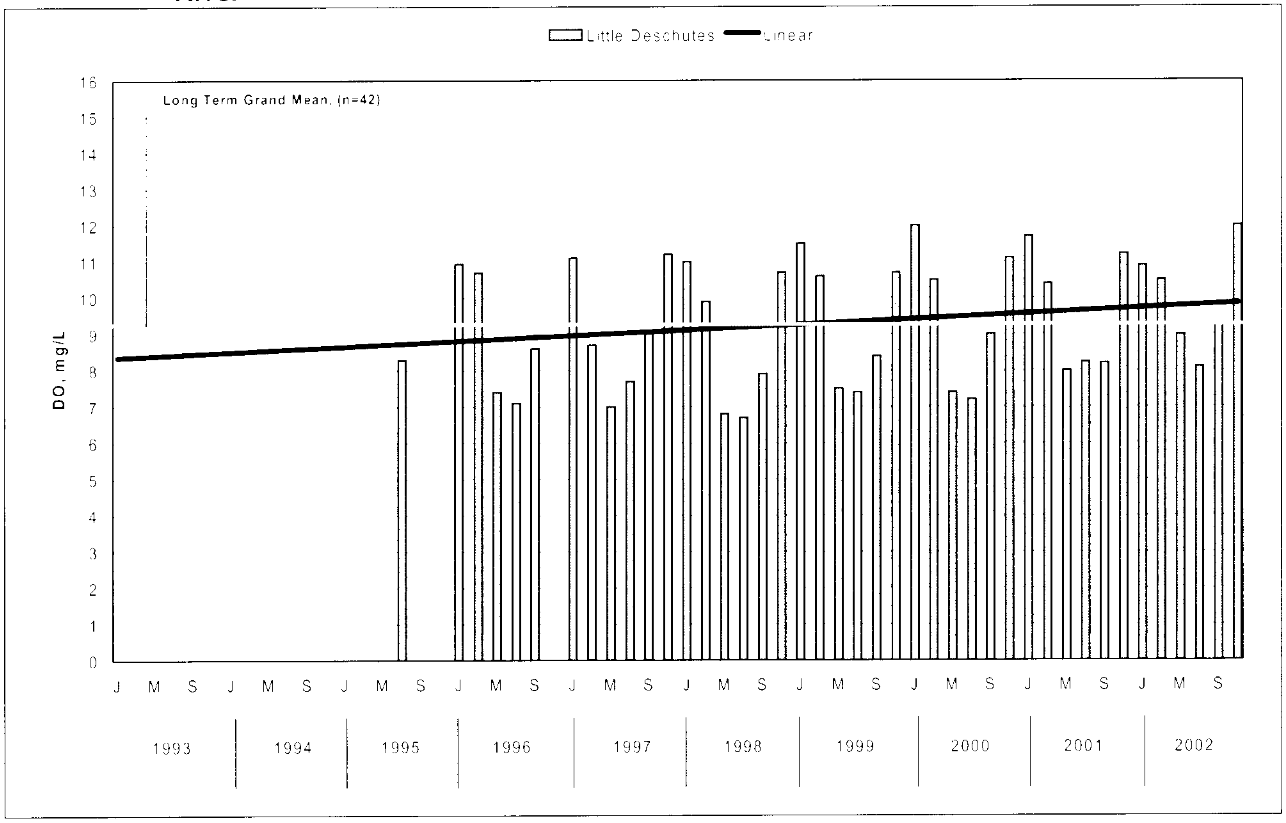


Figure 4.18 Long-term trend in mean dissolved oxygen concentrations within the Little Deschutes River



Dissolved oxygen

The upper Deschutes reach expresses a long-term grand mean DO of 10.0 mg/L. A linear regression results in a positive slope. This indicates a temporal upward trend of mean DO concentrations.

The middle Deschutes reach expresses a long-term grand mean DO of 11.2 mg/L. A linear regression results in a negative slope. This indicates a temporal downward trend of mean DO concentrations.

The Little Deschutes River expresses a long-term grand mean DO of 9.4 mg/L. A linear regression results in a positive slope. This indicates a temporal upward trend of mean DO concentrations.

Figure 4.19 Long-term trend in mean percent saturation values within the upper Deschutes reach

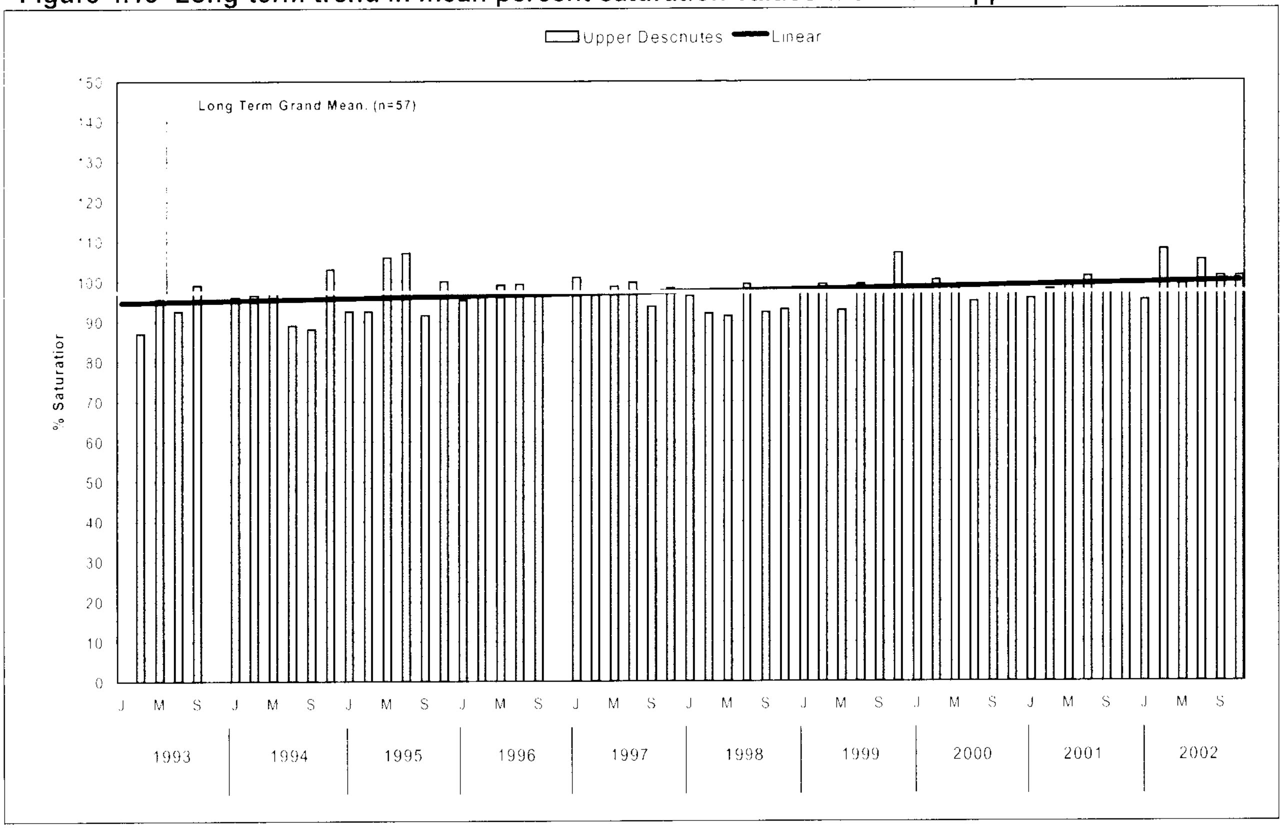


Figure 4.20 Long-term trend in mean percent saturation values within the middle Deschutes reach

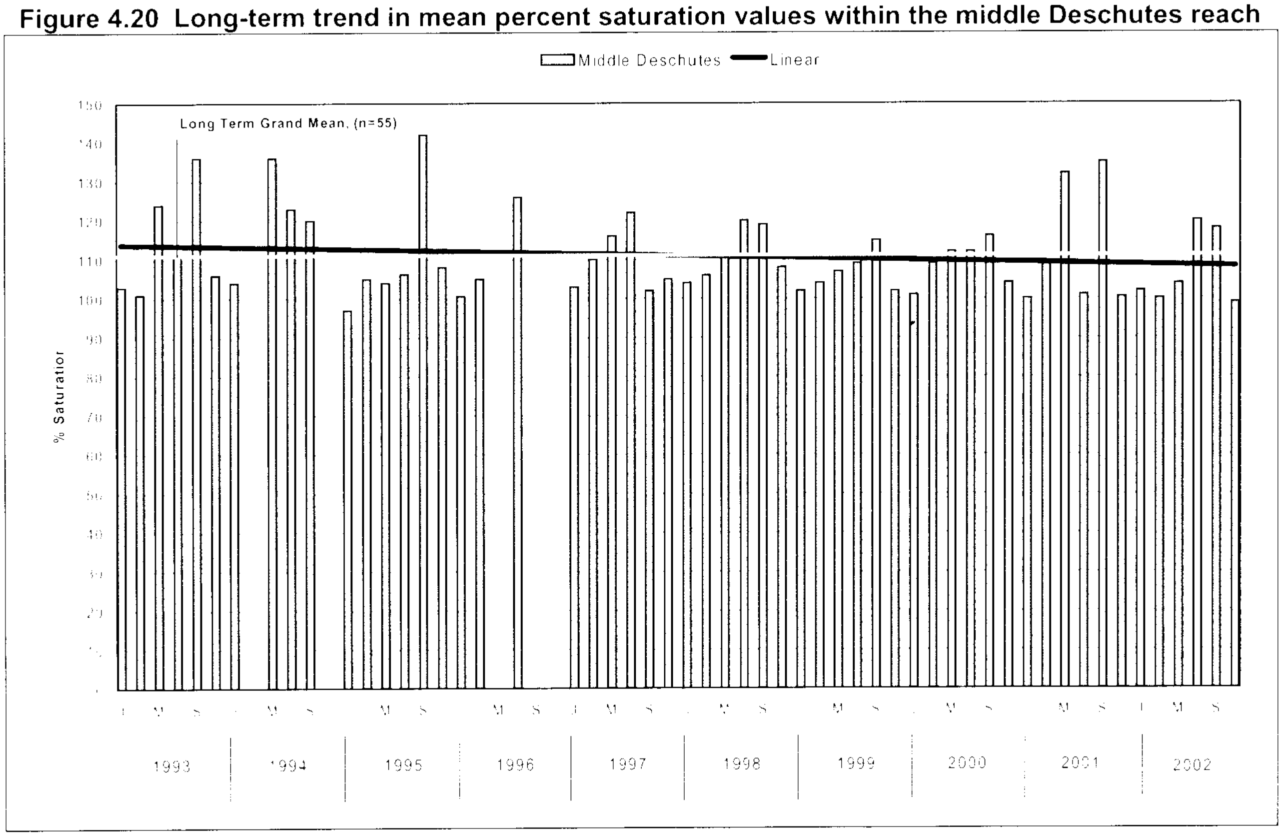
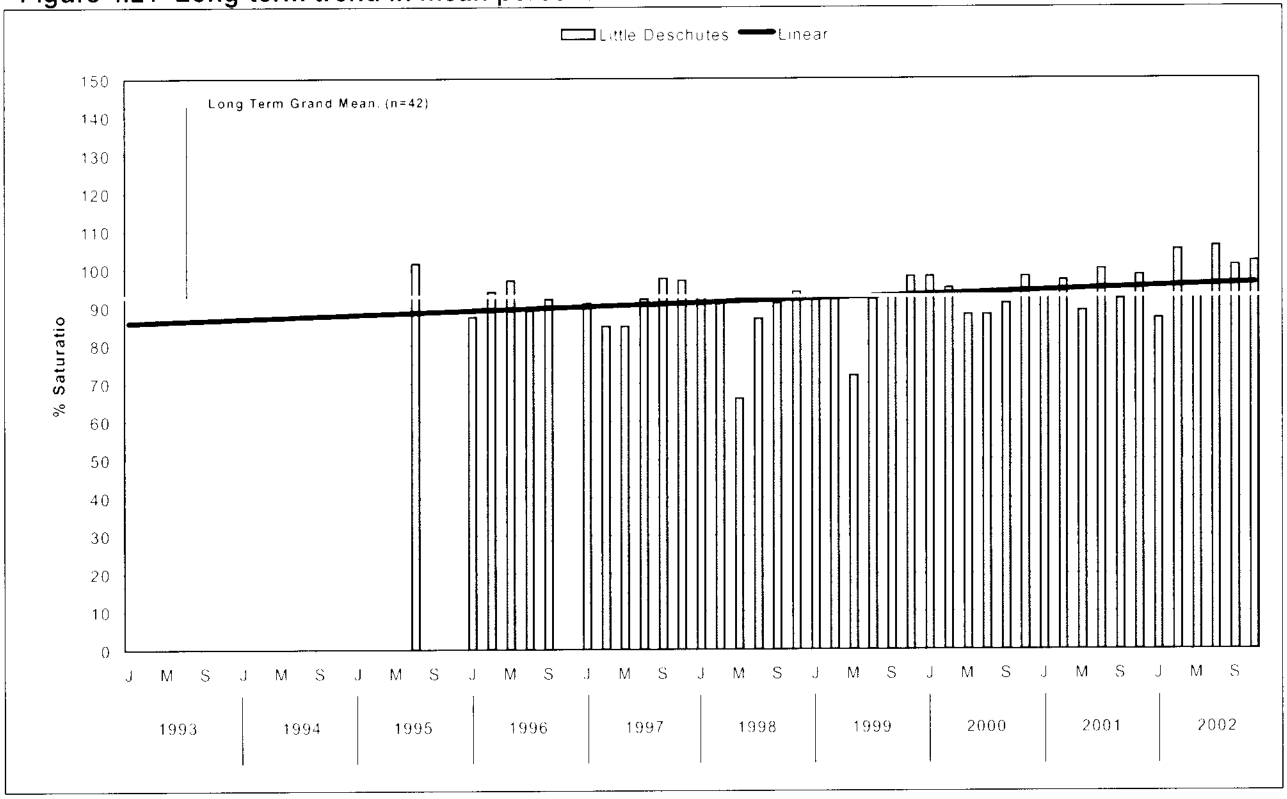


Figure 4.21 Long-term trend in mean percent saturation values within the Little Deschutes River



Percent saturation

The upper Deschutes reach expresses a long-term grand mean percent saturation of 98%. A linear regression results in a positive slope. This indicates a temporal upward trend of mean percent saturations.

The middle Deschutes reach expresses a long-term grand mean percent saturation of 111%. A linear regression results in a negative slope. This indicates a temporal downward trend of mean percent saturations.

The Little Deschutes River expresses a long-term grand mean percent saturation of 93%. A linear regression results in a positive slope. This indicates a temporal upward trend of mean percent saturations.

Figure 4.22 Long-term trend in mean BOD-5 within the upper Deschutes reach

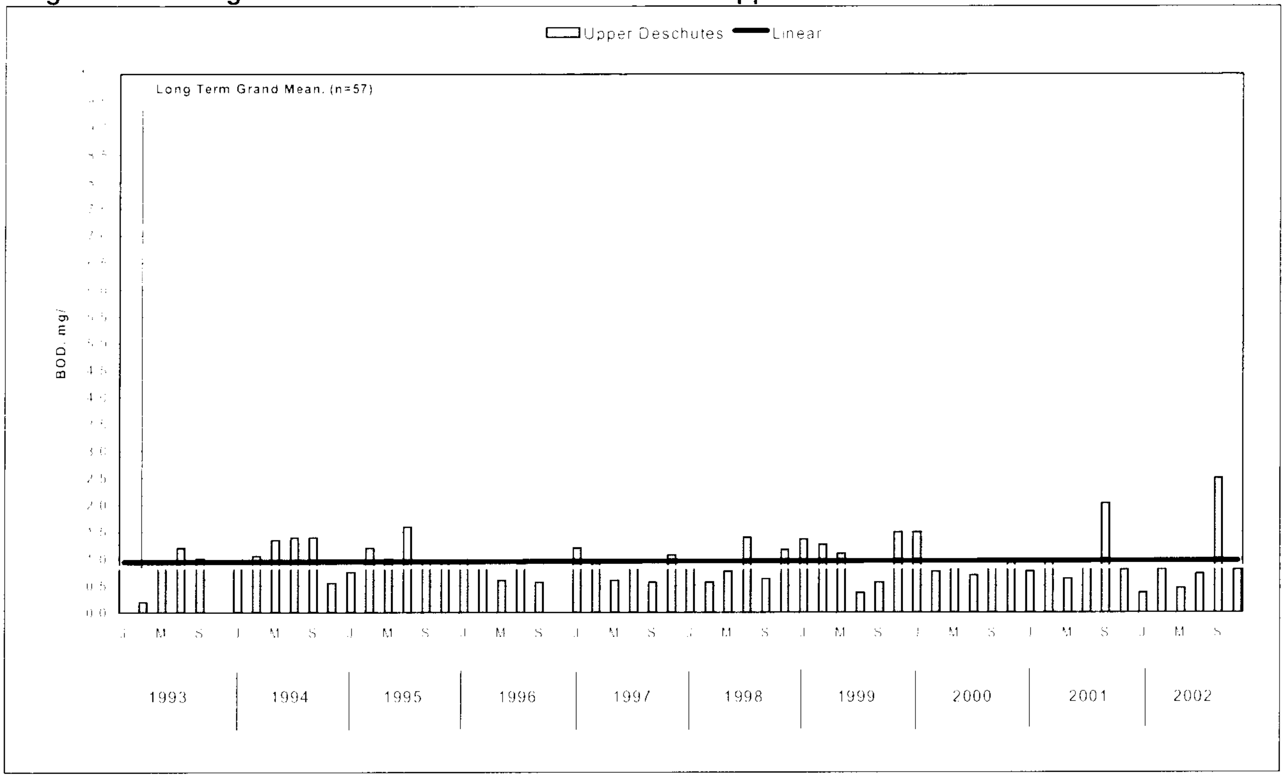
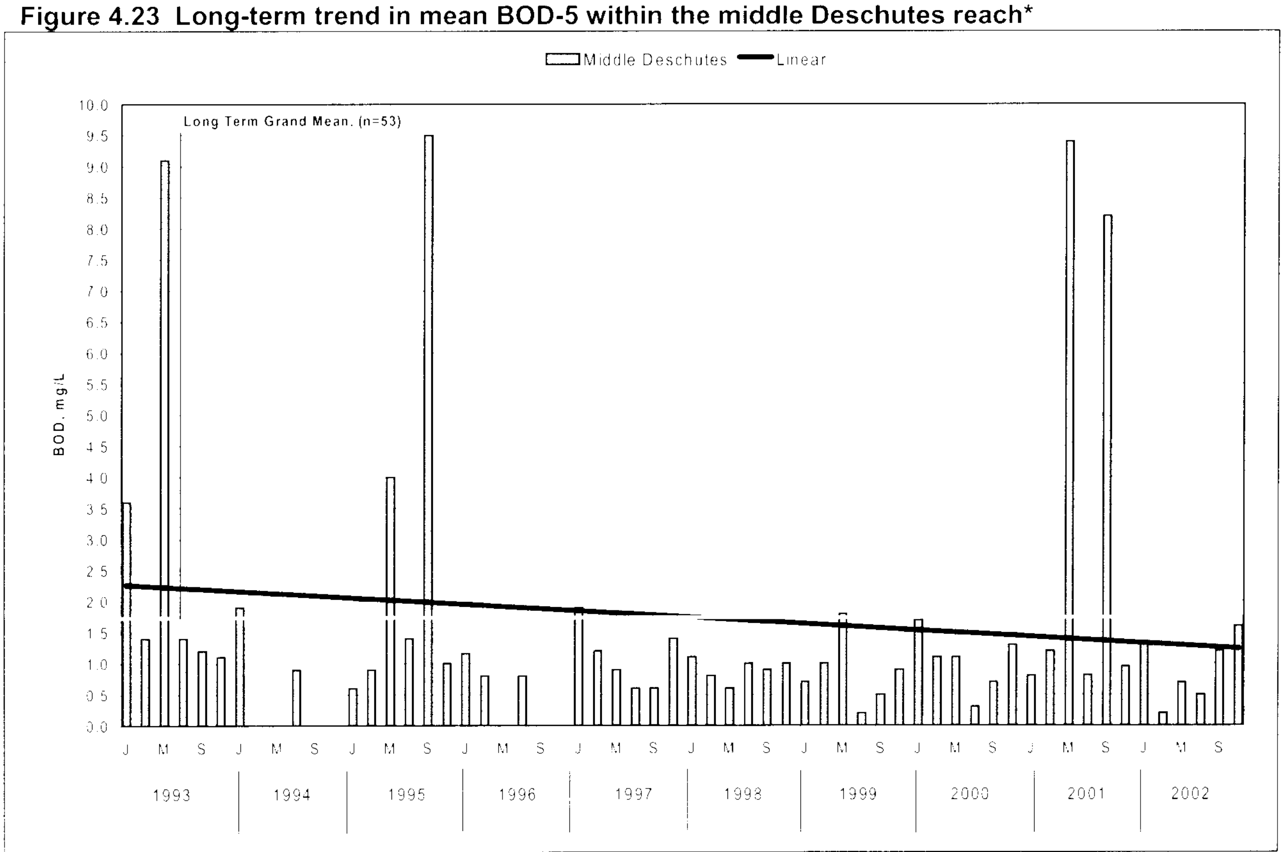
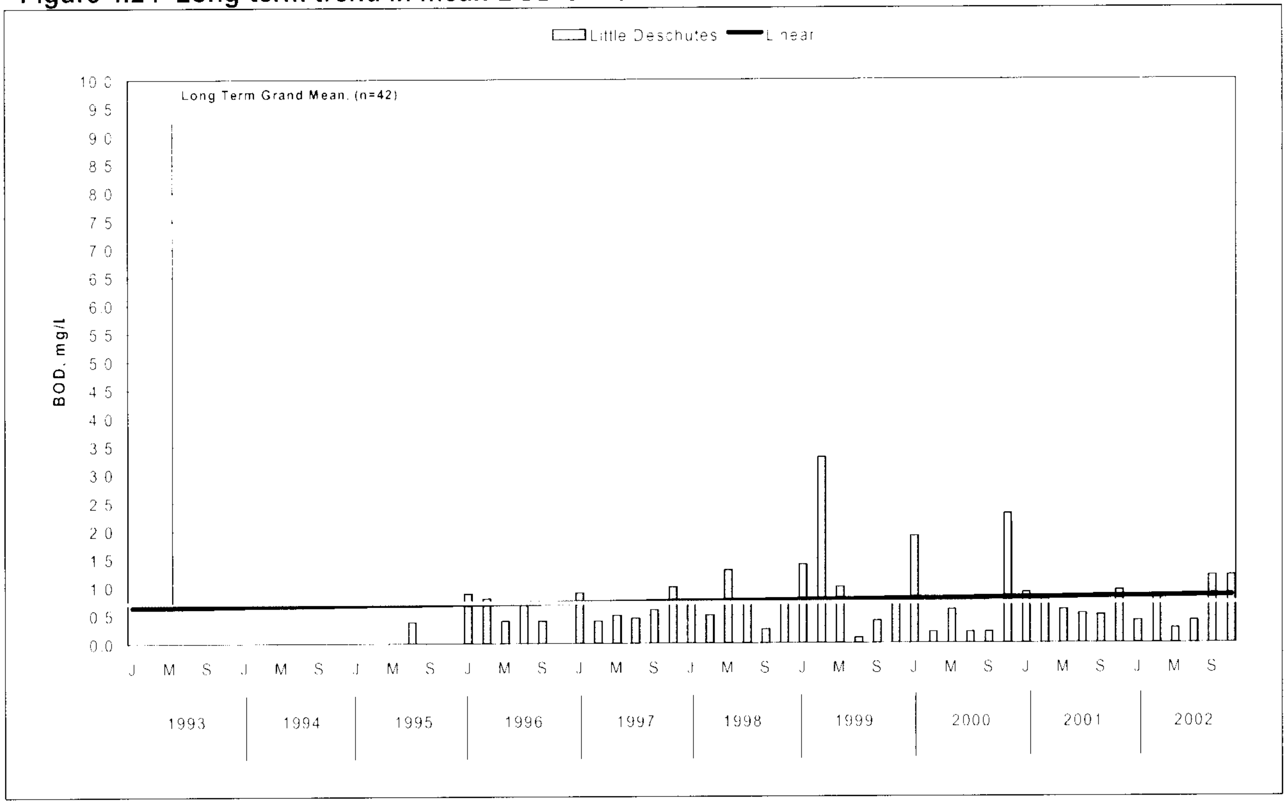


Figure 4.23 Long-term trend in mean BOD-5 within the middle Deschutes reach*



*Bars above 3.0 are months that were only sampled only once at one site.

Figure 4.24 Long-term trend in mean BOD-5 within the Little Deschutes reach



BOD-5

The upper Deschutes reach expresses a long-term grand mean BOD-5 of 1.0 mg/L. A linear regression results in a slope that is not increasing or decreasing. This indicates a temporal trend of constant mean BOD-5.

The middle Deschutes River expresses a long-term grand mean BOD-5 of 1.8 mg/L. A linear regression results in a negative slope. This indicates a temporal downward trend of mean BOD-5.

The Little Deschutes River expresses a long-term grand mean BOD-5 of 0.8 mg/L. A linear regression results in a positive slope. This indicates a temporal upward trend of mean BOD-5.

4.2.4 Are dissolved oxygen concentrations or percent saturation values compliant with regulatory criteria?

Data are evaluated by site and season. The sites and seasons applicable for analyses are displayed in **Table 4.1**. Three upper Deschutes reach sites and one middle Deschutes reach site satisfy the minimal sample number required by the EPA and ODEQ for analyses of compliance with the regulatory criteria. There are no Little Deschutes River sites that satisfy the minimal sample number required for analyses of compliance with the regulatory criteria when data is evaluated by season.

The time periods for the analyses are defined as October 1 – June 30 spawning criteria and July 1 – September 30 cold water criteria. Site analyses according to season are displayed in **Figure 4.25** and **Figure 4.26** for spawning season and **Figure 4.27** and **Figure 4.28** for cold water season. The data are presented in quantiles depicting the minimum, 10%, 25%, median, 75%, 90% and maximum boundaries. The number of samples at a particular site is stated within parentheses. A solid black line represents the data mean. The dashed black line represents the applicable criteria.

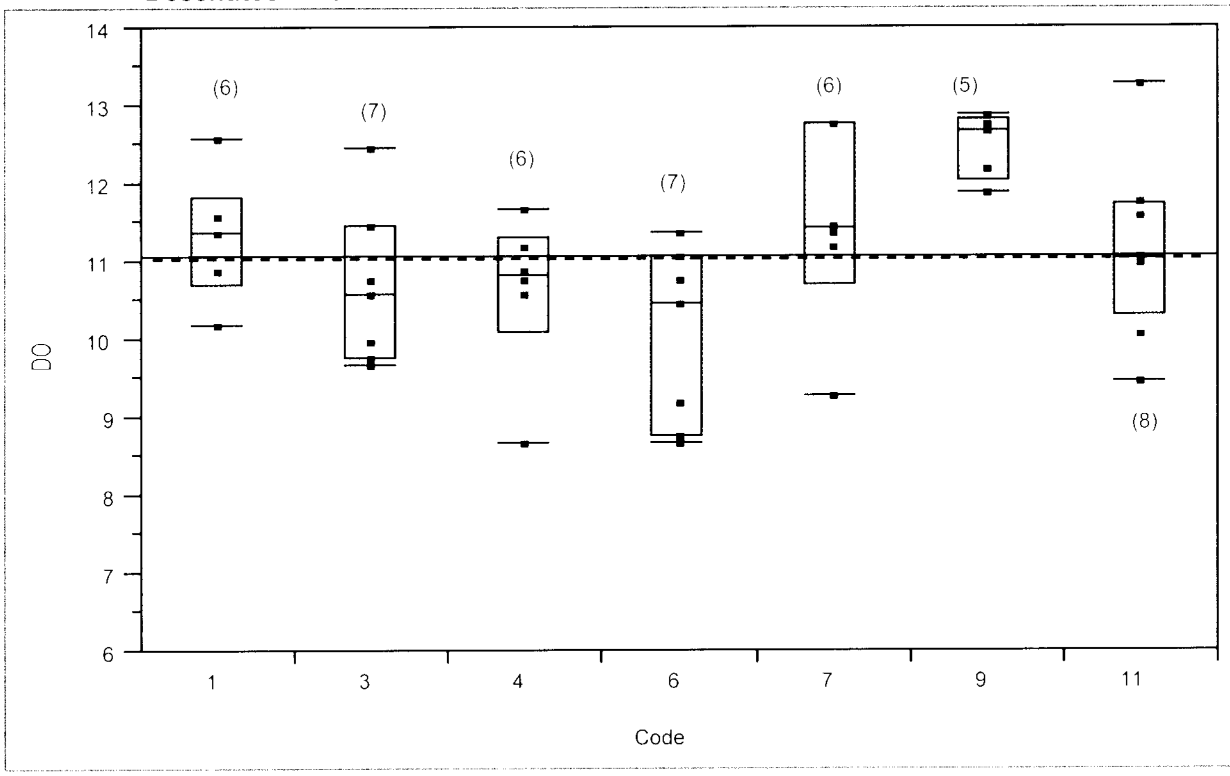
Table 4.1 Dissolved oxygen and percent saturation datasets that meet the minimal sample number required for compliance analyses

Code	Season	RM	Site	Segment	Compliance analyses
1	Spawning 1995/1996	217	Pringle Falls	UDR	**DO WQL** % Sat attaining criteria
2	Cold water 2001	217	Pringle Falls	UDR	DO attaining criteria % Sat attaining criteria **Supersaturated**
3	Spawning 2001/2002	217	Pringle Falls	UDR	**DO WQL** % Sat attaining criteria
4	Spawning 1995/1996	191.5	Harper Bridge	UDR	**DO WQL** **% Sat WQL**
5	Cold water 2001	191.5	Harper Bridge	UDR	DO attaining criteria **% Sat WQL**
6	Spawning 2001/2002	191.5	Harper Bridge	UDR	**DO WQL** **% Sat WQL**
7	Spawning 1995/1996	166.5	Mirror Pond	UDR	**DO WQL** % Sat attaining criteria
8	Cold water 1995	133.5	Lower Bridge	MDR	DO Attaining criteria % Sat attaining criteria **Supersaturated**
9	Spawning 1995/1996	133.5	Lower Bridge	MDR	DO Attaining criteria % Sat attaining criteria
10	Cold water 2001	133.5	Lower Bridge	MDR	DO Attaining criteria % Sat attaining criteria **Supersaturated**
11	Spawning 2001/2002	133.5	Lower Bridge	MDR	**DO WQL** % Sat attaining criteria

S= June 1 through September 30 FWS: October 1 to May 31 WQL = water quality limited

The Little Deschutes River dataset is categorized as having insufficient data for compliance analyses when evaluated by season. The Little Deschutes River is listed from its mouth at RM 0 upstream to RM 54.1 for exceeding the dissolved oxygen criterion for spawning. The 303(d) listing is a result of including all data from multiple years, while the Technical Report methodologies attain the minimal number of samples by including data from a single season.

Figure 4.25 Detail of spawning season dissolved oxygen concentrations (mg/L) within the upper Deschutes River



Quantiles

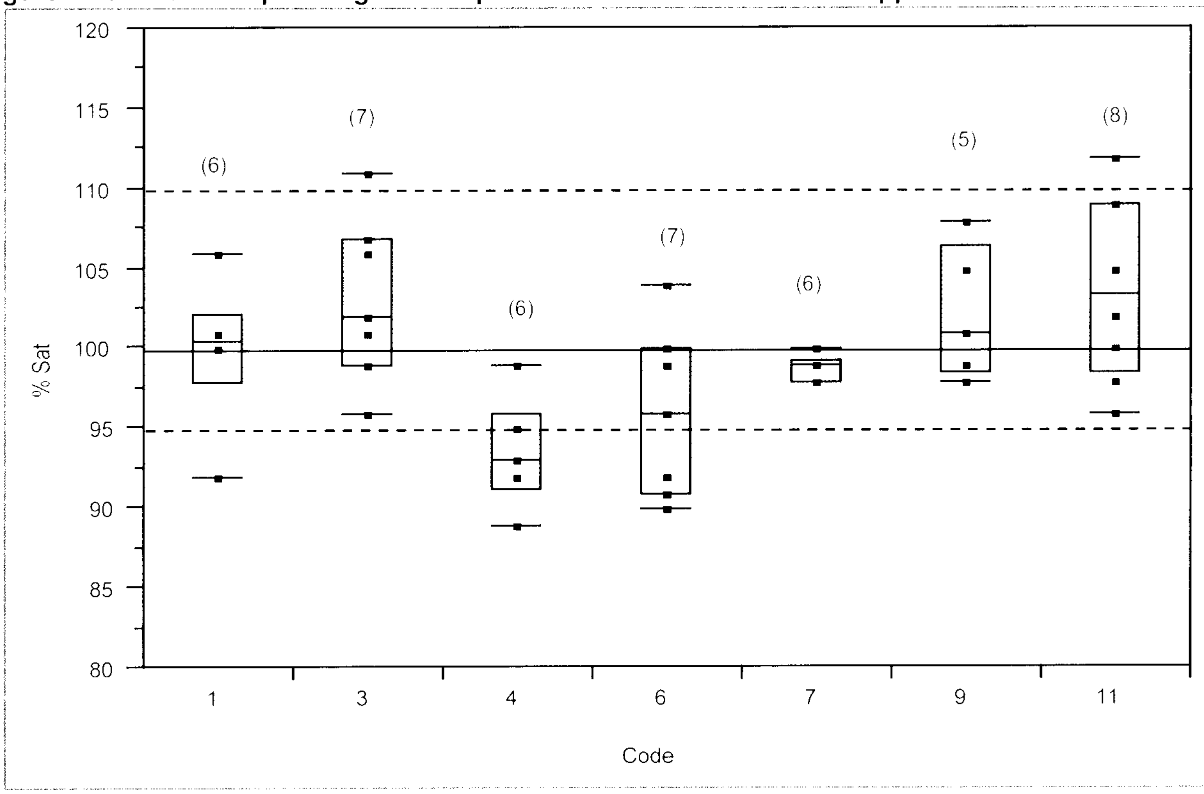
Code	minimum	10.0%	25.0%	median	75.0%	90.0%	maximum
1	10.2	10.2	10.7	11.4	11.9	12.6	12.6
3	9.7	9.7	9.8	10.6	11.5	12.5	12.5
4	8.7	8.7	10.1	10.9	11.3	11.7	11.7
6	8.7	8.7	8.8	10.5	11.1	11.4	11.4
7	9.3	9.3	10.7	11.5	12.8	12.8	12.8
9	11.9	11.9	12.1	12.7	12.9	12.9	12.9
11	9.5	9.5	10.3	11.1	11.8	13.3	13.3

The ODEQ numeric criteria for salmonid spawning until fry emergence states that dissolved oxygen will not be less than 11.0 mg/L.

The upper Deschutes reach sites code 1, 3, 4, and 6 are categorized as water quality limited, because 10% of the dataset and a minimum of two exceedences are not compliant with the applicable criteria.

The middle Deschutes reach sites code 7 and 11 is categorized as water quality limited, because 10% of the dataset and a minimum of two exceedences are not compliant with the applicable criteria. Site code 9 is categorized as attaining criteria, because 90% of the dataset are within the applicable criteria.

Figure 4.26 Detail of spawning season percent saturations within the upper Deschutes River



Quantiles

Code	minimum	10.0%	25.0%	median	75.0%	90.0%	maximum
1	92	92	98	101	102	106	106
3	96	96	99	102	107	111	111
4	89	89	91	93	96	99	99
6	90	90	91	96	100	104	104
7	98	98	98	99	99	100	100
9	98	98	99	101	107	108	108
11	96	96	99	104	109	112	112

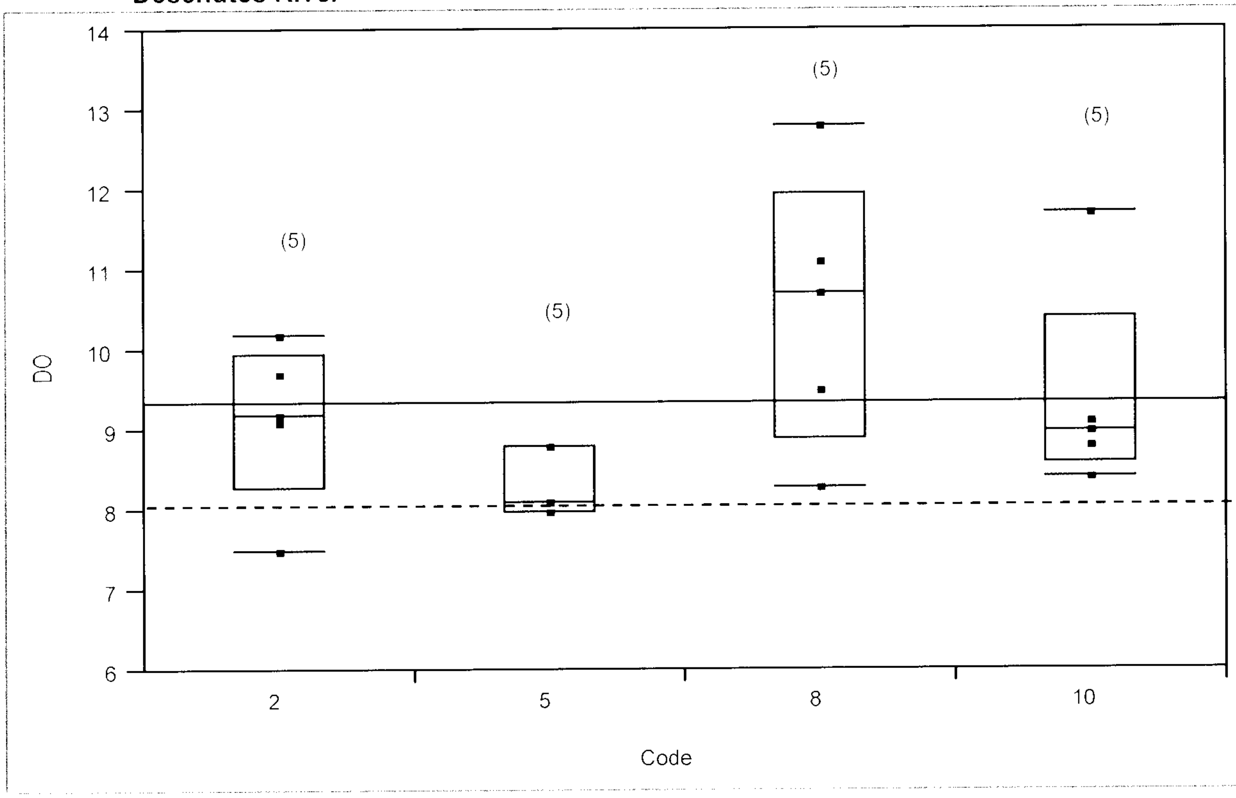
For spawning the criteria for percent saturation is 95% saturation and the guideline for percent saturation is >110% is supersaturated.

The upper Deschutes reach sites code 4 and 6 are categorized as water quality limited, because 10% of the dataset and a minimum of two exceedences are not compliant with the applicable criteria. Sites code 1, 3, and 7 are categorized as attaining criteria, because 90% of the dataset are within the applicable criteria.

The middle Deschutes reach sites codes 9 and 11 are categorized as attaining criteria, because 90% of the dataset are within the applicable criteria.

There are no codes that are categorized as supersaturated during spawning season.

Figure 4.27 Detail of cold water season dissolved oxygen concentrations (mg/L) within the upper Deschutes River



Quantiles

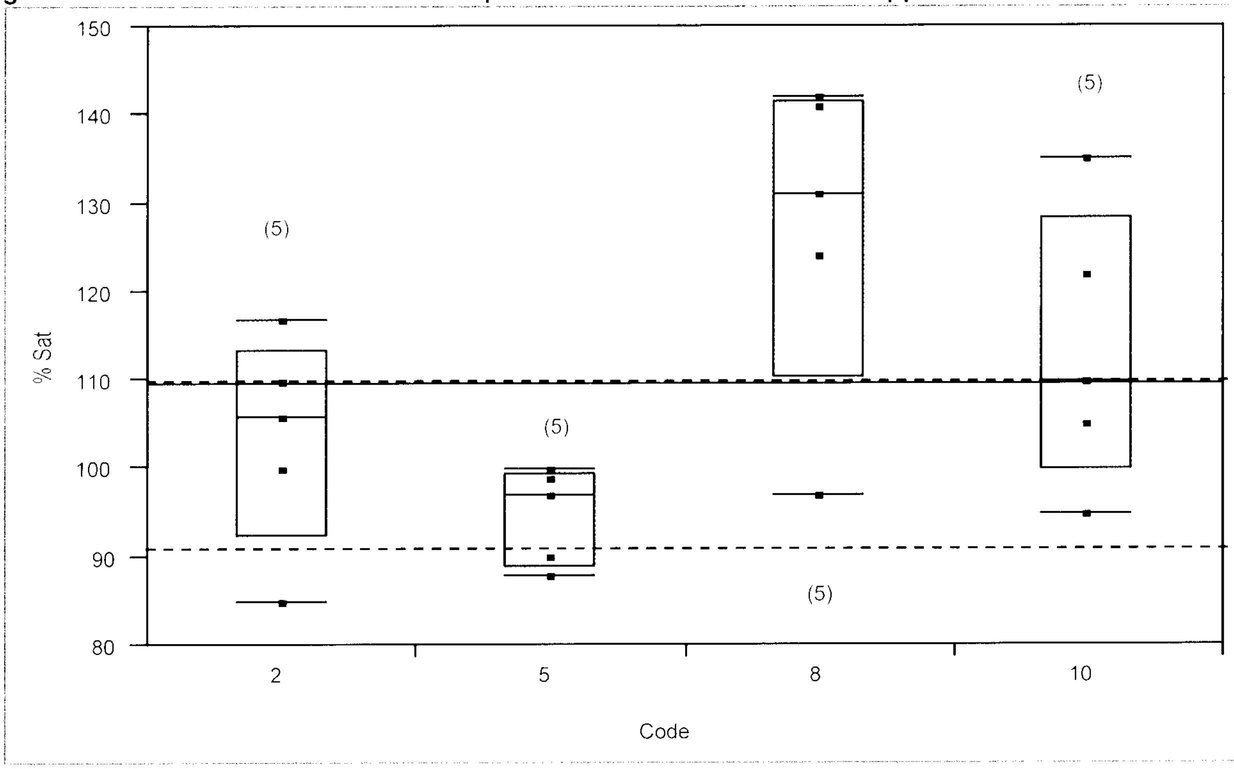
Code	minimum	10.0%	25.0%	median	75.0%	90.0%	maximum
2	7.5	7.5	8.3	9.2	10.0	10.2	10.2
5	8.0	8.0	8.0	8.1	8.8	8.8	8.8
8	8.3	8.3	8.9	10.7	12.0	12.8	12.8
10	8.4	8.4	8.6	9.0	10.4	11.7	11.7

The ODEQ numeric criterion for cold water state that dissolved oxygen is to not be less than 8.0 mg/L.

The upper Deschutes reach, sites code 2 and 5 are categorized as attaining criteria, because 90% of the dataset are within the applicable criteria.

The middle Deschutes reach, sites code 8 and 10 are categorized as attaining criteria, because 90% of the dataset are within the applicable criteria.

Figure 4.28 Detail of cold water season percent saturations within the upper Deschutes reach



Quantiles

Code	minimum	10.0%	25.0%	median	75.0%	90.0%	maximum
2	85	85	92	106	113	117	117
5	88	88	89	97	99	100	100
8	97	97	110	131	141	142	142
10	95	95	100	110	128	135	135

For cold water, the criterion for percent saturation is 90% saturation and the guideline for percent saturation is >110% is supersaturated.

The upper Deschutes reach site code 5 is categorized as water quality limited, because 10% of the dataset and a minimum of two exceedences are not compliant with the applicable criteria. Site code 2 is categorized as attaining criteria, because 90% of the dataset are within the applicable criteria. Site code 2 is categorized as supersaturated, because 10% of the dataset and a minimum of two exceedences are not compliant with the applicable criteria.

The middle Deschutes reach sites code 8 and 10 are categorized as attaining criteria, because 90% of the dataset are within the applicable criteria. Sites code 8 and 10 are categorized as supersaturated, because 10% of the dataset and a minimum of two exceedences are not compliant with the applicable criteria.

4.2.5 What is the qualitative index for BOD-5?

A modified qualitative index is used to score BOD-5 data. **Table 4.2** scores regional mean BOD-5. **Table 4.3** summarizes regional BOD-5 data that is scored very poor and approaches the 10.0 mg/L polluted water indicator value.

<u>Qualitative Index for BOD-5</u>

0.0 – 0.9 mg/L	excellent – fair
1.0 – 2.9 mg/L	poor
>3.0 mg/L	very poor
>10.0 mg/L	polluted

Table 4.2 Mean BOD-5 qualitative index for reaches within the Upper Deschutes and Little Deschutes Subbasins

Segment	Analyses	Mean BOD-5 mg/L	Qualitative Index
Upper Deschutes River	longitudinal extent	1.0	poor
Upper Deschutes River	seasonal	1.4	poor
Upper Deschutes River	long-term	1.4	poor
UDR	longitudinal extent	0.9	excellent-fair
UDR	seasonal	1.0	poor
UDR	long-term	1.0	poor
MDR	longitudinal extent	1.0	poor
MDR	seasonal	1.8	poor
MDR	long-term	1.8	poor
LDR	longitudinal extent	0.6	excellent-fair
LDR	seasonal	0.8	excellent-fair
LDR	long-term	0.8	excellent-fair

Table 4.3 Summary of BOD-5 data that score a qualitative index of very poor within the Upper Deschutes and Little Deschutes Subbasins

Segment	RM	Site	Date	BOD-5 mg/L
UDR	217	Pringle Falls Bridge	Aug-95	9.4
UDR	217	Pringle Falls Bridge	Sep-02	3.4
MDR	133.5	Lower Bridge	Jan-93	3.6
MDR	133.5	Lower Bridge	May-93	9.1
MDR	133.5	Lower Bridge	May-95	4.0
MDR	133.5	Lower Bridge	Jul-95	9.2
MDR	133.5	Lower Bridge	Sep-95	9.5
MDR	133.5	Lower Bridge	May-01	9.4
MDR	133.5	Lower Bridge	Sep-01	8.2

There are no Little Deschutes River sites that score a BOD-5 qualitative index of very poor.

4.3 Discussion and Key Findings

Throughout the subbasins, dissolved oxygen concentrations may reflect a maximization of percent saturation during light hours except for the Little Deschutes River during May possible due to the combination of waters that are not well aerated and low primary production within the water column. Areas of sediment deposition near and within the City of Bend may have the tendency to accumulate nonpoint source pollution carried by uncharacterized urban runoff into deposited sediments, while supersaturated waters within the middle Deschutes reach may be due to high primary productivity and water diversions. The middle Deschutes reach may be more eutrophic than the upper Deschutes Reach and may exhibit increases in decomposition processes possibly due to decreases in flow, increases in primary producer die offs, and increases in organic and inorganic inputs from uncharacterized urban runoff, rural land use, and agriculture. Conditions of the upper Deschutes River at the Lower Bridge site may illustrate the accumulative nature of upstream and long-term impacts.

The dissolved oxygen concentrations and percent saturations along the longitudinal extent of the upper Deschutes River exhibit a downward trend along the upper Deschutes reach and an upward trend along the middle Deschutes reach (**Figure 4.1** and **Figure 4.3**). The lowest mean values for dissolved oxygen and percent saturation for the upper Deschutes River are within the upper Deschutes reach at Crosswater Golf Course and Harper Bridge, yet these relatively low mean levels still reflect an oxygenated aquatic system. The highest mean values for dissolved oxygen and percent saturation for the upper Deschutes River are from the City of Bend to upstream Steelhead Falls. All sites between Columbia River Bridge in the City of Bend to upstream of Steelhead Falls exhibit saturated conditions with mean percent saturations between 100 - 110%, except for Mirror Pond and Riverhouse Hotel sites that exhibit near saturated conditions and the Lower Bridge site that exhibits supersaturated conditions above 110% saturation.

During the day when primary producers are actively photosynthesizing, dissolved oxygen concentrations are high throughout the subbasins and reflect a maximization of percent saturation. During the day, the amount of dissolved oxygen in the water of the subbasins may be dictated by how much the water can hold at that temperature and elevation, therefore the limiting factor is not how much oxygen is being produced in the system but how much oxygen the water can hold. Low levels of dissolved oxygen and low percent saturations are evident at night when primary producers are not photosynthesizing. The maximization of percent saturation is reflected in daily fluctuations that illustrate percent saturation peaks equal to or greater than 100% during light hours and percent saturation valleys around 90% during dark hours (**Figure 4.8**, **Figure 4.10**, and **Figure 4.12**). Yet despite the ability of the systems to achieve saturated conditions during the day, dissolved oxygen levels are still below the state criteria for salmonid spawning till fry emergence during April 2001(**Figure 4.11** and **Figure 4.12**). In addition, unique daily fluctuations are displayed at below Wickiup Reservoir, above Riverhouse Hotel, and Lower Bridge sites.

The unique daily fluctuation patterns expressed at the three sites are likely due to anthropogenic impacts. The site below Wickiup Reservoir illustrates a lack of daily fluctuations and high percent saturations during periods of high flow (**Figure 4.7**, **Figure 4.8**, **Figure 4.11**, and **Figure 4.11**) and a return to daily fluctuations in combination with low percent saturation during periods of low flow (**Figure 4.9** and **Figure 4.10**). The pattern expressed by the site below Wickiup Reservoir may be indicative of flow fluctuations impacting primary production. The site above Riverhouse Hotel depicts a unique daily fluctuation pattern that may be indicative of urban influences (**Figure 4.11** and **Figure 4.12**). The Lower Bridge site expresses the most extreme daily fluctuations in dissolved oxygen and percent saturations. These extreme daily fluctuations may be indicative of high primary productivity photosynthesis during the light hours and degradation process during the light and dark hours. This is supported by BOD-5 results that indicate increased levels of degradation processes at the Lower Bridge site (**Figure 4.5**, **Figure 4.17**, and **Table 4.3**) The conditions at the Lower Bridge site are likely due to upstream anthropogenic impacts including uncharacterized urban runoff, rural land use, and agriculture.

Additional indications of the maximization of percent saturation is reflected in that the mean dissolved oxygen concentrations and mean percent saturations express the same trends along the longitudinal extent, seasonally, and with time (**Figure 4.1, Figure 4.3, Figure 4.13, Figure 4.14, Figure 4.16, Figure**

4.17, Figure 4.19, and **Figure 4.20**). Two exceptions include the middle Deschutes reach during the warm months and the Little Deschutes River in May.

Seasonal fluctuations in mean dissolved oxygen concentrations within the upper Deschutes reach, middle Deschutes reach, and Little Deschutes River exhibit the same trend with lower mean dissolved oxygen concentrations in warmer months and higher mean dissolved oxygen concentrations during cooler months (**Figure 4.13**). The seasonal fluctuations of mean percent saturation for the upper Deschutes reach and the Little Deschutes River, except for May, exhibit the same trend while the fluctuation of mean percent saturation for the middle Deschutes reach exhibit a different trend (**Figure 4.14**). Mean percent saturation within the middle Deschutes reach during May, July, and September indicate supersaturated conditions above 110% saturation while November, January, and March indicate saturated conditions between 100 - 110% saturation. The supersaturated waters are indicative of high primary productivity and low flows within the middle Deschutes reach.

Seasonal trends for the Little Deschutes River during the month of May indicate the lowest saturation means below 85 percent saturation, therefore the water could hold more oxygen at that temperature and elevation (**Figure 4.14**). The seasonal mean dissolved oxygen trend for the Little Deschutes River appears to follow the same trend as the upper Deschutes River yet with slightly lower mean values (**Figure 4.13**). The low mean saturation level and the lower mean dissolved oxygen concentrations illustrates that the Little Deschutes River has increased oxygen demand or decreased oxygen production during May. The low saturation could be the result of oxygen consumption for decomposition of organic matter, yet BOD-5 indicates low organic matter. The low saturation could be the result of decreased oxygen production, which is supported by the seasonal mean chlorophyll-*a* concentrations that indicate low primary productivity within the Little Deschutes River (**Figure 6.3**). The decreased mean dissolved oxygen and percent saturation within the Little Deschutes River are likely due to waters that are not well aerated in combination with low primary production.

Downward trends in mean dissolved oxygen concentrations and percent saturations are evident in long-term analyses of the middle Deschutes reach, while upward trends are evident for the upper Deschutes reach and the Little Deschutes River (**Figure 4.16** and **Figure 4.21**). The downward trend within the middle Deschutes reach may be due to the relationship between water diversions and the influences of the City of Bend uncharacterized urban runoff in combination with increased primary production ultimately leading to eventual decreases in dissolved oxygen. The most impacted site within the City of Bend appears to be the Mirror Pond site. The most impacted segment in the subbasins appears to be the middle Deschutes reach, and the most impacted site appears to be the Lower Bridge site.

Longitudinal extent mean BOD-5 at the Mirror Pond site is approaching values for poor quality waters, while all other sites within the City of Bend have mean BOD-5 that are relatively lower and are categorized as characteristic of excellent – fair quality waters (**Figure 4.5**). The discrepancy in relative BOD-5 may be due to the impacts of sedimentation and uncharacterized urban runoff at this site. Sediments accumulate many organic and inorganic compounds that are present in urban runoff. The degradation of these accumulate compounds may be indicated by the BOD-5 at the Mirror Pond site.

The middle Deschutes reach may be more eutrophic than the upper Deschutes reach and Little Deschutes River and may be exhibiting a different stage within the cycling of primary producers. The upper Deschutes reach and Little Deschutes River may be experiencing increases in primary production, while the middle Deschutes reach may have already experienced increases in primary production and is now showing signs of increases in the decomposition of primary producers. This pattern is evident at the Lower Bridge site patterns in daily fluctuations of dissolved oxygen concentrations and percent saturations that indicate high levels of oxygen producing primary production and high levels of oxygen depleting decomposition (**Figure 4.11 and 4.12**).

The oxygen demand may be greater within the middle Deschutes reach because of increased organic and inorganic matter via the downstream reception of expired primary producers in combination with uncharacterized urban runoff. The organic and inorganic compounds that are entering the upper Deschutes River lend to more microbial uptake of oxygen to undergo redox reactions that transform the organic and inorganic compounds in order to harness energy, which would account for the long-term downward trend in mean dissolved oxygen concentrations within the middle Deschutes reach (**Figure 4.17**).

Along the longitudinal extent of the upper Deschutes River mean BOD-5 are exhibiting a downward trend within the upper Deschutes reach and an upward trend within the middle Deschutes reach (**Figure 4.5**). Most sites within the upper Deschutes River are within the excellent – fair qualitative category, but one upper Deschutes reach site and four middle Deschutes reach sites are within the poor qualitative category; Pringle Falls Bridge (UDR), upstream Tumalo Creek (MDR), Odin Falls Road (MDR), Lower Bridge (MDR), and upstream Steelhead Falls (MDR). The upper Deschutes River and the Little Deschutes River exhibit the same seasonal trend except for March and September on the middle Deschutes reach that exhibit BOD-5 qualitative categories of very poor and poor (**Figure 4.15**). The seasonal results are influenced by small datasets with samples collected from the middle Deschutes reach at Lower Bridge that have very high BOD-5 approaching levels for polluted waters (**Table 4.3**). The Pringle Falls Bridge site within the upper Deschutes reach also has BOD-5 approaching levels for polluted waters. The BOD-5 results indicate pollution events within the upper Deschutes River that may contribute to the eutrophication of the middle Deschutes reach.

Within the middle Deschutes reach, water quality impairment may exist not for a lack of production of dissolved oxygen in the system but rather due to the inability of the system to hold the amount of oxygen that is being produced by high primary production as evident by waters that are supersaturated with oxygen (**Figure 4.3**). Supersaturated waters can occur due to high primary productivity producing oxygen in waters that should hold less oxygen at that temperature and elevation. Eventually, as the increased numbers of primary producers die off, decomposition via microorganisms would decrease mean dissolved oxygen concentrations and percent saturations as evident by the long-term downward trend in mean dissolved oxygen concentration and percent saturation. In addition, high BOD-5 at the Lower Bridge during May and September indicate increased decomposition. Increases in decomposition processes are indicative of eutrophication (**Figure 4.5**).

May and September BOD-5 at the Lower Bridge may reflect natural and anthropogenic impacts and requires further investigation (**Figure 4.15**). As indicated by May, the passage of organic and inorganic matter down the upper Deschutes River may increase due to Wickiup Reservoir storage releases that flush compounds downstream. Additional compounds may be input into the system from uncharacterized urban runoff, rural land use, and agriculture. Spikes in BOD-5 at the Lower Bridge in May indicate microbial degradation of compounds within polluted waters. July months at the Lower Bridge site exhibit BOD-5 that are much lower possibly due to the temporal passing of the disturbance, primary producer photosynthesis, and decreased flows. As indicated by September results, the passage of organic and inorganic matter down the upper Deschutes River may increase due to the ending of water diversions therefore increases in flows. The increase in flows in the middle Deschutes may create a second flush of organic and inorganic materials downstream. The Lower Bridge site appears to be the most impacted site within the relatively more eutrophic middle Deschutes reach.

Although the mean dissolved oxygen and percent saturation within the rivers of the subbasins are generally high, the spawning and cold water seasons dissolved oxygen and percent saturation datasets that meet the minimal sample number required for compliance analyses are not always in compliance with regulatory criteria (**Table 4.1**). The water quality limited status for spawning season at Pringle Falls and Harper Bridge are in agreement with the state 2002 303(d) listing of the segment from RM 168.2 (upstream the City of Bend) to RM 222.2 (downstream Wickiup Reservoir). The following additional listings are suggested for review:

Mirror Pond	Spawning 1995/1996	Percent saturation WQL
Lower Bridge	Spawning 2001/2002	Dissolved oxygen WQL

The Little Deschutes River dataset is categorized as having insufficient data for compliance analyses when evaluated by season. The Little Deschutes River is listed from its mouth at RM 0 upstream to RM 54.1 for exceeding the dissolved oxygen criterion for spawning. The 303(d) listing is a result of including all data from multiple years, while the Technical Report methodologies attain the minimal number of samples by including data from a single season.

Key Findings

- Dissolved oxygen concentrations may reflect a maximization of percent saturation during light hours throughout the subbasins except for the Little Deschutes River during May possibly due to waters that are not well aerated in combination with low primary production within the water column.

- As indicated by BOD-5, areas of sediment deposition near and within the City of Bend may have the tendency to accumulate nonpoint source pollution carried by uncharacterized urban runoff into deposited sediments.

- Within the middle Deschutes reach, supersaturated waters may be due to primary producer photosynthesis during light hours, while undersaturated waters may be due to decomposition processes that continue during dark hours.

- The middle Deschutes reach may be more eutrophic than the upper Deschutes Reach and may exhibit increases in decomposition processes possibly due to decreases in flow, increases in primary producer die offs, and increases in organic and inorganic inputs from uncharacterized urban runoff, rural land use, and agriculture.

- Conditions of the upper Deschutes River at the Lower Bridge site may illustrate the accumulative nature of upstream and long-term impacts from uncharacterized urban runoff, rural land use, and agriculture.

- Additional state 303(d) listings of segments of the upper Deschutes River may be indicated by non-compliance with state criteria in regards to percent saturation and dissolved oxygen.

5.0 TURBIDITY AND SEDIMENTATION

5.1 Introduction

Turbidity and embeddedness measurements are used as an indicator of sediment loading because of ease and relative inexpense, while measuring sedimentation can be a complex, expensive, and time consuming process. Turbidity measures the amount of light able to pass through a sample and is inversely reported as nephelometric turbidity units (NTU); with increasing NTU, decreasing light passage and increasing solids are reported. Turbidity cannot distinguish between suspended sediment and other materials suspended in the water sample, and it does not address the sources of sediment or the rates of sediment deposition. Substrate studies can establish the effects of sediment deposition via embeddedness of aquatic habitats and the ability of a fluvial system to transport the sediment loads.

An aquatic system composed of a range of fine sediments to large boulders provides the habitat for many aquatic organisms. Sediments are naturally produced by the erosion of rock and soil particles into a waterbody. A healthy aquatic system has achieved a balance between the sediment load and sediment transport, thus providing a range of habitat for different aquatic species.

Sediment loading occurs from natural and anthropogenic influences and can contribute to the turbidity of an aquatic system. The local geology, soils, slope, health of the riparian zone, precipitation rates, and natural stream flows all can contribute to natural rates of sediment loading and turbidity. Anthropogenic impacts can increase the sediment load and turbidity above natural levels and include land management practices, construction, logging, roads, flow regulations, and agricultural activities. Turbidity levels also increase due municipal and industrial wastewater discharges, excessive algal growth, and forest fires. When an increase in sediment loading occurs, the aquatic system can become imbalanced due to the inability of that system to transport the increased load of sediment. Sediments entering an aquatic system dissolve (dissolved solids), remain suspended (suspended solids), or settle onto the streambed (deposited solids or sediment). Unnaturally high turbidity levels can indicate an aquatic system that is out of balance.

An imbalanced aquatic system negatively affects the habitat of aquatic organisms. Sediment loading can increase turbidity within the water column and increase the embeddedness of the aquatic substrate via sediment deposition. Sediment loading increases the solids (sediment, leaf litter, algae, plankton, microorganisms, etc) within the water column and affects light passage. Solids within the water column reduce light penetration by scattering and absorbing light lending to changes in the physical parameters of the waterbody including increased temperatures and decreased dissolved oxygen. These changes in the physical parameters of the waterbody decrease beneficial aquatic productivity.

All organisms are affected by increased sediment loading of an aquatic system. Prolonged exposure to increased turbidity within the water column affects the ability of fish to see and obtain food and uptake oxygen due to clogged gill tissues. As solids settle, they can cover the aquatic substrate smothering fish eggs and benthic organisms. Fine sediments can carry toxins into the water column. Once in the water column, some compounds can partition directly into aquatic species such as fish and enter the food chain. Other toxins adhere to fine sediments, deposit onto the aquatic substrate, partition into benthic organisms, and make their way into the food chain.

5.2 Analyses

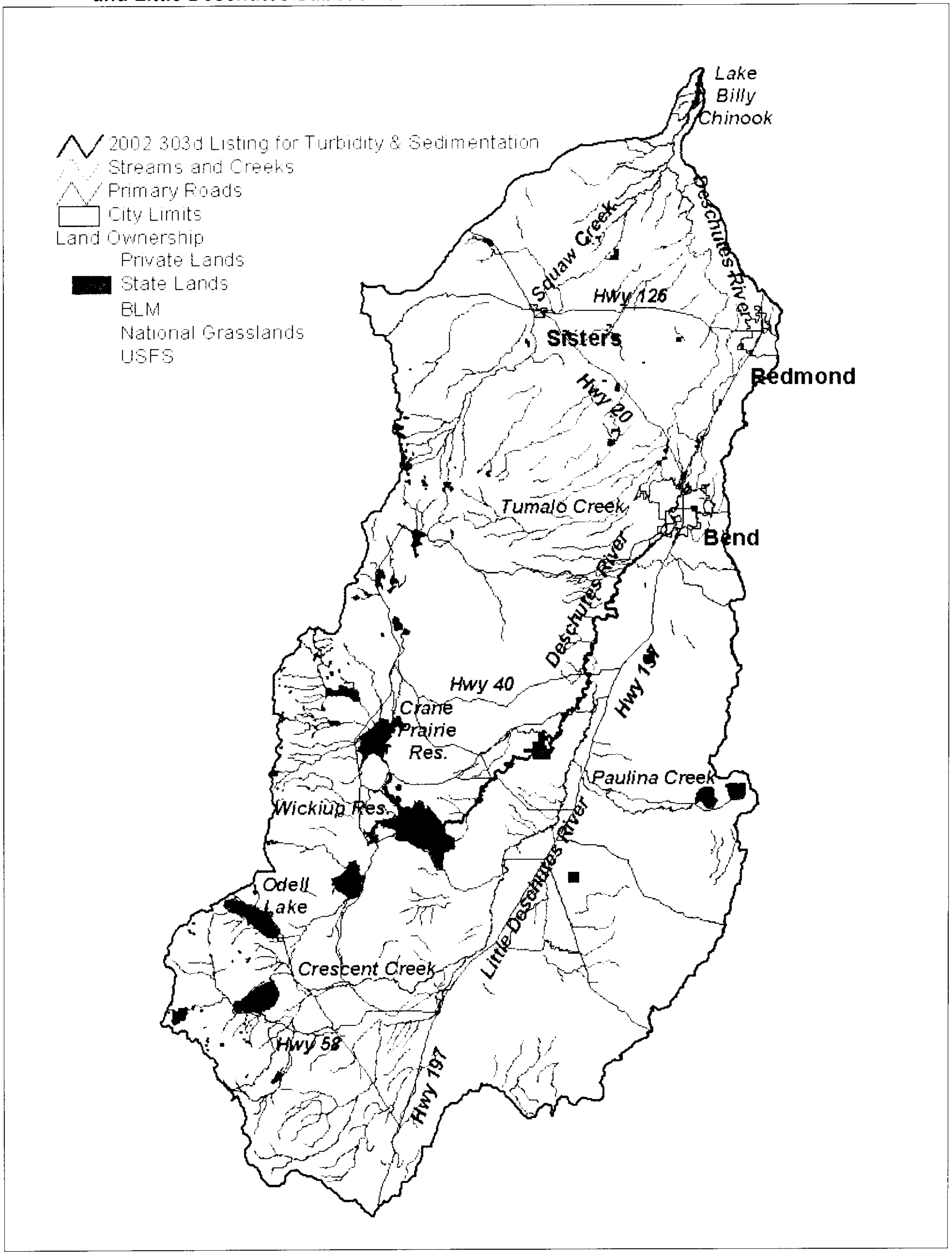
The ODEQ narrative criterion for sedimentation states, "The formation of appreciable bottom or sludge deposits, or the formation of any organic or inorganic deposits deleterious to fish or other aquatic life or injurious to public health, recreation or industry shall not be allowed" (ODEQ, 2001). The ODEQ criterion for turbidity allows no more than a 10% cumulative increase in natural stream turbidities as measured relative to a control point immediately upstream of the turbidity causing activities (ODEQ, 2001). The Deschutes River is on the ODEQ 2002 303(d) list for exceeding both the state sedimentation and turbidity standards from RM 168.2 (upstream of the City of Bend) to RM 222.2 (downstream Wickiup Reservoir) **(Map 5.1)**.

The ODEQ criteria reflect a focus on point source causes of turbidity, but are not useful for evaluating the possible effects of nonpoint sources on turbidity along the longitudinal extent of the aquatic system. The data in the Technical Report are compared to the OWEB guideline of 50 NTU for turbidity, which is based on the beneficial use by salmonids (OWEB, 1999).

Data collected from 1993 to 2002 by ODEQ ambient monitoring and intensive water quality monitoring studies for TMDL development and data collected during 2001 DEQ/USFS Sediment Study are used to illustrate trends along the longitudinal extent of the upper Deschutes reach and middle Deschutes reach. Data collected from 1995 to 2002 by ODEQ ambient monitoring, ODEQ intensive water quality monitoring studies for TMDL development, and REMAP studies and data collected during 2001 DEQ/USFS Sediment Study are used to illustrate trends along the longitudinal extent of the Little Deschutes River.

Data are predominately collected during the odd numbered months of January, March, May, July, September, and November. Some months and years have relatively small datasets compared to other months and years that have relatively large datasets. The year 2001 has the largest dataset due to the 2001 TMDL monitoring efforts. The relatively small amount of data collected on even months is incorporated into odd month data. This is accomplished by consolidating data collected between the first and fifteenth of the month into the previous month dataset and data collected between the sixteenth and last day of the month into the post month dataset.

Map 5.1 Turbidity and sedimentation listed water Bodies segments within the Upper Deschutes and Little Deschutes Subbasins



5.2.1 How does turbidity change along the longitudinal extent of the aquatic system?

Changes along the longitudinal extent of reaches within the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 5.1** and **Figure 5.2**. A solid grey line represents a longitudinal grand mean. A dashed black line represents a linear regression and is provided for insight regarding the trend over the longitudinal extent during the time period.

The upper Deschutes River has a longitudinal grand mean turbidity of 3 NTU.

The upper Deschutes reach has a longitudinal grand mean turbidity value of 3 NTU. A linear regression results in a positive slope. This indicates a downstream upward trend of mean turbidity values.

The middle Deschutes reach has a longitudinal grand mean turbidity value of 2 NTU. A linear regression results in a negative slope. This indicates a downstream downward trend of mean turbidity values.

The Little Deschutes River has a longitudinal grand mean turbidity value of 2 NTU. A linear regression results in a slope that is not increasing or decreasing. This indicates a downstream trend of constant mean turbidity values.

Figure 5.1 Mean turbidity values along the longitudinal extent of the upper Deschutes River

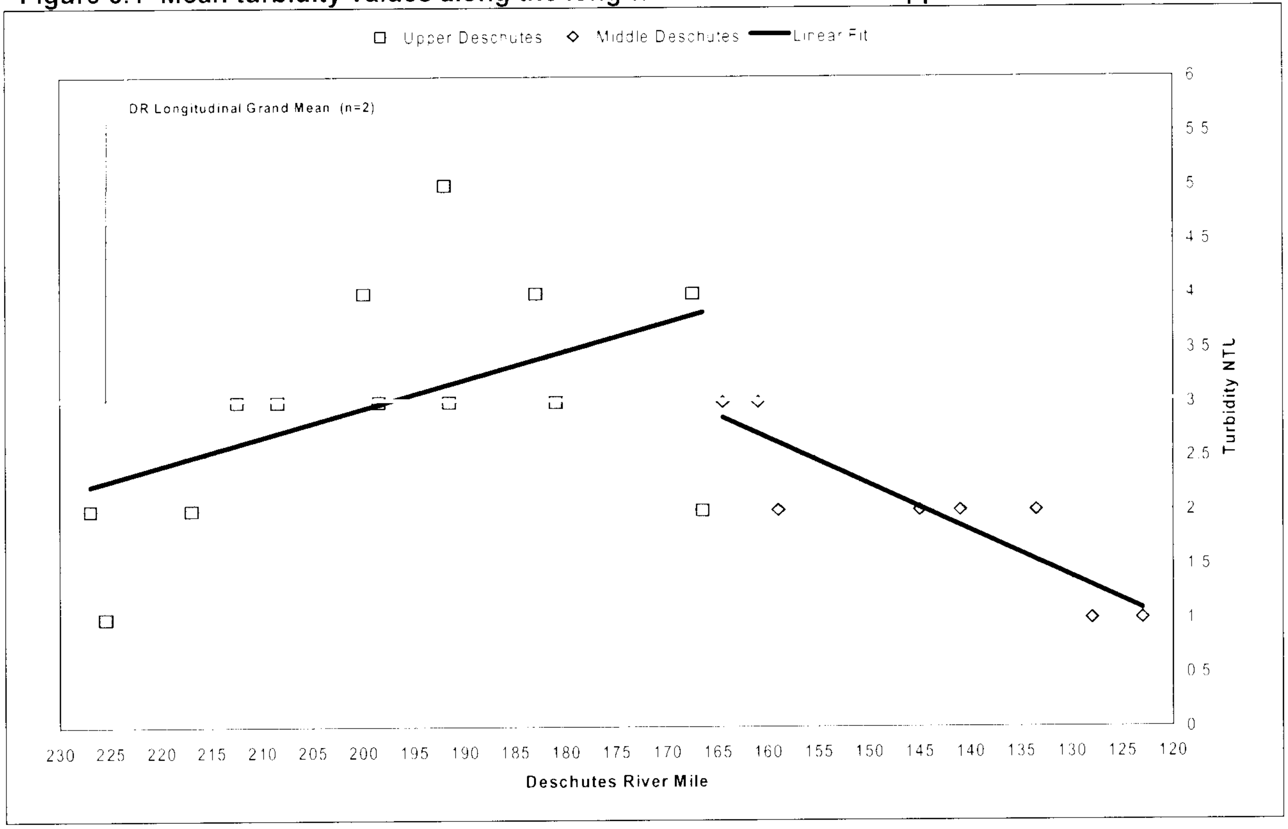
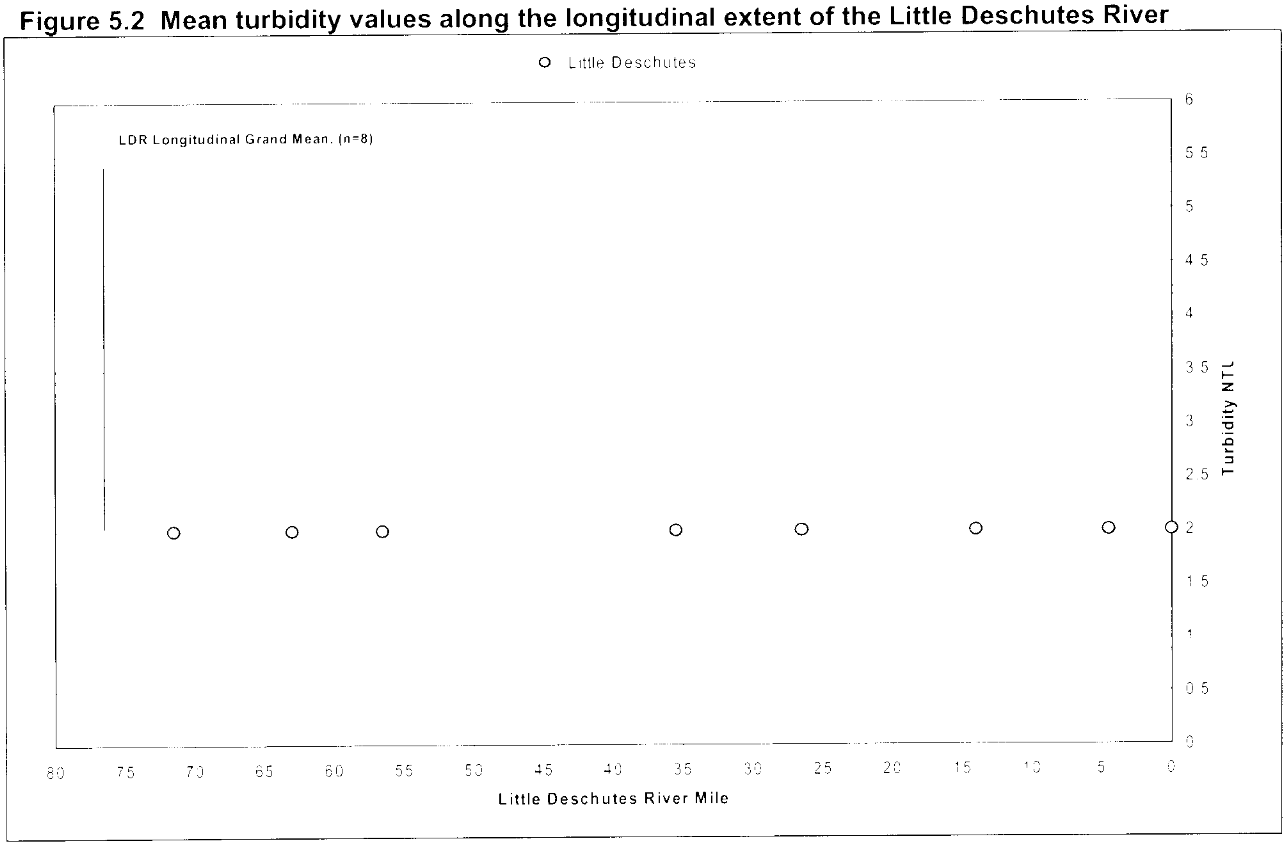


Figure 5.2 Mean turbidity values along the longitudinal extent of the Little Deschutes River



5.2.2 What is the seasonal variability of turbidity?

Seasonal fluctuations within reaches of the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 5.3**.

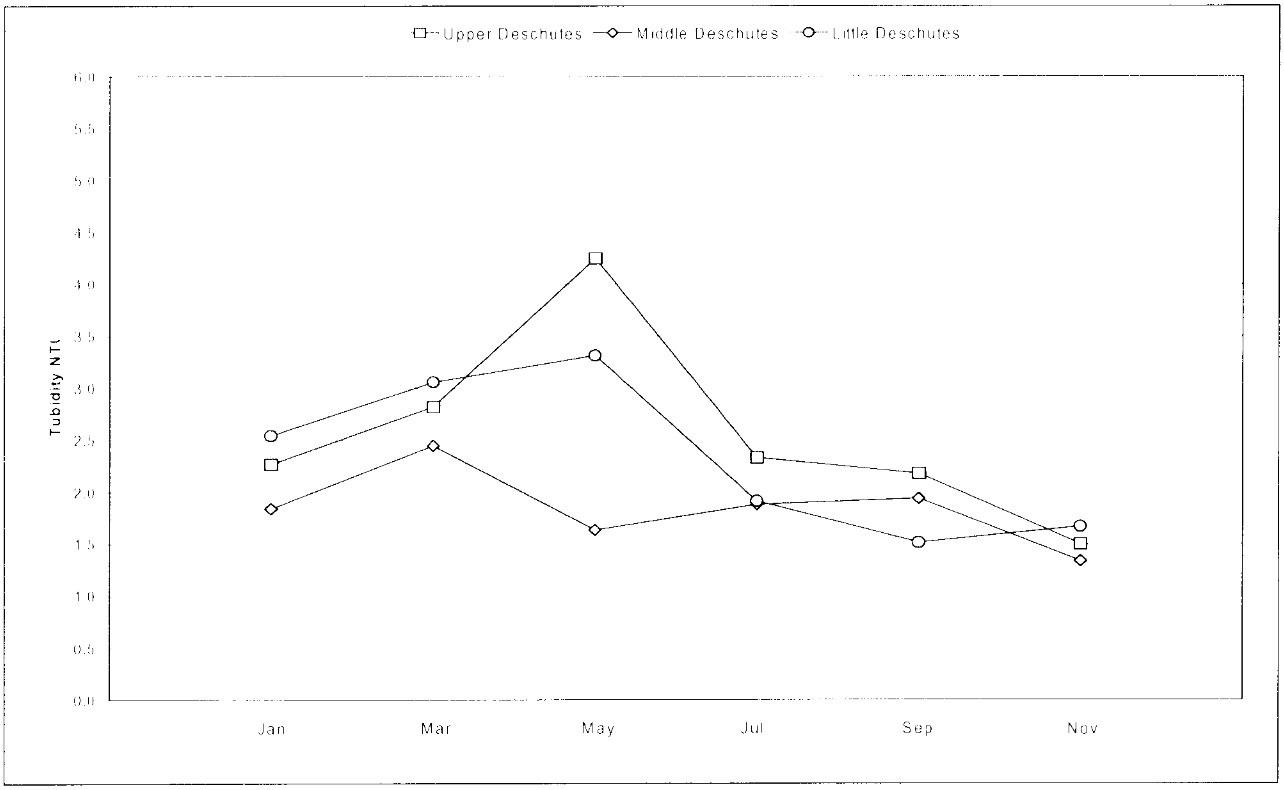
The upper Deschutes River has a seasonal grand mean turbidity value of 3 NTU.

The upper Deschutes reach has a seasonal grand mean turbidity of 3 NTU and a fluctuation in seasonal mean turbidity values ranging from 2– 4 NTU.

The middle Deschutes reach has a seasonal grand mean turbidity of 2 NTU and a fluctuation in seasonal mean turbidity values ranging from 1 – 2 NTU.

The Little Deschutes River has a seasonal grand mean turbidity of 2 NTU and a fluctuation in seasonal mean turbidity values ranging from 2 – 3 NTU.

Figure 5.3 Seasonal fluctuations in mean turbidity values for the upper Deschutes River and Little Deschutes River



5.2.3 *What is the long-term trend in turbidity?*

The long-term trend for reaches within the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 5.4**, **Figure 5.5**, and **Figure 5.6**. A solid grey line represents a long-term grand mean. A dashed black line represents a linear regression and is provided for insight regarding the trend over the time period.

The upper Deschutes River has a long-term mean turbidity of 3 NTU.

The upper Deschutes reach has a long-term trend in mean turbidity of 3 NTU. A linear regression results in a slope that is not increasing or decreasing. This indicates a constant temporal trend in mean turbidity values.

The middle Deschutes reach has a long-term trend in mean turbidity of 2 NTU. A linear regression results in a positive slope. This indicates an upward temporal trend in mean turbidity values.

The Little Deschutes River has a long-term trend in mean turbidity of 2 NTU. A linear regression results in a negative slope. This indicates a downward temporal trend in mean turbidity values.

Figure 5.4 Long-term trend in mean turbidity values within the upper Deschutes River

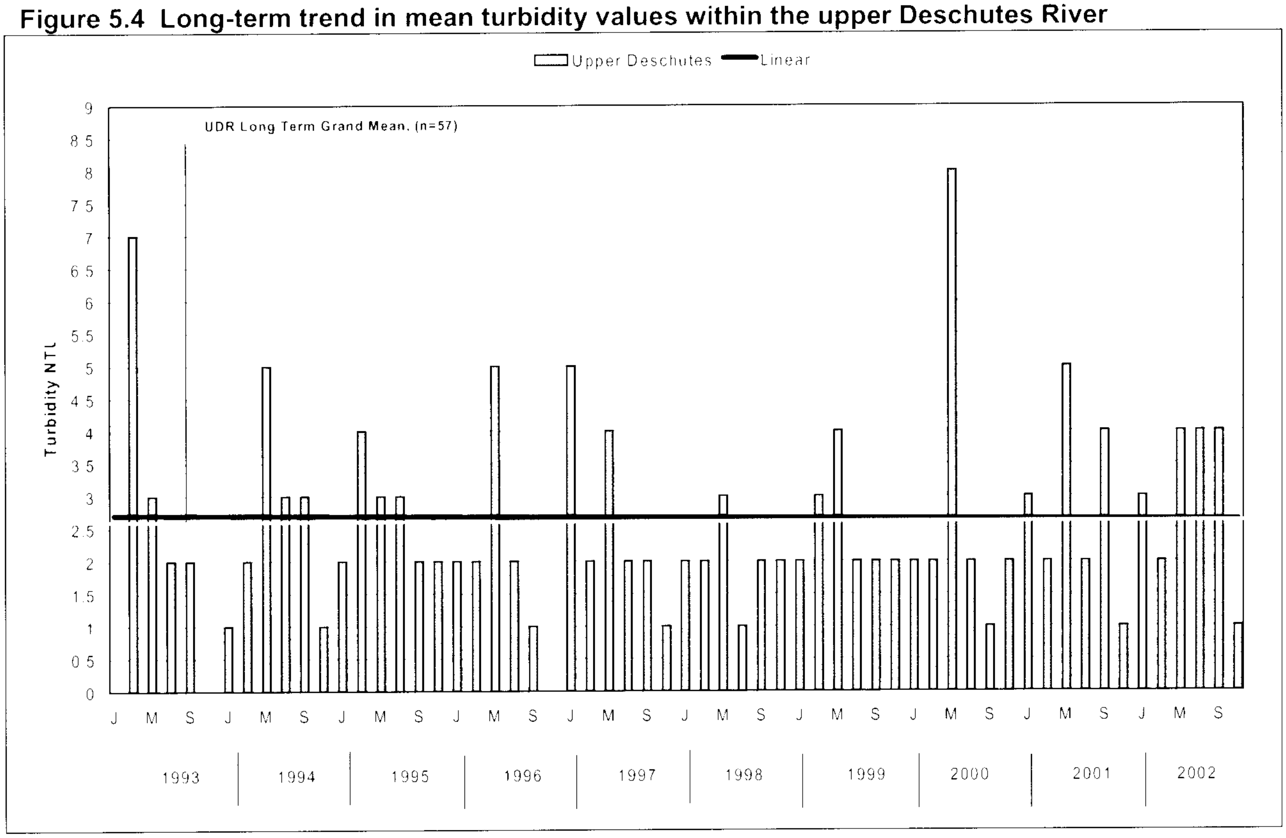


Figure 5.5 Long-term trend in mean turbidity values within the middle Deschutes River

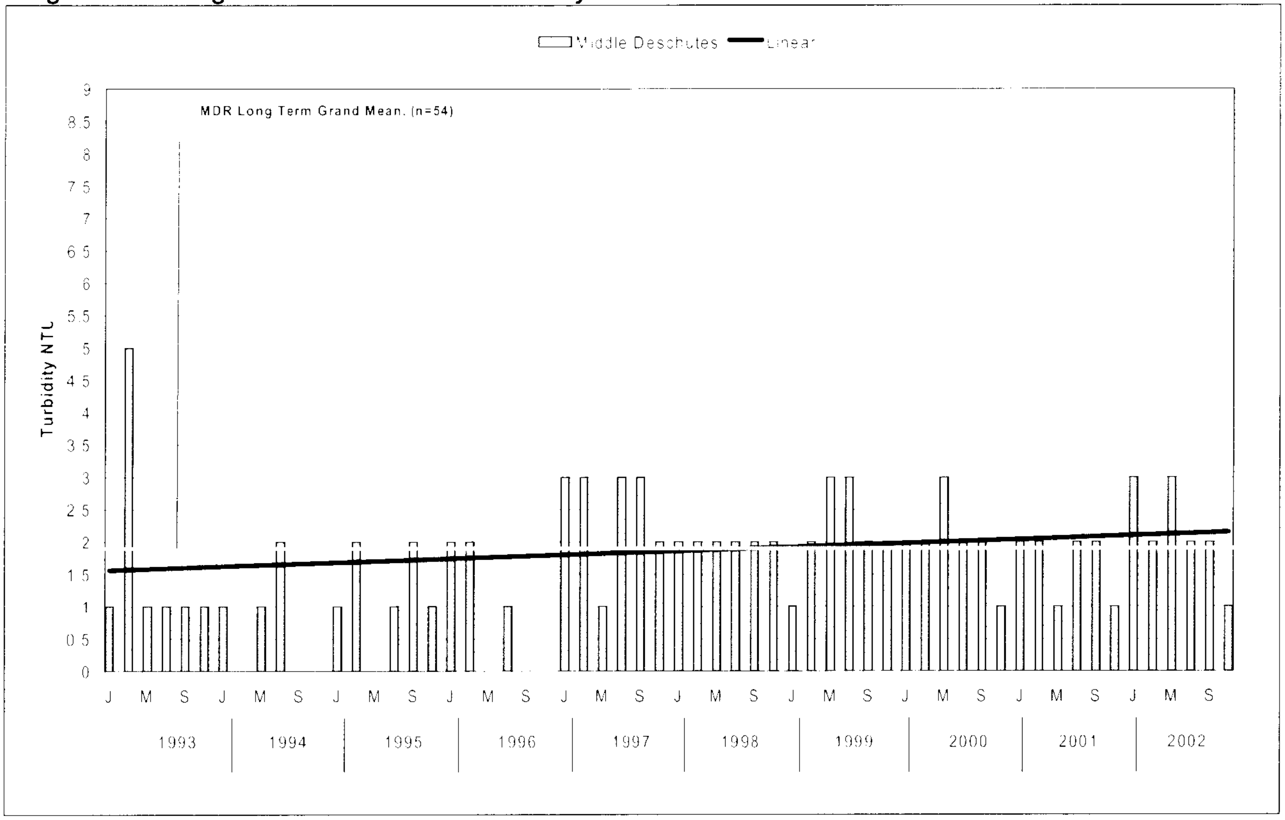
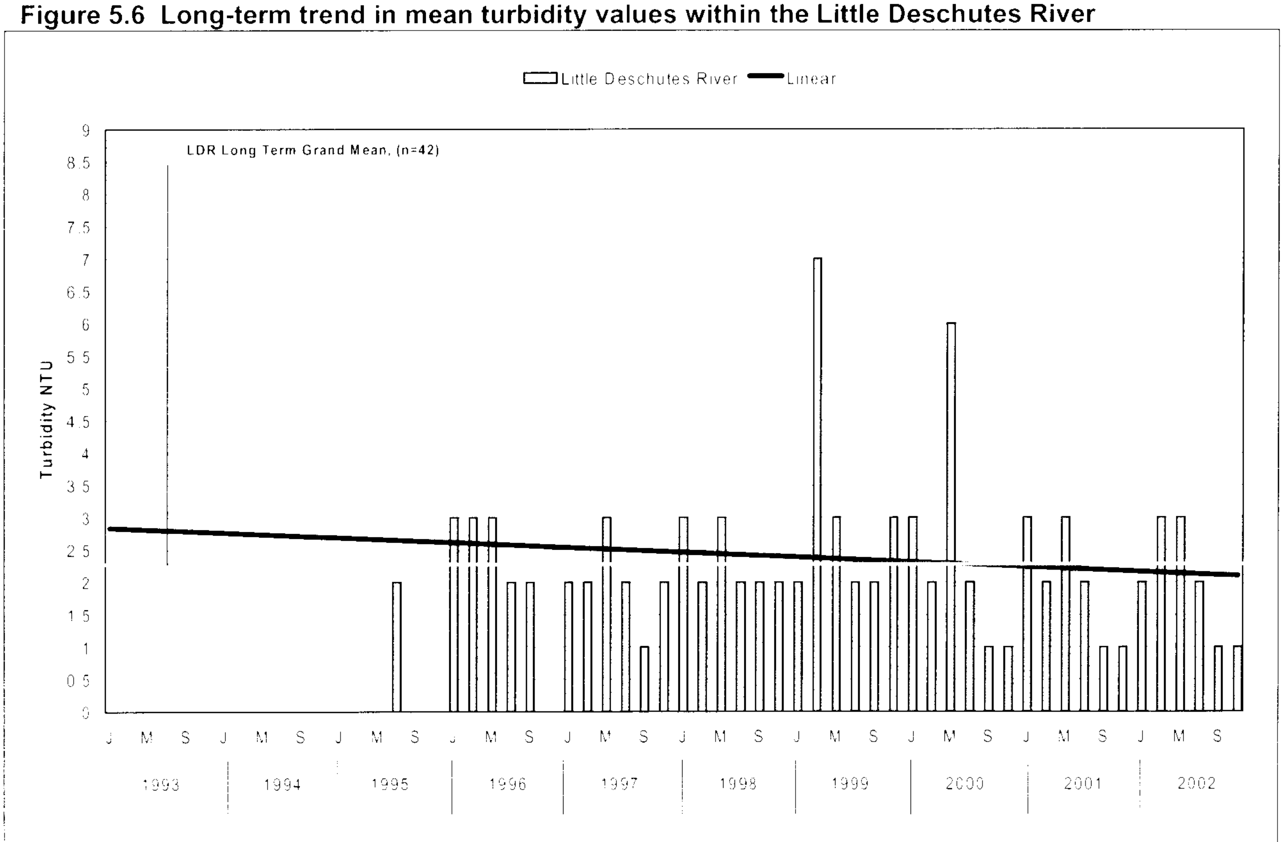


Figure 5.6 Long-term trend in mean turbidity values within the Little Deschutes River



5.2.4 *Are turbidity values compliant with regulatory criteria?*

Data are evaluated by site and season. The time period for analyses is defined as annual. During any one year for any one site, data are compliant with the OWEB 50 NTU guideline for turbidity. Compliance to the OWEB guidelines of 50 NTU may not indicate protection of beneficial uses within an aquatic system that has extremely low turbidity levels. In addition, turbidity fluctuates within a system and single samples measured against the 50 NTU guideline does not address duration of exposure to increased levels of turbidity.

The low turbidity levels that exist are difficult to evaluate by the ODEQ narrative criteria that allows no more than a 10% cumulative increase in natural stream turbidities as measured relative to a control point immediately upstream of the turbidity causing activities (ODEQ, 2001). It is difficult to locate a control point immediately upstream of the turbidity causing activities when the activities are from structures such as reservoirs.

5.3 Discussion and Key Findings

Anthropogenic impacts of water regulation may be increasing bank instability and contributing to a seasonal regime of sediment load transport along the upper Deschutes reach into depositional areas upstream and within the City of Bend. The subbasins may have a naturally high fine sediment component that makes evaluation of sedimentation via fine sediments more difficult due to a lack of knowledge regarding regional background levels for fine sediments. Turbidity levels are well below the recommended guidelines set by OWEB, yet compliance to these guidelines does not indicate protection of beneficial uses within an aquatic system that may have naturally low turbidity levels. Continuous monitoring of turbidity can provide information regarding spatial and temporal turbidity fluctuations and indicate reaches that are vital to salmonid escape and survival. Evaluation of the biological integrity of the region via analyses of existing macroinvertebrate data can indicate any impacts from sedimentation, because these evaluations are based on biological criteria, are not affected by the suspected naturally high fine sediment component, and have a quality historical dataset that can be used in the regional multivariate index that is currently underdevelopment.

The data obtained from the upper Deschutes River indicate an upward trend in mean turbidity along the longitudinal extent of the upper Deschutes reach and a downward trend along the middle Deschutes reach (**Figure 5.1**). Increases in turbidity means are most evident in the data obtained from the upper Deschutes River between RM 227.0 - RM 167.5 corresponding to Wickiup Reservoir and Columbia Street Bridge in the City of Bend respectfully. From RM 166.5 (Mirror Pond), a downstream downward trend in mean turbidity occurs, and may be evidence to sediment load deposition upstream and within the City of Bend.

The longitudinal extent and seasonal mean turbidity values of the Little Deschutes River are likely representative of a balanced system (**Figure 5.2** and **Figure 5.3**). The mean turbidity of 2 NTU is well below the recommended guideline of 50 NTU, and the seasonal fluctuations correspond to influences such as spring runoff, flow, and winter storms. The seasonal mean trends for the upper Deschutes River exhibit additional influences.

The seasonal variability in the mean turbidity for the upper Deschutes River appears to be linked to anthropogenic impacts of water flow regulation. Water storage releases from the Wickiup Reservoir occur in the spring corresponding to the higher seasonal mean turbidity within the upper Deschutes reach during May as compared to March. Concurrently, water diversions for irrigation occur in the spring corresponding to the lower seasonal mean turbidity in the middle Deschutes reach during May as compared to March. The combination of low winter flows and initial spring increases in flow due to water storage release from Wickiup Reservoir may influence mean turbidity seasonally. It is likely that the rapid increase of flow during the spring increases the sediment load by scouring the dry stream banks. The consecutive cycling of flows may transport sediment loads along the upper Deschutes reach into depositional areas upstream and within the City of Bend according to a seasonal regime. Seasonal water releases are addressed by the Upper Deschutes Wild and Scenic River Management Plan Adaptive Flow Management Strategy that recommends modification of the Wickiup Reservoir storage release regime, this influence may be captured in future datasets (USDA, 1996). The seasonal regime is supported by the different seasonal trends exhibited by the upper Deschutes River and Little Deschutes River and by bank stability characterizations for the upper Deschutes River.

In August 2002, the UDWC conducted a River Bank Stability Characterization study to identify sediment sources and to determine the erodability of stream banks along the upper Deschutes River between Wickiup Reservoir to the southern boundary of the City of Bend. Using stream bank characteristics such as bank height, bank angle, vegetation cover, root density and bank materials, 124 reaches along the upper Deschutes River were surveyed. In order to identify and rank relative rates of erosion, the Bank Erosion Hazard Index (BEHI) was used to analyze the survey results (Rosgen, 2001). Of the 124 reaches assessed, 43 reaches are classified as having high, very high, or extreme erosion rates and erodability, 44 reaches are classified as having moderate erosion rates and erodability, and 39 reaches are classified as having low or very low erosion rates and erodability (Yake, 2003). The type of sediment entering the upper Deschutes River from bank instability and flow regime may be high in fine sediments.

From 1991-1995 the USFS sampled fine sediments in potential spawning areas within the upper Deschutes watershed using Whitlock-Vibert (W-V) modified hatch boxes. Since W-V hatch boxes tend to underestimate fine sediments, the USFS switched to the McNeil Sediment Core Sampler method in 1996. According the USFS Forest Plan, a value of greater than 20% of fine sediments will cause a significant decrease in egg viability. The Deschutes River above Crane Prairie Reservoir averages below 20% fine sediments, with many of the samples less than 10%. Below Wickiup Reservoir, limited sampling with the W-V boxes revealed fine sediments generally in the 25-30% range. The core sampling the USFS conducted in 2001-2002 revealed that most samples had fine sediments over 40%. Sample sites are in the reach between Wickiup and Sunriver. A high fine sediment component, usually over 40% of the sample, is expected in low gradient, spring systems that drain volcanic soils (Walker, 2003). Until regional background levels for fine sediments are established, it is difficult to assess if fine sediments are negatively impacting the health of the aquatic system when only based on fine sediment percentages.

Turbidity is well below the OWEB guideline of 50 NTU despite the high fine sediment component, yet the turbidity data may still be used to indicate sediment load transport in the upper Deschutes River. There is a decrease in mean turbidity below RM 167.5 (Columbia Street Bridge in the City of Bend) that correlates with sediment deposition issues upstream and within the City of Bend (**Figure 5.1**). It appears that the Deschutes River may be able to successfully transport the sediment load from Wickiup to upstream and within the City of Bend where due to physical obstructions and decreased gradients the river slows, laterally migrates, and pools possibly causing the sediment load to deposit. The possible deposition of the sediment load is indicative of a system that is unable to transport its sediment load and is not in balance.

A long-term downward trend for mean turbidity within the upper Deschutes reach and Little Deschutes River exists, and an upward trend for mean turbidity within the middle Deschutes reach exists (**Figure 5.4**, **Figure 5.5**, and **Figure 5.6**). Long-term and upstream anthropogenic influences on the turbidity of the middle Deschutes reach are supported.

During any one year for any one site, there are no data that violate the OWEB 50 NTU guidelines for turbidity, yet this compliance does not indicate protection of beneficial uses within an aquatic system that may have naturally low turbidity levels. In addition, the data are well below the criterion for turbidity despite the high fine sediments that have been reported for the region. In a naturally low turbidity aquatic system, slight increases in turbidity may have relatively large impacts. Region specific turbidity levels are likely required for the Upper Deschutes and Little Deschutes Subbasins due to the low turbidity levels.

The OWEB 50 NTU guideline for turbidity is recommended in order to protect salmonid fish populations. Turbidity values for the Upper Deschutes and Little Deschutes Subbasins indicate a system that is naturally low in turbidity. A small amount of turbidity increase in the subbasins can have a great impact on fish populations due to the low turbidity levels that naturally exist. "Salmonid populations not normally exposed to high levels of natural turbidity or exposed to anthropogenic sediment sources may be negatively affected by levels of turbidity considered to be relatively low" (Gregory, 1992).

Without continuous monitoring, turbidity data only provides a series of scattered data points that are not linked to spatial and temporal parameters of the watershed, therefore it is difficult to determine how turbidity levels are affecting the system. The fluctuations of turbidity, both spatially and temporally, influences how salmonid use a system; It may be necessary for salmonid to escape from the area with increased turbidity, and therefore evaluation of continuous turbidity data may indicate reaches that are important to salmonid escape and survival. Conservation, restoration, or enhancement of the reaches used for escape may be critical in protecting the beneficial use of salmonid.

Segments are listed on the state 303(d) list for not being compliant with turbidity and sediment criteria. The narrative for turbidity criteria allows no more than a 10% cumulative increase in natural stream turbidities as measured relative to a control point immediately upstream of the turbidity causing activities (ODEQ, 2001). The narrative for sediment criteria allows primarily aquatic macroinvertebrate data, biomonitoring protocols, data illustrating fish species decline due to water quality conditions, or measurements of embeddedness or percent fines that indicate that there are conditions that are deleterious to fish or other aquatic life (ODEQ, 2001).

Turbidity criteria are based on background levels and the segment from RM 168.2 (upstream of the City of Bend) to RM 222.2 (downstream Wickiup Reservoir) is listed due to turbidity increases of 30 fold above background levels when irrigation water is released in early spring and these turbidity increases remain twice background until late July according to the USFS for 1995 (ODEQ, 2003). It appears that the 303(d) listing of this segment is based on the background levels collected downstream of Wickiup Reservoir, yet if water storage releases from Wickiup Reservoir is considered the turbidity causing activity then listing of the segment between Wickiup Reservoir and the City of Bend may not be based on a control point immediately upstream of the turbidity causing activity. When compared to the OWEB guidelines, mean turbidity values for the upper Deschutes River are very low along the longitudinal extent, seasonally, and with time. Yet these low values may not be relative in an aquatic system that has naturally low turbidity levels and are not obtained from continuous data therefore do not reflect fluctuations in turbidity. Turbidity may be affected by storage and release of waters from Wickiup Reservoir and this may have regional impacts on beneficial uses without violating set guidelines and criteria. In addition, it may be regionally important that the sediment load is increased and analyses of the biological criteria may be more appropriate since continuous turbidity data is not available.

The segment from RM 168.2 (upstream of the City of Bend) to RM 222.2 (downstream Wickiup Reservoir) is listed due to sedimentation that has affected the health of the biological community of the upper Deschutes River. According to the state 303(d) list, this segment is listed because the Upper Deschutes River Instream Flow Assessment in 1994 reports that the spawning gravels contain a high percent of fine sediments that limit embryo survival rates for trout (ODEQ, 2003). Listing this segment of the river based on biological criteria for sediment analyses is more reflective of conditions within the upper Deschutes River, yet still does not reflect the possibility of naturally high percent fines regionally. Evaluation of the biological integrity of the region via analyses of existing macroinvertebrate data can indicate any impacts from sedimentation, because these evaluations are based on biological criteria, are not affected by the suspected naturally high fine sediment component, and have a quality historical dataset that can be used in the regional multivariate index that is currently underdevelopment. Previous and current macroinvertebrate surveys can be utilized to evaluate compliance with sedimentation criteria.

There have been three studies of the aquatic macroinvertebrate populations within the Upper Deschutes and Little Deschutes Subbasins that have resulted in high quality data. The Deschutes National Forest contracted with Aquatic Biology Associates performed benthic invertebrate biomonitoring in the Upper Deschutes and Little Deschutes Subbasins during 1991 – 1993 (DNF, 1991 – 1993). The *Benthic Invertebrate Biomonitoring* report utilizes a sampling and bioassessment protocol for appraising the biological integrity of communities within western North America. An assessment is available in a series of reports prepared by the Bureau of Land Management between 1994 and 1998 (Vinson, 1994 -1998). This assessment has quite a bit of regional aquatic macroinvertebrate data that has been assessed via the Shannon Diversity Index that measures ecological diversity and a modified Hilsenhoff Biotic Index that summarizes the overall pollution tolerances of taxa. REMAP has performed more recent studies on aquatic macroinvertebrate populations within the region and is developing a regional multivariate model for indexing purposes, yet this information is not available as of the time of the Technical Report.

The information from these three studies can be assessed in the future and can provide historical reference to conditions. Future analyses of the aquatic macroinvertebrate populations within the upper Deschutes River and Little Deschutes River can contribute insight regarding the changes within the biological community in response to changes in flow, sediment loads, fine sediments, organic and inorganic compounds, and toxins. Since fine sediments appear to be naturally high in the Upper Deschutes and Little Deschutes Subbasins, studies that measure biological criteria may be more indicative of impacts regarding sedimentation within the subbasins. Aquatic macroinvertebrate surveys can contribute to state 303(d) listing and delisting processes in a way that reflects aquatic community impacts and response.

Key Findings

- Anthropogenic impacts of water regulation may be increasing bank instability and contributing to a seasonal regime of sediment load transport along the upper Deschutes reach into depositional areas upstream and within the City of Bend.
- The subbasins may have a naturally high fine sediment component that makes evaluation of sedimentation via fine sediments more difficult due to a lack of knowledge regarding regional background levels of fine sediments.
- Turbidity levels are well below the recommended guidelines set by OWEB, yet compliance to these guidelines does not indicate protection of beneficial uses within an aquatic system that may have naturally low turbidity levels.
- Continuous monitoring of turbidity can provide information regarding spatial and temporal turbidity fluctuations and indicate reaches that are vital to salmonid escape and survival.
- Evaluation of the biological integrity of the region via analyses of existing macroinvertebrate data can indicate any impacts from sedimentation, because these evaluations are based on biological criteria, are not affected by the suspected naturally high fine sediment component, and have a quality historical dataset that can be used in the regional multivariate index that is currently underdevelopment.

6.0 CHLOROPHYLL-*A*

6.1 Introduction

The primary productivity of an aquatic system refers to the rate of converting sunlight energy into chemical energy via photosynthesis. The conversion occurs when chlorophyll pigments are struck by photons (sunlight energy) resulting in generation of ATP molecules (chemical energy). The ATP molecules are used as energy to manufacture sugars resulting in the release of oxygen as a byproduct. Primary producers include aquatic plants, phytoplankton, and periphyton, while consumers include aquatic macroinvertebrates, fish, and wildlife. Due to the ability to convert sunlight energy into a usable product, primary producers form the basis of the aquatic food chain; sequence of energy as it moves along from organism to organism. Energy is passed along the food chain by the consumption of primary producers by consumers.

It is evident that primary producers are fundamental to a healthy aquatic ecosystem. Extreme primary production levels, low or high, in an aquatic ecosystem can limit biodiversity and indicate an imbalanced aquatic system.

Primary producers utilize several pigments that capture sunlight energy and convert it into chemical energy via photosynthesis. Although there are several types of pigments that may be involved in photosynthesis, all photosynthetic organisms utilize chlorophyll-*a*. Therefore, from a water quality perspective, the most important pigment is chlorophyll-*a*. Chlorophyll-*a* can be used as a measure of primary producers within an aquatic system since the concentration of chlorophyll-*a* is considered to be an indicator of phytoplankton or suspended, sestonic algae concentration.

The quantity of primary producers in an aquatic system directly influences and is influenced by other water quality parameters. Primary producers are associated with increases in dissolved oxygen and decrease in carbon dioxide as a result of photosynthesis. As a result, pH levels increase with the increase in dissolved oxygen and decrease in carbon dioxide. At night when photosynthesis lulls, pH may decrease as continual uptake of dissolved oxygen and production of carbon dioxide by respiring aquatic organisms occurs. High extremes in the quantities of primary producers can increase turbidity and indirectly increase temperature. Factors that influence the growth of primary producers include nutrients (nitrogen and phosphorous), stream flow, and water temperature.

Chlorophyll-*a* concentrations can be utilized to assess the state of primary producers within an aquatic system. In general, chlorophyll-*a* concentrations below 3 µg/L are considered to indicate low productivity while values greater than 15 µg/L are considered to indicate high productivity.

Chlorophyll-*a* concentrations are measured by a fluorometer. When white light strikes chlorophyll–*a*, the molecule fluoresces and releases red light. The fluorometer shines white light on the sample and measures the intensity of the red light emitted, which is proportional to the concentration of chlorophyll-*a* in the water sample. The chlorophyll-*a* concentration is indicative of the concentration of phytoplankton and is relative to the state of primary producers within the aquatic system.

6.2 Analyses

The ODEQ criterion for chlorophyll-*a* for natural lakes that do not thermally stratify, reservoirs, rivers, and estuaries limits chlorophyll-*a* concentrations to no greater than 15 µg/L to protect beneficial uses. Beneficial uses that may be affected by chlorophyll-*a* concentrations include water contact recreation, aesthetics, resident fish and aquatic life, water supply, and livestock watering.

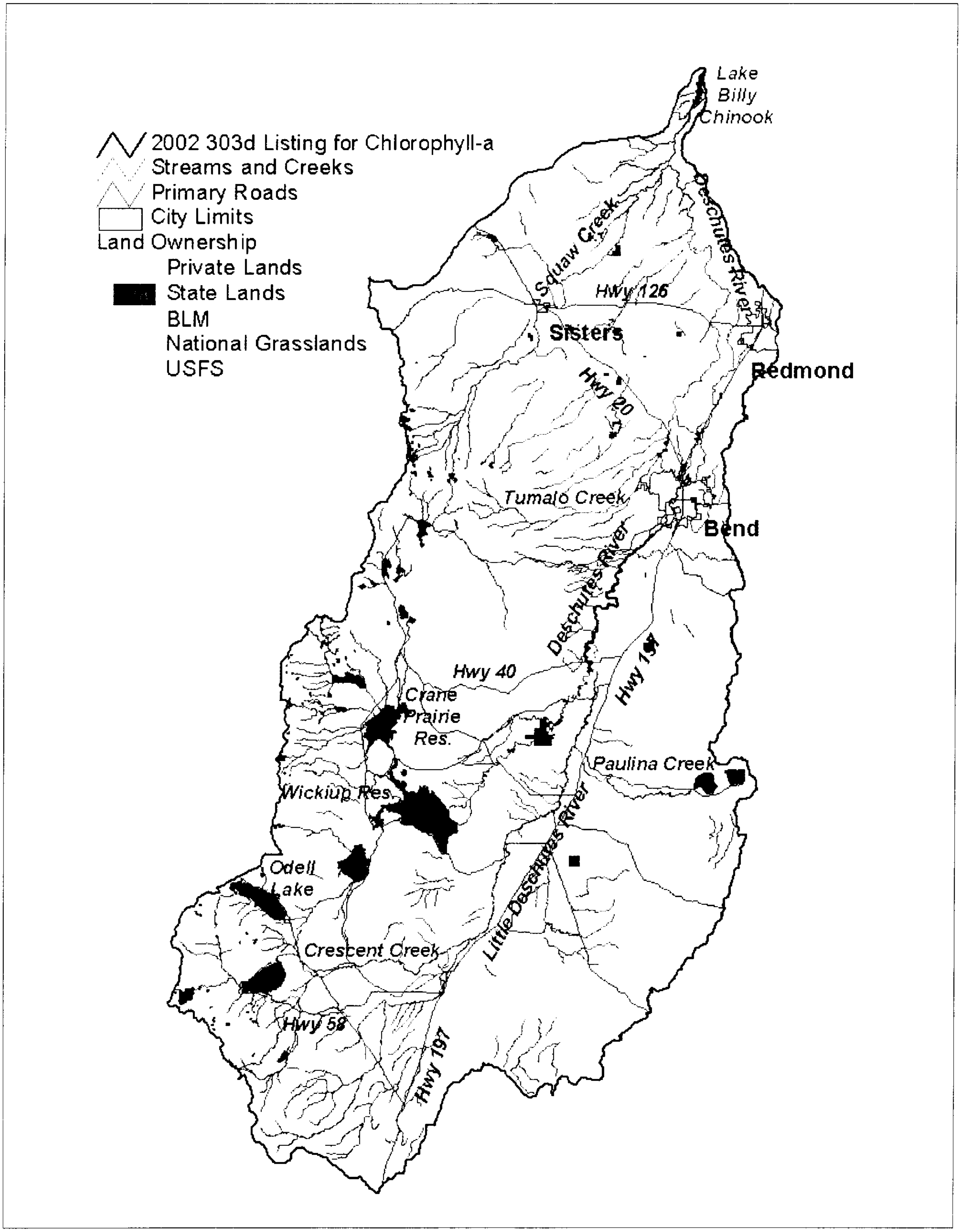
The Deschutes River is listed on the ODEQ 2002 303(d) list for exceeding the chlorophyll-*a* criterion from RM 168.2 (upstream of the City of Bend) to RM 189.4 (below Sunriver).

Map 6.1 is of the waterbodies and segments that exceed the chlorophyll-*a* criterion within the upper Deschutes and Little Deschutes Subbasins.

Data collected from 1993 to 2002 by ODEQ ambient monitoring and intensive water quality monitoring studies for TMDL development are used to illustrate trends along the longitudinal extent of the upper Deschutes River. Data collected from 1995 to 2002 by ODEQ ambient monitoring and intensive water quality monitoring studies for TMDL development are used to illustrate trends along the longitudinal extent of the Little Deschutes River.

Data are collected during odd numbered months between May and September. Some months and years have relatively small datasets compared to other months and years that have relatively large datasets. The year 2001 has the largest dataset due to the 2001 TMDL monitoring efforts. The relatively small amount of data collected on even months is incorporated into odd month data. This is accomplished by consolidating data collected between the first and fifteenth of the month into the previous month dataset, and data collected between the sixteenth and last day of the month into the post month dataset.

Map 6.1 Chlorophyll-*a* 303(d) listed waterbodies and segments within the Upper Deschutes and Little Deschutes Subbasins



6.2.1 *How does chlorophyll-a change along the longitudinal extent of the aquatic system?*

Changes along the longitudinal extent of reaches within the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 6.1** and **Figure 6.2**. A solid grey line represents a longitudinal grand mean. A solid black line represents a linear regression and is provided for insight regarding the trend over the longitudinal extent during the time period.

The upper Deschutes River has a longitudinal grand mean chlorophyll-*a* concentration of 6.2 µg/L.

The upper Deschutes reach has a longitudinal grand mean chlorophyll-*a* concentration of 8.7 µg/L. A linear regression results in a negative slope. This indicates a downstream downward trend of mean chlorophyll-*a* concentrations.

The middle Deschutes reach has a longitudinal grand mean chlorophyll-*a* concentration of 3.7 µg/L. A linear regression results in a negative slope. This indicates a downstream downward trend of mean chlorophyll-*a* concentrations.

The Little Deschutes River has a longitudinal grand mean chlorophyll-*a* concentration of 1.6 µg/L. A linear regression results in a negative slope. This indicates a downstream downward trend of mean chlorophyll-*a* concentrations.

Figure 6.1 Mean chlorophyll-*a* along the longitudinal extent of the upper Deschutes River

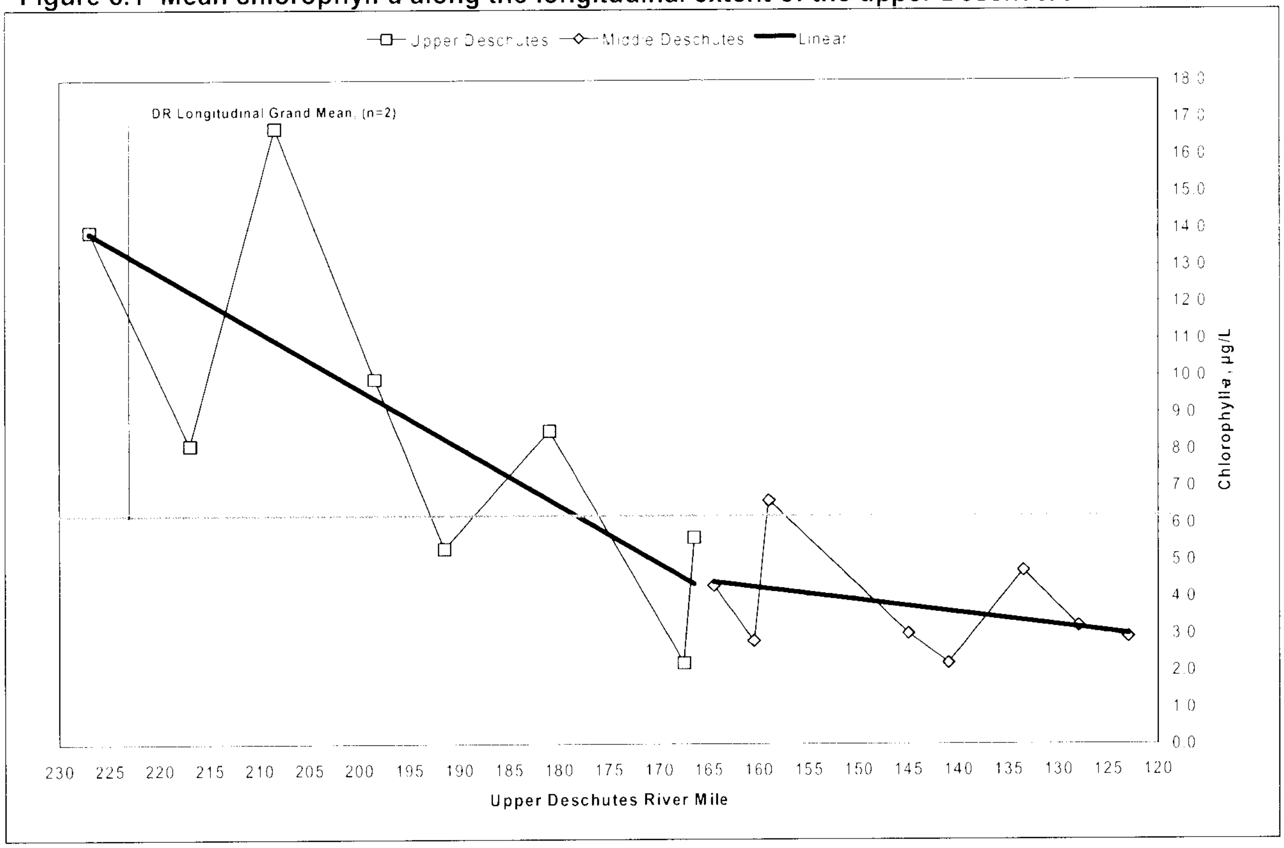
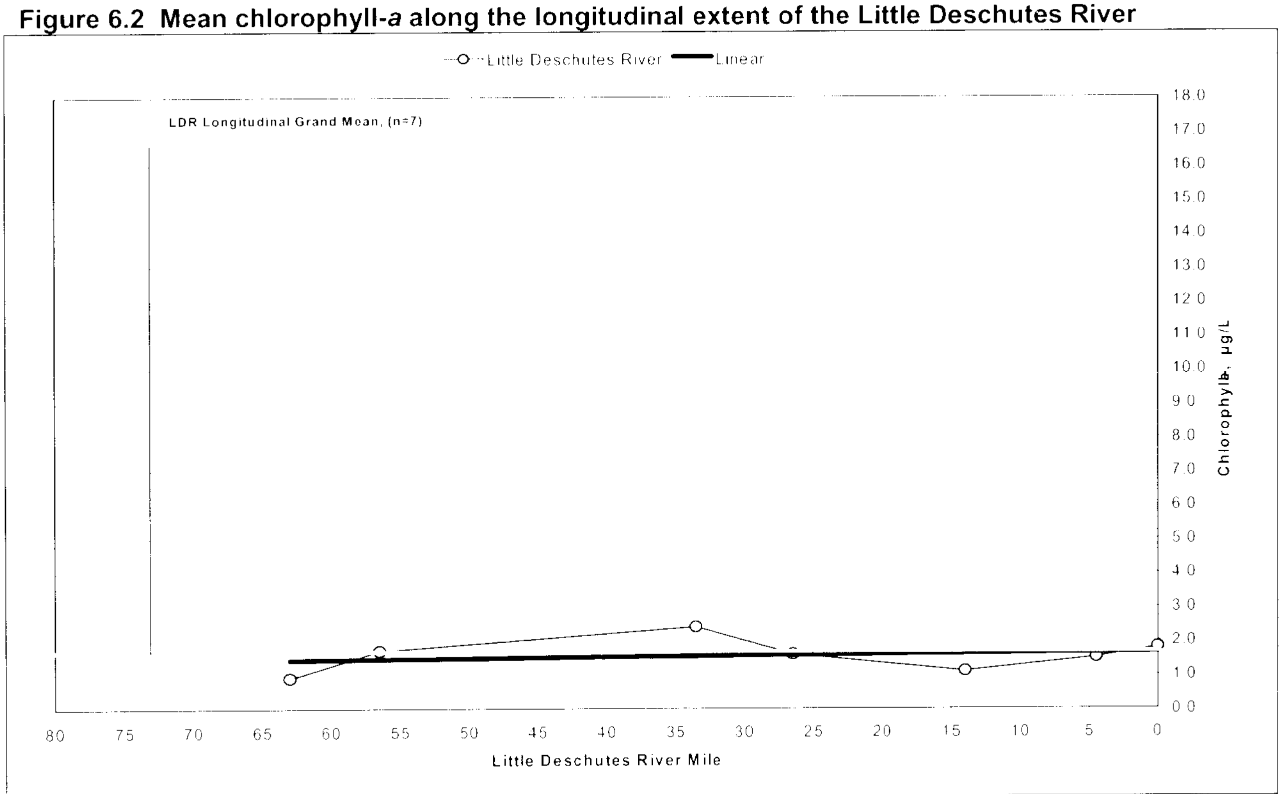


Figure 6.2 Mean chlorophyll-*a* along the longitudinal extent of the Little Deschutes River



6.2.2 *What is the seasonal variability of chlorophyll-a?*

The Upper Deschutes and Little Deschutes Subbasins seasonal fluctuations are illustrated in **Figure 6.3**.

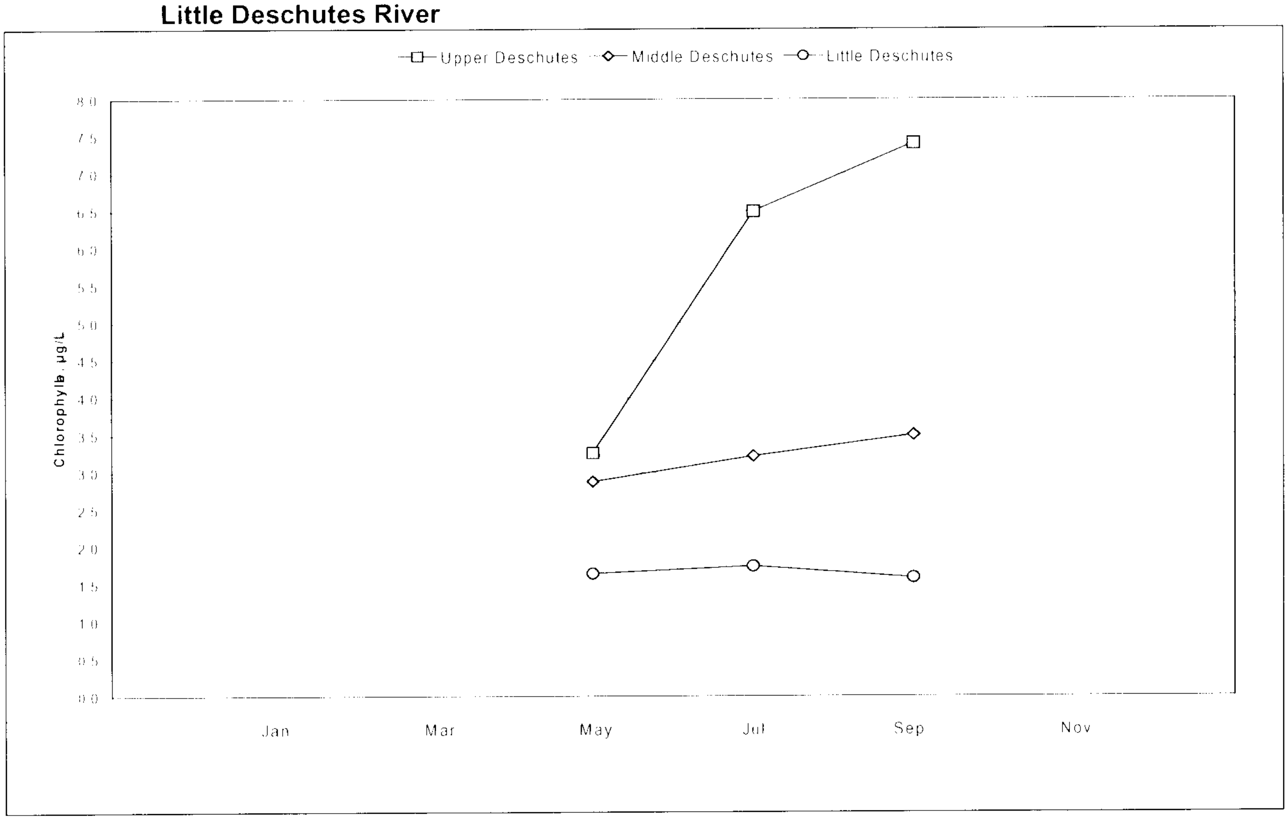
The upper Deschutes River has a seasonal grand mean turbidity value of 4.5 µg/L.

The upper Deschutes reach has a seasonal grand mean chlorophyll-*a* concentration of 5.7 µg/L and a fluctuation in seasonal mean chlorophyll-*a* concentration ranging from 3.3 – 7.4 µg/L.

The middle Deschutes River has a seasonal grand mean chlorophyll-*a* concentration of 3.2 µg/L and a fluctuation in seasonal mean chlorophyll-*a* concentration ranging from 2.9 – 3.5 µg/L.

The Little Deschutes River has a seasonal grand mean chlorophyll-*a* concentration of 1.66 µg/L and a fluctuation in seasonal mean chlorophyll-*a* concentration ranging from 1.6 – 1.7 µg/L.

Figure 6.3 Seasonal fluctuations in mean chlorophyll-*a* within the upper Deschutes River and Little Deschutes River



6.2.3 *What is the long-term trend in chlorophyll-a?*

The long-term trend for reaches within the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 6.4**, **Figure 6.5**, and **Figure 6.6**. A solid grey line represents a long-term grand mean. A solid black line represents a linear regression and is provided for insight regarding the trend over the time period.

The upper Deschutes River has a long-term mean chlorophyll-*a* concentration of 2.5 NTU.

The upper Deschutes reach has a long-term trend in mean chlorophyll-*a* concentration of 1.7 µg/L. A linear regression results in a negative slope. This indicates a downward temporal trend in mean chlorophyll-*a* concentrations.

The middle Deschutes reach has a long-term trend in mean chlorophyll-*a* concentration of 3.2 µg/L. A linear regression results in a negative slope. This indicates a downward temporal trend in mean chlorophyll-*a* concentrations.

The Little Deschutes River has a long-term trend in mean chlorophyll-*a* concentration of 5.8 µg/L. A linear regression results in a negative slope. This indicates a downward temporal trend in mean chlorophyll-*a* concentrations.

Figure 6.4 Long-term trend in mean chlorophyll-*a* concentrations within the upper Deschutes reach

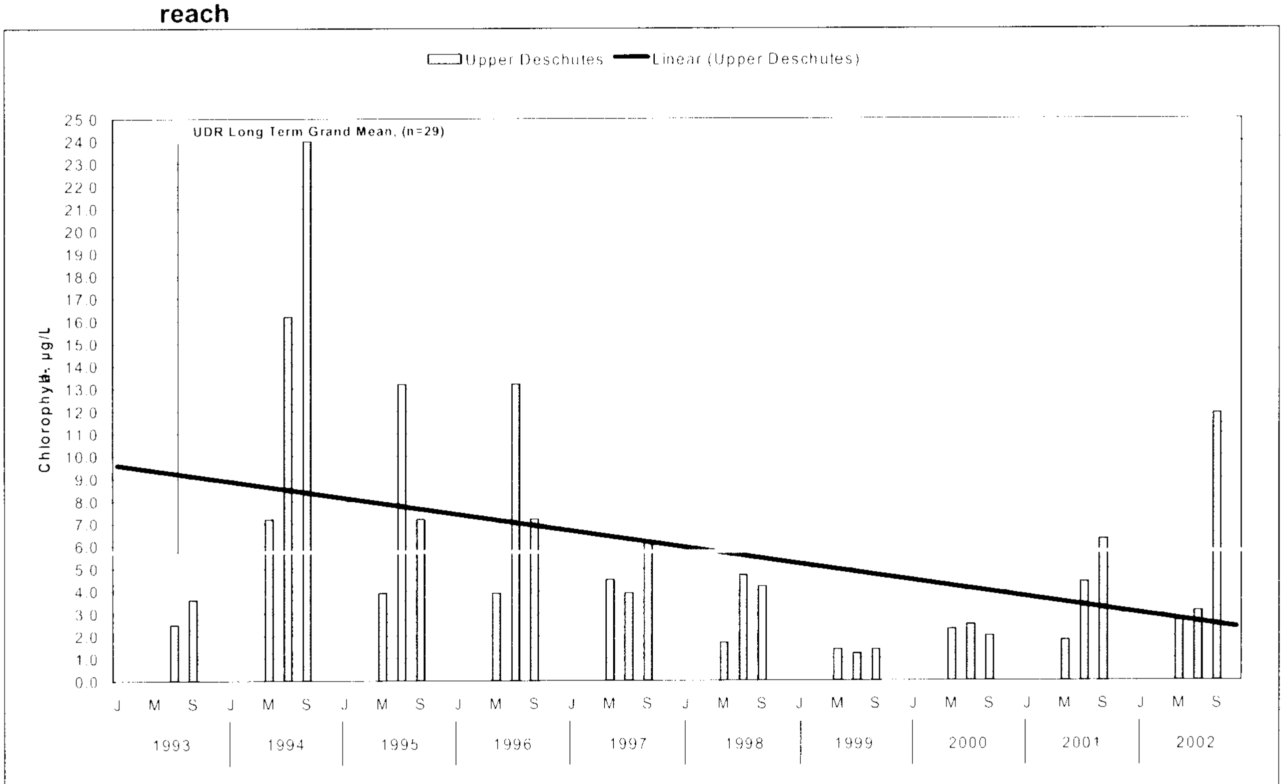


Figure 6.5 Long-term trend in mean chlorophyll-*a* concentrations within the middle Deschutes reach

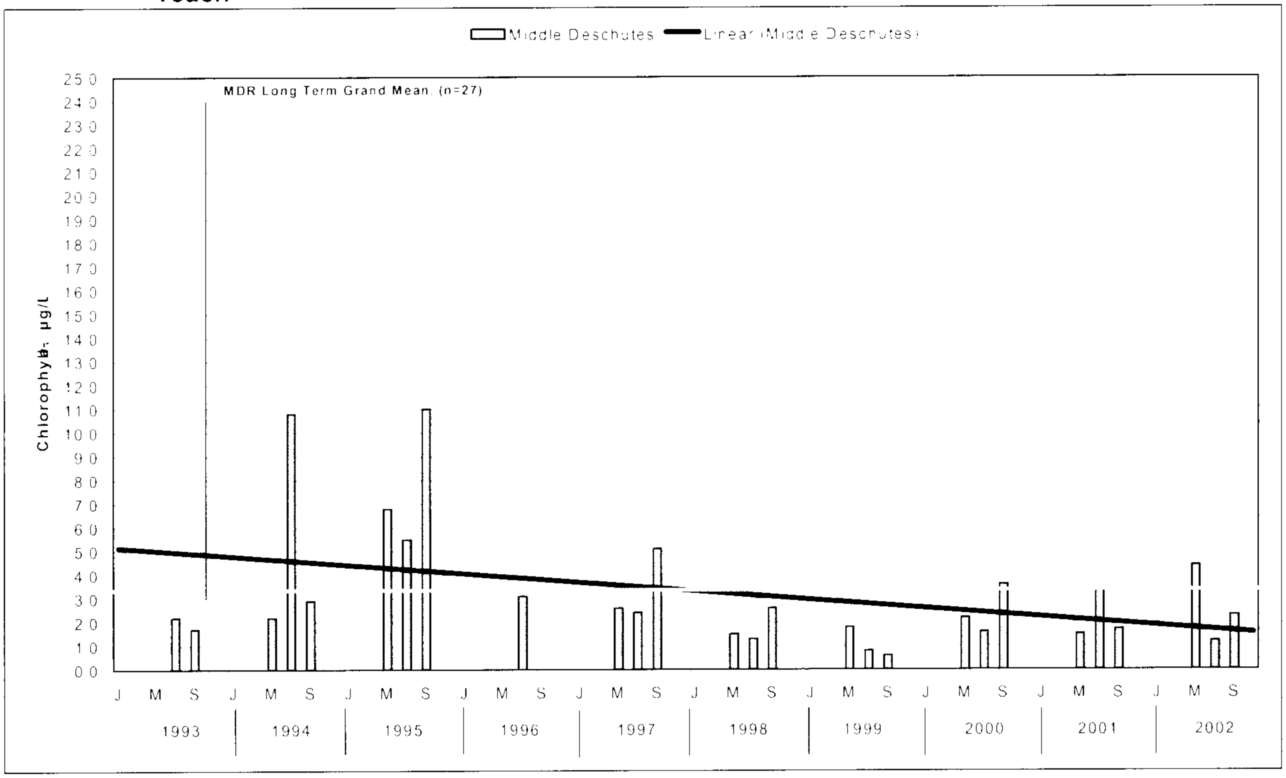
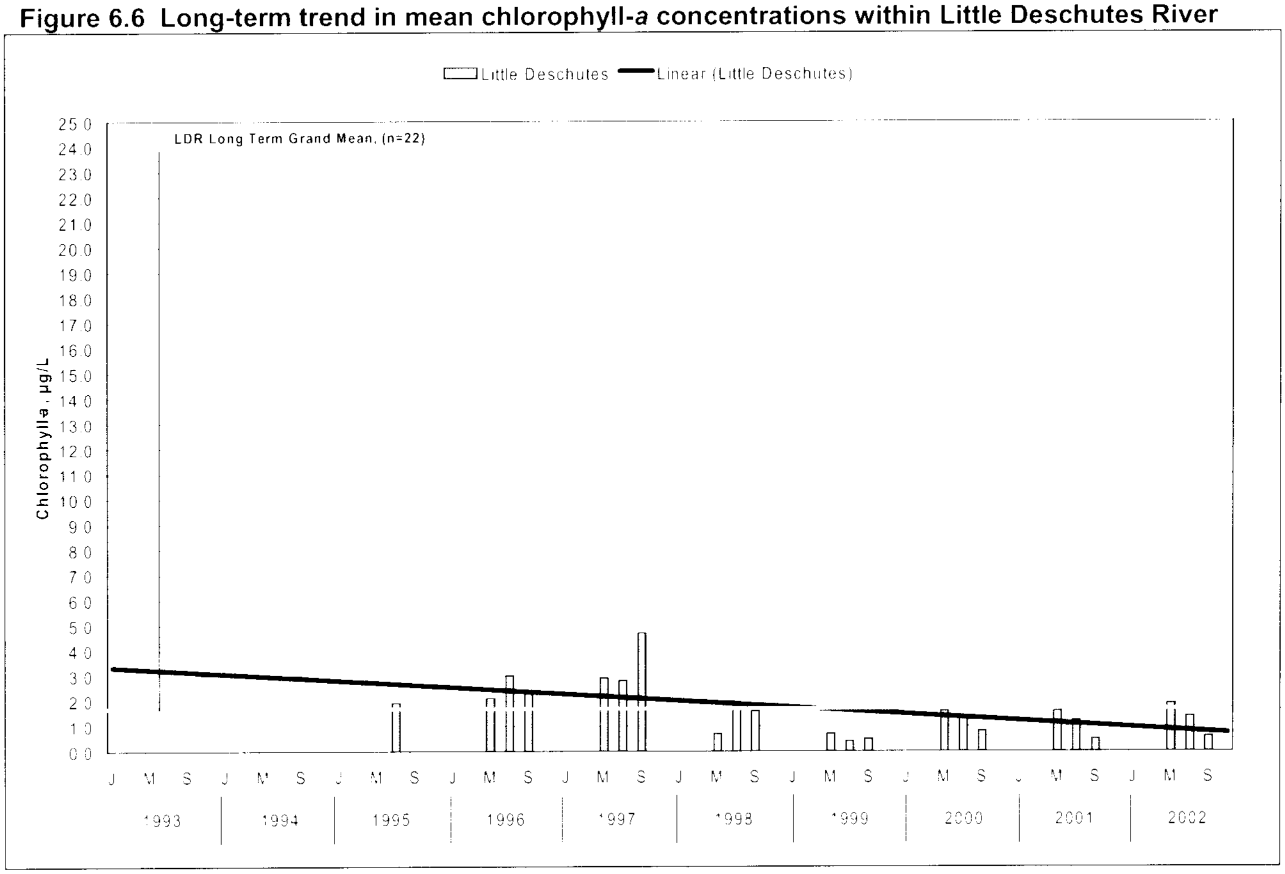


Figure 6.6 Long-term trend in mean chlorophyll-*a* concentrations within Little Deschutes River



6.2.4 Are chlorophyll-a concentrations compliant with regulatory criteria?

Data are evaluated by site and season. The sites and seasons applicable for analyses are displayed in **Table 6.1**. Two upper Deschutes reach sites and one middle Deschutes reach site satisfy the minimal sample number required by the EPA and ODEQ for analyses of compliance with the regulatory criteria. There are no Little Deschutes River sites that satisfy the minimal sample number required for analyses of compliance with the regulatory criteria.

The analyses of all applicable sites and seasons are displayed in **Figure 6.7.** The data are presented in quantiles depicting the minimum, 10%, 25%, median, 75%, 90% and maximum boundaries. The number of samples at a particular site is stated within parentheses. A solid black line represents the mean of data. The dashed black line represents the applicable criteria. A thick solid black line across the quantile box represents the three month average for the site and season.

Per EPA and ODEQ requirements, a three month average from a minimal of three samples per time period is used for compliance analyses. A monthly mean is calculated and used to derive a three month average for the time period.

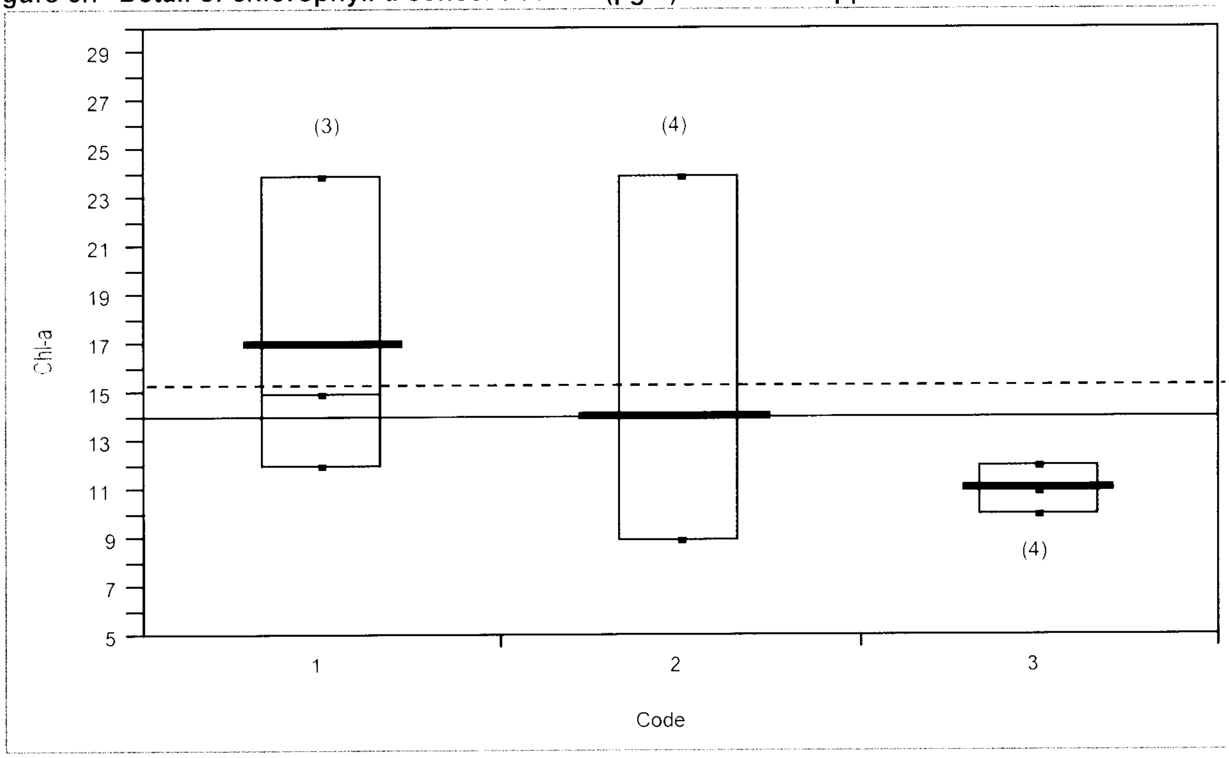
Table 6.1 Chlorophyll–*a* datasets that meet the minimal sample number required for compliance analyses

Code	Season	RM	Site	Segment	Compliance analyses
1	S 1995	191.5	Harper Bridge	UDR	**WQL**
2	S 1995	166.5	Mirror Pond	UDR	Attaining criteria
3	S 1995	133.5	Lower Bridge	MDR	Attaining criteria

S= June 1 through September 30 FWS: October 1 to May 31 WQL = water quality limited

The Little Deschutes River dataset is categorized as having insufficient data for compliance analyses.

Figure 6.7 Detail of chlorophyll-*a* concentrations (µg/L) within the upper Deschutes River



Quantiles

Code	minimum	10.0%	25.0%	median	75.0%	90.0%	maximum
1	12.0	12.0	12.0	15.0	24.0	24.0	24.0
2	8.9	8.9	8.9	8.9	24.0	24.0	24.0
3	10.0	10.0	10.0	11.0	12.0	12.0	12.0

The ODEQ criterion for chlorophyll-*a* for natural lakes that do not thermally stratify, reservoirs, rivers, and estuaries limits chlorophyll-*a* concentrations to no greater than 15 µg/L.

The upper Deschutes reach site code 1 is categorized as water quality limited, because a three month average from a minimal of three samples per time period is not compliant with criteria. Site code 2 is categorized as attaining criteria, because the three month average from a minimal of three samples per time period are compliant with criteria.

The middle Deschutes reach site code 3 is categorized as attaining criteria, because the three month average from a minimal of three samples per time period are compliant with criteria.

6.3 Discussion and Key Findings

The Wickiup/Crane Prairie Reservoir complex may be contributing to increased mean chlorophyll-*a* concentrations as each spring storage release may cause phytoplankton to transport from the complex to the upper Deschutes River. The chlorophyll-*a* dataset is limited by monitoring efforts conducted only during summer months. A nonpoint source pollution issue may exist at the State Recreation Road site near La Pine State Park. The anthropogenic influence of water regulation may be contributing to the optimization of periphyton growth within the upper Deschutes River and may be contributing to a shift in the balance of the upper Deschutes River. There are no benthic chlorophyll-*a* data to evaluate periphyton growth within the rivers of the subbasins. The lack of chlorophyll-*a* data prevents complete analyses of the trophic status of the upper Deschutes River and Little Deschutes River.

Chlorophyll-*a* concentrations have been collected throughout the Upper Deschutes and Little Deschutes Subbasins. The chlorophyll-*a* collected reflects sestonic chlorophyll-*a* and is a measurement of the amount of phytoplankton chlorophyll-*a* in the water column.

The mean chlorophyll-*a* concentrations along the longitudinal extent of the upper Deschutes River indicate higher levels of sestonic chlorophyll-*a* just below Wickiup Reservoir (**Figure 6.1**). The levels in mean chlorophyll-*a* indicate a downstream downward trend from a mean high approaching 17 µg/L to a mean low approaching 2 µg/L between Wickiup Reservoir and the City of Bend. Levels of mean chlorophyll-*a* within the middle Deschutes reach below the City of Bend also indicate a downstream downward trend, and reflect a mean high approaching 7 µg/L to a mean low approaching 2 µg/L. The Little Deschutes exhibits constant mean chlorophyll-*a* along the longitudinal extent (**Figure 6.2**). The Wickiup/Crane Prairie Reservoir complex may be contributing to the higher levels of mean chlorophyll-*a* concentrations as each spring storage release may cause phytoplankton to transport from the complex to the river.

Seasonal chlorophyll-*a* data is only reported for May, July, and September (**Figure 6.3**). There are no chlorophyll-*a* data collected during some months of the year do to the natural decrease in numbers over cooler time periods, therefore the effects of storage releases cannot be evaluated due the inability to compare before, during, and after mean chlorophyll-*a* concentrations. The upper Deschutes reach exhibits an increase in chlorophyll-*a* during the months of May, July, and September. The middle Deschutes reach also exhibits an increase in chlorophyll-*a* during these months, while the Little Deschutes River appears to have constant and low mean chlorophyll-*a* concentrations. The upper Deschutes reach appears to contain relatively more sestonic chlorophyll-*a* during summer high flows, which may be do to transport during storage releases from Wickiup Reservoir.

Longitudinal extent mean chlorophyll-*a* concentrations may be of concern at the State Recreation Road site located near La Pine State Park (**Figure 6.1**). Mean chlorophyll-*a* concentrations at this site are the highest in the subbasins approaching 17 µg/L. Longitudinal extent mean TN and TP concentrations also indicate a situation where nutrient loading may be occurring (**Figure 7.1**). This is evident by the highest mean TP concentrations in the region occurring at this site in combination with relatively average mean TN concentrations. The nutrient levels may be influenced by the demand on TN by primary producers or there may be increased inputs of TP. The high mean chlorophyll-*a* concentrations in combination with the nutrient data may indicate a nonpoint source issue.

The upper Deschutes reach, middle Deschutes reach, and the Little Deschutes River all exhibit a long-term downward trend in mean chlorophyll-*a* concentrations (**Figure 6.4**, **Figure 6.5**, and **Figure 6.6**). Although mean chlorophyll-*a* concentrations are exhibiting a downward trend, this does not indicate a downward trend in primary production. Chlorophyll-*a* data reflects phytoplankton chlorophyll-*a*. Phytoplankton are free floating primary producers, whereas periphyton are primary producers that are attached to the aquatic substrate. The long-term downward trend in mean chlorophyll-*a* for phytoplankton may be indicative of an optimization of periphyton growth. Unfortunately, there are no data for periphyton chlorophyll-*a* concentrations within the subbasins. Anecdotally, within the subbasins periphyton is observed in reaches of sediment transport and is less obvious in reaches of sediment deposition.

Wickiup Reservoir releases water in the summer for downstream irrigation purposes and stores water in the winter, which results in fluctuations of flows between summer highs and winter lows. It is suspected that fluctuations may optimize periphyton growth because periphyton is attached to the substrate and would not wash away with increases in flow. The optimization of periphyton growth downstream of the reservoir complex would result in changes in the balance of the aquatic system.

During the winter low flows, periphyton may die off due to dewatering. During summer high flows, the organic matter resulting from the die off of periphyton would input into the system and may be transported downstream. The increase in organic matter is also indicated by the higher levels of BOD-5 at the Pringle Falls site and for the middle Deschutes reach (**Figure 4.5**).

The segment from RM 168.2 (upstream of the City of Bend) to RM 189.4 (below Sunriver) is on the ODEQ 2002 303(d) list. Compliance analyses on the datasets from the regional database indicate that there are minimal sestonic chlorophyll-*a* data and no periphyton chlorophyll-*a* data for analyses. Although chlorophyll-*a* data has been gathered since 1995, datasets are not able to meet the EPA and ODEQ requirements of a three month average from a minimal of three samples per time period. Sites that do qualify are listed in **Table 6.1**. The state listing of this segment of the upper Deschutes River and the compliance analyses in the Technical Report all reflect sestonic chlorophyll-*a* data collected during the summer of 1995.

The lack of chlorophyll-*a* data prevents complete analyses of the trophic status of the upper Deschutes River and Little Deschutes River. For complete analyses, both sestonic and benthic chlorophyll-a data must be included (**Table 7.4**).

Key Findings

- The Wickiup/Crane Prairie Reservoir complex may be contributing to increased mean chlorophyll-*a* concentrations as each spring storage release may cause phytoplankton to transport from the complex to the river.
- The chlorophyll-*a* dataset is limited by monitoring efforts conducted only during summer months.
- A nonpoint source pollution issue may exist at the State Recreation Road site near La Pine State Park as indicated by chlorophyll-*a* concentrations.
- The anthropogenic influence of water regulation may be contributing to the optimization of periphyton growth within the upper Deschutes River.
- An optimization of periphyton growth may be contributing to a shift in the balance within the upper Deschutes River by increasing the organic compound load.
- There are no benthic chlorophyll-*a* data to evaluate periphyton growth within the rivers of the subbasins.
- The post 1995 dataset displays insufficient data to evaluate chlorophyll-*a* for state 303(d) listing and delisting purposes.
- The lack of chlorophyll-*a* data prevents complete analyses of the trophic status of the upper Deschutes River and Little Deschutes River.

7.0 NUTRIENTS

7.1 Introduction

The trophic state of a waterbody describes its age and primary productivity. Eutrophication is a natural process of gradual waterbody aging. As a waterbody ages, nutrients are released from sediment loads and the waterbody becomes more productive with time. Although aquatic systems may age at different rates, aging normally takes thousands of years to progress.

In a balanced aquatic system, nutrients support primary producers and the rest of the food chain. However, nutrient loading of an aquatic system can cause an imbalance. The primary production of an aquatic system can be naturally growth limited by the lack of a nutrient, therefore with increases in the limited nutrient adverse impacts expressed as accelerated primary production occur. This human caused acceleration of primary production causing changes in the trophic state of a waterbody is termed anthropogenic eutrophication.

Anthropogenic eutrophication of a waterbody occurs from increased loading of primarily nitrogen and phosphorus. Nitrogen and phosphorus nutrients are commonly utilized as fertilizers (nitrogen and phosphorus) and cleaning agents (phosphorus), which have contributed to their increased rate of entry into waterbodies from their surrounding watersheds. Other sources of nutrients from anthropogenic activities include wastewater discharges, septic systems, manure storage areas, disturbed lands, and soil erosion. There are also natural sources of phosphorus from soil and rocks, such as the volcanic soils found in the Upper Deschutes and Little Deschutes Subbasin.

Anthropogenic eutrophication of a waterbody has many adverse impacts. Excessive primary productivity initially increases the dissolved oxygen and pH in the waterbody, but the excess ultimately leads to depletion of the dissolved oxygen and decreases in pH as the primary producers cycle and are decomposed by bacteria. This effect is evident in greater daily fluctuations in dissolved oxygen and increases in BOD-5. The decomposition process utilizes oxygen and inputs nutrients mainly in the form of carbon into the waterbody. Ammonia toxicity is of particular concern in waterbodies with decreased pH.

Nutrients that contribute to the eutrophication of a waterbody include carbon, nitrogen, and phosphorous. Nitrogen and phosphorus are the principal primary production limiting nutrients in water. A waterbody that is in balance is naturally limited in nitrogen or phosphorus. Ratios of nitrogen and phosphorus are utilized to indicate the limiting growth nutrient.

7.2 Analyses

Total phosphorus and total nitrogen are utilized in analyses. Dissolved nutrients are rapidly utilized and depleted by primary producers, thus low levels of dissolved inorganic nutrients do not necessarily indicated low levels of primary productivity or low levels of nutrient loading. Due to the slower rate of cycling within the system, total phosphorus (TP) and total nitrogen (TN) better reflect stream state compared to dissolved, inorganic phosphorus and nitrogen (EPA, 2000). Total phosphorus is established by measuring both inorganic and organic forms of phosphorus that occur as both soluble and insoluble forms. Total nitrogen is established by measuring both inorganic and organic forms of nitrogen including inorganic nitrate, inorganic nitrite, and total Kjeldahl nitrogen (organic nitrogen and ammonia).

Total nitrogen and total phosphorus values are analyzed. OWEB has indicator concentrations they recommend for nitrogen and phosphorus evaluation purposes. OWEB guidelines recommend an indicator concentration of 0.3 mg/L (300 µg/L) for total nitrogen and 0.05 mg/L (50 µg/L) for total phosphorus. These guidelines are aimed towards the desired goal of preventing plant nuisances in streams or other flowing waters.

ODEQ does not have nutrient criteria for the Upper Deschutes and Little Deschutes Subbasins. The closest standard that might apply is the narrative standard for aquatic weeds and algae that states "The development of fungi or other growths having a deleterious effect on stream bottoms, fish, or other aquatic life, or which are injurious to health, recreation, or industry shall not be allowed" (ODEQ, 2001). Nutrient criteria protect the beneficial uses of resident fish, aquatic life, water contact recreation, and aesthetics. Since there are no ODEQ criteria, waterbodies are not specifically listed for exceeding nutrient criterion within the subbasins.

In addition to providing analyses for the critical questions, evaluation of the N:P and trophic state of the Upper Deschutes and Little Deschutes Subbasins are presented. If nitrogen and phosphorus ratios (N:P) are greater than 20:1, then phosphorus can be assumed to be in limiting supply. If the N:P ratio are less than 10:1, then N can be assumed to be in limiting supply. The distinction of the limiting nutrient when ambient N:P ratios are between 10 and 20 to 1 is not precise (EPA 2000). The N:P concentrations along the longitudinal extent of the upper Deschutes River and Little Deschutes River are presented by comparing the TN and TP obtained from the site means over the entire time period

A trophic classification system for streams and rivers based on both algal biomass surrogates of benthic periphyton and sestonic phytoplankton chlorophyll-*a* and nutrients is utilized. Classification of the trophic state of fluvial systems is most appropriately based on algal biomass and secondarily on nutrients. Fast flowing, gravel and cobble bed systems that are periphyton dominated use measurements of benthic chlorophyll-*a* per square meter of substrate. Slow moving, sediment-depositing systems that are phytoplankton dominated use measurements of sestonic chlorophyll-*a* per liter. Benthic chlorophyll-*a* data has not been collected, therefore the Technical Report will consider trophic state based on sestonic chlorophyll-*a* and nutrients.

Data collected from 1993 to 2002 by ODEQ ambient monitoring and intensive water quality monitoring studies for TMDL development are used to illustrate trends along the longitudinal extent of the Upper Deschutes River. Data collected from 1995 to 2002 by ODEQ ambient monitoring, ODEQ intensive water quality monitoring studies for TMDL development, and REMAP studies are used to illustrate trends along the longitudinal extent of the Little Deschutes River. Data are predominately collected during the odd numbered months of January, March, May, July, September, and November. Some months and years have relatively small datasets compared to other months and years that have relatively large datasets. The year 2001 has the largest dataset due to the 2001 TMDL monitoring efforts. The relatively small amount of data collected on even months is incorporated into odd month data. This is accomplished by consolidating data collected between the first and fifteenth of the month into the previous month dataset and data collected between the sixteenth and last day of the month into the post month dataset.

7.2.1 How do nutrients change along the longitudinal extent of the aquatic system?

Changes along the longitudinal extent of reaches within the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 7.1** and **Figure 7.2**. A solid grey line represents a longitudinal grand mean. A solid black line represents a linear regression and is provided for insight regarding the trend over the longitudinal extent during the time period. Both TN and TP are provided on the same graph for discussion of the primary productivity growth limiting nutrient within the aquatic system.

The upper Deschutes River has a longitudinal grand mean of 300.8 TN µg/L and 77 TP µg/L, and a mean N:P of 4.

The upper Deschutes reach has a longitudinal grand mean of 297.8 TN µg/L and 78 TP µg/L, and a mean N:P of 4. A linear regression results in a negative slope for TN and positive slope for TP. This indicates a downstream downward trend of mean TN and upward trend of mean TP.

The middle Deschutes reach has a longitudinal grand mean of 303.8 TN µg/L and 76 TP µg/L, and a mean N:P of 4. A linear regression results in a positive slope for TN and TP. This indicates a downstream upward trend of mean TN and TP.

The Little Deschutes River has a longitudinal grand mean of 240.1 TN µg/L and 46 TP µg/L, and a mean N:P of 5. A linear regression results in a positive slope for TN and TP. This indicates a downstream upward trend of mean TN and TP.

Figure 7.1 Mean TN and TP concentrations along the longitudinal extent of the Deschutes River

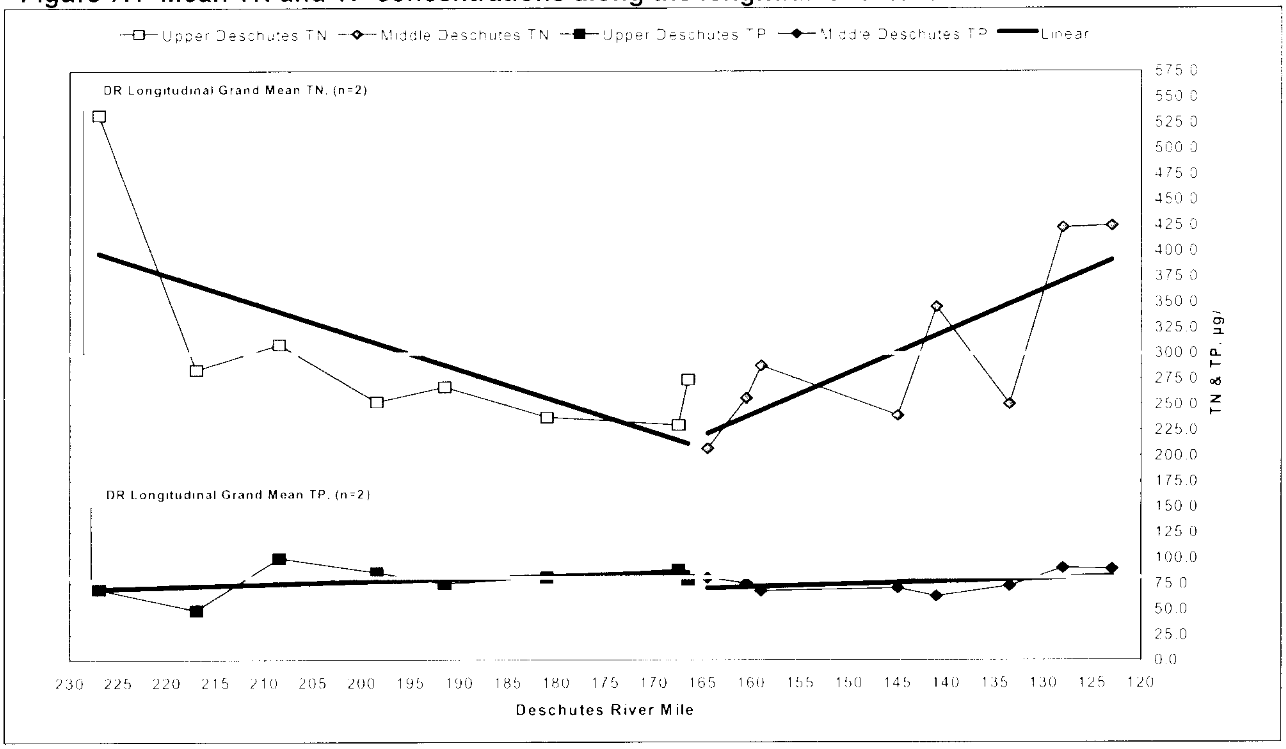
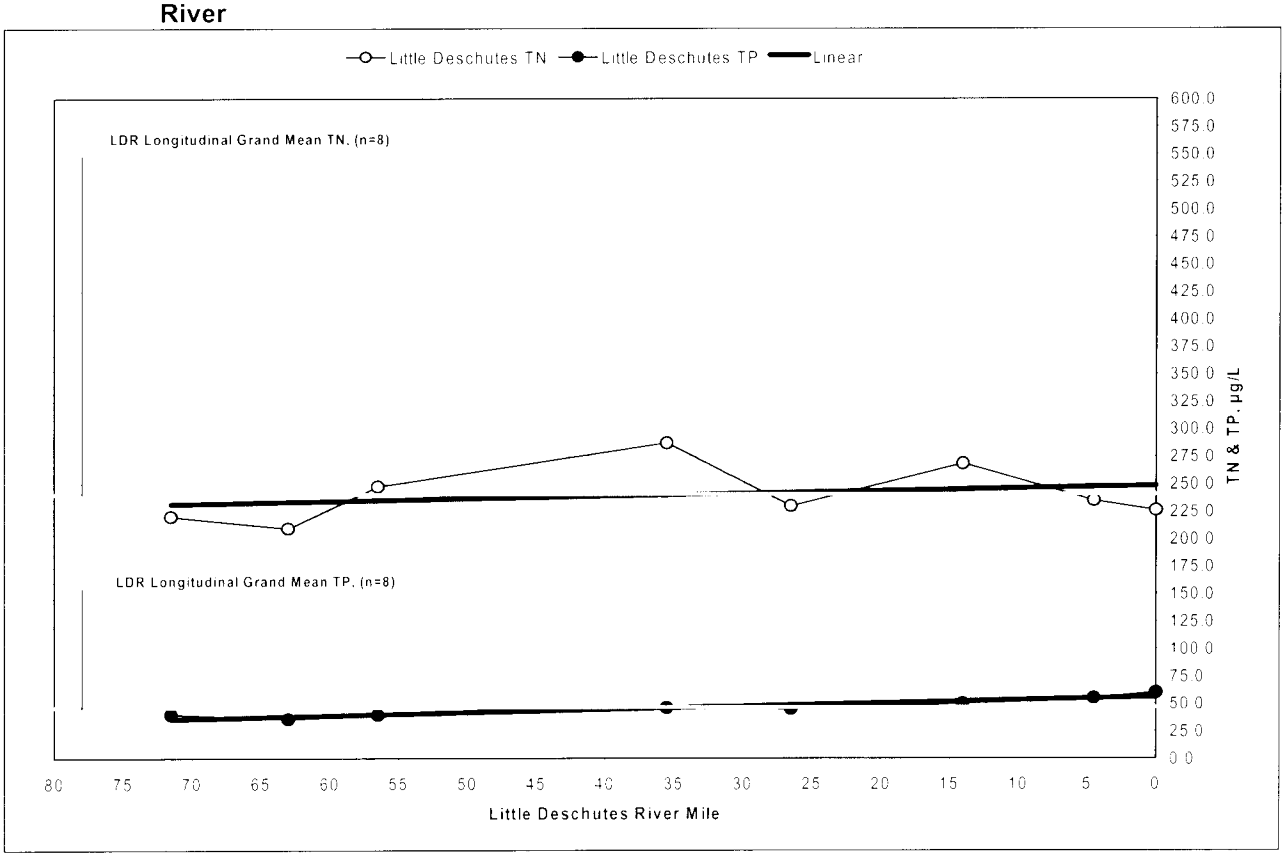


Figure 7.2 Mean TN and TP concentrations along the longitudinal extent of the Little Deschutes River



If nitrogen and phosphorus ratios (N:P) are greater than 20:1, then phosphorus can be assumed to be in limiting supply. If the N:P ratio are less than 10:1, then N can be assumed to be in limiting supply. The distinction of the limiting nutrient when ambient N:P ratios are between 10 and 20 to 1 is not precise (EPA 2000). The N:P concentrations along the longitudinal extent of the upper Deschutes River and Little Deschutes River are presented by comparing the TN and TP obtained from the site means over the entire time period

Table 7.1 TN and TP concentration ratios along the longitudinal extent of the upper Deschutes River and Little Deschutes River

RM	N:P	RM	N:P	RM	N:P
UDR		MDR		LDR	
227	8	164.5	3	71.5	6
217	6	160.5	3	63	6
208.5	3	159	4	56.5	6
198.5	3	145	3	35.5	6
191.5	4	141	6	26.5	5
181	3	133.5	3	14	5
167.5	3	128	5	4.5	4
166.5	3	123	5	1	4

7.2.2 *What is the seasonal variability of nutrients?*

Seasonal fluctuations within reaches of the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 7.3**. Both TN and TP are provided on the same graph for discussion of the primary productivity growth limiting nutrient within the aquatic system.

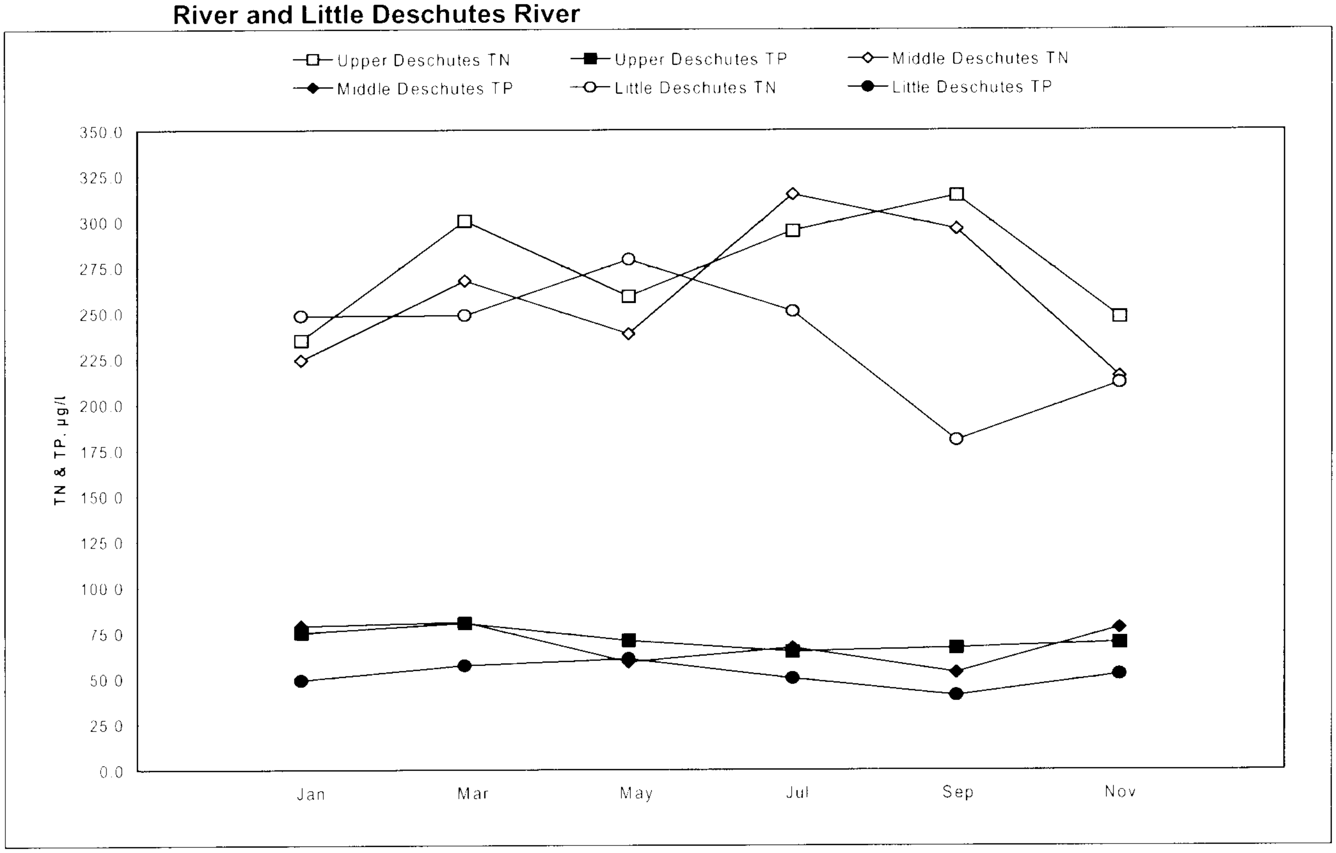
The upper Deschutes River has a seasonal grand mean of 267.3TN µg/L and 70 TP µg/L, and a N:P of 4.

The upper Deschutes reach has a seasonal grand mean of 275.2 TN µg/L and 71 TP µg/L, and a N:P of 4. A fluctuation in seasonal mean concentrations ranges from 235.0 – 314.3 TN µg/L and 65 – 80 TP µg/L.

The middle Deschutes reach has a seasonal grand mean of 259.4 TN µg/L and 69 TP µg/L, and a N:P of 4. A fluctuation in seasonal mean concentrations ranges from 215.3 – 314.9 TN µg/L and 53 – 81 TP µg/L.

The Little Deschutes River has a seasonal grand mean of 236.5 TN µg/L and 52 TP µg/L, and a N:P of 5. A fluctuation in seasonal mean concentrations ranges from 180.3 – 279.2 TN µg/L and 41 – 61 TP µg/L.

Figure 7.3 Seasonal fluctuations of mean TN and TP concentrations within the upper Deschutes River and Little Deschutes River



If nitrogen and phosphorus ratios (N:P) are greater than 20:1, then phosphorus can be assumed to be in limiting supply. If the N:P ratio are less than 10:1, then N can be assumed to be in limiting supply. The distinction of the limiting nutrient when ambient N:P ratios are between 10 and 20 to 1 is not precise (EPA 2000). The seasonal trend in N:P are presented by comparing the TN and TP obtained from the monthly means over the entire time period **(Table 7.2)**.

Table 7.2 Seasonal TN and TP concentration ratios for the upper Deschutes River and Little Deschutes

N:P					N:P				
Year	**Month**	**UDR**	**MDR**	**LDR**	**Year**	**Month**	**UDR**	**MDR**	**LDR**
1993	J	5	2		1998	J	4	3	4
	M	4	4			M	1	3	4
	M	5	6			M	4	0	5
	J	5	9			J	3	4	5
	S		11			S	4	5	5
	N	3	2			N	4	3	4
1994	J	4	3		1999	J	4	3	4
	M	5	5			M	4	4	8
	M	4	5			M	4	3	6
	J	4	7			J	4	4	4
	S	2	9			S	4	3	5
	N	2				N	4	3	4
1995	J	4	3		2000	J	3	3	5
	M	3	2			M	4	3	4
	M	6	6			M	4	3	5
	J	5	6	6		J	9	3	4
	S	3	6			S	3	3	7
	N	2	3			N	3	3	4
1996	J	3	3	8	2001	J	3	3	4
	M	4	3	6		M	4	2	3
	M	5	7	5		M	4	8	4
	J	3		6		J	6	4	5
	S			4		S	4	5	5
	N	3				N	4	3	5
1997	J	3		6	2002	J	3	3	4
	M	4	3	4		M	4	4	3
	M	5	3	4		M	5	3	4
	J	4	6	5		J	5	3	4
	S	5	5	5		S	4	6	5
	N	3	3	4		N		2	3

7.2.3 *What are the long-term trends for nutrients?*

The long-term trend for the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 7.4**, **Figure 7.5**, and **Figure 7.6**. A solid grey line represents a long-term grand mean. A solid black line represents a linear regression and is provided for insight regarding the trend over the time period. Both TN and TP are provided on the same graph for discussion of the primary productivity growth limiting nutrient within the aquatic system.

The upper Deschutes River has a long-term mean of 268.1 TN µg/L and 70 TP µg/L, and a N:P of 4. The upper Deschutes reach has a long-term trend mean of 276.9 TN µg/L and 71 TP µg/L, and a N:P of 4. A linear regression results in a negative slope for TN and TP. This indicates a downward temporal trend in TN and TP.

The middle Deschutes reach has a long-term trend mean of 259.3 TN µg/L and 69 TP µg/L, and a N:P of 4. A linear regression results in a negative slope for TN and a positive slope for TP. This indicates a downward temporal trend in TN and upward temporal trend in TP.

The Little Deschutes River has a long-term trend mean of 242.3 TN µg/L and 52 TP µg/L, and a N:P of 5. A linear regression results in a negative slope for TN and a positive slope for TP. This indicates a downward temporal trend in TN and upward temporal trend in TP.

Figure 7.4 Long-term trend in mean TN and TP concentrations within the upper Deschutes reach

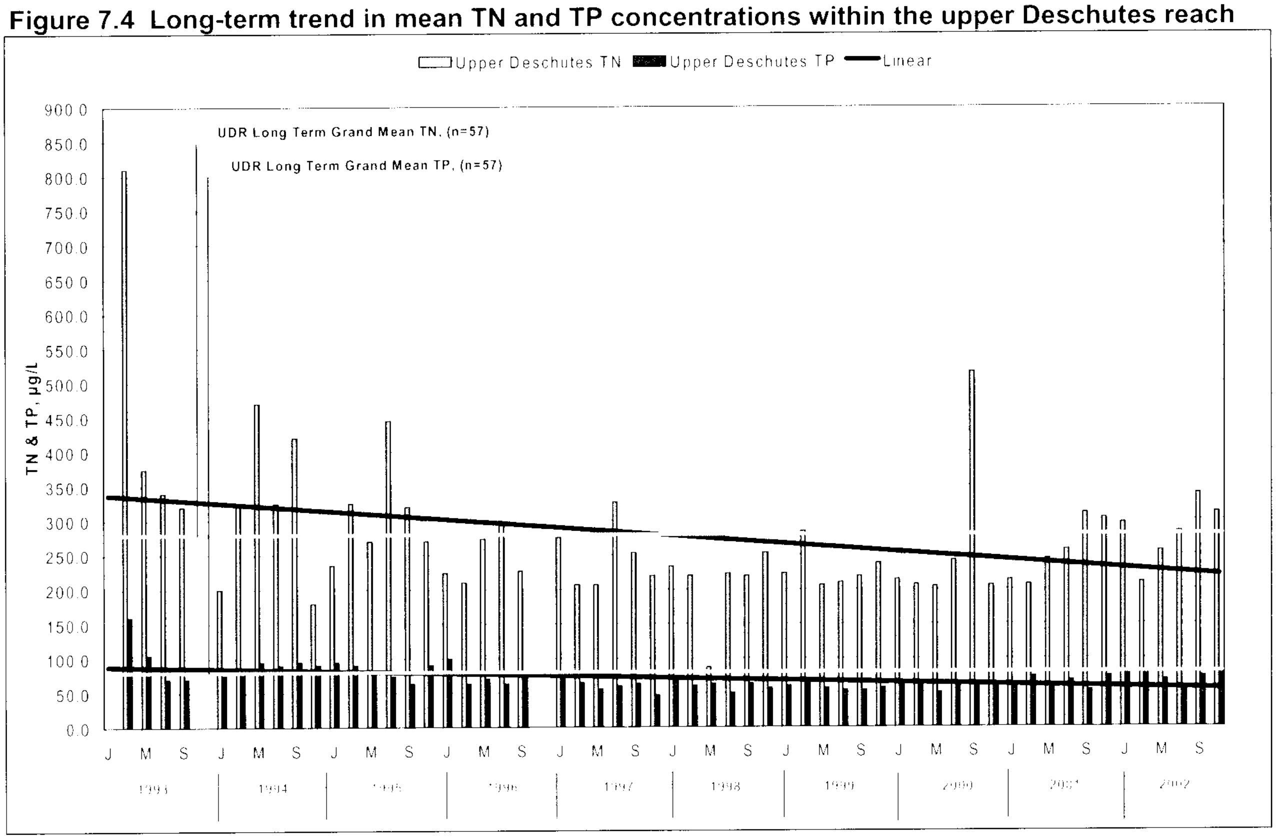


Figure 7.5 Long-term trend in mean TN and TP concentrations within the middle Deschutes reach

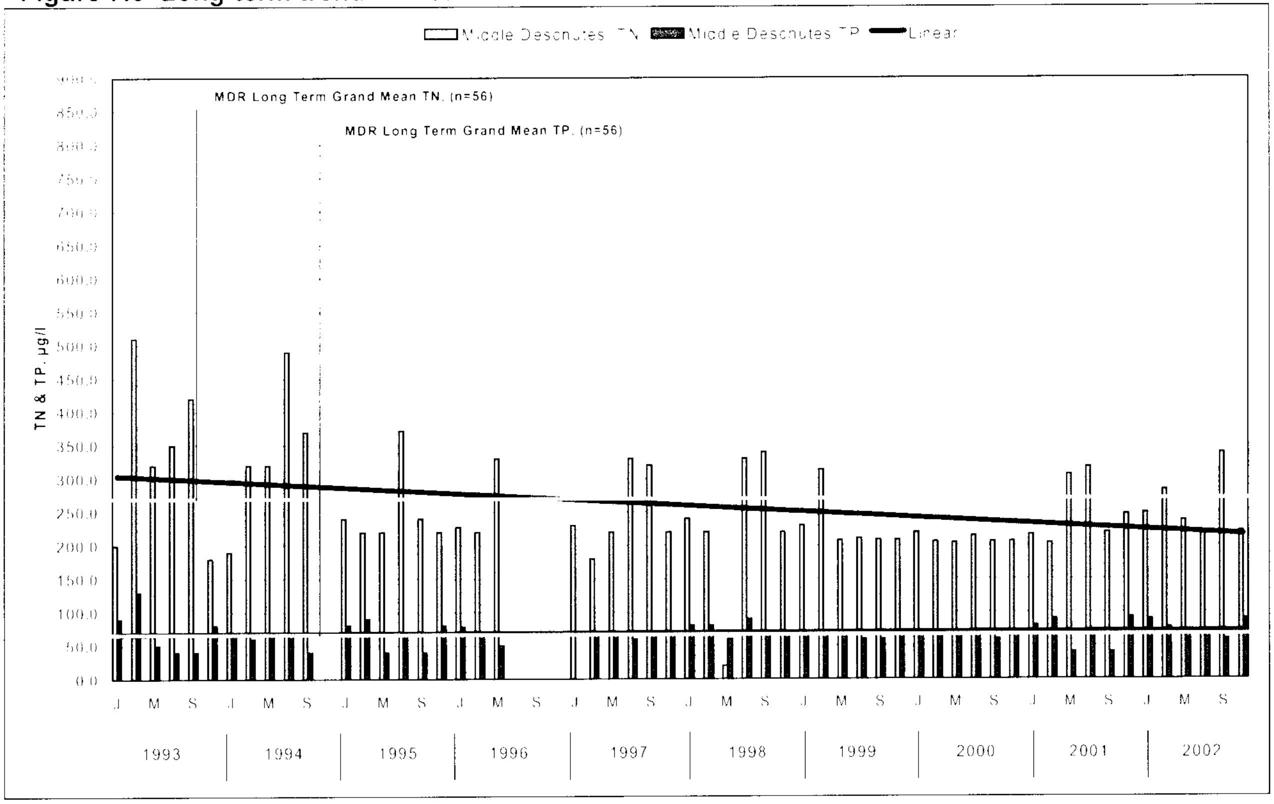
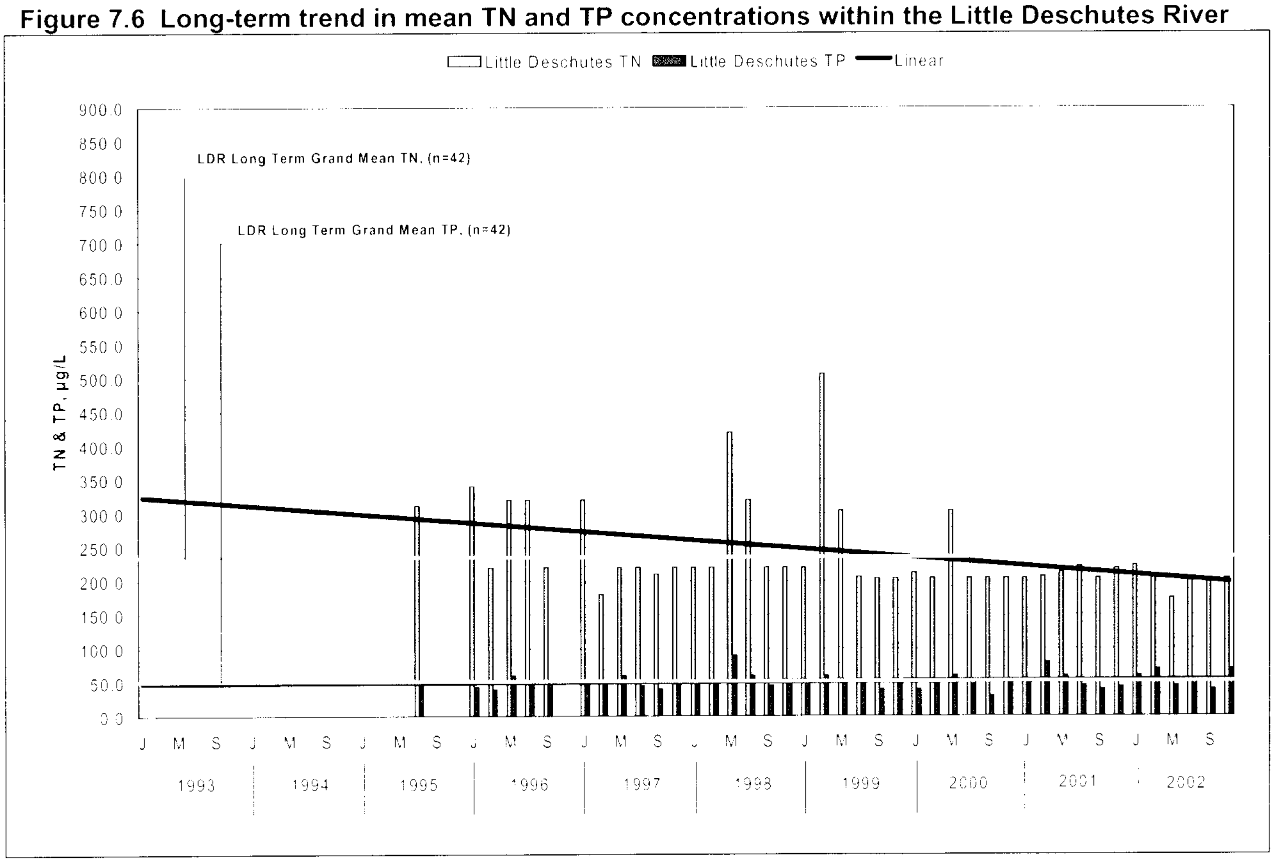


Figure 7.6 Long-term trend in mean TN and TP concentrations within the Little Deschutes River



7.2.4 Are TN or TP concentrations compliant with OWEB guidelines?

Data are evaluated by site and season. The sites and the season applicable for analyses are displayed in **Table 7.3**. Three upper Deschutes reach sites and one middle Deschutes reach site satisfy the minimal sample number required by the EPA and ODEQ for analyses of parameter compliance and are evaluated according to OWEB guidelines. There are no Little Deschutes River sites that satisfy the minimal sample number.

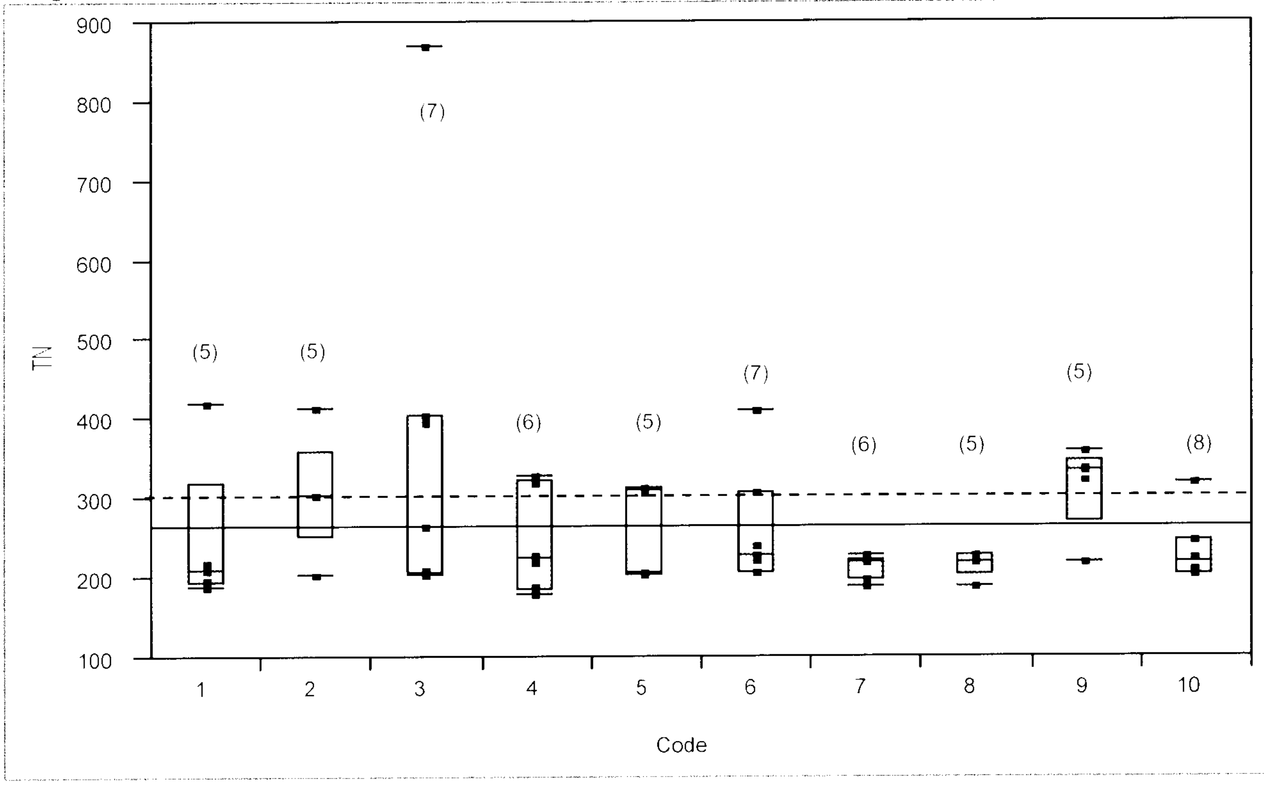
Site analyses are displayed by quantiles in **Figure 7.7** for TN and **Figure 7.8** for TP. The data are presented in quantiles depicting the minimum, 10%, 25%, median, 75%, 90% and maximum boundaries. The number of samples at a particular site is stated within parentheses. A solid black line represents the data mean. The dashed black line represents the guidelines.

Table 7.3 TN and TP datasets that meet the minimal sample number required for compliance analyses

Code	Season	RM	Site	Segment	Compliance analyses
1	FWS 1995/1996	217	Pringle Falls	UDR	**TN WQL** TP attaining guidelines
2	S 2001	217	Pringle Falls	UDR	**TN WQL** **TP WQL**
3	FWS 2001/2002	217	Pringle Falls	UDR	**TN WQL** TP attaining guidelines
4	FWS 1995/1996	191.5	Harper Bridge	UDR	**TN WQL** **TP WQL**
5	S 2001	191.5	Harper Bridge	UDR	**TN WQL** **TP WQL**
6	FWS 2001/2002	191.5	Harper Bridge	UDR	**TN WQL** **TP WQL**
7	FWS 1995/1996	166.5	Mirror Pond	UDR	TN attaining guidelines **TP WQL**
8	FWS 1995/1996	133.5	Lower Bridge	MDR	TN attaining guidelines **TP WQL**
9	S 2001	133.5	Lower Bridge	MDR	**TN WQL** **TP WQL**
10	FWS 2001/2002	133.5	Lower Bridge	MDR	TN attaining guidelines **TP WQL**

S= June 1 through September 30 FWS: October 1 to May 31 WQL = water quality limited

Figure 7.7 Detail of TN concentrations (µg/L) within the upper Deschutes River



Quantiles

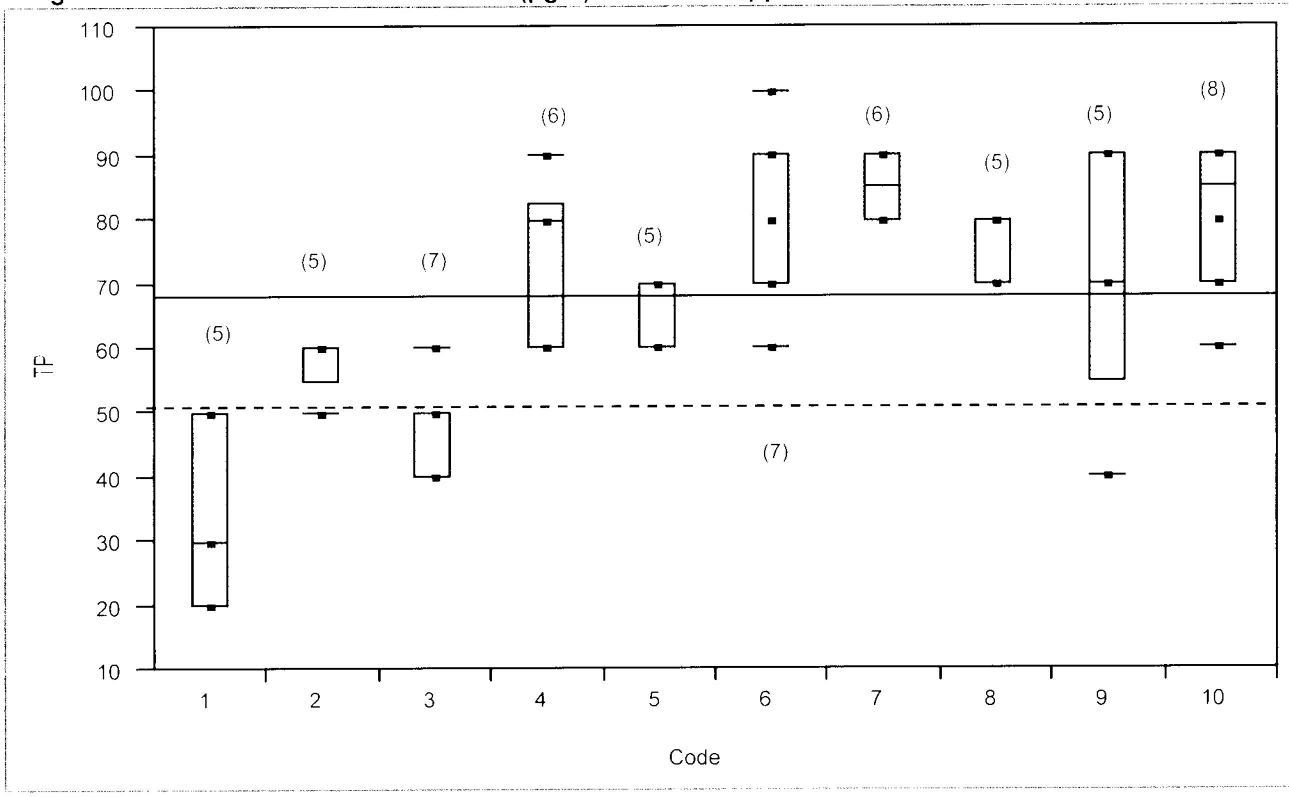
Code	minimum	10.0%	25.0%	median	75.0%	90.0%	maximum
1	190.0	190.0	195.0	210.0	320.0	420.0	420.0
2	206.5	206.5	255.3	306.0	360.2	413.9	413.9
3	204.0	204.0	206.9	264.8	405.3	871.6	871.6
4	180.0	180.0	187.5	225.0	322.5	330.0	330.0
5	204.0	204.0	205.9	207.8	310.8	314.3	314.3
6	208.4	208.4	208.9	230.6	309.9	412.1	412.1
7	190.0	190.0	197.5	220.0	222.5	230.0	230.0
8	190.0	190.0	205.0	220.0	230.0	230.0	230.0
9	219.6	219.6	272.0	336.4	349.2	359.8	359.8
10	205.4	205.4	206.3	219.9	248.3	321.6	321.6

OWEB guidelines recommend an indicator concentration of 0.3 mg/L (300 µg/L) for total nitrogen.

The upper Deschutes reach sites and seasons code 1, 2, 3, 4, 5, and 6 are categorized as water quality limited, because 10% of the dataset and a minimum of two exceedences are not compliant with the guidelines. Site and season code 7 is categorized as attaining criteria, because 90% of the dataset are within the guidelines.

The middle Deschutes reach sites and seasons code 9 is categorized as water quality limited, because 10% of the dataset and a minimum of two exceedences are not compliant with the guidelines. Sites and seasons code 8 and 10 are categorized as attaining criteria, because 90% of the dataset are within the guidelines.

Figure 7.8 Detail of TP concentrations (µg/L) within the upper Deschutes River



Quantiles

Code	minimum	10.0%	25.0%	median	75.0%	90.0%	maximum
1	20	20	20	30	50	50	50
2	50	50	55	60	60	60	60
3	40	40	40	40	50	60	60
4	60	60	60	80	83	90	90
5	60	60	60	60	70	70	70
6	60	60	70	90	90	100	100
7	80	80	80	85	90	90	90
8	70	70	70	70	80	80	80
9	40	40	55	70	90	90	90

OWEB guidelines recommend an indicator concentration of 0.05 mg/L (50 µg/L) for total phosphorus.

The upper Deschutes reach, sites and seasons code 2, 4, 5, 6, and 7 are categorized as water quality limited, because 10% of the dataset and a minimum of two exceedences are not compliant with the applicable criteria. Site and season code 1 and 3 are categorized as attaining criteria, because 90% of the dataset are within the guidelines.

The middle Deschutes reach, sites and seasons code 8, 9, and 10 are categorized as water quality limited, because 10% of the dataset and a minimum of two exceedences are not compliant with the guidelines.

7.2.5 Evaluation of the trophic state of reaches within the Upper Deschutes and Little Deschutes Subbasins

A trophic classification system for streams and rivers based on both algal biomass surrogates of benthic (periphyton) and sestonic (phytoplankton) chlorophyll-*a* and nutrients are utilized **(Table 7.3)**. Classification of trophic state in fluvial systems is most appropriately based on algal biomass and secondarily on nutrients. Fast flowing, gravel and cobble bed systems that are periphyton dominated use measurements of benthic chlorophyll-*a* per square meter of substrate. Slow moving, sediment-depositing systems that are phytoplankton dominated use measurements of sestonic chlorophyll-*a* per liter. Benthic chlorophyll-*a* data has not been collected, therefore the Technical Report will consider trophic state based on sestonic chlorophyll-*a* and nutrients **(Table 7.4)**.

Table 7.4 Suggested classification of stream trophic state developed by Dodds et al. (1998) as summarized in EPA Nutrient Criteria Technical Guidance Manual

Variable	Oligotrophic – Mesotrophic Boundary	Mesotrophic - Eutrophic Boundary
Mean TP (µg/L)	25	75
Mean TN (µg/L)	700	1500
Mean Sestonic Chlorophyll-*a* (µg/L)	10	30
Mean Benthic Chlorophyll-*a* (mg/m^2)	20	70

(EPA, 2000)

Table 7.5 Trophic state of reaches within the Upper Deschutes and Little Deschutes Subbasins

RM	Mean TN µg/L	S	Mean TP µg/L	S	Chlorophyll-*a* µg/L	S	State
UDR							
227.0	532.0	O	69	M	13.9	M	M
217.0	283.4	O	49	M	8.1	O	M
208.5	308.1	O	100	E	16.7	M	E
198.5	252.0	O	86	E	9.9	O	E
191.5	266.7	O	75	E	5.3	O	E
181.0	237.0	O	81	E	8.5	O	E
167.5	229.4	O	88	E	2.2	O	E
166.5	273.7	O	78	E	5.6	O	E
MDR							
164.5	206.6	O	80	E	4.3	O	E
160.5	255.5	O	75	E	2.8	O	E
159.0	287.5	O	68	M	6.6	O	M
145.0	238.8	O	70	M	3.0	O	M
141.0	345.0	O	63	M	2.2	O	M
133.5	250.0	O	72	M	4.7	O	M
128.0	422.5	O	90	E	3.2	O	E
123.0	424.1	O	89	E	2.9	O	E
LDR							
71.5	220.0	O	40	M			M
63.0	209.1	O	36	M	0.9	O	M
56.5	247.3	O	40	M	1.7	O	M
35.5	286.9	O	46	M	2.4	O	M
26.5	229.6	O	45	M	1.6	O	M
14.0	268.2	O	50	M	1.1	O	M
4.5	234.5	O	55	M	1.5	O	M
1.0	225.7	O	60	M	1.8	O	M

S= trophic state, O= oligotrophic, M= mesotrophic, E=eutrophic, State = most trophic state

7.3 Discussion and Key Findings

There appears to be a greater ability of the upper Deschutes reach to process the nutrient load compared to the middle Deschutes reach, which may be due to undocumented increases in periphyton primary production within the upper Deschutes reach in combination with nutrient loads and flow modification. The water storage release from Wickiup Reservoir may affect TN concentrations within the upper Deschutes River. TN concentrations of the middle Deschutes reach may be affected by uncharacterized urban runoff, rural land use, and agriculture, while water diversions may exacerbate conditions and possibly increase the impacts from nutrient loading. A nonpoint source issue at State Recreation Road may exist. The waters of the Upper Deschutes and Little Deschutes Subbasins are nitrogen limited and exhibit a mesotrophic to eutrophic state contributed by high TP concentrations.

Different trends exhibited by mean TN and TP concentrations within the sites of the upper Deschutes reach and the middle Deschutes reach may indicate nutrient loading within the upper Deschutes River. The mean TN concentrations exhibit a downstream downward trend along the longitudinal extent of the upper Deschutes reach and a downstream upward trend along the middle Deschutes reach (**Figure 7.1**). The mean TP concentrations for the upper Deschutes reach, middle Deschutes reach, and Little Deschutes reach exhibit a downstream upward trend in mean TP concentrations that are relatively constant when compared to trends in mean TN concentrations. The difference in the trends for mean TN and TP concentrations may indicate the downstream, accumulative nature of impacts.

Within the upper Deschutes reach, sites downstream of Wickiup Reservoir may experience nutrient loading. There are high mean TN concentrations downstream Wickiup Reservoir, which may be indicative of high TN water release from Wickiup Reservoir (**Figure 7.1**). Within the middle Deschutes reach, mean TN concentrations exhibit a downstream upward trend. It appears that the upper Deschutes reach may be able to process and transport the TN load in the system until the City of Bend, at which point the downstream upward trend in TN within the middle Deschutes reach may be more indicative of a system that is imbalanced and unable to process the nutrient load. Possible impacts causing the imbalance include high nutrient storage water releases, uncharacterized urban runoff, and water diversions all contributing to downstream increasing nutrient concentrations.

The imbalance in the upper Deschutes River is also indicated in the seasonal trends for mean TN and TP (**Figure 7.3**). The Little Deschutes River is likely illustrative of seasonal influences on regional mean TN and TP concentrations. The Little Deschutes River has mean TN and TP concentration trends that display the same pattern, while the upper Deschutes reach and middle Deschutes reach have mean TN and TP concentration trends that appear to fluctuate independently indicating additional influences. TN levels for the upper Deschutes reach and middle Deschutes reach increase during the month of March coinciding with water storage release from Wickiup Reservoir, indicating that waters released from Wickiup Reservoir may have high TN concentrations and increased sediment loading from increased flows may carry additional nutrients into the system. During the summer months, mean TN concentrations for the upper Deschutes reach and middle Deschutes reach appear to increase independently of TP and also indicate high TN waters released from Wickiup Reservoir and possible increased nutrient loading with increased sediment loading. With the seasonal water storage at Wickiup Reservoir and seasonal closing of water diversions, mean TN concentrations decrease for the upper Deschutes reach and middle Deschutes reach while TP concentrations for the upper Deschutes reach, middle Deschutes reach, and Little Deschutes River all exhibit a similar upward trends. The quality of waters released from Wickiup Reservoir and the impact of additional sediment loading appears to have an anthropogenic impact of increased TN concentrations within the upper Deschutes River. Within the middle Deschutes reach additional nutrient loading may occur due to uncharacterized urban runoff, rural land use, and agriculture.

The long-term trend in mean TN and TP concentrations are downward, yet the trend in mean TN concentrations appears to be decreasing faster than the trend in mean TP concentrations (**Figure 7.4**, **Figure 7.5**, and **Figure 7.6**). The TN load into the system may be decreasing, or the uptake of TN may be increasing due to more primary producers. It is not likely that the TN load is decreasing because the region is greatly increasing in population, Wickiup Reservoir water storage releases and flow appear to increase the TN concentrations, and mean sestonic chlorophyll-*a* concentrations appear to be decreasing (**Figure 6.4**, **Figure 6.5**, and **Figure 6.6**) therefore there may be an increase in periphyton chlorophyll-*a* that has not been documented. An increase in periphyton primary production may be responsible for the ability of the upper Deschutes reach to successfully process the nitrogen load and the decreases in long-term mean TN concentrations within the upper Deschutes River and Little Deschutes River.

Nonpoint source nutrient loading may be of concern at the State Recreation Road site located near La Pine State Park. Longitudinal extent mean TN and TP concentrations indicate a situation where nutrient loading may be occurring (**Figure 7.1**). This is evident by the highest mean TP concentrations in the region occurring at this site in combination with relatively average mean TN concentrations. The nutrient levels may be influenced by the demand on TN by primary producers or there may be increased inputs of TP. Mean chlorophyll-*a* concentrations at this site are the highest in the subbasin approaching 17 µg/L (**Figure 6.1**). The nutrient data in combination with the high mean chlorophyll-*a* concentrations may indicate a nonpoint source issue at the State Recreation Road site.

Analyses of the mean N:P indicate that the upper Deschutes River and Little Deschutes River are nitrogen limited, therefore increases in nitrogen are likely to cause increases in primary production (**Table 7.1** and **Table 7.2**). Due to the flow regime, an optimization of periphyton primary production may be evident in the different trends displayed by the mean TN concentrations within the upper Deschutes reach compared to the middle Deschutes reach. Although the sestonic chlorophyll-*a* is not indicative of nitrogen uptake, periphyton primary production may place demand on the TN within the upper Deschutes River. Periphyton primary producers may grant the ability of the upper Deschutes reach to process the nitrogen load until upstream and within the City of Bend where sediment load deposition would decrease periphyton numbers. Within the middle Deschutes reach, mean TN concentrations exhibit a downstream upward trend and may indicate an inability of this reach to process the amounts of TN entering the aquatic system from upstream nutrient loading, uncharacterized urban runoff, rural land use, and agriculture (**Figure 7.1**). This is supported by the saturated and supersaturated conditions during daylight hours that indicate primary production processes uptaking nitrogen are at a maximum within the waters of the middle Deschutes reach (**Figure 4.3**).

There are no state criteria for nutrients, therefore there are no state 303(d) listed waterbodies or segments. In the Technical Report, guidelines recommended by OWEB are applied. The minimal sample number required for compliance analyses as set by the EPA and ODEQ are used in conjunction with the OWEB guidelines. For datasets that meet the minimal sample number required for compliance analyses, ten of ten are categorized as water quality limited (**Table 7.5**). This may be indicative of a system that is imbalanced.

N:P indicate that the rivers of the subbasins are nitrogen limited and have a high level of phosphorus (**Table 7.1** and **Table 7.2**). The high level of phosphorus is likely due to the watershed containing volcanic soils. A nitrogen limited system is susceptible to increases in primary production upon increases in the limiting nutrient.

Evaluation of the trophic state of reaches within the Upper Deschutes and Little Deschutes Subbasin indicate a mesotrophic to eutrophic state. Although nitrogen loading of a nitrogen limited system is of issue and causes increased eutrophication, it appears the current trophic state is more reflective of the naturally high phosphorus levels. The trophic state may reflect the natural state of the system, yet the trophic state was evaluated according to three out of the four criteria used for trophic state evaluation of fluvial systems. The missing variable is benthic chlorophyll-*a* that indicates periphyton concentrations.

Key Findings

- There appears to be a greater ability of the upper Deschutes reach to process the nutrient load compared to the middle Deschutes reach, which may be due to undocumented increases in periphyton primary production within the upper Deschutes reach in combination with nutrient loads and flow modification.
- The water storage release from Wickiup Reservoir may affect TN concentrations within the upper Deschutes River.
- TN concentrations of the middle Deschutes reach may be affected by uncharacterized urban runoff, rural land use, and agriculture, while water diversions may exacerbate conditions.
- A nonpoint source issue at the State Recreation Road site may exist as indicated by nutrient data.
- The waters of the Upper Deschutes and Little Deschutes Subbasins are nitrogen limited and exhibit a mesotrophic to eutrophic state contributed by high TP concentrations.
- Regional datasets that meet the minimal sample number are categorized as water quality limited.

8.0 BACTERIA

8.1 Introduction

Bacteria are single celled microorganisms that are ubiquitous in nature and all life. An important bacterial water quality indicator species are *Escherichia coli* (*E. coli*).

E. coli are considered members of the total coliform group and are a member of the family *Enterobacteriacea*. Total coliforms, a classification of bacteria based on phenotypic similarities and not genetic relations, are found naturally in environmental samples and are present in human feces, manure, soil, and submerged wood. Fecal coliforms describe a subgroup of total coliforms that occupy the enteric niche. However, some fecal coliform genera have species that are outside of the enteric niche and testing for fecal coliforms also detects these thermotolerant non-fecal coliform bacteria species. *E. coli* are abundant in human and animal flora and not usually found in other niches. Therefore, *E. coli* are considered a more specific indicator of fecal contamination than fecal coliforms.

E. coli are widely distributed in the intestines of warm-blooded animals and are essential to maintaining the physiology of a healthy host by occupying the enteric niche of predominant facultative anaerobes of the intestinal flora. Testing for *E. coli* is performed because they indicate the presence of fecal contamination that may contain pathogenic bacteria, protozoa, and viral particles; aggressive pathogens that cause human illness. *E. coli* are not considered aggressive pathogens, but they can be opportunistic pathogens that cause infections in immune compromised hosts, and some strains of *E. coli* cause gastrointestinal illness in healthy humans. Although they indicate fecal contamination, *E. coli* are not a measurement of the concentration of protozoa or viral particles but may indicate their presence. Water borne diseases from protozoa such as *Cryptosporidium spp.* or *Giardia spp.* and viral particles such as the hepatitis A virus occur at low infectious doses. The detection of elevated concentrations of *E. coli* in recreational waters may indicate the presence of other water borne diseases and is a reason for concern.

8.2 Analyses

The ODEQ standard for bacteria has both numeric and narrative portions. The ODEQ numeric criteria for *E. coli* sets criteria limits defined as a 30-day log mean of 126 *E. coli* CFU/100 mL and no single sample shall exceed 406 *E. coli* CFU/100 mL. According to the ODEQ numeric criteria, samples can be evaluated by using the Most Probable Number (MPN) or the membrane filtration protocols. The narrative criteria state "bacterial pollution or other conditions deleterious to waters used for domestic purposes, livestock watering, irrigation, bathing or shellfish propagation, or otherwise injurious to public health shall not be allowed" (ODEQ, 2001). Water contact recreation is the beneficial use jeopardized by fecal contamination.

There are currently no waterbodies or segments within the Upper Deschutes and Little Deschutes Subbasin that are on the state 303(d) list for exceeding the ODEQ *E. coli* criteria. Water contact recreation is quite common during the summer months throughout the subbasin. Waterbodies where fecal contamination may be a concern include reaches with high human water contact and recreational use.

Data collected from 1996 to 2002 by ODEQ ambient monitoring and intensive water quality monitoring studies for TMDL development are used for analyses.

8.2.1 How do E. coli concentrations change along the longitudinal extent of the aquatic system?

Changes along the longitudinal extent of reaches within the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 8.1** and **Figure 8.2**. A solid grey line represents a longitudinal grand mean. A solid black line represents a linear regression and is provided for insight regarding the trend over the longitudinal extent during the time period.

The upper Deschutes River has a longitudinal grand mean *E. coli* concentration of 8 CFU/100 mL.

The upper Deschutes reach has a longitudinal grand mean *E. coli* concentration of 8 CFU/100 mL. A linear regression results in a positive slope. This indicates a downstream upward trend of mean *E. coli* concentrations.

The middle Deschutes reach has a longitudinal grand mean *E. coli* concentration of 7 CFU/100 mL. A linear regression results in a negative slope. This indicates a downstream downward trend of mean *E. coli* concentrations.

The Little Deschutes River has a longitudinal grand mean *E. coli* concentration of 3 CFU/100 mL. A linear regression results in a positive slope. This indicates a downstream upward trend of mean *E. coli* concentrations.

Figure 8.1 Mean *Escherichia coli* concentrations along the longitudinal extent of the upper Deschutes River

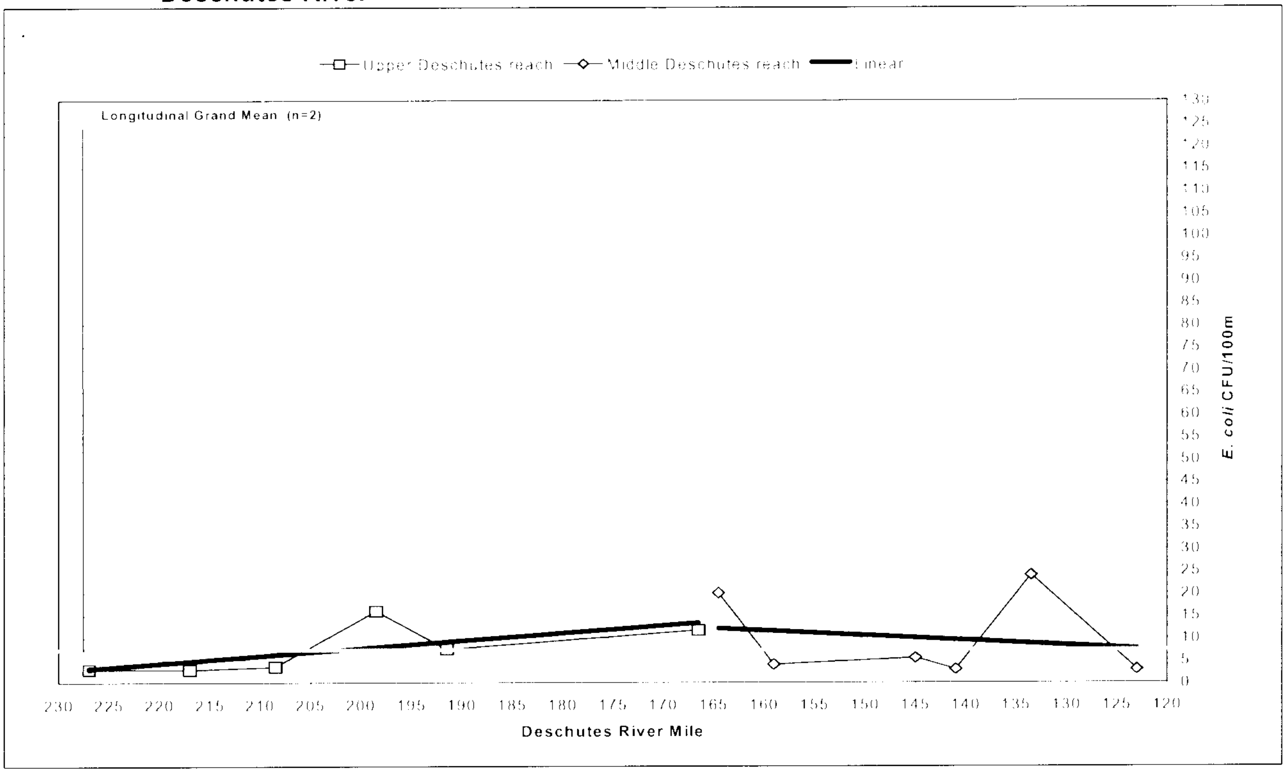
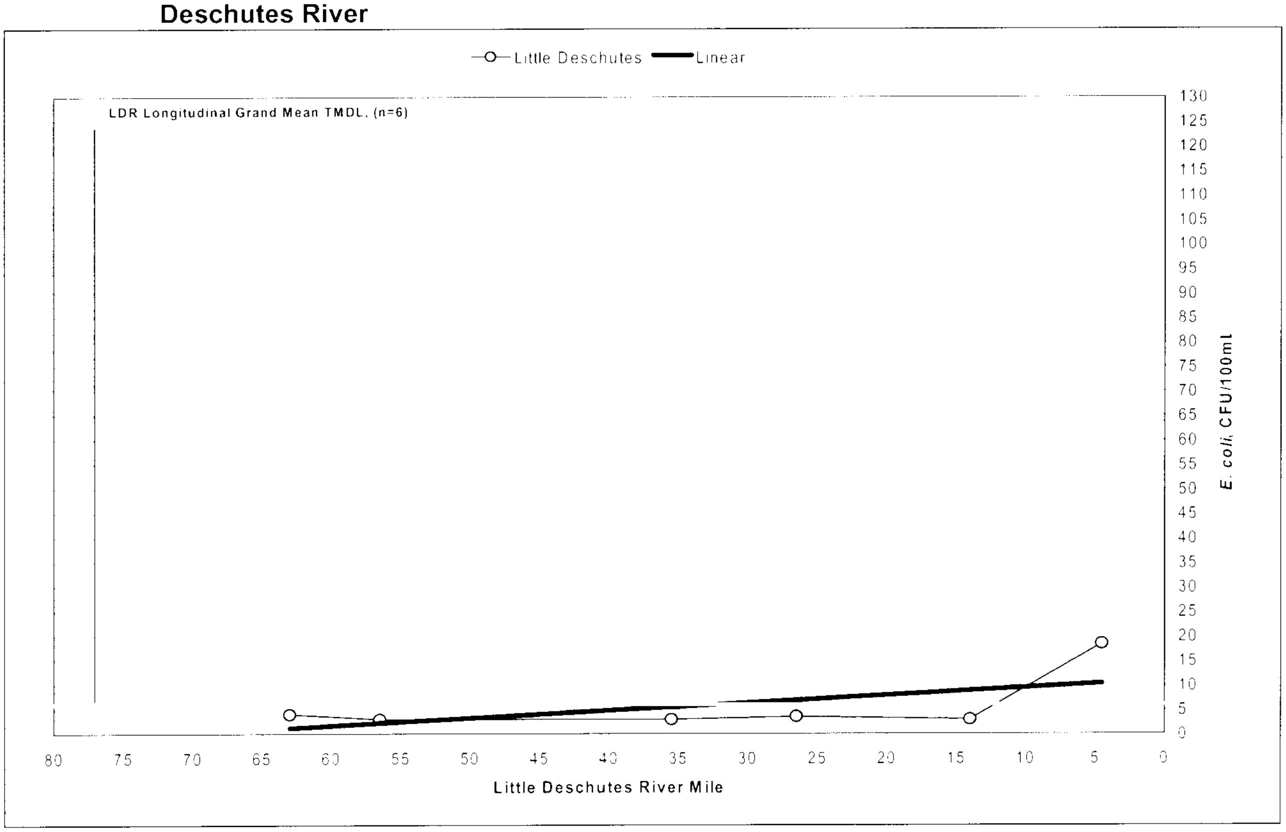


Figure 8.2 Mean *Escherichia coli* concentrations along the longitudinal extent of the Little Deschutes River



8.2.1 What is the seasonal variability of E. coli concentrations?

Seasonal fluctuations within reaches of the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 8.3**.

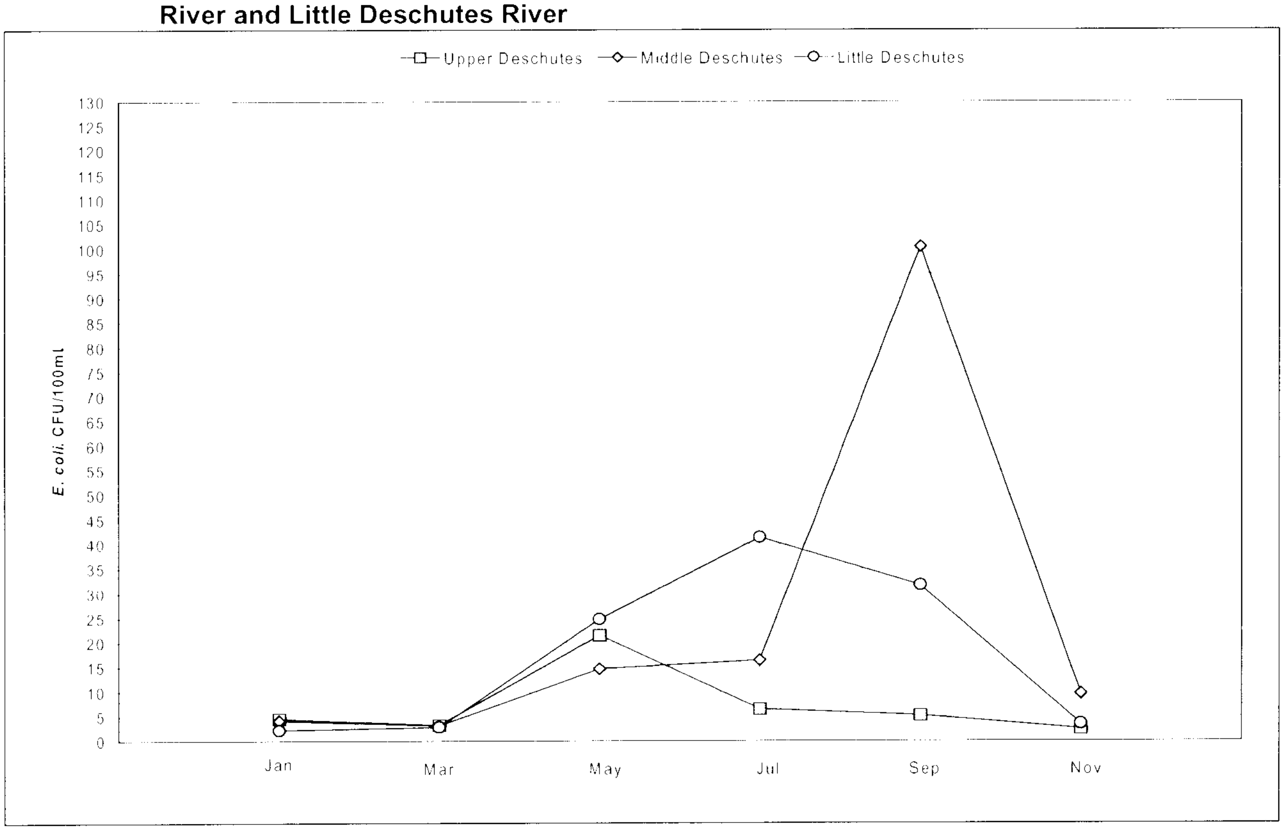
The upper Deschutes River has a seasonal grand mean *E. coli* concentration of 16 CFU/100 mL.

The upper Deschutes reach has a seasonal grand mean *E. coli* concentration of 7 CFU/100 mL and a fluctuation in seasonal mean *E. coli* concentration ranging from 2 – 22 CFU/100 mL.

The middle Deschutes reach has a seasonal grand mean *E. coli* concentration of 25 CFU/100 mL and a fluctuation in seasonal mean *E. coli* concentration ranging from 3 – 101 CFU/100 mL.

The Little Deschutes River has a seasonal grand mean *E. coli* concentration of 18 CFU/100 mL and a fluctuation in seasonal mean *E. coli* concentration ranging from 2 – 41 CFU/100 mL.

Figure 8.3 Seasonal fluctuations of *Escherichia coli* concentrations within the upper Deschutes River and Little Deschutes River



8.2.3 What is the long-term trend in E. coli concentrations?

The long-term trend for reaches within the Upper Deschutes and Little Deschutes Subbasins are illustrated in **Figure 8.4**, **Figure 8.5**, and **Figure 8.6**. A solid grey line represents a long-term grand mean. A solid black line represents a linear regression and is provided for insight regarding the trend over the time period.

The upper Deschutes River has a long-term mean *E. coli* concentration of 16 CFU/100 mL.

The upper Deschutes reach has a long-term trend in mean *E. coli* concentration of 7 CFU/100 mL. A linear regression results in a negative slope. This indicates a downward temporal trend in mean *E. coli* concentrations.

The middle Deschutes reach has a long-term trend in mean *E. coli* concentration of 24 CFU/100 mL. A linear regression results in a negative slope. This indicates a downward temporal trend in mean *E. coli* concentrations.

The Little Deschutes River has a long-term trend in mean *E. coli* concentration of 18 CFU/100 mL. A linear regression results in a negative slope. This indicates a downward temporal trend in mean *E. coli* concentrations.

Figure 8.4 Long-term trend in *Escherichia coli* concentrations within the upper Deschutes reach

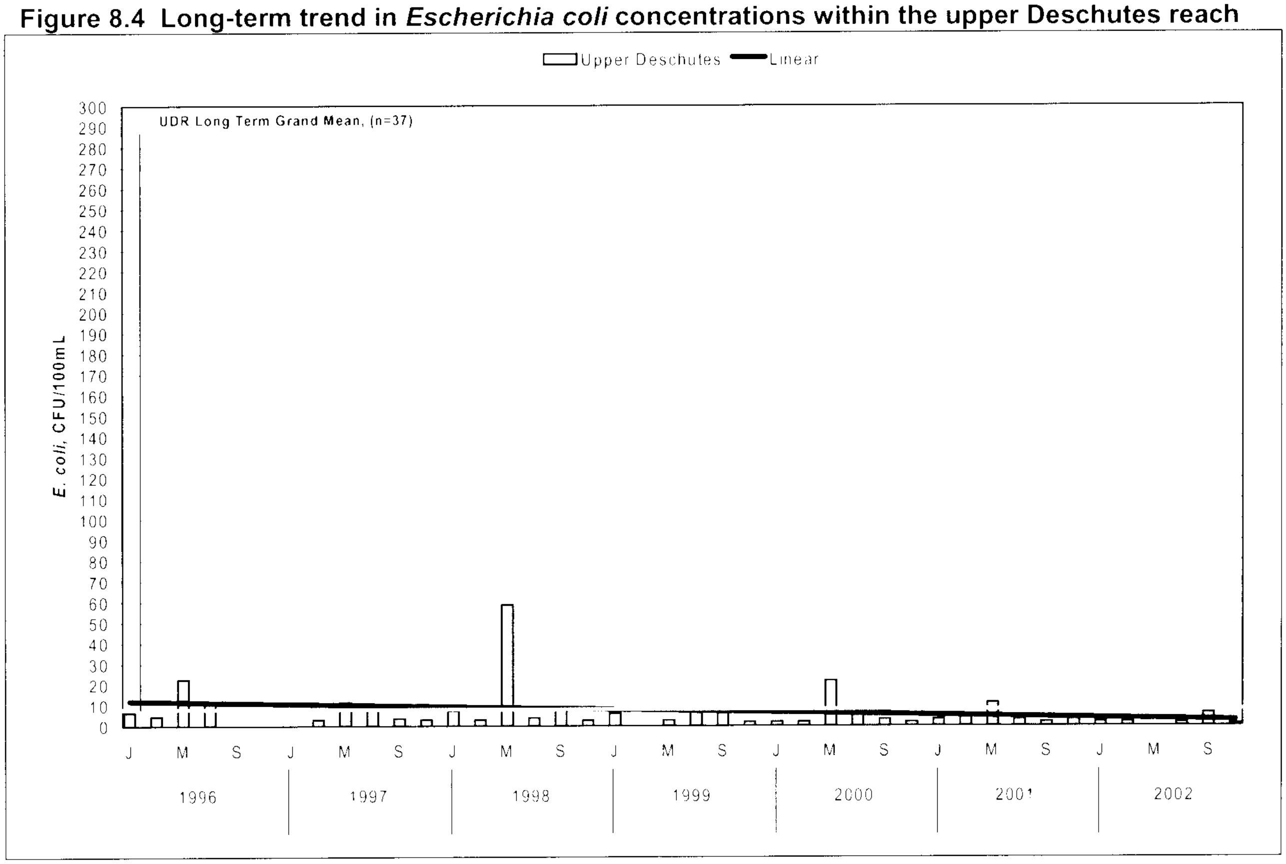


Figure 8.5 Long-term trend in *Escherichia coli* concentrations within the middle Deschutes reach

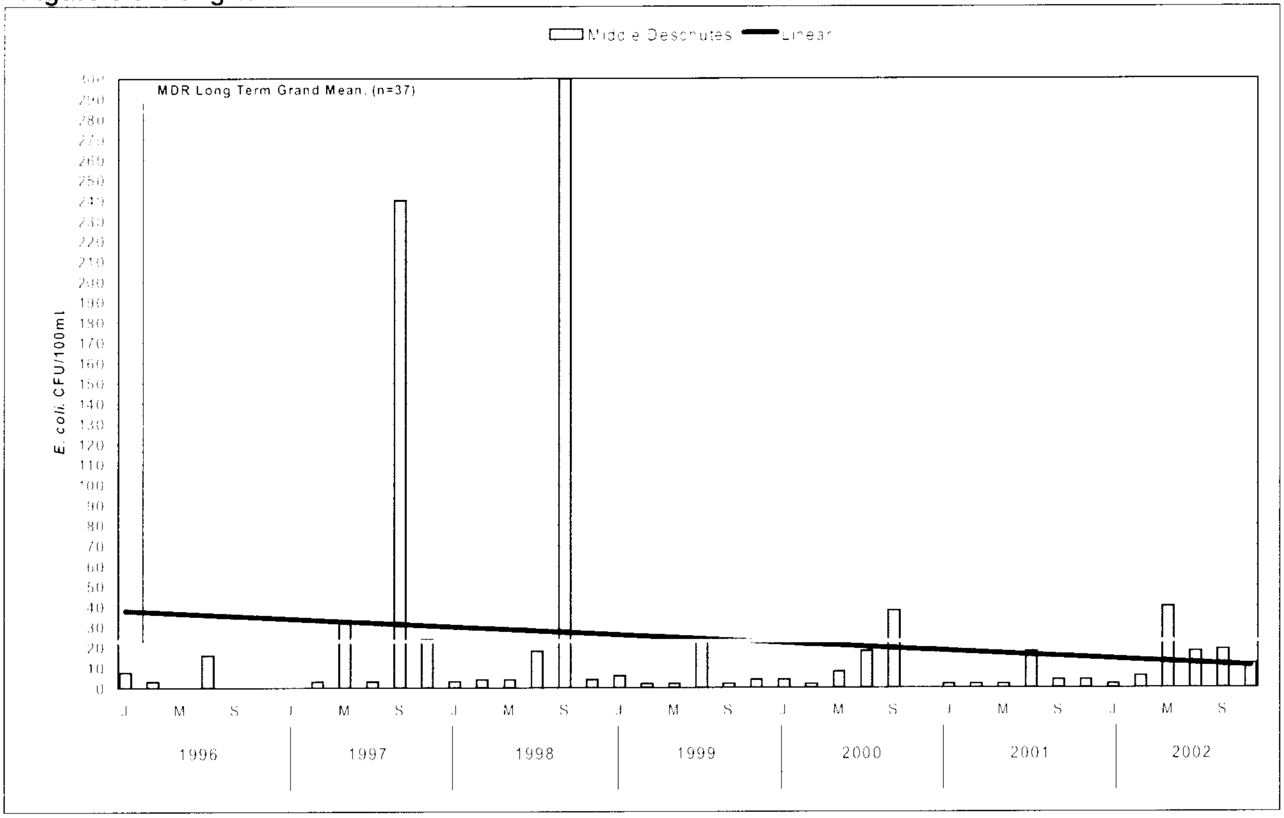
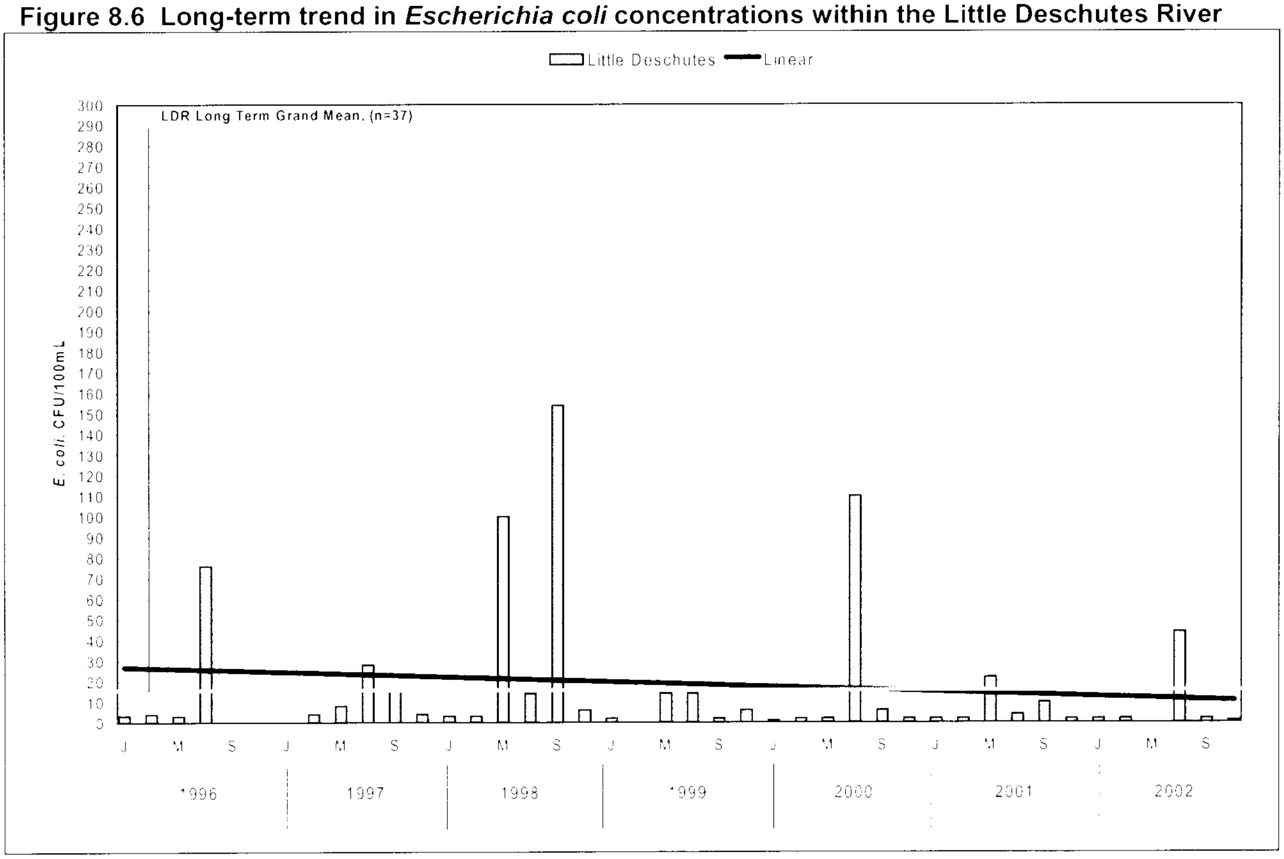


Figure 8.6 Long-term trend in *Escherichia coli* concentrations within the Little Deschutes River



8.2.4 Are E. coli concentrations compliant with regulatory criteria?

E. coli data cannot be evaluated according to the ODEQ numeric criteria that sets a limit as a 30-day log mean of 126 *E. coli* CFU/100 mL since there is insufficient data to perform this analysis.

Data are evaluated by site and season according to the ODEQ numeric criteria that sets 406 *E. coli* CFU/100 mL as the maximum for any one sample. During any one season for any one site, data are compliant with the ODEQ 406 *E. coli* CFU/100 mL criteria.

The ODEQ narrative criterion for *E. coli* sate "bacterial pollution or other conditions deleterious to waters used for domestic purposes, livestock watering, irrigation, bathing or shellfish propagation, or otherwise injurious to pubic health shall not be allowed" (ODEQ, 2001). It appears that bacterial inputs do occur in the Upper Deschutes and Little Deschutes Subbasins as evident by the presence of *E. coli* concentrations ranging from approximately 3 - 300 *E. coli* CFU/100 mL (**Figure 8.4**, **Figure 8.5**, and **Figure 8.6**).

8.3 Discussion and Key Findings

E. coli in the aquatic system indicate the presence of fecal contamination that may contain pathogenic bacteria, protozoa, and viral particles; aggressive pathogens that cause human illness. The detection of higher than normal concentrations of *E. coli* in recreational waters may indicate the presence of other water borne diseases and is a reason for further evaluation. Within the subbasins, a low concentration under 10 *E. coli* CFU/100 mL appears to be the result of natural inputs of *E. coli* from wildlife and can be considered normal. All sites that report levels of bacteria greater than 10 *E. coli* CFU/100 mL are easily accessed and have urban and rural land use influences. Sediment depositional areas may be conducive to accumulation of bacterial inputs from uncharacterized urban runoff, rural land use, and recreational use, while the Lower Bridge site may be representative of consistent, long-term, and upstream impacts from uncharacterized urban runoff, rural land use and flow modifications. There are no state 303(d) listed waterbodies or segments within the upper Deschutes and Little Deschutes Subbasins. The state criteria for bacteria is evaluated according to a single sample maximum of 406 *E. coli* CFU/100mL or a 30 day log mean value no to exceed 126 *E. coli* CFU/100 mL. Single samples have not exceeded the maximum of 406 *E. coli* CFU/100 mL, and the 30 day log mean of bacterial concentrations of the subbasins has not been evaluated. It is recommended that sites with high water contact recreation are evaluated according to the 30 day log mean concentrations in order to protect the beneficial use of recreational waters.

During January 1996, a low consistent survival of *E. coli* along the longitudinal extent of the Little Deschutes River is exhibited by a longitudinal grand mean under 10 *E. coli* CFU/100 mL (**Figure 8.2**). In addition, the upper Deschutes reach and the middle Deschutes reach also exhibit a longitudinal grand mean *E. coli* concentration under 10 *E. coli* CFU/100 mL (**Figure 8.1**). Seasonal *E. coli* data exhibits a seasonal grand mean under 10 *E. coli* CFU/100 mL during January, March, and November for the upper Deschutes River and Little Deschutes River (**Figure 8.3**). Long-term *E. coli* data exhibits many values that are under 10 *E. coli* CFU/100 mL. The under 10 *E. coli* CFU/100 mL concentrations are likely the result of natural inputs of *E. coli* from wildlife and can be considered normal.

10 *E. coli* CFU/100mL is a very low concentration compared to the state criteria. The EPA sets bacteria criteria based on how many illnesses are expected upon exposure to waters with a particular level of indicator *E. coli* bacteria (EPA, 2002). The EPA considers 8 illnesses out of 1000 exposures acceptable for freshwaters and has set indicator concentrations appropriately. The Oregon state criterion of 406 *E. coli* CFU/100mL is based on the EPA recommendations for waters that are lightly used with full body contact. The EPA recommends for waters that are moderately used with full body contact a level of 298 *E. coli* CFU/100mL and for waters that have designated beach areas a level of 235 *E. coli* CFU/100mL. In addition, the EPA recommends that frequent monitoring of known recreation areas should occur to establish a more complete database upon which to determine if the waterbody is attaining the water quality criteria and more intensive surveys when higher than normal levels of bacteria are measured. Within the region, there are areas that are moderately used with full body contact and areas that are considered beach areas. High use recreation areas within the region should be monitored since there are data that report levels greater than the EPA recommendations for waters that are moderately used and waters that have designated beach areas.

There are three sites in the upper Deschutes reach, three sites in the middle Deschutes reach, and one site in the Little Deschutes reach that indicate reaches with recreational use may be of concern due to *E. coli* concentrations that appear higher than normal (**Figure 8.1** and **Figure 8.2**). The upper Deschutes reach sites include the Road 2114 and Harper Bridge sites and the Mirror Pond site. The middle Deschutes reach sites include the Riverhouse Hotel, Cline Falls State Park, and the Lower Bridge sites. The Little Deschutes River site includes the Road 2114 site. All of the sites that appear to have higher numbers of *E. coli* are sites that are easy access due to roads, bridges, and parks and sites that are susceptible to bacterial inputs due to uncharacterized urban runoff and rural land use. More data needs to be collected from sites with common recreational use in order to evaluate the ODEQ criterion of a 30 day log mean limited to 126 *E. coli* CFU/100mL and protect the beneficial use of recreational waters.

In addition to evaluating recreational sites via the ODEQ criterion, sediment samples can be evaluated for *E. coli*. Depositional areas subject to uncharacterized urban runoff, rural land use, agriculture, and high recreational use may be conducive to *E. coli* survival. Sediment deposition zones create a more favorable environment for *E. coli* survival especially if there are organic inputs from uncharacterized urban runoff, rural land use, and agriculture. "Survival of *E. coli* in the secondary habitat (outside the host) requires the ability to overcome low nutrient availability and wide temperature fluctuations", and in addition, half-lives of *E. coli* are longer in sediments than in water (Winfield, 2003). *E. coli* concentrations may also be maintained by regular bacterial inputs from uncharacterized urban runoff, rural land use, agriculture and high recreational use. The combination of depositional areas and uncharacterized urban runoff, rural land use, agriculture and high recreational use may support input and survival of *E. coli* within sediments. The *E. coli* data presented in the Technical Report is collected from water column samples, whereas *E. coli* concentrations can be evaluated from both water column and sediment samples.

The Lower Bridge site may be representative of consistent, long-term, and upstream impacts within the subbasins. Sources for bacterial inputs at the Lower Bridge site include uncharacterized urban runoff, rural land use, and flow modifications. Mean *E. coli* concentrations at the Lower Bridge are the most elevated in the subbasins and reflect a mean *E. coli* concentration of 24 *E. coli* CFU/100 mL, while some data approaches 300 *E. coli* CFU/100 mL (**Figure 8.1** and **Figure 8.5**). Bacterial inputs are further indicated by seasonal and long-term analyses.

The seasonal mean *E. coli* concentrations are illustrated in **Figure 8.3** for the upper Deschutes River and the Little Deschutes River. The upper Deschutes reach exhibits low mean *E. coli* concentrations during July and September that may correspond to high summer flows that create conditions that are not conducive to *E. coli* survival and may even transport *E. coli* downstream. The middle Deschutes reach exhibits a seasonal peak during September that may be indicative of warmer waters more conducive to *E. coli* survival, lower flows that concentrate *E. coli* numbers, and nonpoint source bacterial inputs. The Little Deschutes River illustrates a seasonal fluctuation in *E. coli* survival ability. In the colder months, *E. coli* concentrations for the Little Deschutes River are under 10 *E. coli* CFU/100 mL. During the warmer months of May, July, and September, greater survival rates and continued inputs may occur due to warmer waters, available sediments, and continual bacterial inputs.

Long-term trends in mean *E. coli* concentrations indicate a downward trend for the upper Deschutes River and Little Deschutes River (**Figure 8.4**, **Figure 8.5**, and **Figure 8.6**). The upper Deschutes reach appears to have the least impacts from bacterial inputs, yet this may be due to increased summer flows flushing bacterial inputs downstream during the months of increased human contact and recreation. The middle Deschutes reach exhibits several bacterial inputs predominately in September that reflect data collected from the Lower Bridge site. The Little Deschutes River also exhibits several nonpoint source bacterial inputs. Although the bacterial inputs all occur during May and September for both the middle Deschutes reach and Little Deschutes River, events do not appear to correlate by month and year. The lack of correlation by year indicates that inputs may not be seasonal in nature.

There are currently no waterbodies or segments within the Upper Deschutes and Little Deschutes Subbasins that are on the state 303(d) list for not being compliant with the ODEQ *E. coli* criteria. Data are evaluated by site and season according to the ODEQ numeric criteria that sets 406 *E. coli* CFU/100 mL as the maximum for any one sample. During any one season for any one site, data are compliant with the ODEQ 406 *E. coli* CFU/100 mL criteria. There is insufficient data to evaluate compliance with the ODEQ numeric criteria that sets a limit as a 30-day log mean of 126 *E. coli* CFU/100 mL.

The ODEQ narrative criterion for *E. coli* sate "bacterial pollution or other conditions deleterious to waters used for domestic purposes, livestock watering, irrigation, bathing or shellfish propagation, or otherwise injurious to pubic health shall not be allowed" (ODEQ, 2001). It appears that bacterial inputs may occur in the middle Deschutes reach and Little Deschutes River as evident by levels of mean *E. coli* concentrations that appear higher than normal and as evident by bacterial concentrations reported during the summer months on the middle Deschutes reach and Little Deschutes River (**Figure 8.5** and **Figure 8.6**).

It is recommended that bacterial concentrations at key recreational use sites are evaluated according to the ODEQ criterion of a 30 day log mean limited to 126 *E. coli* CFU/100mL. Investigations that frequently monitor known recreation areas should occur to determine if the waterbody is attaining the water quality criteria and to protect the beneficial use of recreational waters. Investigations should provide more intensive surveys when higher than normal levels of bacteria are measured. In addition, it is recommended to include sediment analyses at recreational use areas characterized by sediment deposition and exposed to inputs from uncharacterized urban runoff and rural land use.

Key Findings

- Consistent and low bacterial concentrations under 10 *E. coli* CFU/100 mL is likely the result of natural inputs of *E. coli* from wildlife and can be considered normal.
- All sites that report levels of bacteria greater than 10 *E. coli* CFU/100 mL are easily accessed and have urban and rural land use influences.
- Sediment depositional areas may be conducive to accumulation of bacterial inputs from uncharacterized urban runoff, rural land use, and recreational use.
- The Lower Bridge site bacterial concentrations may be representative of consistent, long-term, and upstream impacts from uncharacterized urban runoff, rural land use, and flow modifications.
- Waterbodies and segments within the upper Deschutes and Little Deschutes Subbasins are compliant with the ODEQ criterion of 406 *E. coli* CFU/100 mL limit, yet some data indicate that evaluation of bacterial concentrations according to the ODEQ criterion that limits a 30 day log mean to 126 *E. coli* CFU/100 mL may provide a better indicator of conditions and protect the beneficial use of recreational waters.

9.0 Summary of Priority Issues

Regional Water Quality Impairment
The continued investigations into water quality impairments within the subbasins are recommended due to 303(d) listings, nonpoint source pollution, and flow modifications.

303(d) Listings
The subbasins include over 1,800 miles of streams, and many segments are listed as impaired under Section 303(d) of the Clean Water Act. The water quality impairments affect the beneficial uses. Many segments have insufficient data for compliance analyses or surplus data that needs compliance analyses regarding regulatory criteria. Compliance to water quality criteria remains a significant challenge in the region as evident by the increase in listed stream miles between 1998 and 2002.

Nonpoint Source Pollution
There are only five NPDES permitted point-source discharges in the Upper Deschutes subbasins, therefore it is widely agreed that nonpoint sources are the more significant contributors to water quality impairment. Possible nonpoint source pollution discharges that need investigation include uncharacterized urban runoff, rural land use, and agriculture. In addition, bacterial inputs at easily accessed sites, urban areas, and areas of high recreational use need investigation to protect beneficial use of recreational waters.

Flow Modifications
The quantity of water in the subbasins is ultimately tied to water rights and the laws that govern those rights. The Prior Appropriations Doctrine is the basis for western water law and states; first in time, first in right. Those rights held prior to the more junior right holders have first use of the water. In the Upper Deschutes Subbasin, over appropriation has occurred on most of the streams and rivers.

The flow modifications due to out-of-stream uses have possible impacts on the subbasins water quality and beneficial uses. The fluctuations in flows have contributed to temperature 303(d) listings, and segments in the subbasins have also been listed for flow modification. The fluctuation in flows continues to contribute to poor water quality.

Human Health
Investigations of human health indicators are recommended due to possible regional anthropogenic impacts on beneficial uses. The City of Bend is experiencing rapid population growth as evident by the city reports of population increases from 12,000 to over 60,000 people in less than 20 years. The area of Bend is partially served by a piped stormwater system that contributes uncharacterized point source discharges into the upper Deschutes River and contributes uncharacterized nonpoint source overland flow of stormwater discharging into the river. Flow modifications likely result in increases in sediment loads within the upper Deschutes River between Wickiup Reservoir and the City of Bend and increases in sediment deposition upstream and within the City of Bend. Urban runoff may transport compounds that partition into the deposited sediments, accumulate, and may cause human health risks and water borne illnesses upon exposure during recreation and water contact.

Environmental Health
Investigations of environmental health indicators are recommended due to possible regional anthropogenic impacts on beneficial uses. Above the City of Bend, the quality of waters within the Wickiup/Crane Prairie Reservoirs are largely uncharacterized and need to be evaluated, and the quantities of reservoir waters released may have impacts including decreasing bank stability, altering nutrient concentrations, and possibly optimizing periphyton populations. In addition, uncharacterized runoff from urban, rural, and agricultural sources transports compounds into the upper Deschutes River, while water diversions may exasperate conditions. The flow fluctuations and the uncharacterized runoff may be contributing to the anthropogenic eutrophication of the upper Deschutes River. Increasing eutrophication impacts the health of biological communities of the upper Deschutes River.

10.0 FUTURE RECOMMENDATIONS

10.1 Monitoring Efforts

10.1.1 Capacity

- Expand the Technical Report to include other watersheds within the region including Tumalo, Squaw Creek, and Metolius watersheds.
- Incorporate additional parameter sampling during coordinated, regional water quality monitoring efforts; focus on increasing the amount of quality data for a variety of water quality parameters.
- Establish volunteer monitoring project to increase the regional monitoring capacity; focus on assisting coordinated, regional monitoring efforts incorporate additional parameter data collection, increasing QA/QC, and increasing quality data.
- Increase training opportunities between volunteers, agencies, and the ODEQ Water Quality Monitoring Section; focus on increasing data quality via the regional application of standard QA/QC.

10.1.2 Physical Parameters

- Evaluate water quality parameters within the Wickiup/Crane Prairie Reservoir complex; focus on the affects of Wickiup/Crane Prairie Reservoir complex on the upper Deschutes reach water quality parameters.
- Increase future monitoring of daily variability of temperature, pH, and dissolved oxygen; focus on capturing daily and seasonal fluctuations within the subbasins.
- Implement monitoring of turbidity fluctuations; focus on identifying reaches critical for aquatic life refuge.
- Evaluation of natural background levels for percent fine sediments within the subbasins; focus on naturally high percent fine sediments and their relationship to sediment source, sedimentation, and regional biological impacts and adaptations.

10.1.3 Chemical Parameters

- Evaluate nutrients within the Wickiup/Crane Prairie Reservoir complex; focus on nutrient concentrations and sources
- Increase monitoring of biochemical oxygen demand; focus on identifying segments impacted from pollution, prioritizing restoration within impacted segments, and decreasing inputs of organic and inorganic pollution.
- Increase monitoring of nutrients; focus on the influences from Wickiup/Crane Prairie Reservoir complex and stream nitrogen trends, processing analyses, and trophic status indexing.
- Increase ground water to surface water interaction evaluations; focus on nitrogen loading of surface waters.

10.1.4 *Biological Parameters*

- Perform fish gill tissue analyses; focus on identifying if the high fine sediments are impacting the health of the aquatic communities.
- Regionally index historic and current aquatic macroinvertebrate assemblages; focus on identifying if sedimentation is impacting the health of the aquatic communities.
- Quantify benthic chlorophyll-*a*; focus on the optimization of periphyton and associated carbon load impacts from periphyton die offs and stream nitrogen trends, processing analyses, and trophic status indexing.
- Increase future monitoring of sestonic chlorophyll-*a*; focus on influences from Wickiup/Crane Prairie Reservoir complex and stream nitrogen trends, processing analyses, and trophic status indexing.
- Increase future monitoring of bacteria; focus sources of bacterial inputs impacting areas that are easily accessible, have high recreational use, and high human contact.

10.2 Sediment Load Management

- Continue implementation of the Deschutes Wild and Scenic River Management Plan adaptive flow management strategy; focus on decreasing the sediment load entering the upper Deschutes River.
- Monitor sediment sources downstream Wickiup Reservoir; focus on priority sites and possible bank stabilization strategies.
- Increase bank stabilization projects downstream of Wickiup Reservoir; focus on decreasing sediment load entering the upper Deschutes River.
- Evaluate sediment load transport from Wickiup through the City of Bend into the middle Deschutes reach; focus on characterization of transport and deposition.
- Implement sediment deposition management projects upstream and within the City of Bend; focus on developing long-term, effective restoration projects to address sediment deposition.

10.3 Community Health

- Evaluate the evaluate uncharacterized runoff from urban, rural, and agricultural sources; focus on identifying constituents that may affect human health and the integrity of biological communities.
- Develop outreach and education that informs the community of the impacts of urban runoff within the City of Bend; focus on increasing knowledge of what practices negatively and positively impact the upper Deschutes River.
- Address the City of Bend urban runoff; focus on developing urban management and engineering strategies that prevent pollution of the upper Deschutes River, protect human health, and protect the biological integrity of communities within and downstream of the City of Bend.
- Establish intensive water quality and sediment monitoring of sediment depositional areas upstream, within, and downstream of the City of Bend; focus on urban runoff constituents that negatively affect human health, recreational use, and aesthetics.

10.4 Restoration and Conservation Projects

- Establish Squaw Creek and upper Deschutes River water quality monitoring habitat conservation and restoration projects; focus on the beneficial use of salmonid populations.

- Identify and implement conservation of important tributaries; focus on tributaries that are invaluable in offsetting the anthropogenic impacts affecting water quantity and quality.

- Implement conservation of areas that are experiencing increases in human impacts; focus on preserving riparian and upland vegetation, trail designation, and educational signage placements.

- Increase community action in restoration and conservation projects; focus on creating a community that socially values the active, on the ground contribution towards projects.

- Increase community financial contributions towards restoration and conservation projects; focus on creating a community that socially values the financial contributions to projects that enhance environmental resources in order to better the community economy and preserve the central Oregon lifestyle.

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Appendix - A

Description of parameters and waterbodies within the Upper Deschutes and Little Deschutes Subbasins listed on the ODEQ 2002 303(d) list

Parameter	Beneficial Uses	Criteria	Waterbody (Name and River Miles)
pH	water contact recreation resident fish and aquatic life	6.5-8.5 Season: Winter/Spring/Fall	**Deschutes River** (Steelhead Falls to North Main Unit canal) RM 126.4 to162.6
	water contact recreation resident fish and aquatic life	6.5-8.5 Season: Spring/Summer	**Deschutes River** (North Unit Irrigation Canal to Central Oregon Canal) RM 162.6 to 168.2
	water contact recreation resident fish and aquatic life	6.5-8.5 Season: Summer	
	water contact recreation resident fish and aquatic life	6.5-8.5 Season: Summer	**Odell Lake / Odell Creek** RM 11 to 16.3
Dissolved oxygen	salmonid fish spawning	Spawning: 11mg/L or 95% saturation Season: September 1 - June 30	**Deschutes River** (Central Oregon Canal to Little Deschutes River) RM 168.2 to 189.4 **Deschutes River** (Little Deschutes River to Wickiup Reservoir) RM 189.4 to 222.2 **Little Deschutes River** (Mouth to below Crescent Creek) RM 0 to 54.1
	salmonid fish rearing	Cold water: 8 mg/L or 90% saturation Season: July 1 - August 31	**Deschutes River** (Central Oregon Canal to Little Deschutes River) RM 168.2 to 189.4 **Little Deschutes River** (Mouth to below Crescent Creek) RM 0 to 54.1

<table>
<tr><th>Parameter</th><th>Beneficial Uses</th><th>Criteria</th><th>Waterbody
(Name and River Miles)</th></tr>
<tr><td rowspan="2">Sedimentation</td><td>salmonid fish spawning
salmonid fish rearing
resident fish and aquatic life</td><td>Formation of appreciable bottom or sludge deposits
Season: annual</td><td>Deschutes River
(Central Oregon Canal to Little Deschutes River)
RM 168.2 to 189.4
Deschutes River
(Little Deschutes River to Wickiup Reservoir)
RM 189.4 to 222.2</td></tr>
<tr><td>salmonid fish spawning
salmonid fish rearing
resident fish and aquatic life</td><td>Formation of appreciable bottom or sludge deposits
Season: annual</td><td rowspan="2">Deschutes River
(Central Oregon Canal to Little Deschutes River)
RM 168.2 to 189.4
Deschutes River
(Little Deschutes River to Wickiup Reservoir)
RM 189.4 to 222.2</td></tr>
<tr><td rowspan="2">Turbidity</td><td>aesthetics
resident fish and aquatic life
water supply</td><td>No more than 10% cumulative increase in natural stream turbidities
Season: annual</td></tr>
<tr><td>aesthetics
resident fish and aquatic life
water supply</td><td>No more than 10% cumulative increase in natural stream turbidities
Season: annual</td><td rowspan="2">Deschutes River
(Central Oregon Canal to Little Deschutes River)
RM 168.2 to 189.4
Deschutes River
(Little Deschutes River to Wickiup Reservoir)
RM 189.4 to 222.2</td></tr>
<tr><td>Chlorophyll-a</td><td>aesthetics
resident fish and aquatic life</td><td>0.015 mg/L
Season: June 1 – September 30</td></tr>
<tr><td>Nutrients</td><td>aesthetics
water contact recreation
resident fish and aquatic life</td><td></td><td></td></tr>
<tr><td>Bacteria</td><td>water contact recreation</td><td>30-day log mean of 126 E. coli CFU/100 mL, based on a minimum of five samples and no single sample shall exceed 406 E. coli CFU/100 mL</td><td></td></tr>
</table>

(ODEQ, 2003)

Appendix - B

Summary of Upper Deschutes and Little Deschutes Subbasins water quality monitoring studies
River Miles obtained from USGS Quadrangle 1:24 000 7.5 minute series topographic and approximated to the half mile.

Site	RM	DEQ Ambient Monitoring	PGE Monitoring	2001/2002 TMDL Intensive	2001 DEQ/USFS Sediment Study	1997/1998 REMAP Study	1995/1996 TMDL Intensive
Upper Deschutes reach							
Downstream Wickiup Reservoir	227.0			C/G*	G		C/G
Upstream Tenino Boat launch	225.5				C		
Pringle Falls Bridge	217.0	G		G			G
Downstream Tetherow Boat launch	212.5				C		
State Park Road	208.5			G			G
Big River Rd. (upstream road 42 bridge)	200.0				C		
Road 2114	198.5			G			G
Crosswater Golf Course	192.0				C		
Harper Bridge	191.5	G		C/G			C/G
Upstream Benham Falls	183.0				C		
Benham Falls Footbridge	181.0			G			G
Columbia Street Bridge	167.5			G			
Mirror Pond	166.5	G					G
Middle Deschutes reach							
Riverhouse Hotel Bridge	164.5			C/G			C/G
Upstream Tumalo Creek	160.5			G			
Tumalo Bridge	159.0						G
Cline Falls State Park	145.0			G			G
Odin Falls Road	141.0						G
0.2 miles Upstream Lower Bridge	134.0					G	
Lower Bridge	133.5	G		C/G			C/G
Upstream Steelhead Falls	128.0			G			
Downstream Squaw Creek	123.0			G			G
Inflow to Lake Billy Chinook	120.0		G				

Site	RM	DEQ Ambient Monitoring	PGE Monitoring	2001/2002 TMDL Intensive	2001 DEQ/USFS Sediment Study	1997/1998 REMAP Study	1995/1996 TMDL Intensive
Little Deschutes River							
0.5 miles Downstream USFS Rd 100	71.5					G	
Upstream Gilchrist Mill Pond	63.0			C/G			C/G
Road 2320	56.5			G			G
Masten Road	35.5			G			G
Burgess Road	26.5			G			G
State Park Road	14.0			G			G
Road 2114	4.5	G					C/G
Crosswater Golf Course Bridge	1.0			C/G	C		

* C=Continuous Monitoring; G=Grab Samples

Study Descriptions:

DEQ Ambient Monitoring: Grab samples are taken at each site and analyzed for a number of parameters, including: pH, alkalinity, dissolved oxygen, BOD, turbidity, chlorophyll-a (summer only), nutrients, temperature, conductivity and *E. coli* bacteria. Sites are visited once every other month (January, March, May, July, September and November).

PGE Monitoring: PGE takes monthly grab samples at the inflows to Lake Billy Chinook for pH, dissolved oxygen and temperature.

2001/2002 TMDL Intensive Monitoring: Three different sampling events occurred as part of this monitoring program. Samples were collected between 7/31-8/3 in 1995 and 1/22-1/25 in 1996. Continuous data was collected for pH, dissolved oxygen, conductivity and temperature at 15 minute intervals. Some of the continuous monitoring units failed during the course of the study so there may not be data for every site indicated during each sampling event. Grab samples were analyzed for: pH, alkalinity, dissolved oxygen, BOD, TOC, turbidity, TSS, chlorophyll-a (summer only), nutrients, temperature, and conductivity.

2001 Sediment Study: ISCO samplers were used to collect 2-4 “continuous” composite water samples each day from 3/30-6/7 in 2001. Starting in the first week of July, the ISCO samplers were run for approximately 5 days at the beginning of each month, collecting 2 composite samples per day. Samples were collected this way through the first week of October, 2001. In addition to the continuous ISCO samples, grab samples were collected at one location 1-2 times each sampling week throughout the study. Samples were analyzed for turbidity, TSS, total solids, and total volatile solids.

1997/1998 REMAP Study: The REMAP study collected temperature, riparian habitat, water chemistry and biological information at 55 sites throughout the Deschutes Basin. Two of these sites were located in the Upper Deschutes Project Area. Grab samples were taken for water chemistry in 1997 and/or 1998. Samples were analyzed for: pH, alkalinity, dissolved oxygen, BOD, TOC, turbidity, TSS, total solids, nutrients, temperature, and conductivity.

1995/1996 TMDL Intensive Monitoring: Two different sampling events occurred as part of this monitoring program. Samples were collected between 7/16-7/20 and 11/5-11/8 in 2001 and 4/29-5/3 in 2002. Continuous data was collected for pH, dissolved oxygen, conductivity and temperature at 15 minute intervals. Some of the continuous monitoring units failed during the course of the study so there may not be data for every site indicated during each sampling event. Grab samples were analyzed for: pH, alkalinity, dissolved oxygen, BOD, TOC, turbidity, TSS, chlorophyll-a (summer only), nutrients, temperature, conductivity and fecal coliform.

Appendix - C

Summary of Upper Deschutes and Little Deschutes Subbasins water quality monitoring sites, river miles, and parameters used in the Technical Report

River Miles obtained from USGS Quadrangle 1:24 000 7.5 minute series topographic and approximated to the half mile.

Site	RM	pH	DO	BOD	Turb.	Sed.*	Chl-*a*	Nutr.	Bact.
Upper Deschutes reach									
Downstream Wickiup Reservoir	227.0	X	X	X	X		X	X	X
Upstream Tenino Boat launch	225.5				X				
Pringle Falls Bridge	217.0	X	X	X	X		X	X	X
Downstream Tetherow Boat launch	212.5				X				
State Recreation Road	208.5	X	X	X	X		X	X	X
Big River Rd. (upstream road 42 bridge)	200.0				X				
Road 2114	198.5	X	X	X	X		X	X	X
Crosswater Golf Course	192.0		X	X	X				
Harper Bridge	191.5	X	X	X	X		X	X	X
Upstream Benham Falls	183.0				X				
Benham Falls Footbridge	181.0	X	X	X	X		X	X	
Columbia Street Bridge	167.5	X	X	X	X		X	X	
Mirror Pond	166.5	X	X	X	X		X	X	X
Middle Deschutes reach									
Riverhouse Hotel Bridge	164.5	X	X	X	X		X	X	X
Upstream Tumalo Creek	160.5	X	X	X	X		X	X	
Tumalo Bridge	159.0	X	X	X	X		X	X	X
Cline Falls State Park	145.0	X	X	X	X		X	X	X
Odin Falls Road	141.0	X	X	X	X		X	X	X
Upstream Lower Bridge	134.0	X	X	X	X			X	
Lower Bridge	133.5						X		X
Upstream Steelhead Falls	128.0		X	X	X		X	X	
Steelhead Falls	127.5	X							
Downstream Squaw Creek	123.0	X	X	X	X		X	X	X
Little Deschutes River									
Downstream USFS Road 100	71.5	X	X	X	X			X	
Upstream Gilchrist Mill Pond	63.0	X	X	X	X		X	X	X
Road 2320	56.5	X	X	X	X		X	X	X
Masten Road	35.5	X	X	X	X		X	X	X
Burgess Road	26.5	X	X	X	X		X	X	X
State Recreation Road	14.0	X	X	X	X		X	X	X
Road 2114	4.5	X	X	X	X		X	X	X
Crosswater Bridge	1.0	X	X	X	X		X	X	

* Biological criteria for sedimentation evaluation exists and may be assessed in the future.