Wenatchee River Watershed Dissolved Oxygen and pH Total Maximum Daily Load

Water Quality Improvement Report

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Wenatchee River Watershed Dissolved Oxygen and pH Total Maximum Daily Load

Water Quality Improvement Report

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Water Resource Inventory Area 45

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Abstract

The Wenatchee River, Icicle Creek, and some tributaries in the Wenatchee River watershed are on the state of Washington's list of impaired waters for dissolved oxygen and pH. This list is known as the 303(d) list.

In 2002, the Washington State Department of Ecology (Ecology) began a study of several water quality problems noted in the Wenatchee River watershed. Ecology completed TMDLs for DDT in Mission Creek and for fecal coliform bacteria and temperature throughout the Wenatchee River watershed. The U.S. Environmental Protection Agency approved these TMDLs.

This TMDL is for dissolved oxygen and pH in the Wenatchee River watershed. During 2002 and 2003, Ecology collected water quality data from the mainstem Wenatchee River, Icicle Creek, and other tributaries, as well as from permitted facilities discharging to these waters.

In 2005 and 2006, Ecology used these data to:

- Assess the cause of dissolved oxygen and pH violations of Washington State water quality standards in these rivers and streams.
- Show that phosphorus is the limiting nutrient in Icicle Creek and the lower Wenatchee River.
- Calibrate a QUAL2K water quality model for the Wenatchee River and Icicle Creek.

The QUAL2K model simulated natural water quality conditions in the Wenatchee River and Icicle Creek. Ecology then used the model to calculate how much point source and nonpoint source pollution should be reduced to meet water quality standards for dissolved oxygen and pH.

This report also contains an Implementation Strategy that provides direction for developing a *Water Quality Implementation Plan* (WQIP). The WQIP will provide guidance for implementation of best management practices and other restorative activities throughout the Wenatchee River watershed. This guidance will promote compliance with all the TMDLs completed in the Wenatchee River watershed.

Acknowledgements

The authors of this report would like to thank the following people for their contribution to this study:

- Mike Rickel from the Cascadia Conservation District for his major contribution to the collection of data used to develop this TMDL, and for coordinating the development of all TMDLs in the Wenatchee River watershed.
- Members of the Wenatchee Watershed Water Quality Technical Subcommittee for their patient review of all the TMDLs in the Wenatchee River watershed, including this one.
- Staff with the Washington State Department of Ecology:
    - Kirk Sinclair for help with groundwater analysis and making maps.
    - Paul Pickett for peer review.
    - Joan LeTourneau and Cindy Cook for initial formatting and editing of the technical sections of this report.
    - Jane Creech, Greg Bohn, and Mark Peterschmidt for reviewing various versions of this report.
    - Cheryl Niemi and Mark Hicks for peer review.

Executive Summary

The federal Clean Water Act requires that a total maximum daily load (TMDL) be developed for each of the water bodies on the 303(d) list. The TMDL identifies pollution problems in the watershed and specifies how much pollutant loading needs to be reduced or eliminated to achieve clean water. The Washington State Department of Ecology (Ecology) then works with the local community to develop (1) an overall approach to control pollutants, called the *Implementation Strategy*, and (2) a monitoring plan to assess the effectiveness of water quality improvement activities.

Ecology collected data for TMDLs in the Wenatchee River watershed during 2002 and 2003. This technical analysis was completed in 2004. In 2006, the Wenatchee Watershed Water Quality Technical Subcommittee reviewed the technical study, and it was published (Carroll et al., 2006).

This study area is in Water Resource Inventory Area (WRIA) 45.

Table ES-1. Project area water bodies on 2004 303(d) list for dissolved oxygen and pH.

Water Body	Parameter	Medium	Listing ID	Township	Range	Section
Brender Creek	DO	Water	8406	23N	19E	05
Icicle Creek		Water	8416	24N	17E	24
Wenatchee River		Water	10705	25N	17E	09
Icicle Creek	pH	Water	8417	24N	17	24
Mission Creek		Water	34799	23N	19E	04
			11282	23N	19E	05
No Name Creek		Water	41819		--	
Peshastin Irrigation Return[1]		Water	41823		--	
Van Creek		Water	41834	25N	18E	24
Wenatchee River		Water	10702	23N	20E	28
			41269	23N	19E	11

Goals and objectives: clean water and uses

The goal of this TMDL is to achieve water quality standards in the Wenatchee River watershed for dissolved oxygen (DO) and pH by the year 2018. Achieving water quality standards for DO and pH in the watershed will ensure protection of endangered, threatened, and other important aquatic species. To achieve the goals of this TMDL, large reductions of point sources and nonpoint sources of phosphorus loading to the Wenatchee River and Icicle Creek must occur.

[1] Name changed from Pioneer Irrigation Return to Peshastin Irrigation Return on 1/19/06.

Watershed description

The Wenatchee River watershed encompasses 878,423 acres of Chelan County in central Washington. It is formed on the west by the Cascade Mountains, on the north by the Entiat Mountains, and on the south by the Wenatchee Mountains. The Wenatchee River joins the Columbia River at the City of Wenatchee, approximately 15 miles upstream from Rock Island Dam.

The federal Endangered Species Act lists three species of fish as threatened or endangered in the Wenatchee River watershed.

Endangered:

- Upper Columbia River population of Chinook salmon (Oncorhynchus tshawytscha).
- Upper Columbia River population of steelhead trout (Oncorhynchus mykiss).

Threatened:

- Upper Columbia River populations of bull trout (Salvelinus confluentus).

The water quality standards targeted by this TMDL affect fish health and survival.

There are both point and nonpoint sources of phosphorus that affect DO and pH in the Wenatchee River watershed. In this TMDL, point sources are defined as those sources allowed under a National Pollutant Discharge Elimination System (NPDES) permit. These include wastewater treatment plants (WWTPs) and fish hatcheries. Nonpoint sources are diffuse sources not managed by an NPDES permit. Examples of potential nonpoint sources include leaking on-site septic systems.

Allocations summary

To achieve water quality standards, less phosphorus must be discharged to the Wenatchee River and Icicle Creek during the critical period (March-May and July-October). The critical period is the time of year when the river has relatively low streamflows. In the Wenatchee River watershed, the critical period typically occurs from March through October, and is interrupted by increased streamflows due to snowmelt. Snowmelt often occurs between late May and early July.

Ecology calculated wasteload allocations for point sources and load allocations for nonpoint sources that, if achieved, will restore and maintain DO and pH conditions in the lower Wenatchee River and Icicle Creek. See Tables ES-2 and ES-3. In addition, this TMDL sets a zero nitrogen load increase in the upper Wenatchee River mainstem above the town of Leavenworth.

Table ES-2. Summary table showing wasteload and load allocations (as target total phosphorus loads) and necessary phosphorus load reductions in the lower Wenatchee River to meet dissolved oxygen and pH water quality standards during critical low-flow conditions.

Loading source category	Current phosphorus load (kg/day)	Percent reduction	Target phosphorus load (kg/day)
Upstream load	1.24	25%	0.93
Current discharge at municipal WWTPs	27.37	98.6%	0.39
Non-contact cooling water discharges	0.112	48%	0.058
Tributaries, including Icicle Creek	1.75	49%	0.90
Irrigation-management return flow	0.29	10%	0.26
Diffuse loads	19.23	60%	7.54
Withdrawals	-2.39	NA	-0.81
Allocation for design flow at WWTP	NA	NA	0.57
Allocation for future growth	NA	NA	0.0
Margin of safety	NA	NA	NA (implicit)
Totals	47.6	80%	9.8

Table ES-3. Summary table showing wasteload and load allocations (target total phosphorus loads) and necessary phosphorus load reductions in lower Icicle Creek to meet dissolved oxygen and pH water quality standards during critical low-flow conditions.

Loading source category	Current phosphorus load (kg/day)	Percent reduction	Target phosphorus load (kg/day)
Upstream load	0.01	0%	0.01
Leavenworth National Fish Hatchery	1.27	62%	0.48
Diffuse loads	0.19	32%	0.13
Allocation for future growth	NA	NA	0.0
Margin of safety	NA	NA	NA (implicit)
Totals	1.45	57%	0.62

Wasteload allocations

Ecology determined the maximum daily concentration of total phosphorus that can be discharged from permitted facilities to meet the wasteload allocation (Tables ES-4 and ES-5).

Table ES-4. Wasteload allocations for wastewater treatment plants that discharge to the lower Wenatchee River.

WWTPs	Wasteload allocation (micrograms/liter of total phosphorus)
Leavenworth	90
Peshastin	90
Cashmere	90

Two treatment plants hold NPDES permits in the Wenatchee River watershed, but they are not receiving wasteload allocations. It was concluded that their current discharge limits do not contribute to the dissolved oxygen and pH violations seen in the watershed due to the seasonal nature of their discharge.

Table ES-5. Wasteload allocations for the Leavenworth National Fish Hatchery on Icicle Creek.

Facility name	Wasteload allocation (micrograms/liter of total phosphorus)
Leavenworth National Fish Hatchery	5.7

Conclusions

- Portions of the Wenatchee River, lower Icicle Creek, and other tributaries do not meet water quality standards for DO and pH during the critical period identified by this project.
- Point and nonpoint contributions of nutrients cause the Wenatchee River and Icicle Creek to violate Washington State water quality standards for DO and pH. These streams are very sensitive to nutrient additions.
- Phosphorus is the limiting nutrient in the lower Wenatchee River and lower Icicle Creek.
- Phosphorus levels in the Wenatchee River watershed must be reduced to improve DO and pH levels in the watershed, protect Endangered Species Act listed fish, and protect other uses.

Implementation

Implementation of this TMDL will involve reducing phosphorus loading to the lower Wenatchee River and lower Icicle Creek from both point and nonpoint sources of phosphorus. In addition, implementation will target reductions of phosphorus from nonpoint sources in the tributaries, especially Chumstick Creek, Brender Creek, and Mission Creek.

- NPDES permits will include total phosphorus limits designed to reach the loading capacity of the lower Wenatchee River and Icicle Creek. The discharge amounts allowed from point sources will take into account the expected reduction of phosphorus from nonpoint sources.
- Nonpoint sources will be addressed through the enforcement of existing laws and through voluntary steps, with support from education and monitoring components of the implementation plan.
- The need for TMDL effectiveness monitoring will be evaluated every five years.
- Further implementation details will be provided in a comprehensive *Water Quality Implementation Plan* that will be written to describe implementation of all of the TMDLs completed in the Wenatchee River watershed.

What is a Total Maximum Daily Load (TMDL)

Federal Clean Water Act requirements

The Clean Water Act established a process to identify and clean up polluted waters. The Clean Water Act requires each state to have its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of (1) designated uses for protection, such as cold water biota and drinking water supply, and (2) criteria, usually numeric criteria, to achieve those uses.

Every two years, states are required to prepare a list of water bodies – lakes, rivers, streams, or marine waters – that do not meet water quality standards. This list is called the 303(d) list. To develop the list, the Washington State Department of Ecology (Ecology) compiles its own water quality data along with data from local, state, and federal governments, tribes, industries, and citizen monitoring groups. All data are reviewed to ensure that they were collected using appropriate scientific methods before the data are used to develop the 303(d) list. The 303(d) list is part of the larger Water Quality Assessment.

The Water Quality Assessment is a list that tells a more complete story about the condition of Washington's water. This list divides water bodies into five categories:

Category 1 – Meets standards for parameter(s) for which it has been tested

Category 2 – Waters of concern

Category 3 – Waters with no data available

Category 4 – Polluted waters that do not require a TMDL because:
- 4a. – Has an approved TMDL and it is being implemented
- 4b. – Has a pollution control program in place that should solve the problem
- 4c. – Is impaired by a non-pollutant such as low water flow, dams, culverts

Category 5 – Polluted waters that require a TMDL – the 303(d) list

TMDL process overview

The Clean Water Act requires that a total maximum daily load (TMDL) be developed for each of the water bodies on the 303(d) list. The TMDL identifies pollution problems in the watershed and specifies how much pollution needs to be reduced or eliminated to achieve clean water. Ecology then works with the local community to develop (1) an overall approach to control the pollution, called the *Implementation Strategy*, and (2) a monitoring plan to assess effectiveness of the water quality improvement activities.

Ecology worked closely with the Wenatchee Watershed Planning Unit's Water Quality Technical Subcommittee to develop an implementation strategy. The strategy was published by the Wenatchee Watershed Planning Unit in the Wenatchee Watershed Management Plan (Chelan County 2006).

Once the U.S. Environmental Protection Agency (EPA) approves the TMDL, Ecology must develop a *Water Quality Implementation Plan* (WQIP). Usually this is completed within one year. This plan identifies specific tasks, responsible parties, and timelines for achieving clean water. The WQIP for this TMDL will be published in a comprehensive WQIP that describes implementation for each TMDL in the Wenatchee River watershed.

Elements required in a TMDL

The goal of a TMDL is to ensure that impaired water will attain water quality standards. A TMDL includes a written, quantitative assessment of the water quality problems and of the pollutant sources that cause the problem, if known. The TMDL determines the amount of a given pollutant that can be discharged to the water body and still meet standards (the *loading capacity*), and allocates that load among the various sources.

Identifying the pollutant loading capacity for a water body is an important step in developing a TMDL. EPA defines the loading capacity as "the greatest amount of loading that a water body can receive without violating water quality standards" (EPA, 2001). The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a water body into compliance with the standards.

The portion of the receiving water's loading capacity assigned to a particular source is a *wasteload* or *load* allocation. If the pollutant comes from a discrete (point) source, such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a *wasteload allocation*. If the pollutant comes from a set of diffuse (nonpoint) sources such as general urban, residential, or farm runoff, the cumulative share is called a *load allocation*.

The TMDL must also consider seasonal variations, and include a *margin of safety* that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A *reserve capacity* for future loads from growth pressures is sometimes included as well. By definition, a TMDL is the sum of the allocations, which must not exceed the loading capacity. The sum of the wasteload and load allocations, the margin of safety, and any reserve capacity must be equal to or less than the loading capacity.

TMDL = loading capacity = sum of all wasteload allocations + sum of all load allocations
+ margin of safety.

Why is Ecology Conducting a TMDL in this Watershed?

Overview

Ecology is conducting this TMDL to set pollution reduction targets that will bring the Wenatchee River, Icicle Creek, and other tributaries into compliance with Washington State water quality standards for dissolved oxygen (DO) and pH. Correcting DO and pH problems in these streams is important for the protection of fish and other valuable aquatic species listed under the Endangered Species Act.

Ecology's River and Stream Monitoring Program and the Chelan County Conservation District collected water quality data that identified DO and pH impairments in the Wenatchee River, Icicle Creek, and Brender Creek. As a result, these waters were placed on the 1996 and 1998 303(d) lists for DO and pH. Additional information collected for this TMDL showed that DO and pH violations occurred at other locations in the Wenatchee watershed. These water quality impaired stream locations were added to the 2004 303(d) list. Ecology developed this TMDL to address all water quality violations for DO and pH in the Wenatchee River watershed for the 2004 list.

This TMDL document, *Wenatchee River Watershed Dissolved Oxygen and pH Total Maximum Daily Load: Water Quality Improvement Report*, presents the following elements:

- A summary of findings from the 2006 DO and pH technical study (Carroll et al., 2006).
- Updated and additional technical analyses completed after the 2006 DO and pH technical study.
- A quantitative framework for improving water quality in the watershed. This framework (1) describes a natural condition range for phosphorus, and (2) allocates phosphorus loads to sources in the Wenatchee River watershed that will improve DO and pH levels and meet water quality standards.
- An implementation strategy that describes (1) the roles of organizations with responsibility to improve water quality, and (2) the means through which these organizations will address the water quality issues.

Wenatchee River watershed

The study area for this TMDL consists of the Wenatchee River watershed (Figure 1), which is also referred to as Water Resource Inventory Area (WRIA) 45.

The water quality impairments addressed by this TMDL occur in:

- The lower Wenatchee River watershed below the City of Leavenworth and above the confluence with the Columbia River.
- The Icicle Creek watershed below the Leavenworth National Fish Hatchery.

Although most violations occur in the lower portion of the Wenatchee River and tributaries, upstream pollution sources contribute to downstream violations. The impairments typically occur during periods of seasonally low streamflow. Most water quality violations for DO and pH occur in August and September, although impairments also occur during the pre-runoff period in the spring.

There is a mixture of federal, state, county, and private land ownership throughout the Wenatchee River watershed. Most of the upper watershed is federally owned land managed as the Wenatchee National Forest by the United States Department of Agriculture's Forest Service (USFS).

Annual average precipitation varies throughout the watershed, and is usually related to elevation and proximity to the crest of the Cascade Mountains. Near the crest of the mountains, the watershed receives up to 150 inches per year of precipitation as rain and snow. Near the City of Wenatchee, the watershed receives only eight inches of precipitation as rain and snow.

The climate of the watershed affects the flow of the mainstem Wenatchee River, with peak run-off occurring in May and June charged by snowmelt from the upper portion of the watershed. Low flows occur in August and September after alpine snows have melted and Pacific Ocean high-pressure systems dominate the area with relatively dry weather. Figure 2 presents the monthly average streamflow patterns for various sites in the Wenatchee River watershed.

The Endangered Species Act lists three species of fish as endangered or threatened in the Wenatchee River watershed.

- The Upper Columbia River population of Chinook salmon (Oncorhynchus tshawytscha) is listed as endangered.
- The Upper Columbia River population of steelhead trout (*Oncorhynchus mykiss*) is listed as endangered.
- Upper Columbia River population of bull trout (*Salvelinus confluentus*) is listed as threatened.

Achieving the water quality standards targeted by this TMDL will promote fish health and survival of these species, non-listed salmonids, other fish species, and non-fish species.

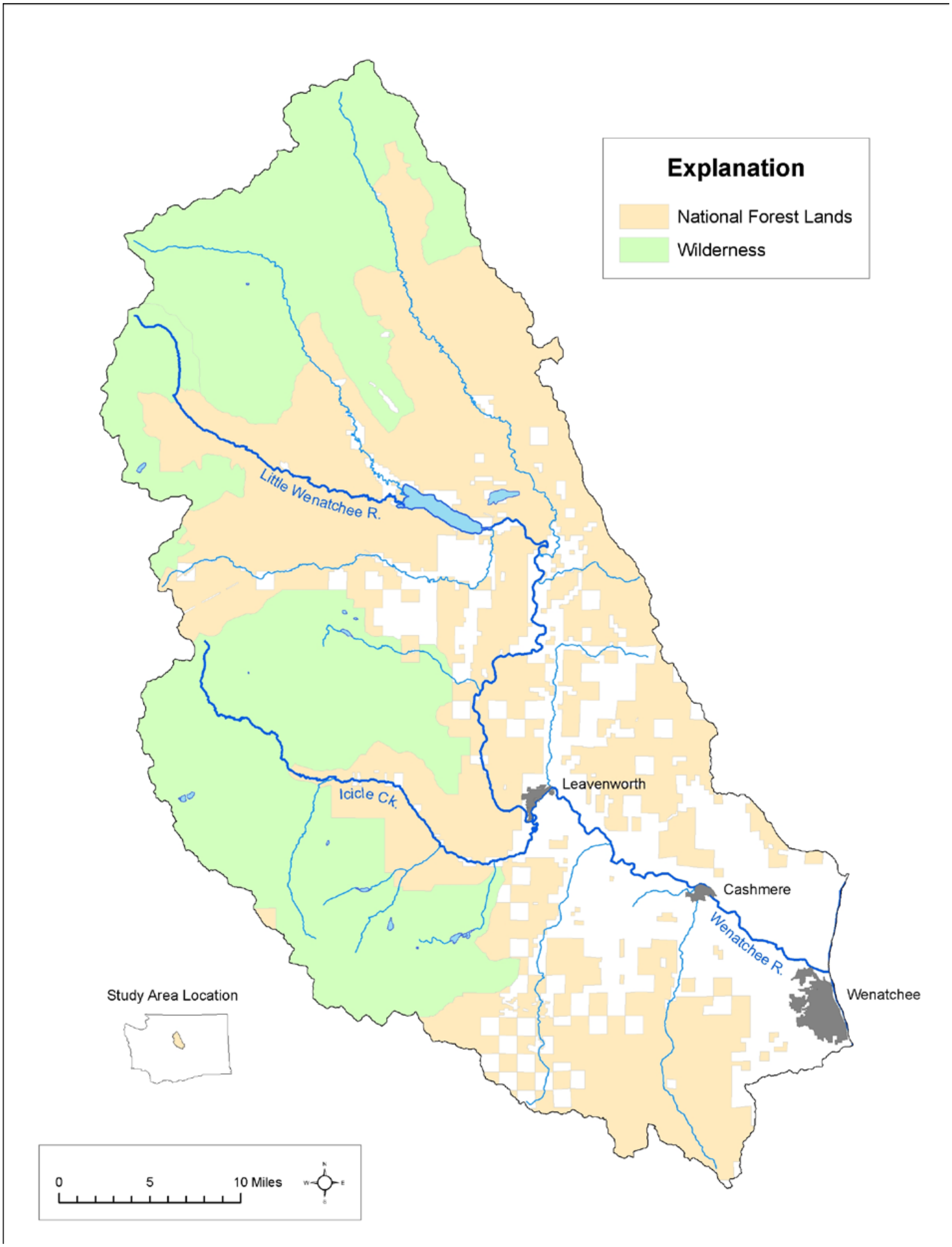

Figure 1. Map of the Wenatchee River watershed.

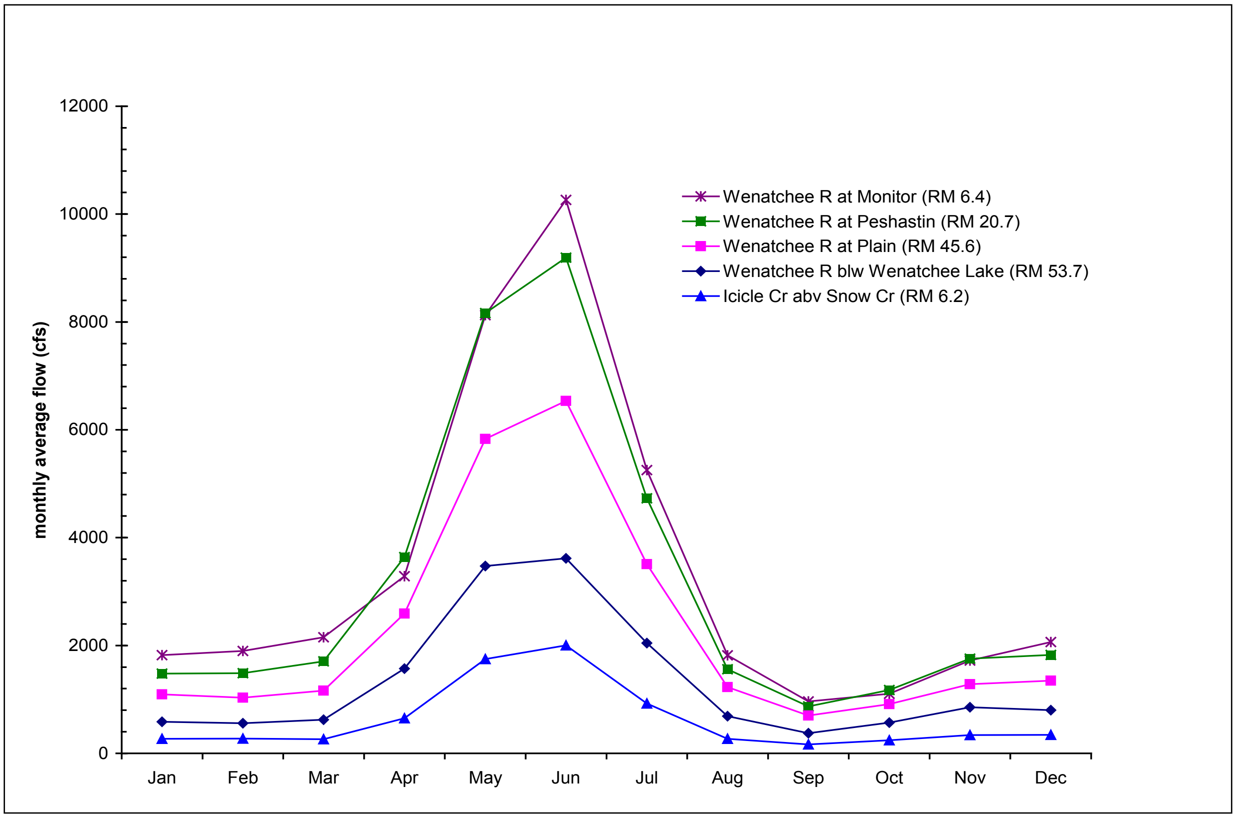

Figure 2. Monthly average streamflows at various gages in the Wenatchee River watershed.

Pollutants addressed by this TMDL

The lower Wenatchee River and lower Icicle Creek do not meet Washington State water quality standards for DO and pH during low streamflow conditions. Results of water quality data analysis and of water quality modeling indicate that excessive nutrient loading to the lower sections of the Wenatchee River and Icicle Creek cause these violations. Analysis also shows that phosphorus is the limiting nutrient in these streams. *The Wenatchee River Basin Dissolved Oxygen, pH and Phosphorus TMDL Study* (Carroll et al., 2006) concluded that lowering phosphorus contributions to the lower Wenatchee River and Icicle Creek would improve DO and pH conditions in these water bodies.

This TMDL sets phosphorus loading capacities for the lower Wenatchee River and Icicle Creek that, if achieved, will result in meeting water quality standards for DO and pH in the Wenatchee River and Icicle Creek.

Impaired beneficial uses and water bodies on Washington State's 303(d) list of impaired waters

Table 1 presents the current 2004 303(d)-listed water bodies in the Wenatchee River watershed for DO and pH. Ecology's River and Stream Monitoring Program and the Chelan County Conservation District collected water quality data that identified DO and pH impairments in the Wenatchee River, Icicle Creek, and Brender Creek. As a result, these waters were added to the 1996 and 1998 303(d) lists for DO and pH. Additional information collected for this TMDL showed that DO and pH violations occurred at other locations in the watershed. These water quality impaired streams were added to the 2004 303(d) list.

Table 1. Project area water bodies on the 2004 303(d) list for dissolved oxygen and pH (Category 5 listings).

Water Body*	Parameter	Medium	Listing ID	Township	Range	Section
Brender Creek	DO	Water	8406	23N	19E	05
Icicle Creek		Water	8416	24N	17E	24
Wenatchee River		Water	10705	25N	17E	09
Icicle Creek	pH	Water	8417	24N	17	24
Mission Creek		Water	34799	23N	19E	04
			11282	23N	19E	05
No Name Creek		Water	41819		--	
Peshastin Irrigation Return[2]		Water	41823		--	
Van Creek		Water	41834	25N	18E	24
Wenatchee River		Water	10702	23N	20E	28
			41269	23N	19E	11

[2] Name changed from Pioneer Irrigation Return to Peshastin Irrigation Return on 1/19/06.

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Water Quality Standards and Beneficial Uses

Dissolved oxygen

Aquatic organisms are very sensitive to reductions in the level of DO in the water. The health of fish and other aquatic species depends on maintaining an adequate supply of oxygen dissolved in the water. Oxygen levels affect growth rates, swimming ability, susceptibility to disease, and the relative ability to endure other environmental stressors and pollutants. While direct mortality due to inadequate oxygen can occur, Washington State designed the criteria to maintain conditions that support healthy populations of fish and other aquatic life.

Oxygen levels can fluctuate over the day and night in response to changes in weather as well as the respiratory requirements of aquatic plants, algae, and bacteria. Since the health of aquatic species depends predominantly on the pattern of daily minimum oxygen concentrations, the criterion is the lowest one-day minimum oxygen concentration that occurs in a water body.

In the Washington State water quality standards (WAC 173-201A), freshwater aquatic life use categories are described using key species (salmonid versus warm-water species) and life-stage conditions (spawning versus rearing). One-day minimum DO concentrations are used as criteria to protect different categories of aquatic communities. In this TMDL, the following designated aquatic life uses and criteria are to be protected:

1. To protect the designated aquatic life use of "Char spawning and rearing," the lowest 1-day minimum oxygen level must not fall below 9.5 mg/l more than once every ten years on average.
2. To protect the designated aquatic life use of "Core summer salmonid habitat," the lowest one-day minimum oxygen level must not fall below 9.5 mg/l more than once every ten years on average.
3. To protect the designated aquatic life use of "Salmonid spawning, rearing, and migration," the lowest 1-day minimum oxygen level must not fall below 8.0 mg/l more than once every ten years on average.

The Wenatchee River watershed above Peshastin Creek and the Icicle Creek watershed are designated waters for either "char spawning and rearing" or "core summer salmonid spawning, rearing, and migration." This means that these waters must maintain a DO concentration higher than 9.5 mg/L (Table 2).

The Wenatchee River watershed below Peshastin Creek (except parts of the Mission Creek watershed within and above the Wenatchee National Forest) is designated as waters for "salmonid spawning, rearing, and migration." This means that these waters must maintain a DO concentration of 8.0 mg/L or higher (Table 2).

Table 2. Designated uses and dissolved oxygen criteria in the water quality standards for streams addressed by this TMDL.

Stream description	Designated use and season	Standard
Wenatchee River watershed above Peshastin Creek including all of the Icicle Creek watershed	Core summer habitat for salmonid spawning, rearing, and migration	Not below 9.5 mg/L as a one-day minimum once every ten years
Wenatchee River watershed below Peshastin Creek	Salmonid spawning, rearing, and migration	Not below 8.0 mg/L as a one-day minimum once every ten years

Washington State uses the criteria described above to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying above the fully protective DO criteria (see *Natural Conditions* below).

While the numeric criteria generally apply throughout a water body, the criteria are not intended to apply to certain atypical areas. This can include shallow stagnant eddy pools where unique natural features are the cause of not meeting the criteria. Therefore, the standards direct that one take measurements from representative portions of rivers and streams. For similar reasons, samples are not taken from anomalously oxygen-rich areas either. For example, in a slow moving stream, focusing sampling on surface areas within a uniquely turbulent area would provide data that is erroneous for comparing to the criteria.

pH

The pH value is a measure of the relative acidity or alkalinity of water. A lower pH value (below 7) indicates that an acidic condition is present, while a higher pH (above 7) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Some natural conditions that can raise or lower freshwater pH include:

- Large amounts of inorganic carbonate from geologic sources.
- Organic processes such as bacterial decomposition or accelerated plant growth.

Excessive natural or human-caused sources of nutrients can cause excessive algae and plant growth, causing large 24-hour swings in pH.

pH is an important factor in the chemical and biological systems of natural waters. pH both directly and indirectly affects the ability of waters to have healthy populations of fish and other aquatic species.

Changes in pH affect the degree of dissociation of weak acids or bases. This effect is important because the toxicity of many compounds is affected by the degree of dissociation. While some compounds (e.g., cyanide) increase in toxicity at lower pH, others (e.g., ammonia) increase in toxicity at higher pH.

Aquatic organisms, including fish and the food they eat, are exposed to high pH levels in parts of the lower Wenatchee watershed. High pH stresses aquatic organisms by impairing their salt and water balancing processes and increasing the toxicity of some contaminants. Anadromous (sea-run) species of fish encounter this stress in their adult upstream migration, and as juveniles in rearing areas and during downstream migration. In addition, salmonid eggs in the substrate are exposed to the high pH as surface water flows through spawning gravels.

In the state's water quality standards, two pH criteria are established to protect different categories of aquatic communities [WAC 173-201A-200; 2006 edition].

1. To protect the designated aquatic life uses of "char" and "core summer salmonid habitat," pH must be kept within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.2 units.

2. To protect the designated aquatic life uses of "Salmonid Spawning, Rearing, and Migration," "Non-anadromous Interior Redband Trout," and "Indigenous Warm Water Species," pH must be kept within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.5 units.

Number 1 applies to the Wenatchee River above Peshastin Creek and to Icicle Creek year-round. Number 2 applies to the Wenatchee River below Peshastin Creek as well as Brender Creek year-round (Table 3).

Table 3. Designated uses and criteria for pH in the water quality standards.

Stream description	Designated use and season	Standard
Wenatchee River watershed above Peshastin Creek confluence including all of Icicle Creek watershed	Core summer habitat for salmonid spawning, rearing, and migration	6.5 to 8.5 pH units with human-caused variation in range less than 0.2 units
Wenatchee River watershed below Peshastin Creek confluence	Salmonid spawning, rearing, and migration	6.5 to 8.5 pH units with human-caused variation in range less than 0.5 units

Nutrients

Nutrients are substances required by organisms to grow and survive, such as nitrogen and phosphorus. Nutrients play an essential role in primary productivity which, in turn, influences DO and pH. Nitrogen and phosphorus are present from natural geologic or organic sources. They also are present in wastewater, fertilizers, and other organic residues. Nitrogen is often fixed from the atmosphere by primary producers living in aquatic environments (Kalff, 2002).

Carbon (C), nitrogen (N) and phosphorus (P) concentrations in aquatic algae are roughly present in a C:N:P mass ratio of 40:7:1. This ratio is used to estimate which available nutrient in the water column is most likely to become depleted first, and therefore limit the growth of the plants and algae. Values of nitrogen-to-phosphorus ratios below 7 suggest growth limitation by nitrogen; values above 7 suggest growth limitation by phosphorus.

Nutrients such as phosphorus and nitrogen are essential for plant growth and aquatic community health. However, as in the lower Wenatchee River, too much of one or both of these nutrients (phosphorus in the lower Wenatchee and Icicle Creek) can cause excessive aquatic plant growth.

In streams affected by eutrophication, natural re-aeration processes cannot compensate for plant and bacterial respiration, and DO levels become too low at night. Additionally, hydrogen ion concentration (pH) becomes high at night and too low during the day. These 24-hour (day to night) swings in DO and pH can be harmful, and even fatal, to fish and aquatic insects.

In addition, nutrients can create nuisance conditions in streams by choking streams with excessive plant and algae growth. These conditions may interfere with water intake structures, water conveyance in irrigation canals, and fishing, boating, and swimming.

Washington State water quality standards do not have numeric nutrient (nitrogen and phosphorus) criteria for streams. However, the 2003 standards [Chapter 173-201A-240 (1) WAC] contain a narrative criterion applicable to nutrients as toxic substances that states the following:

Toxic, radioactive, or deleterious material concentrations shall be below those which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health, as determined by the department.

Target pollutant reductions may be expressed as loads, concentrations, or other appropriate measures [40 CFR 130.2(I)]. Limits on surrogates are allowed in TMDLs to prevent degradation of beneficial uses when a direct connection can be shown in the data. Nutrient load allocations are used in this report since nutrients are identified as the primary controllable factor for the primary productivity affecting DO and pH.

Natural conditions

This TMDL determined that DO and pH conditions in parts of the Wenatchee River watershed will not meet the assigned numeric criteria of the water quality standards due to natural conditions, but these conditions can improve so that they approach natural conditions.

The water quality standards provide guidance for protecting water quality when a water body does not meet the assigned water quality criteria due to natural conditions:

- The designated uses and criteria section of the water quality standards (WAC 173-201A-200) provides how much DO and pH change is allowed from human actions:

- In cases where DO concentrations are lower than the numeric criterion due to natural conditions, the water quality standards allow up to a 0.2 mg/L degradation of DO below natural conditions from cumulative human actions.
- In cases where the pH levels are outside the numeric pH range of 6.5 to 8.5 due to natural conditions, there is no further allowable pH degradation from human actions.

- The WAC 173-201A-260 provides direction on how to apply water quality standards when water bodies do not meet numeric criteria due to natural conditions and irreversible human conditions.

Ecology used data collected for this TMDL to estimate natural concentrations of phosphorus, then used the data to simulate DO and pH levels under natural conditions. This TMDL sets load allocations for nonpoint sources of phosphorus that, if achieved, would allow point source dischargers to the Wenatchee River watershed to release amounts of phosphorus that will not violate criteria for DO concentrations or the pH range downstream of discharges.

As noted above, the DO criteria incorporate a specific cumulative allowance for further lowering naturally poor oxygen by 0.2 mg/l. No such specific allowance is described for pH; thus, any allowed change in pH must effectively represent the goal of not further degrading natural pH levels. Ecology commonly uses a change in pH of 0.1 unit to represent a measurable change in pH in the field; thus, the TMDL target should be based at a minimum on keeping human-caused pH changes to less than 0.1 units.

Sources of Phosphorus in the Wenatchee River Watershed

Both point and nonpoint sources of phosphorus affect DO and pH in the Wenatchee River watershed. This TMDL defines point sources as discharges allowed under a National Pollutant Discharge Elimination System (NPDES) permit. In the Wenatchee River watershed, these include wastewater treatment plants, fruit storage facilities, and the Leavenworth National Fish Hatchery (LNFH). Nonpoint sources are diffuse sources not managed by an NPDES permit.

The communities of Leavenworth, Peshastin, and Cashmere all discharge treated wastewater effluent to the lower Wenatchee River. Ecology permits these discharges under conditions set in NPDES permits. The LNFH also discharges process water and wastewater to Icicle Creek. EPA manages the NPDES permit for the LNFH.

On-site septic systems are used throughout the nation in non-urban areas, including portions of the lower Wenatchee River watershed. Generally, on-site septic systems treat wastewater from one home or business at a time. Some large on-site systems, such as the community of Dryden's, service many residents. Phosphorus may be leaching from on-site septic systems into the Wenatchee River via groundwater in many areas of the lower Wenatchee River.

Other potential nonpoint sources to the lower Wenatchee River may include closed landfills, such as the Dryden Landfill owned by Chelan County, the old Dryden dump, and the old Cashmere dump. All three of these landfills are located on land parcels adjacent to the mainstem lower Wenatchee River.

Additionally, spray fields used to dispose of fruit packing wastewater may be sources of phosphorus to the Wenatchee River. There may be other potential nonpoint sources of phosphorus not yet identified.

The *Wenatchee River Basin Dissolved Oxygen, pH and Phosphorus TMDL Study* (Carroll et al., 2006) identified a small upstream load of phosphorus to the lower Wenatchee River. Upstream sources would most likely be present because of mineral weathering, biological deposition, and natural runoff loading, although some unnatural phosphorus and nitrogen sources do occur in the upper Wenatchee River. Potential human sources include on-site septic systems, fish-rearing facilities, and other land and water uses.

Groundwater influences

In streams, groundwater plays an important role for nutrient balances, as well as DO and pH patterns. Groundwater and surface water interactions vary seasonally and spatially along the length of a stream. Groundwater entering the stream can carry nutrient loads and have different DO and pH concentrations than the stream. The loads can come from geologic or human sources.

2006 Technical Study

The 2006 technical study, *Wenatchee River Basin Dissolved Oxygen, pH and Phosphorus Total Maximum Daily Load Study,* sets preliminary targets for phosphorus loading in the Wenatchee River watershed so that DO and pH will meet Washington State water quality standards (Carroll et al., 2006).

Technical study objectives

Data for the 2006 technical study were collected in 2002-03. The primary objectives for this technical study were to:

- Collect data relevant to stream productivity.
- Assess and model productivity in the streams.
- Set phosphorus reduction targets to establish productivity levels that are healthy for the Wenatchee River and Icicle Creek as defined by state water quality standards.

Technical study quality assurance evaluation

Ecology developed Quality Assurance Project Plans (Bilhimer et al., 2002, 2003) to conduct sampling and modeling of the Wenatchee River watershed. A data quality evaluation was completed and described in the technical study (Carroll et al., 2006). The data collected by Ecology for this 2006 project met the data quality objectives set for the project.

Technical study modeling analysis

Ecology used the EPA-supported QUAL2Kw water quality model to simulate DO, pH, and periphyton (attached algae) growth in the Wenatchee basin. The QUAL2Kw model is considered state-of-the-science. It is also well documented, nonproprietary, and has technical support available (Chapra and Pelletier, 2003).

Water quality data collected for the study were used to calibrate and verify the model. A data summary, data analyses, model set-up, and model calibration results are presented in the technical study (Carroll et al., 2006).

Technical study conclusions

The Wenatchee River and Icicle Creek are very sensitive to the addition of nutrients. Large reductions of phosphorus should occur from both point and nonpoint sources to meet the inorganic-P loading capacity of the lower Wenatchee River and lower Icicle Creek.
Based on water quality data collected in 2002-03, the lower Wenatchee River (from river mile 21.0 to the mouth) and lower Icicle Creek exceeded the upper 8.5 pH criterion during the low-flow season (July-October). Excessive periphyton growth caused the pH to exceed the 8.5 upper

pH limit. Analysis of nitrogen-to-phosphorus ratios of instream bio-available nutrients inferred that dissolved inorganic-P is the most limiting nutrient that controls periphyton growth in the lower Wenatchee River and lower Icicle Creek.

In the upper Wenatchee River (above Leavenworth) and upper Icicle Creek (above the LNFH), DO concentrations were less than the 9.5 mg/L criterion during the summer months due to high land elevations and high water temperatures.

Additional Analyses Since the 2006 Technical Study

The *Wenatchee River Basin Dissolved Oxygen, pH and Phosphorus Total Maximum Daily Load Study* (Carroll et al., 2006) concluded that phosphorus was the limiting nutrient in the lower Wenatchee River and lower Icicle Creek. In addition, the 2006 study provided a mass balance of phosphorus (as inorganic-P) loading to the lower Wenatchee River and Icicle Creek. The report estimated that for the lower Wenatchee River to meet the water quality standards numeric criteria for DO and pH, an overall 80 % reduction of inorganic-P to the Wenatchee River was necessary. A simple application of this load reduction would have resulted in the requirement to reduce nonpoint sources below natural background levels.

The 2006 technical study by Carroll et al. (2006) did not provide wasteload allocations or load allocations. Since then Ecology has:

- Updated the phosphorus loads during critical conditions in the phosphorus mass balance results.
- Evaluated natural condition phosphorus loads.
- Modeled water quality response using natural phosphorus concentration to determine wasteload and load allocations.

Updated phosphorus mass balance for critical conditions for the lower Wenatchee River

The 2006 technical study underestimated the critical-condition flow and therefore the inorganic-P loads from the WWTP dischargers. (September 2002 flows were used instead of 90th percentile flows.) The new mass balance based on the updated flows from the WWTP facilities is presented in Table 4.

In addition, the design flow for the Cashmere WWTP was also increased to match the current draft facility plan.

Table 4. Updated critical-condition loads and loading capacity for inorganic-phosphorus in the lower Wenatchee River during critical low-flow conditions and 90th percentile WWTP effluent discharge. *This table updates Table 22 in the 2006 Wenatchee DO and pH TMDL technical study (Carroll et al., 2006).*

Location	Load (kg/day)		% of total load
Upstream Load		1.24	*2.5%*
NPDES Point Source Loads (90th percentile loads)		27.37	*54.9%*
Leavenworth POTW	9.535		
Peshastin POTW	2.046		
Cashmere POTW	14.956		
Cashmere POTW lagoon leak (estimated)	0.837		
General Permit Loads (non-contact cooling water)		0.02	*0.0%*
Blue Bird	0.016		
Blue Star	0.001		
Bardin Growers	0.004		
Tributary Loads		1.75	*3.5%*
Icicle Creek	0.802		
Chumstick Creek	0.097		
Peshastin Creek	0.153		
Brender Creek	0.339		
Mission Creek	0.354		
Irrigation Spill Returns		0.29	*0.6%*
Cascade Orchard	0.059		
Icicle Irrigation spill near Leavenworth	0.000		
Icicle Irrigation spill at Stines Hill	0.031		
Icicle Irrigation spill at Fairview Canyon	0.047		
Jones Shotwell spill return	0.044		
Wenatchee Reclamation District spill	0.107		
Diffuse Loads (groundwater)		19.23	*38.5%*
Diffuse load between RM 26.2 and RM 21.0 (Leavenworth)	1.944		
Diffuse load between RM 21.0 and RM 17.2 (Peshastin)	2.583		
Diffuse load between RM 17.2 and RM 14.1 (Dryden)	4.478		
Diffuse load between RM 14.1 and RM 10.8	2.856		
Diffuse load between RM 10.8 and RM 6.5 (Cashmere)	7.036		
Diffuse load between RM 6.5 and RM 2.8 (Monitor)	0.335		
Load Abstractions		-2.39	
Wenatchee Reclamation District diversion	-1.869		
Jones Shotwell diversion	-0.439		
Gunn Ditch diversion	-0.083		
Total Loading		49.90	
Total Loading (minus abstractions)		47.51	
Dissolved Inorganic-P Assimilative Capacity		7.76	
Excess Dissolved Inorganic-P Loading		39.75	

NPDES – National Pollutant Discharge Elimination System
POTW – Publicly Owned Treatment Works
RM – River Mile

Table 5. Updated critical-condition inorganic-phosphorus loads for the WWTPs in the lower Wenatchee River at design flow WWTP effluent discharge. *This table updates Table 23 in the 2006 Wenatchee DO and pH TMDL technical study (Carroll et al., 2006).*

NPDES municipal point source (design flow) in the lower Wenatchee River	Inorganic-P load (kg/day)
Leavenworth WWTP (0.84 MGD)	18.7
Peshastin WWTP (0.11 MGD)	3.7
Cashmere WWTP (1.88 MGD)	42.6
Total for lower Wenatchee WWTPs (2.83 MGD)	65

These updates increase the current critical-condition inorganic-P loads to the lower Wenatchee River. The percent contributions from several source categories have changed as a result. The corrected total inorganic-P load to the lower Wenatchee is nearly 50 kg/day, with these source contributions:

- About 40 % results from diffuse sources (including natural background).
- Around 55 % results from the three WWTPs.
- Nearly 4 % is from tributaries.

Similar to the 2006 study, mass-balance modeling still showed that two reaches of the lower Wenatchee River currently exhibit higher diffuse inorganic-P loading than other reaches. Of these reaches, one brackets the community of Dryden and the other brackets the City of Cashmere. In addition, tributaries account for nearly 4 % of the inorganic-P load to the lower Wenatchee River during critical conditions.

Evaluation of natural conditions in the Wenatchee River watershed

Washington State water quality standards do not require that pollutant reductions be lower than natural background levels. Because the 2006 technical report showed that nonpoint sources might need to be reduced below natural conditions if the simple modeling strategy were used, an evaluation of natural conditions is relevant when discussing the load reductions that will be necessary to meet water quality standard. In this current report, we summarize the methods used to separate natural conditions from human-caused nonpoint loads for the Wenatchee watershed tributaries and groundwater.

As defined in the water quality standards, natural conditions are the water quality conditions that occur or would have occurred in the absence of human-derived pollution. Natural sources of nutrients, in this case phosphorus, would allow a certain amount of algae growth with subsequent natural DO and pH diel ranges. Natural phosphorus concentrations are expected to vary spatially and temporally, depending on such things as local geology and seasonal conditions that affect biological processes. Ecology estimated a natural conditions inorganic-P concentration range for tributaries and groundwater based on the distributions of observed values measured in the watershed's tributaries and groundwater during the critical period (March-May and July-October).

Natural inorganic-phosphorus concentration range in tributaries

To estimate a natural inorganic-P concentration range for tributaries, Ecology used the inorganic-P concentrations from 15 tributaries sampled between July and October 2002 and in April 2003 (Figure 3). Most of the tributaries were sampled at their mouths at least twice a month. These were the only tributaries that Ecology found with measurable running water at their mouths during the 2002 low-flow season (July-October).

Figure 4 shows the cumulative frequency distribution for all of the tributary data (number=129). The inorganic-P concentration data are graphed using a log scale on the x-axis (the data significantly fit a log-normal distribution; $\alpha = 0.01$). The data were designated as originating from three general regions in the Wenatchee watershed:

- Upper Wenatchee River: tributaries to the Wenatchee River above Leavenworth and Lake Wenatchee.
- Upper Icicle Creek: tributaries to the Icicle Creek above the Leavenworth National Fish Hatchery.
- Lower Wenatchee River: tributaries to the Wenatchee River from above Leavenworth to the mouth of the Wenatchee.

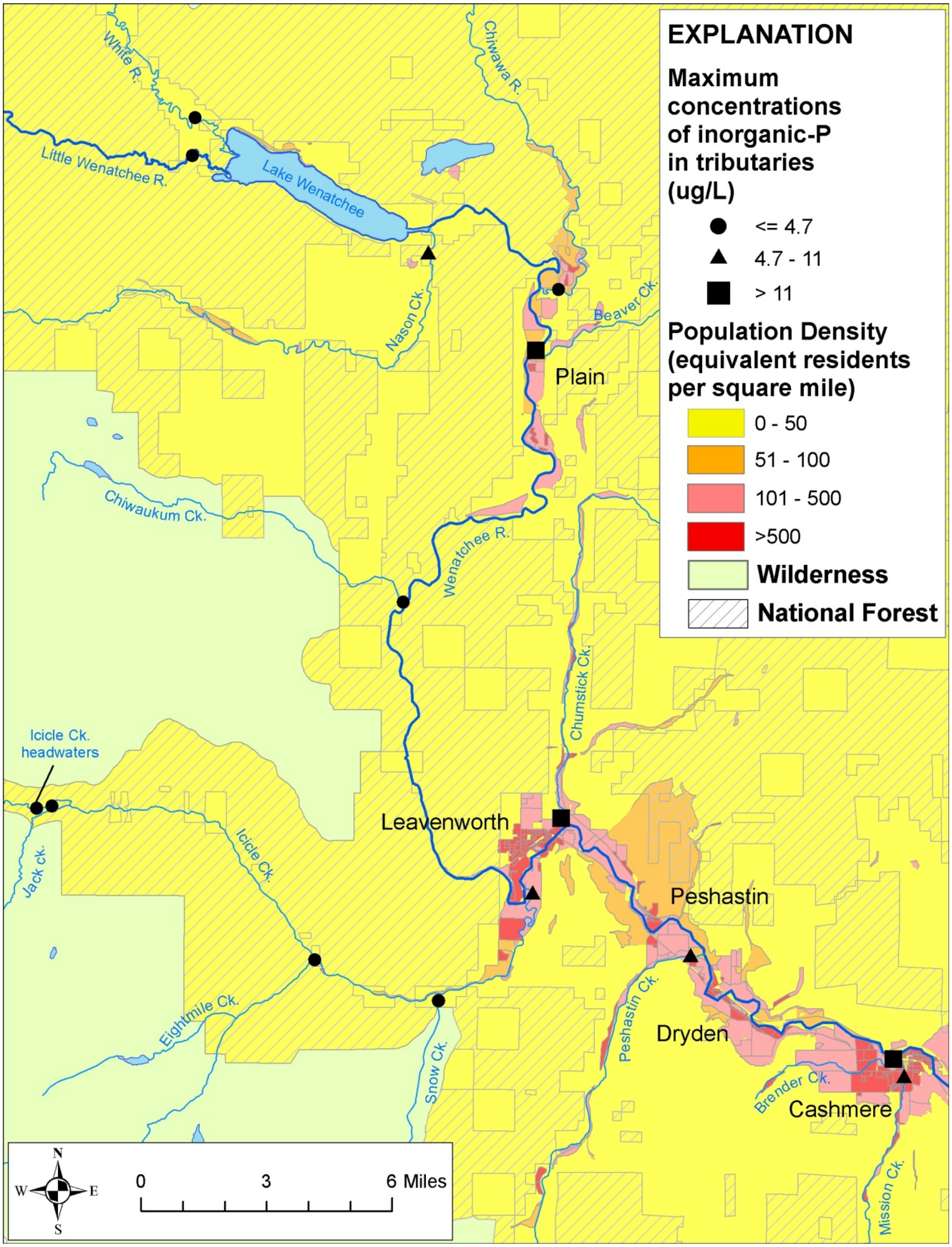


Figure 3. Distribution of maximum inorganic-phosphorus concentrations in tributaries of the Wenatchee River watershed compared to population density distribution (2000 census blocks) and public/private land ownership. *Maximum concentrations measured from July to October 2002 and in April 2003.*

As shown in Figure 4, there is a distinct inflection in the cumulative frequency distribution at a concentration of 4.7 ug/L. This suggests that the overall distribution is comprised of samples from two distinct populations of differing inorganic-P concentrations. It appears that the upper population (above 4.7 ug/L) reflects inorganic-P concentrations from polluted tributaries, while the lower population (below 4.7 ug/L) is indicative of the range of natural inorganic-P concentrations in unpolluted tributaries. Accordingly, Ecology used 4.7 ug/L (the point of inflection) as its upper estimate of the natural inorganic-P concentrations in unpolluted tributaries.

Approximately 70 % of the tributaries measured in the watershed had phosphorus concentrations less than or equal to 4.7 ug/L. These tributaries were found in each of the three regions of the watershed described above. The lower estimate of the natural inorganic-P concentration range would be at or below the reporting limit of 3.0 ug/L.

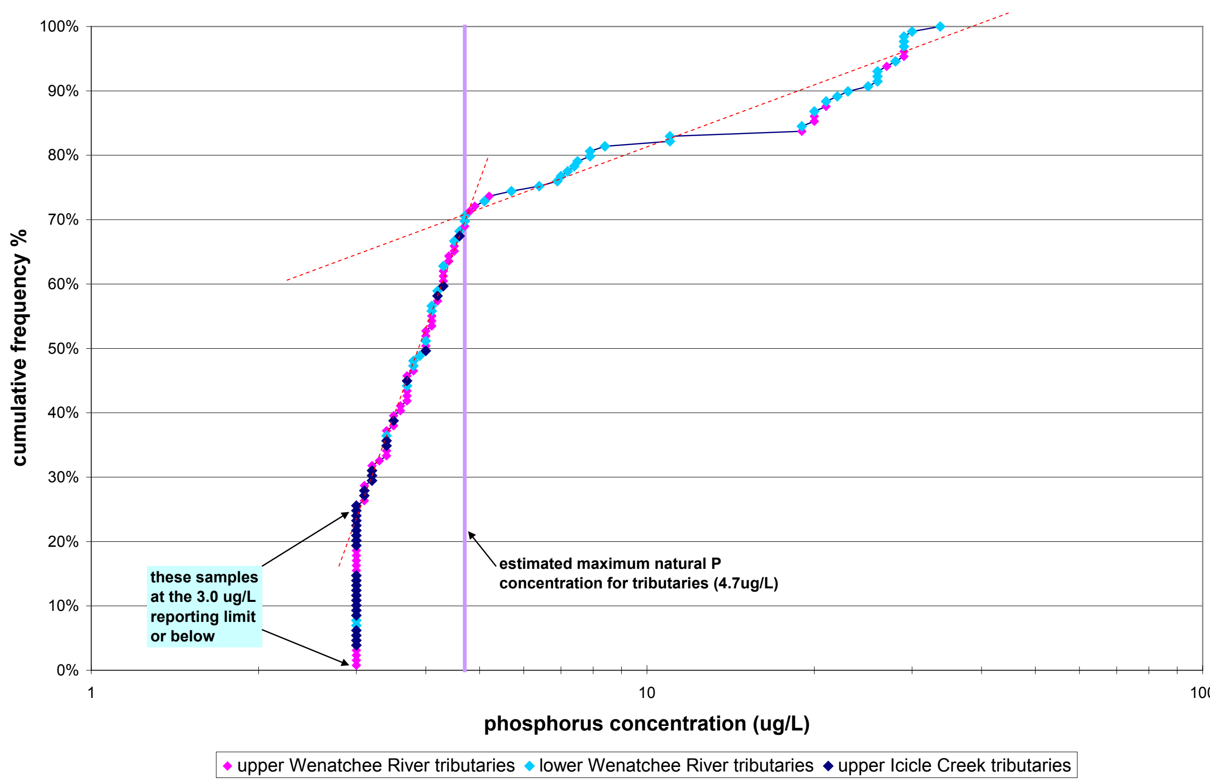


Figure 4. Cumulative frequency distribution of inorganic-phosphorus measurements from samples taken in 15 tributaries during July to October 2002 and April 2003 as part of the 2002-03 Wenatchee TMDL study.

The estimated natural inorganic-P concentration range is compared to each tributary's inorganic-P range in Figure 5. Most tributaries had some concentrations within the estimated natural phosphorus concentration range. All of the inorganic-P concentrations in the upper Icicle Creek tributaries were within the estimated natural inorganic-P concentration range. This would be expected because upper Icicle Creek is pristine, with very little human development. In fact, most of the upper Icicle Creek watershed is in designated wilderness area or within national forest boundaries. The upper headwaters of Icicle Creek and Snow Creek were always at or near the reporting limit (3 ug/L). However, other upper Icicle Creek tributaries, such as Jack Creek and Eightmile Creek, had variability within the estimated natural phosphorus concentration range.

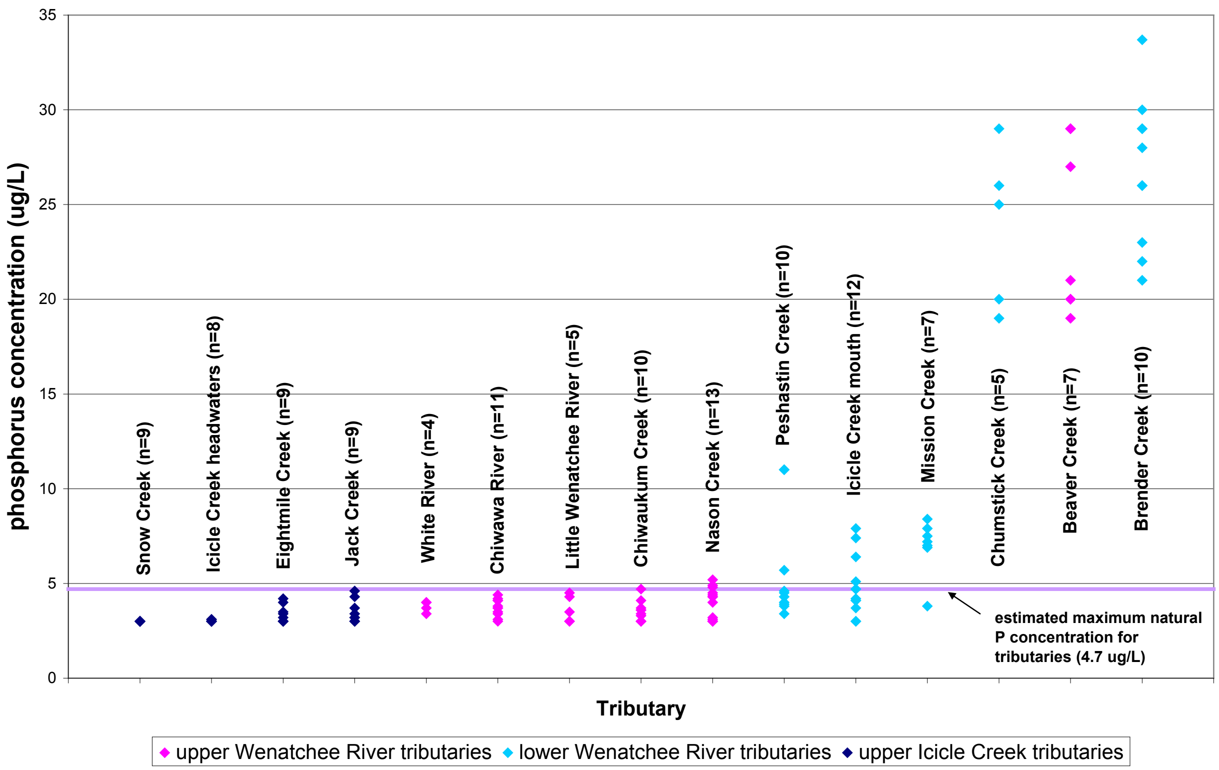


Figure 5. Distribution of inorganic-phosphorus concentrations (ug/L) by tributary from July to October 2002 and April 2003 measured in 15 tributaries in the Wenatchee River watershed during the 2002-03 Wenatchee TMDL study.

Most of the upper Wenatchee River and Lake Wenatchee tributaries also had inorganic-P concentrations that fell within the <3.0 to 4.7 ug/L range estimated for natural concentrations. Most of the upper Wenatchee watershed is pristine and has very limited human development. Some of the tributaries (e.g., Chiwaukum Creek) drain designated wilderness areas and yet had inorganic-P concentrations that varied within the full estimated natural inorganic-P concentration range.

Two of the upper Wenatchee River tributaries (Nason and Beaver Creeks) had measured phosphorus concentrations greater than 4.7 ug/L. Two of 13 samples collected near the mouth of Nason Creek slightly exceeded the estimated upper natural inorganic-P concentration (4.9 and 5.1 ug/L).

In contrast to Nason Creek, Beaver Creek always had high inorganic-P concentrations (Figure 5). Beaver Creek would probably be dry during the summer low-flow season were it not carrying irrigation return flows diverted from the Chiwawa River. Since the Chiwawa River always had phosphorus concentrations within the estimated natural inorganic-P concentration range, Beaver Creek most likely receives inorganic-P from a source within its small watershed. The land uses in the Beaver Creek watershed include agriculture, and residents of the watershed use on-site septic systems for treating wastewater.

The lower Wenatchee River tributaries also have potential sources of inorganic-P. These include denser populations, increased development, and agriculture. Peshastin and Icicle Creeks had inorganic-P concentrations within the natural range most of the time. This showed that the estimated natural inorganic-P concentration range is achievable in the lower part of the watershed, despite differing geology. Two out of ten sampling events in Peshastin Creek exceeded the estimated natural inorganic-P concentration range. Icicle Creek exceeded the estimated natural inorganic-P concentration range mainly in September 2002. This was when there was little flow upstream of the Leavenworth National Fish Hatchery (i.e., the fish hatchery discharge was practically all of the flow in the creek to reach the mouth).

Mission, Brender, and Chumstick Creeks had inorganic-P concentrations greater than the estimated natural phosphorus range. These creeks are impacted by denser populations that rely on on-site septic systems to treat wastewater.

In summary, Ecology believes that natural tributary inorganic-P concentrations can be expected to range from less than 3 to 4.7 ug/L. All of the watershed tributaries with little to no human impacts had inorganic-P concentrations within this range during the dry season. Ecology believes this range is an achievable target for all of the tributaries that currently have concentrations greater than this range.

Natural inorganic-phosphorus concentration range in groundwater

During the 2002-03 TMDL field studies, Ecology installed instream piezometers along the upper and lower Wenatchee River, lower Icicle Creek, and several tributaries, including Chumstick, Brender, and Mission Creeks. Bedrock and boulders prevented successful driving of piezometers in the upper Icicle Creek watershed. Ecology collected water quality samples from piezometers that indicated groundwater discharge to surface water. Populated areas often occur along stream corridors in the Wenatchee River watershed (Figure 6); therefore, groundwater samples were collected from populated areas more frequently than not. Ecology collected 29 inorganic-P samples from 21 instream piezometers during the 2002-03 TMDL studies.

Figure 7 shows the cumulative frequency distribution for the piezometer inorganic-P data (n=29). The inorganic-P concentrations are graphed using a log scale on the x-axis (the data significantly fit a log-normal distribution; $\alpha = 0.01$). As shown in Figure 7, the groundwater data were differentiated into two groups:

- Piezometer samples from areas with a population density equal to or less than 100 equivalent residents per square mile.
- Piezometer samples from areas with a population density from 100 to 500 equivalent residents per square mile.

The cumulative frequency distribution for the groundwater inorganic-P data shows two inflection points, one at approximately 14 ug/L and one at approximately 25 ug/L. This suggests that the distribution is comprised of three different data populations:

1. It appears that the upper population of the distribution (concentrations greater than 25 ug/L) is related to direct sources of pollution to groundwater. This is supported by Ecology's sampling design. The highest concentrations were measured in areas that were sampled because of suspected direct pollution pathways to groundwater. Piezometers were installed below the community of Dryden's drainfield and adjacent to the community of Peshastin in the lower Wenatchee River. A piezometer was also installed below a dense housing area near Plain in the upper Wenatchee basin. Residents in the Plain community use on-site septic systems to treat wastewater.

2. A possible explanation of inorganic-P concentrations in the middle part of the distribution (between 14 and 25 ug/L) is that these data represent groundwater exposed to diffuse (nonpoint) sources of pollution.

3. Inorganic-P concentrations in the lower part of the distribution most likely reflect the natural inorganic-P concentration range in groundwater. Ecology selected the lower inflection point (14 ug/L) as its best estimate of the upper natural range of inorganic-P concentrations in area groundwater. The lower estimate of the natural inorganic-P range would be at or below the lowest observed inorganic-P concentration of 4.6 ug/L.

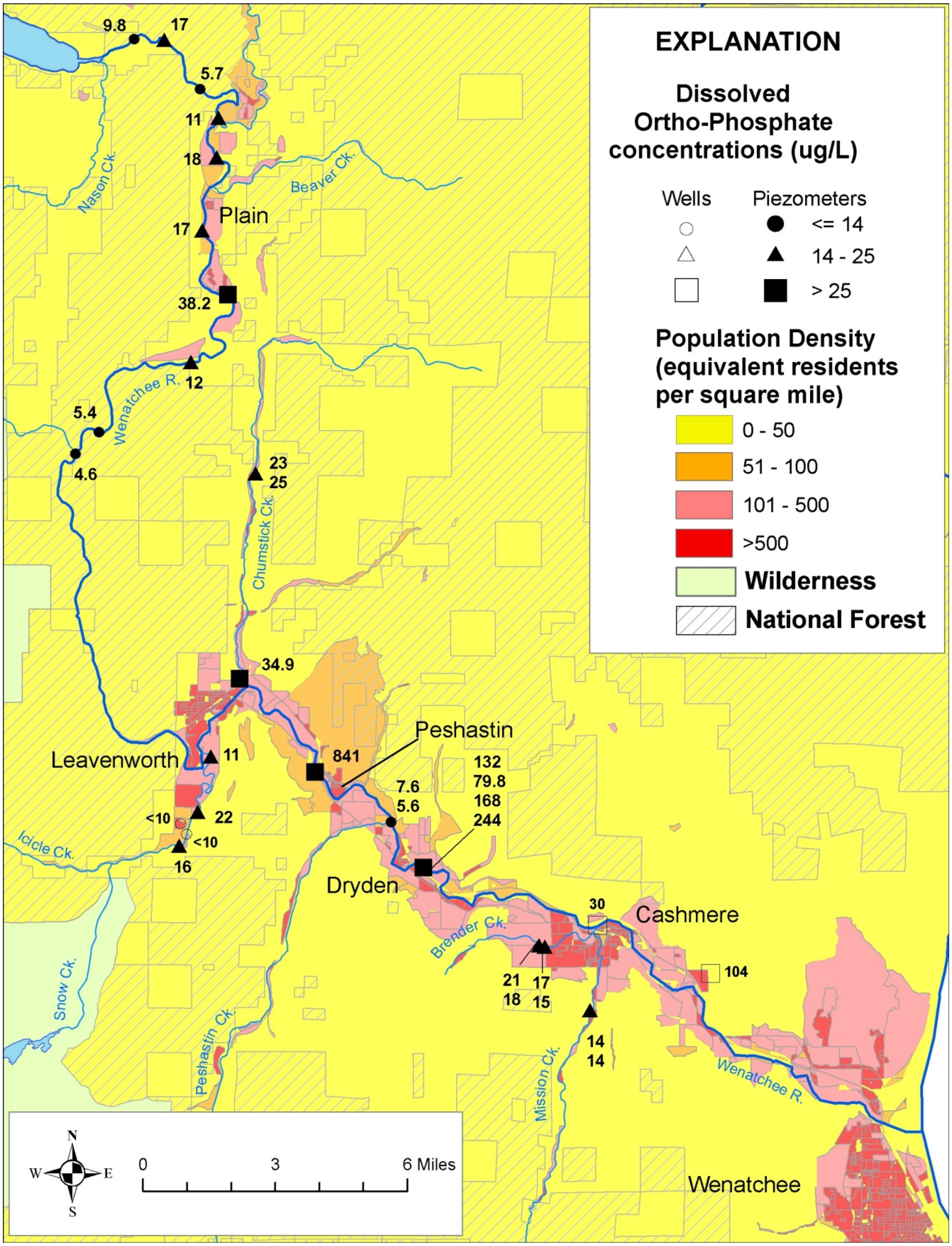


Figure 6. Distribution of dissolved inorganic-phosphorus concentrations in groundwater (measured from piezometers in 2002-03) and off-stream wells (USGS-NWIS from 1961 and 1991) and Ecology (unpublished data 2004) in the Wenatchee watershed compared to population density distribution (2000 census blocks).

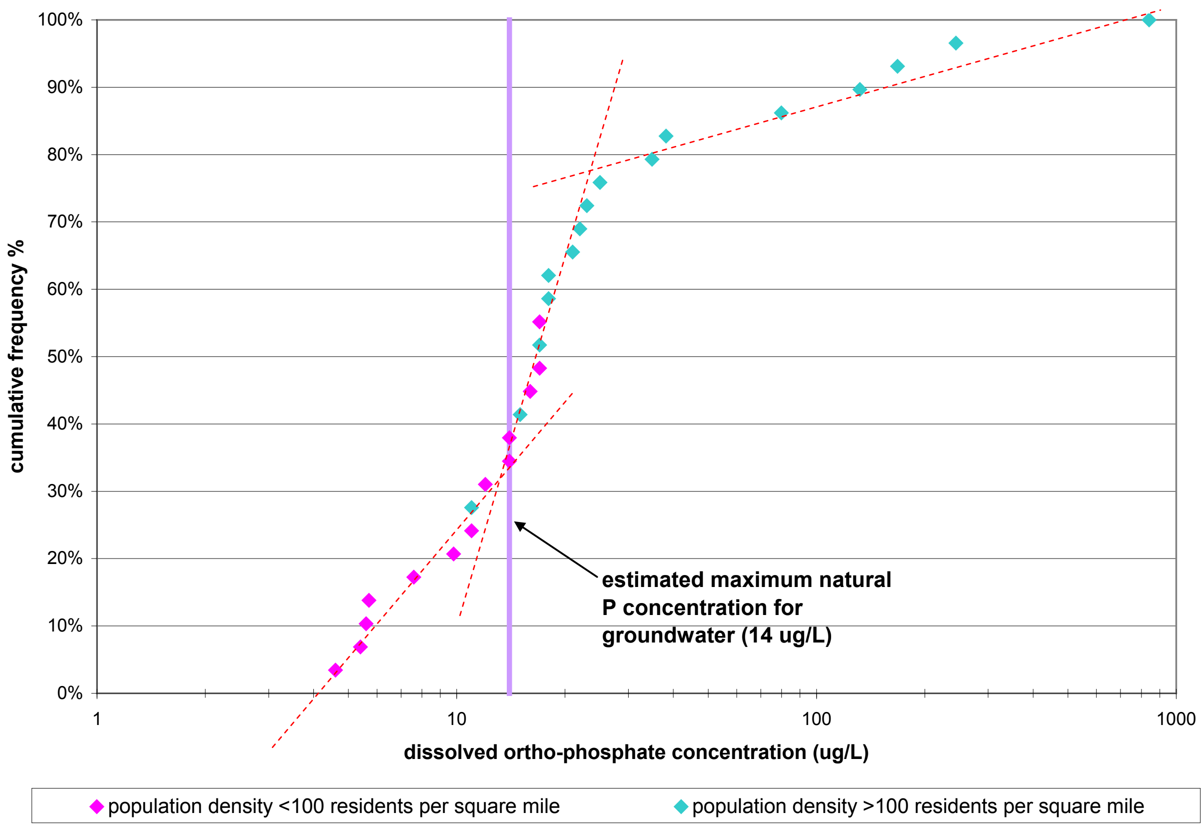


Figure 7. Cumulative frequency distribution of dissolved inorganic-phosphorus measurements taken in 21 instream piezometers as part of the 2002-03 Wenatchee TMDL study.

As shown in Figure 6, groundwater inorganic-P concentrations less than 14 ug/L were usually from areas of lower population density (<100 residents per square mile). Areas that had lower tributary inorganic-P concentrations, such as the upper Wenatchee River and Peshastin Creek, had lower groundwater inorganic-P concentrations. The estimated natural inorganic-P concentration range (concentrations below 14 ug/L) included concentrations found in the lower and upper Wenatchee River watershed, despite the geologic variability that exists within the watershed.

The range of concentrations that Ecology detected in instream piezometers are consistent with limited historic water quality results obtained from area off-stream wells sampled in 1961 and 1991[3] and October 2004[4] (Figure 6). Consistency between the instream piezometer and off-stream well data suggests that the instream piezometer data are representative of ambient groundwater conditions at points of discharge to the river.

[3] USGS database website: http://waterdata.usgs.gov/wa/nwis/gw

[4] Ecology database website: http://apps.ecy.wa.gov/eimreporting/Search.asp

Figure 8 presents box plots depicting inorganic-P concentration distributions for population densities greater than and less than 100 equivalent residents per square mile. The upper estimate of the natural inorganic-P concentration range (14 ug/L) corresponds to the 75th percentile of the inorganic-P concentration data in areas with a population density less than 100.

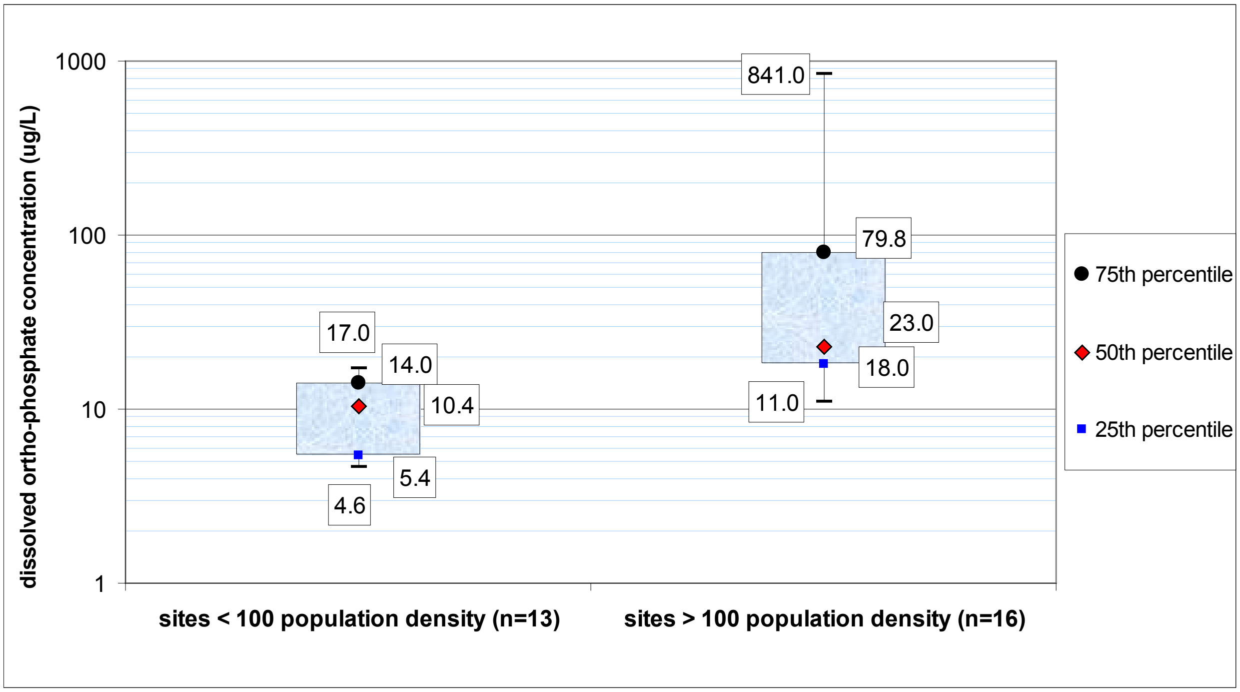


Figure 8. Box plots of the inorganic-phosphorus concentration distributions in groundwater in areas with population density greater than and less than 100 equivalent residents per square mile (based on 2000 census blocks). *Each box plot depicts the minimum, 25th percentile, median, 75th percentile, and the maximum of the distribution for each population density category*.

In Figure 9, the estimated natural inorganic-P concentration range is compared to the inorganic-P concentrations for each groundwater sampling location. As mentioned above, the highest concentrations were found in areas with suspected direct pathways of pollution to groundwater, such as in or near the communities of Peshastin, Dryden, and Plain. Also, higher observed groundwater phosphorus concentrations were found in areas that had polluted tributaries, such as Chumstick and Brender Creeks. Mission Creek is also known to have pollution impacts; however, two groundwater samples taken in the Mission Creek watershed upstream of Cashmere had measurements at the upper estimate of the natural inorganic-P concentration range.

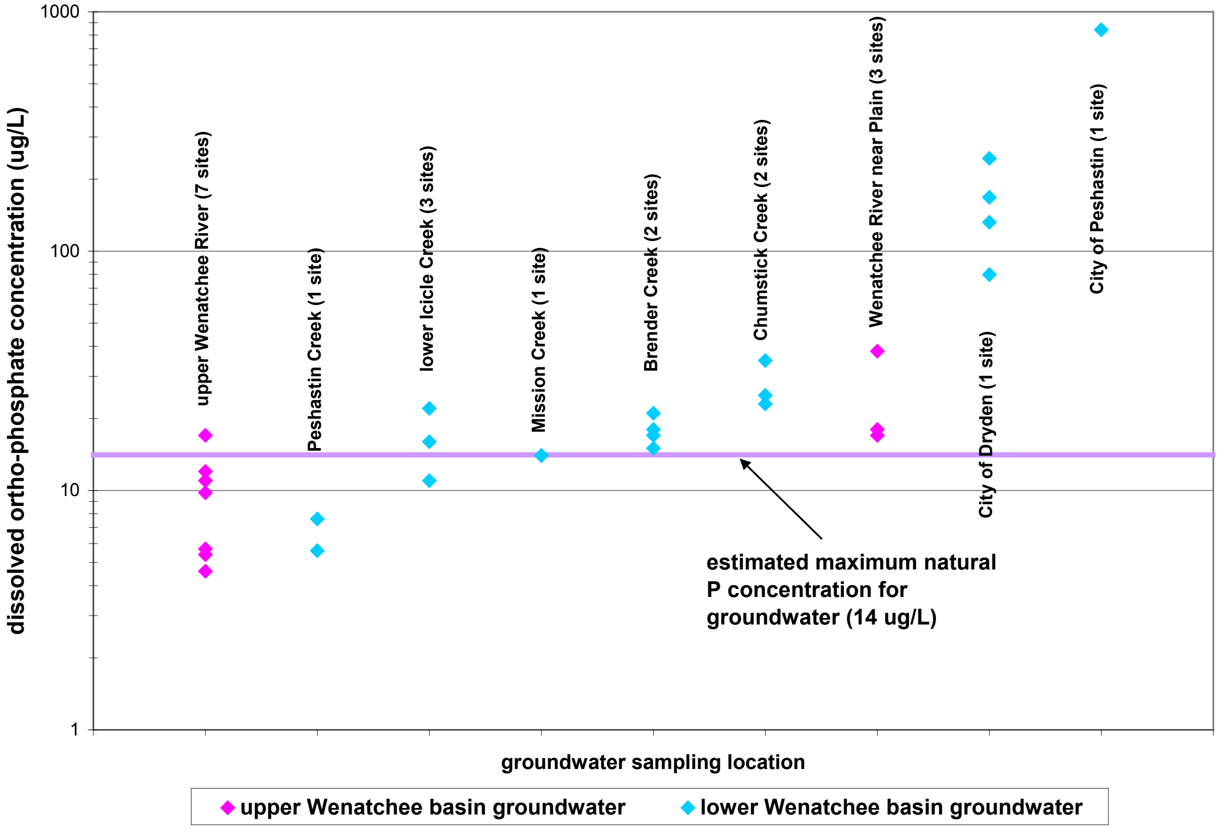


Figure 9. Distribution of inorganic-phosphorus concentrations (ug/L) in groundwater by sampling location from July to October 2002 and in April 2003 measured at 21 locations in the Wenatchee River watershed during the 2002-03 Wenatchee TMDL study.

In summary, there is more uncertainty when estimating a natural inorganic-P concentration range for groundwater than for tributaries because there is less groundwater inorganic-P data. The inability to collect groundwater samples which can represent natural (unpolluted) conditions makes establishing a natural inorganic-P concentration range difficult. However, based on available data, Ecology is estimating that natural groundwater inorganic-P concentrations range between the lowest measured in the watershed (4.6 ug/L) and an upper estimate (14 ug/L). Throughout the watershed, areas with no or very little population density had variable inorganic-P concentrations within this range. Ecology has selected this range as an achievable target for the watershed groundwater that currently has inorganic-P concentrations greater than this range.

Modeling results using natural phosphorus concentration estimates

The calibrated QUAL2K models reported in Carroll et al. (2006) were used to simulate estimated natural conditions in the Wenatchee River and Icicle Creek using the upper estimate of the natural inorganic-P concentration ranges from groundwater and tributaries. The analysis used the upper estimate of the natural inorganic-P concentration range to allow a maximum allocation for natural conditions of water quality.

The models simulated estimated natural conditions during the August 2002 flow condition (a little higher flow than a 7Q2 flow condition with warmer mid-summer temperature conditions) and a 7Q10 flow condition (lower flow, not seen until late September, with cooler temperature conditions).

The 2002 90^{th} percentile flows (or maximum flows) for groundwater, tributaries, and point sources were used for the estimated natural condition simulations. All point sources and tributaries were assigned an inorganic-P concentration of 4.7 ug/L, and groundwater inorganic-P concentrations were reduced to
14.0 ug/L.

Natural inorganic-P loading in lower Wenatchee River and Icicle Creek

Based on natural condition model simulations (using the upper estimate of the natural phosphorus concentration range and critical 7Q10 low-flow condition), the net dissolved inorganic-P loading to the lower Wenatchee River and lower Icicle Creek is estimated to be 8.8 and 0.56 kg/day, respectively.

Dissolved oxygen model results

Figures 10 and 11 show the modeled DO responses in the Wenatchee River and Icicle Creek with estimated natural conditions during August 2002 and 7Q10 flow conditions. Also shown are the DO effects of the 2002 nonpoint and 90^{th} percentile point source loads.

In the Wenatchee River above the Peshastin Creek confluence, the model predicted the minimum DO criterion of 9.5 mg/L would not be met in either the August or the 7Q10 natural condition simulations. In other words, DO saturation levels dependent on temperature and elevation are naturally below 9.5 mg/L. The natural condition rule of the water quality standards for DO states that if the numerical standards are not met due to natural conditions, then there is only a combined 0.2 mg/L allowance for further DO deficit from all other human sources (point and nonpoint).

In the Wenatchee River below the Peshastin Creek confluence, the model predicted the minimum DO criterion of 8.0 mg/L would be met during both the August and 7Q10 natural condition simulations. Existing dischargers cannot cumulatively reduce DO levels below 8.0 mg/L during critical conditions.

In all of Icicle Creek, the model predicted the minimum DO criterion of 9.5 mg/L would not be met during an August natural condition simulation due to lower DO saturation levels caused by the warmer water temperatures in August. To comply with water quality standards, the Leavenworth National Fish Hatchery and nonpoint sources cannot cumulatively reduce the downstream minimum DO concentration more than 0.2 mg/L. During a 7Q10 natural condition simulation (with cooler September weather), the model predicted that natural conditions would meet the DO criterion.

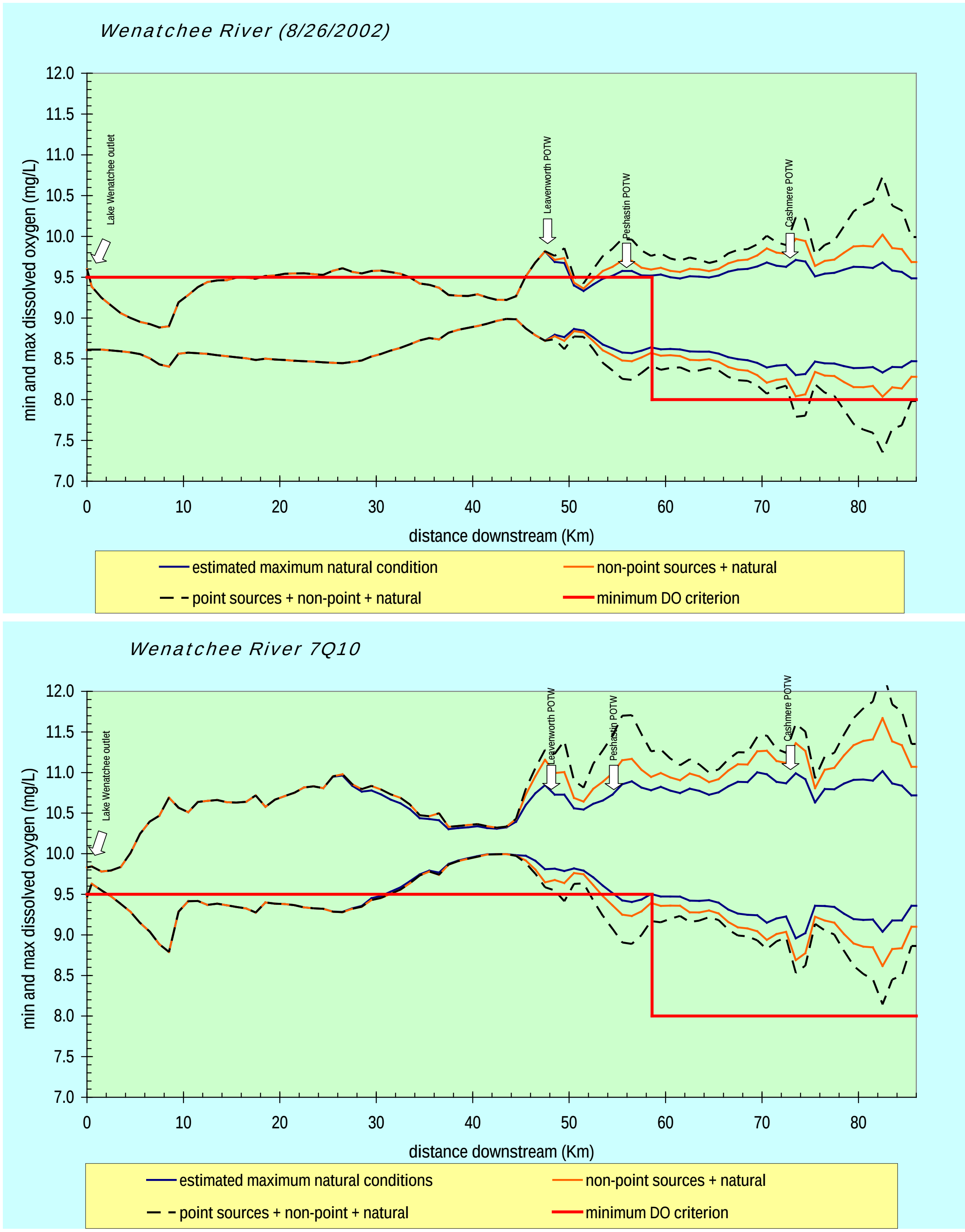


Figure 10. Estimated natural condition, nonpoint, and point source model simulations for DO using August 2002 and 7Q10 flow conditions in the Wenatchee River. Point sources are at 2002 90th percentile loads.

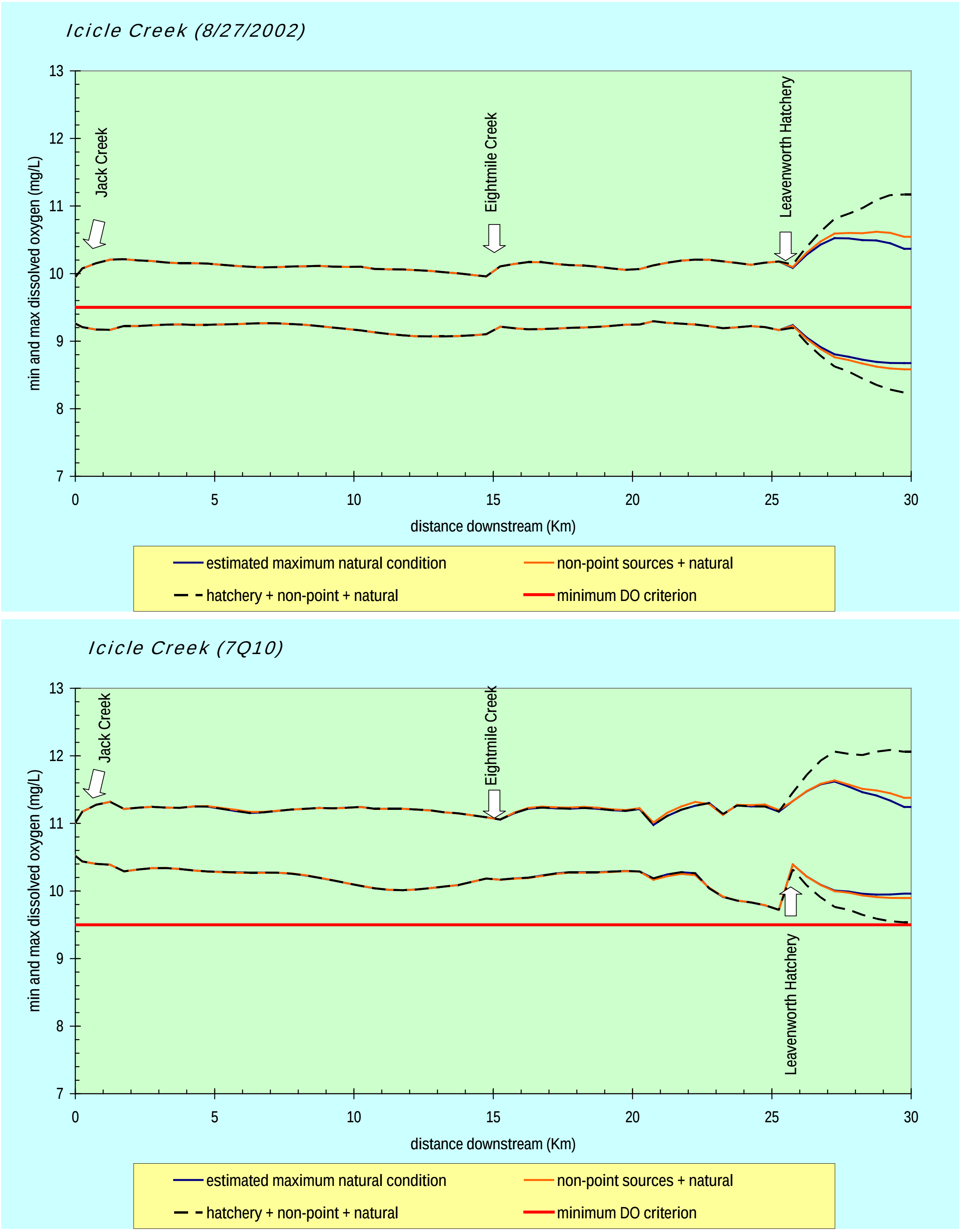


Figure 11. Estimated natural condition, nonpoint, and hatchery model simulations for DO using August 2002 and 7Q10 flow conditions in Icicle Creek. Hatchery sources are at 2002 loads.

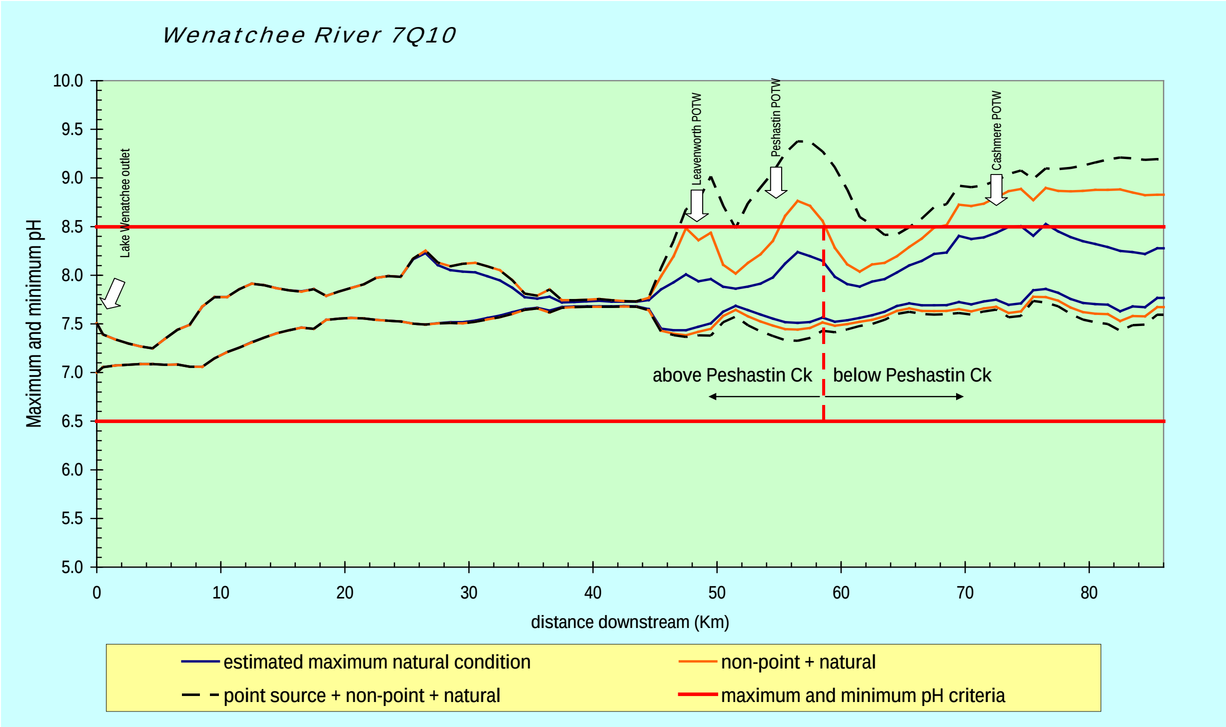
pH model results

Figure 12 and Figure 13 show the modeled pH response in the Wenatchee River and Icicle Creek with estimated natural conditions during August 2002 and 7Q10 flow conditions. Also shown are the effects of the 2002 nonpoint and 90th percentile point source loads on the pH simulations.

In the Wenatchee River above the Peshastin Creek confluence, the model predicted the pH criteria would be met in both the August and 7Q10 natural condition simulations. Therefore, point and nonpoint sources would not be allowed a cumulative increase in the downstream natural condition pH range of more than 0.2 pH units.

In the Wenatchee River below the Peshastin Creek confluence, the model predicted the pH criteria would be met in both the August and 7Q10 natural condition simulations. However, there would be no additional capacity for phosphorus if only a maximum natural condition were achieved. This is because there is no allowance for an increase in pH outside of the pH criteria range (the upper estimate of the natural condition just met the maximum 8.5 pH criterion). Under this condition, discharges may not cause a measurable pH effect, herein defined as less than a 0.1 pH unit increase in the downstream pH range during critical conditions.

In lower Icicle Creek, the model predicted the pH criteria would be met in both the August and 7Q10 natural condition simulations. Therefore, point and nonpoint sources would be allowed a cumulative increase in the pH range of up to 0.2 pH units.



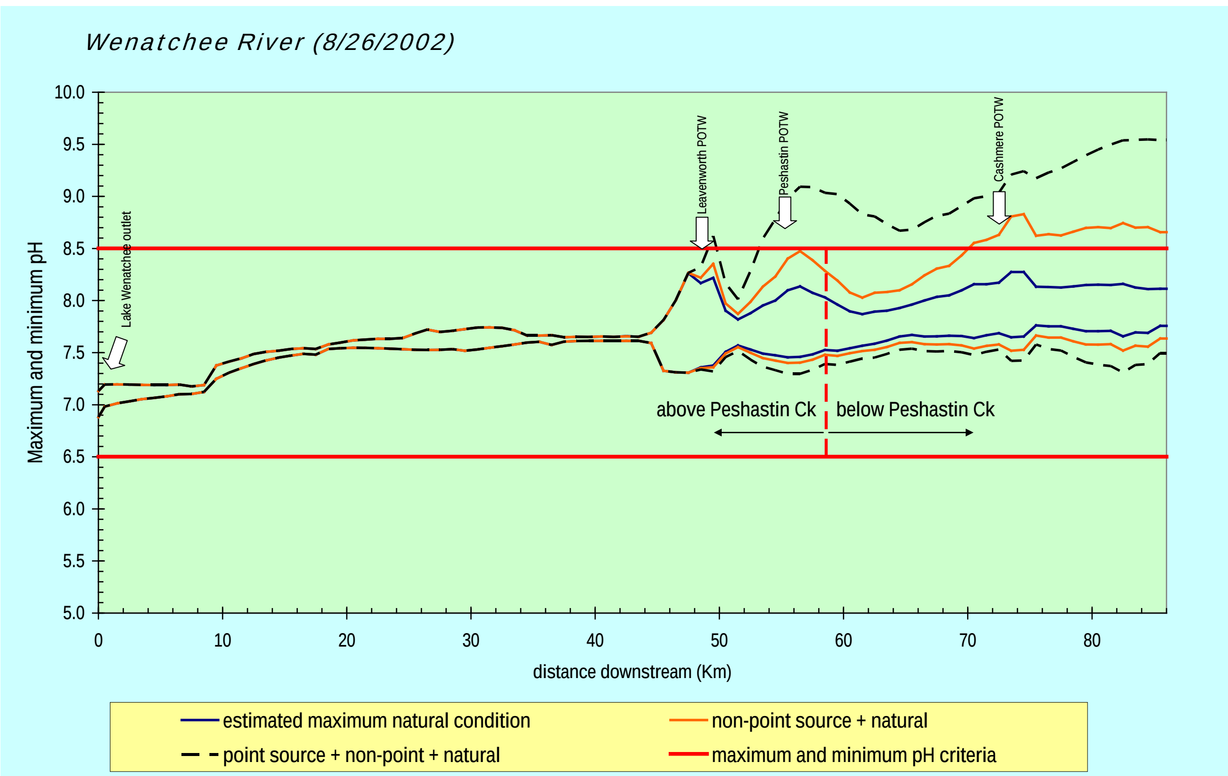
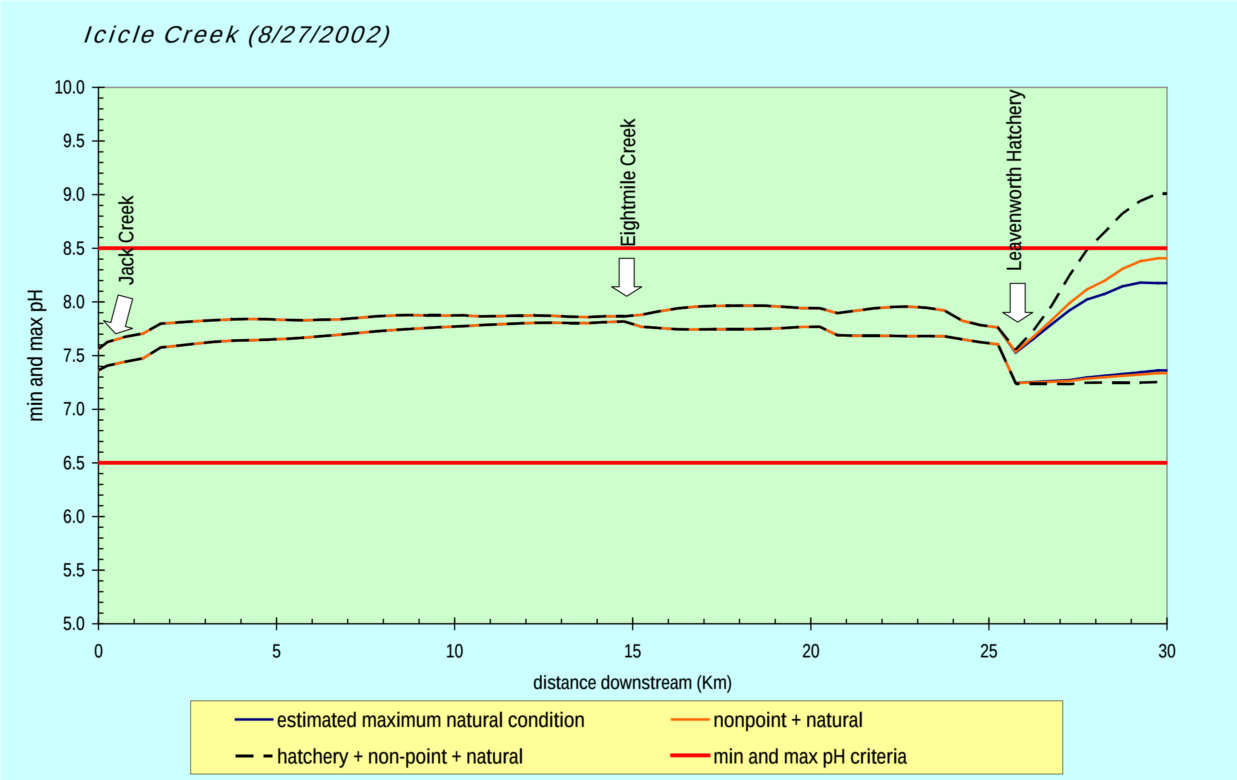


Figure 12. Estimated natural background, nonpoint, and point source model simulations for pH during August 2002 and 7Q10 flow conditions in the Wenatchee River. Point sources are at 2002 90th percentile loads.



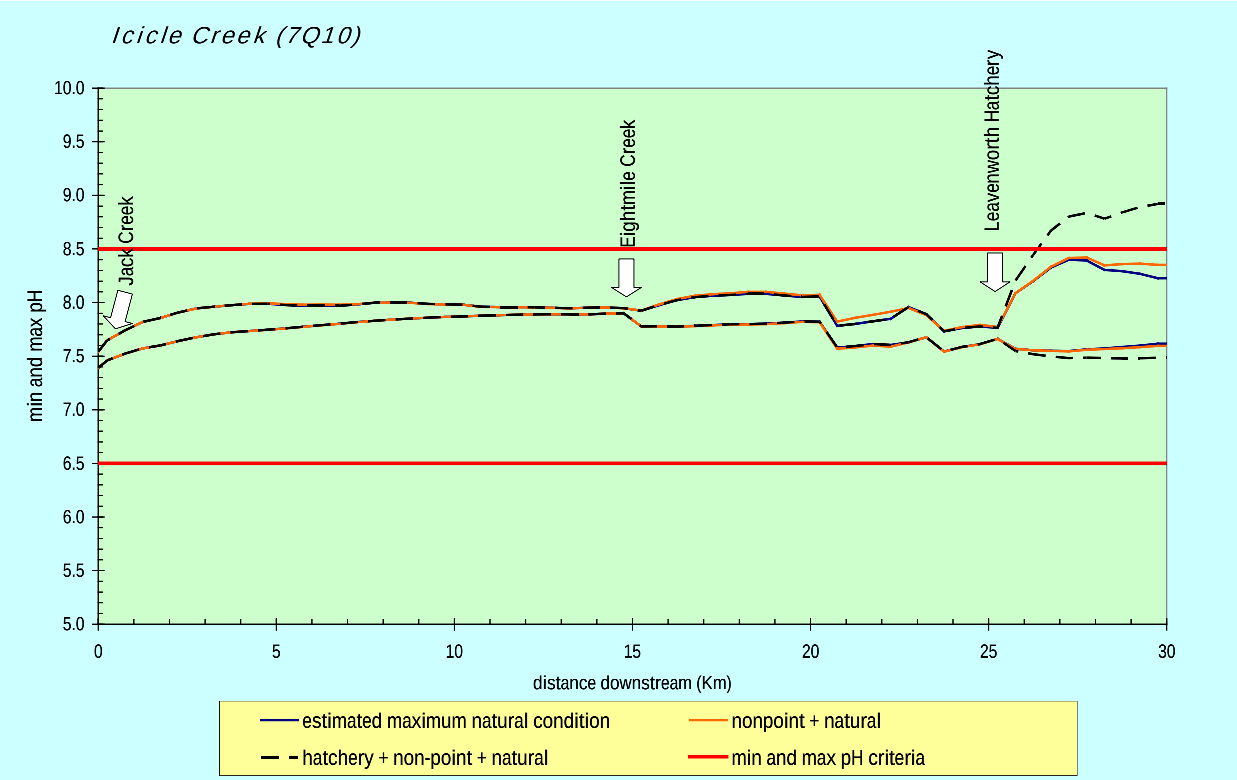


Figure 13. Estimated natural background, nonpoint, and point source model simulations for pH during August 2002 and 7Q10 flow conditions in Icicle Creek. Hatchery sources are at 2002 loads.

Modeled effects of point sources and wasteload allocation determinations

Ecology simulated changes in natural-condition DO and pH levels of the Wenatchee River when adding variable flow and phosphorus concentration levels from point source discharges. The predicted DO and pH changes with:

- 2002 point-source flow rates (Figure 14).
- Facility design flow rates (Figure 15).

Figure 16 shows the predicted change in natural-condition DO and pH levels in Icicle Creek when adding variable phosphorus concentrations levels from the LNFH.

Based on the water quality standards and the simulated measurable effects, pH is more restrictive than DO for setting wasteload allocations for point source discharges to the Wenatchee River and Icicle Creek.

In the Wenatchee River above the Peshastin Creek confluence, combined point sources (Leavenworth WWTP and Peshastin WWTP plus general permit holders) and nonpoint sources may not cause a cumulative increase in the downstream pH range greater than 0.2 pH units. Model simulations show that existing permit holders would need to discharge at a level less than 170 ug/L of phosphorus to not change the pH range greater than 0.2 pH units. However, the downstream effect of phosphorus additions to this reach must not cause a measurable change of pH more than 0.1 units. Therefore, Ecology determined that point source discharge levels of phosphorus should be held to less than 90 ug/L of phosphorus to not cause a measurable pH effect.

In the Wenatchee River below the Peshastin Creek confluence, Ecology determined that point source discharge levels of phosphorus should be held to a level that does not cause a measurable pH effect. Model simulations show that the Cashmere WWTP (at twice the current design flow) would need to discharge at a level less than 90 ug/L of phosphorus to not change the downstream pH to greater than 0.1 pH units during critical conditions.

In lower Icicle Creek, under current critical-condition hydrology, model simulations show that the LNFH (main outfall and abatement pond) would need to discharge at a level less than 5.7 ug/L of phosphorus to not change the downstream pH range greater than 0.1 pH units. The LNFH currently has a dilution factor of nearly 1 because the upstream segment from their discharge in Icicle Creek is seasonally dewatered by upstream diversions.

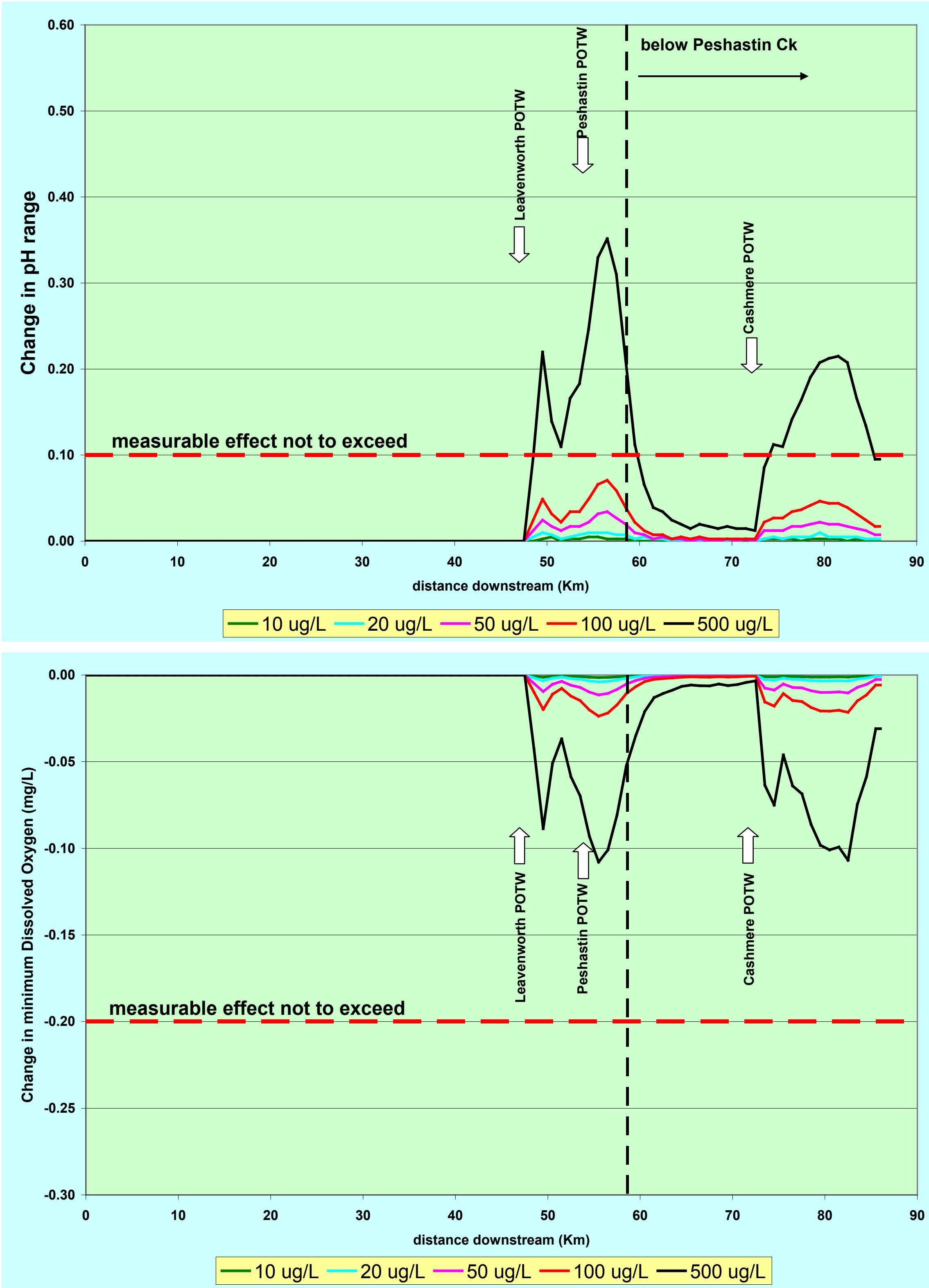


Figure 14. Change in pH range (top) and minimum DO (bottom) downstream of Lake Wenatchee with different levels of point source phosphorus concentration and 2002 point source discharge (departures from natural condition).

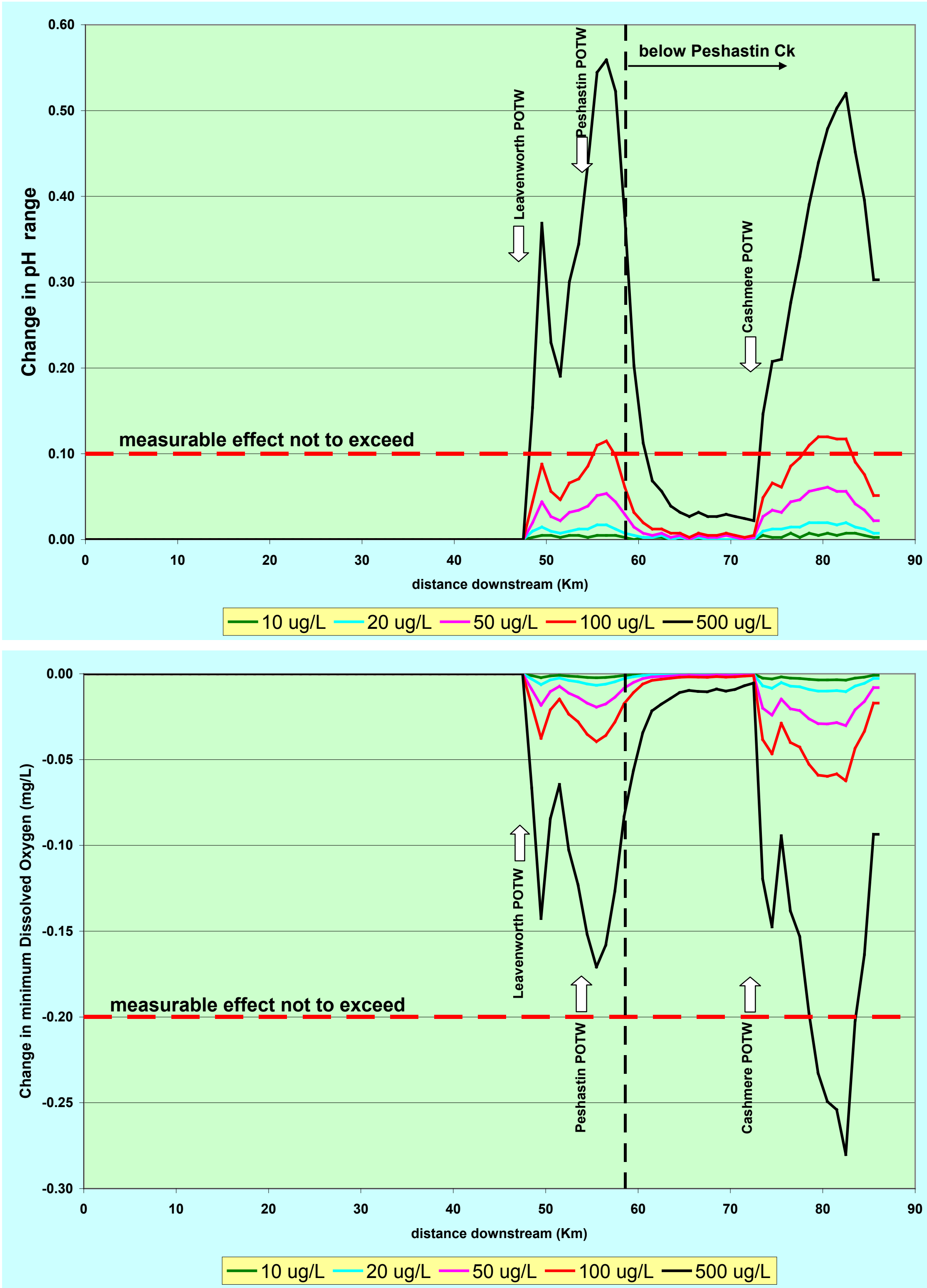


Figure 15. Change in pH range (top) and minimum DO (bottom) downstream of Lake Wenatchee with different levels of point source phosphorus concentration and design point source discharge including Cashmere WWTP at twice the 2002 design discharge (departures from natural condition).

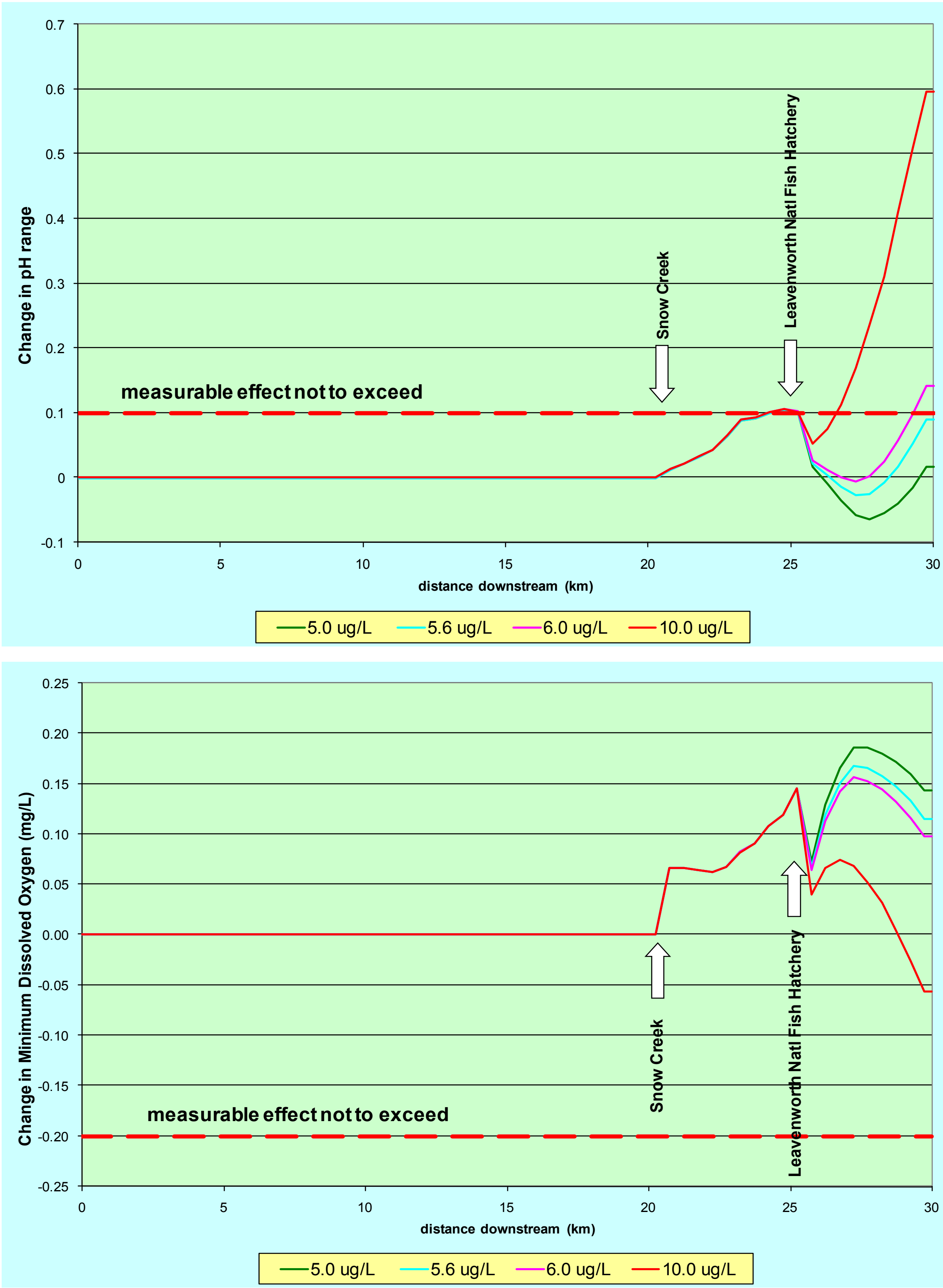


Figure 16. Change in pH range (top) and minimum DO (bottom) downstream of Snow Creek and the Leavenworth National Fish Hatchery (LNFH) in Icicle Creek with different levels of phosphorus discharge from the LNFH (departures from natural condition concentration at the LNFH).

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TMDL Results:
Load Allocations and Wasteload Allocations

In this section, Ecology presents a final allocation strategy with modeling results that verify that the strategy meets Washington State water quality standards.

Seasonal variation

The federal Clean Water Act Section 303(d)(1) requires that TMDLs "*be established at the level necessary to implement the applicable water quality standards with seasonal variations*." The implementing regulations also state that determination of "*TMDLs shall take into account critical conditions for streamflow, loading, and water quality parameters*" [40 CFR 130.7(c)(1)].

The critical period in the Wenatchee River watershed occurs during March through May (prior to snow melt run-off) and July through October (after snow melt run-off). During these two periods, flows are low, and there is enough sunlight and warm enough water temperatures for algal (or biological) productivity.

Pollutant load reduction targets set for total phosphorus

The TMDL for phosphorus in the Wenatchee watershed will be expressed as a daily maximum concentration for total phosphorus. The dissolved fraction of phosphorus (i.e., dissolved inorganic-P) is most important in the QUAL2Kw model as the basis for modeling steady-state solute transport and periphyton growth because it is the form of phosphorus most readily available for biological uptake and algal growth.

Total phosphorus is used for setting wasteload and load allocations in this TMDL because:

- Total phosphorus from permitted WWTPs is dominated by bio-available inorganic-P (Table 6).
- Total phosphorus from natural background sources, such as headwater tributaries and unpolluted tributaries in the watershed, is dominated by inorganic-P (Table 7).
- Total phosphorus loads from groundwater are expected to be in a dissolved inorganic phase.
- Total phosphorus is a more functional and practical pollutant for permit setting and monitoring.
- In cases where organic forms of phosphorus occur, managing total phosphorus will provide a margin of safety by also managing discharged organic phosphorus forms that eventually hydrolyze into bio-available inorganic forms.

Table 6. Percent total phosphorus as dissolved inorganic-phosphorus in wastewater samples during 2002-03 Wenatchee TMDL sampling.

Discharger	Number of composite or grab samples	Average total P (ug/L)	Standard deviation total P (ug/L)	Average dissolved inorganic-P (ug/L)	Standard deviation dissolved inorganic-P (ug/L)	Percent dissolved inorganic-P
Leavenworth WWTP	12	3274	1660	3318	1686	100%
Peshastin WWTP	10	6281	1910	6264	1682	99.7%
Cashmere WWTP	12	4318	1333	4200	1315	97.3%
LNFH (main outfall process water)	11	13.3	4.9	10.3	2.8	77.9%
LNFH (abatement pond)	8	56.3	25.1	30.7	18.4	54.6%

LNFH = Leavenworth National Fish Hatchery. EPA issues the permit for LNFH.
P = phosphorus.

Table 7. Percent total phosphorus as dissolved inorganic-phosphorus in headwater and low-impaired tributaries from July through October 2002 and in April 2003.

Stream name	Number of grab samples	Average total P (ug/L)	Standard deviation total P (ug/L)	Average dissolved inorganic-P (ug/L)	Standard deviation dissolved inorganic-P (ug/L)	Percent dissolved inorganic-P
Upper Wenatchee River[1]	12	3.9	2.7	3.2	0.3	82%
Nason Creek	13	3.8	0.9	4.0	0.5	100%
Chiwawa River	11	3.7	2.0	3.7	0.5	100%
Chiwaukum Ck	10	3.1	0.6	3.6	0.5	100%
Icicle Creek[2]	11	3.6	0.9	3.6	0.6	100%
Upper Icicle	8	3.1	0.4	3.0	0.0	97%
Eightmile Creek	9	3.5	0.7	3.4	0.5	97%
Jack Creek	9	3.0	0.0	3.5	0.6	100%

[1] Upper Wenatchee River at Tumwater Canyon bridge.
[2] Icicle Creek above Snow Creek.
P = phosphorus.

Load and wasteload allocations for phosphorus in the lower Wenatchee River

Load allocations for upstream sources to the lower Wenatchee River

The current critical-condition upstream inorganic-P load to the lower Wenatchee River was estimated as 1.24 kg/day from the upper Wenatchee River watershed (above Leavenworth). By applying maximum natural conditions to the upper Wenatchee River, the upstream load is estimated to be 0.94 kg/day. This requires a reduction of 0.3 kg/day of total phosphorus.

Load allocations for tributaries to the lower Wenatchee River

Load allocations for tributaries are provided as percent reductions of phosphorus needed to reach maximum natural-condition phosphorus levels (Table 8) and the resultant critical-condition load (Table 9).

Table 8. Dissolved inorganic-phosphorus concentrations in lower Wenatchee River tributaries during 2002-03 Wenatchee TMDL sampling (July–Oct 2002; April-May 2003).

Lower Wenatchee Tributary	Number of grab samples at mouth	Average inorganic-P (ug/L)	Standard deviation inorganic-P (ug/L)	90th percentile inorganic-P (ug/L)	Estimated maximum natural condition inorganic-P concentration (ug/L)	% reduction needed at mouth to meet natural condition inorganic-P concentration
Icicle Creek	12	4.9	1.6	6.9	4.7	32%
Chumstick Creek[1]	9	22.7	3.9	27.7	4.7	83%
Peshastin Creek[2]	8	4.3	0.7	5.2	4.7	10%
Brender Creek[1]	15	26.3	3.9	31.3	4.7	85%
Mission Creek[1]	12	7.0	2.1	9.7	4.7	52%

[1] Some additional sampling on Chumstick, Brender, and Mission Creeks in July-Sept 2003.
[2] Only July to October 2002 sampling on Peshastin Creek included in analysis; one sampling in April 2003 was 11.0 ug/L.
P = phosphorus.

Table 9. Existing load contributions and target critical-condition loads (load allocations) for phosphorus in the lower Wenatchee River tributaries.

Tributary name	Current critical condition load (kg/day)	Target critical condition load (kg/day)
Icicle Creek	0.802	0.546
Chumstick Creek	0.097	0.016
Peshastin Creek	0.153	0.138
Brender Creek	0.339	0.051
Mission Creek	0.354	0.172
Totals	1.75	0.92

Load allocations for irrigation water-management return flows to the lower Wenatchee River

Irrigation water-management return flows are discharged into the Wenatchee River as either end-of-line irrigation canal return flows or as return flows from spill points used to balance the irrigation canal system. Table 10 shows the inorganic-P concentration of the diverted water and the resulting inorganic-P concentration of the irrigation-management return flow in September 2002. The data show either a net decrease of phosphorus from the irrigation canal, perhaps due to algal uptake and growth in the canal, or a net increase from other sources of phosphorus to the canals.

Table 10. Percent reduction of phosphorus expected at irrigation-management return flows in the lower Wenatchee River watershed.

Irrigation-management return flow	September 2002 inorganic-P concentration at mouth (ug/L)	September 2002 inorganic-P concentration at diversion (ug/L)	Potential percent reduction
Cascade Orchards Irrigation	5.9	4.1	31%
Icicle return at Stines Hill	4.2	4.5	0%
Icicle return at Fairview	5.4	4.5	17%
Jones Shotwell	5.6	11.3	0%
Wenatchee Reclamation District	3.7	4.65	0%

Table 11. Existing contributions and target load allocations for phosphorus for irrigation-management return flows to the lower Wenatchee River during critical flow conditions.

Irrigation-management return flow	2002 load (kg/day)	Potential percent reduction	Target load (kg/day)
Cascade Orchard	0.059	31%	0.041
Icicle Irrigation at Stines Hill	0.031	0%	0.031
Icicle Irrigation at Fairview Canyon	0.047	17%	0.039
Jones Shotwell	0.044	0%	0.044
Wenatchee Reclamation District	0.107	0%	0.107
Totals	0.29	10%	0.26

Load allocations for nonpoint source loads to the lower Wenatchee River

Load allocations for diffuse (nonpoint) sources are provided as percent reductions of phosphorus needed from 2002 critical-condition loads to reach target natural-conditions loads (Table 12). Diffuse loads enter the Wenatchee River and Icicle Creek as groundwater during the dry low-flow season (July-October). There is more uncertainty associated with the diffuse loads of phosphorus than the other phosphorus loads because the diffuse loads are not directly measured. They are calculated as the residual of the mass balance of phosphorus in a particular reach of the lower Wenatchee River. The largest reductions are needed from the Leavenworth, Dryden, and Cashmere areas.

Table 12. Existing contributions and percent load reductions of phosphorus necessary from nonpoint sources.

Reach name	2002 load (kg/day)	Percent reduction	Target load (kg/day)
Leavenworth (RM 26.2 and 21.0)	1.24	81%	0.369
Peshastin (RM 21.0 and 17.2)	2.583	30%	1.796
Dryden (RM 17.2 and 14.1)	4.478	65%	1.408
Pine Flats (RM 14.1 and 10.8)	2.856	44%	1.437
Cashmere (RM 10.8 and 6.5)	7.036	69%	1.922
Monitor (RM 6.5 and 2.8)	0.335	0%	0.335
Totals	19.23	--	7.54

Wasteload allocations for non-contact cooling water general permit discharges

Non-contact cooling water (NCCW) discharges are allowed by general permit to the lower Wenatchee River. Three fruit processors currently hold general permits for discharge of NCCW to the lower Wenatchee. Levels of total phosphorus in the eight NCCW discharge points ranged from 40.5 to 3,300 ug/L in December 2004 (Table 13). Levels of dissolved inorganic-P in the same discharges ranged from 40.5 to 189 ug/L.

Table 13. Non-contact cooling water (NCCW) phosphorus discharges in the lower Wenatchee River.

Discharger	Permitted discharge point	2004 NCCW discharge (gpd) [a]	Scale inhibitor added ? [b]	Inorganic-P		Total phosphorus		Percent inorganic-P
				(ug/L) [c]	load (kg/day) [d]	(ug/L) [c]	load (kg/day) [d]	
Blue Bird	796A	96000	N	40.7	0.0148	40.7	0.0148	100%
	796B	500	Y	189	0.0004	2380	0.0045	8%
	796C	17280	Y and N	45.6	0.0030	45.6	0.0030	100%
	796D	17280	N	40.5	0.0026	40.5	0.0026	100%
	796E	30000	Y and N	41.7	0.0047	41.7	0.0047	100%
Blue Star Growers	8	2700	Y	139	0.0014	240	0.0025	58%
McDougal Monitor	786A	2985	Y	175	0.0020	2920	0.0330	6%
	786B	3722	Y	150	0.0021	3300	0.0465	4.5%
Total NCCW load contribution		170467	-	-	0.0310	-	0.1116	26.7%

[a] Effluent flow in gallons per day based on data from 2004 monitoring and the Discharge Monitoring Report.
[b] Some discharge points combine flows from several refrigeration buildings at Bluebird.
[c] Concentrations based on sampling in December 2004 by Ecology; not all discharge points sampled at Bluebird.
[d] kg/day for point sources = Effluent GPD / 10^6 x Total Phosphorus in ug/L Phosphorus / 1000 x 3.7854.

The higher levels of total phosphorus were associated with closed, recycling NCCW systems which occasionally discharge small NCCW volumes. A scale inhibitor added to the recycled NCCW appears to be the source of higher levels of phosphorus in the NCCW. All of the fruit processors (except McDougal Monitor) send their process (contact) water to a municipal WWTP for treatment.

Table 14 presents wasteload allocations for the NCCW. At points of discharge where the 2002 concentration levels were below 90 ug/L of phosphorus, the load allocation is set to the 2002 concentration level. The facilities should not increase the phosphorus concentration of NCCW from the levels of phosphorus found in the source water.

Table 14. Non-contact cooling water (NCCW) phosphorus wasteload allocations in the lower Wenatchee River (kg/day).

Discharger	Permitted discharge point	2004 total phosphorus		Total phosphorus wasteload allocation	
		(ug/L) [c]	load (kg/day) [d]	(ug/L)	load (kg/day) [d]
Blue Bird	796A	40.7	0.0148	40.7	0.0148
	796B	2380	0.0045	90	0.000
	796C	45.6	0.0030	45.6	0.0030
	796D	40.5	0.0026	40.5	0.0026
	796E	41.7	0.0047	41.7	0.0047
Blue Star Growers	8	240	0.0025	90	0.001
McDougal Monitor	786A	2920	0.0330	90	0.001
	786B	3300	0.0465	90	0.001
Total NCCW load contribution		-	0.1116	-	0.028

[a] Effluent flow in gallons per day based on data from 2004 monitoring and the 2004 Discharge Monitoring Report.
[b] Some discharge points combine flows from several refrigeration buildings at Bluebird.
[c] Concentrations based on sampling in December 2004 by Ecology; not all discharge points sampled at Bluebird.
[d] kg/day for point sources = Effluent GPD / 10^6 x Total Phosphorus in ug/L Phosphorus / 1000 x 3.7854.

Wasteload allocations for WWTP NPDES permit discharges

The current nutrient loads from all National Pollutant Discharge Elimination System (NPDES) permit holders exceed the loading capacity of waters in the Wenatchee River watershed. The wasteload allocations presented in Table 15 (expressed as daily maximum concentrations) are provided to meet DO and pH criteria during the critical period (March-May and July-October) established for this TMDL. Table 16 presents the wasteload allocations as daily loads in kilograms per day.

Table 15. Wasteload allocation in concentration and kg/day for NPDES dischargers to the lower Wenatchee River (ug/L of phosphorus).

Wastewater treatment plant name and permit number	Wasteload allocation (micrograms/liter) of total phosphorus (daily maximum)	Load at TMDL: 90 ug/L TP daily maximum WLA concentration (kg/day) [a]	
		2002 Flow	Design Flow
Leavenworth WA0020974D	90	0.146	0.286
Peshastin WA0052175C	90	0.021	0.037
Cashmere WA0023183D	90	0.225	0.640

[a] kg/day for point sources = Effluent MGD x TP in mg/L Phosphorus x 3.7854.

Table 16. Wasteload allocations in loads (kg/day) for WWTP NPDES discharges in the lower Wenatchee River.

Wastewater treatment plant (WWTP)	2002 Flow WWTP effluent (mgd) [a]	Design flow WWTP effluent (mgd) [a]	Load at 90th % TP concentration (kg/day) [b]		Load at TMDL: 90 ug/L TP daily maximum WLA concentration (kg/day) [b]		Percent reduction from current and design loads
			2002 Flow	Design Flow	2002 Flow	Design Flow	
Leavenworth	0.43	0.84	9.55	18.67	0.146	0.286	98.5%
Peshastin	0.061	0.11	2.05	3.69	0.021	0.037	99.0%
Cashmere	0.66	1.88	14.97	42.63	0.225	0.640	98.5%
Total WWTP load contribution	1.15	2.83	26.57	64.99	0.392	0.964	98.6%

[a] Effluent flow projections based on data from 2002 monitoring and permit fact sheets, except Cashmere (2xdesign).
[b] kg/day for point sources = Effluent MGD x TP in mg/L Phosphorus x 3.7854.
TP = Total phosphorus.
WLA = Wasteload allocation.

Allocation for future growth

Wasteload allocations were set based on design flow of the WWTPs, leaving an allocation for growth up to the current design flow conditions (proposed design flow for Cashmere WWTP). At current WWTP flow, there would be a 0.57 kg/day reserve allocation for future increased treatment at the WWTPs from current discharges.

Besides the allocation for the design build-out of these facilities, this TMDL presently provides zero allocation for increased phosphorus loading to the lower Wenatchee River or its tributaries. Therefore, this TMDL makes the assumption that growth in the Wenatchee River watershed will have:

1. Controls on phosphorus from permitted sources at levels at or below the wasteload allocations.
2. Ensure that new development or changing of land uses does not contribute to increased nonpoint source loading of phosphorus to the river.

Summary table of load and wasteload allocations for the lower Wenatchee River

Achieving the load reduction targets set for the tributaries, diffuse sources, and point sources in the Wenatchee River watershed is intended to be a watershed scale DO and pH improvement strategy. This report assumes that 303(d) category 5 listings for DO and pH in tributaries to the Wenatchee River will meet standards if the tributaries meet the assigned wasteload allocations presented in this report (Table 17).

Table 17. Summary of target load and wasteload allocations for phosphorus to the lower Wenatchee River.

Lower Wenatchee loading source category	2002 load (kg/day)	Percent reduction	Target load (kg/day)
Upstream load	1.24	25%	0.94
Current discharge at municipal WWTPs	27.37	98.6%	0.39
Non-contact cooling water	0.112	48%	0.028
Tributaries	1.75	47%	0.92
Irrigation-management return flow	0.29	10%	0.26
Diffuse loads	19.23	60%	7.54
Withdrawals	-2.39	NA	-0.81
Allocation for design flow at WWTP	NA	NA	0.57
Allocation for future growth	NA	NA	0.0
Margin of safety	NA	NA	NA (implicit)
Totals	47.6	80%	9.8

WWTP = Wastewater treatment plant.
NA = Not applicable.

Load and wasteload allocations for phosphorus to lower Icicle Creek

Load allocations for upstream sources

The current critical-condition upstream inorganic-P load to lower Icicle Creek was estimated as 0.01 kg/day from the upper Icicle Creek watershed (above the LNFH). By applying maximum natural conditions to upper Icicle Creek, the upstream load is still estimated to be 0.01 kg/day. Upstream of LNFH, Icicle Creek is seasonally dewatered by irrigation, hatchery and drinking water diversions. Increasing flow would afford some dilution for LNFH even though upstream loads may increase slightly.

Load allocations for diffuse phosphorus loads

The Icicle Creek natural condition simulation shows that diffuse (nonpoint) sources could be reduced in lower Icicle Creek. Table 18 shows the target load for diffuse sources in lower Icicle Creek based on meeting a maximum natural condition.

Table 18. Target loads (load allocation) for diffuse sources of phosphorus in lower Icicle Creek during critical conditions.

Reach name	2002 load (kg/day)	Percent reduction	Target load (kg/day)
Above E. Leavenworth Rd. (RM 2.9 to RM 2.3)	0.061	0%	0.061
Below E. Leavenworth Rd. (RM 2.3 to mouth)	0.126	44%	0.071
Totals	0.19	--	0.13

Wasteload allocations for phosphorus

The wasteload allocations presented as a maximum daily concentration in Table 19 are provided to meet DO and pH criteria during the critical period established for this TMDL. The critical period occurs during March through May prior to snowmelt run-off, and July through October after snowmelt run-off. Under existing conditions, the Leavenworth National Fish Hatchery has a wasteload allocation of 5.7 ug/L.

Table 20 presents the wasteload allocation in kilograms per day.

Table 19. Wasteload allocation in concentration (ug/L) of phosphorus) for the Leavenworth National Fish Hatchery.

Facility name and NPDES permit number	Wasteload allocation (micrograms/liter) of phosphorus
Leavenworth National Fish Hatchery WA-000190-2	5.7

Table 20. Wasteload allocations for phosphorus in loads (kg/day) for the Leavenworth National Fish Hatchery.

LNFH discharge point	2002 inorganic-P load	Target maximum load
Process water	1.191	0.51
Abatement pond	0.062	0.008
Total LNFH load contribution	1.25	0.52

Allocation for future growth

This TMDL presently provides zero further allocation for growth in lower Icicle Creek. The lower Icicle Creek would have no additional loading capacity for phosphorus. Therefore, this TMDL makes the assumption that, to achieve and maintain compliance with water quality regulations, growth in the Icicle Creek watershed will:

1. Have controls on phosphorus from permitted sources at levels at or below the wasteload allocation.
2. Ensure that new development or changing of land uses does not contribute to increased nonpoint source loading of phosphorus to the river.

Margin of safety

The federal Clean Water Act requires a margin of safety (MOS) to be incorporated into the loading capacity of TMDLs. The MOS requirement is intended to account for uncertainty in data and modeling. The MOS may be implicit (built into the analysis) or explicit (an added, separate load allocation). This TMDL uses an implicit MOS.

Ecology built in an implicit MOS in the TMDL analysis by using the worst case of both a critical low-flow (7Q10) and 90th percentile critical loads while modeling the loading capacity of the river. For lower Icicle Creek, a hotter August scenario was also simulated. The implicit MOS used for this study is a combination of conservative modeling assumptions that tend to err on the side of a smaller loading capacity.

A MOS is also implicitly built into the permit process by managing for total phosphorus rather than only dissolved inorganic-P. This ensures that all organic phosphorus forms that eventually hydrolyze into bio-available inorganic forms will be included in the allocation.

Summary table of load and wasteload allocations for the lower Icicle Creek

Table 21. Summary of target load allocations and wasteload allocations for lower Icicle Creek.

Lower Icicle Creek loading source category	2002 load (kg/day)	Percent reduction	Target load (kg/day)
Upstream load	0.01	0%	0.01
Leavenworth National Fish Hatchery	1.27	62%	0.48
Diffuse loads	0.19	32%	0.13
Allocation for future growth	NA	NA	0.0
Margin of safety	NA	NA	NA (implicit)
Totals	1.45	57%	0.62

Recommendations for the upper Wenatchee River and upper Icicle Creek

Ecology recommends that no increase in nutrient loading occur in the upper Wenatchee River (above Leavenworth) and Icicle Creek (above LNFH) watersheds during the critical period (March-May and July-October). The 2006 technical study for this TMDL (Carroll et al., 2006) concluded that the upper Wenatchee River and upper Icicle Creek had very limited loading capacities for nutrients. There should be no point source discharges during the critical period in these waters. The Lake Wenatchee WWTP has a permit for only winter-time discharge to the Wenatchee River. The WWTP should apply discharge to land during the critical period.

The current instream nutrient concentrations in the upper Wenatchee River and upper Icicle Creek represent conditions that currently comply with pH water quality standards and nearly reflect natural conditions. Yet model simulations showed slight increases from the maximum natural condition pH range due to nonpoint loading in some areas. Aside from the seasonal discharge from the Lake Wenatchee WWTP, and seasonally affected discharge from the Stevens Pass Sewer District, there are only nonpoint sources of nutrients to the upper rivers. Nonpoint sources may not cause a cumulative increase in the downstream pH range greater than 0.2 pH units.

DO concentrations are less than the 9.5 mg/L criterion during the summer due to high land elevations and high water temperatures. Natural conditions currently restrict any cumulative change in DO greater than 0.2 mg/L due to nonpoint loading.

Controlling nonpoint sources will be critical to protecting the water quality of the upper Wenatchee River. Tributary concentrations to the upper Wenatchee and upper Icicle Creek were generally below the upper estimate of the natural phosphorus concentration (Table 22). Exceptions to this were Nason and Beaver Creeks in the upper Wenatchee River.

Beaver Creek is a small tributary near the Plain bridge that discharges return flow from the Chiwawa Irrigation District during the summer. In addition, the Chiwawa Irrigation District management return flows had a higher average phosphorus concentration (5.3 ug/L) than the average phosphorus concentration of the water at the point of diversion (3.9 ug/L). This suggests additional phosphorus loading during the conveyance of the water. A 26 percent reduction of phosphorus in the management return flow would be needed to match the diversion water concentration.

Table 22. Dissolved inorganic-phosphorus concentration in the upper Wenatchee River and upper Icicle Creek tributaries during 2002-03 sampling (July–Oct 2002; April-May 2003; July-Sept 2003) and reduction needed to meet maximum natural conditions.

Tributaries	Number of grab samples	Average inorganic-P (ug/L)	Standard deviation inorganic-P (ug/L)	90th percentile inorganic-P (ug/L)	Maximum natural condition inorganic-P concentration (ug/L)	% Reduction needed to meet natural condition inorganic-P concentration
Upper Wenatchee Tributaries						
Chiwawa River	11	3.7	0.5	4.3	4.7	0%
Chiwaukum Creek	10	3.6	0.5	4.3	4.7	0%
Nason Creek	13	4	0.5	5	4.7	6%
Beaver Creek	7	23.2	4.5	29	4.7	84%
Upper Icicle Creek Tributaries						
Upper Icicle (above Jack Ck.)	8	3	0.1	3.1	4.7	0%
Eightmile Creek	9	3.4	0.5	4	4.7	0%
Jack Creek	9	3.5	0.6	4.3	4.7	0%

Measured groundwater concentrations were generally low in the upper Wenatchee River watershed. However, they were higher than the upper estimated natural phosphorus groundwater concentration around the Plain area (Figure 6). The Plain area is also an area with higher population densities in the upper watershed.

Reasonable assurance

When establishing a TMDL, reductions of a particular pollutant are allocated among the pollutant sources (both point and nonpoint) in the water body. For the *Wenatchee River Watershed Dissolved Oxygen, pH and Phosphorus TMDL* (Carroll et al., 2006), both point and nonpoint sources contribute to the phosphorus load. TMDLs (and related action plans) must show "reasonable assurance" that contributions from these sources will be reduced to their allocated amounts. Education, outreach, technical and financial assistance, permit administration, and enforcement will all be used to ensure that the goals of this TMDL (water clean-up plan) are met.

Ecology believes that the following activities already support this TMDL and add to the assurance that DO and pH in the Wenatchee River watershed will meet conditions provided by Washington State water quality standards. This assumes that the activities described below are continued and maintained.

The goal of this TMDL is to set targets and provide a strategy to meet the state's water quality standards for DO and pH in Wenatchee River watershed surface waters. There is considerable interest and local involvement toward resolving water quality problems in the watershed. Numerous organizations and agencies are already engaged in stream restoration and source correction actions that will help resolve the DO and pH problem. The following rationale helps provide reasonable assurance that the nonpoint source TMDL goals will be met by 2018.

1. Many members of the Wenatchee Watershed Water Quality Technical Subcommittee and Wenatchee Watershed Planning Unit have conducted education activities in schools and at other events.

2. Technical assistance is available from various organizations in the Wenatchee River watershed. The Cascadia Conservation District (CCD) and U.S. Department of Natural Resources Conservation Service (NRCS) can provide technical assistance for farmers and ranchers. Technical assistance with on-site septic tank management can be obtained by contacting the Chelan-Douglass Health District.

3. The CCD and NRCS have various programs to provide financial assistance to promote agricultural best management practices (BMPs) that reduce nonpoint pollution from agricultural activities. The CCD has received in the past, and is currently the recipient of a Centennial Clean Water Fund grant to assist with developing and implementing TMDLs in the Wenatchee River watershed. The CCD leads several projects that have the potential to reduce inorganic-P loading to the Wenatchee River and Icicle Creek.

4. Chelan County Natural Resources provides incentive money to complete riparian restoration activities. In addition, they have arranged to complete septic tank replacement demonstration projects in the Mission Creek watershed to promote awareness of nonpoint source control in that area.

5. The CCD monitors water quality in the Mission Creek watershed and in other tributaries to the Wenatchee River. Ecology maintains several stream gages in the Wenatchee River watershed that can be used for collection of streamflow data.

6. The Wenatchee Watershed Management Plan provides several recommendations for reducing both point and nonpoint sources of phosphorus to streams in the Wenatchee River watershed.

7. Ecology has instructed the Chelan Public Utility District (PUD) to:
    - Demonstrate that its community drain field at Dryden is not within hydraulic continuity of the Wenatchee River, or
    - Upgrade its wastewater treatment facility to protect water quality standards.

Ecology's participation in a regulatory strategy development uncovered several potential nonpoint sources of phosphorus that may be discharging to the Wenatchee River. The potential sources include:

Potential nonpoint sources in the Dryden Reach:

- The Dryden Landfill (owned by Chelan County).
- On-site septic systems concentrated on the floodplain on the opposite river bank from the Dryden Landfill.
- The Dryden dump and community drainfield.
- Run-off and sprayfield run-off associated with warehouse spray fields, and fruit treatment areas and grounds.

Potential nonpoint sources in the Cashmere Reach:

- Old Cashmere dump.
- Cashmere's leaking wastewater treatment lagoons.
- On-site septic systems leaking to surface waters.
- Leaking sanitary sewer collection systems.

Chelan County, the city of Cashmere, the Chelan PUD Number 1, the city of Leavenworth, and the city of Wenatchee all expressed interest in the investigation of the above nonpoint source phosphorus loads as part of the development of an implementation strategy. Results of nutrient sampling may be useful for developing the *Water Quality Implementation Plan.*

Ecology is authorized under Chapter 90.48 RCW to impose strict requirements or issue enforcement actions to achieve compliance with state water quality standards. However, it is the goal of all participants in the Wenatchee River watershed TMDL process to achieve clean water through voluntary control actions.

Ecology will consider and issue notices of noncompliance, in accordance with the Regulatory Reform Act, in situations where the cause or contribution to the cause of noncompliance with water quality standards can be established.

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Implementation Strategy

Introduction

This implementation strategy describes what will be done to meet water quality standards for dissolved oxygen (DO) and pH in the Wenatchee River and Icicle Creek. It describes the roles and authorities of cleanup partners who are organizations with jurisdiction, authority, or direct responsibility for cleanup. This Implementation Strategy also describes the programs through which the cleanup partners will address these water quality problems.

To implement this TMDL, contributions of phosphorous from both point sources and nonpoint sources need to be reduced. There are several existing programs that, if implemented, will contribute to phosphorus reductions in the Wenatchee River watershed. Also, many projects intended to benefit other existing programs or plans will restore ecological functions or habitat functions that will benefit DO and pH levels in the Wenatchee River watershed.

After EPA approves this TMDL, interested and responsible parties will work together to develop a water quality implementation plan (WQIP). The plan will describe and prioritize specific actions planned to improve water quality and achieve water quality standards.

What needs to be done?

This is a strategy for achieving both point source and nonpoint source reductions of inorganic-P loads in the lower Wenatchee River. There is a limit to the amount of phosphorus reduction that permitted point source dischargers can accomplish to restore water quality in the Wenatchee River. Nonpoint source reductions from known and unknown sources of phosphorus need to occur with as much success as point source reductions. While point source contributions of phosphorus are being addressed, a strategy to identify the solution for nonpoint sources of phosphorus should be developed. This strategy will be included in the WQIP and should include many projects already described by other water quality improvement reports, watershed plans, and habitat improvement programs.

Who needs to participate?

The Wenatchee Watershed Planning Unit's (WPU) Water Quality Technical Subcommittee has served as an advisory group for the development of this TMDL. Individual members of the committee share various participation roles in the implementation of this TMDL. Cities, Chelan County, Chelan Public Utility District, the Cascadia Conservation District, and many others can contribute to the implementation of the TMDL.

Ecology maintains the responsibility of issuing and managing National Pollutant Discharge Elimination System (NPDES) permits that will set phosphorus limits to the Wenatchee River.

NPDES-permitted facilities will be responsible for meeting any NPDES permit limits that result from this TMDL. At the same time, many other entities can contribute to finding reductions of nonpoint sources of phosphorus.

What is the schedule for achieving water quality standards?

Point sources assigned water quality-based effluent standards will comply with a compliance schedule determined by their NPDES permit manager. Compliance schedules are to be no longer than 10 years.

As obvious nonpoint sources of phosphorous are discovered and remedied, a large percentage of the necessary phosphorous reduction should be rapidly achieved. Within five years of completion of this TMDL, 50% of the excessive nonpoint source contributions should be eliminated. The remaining burden of phosphorus resulting from nonpoint sources should be corrected in the following 5 years.

Full compliance with water quality standards is expected to occur by the year 2019.

First Target:	Reduction in 50% of nonpoint source loading	2014
Second Target A:	NPDES permit compliance	2019
Second Target B:	Reduction in the rest of nonpoint source loading	2019
Final Target:	Achieve water quality standards	2019

Adaptive management

As part of this TMDL, Ecology and watershed clean-up participants anticipate using adaptive management that will assure that the designated uses of the Wenatchee River and its tributaries are protected in the most efficient and effective manner. The adaptive management approach will be supported by, but not be limited to, data collection and analysis that:

- Further assesses the assimilative capacity of the Wenatchee River and its tributaries in order to adapt waste load allocations if necessary.
- Compares computer simulated changes (using QUAL2K) in water quality to actual changes in water quality after pollutant sources have been reduced.
- Determine the most effective ways to comply with water quality standards.

Phosphorus loading reductions should be achieved by 2019. Partners will work together to monitor progress towards these goals, evaluate successes, obstacles, and changing needs, and make adjustments to the cleanup strategy as needed.

TMDL reductions should be achieved in ten years from completion of the *Water Quality Improvement Report* (WQIR). However, if water quality standards are met and the load reductions are not met, the objectives of this TMDL shall be satisfied.

It is ultimately Ecology's responsibility to assure that cleanup is being actively pursued and water quality standards are achieved.

Monitoring progress

Monitoring and evaluation will occur throughout the 10-year compliance implementation period. It will be part of the WQIP, and will be done in accordance with a Quality Assurance Project Plan (QAPP). Ecology and clean-up participants anticipate the following schedule.

Phase 1	Point and non-point source reduction activities begin, data collection continued model calibration begins.	2009-2011
Phase 2	Modify load and waste load allocations if appropriate. Identify any additional point and nonpoint source reductions.	2014-2015
Phase 3	Implement additional load reductions.	2015-2019
Phase 4	Achieve water quality standards.	2019

Monitoring is an important element of implementation. Monitoring of DO and pH should occur during the critical period outlined in this TMDL. The critical period of this TMDL is March through October, except during high flows (June) when phosphorus is diluted by cleaner snowmelt and algae growth is limited by high flows, low nutrients, and colder water. Results of monitoring should be compared to the water quality standard relative to the time of sampling and location of sampling.

Monitoring of phosphorus concentrations should be accompanied by streamflow volume monitoring (discharge) to track the amount of phosphorus loading to the Wenatchee River and Icicle Creek.

Monitoring of DO and pH should occur at 5-year intervals at locations representative of the original data set collected for the TMDL. More detailed monitoring plans will be provided in the WQIP.

Quality Assurance (QA) Project Plans must be prepared for all monitoring conducted related to TMDLs. The QA Project Plan should follow Ecology guidelines (Lombard and Kirchmer, 2004) paying particular attention to consistency in sampling and analytical methods. In addition, monitoring conducted related to this TMDL should comply with the Water Quality Data Act codified in RCW 90.48.570 through 90.48.590 and Ecology's Water Quality Program Policy 1-11. Ecology is responsible for effectiveness monitoring programs that will determine if TMDL targets are being met.

Monitoring activities associated with this TMDL include interim monitoring, effectiveness monitoring, and implementation plan monitoring. These monitoring activities are described below.

Interim monitoring

This DO and pH TMDL calls for a decrease in inorganic phosphorous in surface water of lower Icicle Creek, the lower Wenatchee River, and some of its tributaries. Interim monitoring of nutrients during the growing season (March through October) is recommended in surface waters. Monitoring may be required to identify sources of nutrients or determine nutrient levels at sites not sampled during the TMDL study. In addition, the upper Wenatchee River should be periodically monitored to verify that nutrient levels are not increasing.

Implementation plan monitoring

After the WQIP is completed, Ecology will track both current and planned activities. Tracking implementation plan activities is important. This is particularly important if adaptive management is employed. The WQIP will give additional details about the process Ecology will use to track progress in applying identified actions. However, Ecology expects that those groups who conduct restoration projects or install best management practices (BMPs) will be responsible for monitoring and maintaining the BMPs.

Effectiveness monitoring

Effectiveness monitoring results are used to determine if interim targets and/or final water quality standards are being achieved and maintained. Ecology usually performs this type of monitoring 5 years after the WQIP is finished, but may choose to plan the monitoring based on the pace of implementation. Ecology's ability to conduct this monitoring depends upon the availability of resources. However, volunteers and local groups can also conduct nutrient monitoring to measure progress of this TMDL.

If the streams are found to not meet the interim targets and/or water quality criteria, an adaptive management strategy will be developed and future effectiveness monitoring will need to be scheduled.

Potential funding sources

A wide variety of potential funding sources exist for the water quality improvement projects in the Wenatchee River watershed. There is also the potential for collaborating with other planning processes to maximize efficiency. Implementation activities are varied and funding sources appropriate for some projects may not be suitable for others. Therefore, a more detailed analysis of available funding sources is needed as part of the WQIP.

Public sources of funding are administered by federal and state government programs. Private sources of funding normally come from private foundations. Foundations provide funding to nonprofit organizations with tax-exempt status. Forming partnerships with government agencies, nonprofit organizations, and private businesses can effectively maximize funding opportunities.

The U.S. Department of Natural Resources Conservation Service (NRCS) and the U.S. Department of Agriculture Farm Service Agency (FSA) administer federal non-regulatory programs such as the:

- Conservation Reserve Program.
- Conservation Reserve Enhancement Program.
- Continuous Conservation Reserve Program.
- Environmental Quality Incentives Program.
- Wildlife Habitat Incentives Program.
- Grassland Reserve Program.
- Wetlands Reserve Program.
- Conservation Security Program.

Potential funding sources available through Ecology's water quality financial assistance programs include:

- Centennial Clean Water Fund grants.
- Section 319 grants for nonpoint source reductions.
- State Revolving Fund loans.
- Terry Husseman Grants (Coastal Protection Funds).
- 319 Direct Implementation Fund.

Financial assistance for wastewater and stormwater projects is available through the following organizations:

- Washington State Department of Community, Trade and Economic Development.
- Public Works Board.
- USDA Rural Development.
- Washington State Department of Health.

These organizations provide funding for the Public Works Trust Fund, Community Development Block Grants, and Drinking Water State Revolving Fund. Ecology provides loans to cities for upgrades or improvements to their wastewater treatment plants and stormwater projects. Ecology gives grants to communities for wastewater treatment plant upgrades when they can show an economic burden to rate payers.

Other funding sources available to some groups in the Wenatchee River watershed are the Salmon Recovery Funding Board, the Bonneville Power Administration, and the Bonneville Power Foundation.

A directory of many other watershed resources can be found at http://sspa.boisestate.edu/efc/.

Summary of public involvement methods

The Cascadia Conservation District (CCD) conducted extensive outreach during the development of the TMDL. Ecology, CCD, and local organizations hosted workshops, provided presentations, and attended meetings and events to keep people informed as this TMDL was developed.

Ecology worked with the Wenatchee Watershed Water Quality Technical Subcommittee throughout the development of this TMDL. This assured that information about the TMDL was readily distributed when it became available. Ecology met at least seven times per year with the subcommittee since 2002.

Ecology and CCD presented educational information at the Leavenworth National Fish Hatchery's Salmon Fest during most years of TMDL implementation.

Ecology provided funding for the development of a regulatory strategy process.

A public comment period was open between October 1, 2008 and November 30, 2008.

Next steps

After the public comment period on this *Water Quality Improvement Report* is complete and edits and responses to comments are done, Ecology submits the report to the Environmental Protection Agency (EPA) for approval.

Once EPA approves the TMDL the WQIP is developed. Ecology will continue to work with the Water Quality Subcommittee and other residents to create the WQIP. The WQIP expands on information provided in this plan and includes a(n):

- Table of who will do what, where and when.
- Strategy of how to monitor progress.
- Adaptive management strategy.
- List of potential funding sources.

Development of the WQIP will be delayed until EPA approves all TMDLs in the watershed. One WQIP will be developed for all Wenatchee River watershed TMDLs:

- The Mission Creek Watershed DDT TMDL (already approved by EPA).
- Wenatchee River Watershed Fecal Coliform Bacteria (already approved by EPA).
- Wenatchee River Watershed Temperature TMDL (already approved by EPA).
- Wenatchee River Watershed Dissolved Oxygen and pH TMDL (this document).

The Water Quality Subcommittee decided to write only one multi-parameter WQIP because many of the BMPs recommend for this TMDL will also help improve water quality problems identified in the other TMDLs. This approach will allow the most effective implementation strategy to address all the water quality impairments in the watershed.

Regulatory strategy

Ecology is working with Chelan County Public Utility District number 1 and several NPDES dischargers on a strategy to meet the wasteload allocation goals of this TMDL.
The NPDES permit holders may choose to take one of several alternative or additional target pursuit actions below to help meet the TMDL targets. These actions will be recognized as contributing toward achieving phosphorus reduction targets as long as they achieve demonstrated reductions in phosphorus loading to the river.

These additional pursuit actions are:

- **Reclaimed Water:** Publicly-owned dischargers may seek to re-use the Class A reclaimed water they produce as result of technology improvements. All reasonable efforts to re-use rather than directly discharging it to the River, particularly in the March-October timeframe, are strongly encouraged.
- **Regional Treatment Programs:** Publicly-owned treatment plants may participate with other publicly-owned NPDES permit holders to create a regional wastewater treatment program, benefiting economy of scale and extension of services to un-serviced areas.
- **Regional Phosphorus Reduction Programs:** Publicly-owned treatment plants may participate with other publicly-owned NPDES permit holders in regional phosphorus reduction programs, such as conservation and nonpoint source control (see below).
- **Source Control Programs:** Source control actions to limit phosphorus inputs through regulation of phosphorus-containing products and through enforced phosphorus-limiting pre-treatment ordinances may be used to reduce phosphorus loading to the river.

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Appendices

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Appendix A. Glossary and acronyms

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality limited estuaries, lakes, and streams that fall short of state surface water quality standards, and are not expected to improve within the next two years.

7Q10 low flows: Low streamflow conditions that occur on a one-in-ten year recurrence interval.

Anthropogenic: Human-caused.

Anomalous: Deviating from the general or common order or type.

Best management practices (BMPs): Physical, structural, and/or operational practices that, when used singularly or in combination, prevent or reduce pollutant discharges.

Char: Char (genus *Salvelinus*) are distinguished from trout and salmon by the absence of teeth in the roof of the mouth, presence of light colored spots on a dark background, absence of spots on the dorsal fin, small scales, and differences in the structure of their skeleton. (Trout and salmon have dark spots on a lighter background.)

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Critical conditions: Conditions during the critical period but also refers to critical load conditions and critical climate conditions (i.e., generally the worst-case conditions for water quality).

Critical period: March through May and July through October.

Designated uses: Those uses specified in Chapter 173-201A WAC (Water Quality Standards for Surface Waters of the State of Washington) for each water body or segment, regardless of whether or not the uses are currently attained.

Diel: Of, or pertaining to, a 24-hour period.

Existing uses: Those uses actually attained in fresh and marine waters on or after November 28, 1975, whether or not they are designated uses. Introduced species that are not native to Washington, and put-and-take fisheries comprised of non-self-replicating introduced native anywhere from 10 to 10,000 fold over a given period. The calculation is performed by either: (1) taking the nth root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

Inorganic-phosphorus (Inorganic-P): This portion of phosphorus is also called ortho-phosphate. It is the portion of phosphorus occurring in the aquatic environment that is dissolved in the water column and is readily available for biological uptake. Its most common form is PO_4^-.

Load allocation: The portion of a receiving waters' loading capacity attributed to one or more of its existing or future sources of nonpoint pollution or to natural background sources.

Loading capacity: The greatest amount of a substance that a water body can receive and still meet water quality standards.

Margin of safety: Required component of TMDLs that accounts for uncertainty about the relationship between pollutant loads and quality of the receiving water body.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Natural conditions: Mean surface water quality that was present before any human-caused pollution. When estimating natural conditions in the headwaters of a disturbed watershed, it may be necessary to use the less disturbed conditions of a neighboring or similar watershed as a reference condition.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities. This is including but not limited to atmospheric deposition, surface water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the National Pollutant Discharge Elimination System Program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or is likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Salmonid: Fish that belong to the family *Salmonidae*. Basically, any species of salmon, trout, or char. www.fws.gov/le/ImpExp/FactSheetSalmonids.htm

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Total maximum daily load (TMDL): A distribution of a substance in a water body designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Wasteload allocation: The portion of a receiving water's loading capacity allocated to existing or future point sources of pollution. Wasteload allocations constitute one type of water quality-based effluent limitation.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this report:

CV	Coefficient of Variation
DMR	Discharge Monitoring Report
DO	Dissolved Oxygen
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
GPD	Gallons per Day
Inorganic-N	Inorganic Nitrogen
LNFH	Leavenworth National Fish Hatchery
NCCW	Non-Contact Cooling Water
NWIS	National Water Information System (USGS)
POTW	Publicly Owned Treatment Works
RCW	Revised Code of Washington
RM	River Mile
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WQIP	Water Quality Implementation Plan
WWTP	Wastewater Treatment Plant

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Appendix B. Record of public participation

Outreach and announcements

A 60-day public comment period for this report was held from October 1, 2008 through November 30, 2008.

A news release was sent to all local media in the Wenatchee River watershed area.

Advertisements were placed in the following publications:

- Leavenworth Echo
- Wenatchee World
- Cashmere Valley Record

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Appendix C. Response to public comments

Wenatchee River Watershed Dissolved Oxygen and pH TMDL
Public Comment Responsiveness Summary

The public comment period opened on October 1, 2008, and originally was scheduled to close on October 31, 2008. Due to concerns from some comment providers, the public comment period was extended until November 30, 2008. Comments were accepted if they were sent on or before December 1, 2008 because November 30 was a Sunday.

Ecology received comments from the City of Leavenworth, Grant County Public Utility District Number 2, Chelan County Public Utility District Number 1, the Yakama Nation, Wild Fish Conservancy and Chelan County Natural Resources Department. The United States Environmental Protection Agency provided an early review of the project and some changes to the document occurred as a result of this review.

The comments received and the Department of Ecology's (Ecology) responses are provided below. Comments are grouped by topic and by the organization that submitted the comment.

Comments regarding state standards

The City of Leavenworth, Yakama Nation, Chelan PUD, and Grant PUD comments all suggested that the water quality standards were not appropriate for application in the Wenatchee River for various reasons. Some suggested that scientific methodology was not used to designate uses, assign criteria, and or measure compliance with criteria. For example, the City of Leavenworth wrote:

- "Phosphorus limits on the point source WWTP's are not based on best available science yet the TMDL is requiring use of best available technology for phosphorus removal."
- "In addition, it is apparent that the Washington pH Standard WAC 173-201A-200 allowance for a 0.2 or a 0.5 pH unit change due to human influences is not being properly applied."
- "We are also concerned that the Wenatchee River's natural background condition does not meet the 8.5 pH standard that is being applied. If the pH swings above Leavenworth, prior to any significant point or non-point inputs, are above 8.5 (and that is documented to exist by DOE) then the entire model objective of forcing compliance with an 8.5 objective is misplaced. The natural condition would be higher and the standard applied would have to reflect that condition."

Response: Ecology's Environmental Assessment Program and Water Quality Program used the best available science to conduct the TMDL assessment and report. The project incorporates a more comprehensive data set and modeling effort available to characterize nutrients, pH and dissolved oxygen in the Wenatchee River watershed. Ecology followed the Water Quality Data Act (RCW 90.48.570-590) in the development of the 303(d) listings and the collection and analysis of data used in the report. The technical report the TMDL is based on was provided for review by a broad audience of science professionals two times before publication. Ecology's modeler consulted with several experts in the field including the model developer to verify that the model was applied correctly. In addition, the TMDL report itself underwent internal and external scientific review before it was provided for public comment. A third party consulting firm concluded that the model was used appropriately and accurately represented water quality conditions in the Wenatchee River watershed.

The second and third bulleted points above question how state standards were applied to the Wenatchee River. The pH change criterion of no more than 0.2 and 0.5 units applies to water bodies that naturally do not exceed the range of 6.5 to 8.5 pH units. The reviewers and Ecology correctly reach the same conclusion that the Wenatchee River does not meet the numeric criteria. Ecology reported that under natural conditions, the Wenatchee River would not meet state standards for pH during critical periods of the year. Thus, no further measurable change of pH is allowed. The TMDL defines measurable as less than 0.1 pH units.

The Yakama Nation provided the following comment:

> *"We understand that this is not the correct forum for commenting on state water quality standards. However, we do feel that some revisions of the standards where they are applied to the protection of fish and other aquatic species may be in order."*

Response: We agree that this is not the correct forum to provide comment on our standards. The purpose of a TMDL is to define pollutant load conditions that will meet state water quality standards. Furthermore, this is also not the correct forum with regard to the designated uses and measurement of conditions related to standards and listing on the 303(d) list.

The water quality standards undergo triennial review and the 303(d) list is updated with an opportunity for public comment approximately every two years. The standards were recently updated using the most recent water quality data and specific salmon inventories available. Designated uses are assigned based on specific data. Review of the standards again will be conducted during the next triennial review.

An interesting comment regarding the water quality standards came from Grant County Public Utility District and stated that "Achieving DO and pH criteria within the lower Wenatchee River does not, by itself, guarantee protection of endangered or threatened fish species."

It is the objective of this TMDL to be sure that Dissolved Oxygen and pH levels do not harm aquatic life. Many of the other challenges of salmon recovery are outside of the scope of this TMDL; however, restoring habitat processes that might increase the loading capacity of the Wenatchee River system to assimilate nutrients may indeed provide opportunities to synergize water quality and habitat improvement projects.

Comments regarding QUAL2K model and periphyton data

Leavenworth highlighted three primary concerns raised by the consulting firm Hall and Associates. They commented that the QUAL2K model did not:

- *Properly predict periphyton growth*
- *Properly predict DO and pH variability*
- *Target the appropriate critical condition or pollutants of concern*

Response: The questions raised by the Hall and Associates review are similar to those offered by HDR Inc.'s review during an earlier, informal comment period. In order to address these comments, Ecology included the responses to HDR's questions as an appendix to the TMDL report.

Comments regarding natural conditions and salmon carcasses

Leavenworth provided comments from the consulting firm Water Quality Engineering. They were one of several regarding the treatment of cultural oligotrophication due to a decrease in marine derived nutrient availability from salmon carcasses.

Their comment was:

> *"the goal of the TMDL and modeling of natural background conditions in the TMDL may be inconsistent with the concepts of cultural oligotrophication caused by the depletion of marine derive nutrients such as returning salmon."*

Similar comments were received from Grant PUD and the Yakama Nation.

Response: The hypothesis behind carefully treating watersheds for cultural oligotrophication may be valid within the upper Wenatchee River watershed where a little point and non-point source pollution has maintained very low phosphorus levels during baseflow conditions. In the main stem Wenatchee River below the City of Leavenworth cultural oligotrophication caused by depleted salmonid stocks is more than offset by cultural eutrophication from the discharge of dissolved inorganic phosphorus at wastewater treatment plants and additional nonpoint sources of dissolved inorganic phosphorus.

The design capacity daily load of phosphorus from wastewater treatment plants to the Wenatchee River is 65 kg per day. Assuming the average returning adult salmon contains 0.062 kg of phosphorus (data from Yakama Nation Fisheries comment letter) this equates to the phosphorous load of approximately 380,000 adult returning fish. This number of returning fish far exceeds most estimates of historic returns to the main stem Wenatchee River. Given that there are also inputs of nonpoint source phosphorus entering the Wenatchee River it is reasonable to conclude that the lower Wenatchee River experiences cultural eutrophication.

Implementation of the TMDL will focus on reducing sources of dissolved inorganic phosphorus from non-natural sources. Phosphorus from returning adult salmon is part of natural background sources. Reducing the load of non-natural, dissolved nutrients during critical periods in the upper Wenatchee River should benefit salmon recovery by increasing minimum dissolved oxygen concentrations and limiting pH variations in order to protect many ecosystem components that benefit salmon.

The challenge of balancing marine derived nutrients and anthropogenic nutrients can be addressed during TMDL implementation. As the overall understanding of marine derived nutrient partitioning increases, the overall effect of marine derived nutrient fluxes on in-stream water quality may become better understood. The pH and dissolved oxygen affects of increased productivity caused by the return of adult salmon will be considered part of the background. Human sources of nutrients, such as discharges from NPDES permitted facilities or ineffective on-site sewage systems are not part of natural background sources. The non-natural sources of phosphorus will be the focus of implementation.

Comments regarding critical period and adaptive management

The Yakama Nation suggested that load allocations should be adjusted based on the time of year. The City of Leavenworth suggested that wasteload allocations should be examined to allow for different targets during the early season and late season of the critical period. Chelan Public Utility District also wanted seasonally considered effluent limits. The Wild Fish Conservancy felt that the analysis for Icicle Creek did not consider the most critical flow conditions for the TMDL analysis and they were concerned that NPDES permits issued may not be issued for the entire critical period. The United States Environmental Protection Agency (EPA) has suggested we clarify the tables in the TMDL to include information on the critical period.

Several comments requested that Ecology consider adaptive management of the TMDL as the Water Quality Implementation Plan (WQIP) is developed. Adaptive management will be an important process to incorporate new information that assists with meeting water quality standards for dissolved oxygen and pH.

Response: The TMDL set pollutant target goals (reductions) that meet water quality standards on both daily and longer time scales. If water quality standards are not met, then adaptive management provides that the targets would be adjusted appropriately. Effectiveness monitoring and follow-up evaluation will determine if these targets are met. If needed, waste load allocations would be adjusted in order to meet standards.

Presently, the critical period for the TMDL includes March through October excepting the time of the year when snow melt run-off raises stream discharge and lowers water temperature which reduces periphyton growth.

One comment requested that nutrient trading be examined as a means of allowing phosphorus from new fish rearing facilities and Chelan County commented that the TMDL should allow a portion of the loading capacity for growth. Adaptive management could examine lowering point source contributions in order to accommodate growth. At the same time, better technology for treating point sources and preventing nonpoint source pollution may allow for growth as well.

Implementation of wasteload allocations alone will not achieve goal of TMDL

One point that was brought up by the City of Leavenworth's review is the fact that <u>point source reductions</u> alone will not protect salmonid populations from pH and dissolved oxygen excursions from numeric water quality criteria.

Response: This is true: without nonpoint source reductions too, the Wenatchee River may still violate water quality standards for pH and dissolved oxygen.

Grant County PUD comments not addressed above:

> *"Table 17 on page 65 needs further clarification. "*

Response: This table will be edited accordingly.

> *"Grant PUD suggests that WDOE take a closer look at the natural condition simulation, especially at these locations, to determine if there were any errors in the natural condition simulation and if so how that would change phosphorus load and wasteload allocations. If WDOE concludes that the DO and pH spikes are natural, they should explain the reasoning for reaching that conclusion in the final TMDL.*"

Response: The natural conditions simulation reflects the natural increase in stream nutrients and nutrient uptake in the Wenatchee River as well as the natural changes in morphology, light availability, stream temperature and other attributes as input to the model. The output of the model shows a reflection of stream conditions that vary longitudinally. These variations are amplified with higher nutrient concentrations.

> *"Five-year schedule for 50% reduction in phosphorus loads too aggressive due to multiple unknowns."*

Response: The five-year schedule for nonpoint phosphorus load reductions is an aggressive target. The success rate of nonpoint source reductions is often dependent on successful participation in nonpoint source reduction projects conducted by local government and organizations. Ecology will support projects that reduce nonpoint sources of phosphorus as well as other nonpoint sources of pollution in the Wenatchee River watershed.

Chelan PUD Comments not addressed above:

> *"As stated earlier, it is important to recognize the goal of the TMDL process is to maintain and protect designated uses. As different alternatives are analyzed during development of the implementation plan, Chelan PUD requests the effectiveness of these alternatives be based solely on their ability to maintain and protect designated uses, and not whether load allocations or wasteload allocations are met."*

Response: Effectiveness of implementation will be assessed to ascertain whether state water quality standards that protect designated uses are met.

> *"The schedule set forth in the Implementation Strategy in the draft TMDL requires a first target reduction in 50 % on nonpoint loading by the year 2013. Because Chelan PUD's point source (Peshastin wastewater facility) and non-point source (Dryden wastewater facility) implementation alternatives most probably will be tied together, Chelan PUD requests that any nonpoint loading from Dryden wastewater system not be included in*

this first target reduction, but instead included in the target date for the point dischargers."

Response: We agree. We intend to document it in the Water Quality Implementation Plan (WQIP).

Wild Fish Conservancy comments not addressed above:

"Page 15, Tables ES-2 and ES-3. It is unclear if the "Tributaries" category in Table ES-2 includes Icicle Creek. Later in the report (e.g., Table 4), it is clear that it does, so some clarification would help in Table ES-2."

Response: Thank you for this comment. We have added "(including Icicle Creek)" to the table.

"Page 26, pH: We suggest that the first sentence read "The pH value is an estimate of the relative acidity and alkalinity of water" as pH is the measure of hydrogen ion activity (the pH of an . . . "

Response: The sentence now reads "The pH value is a measure of the relative acidity and alkalinity of water."

"We believe that it is past time for Ecology to require operators of freshwater net pens to apply for and receive NPDES permits. Regardless, we hope that the implementation plan, at a minimum, includes best management guidelines for the Lake Wenatchee net pen facility so that problems both in the lake and downstream can be avoided."

Response: The implementation plan will recommend activities to reduce phosphorus from all non-natural sources of phosphorus, such as food waste from fish rearing facilities. Whether or not a facility requires a permit or is addressed as a nonpoint source is not determined by this TMDL; however, practices that minimize phosphorus from these facilities are nevertheless recommended in it.

Chelan County Natural Resource Department comments not addressed above:

"The TMDL proposes narrowly constrained and prohibitively expensive options for addressing nutrient loading in the watershed that would not likely result in a substantial improvement in conditions for aquatic life or measurable improvements in water quality. The WQIP should consider the full range of options for addressing real and measurable water quality concerns."

Response: The TMDL provides the loading capacity, and wasteload allocations and load allocations that when combined will protect the beneficial uses in the Wenatchee River from exceedances of the dissolved oxygen and pH criteria. The WQIP will not limit options for making measurable water quality improvements in the watershed.

Appendix D. Response to HDR Inc.'s review of QUAL2K modeling

Prior to releasing the Wenatchee River Watershed Dissolved Oxygen and pH Total Maximum Daily Load- Water Quality Improvement Report (TMDL), Ecology provided the TMDL to members of the Wenatchee Watershed Planning Unit's Water Quality Technical Subcommittee for review. The City of Leavenworth, City of Cashmere, and Chelan County Public Utility District Number 1 hired HDR Inc., to review the modeling work conducted for the TMDL. Their review and Ecology's responses are provided below.

One primary concern that HDR provided, focused on the use of periphyton data collected to verify that the water quality model did not over-estimate end of season biomass predictions for periphyton. This was also a concern during the public comment period. Ecology's responses provide information regarding the use of periphyton data that should suffice to answer the comments received.

HDR comments:

HDR has completed its initial review of the QUAL 2K Modeling developed by the Department of Ecology in support of the Wenatchee River TMDL for dissolved oxygen and pH. Ecology determined that dissolved oxygen (DO) and pH were not meeting the water quality standards for the beneficial uses assigned to the Wenatchee River. This determination resulted in the Wenatchee River being identified as impaired on the 303(d) list. Waters listed as impaired require an analysis to compute the Total Maximum Daily Load (TMDL) that the water can receive and still meet the water quality standards.

Ecology believes that periphyton, rooted freshwater aquatic vegetation, is the main cause of DO and pH not meeting the standards. Throughout its life cycle, including growth, respiration, and decay, periphyton affects DO and pH. Periphyton may be controlled by managing phosphorus, which is commonly the limiting building block to periphyton growth.

The TMDL is formulated based upon the anthropogenic impact on the river being limited to 0.20 mg/l dissolved oxygen or 0.1 pH. This is a very, very small impact and essentially defines the total loading capacity available for the TMDL. In other words, the TMDL is not based on the River water quality as much as it is based on the definition of an "unmeasurable" impact defined in the Washington State Water Quality standards because in the natural condition, the TMDL finding is that the river would not meet State Water Quality Standards. Ecology has applied the QUAL2K model to the Wenatchee River to conduct modeling in order to help allocate nutrient loading amongst the point and non-point dischargers, while keep the impact to the river limited to 0.20 mg/l dissolved oxygen or 0.1 pH.

A draft report on water quality improvement for the Wenatchee River was recently released titled ***Wenatchee River Watershed Dissolved Oxygen and pH Total Maximum Daily Load, Water Quality Improvement Report, July 2008 Draft, Ecology****. The models used to present scenarios* *and develop conclusions in this report were reviewed by HDR. The report is based on a TMDL Study and modeling completed in 2006 by Ecology,* ***Wenatchee River Basin Dissolved Oxygen, pH, and Phosphorus Total Maximum Daily Load, April 2006, Ecology,*** *and newer modeling completed for this report. These previous reports were also reviewed by HDR to provide context for the current draft report.*

Overall, the modeling appears to be an appropriate and thorough application of the QUAL2K model. However, there are some inconsistencies that could use additional documentation and/or revision. The 2008 modeling approach seems valid and fairly well documented for setting the natural conditions and the process for water quality analysis is similar to presentations seen for other TMDLs completed by Ecology.

However, the reports and documentation provided by Ecology were not sufficient to back-check all of the modeling inputs. Some interpretation and basic comparisons were necessary. For example, while the model simulations provided to HDR to review are not the same as the calibration models presented in the 2006 report, both the August and September simulations have consistently similar results between the 2006 and 2008 models. This suggests that the appropriate models were used for running through the scenarios in the updated draft report and there were no substantial changes to the 2006 model, other than those for the various scenarios, performed by Ecology. HDR was able to recreate Figure 15 (Ecology, 2008), the basis for wasteload allocations, from the models provided by Ecology.

The modeling associated with the ***Wenatchee River Watershed Dissolved Oxygen and pH Total Maximum Daily Load, Water Quality Improvement Report, July 2008 Draft, Ecology*** *was the primary focus of the review. Both the report, and its previous 2006 draft, and the provided QUAL2K model files were reviewed. The models provided by Ecology were designated with the following file names:*

Associated with the 2006 report

1. *Wenatchee_aug02 (construction and calibration)*
2. *Wenatchee_sept02 (construction and calibration)*
3. *Wenatchee_7Q10 (construction and calibration)*

Associated with the 2008 report

4. *Wen_Aug_Natural_Conditions*
5. *Wen_Aug_POTWdesignQ*
6. *Wen_7Q10_POTWdesignQ_90th%P (Sept)*
7. *Wen_7Q10_max_nat_cond (Sept)*
8. *Wen_7Q10_max_nat_cond_POTWdesignQ_500ugP (Sept)*
9. *Wen_7Q10_max_nat_cond_POTWdesignQ_100ugP (Sept)*
10. *Wen_7Q10_max_nat_cond_POTWdesignQ_50ugP (Sept)*
11. *Wen_7Q10_max_nat_cond_POTWdesignQ_20ugP (Sept)*
12. *Wen_7Q10_max_nat_cond_POTWdesignQ_10ugP (Sept)*

1. **Comment about the change in model versions for the model results presented in the 2006 report and 2008 draft report.**

   - *The first three models use a different version of the QUAL2K model code than the last nine models. Different versions of models can generate different results. It is important to verify no difference occur due to the model code. HDR did not find any documentation of the model conversion or whether it was checked. Typically, the different model versions would be verified against the calibration and determined if the converted model fit the calibration better or worse than the previous version.*

   Different Versions of the QUAL2K model (Models 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12)

Response: Both model versions give the same results. The new version of QUAL2K (version 40) was verified as giving the same results as the earlier version of QUAL2K (version 32) by comparing model state variables and results. The newer version added features that did not change the calibration or the underlying algorithms of the earlier version.

2. **Comment about the original calibration report and the statement in the Abstract referencing data collected in 2006.**

   - *Understanding the information that was used to create the model is important to understanding the river system and if the model was applied appropriately. There is no presentation or references to another report of 2006 data or additional model calibration. Were data collected in 2006 and were they used for the modeling? The 2006 data and report were not available to review although these are noted as key to the assessed causes of DO and pH violations (periphyton?), to showing that phosphorus is the limiting nutrient, and calibration or re-calibration of the QUAL2K model.*

   p.11-2008 "The data from this 2006 study were used to:" and "Calibrate a QUAL2K water quality model for the Wenatchee River and Icicle Creek."

Response: The abstract incorrectly assigned the data collection year as 2006. It should have stated 2002-03 and will be corrected. The data collection was conducted in 2002-03; there was no further data collection in 2006. The 2002-03 data and model calibration is reported in "Wenatchee River Basin Dissolved Oxygen, pH, and Phosphorus TMDL Study" (Carroll et al, 2006), available from the Ecology website at http://www.ecy.wa.gov/biblio/0603018.html.

3. **Comment about the season of concern for the TMDL.**

   - *The season of concern from March through October is based on a simple analysis of historical pH data with the exception of snowmelt runoff in May through July. There appears to be no investigation if exceedances are similar for the March through April period as for the August through October period. Additionally, no data were collected between early January and early*

April (p.6-Table 2). Are there documented exceedances in March through April or was this just a low flow period? Rather than having a constant waste allocation based on the worst conditions in August/September, could a seasonally varying allocation be just as protective?

p.30-2006 "There are two clear seasons of excursions at the mouth of the Wenatchee River,……exceedances occurring between August and November, and the rest occurring between March and May."

Response: We believe long-term water-quality records can be used to assess seasonal variation of pH. The 2006 TMDL report reviewed historical data from our two historical water-quality stations on the Wenatchee River. We have collected monthly data from above Tumwater Canyon (ambient station # 45A110) and near the mouth of the Wenatchee River (ambient station # 45A070) for many years. The monthly pH data from 1994 to 2004 was evaluated and presented as box plots in Figure 5 of the 2006 report. The historical record clearly shows exceedances in pH (above 8.5) in the lower Wenatchee beginning in the month of March and continuing into April. Ecology confirmed the springtime pH exceedances in April 2003 by deploying Hydrolab dataloggers that showed pH > 8.5 in the lower Wenatchee River at RM 6.5 and RM 1.0. The results of the deployments were summarized in Table 17 of the 2006 report.

Seasonally varying allocations may be protective outside of the stated TMDL season-of-concern. Ecology used a steady-state model to develop the waste-load and load allocations that would be protective of critical conditions from August to November, but the historical record also shows pH > 8.5 exceedances beginning in the month of March and continuing into April. We believe the waste-load and load allocations should be applied to both the spring and summer/fall season-of-concern to be protective. Outside of the TMDL season-of-concern, seasonal limits may be possible if mitigation actions can be shown to be flexible enough to manage pollutants season-to-season.

4. Comments about the periphyton biomass cause and effect of pH and DO diel changes and Ecology's approach to modeling DO and pH response to periphyton.

- *The hypothesis that the system is driven by periphyton is built upon some strong supporting evidence (DO and pH data); however, there is little direct evidence (actual periphyton data, sampling, photos, etc.) provided. Review of the supporting 2006 Report included little information about the minimal periphyton sampling.*

Response: The QUAL2K models were calibrated to the observed DO and pH diel ranges (the target response variables) and the observed nutrient concentrations (the target control variables). Biomass was measured in order to establish the relative biomass range in the upper and lower Wenatchee River watersheds. The maximum biomass was used to set a ceiling for biomass production in the models. DO and pH diel ranges respond directly to levels of primary productivity and respiration. This fact is well understood and a basic concept of water-quality ecology and water chemistry. We collected many diel DO and pH profiles in the Wenatchee River and Icicle Creek to assess the productivity levels in different parts of the systems. The

2006 report clearly shows the increased DO and pH diel ranges in the lower Wenatchee River and lower Icicle Creek, indicating the increased productivity of those reaches.

We did make visual observations to confirm the difference in biomass in the lower versus upper Wenatchee River. Figure D-17 shows an August photo of the relatively algae-free substrate in the river above Tumwater Canyon and Figure D-18 shows an August photo of the algae-covered substrate in the river at the mouth. More periphyton biomass was observed in all of the lower Wenatchee River (below Leavenworth) including below Peshastin (Figure D-19) and Cashmere Figure D-20).

Figure D-17. Picture from August 2003 showing the relatively algae-free substrate of the Wenatchee River above Tumwater Canyon at the Hwy 2 Bridge.

Figure D-18. Picture from August 2003 showing the algae-covered substrate in the Wenatchee River near the mouth. *A rock without algae from the shoreline was thrown into the water for comparison.*

Figure D-19. Photo from August 2003 showing algae-covered cobble from the Wenatchee River below Peshastin. *White bleached rocks were covered with algae until the water levels lowered. Along the shoreline, filamentous algae was also present in the lower-velocity water***.**

Figure D-20. Periphyton growing downstream of Cashmere WWTP outfall.

- *Periphyton is explained as the key to pH and dissolved oxygen exceedances and is controlled by phosphorus loadings. However, "Periphyton biomass was not sampled for Icicle Creek" (p.67). "Samples were scraped from rocks at five locations in the Wenatchee River in the beginning of September for determination of end-of-season biomass…"(p.56). There is no information about periphyton sampling in the Methods or Data Quality Results sections. Only four points are shown for calibration on model result plots (p.26-Figure 24). The data are for end of the season versus modeled August and September data. The main hypothesis about how the system functions is based on these five unqualified data points. Additional photographic, qualitative, and quantitative data would provide a stronger foundation for the TMDL but are not presented in the studies published by Ecology.*

p.vii-2006 "…were caused by periphyton (attached algae) growth."
p.x-2006 "…phosphorus "feeds" algae attached to rocks in the streambed." "Steady-flow models of pH and attached algae,…."
p.27-2006 "Periphyton (attached algae) plays an important role in the dynamics of pH and DO processes in the Wenatchee River and Icicle Creek. In addition, phosphorus and nitrogen are important parameters because of their role as nutrients for the growth of periphyton in the waterways."

Response: As stated above, our understanding of the productivity in the Wenatchee River and Icicle Creek is based on many observed DO and pH diel ranges and varying nutrient levels. Ecology did enough periphyton sampling to establish a range of biomass levels for the productivity modeling. The same range of biomass levels were used in both the Wenatchee River and Icicle Creek models.

In the beginning of September, Ecology samplers scraped and washed randomly-picked cobbles at 5 cross-sections of the Wenatchee River using a modified USGS protocol (Porter et al, 1993). The sampling cross-sections were at RM 2.8 (upstream of the Sleepy Hollow bridge), RM 6.5 (above the Monitor bridge), RM 10.8 (upstream of Cashmere POTW), RM 21.0 (just above Peshastin), and RM 35.4 (just above the Tumwater Canyon Hwy 2 bridge). The samples at RM 21.0 were only taken from the near bank due to the water depth and current velocity. The bank at RM 21.0 was dominated by mats of aquatic mosses that were deemed not representative of the cross section and were not used in the modeling due to this bias.

The areas of the scraped cobbles were measured using foil, which was later scanned and digitally measured. The scraped periphyton was composited into a known volume (1 L) and submitted to Ecology's Manchester Environmental Laboratory for analysis of total solids, percent total organic carbon (TOC), and ash-free dry weight (AFDW). Composite samples were homogenized and sub-sampled in triplicate. Table D-23 presents lab results of the analysis. Species identification was conducted by Aquatic Analysts, an expert in algae identification located in White Salmon, WA. The periphyton at all sites was dominated by diatoms, primarily *Achnanthes minutissima, Achnanthes linearis,* and *Cymbella affinis,* and *Gomphonema subclavatum*.

Table D-23. Periphyton laboratory results and biomass calculations for the Wenatchee River.

Periphyton worksheet

Wenatchee River TMDL

Sample Date 9/9/2003

sample Id	field id	imageJ area (m^2)	Total Solids mg/L	Total Solids mg/m^2	TOC %	TOC mg/m^2	Biomass based on 32% carbon gD/m^2	Ash-free dry weight mg/L	AFDW biomass gD/m^2	50 % silicon Diatom adjusted AFDW biomass gD/m^2
3374280	45WR02.8	0.0917	3351.4	36,555	32.7	11953	37.4	2240	24.4	36.6
3374281	45WR02.8	0.0917	3333.3	36,358	32.3	11743	36.7	2220	24.2	36.3
3374282	45WR02.8	0.0917	3390.8	36,985	31.9	11798	36.9	2260	24.7	37.0
3374284	45WR06.5	0.0829	2874.4	34,655	28.2	9773	30.5	1850	22.3	33.5
3374285	45WR06.5	0.0829	2893.3	34,883	28.2	9837	30.7	1810	21.8	32.7
3374286	45WR06.5	0.0829	2988.5	36,030	24.4	8791	27.5	1810	21.8	32.7
3374288	45WR10.8	0.0758	3494.1	46,095	22.6	10417	32.6	1600	21.1	31.7
3374289	45WR10.8	0.0758	3537.9	46,673	23.6	11015	34.4	1600	21.1	31.7
3374290	45WR10.8	0.0758	3471.3	45,794	22.4	10258	32.1	1600	21.1	31.7
3374292	45WR21.0	0.0465	12524.6	269,309	13.1	35280	110.2	3340	71.8	107.7
3374293	45WR21.0	0.0465	12033.3	258,745	14.4	37259	116.4	3430	73.8	110.6
3374294	45WR21.0	0.0465	11288.1	242,722	13.7	33253	103.9	3580	77.0	115.5
3374296	45WR35.4	0.0371	804.1	21,690	6.6	1432	4.5	189	5.1	7.6
3374297	45WR35.4	0.0371	788.6	21,272	7.7	1638	5.1	187	5.0	7.6
3374298	45WR35.4	0.0371	825.3	22,262	7.8	1736	5.4	192	5.2	7.8
Totals	45WR02.8	0.0917	3358.5	36,632	32.3	11832	37.0	2240	24.4	36.6
	45WR06.5	0.0829	2918.7	35,189	26.9	9467	29.6	1823	22.0	33.0
	45WR10.8	0.0758	3501.1	46,187	22.9	10563	33.0	1600	21.1	31.7
	45WR21.0	0.0465	11948.7	256,925	13.7	35264	110.2	3450	74.2	111.3
	45WR35.4	0.0371	806.0	21,741	7.4	1602	5.0	189	5.1	7.7

- *Furthermore, given the reliance on the minimal periphyton data (five unqualified data points) and the modeling, some of the model inputs and results seem inconsistent. The location observed in the field does not seem to match the location of the increase in periphyton biomass predicted by the model, which appears to start further upstream (p.26-Figure 24). Additionally, in the model, Reach tab, Bottom Algae Coverage is set at 100% for the entire Wenatchee River. This appears to be a key modeling assumption and it appears be reasonable to question whether it is valid.*

p.43-2006 "In general, there was limited periphyton biomass in these upper reaches" {above RM 17}.
Q2K-Reach - Bottom algae coverage (Models 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12)

Response: Again, the modeling did not rely on periphyton data (see above response). Please see above response for biomass sampling locations too. The simulated periphyton biomass increased exactly in the parts of the river where we observed increased DO and pH diel ranges and increased nutrient levels.

The reference to "above RM 17" in the 2006 report was in reference to the N:P ratios in the river and not to biomass. The general statement,"….there was limited periphyton biomass in these upper reaches…" referred to the upper Wenatchee (above Leavenworth). The wording in the 2006 report probably could have been stated differently for better clarification.

Reach-specific Bottom Algae Coverage in QUAL2K specifies how much of the bottom surface of the channel is available or has the potential to grow periphyton (attached algae). This parameter defines the physical space for growing periphyton in the model application and is selected in the model setup. The model default is 100% and this was not changed in the Wenatchee River QUAL2K models. The substrata of the Wenatchee River are primarily composed of bedrock, boulder, and cobble with some gravel bars that are resistant to movement (at the water velocities seen in August and September), and ideal for periphyton colonization. QUAL2K allows reach-specific adjustment of space availability for cases where the substratum may not be conducive for colonization (e.g., fine sediments). We did not see any reason to limit any areas of the Wenatchee River.

- *Biomass values used in the model varies from an initial amount in the upper reaches as 2 gD/m^2, to 0.5 gD/m^2, and 34 gD/m^2 at the downstream end. What is the basis for the biomass values used in the model? Why are they lower in the middle reach?*

Q2K-Reach - Initial biomass of periphyton (Models 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12)

Response: The biomass initial conditions levels were estimated from the observed biomass range. They are lower in the middle reach because there was less productivity in Tumwater Canyon (the middle reach) than in other parts of the river. Since biomass is controlled by the supply of nutrients, light, and temperature, and these factors may have been different prior to the steady-state modeled condition, QUAL2K handles this temporal variability by allowing the initial condition input of biomass. Reach-specific Initial Biomass of Periphyton in QUAL2K allows the user to set reach-specific initial conditions for periphyton biomass. An estimate of reach-specific periphyton biomass, based on the observed DO, pH, and biomass range, was used for initial conditions in the Wenatchee River model to also minimize model run time during the calibration process. Over 10,000 model runs were used during the auto-calibration process. The initial biomass condition is not very important at the current model run-time (i.e., the run time of the distributed models), as long as it is above zero. Figure D-21 shows the sensitivity of the setting all of the reach-specific initial conditions to zero and 5 gD/m^2, in comparison to the calibrated biomass initial condition. As long as it is above zero, the biomass results are nearly the same as in the original calibration.

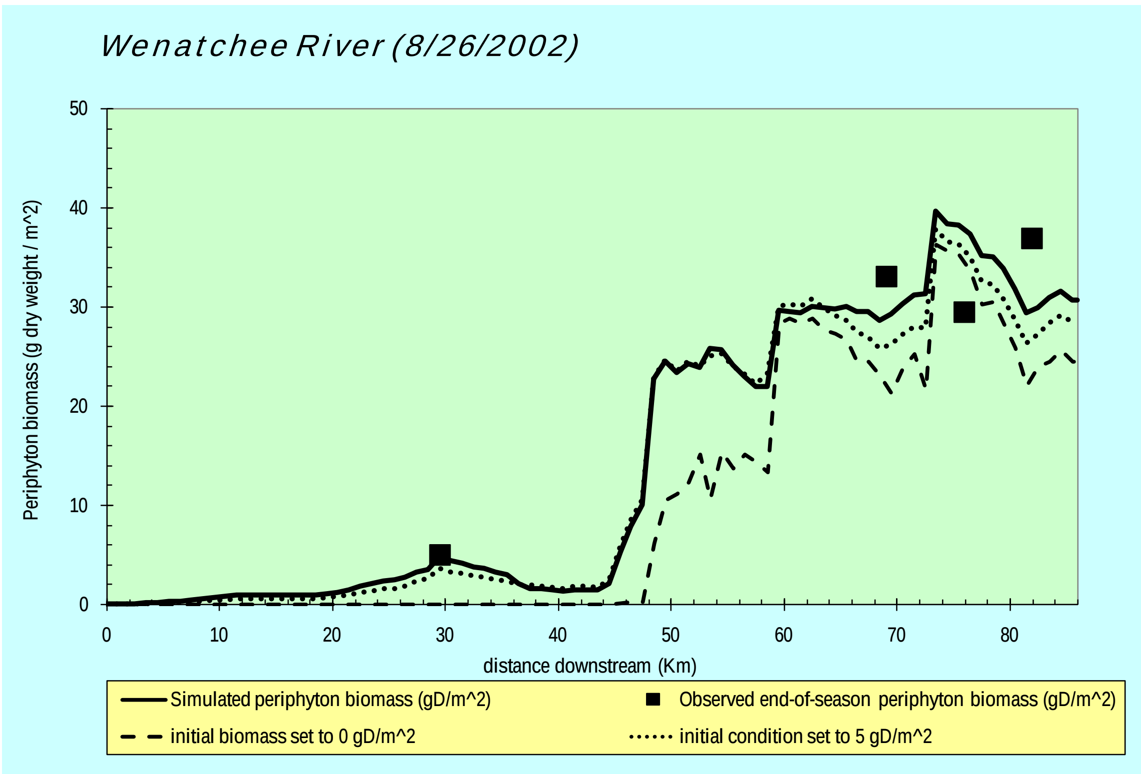


Figure D-21. Sensitivity analysis showing the resulting biomass with different reach-specific initial biomass conditions. *The solid line is the original calibrated biomass, the dotted line is the simulated biomass with all reaches set to 5 gD/m^2, and the dashed line is the simulated biomass with 0 gD/m^2 initial conditions***.**

- *Other than p.45-Figure 15, no data are presented to substantiate that increased bio-P corresponds with increased biomass or referenced to support the statement below. The theory may be true, but it's not demonstrated with sufficient data.*

p.44-2006 "There is an increase in bio-available phosphorus in the lower reach of the Wenatchee River (i.e., below Leavenworth) that fuels an increase in periphyton biomass and growth resulting in the observed pH and DO exceedances found in the lower Wenatchee River reaches."

Response: The effect of nutrients on stream productivity (and resulting DO and pH changes) is part of basic stream water-quality chemistry and is well understood, and as pointed out, the theory is "true". Numerous texts and papers describe these relationships, including Welch and Jacoby (2004); Chapra (1997) and Stevenson et al (1996). We believe the measured increase in nutrient concentrations, diel response of DO and pH, and observed and measured periphyton biomass in the lower versus upper part of the river, support the conclusion that increased levels of nutrients are fueling an increase in periphyton productivity in the lower Wenatchee River and lower Icicle Creek. In addition, the calibrated QUAL2K productivity model of the Wenatchee River, which is based on well-founded water-chemistry principles and fitted to observed conditions, also substantiated this finding. An earlier HDR comment, "*The hypothesis that the system is driven by periphyton is built upon some strong supporting evidence (DO and pH data)*" seems to attest an agreement to this case as well.

The Wenatchee River DO and pH TMDL is focused on limiting phosphorus to control the increase in periphyton biomass because it is the limiting nutrient. There are a number of other TMDLs in Washington State (e.g., Spokane DO TMDL, White River TMDL, Lake Whatcom TMDL) and many in the United States (e.g., Clark Fork River, Snake River) that are using a similar approach to control algal biomass.

- *No investigation of the periphyton stoichiometry was performed for comparison to the stoichiometric ratios used in the model. 40:7:1 is the default ratio in the model, as well as luxury-uptake algorithm. In our experience, carbon-to-nitrogen-to-phosphorus stoichiometric ratios vary between river systems. Without proper sampling and analysis, the amount of phosphorous required for the modeled biomass could vary significantly.*

  p.48 "The QUAL2K model uses carbon-to-nitrogen-to-phosphorus stoichiometric ratios of 40:7:1."
  p.54 "A variable-stoichiometry and luxury-uptake algorithm for nutrients is used in QUAL2K that separates periphyton growth from nutrient uptake. Maximum nutrient uptake rates,…….were iteratively selected from published ranges……until an optimized goodness-of-fit to the observed data was achieved."

Response: We agree that nitrogen and phosphorus stoichiometric ratios in algae can vary between river systems, and could even vary within a single river system. This is the reason we decided to use the QUAL2K model which has a variable-stoichiometry, luxury-uptake algorithm for periphyton. Many studies have confirmed the "luxury uptake" of nutrients by algae. The diatom, *Asterionella*, has been shown to have phosphorus storage that is equivalent to 24 times its absolute cell minimum content (Mackereth, 1953). Therefore, the nutrient content of the algal biomass depends on the nutrient supply in the water and the demand requirement of the algal biomass. The sampled nutrient content of periphyton residing in nutrient-rich water would be expected to differ from that found in nutrient-deficient water.

QUAL2K allows varying nutrient content by using a luxury-uptake algorithm that uses minimum cell quotas, maximum uptake rates, and external water column concentrations tied to Michaelis-Menten kinetics with internal and external half-saturation constants to determine the varying nutrient concentration of the algae. The default fixed stoichiometry ratio (40:7:1) is not used for bottom algae determination, but is used for the phytoplankton determination. The Wenatchee basin had inconsequential amounts of phytoplankton.

Model parameter rates for bottom algae were selected from the range of literature values. Auto-calibration procedures, available in QUAL2K, use a genetic algorithm to iteratively try a selection of values from within the given range. A fitness function scores comparative selections, and the genetic algorithm maximizes successful rate selections. A typical auto-calibration run takes 10,000 model runs (or rate selection trials). The endpoint indicators for the fitness function were primarily the DO and pH diel ranges.

- *These issues highlight some concerns about the foundational periphyton hypothesis and the assumptions used in the modeling. A basic sensitivity analysis of two assumptions revealed the following. If the biomass of bottom plants (periphyton), is reduced by 60 %, then the wasteload allocation for phosphorus could be 100 ug/L. The model appears to be insensitive to biomass bottom plants, periphyton. If the bottom algae coverage (periphyton),is reduced by 3 %, then the wasteload allocation could be 100 ug/L. The model appears sensitive to the percentage of bottom algae coverage. Does the entire reach of the Wenatchee River commonly have 100 % periphyton coverage during low flows? This appears to be a key modeling assumption and a 3% change in the assumption changes the required effluent phosphorus concentration by more than 10%.*

Response: We do not have enough information to properly evaluate or respond to the comment about HDR's basic sensitivity analysis which reduced bottom plants (periphyton) by 60 % causing an apparent 10% change in the waste load allocation. It is not clear how the biomass was reduced. If the sensitivity analysis was based on reducing the reach-specific initial conditions of the biomass, we have already shown that the model is insensitive to this.

The second HDR test where the bottom algae coverage is changed is not a valid sensitivity test. As addressed above, it is not appropriate to change the QUAL2K model set-up without recalibrating the model. The reach-specific area available for periphyton coverage is a basic physical parameter that is fundamental to the model set-up (prior to the calibration process), and fundamentally informs the calibration. It is inappropriate to change the model setup and expect a previous calibration to be accurate. Please see response above.

5. Comments about Ecology's approach to establishing hydrology and channel geometry in the QUAL2K model.

- *The river flows are a key component of the resulting water quality. There is insufficient information presented in the TMDL reports to review the rating curve values. The rating curves establish the flow conditions in the model. Appendix D presents the values and indicates a high level of detail for the hydrology analysis, especially for the depth relationship, but it is unclear how these values were developed. The travel times based on the dye study support the model hydraulics; however, no information or reference for the methodology of the travel dye study is provided.*

  p. 49-2006 Hydrology

Response: Power equations were used to relate mean velocity, depth, and width to flow,

$$U = aQ^b$$
$$H = cQ^d$$
$$B = eQ^f,$$

where U is velocity, H is depth, B is width, Q is discharge, and a,b,c,d,e,f are empirical constants that are determined for each channel cross-section. These flow constants are interrelated by the continuity equation, U = Q / (B * H), such that, the coefficients add up to 1, and the product of the exponents is also 1. Therefore, knowing only two of the hydro-geometric correlations allows the third to be determined.

We developed high-resolution width-to-discharge relationships and velocity-to-discharge relationships and used these to determine depth-to-discharge relationships on a kilometer-by-kilometer basis in the Wenatchee River.

We used GIS to develop reach-specific width-to-discharge rating curve for each river kilometer (model segments were 1 km long). Ecology digitized the channel widths from several aerial ortho-photo coverages representing 2-3 different flows. Aerial ortho-photos were obtained for the Washington Department of Transportation. Channel widths were sampled every 0.1 kilometers and averaged for every kilometer (equal to one model segment). Using a power equation regression of the rating curve for each river kilometer, the reach-specific coefficient and exponent were defined for hydro-geometric correlation.

For the velocity rating curves, long-standing USGS gage-station rating-curve data was obtained from the USGS and used to develop the velocity-to-discharge relationships for different parts of the river. These velocity relationships were verified by determining the time-of-travel of the river with a dye study conducted in September 2002. The Quality Assurance Project Plan for Wenatchee River Temperature, Dissolved Oxygen, and pH TMDL Year 1 Technical Study (Bilhimer et al, 2002) described Ecology's plan to use dye to estimate water travel time, citing the USGS methodology for dye studies (Hubbard et al., 1982). The QAPP is available on the Ecology website at following location: http://www.ecy.wa.gov/biblio/0203069.html.

Table D-24 summarizes the travel time data collected September 9-12, 2002. Overall, we believe the hydrologic characteristics of the river are accurately simulated by the model.

Table D-24. Time-of-travel data from the Wenatchee River dye study conducted Sept. 9-12, 2002.

date	dye injection time or time of peak concentration	segment upstream distance from HW (Km)	segment downstream distance from HW (Km)	segment velocity (m/s)	travel time (d)	cumulative travel time (d)
Dump 1						
9/9/2002	4:45 AM		60.2			
9/9/2002	8:30 AM	60.2	68.1	0.584	0.156	
9/9/2002	12:30 PM	68.1	74.8	0.469	0.167	
9/9/2002	3:30 PM	74.8	81.1	0.581	0.125	
Dump 2						
9/10/2002	5:05 AM		43.8			
9/10/2002	8:00 AM	43.8	48.0	0.399	0.122	
9/10/2002	11:00 AM	48.0	51.7	0.343	0.125	
Dump 3						
9/10/2002	7:50 PM		29.0			
9/10/2002	11:45 PM	29.0	34.8	0.411	0.163	
9/11/2002	3:00 AM	34.8	36.5	0.151	0.135	
9/11/2002	8:00 AM	36.5	43.8	0.402	0.208	
Dump 4						
9/11/2002	5:20 AM		11.9			
9/11/2002	9:00 AM	11.9	19.0	0.536	0.153	
9/11/2002	3:00 PM	19.0	29.0	0.462	0.250	
Dump 5						
9/11/2002	8:20 PM		0.0			
9/12/2002	1:15 AM	0.0	5.1	0.291	0.205	
9/12/2002	7:00 AM	5.1	11.4	0.303	0.240	
SORT BY DISTANCE FROM HEADWATER:						
headwater:	8:20 PM		0			
9/12/02	1:15 AM	0.0	5.1	0.291	0.205	0.205
9/12/02	7:00 AM	5.1	11.4	0.303	0.240	0.444
			11.9		0.018	0.463
9/11/02	9:00 AM	11.9	19.0	0.536	0.153	0.616
9/11/02	3:00 PM	19.0	29.0	0.462	0.250	0.866
9/10/02	11:45 PM	29.0	34.8	0.411	0.163	1.029
9/11/02	3:00 AM	34.8	36.5	0.151	0.135	1.164
9/11/02	8:00 AM	36.5	43.8	0.402	0.208	1.373
9/10/02	8:00 AM	43.8	48.0	0.399	0.122	1.494
9/10/02	11:00 AM	48.0	51.7	0.343	0.125	1.619
		51.7	60.2	0.463	0.213	1.832
9/9/02	8:30 AM	60.2	68.1	0.584	0.156	1.988
9/9/02	12:30 PM	68.1	74.8	0.469	0.167	2.155
9/9/02	3:30 PM	74.8	81.1	0.581	0.125	2.280

- *The rating curves do not match between the models. Typically, the coefficients and exponents provide a relationship that specifically relates velocity and depth of flow to a given reach. It is unclear why these would change between model scenarios, especially when considering the months used for calibrating flows are August and September, both low-flow months. It seems unusual for exponents to be input as zero, as seen in the Ecology model data below. In addition, the values for the 7Q10 vary from the calibrated flow date in the other models.*

Below is a table providing an example of inconsistent data between models for the Reach 1 (the data are similarly varying between models in the other reaches).

	Velocity Coefficient	*Velocity Exponent*	*Depth Coefficient*	*Depth Exponent*
Models 1, 4, and 5	*0.3392*	*0.000*	*0.8793*	*0.000*
Models 2, 6, 7, 8, 9, 10, 11, 12	*0.2400*	*0.000*	*0.7750*	*0.000*
Model 3 and 2006 Appendix D	*0.0800*	*0.590*	*0.3319*	*0.300*

Response: QUAL2K allows either the velocity and depth, or the velocity and width rating curves to be entered on the reach sheet. The rating curves inform the model what the velocity, width, and depth will be for any given flow. We entered reach-specific velocity and width rating curves into the model. Once the model was run with the velocity and width rating curves for a specific flow balance, the model calculated reach-specific velocities, widths, and depths for that given flow balance. As long as the flow balance does not change, these hydro-geometric parameters correctly describe the cross-sectional shape of the water column and the velocity in each model segment. Because of this, the hydro-geometric parameters can be entered in place of the respective coefficient constant with the exponent for discharge set to zero.

We developed individual flow balances for August and September 2002 based on flow measurements and gaging, and a 7Q10 flow balance based on historical flow records. Some of the model set-ups contained the reach-specific velocity and width rating curves and some contained the flow-specific velocities, widths, and depths based on those rating curves. Either way, both set-ups give the same result, and the flow is correctly represented in the model. Again, we believe the model accurately represents the hydraulic character of the river.

6. **Comments about Ecology's approach to establishing headwater water temperature and reach-specific meteorology in the QUAL2K model.**

- *Additional drivers in the model include water temperature, dew point temperature and wind speed. Typically for a river system modeled in low flow, variations in dew point, water temperature, and wind speed would not make a significant impact, but there appear to be inconsistencies between the various models with no explanation. It is unknown if these differences would affect the conclusions and should be corrected and re-examined.*

Response: We agree that variation in air temperature, dew-point temperature and wind speed (all non-radiation terms of surface heat exchange) would not make a significant impact in the QUAL2K productivity models, unless there were accompanying large changes in water temperature. The primary forcing functions of surface heat exchange in QUAL2K are solar radiation and atmospheric long-wave radiation, so only minor changes in water temperature would be expected from changes in non-radiation terms. QUAL2K uses the meteorological inputs (air and dew point temperature and wind speed) to calculate the conduction and evaporation of heat from the water to the atmosphere. The Wenatchee River Temperature TMDL investigated these processes in detail and can be viewed at http://www.ecy.wa.gov/biblio/0503011.html.

For the productivity modeling, we focused only on simulating the observed water temperature range so that water temperature-dependent functions would be properly simulated (i.e., many of the physical processes as well as the biological and chemical transformation of the productivity module of QUAL2K are temperature-dependent). Given we were not simulating temperature changes for the productivity model scenarios; we did not investigate the surface heat processes in detail. During calibration of the August and September models, when the observed water temperature ranges were adequately simulated, then the temperature model terms were accepted without further refinement. The August and September models simulated the minimum, mean, and maximum of the observed water temperatures very well, as shown in Figures D-22 and Figure D-23. The overall RMSE of the water temperature calibration was less than 0.5 ºC (CV% = 3%). Advective heat transfer and radiation heat terms were the main forcing functions for the water temperature calibration.

- *The model values for water temperature appear to have a different diurnal cycle than the data presented in the 2006 Report p.37 Figure 9. The peak appears to occur too early in the afternoon in the model.*

  Headwater - Water temperature (Models 1, 4, 5)

Response: It is a misinterpretation to think the diurnal cycles should be the same at two different stations. The headwater temperature data are different from the data in Figure 9 of the 2006 report because the data in Figure 9 of the 2006 report are collected from RM 35.4 at the Tumwater Canyon Hwy 2 bridge station, 17 miles downstream.

QUAL2K allows hourly water temperatures to be input as an upper boundary condition. The headwater diel water temperatures were measured by Hydrolab dataloggers in August 2002 at the outlet of Lake Wenatchee. Figure D-24 presents the diel water temperature data that was input as the headwater boundary condition (same as reach 0) showing the peak water temperature in the mid-afternoon. Again, this is from actual observed data measured at the lake outlet. Figure D-25 presents the model-simulated diel water temperature at the Tumwater Canyon Highway 2 bridge (same as reach 29), showing the simulated peak water temperature occurring between 6:00 pm and 7:00 pm in the evening. This is the same time as the observed peak water temperatures presented in Figure 9 of the 2006 report. The time of peak water temperature shifted from the afternoon to the evening from Lake Wenatchee to the Tumwater Canyon. The QUAL2K model accurately simulated this shift in time of the peak water temperature.

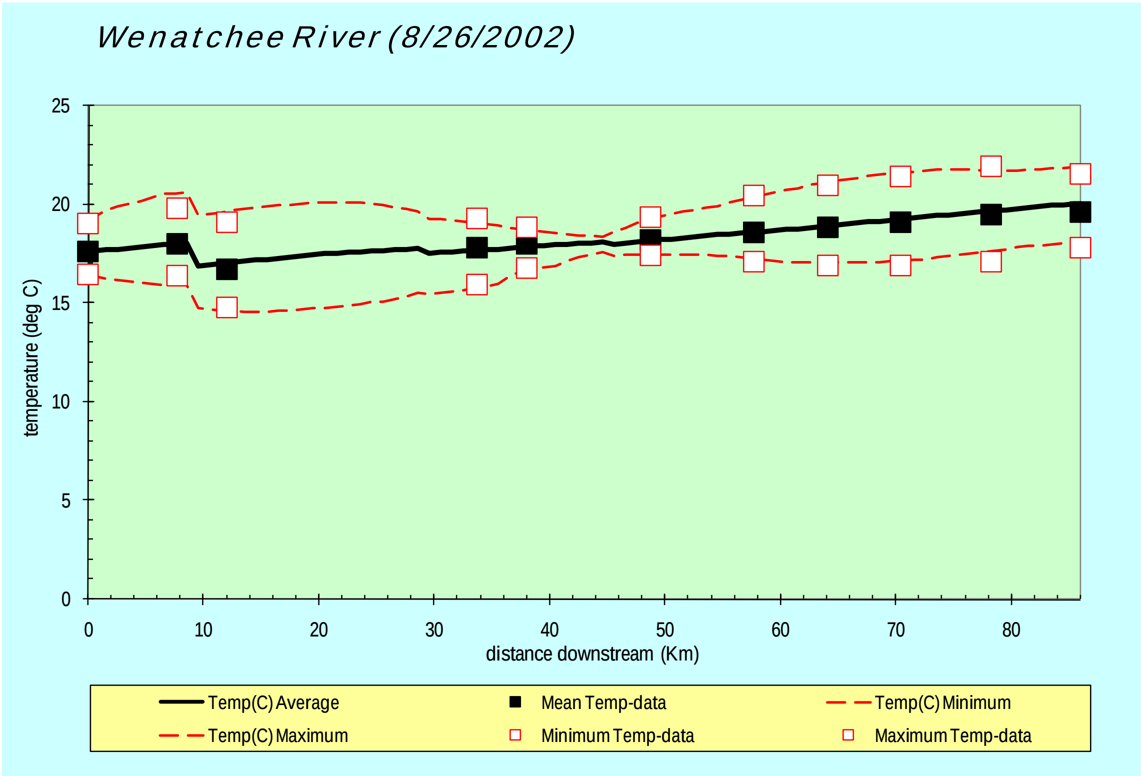


Figure D-22. Simulated (lines) versus observed (squares) minimum, mean, and maximum water temperatures in the August 2002 QUAL2K model calibration.

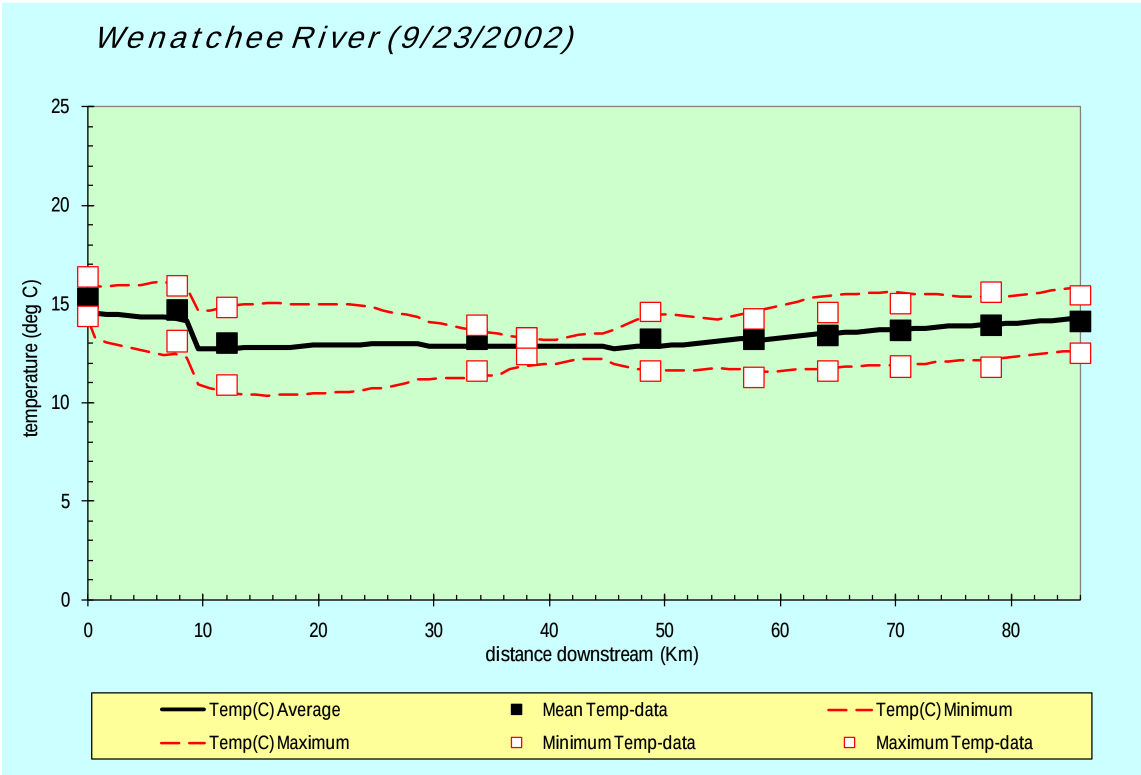


Figure D-23. Simulated (lines) versus observed (squares) minimum, mean, and maximum water temperatures in the September 2002 QUAL2K model calibration.

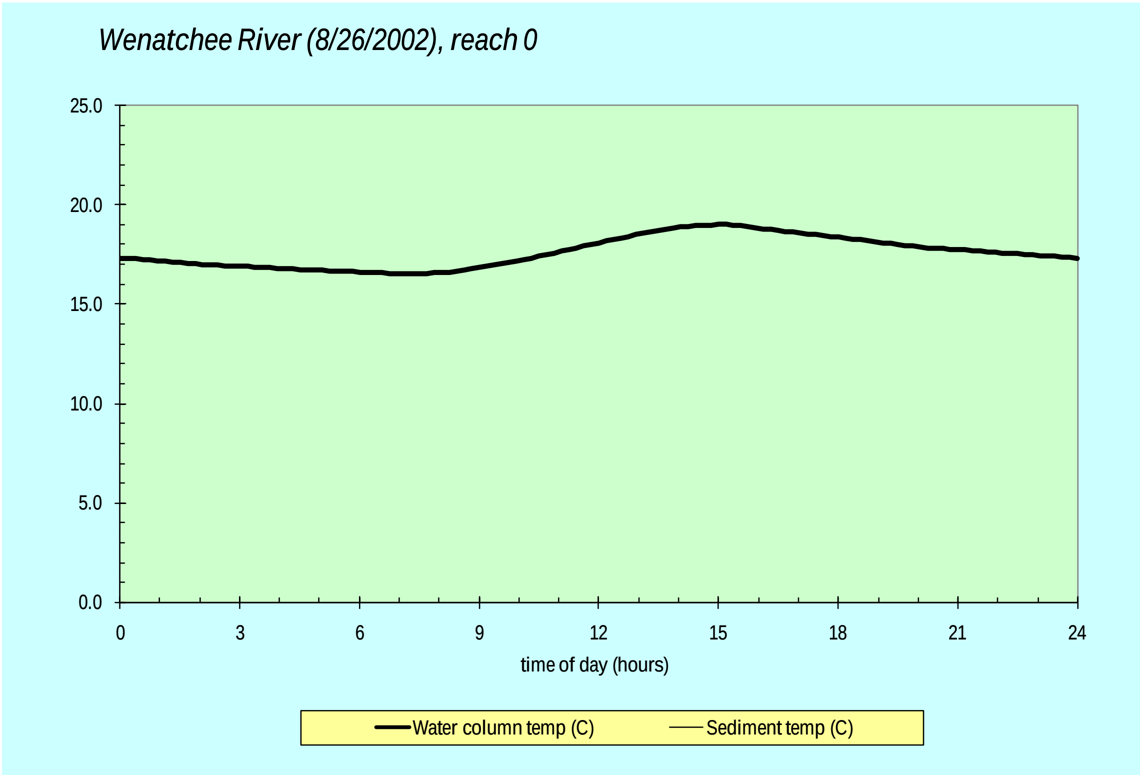


Figure D-24. Observed diel water temperature profile used for the headwater boundary condition.

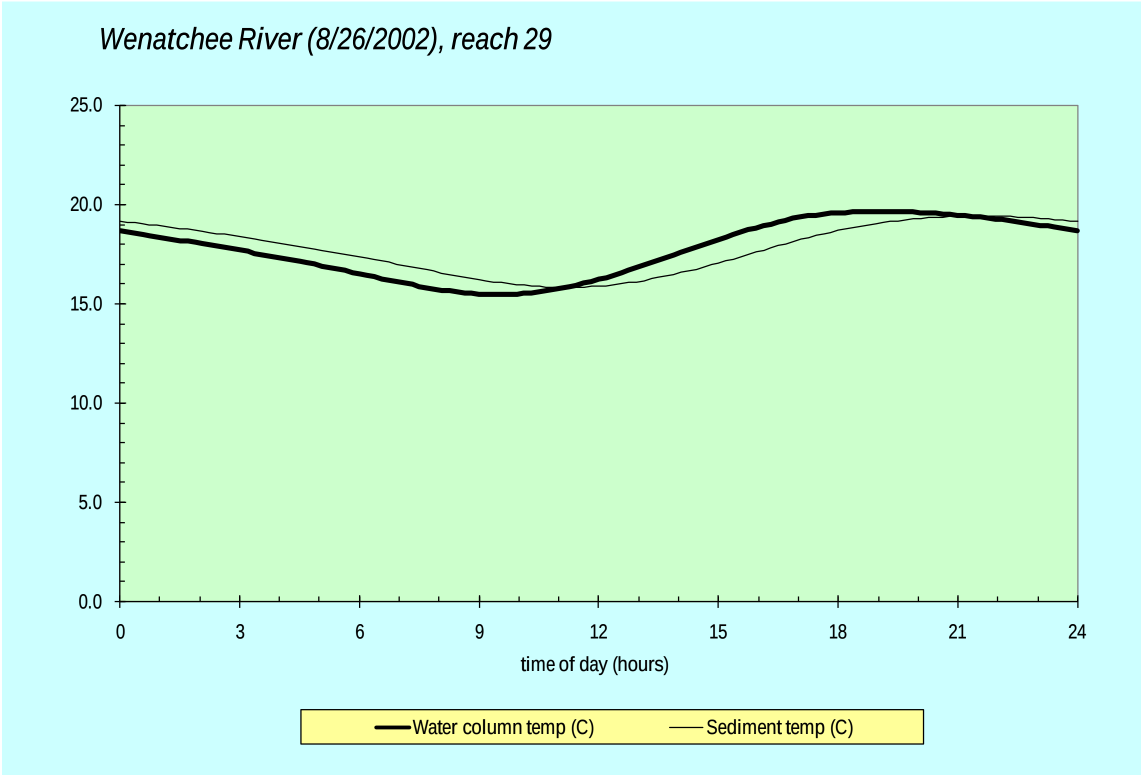


Figure D-25 Simulated diel water temperature profile at the Tumwater Canyon Highway 2 Bridge.

- *The translation of meteorological data into the model inputs is not well explained. Why are air temperatures the same for almost all reaches (excluding the downstream end of models 1, 4, 5) but dew point temperatures are different for nearly every reach? How were these datasets developed? The midday dew point temperatures seem low for many of the reaches (models 2, 3, 6, 7, 8, 9, 10, 11, 12)*

Dew Point Temperature (Models 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12)

Response: The QUAL2K model allows reach-specific, hourly meteorological data inputs. For the Wenatchee River TMDL projects, various meteorological stations were used for data inputs to the water quality models. The goal of the DO and pH TMDL was to adequately simulate the observed water temperature ranges so that water temperature-dependent functions in the productivity model would be properly simulated. Figure D-26 shows the various stations available for meteorological inputs for the Wenatchee River TMDL projects. When necessary, detailed reach-specific meteorological inputs were used.

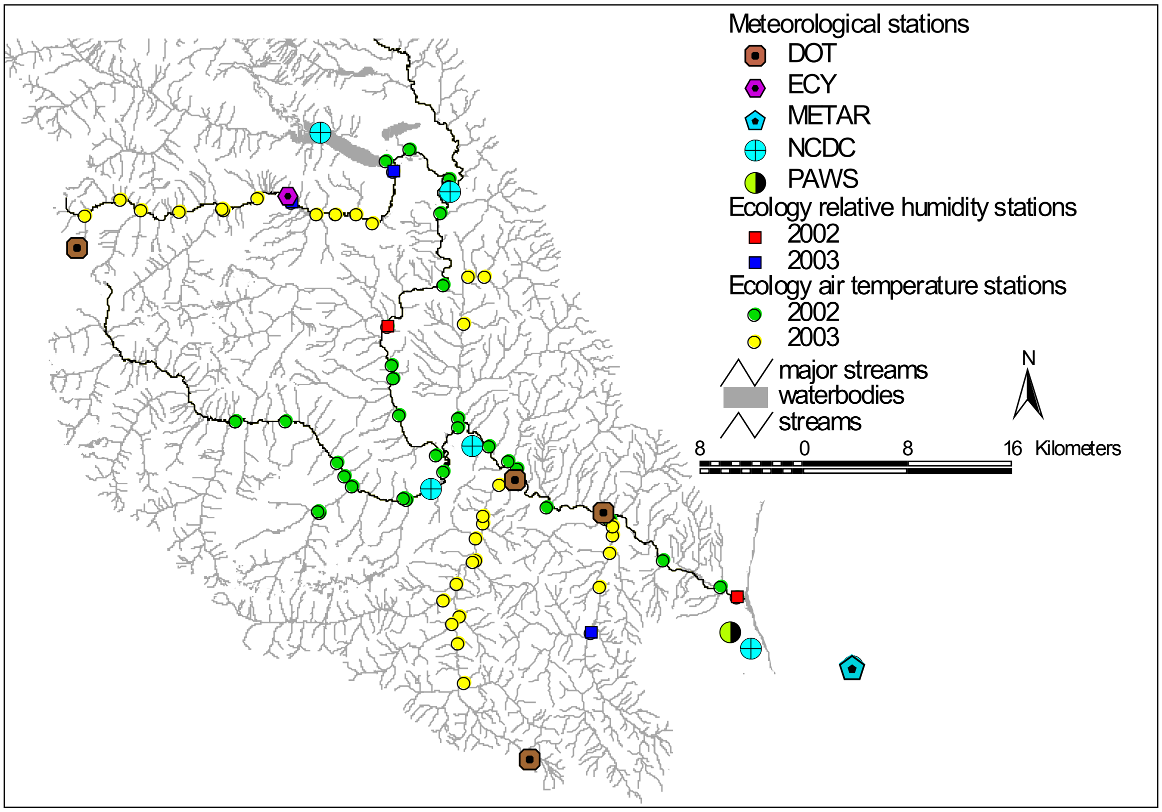


Figure D-26. Meteorological stations and Ecology station data available for the use in the Wenatchee River basin TMDLs.

For the Wenatchee River system, we found that the water temperature calibration was relatively insensitive to air temperature, particularly nearer the headwaters, so default average hourly air temperatures from a DOT meteorological station in Cashmere (closer to the mouth) was used for the entire model length. In the summer, the average difference in air temperatures between the upper and lower Wenatchee River basin was approximately 2-3 ºC. Figure D-27 shows a sensitivity analysis of a ±2 ºC change in the calibration air temperatures on water temperature. The lower basin of the Wenatchee River is more sensitive to variation in air temperature than the upper basin, therefore we found that the use of hourly air temperatures derived from the lower basin weather station at Cashmere was adequate for successful water temperature calibrations. (Cashmere is at Km 70 on Figure D-27.)

The QUAL2K model also allows reach-specific, hourly dew-point temperature inputs. For the Wenatchee River system, we found the water temperature calibration was more sensitive to dew point temperature than air temperature. The average difference between the upper and lower Wenatchee River basin hourly dew-point temperatures could be greater than 5 ºC. Figure D-28 shows a sensitivity analysis of a ±5 ºC change in the calibration dew-point temperatures on calibrated water temperatures. Because of the higher sensitivity, we used an interpolative function to develop reach-specific, hourly dew point temperatures.

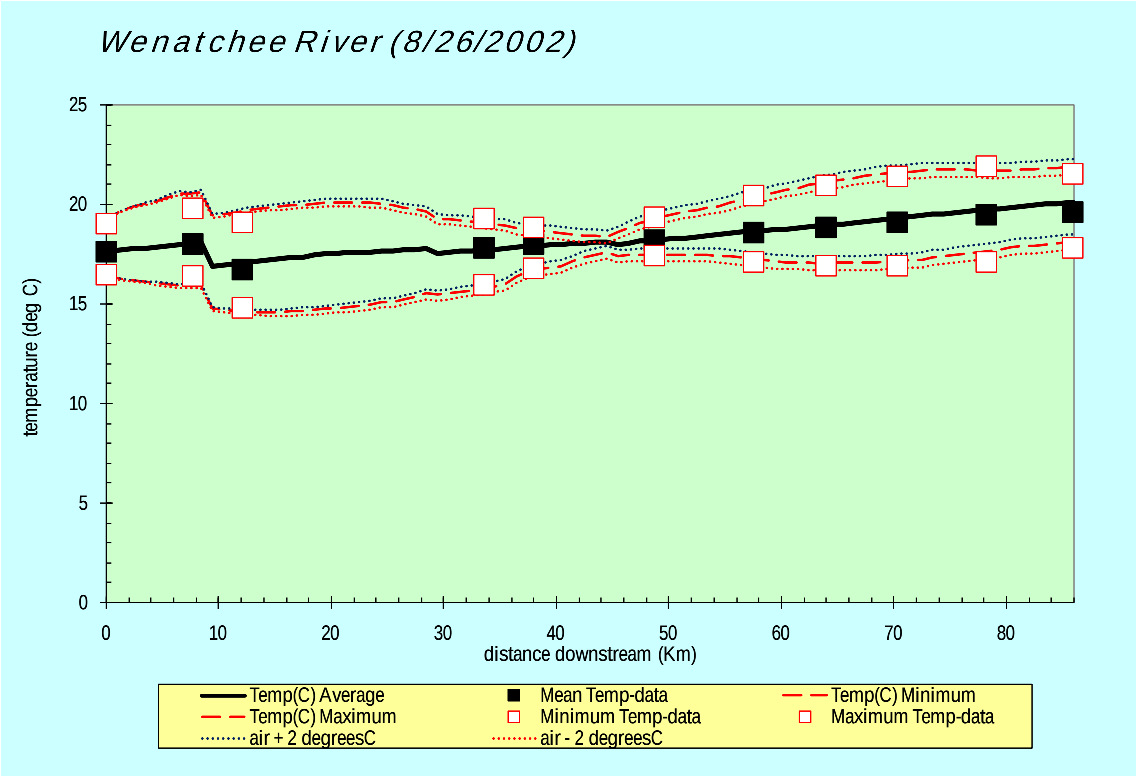
- *Why are the values uniform for all reaches when (models 1, 4, 5) vary by reach? Why do the values appear to have been rounded off (the time series is blocky)?*

Wind speed (Models 2, 3, 6, 7, 8, 9, 10, 11, 12)

Response: We found the QUAL2K model to be relatively insensitive to the wind speeds that were measured in the Wenatchee basin in August and September 2002. Though not necessary, we used an interpolative function to estimate wind speeds between meteorological station data from Lake Wenatchee, Cashmere, and Wenatchee to develop reach-specific wind speeds for the August calibration. The data appears "blocky" as the interpolative function is rounded off to one decimal place. For the September model calibration, wind speed data from only one meteorological station (Cashmere) was used for the model (no interpolation between different stations). The wind speed was inputted as average hourly-interval data in all models, with wind speed varying through the day.

Figure D-29 shows the insensitivity of wind speed on the water temperature calibration for both the August and September 2002 calibrations. The wind speeds used for calibration were increased 2X and also decreased to zero for the sensitivity analysis.

Again, for the productivity modeling, we focused only on simulating the observed water temperatures ranges so that water temperature-dependent functions in the productivity model would be properly simulated. Therefore, we did not do an exhaustive calibration of the surface heat exchange processes for the productivity model. We believe the QUAL2K model calibrations for the Wenatchee River adequately simulate water temperature and its effect on the productivity simulations.



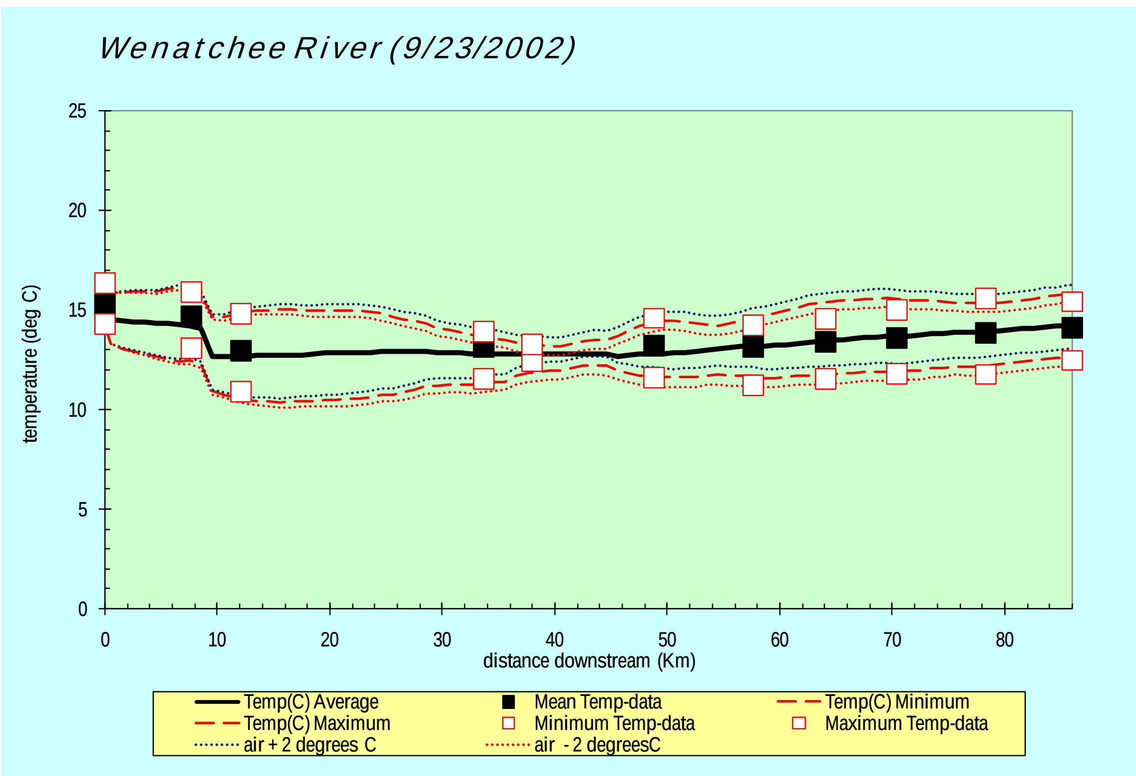
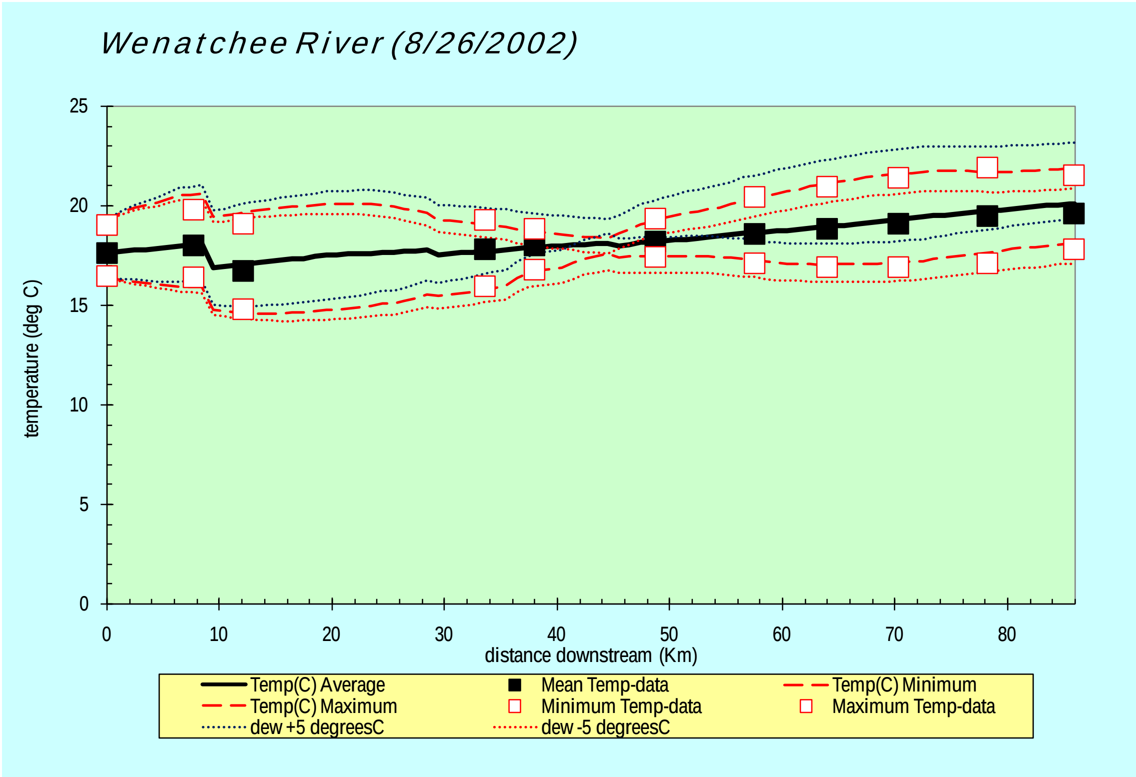


Figure D-27. Comparison of QUAL2K simulated daily mean, maximum, and minimum water temperatures (dashed lines) to observed water temperature data (squares) and sensitivity of using + 2 degrees C air temperature on the maximum and minimum water temperatures.



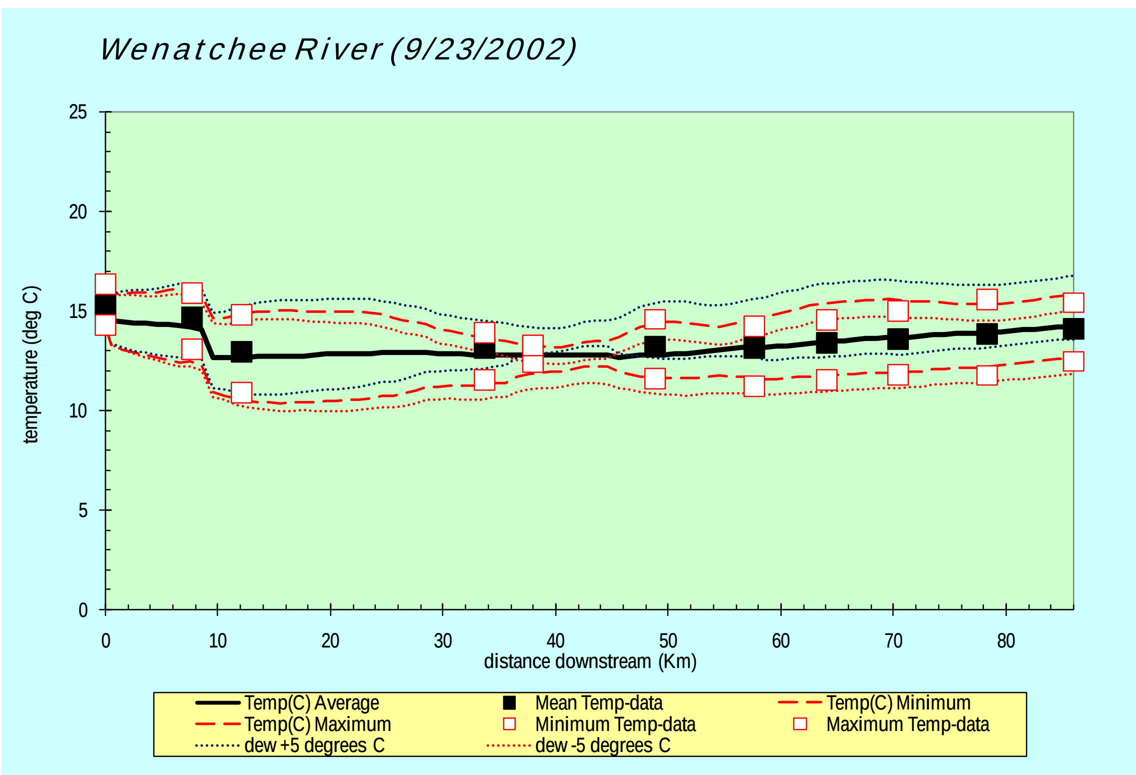
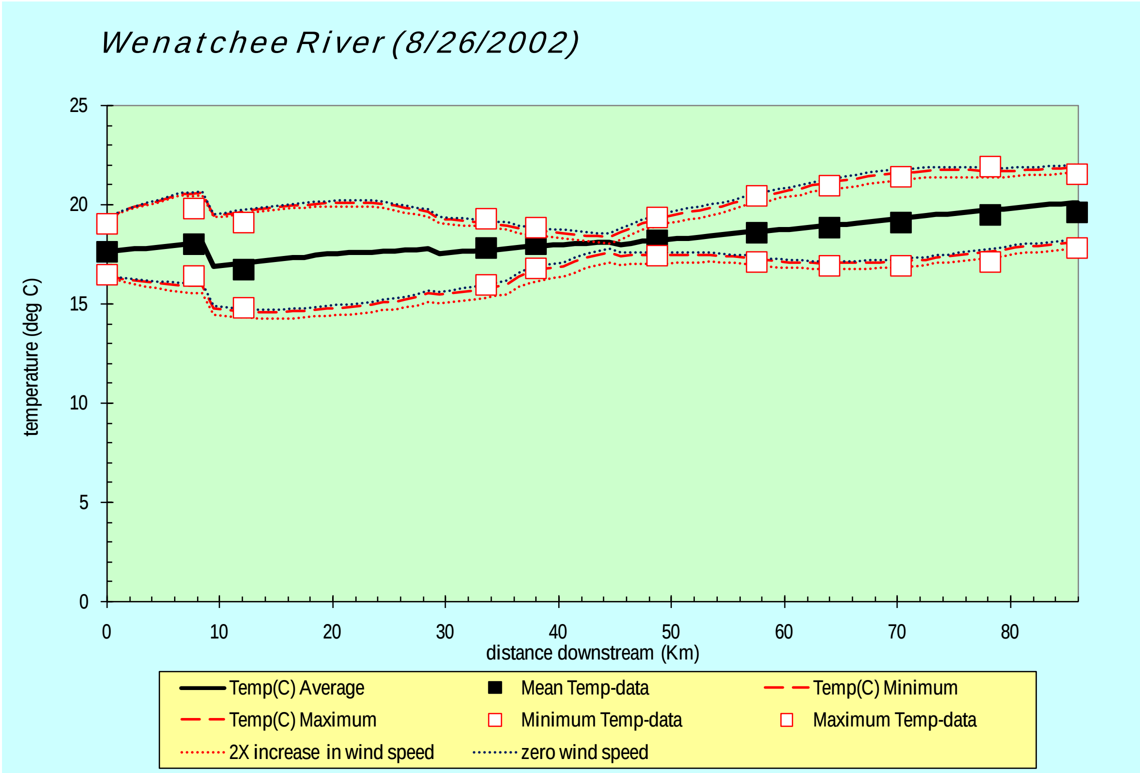


Figure D-28. Comparison of QUAL2K simulated daily mean, maximum, and minimum water temperatures (dashed lines) to observed water temperature data (squares) and sensitivity of using + 5 degrees C dew point temperature on the maximum and minimum water temperatures.



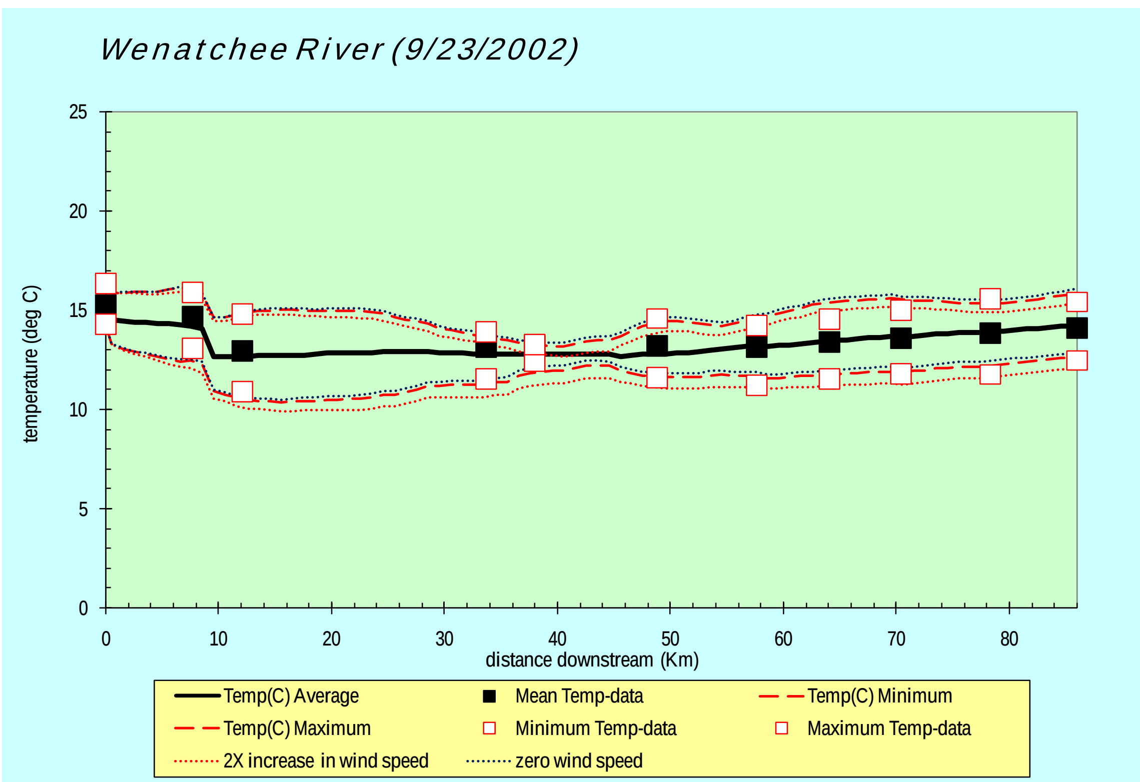


Figure D-29. Comparison of QUAL2K simulated daily maximum and minimum water temperatures (dashed lines) to observed water temperature data (squares) and sensitivity of using zero and 2X the calibrated wind speed for the simulation (dotted lines).