DRAFT – 4-21-08

Lake Whatcom Watershed Total Phosphorus and Bacteria Total Maximum Daily Loads

Water Quality Study Findings

DRAFT – April 2008

Publication No. 08-03-0xx

WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Publication Information

This report is available on the Department of Ecology's website at
www.ecy.wa.gov/biblio/0803xxx.html

Data for this project are available at Ecology's Environmental Information Management (EIM) website www.ecy.wa.gov/eim/index.htm. Search User Study ID, WHATCOM.

Ecology's Study Tracker Code for this study is 02-051.

For more information contact:

Publications Coordinator
Environmental Assessment Program
P.O. Box 47600
Olympia, WA 98504-7600

E-mail: jlet461@ecy.wa.gov
Phone: 360-407-6764

Washington State Department of Ecology - www.ecy.wa.gov/

o Headquarters, Olympia	360-407-6000
o Northwest Regional Office, Bellevue	425-649-7000
o Southwest Regional Office, Olympia	360-407-6300
o Central Regional Office, Yakima	509-575-2490
o Eastern Regional Office, Spokane	509-329-3400

Cover photo: Lake Whatcom looking southeast over the city of Bellingham.

Lake Whatcom Watershed
Total Phosphorus and Bacteria
Total Maximum Daily Loads

Water Quality Study Findings

by

Paul Pickett
Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington 98504-7710

and

Steve Hood
Bellingham Field Office
Washington State Department of Ecology
Bellingham, Washington 98225

Waterbody Numbers
WA-01-9170
WA-01-3150
WA-01-Ande
WA-01-Aust
WA-01-Bran
WA-01-Carp
WA-01-Eucl
WA-01-Mill
WA-01-Silv
WA-01-Smit

This page is purposely left blank

Table of Contents

Page

For this draft report, the following sections are in separate electronic files:

Figures (includes Appendices A and F)

Appendices

List of Figures

List of Tables

Page

Abstract

Lake Whatcom is impaired for dissolved oxygen due to phosphorus loading. Lake tributaries also fail to meet fecal coliform bacteria standards. The goal of this study is to determine total maximum daily loads of these pollutants.

Monitoring surveys were conducted in 2002 and 2003. For dissolved oxygen, a CE-QUAL-W2 lake model was calibrated for those two years. An HSPF watershed model was developed to develop flow and phosphorus lake model inputs based on land use conditions.

Watershed model land uses were adjusted to produce scenarios for evaluating Lake Whatcom's response to phosphorus. Base (2002-03) land uses were changed to mixed forest to estimate natural loading (Full Rollback). Base land uses were changed to maximum allowable development levels to estimate future loading (Full Buildout). Finally, land uses in the Base and Full Buildout scenarios were each partially rolled back to meet water quality standards.

For evaluating standards, the lake model was looped multiple times by rerunning 2003 conditions as if they were consecutive years. Dissolved oxygen levels were compared between scenarios using cumulative lake volumes. The dissolved oxygen lake criterion of 0.2 mg/L was subtracted from the Full Rollback scenario to create site-specific targets for this TMDL.

Loading capacities for total phosphorus and developed acres that generate phosphorus loading at 2003 levels are calculated for two pollutant reduction scenarios, to provide information for the future selection of final loading capacity and allocations.

Bacteria levels in eleven tributary streams and drains did not meet standards. The statistical roll-back method was used to determine geometric mean targets for bacteria corresponding to the 90th percentile criteria of 100 cfu/100 mg/L. A Beales ratio estimator formula was used to calculate the annual fecal coliform loads, and bacteria reduction targets were calculated. Pollutant allocations are recommended for tributary fecal coliform bacteria.

Acknowledgements

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

- City of Bellingham – Peg Wendling, Clare Fogelsong, Mike Sowers, Mike Easley, Anthony Lorenz, Derrick Bullock, Bill Miller, Bill Evans Wendy Steffensen, Geoff Smyth, Bill McCourt, and Michelle Evans.
- Western Washington University – Robin Matthews, Mike Hilles, Joan Vandersypen, and Robert Mitchell.
- Whatcom County – Sue Blake.
- Lake Whatcom Water and Sewer District – Chip Anderson.
- Utah State University – Andy Bookter.
- Department of Ecology – Jing Liu, Bob Cusimano, Charles Pitz, Karol Erickson, Will Kendra, Joan LeTourneau, Helen Bresler, Anise Ahmed, Richard Grout, Doug Allen, Marcia Geidel, Ann Butler.
- U.S. Environmental Protection Agency – Dave Ragsdale, Mark Filippini, Jayne Carlin.
- HydroLogic Services – Joanne Greenberg.
- Portland State University – Scott Wells, Chris Berger, and Robert Annear.
- CDM – Scott Coffey, Steve Wolosoff, Greg McGrath, Malena Foster, Richard Wagner.
- Cadmus Group – Linda Blake.
- GeoEngineers, Inc – Dave Cook.
- National Atmospheric Deposition Program – Christopher Lehmann.

Executive Summary

In response to requirements of the federal Clean Water Act, the Department of Ecology has produced a study that lays the groundwork for restoring dissolved oxygen in Lake Whatcom and reducing fecal coliform bacteria in some of the lake's tributaries to levels that meet state standards.

Meeting those standards will ensure that the lake will continue to be a clean source of drinking water for 96,000 people in Bellingham, and it will support fish, birds, plants and animals, and continue to provide aesthetic and recreational value to the community.

Researchers determined that excess phosphorus in the lake is the main cause of declining oxygen levels. This study quantifies how much phosphorus the lake can process naturally and supply enough oxygen to meet state standards.

To set phosphorus limits, Ecology used scientific computer models to examine the relationship between the acres of developed surfaces such as roads, roofs, decks, and lawns and the amount of phosphorus carried by stormwater into the water below.

Looking at a 2003 snapshot of the watershed, phosphorus limits could be met with 74% fewer acres of development, or 89% fewer acres than the total development allowed under 2003 zoning.

These numbers paint a dramatic picture of how much work needs to be done to meet phosphorus limits. It will be up to local government leaders to develop strategies and pass laws that improve stormwater management so stormwater is absorbed, filtered, and released into the lake more naturally, as if most of the development is not there.

The pollutant limits set by this study will enhance efforts already under way by local governments, advocacy groups, and individual residents to improve and sustain water quality in Lake Whatcom.

The problem with too much phosphorus

In Washington state at least 260 bodies of water are polluted because of phosphorus. Phosphorus is a common ingredient in household detergents and fertilizers, it is used in many industrial processes, and it occurs naturally in soil and human and animal wastes.

Phosphorus behaves as a fertilizer, accelerating plant and algae growth. When plants and algae die, bacteria consume oxygen that is dissolved in the water, leaving less oxygen necessary for fish and aquatic life to survive.

The results of accelerated growth in the water can require an increase in drinking water treatment chemicals that form carcinogenic byproducts and add treatment costs.

State targets Lake Whatcom for improvement

The federal Clean Water Act requires states to set water quality standards and prepare a list of waterbodies that fail to meet those standards, based on tests for specific polluting substances.

For each waterbody on the list, called the 303(d) list of impaired waterbodies, Ecology must determine how much of those pollutants the waterbody can process and still meet standards. The amount of allowable pollutants is called the total maximum daily load, or TMDL.

Years of sampling, data collection and monitoring showed Lake Whatcom dissolved oxygen at levels low enough to land the lake on the 303(d) list. Further study showed fecal coliform levels in most tributaries are too high.

For every TMDL study, an implementation plan addresses how and when sources will reach compliance with their allocation of allowable pollutants, and sets monitoring guidelines for the TMDL's effectiveness.

Standards set to protect lake

In this TMDL, fisheries and aquatic life are protected by dissolved oxygen criteria in Washington State Water Quality Standards. In lakes, human actions may not decrease the one-day minimum oxygen concentration more than 0.2 mg/L below estimated natural conditions.

To protect human health, fecal coliform bacteria in the lake and its tributaries must not exceed a geometric mean value of 50 colony forming units/100 mL, with not more than 10% of all samples exceeding 100 cfu/100 mL.

These criteria are protective enough for drinking water, recreation, and aesthetics.

Watershed description

Lake Whatcom is a large natural lake located in Whatcom County (Figure ES-1). The northwest end of the lake lies within the city of Bellingham.

The lake consists of three distinct lake basins separated by glacial sills. Basin 1, closest to Bellingham, contains only 2% of the lake's volume. Basin 2 is slightly smaller. Basin 3 contains 96% of the lake's volume. The lake is a complex system, and the arrangement of the basins keeps pools of water in the lake a long time rather than moving water through quickly.

Lake Whatcom is included in Watershed Resource Inventory Area (WRIA) 1, which includes the Nooksack watershed. The study area for this TMDL consists of Lake Whatcom and its 22 tributary subbasins, extending to the control dam at the lake's outlet. The diversion from the middle fork of the Nooksack River is also being examined in this study.

Land uses in Lake Whatcom are predominantly urban, rural residential, and forestry. The northwest end of the lake is the most urban, the southeast end is the least developed.

The existing population within the watershed is about 13,000, but current zoning will allow growth in the watershed to about 28,000 people.

Study methods

Study methods followed the procedures described in the Quality Assurance Project Plan for this study. Monitoring surveys were conducted by the city of Bellingham from January to June 2002, and by Ecology from July 2002 to January 2004. Other data collected by various other organizations were used.

Study quality assurance evaluation

Monitoring at all locations followed standard data quality assurance procedures. The quality of the data has been reviewed, unacceptable data have been removed from the analysis, and questionable data qualified. The remaining data are credible and representative, and appropriate for use in TMDL development.

TMDL analyses

Increasing oxygen by decreasing phosphorus

Two linked water quality models were used to develop the dissolved oxygen TMDL.

One model analyzed hydrodynamics, temperature, and water quality constituents. The model was calibrated to 2002-03 observed lake levels and water quality profiles. The other model calculated phosphorus loading from tributaries to the lake. The model looked at existing land uses and was calibrated to measured flow and phosphorus.

The TMDL used the models to examine three different scenarios – full rollback, base, and full buildout:

- Full rollback – Changes 2002-03 land uses to a natural land cover of mixed forest and wetland.
- Base – 2002-03 land uses.
- Full buildout – Changes 2002-03 land uses to the maximum amount of development allowed by current zoning.

To account for changes in pollution and flows over time, the model used 2003 conditions multiple times as if they were consecutive years. This makes the results more dependent on tributary loading and less dependent on initial conditions.

To meet water quality standards, reductions of human caused sources of total phosphorus were calculated by reducing development from both the base and full buildout scenarios.

The loading capacity of the lake was estimated as an annual average of between 7.29 and 7.39 kg/day of total phosphorus, or between 950 and 1,125 of developed acres that generate phosphorus at 2003 levels (see table ES-1), depending on where development occurs and the effectiveness of pollutant control activities.

This represents a 74% reduction of developed acres from the base scenario and an 89% reduction of developed acres from the full buildout scenario.

EPA describes how developed acres translate to phosphorus loading in a 2008 work plan in which pollution control strategies were evaluated for their ability to remove phosphorus. One strategy used to filter 1.6 inches of precipitation through soil reduced phosphorus by 90%. If the same strategy were used for a road or roof, only 10% of the area would count as developed acres that generate phosphorus loading.

Fecal coliform bacteria

Eleven creeks and drains tributary to Lake Whatcom were found to exceed standards for fecal bacteria.

In order to meet standards, the TMDL study sets a 26% to 95% reduction of fecal coliform, depending on the current levels of bacteria and the flow of water through a tributary or drain.

This study recommends pollutant targets for fecal coliform in all tributaries that fail to meet standards. The reductions necessary to meet targets will be used as the basis for load allocations when the final TMDL is submitted to EPA.

Pollutant allocations

The amount of allowable pollutants assigned to each source – stormwater outfalls, creeks, or general runoff – will depend on whether the city and county can provide reasonable assurance that they will reduce pollution throughout the watershed.

If the city and county cannot assure Ecology that they will reduce pollution throughout the watershed, then additional reductions will be required from the stormwater under their permits.

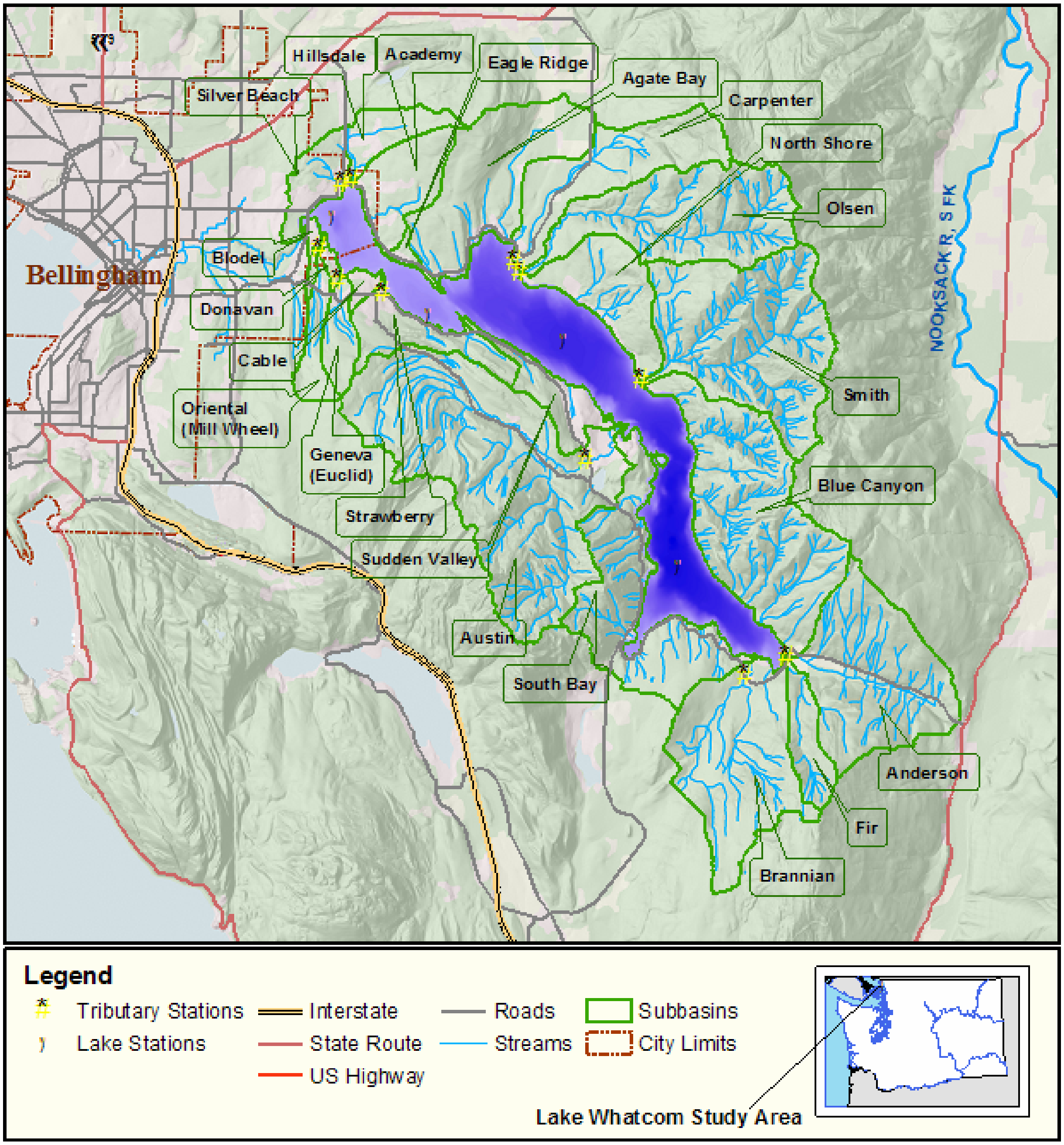

Figure ES-1. Lake Whatcom TMDL Study Area showing tributary watersheds and monitoring locations.

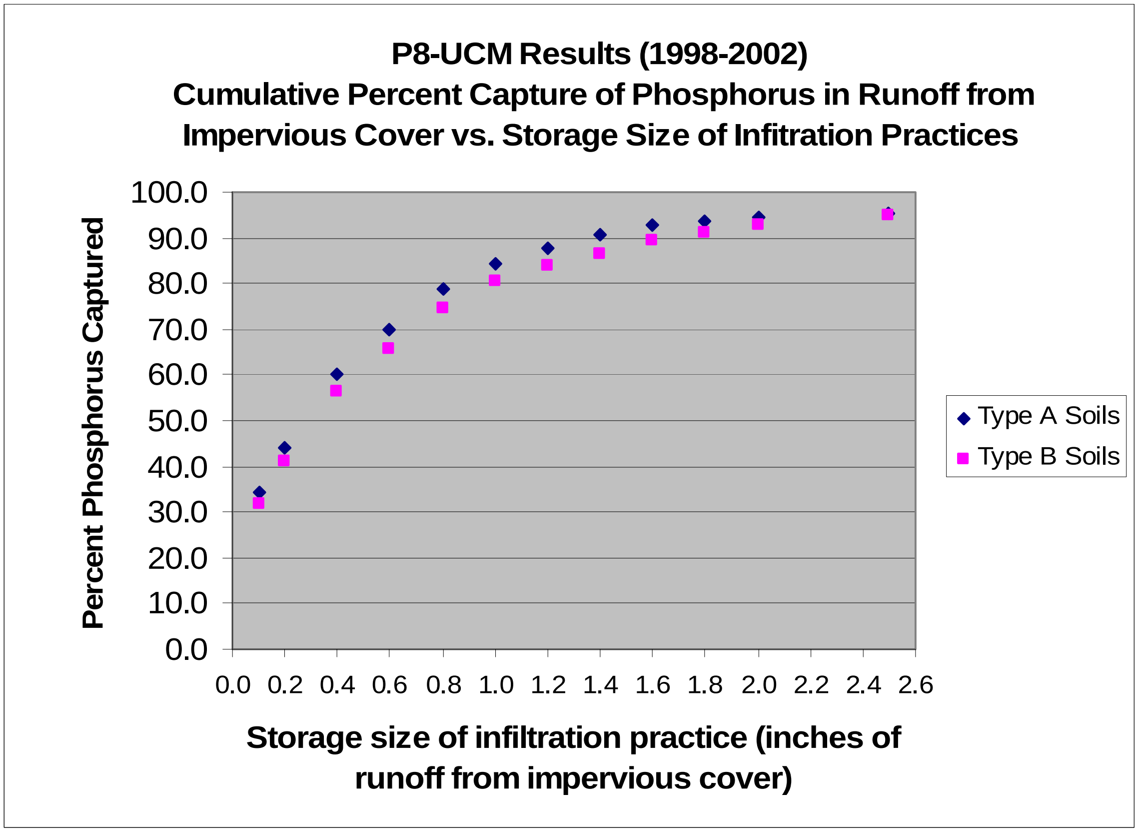

Figure ES-2. Effectiveness of pollution control strategy based on design size.

Table ES-1. Scenarios showing developed acres, undeveloped (forest and wetland) acres, and total phosphorus loading by tributary.

Tributary Name	Full Rollback Scenario		Base Scenario			74% roll back from Base Scenario			Full Buildout Scenario			89% roll back from Full Buildout Scenario		
	forest & wetland acres	total phosphorus (Kg/2003)	developed acres	forest & wetland acres	total phosphorus (Kg/2003)	developed acres	forest & wetland acres	total phosphorus (Kg/2003)	developed acres	forest & wetland acres	total phosphorus (Kg/2003)	developed acres	forest & wetland acres	total phosphorus (Kg/2003)
Academy	780.0	36.3	187.4	592.7	117.1	49.1	731.1	51.9	620.7	159.3	215.4	66.9	713.1	49.0
Agate	2135.5	99.6	512.3	1623.5	320.3	134.1	2001.8	142.3	1698.1	437.4	589.2	183.0	1952.5	134.1
Anderson	2591.5	262.0	225.0	2366.5	256.8	58.9	2532.5	237.8	559.6	2032.0	400.3	60.2	2531.4	248.9
Austin	5331.6	300.8	325.7	5005.5	410.4	85.3	5246.2	318.7	1196.4	4135.0	796.8	128.9	5202.6	342.1
South Bay	2426.8	233.8	292.4	2134.4	367.5	76.5	2350.2	270.4	1121.0	1305.9	730.7	120.8	2306.1	289.3
Bloedel	82.7	1.3	22.9	59.8	8.9	6.0	76.7	3.3	54.2	28.5	19.3	5.9	76.9	3.2
Blue Canyon	3381.1	373.0	229.8	3151.1	407.8	60.1	3320.8	386.6	389.4	2991.7	463.8	41.9	3339.2	386.3
Brannian	2439.9	232.1	112.5	2327.7	232.9	28.8	2410.7	220.1	174.5	2265.3	253.7	18.7	2421.2	220.0
Cable	111.0	2.1	63.1	47.9	16.5	16.5	94.5	5.9	98.4	12.7	22.2	10.6	100.4	4.3
Carpenter	1149.6	68.2	173.0	976.7	142.7	45.3	1104.4	84.0	766.9	382.9	316.9	82.7	1067.1	90.5
Donovan	61.8	1.2	26.1	35.7	7.7	6.8	55.0	2.9	48.1	13.8	12.8	5.2	56.6	2.4
Eagle Ridge	90.1	4.2	21.6	68.5	13.5	5.7	84.5	6.0	71.6	18.5	24.9	7.7	82.4	5.7
Euclid	224.9	6.0	63.8	161.2	18.1	16.7	208.3	9.2	162.0	63.0	34.1	17.4	207.5	9.0
Fir	545.1	58.3	19.3	525.8	64.0	5.0	540.1	59.5	102.1	443.0	91.0	11.0	534.1	61.5
Hillsdale	729.3	13.1	252.2	477.0	133.7	66.1	663.2	44.3	704.6	24.6	256.8	75.9	653.3	39.0
Mill Wheel	583.5	10.3	159.3	424.2	58.8	41.7	541.8	23.0	388.3	195.3	126.3	41.9	541.7	22.8
North Shore	1195.6	72.9	217.8	977.7	163.3	57.1	1138.6	98.9	464.0	731.6	228.7	50.1	1145.5	91.3
Olsen	2423.7	313.3	29.1	2395.1	325.8	7.6	2416.6	316.7	183.7	2240.1	376.1	19.8	2404.0	320.1
Silver Beach Cr.	328.2	15.1	79.4	248.9	49.4	20.8	307.5	21.8	262.0	66.2	91.0	28.2	300.0	20.6
Smith	3192.5	227.5	107.0	3085.4	233.1	29.0	3164.5	229.5	170.5	3021.9	235.5	19.6	3174.2	228.9
Strawberry	774.0	33.2	342.4	431.5	141.0	89.7	684.3	60.7	679.2	94.8	258.8	73.1	700.8	56.5
Sudden Valley	605.6	44.0	163.8	441.6	133.3	42.9	562.6	66.1	516.8	88.7	300.8	55.7	549.8	69.9
Totals	31183.9	2408.3	3625.9	27558.6	3622.7	949.5	30235.7	2659.6	10432.2	20752.2	5845.2	1125.1	30060.4	2695.4

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. Under the Clean Water Act, each state is required to have its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of designated uses for protection, such as cold water biota and drinking water supply, as well as criteria, usually numeric criteria, to achieve those uses.

Every two years, states are required to prepare a list of waterbodies – 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, Ecology compiles its own water quality data along with data submitted by 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 waterbodies into one of 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 a TMDL approved and it is being implemented
    4b. – Has a pollution control plan 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 – on the 303d list.

TMDL process overview

The Clean Water Act requires that a Total Maximum Daily Load or TMDL be developed for each of the waterbodies on the 303(d) list. A TMDL identifies how much pollution needs to be reduced or eliminated to achieve clean water. Then Ecology works with the local community to develop (1) a strategy to control the pollution and (2) a monitoring plan to assess effectiveness of the water quality improvement activities.

Elements required in a TMDL

The goal of a TMDL is to ensure the impaired waters, and any other water not meeting water quality standards, will attain water quality standards. A TMDL includes a written, quantitative assessment of water quality problems and of the pollutant sources that cause the problem. The TMDL determines the amount of a given pollutant that can be discharged to the waterbody and still meet standards (the loading capacity) and allocates that load among the various sources.

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) source 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. 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

Total Maximum Daily Load analyses: Loading capacity

Identification of the contaminant loading capacity for a waterbody is an important step in developing a TMDL. EPA defines the loading capacity as *the greatest amount of loading that a waterbody 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 waterbody into compliance with standards. The portion of the receiving water's loading capacity assigned to a particular source is a load or Wasteload Allocation. By definition, a TMDL is the sum of the allocations, which must not exceed the loading capacity.

Surrogate Measures

Loading of the nutrient phosphorus that causes lower dissolved oxygen levels in Lake Whatcom are calculated in this TMDL in units of kilograms of phosphorus per day. However, it is known that the increased nutrient loading to the Lake is primarily associated with runoff from human development in the Lake Whatcom watershed. A very large fraction of the loading capacity is represented by the natural loading of phosphorus. Expressing loading targets in terms of mass/day is of limited value in guiding management activities needed throughout the watershed to solve existing water quality problems.

To provide more meaningful/measurable pollutant loading targets this TMDL also incorporates measures other than daily loads of phosphorus. This TMDL allocates other appropriate measures, or *surrogate measures* as provided under EPA regulations [40 CFR 130.2(i)]. The Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program (EPA, 1998) includes the following guidance on the use of surrogate measures for TMDL development:

When the impairment is tied to a pollutant for which a numeric criterion is not possible, or where the impairment is identified but cannot be attributed to a single traditional "pollutant," the state should try to identify another (surrogate) environmental indicator that can be used to develop a quantified TMDL, using numeric analytical techniques where they are available, and best professional judgment (BPJ) where they are not.

Why is Ecology conducting a TMDL study in this watershed?

Overview

Ecology is conducting a TMDL study in this watershed because Lake Whatcom was placed on the list of impaired waterbodies in 1998. This decision was made because in the basin closest to Bellingham (Basin 1) the rate at which oxygen levels declined in the bottom of the lake in the summer had increased over time. This information indicated that oxygen levels were below natural levels.

Silver Beach Creek was also on the 1998 list of impaired waterbodies for excess fecal coliform bacteria.

In 2001 all of the potential TMDLs for WRIA 1 were evaluated to determine which projects should be initiated first. Because Lake Whatcom supports aquatic life, is vulnerable to additional degradation, and is a very important drinking water supply, it was determined that it should be started first. The TMDL for bacteria was included because it would be a minimal additional cost to collect the samples for bacteria at the same time as other samples were collected.

The purpose of this TMDL study is to identify the amount of pollution that can enter Lake Whatcom and its tributaries and still meet water quality standards. Meeting the water quality standard based on oxygen levels in the lake will mean controlling the growth of algae through the control of the limiting nutrient (phosphorus).entering the lake from tributaries and other sources in the watershed. For bacteria, meeting standards will mean reducing bacteria in the tributaries themselves.

Study area

The study area for this TMDL consists of Lake Whatcom and its tributary subbasins (Figure 1). The downstream point of the study area is the control dam at the lake's outlet. The diversion from the Middle Fork Nooksack to Lake Whatcom is also being considered in this study.

Lake Whatcom is included in Watershed Resource Inventory Area (WRIA) 1, which includes the Nooksack watershed. This WRIA has been the focus of a watershed planning process since 1998 (www.ecy.wa.gov/watershed/01.html). For this study the Historical, Existing and Future land use covers from the watershed planning process were used in this TMDL. The WRIA 1 Watershed Management Plan was formally adopted in June 2005.

Pollutants addressed by this TMDL

This TMDL addresses low dissolved oxygen levels in Lake Whatcom caused by nutrient inputs to the lake, in particular phosphorus. Tributary streams that do not meet standards for fecal coliform bacteria are also being addressed.

Impaired beneficial uses and waterbodies on Ecology's 303(d) list of impaired waters

The main beneficial uses to be protected by this TMDL are salmonid fisheries, primary contact recreation, aesthetics, and drinking water supply. The 303(d) listings being addressed in this study are shown in Table 1.

Table 1. Waterbodies and Parameters on the 2004 303(d) List Addressed by This Report.

Waterbody	Parameter	Listing ID	Grid Cell Number	Grid Cell Latitude	Grid Cell Longitude
Whatcom Lake	Dissolved Oxygen	5846	48122H4G1	48.765	122.415
Whatcom Lake	Total Phosphorus	8621	48122H3D3	48.735	122.335
Waterbody	Parameter	Listing ID	Township	Range	Section
Silver Beach Creek	Fecal Coliform	7120	38N	03E	22

A detailed description of the analysis that led to the 303(d) listings for total phosphorus and dissolved oxygen can be found in the project plan (Cusimano *et al.*, 2002). The key issue has been the trend of worsening dissolved oxygen over time, particularly anoxic conditions in the hypolimnion that start earlier in the year and persist later in the year. Researchers at Western Washington University (WWU) and Ecology have documented the linkage of nutrient inputs, especially phosphorus, with the worsening dissolved oxygen trend (Matthews, *et al.*, 2002).

This watershed has other water quality issues that will not be addressed in this TMDL. In particular, additional 303(d) listings for contamination of fish tissue by mercury, dieldrin, and PCBs occur in Lake Whatcom, but are not addressed in this report (Table 2).

Table 2. Additional Lake Whatcom 303(d) Listings Not Addressed by This Report.

Waterbody	Parameter	Medium	Listing ID	Grid Cell Number	Grid Cell Latitude	Grid Cell Longitude
Whatcom Lake	Mercury	Tissue	15892	48122H4D0	48.765	122.405
Whatcom Lake	Mercury	Tissue	15893	48122H3B1	48.715	122.315
Whatcom Lake	Mercury	Tissue	15889	48122H4E7	48.745	122.375
Whatcom Lake	Mercury	Tissue	15891	48122G3H1	48.675	122.315
Whatcom Lake	Mercury	Tissue	15895	48122H4F1	48.755	122.415
Whatcom Lake	Mercury	Tissue	15890	48122G2H6	48.675	122.265
Whatcom Lake	Mercury	Tissue	15894	48122H3C2	48.725	122.325
Whatcom Lake	Dieldrin	Tissue	14024	48122H3D3	48.735	122.335
Whatcom Lake	Total PCBs	Tissue	14025	48122H3D3	48.735	122.335

Ecology determined that Mercury is not a suitable parameter to address with a TMDL because the sources are primarily from atmospheric deposition and are not readily controlled by a TMDL (Norton, 2004). However this TMDL will help to address mercury concentration in fish tissue. Mercury in fish tissue is an organic form of mercury, methyl mercury. Sediments in low oxygen conditions favor the conversion of mercury from inorganic forms to organic forms. Decreasing the duration and intensity of low oxygen conditions at the sediment boundary will favor mercury deposition in sediments instead of accumulation in fish tissue. There is not enough information at this time to determine if the control of dissolved oxygen is sufficient to meet water quality standards for mercury in fish tissue.

Total PCBs in fish tissue in Lake Whatcom are at levels similar to lakes without a direct controllable source of PCBs. For pollutants without a source to be controlled, a TMDL is not a suitable tool to ensure meeting water quality standards.

Dieldrin is not registered for use in the United States. Without a source to be controlled a TMDL is not a useful tool to ensure meeting water quality standards.

Why are we doing this TMDL now?

Each year Ecology completes TMDLs and selects new ones to begin on a priority basis as resources become available. This TMDL project was initiated in 2001 as a high priority to address impairment of the use of the lake as source water for municipal drinking water supply, support of aquatic life and the lake’s vulnerability to additional degradation.

There are many ways that the lake is vulnerable to additional degradation. The most obvious is from population growth and on-going development in the watershed. Less obvious is that because of the lake’s long mean water residence time, phosphorus entering the lake may not manifest an immediate water quality impact, but will continue to influence it for several years. The observed acceleration in algae growth and declining dissolved oxygen is caused by the cumulative and increasing amounts of phosphorus entering the lake in recent years. That increase closely correlates with development and human activities in the watershed.

Phosphorus leaves the lake through withdrawals of water, outflow to Whatcom Creek, and deposition in sediments. The most serious but least obvious source of vulnerability to additional degradation is that, as the anoxia of the hypolimnion increases in duration and severity, phosphorus lost to the sediments can reenter the water column. Under low oxygen conditions phosphorus becomes more soluble, and the export of phosphorus from the lake to the sediments is reduced or even reversed, causing the sediments to be a source of phosphorus. The result is a positive feedback loop that may take many years to stabilize. Reductions in loading from runoff may not meet the target dissolved oxygen levels for years because of the internal loading from the sediments.

The decline in water quality associated with increases in pollutants as documented by the Institute of Watershed Studies (Matthews *et al.*, 2003, 2004, 2005, 2006, 2007) highlights the importance of initiating control measures to begin reversing this trend.

Water Quality Standards and Beneficial Uses

Lake Whatcom is a critical water supply source for approximately 86,000 Whatcom County residents, including the City of Bellingham and the Lake Whatcom Water and Sewer District (formerly Water District No. 10). The city uses its water supply for industrial and commercial uses. The number of direct withdrawals by single family residencies is not known but is estimated to be between 150 and 400 (Buroker, 2007).

Lake Whatcom provides habitat to both warm and cold water fish. The lake provides the brood stock for the Brannian Creek Hatchery, which is the state's source of kokanee for fish planting throughout the state. The bass fishing tournaments in Lake Whatcom attract fishers from all of Western Washington.

The lake also provides source water for the Washington State Department of Fish and Wildlife's Whatcom Falls Fish Hatchery, which raises cutthroat and rainbow trout for stocking lakes and ponds throughout northwest Washington. Lake Whatcom also provides flow for water quality purposes in Whatcom Creek during low flow periods.

Lake Whatcom is a regional recreation destination for swimming and boating. Many homes have docks with water craft which residents use throughout the year.

Dissolved oxygen

Aquatic organisms are very sensitive to reductions in the level of dissolved oxygen in the water. The health of fish and other aquatic species depends upon maintaining an adequate supply of oxygen dissolved in the water. Growth rates, swimming ability, susceptibility to disease, and the relative ability to endure other environmental stressors and pollutants are all affected by dissolved oxygen levels. While direct mortality due to inadequate dissolved oxygen can occur, the state's criteria are designed 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 climatic conditions as well as the respiratory requirements of aquatic plants and algae. In a lake, oxygen levels can also vary seasonally as the bottom layers of the lake are isolated from sources of oxygen in the warm months and respiration of aquatic life consumes the supply of oxygen. Since the health of aquatic species is tied predominantly to the pattern of daily minimum dissolved oxygen concentrations, the criteria are typically expressed as the lowest 1-day minimum dissolved oxygen concentration that occurs in a waterbody. However stratified lakes have to be treated differently because, seasonally, dissolved oxygen reaches very low levels under natural conditions that would not support any of the numeric criteria.

In the state water quality standards, fresh water aquatic life use categories are described using key species (salmonid versus warm water species) and life-stage conditions (spawning versus rearing). Minimum concentrations of dissolved oxygen are used as criteria to protect different categories of aquatic communities [WAC 173-201A-200; 2003 edition].

Lakes have specific standards for protecting dissolved oxygen conditions. For all lakes, and for reservoirs with a mean annual retention time of greater than 15 days, human actions considered cumulatively may not decrease the 1-day minimum oxygen concentration more than 0.2 mg/L below estimated natural conditions.

Stratified lakes may be very sensitive to small changes that affect the thermal differences from the bottom of a lake from the top. The thermal differences create stratified layers whose water quality may vary widely over the water column. Therefore, comparing different scenarios on a parcel-by-parcel or time step-by-time step basis may show differences that are indicative of physical changes but not of impairment of aquatic uses.

An alternative approach is to aggregate data on dissolved oxygen levels from the model output over critical segments and over a critical time period. That is, for a critical period of time the results of a model run are compared to an estimate of natural dissolved oxygen levels by examining the cumulative aggregation of oxygen levels by volume.

In practice this is done by identifying the spatial temporal extents of interest and adding up the total volume of the lake in that area that has less than a particular dissolved oxygen level. The cumulative volume at each dissolved oxygen level in one scenario is compared to the dissolved oxygen level for the same cumulative volume from a scenario that estimates the natural dissolved oxygen levels. If for a given aggregated volume of water, the oxygen level in the test scenario water is below the oxygen level of the same volume of natural water by more than 0.2 mg/L, then the criterion is not met. For example if a test case has a million cubic meters of water with less than 2.0 mg/L and under the natural scenario an aggregation of a million cubic meters of water has 2.2 mg/L, at the 2.0 mg/L oxygen level the criteria is met.

Bacteria

Bacteria criteria are set to protect people who work and play in and on the water from waterborne illnesses. In the Washington State water quality standards, fecal coliform is used as an *indicator bacteria* for the state’s freshwaters (e.g., lakes and streams), because it indicates the presence of waste from humans and other warm-blooded animals. Waste from warm-blooded animals is more likely to contain pathogens that will cause illness in humans than waste from cold-blooded animals. The fecal coliform criteria are set at levels that have been shown to maintain low rates of serious intestinal illness (gastroenteritis) in people.

The *Extraordinary Primary Contact* use is intended for waters capable of “providing extraordinary protection against waterborne disease or that serve as tributaries to extraordinary quality shellfish harvesting areas.” To protect this use category: “Fecal coliform organism levels must not exceed a geometric mean value of 50 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100 colonies/100 mL” [WAC 173-201A-200(2)(b), 2003 edition].

Compliance is based on meeting both the geometric mean criterion and the 10% of samples (or single sample if less than ten total samples) limit. These two measures used in combination ensure that bacterial pollution in a waterbody will be maintained at levels that will not cause a greater risk to human health than intended. The water quality standards state:

> *When averaging bacteria sample data for comparison to the geometric mean criteria, it is preferable to average by season and include five or more data collection events within each period. Averaging of data collected beyond a thirty-day period, or beyond a specific discharge event under investigation, is not permitted when such averaging would skew the data set so as to mask noncompliance periods.*

In this study, compliance will be evaluated for seasonal or annual data sets based on the months when bacteria levels are observed to not meet standards.

The criteria for fecal coliform are based on allowing no more than the pre-determined risk of illness to humans that work or recreate in a waterbody. The criteria used in the state standards are designed to allow seven or fewer illnesses out of every 1,000 people engaged in primary contact activities. Once the concentration of fecal coliform in the water reaches the numeric criterion, human activities that would increase the concentration above the criteria are not allowed. If the criterion is exceeded, the state will require that human activities be conducted in a manner that will bring fecal coliform concentrations back into compliance with the standard.

If natural levels of fecal coliform (from wildlife) cause criteria to be exceeded, no allowance exists for human sources to measurably increase bacterial pollution further. While the specific level of illness rates caused by animal versus human sources has not been quantitatively determined, warm-blooded animals (particularly those that are managed by humans and thus exposed to human derived pathogens as well as those of animal origin) are a common source of serious waterborne illness for humans.

Other applicable standards

Aesthetic narrative criteria are defined in WAC 173-201A-160(2)(b) and apply to all existing and designated uses for fresh water. The standards state that: *Aesthetic values must not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste* (see WAC 173-201A-230 for guidance on establishing lake nutrient standards to protect aesthetics).

Although this TMDL is addressing a 303(d) listing for total phosphorus, there are no numeric criteria for phosphorus. The listing is based on the narrative criterion, but the final TMDL will use dissolved oxygen as the criterion to determine loading limits for total phosphorus, which will be linked back to land use practices and nutrient deposition and transport processes. The levels of total phosphorus necessary to meet the numeric dissolved oxygen criterion will also meet the narrative criterion.

Watershed Description

Lake Whatcom is a large natural lake located in Whatcom County, Washington (Figure 1). The northwest end of the lake lies within the municipal boundaries of the City of Bellingham. The lake consists of three distinct lake basins, separated by two glacial sills from north to south (Figures 2 and 3).

The morphological characteristics of each lake basin are summarized in Table 3 (Lighthart et al., 1972). Basin 1 is located at the northwest end of the lake mostly within the city limits of Bellingham, and it is separated from Basin 2 by Geneva sill, which is 3-5 meters below the surface. Basin 2 and Basin 3 are separated by Strawberry sill, which is 10-15 meters deep. Basin 3 is the largest; it contains about 96% of the total volume of the lake with a maximum depth of 103 m. Basins 1 and 2 are small and shallow, with a mean depth of 9.2 and 11.2 m respectively.

Table 3. Lake Whatcom Morphometric Data.

	Basin 1	Basin 2	Basin 3	Entire Lake
Volume ($m^3 \times 10^6$)	19.4	18.0	883.5	921
% of Lake Volume	2.1	2.0	95.9	100.0
Maximum Depth (m)	29	21	103	103
Mean Depth (m)	9.2	11.2	54	46
Surface Area (km^2)	2.1	1.6	16.6	20.3
Length (km)	2.2	2.5	13.3	19.2
Maximum Width (km)	1.1	1.0	1.7	1.7

The watershed topography surrounding Lake Whatcom is dominated by rugged, mountainous terrain adjacent to Basin 3, and low-relief foothills adjacent to Basins 1 and 2. Valleys in the south end of the lake (from Anderson Creek to South Bay) and north of Agate Bay (Carpenter and Olsen Creeks) are filled with unconsolidated glacial sediments. The rest of the watershed is covered by shallow soils over bedrock, with Darrington Phyllite metamorphic bedrock in the southeast end and Chuckanut formation sedimentary bedrock surrounding the rest of the lake. For a map of these formations and a more detailed description of the watershed's geology see Pitz (2005).

As part of developing the WRIA 1 Watershed Management Plan, the 22 sub-drainages of the lake's watershed shown in Figure 1 were delineated. The Plan includes an assessment of existing conditions, and through a contract with Utah State University, the development of computer models for surface and groundwater quantity and quality, a model for assessing instream flow needs, and an integrated Decision Support System. The Plan also provides recommendations for implementation actions, including an Instream Flow Selection and Adoption action process, and recommendations for improved water management, conservation and reuse.

All of the major tributaries and many of the intermittent tributaries in the watershed flow into Basin 3, which receives 87% of the drainage from the watershed. The remaining watershed areas are drained by intermittently flowing streams, surface runoff directly into the lake, or man-made drainage systems (Delahunt, 1990). The seven perennial tributaries flowing into Lake Whatcom are Anderson, Smith, Olsen, Carpenter, Austin, Brannian, and Fir creeks. The principal source of groundwater inflows are the unconsolidated sediments in the valleys, with a minor fraction entering from bedrock areas (Pitz, 2005).

The City of Bellingham diverts water from the Middle Fork of the Nooksack River to Lake Whatcom via Mirror Lake and Anderson Creek at the south end of Basin 3 (Figure 1). The diversion operates during the fall and winter when the Lake is below 312 feet above mean sea level, and continuously during the spring and summer when sufficient water is available in the Middle Fork. During the summer, it is often the major water source for the lake. Recently, the city has voluntarily decreased its diversion during low flow periods to help maintain in-stream flows in the Middle Fork of the Nooksack River and protect salmon. Instream flows are being re-examined by the city, tribes and other parties as agreed to in the WRIA 1 Watershed Management Plan. Future operation and management of the diversion is a core element of these negotiations.

The natural outlet of Lake Whatcom, Whatcom Creek, is located at the northwest end of Basin 1 and drains to Bellingham Bay. The City of Bellingham regulates outlet flow and lake level by a manually controlled dam, which the City constructed in 1938 (URS, 1985). The city operates the dam to provide additional water storage and prevent flooding. Flow into Whatcom Creek can be reduced if water supply is low. The natural flow to Whatcom creek is controlled by a natural sill at 308.8 feet (COB, 2007).

Washington State Department of Fish and Wildlife withdraws water for the Whatcom Falls Hatchery from the lake in Basin 1. The city of Bellingham’s intake is about 12 meters deep and is located about 366 m offshore in Basin 2. The Lake Whatcom Water and Sewer District intake is located in a protected cove of Basin 3 at a depth of 21 meters.

Land uses in Lake Whatcom are predominantly urban, rural residential, and forestry (Figure 4). Only a very small fraction of the watershed is used for agriculture, mostly for grazing. The general trend is that the northwest end of the lake is most urban, the southeast end and northeast shore are the least developed, and the southwest shore is a mixture for forest and pockets of residential development.

The dominant land use dynamic of the watershed is growth in City of Bellingham and development of the unincorporated areas into residential use. The existing population within the watershed is about 13,000 based on the 2000 census. Current zoning will allow an increase of up to about 28,000 residents within the watershed (Hisch Consulting Services, 1998).

Goals and Objectives

Project goals

The major goal of this project is to quantify the impacts of pollutants that affect dissolved oxygen concentrations in Lake Whatcom, and make recommendations for limits of these pollutants with respect to the assimilative capacity of the lake. Another goal of this project is to quantify the concentrations of bacteria in some of the tributaries to Lake Whatcom and make recommendations for limits that will meet the water quality criteria.

Study objectives

The original objectives of this project were described in the Project Plan (Cusimano *et al.*, 2002). This report will address some of those objectives, and the final TMDL report will address the rest.

The specific objectives addressed in this report are:

- Develop a two-dimensional hydrodynamic and water quality model (CE-QUAL-W2 model) of Lake Whatcom to determine the capacity of the lake to assimilate sources of oxygen-consuming substances (i.e., pollutants that directly or indirectly exert an oxygen demand).
- Gather existing data, and conduct water quantity and water quality sampling surveys that can be used to calibrate the CE-QUAL-W2 model.
- Use the CE-QUAL-W2 model to determine the potential to violate the dissolved oxygen criterion.
- Collect bacteria data and quantify the distribution of bacteria concentrations in tributaries to Lake Whatcom.

The specific objectives to be addressed in the final TMDL report are:

- Determine Wasteload Allocations for point sources and Load Allocations for nonpoint sources of oxygen-consuming substances (direct and indirect) that will meet dissolved oxygen criteria.
- Determine bacteria Load Allocations for Lake Whatcom tributaries that will meet the water quality criteria.

Study Methods

Study methods followed the procedures described in the Quality Assurance Project Plan for this study (Cusimano *et al.*, 2002). Details of procedures and deviations from the Plan are provided below.

Ecology conducted surveys to collect water quality samples and field measurements on the following dates:

7/16/2002
8/14/2002
9/17/2002
10/15/2002
11/12/2002
11/19/2002
11/20/2002
12/10/2002
1/7/2003
1/7/2003
1/28/2003
2/18/2003
3/19/2003
4/2/2003
4/8/2003
4/9/2003
4/22/2003
5/28/2003
6/11/2003
7/16/2003
8/20/2003
8/20/2003
9/24/2003
1/28/2004

Additional monitoring was conducted by City of Bellingham on the following dates:

1/23/2002
2/13/2002
3/5/2002
3/26/2002
4/7/2002
4/14/2002
4/16/2002
5/7/2002
5/30/2002
6/19/2002

Western Washington University collects monitoring data as part of the Lake Whatcom Monitoring Project. Monitoring used in this study was conducted on the following dates:

2/14/2002
4/2/2002
4/4/2002
5/7/2002
5/9/2002
6/4/2002
6/14/2002
7/1/2002
7/2/2002
8/6/2002
8/8/2002
8/13/2002
9/3/2002
9/5/2002
10/8/2002
10/10/2002
11/5/2002
11/7/2002
11/13/2002
12/3/2002
12/5/2002
2/4/2003
2/6/2003
4/1/2003
4/3/2003
5/6/2003
5/8/2003
6/3/2003
6/5/2003
7/8/2003
7/10/2003
8/5/2003
8/7/2003
9/2/2003
9/4/2003
10/7/2003
10/9/2003
11/4/2003
11/6/2003
12/4/2003
12/9/2003

Lists of all the parameters analyzed in the laboratory or measured in the field can be found in Appendix B. During synoptic surveys nine tributary sites were monitored, as well as 23 lake stations (4 mid-lake locations at multiple depths) and one station at the lake outlet. A near shore location was monitored for nutrients during one survey, and two catch basins were monitored for bacteria during several surveys. Monitoring locations are shown in Figures 2 and 3.

The original goal of sampling six tributaries during three storm events was only partially met. Only two storm events were monitored: November 19-20, 2002 and April 8-9, 2003; two tributaries were monitored in November and two were monitored in April. Times for the storm event samples are only available for the April event, providing only one opportunity for a pollutant time series and a flow-weighted average of nutrients during a storm event.

Hydrolab® multiparameter meters were used to measure dissolved oxygen, pH, conductivity, and temperature in the tributaries and for lake profile and diurnal measurements. Lake profiles were measured during eight surveys in the four mid-lake stations and over the two sills between basins. Diurnal monitoring occurred in Basin 1 at 30 minute intervals during six surveys (2-3 days duration), including two different depths during four of the surveys. Dissolved oxygen was also measured with the Winkler method as part of quality assurance procedures for the Hydrolab® meters.

Study Quality Assurance Evaluation

A detailed analysis of data quality methods and results are provided in Appendix B. A summary of the conclusions from this analysis follows.

- Data quality for laboratory parameters is acceptable. Laboratory qualifications must be taken into account when using the data. In addition, field duplicates indicate that total suspended solids, total non-volatile suspended solids, and fecal coliform bacteria have more variability than originally targeted. This variability should be taken into account when the data are used.

- Differences for three out of eight paired dissolved oxygen measurements using the Winkler method slightly exceeded the target of ±0.2 mg/L, but the pooled standard deviation for the paired differences met the target. These results are typical of the method, and Winkler measurements are of acceptable quality.

- Hydrolab® dissolved oxygen measurements often failed to meet targets. Some profile measurements were corrected with Winkler data and may have accuracy that approaches the Winkler reading. However, the overall variability is uncertain. The magnitudes of the observed differences between paired values are not unexpected, since dissolved oxygen conditions in the lake can be highly variable temporally and spatially and small changes in the times and locations of the measurements can result in significantly different measurement values. The dissolved oxygen data are considered acceptable for use, but only as qualified data, for which the high observed variability must be taken into account.

- Data collected by the City of Bellingham, Western Washington University, GeoEngineers Inc., and the National Atmospheric Deposition Program meet data quality standards and are acceptable for use in this study.

Results and Discussion

Results of monitoring conducted in this study are provided in Appendix C. Results are also available through Ecology's Environmental Information Management (EIM) system (http://apps.ecy.wa.gov/eimreporting/Detail.asp?Type=Study&ID=4261891). EIM also provides the specific monitoring locations.

Lake Whatcom profiles from Hydrolab® monitoring are shown in Figures 5 through 10. Most interesting are the classic lake stratified temperature profiles in all basins, which are tracked over time by anoxia in the hypolimnion of Basins 1 and 2. Basin 3, however, shows well-oxygenated water over the profile despite the existence of the strong temperature gradient, which reflects the much greater volume and depth of Basin 3. The strong dissolved oxygen gradients and anoxia of Basin 1 represent the critical conditions of this study.

Diurnal measurements in Basin 1 are shown in Figures 11 through 14. The dominant patterns of these time series are the stronger diurnal signal for the meters at the surface, and the higher dissolved oxygen at the five to ten meter depth where there is greater phytoplankton activity and less interaction with the atmosphere.

Figures 15 through 20 show the variation in populations of different phytoplankton over the course of the two study years in the three basins. These graphs illustrate how species composition varies seasonally. Phytoplankton identification summaries are provided in Appendix D.

These results will be discussed in further detail as part of the TMDL analysis.

TMDL Analyses

Dissolved oxygen and total phosphorus

Analytical framework

As called for in the Project Plan, the tool for linking nutrient inputs to Lake Whatcom dissolved oxygen impairment is the lake response model CE-QUAL-W2. As described by the Portland State University (PSU) website - www.ce.pdx.edu/w2/:

CE-QUAL-W2 is a water quality and hydrodynamic model in 2D (longitudinal-vertical) for rivers, estuaries, lakes, reservoirs and river basin systems. W2 models basic eutrophication processes such as temperature-nutrient-algae-dissolved oxygen-organic matter and sediment relationships. The current model release enhancements have been developed under research contracts between the Corps [U.S. Army Corps of Engineers] *and Portland State University under supervision of Dr. Scott Wells.*

The lake model was calibrated to the two calendar years of 2002-2003. However, because of the relatively long time that water resides in Lake Whatcom – 15 years or more – the results of a two year evaluation are highly dependant upon initial conditions.

Therefore, an approach was employed in which model output conditions from the end of a one- or two-year simulation were used as the initial input conditions for rerunning another 1- or 2-year simulation of the model. This *looping* can be repeated multiple times, and provides a means to extrapolate the two-year model to estimate the effects of a longer time frame.

The initial calibrated model began in February near the date when profile measurements were taken. To allow looping, the model was revised to begin on January 1 so that loops could begin and end on the calendar year.

The Project Plan envisioned two possible paths for determining watershed loads for use in the CE-QUAL-W2 lake model. The preferred path was a model developed by Utah State University as part of the WRIA 1 Watershed Management Project. However, the development of this model was delayed and is not yet available for use.

The alternative was to estimate watershed loadings with a multivariate regression approach. This approach has been applied in previous Ecology studies (e.g., Albertson, *et al.*, 2002) based on the approach of Cohn *et al.* (1989). The regressions follow the form:

$$\log(c) = b_o + b_1 \log(Q/A) + b_2[\log(Q/A)]^2 + b_3\sin(2\pi f_y) + b_4\cos(2\pi f_y) + b_5\sin(4\pi f_y) + b_6\cos(4\pi f_y),$$

where:

c = the concentration of the constituent of interest,
Q/A = the flow divided by the watershed area,

f_y = the year fraction (between 0.0 [Jan 1, 00:00] and 1.0 [Dec 31, 23:59]), and
b_n = coefficients (n = 0 to 6) determined by best fit to observed data.

Inputs to the lake model were developed for 22 subbasins based on WRIA watershed delineation. Model input time series of nutrients, total organic carbon, and conductivity were developed for nine index watersheds using the regression approach, and the other 13 watershed were paired with index watersheds.

However, the regression model for tributary inflows has limitations, and local partners involved in TMDL development expressed a desire for a more quantitative linkage between land uses, pollutant control practices, and tributary nutrient concentrations. The regression does not provide this linkage.

Funding from EPA was available to develop a more sophisticated watershed model for flow and total phosphorus. EPA sent out a Request For Proposals, and Cadmus Group (with subcontractor CDM) was selected to work on the project. In consultation with the City of Bellingham, Whatcom County, and Ecology, they examined the data available to calibrate models and selected HSPF. A significant factor in the selection was that the City had contracted with Hydrologic Services to calibrate a related model, HFAM, for the water quantity predictions.

USGS describes HSPF as follows (http://water.usgs.gov/cgi-bin/man_wrdapp?hspf):

HSPF simulates for extended periods of time the hydrologic, and associated water quality, processes on pervious and impervious land surfaces and in streams and well-mixed impoundments. HSPF uses continuous rainfall and other meteorologic records to compute streamflow hydrographs and pollutographs…HSPF is generally used to assess the effects of land-use change, reservoir operations, point or nonpoint source treatment alternatives, flow diversions, etc.

The model was developed in the early 1960's as the Stanford Watershed Model. In the 1970's, water-quality processes were added. Development of a FORTRAN version incorporating several related models using software engineering design and development concepts was funded by the Athens, Ga., Research Lab of EPA in the late 1970's. In the 1980's, preprocessing and postprocessing software, algorithm enhancements, and use of the USGS WDM system were developed jointly by the USGS and EPA.

The overall approach to the TMDL analysis is as follows (see Table 4 for a summary of model scenarios):

- Calibrate the HSPF watershed model to observed flows and phosphorus loads.
- Calibrate the lake model using flows and phosphorus from the watershed model. The calibration run, simulating conditions for calendar years 2002 and 2003, is also called the Base scenario.
- Use the watershed model to develop a pre-development scenario (termed *Full Rollback* or FRB) and a full development scenario (*Full Buildout* or FBO).
- Run the Base, Full Buildout, and Full Rollback scenarios with multiple loops until stable solutions are reached.

- Compliance with dissolved oxygen criteria is determined by comparing the difference in the lake dissolved oxygen results for the Full Rollback scenario and the other scenarios to the 0.2 mg/L criterion.
- Determine the lake's Loading Capacity by reducing development levels from the Base and Full Buildout scenarios until dissolved oxygen standards are met (*Partial Rollback from Base* and *Partial Rollback from Full Buildout*).
- Determine targets for phosphorus loading and developed acres for each subbasin that correspond to the Partial Rollback Loading Capacity scenarios.
- Load and Wasteload Allocations and an implementation strategy will be presented in the TMDL submittal report after consultation with local partners and other public input.

Table 4. Lake Whatcom Model Scenarios.

	Scenario Description			
ID	Name	Concentrations	Hydrology	Purpose
BAS	Base	Calibration (Jan 2002 - Dec 2003)	Calibration (Jan 2002 - Dec 2003)	Reference to observed conditions
FRB	Full rollback	HSPF w/ natural watershed	HSPF w/ natural watershed	Effect of no watershed development
FBO	Full buildout	HSPF w/ projected complete watershed development	HSPF w/ projected complete watershed development	Effect of full watershed development
BAS8003	Partial Rollback from Base of 80.03%	HSPF w/ watershed development reduced by 80.03% from Base to FRB	HSPF w/ watershed development reduced by 80.03% from Base to FRB	Compare partial watershed development to Base (TMDL) to identify % reduction need to meet WQS
BAS7458	Partial Rollback from Base of 74.58%	HSPF w/ watershed development reduced by 74.58% from Base to FRB	HSPF w/ watershed development reduced by 74.58% from Base to FRB	Compare partial watershed development to Base (TMDL) to identify % reduction need to meet WQS
FBO9306	Partial Rollback from FBO of 93.06%	HSPF w/ watershed development reduced by 93.06% from FBO to FRB	HSPF w/ watershed development reduced by 93.06% from FBO to FRB	Compare partial watershed development to Base (TMDL) to identify % reduction need to meet WQS
FBO8399	Partial Rollback from FBO of 83.99%	HSPF w/ watershed development reduced by 83.99% from FBO to FRB	HSPF w/ watershed development reduced by 83.99% from FBO to FRB	Compare partial watershed development to Base (TMDL) to identify % reduction need to meet WQS
NHY	Natural Hydrology and Loading	HSPF w/ natural watershed	No diversion or withdrawals, natural control on Lake Outlet	Evaluate human caused hydrologic change impact to FRB watershed

Development of HSPF watershed model

The results in this report are based on the HSPF model developed by Cadmus and CDM under contract by EPA (Cadmus and CDM, 2007a). The calibration was done based on tributary flow data and water quality measurements for six tributaries: Anderson, Austin, Euclid, Mill Wheel, Olsen, and Smith Creeks. The model was developed using the same meteorological data used for the lake model and the land use cover developed in the WRIA 1 Watershed Management Project. The land use cover was developed by using the 1992 National Land Cover Dataset and updated from aerial photography flown in 2000. The land use cover used for model calibration (Base scenario) is shown in Figure 4. For details of the HSPF model development, refer to Cadmus and CDM (2007a).

The model provided flow and total phosphorus concentration time series for the 22 tributary subbasins that were used for lake model calibration under 2002-2003 conditions. This model was then also applied to develop flow and phosphorus time series for the other TMDL scenarios.

The watershed loading model calculates flow based on

- Input precipitation
- Infiltration rates for different land use covers
- Water flow characteristics for different land use covers
- Routing of water through tributary based on slope and cross section

The watershed loading model calculates pollutant loading based on:

- Pollutant buildup rates
- Pollutant wash-off rates
- Loss of pollutant with infiltration or instream processes

To link the watershed loading model to the lake response model, a translator tool was developed using an Excel spreadsheet and visual basic macros. This tool has several functions:

- Translate data from HSPF watersheds (HSPF output file format) to the WRIA 1 watersheds (CE-QUAL-W2 input file format).
- Convert from US standard units of pounds, feet and acres to metric units of grams and meters.
- Partition total phosphorus into the organic, algal, and inorganic fractions.

Development of CE-QUAL-W2 lake model

The structure of the CE-QUAL-W2 model is shown in Figures 21 and 22. Some definitions of terminology will help the reader in the subsequent discussions:

- **Basin:** As described above, Lake Whatcom has three basins which are like *lakes within a lake* separated by shallow sills. Basin 1 is at the northwest end closest to the City of Bellingham, while Basin 3 is at the southeast end and contains most of the lake’s volume.

Basins are not a unit that is used in the CE-QUAL-W2 model but are important when defining Branches.

- **Waterbody:** A group of Branches with similar properties. In the Lake Whatcom model, Waterbody 1 includes Branches 1, 2, and 3, and Waterbody 2 includes Branches 4 and 5.

- **Branch:** A group of segments with properties similar to each other but different from those in other branches. Branches allow connecting two linear features of a lake such as South Bay to the main lake. Figure 21 shows the five branches used in the Lake Whatcom model: Branch 1 representing Basin 3, Branch 2 representing South Bay, Branch 3 representing Agate Bay, Branch 4 representing Basins 1 and 2, and Branch 5 representing the cove at Silver Beach Creek.

- **Segment:** A section of the lake that runs vertically top to bottom and laterally from shore to shore (numbered 2 through 63 in Figure 21), and made up of multiple layers. Segments range in length from 60 to 800 meters with a median length of 300 m.

- **Layer:** A collection of cells representing a specific depth in all segments (shown in Figure 22 in side view). Layers of 1 meter depth are used for the top 79 layers; layers 80 and deeper are 3 meters thick.

- **Cell:** The computational unit in the CE-QUAL-W2 model, representing a volume in a specific location in the lake. Each cell corresponds to a specific layer in a specific segment in the lake model grid.

Input data for the CE-QUAL-W2 lake model were developed from a variety of sources. A complete list of model input parameters can be found in Appendix E. The methods for developing the principal inputs are described below:

- **Bathymetry.** The bathymetry data file was developed based on data from the Lake Whatcom 1999-2000 Area and Capacity Survey conducted by the U.S. Bureau of Reclamation. The data from this survey were entered into Arc View, and using Spatial Analyst, used to develop 1m interval contour polygons from elevation of -5m to 97m (City of Bellingham datum). Contour polygons were cleaned up and merged into one shape file and used for calculating segment length and cell width. A shapefile for model segmentation was developed, and the contour polygons were intersected with the segmentation shapefile to develop volumes for each model cell. Cell dimensions were then calculated and confirmed by checking against the depth-volume curve of the lake. During calibration some adjustments were made to cell dimensions and bottom elevation at the inter-basin sills to improve the model's ability to match observed data. Lake Volume was preserved overall. In order to match hydrodynamic predictions with data, small volumes of water were eliminated that were artificially distorted by the need to fit grid structure. Lake bathymetry and model segmentation are shown in Figure 23.

- **Initial Conditions.** February 2002 profile data from WWU were used as the first estimate of initial conditions. Initial conditions were then modified as part of model calibration, by interpolating between December 2001 and February 2002 profile data to estimate January 1, 2002 conditions.

- **Lake Level.** Daily lake level data were provided by the City of Bellingham. Lake levels for 2002 were adjusted based on City staff comments about meter calibration.

- **Outflow data.** Outflow data were provided by City of Bellingham and were updated for 2002-2003, by reviewing Sutron data files, paper recording, rating curve, and other reported data with adjustments based on best estimates for missing data or errors in the record.

- **Precipitation Data.** Precipitation data from Geneva Gate House, Smith, and Brannian gauges were used as follows:
    - For Waterbody 1, weighting factors provided by WWU were used to calculate precipitation amounts ([Smith * 0.4610] + [Brannian * 0.3146]).
    - For Waterbody 2, data collected at Geneva Gate House were used for precipitation amounts. For missing data at Geneva a regression with Smith was used.
    - Precipitation temperatures were based on the average air temperature at Smith and Brannian for Branches 1, 3, 4, and 5, while for Branch 2 air temperatures were used from Brannian only.

- **Meteorological Data.**
    - Cloud cover data were from Bellingham Airport (KBLI).
    - Wind speed data were from Smith directly when available; otherwise Airport wind speeds modified by a regression to Smith were used.
    - Wind direction data were from Smith when available; otherwise Airport wind direction values were used adjusted by a correction factor based on the difference between the Smith and Airport directions.
    - Solar radiation was based on the bigger value from either Smith or Brannian. When neither station was available, irradiance was predicted from a Ryan-Stolzenbach model global of solar radiation on a horizontal surface, with values modified by cloud cover.
    - Air temperature and dew point temperatures from Brannian and Smith were averaged.

- **Tributary Flow.** Continuous flow and temperature data were collected on the following major tributaries: Austin, Anderson, Brannian, Carpenter, Euclid, Mill Wheel, Olsen, Silver Beach, and Smith Creeks. WWU maintained flow gauges on Anderson, Austin, and Smith, while USGS gauged Brannian, Carpenter, Euclid, Mill Wheel, Olsen, and Silver Beach Creeks. Flow measurements were used for calibration of the HSPF watershed model.

- **Tributary Temperature.** Temperature time series were collected using tidbit data from the city. For those creeks or watersheds without tidbit data, data from an index creek were used. Gaps in the temperature time series, especially in November and December 2003, were filled using the simple response temperature model rTemp, calibrated to temperature data from earlier in the year. The rTemp model predicts a time-series of water temperatures in response to heat fluxes determined by meteorological data, groundwater inflow, and other forcing functions (see www.ecy.wa.gov/programs/eap/models.html).

- **Tributary Constituents.** As described earlier, multivariate regressions were used to determine time series for inorganic and organic phosphorus; nitrate-nitrite, ammonia, and organic nitrogen; conductivity; and total organic carbon. Total phosphorus time series were modeled using HSPF and then apportioned into phosphorus constituents using ratios from the regressions. Other parameters were assigned values from the study monitoring data, multivariate regressions or from literature values.

- **Groundwater Inputs.** The Lake Whatcom groundwater study (Pitz, 2005) provided the information for groundwater inputs. Inflows from shallow unconsolidated aquifers were represented in the model with eight point tributary inputs representing the alluvial formations in valleys that flow towards the lake. Bedrock aquifer inputs were represented as distributed tributary inputs for Branches 2, 3, and 4. The Branch 5 distributed tributary contains residual flows that complete the water balance for calibration.

  Groundwater inflows were set at the maximum precipitation-based flow (*Scenario 2* in Table 1, Pitz [2005]). Input constituents were derived from the groundwater study data, except for groundwater temperatures which were derived from data collected as part of the Whatcom Creek gasoline spill and fire remediation (Cook, 2005). Groundwater was categorized into three quality regimes and assigned to different areas of the lake based on location of the observed values. Table 5 summarizes the flows and phosphorus concentrations used in the lake model.

  Pitz (2005) notes that his estimates of phosphorus loading from groundwater were *upper-bound* estimates. A number of factors could decrease actual phosphorus inputs from groundwater, including low oxygen and redox conditions in the groundwater and sediments, iron compounds that provide sorption sites for phosphorus, and oxygenated surface water that causes precipitation of these iron compounds. However, the information available for calibration of the model did not suggest that a reduction of phosphorus inputs were needed.

Table 5. Model Groundwater Flow and Phosphorus.

Location	Input type	File name	Flow (cms)	Concentration (mg/L)		
				PO4	ORGP	TP
Basin 3	distributed	Cdt_br1.npt	0	0.038	0.100	0.138
South Bay		Cdt_br2.npt	0.0843	0.095	0.062	0.157
Agate Bay		Cdt_br3.npt	0.0729	0.082	0.093	0.175
Basin 1&2		Cdt_br4.npt	0.0396	0.038	0.100	0.138
Anderson Valley	tributary	Ctr_gw2.npt	0.0843	0.038	0.100	0.138
Brannian Valley		Ctr_gw4.npt	0.0153	0.038	0.100	0.138
South Bay		Ctr_gw8.npt	0.0153	0.038	0.100	0.138
Blue Canyon		Ctr_gw12.npt	0.0153	0.095	0.062	0.157
South of Austin		Ctr_gw16.npt	0.0153	0.038	0.100	0.138
Smith		Ctr_gw20.npt	0.0153	0.038	0.100	0.138
North Shore		Ctr_gw24.npt	0.0153	0.038	0.100	0.138
Olsen		Ctr_gw28.npt	0.0153	0.038	0.100	0.138

PO4 - ORGP - TP – total phosphorus

- **Water withdrawals.** The City of Bellingham provided the flow time series for withdrawals for Water District #10, City of Bellingham water treatment plant, Georgia Pacific, and the Fish Hatchery.

- **Light Extinction.** Light extinction was estimated from the five best solar radiation profiles (i.e., data collected on clear days without cloud effects on the profile data) during summer monitoring in 2002 and 2003.

Portland State University conducted an initial calibration of the CE-QUAL-W2 lake model based on 2002-03 conditions, and published a calibration report (Berger and Wells, 2005). Details of the calibration process and results can be found in that report. The report reaches the following conclusion:

In general, the model reproduces the lake responses to the known boundary conditions. The average absolute mean error of model predictions was 0.64 degrees Celsius for temperature, 0.69 mg/L for dissolved oxygen, 0.97 ug/l for chlorophyll a, 0.22 for pH and 0.004 mg/L for total phosphorus.

During the review of the calibration report for the lake response model, local partners expressed their concern with the ability of the model to predict interactions between water column particulates (including algae), nutrients and the sediments. As a result, Ecology contracted with Portland State University to add a dynamic sediment stoichiometry feature to the CE-QUAL-W2 model and recalibrate the improved the model (Berger and Wells, 2007a). As described by Berger and Wells:

Variable stoichiometry of sediments has been added to the Lake Whatcom water quality model. There are now sediment phosphorus, sediment nitrogen, and sediment carbon compartments. The sediment carbon stoichiometry is variable because organic matter and algae may have differing carbon stoichiometry. The decay rate of sediment in a model cell is the mass averaged decay rate of the labile particulate organic matter (LPOM) and refractory particulate organic matter (RPOM) groups.

As discussed above, an opportunity arose to develop the HSPF model to predict tributary flows and phosphorus. Tributary inputs using this method were developed and an additional recalibration completed for the lake model (Berger and Wells, 2007b).

A calibration history and a summary of calibration statistics for the final calibration are provided in Appendix E. Both static graphs and animations of observed versus modeled results were developed by Portland State University and can be found in their report (Berger and Wells, 2007a) and on Ecology's website: www.ecy.wa.gov/programs/wq/tmdl/watershed/tmdl_info-nwro.html#whatcom_lake.

Ecology is satisfied with the quality of data used in modeling and of the model itself. Model calibration statistics indicate a well-calibrated model that is acceptable for use for this TMDL analysis.

Calibration was conducted with only the two-year model. Then the looping methodology was applied to develop long-term simulations for comparison to standards.

The looping methodology revealed some challenges for developing long-term modeling scenarios. Long-term looped scenarios (nine two-year loops) were evaluated for the stability of results. In general, the changes in results between iterations for all parameters decreased with each loop and they approached equilibrium values. This is a desirable result since it indicates a stable solution resulting from the repetition of the loops.

However, dissolved oxygen results in looped scenarios also were strongly affected by increasing nitrogen limitation in later loops. The scenario with highest loading, Full Buildout, became fully nitrogen limited in two loops, while the scenario with the lowest loading, Full Rollback, became fully nitrogen limited in six loops. This is problematic since the extent of nitrogen limitation has never been observed and distorts dissolved oxygen results, and many of the processes that take over under nitrogen limiting conditions are not modeled.

Several reasons were hypothesized for this trend towards nitrogen limitation:

- The two years of calibration, 2002 and 2003, represent a dry and an average year. Therefore wet years with larger nitrogen loading are not represented.
- Calibration based on two years will be unable to capture other long-term trends, including variable nutrient kinetics that might affect the balance of phosphorus and nitrogen.
- Nitrogen-fixing by blue-green algae which would increase available nitrogen is not simulated in the model.

It's important to note that studies have shown that Lake Whatcom can be nitrogen-limited at times (Matthews *et al.*, 2002). However, nitrogen limitation in the lake usually occurs from the presence of excess phosphorus. Adequate controls on phosphorus are expected to maintain the lake in a phosphorus-limited state. Therefore, the appropriate course for this TMDL is to focus on phosphorus limitation and avoid nitrogen limited conditions.

For the model scenarios, looping was limited to only one year – 2003 – since this was more of an average year with higher nitrogen loading. The approach to scenario development was to run the two years once and then loop 2003 as many times as possible before significant nitrogen limitation (greater than 0.5% of the nutrient limitations) began to appear. Pairs of scenarios were compared using the same number of loops (the number for the scenario with fewer before nitrogen limitation.)

Natural and future conditions scenarios

Land use cover that shows estimates of historic conditions and future conditions were developed as part of the WRIA 1 Watershed Management Plan. The land use cover for historic conditions for Lake Whatcom is all Mixed Forest and Wetland. This cover was applied to the watershed model for the Full Rollback scenario (FRB). The loading of the Full Rollback scenario estimates the loading under natural conditions. In the HSPF model as calibrated, all forests react the same as Mixed Forest, exhibiting the same runoff and phosphorus loading characteristics.

The future land use cover considers all land to be developed to the level allowed by zoning. For large parcels in residential areas a small portion is considered residential and the remainder is pasture. This cover, shown in Figure 24, was applied to the Full Buildout scenario (FBO).

Tables 6 and 7 show the distribution of land uses per subbasin for the Base scenario in terms of acreage and percent of the subbasin, respectively, while Table 8 and 9 show the acreage and percent of the subbasin for land uses under the Full Buildout Scenario. Land uses for Full Rollback are all in the category of *Mixed Forest*. The redistribution of land into land use categories was the mechanism used to increase or reduce total phosphorus loading for the scenarios.

These land use covers were used to develop the watershed model that produced water and phosphorus inputs for the lake model. All other input values remained constant between scenarios. In particular, groundwater inputs were not changed because little information is available about the effect of human activities on groundwater nutrient levels, and the amount of groundwater nutrients that would be present absent human contributions is unknown. The effect of future actions on groundwater levels is also uncertain. Measures to reduce phosphorus in surface tributaries may or may not affect groundwater phosphorus loading. Therefore keeping groundwater nutrient levels constant is preferable to arbitrary estimates of increases or reductions under development levels.

The Full Rollback scenario estimates dissolved oxygen system potential values that are the best estimates of the natural condition of the waterbody. The analysis was based on the cumulative volume of water in critical segments of the lake during critical times. In this case, the estimate of naturally low dissolved oxygen concentrations typifying historic conditions shows that use of this allowance is appropriate.

Critical season and locations

The critical aspect of dissolved oxygen depletion trends observed in Lake Whatcom is formation of anoxia in the hypolimnion earlier in the summer, and the development of anoxia and hypoxia covering a larger portion of the water column over a longer period. The critical time period for oxygen depletion is identified as June - October, which starts with the period where the lake becomes stratified and oxygen depletion of the hypolimnion appears, and ends when stratification breaks up and oxygen depletion in the hypolimnion dissipates. Standards were evaluated using the daily minimum dissolved oxygen values.

No evidence for a critical season was found for phosphorus inputs. Phosphorus that enters the system during the entire year, including the fall or winter, has an effect on algal growth in the spring and summer and has an effect the rate of hypolimnetic oxygen decline during the critical period for oxygen depletion.

The critical segments showing the greatest sensitivity to pollution increases have been identified as Segments 61 and 62. Those segments represent the deepest locations in Basin 1.

Table 6. Total Acres per Subbasin by Land Use Category – Base Scenario.

HSPF Subbasin Name	HSPF Land Use Category								Subbasin
	Agriculture	Deciduous Forest	Developed	Evergreen Forest	Mixed Forest	Open	Water/ Wetlands	Developed– Impervious	Total Acres
Mirror Lake	-	54	-	8	33	25	13	-	134
Anderson Creek	77	591	6	1,015	756	126	6	2	2,579
NE Lake Whatcom Inflow 1	11	152	2	329	161	4	2	1	663
NE Lake Whatcom Inflow 2	2	453	15	1,436	1,106	201	24	4	3,241
Smith Creek	-	498	-	1,486	1,174	105	-	-	3,263
Smith Creek Outlet	-	12	1	4	18	4	0.1	0	40
Olsen Creek	-	375	11	1,220	824	16	0.2	3	2,448
Carpenter Creek	4	147	35	186	347	37	1	10	766
N Lake Whatcom Inflow	1	255	88	187	484	104	14	24	1,156
Silver Beach Creek	0.2	104	175	88	272	27	-	47	712
NW Lake Whatcom Inflow	114	1,355	521	224	1,223	116	24	141	3,718
Brannian Creek	-	493	1	1,071	634	97	2	0	2,298
Brannian Creek Outflow	-	17	10	11	28	2	1	3	70
S Lake Whatcom Inflow	0.4	698	105	489	805	153	28	28	2,307
Upper Austin Creek	1	100	6	1,306	340	5	-	2	1,759
Beaver Creek	0.2	598	99	1,134	1,168	8	1	27	3,036
Austin Creek	-	9	12	62	32	0.5	-	3	118
Austin Creek Outflow	-	26	120	110	109	9	28	32	433
SW Lake Whatcom Inflow 2	0.4	130	197	258	287	9	15	53	950
SW Lake Whatcom Inflow 1	-	69	258	51	122	11	1	70	582
Euclid Creek	-	55	67	66	133	2	-	18	340
Mill Wheel Creek	-	75	123	104	231	3	4	33	574
Total	212	6,264	1,852	10,843	10,288	1,062	164	500	31,185
Percent	1%	**20%**	5.9%	**35%**	**33%**	3%	1%	1.6%	**100%**

Percentages > 10% in **Bold**

Table 7. Percentages per Subbasin by Land Use Category – Base Scenario.

HSPF Subbasin Name	HSPF Land Use Category								Subbasin %
	Agriculture	Deciduous Forest	Developed	Evergreen Forest	Mixed Forest	Open	Water/ Wetlands	Developed–Impervious	Study Area
Mirror Lake	-	**40.7%**	-	5.8%	**24.8%**	**18.9%**	9.9%	-	0.4%
Anderson Creek	3.0%	**22.9%**	0.2%	**39.3%**	**29.3%**	4.9%	0.2%	0.1%	8.3%
NE Lake Whatcom Inflow 1	1.7%	**23.0%**	0.4%	**49.6%**	**24.4%**	0.6%	0.3%	0.1%	2.1%
NE Lake Whatcom Inflow 2	0.1%	**14.0%**	0.5%	**44.3%**	**34.1%**	6.2%	0.7%	0.1%	**10.4%**
Smith Creek	-	**15.3%**	-	**45.6%**	**36.0%**	3.2%	-	-	**10.5%**
Smith Creek Outlet	-	**30.7%**	3.5%	9.2%	**45.3%**	**10.1%**	0.2%	1.0%	0.1%
Olsen Creek	-	**15.3%**	0.4%	**49.8%**	**33.7%**	0.6%	0.0%	0.1%	7.9%
Carpenter Creek	0.5%	**19.2%**	4.6%	**24.2%**	**45.3%**	4.8%	0.1%	1.2%	2.5%
N Lake Whatcom Inflow	0.1%	**22.0%**	7.6%	**16.2%**	**41.8%**	9.0%	1.2%	2.1%	3.7%
Silver Beach Creek	0.0%	**14.6%**	**24.6%**	**12.3%**	**38.2%**	3.7%	-	6.6%	2.3%
NW Lake Whatcom Inflow	3.1%	**36.4%**	**14.0%**	6.0%	**32.9%**	3.1%	0.7%	3.8%	**11.9%**
Brannian Creek	-	**21.5%**	0.1%	**46.6%**	**27.6%**	4.2%	0.1%	0.0%	7.4%
Brannian Creek Outflow	-	**24.0%**	**14.4%**	**15.1%**	**39.5%**	2.3%	0.9%	3.9%	0.2%
S Lake Whatcom Inflow	0.0%	**30.2%**	4.6%	**21.2%**	**34.9%**	6.6%	1.2%	1.2%	7.4%
Upper Austin Creek	0.1%	5.7%	0.3%	**74.2%**	**19.3%**	0.3%	-	0.1%	5.6%
Beaver Creek	0.0%	**19.7%**	3.3%	**37.4%**	**38.5%**	0.3%	0.0%	0.9%	9.7%
Austin Creek	-	7.4%	**10.4%**	**52.3%**	**26.8%**	0.4%	-	2.8%	0.4%
Austin Creek Outflow	-	6.0%	**27.7%**	**25.4%**	**25.1%**	2.0%	6.4%	7.5%	1.4%
SW Lake Whatcom Inflow 2	0.0%	**13.7%**	**20.7%**	**27.2%**	**30.2%**	0.9%	1.6%	5.6%	3.0%
SW Lake Whatcom Inflow 1	-	**11.8%**	**44.3%**	8.8%	**21.0%**	1.9%	0.2%	**12.0%**	1.9%
Euclid Creek	-	**16.0%**	**19.5%**	**19.5%**	**39.0%**	0.7%	-	5.3%	1.1%
Mill Wheel Creek	-	**13.1%**	**21.5%**	**18.2%**	**40.3%**	0.5%	0.7%	5.8%	1.8%

Percentages > 10% in **Bold**

Table 8. Total Acres per Subbasin by Land Use Category – Full Buildout Scenario.

HSPF Subbasin Name	HSPF Land Use Category								Subbasin
	Agriculture	Deciduous Forest	Developed	Evergreen Forest	Mixed Forest	Open	Water/ Wetlands	Developed–Impervious	Total Acres
Mirror Lake	15	41	13	2	21	25	13	3	133
Anderson Creek	283	415	90	986	643	132	5	24	2,579
NE Lake Whatcom Inflow 1	54	107	13	313	120	51	2	3	663
NE Lake Whatcom Inflow 2	73	402	42	1,416	1,035	245	16	11	3,241
Smith Creek	-	490	-	1,476	1,161	136	-	-	3,262
Smith Creek Outlet	1	0	2	-	-	37	0.1	1	40
Olsen Creek	137	308	25	1,205	751	15	0.2	7	2,448
Carpenter Creek	328	26	92	107	157	32	1	25	766
N Lake Whatcom Inflow	176	150	122	159	377	131	8	33	1,156
Silver Beach Creek	258.1	3	328	1	16	18	0.0	89	712
NW Lake Whatcom Inflow	1,789	439	835	11	287	106	24	226	3,717
Brannian Creek	-	487	9	1,070	631	96	2	2	2,297
Brannian Creek Outflow	5	9	12	7	13	20	1	3	70
S Lake Whatcom Inflow	615.3	439	283	316	411	138	28	77	2,307
Upper Austin Creek		87	98	1,239	305	4		26	1,759
Beaver Creek	69.2	532	378	943	1,007	2	1	102	3,036
Austin Creek	-	-	93	-	-	-	-	25	118
Austin Creek Outflow	10	0	303	8	2	-	27	82	433
SW Lake Whatcom Inflow 2	198.9	14	485	56	49	2	14	131	950
SW Lake Whatcom Inflow 1	73	21	350	11	28	2	1	95	582
Euclid Creek	24	31	169	34	35	1	-	46	340
Mill Wheel Creek	-	29	292	67	98	5	4	79	574
Total	4,109	4,032	4,034	9,427	7,147	1,198	146	1,092	31,184
Percent	**13%**	**13%**	**13%**	**30%**	**23%**	4%	0%	**4%**	**100%**

Percentages > 10% in **Bold**

Table 9. Percentages per Subbasin by Land Use Category – Full Rollback Scenario.

HSPF Subbasin Name	HSPF Land Use Category								Subbasin %
	Agriculture	Deciduous Forest	Developed	Evergreen Forest	Mixed Forest	Open	Water/ Wetlands	Developed–Impervious	Study Area
Mirror Lake	**11.3%**	**30.9%**	9.7%	1.5%	**15.8%**	**18.9%**	9.4%	2.6%	0.4%
Anderson Creek	**11.0%**	**16.1%**	3.5%	**38.2%**	**24.9%**	5.1%	0.2%	0.9%	8.3%
NE Lake Whatcom Inflow 1	8.1%	**16.1%**	1.9%	**47.2%**	**18.1%**	7.7%	0.3%	0.5%	2.1%
NE Lake Whatcom Inflow 2	2.3%	**12.4%**	1.3%	**43.7%**	**31.9%**	7.6%	0.5%	0.4%	**10.4%**
Smith Creek	-	**15.0%**	-	**45.2%**	**35.6%**	4.2%	-	-	**10.5%**
Smith Creek Outlet	1.3%	0.0%	4.9%	-	-	**92.2%**	0.3%	1.3%	0.1%
Olsen Creek	5.6%	**12.6%**	1.0%	**49.2%**	**30.7%**	0.6%	0.0%	0.3%	7.9%
Carpenter Creek	**42.8%**	3.4%	**12.0%**	**14.0%**	**20.5%**	4.1%	0.1%	3.2%	2.5%
N Lake Whatcom Inflow	**15.2%**	**13.0%**	**10.6%**	**13.7%**	**32.6%**	**11.3%**	0.7%	2.9%	3.7%
Silver Beach Creek	**36.2%**	0.5%	**46.0%**	0.1%	2.2%	2.5%	0.0%	**12.5%**	2.3%
NW Lake Whatcom Inflow	**48.1%**	**11.8%**	**22.5%**	0.3%	7.7%	2.8%	0.6%	6.1%	**11.9%**
Brannian Creek	-	**21.2%**	0.4%	**46.6%**	**27.5%**	4.2%	0.1%	0.1%	7.4%
Brannian Creek Outflow	7.5%	**13.1%**	**17.1%**	**9.9%**	**18.2%**	**28.7%**	0.9%	4.6%	0.2%
S Lake Whatcom Inflow	**26.7%**	**19.0%**	**12.3%**	**13.7%**	**17.8%**	6.0%	1.2%	3.3%	7.4%
Upper Austin Creek	-	5.0%	5.5%	**70.4%**	**17.3%**	0.2%	-	1.5%	5.6%
Beaver Creek	2.3%	**17.5%**	**12.5%**	**31.1%**	**33.2%**	0.1%	0.0%	3.4%	**9.7%**
Austin Creek	-	-	**78.7%**	-	-	-	-	**21.3%**	0.4%
Austin Creek Outflow	2.2%	0.1%	**70.1%**	1.9%	0.5%	-	6.3%	**19.0%**	1.4%
SW Lake Whatcom Inflow 2	**20.9%**	1.4%	**51.0%**	5.9%	5.2%	0.2%	1.5%	**13.8%**	3.0%
SW Lake Whatcom Inflow 1	**12.6%**	3.7%	**60.2%**	1.9%	4.9%	0.3%	0.1%	**16.3%**	1.9%
Euclid Creek	6.9%	9.2%	**49.7%**	**10.0%**	**10.4%**	0.3%	-	**13.5%**	1.1%
Mill Wheel Creek	-	5.0%	**50.9%**	**11.7%**	**17.1%**	0.9%	0.7%	**13.8%**	1.8%

Percentages > 10% in **Bold**

Application of standards to model results

Conditions in Lake Whatcom pose a particular challenge to evaluating compliance with the standards by comparing two scenarios. Both modeled and measured conditions often show a high level of variability over time and space. Because of changes in lake level, water flow, the lake seiche, thermal stratification, algae levels, and other conditions, it is difficult to make a consistent comparison between a model cell and point in the lake at any given time. Small changes in inflows or evaporation can change the thermal balance and hydrodynamic characteristics. Therefore, conditions in the same cell at the same time in two different model scenarios may differ because of physical processes not directly related to pollutant loading.

To address the variability, an alternative method was developed to compare scenarios and determine compliance with the standards. The method determines whether the same volumes of water have the same dissolved oxygen levels in different scenarios. Or to put it another way, the standards grant a dissolved oxygen allowance of 0.2 mg/L compared to natural conditions. Therefore, the volume of water at or below a target level of a given natural dissolved oxygen concentration less 0.2 mg/L should be equal to the volume of water in another scenario at the target dissolved oxygen level. When these volumes are summed for different dissolved oxygen levels, a curve can be developed of the cumulative volumes as a function of dissolved oxygen levels.

This approach allows a comparison at all oxygen levels. Different aquatic life, from fish to bacteria, have different oxygen needs. A test for meeting water quality criteria must protect all uses, so all oxygen levels are important.

The habitat to be protected could be considered the volume of the water column for free swimming life or the surface area of the bottom for benthic organisms. Quantifying the habitat by model cells was rejected because the volume of cells can vary widely. In the CE-QUAL-W2 model, the cells near the bottom of the water column are much smaller than other cells. By using the volume of each cell in the analysis all water is given the same weight.

Volumes are aggregated from the lowest oxygen levels to the highest oxygen levels, reflecting the need to protect against loss of oxygen. If one scenario’s volume is greater than another’s then extra volume with the highest oxygen levels would be left out of the analysis, introducing a small margin of safety.

Similarly, results are expressed in volume instead of a percentile or relative frequency because in the future we may need to evaluate scenarios that have different total volumes. If percentiles were used, then a scenario that has a larger total volume could have the same percentile of oxygen as a scenario with a lower total volume, but the scenario with less volume overall would also have less volume of high quality water. Therefore, use of volumes is more protective of the highest oxygen levels.

Cumulative volumes of the daily minimum oxygen levels were evaluated for comparison to the standards. The CE-QUAL-W2 model provides results at a user-selected time step. For this project oxygen levels for each model cell were output every 3 hours, or 8 times a day, and daily minimums were selected from the model output. This resolution picked up both diurnal as well as shorter period (16 to 18 hour) oscillations based on internal waves. Shorter intervals would have resulted in slightly lower minimums but the amount of data required would increase substantially.

Data from the critical time period and critical spatial region were aggregated for each day of the critical period based on the volume of water in each model cell and the daily minimum oxygen level in each cell.

The critical spatial region selected was the entire water column. Compared to the Full Rollback scenario, surface waters under the Base and Full Buildout scenarios typically have higher minimum oxygen levels in surface waters, and in all cases the hypolimnion is anoxic. The critical locations are those depths where dissolved oxygen is dropping towards anoxia. Spatially this begins near the bottom in the spring, rises to the metalimnion in the summer, and drops to the bottom again in the fall. Therefore the mid-level water layers correspond to the dissolved oxygen levels just above anoxia that produce deficits exceeding criteria. When the entire water column is evaluated the areas with deficits fall out in the middle of the cumulative volume curve, so limiting the analysis to less than the full water column is unnecessary.

The volume of the surface cells of the model are defined for a one meter thickness. Internally the model adjusts the top layer to slightly greater than or slightly less than one meter to keep an accurate track of the volume of the lake. The comparisons of the cumulative volume aggregation assume the top layer is the nominal 1 meter thickness. This layer has oxygen levels that quickly reach equilibrium with the atmosphere and so will not have significant variation between scenarios. The complexity in calculating the adjusted volume is not justified

The cumulative volume with less than a specified level of dissolved oxygen was developed for the FRB scenario and used as the natural baseline for evaluation of standards. Results of each alternative scenario were then aggregated into a curve of cumulative volume by dissolved oxygen level, and the difference between the curves compared to the 0.2 mg/L less than natural conditions criterion. Figure 25 illustrates this approach.

The comparison of the cumulative volume of oxygen levels was performed using the following numerical method. The daily minimum dissolved oxygen values from the model output were read into the statistical program R: www.r-project.org/. The data were formatted into a three-dimensional array of model layers, segments, and time periods.

The volumes of the cells for each segment, layer, and day were put into data bins based on the oxygen level. The bin size selected for this analysis was 0.1 mg/L of dissolved oxygen. The total volume in each bin was then divided by the number of days, so that periods of different length could be compared. The bin size of one half of the 0.2 mg/L criterion was selected as suitable to ensure capturing measurable changes.

A sensitivity analysis was conducted for the partial rollback scenarios to determine the effect of bin size. Evaluations at 0.05, 0.02 and 0.01 mg/L bin size were conducted. With a bin size of

0.01 an exceedance was found in four bins representing 0.01 mg/L or less of deficit. As this is much smaller than the 0.2 mg/L allowance this was determined to be not significant.

A curve was developed by plotting the dissolved oxygen level on the x axis and the total volume of water in the bins at or below that dissolved oxygen level on the y-axis. Curves developed for the FRB conditions scenario, the criteria based on FRB conditions, and the other model scenarios can then be used to compare these scenarios.

The cumulative volume curve of a scenario is compared to the FRB cumulative volume curve in the following procedure, illustrated in Figure 25:

- Step 1 – Chose a dissolved oxygen level from the test scenario curve and read the corresponding volume.
- Step 2 – Read across to the right to the same volume for the natural scenario curve and determine the dissolved oxygen level for that point on the natural scenario curve.
- Step 3 – The target for the scenario is the FRB oxygen minus 0.2 mg/L, and this target value becomes the criteria for the given volume of water.
- Step 4 – If the dissolved oxygen level for a given volume of water for the test scenario is less than the criterion for that volume, there is a deficit.
- Step 5 – The total deficit between both curves can be expressed in grams of dissolved oxygen (volume of water multiplied by dissolved oxygen concentration). It is the area to the right of the curve for the scenario being evaluated and to the left of the curve for the criteria wherever there is a deficit.

For a scenario to meet standards, the curve for that scenario must show no deficit compared to the curve for FRB less 0.2 mg/L.

Generally the lowest oxygen levels are found in the deepest water. As phosphorus loading increases with increased development, the oxygen levels increase in much of the lake, especially in the unstratified lake and in surface waters during stratification. This is due to the photosynthetic production of oxygen by algae. It is when the algae settles into the hypolimnion and decays that the deeper water experiences a decline in oxygen levels.

It is important to realize, however, that areas and times of elevated oxygen do not compensate for the oxygen deficits. Oxygen deficits are regulated to prevent several sources of resource damage. Low levels of oxygen make phosphorus in sediments more soluble thus fertilizing the lake. There are organisms in lake sediments that cannot migrate to portions of the lake to avoid low oxygen conditions. In very low oxygen conditions bacteria reduce sulfate to sulfide, and the resulting hydrogen sulfide can be toxic to aquatic life. The bacteria that reduce sulfate also enhance the conversation of mercury from relatively innocuous inorganic mercury to methyl mercury that enters the food web and is concentrated in fish. These processes are site specific and excess oxygen at other locations in the lake does not mitigate the oxygen deficit.

The results of applying this approach are shown in Figures 26 and through 30.

- In Figure 26, the dashed blue line is offset 0.2 mg/L from the aggregation of Full Rollback curve to establish the criteria curve for this TMDL, which is then compared to the distribution for the Base scenario. The volume of water that fails to meet the criteria (the difference between the two lines) is shown in red.

- Similarly, Figure 27 shows the comparison of the Full Buildout scenario to the criteria curve. This graph shows that the dissolved oxygen deficit grows with increasing development and phosphorus loading.
- Figure 28 shows a special case where loading is held constant at the FRB level but hydrology is changed.
- Figure 29 shows a Partial Rollback from Base scenario that meets the criteria, and Figure 30 shows a Partial Rollback from Full Buildout scenario that meets the criteria.

Natural loading and natural hydrology

In all of the scenarios above (Full Rollback, Full Buildout, and Partial Rollback) the only hydrologic changes are those associated with altered land use cover. Several other alterations of lake hydrology were held constant:

- The amount of water diverted from the Middle Fork of the Nooksack to Lake Whatcom;
- The amount of water withdrawn for use by the City of Bellingham, Lake Whatcom Water and Sewer District, and the Washington Department of Fish and Wildlife fish hatchery
- Operation of the lake outlet control structure and flow to Whatcom Creek

To evaluate the cumulative effect of these modifications to the lake's hydrology an additional scenario has been evaluated. The Full Rollback scenario was modified to provide a more natural hydrology. In this scenario, the lake level is controlled by using the spillway feature of the CE-QUAL-W2 model, which provides a fixed elevation at the outlet (a simulation of the natural lake outlet) instead of using the dam at the outlet to control flows to Whatcom Creek. The diversion of Middle Fork Nooksack water into the lake is eliminated as well as withdrawals from the lake for consumptive uses. The results of this analysis are shown in Figure 28.

This scenario is not used to estimate natural conditions for the purpose of determining compliance with standards, but is provided to demonstrate the effects of the hydrologic modifications. The reason that it is not used for standards compliance is that any changes in oxygen from flow modification are not the result of a discharge of a pollutant. Also, the changes in loading associated with the Middle Fork Diversion and consumptive withdrawals are associated with the exercise of water rights that are not regulated by a TMDL.

By using constant hydrologic conditions, the evaluation of allowable pollutant loadings should be less dependent on hydrologic variation. If in the future major hydrologic changes are contemplated we can evaluate natural loading under those hydrologic conditions and compare it to the proposed allocations to ensure that water quality standards will still be met.

Loading capacity

To determine the total phosphorus loading capacity of Lake Whatcom, the human caused phosphorus loads from tributary basins were reduced by reducing the acreage of developed lands. The Base and Full Buildout scenarios were selected as conditions to bracket possible TMDL end points. Development at the time of TMDL implementation will be more widespread than the Base scenario (which represents conditions in 2002-2003). Similarly, major land purchases by the City and County to limit future building in the watershed will prevent the Full Buildout scenario from coming to pass. Therefore, these two scenarios bracket the conditions that will be used for planning implementation of the TMDL. Also, these extremes provide information intended to assist land use managers on the choices to be made.

Partial rollback scenarios were used to determine the Loading Capacity. For each rollback scenario the reduction in human caused pollution was calculated by reducing the level of development by a fixed percentage across the watershed (CDM, 2008). In each case the percentage of acreage was subtracted from the Agriculture, Developed, and Open land use categories in the original Existing or Full Build Out scenario and added to the Mixed Forest category. The Evergreen, Deciduous, and Water/Wetlands acreages were not changed. Several iterations of the model were made to find the percent reduction that most closely met the 0.2 mg/L dissolved oxygen deficit criterion.

These scenarios also provide insight to the sensitivity to the location of pollutant inputs. In general the Base scenario and Partial Rollback from Base will have a higher concentration of development at the northwest end of the lake. And the Full Buildout and Partial Rollback from Full Buildout will have a lower concentration of development at the northwest end of the lake.

In addition to identifying the reduction in phosphorus loading necessary to restore water quality in the Lake, this technical assessment determines the relationship between phosphorus loading and human development in the watershed. The loading capacity of the lake for phosphorus was determined by reducing the acreage of development (returning those acres to pre-development conditions) until phosphorus loads allowed dissolved oxygen criteria to be met.

These reduced acreages will be referred to as *developed acres* in this TMDL, and they represent the acreage that generates total phosphorus loading at 2003 levels. Developed acreage qualifies as a surrogate measure for phosphorus loading to fulfill the requirements of Section 303(d). The watershed can support higher levels of development and still meet water quality standards only if those land uses produce nutrient loading that looks like loading levels from much lower levels of development. In other words those acres have effectively less development because of the use of pollution control strategies keep nutrient loading to low levels.

The results of the Partial Rollback analysis are shown in Figures 29 and 30. As can be seen in the figures, there is no oxygen deficit and the scenarios therefore are in compliance with the standards. These two scenarios indicate that the loading capacity of Lake Whatcom is 7.29 to 7.39 kg/day total phosphorus as an annual average, or between 950 and 1125 developed acres that generate phosphorus loading at 2003 levels, depending on where development occurs and where the developed acres are reduced through nutrient pollution control strategies. This represents a 74% reduction in developed acres from the Base scenario and an 89% reduction in developed acres in the Full Buildout scenario.

An example of how the concept of actual developed acres might be translated into developed acres that generate phosphorus loading at 2003 levels is given in an EPA work plan related to the Lower Charles River nutrient TMDL in Massachusetts (EPA, 2008). In the work plan, pollution control strategies are evaluated for their ability to remove phosphorus based on the design size of the strategy. Figure 31 shows that an strategy to infiltrate a 1.6 inch precipitation event would reduce phosphorus on Type B soils by 90%. If this type of pollution control strategy were in place for a road or a roof only 10% of the actual acres would count as developed acres that generate total phosphorus loading at 2002-03 levels.

Different scenarios have a different distribution of where the loading enters the lake. Under Partial Rollback from Full Buildout, development is spread more widely in the basin. The reductions necessary are slightly higher, but the total developed acres that generate phosphorus loading at 2003 levels are also higher. To a small extent this may occur because development in Basin 3 is farther from the more sensitive Basin 1. A more significant factor may be that more of the developed acres are in the agricultural and open land classes.

Process for determining Load and Wasteload Allocations

As discussed under the Loading Capacity section, this report provides two scenarios, derived from Base and Full Buildout conditions that bracket the ultimate loading capacity and pollutant allocations. This report will not recommend Load or Wasteload Allocations. As part of the process to finalize a TMDL and develop an implementation strategy, Ecology will work with its local partners to determine the scenario that is most feasible to implement and Ecology will determine the final loading capacity and allocations from that process.

In general, Wasteload Allocations are provided to National Pollutant Discharge Elimination System (NPDES) discharges, while Load Allocations are provided to all other pollutant sources within the Loading Capacity. In this TMDL Wasteload Allocations will be provided to address the Phase II Municipal Stormwater Permits for the City of Bellingham and Whatcom County (Table 10) and Construction sites covered by NPDES permits. All other sources of phosphorus loading will be provided Load Allocations.

Table 10. Facilities Which Will Receive Wasteload Allocations.

Permit Number	Facility Name	Permit Type	Wasteload Allocation
WAR04-5550	City of Bellingham	General Permit Storm Water Municipal	Based on point of stormwater discharge
WAR04-5557	Whatcom County	General Permit Storm Water Municipal	Based on point of stormwater discharge

This study does not separate phosphorus loading or, developed acres that generate phosphorus loading at 2003 levels as point sources and non point sources. Stormwater runoff is the primary source of nutrient loading, and falls into both point source and non point source categories separated only by whether or not NPDES permit coverage is required for the discharge. It is assumed that all sources will control stormwater runoff contamination to meet either Wasteload Allocation or Load Allocations.

If the City of Bellingham and Whatcom County provide reasonable assurance that sources that are not part of their Municipal NPDES Stormwater permit will be reduced at the same level as the sources that are part of their permit, both the Wasteload Allocation and the Load Allocation are equal to the percent reduction to meet the loading capacity. Each separately-evaluated discharge is expected to meet its respective allocations.

Therefore it is assumed that the Wasteloads Allocations will be dependant upon reductions in Load Allocations being met, and reasonable assurance must be provided that the reductions necessary to meet the Load Allocations will be made. If reasonable assurance can not be provided that the Load Allocations can be met, the Wasteload Allocations will have to be reduced further.

The main method of controlling pollution discharged under an NPDES permit for a Municipal Separate Storm Sewer System (also called a Municipal Stormwater permit) is through the development and implementation of a Stormwater Management Plan. The Municipal Stormwater permit only regulates discharges from a municipality's stormwater system. Therefore the controls are required only on areas that discharge stormwater into the municipal stormwater system.

However many of the provisions are equally applicable to reducing pollution discharges from non point sources. Program elements such as public education and outreach have essentially the same impact on all stormwater discharges regardless of whether they enter a municipal stormwater system or are discharged directly to a receiving water. Other controls, such as responding to complaints of illicit discharges, are relatively simple to extend from municipal stormwater system discharges to all illicit discharges. The City of Bellingham and Whatcom County, by voluntarily extending their program to cover all areas in their jurisdiction within the watersheds of the affected tributaries, can help provide reasonable assurance that Load Allocations will be met.

Allocations, like loading capacity, will be expressed both in terms of total phosphorus loading and developed acres that generate phosphorus loading at 2003 levels. Table 11 shows the total phosphorus loading for each watershed and from the Middle Fork Nooksack diversion, groundwater inflows, and precipitation for the five scenarios. The loading for the five scenarios are shown by category in Figure 32, and pie charts showing the loading in Table 11 for each scenario are presented in Figures 33-37.

Final Load Allocations will likely look like the Partial Rollback scenarios, following an approach that expresses Load Allocations in terms of developed acres that generate phosphorus loading at 2003 levels and the loading generated by those acres. However, the proportion of loading allocated to each subbasin will depend on the implementation strategy selected and how it will address existing development versus new development. Ecology will determine final allocations and an implementation strategy through consultation with local partners prior to the completion and submittal of the TMDL. That determination will be based on the set of pollution control strategies selected and how they are applied to both existing and future developed acres.

Table 11. Scenarios Showing Developed Acres, Undeveloped (forest and wetland) Acres, and Total Phosphorus Loading by Tributary.

Tributary Name	Full Rollback Scenario		Base Scenario			74% roll back from Base Scenario			Full Buildout Scenario			89% roll back from Full Buildout Scenario		
	forest & wetland acres	2003 TP (kg/yr)	developed acres	forest & wetland acres	2003 TP (kg/yr)	developed acres	forest & wetland acres	2003 TP (kg/yr)	developed acres	forest & wetland acres	2003 TP (kg/yr)	developed acres	forest & wetland acres	2003 TP (kg/yr)
Academy	780.0	36.3	187.4	592.7	117.1	49.1	731.1	51.9	620.7	159.3	215.4	66.9	713.1	49.0
Agate	2135.5	99.6	512.3	1623.5	320.3	134.1	2001.8	142.3	1698.1	437.4	589.2	183.0	1952.5	134.1
Anderson	2591.5	262.0	225.0	2366.5	256.8	58.9	2532.5	237.8	559.6	2032.0	400.3	60.2	2531.4	248.9
Austin	5331.6	300.8	325.7	5005.5	410.4	85.3	5246.2	318.7	1196.4	4135.0	796.8	128.9	5202.6	342.1
South Bay	2426.8	233.8	292.4	2134.4	367.5	76.5	2350.2	270.4	1121.0	1305.9	730.7	120.8	2306.1	289.3
Blodel	82.7	1.3	22.9	59.8	8.9	6.0	76.7	3.3	54.2	28.5	19.3	5.9	76.9	3.2
Blue Canyon	3381.1	373.0	229.8	3151.1	407.8	60.1	3320.8	386.6	389.4	2991.7	463.8	41.9	3339.2	386.3
Brannian	2439.9	232.1	112.5	2327.7	232.9	28.8	2410.7	220.1	174.5	2265.3	253.7	18.7	2421.2	220.0
Cable	111.0	2.1	63.1	47.9	16.5	16.5	94.5	5.9	98.4	12.7	22.2	10.6	100.4	4.3
Carpenter	1149.6	68.2	173.0	976.7	142.7	45.3	1104.4	84.0	766.9	382.9	316.9	82.7	1067.1	90.5
Donovan	61.8	1.2	26.1	35.7	7.7	6.8	55.0	2.9	48.1	13.8	12.8	5.2	56.6	2.4
Eagle Ridge	90.1	4.2	21.6	68.5	13.5	5.7	84.5	6.0	71.6	18.5	24.9	7.7	82.4	5.7
Ecuclid	224.9	6.0	63.8	161.2	18.1	16.7	208.3	9.2	162.0	63.0	34.1	17.4	207.5	9.0
Fir	545.1	58.3	19.3	525.8	64.0	5.0	540.1	59.5	102.1	443.0	91.0	11.0	534.1	61.5
Hillsdale	729.3	13.1	252.2	477.0	133.7	66.1	663.2	44.3	704.6	24.6	256.8	75.9	653.3	39.0
Mill Wheel	583.5	10.3	159.3	424.2	58.8	41.7	541.8	23.0	388.3	195.3	126.3	41.9	541.7	22.8
North Shore	1195.6	72.9	217.8	977.7	163.3	57.1	1138.6	98.9	464.0	731.6	228.7	50.1	1145.5	91.3
Olsen	2423.7	313.3	29.1	2395.1	325.8	7.6	2416.6	316.7	183.7	2240.1	376.1	19.8	2404.0	320.1
Silver Beach Ck	328.2	15.1	79.4	248.9	49.4	20.8	307.5	21.8	262.0	66.2	91.0	28.2	300.0	20.6
Smith	3192.5	227.5	107.0	3085.4	233.1	29.0	3164.5	229.5	170.5	3021.9	235.5	19.6	3174.2	228.9
Strawberry	774.0	33.2	342.4	431.5	141.0	89.7	684.3	60.7	679.2	94.8	258.8	73.1	700.8	56.5
Sudden Valley	605.6	44.0	163.8	441.6	133.3	42.9	562.6	66.1	516.8	88.7	300.8	55.7	549.8	69.9
Total	31183.9	2408	3625.9	27558.6	3622	949.5	30235.7	2659	10432.2	20752.2	5845	1125.1	30060.4	2695
Other Sources														
MFN diversion		293			293			293			293			293
Groundwater		1876			1876			1876			1876			1876
Precipitation		158			158			158			158			158
Total		4735			5949			4986			8172			5022

TP = Total Phosphorus; kg/yr = kilograms per year

Figure 38 shows the modeled phosphorus loading from each tributary subbasin for the Base and Full Buildout Scenario with the proportions that originate from each land use category. The relative development of the drainages tributary to Basin 1, such as Hillsdale and Mill Wheel, can be seen from the high proportion of impervious and pervious developed land uses. This graph also shows the relatively undeveloped state of watersheds like Brannian and Smith, and how total phosphorus loading greatly increases with the development of watersheds like Austin and South Bay. The loading level of the Full Rollback scenario is also indicated on the graph.

Figure 39 shows modeled phosphorus loading by tributary and land use in a different format. In this figure loading has been divided by the FRB loading, so that Brannian and Smith are about at 1.0, since they are relatively undeveloped, and highly developed basins like Cable and Blodel have loading ratios over 6 for the Base scenario and exceeding 10 for Full Buildout. The effect of development on increasing total phosphorus loading over FRB levels is demonstrated vividly by this graph.

Figure 40 shows total phosphorus loading for each tributary subbasin and land use for two Partial Rollback scenarios. For these scenarios the loading is only slightly over FRB loading, representing the 0.2 mg/L allowable dissolved oxygen deficit. Figure 41 shows the same data as ratios to FRB loading. For these scenarios the developed basins may have ratios slightly over 2, but far less than the Base and Full Buildout levels.

Allocation for future growth

This study shows that the discharges in the years 2002-2003 exceeded the loading capacity. Reductions from the loading levels that existed at that time are necessary to meet water quality standards from where we were several years in the past. Therefore allocations for future growth will have to be accommodated by additional reductions in existing sources.

The Full Buildout scenario was designed to evaluate the reductions necessary to accommodate future growth. The growth that has taken place since 2003 places us currently somewhere between the Base and the Full Buildout scenarios. It is up to the city and the county to determine how much effort should go into reducing existing sources of pollution to accommodate future growth.

The answer to the question of how to balance demands for reduction from existing sources with demands to accommodate additional sources can be reached many ways. One option is to identify how much growth needs to be accommodated and how much impact it will have and then determine if a plan can be developed that will achieve the reductions from the existing development. A second option is to determine the reductions in pollutant discharges from existing development that are desired to accommodate growth and then any remaining capacity between desired loading levels and the loading capacity can be allocated to growth.

It is also possible to have a tentative identification of the balance between reductions of existing development and future growth, and then use a process similar to water quality trading to alter that balance in the future. In such a scenario, new development not included in a Load Allocation could be included in the allocation by offsetting their pollution through reductions in existing sources beyond those required in the TMDL. Some reasonable assurance would need to be provided that the reduction in existing sources would more than offset the new source. Working out the rules and allowances involved would be a lengthy process and will not likely be achieved before a TMDL must be submitted. However it does provide some flexibility to adapt to changing priorities in the future.

Margin of safety

The federal Clean Water Act requires that Total Maximum Daily Loads be established with margins of safety (MOS). The MOS accounts for uncertainty in the available data, or the unknown effectiveness of the water quality controls that are put in place. The MOS can be stated explicitly (e.g., a portion of the load capacity is set aside specifically for the MOS). But implicit expressions of the MOS are also allowed such as conservative assumptions in the use of data, application of models, and the effectiveness of proposed management practices.

This TMDL includes an implicit MOS based on conservative assumptions used in determining pollutant loading targets. This includes focusing on protecting the most sensitive portions of the lake (the critical location in the basin) during the water quality analysis. The deepest areas of Basin 1 show the greatest dissolved oxygen deficits. Protection of this area will protect all other parts of the lake. Deficits in Basin 3 have been evaluated, which confirmed that protection for Basin 1 is more than adequate to protect Basin 3.

Due to the complexity of the system analyzed and the models used to develop this TMDL, the focus has been on producing an accurate model, and opportunities for conservative assumption have been limited. An *adaptive implementation* approach is proposed to address uncertainty and contribute to the margin of safety.

The U.S. EPA defines *Adaptive Implementation* as *an iterative implementation process that makes progress toward achieving water quality goals while using any new data and information to reduce uncertainty and adjust implementation activities* (EPA, 2006) The approach was first proposed in a report by the National Research Council (2001), which suggested that adaptive implementation include *immediate actions, an array of possible long-term actions, success monitoring, and experimentation for model refinement.*

This concept describes a process where:

- limitations in information about the pollution problem and effectiveness of implementation are identified,
- monitoring and modeling designed to narrow those data gaps, and then
- implementation modified in response to improved information.

The specific features of adaptive implementation for this TMDL will include the monitoring program discussed below and the implementation strategy that will be included in the TMDL submittal report.

The best available information about the effectiveness of pollutant control practices can be used for establishing implementation to meet surrogate measure targets for developed acreage. The information about effectiveness will need to be refined as implementation occurs. This refinement is expected to provide valuable information about the costs and efficiency of implementation activities over time. Reference information about the effectiveness of storm water pollutant control practices (sometimes called *Best Management Practices*, or *BMPs*) for various pollutants can be found at: www.epa.gov/npdes/urbanbmptool.

Monitoring

An adequate and effective monitoring program is critical to the implementation of the dissolved oxygen TMDL. The issues with Lake Whatcom nutrient loading and dissolved oxygen levels are particularly complex due to the nonpoint nature of the nutrient sources and the complexity of lake hydrodynamics and water quality processes.

On-going monitoring of the lake itself is critical, and the continuation of the existing lake monitoring program should be adequate. A long term record of the water quality parameters collected under the program will help to determine whether dissolved oxygen degradation has been halted and reversed and will allow for future modeling of the lake.

Monitoring of nutrient loading from the watershed is particularly critical for implementation of the TMDL. The monitoring conducted for this study under the Project Plan was based on the information, protocols, and resources available at that time. Analysis of monitoring conducted to date shows that tributary monitoring can be improved. Monthly sampling of single nutrient grabs falls short of the ideal monitoring program to effectively characterize nutrient loading. Periodic grabs should occur at greater frequency, such as biweekly or weekly. Flow-weighted sampling over storm events should supplement the periodic monitoring.

An example of a more intensive tributary monitoring program is the Occoquan Watershed Monitoring Program in Virginia (VDEQ, 2006; OWML, 2003). Similar to Lake Whatcom, a TMDL has been developed for dissolved oxygen impairments in several watershed using an HSPF watershed model linked to a CE-QUAL-W2 reservoir model. Baseflow samples are collected on the tributaries weekly and automated flow-weighted composite stormflow samples are collected during rainfall events.

A third area of monitoring is for the effectiveness of pollutant control practices (BMPs) identified as part of the pollutant control strategies. Specific practices intended to control nutrient loading should be evaluated at the field scale for specific land uses, either at the subwatershed or parcel level.

The final area of monitoring is focused on implementation. Measurable targets need to be developed on how much of a given activity needs to take place over what period of time for effective implementation. So for instance, if retrofit of public roads is selected as an implementation strategy, the surface area addressed with retrofits meeting the applicable standards may be the identified target, which will need to be monitored on some frequency.

Similarly, the amount of developed area added will need to be monitored to ensure that it is not growing faster than the amount of pollution reduction implemented for development.

To integrate these monitoring efforts, a comprehensive watershed and lake monitoring plan is recommended to help identify and prioritize the data needs for an adaptive implementation approach. A comprehensive plan can help improve efficiency and focus among the various entities involved in monitoring, and provide a basis for obtaining funding for monitoring.

Bacteria

Analytical framework

The statistical roll-back method (Ott, 1995) was used to establish fecal coliform bacteria reduction targets for Lake Whatcom tributaries. The roll-back method simply compares monitoring data to standards, and the difference is the percent change needed to meet the standards. This approach has been used in many other TMDLs in Washington and the methodology is well-documented (e.g., Joy and Swanson, 2005; Ahmed and Rountry, 2007).

TMDL bacteria reduction targets do not replace the water quality criteria. They are established as a best estimate of what is necessary to meet the most stringent part of the water quality criteira. Any waterbody with fecal coliform TMDL targets is expected to meet both the applicable geometric mean and 'not more than 10% of the samples' criteria and also to meet beneficial uses for the category.

The distribution of fecal coliform bacteria concentrations measured at a station over time is assumed to follow a log-normal distribution. Thus, log-normal distribution properties can be used to estimate the geometric mean and 90th percentile bacterial concentrations. (The 90th percentile value of samples is used in TMDL evaluations for the "not more than 10% of all samples" criteria statistic.)

The rollback method assumes that the coefficient of variation will remain constant. This means that fractional reductions in the geometric mean will be matched by fractional reductions in the 90th percentile. In large watersheds affected by non point sources this has been show to be a reasonable assumption.

When the estimated geometric mean or 90th percentile value is higher than its criterion, the target reductions are simply estimated by rolling back the estimated geometric mean or 90th percentile concentrations (whichever is most restrictive) to the respective water quality standards. A detailed description of the analytical method is provided in Appendix F.

A Beales ratio estimator formula (Dolan et al., 1981) was used to calculate the annual fecal coliform loads at sites with adequate pollutant and streamflow data (Appendix F). The Beales formula provides a better annual or seasonal estimate of pollutant loads compared to the average instantaneous load obtained from a few sampling events. The average instantaneous load was calculated when continuous discharge data were absent or could not be estimated from nearby gaging data.

Development of allowable loads for fecal coliform bacteria for Lake Whatcom tributaries is based upon an analysis of data collected in 2002 and 2003. Excel® spreadsheets were used to evaluate the data, including statistical analyses and plots. Data for each tributary were evaluated to determine a critical season. Data from the critical season were then evaluated to determine the geometric mean, ninetieth percentile, and percent reduction required to meet standards. Load allocations were then determined using the Beale's estimator.

Definition and determination

USEPA regulations define loading capacity as the greatest amount of pollutant loading that a waterbody can receive without violating water quality standards [40CFR§130.2(f)]. The loading must be expressed as mass-per-time or other appropriate measure. Also, the critical conditions that cause water quality standard violations must be considered when determining the loading capacity.

Washington State fecal coliform bacteria TMDLs use a combination of mass-per-time units and statistical targets to define loading capacities. This is necessary since mass-per-time units (loads) do not adequately define periods of fecal coliform criteria violations. Bacteria sources are quite variable, and different sources can cause water quality violations at different times (e.g., poor dilution of contaminated sources during low-streamflow conditions or increased source loading during run-off events). Loads are instructive for identifying changes in bacteria source intensity between sites along a river, or between seasons at a site.

The statistical targets are referenced in the Washington State fecal coliform criteria and provide a better measure of the loading capacity during the most critical period. The Lake Whatcom tributary fecal coliform loading capacities are the applicable two statistics in the state fecal coliform criteria (e.g., the geometric mean less than 50 cfu/100 ml and no more than 10% of the samples may exceed 100 cfu/100 ml). The fecal coliform TMDL target loading capacities in the Table 12 are the criteria, or they are statistics that estimate the reductions necessary to meet the criteria.

The fecal coliform percentage reduction values in Table 12 indicate the relative degree the waterbody is out of compliance with criteria (i.e., how far it is over its capacity to receive fecal coliform source loads and still provide the designated beneficial uses). Sites that require aggressive reductions in fecal coliform sources will have a high percentage reduction value, while sites with minor problems will have a low percentage reduction value.

Since the loading capacity and statistical values are based on the critical condition, Table 12 includes the critical period to provide water quality managers with a sense of when bacteria sources are creating criteria violations. If there is no critical period, then no seasonal changes were noted and data from the entire year were used. Stormwater events were not specifically monitored, but stormwater is assumed to have potential fecal coliform loads at any time of the year.

Table 12. Lake Whatcom Tributaries Fecal Coliform Load Allocations.

Tributary	Critical Season	Geometric Mean Target (cfu/ 100 mL)	10 % Target (cfu/ 100 mL)	Load Allocation (cfu/ day)	Current Load (cfu/ day)	Target Reduction (%)	Listing Status
Anderson Creek	Apr-Nov	10	100	1.0E+10	3.3E+10	70%	Fails to meet standards
Austin Creek	Apr-Dec	18	100	8.6E+09	4.9E+10	82%	Draft 2008 303(d) list
Brannian Creek	May-Sep	31	100	9.5E+08	1.7E+09	43%	Draft 2008 303(d) list
Cable Street Drain	Jun-Dec	4	100	NA	NA	95%	Draft 2008 303(d) list
Carpenter Creek	May-Jan	30	100	8.8E+08	2.5E+09	65%	Draft 2008 303(d) list
Euclid Creek	Annual	15	100	7.9E+08	2.6E+09	70%	Draft 2008 303(d) list
Mill Wheel Creek	Annual	31	100	6.8E+08	4.9E+09	86%	Draft 2008 303(d) list
Olsen Creek	May-Nov	21	100	1.5E+10	3.4E+10	57%	Draft 2008 303(d) list
Park Place Drain	Annual	21	100	NA	NA	92%	Fails to meet standards
Silver Beach Creek	Annual	15	100	6.5E+08	1.4E+10	95%	2006 303(d) list
Smith Creek	May-Sep	46	100	1.9E+09	2.5E+09	26%	Fails to meet standards

Loading capacity

Nine creeks and two storm drains were evaluated for the TMDL. All tributaries were found to not meet fecal Coliform bacteria standards. Only Silver Beach Creek was listed on the 2006 303(d) list, but seven other tributaries are proposed to be included on the 2008303(d) list. Table 12 shows the critical season for each tributary and the calculated geometric mean and 90th percentile target. For all tributaries the 90th percentile target was the limiting criterion, and therefore the geometric mean targets are all below the criterion in the standards.

Load and wasteload allocations

This TMDL technical evaluation of the Lake Whatcom tributaries demonstrated that extraordinary primary contact recreation was not supported in all the tributaries that were investigated and that fecal coliform load reductions are necessary. The fecal coliform allocations may be expressed as loads, concentrations, or other appropriate measures [40 CFR 130.2(I)]. Fecal coliform TMDL target reductions are expressed as both concentrations and loads in this report. Washington State uses concentrations of fecal coliform as the most appropriate measure of meeting allocations because fecal coliform can be directly compared to the water quality standards under all streamflow scenarios. Fecal coliform loads (as cfu/day) are used as a relative measure of pollutant flux between river reaches or from tributary and point source inputs.

Table 12 shows the total allocations recommended for each tributary and the target percent reductions needed to meet standards.

The study did not separate point sources and non point sources of bacteria. Stormwater runoff is the primary source of contamination, and falls into both point source and non point source categories separated only by whether or not NPDES permit coverage is required for the discharge. It is assumed that all sources will control stormwater runoff contamination to meet either Wasteload or Load Allocations. All allocations are equal to the percent reduction to meet the loading capacity. Each separately evaluated discharge is expected to meet the criteria.

Therefore it is assumed that the Wasteloads Allocations are dependant upon reductions identified in Load Allocations being met, and reasonable assurance must be provided that the reductions necessary to meet the Load Allocations will be made.

In this case the point sources will be the City of Bellingham and Whatcom County, as part of their Phase II Municipal Stormwater Permit. The central means of controlling pollution discharged under the permit is the development and implementation of a Stormwater Management Plan. The Municipal Stormwater permit only regulates discharges from a municipality's stormwater system. Therefore the controls only are required on areas that discharge stormwater into the municipal stormwater system.

However many of the provisions are equally applicable to reducing pollution discharges from nonpoint sources. Program elements such as public education and outreach have essentially the same impact on all stormwater discharges regardless of whether they enter a municipal stormwater system or are discharged directly to a receiving water. Others such as responding to complaints of illicit discharges are relatively simple to extend from discharges to a municipal stormwater system to all illicit discharges.

The City of Bellingham and Whatcom County, by voluntarily extending their program to cover all areas in their jurisdiction within the watersheds of the affected tributaries, will provide reasonable assurance that Load Allocations are met.

All dischargers covered by NPDES permits that fall under the Wasteload Allocations must meet the required reductions at the mouth of each tributary that includes their discharge. The municipal stormwater dischargers (Table 6) will have Wasteload Allocations based on the stormwater discharge point. For NPDES permits such as those for stormwater associated with construction activity, not all permits that may need a Wasteload Allocation in the future can be identified. Any NPDES permit that addresses runoff contributing to a Load Allocation will be allocated a Wasteload Allocation equivalent to the Load Allocation it replaced.

Both the Wasteload Allocations and Load allocations expressed as a percent reductions will be the same for each tributary. The allocations are based on the density of bacteria in stormwater runoff. If an area of land is converted to a use that requires coverage under an NPDES discharge permit, the associated Load Allocation is retired and an equivalent Wasteload Allocation is available to the discharger. The geometric mean will be used to measure progress towards attaining the allocated percent reduction.

Allocation for future growth

Since all tributaries fail to meet standards, no allocation for future growth is provided. Additional sources would only be accommodated through additional reductions in existing sources.

Margin of safety

The federal Clean Water Act requires that Total Maximum Daily Loads be established with margins of safety (MOS). The MOS account for uncertainty in the available data, or the unknown effectiveness of the water quality controls that are put in place. The MOS can be stated explicitly (e.g., a portion of the load capacity is set aside specifically for the MOS). But implicit expressions of the MOS are also allowed such as conservative assumptions in the use of data, application of models, and the effectiveness of proposed management practices.

Implicit MOS elements were applied to analyses to provide a large MOS for the Lake Whatcom tributaries fecal coliform TMDL evaluation. The fecal coliform database in most areas of the basin was limited, so this increased the level of uncertainty in the fecal coliform loads and receiving water quality. The fecal coliform reductions and allocations are conservatively set to protect human health and beneficial uses to the fullest extent. The following are conservative assumptions that contribute to the MOS:

- The statistical rollback method was applied to fecal coliform data from the most critical season, and the resultant TMDL target for annual fecal coliform load reductions are more stringent than would be required under the listed Washington State *Extraordinary Primary Contact* fecal coliform criteria (i.e., the geometric mean of 50 and no more than 10% of samples to exceed 100 cfu/100 ml.).
- Since the variability in fecal coliform concentrations during low-flow conditions is usually quite high, the TMDL targets and percent reduction estimated by the statistical rollback method are conservative, especially if a 90th percentile is the critical criterion.

Monitoring

Two kinds of monitoring are recommended as part of bacterial TMDL implementation:

- Monitoring of the effectiveness of specific pollutant control practices (sometimes called *Best Management Practices*) will help assess which control measures are working the best.
- Long-term monitoring of tributaries listed in Table 12 will assess whether the TMDL implementation has been effective at reducing bacteria levels and meeting standards.

Bacteria monitoring should focus on the critical seasons identified in Table 12.

Conclusions

Dissolved oxygen and total phosphorus

- Lake Whatcom is a highly complex system in which dissolved oxygen levels decrease as nutrient loads increase over time.
- Modeling of pre-development watershed conditions provides a baseline for watershed phosphorus loading and lake dissolved oxygen for evaluation of compliance with the standards.
- Modeling of Lake Whatcom with CE-QUAL-W2 and its watershed with HSPF shows that full development of the watershed will cause increased phosphorus loading to the lake, which in turn will degrade oxygen in the lake.
- The lake's loading capacity for phosphorus was determined and correlated to reductions in developed acreage from the 2003 Base condition and from the Full Buildout condition. The loading capacity was found to be 7.29 and 7.39 kg/day (annual average) of Phosphorus when reduced from Base or from Full Buildout, respectively, which represents 950 and 1125 acres of developed land that generate total phosphorus loading at 2003 levels, or a 74% reduction of developed acres from Base and 89% reduction of developed acres from Full Buildout.

Bacteria

- Eleven streams and drains tributary to Lake Whatcom were found to not meet standards for fecal coliform bacterial contamination during monitoring surveys for this TMDL.
- The statistical roll-back method has identified geometric mean bacteria targets that ranged from 4 to 46 cfu/ 100 mL, corresponding to meeting the 90th percentile exceedance criterion of 100 cfu/100 mL.
- A Beales ratio estimator formula was used to calculate annual fecal coliform loads for allocations based on bacteria loading.
- Bacteria reduction targets ranged from 26% to 95% reduction from 2003 levels for the eleven tributaries.

Recommendations

Dissolved oxygen and total phosphorus

- Pollutant allocations are recommended for total phosphorus as shown in Table 7, and for SURROGATE ACREAGE as shown in Tables 10 and 11.
- Final allocations and an implementation strategy should be developed collaboratively with local governments and citizens.
- A basin-wide monitoring strategy should be developed to aid in adaptive implementation of the dissolved oxygen TMDL. The strategy should address monitoring of the lake, tributaries, nutrient delivery from land uses, and the effectiveness of pollution control strategies and practices.

Bacteria

- Pollutant allocations are recommended for fecal coliform bacteria as shown in Table 12.
- An implementation strategy should be developed collaboratively with local governments and citizens.
- NPDES permittees should agree to voluntarily extend relevant portions of their stormwater management plan to control non point sources of bacteria to ensure more stringent limits are not needed on the NPDES regulated sources.
- A effectiveness monitoring program should be developed to assess implementation of the bacteria TMDL.

References

Ahmed, A. and D. Rountry, 2007. Willapa River Fecal Coliform Bacteria Total Maximum Daily Load. Washington State Department of Ecology, Olympia, WA. Publication No. 07-03-021. www.ecy.wa.gov/biblio/0703021.html

Albertson, S.L., K. Erickson, J.A. Newton, G. Pelletier, R.A. Reynolds, and M.L. Roberts, 2002. South Puget Sound Water Quality Study, Phase 1. Washington State Department of Ecology, Olympia, WA. Publication No. 02-03-021. www.ecy.wa.gov/biblio/0203021.html

Aubertin, G.M., Bigelow, D.S., Malo, B.A., eds., 1991. Quality Assurance Plan: NADP/NTN Deposition Monitoring. National Atmospheric Deposition Program Office at the Illinois State Water Survey. Champaign, IL.

Berger, C.J. and S.A. Wells, 2005. Lake Whatcom Water Quality Model. Technical Report EWR-03-05, Maseeh College of Engineering and Computer Science, Department of Civil and Environmental Engineering, Portland State University, Portland, OR.

Berger, C.J. and S.A. Wells, 2007a. Lake Whatcom Model calibration with variable stoichiometry in sediments – REVISED, Memorandum to Paul Pickett and Steve Hood. February 8, 2007. Maseeh College of Engineering and Computer Science, Department of Civil and Environmental Engineering, Portland State University, Portland, OR.

Berger, C.J. and S.A. Wells, 2007b. Lake Whatcom Model recalibration, Memorandum to Paul Pickett, Steve Hood, and Karol Erickson. November 16, 2007. Maseeh College of Engineering and Computer Science, Department of Civil and Environmental Engineering, Portland State University, Portland, OR.

Berger, C.J., 2008. Personal communication. Senior Research Associate, Water Quality Research Group, Department of Civil and Environmental Engineering, Portland State University, Portland, OR.

Buroker, T., 2007. Personal communications. Water Resources Environmental Specialist, Washington State Department of Ecology, Bellingham, WA.

Cadmus and CDM, 2007a. Final Model Report for Lake Whatcom Watershed TMDL Model Project. The Cadmus Group, Inc. & CDM, Bellevue, WA.

Cadmus and CDM, 2007b. Amendment to Lake Whatcom TMDL Final Model Report - Full Buildout/Rollback Scenarios and Translator. Memorandum from The Cadmus Group, Inc. & CDM, November 30, 2007.

CDM, 2008. Final Report for Lake Whatcom Watershed TMDL Model Partial Rollback Scenarios. CDM, Bellevue, WA.

COB, 2007. Personal communication. Geoff Smyth, Operations Supervisor, City of Bellingham, Bellingham, WA.

Cohn, T.A., D.L. Caulder, E.J. Gilroy, L.D. Zynjuk, and R.M. Summers, 1992. The validity of a simple statistical model for estimating fluvial constituent loads . an empirical study involving nutrient loads entering Chesapeake Bay. Water Resources Research, v. 28, no. 9, p. 2353-2363.

Cook, D., 2005. Personal communication. Dave Cook, LG, Associate, GeoEngineers Inc, Seattle, WA.

Cusimano, R.F., S. Hood, and J. Liu, 2002. Quality Assurance Project Plan – Lake Whatcom TMDL Study. Washington State Department of Ecology, Olympia, WA. Publication No. 02-03-074. www.ecy.wa.gov/biblio/0203074.html

Delahunt, R., 1990. Lake Whatcom Watershed On-Site Sewage Disposal Survey. Final Report. Whatcom County Health Department Office of Environmental Health.

Dolan, D.M., A.K. Yui, and R.D. Geist, 1981. Evaluation of river load estimation methods for total phosphorus. J. Great Lakes Research, 7(3): 207-214.

EPA, 1998. Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program. Publication EPA 100-R-98-06, U.S. Environmental Protection Agency, Office of the Administrator, Washington, DC. www.epa.gov/owow/tmdl/faca/facaall.pdf

EPA, 2001. Overview of Current Total Maximum Daily Load - TMDL - Program and Regulations. U.S. Environmental Protection Agency. www.epa.gov/owow/tmdl/overviewfs.html

EPA, 2006. Clarification Regarding "Phased" Total Maximum Daily Loads, Memorandum to Water Division Directors, Regions I – X, from Benita Best-Wong, Director, Assessment and Watershed Protection Division, U.S. Environmental Protection Agency, Washington, D.C., August 2, 2006. www.epa.gov/owow/tmdl/tmdl_clarification_letter.html

EPA, 2008. Contract NO. EP-C-05-046, Work Assignment No. 1-52. Region I, U.S. Environmental Protection Agency, Boston, MA, April 2007.

Hisch Consulting Services, 1998. Lake Whatcom Watershed-Cooperative Drinking Water Protection/Sampling. Narrative Description and Quality Assurance Plan. Prepared for the Washington State Department of Ecology.

Joy, J. and T. Swanson, 2005. Walla Walla River Basin Fecal Coliform Bacteria Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 05-03-041. www.ecy.wa.gov/biblio/0503041.html

Lehmann, Christopher M.B. and Van C. Bowersox, 2003. National Atmospheric Deposition Program Quality Management Plan. National Atmospheric Deposition Program Office at the Illinois State Water Survey. NADP QA Plan 2003-01. Champaign, IL. http://nadp.sws.uiuc.edu/lib/qaplans/NADP-QMP-Dec2003.pdf

Lighthart B., G.F. Kraft, and C.J. Charles, 1972. The Limnology of Lake Whatcom, Washington. Morphometry. Institute for Freshwater Studies. Technical Report No. 15.

Lombard, S. and C. Kirchmer, 2004. Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-030. www.ecy.wa.gov/biblio/0403030.html.

Matthews, R.A. and G.B. Matthews, 1994. Lake Whatcom Monitoring Project 1992-1993. Final Report. Final Report Prepared for the City of Bellingham Public Works Department. 1994. Bellingham, Washington.

Matthews, R.A. and G.B. Matthews, 1995. Lake Whatcom Monitoring Project 1993-1994 Final Report. Final Report Prepared for the City of Bellingham Public Works Department. 1995. Bellingham, Washington.

Matthews, R.A., M. Hilles, and G.B. Matthews, 1997. Lake Whatcom Monitoring Project 1995-1996 Final Report. Final Report Prepared for the City of Bellingham Public Works Department. April, 1997. Bellingham, Washington.

Matthews, R.A., M. Hilles, and G.B. Matthews, 1998. Lake Whatcom Monitoring Project 1996-1997 Final Report. Final Report Prepared for the City of Bellingham Public Works Department. February, 1999. Bellingham, Washington.

Matthews, R.A., M. Hilles, and G.B. Matthews, 1999. Lake Whatcom Monitoring Project 1997/98 Final Report. Final Report Prepared for the City of Bellingham Public Works Department. April, 1999. Bellingham, Washington.

Matthews, R.A., M. Hilles, and G.B. Matthews, 2000. Lake Whatcom Monitoring Project 1998/99 Final Report. Final Report Prepared for the City of Bellingham Public Works Department. April, 2000. Bellingham, Washington.

Matthews, R.A., M. Hilles, and G. Pelletier, 2002. Determining trophic state in Lake Whatcom,Washington (USA), a soft water lake exhibiting seasonal nitrogen limitation. *Hydrobiologia* **468:** 107–121, 2002.

Matthews, R.A., M. Hilles, J. Vandersypen, R.J. Mitchell, and G.B. Matthews, 2001. Lake Whatcom Monitoring Project 1999/2000 Final Report. Final Report Prepared for the City of Bellingham Public Works Department. March, 2001. Bellingham, Washington.

Matthews, R.A., M. Hilles, J. Vandersypen, R.J. Mitchell, and G.B. Matthews, 2002. Lake Whatcom Monitoring Project 2000/2001 Final Report. Final Report Prepared for the City of Bellingham Public Works Department. March, 2002. Bellingham, Washington.

Matthews, R.A., M. Hilles, J. Vandersypen, R.J. Mitchell, and G.B. Matthews, 2003. Lake Whatcom Monitoring Project 2001/2002 Final Report. Final Report Prepared for the City of Bellingham Public Works Department. April, 2003. Bellingham, Washington.

Matthews, R.A., M. Hilles, J. Vandersypen, R.J. Mitchell, and G.B. Matthews, 2004. Lake Whatcom Monitoring Project 2002/2003 Final Report. Final Report Prepared for the City of Bellingham Public Works Department. April, 2004. Bellingham, Washington.

Matthews, R.A., M. Hilles, J. Vandersypen, R.J. Mitchell, and G.B. Matthews, 2005. Lake Whatcom Monitoring Project 2003/2004 Final Report. Final Report Prepared for the City of Bellingham Public Works Department. March, 2005. Bellingham, Washington.

Matthews, R.A., M. Hilles, J. Vandersypen, R.J. Mitchell, and G.B. Matthews, 2006. Lake Whatcom Monitoring Project 2004/2005 Final Report. Final Report Prepared for the City of Bellingham Public Works Department. March, 2006. Bellingham, Washington.

Matthews, R.A., M. Hilles, J. Vandersypen, R.J. Mitchell, and G.B. Matthews, 2007. Lake Whatcom Monitoring Project 2005/2006 Final Report. Final Report Prepared for the City of Bellingham Public Works Department. April, 2007. Bellingham, Washington.

MEL, 2005. Manchester Environmental Laboratory Lab Users Manual, Eight Edition. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

MEL, 2006. Manchester Environmental Laboratory Quality Assurance Manual. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

NADP, 2005. http://nadp.sws.uiuc.edu/. National Atmospheric Deposition Program (NRSP-3), Champaign, IL.

National Research Council, 2001. Assessing the TMDL Approach to Water Quality Management. National Academy Press. Washington, DC. www.nap.edu/catalog.php?record_id=10146

Norton, D., 2004. Mercury in Lake Whatcom Sediments Spatial Distribution, Depositional History, and Tributary Inputs. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-019. www.ecy.wa.gov/biblio/0403019.html

OWML, 2003. Occaquan Watershed Monitoring Laboratory website, www.owml.vt.edu/. Department of Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, Manassas, VA.

Ott, W., 1995. Environmental Statistics and Data Analysis. Lewis Publishers, New York, NY.

Pickett, P.J., 1996. Lower Skagit Total Maximum Daily Load Data Summary. Washington State Department of Ecology, Olympia, WA. Publication No. 96-345. www.ecy.wa.gov/biblio/96345.html

Pitz, C., 2005. Lake Whatcom Total Maximum Daily Load Groundwater Study. Washington State Department of Ecology, Olympia, WA. Publication No. 05-03-001. www.ecy.wa.gov/biblio/0503001.html

Rothert, J., 2003. Quality Assurance Report: National Atmospheric Deposition Program, 2001. NADP QA Report 2003-01. Illinois State Water Survey, Champaign, IL http://nadp.sws.uiuc.edu/lib/qa/qa2001.pdf

URS Corporation, 1985. Draft Lake Whatcom Water Quality Protection Study. Whatcom County, Washington: Volume 1, Technical Report and Volume 2, Management Plan.

VDEQ, 2006. Aquatic Life Impairment in the Occoquan Reservoir, Slide presentation for public meeting, www.deq.state.va.us/export/sites/default/tmdl/pptpdf/occop1o1.pdf. Virginia Department of Environmental Quality, Chantilly, VA.

Wendling, P., 2002. Scope of Work for 2002 Lake Whatcom Tributary Data Collection Effort. City of Bellingham, Bellingham, WA.

Wendling, P., 2005. Data Quality Summary of Lake Whatcom Tributary Pre-TMDL Monitoring 2002. City of Bellingham, Bellingham, WA.

Zar, J.H., 1984. Biostatistical Analysis. Second Edition. Prentice Hall Publishers, Englewood Cliffs, NJ.