



DEPARTMENT OF
ECOLOGY
State of Washington

Quality Assurance Project Plan

Puget Sound Dissolved Oxygen Modeling Study: Large-scale Model Development

January 2009

Publication No. 09-03-103

Publication Information

This plan is available on the Department of Ecology's website at www.ecy.wa.gov/biblio/0903103.html.

Ecology's Project Tracker Code for this study is 09-503-01.

Waterbody Numbers: WA-PS-010 through WA-PS-0300 (entire Puget Sound estuary system).

Author and Contact Information

Brandon Sackmann
P.O. Box 47600
Environmental Assessment Program
Washington State Department of Ecology
Olympia, WA 98504-7710

For more information contact: Carol Norsen, Communications Consultant
Phone: 360-407-7486

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

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

Any use of product or firm names in this publication is for descriptive purposes only and does not imply endorsement by the author or the Department of Ecology.

*If you need this publication in an alternate format, call Carol Norsen at 360-407-7486.
Persons with hearing loss can call 711 for Washington Relay Service.
Persons with a speech disability can call 877- 833-6341.*

Quality Assurance Project Plan

**Puget Sound Dissolved Oxygen
Modeling Study:
Large-scale Model Development**

January 2009

Approved by:

Signature:	Date: January 2009
<hr/>	
Brandon Sackmann, Principal Investigator and Author, EAP	

Signature:	Date: January 2009
<hr/>	
Mindy Roberts, Project Manager, EAP	

Signature:	Date: January 2009
<hr/>	
Karol Erickson, Unit Supervisor for Project Manager, EAP	

Signature:	Date: January 2009
<hr/>	
Will Kendra, Section Manager for Project Manager, EAP	

Signature:	Date: January 2009
<hr/>	
Robert F. Cusimano, Section Manager for Project Study Area, EAP	

Signature:	Date: January 2009
<hr/>	
Andrew Kolosseus, EAP Client, Water Quality Program	

Signature:	Date: January 2009
<hr/>	
Bill Kammin, Ecology Quality Assurance Officer	

Signatures are not available on the Internet version.
EAP – Environmental Assessment Program

Table of Contents

	<u>Page</u>
Abstract.....	5
Background and Project Overview.....	6
Nutrient Pollution and Eutrophication.....	6
Eutrophication in Puget Sound.....	6
Project Description.....	7
Project Goals and Objectives.....	10
Organization and Schedule.....	11
Conceptual Model.....	13
Geographic and Temporal Extent.....	13
Model Components.....	13
Runtime Considerations.....	15
Data Sources for Model Development.....	16
Acceptance Criteria.....	16
Data Set Descriptions.....	16
Model Setup and Nutrient Loading Estimation.....	19
Initial and Boundary Conditions.....	19
Nutrient Sources.....	19
Data Requirements.....	19
Estimation Methods.....	20
Model Calibration and Evaluation.....	22
Methods Overview.....	22
Targets and Goals.....	23
Data Use Preferences.....	23
Sensitivity and Uncertainty Analyses.....	24
Evaluation of Model Scenarios.....	25
Model Output Quality (Usability) Assessment.....	26
Project Deliverables and Schedule.....	26
References.....	27
Appendices.....	30
Appendix A. Glossary and Acronyms.....	31
Appendix B. Descriptions of Available Data Sources.....	33

Abstract

The Washington State Department of Ecology (Ecology) is developing a large-scale computer model for the entire Puget Sound estuary system to further our understanding of processes that affect dissolved oxygen (DO). The hydrodynamic and water quality components will be built using existing tools in the form of the Babson/Kawase/MacCready Puget Sound box model as modified by Ecology (BKM-ECY) and the Environmental Protection Agency's Water Quality Analysis Simulation Program (WASP7), respectively.

The calibrated model will evaluate water quality conditions observed in Puget Sound from 1999 – 2008 and simulate the effects of alternative nutrient-loading scenarios. This project is part of a larger effort to determine (1) if current nitrogen loadings from point and nonpoint sources into Puget Sound are significantly impacting water quality at a large scale and (2) what level of nutrient reductions are necessary to reduce or eliminate human impacts to DO levels in sensitive areas.

The BKM-ECY box model conceptualizes Puget Sound as a series of 10 subbasins, each with a single surface and deep layer allowing for estuarine circulation. While the spatial resolution of this model is coarse, it will be computationally efficient and allow for rapid evaluation of multiple nutrient-loading scenarios. The large-scale model will be used as a screening-level tool to support an intermediate-scale modeling effort being conducted in tandem with this project, and as a community tool for other purposes. The intermediate-scale model will have much finer spatial resolution and an expanded geographic domain. However, much of the freshwater and nutrient-loading information will be used by both modeling efforts.

Each study conducted by Ecology must have an approved Quality Assurance Project Plan. The plan describes the objectives of the study and the procedures to be followed to achieve those objectives. After completion of the study, a final report describing the study results will be posted to the Internet.

Background and Project Overview

Nutrient Pollution and Eutrophication

Nutrient (e.g., nitrogen) pollution is considered one of the largest threats to Puget Sound (Figure 1). Recognized nation-wide, the following characteristics of nitrogen pollution apply equally and imperatively to Puget Sound (Glibert et al., 2005; Howarth, 2006; Howarth and Marino, 2006):

- Human acceleration of the nitrogen cycle over the past 40 years is far more rapid than almost any other aspect of global change.
- Nutrient pollution leads to hypoxia and anoxia, degradation of habitat quality, loss of biotic diversity, and increased harmful algal blooms.
- Technical solutions exist and should be implemented, but further scientific work can best target problems and solutions, leading to more cost-effective solutions.

While eutrophication can be a natural process, anthropogenic nutrient pollution can cause *cultural eutrophication* which is the process of enhanced eutrophication resulting from human activity. Both natural and cultural eutrophication occur when a body of water becomes enriched with nutrients which, in turn, stimulate excessive algal growth. Oxygen consumption results from the subsequent decomposition and respiration of the excess algae by bacteria. This leads to dissolved oxygen (DO) depletion in areas that are not well ventilated (e.g., quiescent bays and near-bottom waters).

Nutrient inputs from oceanic sources, tributary inflows, point source discharges, nonpoint source inputs, sediment-water exchange, and atmospheric deposition determine the nutrient loads to Puget Sound. Hydrodynamic characteristics, such as tides, stratification, mixing, and freshwater inflows, govern transport of nutrients and other parameters. Photosynthetic rates are influenced by light and nutrient availability, temperature, and algal species assemblages. These rates and other processes (growth, death, respiration, settling, and bacterial decomposition) determine nutrient transformations and the degree of DO depletion.

Eutrophication in Puget Sound

In general, large-scale eutrophication in Puget Sound has been thought to be unlikely for two reasons:

1. Puget Sound receives relatively high concentrations of nutrients from the Pacific Ocean so incremental nutrient additions were thought to do little to influence overall phytoplankton productivity.
2. Estuarine circulation and tidal mixing throughout much of Puget Sound ensures a rapid exchange of water (approximately 1 year turnover time). Vertical mixing, especially in Central Puget Sound, further limits exposure of phytoplankton to light and therefore reduces algal growth and biomass accumulation (Mackas and Harrison, 1997).

These characteristics of Central Puget Sound were responsible for the successful diversion of sewage from Lake Washington to West Point (Puget Sound) in the late 1950s (Edmondson, 1991). While nutrient loading to Lake Washington caused excessive algal growth in the lake, the same loading at West Point did not appear to enhance algal growth in marine waters. Much of the current understanding of Puget Sound phytoplankton dynamics has been based on modeling and measurements of ambient productivity and nutrients at West Point (Winter et al., 1975).

In contrast, a more recent study by Newton and Van Voorhis (2002) observed substantial increases in algal primary production when water samples from Central Puget Sound and Possession Sound were artificially enriched with nutrients. Nutrient-enhanced production was observed at all stations, but the degree of enhancement varied both spatially and temporally. This suggests that the system is more complex and that there are likely to be a diversity of responses to nutrient addition. These responses are expected to manifest differently at different times and locations within greater Puget Sound.

Mackas and Harrison (1997) evaluated the issue of eutrophication in the Strait of Juan de Fuca, Georgia Strait, and Puget Sound. They judged potential impacts from eutrophication of Central Puget Sound to be relatively low. However, they reported that the most sensitive sub-regions are likely to be small tributary inlets and fjords that have low flushing rates and that adjoin urbanized shorelines. They speculated that the “early warning signs of eutrophication” were already becoming evident in these areas. At present, most of these areas lie along the south and west margins of Puget Sound.

Bricker et al. (1999) later reported the overall level of expression of eutrophic conditions to be moderate in Central Puget Sound and Whidbey Basin and high in Hood Canal and South Puget Sound. They predicted conditions to worsen, especially in Hood Canal and South Puget Sound, due to increasing population pressures. In response to the increasing threat of nutrient-stimulated eutrophication in Puget Sound, Ecology has both initiated and been actively involved with the continuation of focused water quality studies in these areas (Roberts et al., 2009; Albertson et al., 2007; Roberts et al., 2005; Albertson et al., 2002).

Project Description

This project capitalizes on what has been learned in these prior studies and seeks to expand this foundation to develop a unified water quality model applicable to the entire Puget Sound estuary system. As part of mandates under the Clean Water Act to manage pollutant loading to meet water quality standards, EPA, Pacific Northwest National Laboratory (PNNL), and Ecology have jointly initiated this water quality model development project to address the following nutrient-management questions.

- Are human sources of nutrients in and around Puget Sound significantly impacting water quality?
- How much do we need to reduce human sources of nutrients to protect water quality in Puget Sound?

This document describes the development of the large-scale screening model of Puget Sound. A complementary Quality Assurance (QA) Project Plan will detail the intermediate-scale model development (Sackmann, 2009).

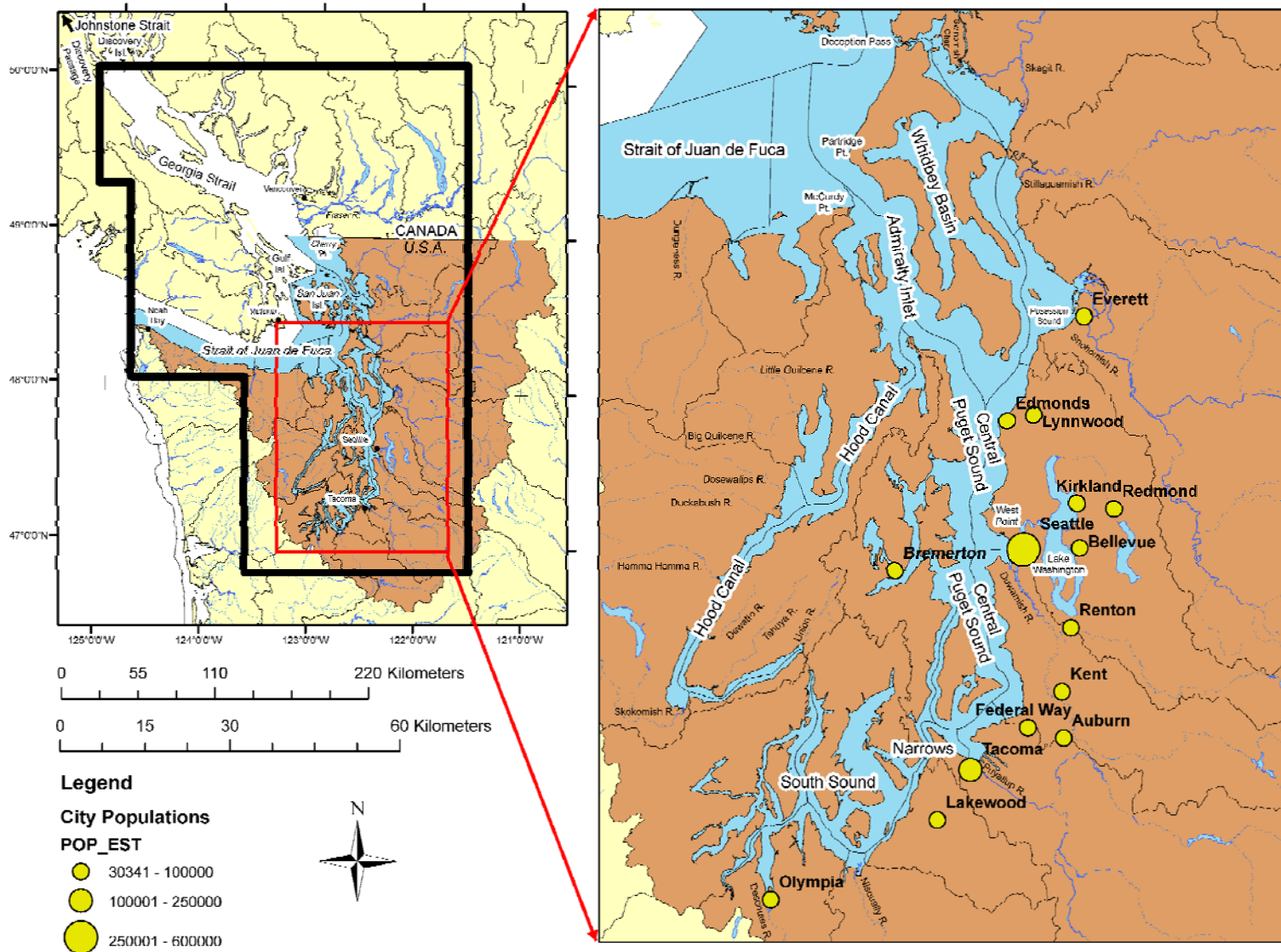


Figure 1. Map of western Washington and lower British Columbia, Canada. Shaded region defines the Puget Sound Action Area. Thick black lines outline the domain of the intermediate-scale model. Red lines outline Puget Sound and the domain of the large-scale screening model. Major rivers are labeled, but the models will include others. Only major Canadian rivers in watersheds that share a border with the U.S. are shown.

Project Goals and Objectives

Mechanistic models provide the quantitative framework necessary to integrate the diverse physical, chemical, and biological information that constitute complex environmental systems and provide a vehicle for an enhanced understanding of how the environment works as a unit (Chapra, 1997). In this study the water quality models to be developed will identify and assess factors and processes that influence water quality in Puget Sound on a significant scale.

The overall goal of this project by Ecology is to work collaboratively with EPA, PNNL, and a Project Advisory Committee (PAC) to conduct DO modeling in Puget Sound in a manner that complements and supports concurrent management initiatives. This project consists of the following components:

- Two multi-purpose hydrodynamic models for the entire Puget Sound, one at a large scale (based on Babson et al., 2006) and one at an intermediate scale. These models can also serve as community tools for other purposes.
- The large-scale model (also called “box model”) to be used as a screening-level tool for the evaluation of nutrient effects on DO, Puget-Sound-wide. The results of this effort will provide quantitative insights that will guide the development of the intermediate-scale model.
- The intermediate-scale model (also called the “intermediate-grid model”) to evaluate the effect of human-caused nutrient enrichment on DO across Puget Sound. This model will help define potential Puget-Sound-wide management strategies and decisions and would support site-specific detailed work that may be completed beyond this project.
- A QA Project Plan for a detailed site-specific analysis for one Puget Sound basin (e.g., Whidbey basin) to determine the nutrient-loading reductions needed to meet water quality standards.

The scope and focus of this QA Project Plan is limited to the development of the large-scale box model (i.e., items 1-2 above) only. The development strategy for the intermediate-grid model will be described in a separate QA Project Plan (Sackmann, 2009). Objectives specific to this project are as follows:

- Develop a large-scale water quality model, calibrated to conditions observed in Puget Sound from 1999 – 2008.
- Estimate effects of nutrient loading on DO.
- Evaluate sensitivity of the model to various input parameters and boundary conditions.
- Based on study findings, make recommendations for the intermediate-scale modeling effort.

Organization and Schedule

The following individuals are involved in this project (Table 1). Except as noted, all are employees of the Washington State Department of Ecology, Environmental Assessment Program.

Table 1. Organization of project staff and responsibilities.

Staff (all are EAP except as noted)	Title	Responsibilities
Brandon Sackmann MIS Unit Statewide Coordination Section (360) 407-6684	Principal Investigator	Writes the QAPP. Develops model and nutrient-loading input files, performs model calibration/evaluation and sensitivity analyses, runs model scenarios, analyzes and interprets model results. Writes the draft and final report.
Mindy Roberts MIS Unit Statewide Coordination Section (360) 407-6804	Project Manager	Develops and oversees all project-related activities. Provides technical guidance and oversight to aid model development and subsequent refinement.
Karol Erickson MIS Unit Statewide Coordination Section (360) 407-6694	Unit Supervisor for the Project Manager	Reviews and approves the QAPP and approves the budget.
Will Kendra MIS Unit Statewide Coordination Section (360) 407-6698	Section Manager for the Project Manager	Reviews the project scope and budget, tracks progress, reviews and approves the QAPP.
Greg Pelletier MIS Unit Statewide Coordination Section (360) 407-6485	Technical Advisor	Provides technical guidance and oversight to aid model development and subsequent refinement.
Ben Cope U.S. Environmental Protection Agency (206) 553-1442	Technical Advisor	Provides technical guidance and oversight to aid model development and subsequent refinement.
Bob Cusimano Western Operations Section (360) 407-6596	Section Manager for the Study Area	Reviews the project scope and budget, tracks progress, reviews and approves the QAPP.
Andrew Kolosseus Watershed Planning Unit Water Quality Program (360) 407-7543	EAP Client	Clarifies scope of the project, provides internal review of the QAPP, and approves the final QAPP.
William R. Kammin (360) 407-6964	Ecology Quality Assurance Officer	Reviews and approves the QAPP.

EAP – Environmental Assessment Program

EPA – U.S. Environmental Protection Agency

MIS – Modeling and Information Support

QAPP – Quality Assurance Project Plan

Table 2 summarizes the expected project schedule. Tasks are limited to the development of the large-scale box model only.

Table 2. Proposed schedule for completing modeling work and reports.

Large-scale modeling work	
Modeling work completed	March 2009
Final report	
Author lead	Brandon Sackmann
Schedule	
Draft due to supervisor and project manager	April 2009
Draft due to client/peer and external reviewers	May 2009
Final report due on web	June 2009

Conceptual Model

To minimize setup time, this project will use hydrographic output from the Babson/Kawase/MacCready Puget Sound box model as modified by Ecology (BKM-ECY; Babson et al., 2006; Pelletier and Mohamedali, in preparation). This output will drive a water quality model for Puget Sound to be created using EPA's Water Quality Analysis Simulation Program (WASP7).

Geographic and Temporal Extent

Puget Sound is a partially mixed estuarine fjord and the largest such body of water in the contiguous 48 states. Admiralty Inlet links the three major branches of Puget Sound together and serves as the primary outlet to the Strait of Juan de Fuca and ultimately the Pacific Ocean (Figure 2). The only other outlet to Strait of Juan de Fuca is the extremely narrow Deception Pass located at the northern end of Whidbey Basin.

The three main branches of Puget Sound include:

1. The deep Main Basin and the shallower South Sound (separated from Main Basin by a sill and constriction at the Narrows).
2. Whidbey Basin.
3. Hood Canal (composed of a northern and southern section).

The BKM-ECY box model will be used to simulate hydrographic conditions in Puget Sound from 1999 – 2008. To estimate 'average' hydrographic conditions in Puget Sound, the entire 10-yr period will be simulated and model results will be post-processed to estimate both average conditions and variances based on the observed inter-annual differences.

Model Components

WASP7 is a generalized framework for modeling water quality and contaminant fate and transport in surface waters and the underlying benthos. It is a dynamic compartment-modeling program that can be used to investigate 1, 2, or 3 dimensional systems. The time-varying processes of advection, dispersion, point and nonpoint mass loading, and boundary exchange are represented in the basic program (DiToro et al., 1983; Ambrose et al., 1993). The DO/eutrophication model implemented in WASP7 (a.k.a. EUTRO) will be used to predict how DO and phytoplankton dynamics are affected by nutrients and organic material sources coming into Puget Sound from both point and nonpoint sources.

The BKM-ECY box model estimates salinity for each box and transport between boxes, including vertical and horizontal mixing and transport of water and salt. The model equations are based on conservation of mass and salt as well as parameterizations of additional dynamics. See Babson et al. (2006) for details specific to the development and configuration of BKM-ECY.

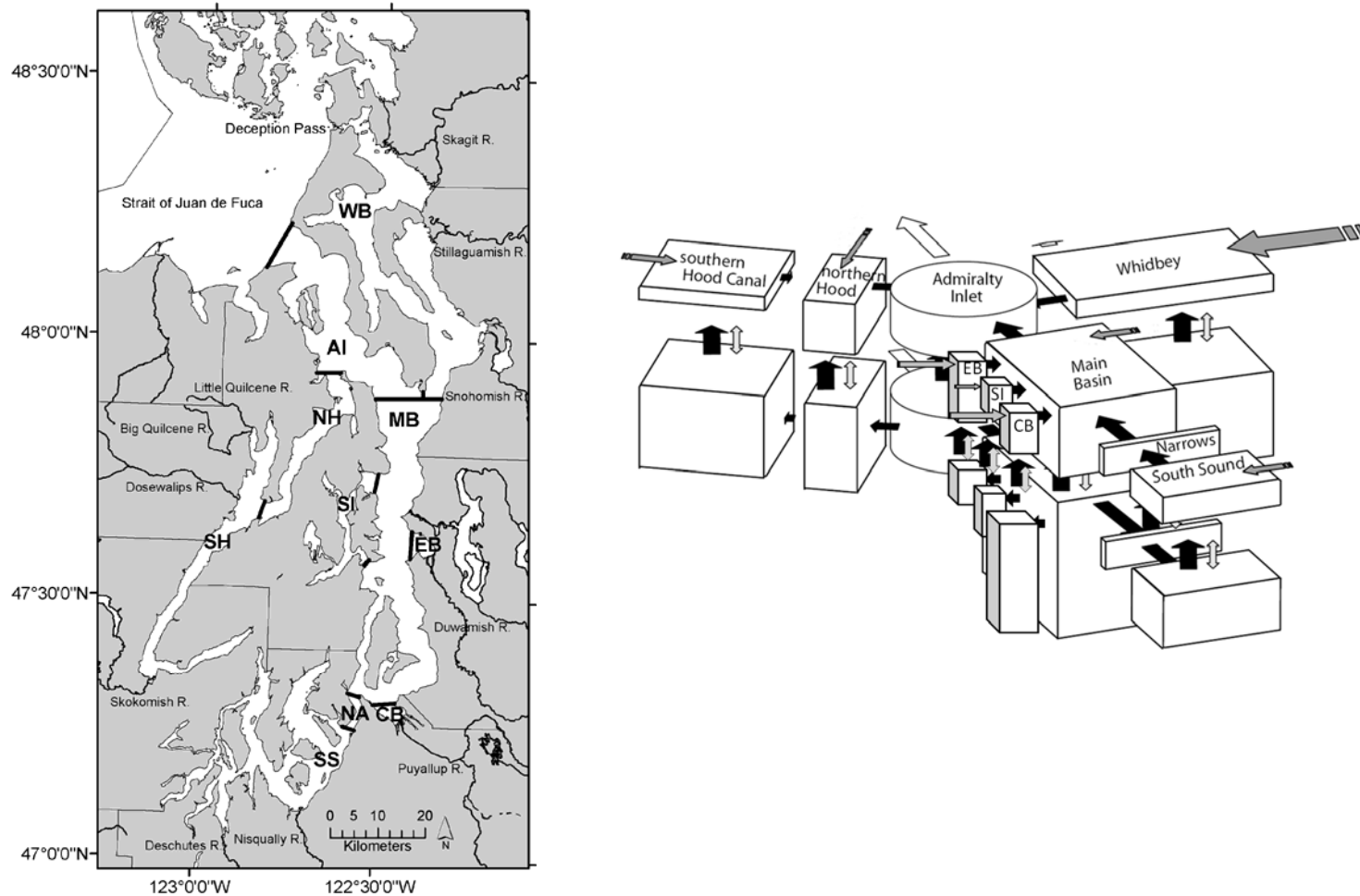


Figure 2. *Left:* Map of Puget Sound. Thick lines mark model basin boundaries labeled as in Table 3. See Table 3 for abbreviations. *Right:* Model schematic. Black arrows represent advection, two-way grey arrows represent mixing, grey arrows with dashed ends represent river inputs, and white arrows are outlets to the Strait of Juan de Fuca. Boxes have been scaled to show relative volumes. Arrows have been scaled to transports within each category. Rivers are proportional on a log scale. The Admiralty Inlet mixing is shown at 50%. Boxes with shaded faces represent basins incorporated into Ecology’s implementation of the model. For the sake of visual clarity Elliot Bay (EB) and Commencement Bay (CB) are shown on the east side of the Main Basin. Figures were adapted from Babson et al., 2006.

For the purposes of developing BKM-ECY, Puget Sound was conceptualized as a series of interconnected basins separated by sills. The original published version of the model identified seven basins. Two-layer estuarine circulation is assumed, and basin-specific depths of no motion are used to divide each basin into a surface and deep box. Ecology's implementation of the box model includes three additional basins (resulting in a total of 10 basins/20 boxes; Table 3): Elliot Bay, Commencement Bay, and Sinclair/Dyes Inlet.

Table 3. BKM-ECY Puget Sound box model configuration.

Basin	Abbreviation	Surface box depths (meters)	Surface volumes 10^{10} (m ³)	Deep volumes 10^{10} (m ³)
Admiralty Inlet	AI	37.0	1.45	1.96
Main Basin	MB	50.2	2.28	3.81
South Sound	SS	29.9	0.71	0.67
The Narrows	NA	21.5	0.04	0.02
Whidbey Basin	WB	9.1	0.40	2.69
Northern Hood Canal	NH	19.8	0.26	0.43
Southern Hood Canal	SH	13.0	0.38	1.68
Elliot Bay	EB	40.0	0.06	0.04
Commencement Bay	CB	23.0	0.05	0.15
Sinclair/Dyes Inlet	SI	20.0	0.03	0.04

By using BKM-ECY as the framework for developing the water quality model, we will create a relatively simple, less computationally intensive model. This model can be used to explore a wide range of scenarios and provide guidance for more advanced models. The model will simulate conventional water quality parameters such as nitrogen, phosphorus, DO, biochemical oxygen demand (BOD), sediment oxygen demand (SOD), phytoplankton, and temperature. The overall process is conventionally known as the eutrophication cycle.

The specific focus of this modeling effort is on the impact of nutrient loads on algal biomass and DO. Nutrient loads will be specified as input variables for all important sources. These loads will be estimated by Ecology using data from the National Pollutant Discharge Elimination System (NPDES) database, the river and stream monitoring network data, and the South Puget Sound Dissolved Oxygen Study (Roberts et al., 2008).

Runtime Considerations

It is expected that fewer runs of BKM-ECY will be needed since it will be necessary to keep the underlying hydrographic conditions constant between runs of the WASP7 water quality model. The BKM-ECY box model will be run using a relatively small timestep (e.g., 0.005 d/0.12 h) to ensure that the hydrodynamics are sufficiently resolved. The more numerous runs of the WASP7 water quality model will use a larger timestep (e.g., 0.05 d/1.2 h) in an attempt to minimize model runtime while maintaining overall model fidelity. This project does not include re-evaluation of the BKM-ECY model. Once the model is functioning as reported by Babson et al. (2006) and Pelletier and Mohamedali (in preparation), the hydrodynamic conditions will be fixed for all scenario runs of the WASP7 model.

Data Sources for Model Development

Acceptance Criteria

No data collection is planned for this project, and quality objectives are not being specified for existing data or for modeling results. However, data from existing repositories will be used for model calibration and evaluation purposes (Appendix B). The following acceptance criteria will be applied:

- *Data Reasonableness.* Data quality of existing data will be evaluated where available. Best professional judgment will be used to identify erroneous or outlier data, and these data will be removed from the data set.
- *Data Representativeness.* Data used will be reasonably complete and representative of the location or time period under consideration. Incomplete data sets will be used if they are considered representative of conditions during the period of interest. Data from outside the period of interest will be used only if no other data are available. In this case, best professional judgment will be used to determine the utility of the available data.
- *Data Comparability.* Long-term water quality monitoring programs often collect, handle, preserve, and analyze samples using methodologies that evolve over time. Best professional judgment will be used to determine whether/if data sets can be compared. The final project report will detail any caveats or assumptions that were made when using data collected with differing sampling or analysis techniques.

Data Set Descriptions

This list identifies those repositories that contain relevant data; however, additional sources of information may be considered as needed and/or as new sources are identified. Below is a description of each repository identified in Appendix B along with a URL describing each program in more detail. In most cases, data are available in electronic format.

Ecology Marine Waters Monitoring Data

Ecology has monitored water quality at approximately 40 stations within Puget Sound on a monthly basis since 1975. Some stations are monitored every year while some are monitored on a rotating schedule.

URL: www.ecy.wa.gov/programs/eap/mar_wat/mwm_intr.html

Ecology South Puget Sound Field Studies

Ecology has been conducting a water quality study focused on low DO levels in South Puget Sound. Field surveys occurred from 1994 to 2007. Data include both river and wastewater treatment plant effluent water quality.

URL: www.ecy.wa.gov/puget_sound/dissolved_oxygen_study.html

Ecology Central Basin/Possession Sound Primary Production Study

From October 1998 through October 2001, Ecology conducted a study to assess whether primary production in Central Puget Sound and Possession Sound would be affected by the addition of nutrients (Newton and Van Voorhis, 2002). Data collected during this study will provide rate estimates for algal production as a function of light, season, and other controlling factors.

URL: www.ecy.wa.gov/biblio/0203059.html

Ecology Puget Sound Mooring Data

Since 2005 Ecology has maintained three moorings in Puget Sound to provide continuous data for investigation of status and trends of marine water quality. The moorings are located at piers and docks in Budd Inlet, Squaxin Passage, and Clam Bay. The moorings provide 15-minute values for temperature, conductivity (used to calculate salinity), DO, and chlorophyll *a* fluorescence.

URL: www.ecy.wa.gov/programs/eap/mar_wat/moorings.html

Ecology Freshwater Ambient Monitoring Data

Ecology maintains a freshwater ambient monitoring network that includes numerous sites on rivers and streams within the greater Puget Sound area.

URL: www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html

Hood Canal Dissolved Oxygen Program

The Hood Canal Dissolved Oxygen Program (HCDOP) is a partnership of 28 organizations that conducts monitoring and analysis to determine sources of and potential corrective actions for the low DO in Hood Canal and its effects on marine life. HCDOP monitors marine water quality as well as water quality in rivers, streams, and groundwater sources that discharge into Hood Canal. Monitoring of present-day water properties in the canal is done using a combination of target field efforts, citizen volunteers, and moorings with near-realtime data transmission capabilities. (See 'APL ORCA Mooring Data' below.)

URL: www.hoodcanal.washington.edu/

APL ORCA Mooring Data

Oceanic Remote Chemical Analyzers (ORCA) are autonomous moored profiling systems that provide real-time data streams of water and atmospheric conditions. The systems consist of a profiling underwater sensor package and a surface mounted weather station. Currently there are four ORCA mooring systems deployed, all in Hood Canal. Past deployments of the ORCA system have been in South Puget Sound (Carr Inlet) and Central Puget Sound (near Point Wells).

URL: <http://orca.ocean.washington.edu/>

UW PRISM Field Studies

In partnership with Ecology, the University of Washington PRISM (Puget Sound Regional Synthesis Model) program conducted approximately twice-annual monitoring cruises encompassing approximately 40 stations located throughout Puget Sound. These cruises ran June 1998 through July 2004.

URL: www.prism.washington.edu/

King County DNR Puget Sound Marine Monitoring Data

King County's Marine and Sediment Assessment Group supports a comprehensive, long-term marine monitoring program that assesses water quality in Central Puget Sound. Their program monitors offshore water quality, beach water quality, as well as intertidal sediment, algae, and clams.

URL: <http://dnr.metrokc.gov/wlr/waterres/marine/>

King County DNR Stream and River Monitoring Data

Many streams and rivers in the King County service area are routinely assessed as part of the King County Major Lake and Stream Monitoring Program. Monthly baseflow water quality samples have been collected at many of these sites since 1976. Data are analyzed to characterize the general water quality of the stream, determine if applicable state and federal water quality criteria are met, and identify long-term water quality trends.

URL: <http://green.kingcounty.gov/WLR/Waterres/StreamsData/>

USGS Freshwater River/Stream Data

The United States Geological Survey maintains a network of streamflow gaging stations, including sites in the Puget Sound study area.

URL: <http://waterdata.usgs.gov/wa/nwis/rt>

Sinclair/Dyes Inlet Flow Data

The U.S. Navy's Puget Sound Naval Shipyard, in partnership with a variety of federal, state, and local governments, tribes, and community groups, developed and maintained a flow network for streams and creeks tributary to Sinclair and Dyes Inlets from 2001 to 2005 (May et al., 2005).

URL: www.ecy.wa.gov/programs/wq/tmdl/sinclair-dyes_inlets/index.html

NPDES Data

Wastewater treatment plant monthly data reported under National Pollution Discharge Elimination System (NPDES) permits are available through the Water Quality Permit Life Cycle System (WPLCS).

URL: www.ecy.wa.gov/programs/wq/permits/wplcs/index.html

Model Setup and Nutrient Loading Estimation

Initial and Boundary Conditions

The selected water quality model will be set up for the entire Puget Sound domain. Following Babson et al. (2006), the BKM-ECY box model and associated water quality model will use inter-annually varying freshwater inflow and nutrient loading from rivers, and a salinity boundary condition in the Strait of Juan de Fuca. Initial conditions for the various state variables in the water quality model will be specified and allowed to vary spatially. These initial conditions will be calculated from the subset of data used for model calibration (see below). Both models will be allowed to spin-up before results will be considered valid for subsequent use. The hydrodynamic spin-up will be at least 45 days before water quality is to be calculated. The water quality spin-up will follow the hydrodynamic spin-up from day 45 through 365.

Nutrient Sources

The term *nonpoint* is used to describe diffuse sources that do not come through a pipe (such as rainfall runoff from agricultural fields and residential yards) and groundwater (including contributions from septic systems). Most of the nonpoint nitrogen loading from the watersheds surrounding Puget Sound enters via rivers and streams.

The term *point source* generally refers to sources that are regulated under the federal Clean Water Act through the NPDES. NPDES permits are issued to municipal and industrial wastewater treatment plants (WWTPs) and stormwater systems, construction sites, boatyards, salmon net pens, and other facilities. Municipal WWTPs that discharge directly to Puget Sound are thought to represent the largest anthropogenic source of direct nitrogen loading from the watershed to the Sound. A few industrial facilities discharge directly to Puget Sound, and these will be included where discharge information is available or can be estimated. Point source loads will be estimated using data from the NPDES database and the South Puget Sound Dissolved Oxygen Study (Roberts et al., 2008). In some cases, smaller wastewater discharges may be lumped as for the smaller streams.

While all rivers are generally considered nonpoint sources, some have upstream WWTPs that discharge to freshwater. In addition, rivers and streams receive discharges from other permitted areas, such as municipal stormwater, which are considered point sources. For this screening level analysis, upstream WWTPs and other permitted sources will not be separated out of the river and stream inputs.

Data Requirements

A major activity as part of the model setup will be developing nutrient-loading input files for all major WWTPs and rivers. Ecology's goal is to develop these files as a separate stand-alone product to facilitate their use by other projects and agencies. This project will require the

following information for specifying nutrient loads from all sources including all WWTPs and river loads:

- Flow rates and temperature data
- Organic phosphorus (particulate and dissolved)
- Dissolved phosphorus (soluble reactive phosphorus)
- Organic nitrogen (particulate and dissolved)
- Ammonia nitrogen
- Nitrate + nitrite nitrogen
- Dissolved oxygen (DO)
- pH
- Total organic carbon (TOC)
- Dissolved organic carbon (DOC)
- Carbonaceous biochemical oxygen demand (CBOD; CBOD will be estimated from TOC or DOC as needed)

When available, measured effluent quality for a particular point source will be used to estimate its loadings. If such data are not available for a particular source, it will be necessary to estimate effluent quality based on measurements from similar facilities.

Organic nitrogen may be estimated as the difference between total Kjeldahl nitrogen and ammonia nitrogen for WWTPs, and between total nitrogen and the sum of ammonium, nitrate, and nitrite for rivers. Organic phosphorus may be estimated as the difference between total phosphorus and orthophosphate phosphorus.

Estimation Methods

There are 17 major rivers that discharge into Puget Sound and its adjacent waters, most of which have real time USGS streamflow gages. Calculation of river loads requires both parameter-concentration and streamflow data. As part of the USGS National Water Quality Assessment, Embrey and Inkpen (1998) estimated nutrient loads to Puget Sound from several major rivers. These loads were based on existing nutrient concentrations and discharge data for the period 1980-1993. Using an analogous approach, time-resolved stream loads will be estimated for 1999-2008. This will require parameter-concentration data compiled from databases maintained by agencies that monitor water-quality in the Puget Sound Basin and streamflow estimates made at the time of water-quality sample collection (Appendix B).

The BKM-ECY box model has been set up with flows from rivers included as boundary source terms. The total ungaged discharge to Puget Sound may be as high as 10% of the total gaged inflow but with potentially higher nutrient concentrations due to agricultural and urban runoff. To include ungaged rivers and compensate for partially-gaged drainage areas, Babson et al. (2006) used a method developed by Lincoln (1977) and adapted following Coklet et al. (1990). Flows from ungaged rivers were estimated by first choosing a representative gaged reference river, based on its similarity to the ungaged area and then multiplying the reference flow by the ratio of the ungaged-to-gaged areas. In cases where rivers are gaged well upstream from the river mouth, the drainage area downstream of the station is used as the ungaged area in the

calculation. Then the estimated flow is added to the gaged flow to obtain total discharge for that river.

Following Mohamedali (2008) and Roberts and Pelletier (2001), daily time series of various parameters and nutrient concentrations will be estimated using multiple linear regressions (Cohen et al., 1992). This analysis is based on the premise that parameter concentrations can be predicted based on flow and time of year. The multiple linear regression equation to be used in this analysis is given by:

$$\log(c) = b_0 + b_1 \log(Q/A) + b_2 [\log(Q/A)]^2 + b_3 \sin(2\pi f_y) + b_4 \cos(2\pi f_y) + b_5 \sin(4\pi f_y) + b_6 \cos(4\pi f_y) \quad (1)$$

where

c is the observed parameter concentration (mg/L), or in the case of temperature or pH, it is in °C and pH units (respectively).

Q is discharge (m³/s).

A is the area drained by the monitored location (km²).

f_y is the year fraction (dimensionless, varies from 0 to 1).

b_i are the best-fit regression coefficient.

All six variables in the above equation are known values (from available concentration data, streamflow data, watershed area, and time of year) except for the coefficients (b_i). The multiple linear regression model attempts to solve equation (1) and determine the optimum combination of b_i coefficients that will yield the best fit between predicted and observed concentrations of a specific parameter. Once these coefficients are determined, the above equation can be used to predict parameter concentrations continuously over any time period (for example, at a daily interval). Daily concentrations will be multiplied with daily streamflow data to predict daily loads for time periods of interest.

In previous applications of this regression model methodology, certain water quality parameters were better characterized by the regression model than others, particularly those highly influenced by flow and seasonality. Though the statistical results from some parameters suggested a poor fit for *concentration*, predicted daily *loads* often compared well with observed loads for most parameters across a wide variety of streams.

There is also evidence that groundwater may contribute significant amounts of freshwater to some basins and should be evaluated as a potential source of distributed nutrients (e.g., Hood Canal). One proposed application of the model will be to test the relative sensitivity of this source, using published and/or order-of-magnitude groundwater flow estimates, to the overall nutrient and DO balance of Puget Sound (Simonds et al., 2008).

Model Calibration and Evaluation

Methods Overview

Once the model setup is completed, the model will be calibrated through comparison with observed data collected in Puget Sound. The term *calibration* is defined as the process of adjusting model parameters within physically defensible ranges until the resulting predictions give the best possible match with observed data. In some disciplines, calibration is also referred to as parameter estimation.

Model *evaluation* is defined as the process used to generate information to determine whether a model and its analytical results are of a quality sufficient to serve as the basis for a decision and whether the model is capable of approximating the real system of interest (EPA, 2008). In some disciplines, evaluation is also referred to as validation, confirmation, or verification.

To help ensure that the process of model calibration and evaluation remain independent, a subset of the available data will be withheld during model calibration. The withheld data will be used to evaluate the model output. In situations involving data scarcity it may be necessary to use all available data for calibration purposes. The final report will describe those data sets (or subsets thereof) that were used for both calibration and evaluation of the model.

Model calibration is an iterative procedure that is achieved using a combination of best professional judgment and quantitative comparison with a subset of the measured data. For example, the nitrogen balance will involve adjustment of nitrification and organic nitrogen hydrolysis rates, as well as uptake rates by phytoplankton. The phosphorus balance will include adjustment of organic phosphorus decay rate and uptakes rates by phytoplankton. Chlorophyll *a* data will represent phytoplankton density and will be used to adjust algal growth, die-off, respiration, and settling. Finally, phytoplankton growth, re-aeration, and BOD, in combination with nearshore SOD, will be specified to obtain the best match with observed DO data. When possible, direct measurements of the rate constants for key processes will be used to calibrate the model (e.g., maximum growth rates of phytoplankton, half-saturation constants).

Both calibration and evaluation of the model will rely on a combination of quantitative statistics for goodness-of-fit and visual comparison of predicted and observed time series and depth profiles (Krause et al., 2005). This methodology is consistent with the standard practice that has been established for similar modeling programs and other detailed studies. These include the following:

- Hood Canal Dissolved Oxygen Program.
- UW PRISM Modeling Program.
- Budd Inlet Scientific Study (Aura Nova Consultants et al., 1998).
- Deschutes River/Capitol Lake/Budd Inlet Water Quality Study (Roberts et al., 2009).
- South Puget Sound Dissolved Oxygen Study (Roberts et al., 2008).

Bias will be assessed by calculating the average residual of paired values [mean(predicted - observed)]. A poor fit between modeled and observed data can sometimes yield a near-zero bias if the positive and negative deviations in a data set are of a similar magnitude. Therefore, measurements of precision will be used to further quantify and refine the goodness-of-fit between the model predictions and observations. Precision will be assessed by calculating the root mean square error (RMSE) of paired values [$\sqrt{\text{mean}((\text{predicted} - \text{observed})^2)}$]. Calibration will aim to decrease both bias and RMSE between predictions and observations, but will predominantly focus on reducing bias.

Targets and Goals

In general, water quality model calibration begins with hydrodynamic model calibration. However, because no detailed hydrodynamics are included in the box model, only the basin volumes will be compared with published values to ensure that overall volumes are correct. Ecology is targeting its predicted volumes in the model to be within 10% of the published values.

The model calibration will focus on representing the overall average DO, chlorophyll, and nutrient concentrations well. Short-term effects of ephemeral events such as storms may not be represented as well. Highest priority will be devoted to describing the DO levels in the summer months, when the lowest levels are expected. Ecology is targeting a bias as close to zero as possible and a RMSE of less than 2.0 mg/L for the bulk of the summer DO data. Ultimately, the box model's calibration will need to be sufficient to meet the goal of being a screening-level tool to inform the intermediate-scale modeling effort.

Data Use Preferences

Data for model calibration and evaluation will be used in a hierarchal fashion. Preference will be to use data that are coincident in both time and space (i.e., Puget Sound from 1999 – 2008) to the model simulations. If data are scarce then only spatially coincident data may be considered (i.e., Puget Sound from any time period). Should data or published guidance for a particular parameter value be lacking entirely for Puget Sound (or a region thereof) then published values from similar aquatic systems may be used. In all cases, best professional judgment will be used for the final determination of what data are used to calibrate and evaluate the model.

Sensitivity and Uncertainty Analyses

To evaluate model performance and the variability of results, *sensitivity* and *uncertainty* analyses will be carried out. Uncertainty can arise from a number of sources that range from errors in the input data used to calibrate the model, to imprecise estimates for key parameters, to variations in how certain processes are parameterized in the model domain. Regardless of the underlying cause, it is good practice to evaluate these uncertainties and reduce them if possible (EPA, 2008; Taylor, 1997; Beck, 1987).

A model's sensitivity describes the degree to which results are affected by changes in a selected input parameter. In contrast, uncertainty analysis investigates the lack of knowledge about a certain population or the real value of model parameters. Although sensitivity and uncertainty analyses are closely related, uncertainty is parameter-specific, and sensitivity is algorithm-specific with respect to model variables. By investigating the "relative sensitivity" of model parameters, a user can become knowledgeable of the relative importance of parameters in the model. By knowing the uncertainty associated with parameter values and the sensitivity of the model to specific parameters, a user will be more informed regarding the confidence that can be placed in the model results (EPA, 2008).

During the calibration process, the responsiveness of the model predictions to various assumptions and rate constants specified will be evaluated. The model setup will likely include parameters based on literature recommendations and best professional judgment, and estimates of loads in the absence of data. Specific areas to address with sensitivity and uncertainty analyses include boundary conditions, meteorologic forcing, sediment fluxes, watershed loads, and process rate parameters.

Fundamental parameters will be varied by (1) increasing and decreasing by a factor of two or an order of magnitude, and (2) the resulting predictions compared to understand whether a factor has a discernible effect on water quality predictions. The final report will document the parameters that are varied and will identify any parameters that have great uncertainty and strongly influence the results.

Evaluation of Model Scenarios

After sensitivity analyses have been performed, the calibrated model will be used to evaluate water quality conditions observed in Puget Sound from 1999 – 2008 and to simulate the effects of various alternative nutrient-loading scenarios. Results from this time period will also be compared to estimated natural background conditions. Natural conditions are characterized by the absence of human impacts on the nutrient-loading and DO regime.

Modeling natural conditions typically involves creating a natural background model run corresponding to the existing conditions model run, except that estimated human influences have been removed as much as possible. Generally, this means removing all point sources and setting tributaries to natural loads. Accurate estimation of pre-development conditions may be difficult, so reasonable estimation methods will need to be developed. One possible strategy would be to set nutrient levels using reference streams/rivers in Puget Sound with the lowest (or nearly the lowest) nutrient levels observed from 1999 – 2008. Additional, more statistically sophisticated methods are also being considered. Some of the parameters may remain unchanged between natural and existing if no information is available to estimate pre-development conditions. The current marine boundary will be assumed to be natural for the purposes of this study.

Ecology will use the model to determine the impact of human activities on DO concentrations in Puget Sound. Using the initial calibration to the current point and nonpoint source loads, the model will be applied to 4 to 6 alternate scenarios. The exact scenarios to be evaluated may change during the project, but likely candidates are as follows:

- Scenario 1 – Natural conditions.
- Scenario 2 – Current rivers and no point sources.
- Scenario 3 – Current point sources and natural conditions for rivers.
- Scenario 4 – Current rivers and maximum permitted point sources.
- Scenario 5 – Current rivers and point sources at projected loadings in 25 years.

Scenario results will be evaluated both as predicted patterns for that scenario and as differences between scenarios. Example scenarios were chosen so that (1) results from the large-scale model can be used to aid the development of the intermediate-scale model, and (2) both models can evaluate analogous scenarios to compare and contrast results from each.

Model Output Quality (Usability) Assessment

Final assessment of model performance will be conducted and summarized in the final report. This summary will evaluate whether the outcomes have met the project's original objectives. Criteria to be evaluated include whether or not the water quality model:

- Behaves in a manner that is consistent with the current understanding of processes known to affect water quality in the Puget Sound estuary system.
- Realistically reproduces variations in water quality observed within individual subbasins of Puget Sound on inter-annual, seasonal, and possibly intra-seasonal timescales.
- Provides quantitative insights that help to guide subsequent model development efforts (with particular emphasis on the development of the intermediate-grid model).

Project Deliverables and Schedule

The following deliverables will be developed for this project according to the schedule presented in Table 2:

- Final project report and summary. This will include detailed documentation of the results and methods used to estimate loading from nonpoint and point sources.
- Puget Sound-specific WASP7 input files. These will be made available as electronic Appendices.

Ecology will prepare a draft report summarizing the development of the large-scale water quality box model for Puget Sound. The report will present a review of available data used in model development. The model setup section will include a summary of the point source and the tributary load data, the model configuration, and a description of initial and boundary conditions. The qualitative and quantitative calibration of the model will be discussed along with model behavior and its ability to reproduce the salient Puget Sound features. The responsiveness of the model and the uncertainty associated with the model predictions will be discussed to summarize the results from the sensitivity analyses. Also, application of the model for the selected scenarios will be included along with a discussion of the implication of the results. A final report will be prepared after incorporating internal and external reviewers' comments on the draft report.

References

- Albertson, S.L., J. Bos, K. Erickson, C. Maloy, G. Pelletier, and M.L. Roberts, 2007. South Puget Sound Water Quality Study, Phase 2: Dissolved Oxygen. Washington State Department of Ecology, Olympia, WA. Publication No. 07-03-101. www.ecy.wa.gov/biblio/0703101.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
- Ambrose, R.B., Jr., T.A. Wool, and J.L. Martin, 1993. The Water Quality Analysis Simulation Program, WASP5; Part A: Model Documentation. U.S. Environmental Protection Agency, Center for Exposure Assessment Modeling, Athens, GA. 209 pp.
- Aura Nova Consultants, Brown and Caldwell, Inc., Evans-Hamilton, Inc., J.E. Edinger and Associates, Washington State Department of Ecology, and A. Devol, University of Washington Department of Oceanography, 1998. Budd Inlet Scientific Study. Prepared for Lacey, Olympia, Tumwater, Thurston Alliance (LOTT) Wastewater Management District. 300 pp.
- Babson A., M. Kawase, and P. MacCready, 2006. Seasonal and Interannual Variability in the Circulation of Puget Sound, Washington: A Box Model Study. *Atmosphere-Ocean* 44(1): 29-45.
- Beck, M.B., 1987. Water Quality Modeling: A Review of the Analysis of Uncertainty. *Water Resources Research* 23(8), 1393.
- Bricker, S.B., C.G. Clement, D.E. Pirhalla, S.P. Orlando, and D.R.G. Farrow, 1999. National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment in the Nation's Estuaries. NOAA, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Science, Silver Spring, MD. 71 pp.
- Chapra, S.C., 1997. *Surface Water-Quality Modeling*. WCB/McGraw-Hill, Boston, MA.
- Cohen, 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* 28(9), 2353-2363.
- Cokelet, E.D., R.J. Stewart, and C.C. Ebbesmeyer, 1990. The Annual Mean Transport in Puget Sound. National Oceanic and Atmospheric Administration (NOAA) Technical Memorandum, ERL-PMEL-92. 54 pp.
- DiToro, D.M., J.J. Fitzpatrick, R.V. Thomann, and Hydroscience, Inc., Westwood, N.J., 1983. Documentation for Water Quality Analysis Program (WASP) and Model Verification Program (MVP). U.S. Environmental Protection Agency, Environmental Research Laboratory, Duluth, MN. Publication No. EPA-600/3-81-044. 145 pp.

EPA, 2008 (draft). Guidance on the Development, Evaluation and Application of Environmental Models. Council for Regulatory Environmental Modeling, U.S. Environmental Protection Agency, Washington D.C., EPA Publication No. ###-##-###. In review.

Edmondson, W.T., 1991. The Uses of Ecology: Lake Washington and Beyond. University of Washington Press, Seattle, WA.

Embrey, S.S. and E.L. Inkpen, 1998. Water-Quality Assessment of the Puget Sound Basin, Washington, Nutrient Transport in Rivers, 1980-93. U.S. Geological Survey Water-Resources Investigations Report 97-4270, Tacoma, WA. 30 pp.

Glibert, P.M., S. Seitzinger, C.A. Heil, J.M. Burkholder, M.W. Parrow, L.A. Codispoti, and V. Kelly, 2005. The Role of Eutrophication in the Global Proliferation of Harmful Algal Blooms: New Perspectives and New Approaches. *Oceanography* 18(2), 198-209.

Howarth, R., 2006. From presentation to the White House Office of Science and Technology Policy by Robert W. Howarth, David R. Atkinson Professor of Ecology & Environmental Biology, Cornell University, November 3, 2006.

Howarth, R. and R. Marino, 2006. Nitrogen as the Limiting Nutrient for Eutrophication in Coastal Marine Ecosystems: Evolving Views Over Three Decades. *Limnology and Oceanography* 51(1, part 2): 364-376.

Lincoln, J.H., 1977. Derivation of Freshwater Inflow into Puget Sound. University of Washington Department of Oceanography Special Report No. 72. University of Washington, Seattle, WA. 20 pp.

Mackas, D.L. and P.J. Harrison, 1997. Nitrogenous Nutrient Sources and Sinks in the Juan de Fuca Strait/Strait of Georgia/Puget Sound Estuarine System: Assessing the Potential for Eutrophication. *Estuarine, Coastal and Shelf Science* 44, 1-21.

May, C.W. et al., 2005. An Analysis of Microbial Pollution in the Sinclair-Dyes Inlet Watershed. Washington State Department of Ecology, Olympia, WA. Publication No. 05-03-042. www.ecy.wa.gov/biblio/0503042.html

Mohamedali, T., 2008. Personal communication with Mindy Roberts. Washington State Department of Ecology, Olympia, WA.

Newton, J.A. and K. Van Voorhis, 2002. Seasonal Patterns and Controlling Factors of Primary Production in Puget Sound's Central Basin and Possession Sound. Washington State Department of Ecology, Olympia, WA. Publication No. 02-03-059. www.ecy.wa.gov/biblio/0203059.html

Roberts, M.L. and G. Pelletier, 2001. Estimating Loads from 71 Watersheds Tributary to South Puget Sound. Proceedings of the 2001 Georgia Basin/Puget Sound Research Conference, Bellevue, WA.

Roberts, M.L., J.A. Newton, and D. Hannafious, 2005. Hood Canal Dissolved Oxygen Program Integrated Assessment and Modeling Study Year 1 Activities. Washington State Department of Ecology, Olympia, WA. Publication No. 05-03-114. www.ecy.wa.gov/biblio/0503114.html

Roberts, M.L., J. Bos, and S.L. Albertson, 2008. South Puget Sound Dissolved Oxygen Study: Interim Data Report. Washington State Department of Ecology, Olympia, WA. Publication No. 08-03-037. www.ecy.wa.gov/biblio/0803037.html

Roberts, M.L., A. Ahmed, and G. Pelletier, 2009 (draft). Deschutes River, Capitol Lake, and Budd Inlet Temperature, Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Fine Sediment Total Maximum Daily Load Water Quality Study Findings. Washington State Department of Ecology, Olympia, WA. Publication No. 09-03-xxx. In review.

Sackmann, B.S., 2009. QAPP Puget Sound Dissolved Oxygen Modeling Study: Intermediate-scale Model Development. Washington State Department of Ecology, Olympia, WA. Publication No. 09-03-XXX. In review.

Simonds, F.W., P.W. Swarzenski, D.O. Rosenberry, C.D. Reich, and A.J. Paulson, 2008. Estimates of nutrient loading by ground-water discharge into the Lynch Cove area of Hood Canal, Washington. U.S. Geological Survey Scientific Investigations Report 2008-5078, Reston, VA. 54 pp.

Taylor, J.R., 1997. An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements, Second Edition. University Science Books, Sausalito, CA.

Winter, D.F., K. Banse, and G.C. Anderson, 1975. The dynamics of phytoplankton blooms in Puget Sound, a fjord in northwestern U.S. *Marine Biology* 29, 139-175.

Appendices

Appendix A. Glossary and Acronyms

Ambient: Referring to large-scale or area-wide conditions (i.e., conditions not associated with a specific point source, facility, or property).

Anthropogenic: Human-caused.

Benthos: Sediment-dwelling invertebrates.

Biotic: All the plant and animal life of a particular region.

Central Puget Sound: That portion of Puget Sound south of Edmonds and north of the Tacoma Narrows.

Eutrophication: An increase in productivity resulting from nutrient loads from human activities such as fertilizer runoff and leaky septic systems.

Hypoxia: Low oxygen.

Marine water: Salt water.

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

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

Nutrient: Substance used by organisms to live and grow. Marine plant (algae or phytoplankton) growth often is limited by the nutrient, nitrogen.

Parameter: A measurable quantity that defines certain water quality characteristics of a system.

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

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

South Puget Sound: That portion of Puget Sound south of the Tacoma Narrows.

Acronyms and Abbreviations

BKM-ECY	Babson/Kawase/MacCready Puget Sound box model as modified by Ecology
BOD	Biological oxygen demand
DNR	Department of Natural Resources
DO	Dissolved oxygen
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
PNNL	Pacific Northwest National Laboratory
QA	Quality assurance
SOD	Sediment oxygen demand
USGS	U.S. Geological Survey
WASP7	EPA's Water Quality Analysis Simulation Program
WWTP	Wastewater treatment plant

Appendix B. Descriptions of Available Data Sources

Data Sources (Curator/Description/Parameters)	Geographic Extent											Time span	Frequency			Design				
	SJF	AI	MB	SS	WB	NH	SH	NA	EB	CB	SI		0-1/ MO	1-2/ MO	3-6/ MO	SURF	DEEP	PROF	FW	WWTP
Washington State Department of Ecology (ECY)																				
Marine Waters Monitoring Data																				
T, S, DO, pH, CHL, SECCHI	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
NUTS	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
T, C, P, DO, FLUOR, BEAM-C	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X		
South Puget Sound Field Studies																				
T, S, DO, pH, CHL, PPROD, NUTS, SECCHI				X										X	X	X				
T, C, P, DO, FLUOR, BEAM-C, PAR				X										X			X			
T, DO, pH, DOC, POC, NUTS			X	X							X							X		
T, DO, pH, DOC, POC, NUTS, CBOD			X	X							X								X	
Central Basin/Possession Sound Primary Production Study																				
CHL, PPROD, PAR		X	X											1998-2001	X		X			
Puget Sound Mooring Data																				
T, C, DO, FLUOR				X							X			2005-2008+	X		X			
Freshwater Ambient Monitoring Data																				
FLOW, T, DO, pH, DOC, TOC, NUTS	X		X	X	X	X	X		X	X	X			1959-2008+	X				X	
Hood Canal Dissolved Oxygen Program																				
Citizen Monitoring Data																				
DO						X	X							2003-2008+	X		X	X		
Comparative Cross Sections																				
T, C, P, DO						X	X							2005-2008+	X			X		
Freshwater Monitoring Data																				
DOC, POC, NUTS						X	X							2005-2008+	X				X	
Applied Physics Laboratory of the University of Washington (APL)																				
ORCA Mooring Data																				
T, C, P, DO, FLUOR				X										2000-2003	X			X		
T, C, P, DO, FLUOR			X											2003-2004	X			X		
T, C, P, DO, FLUOR						X	X							2005-2008+	X			X		
University of Washington, Seattle, WA (UW)																				
PRISM Field Studies																				
T, S, DO, pH, CHL, PPROD, NUTS, SECCHI	X	X	X	X	X	X	X	X	X					1998-2004		X	X	X		
T, C, P, DO, FLUOR, BEAM-C	X	X	X	X	X	X	X	X	X					1998-2004		X		X		
King County Department of Natural Resources																				
Puget Sound Marine Monitoring Data																				
T, S, DO, pH, CHL, NUTS, DOC, POC, SECCHI		X	X		X						X			1964-2008+	X		X	X		
T, C, P, DO, FLUOR, BEAM-C, PAR		X	X		X						X			1998-2008+	X			X		
Stream and River Water Quality Monitoring Data																				
FLOW, T, DO, pH, NUTS			X											1976-2008+	X				X	

Data Sources (Curator/Description/Parameters)	Geographic Extent												Time span	Frequency					Design				
	SJF	AI	MB	SS	WB	NH	SH	NA	EB	CB	SI	0-1/ MO		1-2/ MO	3-6/ MO	SURF	DEEP	PROF	FW	WWTP			
United States Geological Survey (USGS)																							
Freshwater River/Stream Data																							
	FLOW, T	X		X	X	X	X	X		X	X	X	pre 1950-2008+	X					X				
United States Navy's Puget Sound Naval Shipyard																							
Sinclair/Dyes Inlet Flow Data																							
	CHL, NUTS										X	1997-1998	X			X	X						
	T, C, P, DO, FLUOR, BEAM-C, PAR										X	1997-1998	X					X					
	FLOW, T, NUTS										X	2002-2005	X						X				
National Pollution Discharge Elimination System																							
	FLOW, DO, pH, NUTS, CBOD	X	X	X	X	X	X	X	X	X	X	X	pre 1999-2008	X						X			

Measured Parameters

- T Temperature
- S Salinity
- C Conductivity (used to calculate salinity)
- P Pressure (used to calculate depth)
- DO Dissolved Oxygen concentrations estimated using Winkler titration method (discrete samples) or electronic sensor (freshwater and profile data)
- CHL Chlorophyll *a* and phaeopigment concentrations estimated using standard acidification method
- FLUOR Chlorophyll *a* concentration estimated from *in vivo* fluorescence
- PPROD Phytoplankton primary production estimated from ¹⁴C uptake experiments
- NUTS Nutrient concentrations to include some combination of total and total dissolved nitrogen and phosphorous and separate estimates of dissolved NO3 (nitrate), NO2 (nitrite), NH4 (ammonium), PO4 (orthophosphate), and SiOH4 (silicate)
- DOC Dissolved organic carbon
- POC Particulate organic carbon
- TOC Total organic carbon
- pH Potential hydrogen
- BEAM-C Light transmission
- SECCHI Secchi disk measurement (surface only)
- PAR Photosynthetically available radiation (400-700 nm)
- CBOD Carbonaceous Biochemical Oxygen Demand
- FLOW River/stream flow and effluent discharge

Geographic Extent

- SJF Strait of Juan de Fuca
- AI Admiralty Inlet
- MB Main Basin
- SS South Sound
- WB Whidbey Basin
- NH Northern Hood Canal
- SH Southern Hood Canal
- NA The Narrows
- EB Elliot Bay
- CB Commencement Bay
- SI Sinclair/Dyes Inlet

Time span/Frequency/Design

- SURF Discrete surface samples available
- DEEP Discrete deep/near-bottom samples available
- PROF Continuous vertical profile data available
- FW Freshwater samples available
- WWTP Wastewater treatment plant samples available
- + Ongoing data collection