Interim Results from the Budd Inlet, Capitol Lake, and Deschutes River Dissolved Oxygen and Nutrient Study

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Abstract

Budd Inlet and the Deschutes River do not meet the water quality standards for dissolved oxygen. An ongoing study included supplemental data collection and model development to simulate nutrient dynamics in the Deschutes River, Capitol Lake, and Budd Inlet. Nitrogen concentrations increase in a downstream direction within the Deschutes River, due to natural and anthropogenic sources. The shallow waters and limited circulation of Capitol Lake enhance primary productivity, and algae blooms produce supersaturated oxygen conditions while decreasing dissolved nutrient concentrations during the growing season. A three-dimensional hydrodynamic and water quality model of Budd Inlet and Capitol Lake will simulate future conditions to quantify the nutrient load reductions necessary within the Budd Inlet watershed to meet the water quality standards in both marine and freshwater.

Introduction

Monitoring conducted by the Department of Ecology (Ecology), Thurston County, the Squaxin Island Tribe, and others identified portions of Budd Inlet, Capitol Lake, the Deschutes River, and tributaries that do not meet the state water quality standards for a variety of parameters (Figure 1). In total, 24 water bodies were placed on the 1996 and/or 1998 Clean Water Act Section 303(d) list of impaired waters for at least one of the following: dissolved oxygen, nutrients, pH, temperature, fecal coliform bacteria, or fine sediment. Ecology began a total maximum daily load (TMDL) study in March 2003 to assess the current condition of the water bodies and to identify and quantify factors contributing to the impairments.

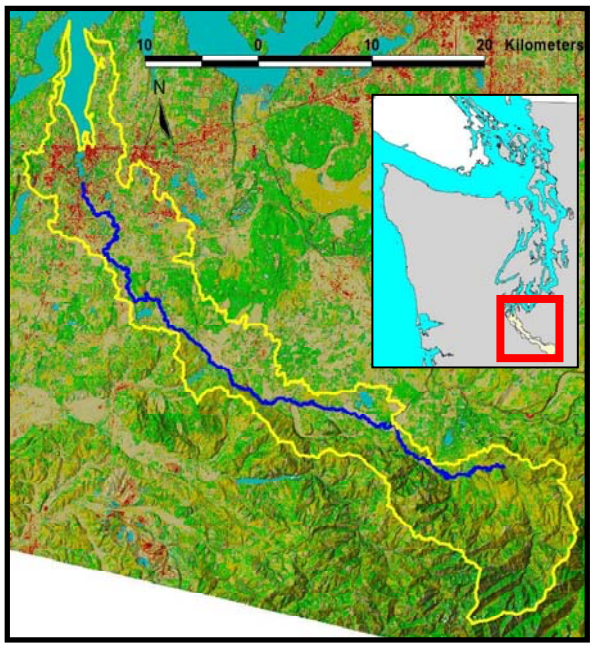

Figure 1. Budd Inlet watershed water quality study area.

Several South Puget Sound inlets experience low near-bottom dissolved oxygen levels in late summer, when seasonal cycles produce the lowest dissolved oxygen concentrations

that may be exacerbated by human activities (Figure 2). While levels vary from year to year, in any given year Budd Inlet experiences the lowest concentrations of dissolved oxygen.

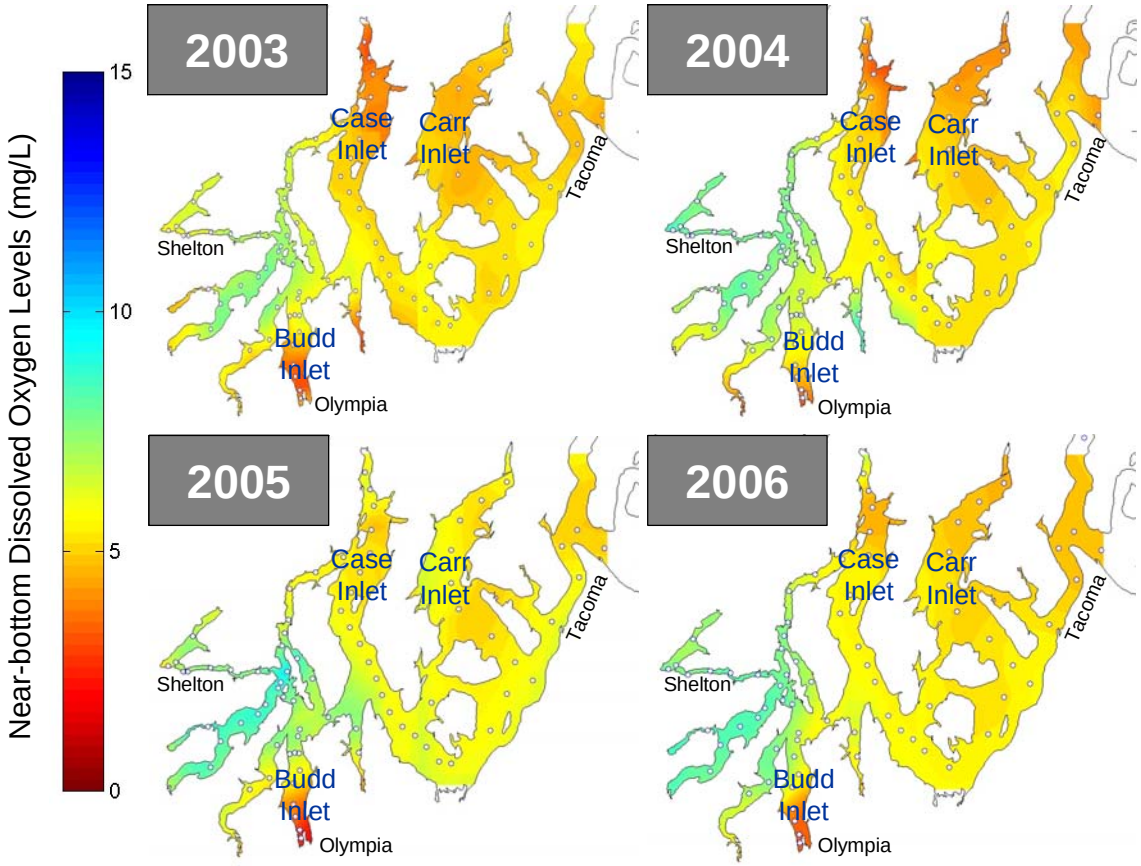

Figure 2. Near-bottom dissolved oxygen levels in South Puget Sound. Levels are from September data collection cruises over a four-year periods.

Sources of nutrients to South Puget Sound include both point sources and nonpoint sources. The wastewater treatment plant effluent from the Lacey Olympia Tumwater Thurston County (LOTT) alliance is the largest point source, while the combined Deschutes River and Capitol Lake discharge is the largest nonpoint source, both by volume and nutrient load. A study conducted by Ecology found that both point sources and nonpoint sources produce significant loads of dissolved inorganic nitrogen (DIN, the sum of nitrate, nitrite, and ammonium) and that many South Puget Sound inlets are sensitive to increasing loads of nitrogen (Albertson et al 2002a; 2002b).

Ecology required that LOTT upgrade wastewater treatment facilities to reduce nitrogen loads to Budd Inlet, and in 1994 LOTT began including denitrification between April and October each year.

Capitol Lake was created in 1951 as an impoundment of the former Deschutes River estuary. Capitol Lake was created to provide a reflecting pool for the Capitol building, which sits on a bluff to the east of the central basin (Figure 3). The Deschutes River enters the

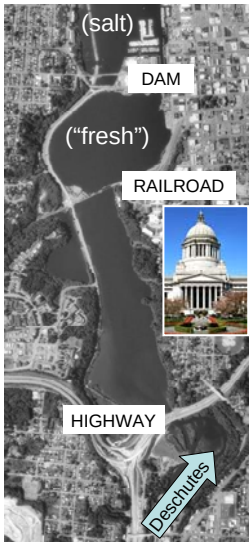

Figure 3. Capitol Lake and the Washington State Capitol campus.

lake from the south. Two major constrictions, the Interstate 5 and railroad bridges, create three distinct basins with varying water depths and morphological attributes. General Administration, a state agency, operates the dam outlet of the lake as part of the overall Washington State Capitol Campus. General Administration convened a group of stakeholders, called the Capitol Lake Adaptive Management Plan (CLAMP) Committee, to determine whether the lake should remain as is or revert to the Deschutes estuary. An ongoing process is evaluating the costs and benefits of a variety of options, and the decision may not be made for many years.

Methods

The ongoing study includes both supplemental data collection and model development to simulate nutrient dynamics in the Deschutes River, Capitol Lake, and Budd Inlet. Primary data collection occurred from July 2003 through December 2004. Freshwater and marine model development is ongoing and will be presented in a final project report due in 2008.

Monthly samples collected along the length of the Deschutes River and Capitol Lake as well as tributaries were analyzed for nutrient content (total phosphorus, orthophosphate, total nitrogen, nitrate plus nitrite, and ammonium), as described in the monitoring plan (Roberts et al. 2004). In addition, Hydrolabs were installed in the Deschutes River and Capitol Lake to record dissolved oxygen, pH, temperature, and conductivity continuously over a three-day period during late-summer conditions. No additional monitoring was conducted in Budd Inlet; the extensive dataset developed in the Budd Inlet Scientific Study (Aura Nova Consultants et al. 1998) and ongoing ambient monitoring conducted by Ecology will be used to refine the Budd Inlet model.

The one-dimensional QUAL2Kw model (Pelletier et al. 2006) will be used to simulate dissolved oxygen, nutrients, and temperature in the Deschutes River during critical late-summer conditions. However, monitoring data from the system provides insight to the processes affecting productivity in the watershed.

The model previously used in the Budd Inlet Scientific Study to simulate marine dissolved oxygen levels is being refined for the present study. The Generalized Environmental Modeling System for Surface Waters (GEMSS, http://www.erm-smg.com/) is an updated version of GLHVTT, which was the model previously applied during the Budd Inlet Scientific Study (Aura Nova Consultants et al. 1998). J.E. Edinger Associates, now ERM Consultants, developed GEMSS as an integrated hydrodynamic and water quality model system with geographical information system and environmental data management capabilities. Under the present project, the previously developed grid and model input for Budd Inlet will be transferred to the new software platform and the grid will be extended from the Capitol Lake outlet structure to the Deschutes River inflow to Capitol Lake, such that Capitol Lake and Budd Inlet can be modeled as an integrated system. While model development is ongoing, marine data collection provides insight to the processes influencing dissolved oxygen levels in Budd Inlet.

Results

Deschutes River dissolved oxygen and nutrients

Dissolved oxygen levels in portions of the Deschutes River fall below the minimum values established in the water quality standards (Figure 4). The water quality standards in place at the beginning of the project stipulated that DO concentrations cannot fall below 8.0 mg/L;

however, the standards have been revised recently and the Deschutes River reclassified such that DO concentrations must meet a more stringent standard and not fall below 9.5 mg/L.

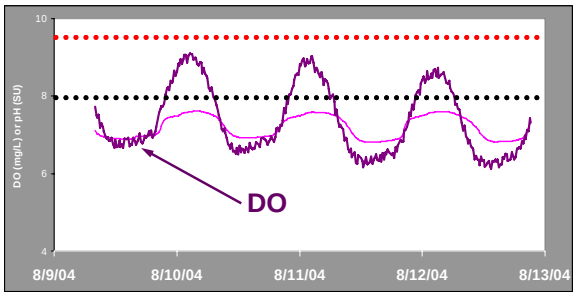

Figure 4. Deschutes River dissolved oxygen (thick purple line) and pH (thin pink line) levels in the upper watershed. The black dotted line is the water quality standard for DO when the project began, while the red dotted line indicates the current DO target in the revised water quality standards.

Cycles of algal respiration consume oxygen during the night and produce oxygen during daylight hours, giving rise to a diel pattern with minimum concentrations near sunrise. In the morning, concentrations fall below 8.0 mg/L, due in part to natural cycles but likely exacerbated by anthropogenic sources of nutrients in the watershed. The Deschutes River also is warmer than the water quality standards for temperature during the summer. Increasing riparian shade will reduce stream temperatures, which will also improve dissolved oxygen concentrations because saturation is a function of stream temperature. However, watershed nutrient load reductions may be necessary to improve dissolved oxygen concentrations to healthy levels.

Nutrient concentrations exhibit an increasing trend from upstream to downstream in the Deschutes River (Figure 5), indicating steady increases in loads. This pattern is not unique to the Deschutes River but is representative of patterns identified throughout the Puget Lowland ecoregion. Nutrient concentrations decrease within Capitol Lake, indicating that Capitol Lake may buffer nutrient loads to Budd Inlet during some parts of the year through significant in-lake productivity and settling.

However, the warm, shallow waters of Capitol Lake provide optimal conditions for algal growth. Blue-green algae blooms often occur in August (Figure 6), and the considerable biomass likely contributes spikes in organic matter loading to Budd Inlet which could exacerbate near-bottom dissolved oxygen levels. Because of the uncertainty in whether Capitol Lake will remain a lake

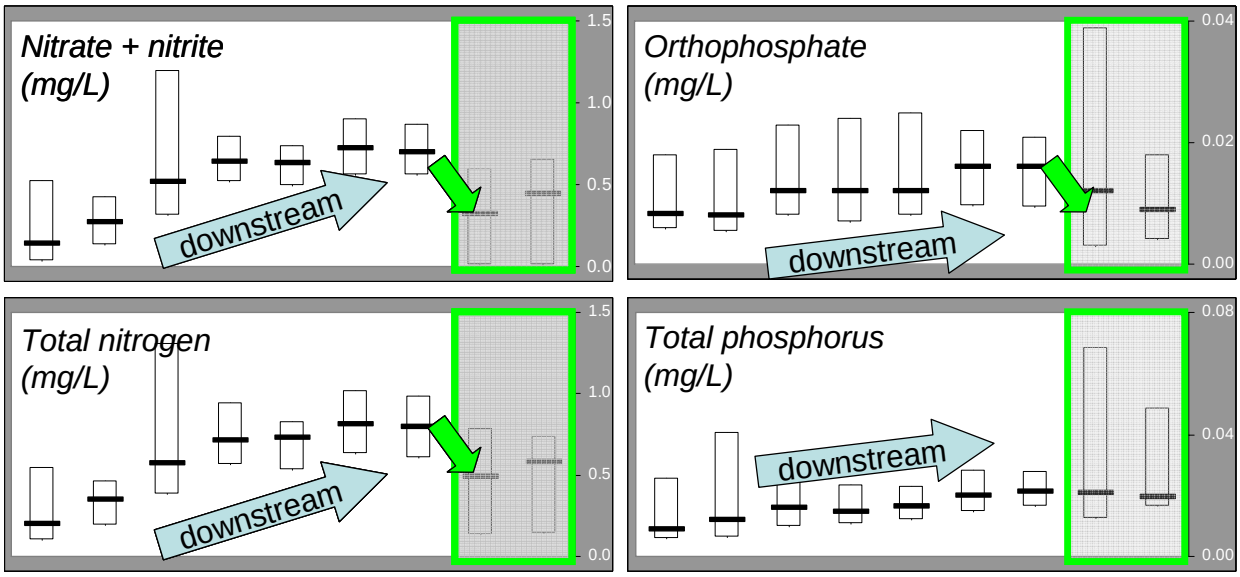

Figure 5. Deschutes River and Capitol Lake nutrient profiles. Green box identifies Capitol Lake monitoring stations at the railroad bridge and lake outlet.

or revert to an estuary, and because the lake likely exerts considerable seasonal influence on water quality in Budd Inlet, future model efforts will characterize Budd Inlet dissolved oxygen levels with and without the Capitol Lake outlet structure in place.

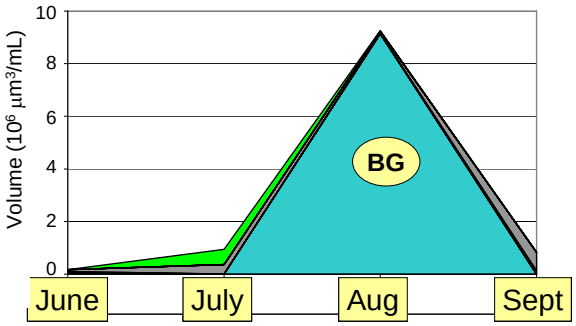

Figure 6. Algae levels at the railroad trestle within Capitol Lake in summer 2004. Green algae are indicated in green, diatoms in gray, and blue-greens in aqua.

Deschutes River and Budd Inlet nutrient and dissolved oxygen trends with time

Ambient monitoring conducted near the mouth of the Deschutes River indicates that summer dissolved inorganic nitrogen (DIN) concentrations exhibit an increasing trend (Figure 7), although the summer monthly grab samples also exhibit a wide range of concentrations. Recently, summer concentrations have been at the top of the historical range of concentrations.

Summer baseflows have decreased in the Deschutes River, based on U.S. Geological Survey discharge monitoring near the mouth of the river. The site was gaged continuously between 1945 and 1964, then discontinued for many years before continuous monitoring resumed in 1999. Summer low flows, as indicated by the lowest 7-day average discharge that occurs on average once every ten years (7Q10), have decreased from 78 cfs historically to 56 cfs for the more recent period. Much of that decline could be attributed to a shift in the climate cycle, since the historical gaging coincided with a wet-period Pacific Decadal Oscillation (PDO) while the more recent time period coincides with a dry-period PDO.

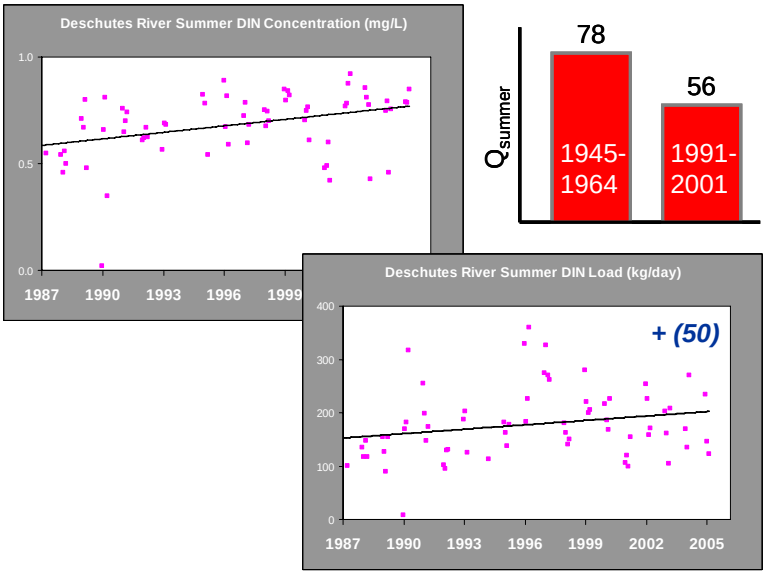

Figure 7. Deschutes River DIN concentrations (mg/l), discharge (cfs), and DIN load (kg/d) over time. Source: Ecology station 13A060 and USGS station 12080010.

The load, generated by multiplying the concentration by the flow, also exhibits a weak upward trend in the Deschutes River of approximately 50 kg/d on average (Figure 7). Monthly and interannual variability are high, however.

DIN loads from the LOTT wastewater treatment plant declined dramatically once denitrification was implemented in 1994. Figure 8 illustrates that the monthly ammonium loads decreased from 400 to 600 kg/d prior to denitrification to <50 kg/d since denitrification. Because the increase in DIN loads from the Deschutes River is much lower than the precipitous decrease

from the LOTT wastewater treatment plant, the sum of point source and nonpoint source DIN loads has decreased substantially to Budd Inlet in summer months.

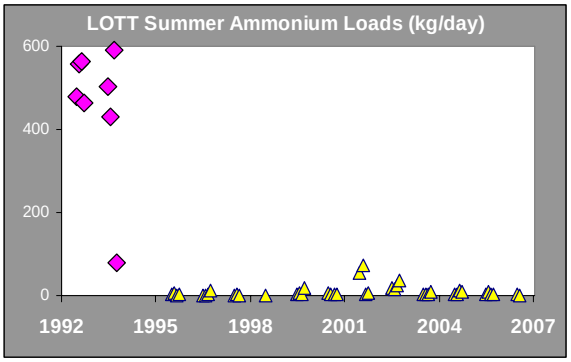

Figure 8. Ammonium loads from the LOTT wastewater treatment plant before and after denitrification was added in 1994. Source: monthly monitoring reports from LOTT.

The near-bottom dissolved oxygen concentrations in central Budd Inlet have continued to decline (Figure 9), even with the decrease in DIN loads from the primary point source. Other confounding factors, in addition to the point source and nonpoint source loads, may be influencing dissolved oxygen concentrations in the central inlet. The biggest benefit to the decreased summer nutrient loads likely occurred in southern Budd Inlet, which may be more sensitive to nearshore loading than central Budd Inlet. However, no long-term monitoring has been conducted in this sensitive location with which to quantify the actual benefits. Also, near-bottom concentrations in central Budd Inlet may have declined even further had the summer loads not been reduced, and point source load reductions represent the first step in a longer-term adaptive management process.

Status of marine modeling

To date, the grid used to model the marine waters for the Budd Inlet Scientific Study (Aura Nova Consultants et al. 1998) has been redeveloped for the updated GEMSS software system, and the grid has been extended southward to include Capitol Lake (Figure 10). With the 1996-1997 boundary condition data used in the Budd Inlet Scientific Study, we have reproduced the original model calibration results (Figure 11). Current efforts target the Capitol Lake simulation and in particular, the effect of macrophyte growth and algae blooms on water quality.

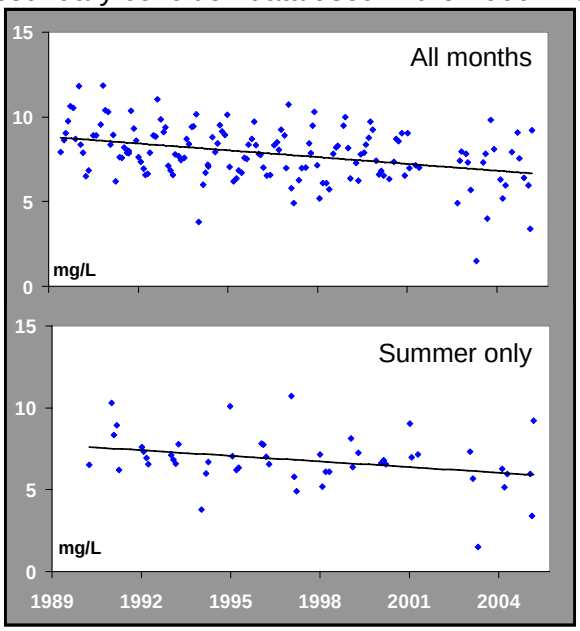

Figure 9. Near-bottom dissolved oxygen levels in central Budd Inlet. Source: Ecology station BUD005.

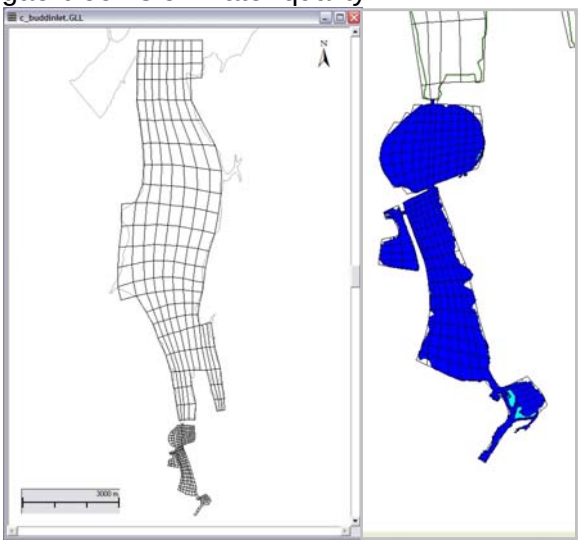

Figure 10. GEMSS model grid of Budd Inlet and Capitol Lake.

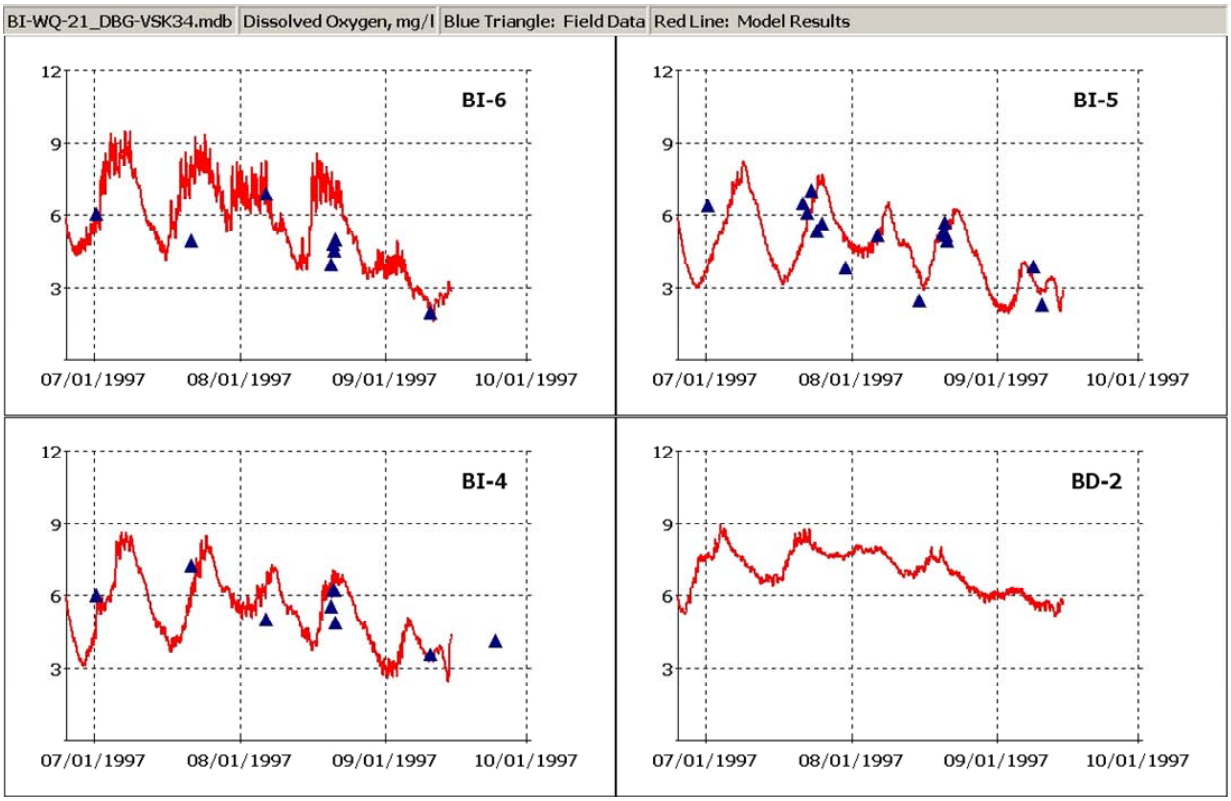

Figure 11. Comparing current Budd Inlet model output data from the GEMSS framework to calibration data from the Budd Inlet Scientific Study (1996-1997).

Future work

Deschutes River model

Because dissolved oxygen saturation is temperature dependent and because the Deschutes River currently is too warm in critical summer months, the first step in improving dissolved oxygen concentrations is cooling the water. Scenarios will include increasing shade and decreasing channel width, both of which can be targeted for quantitative changes under a TMDL study. In addition, we will evaluate alternative flow regimes that involve increasing summer baseflow and the benefits to temperature. However, the TMDL process cannot establish alternative minimum instream flow requirements, and the findings from these scenarios will be for information purposes only.

The first dissolved oxygen scenario will be the benefits of achieving cooler water. If cooler water, with the existing flows and nutrient loads, results in dissolved oxygen levels that meet the water quality standards, then implementing the temperature findings will rectify the freshwater DO problems. However, if DO still falls below the water quality standards, the TMDL study will recommend a series of nutrient load reductions throughout the watershed necessary to meet the standards. Generally phosphorus controls productivity and DO dynamics in freshwater, and phosphorus reductions would likely be included. However, because the Deschutes River is the primary nonpoint nitrogen source to Capitol Lake and Budd Inlet, additional nitrogen reductions may be recommended to benefit these downstream waterbodies, even though nitrogen may not be the limiting nutrient in freshwater. Therefore, the nitrogen load reductions for the Deschutes

River may be established using the coupled Budd Inlet/Capitol Lake model under both the Capitol Lake and the Deschutes estuary alternative future scenarios.

Budd Inlet and Capitol Lake model

Once the marine model has been finalized to include the current Capitol Lake configuration and reapplied to the 1996-1997 calibration conditions, we will evaluate two families of scenarios, with and without Capitol Lake in place. The first includes Capitol Lake under the current outlet configuration and operating rules and the second evaluates water quality with an estuary in place. Several estuary alternatives currently are being evaluated by the independent CLAMP process and Deschutes Estuary Feasibility Study, and we will coordinate with that process on an estuary definition. Therefore, we will recommend point source and nonpoint source reductions necessary to achieve water quality standards within Budd Inlet and either Capitol Lake or the Deschutes Estuary.

Conclusions

Budd Inlet offers a microcosm for South Puget Sound water quality issues and an example of adaptive management that continues after the first nutrient load reduction was implemented 13 years ago. Historically, the LOTT wastewater treatment plant was a large contributor to summer DIN loads to the southern inlet. While point source reductions were implemented through tightening permit limits, nonpoint sources may be increasing. Nonpoint source control is more indirect but must be included in any long-term nutrient management plan for Budd Inlet and also for South Puget Sound. The coupled Budd Inlet/Capitol Lake model will improve our understanding of the effects of potential management activities or changes to forcing functions that result from climate change or farfield activities.

References

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

Albertson, S.L., K. Erickson, J.A. Newton, G. Pelletier, R.A. Reynolds, and M.L. Roberts, 2002b, Summary of South Puget Sound Area Water Quality Study, Washington State Department of Ecology Publication No. 02-03-020. www.ecy.wa.gov/biblio/0203020.html.

Aura Nova Consultants, Brown and Caldwell, Evans-Hamilton, J.E. Edinger and Associates, Ecology, and the University of Washington Department of Oceanography, 1998, Budd Inlet Scientific Study Final Report, prepared for the LOTT Partnership, Olympia, WA.

Pelletier, G.J., S.C. Chapra, and H. Tao, 2006, QUAL2Kw – a framework for modeling water quality in streams and rives using a genetic algorithm for calibration. Environmental Modelling & Software, 21(2006)419-425.

Roberts, M., B. Zalewsky, T. Swanson, L. Sullivan, K. Sinclair, and M. LeMoine, 2004, Quality Assurance Project Plan for the Deschutes River, Capitol Lake, and Budd Inlet Temperature, Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Fine Sediment Total Maximum Daily Load Study. Washington State Department of Ecology Publication No. 04-03-103, Olympia, WA. www.ecy.wa.gov/biblio/0403103.html.