Summary of South Puget Sound Water Quality Study

The purpose of the South Puget Sound Study is to evaluate the potential effects of increased nutrients on phytoplankton growth and associated changes in dissolved oxygen concentrations.

Why is South Puget Sound of concern?

Previous studies (*Newton et al., 1997*) suggest that near-bottom levels of dissolved oxygen in South Puget Sound may be depleted in areas that have strong stratification, high production, and subsequent oxidation of organic material. South Puget Sound exhibits all of these characteristics *(Figure 1)*. Low dissolved oxygen may harm aquatic life.

Objectives

- ❖ Identify areas within South Puget Sound susceptible to eutrophication and its effects
- ❖ Assess flushing and nutrient cycling in inlets and bays
- ❖ Estimate existing point- and nonpoint-source loads
- ❖ Develop a three-dimensional hydrodynamic and water quality model to evaluate the capacity to assimilate existing and future pollution loads

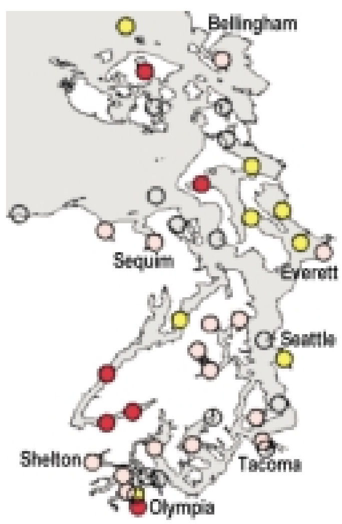


Figure 1. Data compiled from 1990-97 show stations exhibiting low concentrations of dissolved oxygen (red 3 mg/l; yellow 5 mg/l) or sensitivity to eutrophication (pink) based on physical and chemical characteristics. South Puget Sound has a high incidence of both.

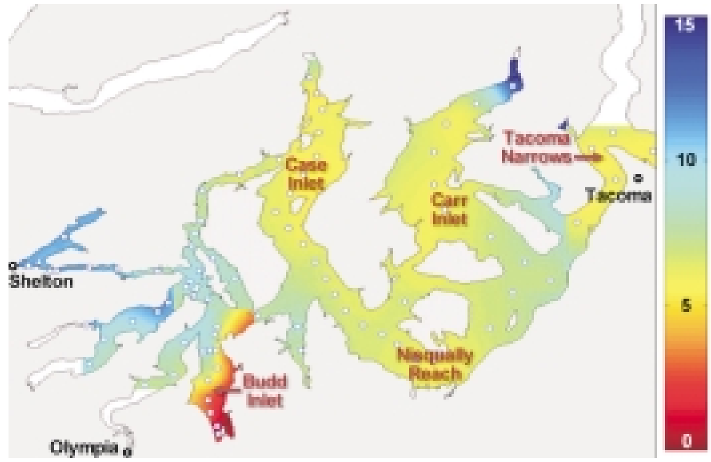
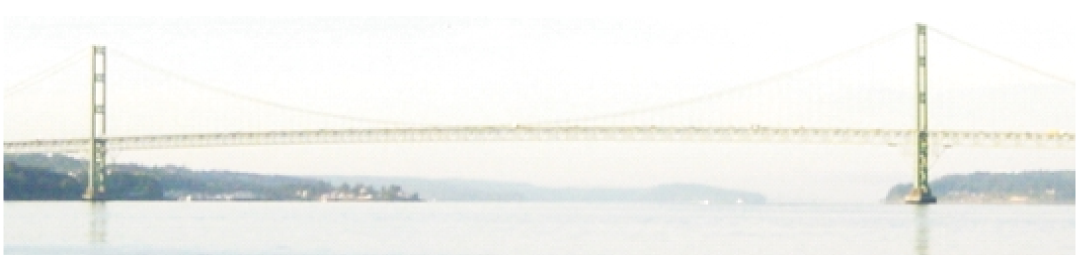


Figure 2. Dissolved oxygen levels (mg/L) measured within five meters of the bottom at sampling stations (circles) during cruises illustrate the spatial distribution of low levels. In September 1999, near-bottom concentrations in Budd Inlet were <3 milligrams per liter (mg/L), while concentrations in Carr and Case inlets had values approaching 5 mg/L. Carr, Case, and Budd inlets are particularly susceptible to further decreases in near-bottom dissolved oxygen resulting from increased nutrients.

Increasing development may impair marine water quality through elevated point- and nonpoint-source loads of nutrients, which stimulate production. Although individual sources may not have a measurable influence, their combined impacts could significantly degrade water quality.

South Puget Sound exhibits slow flushing rates, which limit the ability of the basin to dilute and exchange nutrients with the Pacific Ocean. Extensive shorelines and the rural nature of the upland and lowland areas attract significant residential development, and many recreational farms now exist in the watersheds.



What areas are most sensitive?

Oceanographic cruises conducted periodically record concentrations of dissolved oxygen and other parameters throughout South Puget Sound. The lowest dissolved oxygen levels of the year typically occur in late summer.

Budd Inlet, Carr Inlet, and Case Inlet exhibit the lowest levels of dissolved oxygen within South Puget Sound *(Figure 2)* and may be most sensitive to increases in nutrient loads.

Other smaller inlets appeared to have stronger mixing that did not allow the low oxygen levels to persist. However, loading of other substances, like viruses or fecal coliform bacteria, in these areas would be of concern due to the inlets' slow overall flushing rates.

What is primary production?

This term refers to the creation of organic material by photosynthetic organisms. In marine waters like Puget Sound, this is done primarily by one-celled microscopic algae, known as phytoplankton. Phytoplankton live suspended in the water, needing sunlight and nutrients, such as nitrogen and phosphorus, to grow. Low nitrogen levels typically limit phytoplankton growth in marine waters, but phosphorus limits growth in freshwater.

Securing a stable environment where phytoplankton have sufficient light, nutrients, and time to grow is not always easy in a fluid, since water moves and the cells must move with it. Light is brightest at the surface. Nutrients tend to be richer on the bottom, as bacteria release them from sunken organic material upon which they feed (*Figure 3*). If the water is well-mixed, cells might travel out of the zone where light is available, even though they have plenty of nutrients. Forces such as tides and winds can cause strong mixing in Puget Sound. Alternatively, the water may have distinct density layers, like oil riding on top of water, due to fresh or warm water overlying cold, salty water. As long as the layering is not disrupted by mixing, then the phytoplankton can stay in the stable top layer where light is available (*Figure 4*). Growth will be strong until nutrients run out. Phytoplankton "blooms" occur when cells have both light and nutrients for sustained periods, causing the phytoplankton population to increase markedly.

How does primary production influence water quality?

"Water quality" is a complex term that covers many attributes of water. Characteristics as diverse as the presence of fecal coliform bacteria, low levels of dissolved oxygen, and even altered water temperature indicate poor water quality. Water quality is evaluated against what the natural state is presumed to be.

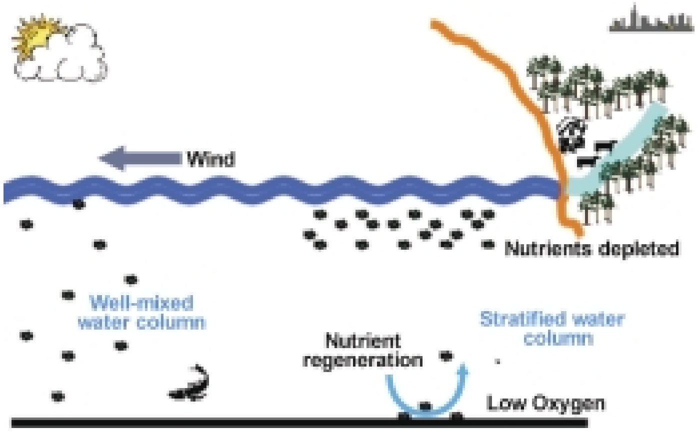


Figure 3. Where the waters are mixed, nutrients, phytoplankton, and dissolved oxygen also mix over the entire water depth. In stratified waters, phytoplankton tend to remain near the surface where sunlight is brightest but low nutrient levels limit growth. As the phytoplankton die and sink to the bottom, other organisms consume the organic material, using oxygen in the process. Because oxygen diffuses from the surface layer very slowly, oxygen levels near the bottom decrease.

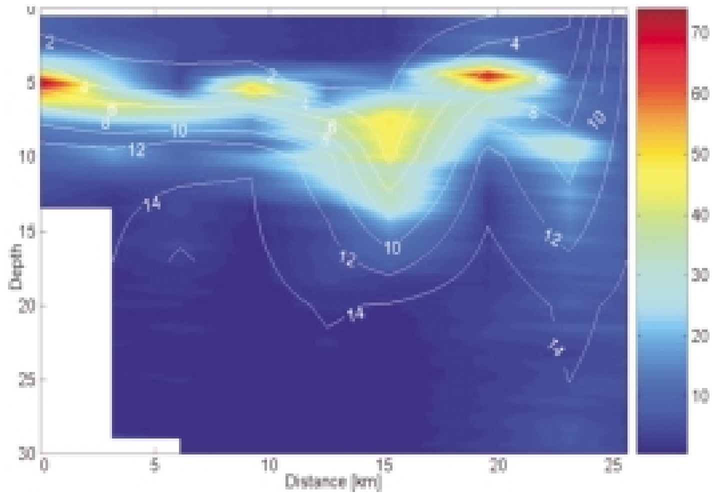


Figure 4. The false-color plot compares chlorophyll a fluorescence (color in relative units), a measure of phytoplankton biomass, with contours of nitrate concentrations (uM), illustrating the effect of phytoplankton on surface nutrients in Carr Inlet. Experimental results indicate nitrogen limits phytoplankton growth; therefore, Carr Inlet is nitrogen limited.

Phytoplankton production can affect water quality. Algae respond to nutrients that humans may have added into the Sound by changing the amount of dissolved oxygen available in the deep waters. When low nutrient levels limit phytoplankton growth, as commonly happens in summer, the added nutrients will cause more phytoplankton than normal to grow. The excessive algal population will sink and accumulate on the seafloor, where bacteria will break down the organic material, consuming oxygen in the process. Thus, excessive algae growth can cause lower oxygen concentrations than normal. Low concentrations of dissolved oxygen are bad for aquatic animals, such as fish or crabs, that need to breathe.

How do increased nutrient loads influence primary production and water quality?

The extra load of nutrients from human activities (farms, runoff, and sewers) can stimulate phytoplankton growth by providing more food. Excessive accumulation (blooms) can result in dangerously low oxygen concentrations in deep waters of the Sound. However, this phenomenon occurs only when low ambient nutrient levels, rather than other factors such as low sunlight, limit growth.

If cells have plenty of nitrogen available, then adding more will not have an effect. This is the situation found in well-mixed areas, such as the Narrows or Dana Passage, where nutrient-rich deep waters are mixed to the surface and diffused with air. But if the waters have layers of water that do not mix, then low-oxygen zones can develop from stimulated phytoplankton growth. This is the situation in places like Budd, Carr, and Case inlets, where freshwater inflows cause density layering or where tidal mixing is gentler. Some areas are naturally more sensitive to nutrient loading than others, and the amount that water quality will be affected varies.

What is the flushing rate?

The flushing rate is how quickly all water within the basin is replaced, or the inverse of the residence time. A simple way to estimate the flushing rate takes the volume of South Puget Sound at high tide (1.6×10^{10} m^3) divided by the mean intertidal volume (1.7×10^{9} m^3/cycle), which is ten tidal cycles, making the gross flushing rate once in five days. However, the Sound is stratified and incompletely mixed, so the effective residence time is on the order of two months, or a flushing rate of once every two months.

Why does South Puget Sound flush so slowly?

South Puget Sound flushes slowly because its complex shape and large number of inlets retain water longer than simpler systems. The water column stratifies seasonally, and nutrients entering South Sound from freshwater generally mix with the upper water column only. This limits overall mixing and dilution.

The tidally averaged flow *(Figure 5)* identifies flushing rates by area. The Tacoma Narrows and Nisqually Reach areas flush quickly; areas such as Carr and Case inlets flush slowly.

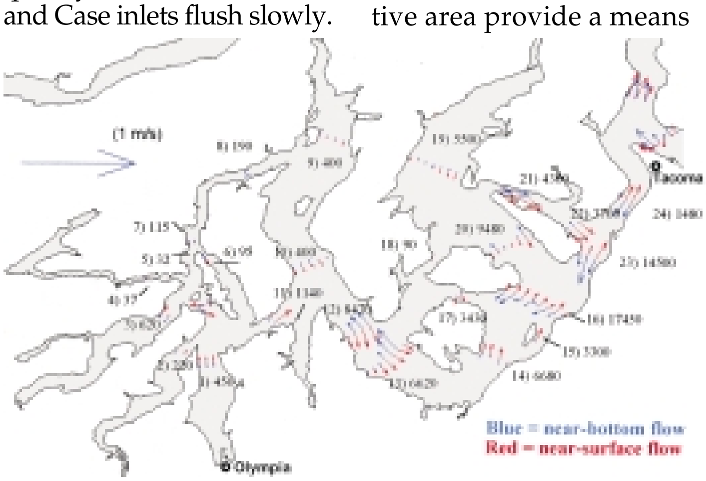


Figure 5. Arrows indicate level of flushing, with longer arrows indicating greater flushing. Arrows are based on the tidally averaged flow for August 1997.

How important are direct point-source discharges, watershed inflows, and atmospheric deposition?

Direct point sources are those that discharge to marine waters. Watershed inflows include other point sources that discharge to freshwater and nonpoint sources (e.g., storm runoff). Atmospheric deposition includes airborne contaminants only.

Direct point sources and watershed inflows contribute comparable loads, as evident in *Figure 6* for dissolved inorganic nitrogen. While direct point-source volumes are 2 percent of the watershed inflows to South Puget Sound, direct discharges represent 36 percent of the total nitrogen load and 54 percent of the total phosphorus load to South Puget Sound, as well as 43 percent of the organic nitrogen load and 30 percent of the dissolved inorganic nitrogen load. Atmospheric deposition contributes loads several orders of magnitude smaller.

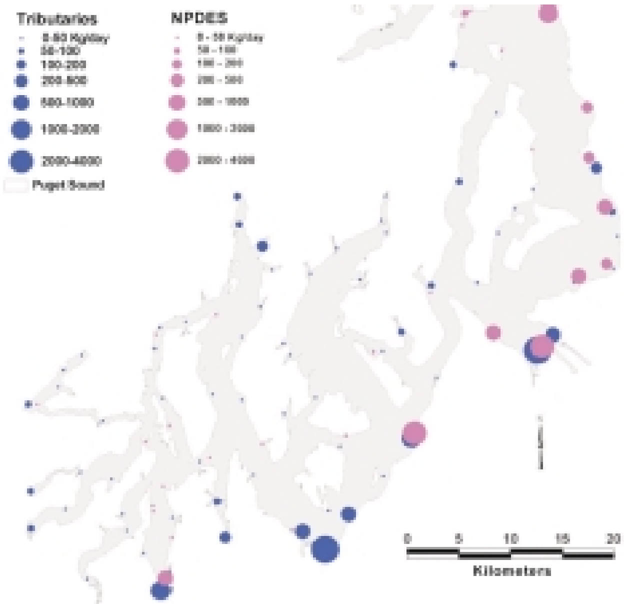


Figure 6: Annual average dissolved inorganic nitrogen loads (kg/d) by magnitude for direct point sources and watershed inflows, which include point sources discharging to freshwater.

What areas contribute the highest nitrogen loads?

Generally, larger watersheds contribute higher loads, due in part to the higher flows. However, loads normalized by relative contribution and relative area provide a means of comparing among watersheds of varying sizes. Several large and small watersheds contribute higher loads per unit area than average for the entire South Puget Sound watershed *(Figure 7)*.

What is the critical time of year for South Puget Sound water quality?

Water temperature and salinity strongly influence physical, chemical, and biological processes in South Puget Sound, leading to strong seasonal variations. Late summer appears to be the most important time of year for water quality. Near-bottom levels of dissolved oxygen are lowest *(Figure 2)*, due to the persistence of strong stratification.

In the winter, surface water temperatures are coldest but salinity levels are the lowest of the year; thus, winter stratification is relatively strong. In inlets, where stratification persists through spring and summer, conditions are favorable for phytoplankton growth and accumulation in the surface layers, resulting in depleted inorganic nutrients at the surface and depleted dissolved oxygen in underlying waters *(Figure 3)*. Experimental results also indicate nitrogen limits phytoplankton.

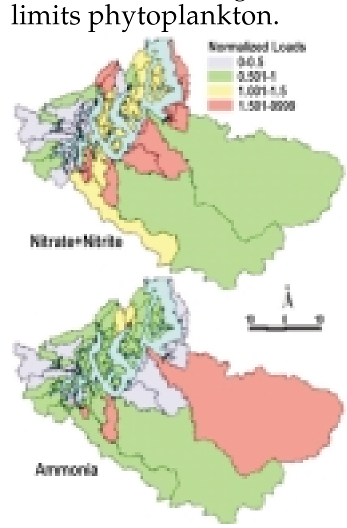


Figure 7: Normalizing loads by watershed area allows comparison among watersheds of different sizes. Several watersheds contribute more than the average load per unit area for the entire South Puget Sound watershed.

What models are being applied to South Puget Sound?

The Department of Ecology selected the Environmental Fluid Dynamics Code (EFDC) to simulate hydrodynamics, salinity, temperature, and nutrients in three dimensions. Grid size averages 630 meters by 630 meters in each of four layers.

Model inputs include time series of tide amplitude and period near Alki Point, freshwater inflows and loads throughout the Sound, solar radiation, and other meteorological data. EFDC models how dissolved oxygen concentrations respond to nutrient loads and phytoplankton primary production using both oxidation of organic material and sediment flux.

Does the model represent South Puget Sound conditions?

Hydrodynamic components of the model represent tides, wind effects, and water motion throughout the system appropriately, and sea-surface elevations match measured data (*Figure 8*). Currently, the model over-predicts bottom friction, resulting in slightly longer residence times and slower flushing rates than actual conditions. An initial comparison of predicted and measured salinity and temperature indicates the model does not represent these properties adequately.

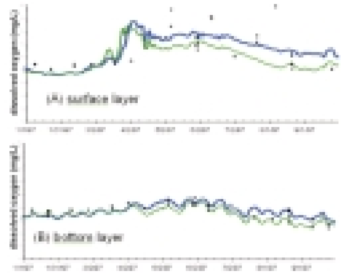


Figure 9. Model predictions of surface and near-bottom dissolved oxygen concentrations for central Budd Inlet. Measured data are shown as diamonds. The thick blue line represents model runs using values calibrated for Chesapeake Bay, while the thin green line represents values calibrated for Budd Inlet by others.

The model simulates seasonal water quality patterns. Results show increasing chlorophyll from April to September coupled with decreasing dissolved inorganic nitrogen, which represents nutrient food sources, based on limited monitoring data. *Figure 9* shows that central Budd Inlet, site of the most extensive dataset (*Aura Nova Consultants et al., 1998*), is represented well.

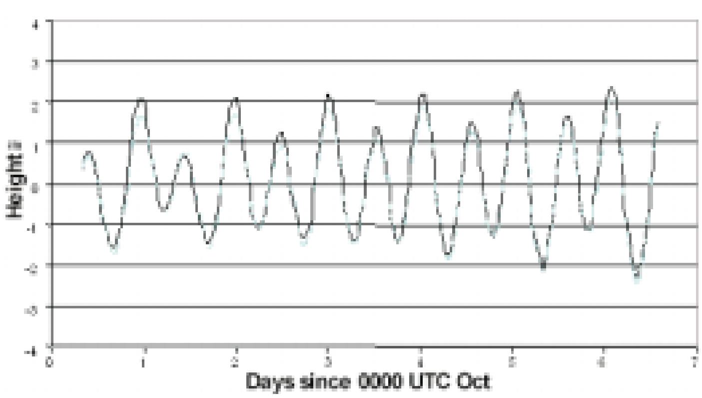


Figure 8. Representative time series of observed tides with no wind (dashed lines) compared with model output (solid lines) in Budd Inlet.

What are the greatest uncertainties?

The hydrodynamic components were calibrated using measured sea-surface elevations and tidal predictions because no domain-wide current velocity data are available. Measured current velocity data would provide a more sensitive indicator of model accuracy.

While both hydrodynamic and water quality components of the model compare reasonably well with available data, those data are limited both spatially and temporally. Water quality sensitivity analyses indicate near-bottom levels of dissolved oxygen are most sensitive to sediment oxygen demand, settling rates of phytoplankton and particulate organic matter, as well as algal metabolism, growth, and predation rates. However, no field studies are available that would aid in calibrating individual processes.

What are the next steps?

Ecology is currently assessing available funding for the next phase of this project. Next steps, as funding allows, are to

1. Establish an advisory committee, with representation from Tribes, agencies, and other groups.

2. Collect additional oceanographic and watershed data. Ecology anticipates continuing its annual fall cruises to capture conditions during the critical fall period.

The highest priority geographic areas for further monitoring are Case and Carr inlets. Additional monitoring should target the biological and chemical processes that most affect dissolved oxygen and are sensitive to model input values, in particular those in the sediment/water interface.

3. Further develop and calibrate the hydrodynamic and water quality components for the model.

References

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 Dept. of Ecology, Pub. No. 02-03-021.

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Newton, J.A., S.L. Albertson, and A.L. Thomson. 1997. Washington State Marine Water Quality in 1994 and 1995. Washington State Department of Ecology, Olympia, WA. Pub. No. 97-316.

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This publication is based on the South Puget Sound Water Quality Study Phase 1 Report, available on the Department of Ecology home page on the World Wide Web at http://www.ecy.wa.gov/biblio/0203021.html.

For more information, please contact Jeannette Barreca at 360-407-6556 or jbar461@ecy.wa.gov.

Authors: Storrs "Skip" L. Albertson, Karol Erickson, Jan A. Newton, Greg Pelletier, Rick A. Reynolds, and Mindy Roberts.