'Natural conditions' are at the center of disputes over dissolved oxygen standards

Questions over water quality standards have centered around nutrients that can lead to algal blooms and low oxygen levels. (Above) An algal bloom in Liberty Bay, WA in 2016. Photo: Ecology

KEYWORDS: EUTROPHICATION, HYPOXIA, SALISH SEA CURRENTS MAGAZINE, WATER QUALITY

By Christopher Dunagan

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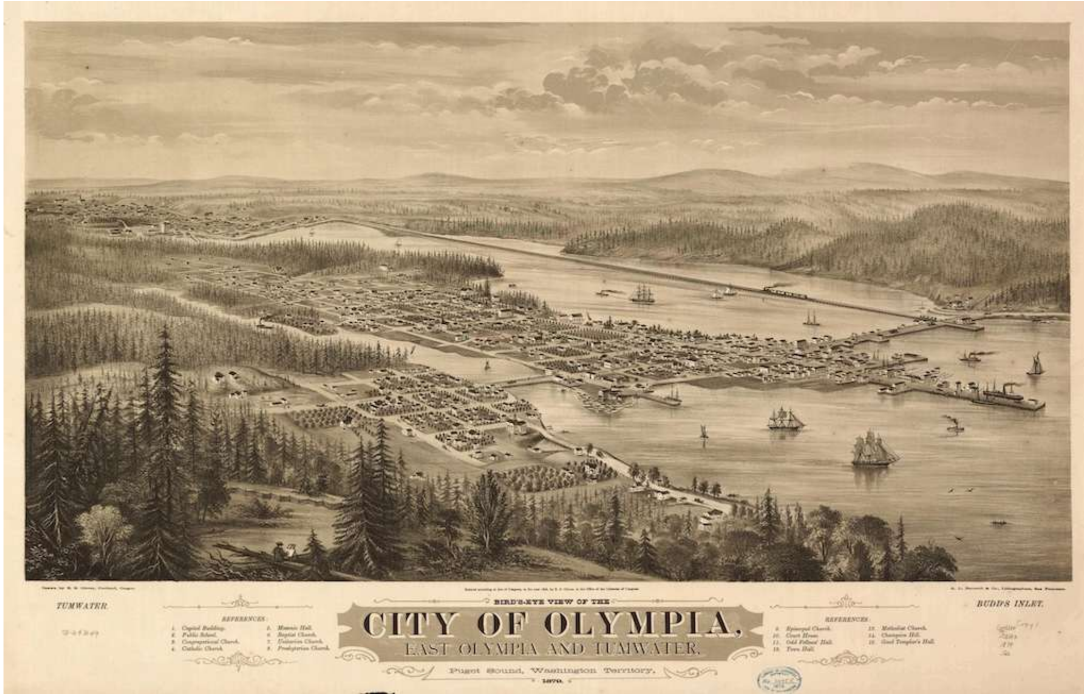
Oxygen is indisputably essential to aquatic life, but conflicts are brewing over water quality standards mandated in state regulations. This article is part of a series of reports funded by King County about the quest to define healthy oxygen levels in Puget Sound. By some estimates, those definitions could affect billions of dollars in state and local spending. [Editor's note: King County is currently in litigation with the Washington State Department of Ecology over the issue of dissolved oxygen water quality standards.]

Before early settlers built the region's first sawmill at Tumwater in 1848, before Arthur Denny and his party settled the future city of Seattle in 1851, and before the federal government created Washington Territory in 1853, the waters of Puget Sound and its freshwater streams were as clean as nature could provide. Fish and wildlife were abundant, having adapted to local conditions alongside native people of the area.

Needless to say, things have changed since those days. In the parlance of today's water-quality regulations, the clean waters of yesteryear are known as "natural conditions." Nobody believes that we will ever see those conditions again, but the term "natural conditions" has taken on a profound meaning as a point of reference. How far do we humans want to go in restoring polluted waters and limiting unhealthy discharges of wastewater into Puget Sound?

Washington Department of Ecology is currently struggling to establish a regulatory system involving natural conditions, based on the idea that it makes no sense to set cleanup goals beyond the best that nature has ever provided. The federal Environmental Protection Agency, which maintains ultimate authority over the nation's waterways, overturned



Illustrated view of the city of Olympia, East Olympia and Tumwater, Puget Sound, Washington Territory, 1879. Image: Illustrated perspective map: [Library of Congress, Geography and Map Division]

Ecology's existing natural conditions rule in 2021. Since then, Ecology has been working on a revision, particularly addressing water-quality goals for temperature and dissolved oxygen.

The agency recently completed [limited rules] for setting cleanup standards in defined locations. The ongoing effort is to create an enduring "performance-based" program that would empower experts to identify natural conditions anywhere in Puget Sound, along with an approved allowance for human degradation. The first draft received rather harsh comments from the EPA. A revised proposal that addresses only dissolved oxygen for marine waters [was released for public comment this week.]

In a letter to Ecology about the first draft, Rebecca Garnett, manager of standards and assessment for EPA's Region 10, said any new water quality criteria must meet scientific standards, be spelled out in sufficient detail, and fully protect aquatic creatures. "As currently proposed," she wrote, "the EPA is concerned that Ecology's performance-based approach for developing site-specific natural conditions criteria is not sufficiently 'binding, clear, predictable, and transparent.'"

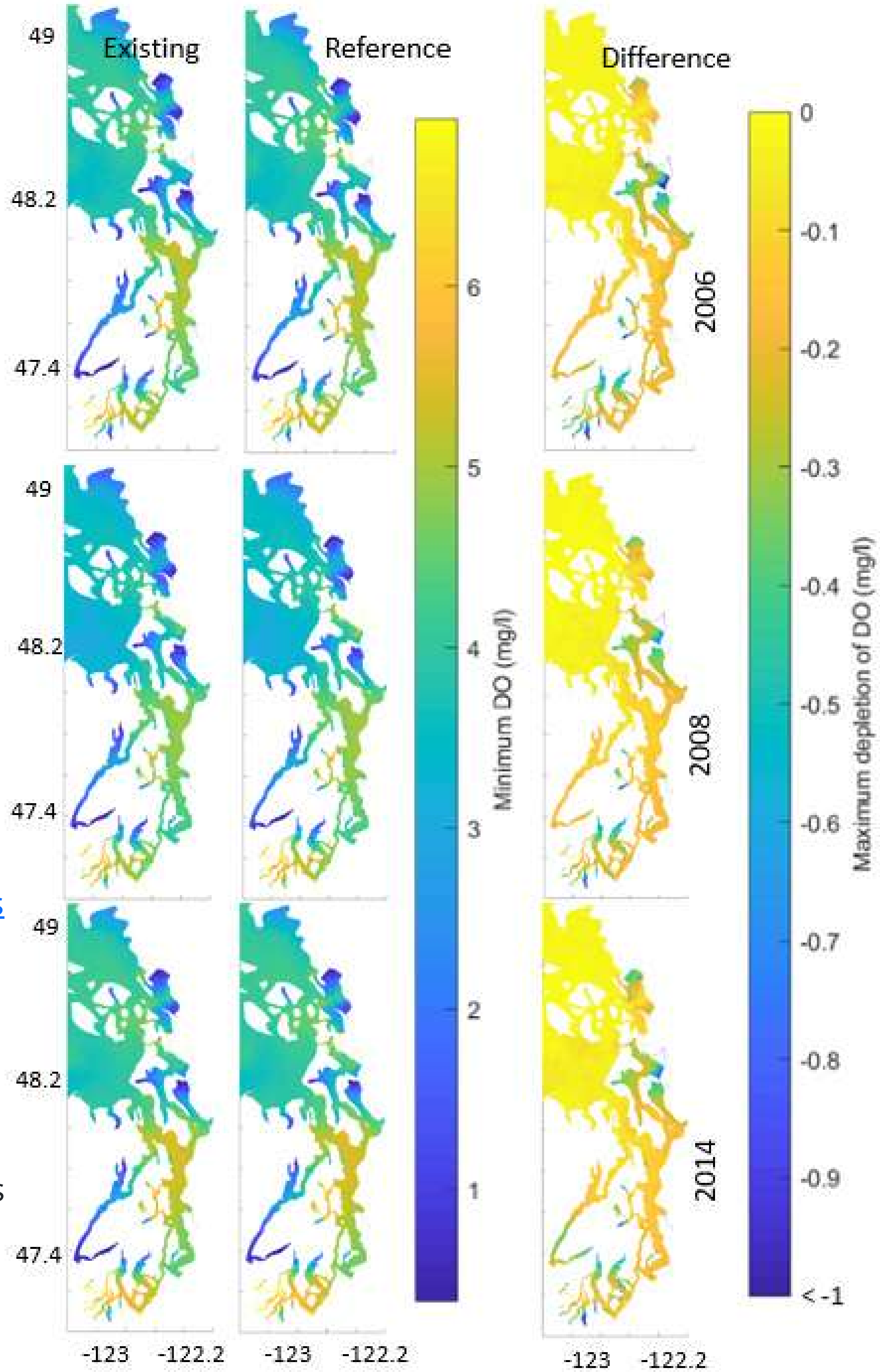
In a legal sense, water quality standards are essential, because they determine how much money is spent by government and industry to clean up our troubled waterways and improve survival for fish, crabs and other animals. According to some estimates, billions of dollars may be needed to bring major sewage-treatment plants into compliance.

> Documentation used to justify dissolved oxygen standards, developed more than 50 years ago, appear to be lost, according to Ecology's Water Quality Program, but agency officials maintain that available studies still support those numeric limits as protective of aquatic creatures.

Developing these new water-quality standards is complicated and intriguing, involving computer models to describe water-quality conditions that existed long before people changed the environment. A typical method of estimating natural conditions is to go out and measure current conditions in specific areas and then subtract all known causes of human degradation, often with the help of computers.

Natural conditions criteria may come into play when a body of water fails to meet established "numeric criteria." Numeric criteria are levels of oxygen and temperature that scientists say will meet the biological needs of aquatic creatures. Exceptions to numeric criteria are allowed for areas that have naturally lower levels of oxygen or naturally higher temperatures than the numeric criteria. For oxygen, the numeric criteria for most of Puget Sound is no less than 6 or 7 milligrams per liter, depending on the location. Based on studies, it appears that most of Puget Sound has never met those standards — not even in prehistoric times. This means that we could eliminate all human causes of low oxygen and still come up short of the approved numeric criteria.

This dilemma raises the stakes for choosing the correct natural conditions criteria. It also raises questions about whether Puget Sound is using the correct numeric standards, originally developed in 1967. Some officials in local government and industry as well as some scientists are calling for Ecology to overhaul the numeric criteria for oxygen throughout Puget Sound. The nonprofit advocacy group Association of Washington Cities, among others, would like the Legislature to fund a study to determine the actual needs of aquatic creatures in Puget Sound. For now, Ecology has placed a higher priority on developing natural conditions criteria.



The minimum dissolved oxygen level for most of Puget Sound is 7 mg/l, and 6 mg/l for areas to the west of Whidbey Island and into Bellingham Bay. The natural or "reference" condition map (center) shows that few areas of Puget Sound meet these minimum numeric standards. Areas in the difference map (right) that are green to blue are most sensitive to depletion of dissolved oxygen from human sources. Map: Ecology

"This matters," states a [news release](#) from the agency, "because Ecology and all organizations working on clean water efforts need to focus the state's pollution-reduction efforts on waterbodies where humans are causing pollution, not on waterbodies that are naturally different."

FITTING NATURE INTO A REGULATORY FRAMEWORK

Arguments over how far to go in cleaning up the streams, bays and open waterways of Puget Sound have their regulatory foundation within the federal Clean Water Act of 1972. The law establishes a national policy to “restore and maintain the chemical, physical and biological integrity of the nation’s waters.” The law asserts a goal of eliminating all water pollution and directs the Environmental Protection Agency to follow a specific process, in concert with the various states.

The Department of Ecology, authorized by the EPA to administer the Clean Water Act in Washington state, has its hands full in issuing permits for pollutant discharges, developing cleanup plans for polluted waterways, enforcing regulations to protect marine and fresh waters, and safeguarding the health of humans and animals.

Water quality standards have been developed and formally approved to protect aquatic species, human health, human activities and even esthetics, such as odor and appearance. For aquatic species, the numeric limits for physical and chemical conditions are based on the goal of protecting the most sensitive species in designated areas.

Oxygen is considered an essential element for sea life in marine waters. Numeric criteria for oxygen in Puget Sound, ranging from 4 to 7 milligrams per liter, date back to 1967 under the Federal Water Pollution Control Act, the predecessor to the Clean Water Act. Documentation used to justify those standards, developed more than 50 years ago, appear to be lost, according to Ecology’s Water Quality Program, but agency officials maintain that available studies still support those numeric limits as protective of aquatic creatures.

Most of Puget Sound is designated for a minimum of 7 mg/l. Areas to the west of Whidbey Island and into Bellingham Bay are designated for no less than 6 mg/l. The innermost portions of Tacoma’s Commencement Bay, Olympia’s Budd Inlet and Shelton’s Oakland Bay are designated for 5 mg/l, down to 4 mg/l in a few relatively tiny areas of those waterways.

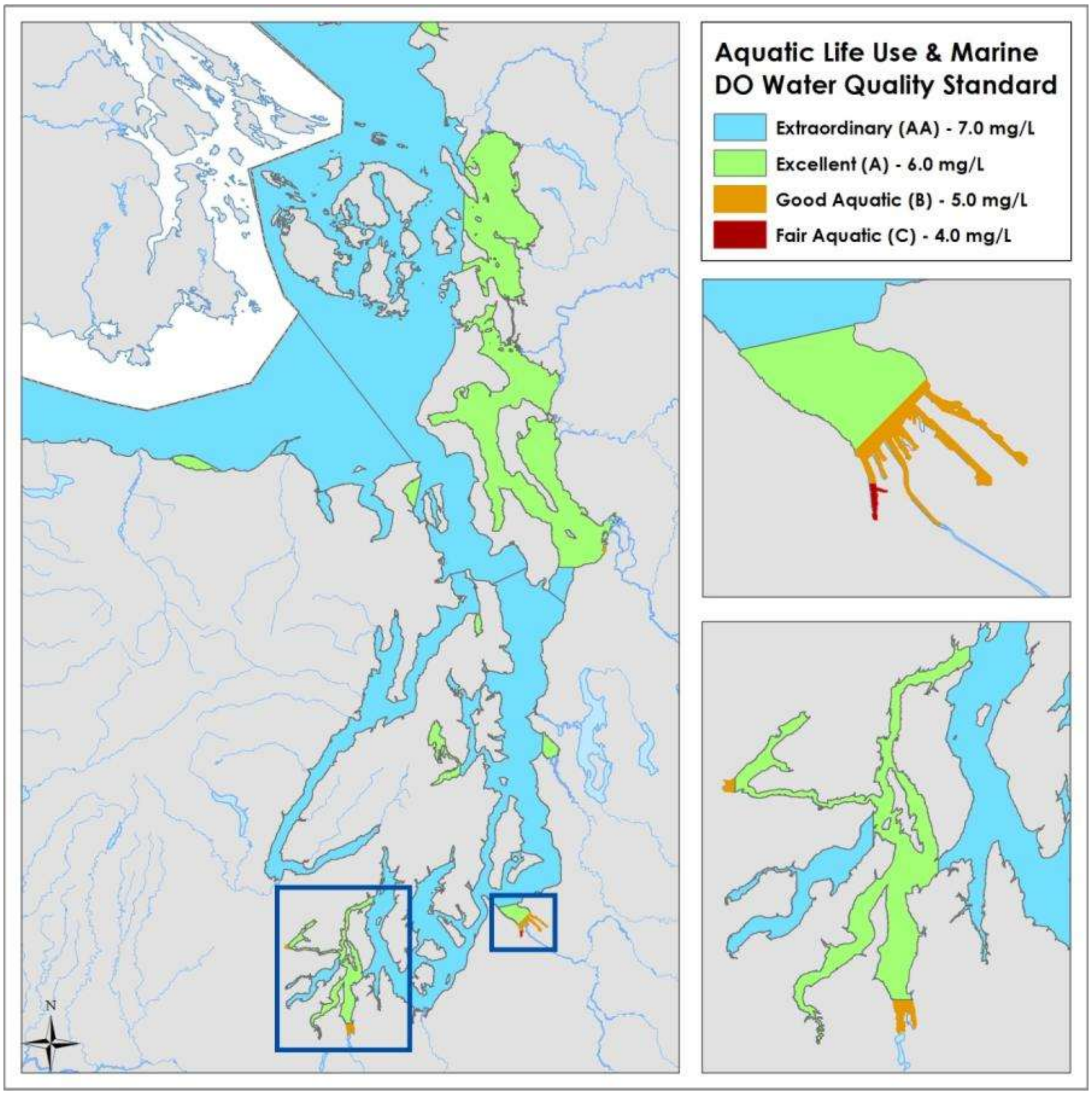
Critics argue that 6 or 7 mg/l is generally overly protective of water quality, since most areas of Puget Sound apparently never met those standards, not even in prehistoric times when marine species were abundant. Some say the criteria should be updated with more recent science, perhaps considering the depth of channels and other factors that affect natural oxygen levels. Chesapeake Bay on the East Coast has taken this approach. As things stand, the numeric criteria for Puget

Sound are destined to be largely displaced by natural conditions criteria based on computer models.

BIOLOGICAL NEEDS OF SPECIES

The concept of using a numeric standard for water quality is rather simple, perhaps too simple, some people say. For example, one can estimate, based on laboratory studies, the biological needs of salmon, including healthy levels of temperature and oxygen. These biological requirements may vary, depending on the activity of the fish, its body condition and other factors.

The biological needs may be complex and dynamic, yet Washington's numeric water quality criteria are reduced to single numbers. Much of Puget Sound has been designated as "extraordinary" water quality, a category that calls for a minimum oxygen level of 7 mg/l and a maximum temperature of 13 degrees C (55.4 F). Other criteria establish limits for turbidity, acidity and bacteria. Besides "extraordinary," various areas of Puget Sound have been designated as "excellent," "good" or "fair," each with their own criteria to protect named species residing there.



According to water quality standards for Puget Sound, as shown on the map, most of the waterway should contain at least 7 milligrams per liter of dissolved oxygen to meet numeric criteria. Where natural levels of oxygen are believed to be lower than these numeric criteria, the Washington Department of Ecology would allow for "natural conditions criteria." The agency is currently revising its process for determining natural conditions. Map: Ecology

Oxygen and temperatures can vary by location and depth in Puget Sound. State regulations call for taking measurements at depths that represent the "dominant aquatic habitat" at each monitoring site. Such monitoring helps to determine whether a water body complies with established criteria or is "impaired" for certain water quality parameters. Because conditions change over time, particularly with seasonal cycles, some areas may comply at one time but not another.

Since few areas of Puget Sound can meet the numeric criteria for dissolved oxygen at all times, even under natural conditions, some individuals and groups are calling for revisions to the criteria. They contend that limits of 6 or 7 mg/l are considerably higher than needed to protect marine life in Puget Sound. Rather than resorting to computer models to determine natural conditions criteria, scientific studies could help establish new numeric criteria based on biological needs.

“Ecology has acknowledged that it has no documentation as to the scientific basis for the marine DO standards that were adopted by a predecessor agency in 1967,” said Carl Schroeder of the Association of Washington Cities, commenting on the proposed natural conditions criteria.

Schroeder noted that cities are responsible for many of the sewage-treatment plants in Puget Sound, including those facing costly upgrades to improve oxygen conditions. Since costs must be passed on to customers via higher sewer rates, local governments must be able to explain the rationale for Ecology’s water quality standards, he said.

After 56 years without a clear scientific foundation, he continued, “it is startling that Ecology continues to move forward without seeking or incorporating information on the dissolved oxygen needs of the organisms present in Puget Sound.”

During last year’s legislative session, Schroeder and others attempted to get Washington lawmakers to appropriate $500,000 for a scientific review of the biological needs of Puget Sound species in connection with the state’s cleanup standards. The proposed study would have involved the Washington Academy of Sciences. Funding for the study was approved by the House but failed to survive final negotiations in the Senate. This year, Schroeder continues to push for legislative funding, despite tight budget conditions.

Lincoln Loehr, a retired oceanographer and environmental consultant, has been on a crusade of sorts to get Ecology to review the numeric criteria for oxygen. He first petitioned the agency to review the oxygen criteria in 1998, before most people were aware that natural conditions criteria would become such a key factor in setting cleanup targets. Loehr shared his views with many technical groups working on the low-oxygen problems of Puget Sound, and in 2017 he petitioned Ecology again to review the numeric criteria.

“Washington’s marine DO water quality criteria, adopted in 1967, have no discoverable scientific basis,” Loehr wrote in a report reviewing the history of numeric criteria and recommending that the EPA step in and develop new criteria. “While the state can identify waters as not meeting these criteria, that determination does not demonstrate that the waters are impaired, as the comparison is made with baseless criteria. Similarly, computer modeling to compare to a 0.2 mg/l decrease in DO from human causes (part of the state's criteria) is not a basis for demonstrating impairment, as it has no biological basis.”

Responses from EPA officials have offered no support for revising the state’s numeric criteria, which federal law says can be more restrictive than federal requirements. Ecology officials defend the existing criteria as being protective of marine species, but critics contend they are overly protective. Loehr argues in favor of changes to the numeric criteria, saying the Clean Water Act calls for standards that accurately reflect the “latest scientific knowledge.”

Sara Thitipraserth, director of natural resources for the Stillaguamish Tribe, expressed similar concerns in letters to Ecology and the EPA.

“It is the view of the Stillaguamish Tribe that the Marine Dissolved Oxygen Water Quality Criteria of Washington state are in need of thoughtful, science-based revision,” she wrote. “They are outdated, simplistic, and fail to consider the geography and hydrology of Puget Sound. Neither are they based on or referenced with scientific research…

“Once appropriate standards are established,” she added, “it is likely that many so-called water quality exceedances will cease to exist. Currently, marine waters with 5 mg/l dissolved oxygen in many deep-water basins are considered noncompliant, when in fact the oxygen level poses no threat to organisms that might be using it. Scientists in the region commonly acknowledge that the harm to a deep-water marine biological community does not occur until the water becomes hypoxic, that is, when oxygen levels drop below 2 mg/l.”

MEASURING THE NEEDS FOR OXYGEN

Tim Essington, a fisheries ecologist at the University of Washington, has studied the effects of oxygen depletion on many species in Puget Sound. Although not directly involved in regulatory issues, Essington’s research involves studying biological thresholds. For example, declining oxygen levels eventually reach a point when fish must respond with physiological or behavioral changes if they are to survive. This level of oxygen is called the “critical threshold” for a given species, and it varies by temperature.

A key issue is whether the laboratory environment accurately represents conditions faced by aquatic animals in the real world. Fish in a lab, for example, are held under precise conditions of oxygen and temperature to see how they respond, whereas fish in the wild are likely to swim away and seek better conditions when faced with low oxygen levels. Activity and stress can affect their metabolism and their need for oxygen. Temperature is another factor.

“In the lab, you are measuring routine behavior; the fish is not trying to chase down food,” Essington said. “But in terms of ecological relevance, animals do need to eat. The process of finding food costs oxygen, and there is also the need to avoid predators.”

Animals can acclimate to low-oxygen conditions, such as what occurs when a human athlete trains at high altitude, he continued. The oxygen capacity of the blood can change, and fish can even increase the surface area of their gills. Meanwhile, over generations, localized populations within a species may adapt to low-oxygen conditions and pass on those traits to their offspring.

Studying the presence or absence of species under various oxygen conditions can provide clues to their needs in the wild, Essington said, but one needs to understand that the most sensitive species may already be gone. Such observations of wild behavior can be compared to observations in a lab to better understand the oxygen needs of Puget Sound species.

In Chesapeake Bay on the East Coast, the EPA faced the challenge of low-oxygen conditions by dividing the bay into five habitat types, including considerations for the depth of the water. Since deeper water typically contains less oxygen, dominant species are more tolerant of those conditions. The resulting guidelines (PDF) were completed in 2003 with numeric criteria for oxygen, water clarity and chlorophyll. They were subsequently adopted into regulations by the four governmental jurisdictions around the bay: Washington, D.C. and the states of Maryland, Virginia and Delaware.

Proponents of changing Washington state’s numeric criteria for oxygen often point to Chesapeake Bay as an example of how to fit biological needs into a regulatory framework.

EPA identified and described five habitats to ensure the protection of the living resources of the Chesapeake Bay and its tidal tributaries. Some say a similar approach would be appropriate for Puget Sound.

An alternative approach

In establishing numeric criteria for Chesapeake Bay, the Environmental Protection Agency divided the bay into five habitat types to protect species in each location. Each has its own standards for dissolved oxygen:

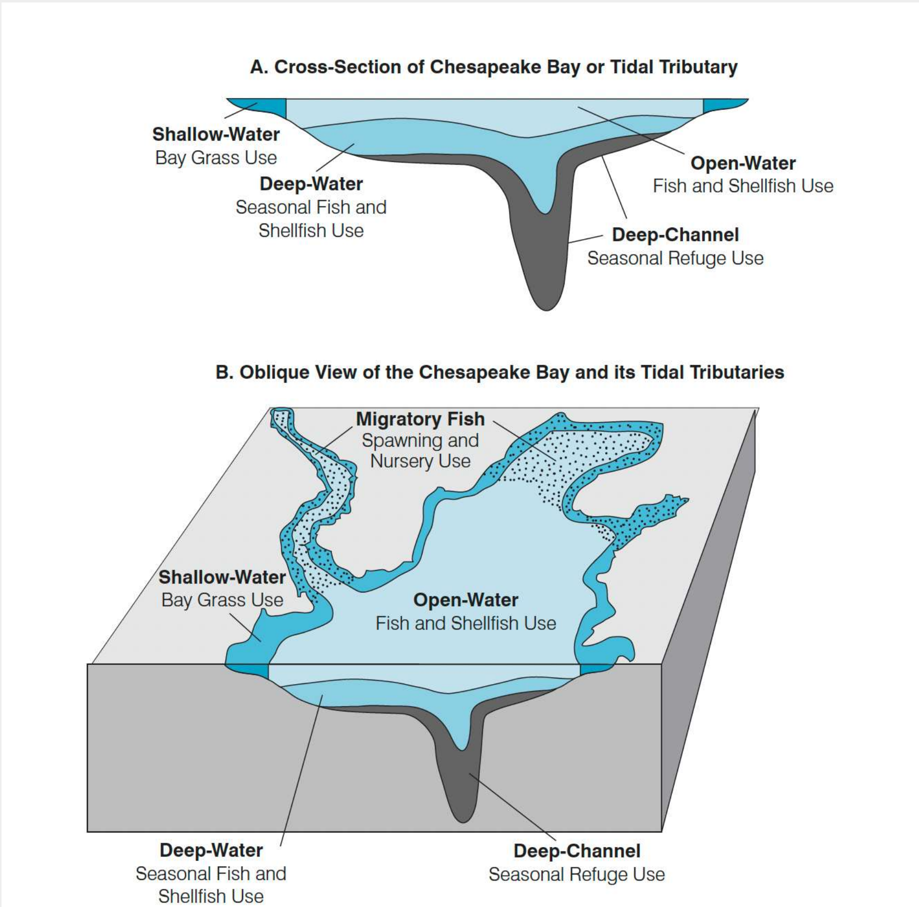
Migratory fish spawning and nursery. Largely freshwater streams and tidally influenced locations where freshwater comes into saltwater. Oxygen levels must generally be above a seven-day average of 6 mg/l from Feb. 1 to May 31, when young fish are migrating. Levels are allowed to drop to 5.0 or 5.5 mg/l, depending on salinity, from June 1 to Jan. 31.

Shallow water bay grass. Mostly underwater areas near the shore where fish and crab find food and protection from predators among the vegetation. Oxygen criteria call for a 30-day average no lower than 5.0 or 5.5 mg/l, depending on salinity, although a seven-day average of at least 4 mg/l also meets the standard.

Open-water fish and shellfish. Includes surface waters in streams, embayments and open waters of the bay where diverse populations of fish spend their time. Oxygen criteria call for a 30-day average no lower than 5.0 or 5.5 mg/l, depending on salinity, although a seven-day average of at least 4 mg/l also meets the standard.

Deep-water seasonal fish and shellfish. Representing transitional waters between the well-mixed surface waters and the deep channels of the bay where bottom-feeding fish, crabs, oysters and other species live. Numeric criteria call a 30-day average oxygen concentration of at least 3 mg/l or a one-day average of 2.3 mg/l, except for Oct. 1 to May 31 when the higher "open-water" criteria apply.

Deep-channel seasonal refuge. The home of sediment-dwelling worms and small clams consumed by bottom-feeding fish and crabs, a habitat known for very-low oxygen levels. To meet the criteria, oxygen levels must never get below 1 mg/l.



Five habitats types designated for Chesapeake Bay. Illustration: EPA

Note: These five habitats also include absolute minimums, separate from averages, which must never be exceeded. For some species, temperature is also considered.

NATURAL CONDITIONS APPROACH

From the beginning, Ecology officials realized that some areas of Puget Sound contained naturally low levels of oxygen that could never meet the numeric criteria, even under the best conditions.

"We have long acknowledged that (portions of) Puget Sound is naturally impaired for DO," said Leanne Weiss, unit supervisor in Ecology's Water Quality Management Division, "and that's why these other processes and options are so important."

In fact, when considering all the nation's waterways, EPA recognized as early as 1997 that natural conditions, absent human impacts, might be lower in oxygen or higher in temperature than numeric criteria in some areas. A (1997 EPA memo) establishes a policy allowing for numeric limits to be supplanted by natural levels.

Current revisions to Ecology's natural conditions regulations came about from a lawsuit filed by Northwest Environmental Advocates. In response to the lawsuit, the EPA agreed to reconsider its 2008 approval of Ecology's natural conditions rule. After review, the EPA reversed its approval (EPA document from 2022), leaving Washington without a natural-conditions option for cleanup goals.

One reason for the reversal was the lack of a clear statement that the natural conditions criteria applied only to aquatic life, not to human health standards, according to the EPA. As described in the 1997 EPA memo on natural conditions criteria, aquatic species may adapt over time to waters with naturally low levels of oxygen or high temperature, but that's not the case for humans. People should be protected from harmful natural conditions by changing the "designated use" of a waterway, the memo says. That might mean excluding fishing or other recreational activities or even issuing public-health warnings.

Ecology's revised rule is written to limit its application to aquatic species.

"Having a standard to determine what is normal and natural for a particular waterbody is important information for setting discharge limits and knowing when action is needed to protect or restore water quality," Ecology states on its rule-making webpage. "Nearly every state and many tribal nations have a provision in their EPA-approved water quality standards to protect aquatic life based on natural conditions of the water bodies."

EPA specifically overturned Ecology's natural conditions criteria for both oxygen and temperature in marine waters and freshwater streams. It did not overturn the criteria in lakes, which EPA determined to be adequately protective as written into the rule.

Oxygen is often the driving factor for marine creatures, and it has received much attention from Ecology because low-oxygen conditions are creating serious problems in Puget Sound. While oxygen levels are a concern in some streams, temperature can be a critical factor for fish where logging has removed large trees that help keep the waters cool (Taking the temperature of salmon).

As with oxygen, when studies show that natural conditions are warmer than designated temperatures, streams have been allowed to reach their estimated “natural” temperatures plus 0.3 degrees — the “human use allowance.”

EPA did not determine whether the human use allowance of 0.2 mg/l for oxygen and 0.3 degrees C for temperature was or was not close enough to the actual levels expected under natural conditions, but the agency did insist that Ecology provide scientific justification for those allowances. EPA’s 1997 memo allowing for natural conditions does not mention any such allowance.

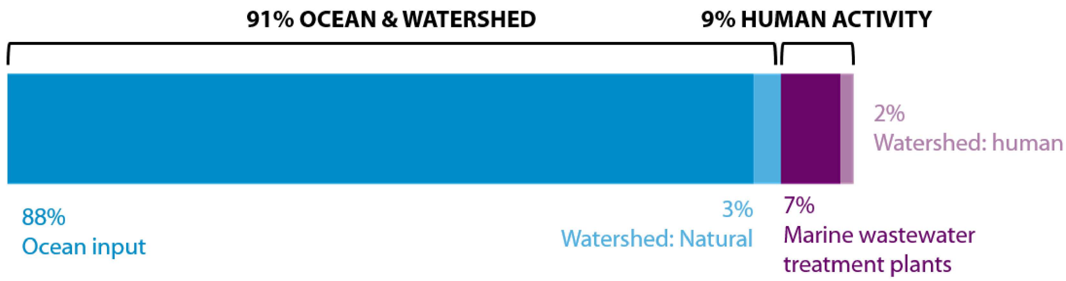
To get natural conditions back into play, Ecology has been working on a performance-based approach — a step-by-step process approved through a formal rule-making procedure. Public comments on the new proposal are being accepted until May 22. Once the process is adopted by Ecology and approved by the EPA, anyone could theoretically follow the process. Ecology would be responsible for establishing allowable limits for temperature or oxygen anywhere in Puget Sound. The resulting natural conditions criteria, based on careful modeling, would be accepted by authorities without further approval.

The first draft maintained 0.2 mg/l and 0.3 degrees C as allowable deviations, consistent with rules adopted years ago and renewed in November. Without these allowances, cleanup standards for oxygen and temperature would need to be set at the natural levels seen in prehistoric times, officials say. Such levels would be unattainable in today’s world of human impacts.

Ecology has approved one change to tighten the human use allowance. When natural oxygen conditions are found to be very low — specifically below 2 mg/l — the human use allowance is limited to 10 percent below the natural level. For example, if the natural oxygen level is 1 mg/l, then the allowance can be no more than 0.1 mg/l, setting the cleanup target at 0.9 mg/l.

ENDANGERED SPECIES PROTECTIONS

During the 2008 approval of the natural conditions criteria, federal agencies responsible for protecting listed species under the Endangered Species Act analyzed the effects of Ecology's revised water quality standards for oxygen and temperature, including the relevant human use allowances: 0.2 mg/l for oxygen and 0.3 degrees C for temperature. While the standards may not fully protect listed salmon during all life stages, they are "not likely to jeopardize the continued existence" of the listed species, according to the National Marine Fisheries Service. When the current revisions are complete, the federal agencies are expected to undertake a new analysis of the natural conditions rule, taking into account changing conditions and new research. They must show that the new rule is protective of threatened and endangered species before it can become effective.



Most of the nitrogen in Puget Sound (~91%) comes from natural sources –– mainly the ocean, with a small amount carried in from surrounding watersheds via surface runoff and rivers. Less than 10 percent is attributed to human activity, including wastewater treatment plants (7%) along with agriculture and urban runoff (2%). Levels of dissolved oxygen in Puget Sound are largely determined by how much of this nitrogen reaches the surface layer, where sunlight encourages the rapid growth of plankton. The plankton eventually die and decay, consuming oxygen in the process. Graphic: PSI

Because the performance-based approach relies on computer modeling to identify natural conditions, the process outlined by Ecology prescribes model selection, assumptions, operation and reliability; choice of data; considerations of climate change; interpretation of model outcomes; documentation; peer review; and many other issues. Ecology's proposed revisions have been drafted with guidance from EPA's natural conditions "framework" (PDF).

When the first version of the performance-based approach was released for public comment last May, the document was met with many questions and concerns. Among other things, the EPA called for adding "critical steps" in the process; stronger language to convey that each step is "binding" on the applicant, not voluntary; plus additional detail to "ensure a repeatable and transparent process."

One of the challenges in determining natural conditions is to identify ALL the human sources affecting the waterway. If any human sources are missed, the resulting estimate of natural conditions could lead to cleanup standards that adversely affect species that are still present and preclude the return of missing species.

While an approved performance-based approach would allow Ecology to establish water quality goals without further rulemaking, another approach is to study a particular area and propose water quality criteria that meets the needs of species in that area. Results from this "site-specific approach" would be proposed and adopted as a rule by Ecology with final approval from the EPA.

In the end, whether cleanup goals are based on numeric criteria or on natural conditions, the ultimate goal is to restore water quality for all species in Puget Sound — including, as much as possible, those species that thrived when natural conditions prevailed.

This article was funded in part by King County in conjunction with a series of online workshops exploring Puget Sound water quality. Its content does not necessarily represent the views of King County or its employees.

Related Link

Oxygen for life: The biological impacts of low dissolved oxygen

About the Author

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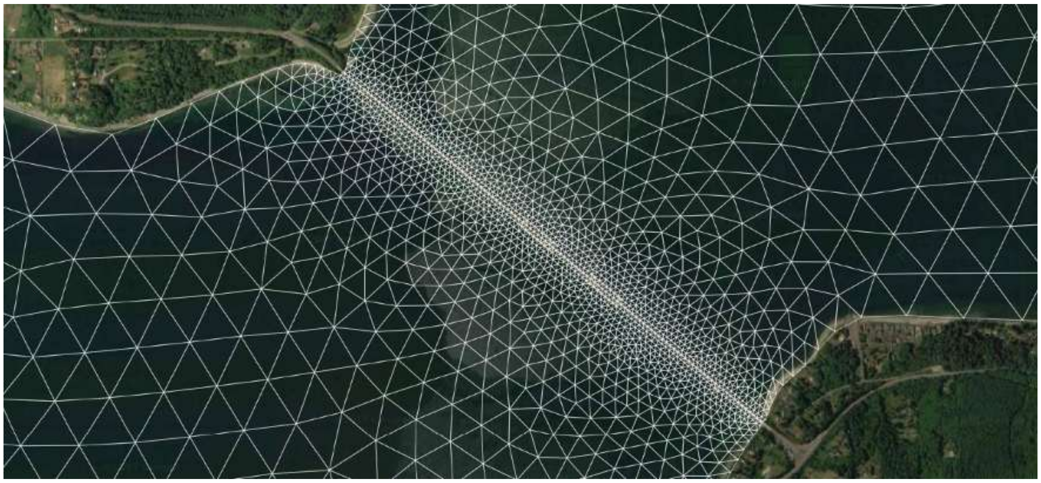

The "unstructured grid" used in the Salish Sea Model allows for greater resolution (smaller triangles) when studying complex water circulation, such as around the Hood Canal bridge. The model is being used to study ocean alkalinity enhancement. Graphic: Tarang Khangaonkar

WATER QUALITY, MODELING

Unpacking uncertainty: How experts recommend improving Puget Sound modeling

By Marielle Kanojia Published April 2, 2025 Comments Closed

An external scientific review by independent experts is a common and valuable practice, particularly when the models have significant management implications. This ethos is why peer review is foundational to science in general. By providing an objective assessment, external reviewers can help ensure the models are robust and appropriate for the management decisions they're being applied to. For example, the Chesapeake Bay Program's suite of modeling tools has undergone several expert reviews over the last 30 years. In 2023, the Southern California Coastal Water Research Project Authority similarly launched an independent expert panel to review their coastal eutrophication numerical modeling.

We are navigating complex decisions

Our region is navigating complex decisions on how best to manage nitrogen to maintain healthy habitats. Excess nitrogen from human activities can potentially increase harmful algal blooms, decrease dissolved oxygen, compound ocean acidification, and cause other changes that may harm marine life. Recent regulations are particularly focused on the impacts of excess nitrogen on low dissolved oxygen in Puget Sound. While low dissolved oxygen occurs naturally, excess nitrogen from human activities may change the timing, location, and size of algae blooms and by extension marine life's exposure to low dissolved oxygen.

Modeling is driving nutrient management in Puget Sound

The Salish Sea Model was developed to help inform these complex decisions. Washington State uses monitoring data and the Salish Sea Model to determine compliance with Washington's dissolved oxygen water quality standard and to establish each 303(d) listing. The state also uses the model to explore the effectiveness of potential nutrient reductions and to establish targets for load reductions at wastewater treatment plants. Regulation using the model may result in billion-dollar wastewater treatment plant upgrades. The nutrient management decisions we make now could shape the future of wastewater treatment, water quality, and our communities for decades to come. Consequently, there is heightened interest in assessing the Salish Sea Model's performance, particularly the regulatory application.

Regulatory Application: Determining Non-Compliance
Since parts of Puget Sound naturally have low dissolved oxygen, it's important to determine the decrease in dissolved oxygen due to excess nutrients from human activities, specifically. The Department of Ecology uses monitoring data and the Salish Sea Model to determine compliance with Washington's dissolved oxygen water quality standard and to

establish each 303(d) listing. The Salish Sea Model simulates both **existing conditions** and **natural conditions** (i.e., an approximation of conditions before western settlement). A location in Puget Sound is predicted to be **non-compliant** if any of the 10 depth-layers:

1. Fall below the numeric criteria (e.g., 7 mg/L) **or** natural conditions at that location, whichever is lower

AND

2. The existing condition is at least 0.2 mg/L or 10% lower than the natural conditions, whichever change is smaller.

If a single layer at any location is non-compliant for at least an hour, the day is considered non-compliant.

**Ecology adopted revisions to the natural conditions provision and shared updated Performance-Based Approach guidance for public comment by May 22, 2025.*

Learning from global experts

When addressing complex environmental challenges, valuable insights can be gained from the extensive experience of scientists in other regions like the Chesapeake Bay and the Baltic, where models have been used to manage nutrients for decades. In 2024, the University of Washington Puget Sound Institute convened global experts to advise on how to improve the application of the Salish Sea Model to inform recovery goals and nutrient management decisions in Puget Sound. We were fortunate to benefit from the expertise of scientists who have led cutting-edge research and advised regional managers on the application of modeling and monitoring in nutrient management programs in other regions. The Model Evaluation Group included:

- **Bill Dennison:** Vice President for Science Application and Professor at University of Maryland Center for Environmental Science
- **Jacob Carstensen:** Professor at Aarhus University, Denmark
- **Jeremy Testa:** Associate Professor at University of Maryland Center for Environmental Science
- **Kevin Farley:** Professor and the Blasland, Bouck and Lee Faculty Chair at Manhattan College
- **Peter Vanrolleghem:** Professor at Université Laval, Canada

Meet the Model Evaluation Group

Expert findings

In analyzing the existing literature and available data on the Salish Sea Model at the time, the experts found:

- On average, Salish Sea-wide model simulations have comparable performance to other models used to set water quality standards and nutrient discharge limits elsewhere in the USA. Evaluating the average model skill for the entire region can miss important local nuances in specific areas where non-compliance is predicted. However, while other states use models to set water quality standards and nutrient discharge limits, to our knowledge, they only use monitoring data to assess compliance with nutrient and dissolved oxygen water quality standards.
- Dissolved oxygen non-compliance in Puget Sound occurs primarily in portions of Hood Canal and 16 shallow embayments. Within these non-compliant areas, the model error is greater. For example, the 2014 modeled results for current conditions ranged from 1.04 – 3.05 mg/L DO RMSE across 22 sites in these embayments. These RMSE results are approximately an order of magnitude greater than the 0.2 mg/L DO human allowance that is used to determine regulatory compliance. This highlights the value of looking at model performance analysis specifically in the places and at the times where model outputs are used in regulatory decision-making.
- The regulatory determination of non-compliance was found to be quite sensitive to the natural conditions threshold defined by the state's water quality standards. For example, in 2014, 58% of the non-compliant area was at most 0.1 mg/L above the 0.2 mg/L human allowance threshold.

Expert recommendations

In 2024, the Model Evaluation Group recommended the following model analysis to increase confidence in the regulatory application and strengthen a process-based approach to understanding water quality drivers of change:

- Focus additional validation studies on shallow embayments and portions of Hood Canal where human activities may further reduce low dissolved oxygen levels. Preliminary analysis suggests there is larger model error in these areas. Long-term, increased monitoring in these areas could also support refined modeling of these shallow embayments.

- Perform validation studies using sub-sets of data above/below the pycnocline to better understand the importance of and model skill related to processes influencing dissolved oxygen, such as vertical mixing, stratification, phytoplankton growth, and water-sediment interactions.
- Analyze model performance for non-calibration years and across multiple years to characterize model skill beyond the three existing, single-year runs. Consider performing additional sensitivity scenarios for model years that are at opposite ends of the spectrum of interannual variability.
- Use new monitoring data to analyze model performance for sediment oxygen demand and to validate related processes like carbon fluxes and denitrification.
- Characterize the potential propagation of error associated with uncertainties in model parametrization, loadings, etc., and how this may influence confidence in the model-to-model comparison used when determining regulatory compliance.

Read the Modeling Recommendations in detail

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Up Next: Research and whale watching enhanced with artificial intelligence to identify individual orcas

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A century of warming has reduced dissolved oxygen in Puget Sound

At Carr Inlet, warming temperatures account for about 50 percent of the dissolved oxygen loss over the past century. Photo: Washington Department of Ecology (CC BY-NC 2.0)

KEYWORDS: HYPOXIA, NUTRIENT POLLUTION, SALISH SEA CURRENTS MAGAZINE, WATER QUALITY, MARINE HABITAT

By Sarah DeWeerdt

Published June 10, 2025

A new study outlines the strong link between dissolved oxygen declines and increasing water temperatures, raising questions about the effect of future climate change on Puget Sound.

Warming waters likely contribute to decreasing dissolved oxygen levels in Puget Sound, adding another layer of complexity to efforts to understand the health of the estuary and ensure healthy conditions for aquatic life ranging from zooplankton and crabs to salmon and killer whales.

The finding emerges from a preliminary University of Washington analysis of temperature and dissolved oxygen measurements taken at multiple locations in Puget Sound over the past century. The work, which is available on ESS Open Archive but has not yet been peer-reviewed, suggests that increasing temperatures account for roughly half of the dissolved oxygen decline documented in central Puget Sound over the last 100 years.

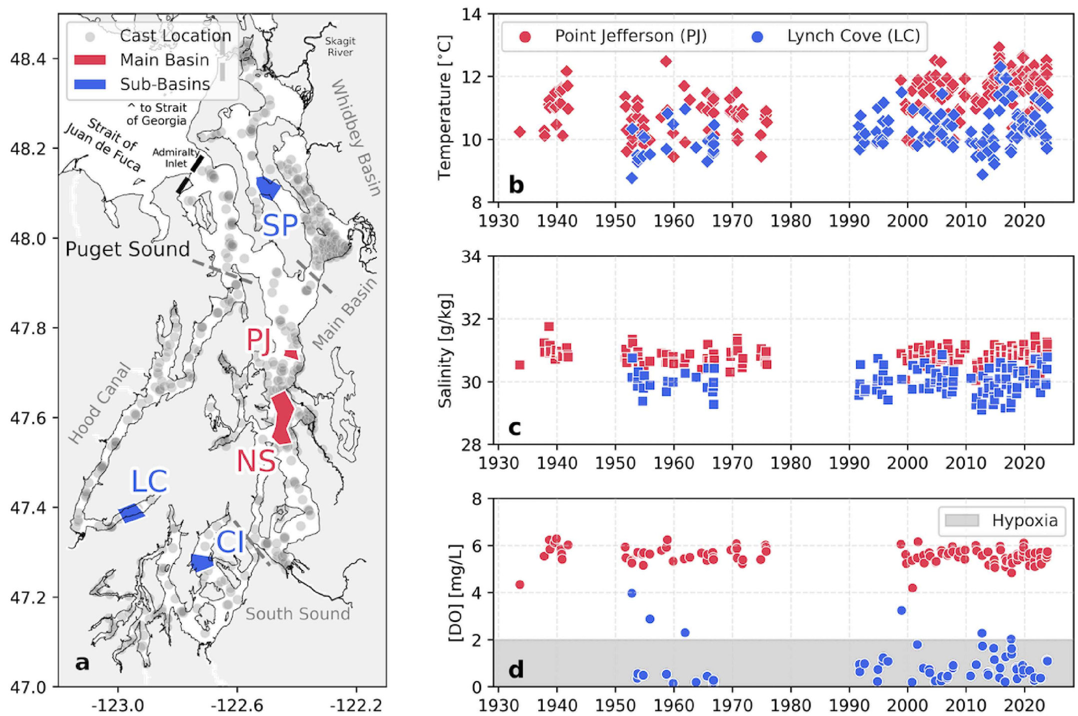
Puget Sound is “a very complex system that has many other things going on,” says University of Washington doctoral student Dakota Mascarenas, the study’s first author. But, she says, “we've identified a mechanism that, on a century scale, might have about this level of impact.” Mascarenas also presented the unpublished data at an online Science of Puget Sound Water Quality workshop in February.

It’s well known that warmer water holds less dissolved oxygen and other dissolved gases. As water gets warmer, water molecules move faster and jostle against each other more, making it more likely that oxygen molecules will get pushed out of the surface of the water.

In fact, scientists have documented temperature-related oxygen decreases at a global scale. There’s widespread concern that climate change and continued increases in temperature could further reduce oxygen levels in marine ecosystems. And so, the look backwards: "The first step in trying to predict the future is to know what happened in the past," says University of Washington oceanographer [Parker MacCready](), a senior author of the new study.

The researchers analyzed more than 12,000 measurements of water quality parameters (temperature, salinity, and dissolved oxygen) dating all the way back to 1932. The measurements were taken near the bottom of the water column in late summer and early fall – where and when low-oxygen conditions are most likely to develop in Puget Sound.

They identified five locations with at least 60 years' worth of the requisite data: Saratoga Passage in the Whidbey Basin, Lynch Cove in Hood Canal, Carr Inlet in South Sound, and Point Jefferson and a location near Seattle in the Main Basin of Puget Sound.



Map (a) of five Puget Sound data collection locations with sufficient data for century-scale trend analysis (SP= Saratoga Passage, PJ=Point Jefferson, NS=Near Seattle, LC=Lynch Cove. CI=Carr Inlet) and August-November, bottom values at selected sites for (b) temperature, (c) salinity, and (d) DO between 1930 and 2025. Source: Mascareneas et al. 2025 DOI: [10.22541/essoar.174461801.10035683/v1]()

The long timeframe was necessary to discern patterns that transcend the variations in ocean conditions that happen seasonally, from year to year, and on longer cycles (such as the Pacific Decadal Oscillation and El Niño-Southern Oscillation) affecting Puget Sound. "There's a lot of different timescales of potential variation," says Mascarenas. "We've done our best to look as long as we can."

The full series of measurements revealed that the five Puget Sound sites have warmed by about 1.4 °C over the past century. This is in line with regional trends in ocean and atmospheric warming.

Meanwhile, dissolved oxygen has decreased at a rate of 0.3-0.9 milligrams per liter per century at the two Main Basin sites. Outside of central Puget Sound, dissolved oxygen trends were more variable: declining at Carr Inlet, stable at Saratoga Passage, and slightly increasing at Lynch Cove.

The researchers then used a well-established equation to calculate the reduction of oxygen in the water, given how much it has warmed. This revealed an expected decrease in dissolved oxygen of 0.31 milligrams per liter per century on average, across all locations.

At Point Jefferson and the near-Seattle location in the Main Basin, this warming-related, expected decline explains 40-100% of the actual decrease in dissolved oxygen observed over the past century. At Carr Inlet, warming accounts for about 50% of the dissolved oxygen loss. Elsewhere, measurements were too variable to draw conclusions.

The marked effect of temperature in explaining oxygen decline was surprising, says MacCready. Although the relationship between temperature and dissolved oxygen is well known, the scientific conversation about dissolved oxygen in Puget Sound has been so focused on nutrient pollution that he hadn't given temperature much thought, he says.

Globally, an estimated 15% of the ocean's oxygen loss between 1960 and 2010 can be attributed to the effects of increasing temperature, according to a report from the International Union for the Conservation of Nature. Warming may explain roughly half of the oxygen loss in the upper 1,000 meters of the ocean, the report says.

Because Puget Sound's Main Basin is deep, contains about 65% of the total volume of Puget Sound, and supplies water to other sub-basins, the Main Basin findings likely reflect changes affecting Puget Sound as a whole, the researchers argue. "That's probably the closest to the background trend that we're going to be able to see," says Mascarenas.

Similar findings have been documented in the Chesapeake Bay – another large estuary adjacent to urban and agricultural development but with a very different structure compared to Puget Sound. This suggests that temperature-related oxygen declines may be a general phenomenon affecting estuaries around the world.

The new study does not make any predictions about how warming may affect dissolved oxygen in Puget Sound in the future, as climate change intensifies. The relationship may not be a linear one and the system could encounter “tipping points” that magnify the effects, Mascarenas says.

The policy implications of these changes are also uncertain. Will climate change make Puget Sound more sensitive to nutrient loadings and make action to control human-caused nutrient inputs more urgent? Or will warming simply overwhelm any proposed gains from controlling nutrients?

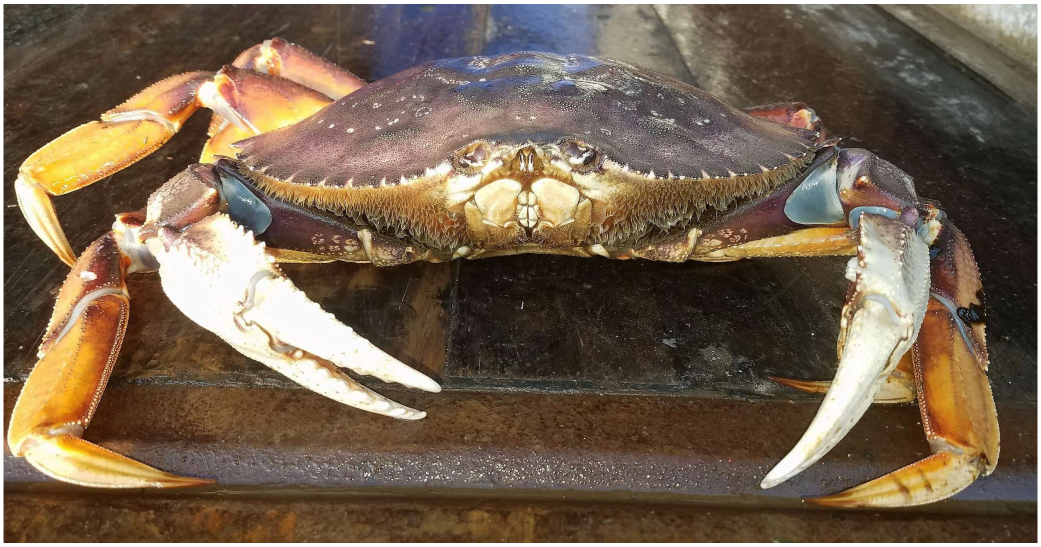
What’s predictable, for now, is further warming, says MacCready. "There's every reason to think that that trend will continue."

This article was funded in part by King County in conjunction with a series of online workshops exploring Puget Sound water quality. Its content does not necessarily represent the views of King County or its employees.

About the Author

Sarah DeWeerdt is a Seattle-based freelance science writer specializing in biology, medicine, and the environment. Her work has appeared in publications including Nature, Conservation, and Nautilus.

Waters.



Dungeness crabs are one of many Puget Sound species that can be impaired by low-oxygen conditions. Photo: Crabmanners via Wikimedia Commons

WATER QUALITY

Low oxygen challenge, part 1: The debate over oxygen in Puget Sound

By Christopher Dunagan Published June 12, 2025 2 Comments

A new report, Draft Puget Sound Nutrient Reduction Plan, is out today for public review. Experts at the Washington Department of Ecology along with many other researchers have spent years studying and debating the *problem of low oxygen in Puget Sound. Now, many new developments — technical, scientific and legal — are reaching a critical stage and setting up a framework to make some major decisions. This four-part series in Our Water Ways looks back on how we have reached our present condition, including a consideration of possible solutions. Part 3 describes findings in the new report.*

In Puget Sound, low oxygen levels are a proven threat to marine creatures, from fish to shellfish and even tiny organisms. This threat has long been recognized by scientists — particularly within slow-flushing bays and inlets where low levels of dissolved oxygen can impair sea life and occasionally create deadly conditions in late summer and fall.

For decades, government agencies have been studying the low-oxygen problems of Puget Sound, some natural, some man-made. Now, the Washington Department of Ecology has put together a plan to reduce the inflow of nutrients, particularly nitrogen, which can fuel a rapid growth of plankton, setting off a natural process of deoxygenation. A draft plan, released today, will be discussed in parts 3 and 4 of this series. Comments on the plan will be accepted by Ecology until Aug. 27.

Altogether, recent scientific discoveries, advances in computer modeling and a series of legal rulings have established an atmosphere for change. Ecology is pushing forward with plans to control nitrogen coming from sewage-treatment plants and from upstream sources, such as farms and urban areas. Critics on one side say Ecology has overstated the problem and failed to come up with workable solutions. Critics on the other side say actions have been taking way too long.

In this blog post and the next, I hope to describe how we got into our current situation and the factors that will help shape the future health of Puget Sound and ultimately determine which marine species will survive.

Biological effects

Pacific herring spawning in eelgrass, Holms Harbor, Whidbey Island. Photo: Florian Graner, Sealife Productions

Although we rarely see dead fish washing up on shore, marine organisms may succumb to a multitude of unseen stresses caused by low-oxygen waters, stresses that reverberate through the food web, affecting species from plankton to killer whales.

Many aquatic creatures respond to oxygen deficiency with a shift in their physiological makeup, according to Tim Essington, professor of aquatic and fishery sciences at the University of Washington. Without adequate oxygen, they may struggle to find food and avoid predators. They may become susceptible to disease and reproductive failure. Although very real, these and other effects are difficult for researchers to observe in real-world conditions.

“Organisms have a range of responses available to them to try to cope with thresholds of low oxygen,” Essington said in a presentation summarized in the Encyclopedia of Puget Sound. “Typically, they can move, acclimate, or in the worst-case scenario, they may die.”

Essington has compared low-oxygen conditions for marine organisms to high-altitude effects on humans, an analogy supported by Mindy Roberts, director of the Puget Sound Program for Washington Conservation Action, an environmental group.

"Imagine if you were suddenly transported to the summit of Mount Rainier, where oxygen is 40 percent lower than sea level," said Roberts, a former environmental engineer for Ecology. "In addition to finding it difficult to breathe, your cognitive processes are affected. With my climbing background, I know that this occurs."

Some species are more tolerant of low-oxygen conditions than others. In areas of Puget Sound where oxygen levels are chronically low, some species are no longer present and those that remain are fewer in number. As scientists say, oxygen levels can affect both biodiversity and abundance, causing shifts throughout the entire food web.

Oxygen levels often decline the most at the bottom of Puget Sound, particularly in smaller bays and inlets where the habitat supports a multitude of invertebrates and fish. As oxygen levels decline, sometimes on annual cycles, fish and other mobile species may seek more breathable waters at shallower depths, thus increasing the risk that predators will eat them. Less mobile species may acclimate over time, or they may die out.

While some researchers strive to understand the complex physiological changes at work in low-oxygen conditions, others are using computer models to better understand how nitrogen enters and flows through the waters of Puget Sound, feeding a variety of planktonic species at the base of the food web.

Plankton are an essential food source for many higher-level animals, but excessive nitrogen can produce massive plankton blooms that overwhelm the consumptive capacity of the food web. When that happens, the excess plankton die, sink, and decay, enhancing bacterial growth that consumes the available oxygen (Encyclopedia of Puget Sound).

The latest computer models are designed to replicate the physical and biological conditions throughout Puget Sound, revealing when and where low-oxygen conditions are likely to occur. They also help researchers figure out how to rectify the problem by reducing nitrogen inputs at locations where reductions would have the greatest effect.

A large plankton bloom photographed by Ecology's Eyes Over Puget Sound program in 2023, looking from Seattle to Bainbridge Island. Photo: Washington Department of Ecology.

A major focus of Ecology's strategy is sewage treatment plants, most of which discharge nitrogen directly into Puget Sound. Also important are diffuse sources such as farms and housing developments, where nitrogen from fertilizers and animal wastes get into stormwater and enter rivers and streams that discharge to Puget Sound.

Computer models must also account for complex circulation patterns as well as a massive flows of nitrogen in seawater that move into Puget Sound from the ocean. This oceanic seawater, being saltier and denser than other water in Puget Sound, comes in along the bottom, as lower-density freshwater moves out at the surface. This is typical estuarine flow found in many parts of the world. Because of turbulence, some of the deeper, nitrogen-rich water mixes into the surface layers, where sunlight allows for the growth of plankton and low-oxygen conditions.

The worst conditions can be seen near the bottom in areas with low circulation, where mixing with oxygen-rich water is slow and organic decay draws down oxygen levels. Southern Hood Canal and inlets in South Puget Sound are among the vulnerable areas. These waters can, on occasion, create conditions uninhabitable to most sea life.

Ecology's regulatory efforts to constrain human sources of nitrogen have been on a bumpy course, sometimes challenged by both environmental groups and treatment plant operators.

Most recently, Ecology's plan to control nitrogen from sewage effluent using a new "general permit" has hit a roadblock in a ruling from the state's Pollution Control Hearings Board. The board ruled that Ecology cannot legally require a treatment plant to comply with a general permit if the facility already operates under an individual permit, as most do. As a result, Ecology has shifted its regulatory approach, as will be explained in the final part of this series.

King County is among the local entities participating in studies of low-oxygen conditions and exploring how dissolved oxygen levels affect Puget Sound's varied species and habitats. With billions of dollars needed to upgrade sewage-treatment plants, county officials are asking for a regional strategy focused on the most cost-effective actions.

"King County is committed to protecting Puget Sound, including addressing nutrients," said Akiko Oda, public information officer for the county's Wastewater Treatment Division. "We are continuing the water quality monitoring, technology evaluation and treatment planning that was originally required under the original nutrient general permit."

Roberts, who helped develop early computer models for Ecology, is now a leader in the environmental community. It is past time, she says, to get the major sources of nitrogen under control and begin to restore the health of the waterway.

Natural and unnatural conditions in history

While some areas of Puget Sound are naturally low in oxygen, human activities have been affecting water quality since the first settlers began altering the landscape in the 1800s. References to low-oxygen problems date back to the 1920s, a time when several pulp mills were dumping their industrial wastes into local bays. Cities with one or more mills at that time include Port Angeles, Port Townsend, Shelton and Tacoma, and later Everett (1936) and Bellingham (1938).

A lumber and pulp mill in Shelton, 1947, Ellis Postcard Co. // Photo courtesy of Washington State Historical Society

Effluent from the production of pulp, used to make paper, contains chemicals that can be toxic to fish, shellfish and other organisms. In those early days, another effluent constituent, wood waste, triggered the growth of bacteria that consumed nearly all the oxygen in the vicinity of the mills, upsetting the food web and sometimes creating "dead zones" where nothing could live. Oxygen levels often remained low even after the industrial chemicals dispersed. Chemists at the time debated whether it was toxic compounds or a lack of oxygen causing the most damage to nearby oyster beds.

The Washington Pollution Control Commission, established in 1945, became the first agency authorized to rein in pollution. But early commissioners saw their role as educators more than enforcers, launching a statewide campaign called "Keep Washington Clean," according to a 1967 article by L.A. Powe Jr. in Washington Law Review.

Commercial oyster growers, already fighting to protect their depleted beds, wanted stronger action from the commission. Scientific studies, public hearings and lawsuits became part of the battle by local oystermen, led by the Pacific Coast Oyster Growers Association.

In 1955, the Legislature imposed a permit system to control pollution, giving the commission new authorities. "Instead of waiting for a complaint and then investigating, the commission was placed in a position where industry came to them to request permission to discharge wastes," Powe explained.

Although oyster growers were not satisfied with the pace of progress, stricter limitations on effluent were added to permits over time, and the waters got cleaner. But getting some operations to comply with new requirements remained a concern, according to Dave Nunnallee, who joined the Washington Department of Ecology in 1969 and became an inspector.

"We had laws, but the enforcement was very weak," Nunnallee said in an interview for a "Historically Speaking" (PDF), an Ecology publication celebrating the agency's 35th anniversary in 2005. Nunnallee, who retired in 2006, recently recalled several investigations of untreated wastes, including those from a concrete plant in Renton, a slaughterhouse in Auburn and fish-processing plants on the Seattle's "filthy" waterfront.

In 1973, during a growing environmental movement, the Legislature increased penalties for permit violations from $100 to $5,000 a day, strengthening Ecology's hand with pollution, Nunnallee said.

Effects of sewage

Besides industrial effluent, state pollution officials were aware that sewage treatment plants of the 1970s were releasing organic materials that could deplete oxygen levels — particularly in small, enclosed bays. The Pollution Control Commission, whose name was changed in 1967 to the Water Pollution Control Commission, had long pushed local governments to build "primary" treatment plants to end the practice of discharging raw sewage. But when it came to organic pollutants and dissolved oxygen, the commission was more focused on lakes and rivers than on Puget Sound, Nunnallee recalled.

"Frankly, we weren't too concerned about Puget Sound," he said during the 2005 interview. State officials generally believed that Puget Sound, outside a few small bays, had the capacity to absorb the organic pollution, he said. For example, the costly effort to clean up Lake Washington during the 1960s was declared a tremendous success, but it led to releasing considerably more organic wastes into Puget Sound.

One of the standard tests used to quantify the effects of sewage effluent on water quality involves a calculation of "biochemical oxygen demand," or BOD. The test typically measures the concentration of oxygen in an effluent sample at the beginning and at the end of a five-day period. The result represents the amount of oxygen required for bacteria to break down organic waste in the sample — a rough indicator of the environmental impact. The BOD of raw sewage is typically 300-600 milligrams per liter.

In the midst of an environmental movement that began in the 1960s, Congress took an ambitious leap to clean up the nation's waters by passing the Clean Water Act of 1972. This powerful law has elicited profound changes in regulations by federal, state and local governments — right up to today.

Among its many provisions is a requirement that sewage treatment plants nationwide be upgraded to reduce organic pollutants and improve oxygen conditions. Federal water-quality standards were established based on the capability of existing treatment systems — which could produce effluent with an average BOD less than 45 milligrams per liter. These standards and the processes that could meet them became known as "secondary treatment." Initially, municipalities were given until 1977 to begin construction on the upgrades, although deadlines were extended, and federal waivers were allowed when warranted by water conditions.

At first, Washington state officials refused to push for secondary treatment for facilities discharging into Puget Sound, Nunnallee said. Studies at the time failed to show that major problems resulted from sewage effluent, except in the immediate vicinity of the outfall, he noted. "So, we encouraged the entities to apply for their waivers, not thinking it was that big a water-quality issue."

By 1983, with concerns growing over pollution in Puget Sound, proponents of sewer upgrades argued that state law mandated improvements, specifically because secondary treatment was well-proven technology. They cited the water pollution law of 1945:

"Section 1. It is declared to be the public policy of the State of Washington to maintain the highest possible standards to insure the purity of all waters of the state consistent with public health and public enjoyment thereof … and to that end require the use of *all* *known available and reasonable methods* by industries and others to prevent and control the pollution of the waters of the State of Washington (emphasis added)."

Amendments in 1967 had changed the law slightly to require wastes to undergo "all known, available, and reasonable methods of treatment prior to their discharge," but the intent has remained the same since 1945. This idea of keeping the waters as clean as possible imposed what became known as a "technology-based standard," which Ecology must enforce "regardless of the quality of the water," according to the statute. Many lawsuits would follow, and AKART — "all known, available, and reasonable treatment" — appeared in legal documents again and again right up to recent court rulings, which will be discussed in the next part of this series.

Donald Moos, director of Ecology in 1983, asked for a state attorney general's opinion to determine whether the language of the law would expressly require secondary treatment at all sewage facilities in Washington state.

In his response, Attorney General Ken Eikenberry said "secondary treatment" is not specifically defined in the law. So, while the law clearly calls for modern treatment technology, it must also be "known," "available," and "reasonable." This is an engineering, not a legal question, he said in his legal opinion.

"A review must be conducted by the department of existing engineering technologies in order to enable it to decide which methods of treatment … are suitable with respect to the waste situation involved in the particular case," Eikenberry stated.

After a review by Ecology officials, the agency drafted a policy defining water quality standards that were consistent with secondary treatment. Although some treatment plant operators objected, the standards were generally upheld by the state's Pollution Control Hearings Board. As a result, the issue of feasible technology (AKART) has become a factor in setting effluent limits in permits for all sewage treatment plants.

"The basic problem, however, was that most of us in Ecology didn't feel that secondary treatment was needed, and ultimately we were proved wrong," Nunnallee said in the 2005 interview. Secondary treatment, now the universal standard, has effectively reduced the discharge of organic pollutants into Puget Sound. But the typical secondary-treatment process does little to reduce nitrogen, which can trigger the rapid growth of plankton and produce low-oxygen conditions. The question of what should be done to control nitrogen in Puget Sound has been engaging a host of scientists while prompting legal battles along the way.

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This article was funded in part by King County in conjunction with a series of online workshops exploring Puget Sound water quality. Its content does not necessarily represent the views of King County or its employees.

The series

Part 1: The debate over oxygen in Puget Sound

Part 2: Water-cleanup plans and the search for 'reasonable' actions

Part 3: Computer models spell out the extent of the water-quality problem.

Part 4: Many actions may be needed to improve Puget Sound waters

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Previous: Follow the herring: Why sea lions have been calling Shilshole Marina home

Up Next: Low oxygen challenge, part 2: Water-cleanup plans and the search for 'reasonable' actions

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2 Replies to "Low oxygen challenge, part 1: The debate over oxygen in Puget Sound"

JD Ridgley, 1 month ago

I support scientific study and scientific resolution of the problem. I live on the Sound and still do not feel that it is safe enough for swimming, etc.

Jimmie Matei, 1 month ago

After many years of traveling the world on the ocean and much of my research on what happened to the abundance of marine life in my eariler years, has caused me to realize that where ever there is human populations there is ocean floor anoxic conditions or in fresh water creeks, rivers and lakes in some degree of deterioration.
I have been working on a means to convert the anoxic / hypoxic ocean and lake floors to compost and get growing again.
Please contact me if you may wish to learn more as I continue to develop my Ocean Floor Composter.

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