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Nitrogen in Puget Sound: a story map

Sheelagh McCarthy
Washington State Dept. of Ecology, United States, shem461@ECY.WA.GOV

Teizeen Mohamedali
Washington State Dept. of Ecology, United States, tmoh461@ecy.wa.gov

Paula Cracknell
Thurston County, United States, cracknp@co.thurston.wa.us

Nitrogen in Puget Sound, A Story Map

Sheelagh McCarthy, Teizeen Mohamedali, Paula Cracknell

Washington State Department of Ecology

Salish Sea Ecosystem Conference – April 2018

DEPARTMENT OF ECOLOGY
State of Washington

Acknowledgements

Story Map Co-Authors

Teizeen Mohamedali, Paula Cracknell

Data + Information

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King County

Herrera Environmental Consultants

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Washington State Department of Health

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Washington State University

United States Geological Survey

University of Maryland Center for Environmental Science

University of Washington

Guidance + Content + Review

Dustin Bilhimer
Julia Bos
Tom Buroker
Barb Carey
Maggie Dutch
Cristiana Figueroa-Kaminsky
Melissa Gildersleeve
Curt Hart
Ty Keltner
Christopher Krembs
Brian Lamb (Washington State University)
Linda Lane (External, Photo Credit)
Carol Maloy
Vince McGowan
Shawn McKone
Brad McMillan
Tsengel Nergui (Washington State University)
Dale Norton
Adam Oestrich
Diana Olegre
Ben Rau
Darby Veeck
Marcus Von Prause
Daniel Wise (USGS)
Greg Zentner

Nitrogen in Puget Sound

A story map of nitrogen in Puget Sound, created by the Washington State Department of Ecology

Overview | Excess Nitrogen | Nitrogen Sources & Pathways | Monitoring Nitrogen | River Trends | Marine Trends | Acknowledgements & References

This story map was created by scientists at the Washington State Department of Ecology to allow you to explore what we know about nitrogen in Puget Sound.

Puget Sound is the second largest estuary in the United States and is part of the Salish Sea. It is a dynamic system influenced by a variety of local and global processes. The system is sensitive to changes in the Pacific Ocean, but excess local human nitrogen inputs also have an impact on its water quality.

We are involved in various efforts to understand how, and to what extent, excess nitrogen and other nutrients are a problem. This involves identifying nitrogen sources, monitoring nitrogen levels, analyzing how things are changing, and determining what we need to do to improve water quality as part of the Puget Sound Nutrient Reduction Strategy.

What we know about nitrogen in Puget Sound:

- The Pacific Ocean is the largest source of nitrogen to Puget Sound. These oceanic nitrogen contributions can be considered part of the 'baseline' nitrogen load, and our local human sources add to this amount.
- Wastewater effluent is the largest local source of nitrogen to the Sound.
- Upstream watershed activities that generate nitrogen are the second largest local source of nitrogen and get delivered to the Sound via rivers and streams.
- Nitrogen (and other nutrient) levels in marine waters are changing.
- We are observing more frequent algae blooms.
- Levels of oxygen are low in many places, and human nitrogen inputs further deplete oxygen levels in bottom waters and contribute to acidification.
- Population growth and climate change will further stress the ecosystem.

Questions we are asking:

- What are the specific mechanisms responsible for changes in nutrient levels and nutrient cycling in marine waters?
- What are the relative contributions of upstream nitrogen sources in watersheds to freshwater nitrogen loading?
- What improvements can we make to dissolved oxygen levels with different management actions?

This story map synthesizes information from a number of sources and its contents may be periodically updated with new information, data, and analysis as it becomes available. The map was created by Sheelagh McCarthy and Teizeen Mohamedali at the Washington State Department of Ecology, with initial framework development by Paula Cracknell. Feedback is welcome and can be sent to: teizeen.mohamedali@ecy.wa.gov

DEPARTMENT OF ECOLOGY State of Washington

Excess nitrogen

Nitrogen is a nutrient that is present in the natural environment and is needed by marine plants and animals to grow. Nitrogen from various sources (both human and natural) enters Puget Sound via different pathways. People increase the amount of nitrogen entering the Sound above natural levels. For example, nitrogen is present in human wastewater and in plant fertilizers.

Excess nitrogen can fuel algae blooms that eventually decompose and sink through the water column. This organic matter decomposition process decreases dissolved oxygen levels, typically near the bottom of Puget Sound waters.

Fish and other marine organisms depend on oxygen to survive and thrive. Oxygen levels in many parts of Puget Sound are below levels that are needed for these organisms to thrive successfully.

PHOTO: red-brown algal bloom in Ostrich Bay, Dyes Inlet (taken August 28, 2017).

The nitrogen cycle

Nitrogen has many components and is present in the environment in inorganic and organic forms as well as in dissolved and particulate forms. Nitrogen released into the environment in one form can be transported or transformed into other forms. It can also move from one compartment of the ecosystem into another (e.g. land, sub-surface, vegetation, groundwater, surface water, and marine waters). The **nitrogen cycle** is illustrated in this graphic.

Many of the estimates and plots presented in this story map focus on dissolved inorganic nitrogen (DIN). Of all forms of nitrogen, DIN is the form of greatest interest, since it is the most bio-available form of nitrogen used by marine algae. DIN is the sum of nitrate, nitrite, and ammonia nitrogen - three different forms of inorganic nitrogen. Organic forms of nitrogen are also present, but in much smaller amount.

The graphic below illustrates the partitioning of total nitrogen into the various forms found in the environment.

Excess nitrogen

Algal Blooms

Algal blooms are a common feature in marine waters, but we are observing a higher frequency of blooms in Puget Sound. This graphic illustrates how excess nitrogen loading contributes to low dissolved oxygen when algal cells decompose after a bloom occurs.

Other factors also enhance or inhibit algal growth and decomposition, including:

- circulation, temperature, and other weather conditions
- different species of algae respond differently nitrogen inputs
- levels of other nutrients e.g. total organic carbon
- changes in the food web and at other trophic levels e.g. presence/absence and type of zooplankton, which feed on algae

Dissolved oxygen levels are low

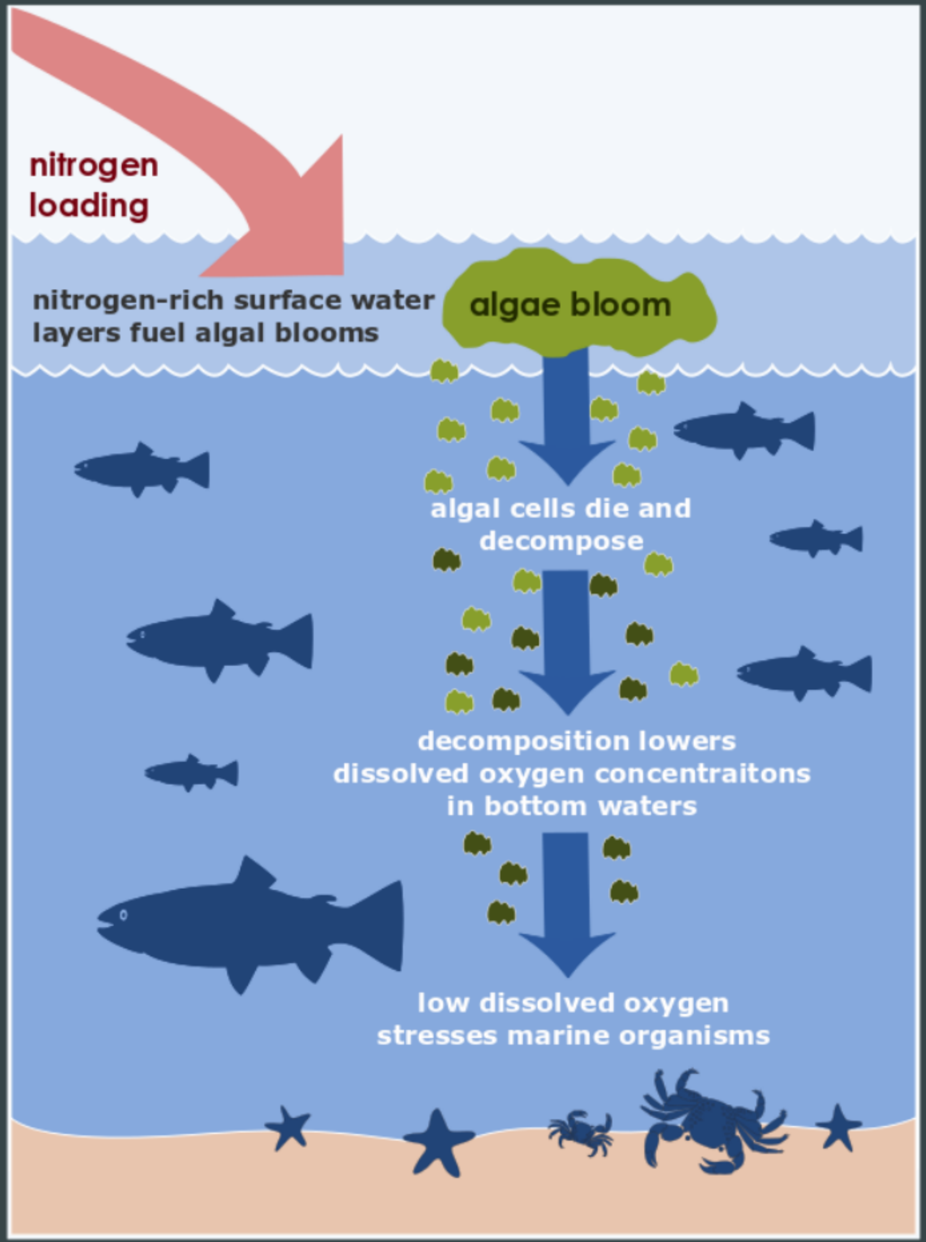
Low dissolved oxygen levels have been observed in Puget Sound for a number of years, but were also present historically. Low dissolved oxygen conditions are sometimes referred to as hypoxia, which means that there may not be enough oxygen for marine organisms to thrive. Washington State's water quality standards define minimum levels of dissolved oxygen that marine organisms, such as salmon, need to thrive.

This map illustrates areas in Puget Sound where measured dissolved oxygen levels are either below the water quality standard (impaired) or close to being at this minimum threshold (waters of concern) based on the 2014 Water Quality Assessment. The minimum dissolved oxygen water quality standard in most of Puget Sound is set to 7.0 mg/L. A few smaller inlets and bays of Puget Sound have a minimum dissolved oxygen standard of 5.0 or 6.0 mg/L.

In addition to dissolved oxygen depletion due to algal and other organic matter decomposition, a number of other factors also affect oxygen levels. These include:

- circulation and stratification patterns
- bathymetry of Puget Sound
- chemistry of incoming Pacific Ocean water
- water temperature, salinity and density
- timing and magnitude of freshwater flows
- biochemical or ecosystem-induced changes in the sediment layer
- local weather and regional climate

Modeling dissolved oxygen



Nitrogen in Puget Sound

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Excess nitrogen

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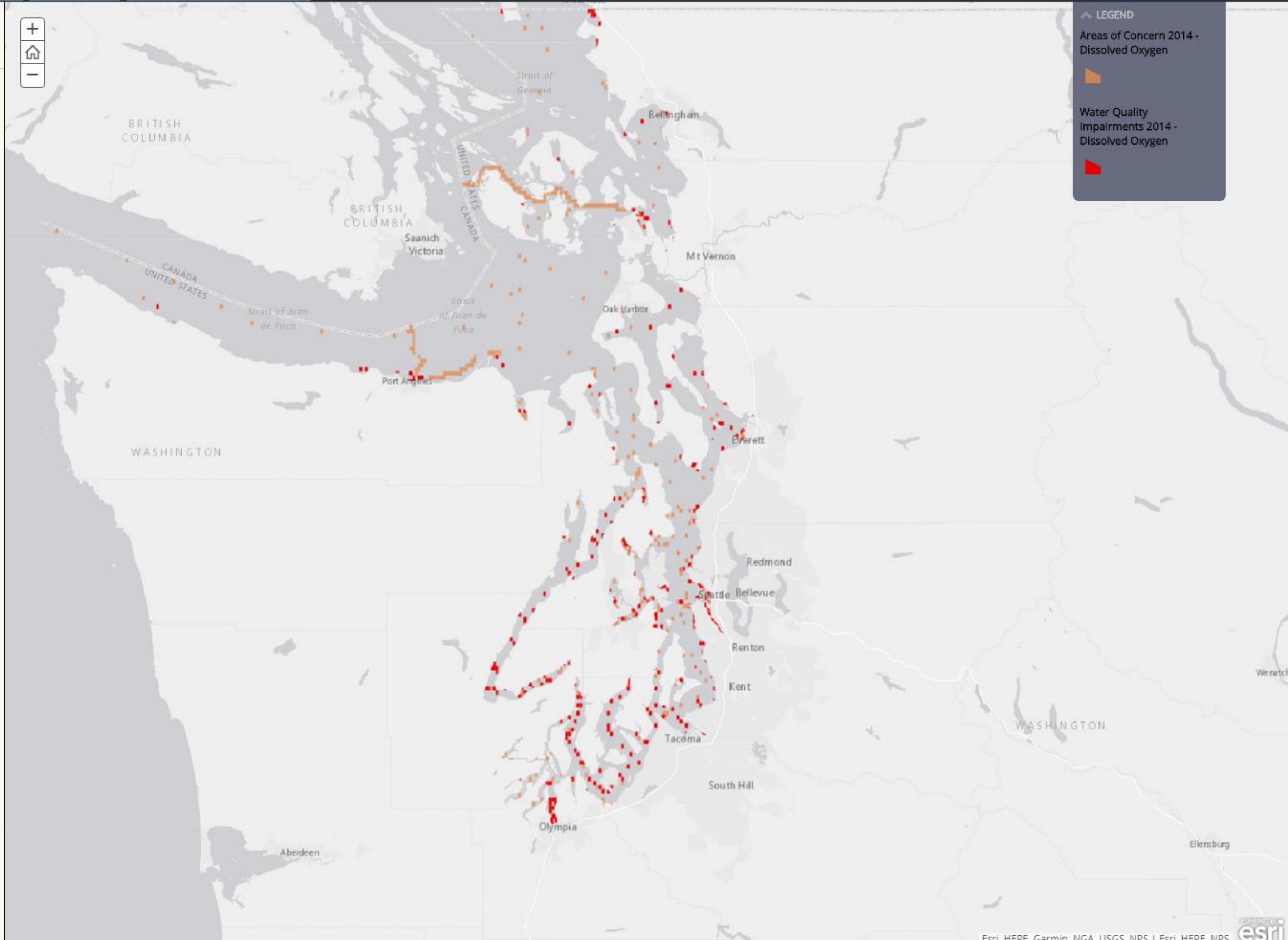
Modeling dissolved oxygen

The Salish Sea Model takes into account the physical, chemical, and biological processes that affect oxygen levels, to simulate nutrient and oxygen levels in Puget Sound. This video shows an animation of results from the model, illustrating levels of dissolved oxygen in the surface (left) and bottom (right) of Puget Sound in 2008. The model results show that:

- Oxygen levels are significantly lower at the bottom than at the surface of the Sound
- Oxygen levels are lowest in the late summer/early fall period (August - September)
- Oxygen levels vary spatially within Puget Sound

One of the questions that we are trying to answer using the Salish Sea Model, is: How much of the observed dissolved oxygen problems in Puget Sound are a result of human sources of nitrogen from this region?



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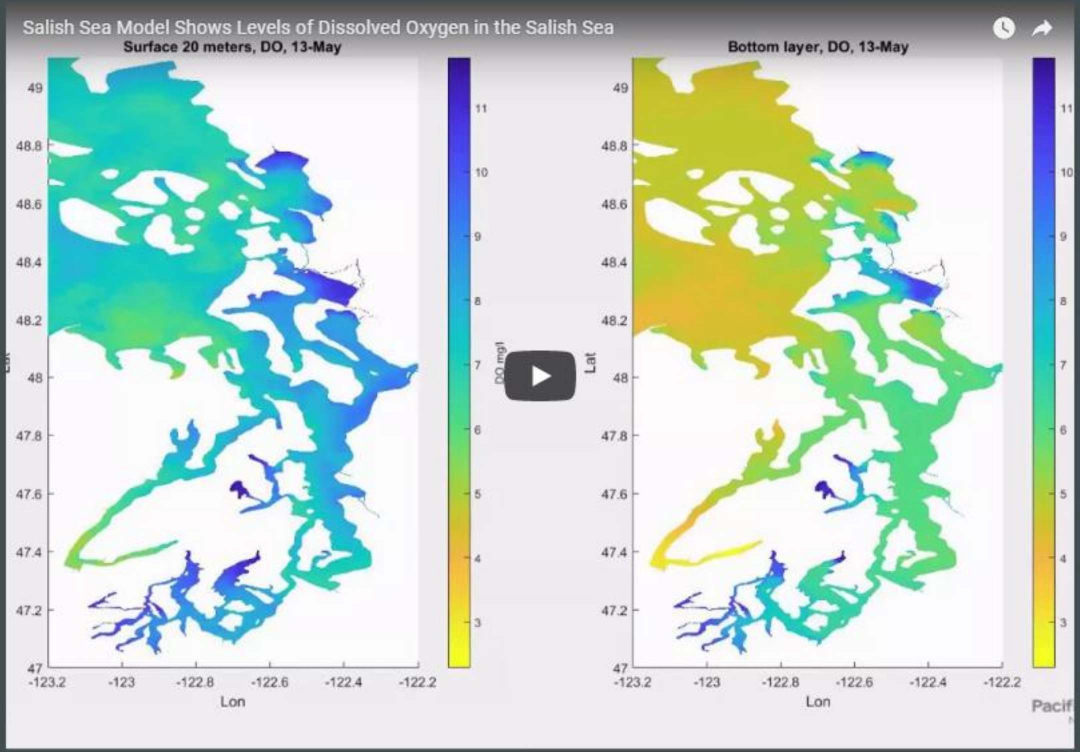
One of the questions that we are trying to answer using the Salish Sea Model, is: **How much of the observed dissolved oxygen problems in Puget Sound are a result of human sources of nitrogen from this region?**

The model will be used to guide management actions as part of the Puget Sound Nutrient Reduction Project.



Ocean Acidification

Ocean acidification is the scientific term used to describe how seawater chemistry is changing primarily due to increased amounts of carbon dioxide (CO_2) in the ocean from human activities. This extra CO_2 has changed the chemistry of seawater, making it more acidic. Puget Sound is affected by global ocean acidification particularly when deep ocean water upwells into the coastal zone and enters the Sound and coastal inlets. As seawater becomes acidic, it contains fewer carbonate ions that are available for marine organisms. This shift in chemistry affects marine organisms that need calcium carbonate to form skeletons and shells.

In Puget Sound, nitrogen loading and organic-matter inputs from various local sources increase acidification in some areas (e.g. in the main basin of Puget Sound) and reduce acidification in other areas (e.g. the shallow inlets and bays of South Puget Sound). The mechanisms for this include:

1. An increase in primary productivity, which increases uptake of CO_2 and increases pH, primarily in the surface layers (makes water less acidic).
2. Subsequent release of CO_2 when the algae and organic matter decompose, which then reduces pH levels (makes water more acidic) in the bottom waters.

This 2017 report found that increased dissolved inorganic nitrogen and non-algal

Nitrogen Sources & Pathways

Where does nitrogen come from?

Nitrogen from many sources and pathways enter Puget Sound, as illustrated in the image to the right. **Find details about each source and pathway by clicking on the tabs above.**

We are using the Salish Sea Model to evaluate the relative effects of human (anthropogenic) and natural nutrient sources on dissolved oxygen levels in Puget Sound. This model is being used to guide the Puget Sound Nutrient Reduction Project.

Nitrogen concentrations in different sources

This graphic illustrates the typical range of nitrogen concentrations we see in different sources. Note that the y-axis of the figure is on a log scale, so septic system effluent and wastewater treatment plant effluent concentrations are one to two magnitudes higher than most other sources.

Nitrogen load contributions

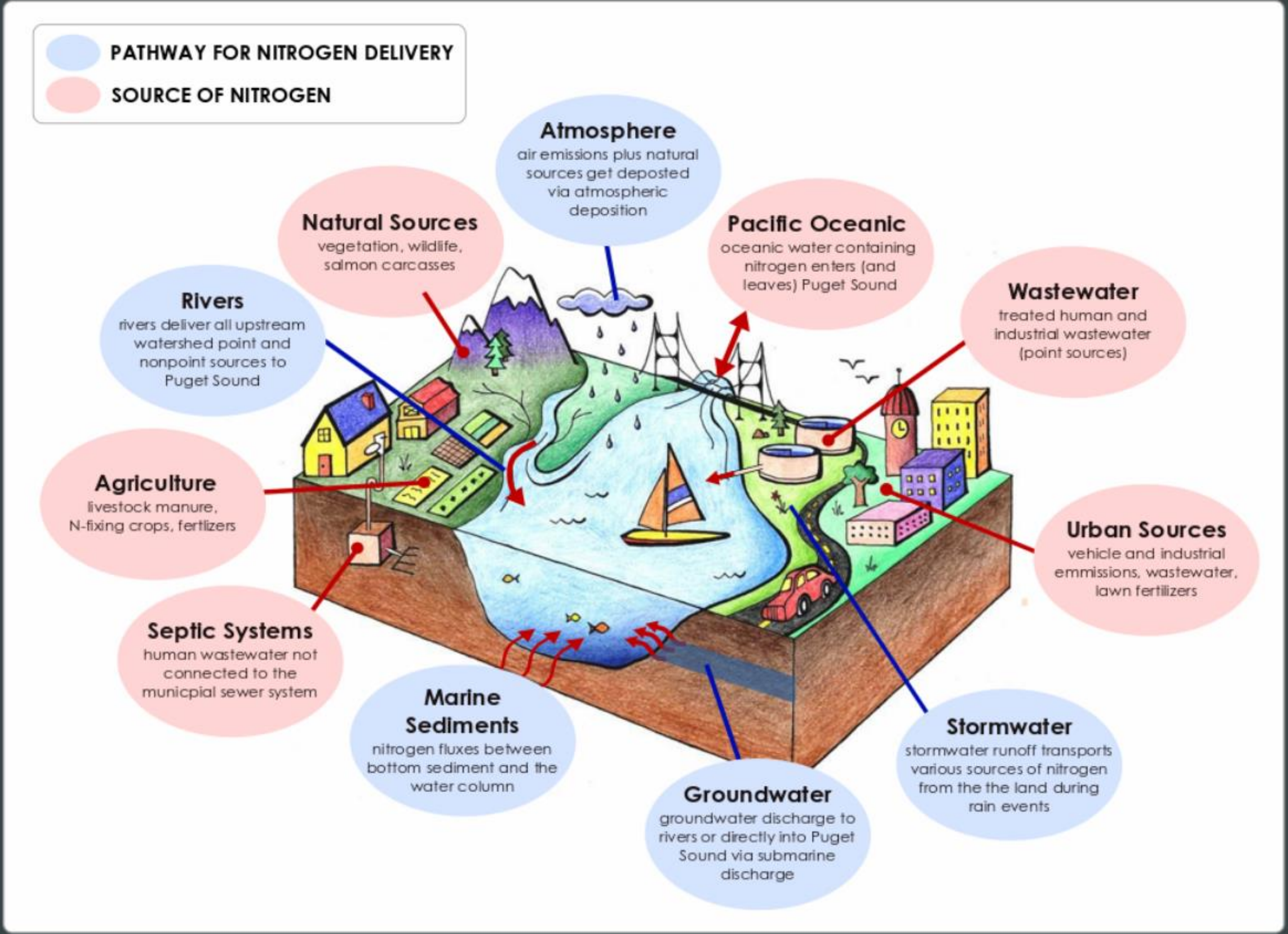
Even though concentrations of nitrogen in the incoming deep Pacific Ocean water are not the highest (relative to other sources), the large amount of water flowing into Puget Sound and the Salish Sea from the ocean means the Pacific Ocean contributes the largest load. "Load" is an important way to quantify nitrogen contributions, and is simply calculated as:

nitrogen load = nitrogen concentration x flow

After the Pacific Ocean, there are two main regional inputs of nitrogen to Puget Sound:

1. Wastewater treatment plant effluent discharging to Puget Sound via marine outfalls.
2. Rivers and streams delivering sources from the watersheds they drain.

The load entering Puget Sound from rivers and streams includes contributions

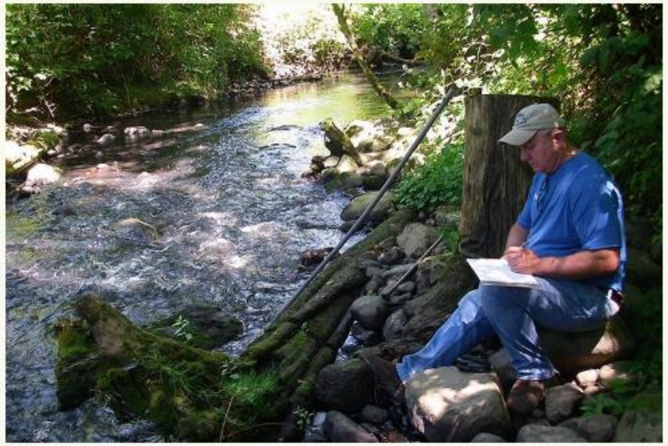


Nitrogen Monitoring

Freshwater Monitoring

The freshwater monitoring program has conducted ambient monitoring of rivers and streams in Washington state for a number of other parameters, including nitrogen, for over 20 years. Most data are collected at monthly intervals. The data are available online and also summarized in annual monitoring reports.

You can click on each station on this map to find out more details about each monitoring location within Puget Sound watersheds.

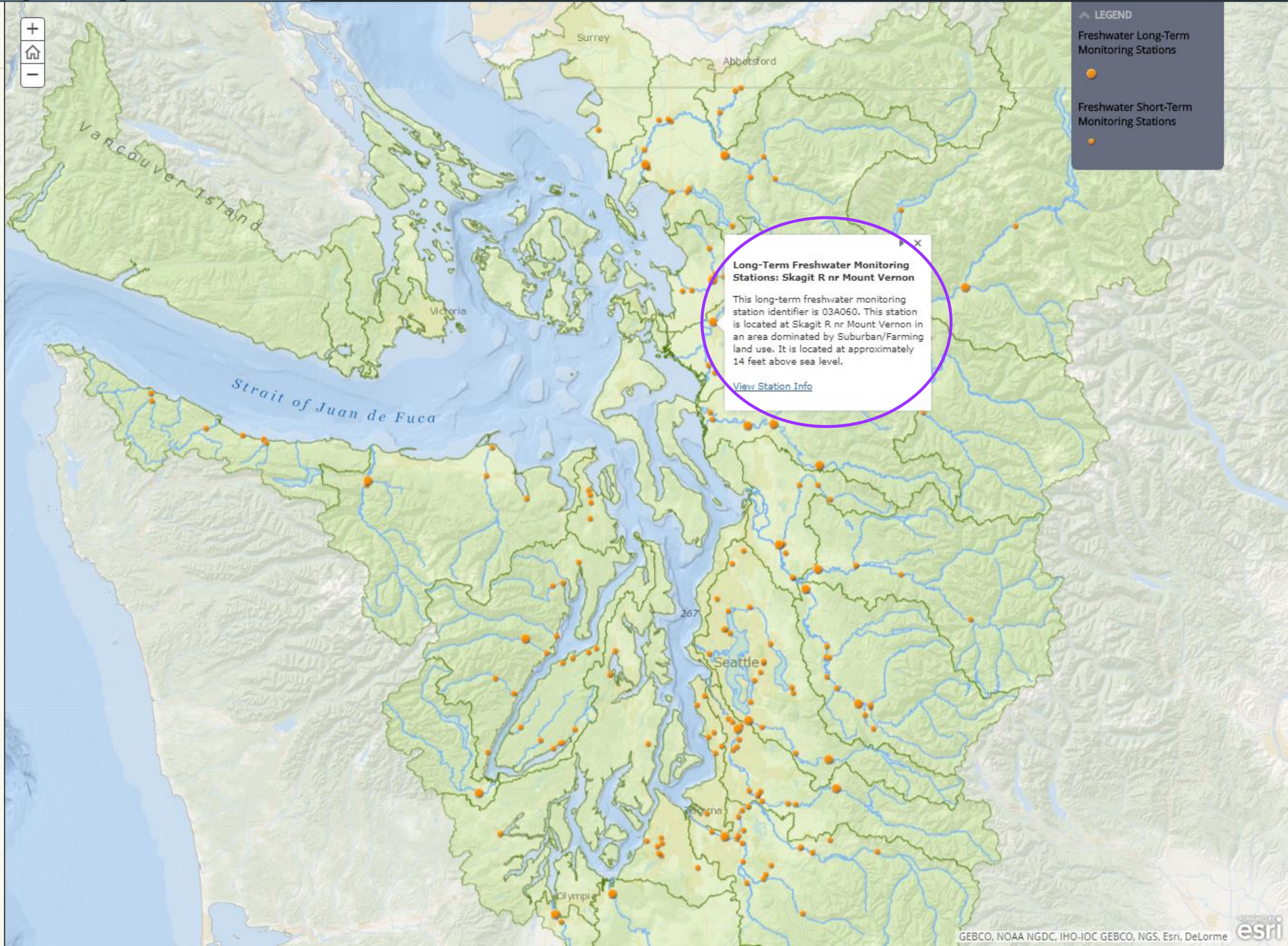


Collecting freshwater data.

Our scientists are currently exploring options to expand our monitoring efforts to include continuous nitrogen monitoring at some of these freshwater monitoring stations in order to refine our river loading estimates.

Marine Monitoring

The marine monitoring program has monitored physical, chemical and biological water quality variables monthly in Puget Sound since 1973, and has used consistent monitoring methods since 1999. The program provides information on the variability and status and trends in water quality in the form of the Marine Water Condition Index and yearly marine waters reports. Long-term data are available online.



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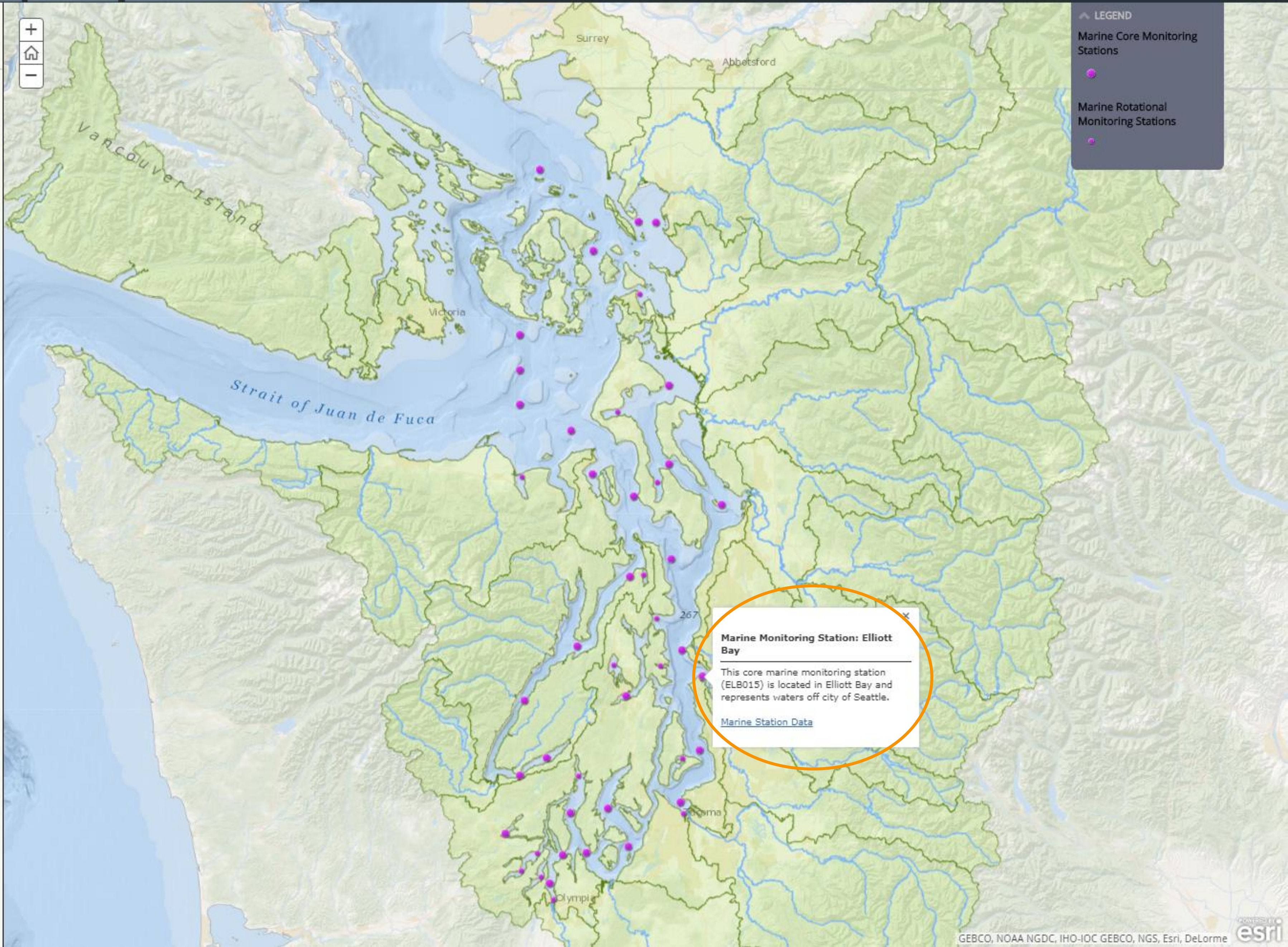
Preparing for marine flight sampling

Eyes Over Puget Sound

Eyes Over Puget Sound (EOPS) is a monthly report that provides a unique vantage point on water quality issues and processes in Puget Sound using aerial photography.

High-resolution aerial photo observations of Puget Sound are taken from a float-plane at the same time as we gather water quality data at marine monitoring stations. These images are combined with monitoring data to provide a more tangible snapshot of the health and conditions in Puget Sound on a scale that resonates with people.

Focused Nitrogen Monitoring Studies



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Focused Nitrogen Monitoring Studies

Bertrand Creek Nitrogen Monitoring

Most of the nitrogen monitoring we currently do happens at monthly intervals. In Bertrand Creek, we installed monitoring equipment to continuously monitor nitrate (and other parameters) starting in 2013. This project was initiated to measure the effectiveness of water quality clean up and management activities in the Bertrand Creek watershed, a sub-watershed of the Nooksack River in Whatcom County. The data will be used to determine the movement (flux), continuous annual loading (yield) and behavior (seasonal patterns) of nitrate concentrations in the creek. Two of these stations transmit live data via satellite to our webpage every three hours. That data can be viewed here:

- Bertrand Cr. nr mouth (current)
- Bertrand Cr.@ 0 St. (ended 10/2016)

Quartermaster Harbor Nitrogen Management Study

King County, in collaboration with Ecology and the University of Washington-Tacoma, conducted the Quartermaster Harbor Nitrogen Management Study (2008-2013). This work studied the influence of nutrients from a human and natural sources on dissolved oxygen in Quartermaster Harbor. The long-term goals of this project were to improve water quality management policies in the King County Comprehensive Plan and protect the water quality in Quartermaster Harbor. More information about this study can be found at King County's Quartermaster Harbor Nitrogen Management Study website and in the final report, along with other related study documents, data, and maps.

Deschutes River Nitrogen Monitoring

Between October 2009 and November 2011, a continuous nitrate monitoring device, called a Submersible Ultraviolet Nitrate Analyzer (SUNA), was deployed in the Deschutes River (at the E. Street Bridge in Tumwater). The high-resolution time-series of nitrate data was used to develop statistical methods to quantify uncertainties associated with annual nitrate loading estimates derived from more coarsely sampled time series. For more information, see the Deschutes River Continuous Nitrate Monitoring report.

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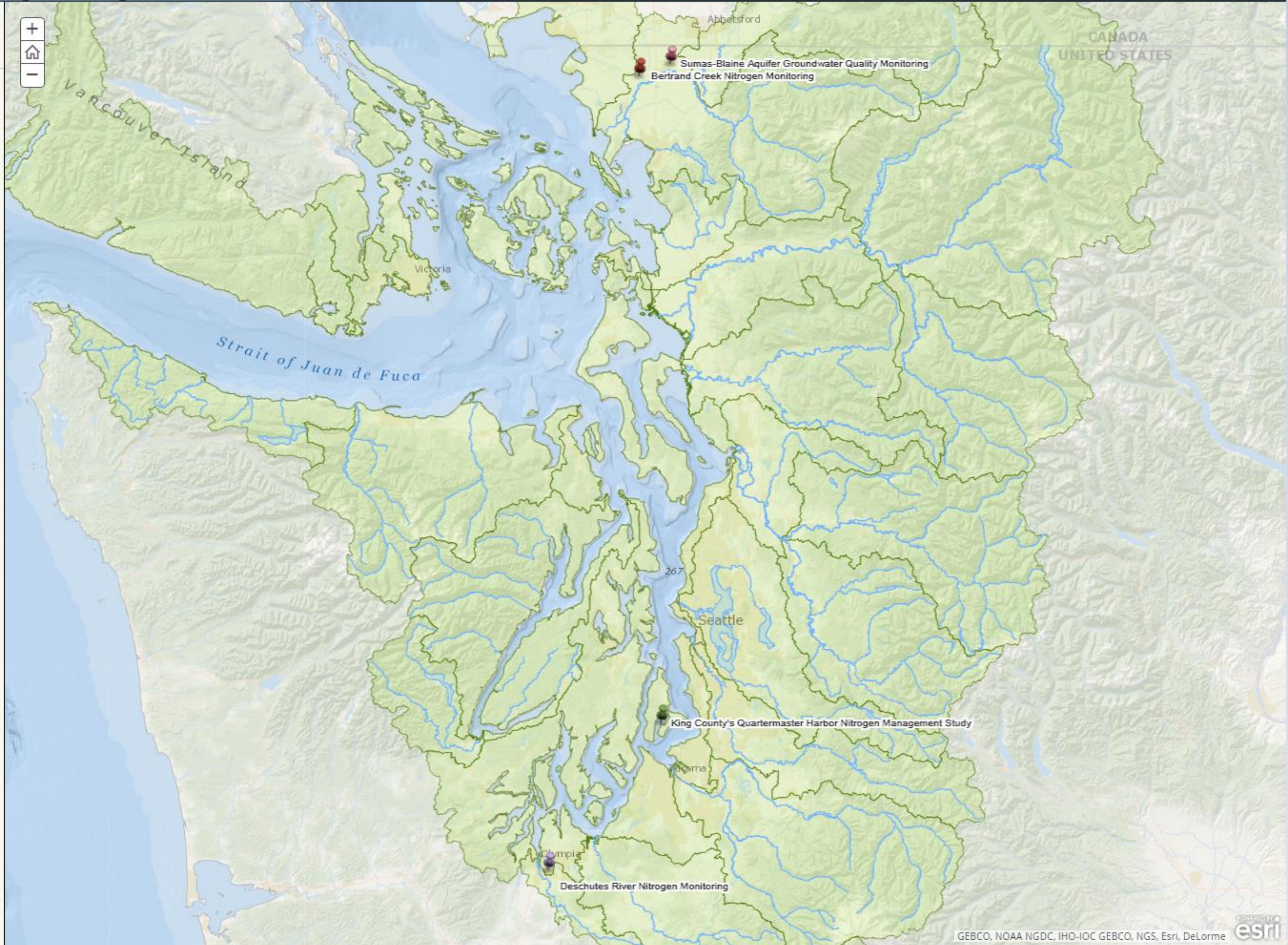
Sumas-Blaine Aquifer Groundwater Quality Monitoring

The Sumas-Blaine Aquifer is one of the most severely contaminated aquifers in Washington state, and we have been studying groundwater in the Sumas-Blaine Aquifer for over 25 years as part of the Sumas-Blaine surficial aquifer long-term ambient groundwater monitoring program. We sampling wells annually for nitrate (and chloride and bromide), to track broad-scale changes in groundwater nitrate over time. The 2009-2016 report includes the most recent analysis of trends, finding that nitrate concentrations decreased significantly in 9 out of 25 wells, and the percent of wells that exceeded 10 mg/L also decreased. However, the study did include some limitations (small sample size relative to the size of the aquifer, unreliable access to well, and long-term climate influences), and monitoring is ongoing.



Marine Trends

Concentrations of nitrogen in Puget Sound marine waters are changing, and influenced by both nitrogen inputs from the ocean and nitrogen loading from local sources, among other things.

Because of the number of factors that influence these concentrations, our scientists are currently trying to isolate the influence of local nutrient sources on nitrogen concentrations in Puget Sound, using statistical analysis to remove the effect that oceanic nitrogen inputs have on these measurements. This can be instructive because it allows us to isolate how much of the change (based on marine monitoring data) is due to local nitrogen sources vs. larger oceanic processes beyond our influence.

Changes in nitrogen levels and other nutrient cycles can affect the Puget Sound ecosystem and food web e.g. the species composition of algae or the timing and extent of algae blooms. Our scientists have proposed a hypothesis of how changing nutrient ratios drive changes in the Puget Sound food web, which you can read more about in this poster.

Photo: Large Noctiluca bloom in Central Puget Sound near Bainbridge Island (taken June 12, 2012)

Marine nitrate levels

This "heat map" shows nitrate concentrations between 1999 and 2015 at several monitoring stations in Puget Sound relative to baseline levels. Darker shades of orange and blue indicate greater deviations from baseline conditions:

- orange - nitrate concentrations are above baseline conditions
- blue- nitrate concentrations are below baseline conditions
- black - nitrate concentrations are similar to baseline conditions
- gray - no data

Nitrate concentrations were generally below baseline conditions between 1999-2005, and then consistently higher b[illegible] 2008 and 2012. Since 2013, concentrations have fluctuated, with n[illegible] declines in 2013 and 2015.

Access Ecology's Nitrogen in Puget Sound Story Map online at:

bit.ly/nitrogenstorymap

QUESTIONS + DISCUSSION

Sheelagh McCarthy, Washington State Dept. of Ecology
shem461@ecy.wa.gov

Teizeen Mohamedali, Washington State Dept. of Ecology
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Nitrogen in Puget Sound Story Map

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The Nitrogen Cycle Diagram: University of Maryland Center for Environmental Science. Source: Dennison, W.C., J.E. Thomas, T.J.B. Carruthers, M.R. Hall, C.E. Wazniak, and D.E. Wilson. 2009. Shifting Sands: Environmental and cultural change in Maryland's Coastal Bays. IAN Press, University of Maryland Center for Environmental Science.

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Conceptual Diagram illustrating a typical septic system courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science. Source: Dennison, W.C., J.E. Thomas, C.J. Cain, T.J.B. Carruthers, M.R. Hall, R.V. Jesian, C.E. Wazniak, and D.E. Wilson. 2009. Shifting Sands: Environmental and cultural change in Maryland's Coastal Bays. IAN Press, University of Maryland Center for Environmental Science.

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Conceptual Diagram illustrating the basic cycle of groundwater transport in relation to the Maryland Coastal Bays courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science. Source: Dennison, W.C., J.E. Thomas, C.J. Cain, T.J.B. Carruthers, M.R. Hall, R.V. Jesian, C.E. Wazniak, and D.E. Wilson. 2009. Shifting Sands: Environmental and cultural change in Maryland's Coastal Bays. IAN Press, University of Maryland Center for Environmental Science.

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