Title: Tracking Puget Sound Nutrient Loading Trends and Water Quality Response

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ABSTRACT
The Puget Sound region has long been recognized for its ecological significance, serving as a vital marine ecosystem and supporting diverse aquatic life. This paper focuses on trends in wastewater nitrogen loadings and the resulting water quality response in Puget Sound. The objective is to quantify the extent of nitrogen inputs from wastewater sources and their subsequent effects on measures of water quality. Puget Sound water quality depends on many factors, including not only point and non-point nutrient loadings but also the extent of mixing of nutrient-rich, oxygen-poor ocean water within the estuary.

KEYWORDS
Puget Sound, Salish Sea, Nitrogen, Nutrients, Water Quality, Compliance, Permitting, Narrative Limits, Water Quality Modeling, Optimization, Water Quality Standards, Water Quality Index, Dissolved Oxygen

INTRODUCTION | BACKGROUND

The Puget Sound region has long been recognized for its ecological significance, serving as a vital marine ecosystem and supporting diverse aquatic life. This paper focuses on trends in wastewater nitrogen loadings and the resulting water quality response in Puget Sound. The objective is to quantify the extent of nitrogen inputs from wastewater sources and their subsequent effects on measures of water quality.

This paper presents an initial examination of the overall trends in cumulative nitrogen loadings to Puget Sound from all marine wastewater dischargers regulated under the Puget Sound Nutrient General Permit (PSNGP) and compared with receiving water conditions in the Sound. Topics addressed are summarized as follows:

1. Puget Sound Nutrient General Permit (PSNGP)
2. Trends in Nitrogen Loading to Puget Sound
3. Trends in Puget Sound Water Quality

4. Factors Controlling Puget Sound Water Quality

METHODOLOY

The Puget Sound Nutrient General Permit (PSNGP) calls for optimization efforts to reduce nitrogen loadings from wastewater facilities (Ecology 2021). Annual performance reports for 58 marine wastewater dischargers provides a data set to initiate a trends analysis of nitrogen loadings for the years 2020/21/22/23/24. The marine discharges in Washington State and British Columbia are shown in Figure 1. In this paper, trends in the cumulative point source loadings from wastewater dischargers will be compared with receiving water quality measures and the factors controlling Puget Sound water quality.

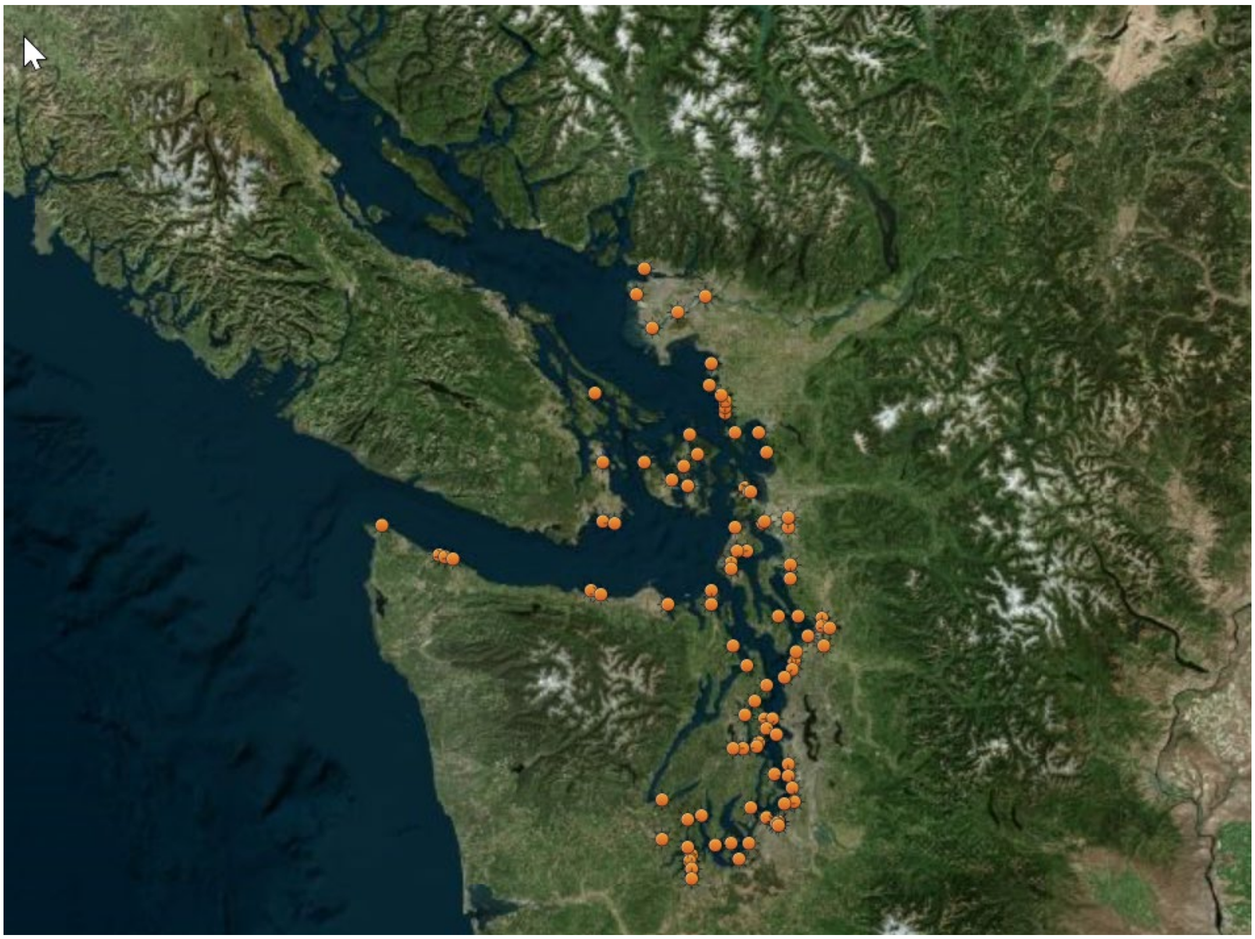


Figure 1: The Salish Sea in Washington State and British Columbia with Marine Point Source Discharges

Puget Sound water quality depends on many factors, including not only point and non-point nutrient loadings but also the extent of mixing of nutrient-rich, oxygen-poor ocean water within the estuary. Historical characterizations over the past century, contemporary monitoring data for key parameters, elaborate simulators such as the Salish Sea Model (SSM), and potentially water quality indices provide an aggregate characterization of conditions.

A comprehensive water quality index integrates multiple parameters to provide an overall assessment. Consideration has been given to comparison of nitrogen loading trends with key water quality metrics, available water quality indices, and other characterizations of interest. The Puget Sound Partnership's Puget Sound Vital Signs includes multiple water quality characteristics, although its development is incomplete (dissolved oxygen, nutrients, marine benthic index, acidification, sediment chemistry index, etc.). The Department of Ecology's Marine Waters Condition Index (MWCI) has been updated and focuses on changes in nutrients, eutrophication, the oxygen budget, and environmental conditions of lower trophic levels.

RESULTS

The Puget Sound Nutrient General Permit (PSNGP) includes seven wasteater dischargers as Dominant Dischargers with Action Levels expressed as Total Inorganic Nitrogen (TIN) mass discharges in pounds per year (lbs/year) and kilograms per year (kg/year) summarized in Table 1. Each of the Dominant Dischargers have a TIN loading of about 1 million lbs/year or more, including King County's three large treatment plants (West Point (6,670,000 lbs/yr), South Plant (7,340,000 lbs/yr), and BrightWater (1,810,000 lbs/yr)).The other Dominant Dischargers are the City of Everett (1,530,000 lbs/yr), City of Tacoma (2,410,000 lbs/yr), Pierce County (1,880,000 lbs/yr) and the City of Bellingham (993,000 lbs/yr).

Table 1. Total Inorganic Nitrogen (TIN) Action Levels for Dominant Dischargers from the Puget Sound Nutrient General Permit (PSNGP)

Wastewater Treatment Plant	Action Level	
	lbs/year	kg/year
Everett STP	1,530,000	695,000
King County Brightwater WWTP	1,810,000	823,000
King County South WWTP	7,340,000	3,336,000
King County West Point WWTP	6,670,000	3,032,000
Pierce County Chambers Creek WWTP	1,880,000	855,000
Bellingham Post Point WWTP	993,000	451,000
Tacoma Central No. 1 WWTP	2,410,000	1,095,000

The PSNGP includes 20 Moderate Dischargers with TIN Action Levels ranging from 18,000 to more than 625,000 lbs/yr. The Moderate Dischargers include the City of Bremerton (602,000 lbs/yr), Kitsap County (306,000 lbs/yr),the Lakehaven Utility District (LUD) Lakota Plant (597,000 lbs/yr), Lacey Olympia Tumwater Thurston Count LOTT (338,000 lbs/yr), and the City of Mt Vernon (396,000),

There are 31 permittees designated as Small Loaders that do not have numercial Action Levels in the PSNGP.

Recent Nitrogen Loadings

Nitrogen loadings for recent years from PSGNP reporting for Dominant Dishcargers are illustrated in Figure 2. Figure 3 illustrates TIN loadings for the Moderate Dischargers. Reporting over the limited period of the PSNGP (2020 to 2023 in Figures 2 and 3) limits the potential for trends analysis to compare nutrient management efforts with trends in the water quality response in Puget Sound. This highlights the need for a longer period of record for wastewater nutrient discharges to associate with Puget Sound water quality.

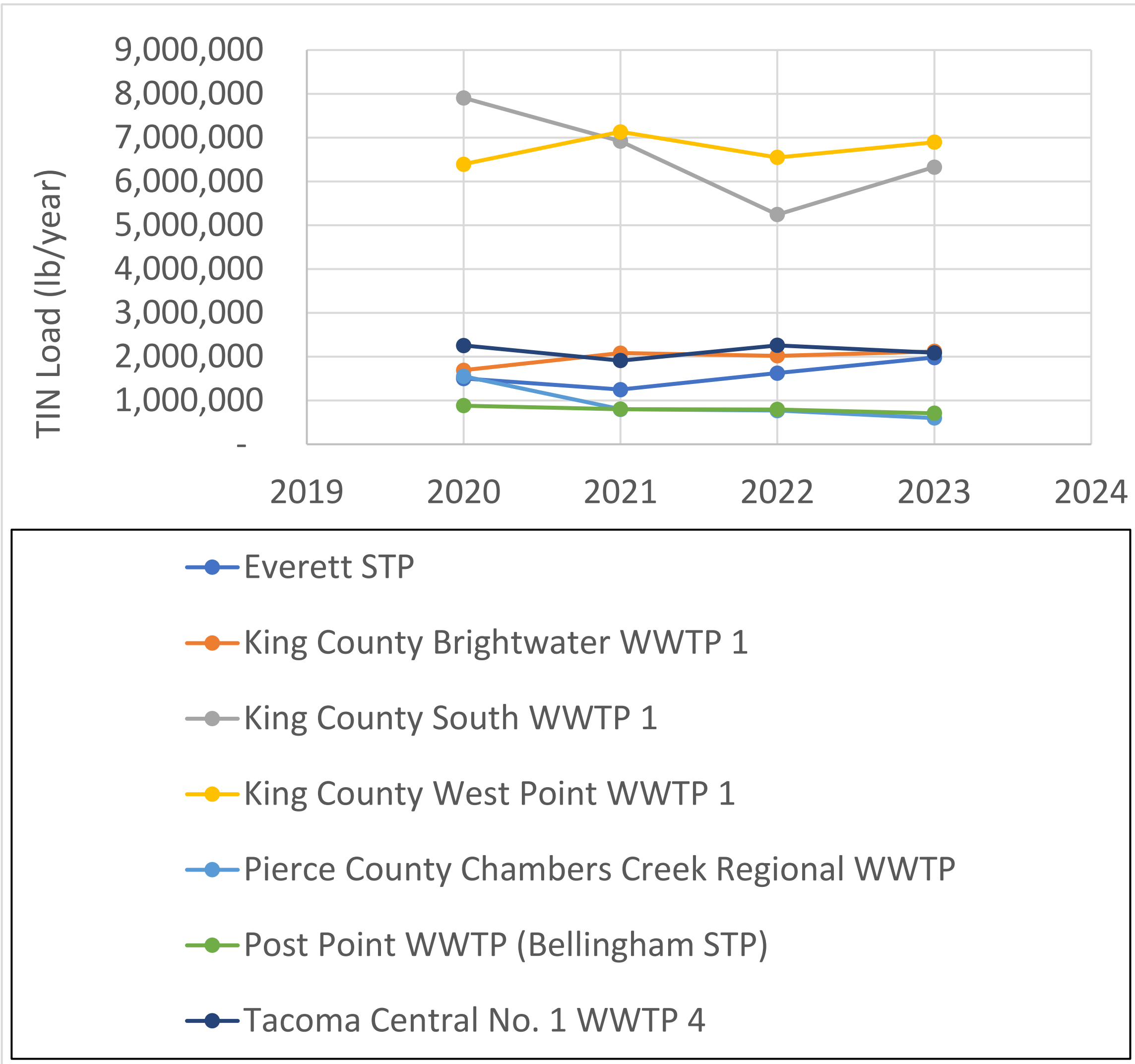


Figure 2: Nitrogen Loadings from PSNGP Reporting by Dominant Dischargers, 2020 to 2023

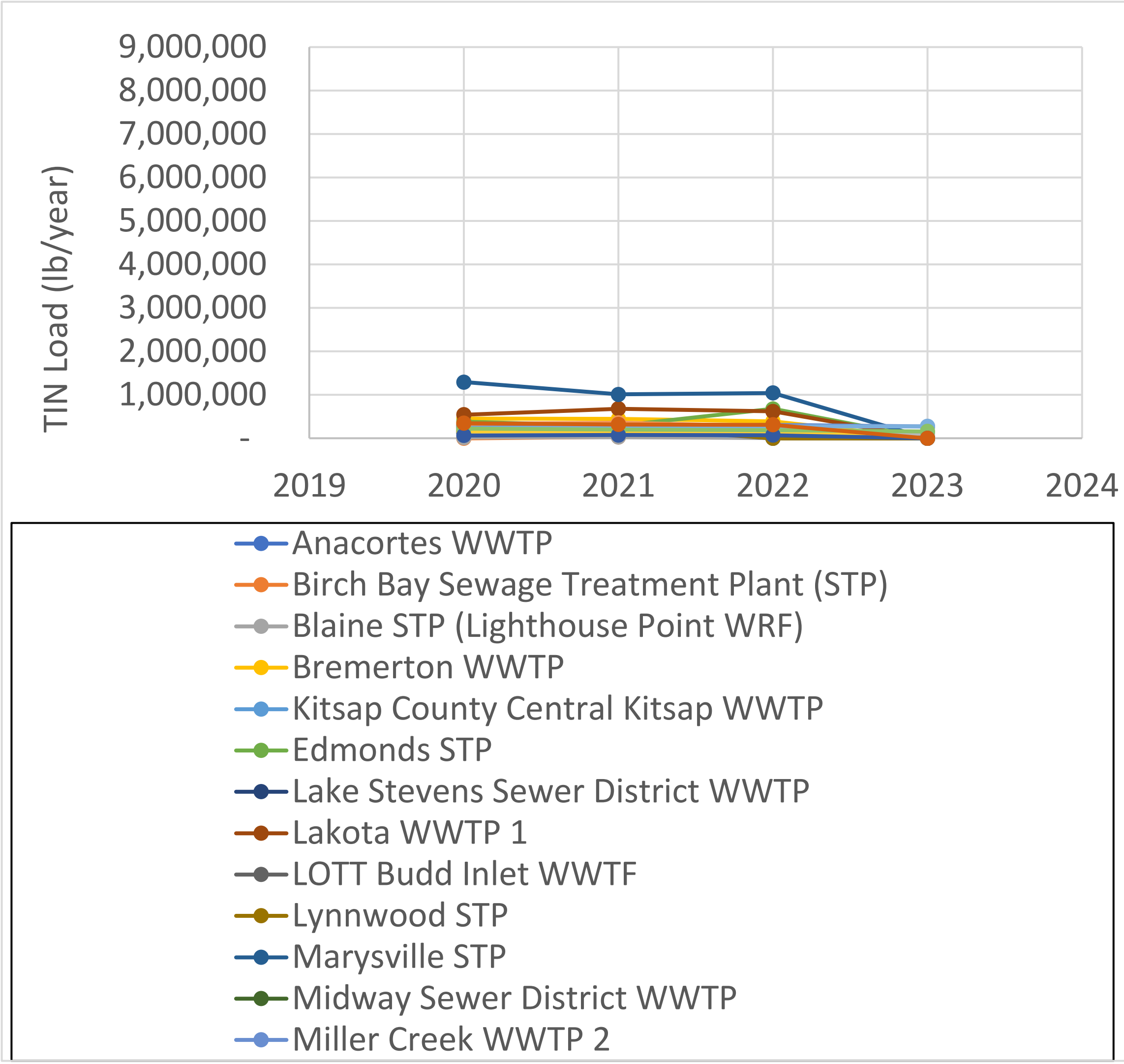


Figure 3: Nitrogen Loadings from PSNGP Reporting by Moderate Dischargers, 2020 to 2023

Reissued Puget Sound Nutrient General Permit

The Puget Sound Nutrient General Permit was appealed and on February 28, 2025 the Washington state Pollution Control Hearings Board (PCHB) invalidated the PSNGP. The PCHB ruled that it was unlawful for Ecology to require coverage under both an individual and general permit for the same discharge, finding as follows :

- “Pursuant to WAC 371-08-540(2), the Board INVALIDATES the PSGNP insofar as it is mandatory for already-permitted dischargers and REMANDS the permit to Ecology for further actions consistent with the law and this decision.”

As a result of the PCHB decision, Ecology reissued a draft voluntary version of the nutrient general permit in mid 2025 (Ecology 2025a). The reissued voluntary nutrient general permit has been modified only slightly and includes similar requirements to the original PSNGP for optimization and preparation of a Nutrient Reduction Evaluation (NRE), with some exceptions for facilities already discharging effluent nitrogen less than 10 mg/L. Dischargers have a choice between selecting the general permit or having similar nitrogen management requirements incorporated into the individual NPDES permit for the facility. The reissued voluntary nutrient general permit is expected have an effective date in 2026 and to expire in 2027.

Puget Sound Nutrient Reduction Plan

In June 2025, Ecology published a draft Nutrient Reduction Plan for review that incorporates the results of Salish Sea Model simulations for nitrogen reductions (Ecology 2025b). The Nutrient Reduction Plan is intended to be an Advance Restoration Plan to address dissolved oxygen impairments as an alternative to a Total Maximum Daily Load (TMDL). Ecology has conducted water quality modeling of optimization scenarios using the Salish Sea Model that include reductions in point source nitrogen discharges and reductions in watershed loadings delivered by tributaries to Puget Sound (Ecology 2025c). Ecology has selected seasonal effluent wastewater discharge nitrogen concentrations for three seasons designated as cool (Jan, Feb, Mar, Nov, Dec), warm (Apr, May, Jun, Oct), and hot (Jul, Aug, Sep). Generally, the effluent nitrogen targets for most dischargers are 8, 5, and 3 mg/L for cool, warm, and hot seasons defined as total nitrogen (TN) in the Nutrient Reduction Plan. Some discharges to embayments have more restrictive effluent TN targets of 3 mg/L year around. Ecology has also added an effluent CBOD target of 8 mg/L to the assumed future effluent target.

Extended Record of Wastewater Nitrogen Loadings

To extend the period of record for wastewater nitrogen discharges to Puget Sound, data has been mined from the discharge monitoring database and data used in Salish Sea Model simulations. Historical flows and ammonia, NOx, and TIN loads were estimated using data obtained from the Washington Department of Ecology's (Ecology) Water Quality Permitting and Reporting Information System. Daily mass loading rates (kg N/d) for ammonia, NOx, and TIN were calculated by multiplying daily concentration values by the corresponding daily average flow (e.g., kg N/d = mg N/L × MGD × 3.785). The average annual mass loading rates were calculated by averaging the daily loading rates for each year. Aggregate loading rates (i.e., for subbasins) are estimated by summing the average annual loading rates. Where multiple monitoring points represent a single discharger, the loading rates are calculated separately and summed. Data prior to July 31, 2017 were obtained as monthly averages from Ecology's webpage containing downloadable files used in the Salish Sea Model. Missing monthly average values were filled using a third-order spline fitted to the available monthly averages aggregated across all available years of data. A variety of data cleaning steps were taken, including removing outliers above the 0.9999th quantile, values below zero, and other clearly erroneous data.

Trends in nitrogen loadings for Dominant Dischargers from 1999 through 2024 are shown in Figure 4. Nitrogen loadings from the two largest discharges, the King County West Point and South Plant, appear to be trending downward over time. Trends in the nitrogen loadings from the other Dominant Dischargers have incresed modestly over time.

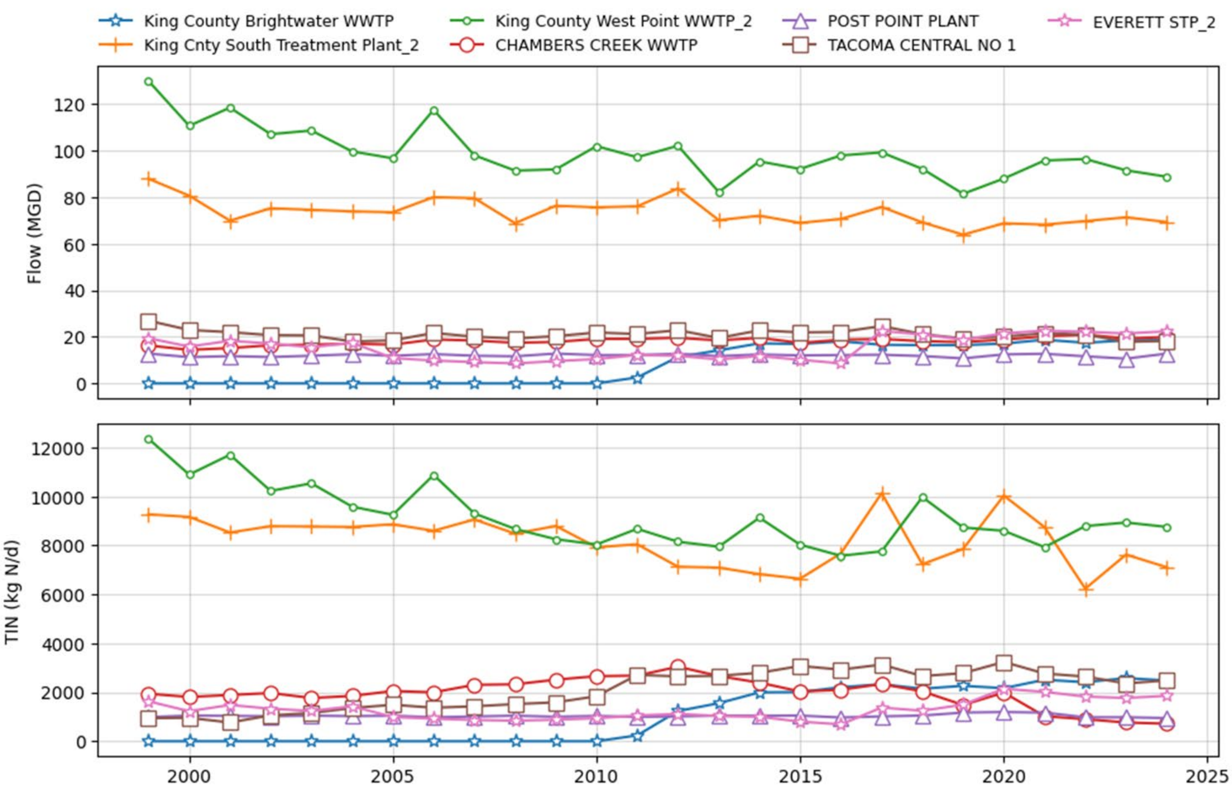


Figure 4: Trends in Nitrogen Loadings for Dominant Dischargers from 1999 through 2024

Figure 5 illustrates the trend in nitrogen loadings for the Moderate Dischargers for the same period of 1999 through 2024. Trends in nitrogen loadings from Moderate Dischargers are mixed over time. The LOTT WWTP is one of the larger facilities in the Moderate category and has long operated for nitrogen removal with varying mass discharges that have been reduced over time. Loadings from the Lakota WWTP and Marysville STP show distinct increases. The Edmonds STP loadings have decreased significantly. In recent years, nitrogen loads have decreased from the Anacortes WWTP, Bremerton STP, and Mt Vernon.

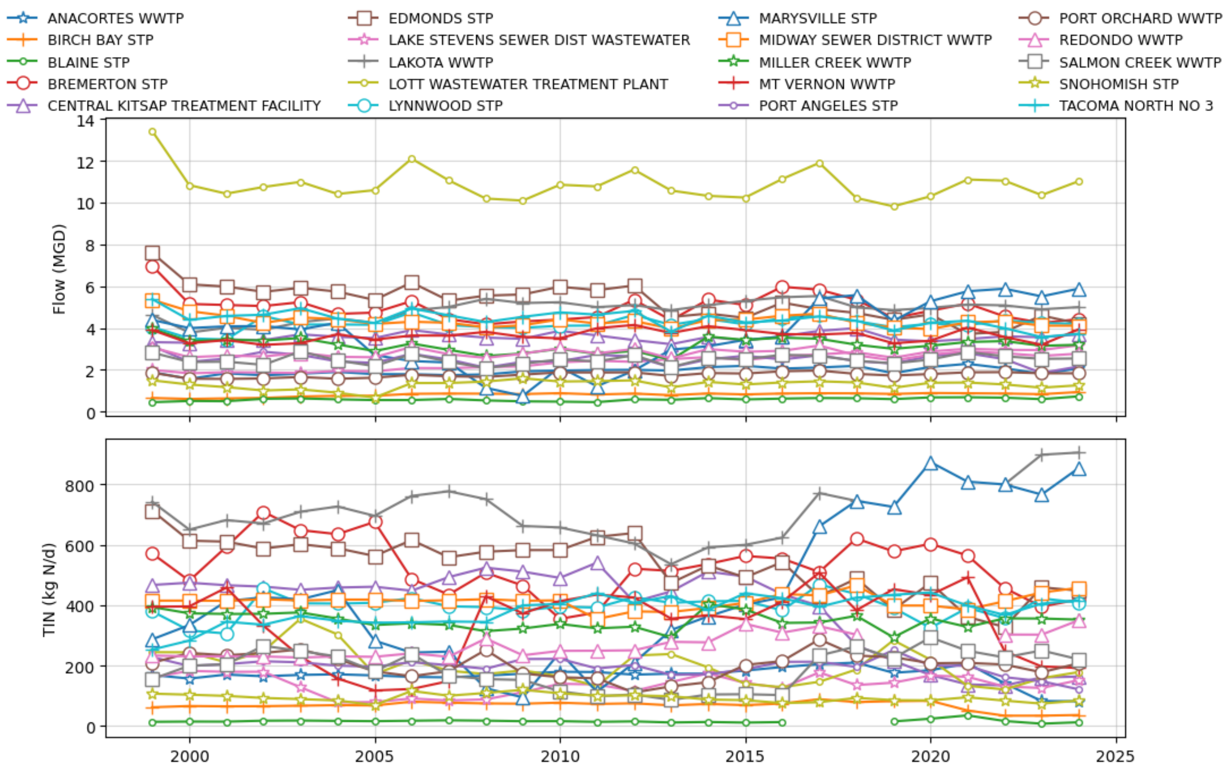


Figure 5: Trends in Nitrogen Loadings for Moderate Dischargers from 1999 through 2024

Figure 6 illustrates the trend in nitrogen loadings for the Small Dischargers for the period 1999 through 2024. The nitrogen loading from two of the largest of the Small Dischargers, Alderwood STP and Oak Harbor STP, have been reduced significantly. Both of those facilities have been upgraded to membrane bioreactors (MBR). The Alderwood STP was upgraded in 2014/15 and the Oak Harbor STP in 2018/19.

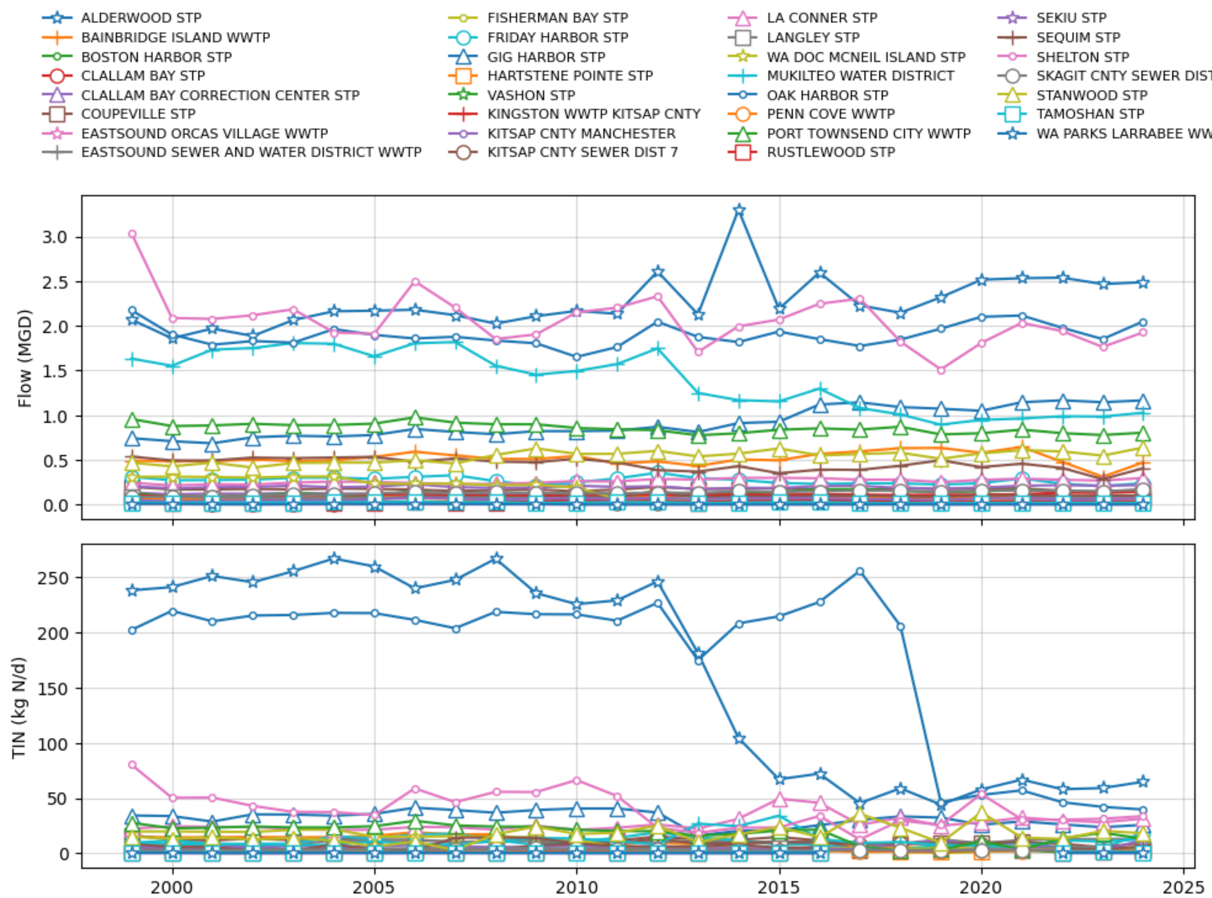


Figure 6: Trends in Nitrogen Loadings for Small Dischargers from 1999 through 2024

The effluent monitoring data reported for the Puget Sound Nutrient General Permit and the data mined from the Ecology's discharge monitoing database provides nitrogen loadings for both individual dischargers and the cumulative loading from all discharges. An example of an individual discharger flow and nitrogen concentration and loading data is shown in Figure 7. Figure 7 illustrates the impact that the wet season has on peak wastewater flows that influence seasonal effluent nitrogen performance.

Figure 8 illustrates a marked reduction in effluent nitrogen discharge from the City of Oak Harbor, WA discharging to Oak Harbor. Oak Harbor was one of the embayments in Puget Sound identified in Salish Sea Model simulations based on the year 2014 as impaired for dissolved oxygen. The City invested approximately \$100M in a facility improvement project to upgrade treatment technology to a membrane bioreactor (MBR) in 2019. Effluent nitrogen levels have been reduced substantially. Unfortunately, the 2014 base year used for the Salish Sea Model simulations do not reflect the water quality response in Oak Harbor from this improved nitrogen removal performance.

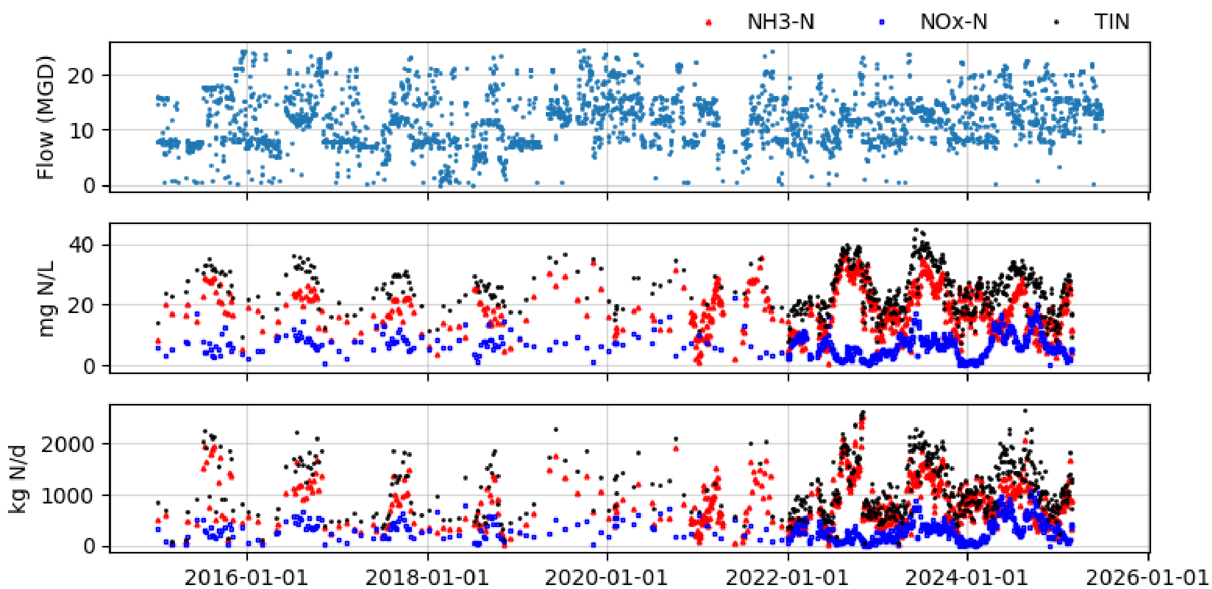


Figure 7. Example Individual Plant Flow and Effluent Nitrogen Concentration and Mass, 2017 to 2025

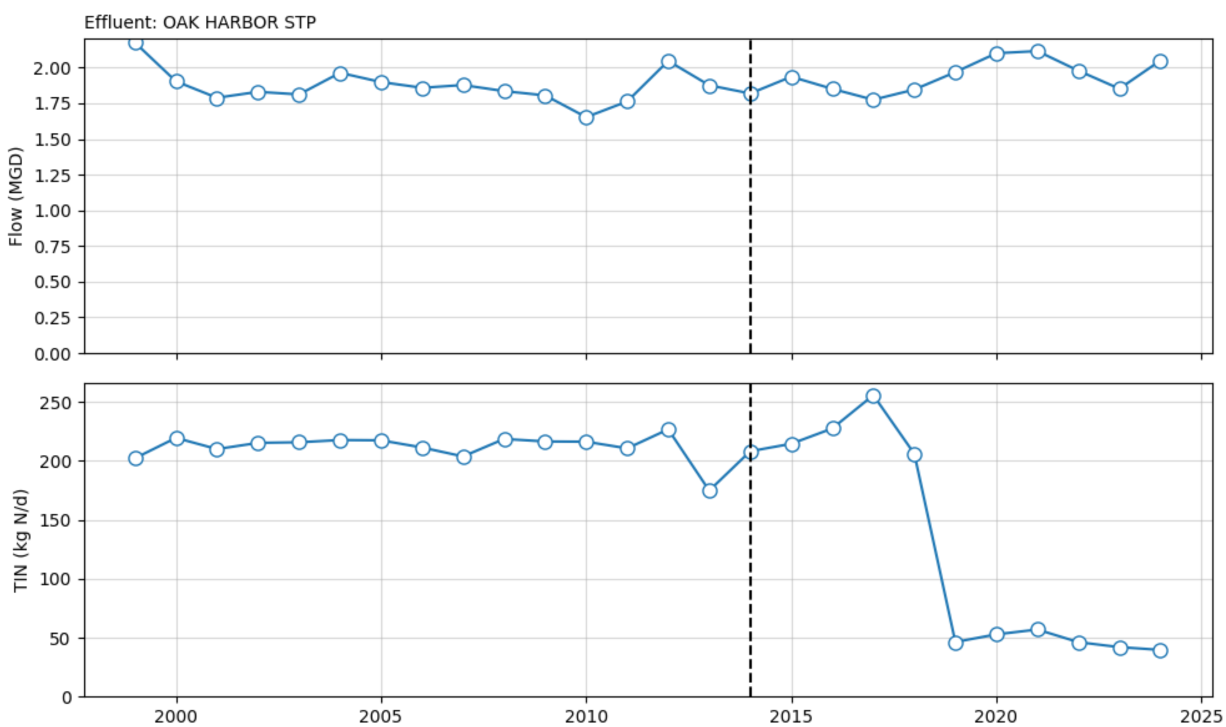


Figure 8. Oak Harbor STP Flow and Effluent TIN Before in the 2014 Salish Sea Model and After 2019 Facilities Improvements Reduced Effluent Nitrogen

A trends analysis of the Dominant, Moderate, and Small Dischargers effluent nitrogen loadings to Puget Sound has been conducted by linear regression to examine the pattern in loadings over the period 1999 through 2024. Figure 9 illustrates the results for comparison with trends in Puget Sound water quality. Over the period 1999 through 2024, the aggregated Dominant Discharges increased modestly at a average rate of approximately 0.2 percent annually (however, the slope of the trend line over this period is not statistically significant at a confidence level of 95%). Both Moderate and Small Dischargers appear to exhibit a slight decrease in effluent nitrogen loading over the same period, but only the decrease for Small Dischargers appears to be statistically significant (95% confidence). Overall, the aggregate nitrogen loading to Puget Sound for all wastewater discharges increased on average by approximately 0.3 percent annually from 1999 to 2024, however the slope of linear regression trendline over this period is not statistically significant (95% confidence).

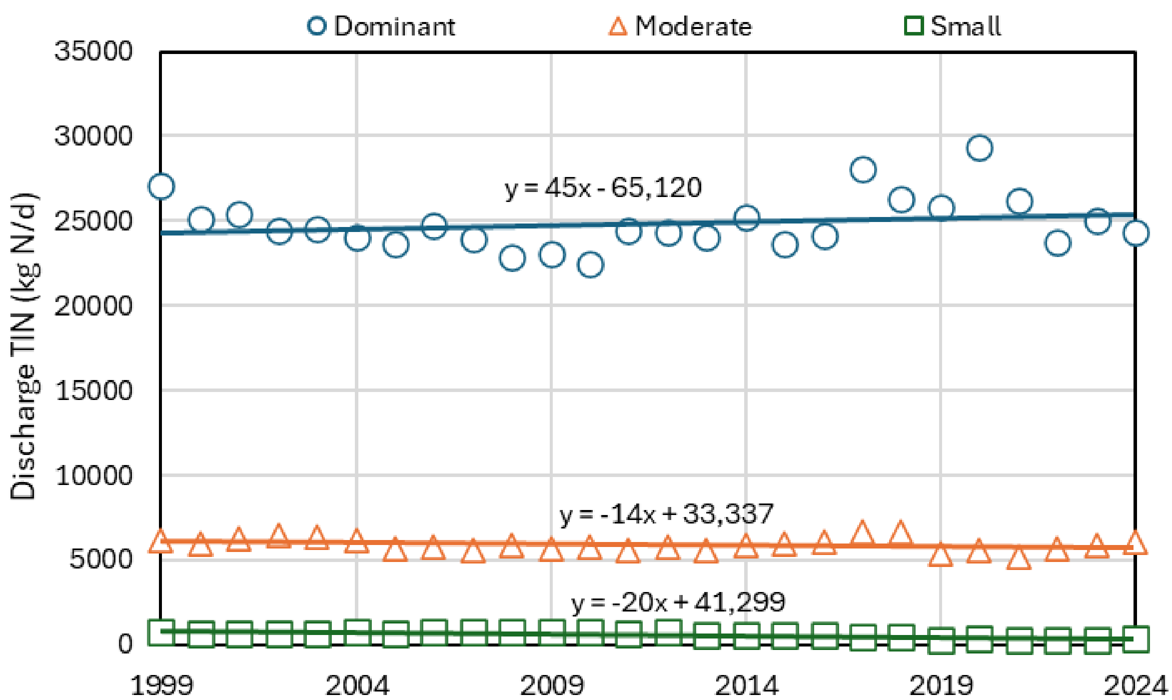


Figure 9. Trends in Nitrogen Loadings from Dominant, Moderate, and Small Dischargers from 1999 through 2024

Marine Water Condition Index

The Washington Department of Ecology has developed a Marine Water Condition Index (MWCI) that provides an overall assessment of water quality conditions in Puget Sound. The MWCI includes four modules and two indicies forming the index to reflect eutrophication and physical proceses. Figure 10 illustrates MWCI scores extended over a period of 1999 to 2023. Data to support the index was not available for the year 2020. Generally, the MWCI for Puget Sound reflects declining water quality from 1999 to 2023.

Marine Water Condition Index Scores for 12 Regions of Puget Sound
1999-2023

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Admiralty Reach	20	13	8	4	0	-5	-3	-5	4	0	-3	-3	14	12	8	3	-7	-1	-1	3	-4		-1	-4	5
Georgia Basin	-2	14	13	1	-2	10	-2	-7	1	9	-9	7	18	-5	2	-9	-2	-11	-6	-9	-5		-6	0	-23
South Hood Canal	16	7	9	3	-4	-9	-1	-11	6	10	-1	-13	-11	2	4	5	-9	-1	4	2	-5		-13	-19	10
Central Basin	15	14	12	8	-1	-6	-8	-3	4	1	-7	-10	6	3	1	-3	-5	-5	2	3	-6		-5	-1	-2
Bellingham Bay	10	13	23	-3	1	6	-12	-8	7	2	-12	-11	7	-10	-3	-23	0	2	-9	-12	3		-2	-4	0
Sinclair Inlet	8	16	13	1	-3	-6	-5	-11	4	1	3	-13	-3	-4	-7	-5	-6	-6	-18	-2	6		-6	-7	-8
Oakland Bay	16	13	14	-4	-7	-9	-5	1	4	-3	1	-2	0	1	2	-14	-5	0	-3	3	-2		-1	-3	4
South Sound	19	14	14	-2	2	0	-4	-2	3	0	-8	-13	8	7	9	-4	-1	-1	7	-1	-3		-5	0	-11
Elliott Bay	28	19	5	-3	-9	3	-15	-9	3	4	-8	-2	4	5	7	-2	-6	0	7	-1	-5		-4	10	-3
Commencement Bay	17	8	13	-3	-5	0	-3	-1	7	-5	-8	-13	3	5	5	3	-4	-6	2	-7	-2		-6	3	-2
Whidbey Basin	11	8	8	-5	-2	-10	-1	1	9	7	-9	-13	-2	-2	-2	-6	1	-14	-12	-4	-11		-4	-14	0
Budd Inlet	8	14	17	1	-13	-9	-7	-1	8	5	3	-11	-5	-6	-1	-14	-3	-10	-2	-3	-1		0	-3	15

Figure 10. Puget Sound Marine Water Condition Index (MWCI) Scores, 1999 to 2023

LINKING LOADINGS TO CONCENTRATIONS: FACTORS CONTROLLING PUGET SOUND WATER QUALITY

A defining characteristic of the Puget Sound estuary is the large tidally-driven exchange with Northeastern Pacific water. This relatively cold and salty water moves in and out of the deeper channels of Puget Sound twice per day, delivering ocean-derived nutrients, dissolved oxygen, and plankton while sweeping materials that enter Puget Sound bottom waters out to the ocean. From a water quality perspective, this tidal mixing moderates influences from pollutant loadings from the watershed, including from the rivers and from direct wastewater treatment plant discharges. Temporal trends in Puget Sound water quality are also strongly influenced by regional and global changes in ocean conditions, especially temperature, dissolved oxygen, and mixing.

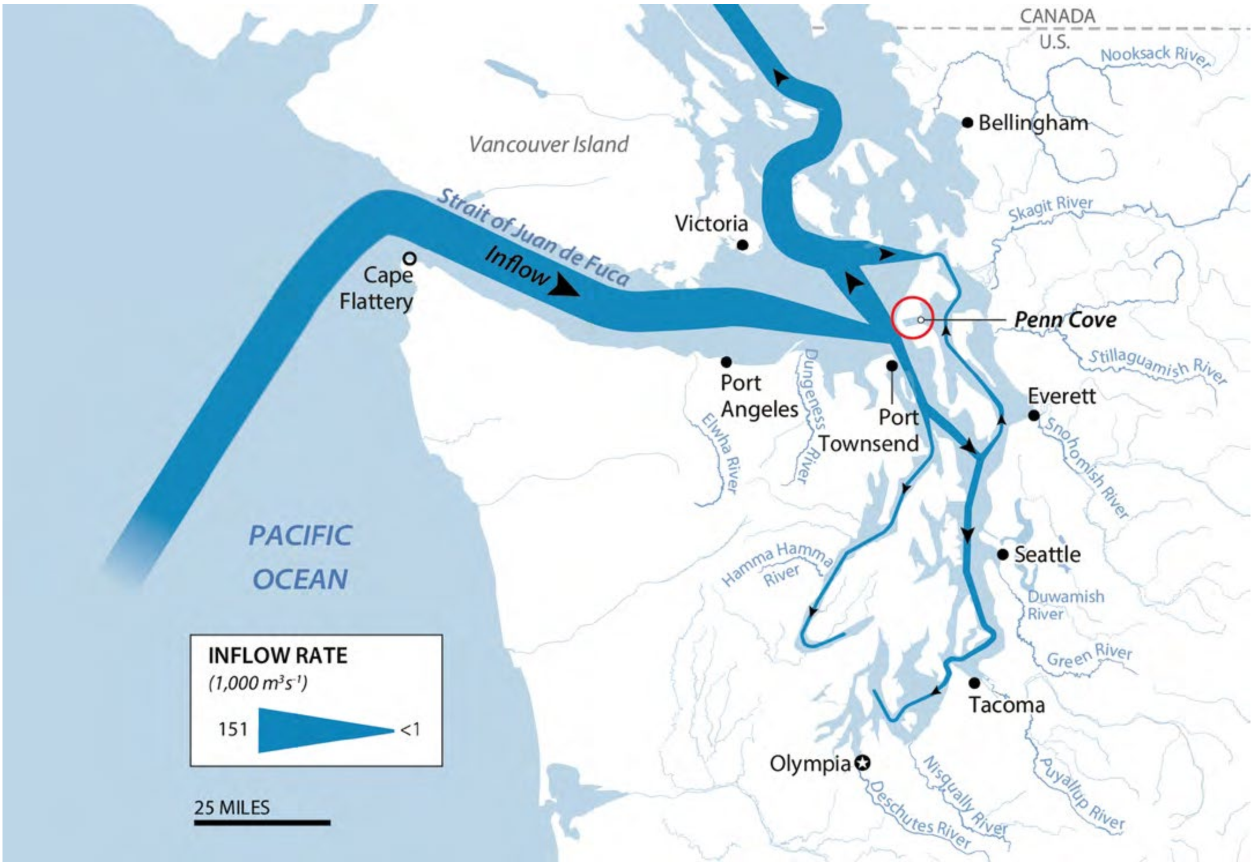
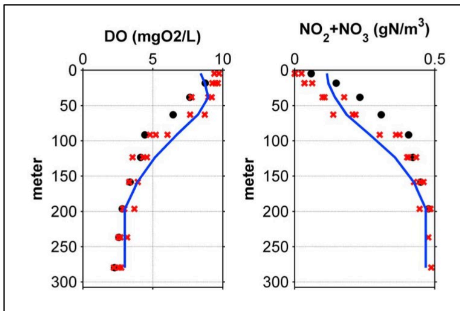


Figure 11. Puget Sound Circulation Patterns

Penn Cove (circled in red), like many parts of Puget Sound is naturally prone to low oxygen due to circulation patterns. Arrows and width of the blue path shown on the map indicate both direction and change in average annual inflow rate of ocean waters for 2017. The ocean inflow rate at the Strait of Juan de Fuca diminishes the volume of ocean water that enters Puget Sound (indicated by arrow width) as it reaches the end of narrow bays and inlets like Penn Cove taking longer to flush out excess nutrients and pollutants. Map: Puget Sound Institute; Data source: MacCready et al. 2021



Ocean boundary conditions, June 2000
(Khangaonkar *et al.*, 2019)

Figure 12. Ocean Waters Entering Puget Sound Rich in Nitrogen and Depleted in Oxygen

Ocean water that enters the Puget Sound is relatively depleted in dissolved oxygen and enriched in inorganic nitrogen, resulting in large daily mass loadings of nitrogen to the system. While much of this ocean-derived nitrogen leaves Puget Sound on the following ebb tide, some potentially important fraction mixes into the surface waters where it can contribute to the growth of phytoplankton. It is this "up welled" oceanic nitrogen that is important to consider when evaluating the nutrient status of Puget Sound.

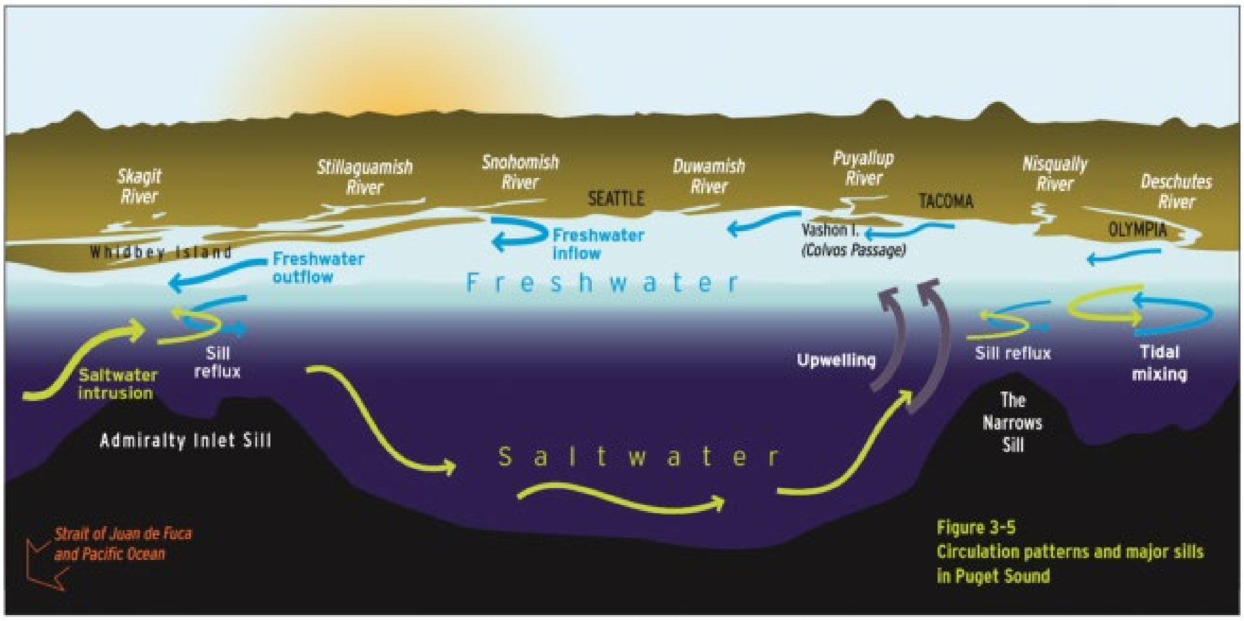


Figure 13. Puget Sound Circulation Patterns (From Encyclopedia of Puget Sound)

Evidence suggests that the composition of the ocean water entering Puget Sound is changing in response to global forcings, including climate change. Dissolved oxygen has decreased by about 20% over the past 40 years in the Northeast Pacific Ocean at the depth of the shelf break (*i.e.*, the layer of water that enters Puget Sound). Because the vertical gradients in nutrients and dissolved oxygen are very strong in this part of the Pacific, any changes in the depth of the source of the exchange flow will have large changes in Puget Sound water quality.

Implications of Determining "Reference Conditions" on Managing Puget Sound Water Quality

Because locations in Puget Sound naturally contain relatively low dissolved concentrations during part of the year, water quality managers must use modeling tools to determine how much of existing dissolved oxygen levels are due natural processes and how much can be linked to current anthropogenic sources. To do this, "reference condition" modeling scenarios are run that represent the maximum improvement in dissolved oxygen possible in the existing Puget Sound. In these scenarios, the same hydrodynamics and climate as existing conditions are used and the river and wastewater treatment plant nutrient loads are replaced with estimated loads before the adoption of modern land-use practices and population growth in Washington State.

As an example, an analysis of the Skagit River system compares nitrogen (DIN and TON) and carbon (DOC and POC) concentrations and loadings with ('existing') and without ('reference') modern anthropogenic loads (*From [Appendix B3](#) of Figueroa-Kaminsky et al. ,2025).*

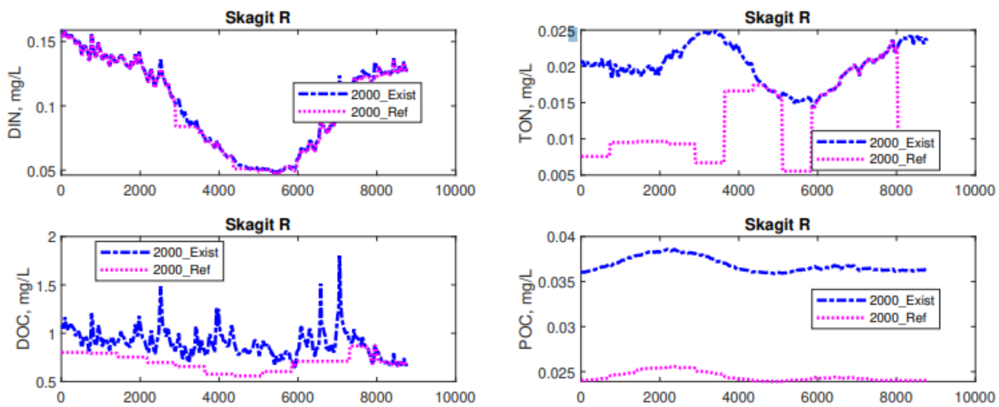


Figure 14. Skagit River Existing and "Reference" (without Anthropogenic Loads) Nitrogen (DIN and TON) and Carbon (DOC and POC)

Table 2. Example Comparison of Existing and "Reference" Nitrogen and Carbon Loadings for the Skagit River

Skagit River Figueroa-Kaminsky et al. (2025)	**2014 Existing**	**2014 Reference**[1]	**Percent Change**
Flow (cms)	217,000	217,000	0
Dissolved Inorganic Nitrogen (DIN) kg/year	2,220,000	2,030,000	9
Total Nitrogen (TN) kg/year	2,580,000	2,260,000	14
Total Organic Nitrogen (TON) kg/year	366,000	229,000	60
Dissolved Organic Carbon (DOC) kg/year	24,300,000	13,200,000	84
Particulate Organic Carbon (POC) kg/year	687,000	457,000	50
Total Organic Carbon (TOC) kg/year	25,000,000	13,600,000	84
[1] downloaded from AllInflows-AnnualTot_wq_2014_W3_Lake_Ref.xlsx			

Wastewater Nitrogen in Context: Nitrogen Loads Entering Puget Sound Waters

Nitrogen loading carried by tributaries into Puget Sound reflect both natural and anthropogenic sources (which include agriculture, forestry practices, upstream septic and wastewater discharges, etc.). Understanding the relative importance of any individual nitrogen source type requires a complete inventory of all nitrogen sources to the watershed. Recent advances in watershed scale modeling are improving the understanding of current nitrogen sources in the

Puget Sound waters and allow for evaluation of possible management actions to control nitrogen as well as potential impacts of population growth and climate change. Recent modeling by USGS SPARROW, in collaboration with the State, has made important progress in understanding nutrient sources and their seasonal patterns. The current pre-print results (Schmadel et al., 2025) report combines contributions from marine point sources and watershed sources as defined in the Draft Puget Sound Nutrient Reduction Plan. The Puget Sound Integrated Modeling Framework is developing a connected terrestrial-freshwater-marine-human system modeling framework will help us understand the interactive effects of future threats to our region, and evaluate their impacts on ecological, social, and economic objectives. As part of this project, the EPA-produced VELMA watershed model is expanding their modeling to the 24 Puget Sound watersheds.

Overall, nutrient budgets suggest that currently 9% of the nitrogen entering Puget Sound results from human activities.

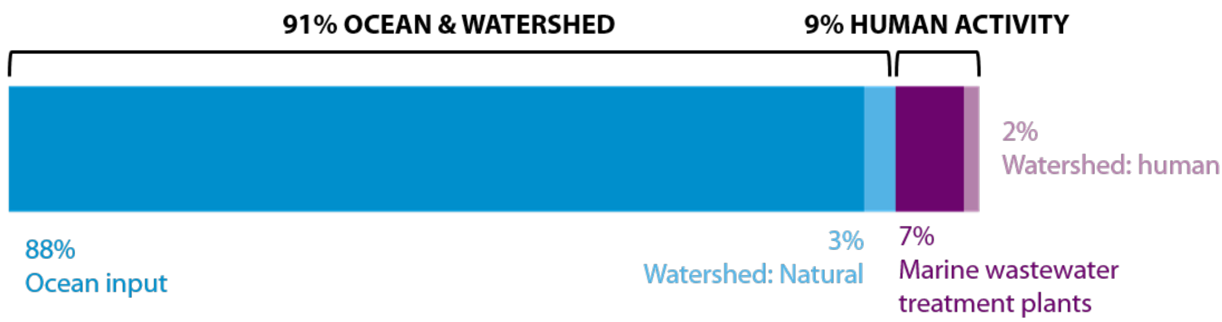


Figure 15. Comparison of Nitrogen Loadings from Ocean and Watershed v. Human Activity

Assessing the Impact of Nitrogen Loadings on Puget Sound Water Quality

The Salish Sea model was used to determine the influence of wastewater discharges directly into Puget Sound (the so-called 'marine dischargers'). Results for the Strait of Georgia suggest:

1. The U.S. waters of the Strait of Georgia and Northern Bays exhibit dissolved oxygen levels that trigger 'non-compliance' primarily during two months in spring and early summer. During these times, up to 0.025% of the water (by volume) is estimated to trigger non-compliance, compared to approximately 2.5% modeled in the Whidbey Region.
2. Estimated annual nitrogen loadings to the study area from the 15 wastewater dischargers is 0.5 million kg/year compared with 2.4 million kg/year from the 7 local rivers (which include upstream anthropogenic and natural sources of nitrogen)
3. Eliminating nitrogen loadings from the 14 smaller permitted wastewater dischargers in the study area has very little demonstrable effect on the dissolved oxygen levels in this highly energetic region of Puget Sound.

4. Eliminating nitrogen loadings from the largest permitted wastewater discharger reduces the estimated number of days the immediate region is considered ‘non-DO compliant’; from 39 to 20 days per year.
5. The current modeling suggests that nitrogen loadings into the study area have minimal impact on dissolved oxygen levels in other Puget Sound regions. However, these differ by region. Hood Canal was the most impacted by both WWTPs and riverine loading (particularly by large increases in riverine loading), while the Main Basin and South Sound remained largely unchanged. Potential impacts on Canadian waters were not assessed here

Similar results for Whidbey Basin suggest:

1. The waters of the Whidbey region exhibit modeled dissolved oxygen levels that trigger continuously sustained levels of non-compliance for 4 months of the year, peaking in August and September. During these times, a maximum of approximately 3% of the water in Whidbey (by volume) is estimated to be non-compliant, compared to approximately 0.06% predicted in the Main Basin and 7% in the South Sound regions. Throughout the year, the modeled total days of non-compliance for the Whidbey region is 174 days*.
2. Within the Whidbey region, the waters in and around Penn Cove and Port Susan have the greatest sustained periods of calculated hypoxia (<2 mg/L), reaching their maximum extent by area around 22 September. The maximum extent of days non-compliance in each of these embayments is around August 19 and 15 respectively.
3. Nitrogen loading to the Whidbey region is dominated by rivers to a greater extent than other regions, and the estimated naturally occurring loading of these rivers is high. The estimated total annual nitrogen loads is 6.4 million kg/year for the four rivers entering Whidbey region, of which 4.4 million kg/year are from human contributions and 2.0 million are naturally occurring. Of these rivers, the Skagit has the highest proportion of nitrogen load that is naturally occurring (94% of the Skagit’s total load). In comparison to river loading, the load from the 16 wastewater outfalls total 1.2 million kg/year (approximately 1/6th of river loading) to the region, while Sound-wide these two loading sources are roughly equal.
4. In the Whidbey region, eliminating the nitrogen loads from all 16 modeled wastewater treatment plants reduced non-compliance from 174 to 139 days and changed the corresponding magnitude and persistence of non-compliance throughout the year. The calculated maximum non-compliant volume for the waters of the region was reduced from approximately 3% to just over 1%. The period of sustained non-compliance was also shortened to end in early rather than late October, with the smaller spike of noncompliance in November reduced.
5. Reducing modeled nitrogen loading at treatment plant outfalls generally reduced the calculated non-compliance, proportional to the total load reduction applied across the

Whidbey region. Within the Whidbey region, eliminating modeled nitrogen loading from the 10 smaller wastewater dischargers reduced the estimated days of noncompliance by only 1 day, the 5 medium discharges reduced non-compliance from 174 to 158 days, and the two outfalls (combined) for the largest permitted wastewater discharger, reduced non-compliance to 149 days. When considered individually, each reduced non-compliance to 161 days.

CONCLUSIONS

Sustaining this analysis underscores the importance of tracking nutrient loadings and the water quality response to guide management efforts, prioritize investments, and make adjustment to adapt to the most effective means of preserving and enhancing the health of the marine ecosystems for future generations.

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