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State of Washington

Quality Assurance Project Plan

Puget Sound Spatially Referenced Regression on Watershed Attributes (SPARROW)

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COVER PHOTO: Nooksack River.
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Quality Assurance Project Plan

Puget Sound Spatially Referenced Regression on Watershed Attributes (SPARROW)

by

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October 2022

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WQP: Water Quality Program, Department of Ecology
USGS: U.S. Geological Survey

1.0 Table of Contents

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2.0 Abstract

The United States Geological Survey (USGS) and the Washington State Department of Ecology (Ecology) are collaborating on the development of refined, seasonal load estimates of total nitrogen and total phosphorus within watersheds draining to Washington waters of the Salish Sea for the period 2005-2020. The modeling approach for this work is based on SPARROW (Spatially Referenced Regression on Watershed Attributes), a watershed modeling technique developed by the USGS. SPARROW is typically used to estimate stream loads throughout a stream network.

The estimated loads will be used within the context of the Puget Sound Nutrient Source Reduction Project to evaluate the influence of watershed contributions of nutrients throughout the stream network and to marine waters. This quality assurance project plan (QAPP) contains details about the technical approach, observational data, spatial and temporal source data, limitations, and quality assurance procedures that will be employed to develop the SPARROW models so that they can be used to inform additional actions to address excess nutrients.

3.0 Background

3.1 Introduction and problem statement

Nutrient reduction efforts for the Puget Sound region are underway, and this project is intended to provide information on watershed point and nonpoint sources to support those efforts. Numerical modeling has shown compliance with dissolved oxygen (DO) standards in the bottom layers of marine waters depends on nutrient reductions from both point and nonpoint sources of nutrients. Previous efforts estimated watershed nutrient inflows into marine waters from rivers and streams in the Puget Sound region. The goal of this project is to improve Ecology's understanding of the *contribution* of watershed loads from discernable point and nonpoint nutrient sources and/or relevant nutrient transport pathways. SPARROW will not be used as the primary tool to estimate freshwater loads discharged into marine waters for the purpose of biogeochemical modeling of Salish Sea waters.

3.2 Study area and surroundings

For the purposes of this QAPP, the Puget Sound region refers to watersheds draining into the Washington waters of the Salish Sea (Figure 1).

The Puget Sound region includes various land cover and land use patterns that affect the delivery of nutrients to waterways. The major land cover types in the Puget Sound region are forested land (62%), grassland/scrubland (12%), and developed areas (12%) based on the 2016 National Land Cover Dataset (NLCD). Developed land, including major cities and urban areas (Seattle and Tacoma), is concentrated along marine shoreline areas and estuaries, whereas the headwaters of watersheds draining into Washington waters of the Salish Sea are mainly forested. Pockets of agricultural land can be found in the northern watersheds, such as the lower Nooksack and Skagit Rivers.

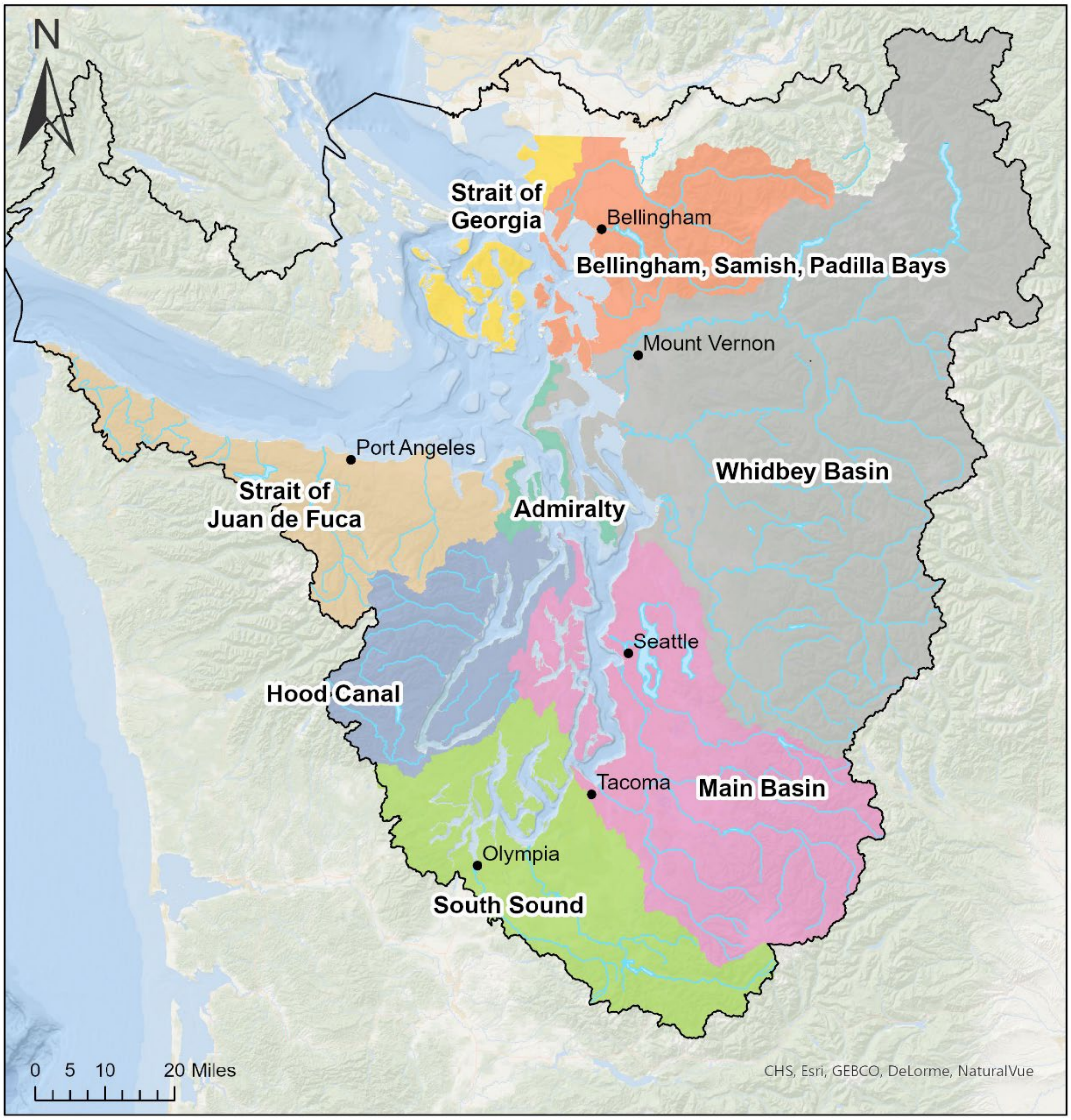

Figure 1. Watersheds draining into Washington waters of the Salish Sea.

Table 1. Land cover in Puget Sound region watersheds (NLCD, 2016).

Land Cover	Area (acre)	Percentage (%)
Developed	1,086,414	12
Forest	5,432,287	62
Grassland/Scrubland	1,098,073	12
Agriculture	434,163	5
Wetlands	251,420	3
Water	221,378	3
Other	290,110	3

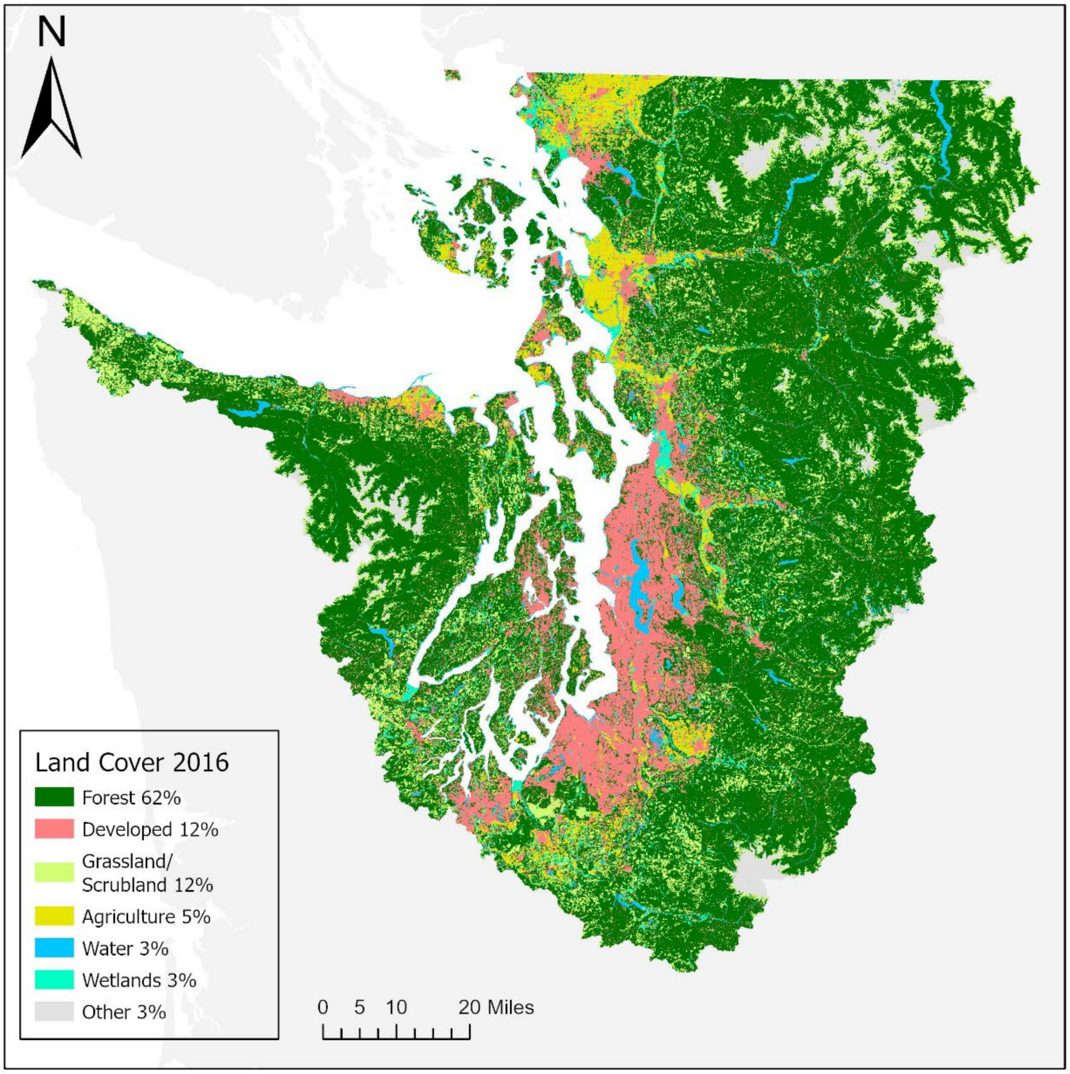

Figure 2. Land cover in Puget Sound region watersheds (NLCD, 2016).

3.2.1 History of relevant projects in the study area

Puget Sound Nutrient Source Reduction Project

Ecology's Puget Sound Nutrient Source Reduction Project (PSNSRP) is a collaborative effort with communities and stakeholders to address human sources of nutrients with a restoration plan implemented through Ecology's National Pollutant Discharge Elimination System (NPDES) and 319 nonpoint programs. The PSNSRP focuses on using the latest science to find solutions for regional investments to control nutrients from point and nonpoint sources and help Washington waters of the Salish Sea consistently meet DO water quality criteria. The PSNSRP objective is to improve Puget Sound water quality to support salmon and orca recovery and increase resiliency to climate impacts. Results from this report will help inform the continuing stakeholder process.

PSNSRP uses the Salish Sea Model (SSM) results to inform nutrient management within marine waters. Results from the first phase of PSNSRP model runs are documented in *Puget Sound Nutrient Source Reduction Project Volume 1: Model Updates and Bounding Scenarios* (Ahmed et al., 2019). The model scenarios show a range of marine water quality conditions from different nutrient loads. Model scenarios evaluated water quality conditions with (1) current levels of nutrient loading from marine and estuarine point sources and watersheds into the Washington waters of the Salish Sea and (2) potential improvements in nutrient removal technologies applied to municipal wastewater treatment plants (WWTPs). PSNSRP will use results from the SSM as guidance for establishing nutrient loads targets for marine wastewater discharges and watershed inflows.

The first phase of modeling for the PSNSRP assessed the response of water quality in Washington waters of the Salish Sea to reductions in nutrient loads from WWTPs (Ahmed et al., 2019). The second phase includes the optimization scenarios, which involve additional model runs to evaluate various management scenarios. These optimization scenarios considered two sets of different combinations of nutrient reductions at marine point sources and watersheds in Year 1 scenarios (Ahmed et al., 2021) and Year 2 scenarios (expected at the end of 2023).

PSNSRP considers the influence of watershed contributions of nutrients on marine DO. Since the SSM domain does not extend up into the watersheds, it does not differentiate between different types and locations of upstream nutrient sources. Nutrient load estimates throughout the watersheds from SPARROW will therefore be helpful to fill this gap and identify nutrient sources and transport pathways at the watershed and sub-watershed scale and their relative contribution to marine waters. Understanding these relative contributions of nitrogen from different upstream sources and pathways will inform future nutrient management decisions in the watersheds.

As a separate but complementary project to the PSNSRP, the Puget Sound Partnership's Marine Water Quality Implementation Strategy may draw on results from this work or utilize the refined SPARROW model for the state-of-knowledge report developed by the Puget Sound Partnership to inform strategies and actions.

3.2.2 Summary of previous studies and existing data

SPARROW Model

SPARROW (Spatially Referenced Regression on Watershed Attributes) is a watershed modeling technique developed by the United States Geological Survey (USGS; Schwarz et al., 2006) that is used nationwide. SPARROW estimates stream loads, including nutrients, throughout a stream network. The model calculates nutrient loading based on water quality measurements at distributed stations linked with watershed characteristics based on geospatial data sets (Smith et al., 1997). These geospatial data sets describe land cover and other attributes and are used to quantify nutrient loads from a variety of sources throughout the watershed. A list of publications and associated materials for model applications can be found on the SPARROW webpage (USGS, 2021).

The SPARROW model uses a combination of deterministic and empirical approaches for water quality modeling (Schwarz et al., 2006). Monitoring data and watershed attributes are used to identify and explain factors affecting water quality. The model examines the statistical significance of nutrient sources, environmental factors, and transport processes to estimate nutrient loads (Smith et al., 1997).

Wise and Johnson (2013) developed a Pacific Northwest application of SPARROW to simulate annual nutrient loading using 2002 as the base year. The model uses land cover information and water quality data from monitoring stations to estimate nutrient loads throughout Pacific Northwest stream segments, and attributes those loads to different nutrient sources or pathways. In the Wise and Johnson (2013) Pacific Northwest application, nutrient loads (reported as kg/yr) are calculated as the product of nutrient concentration and streamflow for the year 2002. These estimates can be used to identify the relative nutrient loads and sources in different watersheds in the Puget Sound region.

In addition to the Pacific Northwest application, regional SPARROW applications include Chesapeake Bay, New England, Mississippi River, and others. Many of these regional applications also include web-mapping tools that allow for visualization and interaction with results.

Puget Sound Nutrient Synthesis Report

The Puget Sound Nutrient Synthesis Report, Part 2: Comparison of Watershed Nutrient Load Estimates (referred to as 'Nutrient Synthesis Report' by McCarthy, 2019) identifies and quantifies nutrient sources within watersheds draining into Puget Sound. The report contains a summary of available nutrient load estimates from regional water quality models and studies. It includes background and overview of watershed nutrient sources to Puget Sound and regional water quality models with nutrient load estimates (USGS SPARROW, Ecology Salish Sea Model). It provides an exploratory analysis of nutrient load estimates in the Puget Sound region from results of the 2002 USGS SPARROW model Pacific Northwest application (Wise and Johnson, 2013) and identifies watersheds with high nutrient loading and relative nutrient source contributions based on model results. The report also includes a comparison of SPARROW nitrogen load estimates with the Salish Sea Model (SSM, next section) nitrogen load inputs.

Results from the Nutrient Synthesis Report (based on output from Wise and Johnson, 2013) indicate:

- About one-half of the land-based total nitrogen (TN) load into Puget Sound is estimated to be from urban sources, one-quarter is from forests, and the remainder is from agricultural sources or from a mix of sources through the atmospheric deposition pathway.
- The Snohomish and Skagit Rivers (Whidbey Basin) have the highest overall TN loads into Puget Sound. The Skagit River has the highest overall total phosphorus (TP) load into Puget Sound. For TN yield (load per unit area), the Stillaguamish, Nooksack, and Snohomish Rivers are the highest.
- Aggregating loads discharging into Puget Sound by basin indicates that the Main Basin receives the overall highest TN load (9 million kg/yr) followed by Whidbey Basin (8 million kg/yr).
- Overall TN loads are similar between SPARROW TN load estimates and load inputs to SSM (25.45 million kg/yr and 25.43 million kg/yr, respectively). Differences are apparent when comparing nutrient loads at the watershed level.

Recommendations from the Nutrient Synthesis Report that will be carried into this work include:

- Compile available relevant regional watershed data into a comprehensive Puget Sound region data inventory.
- Collaborate with local stakeholders to procure refined, local data and resources to inform data inventory.
- Further investigate nutrient loads using SPARROW as part of nutrient management in Puget Sound region watersheds.

Salish Sea Model

The Pacific Northwest National Laboratory (PNNL), in collaboration with Ecology, developed the Salish Sea Model (SSM) as a predictive ocean-modeling tool (Khangaonkar et al., 2012, 2018; Ahmed et al., 2019). The SSM is a state-of-the-science computer-modeling tool that simulates the complex physical, chemical, and biological patterns inherent in this system. SSM simulates connected estuarine processes, including hydrodynamics (tides, stratification, mixing, freshwater inflows, salinity, and temperature) and water quality (algal biomass, nutrients, carbon, DO, and the carbonate system). The model domain includes all of Puget Sound, the Strait of Juan de Fuca, the Strait of Georgia, and expands out to the continental shelf in the Pacific Ocean and around Vancouver Island.

The SSM uses nutrient load estimates as model inputs to simulate water quality conditions in Puget Sound. SSM model inputs are separated and quantified into two categories:

- *Marine point sources:* 99 point sources (United States and Canada) that discharge into the marine waters of Puget Sound and the greater Salish Sea (WWTPs and industrial facilities).
- *Watershed inflows:* 161 watersheds (United States and Canada) that represent nutrients entering marine waters from rivers or streams. In the SSM, watershed nutrient loading estimates are based on monitoring data collected at most down gradient freshwater locations, and thus integrate the influence of all upstream sources from the monitoring location (including upstream point sources that do not discharge directly to marine waters)[1].

Nutrient loads from the above two categories were estimated using a multiple linear regression technique using flow data and monthly water quality data to develop daily time series of water quality conditions entering Puget Sound (Ahmed et al., 2019; Mohamedali et al., 2011), which will be compared to the seasonal SPARROW estimates.

3.2.3 Parameters of interest and potential sources

The primary parameters of interest for this project are TN and TP. The biogeochemical cycling of these nutrients from local natural and anthropogenic sources stimulate phytoplankton growth and autotrophic and heterotrophic respiration. DO is consumed by oxidation of the decomposing organic matter, and some of the organic nitrogen is re-mineralized and released back into the water. Therefore, freshwater nutrient contributions, including TN and TP, are key parameters for understanding DO impairments in estuarine and marine waters.

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[1] Some WWTPs discharges to brackish waters are not represented by data from the most down gradient watershed monitoring location because the data is collected upstream of the source's discharge point. WWTP discharges to both marine and brackish waters are explicitly included in the SSM.

Potential sources of nutrients and their transport pathways

There are various sources of nutrients delivered to freshwater systems through different pathways that ultimately drain into Washington waters of the Salish Sea. Potential nutrient sources are generalized by the following categories (not in order of relative impact, which varies spatially and temporally):

- Forests
- Urban sources
- Agricultural sources
- Other sources (e.g., geologic materials that are a source of phosphorus)

Atmospheric deposition is a pathway that includes both natural and anthropogenic sources of TN. The major human sources of nitrogen emissions come from transportation, agriculture, power plants, and industry (Fenn et al., 2003). In the Puget Sound region, anthropogenic sources contribute more to nitrogen emissions than natural sources (Herron-Thorpe et al., 2018).

Nutrients from agricultural sources including livestock manure and crop fertilizer are delivered to rivers and ultimately into marine waters. Impacts of agricultural practices on water quality have shown that livestock with direct access to streams and waterways can impact DO conditions downstream (Sheffield et al., 1997; Belsky et al., 1999). Additionally, over-application of manure to cropland enters surface waters through runoff (Almasri and Kaluarachchi, 2004). Fertilizer application can also cause excess nutrients to enter surface waters and groundwater (Almasri and Kaluarachchi, 2004; Ongley, 1996). Local studies in the Sumas-Blaine aquifer (Nooksack watershed area in Whatcom County) have found elevated levels of nitrate in groundwater in areas with high rates of fertilizer application and manure application (Carey and Harrison, 2014; Carey and Cummings, 2012). Nutrient management plans using best management practices (BMPs) enable agricultural operators to decrease nutrient fluxes to surface waters and groundwater.

Sources of nitrogen and phosphorus from developed areas include both point and nonpoint sources from urban, suburban, and rural environments. Point sources are regulated discharges of wastewater and stormwater, and include domestic WWTPs, industrial facilities, and hatcheries. Nonpoint developed area sources may include transportation and vehicle emissions, fertilizer application on lawns, and on-site septic systems.

Nutrients may be transported to streams and rivers through atmospheric deposition, stormwater runoff, and groundwater that ultimately lead to marine waters. Regional studies indicate that the largest local sources of nitrogen into Puget Sound are marine point sources, including WWTPs, followed by upstream watershed sources transported via rivers and streams (Ahmed et al., 2019; Mohamedali et al., 2011).

Nutrient releases from forests and other sources can be driven by biotic and abiotic processes. Nitrogen is found naturally in streams and rivers through atmospheric deposition (naturally occurring and from human emissions), instream processes (e.g., salmon carcasses and woody debris), and forests (e.g., alder trees). Due to the expanse of active forestry throughout the Pacific Northwest, activities such as timber harvesting, forest fertilization, and other associated forestry management activities can increase the export of nitrogen in streams directly and indirectly (Anderson, 2002; Binkley and Brown, 1993; Gravelle et al., 2009; Harr and Fredriksen, 1988).

The most common hardwood species throughout the Pacific Northwest is red alder (Deal and Harrington, 2006). Red alders favor areas with direct sunlight and exposed soil. Due to this, land use practices, such as timber harvesting and burning, have favored alder growth throughout the region (Deal and Harrington, 2006). Historical pollen records indicate higher distributions of alder stands since the twentieth century than in previous centuries (Heusser, 1964; Davis, 1973). Alders fix atmospheric nitrogen and contribute nitrogen to surrounding soil (Berg and Doerksen, 1975; Tarrant and Miller, 1963). In a coastal Oregon watershed, nitrogen leaching from alder stands to surface waters is estimated at 14.2 kg/acre/yr (Compton et al., 2003).

Many of the same sources and pathways of nitrogen also deliver phosphorus into marine waters, with the additional phosphorus source of weathering of geologic materials.

3.2.4 Regulatory criteria or standards

Washington State Water Quality Standards are the basis for protecting and regulating the quality of surface waters in Washington. The standards implement portions of the federal Clean Water Act by specifying the designated uses of water bodies in the state. Source or pathway load contributions predicted using this project's refined SPARROW model will be used to compare to the watershed inflow nutrient load targets established in the 2024 Puget Sound Nutrient Reduction Plan. Those nutrient load targets are evaluated with the Salish Sea Model to determine compliance with marine DO standards, and do not include an evaluation of freshwater DO standards attainment.

The standards set water quality criteria to protect those uses. The standards also contain policies to protect high quality waters (anti-degradation) and, in many cases, specify how criteria will be implemented, such as through permits. The standards are established to sustain (1) public health and public enjoyment of the waters and (2) the propagation and protection of fish, shellfish, and wildlife.

The Water Quality Standards for DO are found in WAC 173-201A-210(1)(d)[2] and have two parts:

- First, minimum concentrations of DO are used as criteria to protect different categories of aquatic communities. Since the health of aquatic species is tied predominantly to the pattern of daily minimum oxygen concentrations, the criterion is based on the lowest 1-day minimum oxygen concentrations that occur in a water body.
- The second part supplements the numeric DO criteria. It states that "when a water body's DO is lower than the numeric criterion in the DO standard (or within 0.2 mg/L of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the DO of that water body to decrease more than 0.2 mg/L." Mechanistic modeling tools are available for estimating DO concentrations in marine or freshwaters. SPARROW will be used to calculate contributions and loads of nutrients from watersheds (Mathieu et al. 2022).

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[2] These criteria are not currently in effect for Clean Water Act purposes as a result of EPA's 2021 reconsideration and disapproval of Washington's natural conditions criteria in the water quality standards. These criteria remain in effect for other statewide water quality actions. Ecology is planning to initiate rulemaking in 2022 to revise the natural condition provisions that will respond to EPA's concern and will again meet Clean Water Act approval. For more information, please visit Ecology's website: https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-quality-standards/Updates-to-the-standards.

4.0 Project Description

4.1 Project goals

This project will refine the USGS SPARROW model for the Puget Sound region through collaborative work between the USGS and Ecology to include seasonal nutrient (TN and TP) load estimates for watersheds draining into Washington waters of the Salish Sea. The resulting dynamic SPARROW models will improve Ecology's understanding of the contribution of watershed loads from point and nonpoint sources. Results will be used to identify and quantify statistically significant nutrient source categories as part of a watershed nutrient source assessment for the PSNSRP. In the future, results will also inform target setting decisions.

Calibrated dynamic SPARROW models will be used to attain this project's goal: estimating seasonal TN and TP loads from 2005-2020 in the Puget Sound region. To accomplish this, the project involves detailed scrutiny of model inputs, selection of explanatory variables, model structure, calibration statistics, and validation. The models will also be used to compare field-derived river attenuation magnitudes across the watersheds and explore ways to point to reaches with degraded natural function for nitrogen or phosphorus attenuation as defined by reaction rates which fall below that of first-order assumptions due to prolonged high nutrient concentrations (Schmadel et al., 2020).

The dynamic SPARROW models will provide seasonal load estimates for river and stream segments within each Puget Sound watershed that will inform future pollution reduction actions and analyses. Watershed load freshwater boundary inputs into SSM will be compared with the seasonal SPARROW load estimates, but the SPARROW estimates will not be used as inputs into SSM. The exact seasonal breakdown will be determined during the project. The Analytical Framework section (7.3.1) contains more details about the approach.

Ultimately, the dynamic SPARROW models will serve to help inform a regional assessment of watershed nutrient sources, implementation of nitrogen reduction actions initiated in the Nutrient Reduction Plan, and ongoing implementation in watersheds with approved freshwater DO TMDLs. If funding is secured to create an interface with EPA's River Basin Export Reduction Optimization Support Tool (RBEROST, Chamberlain et al. 2022), it may also be used to further inform options for regional reductions using that tool.

4.2 Project objectives

Ecology will use the dynamic SPARROW models to help develop watershed nutrient management actions designed to meet the TN load targets (identified in the Puget Sound Nutrient management plan) allocations for Puget Sound watersheds. The dynamic SPARROW models will also provide information about TP watershed loads, sources and pathways which may be utilized in the future to conduct mechanistic modeling to determine autochthonous watershed organic carbon spatial and temporal fluxes.

Project objectives for the dynamic SPARROW models include:

- Develop data inventory of available regional nutrient source datasets for model inputs.
- Identify and consolidate water quality (nutrients) and quantity (flow) datasets that can be used for model calibration.
- Expand the SPARROW modeling technique for the Puget Sound region and seasonal time periods using local data.
- Estimate TN and TP loads on seasonal time periods throughout the network as represented in the 1:100,000 National Hydrography Dataset.
- Identify and quantify the relative contribution of major nutrient sources contributing to watershed loads to Puget Sound throughout the network, and particularly, loads at the mouths of rivers and streams.

While the SPARROW model can be used to inform efforts to protect or restore freshwater DO conditions, any such efforts would be addressed in a different QAPP or study design. Also, a consideration for this project is to lay the groundwork so that the SPARROW model may eventually interface its output with EPA's RBEROST.

Ecology is conducting a detailed inventory of available data sets so that model input files for SPARROW refinement are based on the best available local data. Once the refinement of the seasonal Puget Sound SPARROW models is complete and documented with a USGS Scientific Investigations Report and data release, USGS will transfer the models and associated model files to Ecology for future use (such as watershed-specific projects and/or evaluating the effectiveness of different management scenarios). Ecology may share or modify the models and files, and will cite the documented report and data release when doing so.

4.3 Information needed and sources

Due to the data-intense requirements for the seasonal SPARROW models, this project requires developing a comprehensive data inventory of land use and nutrient-related data sources throughout the Puget Sound region watersheds. Similar to previous applications, nutrient source or pathway categories will be used to organize data in the SPARROW models including, urban, atmospheric deposition, forests, agriculture and other sources and pathways.

Section 7 includes descriptions of data sources for each of the above nutrient source categories. Additional data information and sources can be found in Appendix A.

4.4 Tasks required

This project includes a suite of tasks that will be completed by Ecology and USGS.

Ecology's Environmental Assessment Program will complete the following tasks:

- Produce an inventory of local, regional and updated data that can be used for the project.
- Provide available data to the USGS for model input development.
- Participate in internal and external meetings to discuss data inventory, ongoing model development, and review of materials.
- Collaborate with the USGS during model development and calibration, as appropriate.
- Review model output and performance and associated USGS documentation.

- Acquire capability to run model scenarios.
- Develop a short summary of the results of the seasonal SPARROW model refinement efforts for stakeholders.

USGS will complete the following tasks:

- Develop model inputs for seasonal TN and TP SPARROW models.
- Conduct SPARROW model calibration and refinement for Puget Sound region.
- Develop and document options for operationalizing linkage between the completed Puget Sound EPA RBEROST model and refined SPARROW outputs.
- Complete Scientific Investigations Report (SIR) and data release upon model completion.
- Participate in meetings with Ecology regarding model development and in meetings with stakeholders to discuss the models.
- Transfer model and technology to Ecology once models are complete and documented.

4.5 Systematic planning process

This project was designed with input from Ecology's Water Quality Program, Ecology's Environmental Assessment Program, and the USGS during a scoping project in the fall of 2020. This QAPP constitutes the next phase of the planning process.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 2 shows the key individuals involved in this project.

Table 2. Organization of project staff and responsibilities.

Staff[1]	Project Role/Title	Responsibilities
Dustin Bilhimer Water Quality Program Phone: 360-407-7143	EAP Client	Clarifies scope of the project. Provides internal review of the QAPP and approves the final QAPP. Coordinates WQP input and communicates project updates to WQP.
Robert Black USGS Washington Water Science Center Phone: 253-761-7831	Supervisory Hydrologist	Serves as a regional expert and writer. Provides high-level management of project milestones, evaluates results based on local knowledge, and writes and reviews report and data release.
Cristiana Figueroa-Kaminsky Modeling and TMDL Unit Western Operations Section, EAP Phone: 360-407-7392	Ecology Project Lead, Environmental Engineer	Provides direction for the overall project. Compiles and analyzes data for the inventory. Reviews model output and performance. Writes and reviews report/ summary.
John Gala Modeling and TMDL Unit Western Operations Section, EAP	Hydrologist	Serves as a data scientist, compiles water quality and modeled flow data.
Zachary Johnson USGS Washington Water Science Center Phone: 253-552-1681	Hydrologist	Serves as a data scientist, modeler, and writer. Performs and evaluates model calibrations, assesses conceptual theory, generates and evaluates results, writes report and data release, and transfers knowledge/models.
Arati Kaza Phone: 360-407-6964	Ecology Quality Assurance Officer	Reviews and approves the draft QAPP and the final QAPP.
Sheelagh McCarthy Previously with MTU Western Operations Section, EAP Phone: 360-407-7395	Data Inventory Lead (through December, 2021)/Hydrogeologist	Served as a data scientist. Started the compilation of local data.
Stacy Polkowske Western Operations Section, EAP Phone: 360-407-6730	Section Manager for the Project Manager	Reviews the project scope and budget, reviews the draft QAPP, and approves the final QAPP.
Noah Schmadel USGS Oregon Water Science Center Phone: 928-699-5580	Hydrologist, Principal Investigator	Serves as the Principal Investigator, data scientist, modeler, and writer. Develops initial data input and models, performs and evaluates model calibrations, assesses conceptual theory, generates and evaluates results, writes report and data release, and transfers knowledge/models.
Suzan Pool Modeling and TMDL Unit Western Operations Section, EAP	Environmental Specialist	Serves as a data scientist. Compiles, analyzes and processes data for inventory
Jamie Wasielewski Modeling and TMDL Unit Western Operations Section, EAP Phone: 360-407-6070	Data inventory Lead/ Environmental Specialist	Coordinates data inventory acquisition and organization. Serves as a data scientist. Compiles and processes data for inventory. Analyzes and visualizes data. Reviews model output and performance.
Dan Wise USGS Oregon Water Science Center Phone: 503-251-3213	Hydrologist	Serves as a SPARROW modeling expert, data scientist, and writer. Assesses and evaluates datasets and model calibrations, performs model calibrations, evaluates results, and writes and reviews report and data release.

EAP: Environmental Assessment Program
QAPP: Quality Assurance Project Plan
WQP: Water Quality Program

5.2 Special training and certifications

USGS project personnel have previous experience developing, calibrating, and applying SPARROW models. See Section 3.2.2 for a summary of previous studies related to this work.

5.3 Organization chart

An organizational chart is not deemed necessary for this QAPP, since Table 2 lists the key individuals, their current position, and their responsibilities for this project. The ultimate authority for quality assurance (QA) and quality control (QC) of this work rests on the authors of this QAPP.

5.4 Proposed project schedule

Table 3 presents the proposed project schedule for this project. The schedule and data products may change as this project progresses and may be outside the control of the modeling team.

Table 3. Proposed project schedule.

Work Task	Expected Completion	Lead
Data inventory complete	June 2022	Ecology
Develop model input files	August 2022	USGS
Evaluate and refine SPARROW data files	January 2023	USGS
Puget Sound SPARROW refinement	June 2023	USGS
Draft Scientific Investigations Report and Data Release ready for peer review	December 2023	USGS
Presentation of Scientific Investigations Report	March 2024	USGS
Technology transfer to Department of Ecology	May 2024	USGS
Publication of Scientific Investigations Report and Data Release	June 2024	USGS
Summary of model refinement	June 2024	Ecology

5.5 Budget and funding

Table 4 presents the project budget, including Ecology and USGS contributions for different project tasks.

Table 4. Project budget and funding.

Task	Ecology Contribution	USGS Contribution
Quality assurance project plan (QAPP)	$9,000*	$6,000
Model input developed	$4,080*	$2,720
SPARROW model refinement, SIR Report, meetings, collaboration and technology transfer	$164,348*	$101,500
SAS license	$7,200	--
Total	$184,628	$110,220

*Ecology contribution for contract with USGS

6.0 Quality Objectives

6.1 Data quality objectives

Since the dynamic SPARROW models will be used to evaluate seasonal nutrient loads and contributions of sources within a spatially distributed hydrological network, the model requires measured nutrient data within the stream network as well as spatial and temporal data on watershed properties and attributes. To quantify nutrient fluxes from individual source/pathway categories, source-dependent processes, land to water delivery factors, and instream attenuation processes must be specified or calculated during calibration of the model.

The primary data quality objective is to use data which accurately characterizes observed patterns in time and space that can be used for model input, calibration and/or to assess model performance. The USGS has determined that, based on assessment of the available data, there will be enough calibration targets across the model domain to identify coefficients.

Observational data used for model development, calibration or assessment will be acceptable if they are obtained from credible sources that document and implement their own respective QA and QC procedures in a QAPP or other equivalent QA document. Data will follow Ecology's credible data policy (Ecology, 2007). This QAPP does not address the QA procedures for any individual observational data set used in the study, but does reference their respective QAPPs or relevant QA information. Appendix B includes a table with further details describing QA information about the available observational data sets that may be utilized for this effort.

In addition to observational data, geospatial data and mechanistic process model output will be used. Additional sources of information may be considered as needed or as new sources are identified. Any additional sources of data and information used will be included in the final published documents.

6.2 Measurement quality objectives

Not applicable; no new field measurements are included.

6.3 Acceptance criteria for quality of existing observational data

Criteria for data acceptance includes:

- **Data Reasonableness**. Outliers consisting of values exceeding 1.5 times the upper bound of the interquartile range may be flagged. Best professional judgement will be used to identify potentially erroneous values or extreme outliers, and these data will be removed from the data set.
- **Data Representativeness**. Data used will be reasonably complete to obtain seasonal means and representative of at least the major drainage basins. Incomplete data sets will be used if they are considered representative of conditions during the period of interest. Data from outside the period of interest will be used only if no other data are available. In this case, best professional judgement will be used to determine the utility of the available data.
- **Data Comparability**. Long-term water quality monitoring programs often collect, handle, preserve, and analyze samples using methodologies that evolve over time. Best professional

judgement will be used to determine whether or if data sets can be compared. The report or technical memoranda will detail any caveats or assumptions that were made when using data collected from differing sampling or analysis techniques.

- **Data Consistency**. Consistency in the spatial and temporal scale of data used for calibration will be sought.

Continuous data

Continuous data are available at certain sites with monitoring data recorded for parameters at specific time-intervals (e.g., 15 minutes) for an extended duration. Continuous data are often used in a quantitative manner to compare to model output if the data meet quality standards for the intended application.

Continuous data is not available for TN or TP. However, data from one continuous ambient nitrate station is available. Data from this station will be used to help evaluate model predictions rather than be used as a calibration target (see section 13.4.1.4).

For continuous data collected by Ecology, data must go through data verification and adjustment QA/QC procedures. These data checks may be performed in the field and then again during the review process or as needed to adjust data. These data checks include reviewing instrument's operational history and possible malfunctions, reviewing residuals and adjusting data as appropriate using a weight-of-evidence approach, and using best professional judgement visual review to confirm any adjustments. These QA/QC procedures for continuous data are described in more detail in each project-specific QAPP, as well as in the Programmatic QAPP (McCarthy and Mathieu, 2017) and in related standard operating procedures (SOPs).

Agencies and organizations outside of Ecology have their own specific QA/QC procedures that they follow to assess the quality of their continuous data and measurement procedures. Such QA/QC procedures should be accessible and reviewed prior to utilizing the data. The project team will determine whether to use continuous data based on relevant data usability assessments, comparability with other observations, other data sources, and professional judgement. If questions about the quality of the data or potential data qualifiers arise, then contacting the sources of the data for verification and further information may be necessary. Any suspect data from point sources will be checked by contacting the appropriate permit manager for the site. Data that are suspect without sufficient documented QA/QC information will be discarded and not used.

Missing data and data gaps

Due to the large number of data sources possible in this work, missing data and data gaps, or an overlooked data set in the data inventory may be encountered. Missing or overlooked data may be addressed using different approaches agreed to by the project team, and depending on the intended use of the data. Other processes to determine acceptance of additional existing data may be generated during the course of the study.

6.4 Model quality objectives

Model quality objectives may be evaluated in terms of overall model performance, or at the basin or sub-basin level. We will not evaluate model performance on one metric alone. Section 13.4 (Model quality assessment) provides detailed information about the global context that will be used to evaluate the quality of the model.

The refined SPARROW model should meet the following quality objectives:

- Incorporate and detect cumulative effects of transformation and removal processes including mineralization, nitrification and uptake by aquatic plants that operate in seasonal time scales.
- Incorporate and detect nutrient losses that occur in watersheds along the full gradient of soil and topographic properties.
- Detect long-term multi-year and seasonal trends that occur due to source or pathway changes.
- Computed instream attenuation values will be NHDPlus reach-specific and representative of field conditions.
- Computed 90th percentile confidence intervals for predicted loads at individual reaches will fall within similar magnitudes as achieved for other SPARROW studies (Wise, 2019; Schmadel et al., 2021), but larger values may occur due to novel dynamic improvement that may be deemed acceptable.
- The overall average percent root mean square error (RMSE) of predictions of mean seasonal load will fall within similar magnitudes as achieved for other SPARROW studies (Wise, 2019; Schmadel et al., 2021; Preston et al., 2011), but larger values may occur due to novel dynamic improvement that may be deemed acceptable. For reference, reported RMSEs for TN and TP models in natural log space for an annual average model and a seasonal average model are listed below:
    i. TN annual average: 0.32 to 0.744 (Preston et al. 2011)
    ii. TP annual average: 0.49 to 1.01 (Preston et al. 2011)
    iii. TN seasonal average: RMSE = 0.45 (Schmadel et al. 2021)
    iv. TP seasonal average RMSE = 0.69 (Schmadel et al. 2021)
- Explanatory variable coefficients will typically have associated p-values of 0.05 or less, but there may be instances when a slightly (e.g., still near 0.10, but less than 0.20) higher p-value may be acceptable.
- At least 60% of the overall variability in the loads will be explained by the model.

7.0 Study Design

7.1 Study boundaries

The specific area of focus for this study is the Puget Sound region watersheds and watersheds draining into the Washington waters of the Salish Sea. Including areas outside of the Puget Sound region with different hydrological characteristics could be necessary to better resolve processes within the region of interest.

Thus, the initial modeling domain will include hydrological unit code (HUC) 4 area 1711 (Puget Sound) (Figure 3). However, expanding the modeling domain to include 1710 (Oregon-Washington Coastal), 1702 (Upper Columbia), 1703 (Yakima), 1707 (Middle Columbia), and 1708 (Lower Columbia) may be considered if necessary to better estimate model coefficients. If the domain is expanded, data sets for all categories will be expanded following approaches used by Wise and Johnson (2013) and Wise et al. (2021). In particular, estimates for agricultural practices will reflect regional variations.

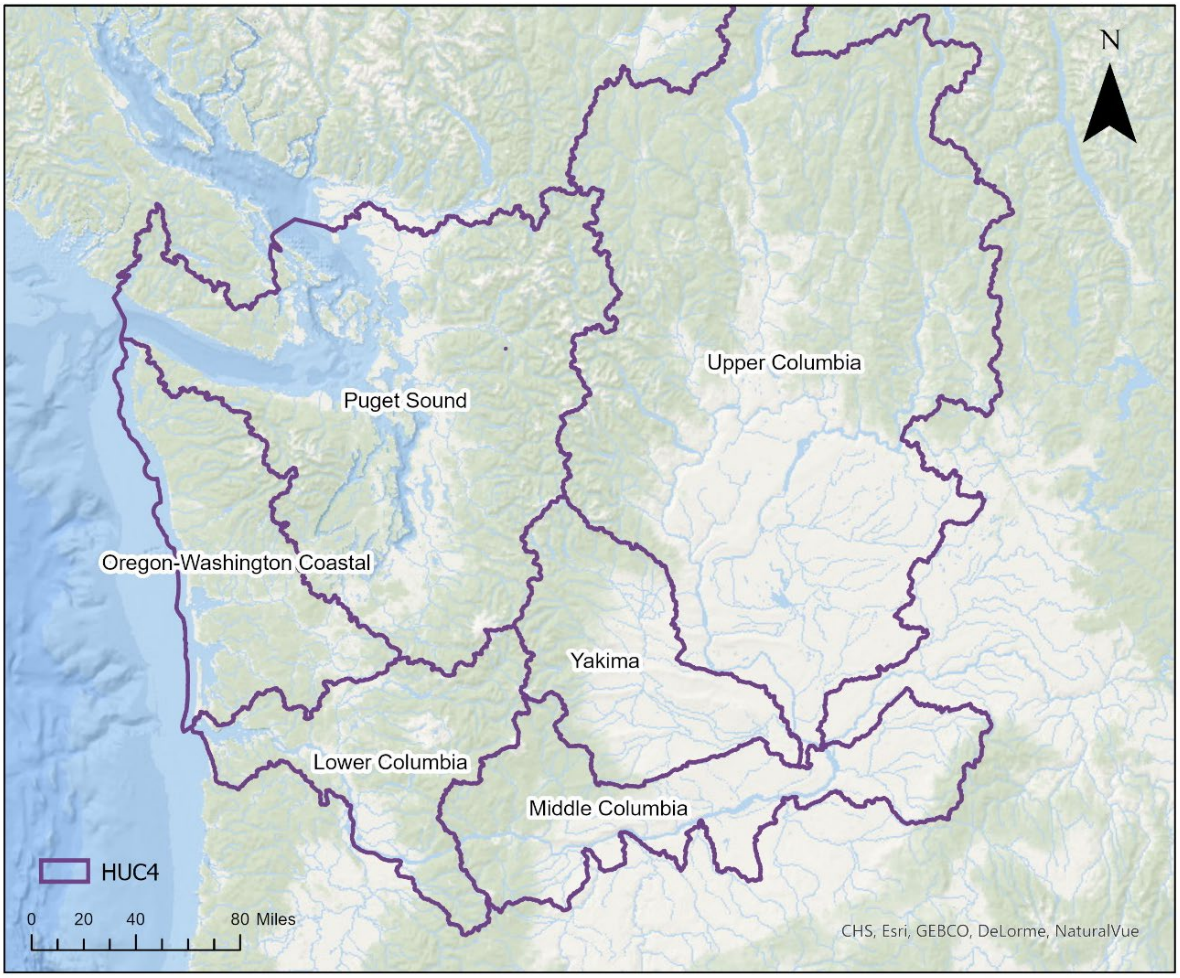

Figure 3. Map showing Puget Sound HUC study area (watersheds draining into WA Waters of the Salish Sea) boundary of project study area and adjacent basins.

7.2 Field data collection

Not applicable; no sampling or laboratory analysis is planned.

7.3 Modeling and analysis design

There are many different data sets and types that could be used to drive and calibrate the SPARROW models. Here we list possible data sets that may be tested and used, which are based on prior mean annual model calibrations. However, we will not be able to identify which are the most useful datasets until we begin model testing, calibration, and validation of predictions. Similarly, we may find that another dataset not listed here may improve model predictions. If we do find that an additional dataset is useful, data needs will be revised accordingly.

7.3.1 Analytical framework

SPARROW is a hybrid statistical-mechanistic model for estimating pollutant source contributions and transport in surface waters (Schwarz et al. 2006). SPARROW will be used to provide estimates of total nutrient loading (TN and TP) and the relative contribution of nutrients from upstream distinct sources or pathways based on land use patterns and other geographic characteristics.

The mechanistic mass transport components of SPARROW include the capability for mass balance constraints on model inputs, instream losses and outputs as well as flow path physical constraints (Schwarz et al. 2006). Refinement of SPARROW to a seasonal temporal scale was chosen for this project due to its successful application at (1) an annual scale in the Pacific Northwest by Wise and Johnson (2013) and Wise (2019), and (2) a seasonal temporal scale elsewhere (Schmadel et al. 2021). However, refining the model from an annual to seasonal time scale is not trivial.

The analytical framework of the dynamic SPARROW models for this project will be guided by the approaches and findings in Schmadel et al. (2021). The framework will use seasonal explanatory data and calibration data (see below for details). Seasonal load will be estimated at each monitoring station for, at minimum, the years 2005 to 2020, or 64 periods (seasons) to serve as the calibration data. Therefore, initial models will be built and calibrated for 64 periods. However, if calibration does not meet the specified criteria, as a tradeoff, a long-term mean seasonal model of four periods of a larger region will be explored to provide estimates of seasonal loads for a given base year. Regardless, the framework will produce seasonal nutrient load estimates for every river reach, either year-to-year estimates of many consecutive seasons or long-term mean estimates of four seasons.

We are not evaluating model performance on one metric alone, we are evaluating multiple aspects relating to overall model skill. These include model performance metrics (RMSE, Nash Sutcliffe efficiency (NSE), average of the residuals) and patterns in residuals. The model will likely not perform with equal skill everywhere or during all time periods. By comparing model skill to established criteria as specified in Sections 6.4 and 13. (e.g. Moriasi et al (2007) NSE performance rating), we will be able to identify areas which are deemed to have satisfactory model performance, and compare them with others that may not. In that sense, the model will have served a useful purpose. Whatever we learn that leads to next steps is a success.

The data sets used for this study will rely heavily on findings from Wise and Johnson (2013), which simulated nutrient loading in the Pacific Northwest with 2002 as the base year. The base year, if the long-term seasonal method of only four periods is determined to be needed, for the refined SPARROW work will be determined during the first phase of the investigation following similar procedures as described in Wise (2019). The seasonal load for each model calibration station for, at minimum, the years 2005-2020 will be estimated using an appropriate method such as the Beale's Ratio Estimator (BRE) as described in Saad et al. (2019), the USGS Fluxmaster regression method (Schwarz et al., 2006), or the Weighted Regressions on Time, Discharge, and Season with Kalman filtering (WRTDS-K; Lee et al., 2019). BRE may be used to estimate a seasonal load when there is no trend in the load, as suggested by Lee et al. (2016). If a long-term approach is needed, and given a significant trend in load is found, Fluxmaster may be used to estimate a mean seasonal load for 2005–2020. However, the preferred method to estimate seasonal load at each calibration site is WRTDS-K.

Model specification approaches for source-dependent, land-to-water delivery and attenuation processes are covered in Wise and Johnson (2013), Wise (2019), Wise (2020), and Schmadel (2021). In addition, we will consider Sheibley et al. (2016) to determine appropriate specification approaches for attenuation.

Software that is needed to conduct analyses using SPARROW includes either Statistical Analysis System Institute (SAS) software components version 8 or higher, supported on Windows NT Version or higher; or R statistical computing platform using the Shiny application.

An Intel- compatible Pentium class processor with 64 megabytes of memory and monitor resolution of at least 800 x 600 is the minimum hardware configuration that is needed to conduct SPARROW analyses. Sufficient storage space of hundreds of gigabytes is also needed. The team may also consider the benefits of utilizing a supercomputer for conducting runs.

7.3.2 Model setup and data needs

7.3.2.1 Hydrologic Framework

This SPARROW application will use the National Hydrography Dataset Plus Version 2.1 (NHDPlusV2) and its enhanced hydrologic framework (Schwarz, 2019). NHDPlusV2 incorporates the 1:100,000 -scale stream network and catchments. NHDPlusV2-based estimates of both mean annual and mean monthly stream flows account for excess evapotranspiration, major flow additions and removals, and gaged flow adjustments (Dewald, 2017). There are a host of additional NHDPlusV2-based attributes that may serve as useful non-dynamic explanatory data such as watershed slope or average overland flow distance to rivers (Wieczorek et al., 2018). However, these attributes will be supplemented, where appropriate, by data from other sources if deemed by the team an improved representation such as newly estimated surface-water transfers and removal (Wise et al., 2021).

NHDPlus High Resolution (NHDPlus HR) is also available, and attributes from it (Schmadel and Harvey, 2020) as well as the 1:4000 dataset digitized for Washington will be used. The team will test for the effects of high-resolution (1:24,000 and 1:4000) in small pond and small stream features.

In addition, simulated streamflow data from the National Water Model, described below in section 7.3.2.2, will be evaluated for use either as synthetic gauge data to be coupled with observations or in lieu of NHDPlusV2 flows.

7.3.2.2 Model Input

SPARROW uses data and information from multiple sources to estimate nutrient loading (Smith et al., 1997; Alexander et al., 2008; Wise and Johnson, 2011, 2013). Nutrient sources include both point sources and nonpoint sources. Point sources are regulated, identifiable discharges at a specific location (e.g., WWTP outfalls). Nonpoint sources refer to pollution from dispersed activities (e.g., runoff from urban and agricultural lands). Some point sources, such as municipal stormwater, represent a discharge pathway for nonpoint sources.

Geospatial data (e.g., land cover) provide the explanatory variables for potential sources of nutrients and land-to-water delivery factors. Instream attenuation and nutrient delivery are estimated based on a combination of instream and watershed characteristics, such as morphology and soils, respectively. Regional data sets (e.g., fertilizer use over croplands) will be used to improve representation of regional conditions for the Pacific Northwest application by Wise and Johnson (2013). The selection of explanatory data sets used for this study will rely heavily on findings from Wise and Johnson (2013) and (2019), which simulated long-term mean annual nutrient loading in the Pacific Northwest for the 2002 and 2012 base years. The key updates include using available seasonal datasets such as precipitation and air temperature to predict seasonal loads.

Land cover data

Geospatial land cover data will be used from the USGS national land cover dataset (NLCD), available for five-year intervals, the latest of which is for the year 2019 (Dewitz, 2021). The NLCD provides spatially explicit land cover information for sixteen land classes at a 30-meter resolution throughout the United States. Previous SPARROW models used earlier versions of NLCD data.

Soils

Surface geological data describing soil characteristics will be used from variables related to soil properties such as hydrologic group, soil erodibility, or percent sand, silt, or clay (e.g., STATSGO or SSURGO; Wieczorek et al., 2018). These soil-type variables are available at NHD-catchment means or percent areal coverage per NHD catchment. We will be using both means and percent coverage, depending on the parameter. For example, the clay content of a catchment is the mean percent clay in catchment, but for a soil (e.g., loam) type, a percent areal coverage will be used (percent of loam in catchment area). For soil erodibility per catchment, we will use the mean value per catchment (k-factor).

Atmospheric deposition data

Previous SPARROW models incorporated the atmospheric deposition pathway for TN. The atmospheric deposition of phosphorus is often assumed negligible relative to other sources (Smith et al., 1997). Natural, agricultural and urban sources of nitrogen emissions are inherently included within atmospheric deposition estimates.

Wise et al. (2011) used estimates of wet inorganic nitrogen deposition based on interpolated data collected at observational stations. In more recent work (Wise, 2020) atmospheric deposition was represented by the mean total deposition for 2010–12 estimated by the U.S. EPA's Community Multiscale Air Quality Modeling System (CMAQ; USEPA, 2002, 2022).

For this dynamic SPARROW modeling effort, atmospheric deposition model output may be obtained and tested, depending on availability. Potential data sets include the Community Multiscale Air Quality (CMAQ) model or from interpolated observational data to assess filling in temporal data gaps as needed. https://www.epa.gov/cmaq/equates

The National Atmospheric Deposition Program (USGS-NADP, 2022) 4-km wet deposition estimated observations are available and will be spatially interpolated between monitoring stations and multiplied by 4-km PRISM monthly precipitation grid (see Climate data section below) to provide 4-km monthly wet deposition estimates. AIRPACT (Air Quality Forecasting for the Pacific Northwest), a consortium initiated effort led by Washington State University, produces regional CMAQ monthly nitrogen deposition data in kg/ha. This data set may be more representative of regional deposition than the national CMAQ model. The team will explore this alternative data source. We will also compare the two CMAQ estimates for consistency and bias and compare to NADP.

Both atmospheric deposition and stormwater conveyances serve as transport pathways for nutrients into waterways. Atmospheric deposition of nutrients gets picked up in stormwater runoff. To differentiate between TN atmospheric deposition and stormwater transport pathways, the team will remove raster cells from the atmospheric deposition data that overlap with areas served by regulated municipal stormwater collection infrastructure.

Agricultural sources data

Data sets pertaining to agricultural fertilizer application and livestock manure are used to estimate agricultural nutrient loads using SPARROW. For the SPARROW Pacific Northwest application, estimates of manure from cattle in confined dairies and feedlots were combined with cattle and non-cattle grazing livestock (Wise and Johnson, 2013), using the same methodology described in Falcone (2020). Location and population information for cattle at dairies and feedlots were determined from permitting and inspection records. This SPARROW application will use estimates for dairy operations derived from available location data provided by the Washington State Department of Agriculture (WSDA) and permit records.

A set of annual WSDA cropland geospatial data layers are available (WSDA, 2022) and will be used for this study. These data layers are expected to provide better representation of the distribution of crops within the model domain. Seasonal estimates of fertilizer application for the top 17 crops (by acreage) in the Puget Sound region will be based on regional practices for crop fertilization rates and timing compiled from local publications by Oregon State University (OSU) and Washington State University (WSU) agricultural extensions and personal communication with crop specialists.

Additional crop-specific distribution information is available from the USDA National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL), a raster, geo-referenced, crop-specific land cover data layer produced using satellite imagery collected during the current growing season. However, we have found inaccuracies in coverage for pasture, and so we will not use this data set. Spatial distribution of agricultural acreage for broader crop categories is also available from NLCD data for 2004, 2008, and 2011 (Dewitz, 2019). USDA CDL and/or

NLCD data will be used for comparative purposes and to fill in data gaps in the WSDA data as needed (Appendix A).

Falcone (2020) developed five-year average TN and TP annual fertilization rates by county. These data will be used for comparison purposes for nitrogen and phosphorus fertilization. Stranik (2022) pointed out that most regional agricultural operations that utilize manure apply based on the crop's nitrogen needs. This means that these crops typically receive more phosphorus than is needed by the crop. If a soil test shows that phosphorus levels are reaching a critical level, then the farmer may apply manure based on phosphorus needs. Farmers will then need to apply commercial fertilizer to fill the remaining nitrogen need. Falcone (2020) estimates of total TP applied by county will be apportioned according to the needs of crop type. It is possible that estimated phosphorus content of the soil may be used to further refine these estimates.

The Nutrient Use Geographic Information System (NuGIS) integrates annual tabular and spatial datasets to provide county-level estimates of nutrients from fertilizer application and livestock manure. Commercial fertilizer estimates were provided by the Association of American Plant Food Control Officials (AAPFCO) and are used to estimate nutrients applied on farmland at the county level. Nutrients from manure are estimated based on a combination of livestock inventory and sales data from the Census of Agriculture. Nu-GIS data will be used to calculate the ratio of manure and commercial fertilizer utilized for grass, hay and corn, which are typical crops that can receive manure application (Appendix A). In addition, these annual county level estimates of TN and TP will be compared with rates produced from the sum of local seasonal estimates and WSDA crop cover or used directly to distribute the inputs of TN and TP in the landscape using the spatial distribution of WSDA crop cover or NLCD land cover layers.

Tile drainage can have a significant impact on the hydrology and delivery of nutrients to surface waters. Valayamkunnath et al. 2020 (Appendix A, Figure A-5) developed a geospatial model to map tile drainage areas based on soil drainage information and a topographic slope threshold within agricultural land cover. These data, and other relevant data, will be used to modulate the land to water delivery factors in the dynamic SPARROW models.

Another data set that will be considered is a spatial layer that represents, without confidential information, the best management practice (BMP) projects that the Washington State Conservation Commission has funded (Cochrane, 2022). These are verified projects which include implementation monitoring on 25% of the practices.

A potential resource for agriculture coefficients and conservation practices is the Agricultural Conservation Reduction Estimator (ACRE). ACRE is a tool that uses an extensive national database of export coefficients developed using the Texas Best management practice Evaluation Tool (TBET) and Soil and Water Assessment Tool (SWAT) models combined with conservation practice efficiency derived from a mixture of literature values and model simulations (White et al, 2019). USDA estimated current frequency of common agricultural conservation practices detectable via aerial imagery based on a probabilistic survey of farm fields. EPA is making use of ACRE to quantify the impact of various agricultural BMPs in RBEROST. RBEROST is in development for the Puget Sound region and will use the seasonal SPARROW estimates as the baseline nutrient loadings.

Biosolids and septage application on land data are not available in electronic form for the period of interest. However, we will obtain limited data that are available and use to provide context of the potential locations and scale of those operations.

Urban, sub-urban, and rural sources data

Municipal separate storm sewer systems (MS4) carry stormwater loads from urban and suburban areas into waterways. Areas served by regulated MS4 systems will be generally represented by an improved stormwater outfall data layer originally provided by Barnes (2022). Oestrich (2022) conducted high level QA of this data layer, as detailed in Appendix A. It is expected that the MS4 areas have remained relatively stable over time, and some adjustments are feasible during the time period of interest (2005-2020) based on data available that reflects the changes in urban growth areas (Stockwell and Trewhitt, 2022). Outfall location information, however, does not describe stormwater collection and conveyance systems, and thus the areas served by the MS4 infrastructure will be generalized, and will not identify smaller-scale private stormwater collection and conveyance infrastructure that do not tie into municipal stormwater systems. Thus, these data alone do not provide estimates of discharge or load; these outflow locations may be used to adjust other datasets such as urban coverage, which, when paired with a significant model coefficient, can provide estimates of load.

Septic systems constitute another source of nutrients from unsewered urban, sub-urban and rural areas. We compiled a spatial file of septic systems in operation within each of the counties in the model domain. These data will be modulated in time using census population data.

Alternatively, developed land can be used as a surrogate for nutrient sources originating from residential, commercial, and industrial land. These sources are intended to contain nonpoint sources of nutrients from commercial fertilizer, animal waste, and failing sewer systems. The runoff loads of nutrients from developed land within each catchment can be estimated by the total area of NLCD low, medium, and high intensity developed land, and open space using a method published by Schueler (1987). Developed land classes can be derived from percent developed impervious surface (Dewitz, 2021). Hobbs et al. (2015) developed a regional dataset of stormwater concentrations associated with various land use types.

Forests and other data sources

The extent of forestland and wetlands will be determined based on the appropriate and available NLCD for the year or time period of interest. TN from forests in SPARROW are estimated using the fixation rate of atmospheric nitrogen in forests. Nitrogen leaching from alder trees will be estimated based on the spatial distribution and basal area of alder forests throughout the Pacific Northwest as was done by Wise (2011) using data from the Landscape Ecology, Modeling, Mapping, and Analysis project (Oregon State University, 2022).

For total phosphorus (TP), previous SPARROW models have represented the contribution from upland geologic sources to stream phosphorus load in different ways. Other approaches have been the use of surrogate land cover types with low human impact (forestland, grassland, and scrubland) and the use of estimated concentrations of naturally occurring soil phosphorus. These two approaches will be evaluated as part of the calibration of the SPARROW models developed for this study. Instream phosphorus has also been included in SPARROW as a separate source from upland sources (Wise, 2019), and will be evaluated in this application of the model as well.

For reference condition forest cover intended to represent historical forested areas in pre-industrial condition, we will make the same key assumptions made by Stanley et al. (2016): (1) 100% forest cover in the pre-development state with adjustments in high-elevation areas to account for rock/ice, and (2) depressional wetland coverage for pre-development state should include not only existing wetland coverage, but also current urban and rural areas with underlying hydric soils and on slopes of less than 2%. We may modify the basal area of species using the estimates for the mid-19th century developed by Collins et al. (2003) to account for changes in tree species composition.

Point Sources

Point sources represent municipal WWTPs, and industrial facilities with NPDES permits as well as other sources permitted via general permits. Data such as outfall location and discharge monitoring reports are available for permitted discharges (e.g., point sources) to surface waters and to ground in Ecology's Permitting and Reporting Information System (PARIS) database. Monthly load estimates for point sources are based on measured flow and either on-site measurements or regional average estimates for a specific industrial classification. Monthly load data cannot be quantified for general permit sources, but their location is available, and therefore can be accounted for as point sources if assumed steady discharge. Point source data will be retrieved from Ecology's PARIS database**.**

Locational and operational data for hatcheries (monthly pounds of fish and feed) is also available from PARIS. These data will be used to estimate nutrient loads originating from hatcheries using a mass-balance approach. Niewolny and Merz (2022) provided supplementary information about hatcheries that will be used to estimate loads.

The seasonal SPARROW model will segregate point sources discharging to freshwater from those discharging into marine, brackish or near-marine waters (which are included in the Salish Sea Model input) for comparative and analytical purposes. Appendix A contains available information for WWTPs and other point sources, including a list of all point sources to be included in the SPARROW model with quantitative load estimates, maps depicting point source location, and maps showing SSM point sources compared with SPARROW point sources.

Streamflow data

In most situations, the lack of co-located streamflow gauges and water quality observations limits the number of data points that can be used for SPARROW calibration. The team will explore using simulated or synthetic streamflow data to expand the number of stations that can be used in the SPARROW analysis. For example, there are some ungaged lowland areas in the basin with corresponding intensive human activity that could potentially add bias to local load predictions if streamflow estimates were not included.

Mean annual streamflow predictions are available for every NHDPlusV2 reach in the Puget basin, and together with USGS streamflow gage data, can be used to estimate seasonal streamflow for every reach. However, NHDPlusV2 provides long-term (1971-2000) monthly streamflow estimates that will be used as a starting point for comparison. Streamflow simulations are also available at high temporal resolution within the NHDPlusV2 network via the National Water Model. The Weather Research and Forecasting Model Hydrological (WRF-Hydro) modeling system (Gochis et al. 2018) constitutes the foundation of the National Water Model which links multi-scale process models of the atmosphere and terrestrial hydrology. It includes multi-scale mechanistic representations of land and atmospheric processes and is used for the prediction of major water cycle components such as: precipitation, soil moisture, snow pack, ground water, streamflow, and inundation.

Gala (2021) compared WRF-Hydro National Water Model (NWM) Version 1.2 streamflow output in Washington watersheds and found that reliable streamflow predictions occur in calibrated basins that are not impacted by hydrological diversions or reservoir operations. WRF-HYDRO NWM Version 2.1 is now available and provides hourly flow predictions that will be integrated into the analysis to derive seasonal flow estimates at each location. HYDRO NWM flow predictions will be compared to published NHDPlusV2 flow estimates that include diversion estimates to assess whether adjustments are needed, with available nutrient observational data.

Ambient Nutrient observations

Nutrient observations used in this study for calibration will meet the data quality objectives outlined in Section 6.3. These data are found in three potential data repositories: Ecology's Environmental Information Management System (EIM), the USGS' National Water Quality Information System (NWIS), EPA's Water Quality Exchange, previously known as the Storage and Retrieval (STORET) database, or procured from other sources. Figure 4 shows the sites that we compiled data for, and which will be evaluated for use during calibration. A subset of the data may be selected for model verification purposes and will therefore not be used for calibration.

Table A-1 in Appendix A shows data sets that will be considered for this study. It includes:
- Data source/reference
- Data description
- Years with data

Some watersheds within the Puget Sound SPARROW modeling domain are in Canada where there is limited or no representation of the landscape data that may be used to calibrate the models. Stream load at the cross-border watersheds may be estimated similar to previous approaches. Previous SPARROW modeling for the Pacific Northwest (Wise and Johnson, 2011) used a combination of approaches to estimate nutrient loads contributed by these cross-boundary watersheds. When possible, the estimated loads at monitored sites near the Canadian border were used as boundary conditions in the models. For watersheds with less than 50% of the area in Canada, the stream load discharged from unmonitored cross-border watersheds was estimated by extrapolating the landscape data from the available U.S. datasets to the entire watershed. For watersheds with more than 50% area in Canada, the stream load discharged from unmonitored cross-border watersheds was estimated by having SPARROW estimate a coefficient for watershed area, which was the only source term for those watersheds.

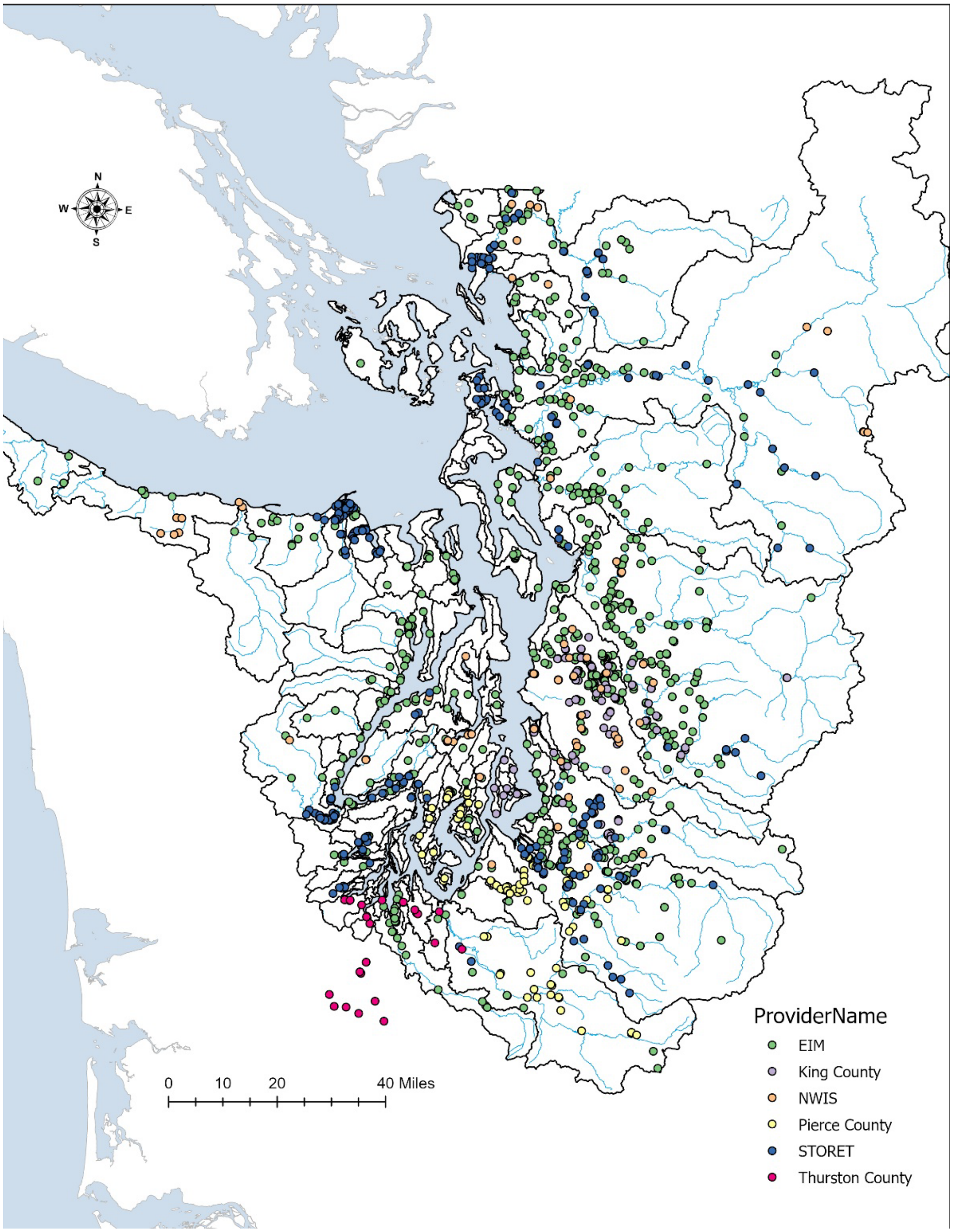

Figure 4. Map showing locations with available total nitrogen (TN) and total phosphorus (TP) ambient nutrient data from different database sources.

Climate data

Climate parameters play a role in the timing and magnitude of nutrient discharges into rivers and streams. Various climate datasets are available and will be considered.

The PRISM Climate Group at Oregon State University develops air temperature and precipitation datasets. Wolock and McCabe (2018) produced monthly input and output data covering the period 1900-2015 using a water-balance model. The input datasets are precipitation and air temperature from the PRISM. The model outputs include estimated potential evapotranspiration, actual evapotranspiration, runoff (streamflow per unit area), and soil moisture. These data are in the process of being extended through 2020. Wieczorek et al. 2022 also produced monthly climate data based on NOAA's monthly Climate Gridded dataset. Any of these datasets are potential options for use in the Puget Sound SPARROW application.

Stream temperatures may be used if they improve stream attenuation estimates, which will be tested in the model calibration. NorWEST produced modeled daily stream temperatures for June, July, August, and September for 2005 through 2015 for the Puget Sound region. If stream temperatures are deemed helpful for improved stream attenuation estimates, modeled stream temperatures may be produced using NorWEST model or the EPA's River Basin Model (RBM), developed by Yearsley (2009).

7.3.2.3 Nutrient Load and Attenuation Estimates

A nutrient load will be estimated for the seasonal, or shorter timeframe, and will be reported in kilograms per time period (season). Seasonal nutrient concentrations can then be estimated using seasonal streamflow. The model estimates nutrient loads (TN and TP) for each incremental sub-basin and as a total load. An incremental sub-basin is the area that drains directly to a reach without passing through another reach. The total load is the predicted load with contributions from all upstream nutrient sources, while accounting for instream attenuation processes, including nutrient loss from uptake or nutrient decay, based on stream categories.

Nutrient load estimates are attributed to specific NHDPlusV2 segments by a distinct identifier code. SPARROW results are joined to its corresponding NHDPlusV2 river or stream reach to analyze the results spatially and identify results at a specific river segment.

SPARROW attenuation estimates are typically a model-calibrated parameter, and then compared to estimates derived from field observations for general validation. Variable estimates of nutrient attenuation for every river reach can be accomplished via calibration (e.g., by including stream temperature), but the typical approach is limited by assuming all rivers are equally reactive.

Sheibley et al. (2016) estimated nitrate attenuation in rivers and streams in the Puget Sound Basin which will be used either as additional explanatory data or for model evaluation and interpretation.

Runs and scenarios after model refinement

Model refinement will make it possible to address the following questions by either analyzing model output or designing specific model runs and scenarios:

- What are the current nutrient (TN and TP) load contributions from significant anthropogenic nonpoint and point source categories?

- What is the TN loading to Puget Sound resulting from nutrient source reductions in its watersheds?
- What is the estimated fraction of each watershed's total nutrient loads (TN and TP) attributed to watershed WWTPs? How does it compare in relative terms to other source categories in that watershed?
- How much relative reduction is needed (and from which source categories) to meet each watershed inflow load targets (TN) established in the PSNSRP?

After refining the SPARROW model for the Puget Sound region, the USGS will explore the feasibility of developing a SPARROW model scenario to represent nutrient conditions that existed within the Puget Sound Basin before intensive settlement, agriculture, and forestry arrived during the 19th century. The reference conditions model scenario will have limitations due the lack of a comprehensive coverage for habitats or regional climatological differences in the 19th century. Existing and relevant appropriate historic data will be selected and documented. Assuming the parameters included in the updated Puget Sound Basin models are appropriate for historical loading estimates, it is possible that historic predictions will be estimated but will have greater uncertainty than those for current conditions.

7.4 Assumptions underlying design

Schwarz et al. (2006) covers various assumptions and approaches that will also pertain to the current study:

1. Specific explanatory variables evaluated with SPARROW reflect key physical, chemical and biological properties driving the supply, transport and fate of nutrients in watersheds and are represented as area-weighted sums of source inputs. Appendix C contains a general framework of the dynamic SPARROW mathematical formulation.
2. Land to water delivery factors reliably modulate source inputs of nutrients.
3. Modeled fluxes at any reach are conditioned by fluxes entering the stream network anywhere upstream of that reach.
4. Nutrients delivered to a stream reach from its incremental drainage area are introduced at midpoint of the reach and are therefore attenuated through only half of the full reach length.
5. Errors in the model are assumed to be independent across observations and have zero mean.
6. The optimal weight for an observation is proportional to the inverse of the variance of the observation's error.

7.5 Possible challenges and contingencies

7.5.1 Logistical or potential communication problems

SPARROW results may not be intuitive or easily grasped, so clarity in communication of results is important and needs to be achieved by reaching agreements within the team. The list below are items that require consideration in terms of clarity in communication:

- Comparisons between seasonal results and observational (i.e., ambient) data at a specific location and time
- Meaningful way of describing results from categories that include both pathways and sources
- Characterization and grouping of source inputs and nutrient export potential

- Comparisons of SPARROW predicted loads and Salish Sea Model watershed inflow loads
- Model prediction uncertainty
- Strengths and limitations of the model for TN target setting based on model performance

7.5.2 Practical constraints

Data availability

- Headwater streams are often poorly represented in observations. While data at headwater streams often constitutes a limitation in SPARROW model development, the addition of a larger set of observational sites will support the overall model robustness.
- Manure may be exported outside of the location where it is generated and applied to other fields within the same county. We do not have specific data about manure transport and application. This poses a limitation.
- Reference condition scenario development is a novel endeavor using SPARROW.

  Since a SPARROW application has not yet been developed to model reference (natural) conditions, this study will face possible challenges identifying appropriate data sources. Limitations may be encountered related to availability of spatial datasets to represent pre-industrial conditions and data used to calibrate or evaluate the model. Complete and detailed documentation of the datasets used for the reference condition will be essential, as will be a description of the limitations of the data and the approach used. Assumptions used to develop a reference scenario will also need to be fully documented.

Improving upon nutrient loading estimates from watersheds with little or no updated/ refined explanatory data.

Missing an explanatory variable or a key source in watersheds that have little or no observational data presents a challenge. Investigating potential anomalies early on during the project to allow for addition of local knowledge (e.g., known septic issues, subsurface issues, or key missing sources) will require extra effort on behalf of the team. Sufficient time should be allotted to this task.

Covariance of pathways and/or sources limits the ability to provide details that stakeholders may seek

Wise (2019) reported that certain categories were not found to be significant when the model included other categories. For instance, forest land and grazing cattle manure were found to be not significant (at the $p <= 0.05$ level) when the model also included atmospheric deposition estimates likely due to the strong, positive covariance between those sources and the amount of atmospheric nitrogen deposited in a catchment. Another example is onsite wastewater treatment which was also not found to be a significant source likely due to its strong covariance with developed land.

The key approach here is for the team to distinguish between categories that exhibit strong covariance early on, determine if there is confounding of pathways and sources, and then decide how the *sources* are best represented and communicated in the model. For example, atmospheric deposition is a pathway that is influenced by numerous sources—while SPARROW will make use of spatially and temporally allocated atmospheric deposition predictions (Section 7.3.2.2), ascribing estimated contributions to that pathway, it will be necessary to reference other work that describes the sources that contributed to the atmospheric deposition calculated loads such as emissions from automobiles and agricultural areas.

7.5.3 Schedule limitations

Stakeholder input at key junctures was identified as a need during the scoping process for this project. The team will need to determine the best timing and opportunities for that to occur so that stakeholder input is considered and incorporated.

8.0 Field Procedures

Not applicable.

9.0 Laboratory Procedures

Not applicable; no sampling or laboratory analysis is planned.

10.0 Quality Control Procedures

10.1 Table of field and laboratory quality control

Not applicable; no sampling or laboratory analysis is planned.

10.2 Corrective action processes

No sampling or laboratory analysis is planned. See Section 7.3 for model setup and testing, and Section 13.4.1 for model calibration and sensitivity testing. Calibration is, by nature, an iterative process that seeks to optimize model performance to a level consistent with understanding of underlying processes and data gaps.

If corrective action processes are needed based on the evaluation of model performance and results, project personnel and technical experts will convene to decide on the next steps that need to be taken to improve model performance. USGS and Ecology will meet on a regular basis during the duration of this project to discuss progress, results, and challenges and determine if any corrective actions are needed.

11.0 Data Management Procedures

11.1 Data recording and reporting requirements

USGS responsibilities: Scientific Investigations Report and data release

The techniques used to develop the SPARROW models for this study and the interpretation of the model results will be documented in a Scientific Investigations Report (SIR) that will be published by the USGS. The data used as input for the models and the model predictions will be documented in an accompanying USGS data release that will be publicly available from the USGS Science Base digital repository. The USGS will also create and maintain a public web page that will include a project description, links to related web content, and access to products published from the study.

Technology transfer

Technology transfer from USGS to Ecology/EAP of the dynamic SPARROW model will include training using scripts to modify input files and using the SAS control files and datasets to run the model. The training will also include an overview of the model output and performance statistics.

11.2 Laboratory data package requirements

Not applicable; no sampling or laboratory analysis is planned.

11.3 Electronic transfer requirements

Not applicable; no sampling or laboratory analysis is planned.

11.4 EIM/STORET data upload procedures

Not applicable; no sampling or laboratory analysis is planned.

11.5 Model information management

Post Technology transfer

Ecology will retain a SAS license to conduct SPARROW modeling activities after the technology transfer efforts described in 11.1. We will use servers that are backed up following Ecology and USGS information technology procedures.

SPARROW Ecology archive

Ecology will create a model archive to be stored on the Ecology computer servers that mirrors the archive kept at the USGS (described below). This archive will include all the study's input and output files.

*Management system (e.g., folder structure, where files will be stored, made available online***)**

The USGS will create an internal archive of the SPARROW models developed for this project following USGS guidance and policies. Under the existing USGS policy, water-quality model archives are reviewed and stored internally on a computer server located at the USGS science center where the model was developed and are not publicly available. The USGS internal model archive for this study will be stored at the USGS WA Water Science Center. In addition to the internal model archive, the USGS will create and publish a public model release of the components of the final SPARROW model in the form of an SIR and data release that support the interpretive conclusions of the project's scholarly report(s), consistent with the USGS plan, "Public Access to Results of Federally Funded Research at the U.S. Geological Survey: Scholarly Publications and Digital Data."

Because Ecology is collaborating on model development for this study, Ecology will have the ability to run the models. Therefore, Ecology will be able to create its own model archive to be stored on the Ecology computer servers. Ecology assumes responsibility of the model archive stored on their servers, including any further distribution to make publicly available according to their internal review policies that cite the USGS corresponding publications documenting the USGS-stored model archive.

12.0 Audits and Reports

12.1 Field, laboratory, and other audits

Ecology and USGS will communicate regularly to review recent model progress, evaluate project needs, and revisit next steps to meet project objectives. This provides an internal and external peer review function.

12.2 Frequency and distribution of reports

USGS will publish the SIR upon the completion of the Puget Sound SPARROW model.

Following the technology transfer of the SPARROW model, Ecology will develop a model refinement summary.

12.3 Responsibility for reports

USGS will publish the SIR. This report will provide all details including all supplementary information needed to fully document the refined SPARROW models such as model specifications. Accompanying the SIR, will be a data release of model input and output files. In addition, the SIR will address each of the key questions identified during the scoping phase of this project:

1. What local datasets and information were used to refine the SPARROW model for the Puget Sound region to estimate nutrient (TN and TP) loading from different nutrient sources on a watershed-scale?
2. Which watersheds are the top contributors to the TN and TP loads on a seasonal basis to Puget Sound?
3. What are the seasonal TN and TP loading trends and spatial patterns in Puget Sound?
4. What are the nutrient load (TN and TP) contributions from major nutrient source categories such as agriculture (crop and livestock), forests, developed areas, and point sources?
5. How can Ecology prioritize implementation of best management practices (BMPs) based on SPARROW results?

Peer review of the SIR will be conducted by two USGS-selected reviewers. The SIR will go through additional USGS supervisory review, in addition to a review/approval by the WA Water Science Center (WAWSC) director and the USGS regional a Bureau Approving Official to confirm USGS policies are met.

13.0 Data Verification

This section describes data verification approaches used for the model calibration process and the analysis methods used for assessing model uncertainty.

Data used to calibrate the refined SPARROW models will undergo the data quality assessment process, using the quality objectives described in sections 4.3 and 6.3. During model calibration, consistency with approaches used for previous SPARROW projects will be sought, though there may be instances when novel approaches are required. Mean seasonal load estimates at monitored locations with a standard error greater than 50% will be removed from the set of calibration loads. Potential bias in calibration loads can be calculated (e.g., can be estimated using Fluxmaster). The effects of potential bias in calibration loads on identifiability of model coefficients will be explored and corrected if necessary.

13.1 Field data verification, requirements, and responsibilities

Not applicable; no sampling or laboratory analysis is planned.

13.2 Laboratory data verification

Not applicable; no sampling or laboratory analysis is planned.

13.3 Validation requirements, if necessary

Not applicable; no sampling or laboratory analysis is planned.

13.4 Model quality assessment

13.4.1 Calibration and model evaluation

Model calibration procedures for SPARROW models are detailed by Scharwz et al. (2006). P-values and 90th percentile confidence intervals will be computed for all source-specific, attenuation and land-to-water delivery coefficients. Parameter-by-parameter statistics other than p-value, such as standard error (SE), and spatial site-by-site, season-by-season residual plots and maps will be examined to optimize calibration, seasonal and spatial performance.

Model evaluation depends heavily on the quality and quantity of data in the observational network. Model accuracy and precision for sub-basins with no or very little observational data, and/or with a large degree of variation, may be estimated and weighted with a greater degree of uncertainty.

Various statistics will be used to quantify goodness of model fit. Wise (2020) points out that the coefficient of determination (R^2) of yields is considered a better measure of goodness of fit than R^2 of loads because it accounts for the effect of contributing area which may explain a large portion of the variation of the contributing load. For that reason, both coefficients of determination based on both loads and yields, will be computed for this project.

The overall quality of the model predictions will not depend on a single statistic alone or comparison to a single established criterion. Even if a single criterion is deemed as unsatisfactory overall or in a specific region, the model may be found to meet other criteria overall, regionally or at the basin or sub-basin scale. Consequently, the model's usefulness will be in improving our understanding and pointing to next steps, which may include filling observational data gaps in one or more source categories.

Statistics to quantify goodness of model fit will include:

- Coefficient of determination of the natural logarithm of predicted versus measured loads or fluxes (R^2).
- Coefficient of determination of the natural logarithm of predicted versus measured yields (R^2).

- Nash Sutcliffe Efficiency (NSE) coefficient. We will use NS ratings as published in Moriasi et al. [Table 4: General performance ratings for recommended statistics for a monthly time step.]
- Seasonal, or shorter time scale, overall domain-wide *and* reach-specific:
    - Percent error of predicted loads compared to measured loads,
    - Root mean squared error (RMSE) as computed in Schwarz et al. 2006, page 96
    - Normalized or relative standard deviation (RSD)
    - 90th percentile confidence intervals.

The variance of prediction error will be computed via a bootstrap analysis, as described in Schwarz et al. (2006) section 1.6.4.

13.4.1.1 Precision

Model precision is usually assessed by comparing the "absolute distance" between modeled results and field measurements representing a similar time and location (positive and negative differences will be treated the same). A metric for precision that will be computed for this study is the RMSE.

13.4.1.2 Bias

Bias is also usually assessed by comparing modeled results to field measurements from a similar time and location. However, bias is indicated by the average shift between the two (positive and negative differences "cancel out") which helps determine how much precision deviates from being equally balanced. A metric for bias used in this study is the percent error. The percent error (average of paired observed minus modeled values divided by observed value), is computed using actual values and not absolute values.

Bias in the model parameterization could be caused by spatial autocorrelation and temporal serial correlation among model residuals. Therefore, because SPARROW model predictions are spatially distributed across the landscape, and now through seasons and years, the spatial and temporal patterns of model error will be examined, with appropriate corrections to standard errors of model coefficients to adjust for potential bias. However, both pieces have not been considered in combination in previous SPARROW applications, so novel approaches may be employed.

Spatial autocorrelation in the model residuals may be evaluated among loose and tight clusters of calibration sites. Loose clusters are, for example, those located within the same watershed while tight clusters are sites within five kilometers of each other with similar drainage areas. This type of spatial correlation can be addressed by removing the upstream site in each pair from the calibration data set.

Model residuals will be examined for seasonal patterns and heteroscedasticity to potentially apply weights and error corrections. If seasonal patterns are significant, weighting of calibration targets with the inverse of residuals will be explored in a new model calibration to account for potential bias due to heteroscedasticity. If serial correlation in the model residuals, which are assumed to be independent, is also significant, a first-order autoregressive analysis of the model residuals will be applied to correct standard errors of the model coefficients based on potential bias from serial correlation.

13.4.1.3 Representativeness

The final set of calibration loads for TN and TP will be selected based on the results from an evaluation of their accuracy and representativeness in time and space. Since the seasonal, or shorter period, mean load estimate's standard error will be computed using the standard deviation of estimated load (based on one or more estimation tools such as Beale's Ratio Estimator (BRE), Fluxmaster, or WRTDS-K) at each location with observations, estimated loads at locations with higher number of observations or showing less variability are expected to match predicted seasonal means more closely.

13.4.1.4 Qualitative assessment

- We will look for patterns in the residuals.
- We will compare model output with available continuous nutrient data.

Continuous measures of nitrate-N are available at least at one location and will be used to estimate mean seasonal nitrate-N concentrations along with their associated confidence intervals. These statistics will be compared with the seasonal statistics for TN generated by the SPARROW model. The lack of overlapping confidence intervals or lack of similar seasonal patterns in these two forms of nitrogen for the location of interest will be a potential indicator of model bias that will be addressed in relation to other measures of model fit and bias.

It is expected that predicted seasonal TN concentrations will be higher than mean seasonal nitrate-N concentrations from continuous monitoring instruments on a site-by-site basis. If TN values are lower than mean seasonal nitrate-N concentrations at a site, an explanation and correction to the model will need to be examined. While continuous nitrate data provides insight into seasonal dynamics of a form of nitrogen, the temporal dynamics of nitrate-N and TN can be responding to a different suite of site-specific chemical processes that may be responsible for seasonal variations in these forms of nitrogen.

13.4.2 Analysis of sensitivity and uncertainty

The model will be tested for sensitivity to additional parameters that can be used as predictor variables. For example, the model team will test sinuosity as a predictor variable to scale the uptake velocity (refer to Appendix C). If significant, we anticipate higher uptake velocity with higher sinuosity, as Sheibley et al.(2016) described for Puget Sound river systems and allow for a comparison between including this new piece of information or not and evaluation of its importance.

Model uncertainty will be characterized as detailed in section 13.4.1. Model uncertainty will be reported based on both the calibration data set as well as a segregated, randomly selected observational sub-data set that was not used for calibration purposes. Overall domain statistics using this dataset (R^2, RMSE and percent error) will be reported using this segregated data set.

14.0 Data Quality (Usability) Assessment

14.1 Process for determining project objectives were met

Section 6.4 details the model quality objectives. Section 13.4.1 details the statistics that will be used to characterize model performance. To determine overall model quality, the Ecology and USGS study team will review model performance statistics and visualizations of model results and residual patterns at key junctures of the model calibration process. If model quality objectives are not met, the team will discuss and decide on next steps. It is expected that this will be an iterative process until the team is satisfied that all model quality objectives have been met. The team will use a segregated portion of the observations for independent evaluation of model performance which will facilitate the determination of whether model quality objectives are met.

14.2 Treatment of non-detects

When estimating calibration targets, any non-detects in the water-quality data, although shown to be a very small number of the compiled observations, will still be included as indeterminate values between zero and the detection limit to prevent additional bias. Therefore, non-detects will be represented in the final estimates of seasonal nutrient load at the monitoring stations (i.e., the calibration targets).

14.3 Data analysis and presentation methods

Data analysis and presentation methods will be similar to those of Wise and Johnson (2013), Wise (2019), Wise (2020), and Schmadel (2021).

14.4 Sampling design evaluation

Not applicable; no sampling or laboratory analysis is planned.

14.5 Documentation of assessment

The USGS will publish a SIR that includes items detailed in Section 12.3.

Ecology will produce a summary of the dynamic seasonal SPARROW models that covers key results that are applicable to the continued development of nutrient management strategies for the Puget Sound region.

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16.0 Appendices

Appendix A. Model Input Data

Table A-1. List of Puget Sound SPARROW Data Sources.

Nutrient Source Category	Data Source	Years	Description	Links to Data/ QA Information
Land Cover Data	NLCD	2004 2008 2011 2013 2016 2019	The U.S. Geological Survey (USGS), in partnership with several federal agencies, has developed and released the National Land Cover Database (NLCD). This provides spatially explicit and reliable information on the Nation's land cover and land cover change. Datasets are from the 2019 data release by the Multi-Resolution Land Cover Consortium (MLRC)	https://www.mrlc.gov/data/nlcd-2019-land-cover-conus
Soils	SSUROGO/STATSGO2	2005-2020	Datasets collected by the USDA National Cooperative Soil Survey.	https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627 https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053629
Atmospheric Nitrogen Deposition	EPA Community Multiscale Air Quality (CMAQ) model			https://www.epa.gov/cmaq
Atmospheric Nitrogen Deposition	National atmospheric deposition observations	2005-2020		https://nadp.slh.wisc.edu/networks/national-trends-network/
Agriculture - Dairy	Washington State Department of Agriculture	2006 2008 2010 2013 2014 2017 2016 2018 2022	WSDA & WA Dept. of Ecology Dairy Nutrient Management Plan maintained dataset of spatial distribution of active milking dairies including dairy size and count of animals.	https://nras.maps.arcgis.com/apps/webappviewer/index.html?id=187a52c48d8047f3b699206c8ae54d38
Agriculture - Livestock grazing	NLCD	2004 2008 2011 2013 2016 2019	NLCD land use categories for grazing	https://www.mrlc.gov/data/nlcd-2019-land-cover-conus
Agriculture - Cropland	Washington State Department of Agriculture	2005-2020	WSDA agricultural land use geodatabase obtained through windshield surveys, producers, aerial and satellite imagery, USDA NASS Cropland Data Layer (CDL) and other sources to identify agricultural landuse.	https://agr.wa.gov/departments/land-and-water/natural-resources/agricultural-land-use
Agriculture – Fertilizer and manure application	NuGIS and Association of American Plant Food Control Officials (AAPFCO)	2016	County level estimates of fertilizer sales and manure application for Washington State gathered from AAPFCO.	https://nugis.tfi.org/Methods/Fertilizer

Nutrient Source Category	Data Source	Years	Description	Links to Data/ QA Information
Agriculture - Fertilizer	WSU & OSU extension publications and crop specialists	2005-2020	Seasonal estimates of fertilizer application for the top 25 crops (by acreage) in the Puget Sound region. Sources included publications by Oregon State University (OSU) and Washington State University (WSU) agricultural extensions and communication with WSU crop specialists.	See Table A-2 for detailed source list
Urban - MS4	DNR 2016 MS4 outfall data collection	2016	Location of stormwater outfalls for areas served by MS4 systems voluntarily provided by permittees for a 2016 mapping project by WA DNR.	
Urban - Septic Systems	Counties, Department of Health	2016-2021	Parcels or households on septic system by county. Large on site sewage system locations.	
Urban-Developed Land	NLCD	2004 2008 2011 2013 2016 2019	Percent developed impervious area from NLCD land use geospatial data.	https://www.mrlc.gov/data/nlcd-2019-land-cover-conus
Forest and Wetlands	NLCD	2004 2008 2011 2013 2016 2019	Extent of forested and wetland areas from NLCD land use geospatial data.	https://www.mrlc.gov/data/nlcd-2019-land-cover-conus
Forests - Red Alder	Landscape Ecology Modeling, Mapping, and Analysis Group led by USFS Pacific Northwest Research Station and Oregon State University	2005-2017	Gradient nearest neighbor (GNN) data that is a multivariate, imputed map of forest attributes based on 30-m Landsat imagery, Forest Inventory and Analysis data, and other geospatial data products. Data set showing the distribution and basal area of alder species.	https://lemmadownload.forestry.oregonstate.edu/ Bell et al, 2020. Gradient Nearest Neighbor Map Data Quality Summary: GNN-2020
Point Sources	Ecology's Water Quality Permitting and Reporting Information System (PARIS)	2005-2020	Permit records and discharge monitoring reports for WWTPs and industrial point sources discharging to freshwater.	https://apps.ecology.wa.gov/paris/PermitLookup.aspx
Climate - Air Temperature & Precipitation	PRISM	2005-2020	monthly air temperature & precipitation datasets developed by the PRISM Climate Group at Oregon State University	https://www.prism.oregonstate.edu/
Climate - Stream Temperature	NorWEST	2005-2015	Modeled daily stream temperatures for June, July, August, & September	https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html

Point Sources

Nutrient loads can be calculated using data reported to the PARIS database for point sources shown in Figure A-1. A set of industrial and municipal WWTP permitted sources with quantifiable loads will be assembled following the approach used by Ahmed et al. (2019). For QA, Ecology permit managers will:

- Flag any changes or updates in treatment technologies from 2005-2020.
- Confirm the type of discharge (e.g., ground, surface, to treatment) and whether it varies throughout the year.
- Confirm the discharge points and their active/inactive timeframes, if applicable.
- Review calculated TN and TP concentrations.

Other point sources which are permitted, but for which loads cannot be calculated with data available are shown in Figure A-2. Figure A-3 shows the point sources which discharge into, or close, to marine waters and which constitute effluent inputs to the SSM.

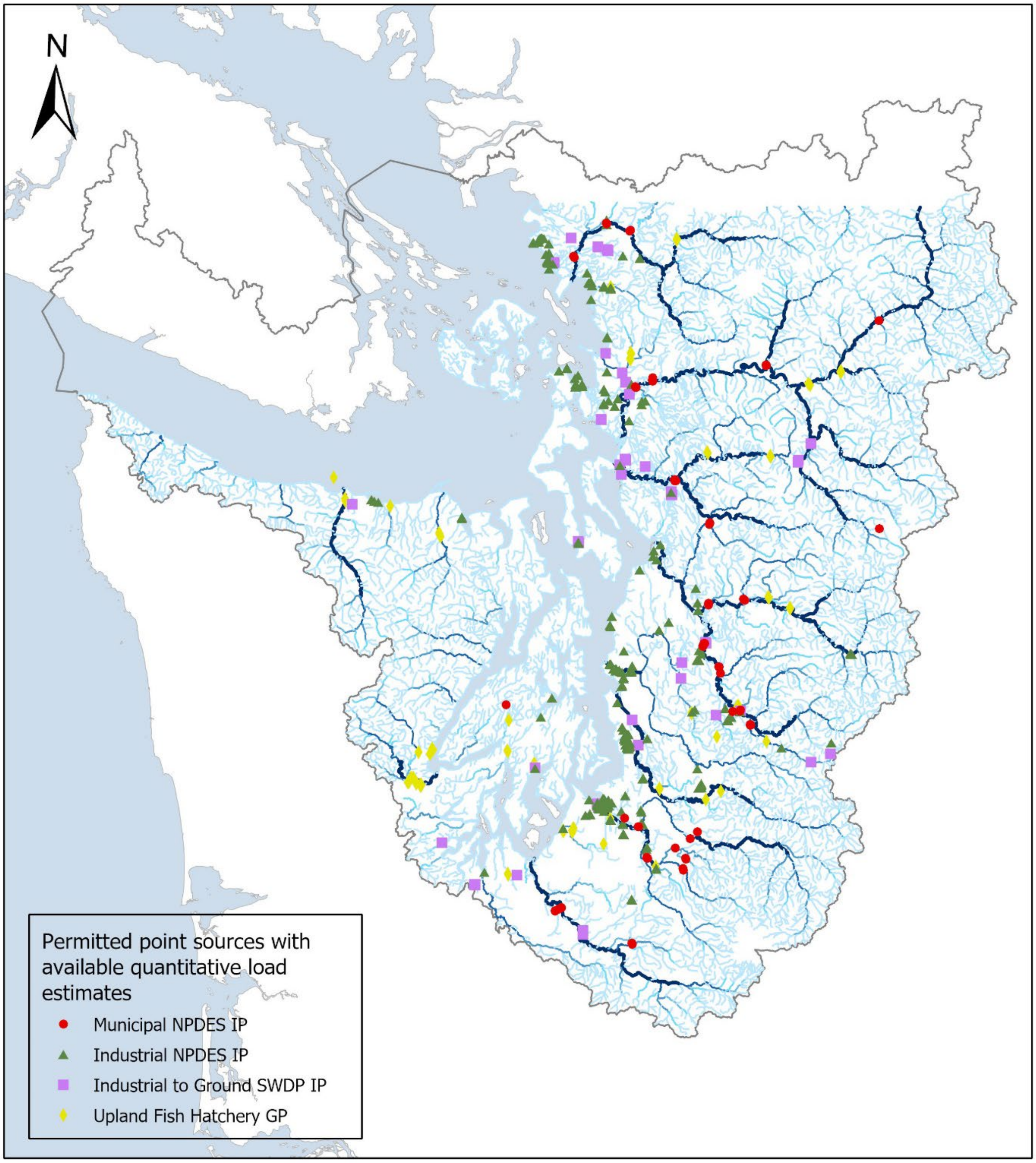

Figure A-1. Permitted point sources with available quantitative load estimates.

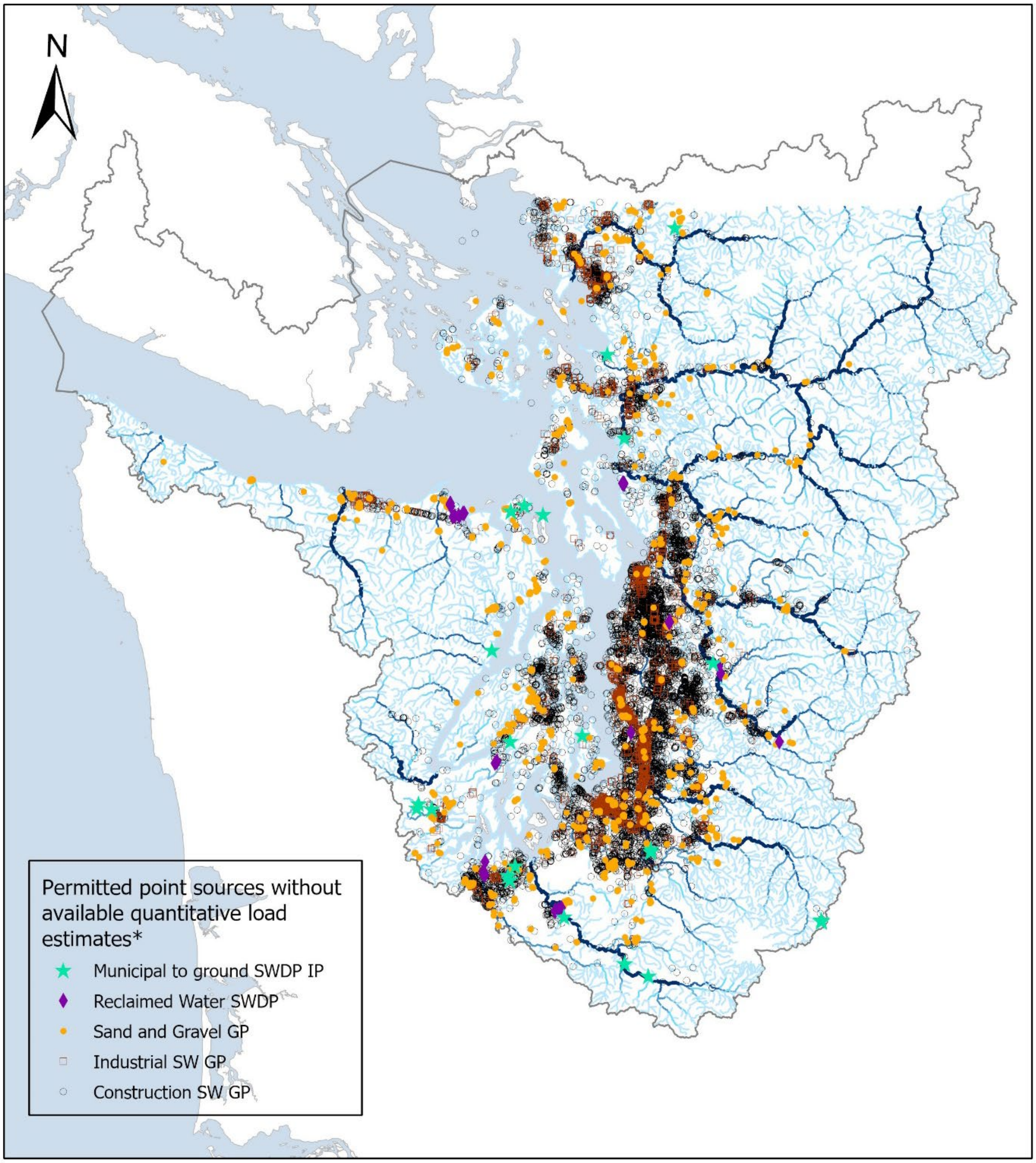

Figure A-2. Permitted sources without available quantitative load estimates.

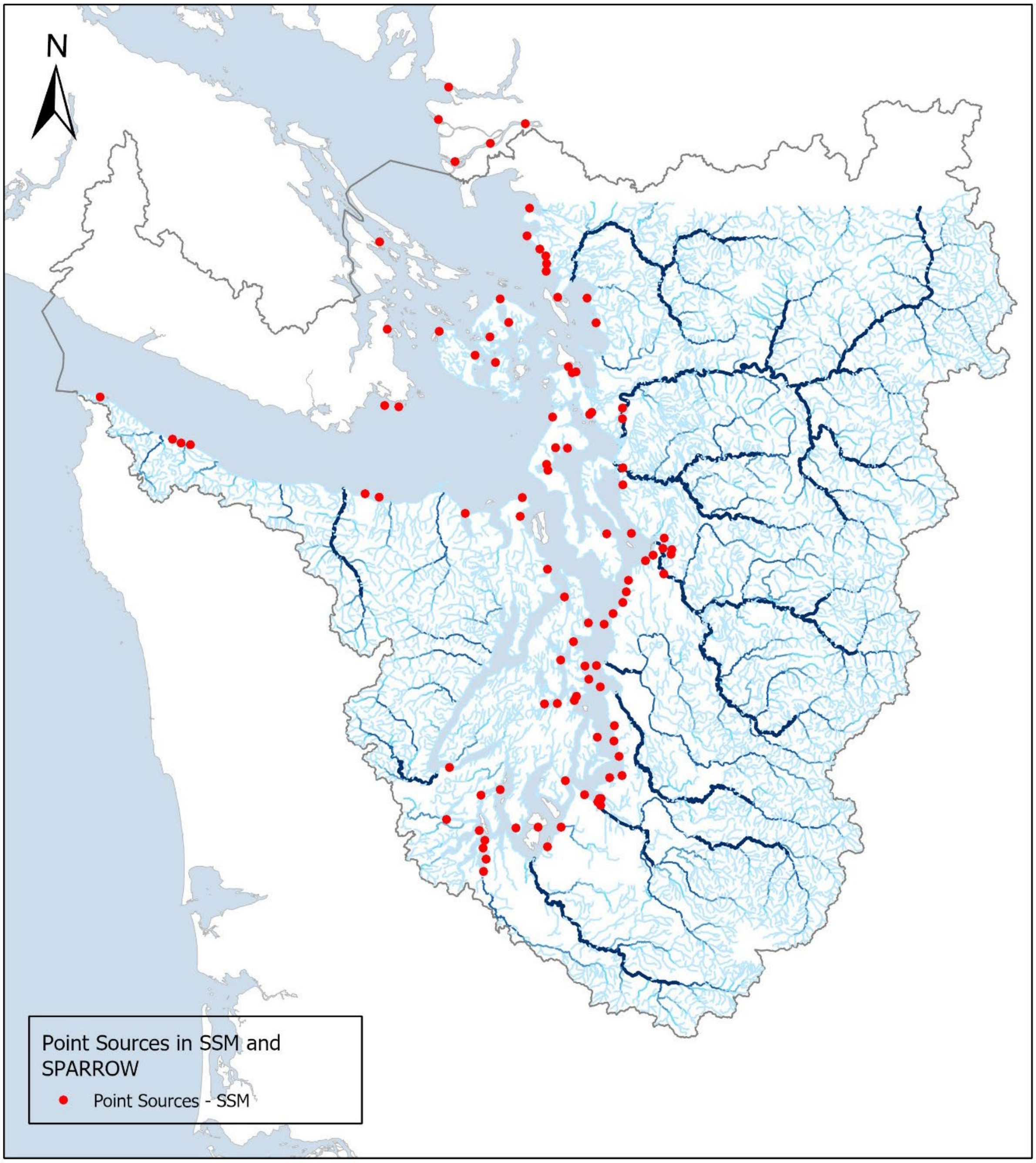

Figure A-3. Point sources currently consistent in SSM and previous SPARROW applications .

Agricultural Loads

We consulted with local agronomists, as detailed in Table A-2, to obtain estimates of crop fertilization rate and timing. In addition, we obtained general information influencing fertilizer application from conversations with local experts, as detailed below.

Whatcom Conservation District has conducted edge of field nutrient measurements for five years on silage grass fields that are applied with dairy manure (Graham, 2022). Summaries of these measurements may be provided after removal of confidential information. Natural Resources Conservation Survey (NRCS) used to install drain tiles as a common practice. They stopped 20-30 years ago. Electronic records of installed drain tiles are not available (Graham, 2022).

When considering manure application, fields closest to the farm facility are most convenient and tend to get the most application but recommendations are to apply manure based on soil tests (Stranik, 2022). Local farmers are required to utilize soil tests to determine appropriate nutrient application rates. They may supplement with commercial fertilizers if needed. This may be due to high soil phosphorus or running out of manure. Limited manure is applied during November 1 through February 28/29 due to wet conditions and slow plant growth. December and January see very little manure application. During periods of excessive precipitation, and when manure storage capacity at the facility become scarce, manure can be exported to other facilities within the county where it can be stored or possibly applied if field condition is acceptable. For example, due to abundant precipitation and flooding in Winter 2021-22, a large volume of manure—over 26 million gallons--was transferred within Whatcom County (Stranik, 2022).

Silage grass, hay and silage corn are the three crops that typically have the most manure application (Phay, 2022; Stranik, 2022). About 10,000 gallons per acre is a reasonable application rate for a single application to silage grass. Manure is sometimes applied to berries, but there is a more limited application window (Stranik, 2022).

We will use the data above, data from Table A-2, and data from NuGIS and Falcone (2020) to estimate seasonal application of TN and TP for each crop type, based on the spatial annual distribution provided by the WSDA cropland, USDA cropland, or NLCD land cover layers.

WSDA crop acreage data prior to 2011 is discordant with the acreage calculated from NLCD land cover layers, likely due to changes in WSDA mapping methods over time (Demory, 2022). WSDA data after 2011, which includes more comprehensive mapping of pasture land, more closely aligns with USDA cropland and NLCD land cover layers. The WSDA cropland layer and the USDA CDL are mapped by individual crop type and classified into broader crop groups. For example, alfalfa hay and grass hay crop types are part of the hay/silage group, while field corn, barley, and wheat are part of the cereal grain group.

In the NLCD land cover layers, agricultural land uses are defined by two broader classification categories and codes as revised in the 2001 release of NLCD data:

- Pasture/Hay (81): Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle;
- Cultivated Crops (82): Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards.

When possible, the more detailed WSDA spatial data will be used to estimate seasonal application of TN and TP, but WSDA data for years 2005-2010 will be compared and corrected, as needed, using the USDA CDL, available for 2008-2020 and/or the NLCD land cover layers from 2004, 2008, and 2011.

Table A-2. Agriculture Fertilizer Estimates and Data Sources.

WSDA Crop Group	WSDA Crop Type*	Acres** (2020)	Nitrogen Application Rates	Nitrogen Application Timing	Phosphorus Application Rates***	Phosphorus Application Timing	Sources
Other	Pasture	73,333	100 lbs/acre/year ^depending on mixture of grasses & legumes	2-3 applications per year of 30-50 lbs/acre after each grazing cycle			Shewmaker & Bohle 2010. Pasture and Grazing Management in the Northwest. PNW 614, Oregon State University. Stacey et al. 2020. Estimating and comparing cropland nitrogen need with dairy farm nutrient recovery: a case study in Whatcom County, WA. Renewable Agriculture and Food Systems 36, 130–137.
	Fallow	10,598	None				
Hay/ Silage	Grass Hay	80,686	180 lbs/acre/year	4-6 applications per year of ~40 lbs/acre between March & October after each cutting cycle	0-100 lb P2O5/ acre/year depending on soil content of P	fall and spring	Jiajia Lin, from "Seasonal fertilization-Calapooia" spreadsheet, provided by e-mail to C. Figueroa-Kaminsky, 12/7/2021. Oregon State University Extension Publication EM 8585-E. 2020. Manure application rates for forage production. Stacey et al. 2020. Estimating and comparing cropland nitrogen need with dairy farm nutrient recovery: a case study in Whatcom County, WA. Renewable Agriculture and Food Systems 36,130-137.
	Alfalfa Hay	1,305	None	N fertilizer not required or recommended (legumes)			
	Alfalfa/ Grass Hay	958	None	N fertilizer not required or recommended (legumes)			
Cereal Grain	Corn, Field	34,413	100 lbs/acre/year ^mean, rates variable depending on soil constituents	100 lbs/acre when planting at end of April/May/June	0- 100 lb P2O5/ acre/year depending on soil content of P		Hart et al. 2009. Silage Corn Field Guide. EM8978E, Oregon State University.
	Barley	8,166	120 lbs/acre/year ^unless planted on land with previous crops that retained N in soil	Spring barley: 120 lbs/acre/year 120 lbs/a prior to planting in March to mid April ^ spring barley is more prevalent than winter barley; there is minimal difference in fertilizer rates and timing	0-60 lb P2O5/ acre/year depending on soil content of P	prior to planting in spring	Meints et al. 2021. Growing Barley in Western Washington. EM122E, Washington State University Extension. California Dept of Food and Agriculture: https://www.cdfa.ca.gov/is/ffldrs/frep/FertilizationGuidelines/Barley.html. Bramwell, Stephen. WSU Thurston County Director, personal communication, March 2nd, 2022. Brouwer, Brook O. WSU San Juan County Extension Direct and Regional Agriculture Specialist, personal communication, March 2nd, 2022.
				Winter barley: ~120 lbs/acre/year 100 lbs/acre in spring + 20 lbs/acre in fall	0-60 lb P2O5/ acre/year depending on soil content of P	prior to planting in fall	

WSDA Crop Group	WSDA Crop Type*	Acres** (2020)	Nitrogen Application Rates	Nitrogen Application Timing	Phosphorus Application Rates***	Phosphorus Application Timing	Sources
	Wheat	3,141	180 lbs/acre/year ^mean of rates cited: 45 to 200 lbs/acre/year	Winter wheat: 160-200 lbs/acre/year 20 lbs/acre at planting at end of Sept to mid-Oct 140-180 lbs/acre before shoots emerge (jointing) mid-March to end of April	0-60 P2O5 lbs/acre/year depending on soil content of P	September to early October	Hart et al. 2000. Fertilizer Guide: Winter Wheat, Western Oregon--West of the Cascades. FG9, Oregon State University. Miles et al. Growing Wheat in Western Washington. EM022E, Washington State University. USDA Cereal Rust Bulletin, 2021: https://www.ars.usda.gov/ARSUserFiles/50620500/CRBs/2021%20CRB%20June%2014.pdf Brouwer, Brook O. WSU San Juan County Extension Direct and Regional Agriculture Specialist, personal communication, March 2nd, 2022.
				Spring wheat: 160-200 lbs/acre/year 20 lbs/acre at planting March/April 140-180 lbs/acre before jointing late April to May			
Vegetable	Potato	13,235	210 lbs/acre/year ^mean of rates cited: 80-350 lbs depending on soil test & target yield	70 lbs/a (1/3 of total) at planting in late April/May/June + ~35 lbs/a each week starting 2 to 3 weeks after planting to support uptake rates during tuber bulking	60 lb P2O5 lbs/acre/year depending on soil content of P	late April/May/June	Lang et al. 2019. Potato Nutrient Management for Central Washington. EB1871, Washington State University.
	Market Crops	4,542	highly variable depending on specific crops grown				
	Corn, Sweet	995	165 lbs/acre/year ^mean of rates cited: 130 to 200 lbs	30–50 lbs/a starter application end of April/early May + 100–150 lbs/a ~4-6 weeks after planting, mid-June to mid-July	30 lb P2O5/ acre/year depending on soil content of P	end of April/early may	Sullivan et al. 2020. Nutrient and Soil Health Management for Sweet Corn (Western Oregon). EM9272, Oregon State University. Daniels, Catherine 2013. Vegetables: Growing Sweet Corn in Home Gardens. FS104E, Washington State University Fact Sheet.
	Cucumber	925	30 lbs/acre/year ^mean of rates cited: 20 to 40 lbs	20 - 40 lbs/a starter application late April/May/early June	10 lb P2O5/ acre/year depending on soil content of P	late April/May/June	Sullivan et al. 2017. Nutrient Management for Sustainable Vegetable Cropping Systems in Western Oregon. EM9165, Oregon State University.
	Cabbage	835	90 lbs/acre/year ^mean of rates cited: 60-120 lbs	20 - 40 lbs/a starter application May/early June + ~40-80 lbs/a, 6-8 weeks after seeding mid-July/early Aug	55 lb P2O5/ acre/year depending on soil content of P	May/early June	Sullivan et al. 2017. Nutrient Management for Sustainable Vegetable Cropping Systems in Western Oregon. EM9165, Oregon State University.
Berry	Caneberry	10,649	60 lbs/ acre/year divided into two applications	First application in March or early April, second application in late July to early August			Erickson & Norton 1990. Washington State Agricultural Chemicals Pilot Study, Final Report. 90-46, Washington Department of Ecology.
	Blueberry	9,149	130 lb per acre/year divided in two applications	First application: Mid-late March; Second application: Mid-May			Strick et al. 2020. Growing Blueberries in Your Home Garden. EC1304, Oregon State University.
Turfgrass	Sod Farm	1,290	175 lbs/acre/year divided into four applications	Divided into four applications: mid-April/May, mid-June to mid-July, mid-Aug to mid-Sept, mid-Oct to mid-Nov:	40 lb P2O5/ acre/year depending on soil content of P	Assume: applied at same times as N, 10 lbs/acre each time	Cook & McDonald, 2005. Fertilizing Lawns. EC1278, Oregon State University.

*Fertilization rates for largest 17 crops by acreage (excluding shellfish) in Puget Sound HUC 1711. **Number of acres within Puget Sound HUC 1711

***Phosphorous application rates are variable and dependent on soil testing.

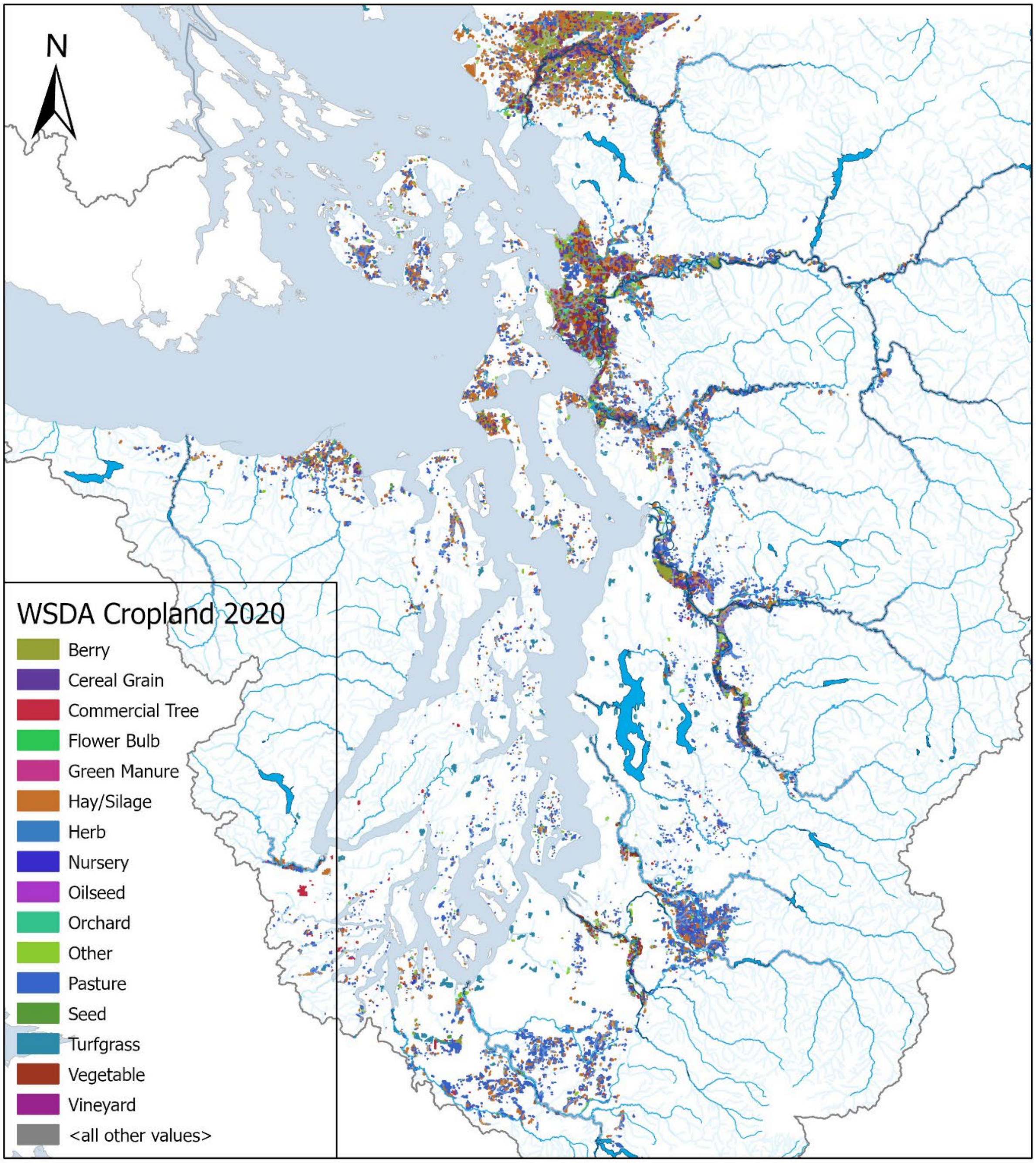

Figure A-4. WSDA Cropland Parcels 2020.

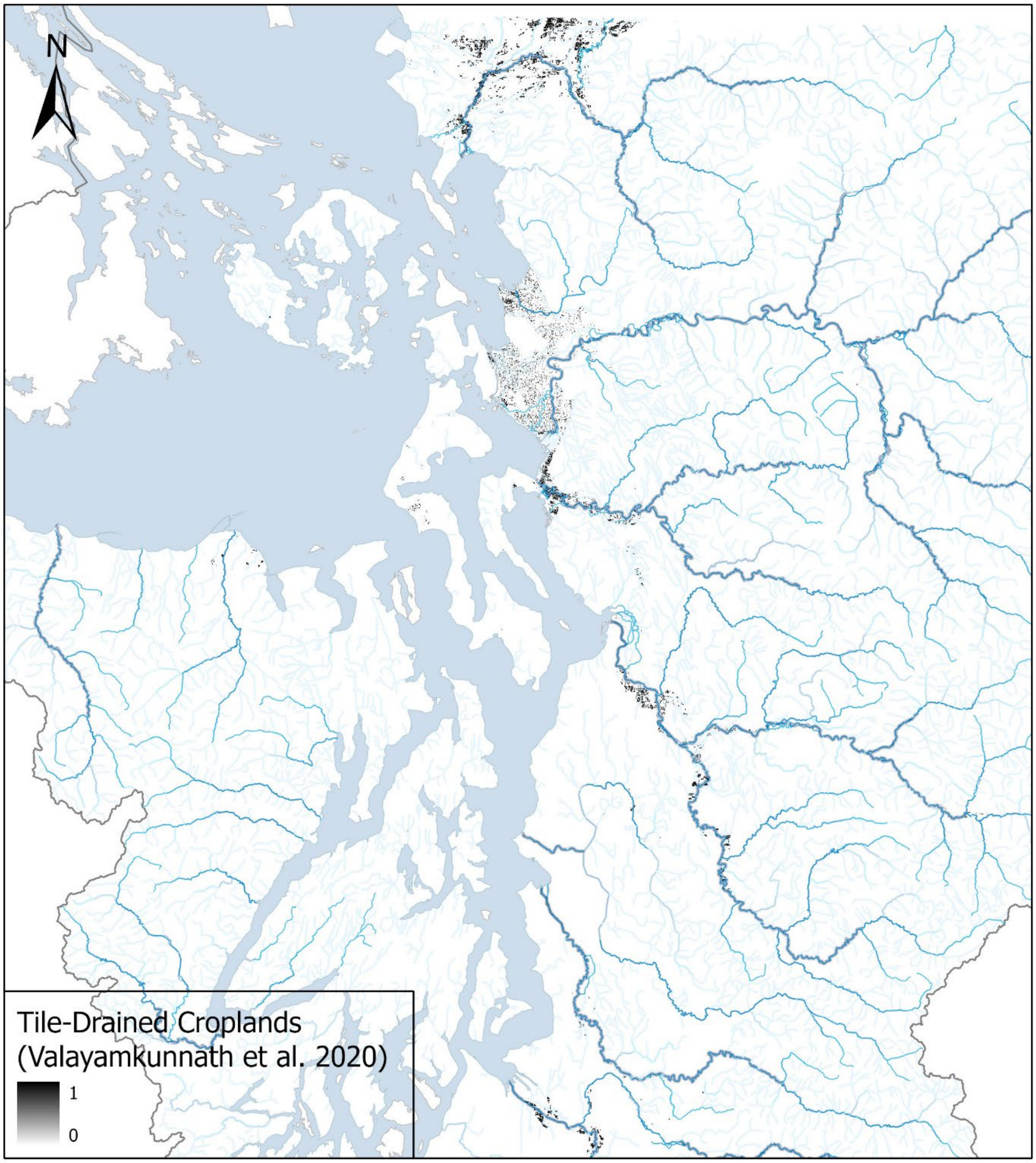

Figure A-5. Predicted Agricultural Tile Drain Locations.

Metadata record for: Mapping of 30-meter resolution tile-drained croplands using a geospatial modeling approach (Valayamkunnath et al. 2020).

Stormwater Outfall Spatial Layer

Barnes (2022) provided a spatial data layer depicting the location of stormwater outfalls. Since these data were not previously checked for quality, Adam Oestrich (2022) developed and conducted the following procedure to evaluate the municipal stormwater outfall points.

Procedure for Evaluating Municipal Stormwater Outfall Points

The following procedure describes steps performed within a Python script for evaluating outfall point locations with respect to the distance that point lies from the designated permittee's jurisdiction boundary and distance from any described receiving water.

1. Add the point dataset representing outfall features into a file geodatabase.
2. Create a "Jurisdiction" feature class by performing a Union geoprocessing task on the City/UGA boundaries and County boundaries together and dissolving into single-part features (one feature for each discrete polygon, created with the same name) by a single, jurisdiction name field.
3. Open a map project containing layers for:
    a. The outfall feature class (Outfalls)
    b. The jurisdiction feature class (Jurisdiction)
    c. NHDFlowline (linear hydrography features representing stream lines)
    d. NHDArea (polygon hydrography features representing oceans and large rivers/canals)
    e. NHDWaterbody (polygon hydrography features representing lakes and estuaries)
4. Add and populate a field into the Outfalls to store the corresponding GNIS name that matches those of the NHD hydrography features, based on the provided receiving water field values
5. Add and populate a field into the Outfalls to store the corresponding Jurisdiction name, based on the provided permittee values
6. Run geoprocessing step to evaluate each Outfall point, find the closest Jurisdiction dataset features that correspond with the Jurisdiction name for the Outfall and add the Name, Distance, and OBJECTID of the Jurisdiction feature to the Outfall attribute table.
7. Run the same geoprocessing step for each of the Hydrography datasets.
8. Evaluate the "Distance" fields added by the geoprocessing step, to evaluate points that occur excessively far (>1300 feet) away from their corresponding jurisdiction or hydrographic feature.

Appendix B. Datasets for Nutrient Observations and their Respective Quality Assurance and Quality Control Documents

We compiled observational datasets for this study from several databases:

- Ecology's Environmental Information Management (EIM) database
- EPA's Water Quality Exchange (WQX), previously known as the Storage and Retrieval Data Warehouse (STORET)
- USGS's National Water Information System (NWIS)
- Several individual local entities (King County, Pierce County, Thurston County).

Tribal nations also collect data and make it available through WQX/ STORET.

We also collected QAPPs and reviewed analytical methodologies for the entities listed in Table B-1. The project team may also decide to use data from the following entities: Clallam County, Puyallup Tribe, Samish Indian Nation, Skagit River Watershed Grant, Snoqualmie Tribe, Swinomish Tribe, Tulalip Tribe, Western Washington University, and Wild and Scenic Rivers. If so, the project team will seek the respective QAPP information from each of these entities.

Table B-1. Total nitrogen and total phosphorus observational datasets compiled for this study.

Monitoring Entity	Data Source	QAPPs	Method TN	Method TP	Years of Data
Ecology	EIM	*Programmatic Quality Assurance Project Plan: Water Quality Impairment Studies*	SM4500NB[1], SM4500NC[2], Valderrama (1981)[3]	SM4500-P E,[4] SM4500-PH[5], EPA-365.1[6]	1999-2021
Jamestown S'Klallam Tribe	WQX/ STORET	*Jamestown S'Klallam Tribe Natural Resources Quality Assurance Project Plans (QAPPs)*	TN not collected	Unesco (1994)	2005-2014
King County	King County	*Green – Duwamish Watershed Water Quality Assessment Comprehensive Monitoring Program Sampling and Analysis Plan*	SM 4500NC[2]	SM 4500-PB[7],	1999-2021
Lummi Nation	WQX/ STORET	*Quality Assurance Project Plan Lummi Nation Nutrient, Metal, and Hydrocarbon Monitoring Project*	EPA 351.2 for TKN and EPA 353.2 for Nitrate/Nitrite[8]	SM4500-PF[9], SM 4500-PB,	2002-2020
Muckleshoot Tribe	WQX/ STORET	*Quality Assurance Project Plan For Water Quality Monitoring of White River*	SM 4500-NC[2]	EPA 365.2 and SM4500-PF[9]	2009-2012

Monitoring Entity	Data Source	QAPPs	Method TN	Method TP	Years of Data
Nooksack	WQX/ STORET	*Nooksack Indian Tribe Nooksack River Watershed Surface Water Quality Monitoring Project Quality Assurance Project Plan*	SM4500NorgC[2], SM4500-NO3-F, EPA 300.0, EPA 351.2, and EPA 351.3[8]	SM4500-PE and EPA 365.1[6]	2009-2015
Pierce County	Pierce County	*Quality Assurance Monitoring Plan Pierce County Ambient Monitoring Program*	SM 4500-NC[2]	SM 4500-P F[9]	2012-2021
Skokomish Tribe	WQX/ STORET	*Quality Assurance Project Plan For Water Quality Monitoring Skokomish Indian Tribe*	TN not collected	TP not collected	2008-2012
Squaxin Island Tribe	WQX/ STORET	*Quality Assurance Project Plan Squaxin Island Tribe Long-Term Water Quality Monitoring Program*	TN not collected	SM 4500-PF[9]	2013-2015
Thurston County	Thurston County	*Thurston County Surface Water Ambient Monitoring Program*	TN not collected	SM4500-PF[9]	1999-2012
USGS	NWIS	*Quality Assurance Project Plan for Water Quality Activities in the U.S Geological Survey Washington Science Center*	Patton and Kryskalla (2003)[10]		2005-2021

References to Methods

1 *In-Line UV/Persulfate Digestion and Oxidation with Flow Injection Analysis* in Standard Methods Committee of the American Public Health Association, American Water Works Association, and Water Environment Federation. 4500-n nitrogen In: Standard Methods For the Examination of Water and Wastewater. Lipps WC, Baxter TE, Braun-Howland E, editors. Washington DC: APHA Press. DOI: 10.2105/SMWW.2882.086

2 *Persulfate Method* in Standard Methods Committee of the American Public Health Association, American Water Works Association, and Water Environment Federation. 4500-n nitrogen In: Standard Methods For the Examination of Water and Wastewater. Lipps WC, Baxter TE, Braun-Howland E, editors. Washington DC: APHA Press. DOI: 10.2105/SMWW.2882.086

3 Valderrama, J.C. 1981. The Simultaneous Analysis of Total Nitrogen and Total Phosphorus in Natural Waters. Marine Chemistry, 10, 109-122.

4 *Ascorbic Acid Method* in Standard Methods Committee of the American Public Health Association, American Water Works Association, and Water Environment Federation. 4500-n nitrogen In: Standard Methods For the Examination of Water and Wastewater. Lipps WC, Baxter TE, Braun-Howland E, editors. Washington DC: APHA Press. DOI: 10.2105/SMWW.2882.086

5 *Manual Digestion and Flow Injection Analysis for Total Phosphorus* in Standard Methods Committee of the American Public Health Association, American Water Works Association, and Water Environment Federation. 4500-n nitrogen In: Standard Methods For the Examination of Water and Wastewater. Lipps WC, Baxter TE, Braun-Howland E, editors. Washington DC: APHA Press. DOI: 10.2105/SMWW.2882.086

6 *Method 365.1, Revision 2.0: Determination of Phosphorus by Semi-Automated Colorimetry,* Environmental Protection Agency, Environmental Monitoring Systems Laboratory, August 1993

7 Sample Preparation in Standard Methods Committee of the American Public Health Association, American Water Works Association, and Water Environment Federation. 4500-n nitrogen In: Standard Methods For the Examination of Water and Wastewater. Lipps WC, Baxter TE, Braun-Howland E, editors. Washington DC: APHA Press. DOI: 10.2105/SMWW.2882.086

8 Method 351.2, Revision 2.0: Determination of Total Kjeldahl Nitrogen by Semi-Automated Colorimetry in Standard Methods Committee of the American Public Health Association, American Water Works Association, and Water Environment Federation. 4500-n nitrogen In: Standard Methods For the Examination of Water and Wastewater. Lipps WC, Baxter TE, Braun-Howland E, editors. Washington DC: APHA Press. DOI: 10.2105/SMWW.2882.086

9 Automated Ascorbic Acid Reduction Method, in Standard Methods Committee of the American Public Health Association, American Water Works Association, and Water Environment Federation. 4500-n nitrogen In: Standard Methods For the Examination of Water and Wastewater. Lipps WC, Baxter TE, Braun-Howland E, editors. Washington DC: APHA Press. DOI: 10.2105/SMWW.2882.086

10 Patton, C. and Kryskalla, J. Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory—Evaluation of Alkaline Persulfate Digestion as an Alternative to Kjeldahl Digestion for Determination of Total and Dissolved Nitrogen and Phosphorus in Water, U.S. Geological Survey Water-Resources Investigations Report 03–4174

Appendix C. Dynamic SPARROW Model

The dynamic SPARROW model is refined here to estimate seasonal nutrient load and reactivity in rivers as (Schmadel et al., 2021):

$$L_{out,t,i} = \left[\sum_{n=1}^{N} \alpha_n I_{t,n,i} f_{I,t,n,i} + \alpha_S L_{t-1,i} f_{S,t,i}\right] \exp\left(-\nu_{f,i} \frac{\tau_{t,i}}{d_{t,i}}\right) \tag{1}$$

where L_{out} [M T^{-1}] is the river load delivered to the outlet of each NHDPlusV2 catchment *i* across the river basin; *L* [M T^{-1}] is the load delivered from the catchment to the river (i.e., edge-of-stream flux); *I* [M T^{-1}] is the mass of new within-season source input to the catchment (e.g., crop fertilizer and manure); *t* is the time period (i.e., season); α_n are positive source input coefficients that estimate the mean fraction of source input *n* that is delivered to the river; *N* is the number of source inputs including human and natural; α_S is a positive coefficient that represents the average fraction of *L* that is delivered from the storage repository; f_I and f_S are the land-to-water delivery functions that include the explanatory data; τ [T] is the travel time through the river reach for mean seasonal streamflow; *d* [L] is the water depth for mean seasonal streamflow; and v_f is the uptake velocity [L T^{-1}], which estimates the net rate of biogeochemical reactions in the river that remove and replenish instream TN or TP. For simplicity, equation (1) excludes any attenuated load entering from upstream, but that load is accounted for within SPARROW.

A dynamic modeling approach should allow for improved partitioning of the total load delivered to the river in the current season, L_t [M T^{-1}], into new inputs generated and delivered from the catchment to the river within in the current season, $L_{I,t,n,i} = \sum_{n=1}^{N} \alpha_n I_{t,n,i} f_{I,t,n,i}$ [M T^{-1}], and release from storage repositories in the catchment and delivered to the river, $L_{S,t,i} = \alpha_S L_{t-1,i} f_{S,t,i}$ [M T^{-1}]. The rate of release from each catchment's storage repositories is estimated as $\alpha_S f_{S,t,i}$, and its inverse provides an approximate mean transit time mass is lagged. The load component delivered from each within-season input is estimated as:

$$L_{I,t,i} = \sum_{n=1}^{N} \alpha_n I_{t,n,i} f_{I,t,i} \tag{2}$$

$$f_{I,t,i} = \exp\left(\sum_m \theta_m X_{m,t,i}\right) \tag{3}$$

where the delivery function for input *n* in equation (2) is $f_{I,t}$, α_n are positive source input calibration coefficients that represent the mean fraction (or, in the case of land area sources, yield) of input *n* that is delivered to rivers across all periods, *N* is the number of source inputs including human and natural such as fertilizer and atmospheric deposition, θ_m are calibration coefficients that mediate the interaction between land-to-water delivery variables and the delivery of inputs to rivers, and X_m are the data-driven land-to-water delivery variables, centered on their mean annual value, that represent both static (e.g., surficial geology) and seasonally varying (e.g., runoff) catchment characteristics. Therefore, there are *m* processes affecting input *n*. For example, the delivery of fertilizer is often explained by mediating data such seasonal runoff, vegetation indices, and soil type, in which each data type has a corresponding calibration coefficient.

For each season, the amount of load delivered to rivers from storage repositories can be estimated as:

$$L_{S,t,i} = \alpha_S L_{t-1,i} f_{S,t,i} \tag{4}$$

$$f_{S,t,i} = \exp\left[\sum_m \gamma_m X_{m,t-1,i} + \sum_d \beta_d \left(\frac{X_{d,t,i}}{X_{d,t-1,i}}\right)\right] \tag{5}$$

where α_S is a positive coefficient that represents the average fraction of total load that is released from the storage repository, γ_m are calibration coefficients that mediate the influence of previous period land-to-water delivery variables on the amount of current period mass flux from storage, β_d are calibration coefficients that mediate the effects of changing seasonal conditions on storage, and X_d are the data-driven land-to-water delivery variables that represent seasonally varying catchment characteristics expressed as a ratio, or a difference if log-transformed, to quantify the effects of season-to-season change on storage delivery. Dynamic SPARROW does not directly estimate the change in stored mass from one season to the next—which can be positive or negative—it estimates the amount of source that originated from storage repositories. Note that storage is a new concept within SPARROW models and, therefore, its formulation is likely to evolve, improve, or be simplified as model calibrations are tested in new basins.

Aquatic Decay

When multiplied by riverine nitrogen concentration (C; g m^{-3}), the uptake velocity estimates the areal nitrogen uptake flux (U; g m^{-2} d^{-1}):

$$U = v_f C. \tag{6}$$

If first-order behavior is assumed, the nitrogen uptake flux grows unbounded as a linear function of concentration. However, nitrogen uptake velocities may vary nonlinearly as a function of concentration. The power-law relationship between decreasing uptake velocity and increasing concentration (Mulholland *et al.* 2008), specified as:

$$v_{f,i} = a{C_i}^b \tag{7}$$

where a and b are constant calibration parameters. Another expression (Equation 8) applies a Michaelis-Menten (MM) equation, a widely used formulation that describes the response of biological reaction rates to increased concentrations (Böhlke *et al.* 2009), specified as:

$$v_{f,i} = \frac{U_{max}}{K_s + C_i} \tag{8}$$

where U_{max} (g m^{-2} d^{-1}) is the maximum U possible at low concentrations, K_s (g m^{-3}) is the concentration at which $U = 0.5U_{max}$, and U_{max} and K_s are constant calibration parameters. The key difference between the first two expressions is that uptake velocity estimates at very low concentrations are bounded at $\frac{U_{max}}{K_s}$ from the MM equation yet are unbounded for the power-law function.

A more flexible statistical optimization approach may be explored in SPARROW where the mean uptake velocity (v_0; m d^{-1}) is adjusted by a mean-centered concentration, such that (after Schmadel *et al.* (2020)):

$$v_{f,i} = v_0 + \beta \ln(C_i)' \tag{9}$$

where β (m d^{-1}) represents the effect of concentration on v_0, and β and v_0 are constant calibration parameters. Concentration is mean-centered to provide a meaningful estimate of v_0, $\ln(C_i)' = \ln(C_i) - \overline{\ln(C)}$, and log-transformed to add model calibration stability and reduce the dependence on the shape of the distribution. For this mean-centered approach, a negative value of β, for example, implies a reduction in nitrogen uptake velocity caused by a concentration above the mean concentration.

The mean uptake velocity may similarly be adjusted by a mean-centered temperature:

$$v_{f,t,i} = v_0 + \beta_T \ln\left(T_{t,i}\right)' \qquad (10)$$

where β_T [L T^{-1}] represents the effect of temperature on v_0, and β_T and v_0 are constant calibration coefficients. Temperature, T [K], is mean-centered to provide a meaningful estimate of v_0, $\ln(T_i)' = \ln(T_i) - \overline{\ln(T)}$, and log-transformed to add model calibration stability and reduce the dependence on the shape of the distribution. A positive value of β_T, for example, implies an increase in uptake velocity caused by a temperature above the mean temperature.

Sheibley et al. (2016) evaluated nitrogen and phosphorus attenuation in Puget Sound streams using the nitrogen uptake velocity model described above. Their conclusion is that physical characteristics of the channel (e.g., sinuosity, slope) can be effective predictors of relative nitrate attenuation particularly for main stem reaches, and biological factors can be more effective predictors in headwater reaches. Adjustments to the nitrogen uptake velocity may be adopted in specific streams and reaches based on measurements or predictions as detailed in Sheibley et al. (2016).

Additional References for Aquatic Decay

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Appendix D. Glossaries, Acronyms, and Abbreviations

Glossary of General Terms

Ambient: Background or away from point sources of contamination. Surrounding environmental condition. For example, with respect to water quality, represents conditions of a surface water of the state or receiving water body.

Anthropogenic: Human-caused.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Effluent: An outflowing of water from a human-made structure. For example, the treated outflow from a wastewater treatment plant.

Load allocation: The portion of a receiving water's loading capacity attributed to one or more of its existing or future sources of nonpoint pollution or to natural background sources.

Loading capacity: The greatest amount of a substance that a water body can receive and still meet water quality standards.

Municipal separate storm sewer systems (MS4): A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains): (1) owned or operated by a state, city, town, borough, county, parish, district, association, or other public body having jurisdiction over disposal of wastes, stormwater, or other wastes and (2) designed or used for collecting or conveying stormwater; (3) which is not a combined sewer; and (4) which is not part of a Publicly Owned Treatment Works (POTW) as defined in the Code of Federal Regulations at 40 CFR 122.2.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities or municipalities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Nutrient: Substance such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms.

Point source: Source of pollution that discharges at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Reach: A specific portion or segment of a stream.

Riparian: Relating to the banks along a natural course of water.

Sediment: Soil and organic matter that is covered with water (for example, river or lake bottom).

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Streamflow: Discharge of water in a surface stream (river or creek).

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Total Maximum Daily Load (TMDL): A distribution of a substance in a water body designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a margin of safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Wasteload allocation: The portion of a receiving water's loading capacity allocated to existing or future point sources of pollution. Wasteload allocations constitute one type of water quality-based effluent limitation.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

303(d) list: Section 303(d) of the federal Clean Water Act, requiring Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

90th percentile: An estimated portion of a sample population based on a statistical determination of distribution characteristics. The 90th percentile value is a statistically derived estimate of the division between 90% of samples, which should be less than the value, and 10% of samples, which are expected to exceed the value.

Acronyms and Abbreviations

BMP	Best management practice
CDL	Cropland Data Layer
DO	(see Glossary above)
e.g.	For example
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
et al.	And others
GIS	Geographic Information System software
i.e.	In other words
NLCD	National Land Cover Dataset
NPDES	(See Glossary above)
QA	Quality assurance
QAPP	Quality Assurance Project Plan
QC	Quality control
RMSE	Root mean square error
RPD	Relative percent difference
SIR	Scientific Investigations Report
SOP	Standard operating procedures
SSM	Salish Sea Model
TMDL	(see Glossary above)
TN	Total nitrogen
TP	Total phosphorus
TSS	(see Glossary above)
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WSDA	Washington Department of Agriculture
WQA	Water Quality Assessment
WRTDS-K	Weighted Regressions on Time, Discharge, and Season with Kalman filtering
WWTP	Wastewater treatment plant

Units of Measurement

ha	hectare, a unit of area equal to 10,000 square meters or 2.471 acres
kg	kilograms, a unit of mass equal to 1,000 grams
kg/yr	kilograms per year
km	kilometer, a unit of length equal to 1,000 meters
m	meter
mg	milligram
mg/L	milligrams per liter (parts per million)

Quality Assurance Glossary

Accreditation: A certification process for laboratories, designed to evaluate and document a lab's ability to perform analytical methods and produce acceptable data. For Ecology, it is "Formal recognition by (Ecology)…that an environmental laboratory is capable of producing accurate analytical data." [WAC 173-50-040] (Kammin, 2010)

Accuracy: The degree to which a measured value agrees with the true value of the measured property. USEPA recommends that this term not be used, and that the terms *precision* and *bias* be used to convey the information associated with the term *accuracy* (USGS, 1998).

Analyte: An element, ion, compound, or chemical moiety (pH, alkalinity) which is to be determined. The definition can be expanded to include organisms, e.g., fecal coliform, Klebsiella (Kammin, 2010).

Bias: The difference between the sample mean and the true value. Bias usually describes a systematic difference reproducible over time and is characteristic of both the measurement system and the analyte(s) being measured. Bias is a commonly used data quality indicator (DQI) (Kammin, 2010; Ecology, 2004).

Blank: A synthetic sample, free of the analyte(s) of interest. For example, in water analysis, pure water is used for the blank. In chemical analysis, a blank is used to estimate the analytical response to all factors other than the analyte in the sample. In general, blanks are used to assess possible contamination or inadvertent introduction of analyte during various stages of the sampling and analytical process (USGS, 1998).

Calibration: The process of establishing the relationship between the response of a measurement system and the concentration of the parameter being measured (Ecology, 2004).

Check standard: A substance or reference material obtained from a source independent from the source of the calibration standard; used to assess bias for an analytical method. This is an obsolete term, and its use is highly discouraged. See Calibration Verification Standards, Lab Control Samples (LCS), Certified Reference Materials (CRM), and/or spiked blanks. These are all check standards but should be referred to by their actual designator, e.g., CRM, LCS (Kammin, 2010; Ecology, 2004).

Comparability: The degree to which different methods, data sets and/or decisions agree or can be represented as similar; a data quality indicator (USEPA, 1997).

Completeness: The amount of valid data obtained from a project compared to the planned amount. Usually expressed as a percentage. A data quality indicator (USEPA, 1997).

Continuing Calibration Verification Standard (CCV): A quality control (QC) sample analyzed with samples to check for acceptable bias in the measurement system. The CCV is usually a midpoint calibration standard that is re-run at an established frequency during the course of an analytical run (Kammin, 2010).

Control chart: A graphical representation of quality control results demonstrating the performance of an aspect of a measurement system (Kammin, 2010; Ecology 2004).

Control limits: Statistical warning and action limits calculated based on control charts. Warning limits are generally set at +/- 2 standard deviations from the mean, action limits at +/- 3 standard deviations from the mean (Kammin, 2010).

Data integrity: A qualitative DQI that evaluates the extent to which a data set contains data that is misrepresented, falsified, or deliberately misleading (Kammin, 2010).

Data quality indicators (DQI): Commonly used measures of acceptability for environmental data. The principal DQIs are precision, bias, representativeness, comparability, completeness, sensitivity, and integrity (USEPA, 2006).

Data quality objectives (DQO): Qualitative and quantitative statements derived from systematic planning processes that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions (USEPA, 2006).

Data set: A grouping of samples organized by date, time, analyte, etc. (Kammin, 2010).

Data validation: An analyte-specific and sample-specific process that extends the evaluation of data beyond data verification to determine the usability of a specific data set. It involves a detailed examination of the data package, using both professional judgment and objective criteria, to determine whether the MQOs for precision, bias, and sensitivity have been met. It may also include an assessment of completeness, representativeness, comparability, and integrity, as these criteria relate to the usability of the data set. Ecology considers four key criteria to determine if data validation has actually occurred. These are:

- Use of raw or instrument data for evaluation.
- Use of third-party assessors.
- Data set is complex.
- Use of EPA Functional Guidelines or equivalent for review.

Examples of data types commonly validated would be:

- Gas Chromatography (GC).
- Gas Chromatography-Mass Spectrometry (GC-MS).
- Inductively Coupled Plasma (ICP).

The end result of a formal validation process is a determination of usability that assigns qualifiers to indicate usability status for every measurement result. These qualifiers include:

- No qualifier – data are usable for intended purposes.
- J (or a J variant) – data are estimated, may be usable, may be biased high or low.
- REJ – data are rejected, cannot be used for intended purposes.
  (Kammin, 2010; Ecology, 2004).

Data verification: Examination of a data set for errors or omissions, and assessment of the Data Quality Indicators related to that data set for compliance with acceptance criteria (MQOs). Verification is a detailed quality review of a data set (Ecology, 2004).

Detection limit (limit of detection)**:** The concentration or amount of an analyte which can be determined to a specified level of certainty to be greater than zero (Ecology, 2004).

Duplicate samples: Two samples taken from and representative of the same population and carried through the steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variability of all method activities including sampling and analysis (USEPA, 1997).

Field blank: A blank used to obtain information on contamination introduced during sample collection, storage, and transport (Ecology, 2004).

Initial Calibration Verification Standard (ICV): A QC sample prepared independently of calibration standards and analyzed along with the samples to check for acceptable bias in the measurement system. The ICV is analyzed prior to the analysis of any samples (Kammin, 2010).

Laboratory Control Sample (LCS): A sample of known composition prepared using contaminant-free water or an inert solid that is spiked with analytes of interest at the midpoint of the calibration curve or at the level of concern. It is prepared and analyzed in the same batch of regular samples using the same sample preparation method, reagents, and analytical methods employed for regular samples (USEPA, 1997).

Matrix spike: A QC sample prepared by adding a known amount of the target analyte(s) to an aliquot of a sample to check for bias due to interference or matrix effects (Ecology, 2004).

Measurement Quality Objectives (MQOs)**:** Performance or acceptance criteria for individual data quality indicators, usually including precision, bias, sensitivity, completeness, comparability, and representativeness (USEPA, 2006).

Measurement result: A value obtained by performing the procedure described in a method (Ecology, 2004).

Method: A formalized group of procedures and techniques for performing an activity (e.g., sampling, chemical analysis, data analysis), systematically presented in the order in which they are to be executed (EPA, 1997).

Method blank: A blank prepared to represent the sample matrix, prepared and analyzed with a batch of samples. A method blank will contain all reagents used in the preparation of a sample, and the same preparation process is used for the method blank and samples (Ecology, 2004; Kammin, 2010).

Method Detection Limit (MDL): This definition for detection was first formally advanced in 40CFR 136, October 26, 1984 edition. MDL is defined there as the minimum concentration of an analyte that, in a given matrix and with a specific method, has a 99% probability of being identified, and reported to be greater than zero (Federal Register, October 26, 1984).

Percent Relative Standard Deviation (%RSD): A statistic used to evaluate precision in environmental analysis. It is determined in the following manner:

$$\%RSD = (100 * s)/x$$

where s is the sample standard deviation and x is the mean of results from more than two replicate samples (Kammin, 2010).

Parameter: A specified characteristic of a population or sample. Also, an analyte or grouping of analytes. Benzene and nitrate + nitrite are all parameters (Kammin, 2010; Ecology, 2004).

Population: The hypothetical set of all possible observations of the type being investigated (Ecology, 2004).

Precision: The extent of random variability among replicate measurements of the same property; a data quality indicator (USGS, 1998).

Quality assurance (QA): A set of activities designed to establish and document the reliability and usability of measurement data (Kammin, 2010).

Quality Assurance Project Plan (QAPP): A document that describes the objectives of a project, and the processes and activities necessary to develop data that will support those objectives (Kammin, 2010; Ecology, 2004).

Quality control (QC): The routine application of measurement and statistical procedures to assess the accuracy of measurement data (Ecology, 2004).

Relative Percent Difference (RPD): RPD is commonly used to evaluate precision. The following formula is used:

$$[\mathrm{Abs}(a-b)/((a + b)/2)] * 100$$

where “Abs()” is absolute value and a and b are results for the two replicate samples. RPD can be used only with 2 values. Percent Relative Standard Deviation is (%RSD) is used if there are results for more than 2 replicate samples (Ecology, 2004).

Replicate samples: Two or more samples taken from the environment at the same time and place, using the same protocols. Replicates are used to estimate the random variability of the material sampled (USGS, 1998).

Representativeness: The degree to which a sample reflects the population from which it is taken; a data quality indicator (USGS, 1998).

Sample (field): A portion of a population (environmental entity) that is measured and assumed to represent the entire population (USGS, 1998).

Sample (statistical): A finite part or subset of a statistical population (USEPA, 1997).

Sensitivity: In general, denotes the rate at which the analytical response (e.g., absorbance, volume, meter reading) varies with the concentration of the parameter being determined. In a specialized sense, it has the same meaning as the detection limit (Ecology, 2004).

Spiked blank: A specified amount of reagent blank fortified with a known mass of the target analyte(s); usually used to assess the recovery efficiency of the method (USEPA, 1997).

Spiked sample: A sample prepared by adding a known mass of target analyte(s) to a specified amount of matrix sample for which an independent estimate of target analyte(s) concentration is available. Spiked samples can be used to determine the effect of the matrix on a method’s recovery efficiency (USEPA, 1997).

Split sample: A discrete sample subdivided into portions, usually duplicates (Kammin, 2010).

Standard Operating Procedure (SOP): A document which describes in detail a reproducible and repeatable organized activity (Kammin, 2010).

Surrogate: For environmental chemistry, a surrogate is a substance with properties similar to those of the target analyte(s). Surrogates are unlikely to be native to environmental samples. They are added to environmental samples for quality control purposes, to track extraction efficiency and/or measure analyte recovery. Deuterated organic compounds are examples of surrogates commonly used in organic compound analysis (Kammin, 2010).

Systematic planning: A step-wise process which develops a clear description of the goals and objectives of a project, and produces decisions on the type, quantity, and quality of data that will be needed to meet those goals and objectives. The DQO process is a specialized type of systematic planning (USEPA, 2006).

References for QA Glossary

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