South Puget Sound Dissolved Oxygen Study

Interim Nutrient Load Summary for 2006-2007

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For more information contact:

Publications Coordinator
Environmental Assessment Program
P.O. Box 47600, Olympia, WA 98504-7600
Phone: (360) 407-6764

Washington State Department of Ecology - www.ecy.wa.gov/

- Headquarters, Olympia (360) 407-6000
- Northwest Regional Office, Bellevue (425) 649-7000
- Southwest Regional Office, Olympia (360) 407-6300
- Central Regional Office, Yakima (509) 575-2490
- Eastern Regional Office, Spokane (509) 329-3400

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South Puget Sound Dissolved Oxygen Study

Interim Nutrient Load Summary for 2006-2007

by

Teizeen Mohamedali, Mindy Roberts, and Brandon Sackmann
Environmental Assessment Program

and

Anthony Whiley and Andrew Kolosseus
Water Quality Program

Washington State Department of Ecology
Olympia, Washington 98504-7710

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Abstract

Nutrient loads, particularly nitrogen, have been identified as a potential stressor to the Puget Sound ecosystem. One consequence of excessive nutrient loads may be low dissolved oxygen concentrations. Field data have shown that portions of South Puget Sound fall below Washington State numeric water quality standards for dissolved oxygen. The Washington State Department of Ecology initiated the South Puget Sound Dissolved Oxygen Study to determine whether human sources of nitrogen contribute to low levels of dissolved oxygen. One critical step is to identify nutrient loads to South Puget Sound. The study also involves developing a hydrodynamic and water quality model to assess alternative management scenarios.

As part of this effort, water quality data were collected from July 2006 through October 2007 from a number of wastewater treatment plants (WWTPs), rivers, and streams within South and Central Puget Sound. These field data, however, were collected at monthly intervals. A statistical method called *multiple linear regression* was applied to the field data to develop continuous daily loads of nutrients into South and Central Puget Sound for the years 2006 and 2007. This statistical approach relates concentrations to seasons of the year and streamflow patterns using a best fit to monitoring data. The resulting daily loads provide a better fit to monitoring data than simply using monthly or annual averages.

This report presents the results of this effort and describes the magnitudes and sources of nitrogen loading into South and Central Puget Sound. Rivers and WWTPs are both significant sources of nitrogen, particularly dissolved inorganic nitrogen (DIN; sum of ammonium and nitrate + nitrite). DIN concentrations and loads from WWTPs are generally greater than those from rivers. River DIN loads vary with the seasons such that 77% of river DIN loading to South and Central Puget Sound occurs during the wetter months of November through March. In contrast, DIN loads from WWTPs are relatively constant throughout the year, but contribute to 90% of watershed DIN load in the summer when rivers loads are much lower. Watershed DIN loads into Central Puget Sound (north of Tacoma Narrows) are 3.8 times greater than those into South Puget Sound.

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The South Puget Sound Dissolved Oxygen Study Advisory Committee reviewed the document.

Executive Summary

Introduction

Portions of South Puget Sound have low dissolved oxygen (DO) levels that fall below Washington State water quality numeric criteria. Low DO levels impair the ability of marine life to survive or thrive, and can affect the healthy functioning of the Puget Sound ecosystem. DO levels decrease when significant quantities of nitrogen enter Puget Sound and stimulate extensive algae growth. When these algae bloom and die, the decomposition process uses up DO in the bottom waters, decreasing DO levels.

The Washington State Department of Ecology initiated the *South Puget Sound Dissolved Oxygen Study* to determine the extent of low DO levels and understand how nitrogen from a variety of sources affects DO levels. The study began with field data collection between July 2006 and October 2007 to support the development of hydrodynamic and water quality models. The results of the field data were published in the Interim Data Report (Roberts et al., 2008). Ongoing modeling efforts will show if human-related sources of nitrogen need to be reduced to protect water quality. The modeling will also be used to assess alternative management scenarios.

Information on the *South Puget Sound Dissolved Oxygen Study* is available at www.ecy.wa.gov/puget_sound/dissolved_oxygen_study.html. The study focuses on South Puget Sound, south of Tacoma Narrows. However, since nitrogen loads into Central Puget Sound (between Tacoma Narrows and Edmonds) may influence South Puget Sound water quality, the entire South and Central Sound are included in the study (Figure ES-1).

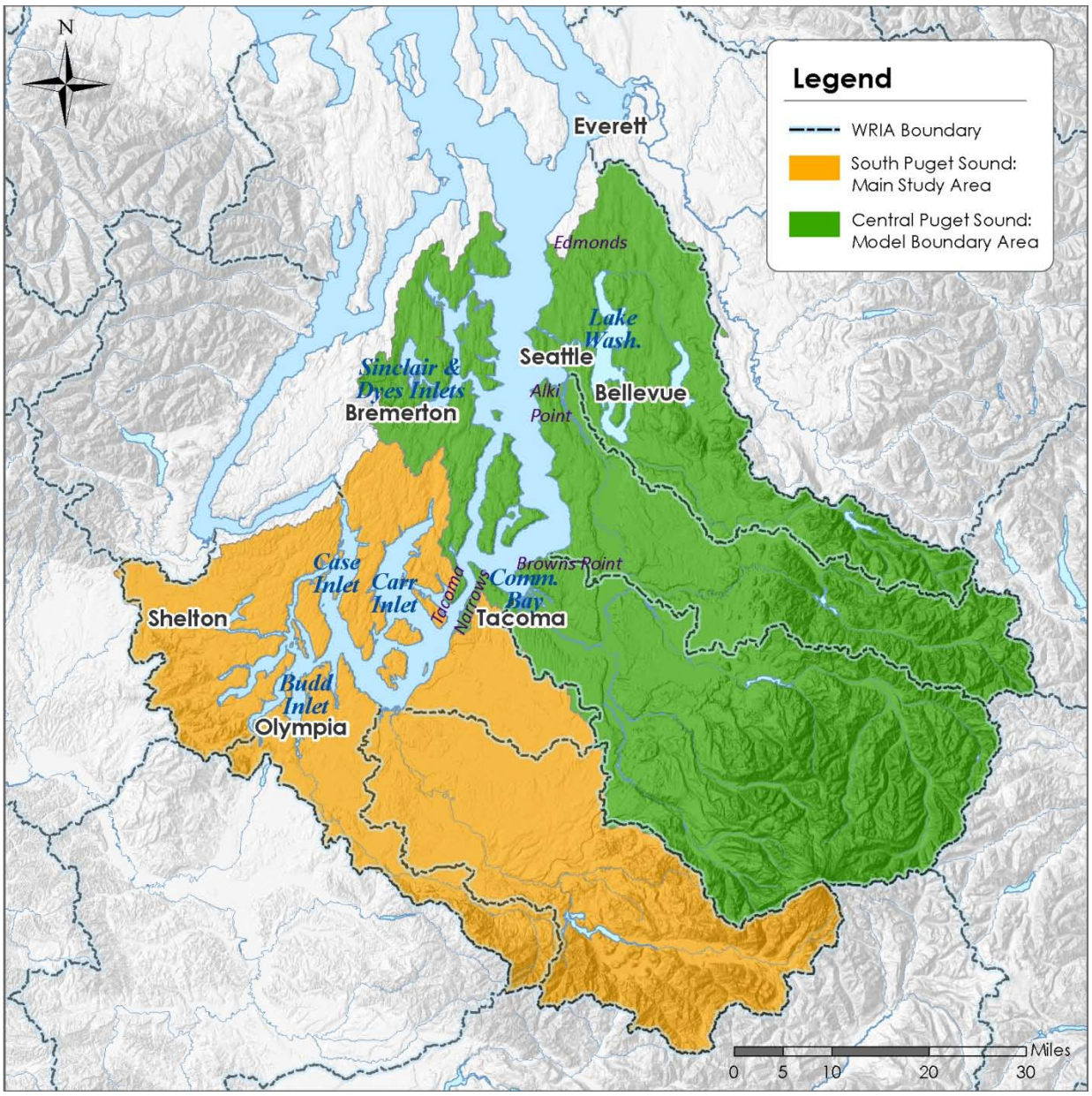

Figure ES-1. Study area for the South Puget Sound Dissolved Oxygen Study.
WRIA: Water Resource Inventory Area.

Methods

Although nutrient data collected from rivers and WWTPs that discharge directly to Puget Sound were already summarized in the Interim Data Report, these data were collected at a *monthly* interval. The models being used, however, require *daily* data on streamflows and nutrient loads into South and Central Puget Sound to simulate seasonal and sub-seasonal variations in South Puget Sound.

This report specifically describes the development of daily nutrient loading estimates from the monthly field monitoring data. A multiple linear regression method was applied to the field data to develop continuous daily concentrations and loads of nutrients for calendar years 2006 and 2007. This method relates concentrations to flow and time of year using a best fit to monitoring data. The resulting daily loads provide a better fit to monitoring data than simply using monthly or annual averages.

Overall, 82% of the total study area (both South and Central Puget Sound) was included in monitored watersheds, and 89% of all the WWTP discharges (in terms of the magnitude of effluent flow) were monitored. The regression-derived estimates compared relatively well with the field data and were also used to estimate loads from watersheds and WWTPs that were not monitored at all, or only monitored briefly.

Continuous daily nutrient load data are not only needed for the calibration and validation of the hydrodynamic and water quality model, but these data also provide us with a more comprehensive understanding of nutrient loads. The development of daily nutrient data allows us to quantify the relative magnitude of nutrient loads from rivers and WWTPs, describe the seasonal nature of these loads, and compare loads going into South and Central Puget.

This report primarily focuses on, and presents nitrogen load summaries from WWTPs and rivers, loads that include groundwater and on-site septic systems. However, in addition to these sources of nitrogen, the water quality model will also include nitrogen loading from the ocean, the atmosphere, and internal sediment fluxes. This will allow us to analyze the effect of all these sources on DO levels.

In addition to estimating nutrient concentrations and loads for 2006-2007, we also calculated natural (i.e., no human influence) nutrient concentrations and loads for inflows into South and Central Puget Sound. Natural conditions in this study refer to the concentrations of nutrients in rivers and streams without significant human influences/sources of nutrients. By definition, there would be no WWTP or septic system inputs into Puget Sound under natural conditions. Once these concentrations are established, they can be used as inputs into the water quality model so that we can evaluate the water quality of Puget Sound under natural conditions.

Natural conditions were established from the results of a meta-analysis where we considered concentration data from various sources: historic and current ambient monitoring data, rainfall data, and data from other studies. The mean value from these various methods was then used to calculate the natural condition.

Results and Discussion

Of all the forms of nitrogen, dissolved inorganic nitrogen (DIN; sum of nitrate+ nitrite and ammonium) is of greatest interest since this form of nitrogen is the most available for algae. Figure ES-2 compares median DIN concentrations in rivers and WWTPs discharging directly into South and Central Puget Sound during 2006 and 2007. River DIN loads include all point (discrete) and nonpoint (diffuse) sources that discharge into these rivers.

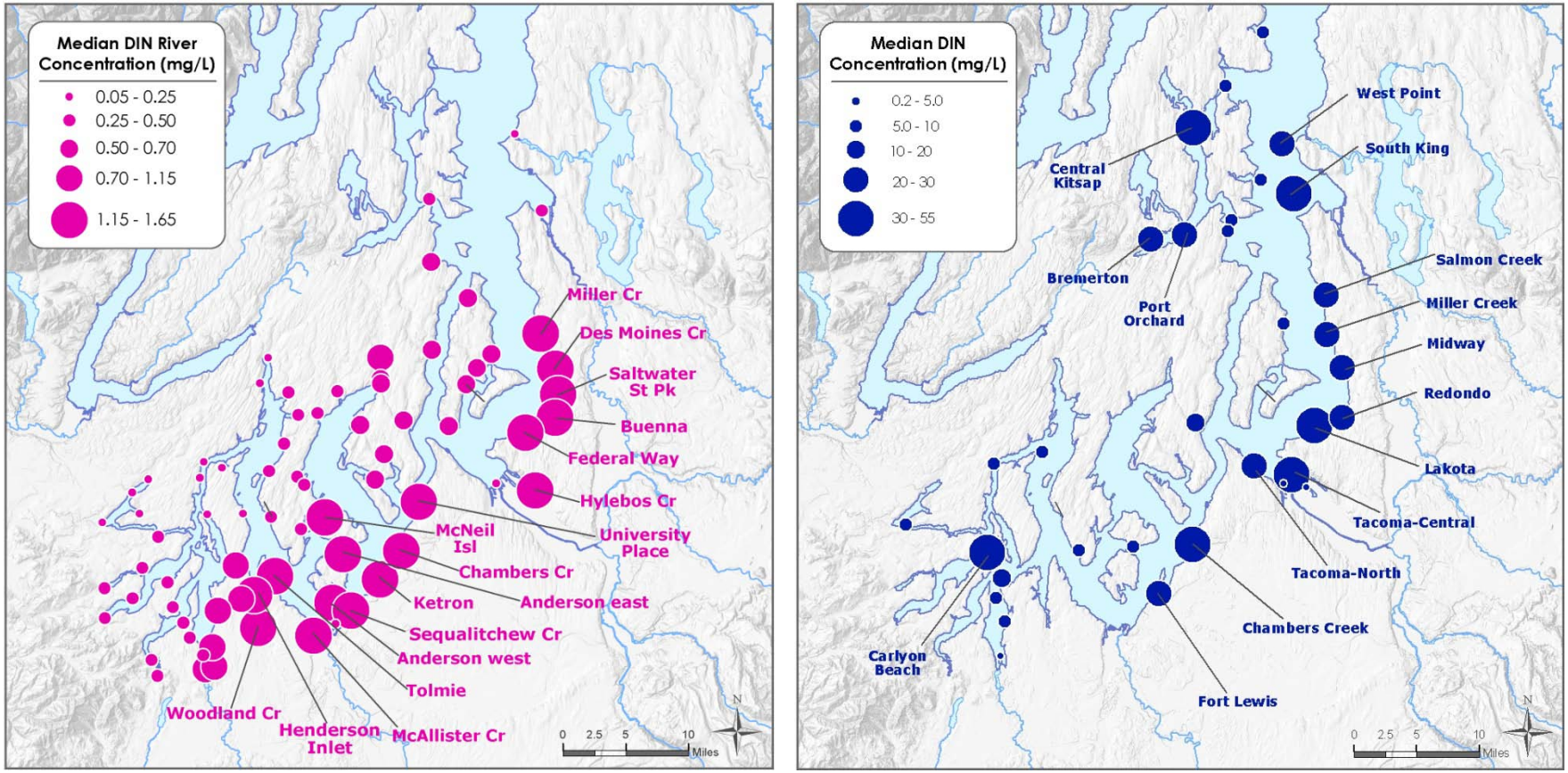

Figure ES-2. Median river (left) and WWTP (right) dissolved inorganic nitrogen (DIN) concentrations for 2006-07.

Even though DIN concentrations, as shown in Figure ES-2, are useful in identifying nutrient hotspots, high and low DIN concentrations do not always translate into respectively high and low DIN loads. For example, a river with low DIN concentration might have a high DIN load if that particular river is large and subsequently has very high streamflows. Therefore, rivers and WWTP effluents with the highest DIN concentrations do not necessarily have the highest DIN loads. DIN loads were therefore also calculated (where load = concentration x flow) for all rivers and WWTPs.

Annual DIN loads from rivers and streams are relatively low but dominated loading into many of the western inlets in South Puget Sound, including Totten, Eld, Henderson, Case, and Carr Inlets (Figure ES-3).

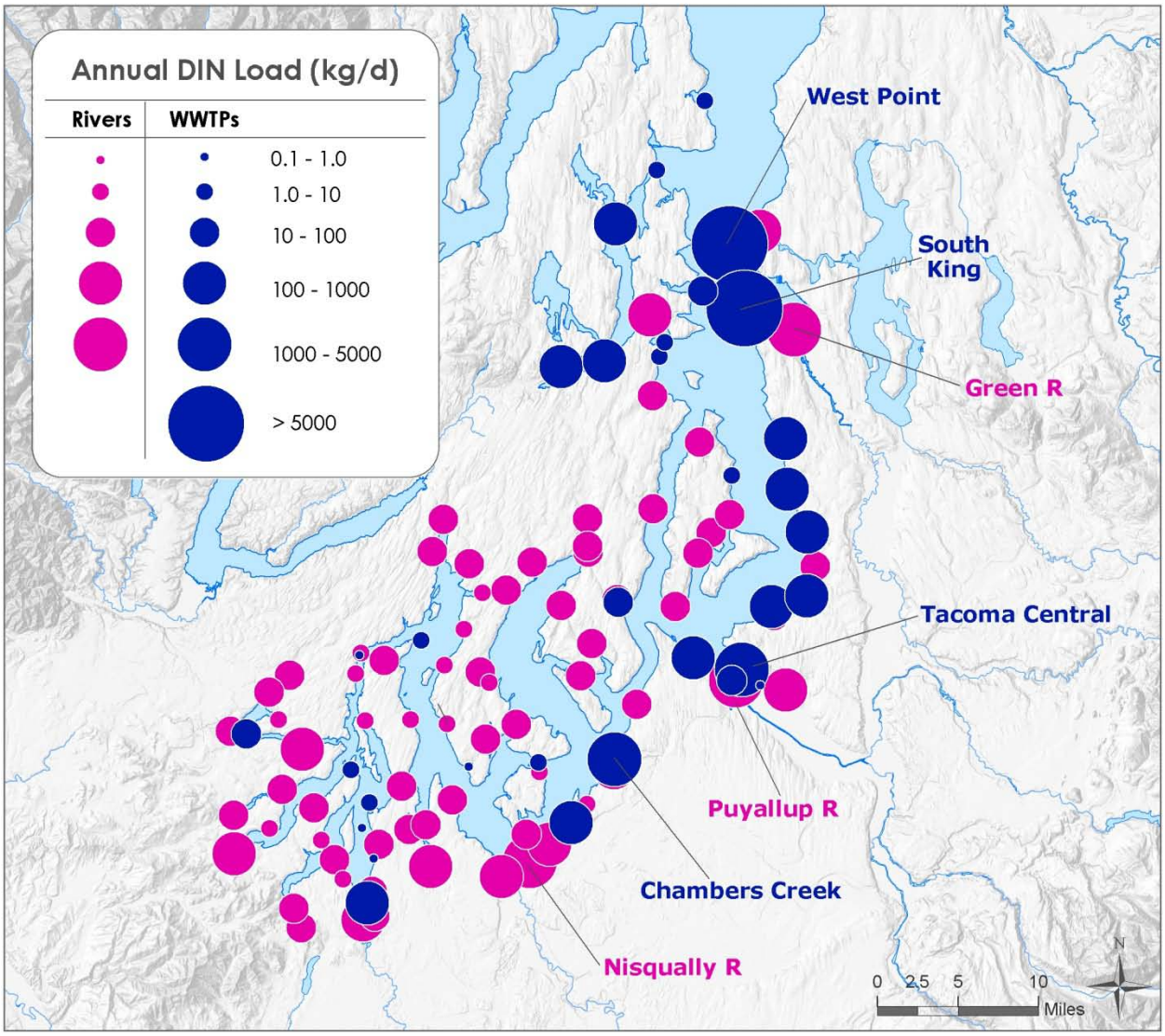

Figure ES-3. Mean annual dissolved inorganic nitrogen (DIN) loads from rivers and WWTPs into South and Central Puget Sound from 2006-07.

The rivers with the largest loads are, in order, the Puyallup, Green, Nisqually, and Deschutes Rivers, which together contribute an annual DIN load of 7100 kg/d. In Central Puget Sound, WWTP loads dominate because there are a larger number of WWTPs serving larger populations than there are in South Puget Sound. West Point and South King WWTPs are the two greatest DIN sources, together contributing 18,500 kg/d, which is more than twice the load of the four rivers with the highest load.

DIN loads from WWTPs also dominate in the summer (average of July, August and September), which is a critical time for DO conditions (Figure ES-4). During this time, river loads are lower because of lower flows.

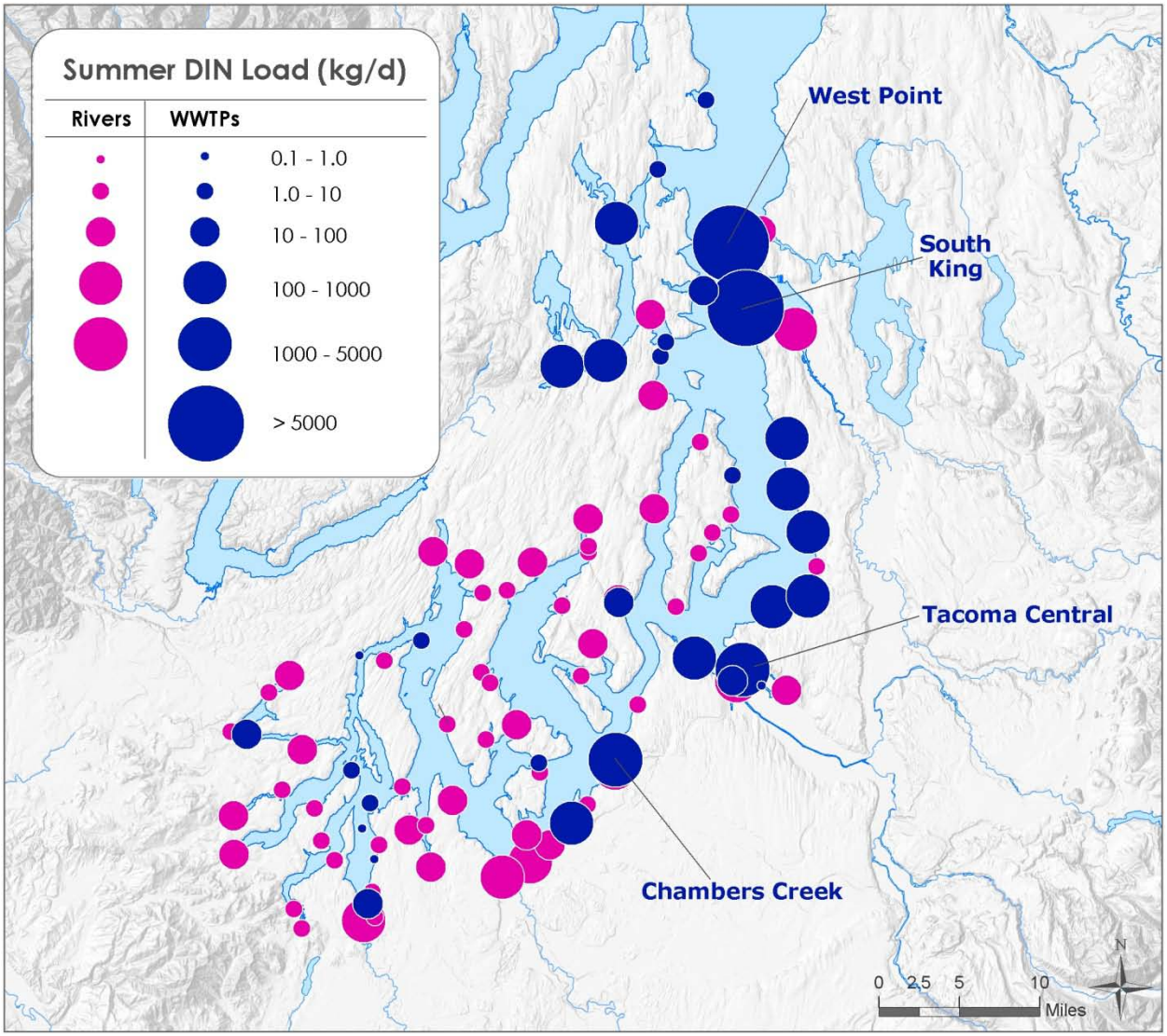

Figure ES-4. Mean summer dissolved inorganic nitrogen (DIN) loads from rivers and WWTPs into South and Central Puget Sound from 2006-07.

Loads from WWTPs are also less variable throughout the year, while loads from rivers respond more strongly to seasons due to changes in precipitation and flow. Daily loads into Central Puget Sound are consistently greater than those into South Puget Sound (Figure ES-5). WWTPs contribute 59% of the total DIN load during the winter (November through March), and 90% of the total DIN load during the summer (July through September; Figure ES-5).

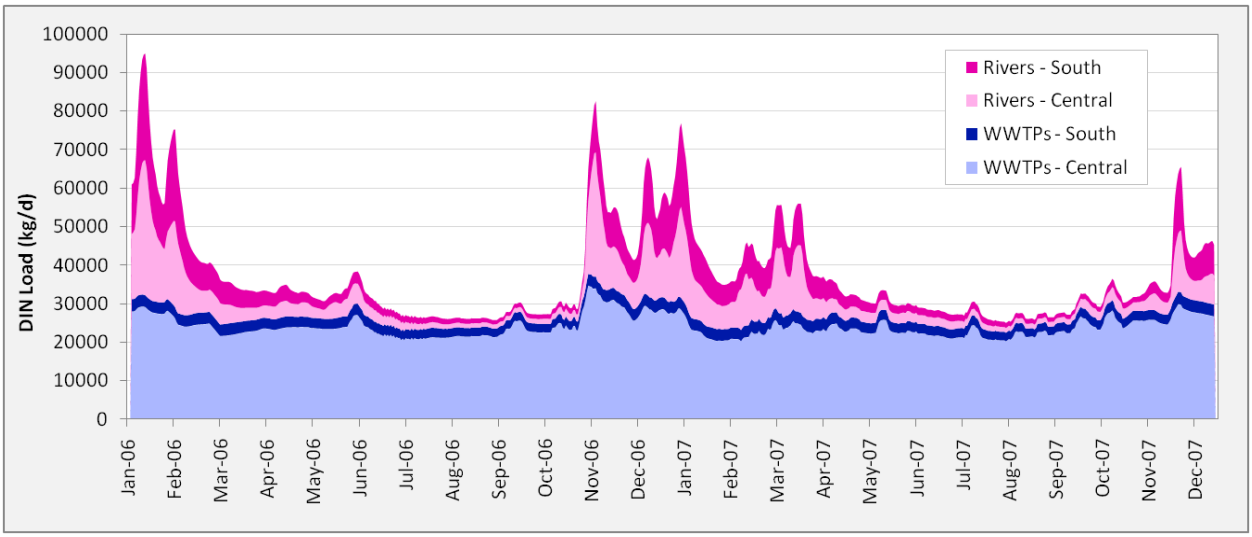

Figure ES-5. Seven-day average of daily dissolved inorganic nitrogen (DIN) loads from rivers and WWTPs into South and Central Puget Sound during 2006-07.

In South Puget Sound, rivers contribute 65% of the total DIN load on an annual basis. During the summer, however, when river loads are significantly lower, rivers contribute 37%, while WWTPs contribute 63% of the total DIN load (Figure ES-6, top).

In Central Puget Sound, WWTP loads dominate regardless of the time period of analysis, contributing 81% of the total DIN load on an annual basis and 94% of the total DIN load during the summer (Figure ES-6, center).

When loads into South and Central Puget Sound are combined, WWTPs still dominate, contributing 71% of the total DIN load on an annual basis and 90% of the total DIN load during the summer.

Rivers contribute comparable annual DIN loads to South and Central Puget Sound: 5080 kg/d to South Puget Sound and 5810 kg/d to Central Puget Sound. WWTPs contributions, however, vary greatly between South and Central Puget Sound: 2700 kg/d to South Puget Sound and 24,050 kg/d to Central Puget Sound. The WWTPs in Central Puget Sound serve higher population centers and therefore treat and discharge a much larger volume of wastewater than WWTPs in South Puget Sound.

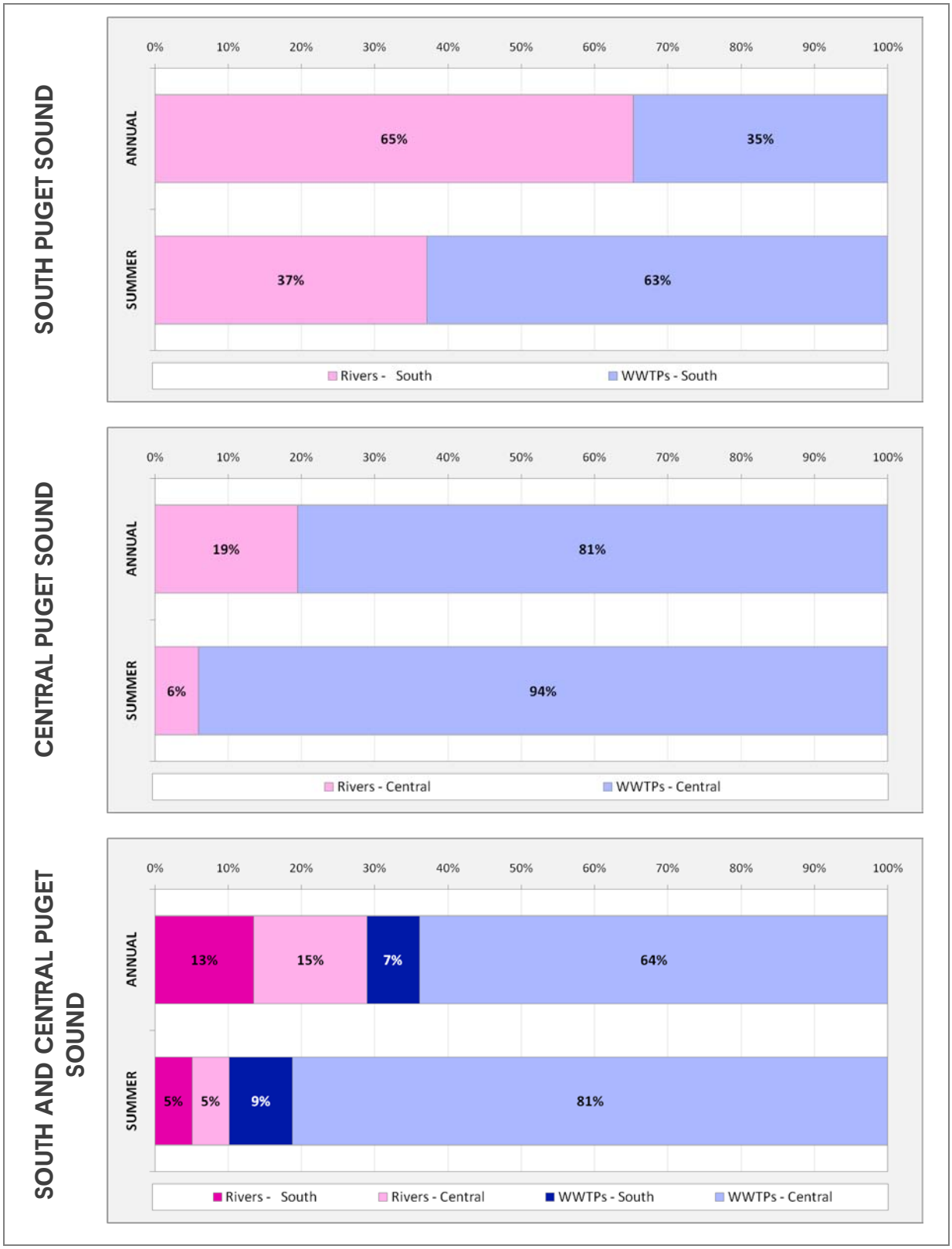

Figure ES-6. Pie charts comparing the relative contributions of dissolved inorganic nitrogen (DIN) loads from rivers and WWTPs into South and Central Puget Sound on an annual basis and during the summers of 2006-07.

Overall, DIN loads into Central Puget Sound are 3.8 times greater than DIN loads into South Puget Sound (Figure ES-7).

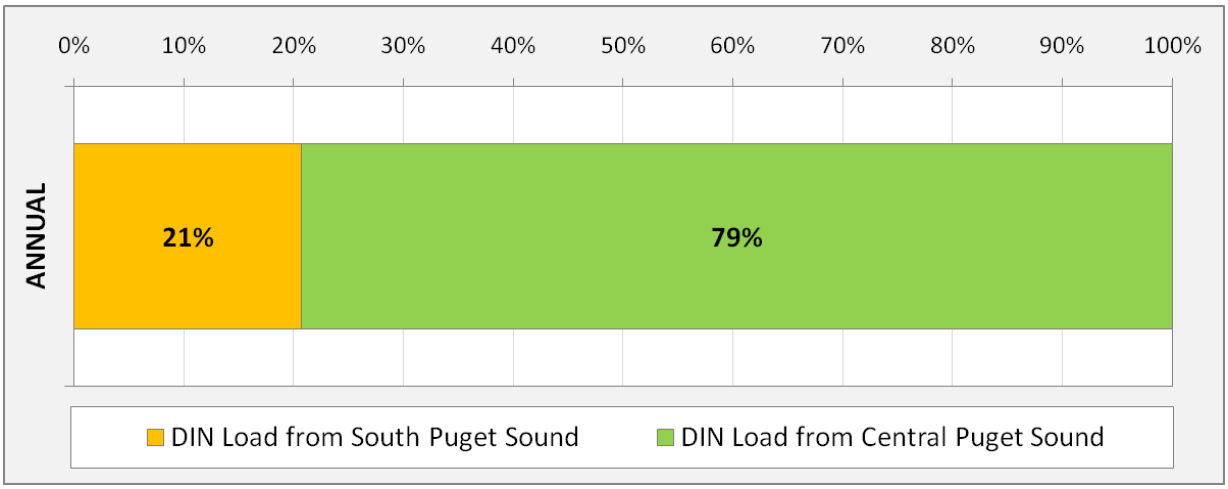

Figure ES-7. Comparison of annual dissolved inorganic nitrogen (DIN) loads from rivers and WWTPs into South and Central Puget Sound.

When we include the DIN load from atmospheric deposition onto the surface waters of South and Central Puget Sound, we see that this constitutes only 1% of the total DIN load (Figure ES-8).

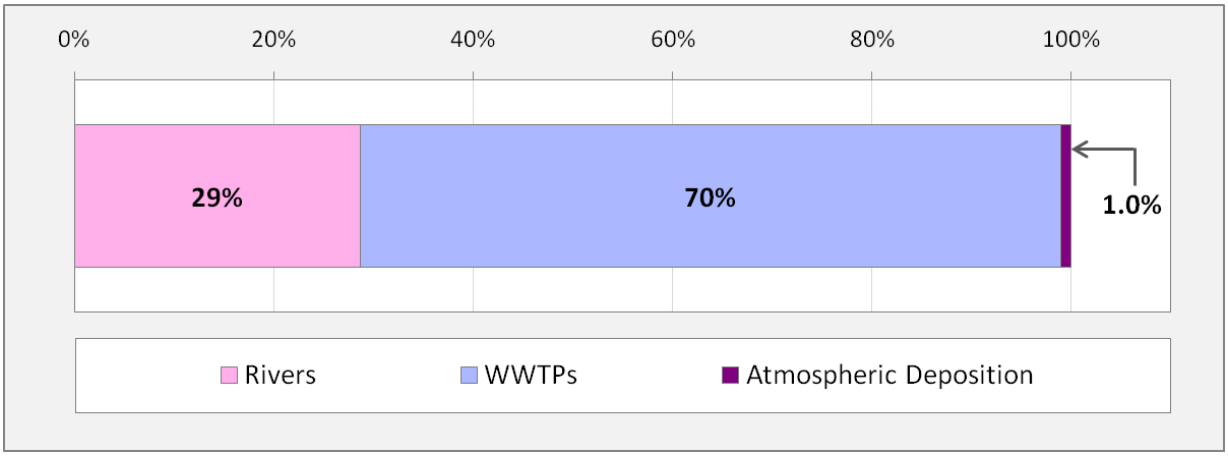

Figure ES-8. Annual dissolved inorganic nitrogen (DIN) loads from rivers, WWTPs, and the atmosphere

Loads from on-site septic systems and groundwater are included in the 'Rivers' share of the bar chart.

The Impact of Nitrogen Loading

Though the magnitude of sources of nitrogen is important, several other factors also play a role in determining the effect of these loads on DO concentrations in the marine water. The time, location, and depth of the discharge are all important due to circulation patterns in South and Central Puget Sound. Other important factors that determine DO concentrations are temperature, sunlight, the incoming oceanic water, and other environmental variables.

The water quality model will account for these different variables in evaluating the impact of nutrient loads on DO concentrations in South and Central Puget Sound. The modeling will also allow us to assess what fraction of loads entering Central Puget Sound eventually circulate to South Puget Sound, and whether these loads affect South Puget Sound DO levels. The loading results presented here provide valuable information but, prior to modeling, cannot be used to calculate the impact of the different sources of nitrogen on DO concentrations.

Natural Conditions

We also calculated the natural nutrient conditions, which includes the concentrations and loads of nutrients in rivers and streams that drain into South and Central Puget Sound in the absence of human sources of nitrogen. To do this, we performed a meta-analysis using various methods and sources of data including historical and current ambient monitoring data, rainfall data, and data from other studies. We then used the mean value from these various methods to calculate the natural condition for each month of the calendar year.

Table ES-1 compares annual average DIN loads from 2006-07 with natural DIN loads based on our calculation of natural conditions.

Table ES-1. Comparison of natural and 2006-07 average annual DIN loads from rivers and WWTPs discharging into South and Central Puget Sound.

Area of Puget Sound	Average Annual DIN Load (kg/d)		
	Natural Conditions	2006-07 Rivers Only	2006-07 Rivers + WWTPs
South	2302	5080	7785
Central	3866	5814	29861
South + Central	6168	10894	37646

Current DIN loads from rivers and streams, which include WWTPs discharging to freshwater, are 1.8 times natural condition loads to South and Central Puget Sound. When we include rivers and all WWTPs, including those discharging to marine (salt) waters, current loads are 6.1 times natural condition loads. The difference between current and natural loads reflects the influence of anthropogenic sources of nutrients, including changes in land use and development, increases in population, and loads from WWTPs.

Conclusions

As a result of this 2006-07 study, we now have comprehensive daily estimates of nutrient loads, which we can use to better understand the magnitudes and sources of nitrogen loading into South and Central Puget Sound. We can now also describe how the relative contributions of DIN loads change over the course of the year and for different regions in the study area.

The water quality modeling effort will be key in identifying how sensitive DO levels in South Puget Sound are to the higher DIN loads coming from Central Puget Sound by analyzing how nutrients circulate once they enter Puget Sound. We recommend that these nutrient loading data be used as part of the water quality modeling effort. If certain watersheds or WWTPs where we did not collect data appear to have a large influence on DO levels, it will be important to collect data for these specific locations.

Using these nutrient loading estimates from 2006-07, the water quality model will also allow us to (1) assess alternative management scenarios by reducing/changing DIN loads from particular sources and (2) evaluate how effective these changes might be in improving DO levels in South Puget Sound.

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Introduction

This report is part of a larger multi-year study investigating the water quality of South Puget Sound. The Washington State Department of Ecology (Ecology) initiated the *South Puget Sound Dissolved Oxygen Study* to understand the behavior of South Puget Sound under current and future conditions based on water quality monitoring as well as hydrodynamic and water quality modeling.

The *South Puget Sound Dissolved Oxygen Study* was designed to determine whether point and nonpoint source nutrient loadings contribute to low dissolved oxygen (DO) concentrations in South Puget Sound. Dissolved oxygen levels that fall below Washington State Water Quality Standards have been observed in several parts of South Puget Sound. Figure 1 illustrates how areas of South Puget Sound, including Budd, Carr, and Case Inlets, are of concern due to low DO concentrations.

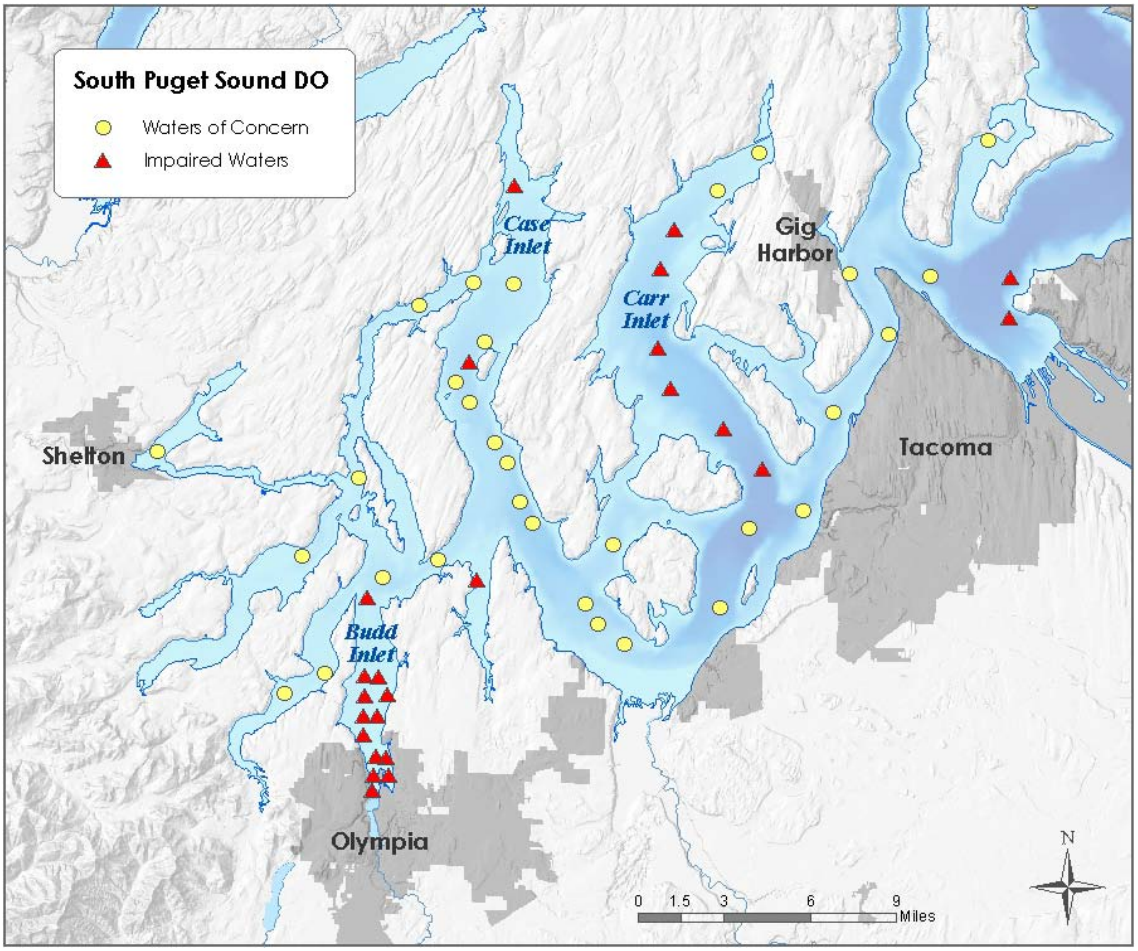

Figure 1. Results from the 2008 Water Quality Assessment for dissolved oxygen in South Puget Sound.

Dissolved oxygen levels decrease when excess nutrients, particularly nitrogen, enter Puget Sound, stimulating algae growth. These algae subsequently die and decompose a process which consumes DO. Coastal upwelling of low DO water may also influence Puget Sound oxygen levels (Landry and Hickey, 1989). Low DO levels can be harmful to fish and other marine life, raising concerns about the health of the Puget Sound ecosystem.

The purpose of the *South Puget Sound Dissolved Oxygen Study* is to determine how nutrients from a variety of sources affect DO levels in South Puget Sound, which is defined as the area south of the Tacoma Narrows (Figure 2) and the watersheds that drain into these marine waters.

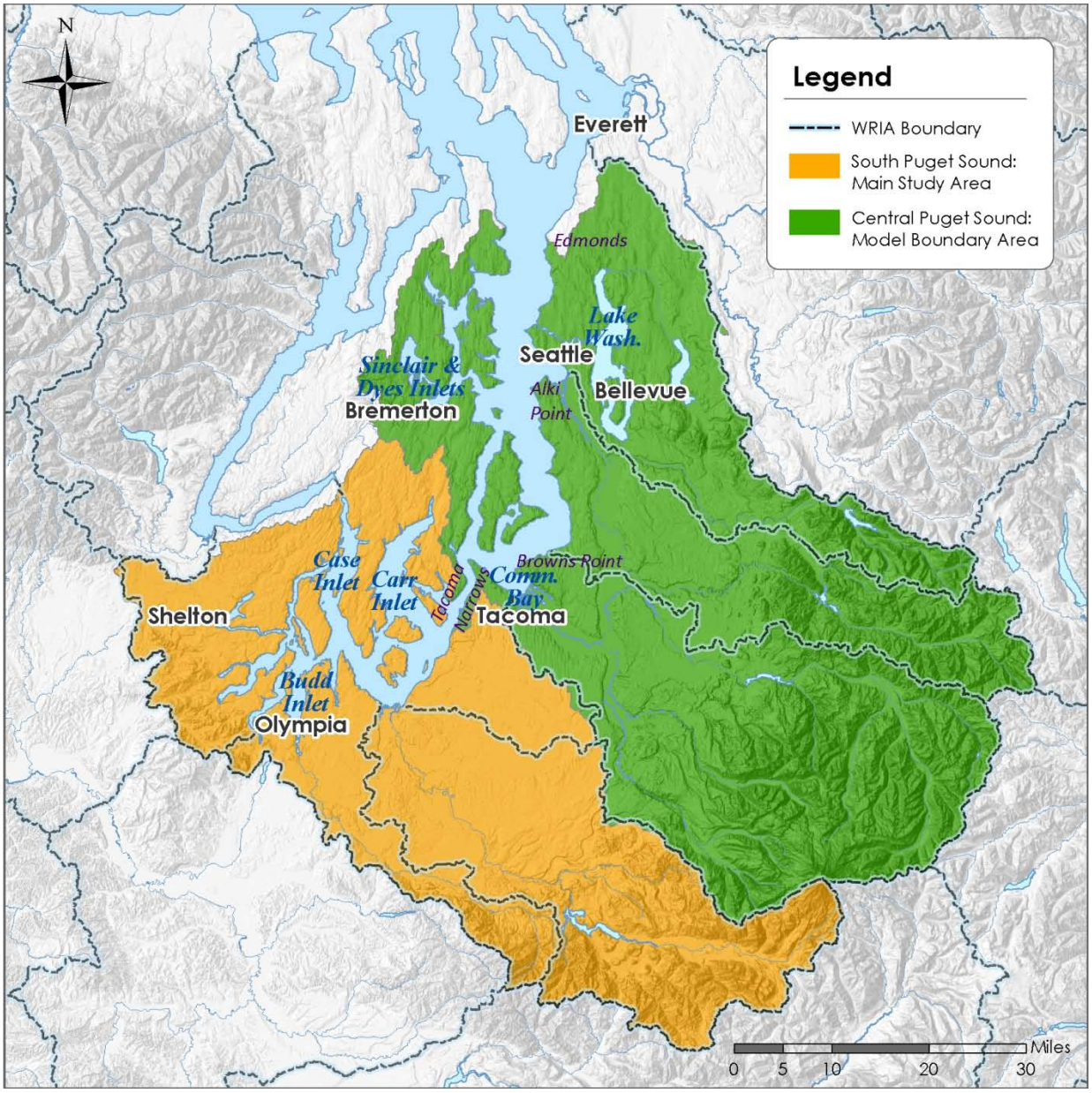

Figure 2. Study area for the South Puget Sound Dissolved Oxygen Study.
WRIA: Water Resource Inventory Area.

Even though South Puget Sound is the primary focus of the *South Puget Sound Dissolved Oxygen Study*, the model boundary extends further north to also include the marine waters of Central Puget Sound. This is because the more highly populated watersheds that drain into Central Puget Sound contribute higher nutrient loads and may also impact South Puget Sound water quality. Table 1 compares the characteristics of South and Central Puget Sound. The population density in Central Puget Sound is more than twice that of South Puget Sound.

Table 1. Characteristics of the study area for the South Puget Sound Dissolved Oxygen Study.

Characteristics	South Puget Sound	Central Puget Sound	Total Study Area
Land Area	4,290 km^2 (1,660 mi^2)	6,420 km^2 (2,480 mi^2)	10,710 km^2 (4,140 mi^2)
Marine Water Area	425 km^2 (165 mi^2)	630 km^2 (240 mi^2)	1055 km^2 (405 mi^2)
Marine Basin Volume[1]	19.6 km^3	68.0 km^3	87.6 km^3
Population[2]	661,700	2,307,200	2,968,900
Population Density	155 people/km^2	360 people/km^2	280 people/km^2

[1]These volumes are based on Finlayson's (2003) digital elevation model of Puget Sound (grid size of 9.1 m x 9.1 m) clipped to match the model domain. Elevations lower than 10 m (based on North American Datum of 1988) were extracted, and then multiplied by the grid area to calculate volumes.
[2]2001 census block population data from the Office of Financial Management.

The *South Puget Sound Dissolved Oxygen Study* was initiated with a large field data collection effort from July 2006 through October 2007. The field effort included the measurement of various water quality parameters within South Puget Sound. This effort also included monthly grab samples from rivers, streams, and wastewater treatment plants (WWTPs) that drain or discharge into South or Central Puget Sound. The experimental design for this is described in detail in the Quality Assurance (QA) Project Plan (Albertson et al., 2007), and the results from this field data collection effort were subsequently published in an Interim Data Report (Roberts et al., 2008).

The data from the monitoring effort is being used to model South and Central Puget Sound using the Generalized Environmental Modeling System for Surface Waters (GEMSS), a three-dimensional hydrodynamics and water quality model. This model will be used to characterize and evaluate nutrient loads into South and Central Puget Sound.

GEMSS requires daily time series of flows and nutrient loads from discrete watershed inflow points to simulate seasonal and sub-seasonal variations in South Puget Sound. Water quality parameters required by the model include various forms of nitrogen, phosphorus, and carbon. This report specifically describes (1) the development of *daily* nutrient loading estimates from the *monthly* field monitoring data and (2) the results of this process in the context of nutrient

loading into South and Central Puget Sound. A statistical method called *multiple linear regression* was applied to the field data to develop continuous daily loads of nutrients for the calendar years 2006 and 2007.

Continuous daily nutrient load data are not only needed to calibrate and validate the hydrodynamic and water quality model being developed, but also to more completely understand nutrient loads. Developing daily nutrient data also allows us to quantify the relative magnitude of nutrient loads from rivers and WWTPs, describe the seasonal nature of these loads, and compare Central Puget Sound loads to South Puget Sound loads.

On-site septic systems, particularly along the shoreline fringe, are another source of nutrient loading. Since monitoring locations were not always directly at the mouth of each river or stream, extrapolating monitoring locations to the mouth may not accurately capture loading from on-site septic systems if there are a higher number of these in shoreline fringe than within the monitored areas. The monitoring program captured 82% of the watershed contributions (in terms of area) to South and Central Puget Sound, and loads from monitored areas include on-site septic system loads upstream of monitoring locations.

Load data from monitored watersheds were then extrapolated to the entire watershed using local load per unit area. Since septic systems contribute to nutrient loads estimated for monitoring stations, the extrapolation should reflect shoreline septic systems. However, if shoreline septic system in the areas immediately adjacent to South Puget Sound are more numerous or if effluents are less attenuated, then the extrapolation could underestimate septic contributions. To account for this, a separate estimate of nutrient loading was developed for on-site septic systems located within the study area but outside of municipal wastewater services areas and monitored watersheds.

We also calculated the natural nutrient conditions, which includes the concentrations and loads of nutrients in rivers and streams that drain into South and Central Puget Sound in the absence of human sources of nitrogen. We carried out a meta-analysis using various methods based on historical and current ambient monitoring data, rainfall data, and data from other studies. We then used the median value from these various methods to calculate the natural condition.

Methods

To gain a comprehensive understanding of nutrient loading into South and Central Puget Sound, we need estimates of nutrient loads from multiple sources. These estimates are also necessary for input data into the GEMSS model. The major terrestrial sources of nutrients discussed in this report are:

1. *Watershed Loads:* from rivers and streams whose watersheds drain the study area. Contributing sources include atmospheric deposition, natural watershed sources, septic systems, fertilizer applications, upstream WWTPs, stormwater, and other point and nonpoint sources. This study did not distinguish relative contributions of these different sources within the watersheds. If the modeling effort determines that rivers and streams contribute to low DO, then additional efforts will be needed to understand which of the sources must be controlled.
2. *Septic System Loads:* from near-shore, on-site septic systems (outside of monitored watersheds) that enter groundwater and eventually marine waters within the study area
3. *Wastewater Treatment Plant Loads:* from WWTP and industrial effluent discharging directly into marine waters. The term "WWTP" is used to represent both WWTP and industrial effluent.

Watershed Loads

Field Data Collection

Monthly monitoring was conducted at 38[1] rivers and streams throughout the study area between July 2006 and October 2007. This included physical in-situ instantaneous measurements of temperature, conductivity, pH, as well as grab samples for laboratory analysis for several water quality parameters (Table 2). Included in Table 2 are a few additional parameters that were calculated from these measured parameters. These parameters are needed by the model to adequately characterize the water quality of inflows into South and Central Puget Sound.

Four of the 38 monitoring locations were on major rivers that flow into South and Central Puget Sound (Deschutes, Nisqually, Puyallup, and Green) where Ecology conducts monthly ambient monitoring. Since these sites were already monitored monthly for various parameters, only supplemental monitoring was conducted.

[1] Originally, there were 39 sampling locations, including Sequalitchew Creek, which was found to be diverted upstream of the mouth and no outlet could be located. Also, intense winter storm events and widespread flooding precluded sampling at all sites during the November 2006 sampling run.

Table 2. Nutrient parameters included in the field monitoring effort.

Parameter Name	Parameter Abbreviation	Calculation Method
Measured Parameters		
Nitrate + Nitrite	NO23N	--
Ammonium	NH4N	--
Total Persulfate Nitrogen	TPN	--
Dissolved Total Persulfate Nitrogen	DTPN[1]	--
Ortho-Phosphate	OP	--
Total Phosphorus	TP	--
Dissolved Total Phosphorus	DTP	--
Total Organic Carbon	TOC	--
Dissolved Organic Carbon	DOC	--
Calculated Parameters		
Dissolved Inorganic Nitrogen	DIN	NO23N + NH4N
Particulate Organic Nitrogen	PON	TPN – DTPN[2]
Dissolved Organic Nitrogen	DON	DTPN – (NO23N + NH4N)[2]
Particulate Organic Phosphorus	POP	TP – DTP[3]
Dissolved Organic Phosphorus	DOP	DTP – OP[3]
Particulate Organic Carbon	POC	TOC - DOC

[1]DTPN data collected at ambient stations were rejected due to a filter contamination issue
[2]For the stations where there were no DTPN data: PON = DON = 0.5*[TPN – (NO23N + NH4N)]
[3]For the stations where there were no DTP data: POP = DOP = 0.5*(TP – OP).

A total of 18 of the 38 locations were monitored for each of the 15 months between August 2006 and October 2007, while 20 smaller tributaries were monitored monthly for the last four months (Figure 3). All samples were collected using standard operating procedures and processed at Ecology's Manchester Environmental Laboratory using standard procedures. All lab replicates met the target mean relative standard deviation (RSD) for the entire dataset (Roberts et al., 2008). Further details of the experimental design can be found in the QA Project Plan (Albertson et al., 2007).

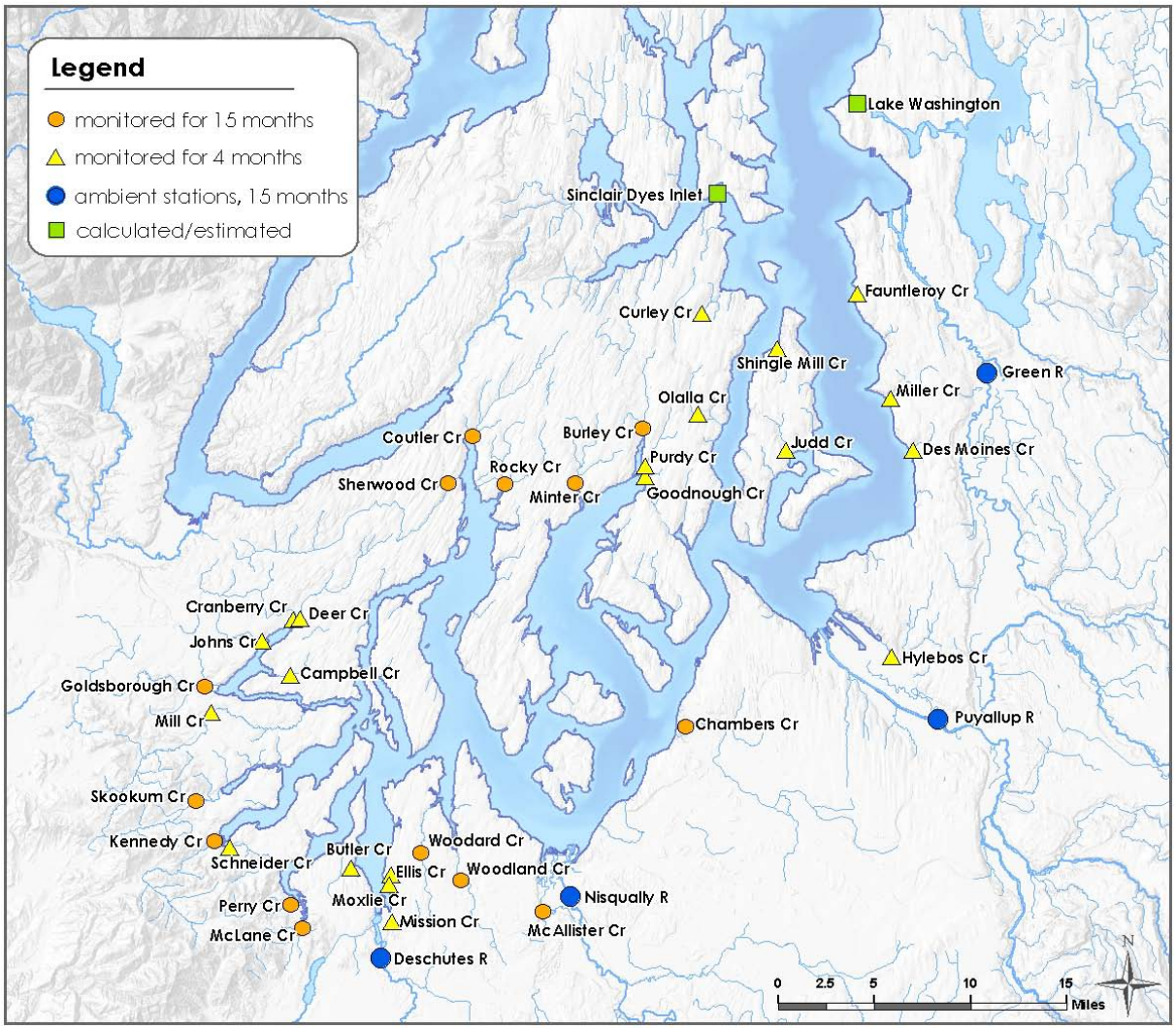

Figure 3. Locations of freshwater inflows monitored within the study area.

Even though no actual monitoring took place at Sinclair Dyes Inlet and Lake Washington/Ship Canal during the field effort, flow and concentration data for these two locations were estimated using data and information from the watersheds that they drain or from adjacent watersheds. These methods are described in more detail in the Interim Data Report (Roberts et al., 2008). Fifteen months of concentration data were estimated at both Sinclair Dyes Inlet and Lake Washington for all parameters in Table 2 except for DTPN and DTP.

Estimating Daily Streamflow

In addition to water quality grab samples, field staff measured instantaneous streamflow at tributary streams during most sampling events. The United States Geological Survey (USGS) also maintains permanent continuous stream gages on several streams and on all four of the large rivers (Deschutes, Nisqually, Green, and Puyallup).

For rivers and streams that had a USGS gaging station located within their watershed, data from the USGS were retrieved and extrapolated to the mouth of the watershed by scaling the streamflow record by the larger watershed area and average annual rainfall.

Continuous streamflow was also estimated for watersheds which did not have a USGS gaging station located within their watershed, but where Ecology collected discrete streamflow measurements. This was done as follows:

1. Identifying nearby continuously gaged stations in watersheds of similar size, land use, and proximity.
2. Normalizing this continuous streamflow record by drainage area and average annual rainfall.
3. Scaling the normalized streamflow by the area and average annual rainfall of the target watershed.

The same approach was used for watersheds with no flow measurements, such as direct inflows. In the end, we had a suite of predicted continuous daily streamflows at the *mouth* of each gaged and ungaged watershed within the study area. Estimated flows were compared to discrete measurements where available. Plots of predicted and observed flows at all stations which did not have a USGS gage station and where instantaneous flow measurements were made are presented in Appendix B.

Observed and predicted flows were comparable across all sites; however, predicted flows were noticeably lower than observed flows at the following four creeks: Moxlie, Olalla, Purdy, and Shingle Mill. These creeks may have a stronger groundwater influence which is not captured by our predictions. The small size of these inflows means that they will not have much of an individual impact on the circulation or water quality of Puget Sound.

Flow formulations for a few rivers/watersheds used a slightly more complex equation using data from more than one USGS gage. Note that some of these have been revised from the original formulations presented in the Interim Data Report using updated watershed areas and flow scale factors. Flows for the Nisqually River were also updated to account for a water diversion by the Centralia Power Company. The updated flow equations are presented in Table 3.

Table 3. Source information for estimating streamflow from watersheds that used multiple USGS flow gages.

Watershed	USGS Source Gages	Equation to Estimate Flow
Lake Washington	Cedar River Mercer Creek Juanita Creek Issaquah Creek Sammamish River	$Q_{Lk\ Wash} = 1.7080 * (Q_{Cedar} + Q_{Mercer} + Q_{Juanita} + Q_{Sammamish})$
Sinclair/Dyes	Huge Creek	$Q_{Sinclair} = 26.98 * (Q_{Huge})$
Green River	Green River – Auburn Sammamish River	$Q_{Green} = 1.1028 * (Q_{Auburn}) + 0.3701 * (Q_{Sammamish})$
Nisqually River	Nisqually River – McKenna Centralia Power Canal	$Q_{Nisqually} = 1.2230 * (Q_{McKenna} + Q_{Centralia\ Power})$

Watershed Delineations

River and stream monitoring did no always occur at the mouth of each watershed. To capture the nutrient loading from all the watersheds areas draining into South and Central Puget Sound, we extrapolated nutrient loads from the monitoring station (where data were collected) to the mouth of each watershed, as well as to all unmonitored locations. This extrapolation is described in the next few sections.

Figure 4 shows the delineations for monitored watersheds, unmonitored watersheds, and the final set of watersheds for which we developed nutrient loading estimates (right-most figure).

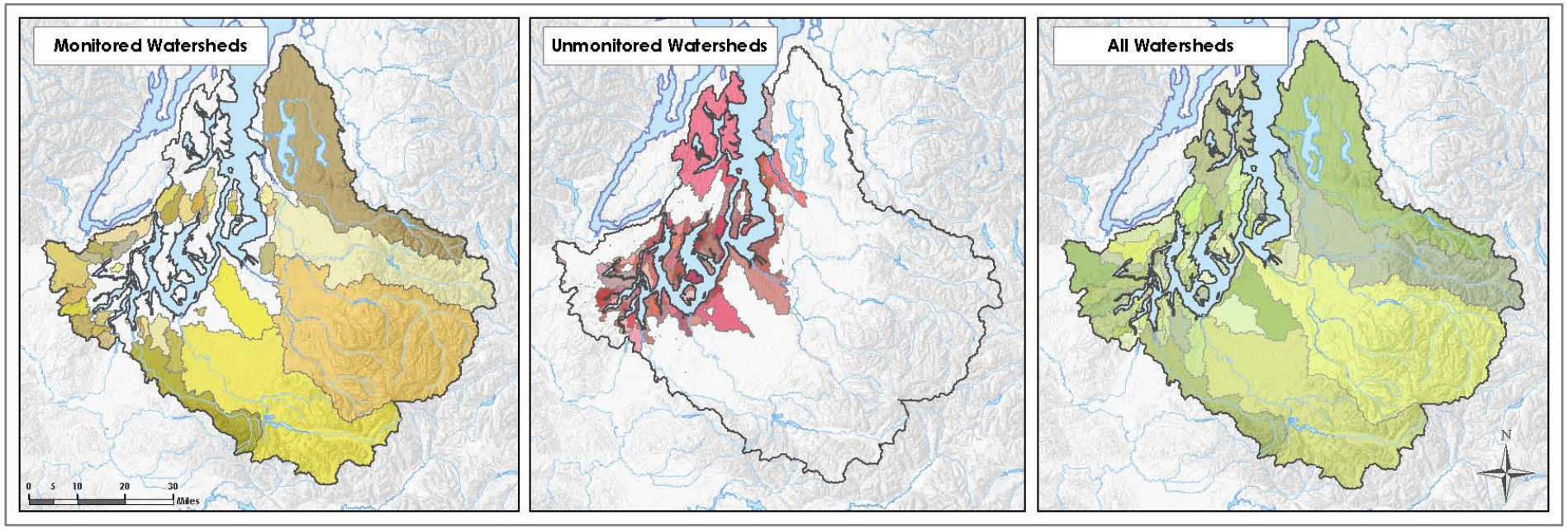

Figure 4. Delineations of monitored watersheds (left), unmonitored watersheds (center), and the final set of all 75 watersheds in the study area for which nutrient loading estimates were developed.

There are 75 watersheds in the study area (Figure 4, right). These watersheds were delineated during Phase 1 of the *South Sound Water Quality Study*(Albertson, et al., 2002). These delineations were based on a 30-meter digital elevation model (DEM) and performed using available tools in ArcGIS. ArcGIS uses the information derived from the DEM to assess how water flows across the landscape and then determines watershed boundaries.

Each of the 75 watersheds in Figure 4 is further identified in Figure 5, with labels for the watershed name and the location at which each watershed flows into South or Central Puget Sound. The watersheds that were monitored for 15 months were used in the statistical analysis, (described in the next section) to develop daily nutrient loading estimates for all 75 watersheds in the study area.

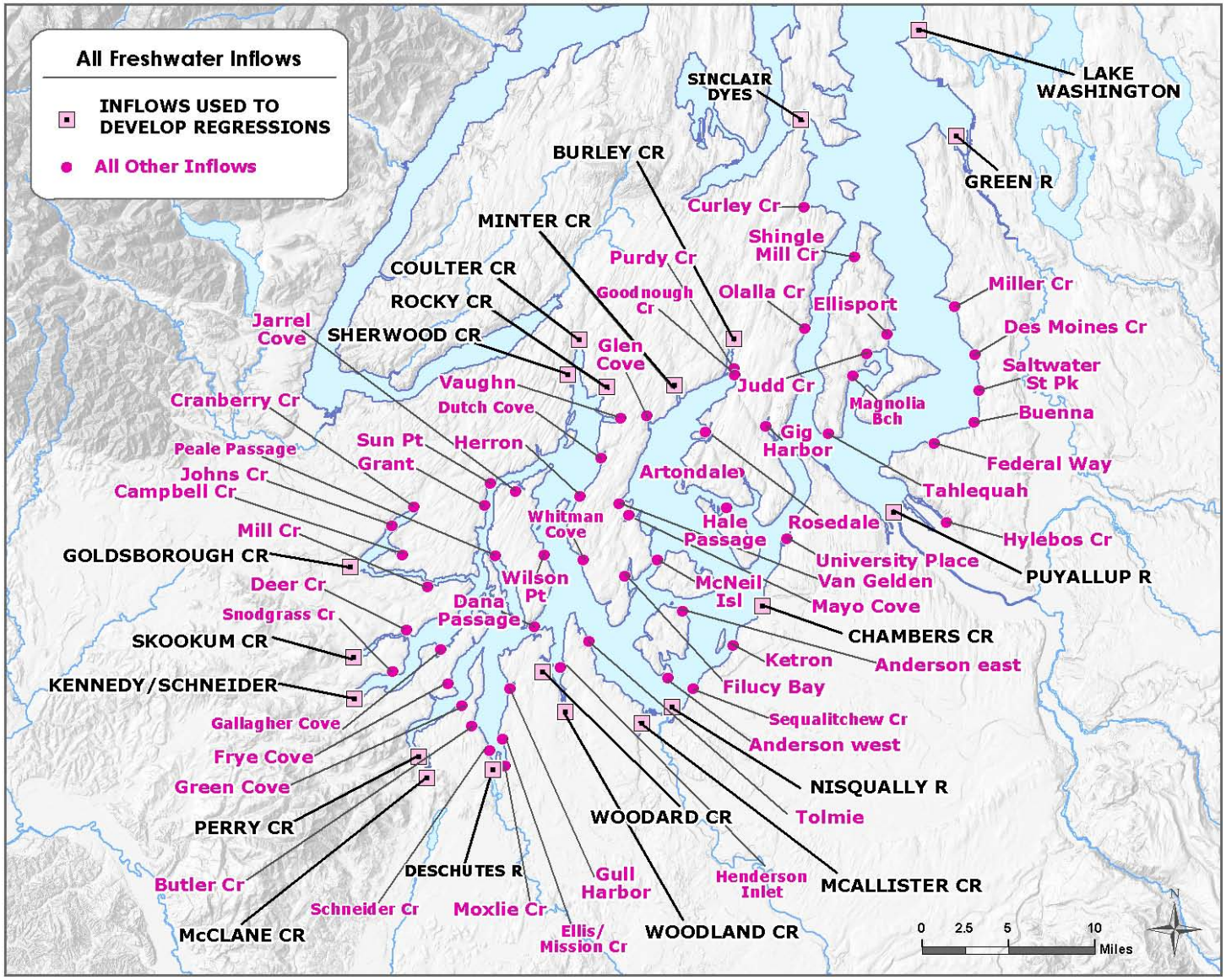

Figure 5. All 75 freshwater inflows included in the GEMSS water quality and hydrodynamics model of South and Central Puget Sound for which daily nutrient concentrations were developed for the 2006-07 calendar years.

Predicting Daily Concentrations

Data from the field monitoring effort were used to estimate daily nutrient concentrations for all 75 watersheds/tributaries that drain South and Central Puget Sound, as identified in Figure 5. A statistical method called *multiple linear regression* was used to predict daily nutrient concentrations for the rivers and streams draining these watersheds. This statistical approach relates concentrations to flow patterns, time of year, and season using a best-fit to monitoring data. The same method was used by Roberts and Pelletier (2001) to estimate daily concentration time-series concentrations of nutrients.

The multiple linear regression equation used in this analysis is given by:

Equation 1

$$\log(C) = b_0 + b_1 \log(Q/A) + b_2 [log(Q/A)]^2 + b_3 \sin(2\pi f_y) + b_4 \cos(2\pi f_y) + b_5 \sin(4\pi f_y) + b_6 \cos(4\pi f_y)$$

where

C is the observed parameter concentration (mg/L).
Q is streamflow (cms).
A is the area drained by the monitored location (km^2).
f_y is the year fraction (dimensionless, varies from 0 to 1).
b_i are the best-fit regression coefficients.

Logarithms of concentration and flow were used given the order of magnitude variability in the source data between different watersheds.

Of the 75 watersheds within the study domain, 20 had sufficient monitoring data available to calculate regression coefficients. These were the 14 watersheds where we collected 15 months of monitoring data, plus the four ambient stations, as well as Lake Washington and Sinclair/Dyes Inlet. These 20 watersheds occupy 82% of the total study area.

For these 20 more intensely monitored locations, all six variables in Equation 1 are known values (from available concentration data, streamflow data, watershed area, and time of year) except for the coefficients (b_i). The multiple linear regression model solves Equation 1 and determines the optimum combination of b_i coefficients that will yield the best fit between predicted and observed concentrations for each parameter of interest. The regression coefficients, b_i, were determined for each measured parameter[2] listed in Table 2 and for all 20 watersheds where sufficient monitoring data were collected.

Regressions were performed using the *Regression* tool within the *Analysis ToolPak* add-in for Microsoft Excel. In addition to the best-fit coefficients, the Excel output included an F value indicating the significance of the relationship, an R^2 and adjusted R^2, as well as a table of residuals. Model fit was evaluated based on the significance of the regression relationship (F value and p value), the adjusted R^2 value, and the R^2 value generated by fitting a linear trend line to a plot of predicted vs. observed concentrations, and an evaluation of residual plots.

[2] Regressions were also developed for temperature, dissolved oxygen and pH, but are not included in this report.

Outliers in the observed data were identified and removed from the dataset since the regression model would bias the relationship by trying to fit one extreme data point. The reported value was considered an outlier if it was more than three standard deviations away from the mean of the observed dataset for each parameter and stream. In many cases, however, the outlier was an unusually high concentration of a particular parameter that occurred only during the November 2006 sampling run which coincided with a storm event that caused widespread flooding. In this case, the observed value was not considered an outlier but representative of the natural response of the river or stream to the high-flow event. Outliers associated with high-flow events were therefore retained in the regression analysis.

If the regression relationship was not significant ($P > 0.05$), the least significant variable (the one with the largest p value) was removed from the equation, and the regression was run for a second time to generate a new set of regression coefficients. This was done iteratively by removing up to two variables for each parameter. If the regression was still not significant after removing two of the least significant variables, the original coefficients determined by including all six original variables were used.

In the end, we had a set of watershed-specific multiple regression model coefficients (b_i) for each parameter at each of the 20 watersheds where we had 15 months of data. The watershed-specific regression coefficients were first used to predict daily concentrations using daily streamflows at the mouth of these watersheds for the calendar years 2006-07.

Daily concentrations were compared to observed concentrations to see how well the model performed. Since monitoring did not always occur during the largest flow event, the regression model tends to extrapolate patterns to higher flows, potentially producing a source of error. To minimize the error due to this extrapolation, the maximum concentrations recorded in the monitoring data were used to cap predicted concentrations for all parameters. In addition, predicted concentrations below the detection limit were replaced with a value equal to the detection limit for the specific parameter. A smearing adjustment was then applied to correct for bias due to retransformation from log space (Cohn, et al., 1992).

Model coefficients developed for these 20 'original' watersheds were then applied to (1) 'target' watersheds where we had only four months of data and (2) watersheds where we had no data. In other words, the model coefficients were applied to the 18% of the study area that did not have sufficient data to develop regression coefficients. Regression coefficients developed for 'original' watersheds were applied to 'target' watersheds that were in close proximity. For example, the regression coefficients determined for the McLane Creek watershed, using the 15 months of data collected from McLane Creek, were also applied to Butler Creek and Schneider Creek. Equation 1 was then used to predict daily concentrations of parameters for these target watersheds using the target watershed's streamflow and area for the Q and the A in Equation 1.

Figure 6 illustrates which set of regression coefficients were applied to which target watersheds. The watersheds where we collected four months of data served as spot checks to see how well predicted concentrations matched observed data. The result was continuous daily streamflow and concentration data for all parameters of interest and for all 75 watersheds draining into South and Central Puget Sound.

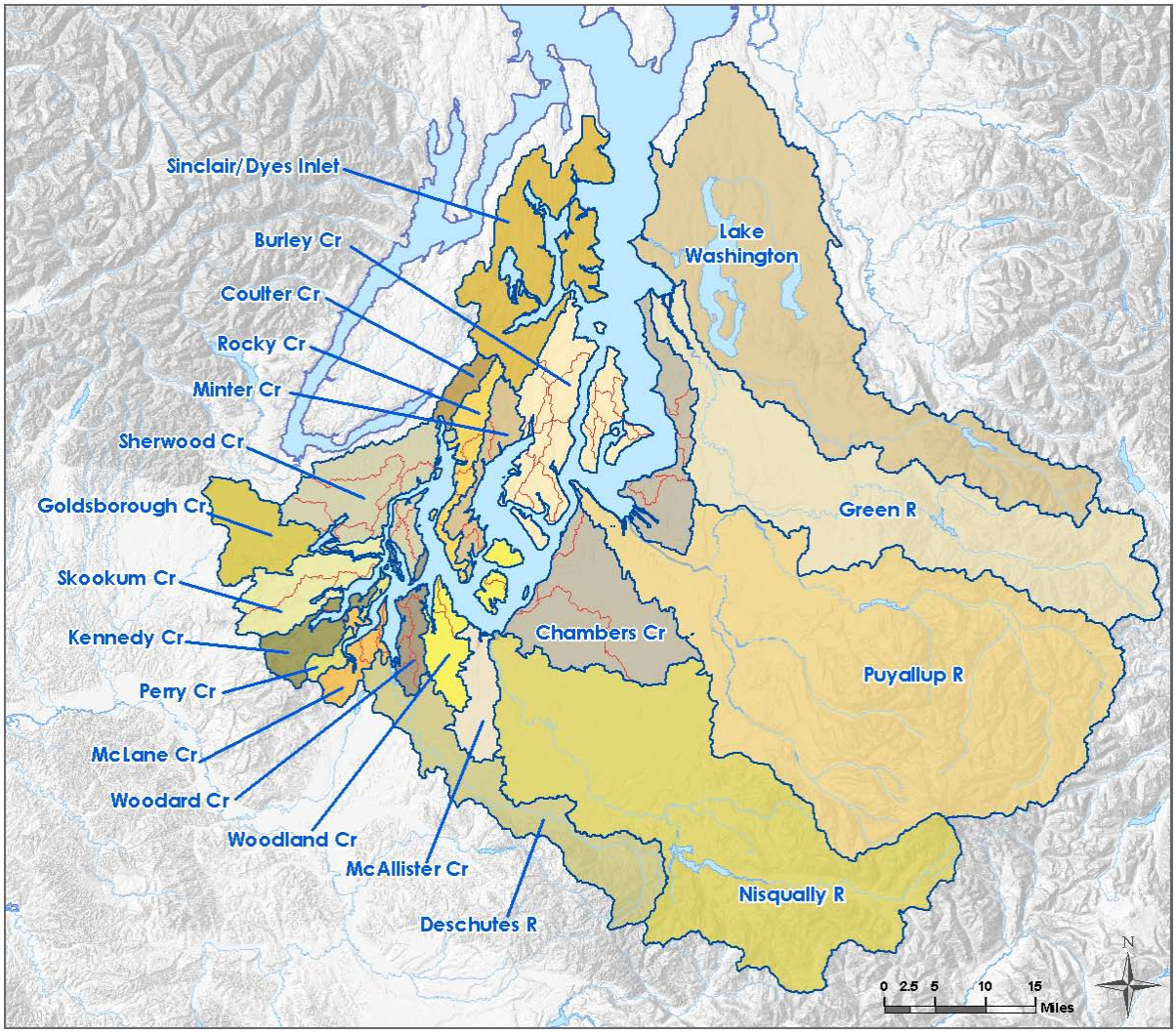

Figure 6. Map showing groupings of target watersheds labeled according to the 20 rivers and streams for which regressions were developed and then applied to these target watersheds.

Calculating Daily Loads

Continuous daily loads from rivers and streams were calculated from the predicted daily concentrations and daily flows for the years 2006 and 2007 as follows:

Daily load = (predicted daily concentration) x *(daily streamflow)*

Predicted loads were then compared with observed loads for those locations where we had data.

Septic System Contributions

On-site septic systems are another source of nutrient loads into marine waters within the study area. On-site septic system nutrient loads *upstream* of the monitoring location are included in our estimates of watershed loads. The extrapolation to the mouth of each watershed (and to unmonitored watersheds) should therefore reflect septic systems near the marine shoreline. However, if on-site septic systems in the unmonitored regions adjacent to South Puget Sound are more numerous or if effluents are less attenuated, this extrapolation could underestimate DIN load contributions from septic systems.

We estimated DIN loads from on-site septic systems from regions outside of monitored watersheds and outside of municipal wastewater service areas; this region is referred to as the *exclusive area*. The estimate was developed by an analysis by Whiley (2010) using a Geographic Information System (GIS) based approach. This approach used the following information: residences using on-site wastewater systems, wastewater flow rates, DIN concentrations in the wastewater, and DIN attenuation levels (percent loss of DIN as it moves from the septic system to the marine water) in the environment.

Since many of the parameters (e.g. DIN attenuation) used in the analysis can have significant variability, a Monte-Carlo analysis approach was applied to generate a range of potential DIN loading estimates from the exclusive area. DIN loading from on-site septic systems within the exclusive area were estimated for both upland (> 150 m from the shoreline) and shoreline (< 150 m from the shoreline) regions, since attenuation levels vary as a function of distance from the shoreline. The method is described in more detail in Appendix C.

We used the results from Whiley's (2010) analysis to see if our extrapolated watershed loads adequately capture on-site septic system loads from the shoreline fringe. This was done by first calculating the difference between the mean annual DIN load per unit area from *all* watersheds (i.e. extrapolated loads) and the mean annual DIN load from just the monitored watersheds. This difference was then compared to the load per unit area from on-site septic systems. If septic system loads are much *smaller* than the difference in loads from extrapolated and monitored regions, our extrapolated loads adequately capture nutrient loads from on-site septic systems in the exclusive area. If septic system loads are *larger* than the difference in loads from extrapolated and monitored regions, our extrapolated loads do not adequately capture nutrient loads from on-site septic systems in the exclusive area, and these loads will need to be added as a subsidy. This comparison is discussed in the *Results* section.

Wastewater Treatment Plant Loads

Field Data Collection

There are 31 domestic WWTPs[3] and two industrial facilities[4] that discharge directly to South and Central Puget Sound. Each of these facilities operates under an individual National Pollutant Discharge Elimination System (NPDES) permit. This permit requires facilities to test their effluent on a routine bases (daily to weekly depending on the parameter) and report concentrations of these parameters to Ecology. Biochemical oxygen demand (BOD) and total suspended solids are required parameters, but most permits do not require monitoring for nutrients, including nitrogen, phosphorus, or carbon.

During the 2006-07 field monitoring effort, supplemental monitoring was conducted at 29 of these WWTPs. Seventeen of these 29 WWTPs were monitored for each of the 15 months between August 2006 and October 2007. Twelve smaller WWTPs were monitored monthly for the last three months; this included sampling at Simpson Kraft in Tacoma, one of two industrial effluents in the study area. Three WWTPs and one industrial effluent (US Oil & Refining) within the study area were not monitored (Figure 7), but effluent concentrations for these were estimated as described later. From this point forward, reference to 'WWTPs' includes the two industrial discharges (Simpson Kraft and US Oil & Refining) in the study area.

Samples were 24-hour composites collected by each plant's sampling equipment (as required by their permit) and reserved for Ecology staff to collect each month[5]. The location where the water quality sample was collected varied from plant to plant, but was within the plant and as close to the outfall as possible. For smaller plants without 24-hour composite sampling equipment, Ecology staff collected grab samples. Samples were analyzed for each measured parameter listed in Table 2 (same as for freshwater monitoring stations), plus one additional parameter: carbonaceous biochemical oxygen demand (CBOD)[6]. All samples were collected using standard operating procedures and processed at Ecology's Manchester Environmental Laboratory using standard procedures. All lab replicates met the target mean RSD for the entire dataset (Roberts et al., 2008). Further details of the experiment design can be found in the QA Project Plan (Albertson et al., 2007).

[3] This does not include the Messenger House Care Center, which we considered small enough to be negligible.
[4] There is a third industrial facility (Abitibi in Steilacoom), but their NPDES permit is currently inactive.
[5] Occasionally, WWTPs failed to reserve a sample for Ecology staff, so fewer months of data are available.
[6] CBOD was not analyzed in rivers and streams where concentrations are nearly always below the reporting limit of 4 mg/L. Instead, CBOD is estimated from dissolved organic carbon (DOC).

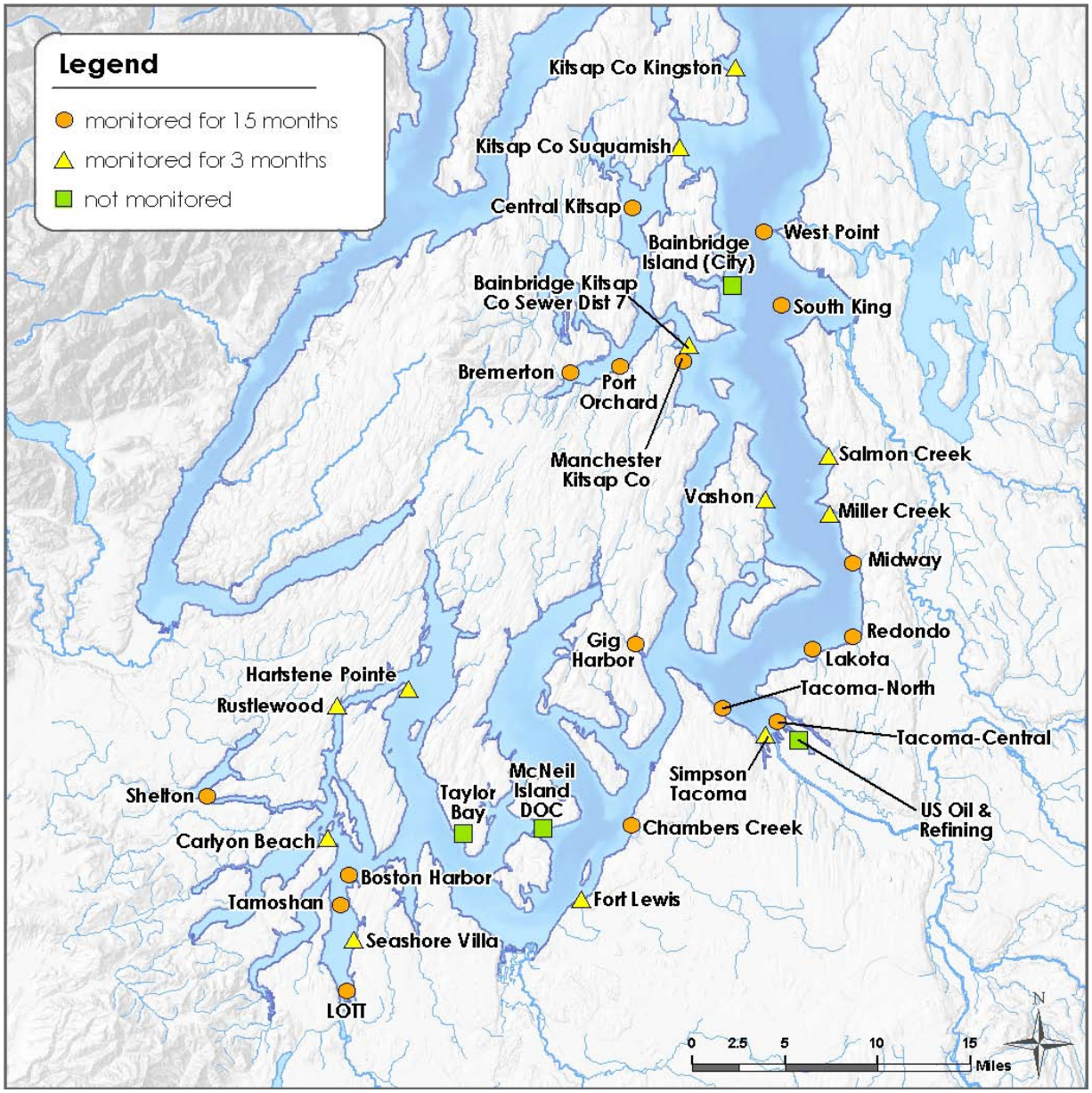

Figure 7. Locations of monitored and unmonitored WWTP discharges within the study area.

Wastewater Treatment Plant Reported Data

In addition to in-situ nutrient data from the 24-hour composite samples, we were able to get data from Discharge Monitoring Reports (DMRs) that WWTPs are required to submit as part of their NPDES permit. Many of these data are available online through Ecology's Water Quality Permit Life Cycle System (WPLCS), and in most cases, include data on effluent flow and CBOD. Data reported in DMRs were often used for WWTPs where we had fewer or no data. Because most plants are not required to monitor nutrients, little supplemental data were available.

Daily Effluent Flow

WWTPs report daily flows on paper copies of the DMRs, which are submitted to Ecology or the U.S. Environmental Protection Agency (EPA). However, only monthly average flows are captured electronically by Ecology or EPA.

All large (> 10 mgd) and most of the medium (4-10 mgd) WWTPs participated in this study by providing electronic daily effluent flow data to Ecology during the field monitoring effort (July 2006 – October 2007). For the rest of the medium WWTPs and a few small ones (< 4 mgd), daily effluent flow data reported in paper-copy DMRs were physically entered by Ecology staff for this same time period. For all other small WWTPs, monthly average flows were retrieved electronically and used to represent daily flows.

Predicting Daily Concentrations

Daily concentrations of nutrients were predicted for all 33 WWTPs within the study area using a similar approach to that used to estimate watershed concentrations. Monthly data from the field monitoring effort were used to estimate daily nutrient concentrations for these 33 WWTPs using a statistical method called *multiple linear regression*. This statistical approach relates concentrations to flow patterns, time of year, and season using a best-fit to monitoring data. The multiple linear regression equation used for WWTPs is given by:

Equation 2

$$\log(C) = b_0 + b_1 \mathrm{Q} + b_2 Q^2 + b_3 \sin(2\pi f_y) + b_4 \cos(2\pi f_y) + b_5 \sin(4\pi f_y) + b_6 \cos(4\pi f_y)$$

where

C is the observed parameter concentration (mg/L).
Q is effluent flow (cms).
f_y is the year fraction (dimensionless, varies from 0 to 1).
b_i are the best-fit regression coefficients.

Note that unlike Equation 1 used for watersheds, Equation 2 does not have the flows normalized by the area since drainage area is irrelevant to WWTPs, and the effluent flow is not transformed into log space since there is much less flow variability in WWTPs than in rivers.

WWTP and parameter-specific regression coefficients were determined for all 17 WWTPs that were monitored for 15 months. These WWTPs account for 89% of the total mean annual discharge of all WWTPs within the study area. For these 17 more intensely monitored WWTPs, all six variables in Equation 1 are known values (from available concentration data, effluent flow data, and time of year) except for the coefficients (b_i). The multiple linear regression model solves Equation 2 to determine the optimum combination of b_i coefficients that will yield the best fit between predicted and observed concentrations for each parameter of interest. The regression coefficients, b_i, were determined for each measured parameter listed in Table 2 (as well as for CBOD) using the same Excel tool as we did for estimating watershed concentrations.

In the end, we had a set of WWTP-specific multiple regression model coefficients (b_i) for each parameter at each of the 17 WWTPs where we had 15 months of data. The WWTP-specific regression coefficients were first used to predict daily concentrations using daily effluent data at these WWTPs for the calendar years 2006-07. In addition, concentrations of additional parameters were calculated from these predicted concentrations, as listed in the bottom half of Table 2.

Daily concentrations were compared to observed concentrations to see how well the model performed. Since monitoring did not always occur during the largest or smallest effluent flow, the regression model tends to extrapolate patterns to higher and lower flows, potentially producing a source of error. To minimize the error due to this extrapolation, predicted concentrations were capped by the maximum and minimum observed concentrations in the monitoring data for each specific plant.

As mentioned earlier, 12 WWTPs had limited data, while three others had no data. These 15 WWTPs contribute to 11% of the mean annual flow of all WWTPs that discharge within the study area. Since the available data for these 15 WWTPs were insufficient to develop plant-specific regression coefficients, a different approach was used to estimate daily nutrient concentrations:

1. All WWTPs for which regressions were developed were first divided into three size groups according to the magnitude of their effluent flow: large (> 10 mgd), medium (4-10 mgd), and small (< 4 mgd).
2. Daily concentration templates were developed for each size group. These concentrations were the average of each nutrient parameter averaged across all plants that fell within each size group. In other words, for the 'medium' template, the NO23N concentration was the average NO23N concentrations of all medium plants. We therefore had concentration templates representative of all large, medium, and small WWTPs in the study area for which regressions were developed.
3. These templates were applied to all other WWTPs (those that were monitored for three months or not monitored at all) according to which size group they fell in. For example, Fort Lewis, Miller Creek, and Salmon Creek WWTPs are all medium plants that were monitored for only three months. The medium concentration template was therefore applied to all three plants to represent their daily nutrient concentrations.

The WWTPs where we collected three months of data served as spot checks to see how well the template concentrations matched observed data.

The above methodology was applied to all WWTPs except the Carlyon Beach WWTP and the two industrial discharges. Nitrogen concentrations at Carlyon Beach (53 mg/L median for TPN and NO23N) are much higher than the typical small WWTPs in the study area (9.81 mg/L annual average TPN for small plants). The concentration templates were therefore an inaccurate representation of the effluent water quality for this particular plant. Since we collected three months of data at this plant, we calculated the average of these three months of data for all parameters and applied these averages for the full 2006-07 time period.

Three months of data were also collected at Simpson Kraft (Tacoma), which had effluent nitrogen concentrations that were much lower than typical municipal wastewater effluent. We used these data to develop a *simple* linear regression relationship (not *multiple* linear regression) between flow and effluent concentration for all parameters except CBOD; a simple rather than a multiple linear regression was used because of insufficient data. These linear equations were then used to predict daily concentrations for these parameters using daily flows. Since sufficient CBOD data were available from the DMRs for Simpson Kraft, we were able to develop a specific multiple linear regression for CBOD.

We did not collect any data at US Oil & Refining, and since this is not a WWTP, the concentration templates developed using WWTP data and regressions could not be applied to their effluent. However, NH4N and CBOD data were available through WPLCS, and site-specific multiple linear regression relationships were developed for these two parameters. For the rest of the parameters, we worked with the industrial permit manager who had typical values for a few parameters. In addition, we made the following assumptions for US Oil & Refining:

- All nitrogen in their effluent was in the form of NH4N.
- OP concentrations were assumed to be a constant 0.4 mg/L, about 10 times lower than that typical of municipal wastewater effluent. This is based on an estimate by EPA for petroleum refineries (EPA, 1996).
- All organic carbon was in dissolved form (i.e. TOC = DOC).

Once we had daily flow and concentration data for all WWTPs in the study area, we sent a letter to each WWTP describing the specific method we had used to develop the data for their plant. The letters also included a description of the *South Puget Sound Dissolved Oxygen Study* and included a spreadsheet attachment of the daily effluent flow and daily nutrient concentration data we had established for each plant (either using regressions or using the templates). WWTPs reviewed the data for their plant and either confirmed that these data were reasonable or responded with better or new data.

A few WWTPs for which we had used monthly average flow instead of daily flows responded by providing us with daily flows; we therefore replaced our monthly values with their daily values. If plants responded with new or more extensive data for any particular parameter (e.g. South King and Fort Lewis), we used those data to developed plant-specific regressions for that parameter. We also replaced the original daily concentration estimates we had for that plant with the concentrations predicted by the new regression results.

Calculating Daily Loads

Continuous daily nutrient loads from WWTPs were calculated from the predicted daily concentrations and daily flows for the years 2006 and 2007 the same way as for watershed loads:

Daily load = (predicted daily concentration) x *(daily effluent flow)*

Even though we capped WWTP concentrations by the maximum of observed instantaneous concentrations, many WWTPs had a few unusually high spikes in their loads due to a

combination of regression parameters and coincident high plant flows. Though these spikes do not strongly influence seasonal inputs, we also capped all loads by the maximum instantaneous loads measured in the data collection program. Predicted loads were then compared with observed loads for those locations where we had data.

Natural Conditions

An important part of this study involves the development of natural conditions. Natural conditions in this study refer to the concentrations of nutrients in rivers and streams without significant human influences/sources of nutrients. By definition, there would be no WWTP or septic system inputs into Puget Sound under natural conditions. There are various natural sources and sinks of nitrogen in streams. These include rainfall, riparian and terrestrial vegetation, spawning salmon, various instream nitrogen biogeochemical cycling processes, and decomposition of organisms.

Once natural watershed concentrations are established, they can be used as inputs into the water quality model so that we can evaluate the water quality of Puget Sound under natural conditions.

Since monitoring of rivers and streams has occurred post-human development, we do not have historic water quality data that go back far enough in time to reflect pristine, natural, or pre-development conditions in rivers and streams draining to South and Central Puget Sound. Therefore, recent data need to be used to determine natural concentrations of nutrients in rivers and streams, based on the least developed and most forested watersheds or older data reflecting lower populations and possibly less intense land use.

Ambient monitoring data indicate seasonal variability. Many of the less developed watersheds have very low nutrient concentrations in the summer months. At these times, nitrogen becomes the limiting nutrient for primary productivity, and instream processes likely decrease nitrogen export (Kantor et al., 1998). However, in other watersheds where groundwater nitrogen levels are high, such as the Deschutes River, decreasing streamflows reduce dilution in the summer months, resulting in higher concentrations.

We performed a meta-analysis to establish natural conditions for rivers and streams that drain into South and Central Puget Sound for the following parameters: TPN, NO23N, NH4N, TP, and OP. This meta-analysis involved the use of several methods. The results of these different methods were then analyzed to establish natural nutrient concentrations for each month of the year to capture changes in concentration due to seasonality. Each of the methods we used in our meta-analysis is described below.

Recent Ambient Water Quality Data at the Mouths of Rivers

Ecology maintains several ambient freshwater monitoring stations located throughout Washington. We used data collected between water years 2002-09 from monitoring stations located closest to the mouths of watersheds that drain into South and Central Puget Sound as well as nearby less developed regions around Puget Sound. Table 4 lists the station locations selected.

We calculated monthly 10th percentiles for each parameter within each region listed above to represent a reasonable estimation of natural conditions. For TP, however, we used data onl from water years 2008-09 since there was a change in Manchester Environmental Laboratory methods in 2003 and again in 2007. This change did not allow us to pool older data with newer data.

Table 4. List of ambient monitoring stations grouped into different regions of Puget Sound that were used as part of the meta-analysis to establish natural conditions.

Puget Sound Region	Station Name(s)	Station ID	Percent Developed*
Within Model Domain			
Puget South	Deschutes River at E St. Bridge Nisqually River at Nisqually	13A060 11A070	23%
Commencement Bay	Puyallup River at Meridian St.	10A070	19%
Puget Main	Cedar River at Logan St./Renton	08C070	48%
Elliott Bay	Green River at Tukwila	09A080	33%
Near but Outside Model Domain			
Hood Canal	Skokomish River near Potlatch Duckabush River near Brinnon	16A070 16C090	5%
Strait of Juan de Fuca/ Strait of Georgia (SJF/SOG)	Nooksack River at Brennan Samish River near Burlington Elwha River near Port Angeles	01A050 03B050 18B070	16%
Whidbey Basin	Skagit River near Mount Vernon Stillaguamish River near Silvana Snohomish River at Snohomish	03A060 05A070 07A090	8%

* Percent non-forested land cover based on the National Land Cover Dataset MRLC (Herrera, 2010).

Ambient Water Quality Data from Less-Developed Watersheds

Data from watersheds with less human development can serve as good indicators of natural conditions. We therefore chose Ecology's ambient stations located in the Nisqually and Skagit River watersheds, which are both less developed than other watersheds in Puget Sound. These two watersheds are also located in different regions of Puget Sound, providing broader geographic coverage. Ambient data from the following three stations were used:

1. Nisqually River at McKenna (11A080).
2. Skagit River near Mount Vernon (lower Skagit, 03A060).
3. Skagit River at Marblemount (upper Skagit, 04A100).

The monthly medians were calculated for each parameter for each station listed above using historic data from the 1960s and 1970s. In addition, we also calculated the overall medians of recent data from water year 2009.

Atmospheric (Rainfall) Data

The National Atmospheric and Deposition Program's National Trends Network has stations that measure concentrations of nitrate and ammonia in rainfall throughout Washington State. Data from the following four stations in western Washington were retrieved for water years 2002-2009:

1. Olympic National Park – Hoh Ranger Station (WA14).
2. North Cascades National Park – Marblemount Ranger Station (WA19).
3. Mount Rainer National Park – Tahoma Woods (WA99).
4. La Grande (WA21).

We calculated monthly median concentrations of NO23N and NH4N for (1) the Olympic station only and (2) all four stations pooled together. Of these four stations, the one located in the Olympics is upwind from Puget Sound watersheds and is therefore least influenced by local anthropogenic sources of nutrients. Therefore, we chose this station to consider for natural conditions.

Puget Sound Toxics Runoff Project

Ecology has an ongoing study, the Puget Sound Toxics Loading Project, which estimated the concentrations of nutrients in surface runoff for both baseflow and stormwater events from watersheds with different land cover types (Herrera Environmental Consultants, 2010).

Field data for this project were collected and measured by Herrera Environmental Consultants. For this 2006-07 study, we used the median of the data collected from predominantly forested sub-basins within the Puyallup and Snohomish watersheds. These data were selected because under natural conditions, most of the watersheds that drain into Puget Sound were forested. A single median value was used to represent each month out of the year since these data were not collected at monthly intervals.

Hood Canal Dissolved Oxygen Program

The Hood Canal Dissolved Oxygen Program is a partnership of various organizations that conduct monitoring and analysis to address low DO levels in Hood Canal. As part of their analysis, they estimated natural background NO23N concentrations for rivers and streams entering Hood Canal (Steinberg et al., 2010).

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Results

Multiple Linear Regression

The *multiple linear regression* method used to estimate daily nutrient concentrations performed well in estimating the concentrations of most parameters when compared to observed data for both rivers and WWTPs. Overall, the method provides a better estimate of daily concentrations in rivers and WWTPs than using constant values or monthly averages. The method was also able to capture changes in concentration due to flow and seasonality.

For most parameters, predicted vs. observed nutrient *loads* compared better than predicted vs. observed nutrient *concentrations* across all streams and WWTPs. This was true even for those parameters that did not yield significant regression relationships or did not have high adjusted R^2 values. This is because the variability in flow exceeds the variability in concentration, resulting in predicted loads that match well to observed loads.

Table 5 presents a summary of the significance and adjusted R^2 values of the multiple linear regression relationships developed using concentration data in each of the 20 watersheds that had sufficient data. The majority of parameters (9 out of 13) had significant regression relationships for the majority of watersheds. For these watersheds, the regression equation explains 53-81% of the variability (median R^2 = 0.53-0.81) in measured concentrations.

Table 5. Overall significance and median adjusted R^2 values of regression relationships developed for nutrient concentration parameters for the 20 watersheds used to develop regressions.

Parameter	% significant relationships	Median Adjusted R^2
DTPN	93%	0.75
NO23N	90%	0.81
OP	90%	0.78
DOC	90%	0.74
TP	85%	0.77
TPN	80%	0.68
DTP	78%	0.71
NH4N	68%	0.53
POP	61%	0.62
DON	43%	0.38
DOP	33%	0.17
POC	20%	0.01
PON	14%	0.17

Regressions for all forms of nitrogen except NH4N performed very well. Concentrations of NH4N are generally much lower than the other forms nitrogen, so even if NH4N predictions are less accurate, these concentrations will not significantly affect overall nitrogen loading estimates. The same applies to phosphorus and carbon. Inorganic forms of phosphorus and carbon generally had stronger regression relationships than the organic forms of phosphorus and carbon, which typically have lower concentrations.

Table 6 presents a summary of the significance and adjusted R^2 values of the multiple linear regressions relationships developed using concentration data at each of the 17 WWTPs that had sufficient data. Regression relationships developed for WWTPs were not as strong as those that were developed for rivers. However, the regression method still provided a better fit to monitoring data than simple averages, as indicated by the root mean square errors calculated using multiple methods for the Tacoma-Central WWTP. The Tacoma-Central plant was used for comparison because nitrogen levels in the effluent were more variable than at other plants.

Table 6. Overall significance and median adjusted R^2 values of regressions relationships developed for nutrient concentration parameters for the 17 WWTPs used to develop regressions.

Parameter	% significant relationships	Median Adjusted R^2
DTP	47%	0.51
NO23N	41%	0.56
DTPN	35%	0.27
NH4N	35%	0.36
TPN	29%	0.20
TP	29%	0.41
OP	29%	0.32
TOC	24%	-0.03
CBOD	6%	0.10
DOC	0%	0.06

Plots of predicted and observed concentrations and loads for all four large rivers (Deschutes, Nisqually, Puyallup, and Green) and all large WWTPs (> 10 mgd) are presented in Appendix D and Appendix E. These appendices also include tables presenting the difference and the root means square error (RMSE) between predicted and observed concentrations for all rivers, streams, and WWTPs where water quality data were collected.

The rest of this report focuses primarily on DIN since (1) nitrogen is the nutrient of greatest concern in South Puget Sound and (2) of all the forms of nitrogen, DIN is the most bioavailable form of nitrogen and therefore the most relevant in the context of low DO levels. Based on our estimates, 86% of the total nitrogen load from rivers is in the form of DIN while 90% of total nitrogen load from WWTPs is in the form of DIN. Figures presenting our data for various other forms of nitrogen, phosphorus, and carbon are included in Appendix F and Appendix G. These various other forms of nutrients will be accounted for in the water quality model.

Watershed Loads

Table 7 compares annual and September 2007 DIN loads calculated from the multiple linear regression method with those calculated from the monthly field monitoring data. The annual DIN load is the mean for water year 2007.

The purpose of this comparison is to illustrate that the regression method is a realistic and reasonable method of estimating loads since, in most cases, these estimates are similar to measured loads. It should be noted that the annual subtotals and totals for the monthly data do not include loads from streams that were monitored for four months. However, the loads from these streams make up only 4% of the annual South Puget Sound subtotal. Overall, DIN loads derived from the regression are slightly higher but comparable to loads calculated from the monthly data.

The annual monthly data values in Table 7 are different from those presented in Table 18 of the Interim Data Report (Roberts, et al., 2008). Table 18 in the data report requires clarifications and a correction;

- Table 18 included *all* streams monitored as part of the 2006-07 data collection program. However, 20 of these streams did not have year-round data. The annual loads were calculated from the available data, which are biased low due to dry-season flow characteristics. No equivalent year-round data are available with which to compare regression results, and these sums have not been included in the present loading report.
- The annual averages in Table 18 of the Interim Data Report also did not include November 2006 information because a large storm event precluded sampling during this month. This results in annual values biased low since loads tend to be higher in November, particularly during such large storm events.
- The annual averages included averages of both August 2006 and 2007, September 2006 and 2007, and October 2006 and 2007. However, to provide a direct comparison for this report, the water year 2007 monthly (October 2006 through September 2007) values were used.
- The annual averages for the larger river systems (Deschutes, Nisqually, Puyallup, Green) and Lake Washington and Sinclair Dyes Inlets included a calculation error that resulted in loads biased low. This report corrects those values and presents the annual averages for water year 2007.

The estimates derived from the regression method are our best estimate of nutrient loading for several reasons: (1) these estimates are available at a daily time step, accounting for changes with flow and season, (2) the estimates include loads from unmonitored regions, and (3) there are no gaps throughout the 2006-07 study period. A complete table of summer and annual DIN loads estimated from the regression method for all watersheds in South and Central Puget Sound is included in Appendix F.

Table 7. Comparison of DIN loads from rivers estimated from (1) the regression method and (2) monthly data collected during the 2006-07 field monitoring period.

Stream/River Name	ANNUAL DIN Load (kg/d)[1]		SEPT. 2007 DIN Load (kg/d)[2]	
	Regression	Monthly Data	Regression	Monthly Data
South Puget Sound				
Burley Cr	42	60	24	24
Butler Cr	1.4	--	0.1	0.1
Campbell Cr	4.3	--	0.9	0.2
Chambers Cr	428	422	136	112
Coulter Cr	8.8	14	1.8	2.6
Cranberry Cr	18	--	3.8	2.1
Deschutes R	921	729	197	198
Ellis Cr	4.8	--	1.3	1.0
Goldsborough Cr	66	74	6.8	4.9
Goodnough Cr	5.1	--	1.5	2.4
Johns Cr	17	--	3.5	4.4
Kennedy Cr	68	98	9.0	3.5
McAllister Cr	168	240	36	51
McLane Cr	25	39	3.3	0.8
Mill Cr	68	--	7.1	1.0
Minter Cr	40	63	12	13
Mission Cr	2.6	--	0.7	0.8
Moxlie Cr	4.0	--	0.9	15
Nisqually R	1288	1011	190	199
Perry Cr	14	10.0	4.9	0.6
Purdy Cr	3.0	--	0.2	1.0
Rocky Cr	30	28	12	3.2
Sherwood Cr	3.4	3.2	0.7	0.4
Skookum Cr	50	76	5.2	0.4
Woodard Cr	26	18	7.2	6.5
Woodland Cr	148	148	48	57
South Sound Subtotal	**3454**	**3033**	**713**	**705**
Central Puget Sound				
Curley Cr	38	--	11	4.1
Des Moines Cr	21	--	5.6	2.2
Green R	1978	2279	429	427
Hylebos Cr	71	--	19	18
Judd Cr	13	--	3.7	3.7
Lake Washington	509	559	28	36
Miller Cr	33	--	8.9	6.4
Olalla Cr	2.7	--	0.2	5.1
Puyallup R	2353	1862	613	734
Shingle Mill Cr	3.1	--	0.2	4.1
Sinclair Dyes Inlet	384	457	85	107
Central Sound Subtotal	**5405**	**5157**	**1204**	**1347**
South and Central Puget Sound TOTAL	**8859**	**8190**	**1917**	**2055**

[1]For the regressions, these values are the mean of the daily regressions for WY07 (October 2006 through September 2007). For monthly data, the DIN loads for these values are calculated from monthly grab samples collected in WY07, but without November 2006. No annual values are reported for streams with four months of data (denoted by '--').

[2]For the regressions, these values are the mean of September 2007 daily regressions. For monthly data, these values are the instantaneous loads calculated from the September 2007 grab samples.

For all 75 watersheds in the study area, the mean annual DIN load in 2007 was less than that in 2006. The mean annual DIN loads from these watersheds were 21% lower in 2007 than in 2006. Mean annual flows from all watersheds were also lower in 2007, by 19%, potentially accounting for a large proportion of this difference.

Figure 8 geographically illustrates median DIN concentrations for all watersheds in the study area for 2006 -2007. Note that only those watersheds that fall into the highest concentration category (i.e. largest dot size) are labeled. In addition, Figure 9 presents box and whisker plots of watershed DIN concentrations.

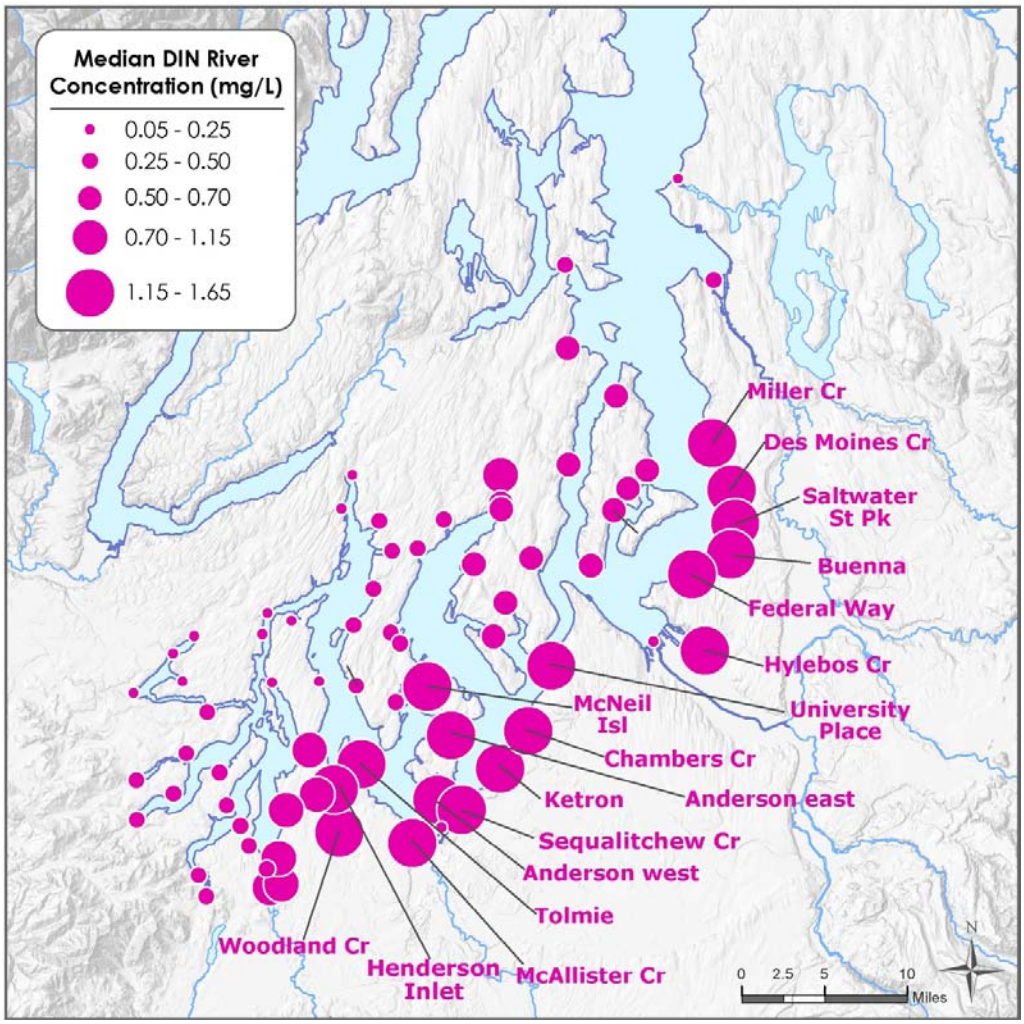

Figure 8. Median watershed dissolved inorganic nitrogen (DIN) concentrations for 2006-07. *Only watersheds that have DIN concentrations greater than 1.15 mg/L are labeled.*

The highest median concentrations of DIN (the form of nitrogen of greatest interest) are found in Woodland Creek. These concentrations were then extrapolated to the following nearby watersheds: Anderson east and west, McNeil Island, Tolmie, and Henderson Inlet, which also have high median DIN concentrations. High median DIN concentrations were also found in McAllister Creek, for which concentration estimates were not extrapolated from another watershed but were based on measurements taken at the monitoring station on McAllister Creek.

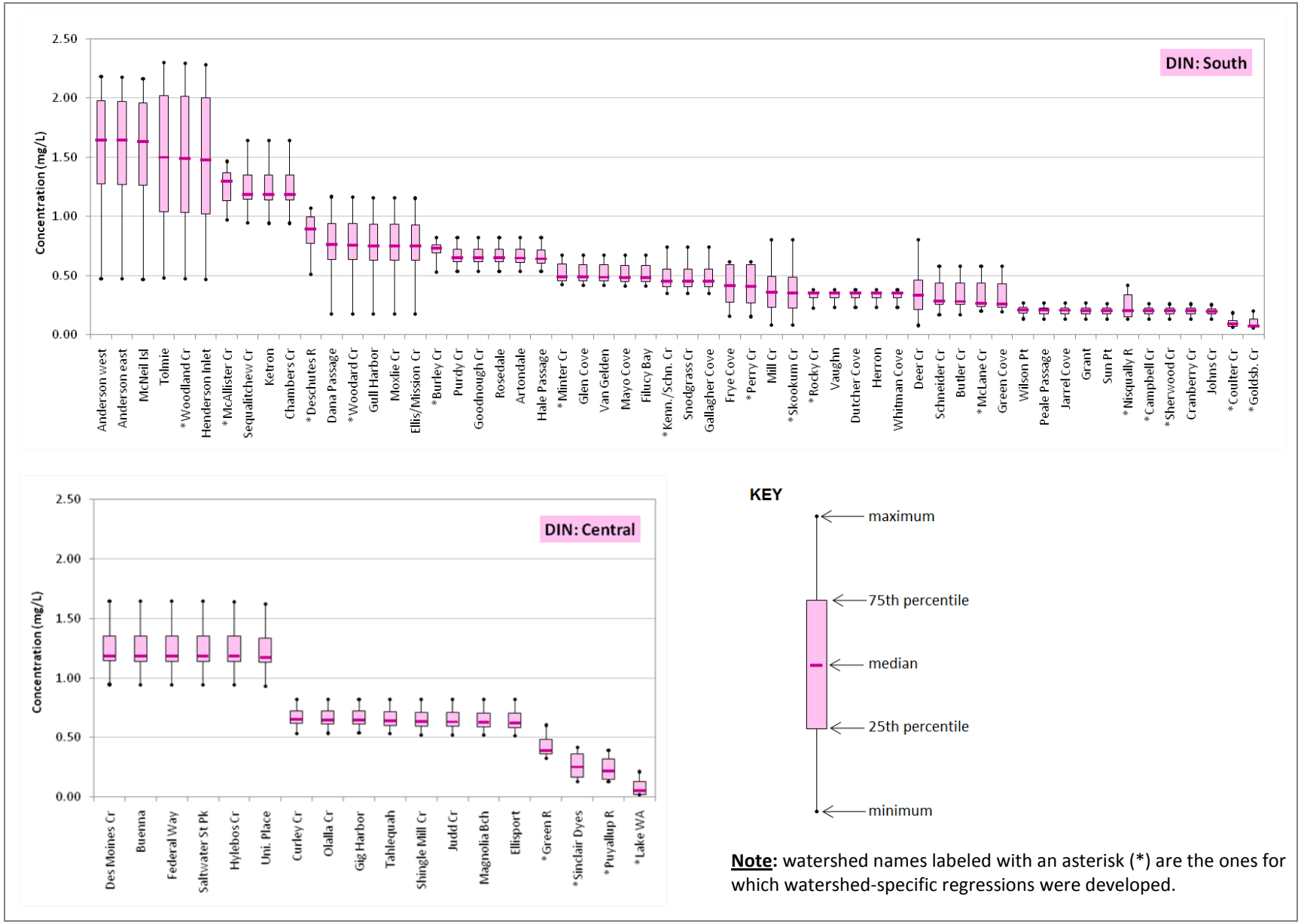

Figure 9. Box plots of dissolved inorganic nitrogen (DIN) concentrations for watersheds in South (top) and Central (bottom) Puget Sound, 2006-07.

The box and whisker plots also show that most of these watersheds also have similar DIN concentration patterns. These watersheds are ones that are in close geographic proximity to each other, and where the same regressions relationships were applied (in this case, from Woodland Creek), resulting in similar predictions of DIN. The range of DIN concentrations found in rivers and streams in South Puget Sound are generally greater than the range of DIN concentrations found in rivers and streams in Central Puget Sound.

The watersheds that have high DIN concentrations are not necessarily the same ones that have high DIN loads since loads are generally higher for watersheds with higher flows and drainage areas. Figure 10 illustrates how all the larger rivers/watersheds in the study area have DIN loads that are an order of magnitude higher than the rest of the watersheds in the study area. The three watersheds with the highest DIN loads are the Puyallup (2420 kg/d), Green (1942 kg/d), Nisqually (1748 kg/d), and Deschutes Rivers (993 kg/d).

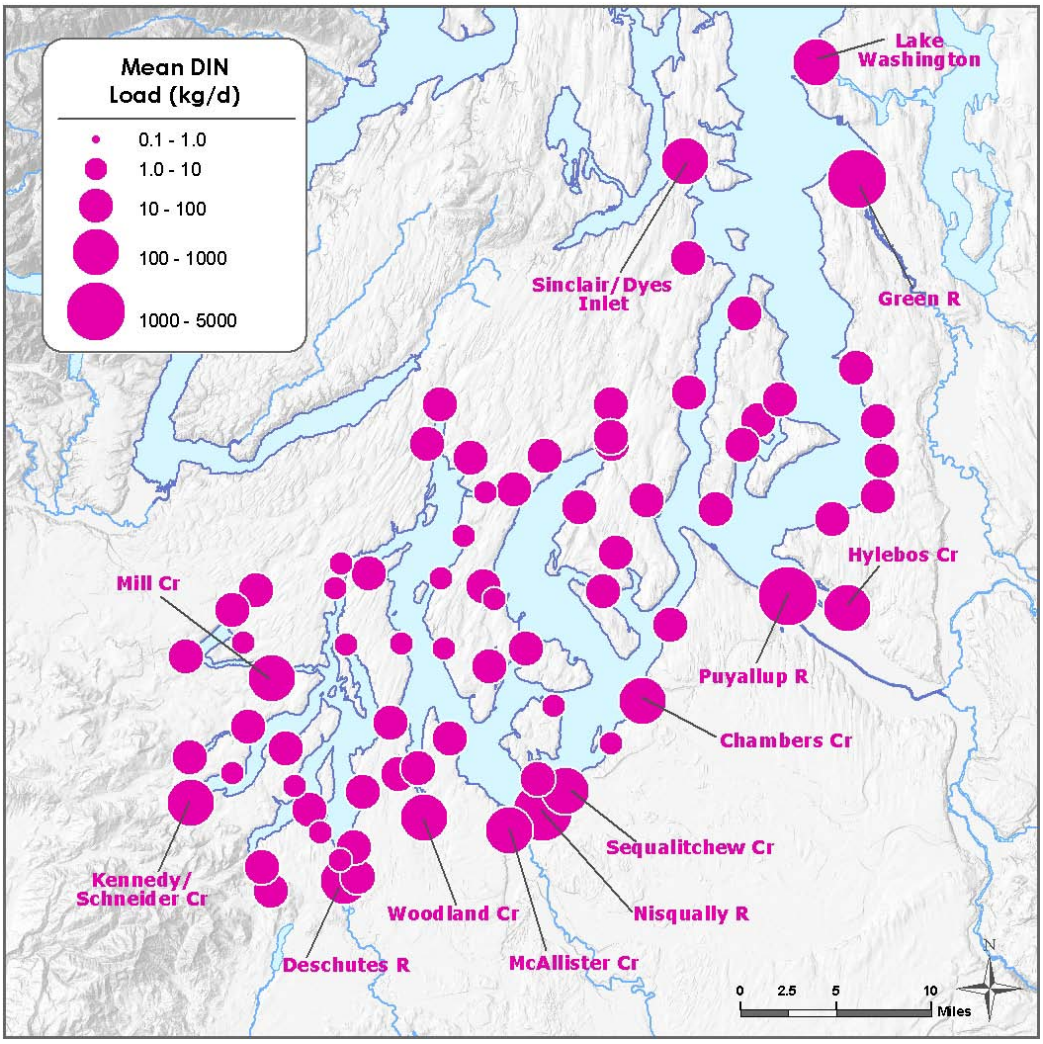

Figure 10. Mean dissolved inorganic nitrogen (DIN) loads from watersheds into South and Central Puget Sound during 2006-07.

Only watersheds that have DIN loads greater than 100 kg/d are labeled.

Though Figure 10 is useful for identifying the watersheds with the highest DIN loads, it does not account for difference in the size of each watershed (relative to other watersheds). We therefore normalized these loads by the size of each watershed to determine the 'relative load', as follows:

$$Relative\ Load = \frac{load\ for\ watershed\ i / total\ load\ from\ all\ watersheds}{drainage\ area\ of\ watershed\ i / total\ area\ of\ all\ watersheds}$$

where *i* in the above equation represents a particular watershed in the study area. Relative loads greater than 1.0 are higher than average, while relative loads below 1.0 are less than average (relative to the rest of the study area).

For example, the Puyallup River Watershed occupies 24.5% of the study area but accounts for 22.2% of the total DIN load. Its relative load is therefore 22.2 divided by 24.5, which is equal to 0.91 (i.e. below average). Figure 11 illustrates the relative loads for all the watersheds in the study area, where darker colors represent higher relative loads.

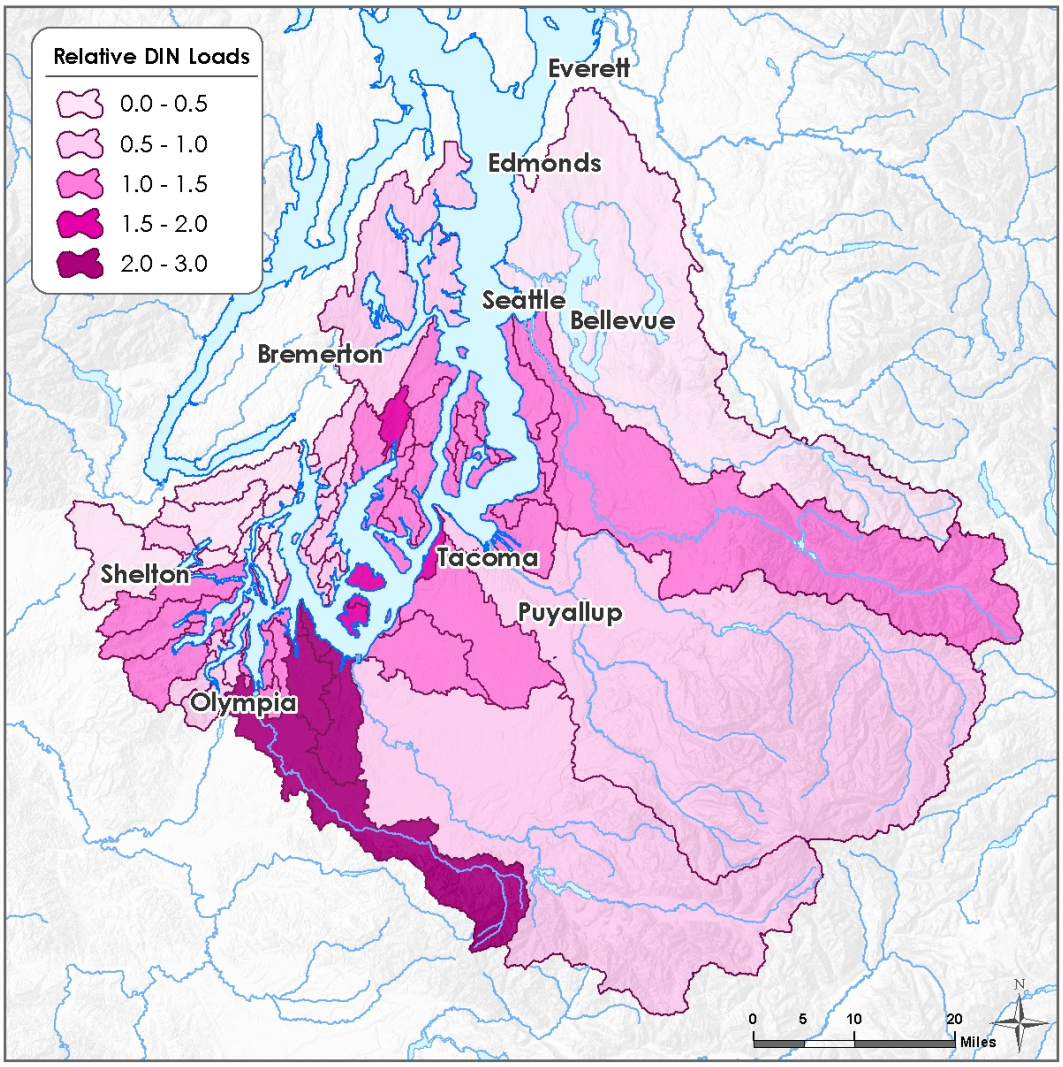

Figure 11. Annual relative dissolved inorganic nitrogen (DIN) loads (ratio of fractional load to fractional area) from watersheds in the study area during 2006-07.

Watersheds draining into Budd and Henderson Inlets in South Puget Sound, including the Deschutes River watershed, have the highest relative loads in the study area. These watersheds are generally more densely populated (higher population per area) than others within the study area, which might be the reason for higher relative DIN loads.

Since the Deschutes River drains into Capitol Lake before entering Budd Inlet, we also estimated daily flows, daily nutrient concentrations, and daily loads at the outflow of Capital Lake. These concentrations and loads are seasonally lower than those in the Deschutes River since some of the nutrients get assimilated within Capital Lake before entering Budd Inlet. In this report, we are only presenting loads from the Deschutes River so that we can compare these with loads from other watersheds. However, the model will use the Capital Lake data to represent the inflow into Budd Inlet.

Some regions within the study area may be more sensitive to nitrogen loading than others. It is therefore constructive to separate nitrogen loads into different regions of South and Central Puget Sound, as identified in Figure 12. These regions coincide with the regions in the Puget Sound Box Model, which is another model that is being developed and used by Ecology.

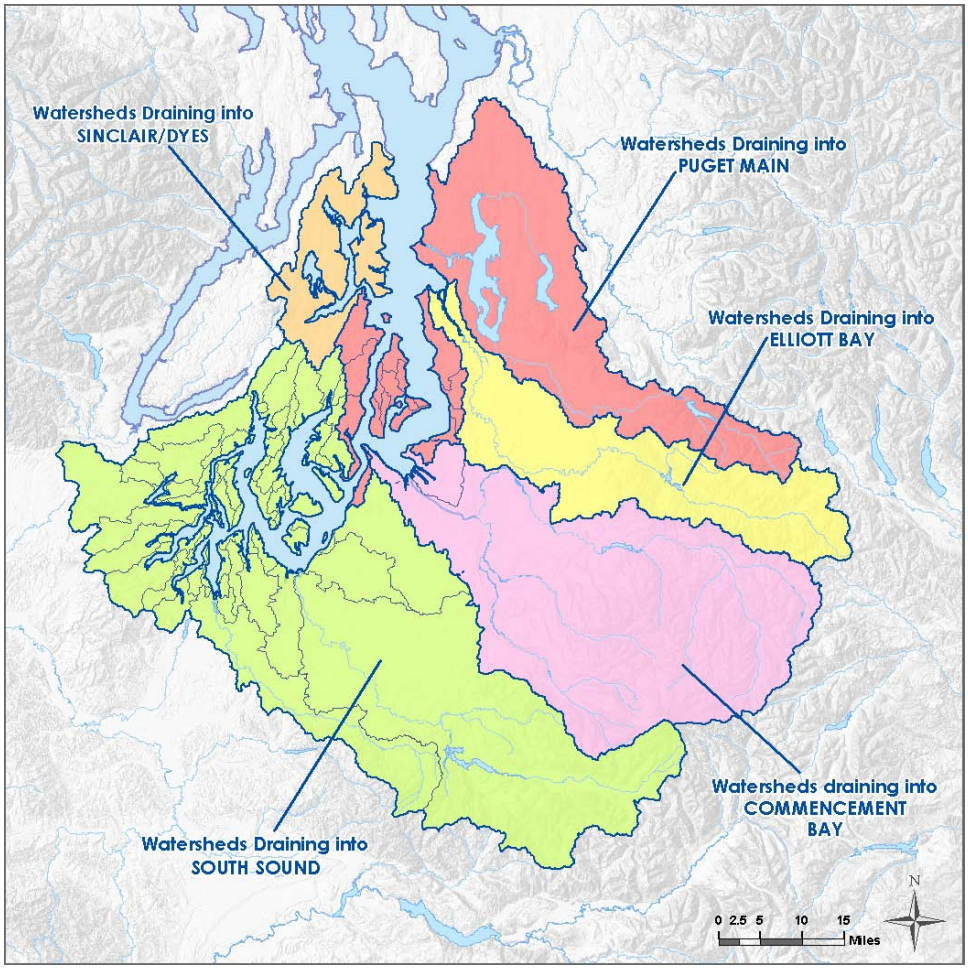

Figure 12. Watersheds in the study area color-coded by the regions in South and Central Puget Sound into which they drain.

Figure 13 illustrates that total monthly river DIN loads into South Sound are comparable in magnitude to river DIN loads into Central Puget Sound boxes (Sinclair Dyes, Puget Main, Elliott Bay, and Commencement Bay).

DIN loads follow a seasonal pattern that coincides with high and low precipitation and streamflow over the course of the year. Rivers and streams discharging between November and March contribute 77% of the total annual DIN load from watersheds, and average DIN loads are 1.8 times higher than the annual average during this same time period.

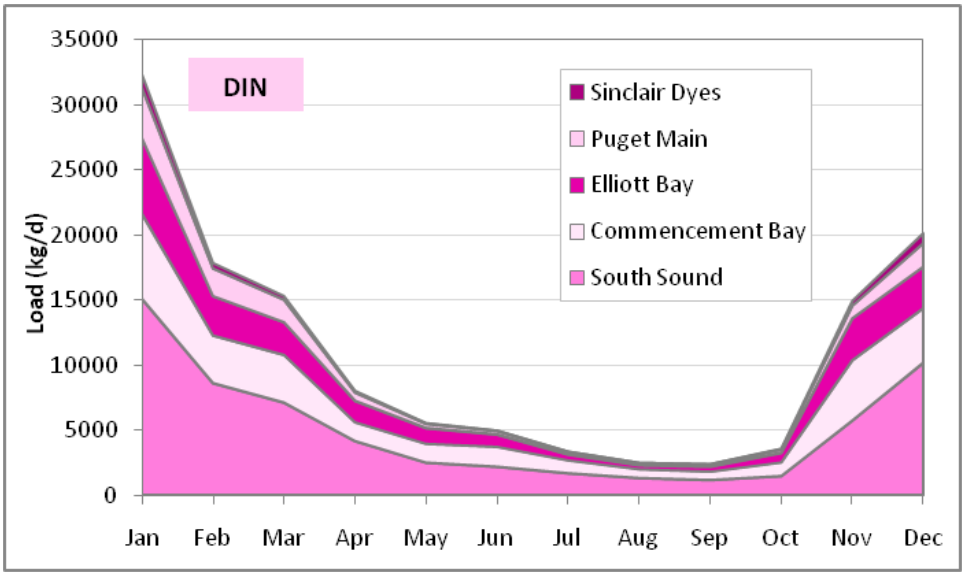

Figure 13. Mean 2006-07 monthly dissolved inorganic nitrogen (DIN) loads from watersheds, totaled according to the regions in South and Central Puget Sound into which they drain.

Septic System Loads

Estimates of DIN loading from on-site septic systems in the exclusive area were provided by Whiley (2010, Appendix C). Again, these estimates are for loads from septic systems in the exclusive area, which do not include areas served by municipal WWTPs or areas that fall within monitored watersheds.

Figure 14 presents a summary of the range of DIN load estimates from septic systems, assuming a 10% loss in DIN from septic systems located less than 150 m from the shoreline, a 70% loss from septic systems located greater than 150 m from the shoreline, and a 58% overall loss from all regions within the exclusive area.

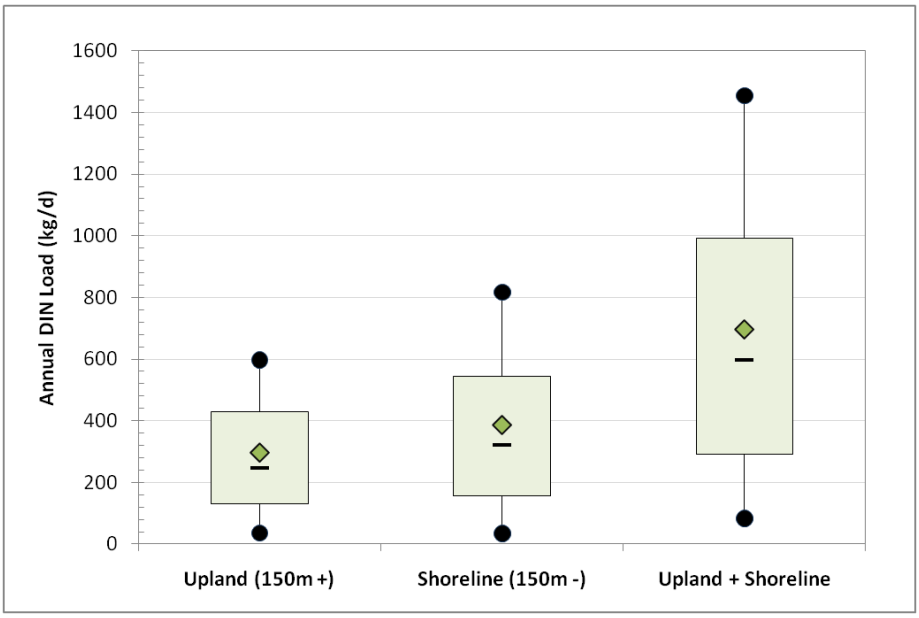

Figure 14. On-site septic systems dissolved inorganic nitrogen (DIN) loading estimates from upland regions, shoreline regions, and both regions combined for water year 2007.
Up/down bars represent 90th and 10th percentiles, boxes represent 75th and 25th percentiles, diamonds represent averages, and the black lines represent the median (adapted from Whiley, 2010).

Table 8 compares the difference in DIN loads between extrapolated areas and monitored areas to those from combined on-site septic systems (values are the 25th and 75th percentile combined values from Figure 14). The difference in load per area between extrapolated and monitored watersheds (515 kg/km^2-yr) is much greater than the range of on-site septic system loads (54 – 184 kg/km^2-yr) in the exclusive area. Because this difference is 2.8 to 9.5 times greater than the estimate of on-site septic system loads, we assumed that the extrapolated watershed loads adequately capture loads from on-site septic systems in the exclusive area.

Table 8. Comparison of DIN loads from monitored areas, extrapolated areas, and on-site septic systems for water year 2007.

	DIN load (kg/d)	Relevant Area (km^2)	DIN Load (kg/ km^2-yr)
Watershed Loads			
Sum of loads at monitoring locations	8859	8775	368
Sum of extrapolated loads	11580	10705	395
Difference:	2722	1930	515
On-site Septic System Loads (in exclusive area)			
Septic system loads: 25th %tile	287	1930	54
Septic system loads: 75th %tile	972	1930	184

Wastewater Treatment Plant Loads

Table 9 compares mean WWTP DIN loads calculated from the multiple linear regression method with those calculated from the monthly field monitoring data. Overall subtotals and totals are comparable, though for individual WWTPs, estimates derived from the regression method are slightly higher than estimates from the monthly data.

Table 9. Comparison of DIN loads from WWTPs estimated from (1) the regression method and (2) monthly data collected during the field monitoring period, 2006-07.

WWTP Name	ANNUAL DIN Load (kg/d)[1]		SEPT. 2007 DIN Load (kg/d)[2]	
	Regression	Monthly Data	Regression	Monthly Data
South Puget Sound				
Boston Harbor	2.4	2.2	1.3	1.2
Carlyon	4.1	3.8*	4.2	3.3
Chambers Creek	2162	2431	1809	2491
Fort Lewis	333	229*	337	208
Hartstene Pointe	2.5	0.3*	0.9	0.3
LOTT	154	142	87	76
Rustlewood	0.9	0.8*	0.4	0.1
Seashore Villa	0.5	0.7*	0.4	0.7
Shelton	57	48	23	13
Tamoshan	0.7	0.6	0.9	0.6
South Sound Subtotal	**2716**	**2858**	**2264**	**2794**
Central Puget Sound				
Bainbridge Kitsap Co 7	3.1	5.9*	2.1	5.9
Bremerton	351	299	149	203
Central Kitsap	457	434	427	507
Gig Harbor	38	40	23	19
Kitsap Co Kingston	3.7	5.4*	3.1	4.6
Lakota	800	753	648	578
Manchester	6.5	5.7	5.6	2.9
Midway	421	432	367	356
Miller Creek	345	241*	268	241
Port Orchard	131	122	118	108
Redondo	239	240	171	202
Salmon Creek	303	104*	193	93
Simpson Kraft	15	5.8	10.5	1.9
South King	9002	8880	8469	8376
Suquamish	7.1	18*	4.3	18
Tacoma Central	1978	1946	1918	1704
Tacoma North	385	359	376	380
Vashon	5.2	4.4*	3.0	0.1
West Point	9382	8300	9867	8847
Central Sound Subtotal	**23871**	**22195**	**23024**	**21647**
South and Central Puget Sound TOTAL	**26587**	**25054**	**25288**	**24442**

[1]For the regressions, these values are the mean of the daily regressions for WY07 (October 2006 through September 2007). For the monthly data, the DIN loads for these values are calculated from monthly grab samples collected in WY07. Any missing monthly grab values are not factored into the annual averages.

[2]For the regressions, these values are the mean of September 2007 daily regressions. For the monthly data, these values are the instantaneous loads calculated from the September 2007 grab samples.

* Indicates WWTPs only monitored for only 3 months between August and September 2007, so the equivalent average is used for the annual average given that effluent loads generally do not vary significantly compared with streams.

The purpose of this comparison is to illustrate that the regression method is a realistic and reasonable method of estimating DIN loads (and loads for other nutrient parameters) since in most cases, these estimates are similar to measured loads.

The mean monthly data in Table 9 are different WWTP loads listed in Table 17 of the Interim Data Report (Roberts et al., 2008). The values in Table 17 were calculated for a 12-month period; however, the three months for which two years of data were available were averaged across the two years. For the purposes of comparison in this current report, annual averages are presented for water year 2007. Missing months are not considered in these averages. Also, WWTPs for which three months of data are included and averaged as indicative of annual average values. These are noted with an asterisk in Table 9 but included for completeness. WWTPs do not show as much seasonal variability as rivers and streams, but the loads may still be biased low somewhat compared to a true annual average.

The estimates derived from the regression method are our best estimate of loading for several reasons: (1) these estimates are available at a daily time step accounting for changes over the course of the year, (2) they include loads from all WWTPs in the study area, and (3) there are no gaps throughout the 2006-07 study period. A complete table of summer and annual DIN loads for all WWTPs in South and Central Puget Sound is included in Appendix G.

Most WWTPs had slightly lower mean annual DIN loads in 2007 than in 2006, but the difference in DIN loads between the two years was much less than the difference in watershed loads. The total mean annual DIN loads from all WWTPs in the study area were 4% lower in 2007 than in 2006. Mean annual effluent flows from WWTPs were also slightly lower in 2007, by 9%.

Figure 15 geographically illustrates median DIN concentrations for all WWTPs in the study area. Figure 16 presents box and whisker plots of WWTP DIN concentrations.

Effluent from the following WWTPs have the highest median concentrations of DIN based on monitoring data (Carlyon Beach) or regressions developed from monitoring data (Chambers Creek, Lakota, Central Kitsap and Tacoma-Central). Overall, effluent DIN concentrations are higher for WWTPs located in Central Puget Sound relative to WWTPs located in South Puget Sound.

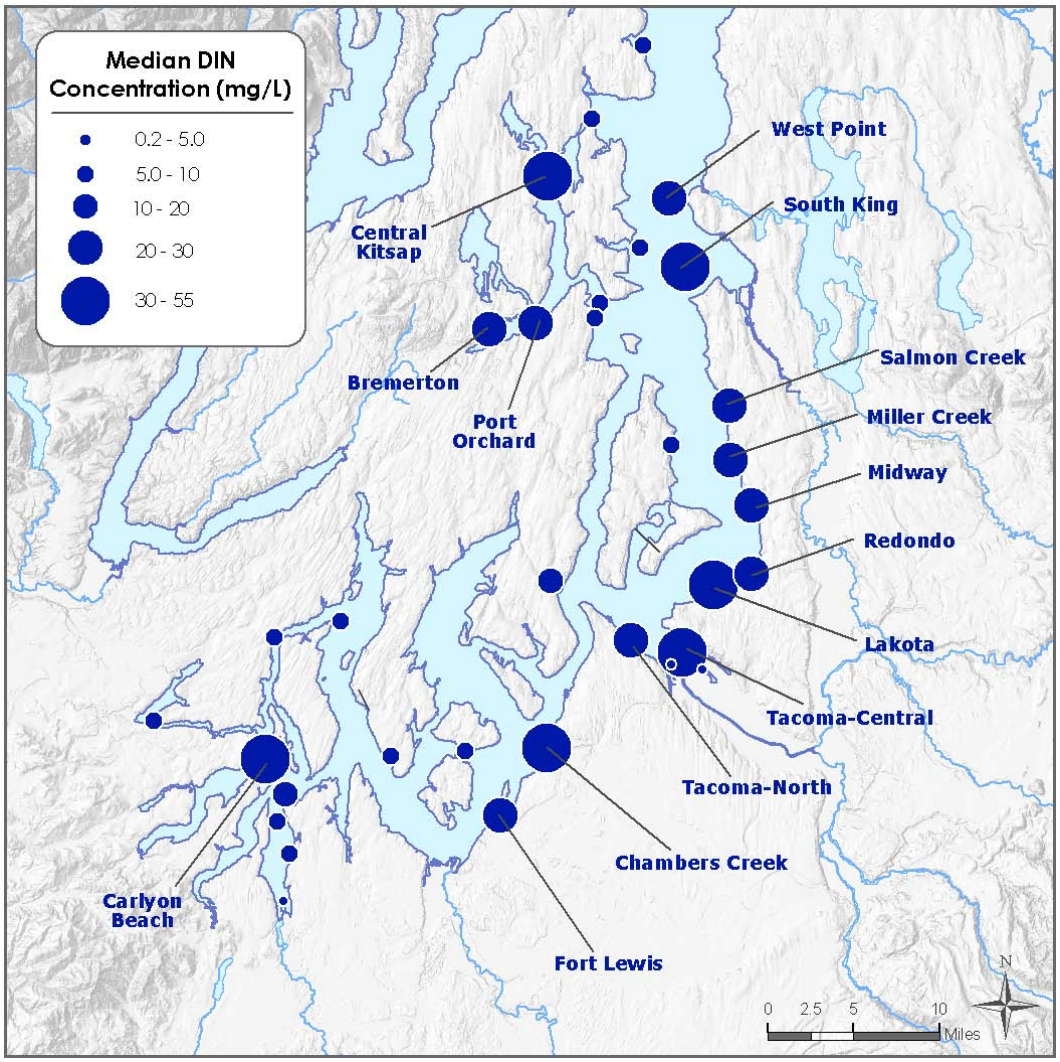

Figure 15. Median WWTP dissolved inorganic nitrogen (DIN) concentrations, 2006-07.
Only watersheds that have DIN concentrations greater than 20 mg/L are labeled.

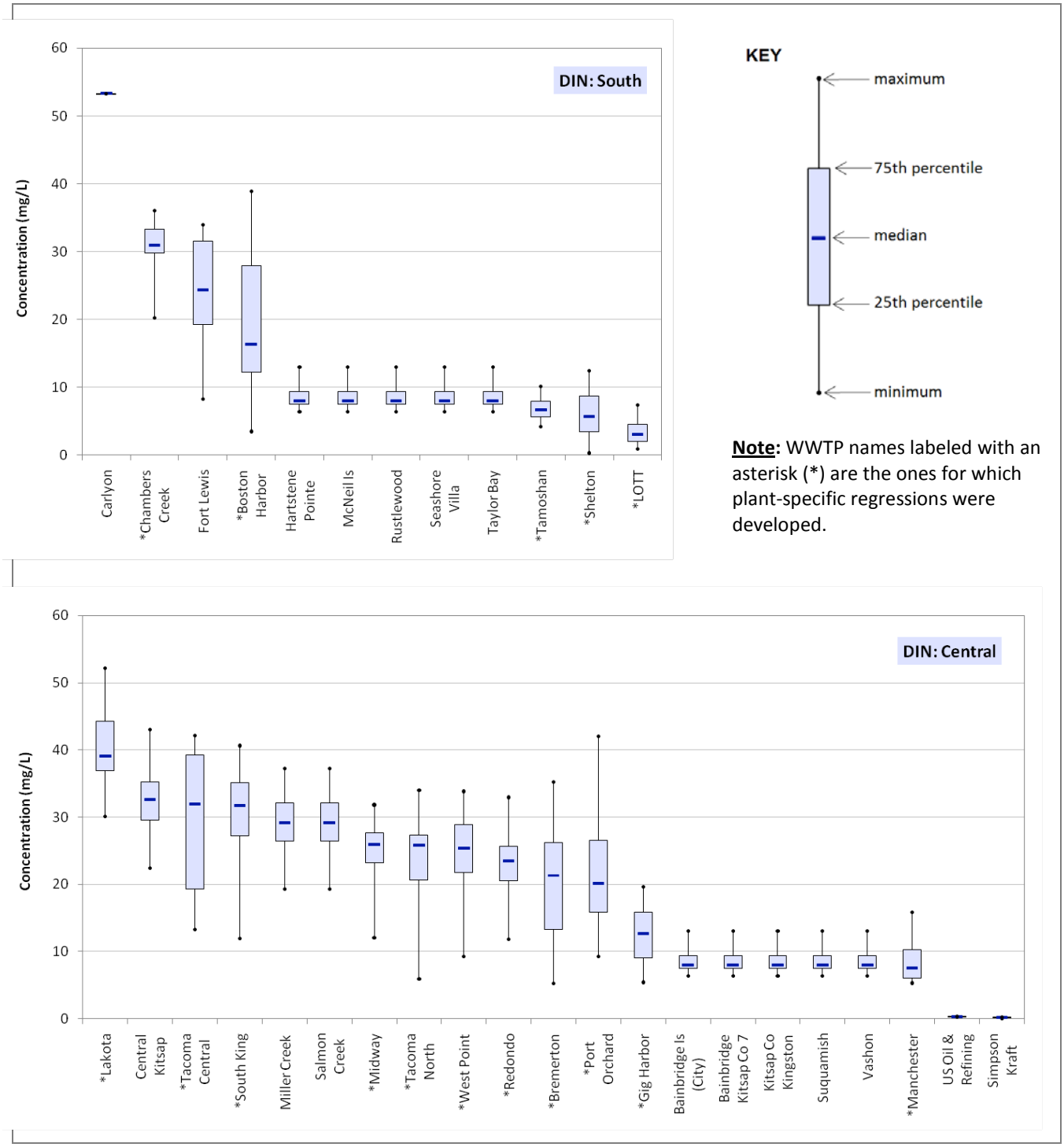

Figure 16. Box plots of dissolved inorganic nitrogen (DIN) concentrations for WWTPs in South (top) and Central (bottom) Puget Sound, 2006-07.

Since some WWTPs are larger than others in terms of the magnitude of their effluent flow, the WWTPs that have the highest nitrogen concentrations are not necessarily the same ones that have the highest nitrogen loads. For example, even though Carlyon Beach has relatively high nitrogen concentrations compared to other WWTPs in the study area, the nitrogen loading from this WWTP is relatively low. Figure 17 illustrates annual DIN loads from all WWTPs in the study area.

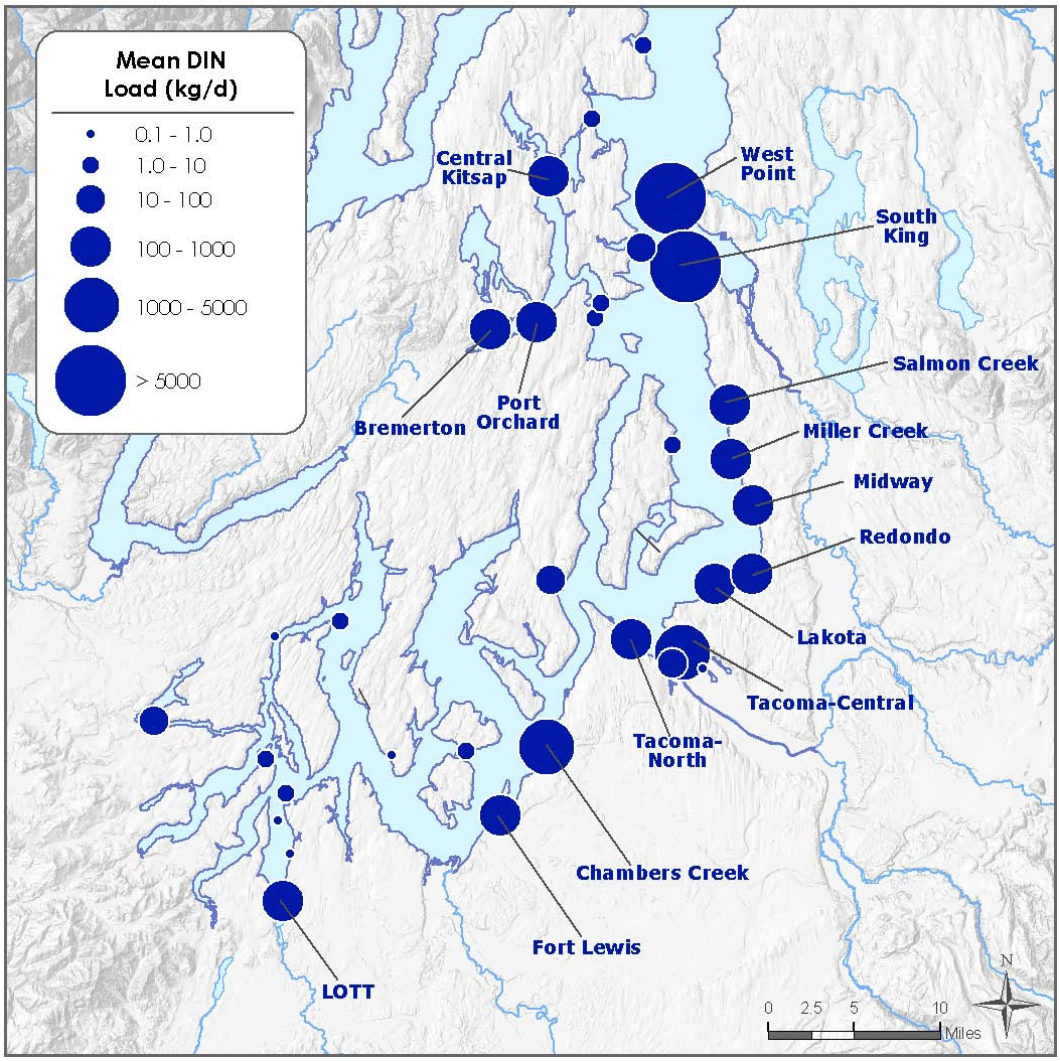

Figure 17. Mean dissolved inorganic nitrogen (DIN) loads from WWTPs from watersheds into South and Central Puget Sound during 2006-07.

Only WWTPs that have DIN loads greater than 100 kg/d are labeled.

West Point and South King have the highest annual DIN loads, discharging an average of 9670 kg/d and 8810 kg/d of DIN, respectively. Chambers Creek (2140 kg/d) and Tacoma Central (2060 kg/d) are the next highest sources of DIN loading.

Monthly average nitrogen loads do not vary greatly over the course of the year (Figure 18). WWTPs located in the Puget Main region contribute 75% of the average annual DIN load of all WWTPs in the study area. In contrast, WWTPs in the South Sound contribute 12% of the average annual DIN load of all WWTPs in the study area. This is a reflection of the higher population areas and larger urban centers served by WWTPs that discharge into Puget Main.

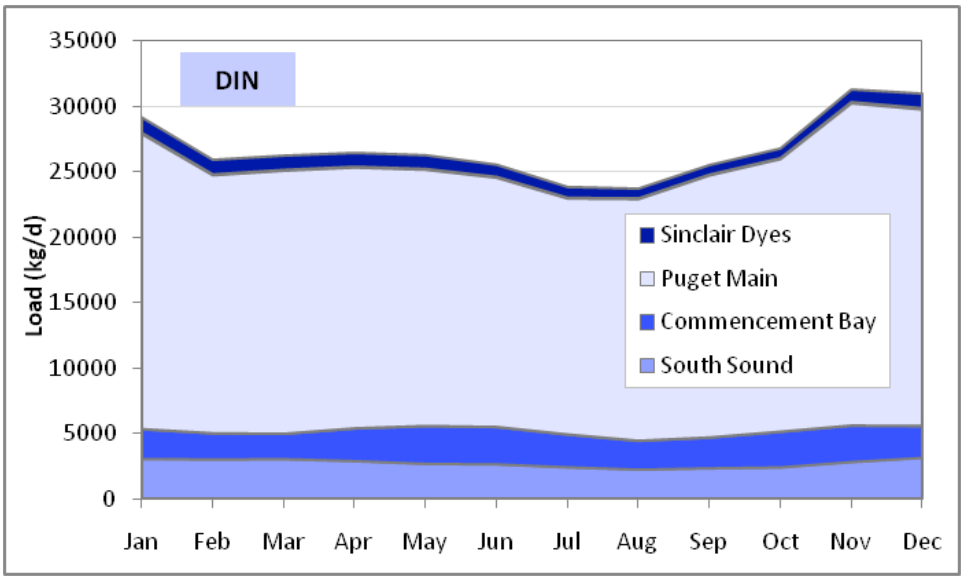

Figure 18. Mean 2006-07 monthly dissolved inorganic nitrogen (DIN) loads from WWTPs totaled according to the regions in South and Central Puget Sound into which they discharge effluent.

Combined Loads

In addition to nitrogen loads from rivers, WWTPs, and on-site septic systems, the water quality model will include nitrogen loading from ocean, the atmosphere, and internal sediment fluxes. This will allow us to show the effect of all these sources on DO levels. Combined loads in this portion of the report, however, focus primarily on rivers and WWTPs.

Figure 19 compares and contrasts NH4N and NO23N concentrations for all rivers and WWTPs within the study area. These box plots were created by summarizing statistics on the *median* concentrations of NH4N and NO23N. For example, the minimum values in Figure 19 (lower bars with black dot) are the minimum of all median concentrations of NH4N and NO23N for all rivers and WWTPs.

WWTPs have NH4N concentrations that are two to three magnitudes higher than rivers, and NO23N concentrations that are about one magnitude higher than rivers. NO23N concentrations in rivers are generally higher than NH4N concentrations, while the opposite is true for WWTPs, which have higher NH4N concentrations than NO23N concentrations.

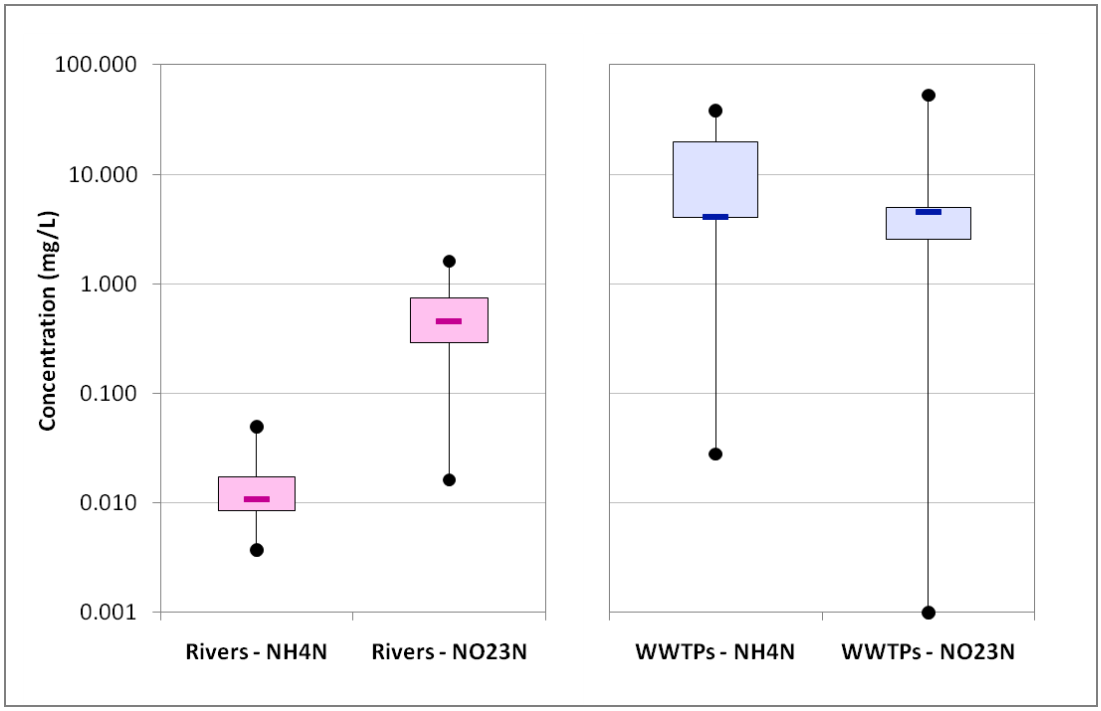

Figure 19. Box plots comparing the range of median concentrations of NH4N and NO23N across all rivers and WWTPs in the study area, 2006-07.

The y-axis is on a logarithmic scale.

Combined average daily DIN loads for 2006-07 from rivers and WWTPs are presented geographically in Figure 20. Watershed loads dominate in Eld, Totten, Case, and Carr Inlets. Watersheds and WWTPs discharge comparable loads in Commencement Bay and in portions of South Puget Sound east of Budd Inlet. Loads from three of the four largest rivers (Nisqually, Puyallup, Green) are comparable in magnitude to loads from Chambers Creek and Tacoma-

Central. West Point and South King in Central Puget Sound have the largest DIN loads of the sources quantified to date.

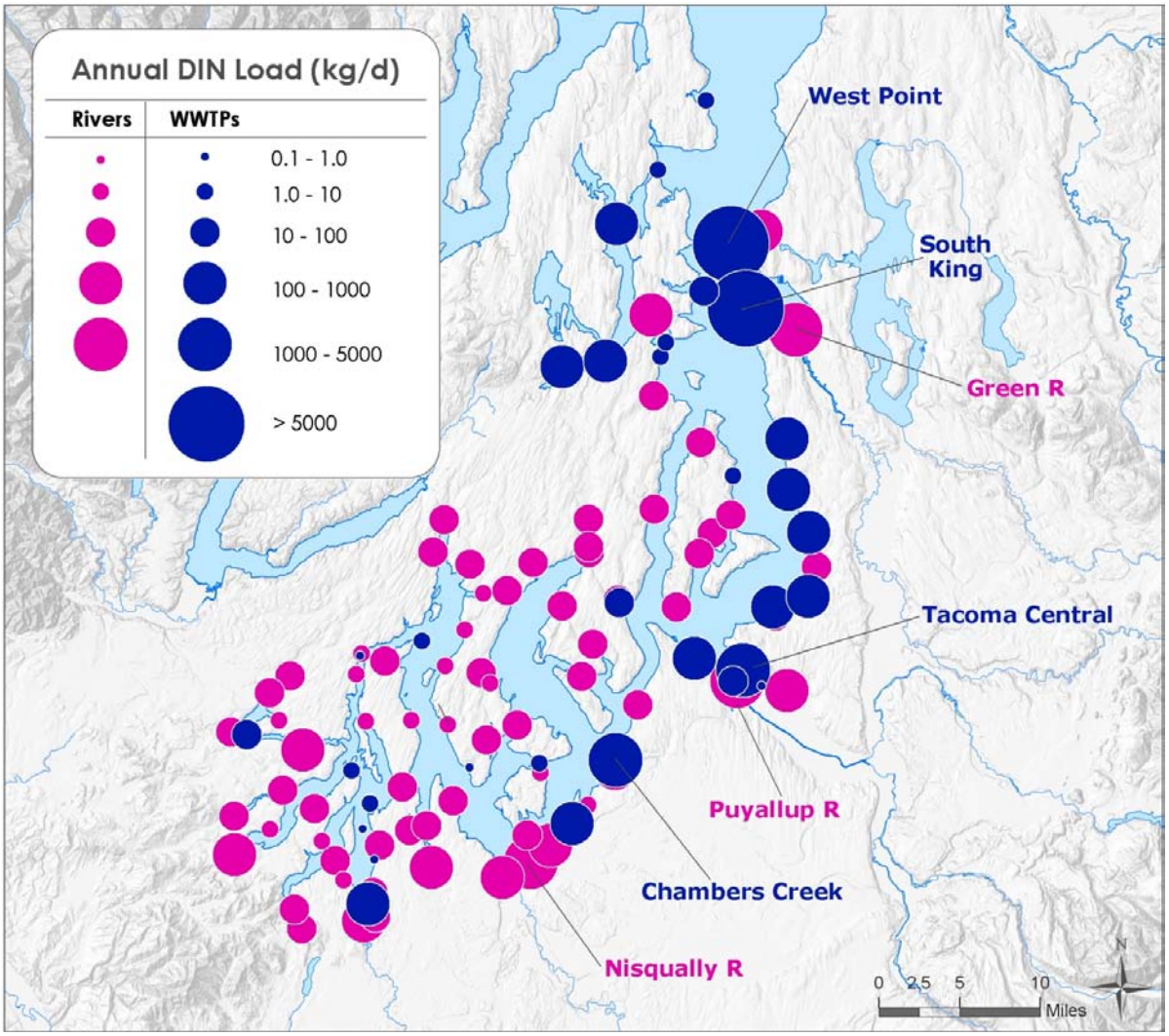

Figure 20. Average daily dissolved inorganic nitrogen (DIN) loads from rivers and WWTPs into South and Central Puget Sound during 2006-07.

The relative magnitude of average daily DIN loads from rivers and WWTPs changes when evaluated only during the summer (average of July, August, and September). These summer months are critical since near-bottom DO levels were generally found to be lowest in September (Roberts, et al., 2008). The months preceding these low DO conditions are therefore an important time period.

As illustrated in Figure 21, DIN loads from rivers drop during the summer because of lower streamflows and less precipitation; all DIN loads from rivers during the summer are below 1000 kg/d. Although WWTP DIN loads during the summer are also slightly lower than during the rest of the year, they still dominate. West Point and South King are the two largest single sources of DIN, followed by Chambers Creek and Tacoma-Central.

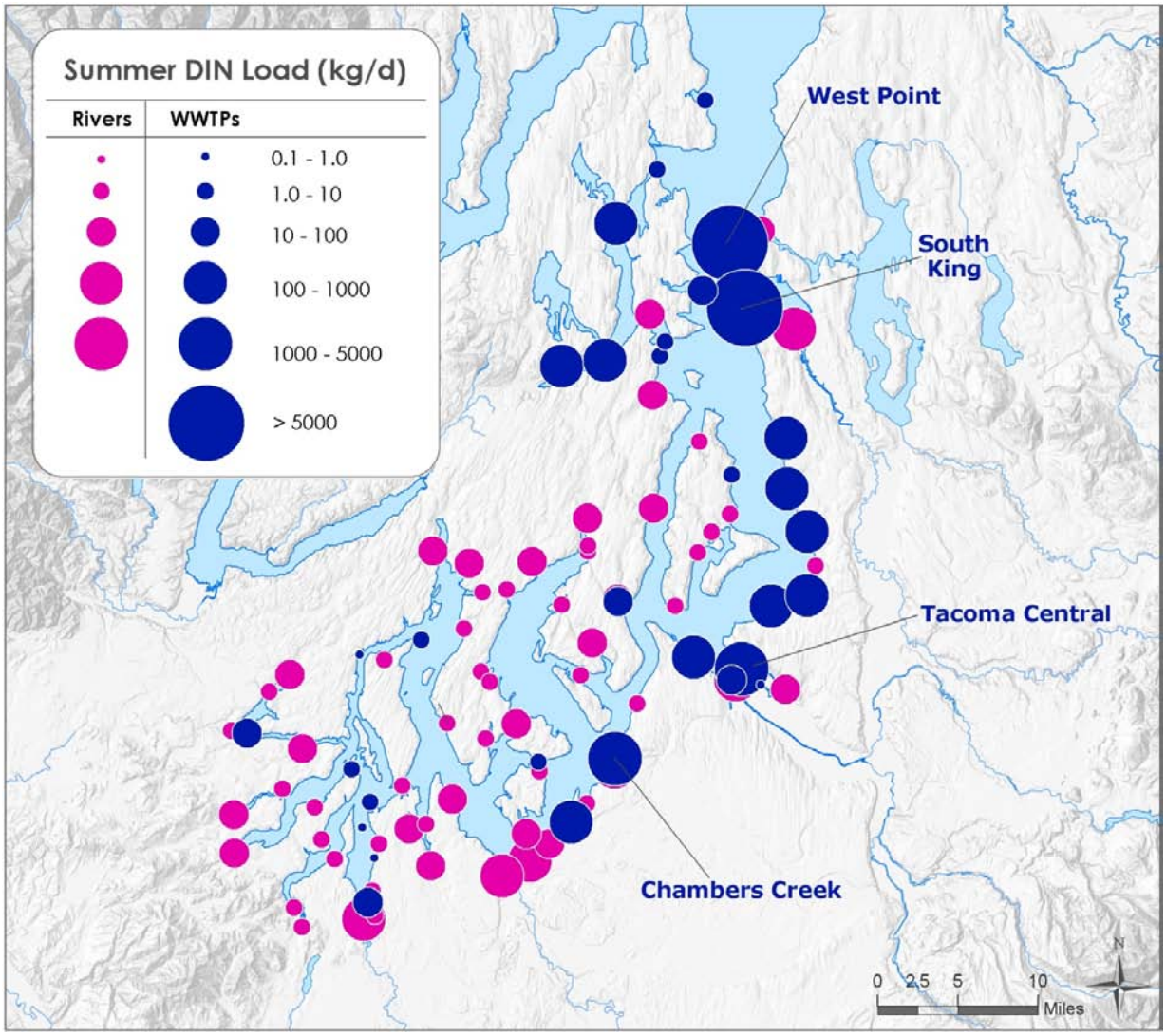

Figure 21. Summer (average July, August, and September during 2006-07) daily dissolved inorganic nitrogen (DIN) loads from rivers and WWTPs into South and Central Puget Sound.

Daily river DIN loads are more variable than daily WWTP DIN loads since river loads reflect variability in river flows, which change with seasons (Figure 22). In South Puget Sound, daily river DIN loads are much greater than WWTP DIN loads during November through April, but the two sources are comparable in magnitude during the drier months (Figure 22, top). In central Puget Sound, however, WWTP DIN loads are greater than river DIN loads throughout the year except during a few large storm events during the winter (Figure 22, bottom).

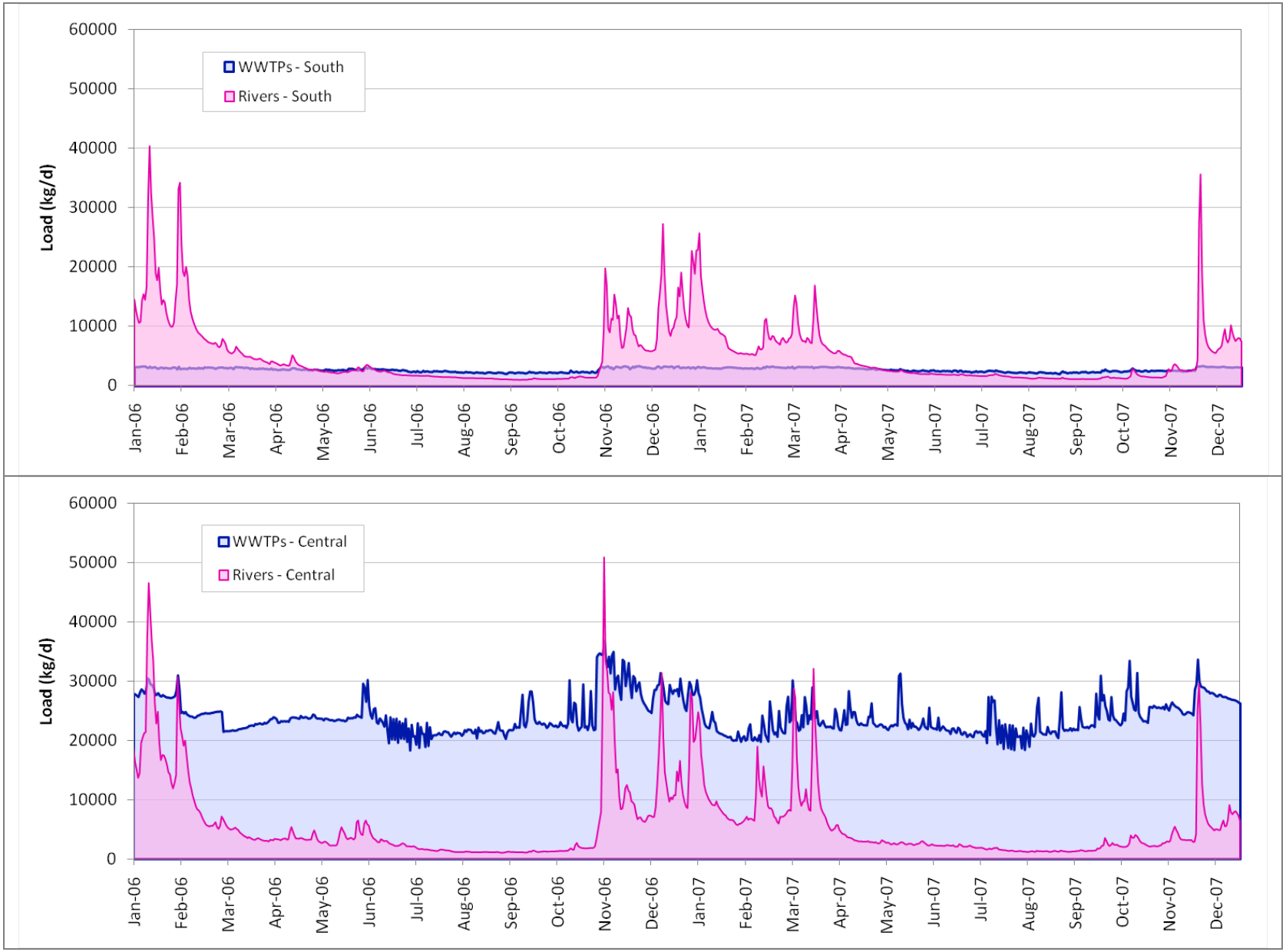

Figure 22. Daily dissolved inorganic nitrogen (DIN) loads from rivers and WWTPs into South (top) and Central (bottom) Puget Sound, 2006-07.

Figure 23 presents the 7-day average of daily DIN loads from rivers and WWTPs in South and Central Puget Sound, stacked on top of each other. The 7-day average of daily DIN loads (rivers plus WWTPs) into South and Central Puget Sound ranges from approximately 25 – 95 metric tons/day, and 64-89% of this load is from Central Puget Sound.

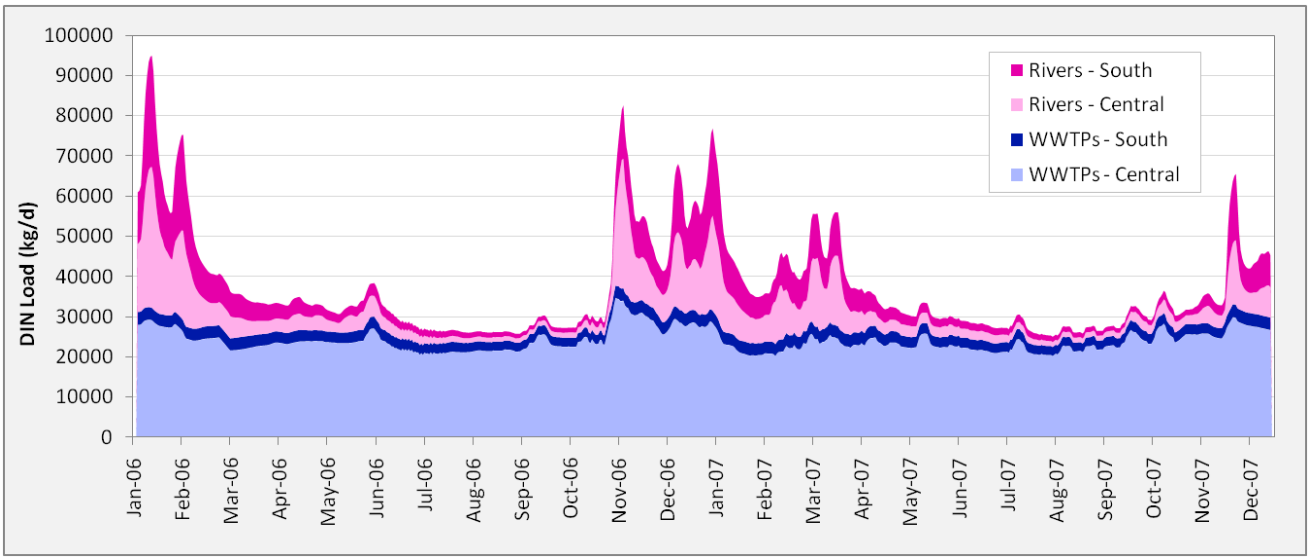

Figure 23. Seven-day average of daily dissolved inorganic nitrogen (DIN) loads from rivers and WWTPs into South and Central Puget Sound, 2006-07.

Figure 24 summarizes the relative DIN loads from rivers and WWTPs into South and Central Puget Sound on an annual basis and during the summer.

In South Puget Sound, rivers have higher DIN loads (65%) than WWTPs (35%) on an annual basis (Figure 24, top left). The ratio of river to WWTP load flips during the summer when river loads are low due to lower flows, and they contribute to 37% of the load while WWTPs contribute 63% (Figure 24, top right).

In Central Puget Sound, WWTPs contribute 81% of the annual average DIN load (Figure 24, center left) and 94% of the average summer DIN load (Figure 24, center right). When DIN loads from rivers that are tributary to South and Central Puget Sound are combined, rivers draining into South Puget Sound contribute almost the same share of DIN loads as rivers draining into Central Puget Sound. Of the total combined loads into South and Central Puget Sound, WWTPs contribute 71% of the load on an annual basis, and 90% of the load during the summer.

Overall, DIN loads from rivers and WWTPs into Central Puget Sound are three and half times greater than DIN loads into South Puget Sound (Figure 25).

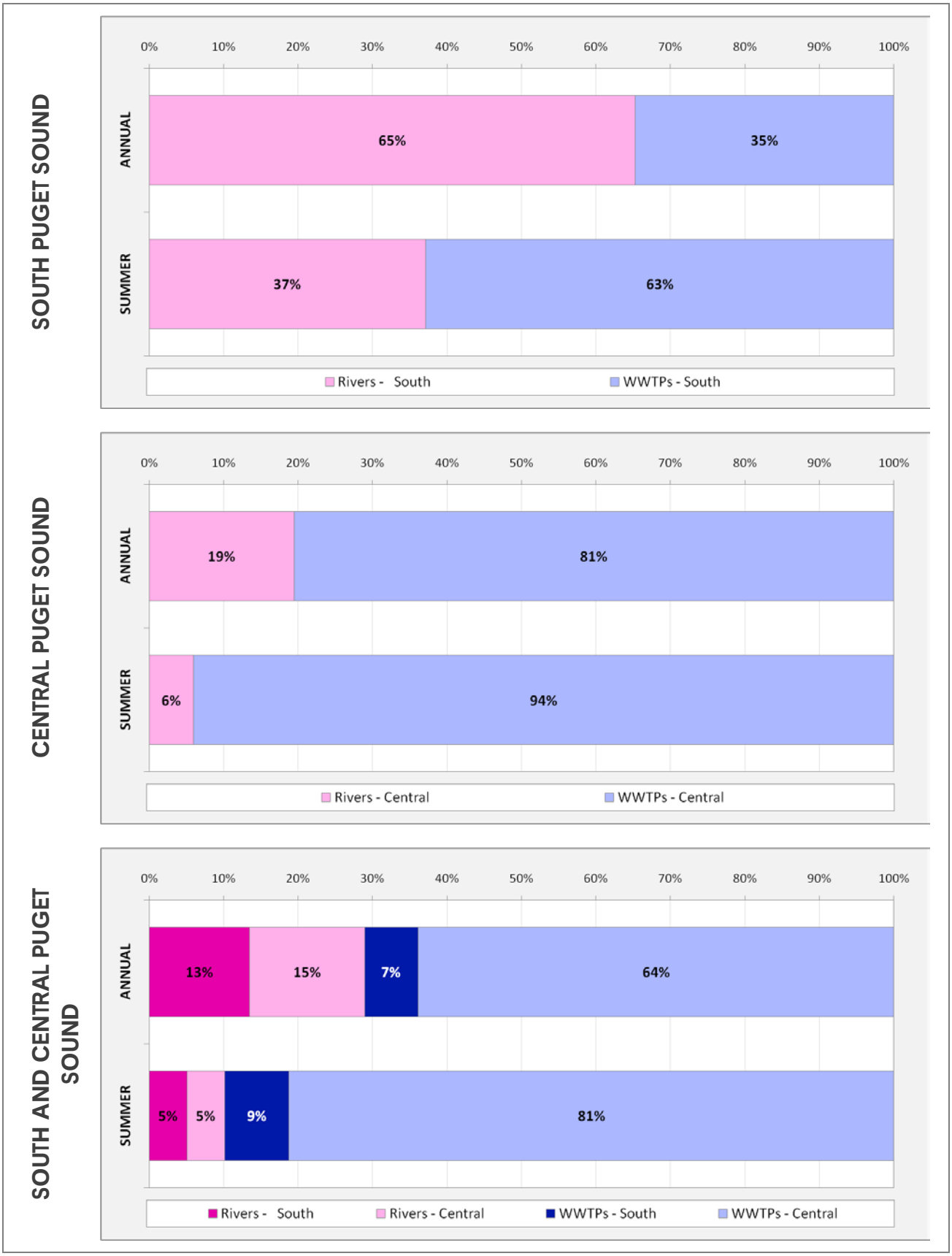

Figure 24. Pie charts comparing the relative contributions of dissolved inorganic nitrogen (DIN) loads from rivers and WWTPs into South and Central Puget Sound on an annual basis and during the summers of 2006-07.

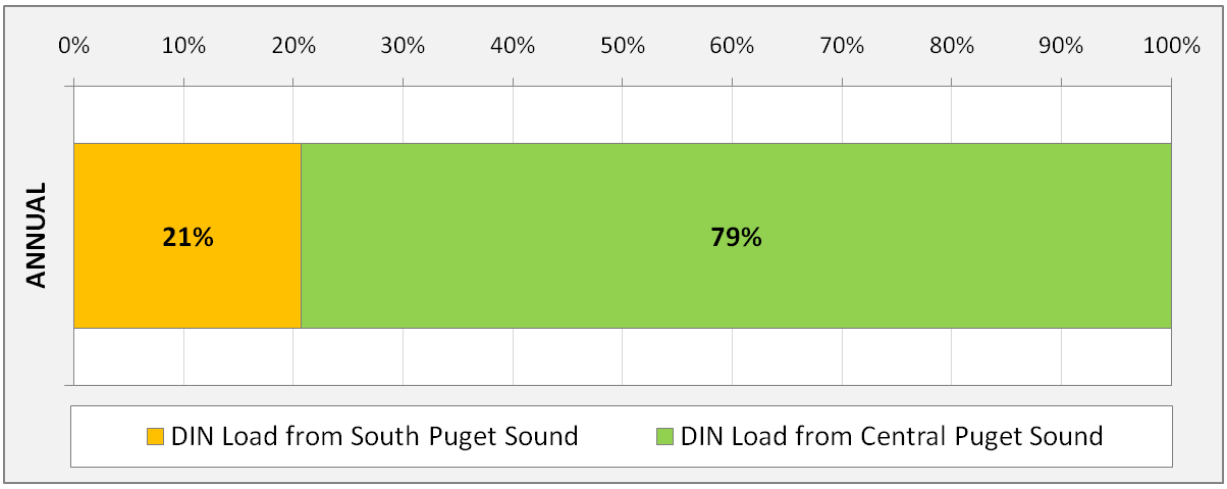

Figure 25. Annual dissolved inorganic nitrogen (DIN) loads from rivers and WWTPs into South vs. Central Puget Sound, 2006-07.

Groundwater Loads

We also estimated DIN loads from groundwater discharging *directly* into the marine waters of South and Central Puget Sound. These estimates are based on Puget Sound-wide groundwater-to-marine discharge volumes presented in Vaccaro et al. (1998) extrapolated to South and Central Puget Sound (Pitz, 2010).

Though groundwater DIN load estimates are presented separately here, these loads are included in our estimate of watershed loads. Watershed loads include baseflow (which is predominantly groundwater), and the extrapolation of watershed loads from the monitoring location to the mouth of each watershed also includes groundwater loads into South and Central Puget Sound from shallow near-shore areas. Because marine discharges of groundwater likely occur in shallow marine waters and represent sources near the shoreline, the nutrient sources in these regions are likely captured within the surface water pathway even though a small proportion may be delivered via a groundwater pathway.

To estimate groundwater DIN loads, we relied on information from other groundwater studies. In a USGS study, Vaccaro et al. (1998) estimated that the volume of groundwater discharge to saltwater bodies in the Puget Sound Lowland varied from 100 to 1000 ft^3/s (2.8 to 28 m^3/s). However, their estimate was averaged across the entire Puget Sound Lowland, including areas outside our study area and areas north of Edmonds.

Pitz (2010) performed an analysis to distribute this 2.8 to 28 m^3/s estimate of groundwater discharge into different regions of Puget Sound using the shoreline length associated with each of these regions. Using Pitz's (2010) estimates, groundwater discharge into South Puget Sound ranges from 1.0 to 10 m^3/s. Groundwater discharge into Central Puget Sound is about half of that in South Puget Sound, ranging from 0.5 to 5.0 m^3/s. This reflects the longer shoreline length in South Puget Sound due to its many inlets. Groundwater is therefore 0.8% to 7.0% of the total freshwater inflow (rivers plus groundwater) into South Puget Sound, and 0.2% to 2.2% of the total freshwater inflow into Central Puget Sound.

We then used this groundwater discharge information to develop a range of estimates of DIN loads by multiplying groundwater flow by groundwater DIN concentrations. Pitz (1999) estimated concentrations of nitrate in groundwater discharging into South Puget Sound using water quality data from wells monitored by the Washington State Department of Health (WDOH). The geometric mean of concentrations from WDOH well data ranged from 0.25 to 0.65 mg/L in different regions of South Puget Sound. Pitz (1999) explains how these concentrations generally under-predict nitrogen concentrations in groundwater and can be biased low. The main reason for this bias is that WDOH wells are production wells which are used for water supply; these wells are deep and therefore capture water from aquifers which generally have higher water quality and therefore less nitrogen.

To develop a conservative estimate of DIN loads, we selected a groundwater DIN concentration of 0.65 mg/L, which is the high end of WDOH data (assuming most of DIN in groundwater is in the form of nitrate). Multiplying this concentration by our range of groundwater flows, we calculated a range of groundwater DIN load estimates. The results of this analysis, including estimates of DIN loads, are summarized in Table 10.

The lower range of DIN loads (~ 1%) are within the noise of flow measurements. Even using the higher estimate of DIN loads (just under 10%), groundwater DIN loads are not likely to be a major determinant of nutrient levels in the Puget Sound region.

Table 10. Estimates of groundwater discharge and groundwater DIN loads into South and Central Puget Sound.

	Minimum estimate	Maximum estimate
Total groundwater discharge		
South Puget Sound	1.0 m^3/s (35 cfs)	10 m^3/s (352 cfs)
Central Puget Sound	0.5 m^3/s (18 cfs)	5 m^3/s (178 cfs)
Groundwater discharge as a % of freshwater inflows		
South Puget Sound	0.8%	7.0%
Central Puget Sound	0.2%	2.2%
Groundwater DIN load		
South Puget Sound	56 kg/d	560 kg/d
Central Puget Sound	28 kg/d	283 kg/d
Groundwater DIN load as a % of freshwater DIN loads		
South Puget Sound	1.1%	9.9%
Central Puget Sound	1.0%	8.8%

Atmospheric Loads

Atmospheric deposition of DIN to the surface waters of South and Central Puget Sound were estimated by Roberts et al. (2008) and make up only 1% of the annual DIN loads in the study area. Figure 26 compares DIN loads into South and Central Puget Sound from rivers, WWTPs, and the atmosphere.

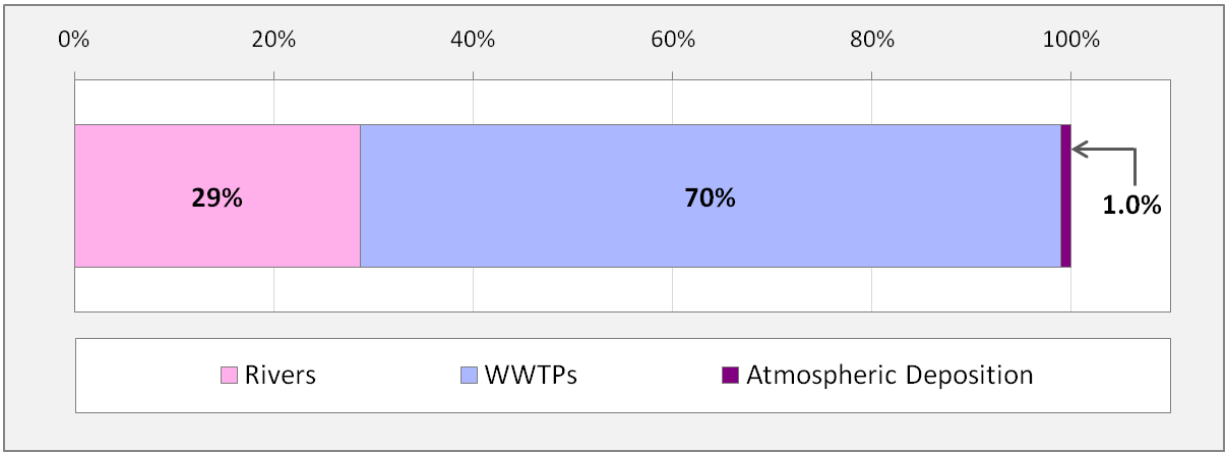

Figure 26. Annual dissolved inorganic nitrogen (DIN) loads from rivers, WWTPs, and the atmosphere.

Loads from on-site septic systems and groundwater are included in the 'Rivers' share of the bar chart.

Oceanic Loads

Oceanic loads will be calculated as part of the modeling effort and are not specified using the same method as that used for WWTP or river loads. Instead of a flow rate, tidally-varying water levels are specified at the northern model boundary. Differences in water levels induce flow back and forth throughout the model. Marine concentrations are specified for the incoming tide using observed data collected at monitoring stations near Edmonds. The data are monthly but are interpolated to finer time scales. Concentrations for the outgoing tide reflect complex physical, chemical, and biological processes that are simulated within the modeling domain. The loads in and out of the model at the Edmonds boundary, as well as the net effect, will be calculated once the model is calibrated and applied to a series of scenarios.

Natural Conditions for Nutrient Loads

Table 11 summarizes results from our meta-analysis used to calculate natural conditions for rivers and streams within the South and Central Puget Sound watersheds.

Table 11. Nutrient result summary for rivers and streams in South and Central Puget Sound and nearby reference areas.

Location	Statistic	TPN (mg/L)	NO23N (mg/L)	NH4N (mg/L)	TP (mg/L)	OP (mg/L)	Notes
Recent Ambient Data (within model domain)							
Puget South	annual mean of monthly 10%iles	0.238	0.200	0.010	0.020	0.008	1
Commencement Bay	annual mean of monthly 10%iles	0.205	0.152	0.012	0.107	0.014	1
Puget Main	annual mean of monthly 10%iles	0.206	0.169	0.010	0.011	0.005	1
Elliott Bay	annual mean of monthly 10%iles	0.362	0.284	0.013	0.034	0.010	1
	Mean for this method:	0.253	0.201	0.011	0.043	0.009	
Recent Ambient Data (near model domain)							
Hood Canal	annual mean of monthly 10%iles	0.041	0.027	0.010	0.009	0.005	1
SJF/SOG	annual mean of monthly 10%iles	0.031	0.016	0.010	0.012	0.004	1
Whidbey	annual mean of monthly 10%iles	0.141	0.107	0.010	0.018	0.004	1
	Mean for this method:	0.071	0.050	0.010	0.013	0.004	
Historical Ambient Data (less developed watersheds)							
Nisqually	annual mean of monthly medians	--	0.212	--	--	--	2
Lower Skagit	annual mean of monthly medians	--	0.346	0.043	0.019	0.010	2
Upper Skagit	annual mean of monthly medians	--	0.238	0.027	0.012	0.012	2
	Mean for this method:	--	0.265	0.035	0.016	0.011	
Recent Ambient Data (less developed watersheds)							
Nisqually	median of most recent water year	0.203	0.163	0.01	0.025	0.009	2b
Lower Skagit	median of most recent water year	0.141	0.113	0.01	0.019	0.004	2b
Upper Skagit	median of most recent water year	0.079	0.062	0.01	0.006	0.003	2b
	Mean for this method:	0.141	0.113	0.010	0.017	0.005	
Atmospheric (rainfall) data							
Olympics station only	annual mean of monthly medians	--	0.120	0.013	--	--	3
All 4 Stations	annual mean of monthly medians	--	0.291	0.035	--	--	3
Toxics in Surface Runoff							
Forested basins	median of data	0.270	0.210	0.010	0.015	0.005	4
Hood Canal Dissolved Oxygen Program							
Forested basins	Unclear	--	0.070	--	--	--	5

Notes: General: Non-detects, primarily for ammonia, are represented at the detection limit.

1. These are the 10%ile of recent data collected at several of Ecology's ambient monitoring stations, aggregated into different regions of Puget Sound. For all parameters except TP, these are the 10%tile of data collected between WY 2002 and WY 2009. For TP, data are from WY 2008 and WY 2009 since there was a change in lab methods in 2003 and again in 2007 which did not allow us to pool the older data with the newer data.
2. Historical ambient monitoring data collected by Ecology were used. The Nisqually and Lower and Upper Skagit Rivers were chosen because these watersheds have less development than other watersheds in Puget Sound, and are potential reference sites for natural conditions. Data for the following years were used for each parameter: NO23N: WY 1960-1970; NH4N and OP: WY 1976-1979; TP: WY 1975-1979. Dashes ("--") mean that data were not available.

2b. The most recent ambient monitoring data from Ecology are for October 2008 through September 2009.

3. Atmospheric concentration data (i.e. rainfall) for WY 2002-2009 were downloaded from the National Atmospheric Deposition Program. There are four stations located in Western Washington: one in the Olympics, two near Mt. Rainier, and one in the North Cascades. The station located in the Olympics, however, is upwind from the other stations and least affected by local sources of nutrients, therefore serving as a better reference station for natural conditions.
4. Nutrient concentrations in surface runoff (baseflow and stormwater events) were measured by Herrera Environmental Consultants as part of the Puget Sound Toxics Loading project (www.ecy.wa.gov/biblio/0910052.html). The values here are the median of data collected from predominantly forested sub-basins in the Puyallup and Snohomish watersheds.
5. The Hood Canal Dissolved Oxygen Program has estimated this value as the natural background DIN concentrations for Hood Canal as part of their study (Steinberg et al., 2010). The value is intended to represent baseline stream water DIN concentrations.

Nutrient concentrations generally reflect development levels, with lower values in less developed watersheds such as Hood Canal and higher in more developed watersheds such as Elliott Bay. It is also interesting to note that recent median concentrations of nitrogen in the Skagit River are generally *lower* than 1960s and 1970s median concentrations. Although the exact reason for this is unknown, it may be a combination of factors including improved lab analysis methods, and higher historical contributions from nonpoint sources of nitrogen in the 1960s and 1970s.

Mean annual nitrogen concentrations from the atmospheric station in the Olympics are lower than those for all four stations pooled together. The Olympic station does experience higher rainfall and, as a result, concentrations may be biased low. However, it is more relevant to the calculation of natural conditions since it is upwind of local atmospheric nitrogen sources within the Puget Lowland. These sources influence the other atmospheric stations located in western Washington.

Median concentrations of nutrients in surface runoff (from forested basins) were estimated as part of the Puget Sound Toxics Loading Project. These concentrations are comparable to the mean annual 10th percentile of monthly ambient data.

A number of methods are presented in Table 12 for context, but only a subset of the methods was eventually selected to calculate monthly natural condition concentrations. Table 12 presents the annual mean for each of these selected methods as well as the overall annual mean for all these methods.

Table 12. Mean annual concentrations of different parameters for selected methods within the meta-analysis.

Method / Statistic	TPN	NO23N	NH4N	TP	OP
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Recent ambient data within model domain (annual mean of monthly 10%iles)	0.253	0.201	0.011	0.043	0.009
Historic data from less developed watersheds (annual mean of monthly medians)	0.375*	0.265	0.035	0.016	0.011
Atmospheric (rainfall) data from Olympics (median)	0.166*	0.120	0.013	--	--
Surface runoff in forested basins (median, from PS Toxics Loading Project)	0.270	0.210	0.010	0.015	0.005
Hood Canal Dissolved Oxygen Program (baseline DIN concentration)	0.088*	0.070	--	--	--
Overall Mean For Selected Methods	**0.230**	**0.173**	**0.017**	**0.025**	**0.008**

* Where TPN data were not available, the estimate was based on a relationship developed from Table 10, where DIN = 80% of TPN on average.

Only annual means are presented in Table 12. However, the natural condition was calculated for each month out of the year. Where monthly values were not available for a particular method, a single value was used to represent each month of the year. Figure 27 illustrates this visually, showing how the natural condition for DIN (i.e. concentration of DIN) was calculated as the mean of all the other methods in Table 12.

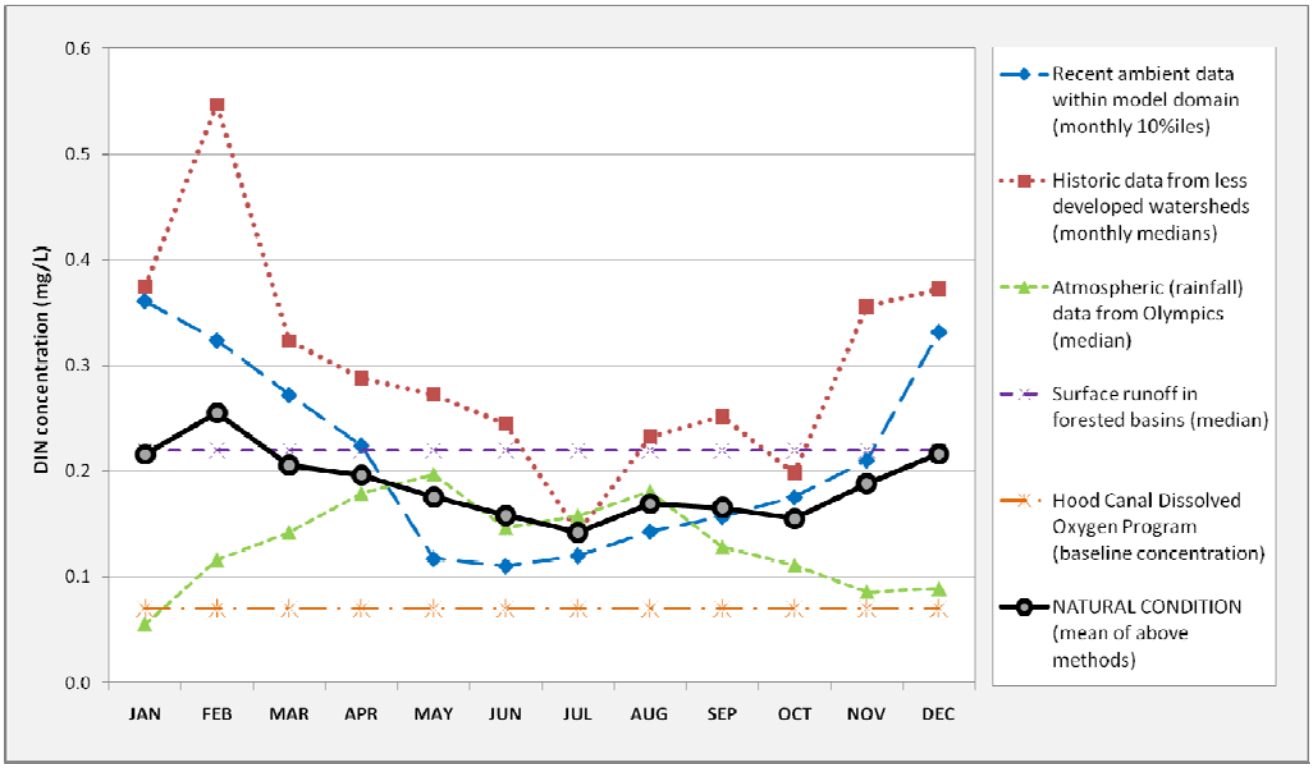

Figure 27. Mean monthly dissolved inorganic nitrogen (DIN) concentrations from the different methods used to calculate natural conditions.

The black solid line is the mean value of all the other methods and was used to represent natural conditions for all rivers and streams within the study area.

Figure 27 illustrates how natural DIN concentrations are lower in the summer when primary productivity converts nitrogen in the water to gaseous form that is lost to the atmosphere, and higher in the winter. Natural DIN concentrations range from 0.142 mg/L to 0.217 mg/L.

We then calculated daily DIN loads under natural conditions by multiplying the DIN concentrations in Figure 27 with the total daily streamflow for all rivers and streams in South and Central Puget Sound (i.e. for the entire watershed, not just monitored rivers) as follows:

$$DIN\ Load\left(\frac{kg}{day}\right)=\frac{\sum(DIN\ Concentration * Total\ Daily\ Streamflow^{7}\ 2006\ \&\ 2007)}{730\ days}$$

[7] The daily streamflow was the sum of streamflows from all 75 rivers and streams included within the study area

Under natural conditions, the DIN load was found to be 2302 kg/d for South Puget Sound and 3866 kg/d for Central Puget Sound, adding up to a total of 6168 kg/d of DIN. These loads vary seasonally primarily due to seasonal flow fluctuations.

Comparison to Other Estuaries

We also normalized loads by the total land area within our study (sum of the areas of all South plus Central Puget Sound watersheds) as well as by the surface area of the receiving marine waterbody. This calculation allows us to describe nutrient loads as *load per unit area*, and allowed us to compare nutrient loads into South and Central Puget Sound to nutrient loads into San Francisco and Chesapeake Bay, which are two large estuaries in the U.S.

Nutrient loading data for San Francisco Bay were based on estimates included in a national-level assessment of nutrient enrichment in estuaries from a 2007 National Oceanic and Atmospheric Administration (NOAA) report (Bricker et al., 2007). Nutrient loading data for Chesapeake Bay were from a report called the *Bay Barometer* (Chesapeake Bay Program, 2009a).

Tables 13 presents load per unit area of total nitrogen (TN) and total phosphorus (TP) into South and Central Puget Sound. These loads are compared with loads of TN and TP into San Francisco Bay and Chesapeake Bay, based on the land area drained by each of these estuaries.

Table 13. Total nitrogen and total phosphorus nutrient loads into South and Central Puget Sound, San Francisco Bay, and Chesapeake Bay normalized by drainage area.

	Drainage Area (km^2)	Load Per Unit Area		Source of Nutrient Loading Data
		TN (kg/ km^2-yr)	TP (kg/ km^2-yr)	
South Puget Sound	4,287	778	77	This study
Central Puget Sound	6,416	1,835	269	This study
San Francisco Bay - North	150,000 [1]	133	13	2007 NOAA assessment
Chesapeake Bay	165,759 [2]	657	30	2009 Bay Barometer

[1] Cloern, 1996
[2] Chesapeake Bay Program, 2009a

Table 14 is similar to Table 13, but instead of normalizing loads by the land area drained by each of these estuaries, loads are normalized by the surface area of the receiving marine waterbody.

Table 14. Total nitrogen and total phosphorus nutrient loads into South and Central Puget Sound, San Francisco Bay, and Chesapeake Bay normalized by estuarine surface area of the receiving waterbody.

	Estuarine Surface Area (km^2)	Load Per Unit Area		Source of Nutrient Loading Data
		TN (kg/ km^2-yr)	TP (kg/ km^2-yr)	
South Puget Sound	425	7,845	773	This study
Central Puget Sound	632	18,629	2,734	This study
San Francisco Bay - North	837 [1]	23,895	2,389	2007 NOAA assessment
Chesapeake Bay	11,603 [2]	9,382	430	2009 Bay Barometer

[1] Bricker et al., 2007
[2] Chesapeake Bay Program, 2009b

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Discussion

Rivers and Wastewater Treatment Plants

Rivers and WWTPs discharge an annual average total of 10,890 and 26,750 kg/d of DIN into South and Central Puget Sound, respectively; a total of 37,650 kg/d. On an annual average basis, DIN loads into South Puget Sound are dominated by rivers, while DIN loads into Central Puget Sound are dominated by WWTPs. Overall, loads from Central Puget Sound are much greater than those from South Puget Sound, and loads from WWTPs are greater than loads from rivers.

WWTPs in Central Puget Sound serve higher population centers and larger service areas than WWTPs in South Puget Sound. These WWTPs therefore treat a much larger volume of wastewater than those in South Puget Sound. Even if treatment processes at these plants lower the *concentration* of nitrogen in the effluent, nitrogen *loads* are still high since effluent flows are high; higher flows result in higher loads. Of all WWTPs in the study area, West Point and South King in Central Puget Sound contribute the highest loads (> 5000 kg/d). Overall, the load summaries for WWTPs determined from the regression approach are comparable to those from the monthly grab samples.

Rivers exhibit a seasonal pattern in nitrogen loading over the course of the year because of variations in flow that are a response to variations in precipitation. Though the largest rivers do not necessarily have the highest nitrogen concentrations, they do tend to have larger nitrogen loads relative to the rest of the rivers and streams in the study area. The four largest rivers in the study contribute the largest watershed DIN loads in the following order: Puyallup, Green Nisqually, and Deschutes. The former two are located in Central Puget Sound while the latter two are located in South Puget Sound. These river loads, however, also include loads from WWTPs and septic systems located upstream of monitoring locations. Overall, the load summaries for rivers determined from the regression approach are comparable to those determined from the monthly grab samples.

Septic System Loads

Estimates of annual DIN loads from on-site septic system loads located within the exclusive area are two orders of magnitude lower than the all river and WWTP loads within the study area. The 25th to 75th percentile of these estimates range from 290 – 970 kg/d.

When we extrapolated loads from monitoring locations to unmonitored locations, we found that this extrapolation adequately accounted for loads from on-site septic systems located within the exclusive area.

The Impact of Nitrogen Loading

Though the magnitude of sources of nitrogen is important, several other factors also play a role in determining the effect of these loads on DO concentrations in the marine water. The time, location, and depth of the discharge are all important due to circulation patterns in South and Central Puget Sound. Other important factors that determine DO concentrations are temperature, sunlight, the incoming oceanic water, and other environmental variables.

The water quality model will account for these different variables in evaluating the impact of nutrient loads on DO concentrations in South and Central Puget Sound. The modeling will also allow us to assess what fraction of loads entering Central Puget Sound eventually circulate to South Puget Sound, and whether these loads affect South Puget Sound DO levels. The loading results presented here provide valuable information but, prior to modeling, cannot be used to calculate the impact of the different sources of nitrogen on DO concentrations.

Natural Conditions

River and stream nutrient levels reflect the overall population and development levels within the watersheds. Using several methods, including less developed reference sites and statistical analyses, we identified natural condition concentrations for nitrogen and phosphorus. These lower concentrations translate to lower DIN loads under natural conditions. Table 15 compares DIN loads from the 2006-07 data with the natural DIN loads that were estimated from the meta-analysis.

Table 15. Comparison of natural and 2006-07 average annual DIN loads from rivers and WWTPs into South and Central Puget Sound.

Area of Puget Sound	Average Annual DIN Load (kg/d)		
	Natural Conditions	2006-07 Rivers Only	2006-07 Rivers + WWTPs
South	2302	5080	7785
Central	3866	5814	29861
South + Central	6168	10894	37646

Current average annual DIN loads (2006-07) from rivers and streams are higher than those established for natural conditions. This analysis indicates that current loads from rivers and streams are 2.2 times higher than natural conditions for South Puget Sound, 1.5 times higher for Central Puget Sound, and 1.8 times higher overall. When we include WWTPs, current loads are 3.4 times higher than natural conditions for South Puget Sound, 7.7 times higher for Central Puget Sound, and 6.1 times higher overall.

Conclusions

The daily nutrient loading estimates that we have developed for rivers and WWTPs provide a better estimate of nutrient loads into South and Central Puget Sound during 2006-07 than using just the monthly field monitoring data. The *multiple linear regression* method used to develop these estimates are based on monitoring data from watersheds that cover 82% of the study area and from WWTPs that account for 89% of all WWTP discharges for the study area.

The comprehensive load estimates for 2006-07 also fill in information that was missing because of gaps in the field monitoring data. For example, one or two months of data were missing for a few WWTPs where 24-hour composite samples were not collected, but the *multiple linear regression* approach is able to fill these data gaps. We also now have estimates of nutrient loading from several smaller watersheds, drainage areas, and streams were not monitored.

We can now compare the relative magnitudes and sources of nutrients to South and Central Puget Sound. Of these nutrients, dissolved inorganic nitrogen (DIN) is of greatest interest since this is the form of nitrogen most available to algae. DIN loads to Central Puget Sound are 3.8 times greater than DIN loads to South Puget Sound. WWTPs produce 71% of the annual DIN load; rivers produce 29%. WWTP DIN loads remain fairly constant throughout the year; river DIN loads vary though the seasons, with 77% of river DIN load occurring during wetter months of November through March. Therefore, the percent of DIN load coming from WWTPs is higher in summer.

DIN loads relative to watershed size are higher in some South Puget Sound watersheds than in Central Puget Sound watersheds, despite the former's lower *absolute* DIN loads.

WWTPs discharging into Central Puget Sound have higher DIN loads than those discharging into South Puget Sound. This is because WWTPs that serve more people produce higher loads.

DIN loads from rivers and streams, which include WWTPs discharging to freshwater, are 1.8 times higher than natural condition loads to both South and Central Puget Sound. DIN loads from all rivers and WWTPS, including those discharging to marine waters, are 6.1 times higher than natural condition DIN loads. Human activity, such as changes in land use and development and growing population, has increased DIN loads.

These nutrient load estimates will support the ongoing modeling effort, which will help us understand their effects on dissolved oxygen concentrations in South and Central Puget Sound. These loading estimates also help us to compare the relative magnitudes and sources of nutrient loads, communicate our results, and improve our understanding of Puget Sound water quality.

Recommendations

For future analysis, refined estimates of DIN loads from on-site septic systems within monitored catchments would be helpful. This would allow us to determine the proportion of current watershed loads that are from on-site septic systems. Better estimates of attenuation of nitrogen in the soil would also improve our estimates of loading from septic systems.

In terms of future monitoring, it would be useful to compare the daily nutrient concentration and load estimates derived from the regression approach to continuous daily observed data. Ecology is currently conducting a pilot project on the Deschutes River which involves automatic nitrate sampling every 15 minutes (Sackmann, 2009). Once Ecology has sufficient data from this project, the regression approach should be used to predict nitrogen concentrations for the same time period and then compare the daily predicted and observed data.

The models that are currently being developed should be used to assess the impact of loading from watersheds and WWTPs where site-specific regressions have not been developed. This will help determine if the models are sensitive to the estimates of nitrogen from these specific sources. Since few data were available for the Lake Washington and Sinclair/Dyes Inlet watersheds, this might be another target for a more detailed analysis during the modeling phase.

With this better understanding of the magnitudes and sources of nutrient loads to South Puget Sound, we can assess the impact of these nutrient loads on water quality and dissolved oxygen levels in South Puget Sound. This is a major goal of the modeling effort which is currently underway.

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Appendices

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Appendix A. Glossary, Acronyms, and Abbreviations

Glossary

Ambient monitoring: Background or away from point sources of contamination.

Anthropogenic: Human-caused.

Catchment: The area draining to a point (e.g. a storm drain).

Central Puget Sound: Puget Sound below Edmonds and above the Tacoma Narrows

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

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

Exclusive area: Area outside of monitored catchments/watersheds and outside of municipal wastewater service areas, but within the study area.

Extrapolated area: Area outside of monitored catchments/watersheds but within the study area.

Grab sample: A discrete sample from a single point in the water column or sediment surface.

Dissolved inorganic nitrogen (DIN): The sum of nitrate, nitrite and ammonium, which are all different inorganic forms of nitrogen. DIN is the most available form of nitrogen to algae.

Loading: The input of pollutants into a waterbody.

Marine water: Salt water.

Multiple linear regression method: A statistical technique used to determine the linear relationship between one dependent variable and two or more independent variables. In this study, the dependent variable is *concentration* and the independent variables are various terms that represent *streamflow* (or WWTP effluent flow) and *time of year*.

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 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.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Point source: Sources of pollution that discharge 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 that clear more than 5 acres of land.

Regression: A technique used to determine the mathematical relationship between a dependent variable and an independent variable(s) using a set of data points. The mathematical relationship can then be used to predict the dependent variable given a different values for the independent variable(s).

Sediment: Solid fragmented material (soil and organic matter) that is transported and deposited by water and covered with water (example, river bottom).

South Puget Sound: Puget Sound below the Tacoma Narrows.

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.

Study area: In this report, the study area includes South and Central Puget Sound marine waters as well as watersheds that drain into these marine waters.

Study period: In this report, the field monitoring study period is July 2006 through October 2007, while the study period for the loading estimates is January 2006 through December 2007.

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.

Water year (WY): October 1 through September 30. For example, WY07 is October 1, 2006 through September 30, 2007.

10th percentile: A statistical number obtained from a distribution of a data set, above which 90% of the data exists and below which 10% of the data exists.

25th percentile: A statistical number obtained from a distribution of a data set, above which 70% of the data exists and below which 25% of the data exists.

75th percentile: A statistical number obtained from a distribution of a data set, above which 25% of the data exists and below which 75% of the data exists.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

DMR	Discharge Monitoring Reports
DO	(See Glossary above)
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
LOTT	Lacey, Olympia, Tumwater, and Thurston County Alliance
GEMSS	Generalized Environmental Modeling System for Surface Waters
MEL	Manchester Environmental Laboratory
NOAA	National Oceanic and Atmospheric Administration
NPDES	(See Glossary above)
QA	Quality assurance
RMSE	Root means square error
RSD	Relative standard deviation
SOP	Standard operating procedures
USGS	U.S. Geological Survey
WPLCS	Water Quality Permit Life Cycle System
WRIA	Water Resources Inventory Area
WWTP	Wastewater treatment plant
WY	Water year

Nutrient Parameters

BOD	Biological oxygen demand
CBOD	Carbonaceous biochemical oxygen demand
DIN	Dissolved inorganic nitrogen
DOC	Dissolved organic carbon
DON	Dissolved organic nitrogen
DOP	Dissolved organic phosphorus
DTP	Dissolved total phosphorus
DTPN	Dissolved total persulfate nitrogen
NH4N	Ammonium
NO23N	Nitrate + nitrite
OP	Ortho-phosphate
PON	Particulate organic nitrogen
POP	Particulate organic phosphorus
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TPN	Total persulfate nitrogen

Units of Measurement

cms	cubic meters per second, a unit of flow.
kg	kilograms, a unit of mass equal to 1,000 grams.
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters.
m	meter
mg	milligrams
mg/L	milligrams per liter, a unit of concentration; equivalent to mg-N/L, mg-P/L, or mg-C/L for nitrogen, phosphorus, and carbon compounds, respectively
mgd	million gallons per day
mi	mile, a unit of length equal to 1,609 meters.

Appendix B. Observed and Predicted Streamflows

Figures B-1 and B-2 compare predicted and observed flows at creeks which did not have USGS gages within their watersheds, but where Ecology measured instantaneous flow for 15 months.

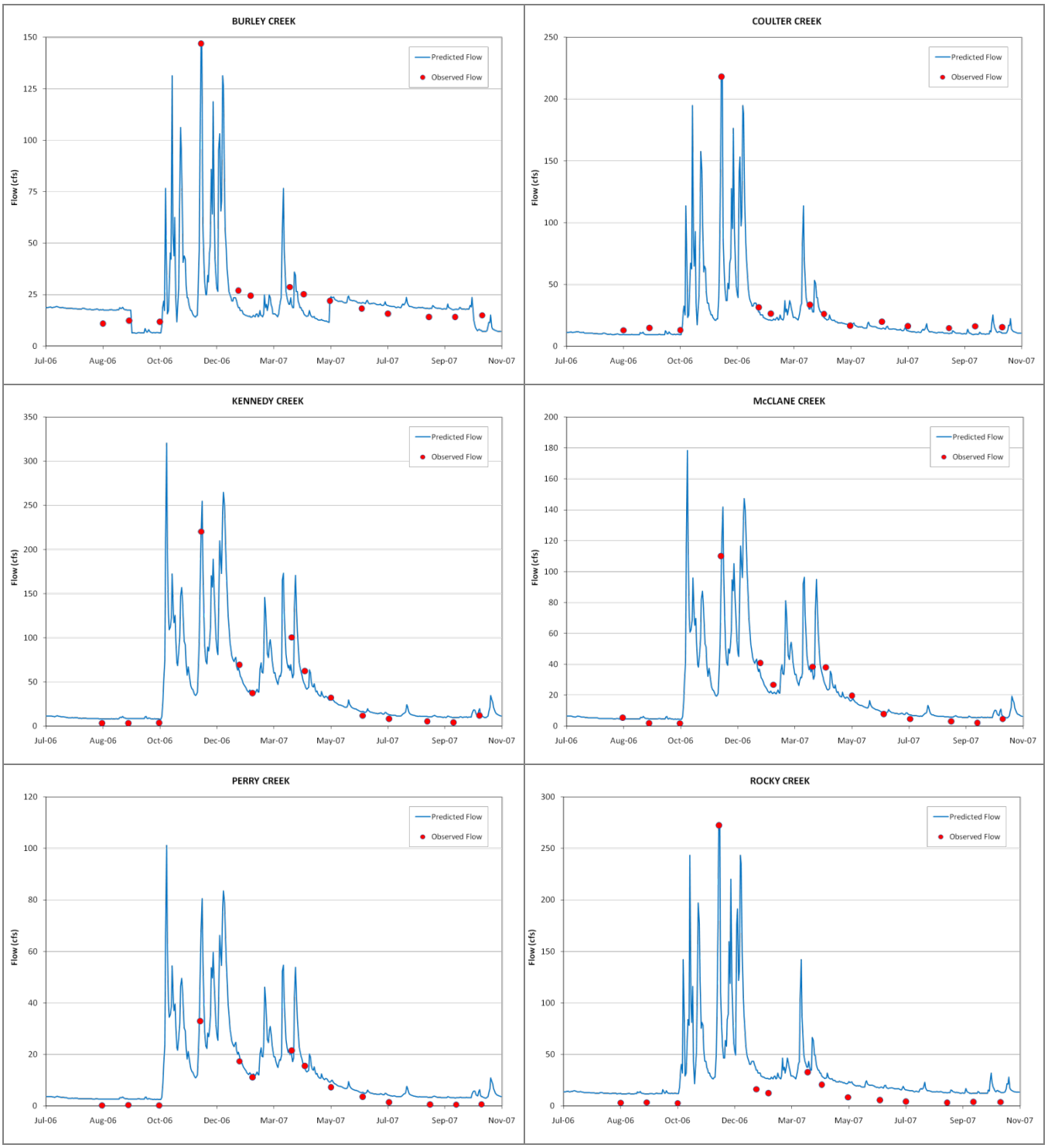

Figure B-1. Predicted and observed flows on creeks where 15 months of data were collected between July 2006 and October 2007.

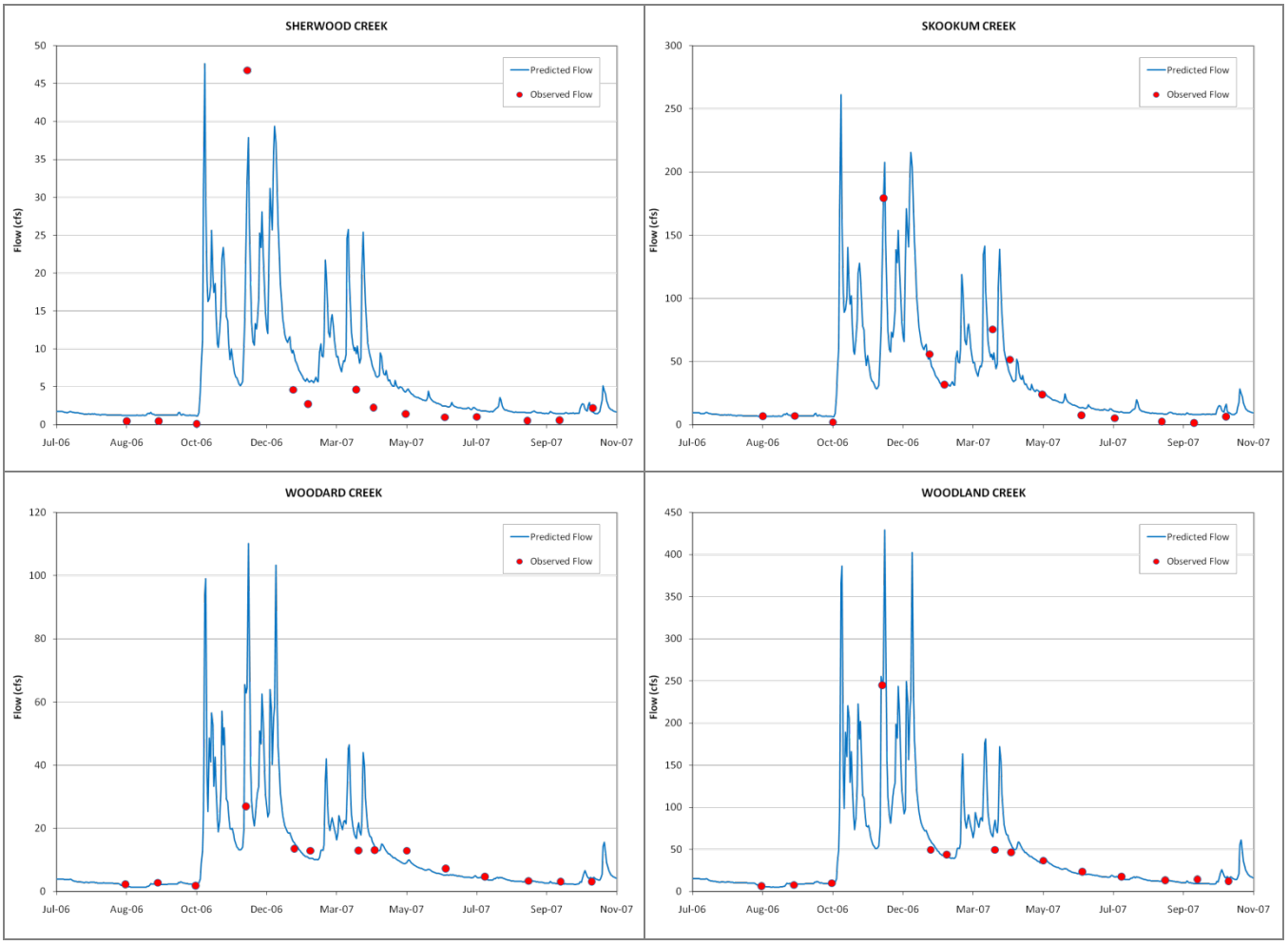

Figure B-2. Predicted and observed flows on creeks where 15 months of data were collected between July 2006 and October 2007.

Figures B-3 through B-5 compare predicted and observed flows at creeks which did not have USGS gages within their watersheds, but where Ecology measured instantaneous flow for 15 months.

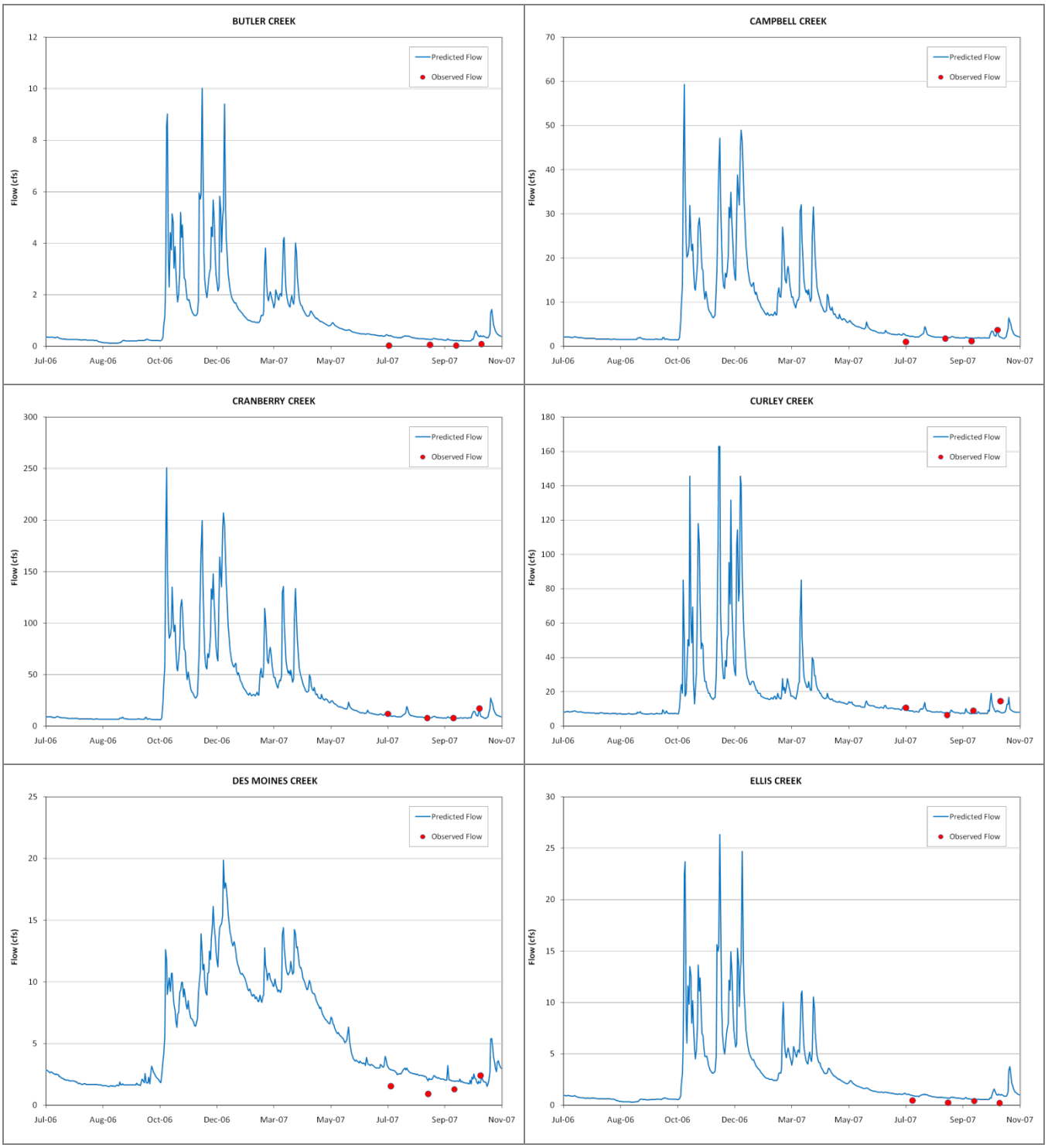

Figure B-3. Predicted and observed flows on creeks where four months of data were collected between July 2006 and October 2007.

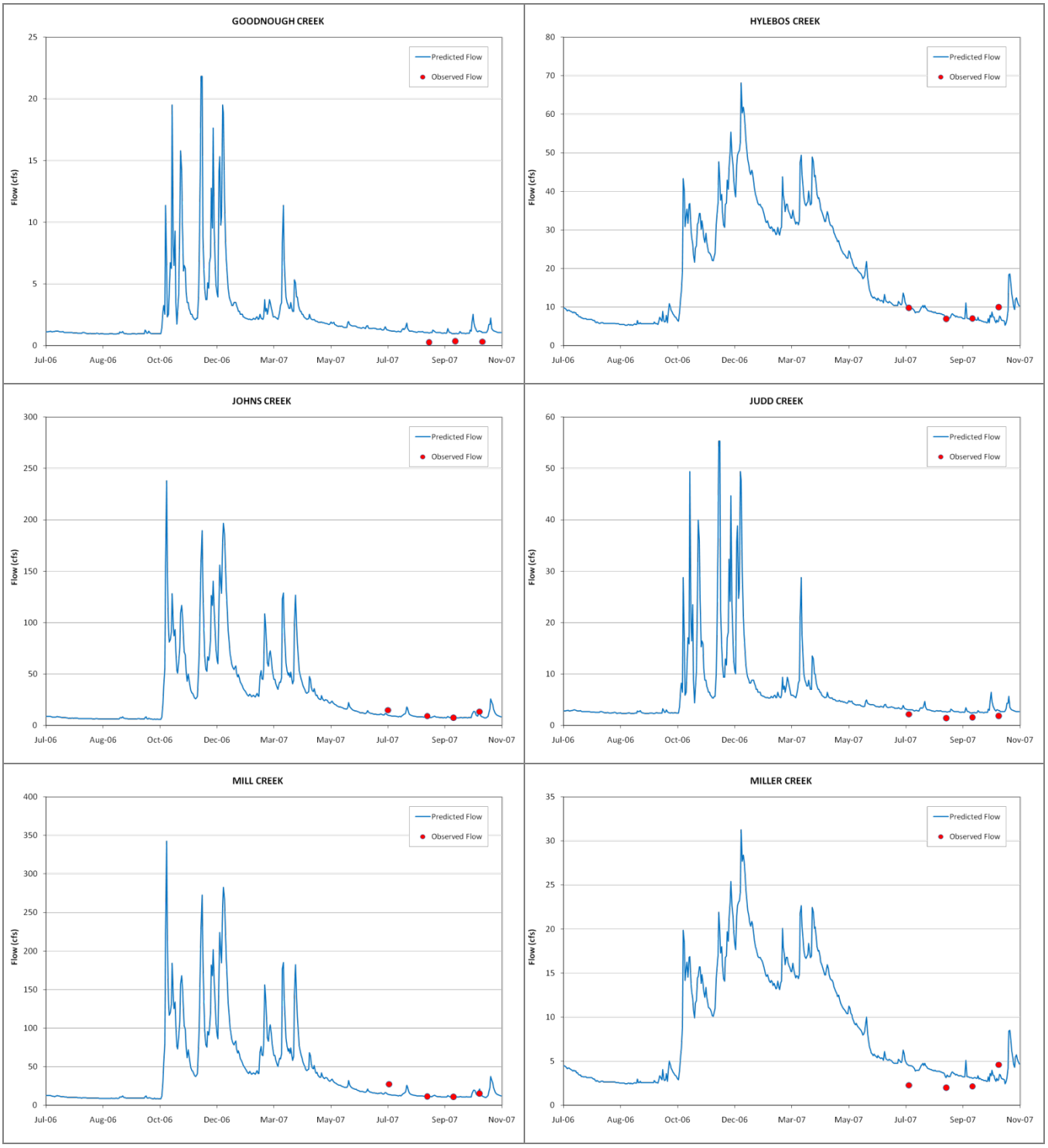

Figure B-4. Predicted and observed flows on creeks where four months of data were collected between July 2006 and October 2007.

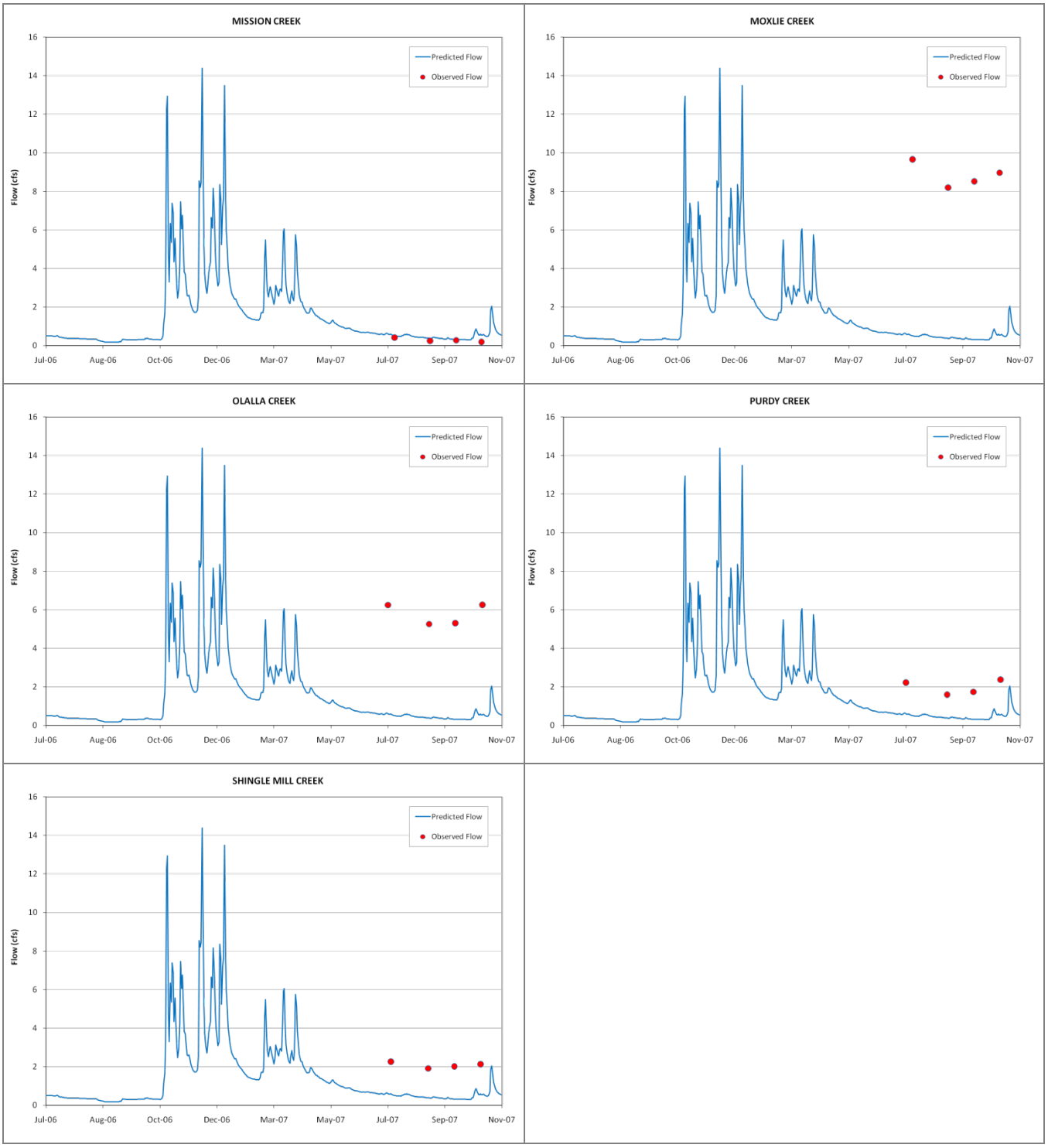

Figure B-5. Predicted and observed flows on creeks where four months of data were collected between July 2006 and October 2007.

Appendix C. Analysis of On-Site Septic System Loads

This appendix is a separate report which has an “Appendix A” within it. The main report also has an Appendix A (Glossary, Acronyms, and Abbreviations). The two “Appendix A” are therefore not the same.

TECHNICAL MEMORANDUM

November 29, 2010

By Anthony J. Whiley, P. E.

Washington State Department of Ecology

Estimate of dissolved inorganic nitrogen (DIN) loading associated with on-site wastewater systems situated outside of monitored catchments and municipal wastewater service areas within the south Puget Sound study area.

Analysis Purpose

This analysis was initiated to provide an estimate of the annual average dissolved inorganic nitrogen (DIN) entering the south Puget Sound study area associated with on-site wastewater system discharge. It serves as a supplement to the on-going South Puget Sound Dissolved Oxygen Study which is examining DIN loading, its movement within the south Puget Sound, and its organic and inorganic effects to water quality. That effort monitored DIN levels within 39 catchments which together comprised 8,737 km^2 or about 75% of the 11,711 square kilometer (km^2) study area. The surface area of marine waters comprises approximately 8% of the study area therefore the monitored catchments comprise about 81% of the land-based drainage. The south Puget Sound study applied the catchment monitoring data to calculate annual DIN loads. In addition, annual DIN loads were determined for 29 point source discharges (primarily municipal wastewater treatments systems). However, missing was an assessment of the DIN load from sources lying outside those served by the municipal wastewater treatment systems and the monitored catchments. For this reason, this analysis examined these "unknown" areas, which will be referred to in this memorandum as the exclusive area, with a focus on providing an estimate of the annual DIN load associated with on-site wastewater systems. (The greater study area, monitored catchments, municipal wastewater service areas along with the exclusive area are presented in Figure A1 (refer to Appendix A.)

Methods

To estimate the DIN load associated with on-site wastewater systems in the exclusive area the following variables were considered:

- Number of residences (and associated population) utilizing on-site wastewater systems.
- Wastewater flow rates.
- DIN wastewater concentrations.
- DIN attenuation levels in environment.

Application of Geographic Information Systems

The majority of this analysis was conducted through application of the geographic information systems software Arc View (ver. 9.3). The following data layers (covers) were assembled to initiate the project:

- Land parcels with current (2008) county assessors designations of residential housing type and other land use designations.
- Delineation of municipal wastewater service areas discharging to Puget Sound within study area.
- Delineation of monitored catchments.
- Delineation of Puget Sound shoreline.
- Census (2000) tracts, which includes data on population and housing levels.
- Delineation of study area.
- Water resource inventory areas within study area.
- Surface water drainage network (1:24,000).

Central to this analysis was the use of a polygon cover of tax parcels that included Washington State Department of Revenue land use designations. Among the land use designations, or codes, ascribed to each parcel were several describing various types of residential housing. This analysis focused on parcels identified by the following designations: single family units, residential 2-4 units, multi-residential (x>5 units), residential condominium, mobile home park, hotel/motel, institutional lodging, other residential, and vacation/cabin.

To both streamline and refine the analysis the land parcel polygons were converted to centroids (point cover indicating the center of each parcel polygon) through the x-tools extension within Arc View. Following the conversion, the parcel centroids (covering the state) were clipped to the greater study area boundary. This then provided an assessment of all parcels located within the study area.

The parcels of interest were, however, those exclusive of the monitored catchments and municipal wastewater service areas. Therefore, centroids situated within either of these types of delineations, throughout the study area, were selected and removed. Left were all parcels located in the exclusive area residential and otherwise. It was assumed that all parcels with a residential-type designation utilized an on-site wastewater treatment system. The monitored catchments, municipal wastewater service areas and parcel centroids (defining the exclusive area) are presented in Figure A1 (refer to Appendix A).

Application of Parcel and Census Tract Data

The primary reason for utilizing the tax parcel information was to identify all residential-type land use and, therefore, locations of on-site wastewater systems within the exclusive area. An accounting of the various types of housing also provided a means of estimating population, a critical variable in estimating the DIN load associated with on-site systems. In order to complete that type of assessment the relationship between the number of housing units identified by Census tract was compared with that determined by the tax parcel data.

Twelve Census tracts situated entirely within the study area were selected at random. An accounting of all parcels situated within each of the Census tracts was determined. (For this part of the analysis the entire set of parcel centroids (within the study area) was considered.) From the parcel information, the various residential-types were enumerated and compared to those reported through the Census. A weighting factor was used to relate the various types of residential housing to a single family unit equivalent. For instance, single family residences were given a weighting factor of 1 while vacation/cabin residences were given a weighting factor of 0.25, reflecting that a cabin is occupied only a portion of the year (estimated at around 3-months). The ultimate weighting factors applied were

as follows: single family units (1), residential 2-4 units (3), multi-residential (x>5 units) (5), residential condominium (2), mobile home park (5), hotel/motel (100), institutional lodging (100), other residential (0.25), and vacation/cabin (0.25). While many of the weighting factors used follow from the designation (i.e. 3 for a 2-4 residential unit), the weighting factors for condominium, mobile home park, hotel/motel and institutional lodging were determined based on providing the best fit linear relationship between the two sets of data (r^2=0.82, refer to Figure A3 in Appendix A). Relating the 2008 parcel information to 2000 Census data provides a conservative estimate of housing due to the expected increased development occurring during this period. However, much of the exclusive area is relatively rural with a reduced level of development pressure. Higher levels of development would be expected to occur in proximity to municipal wastewater service, areas that were excluded from consideration by this analysis.

To determine the average number of occupants per residence all census tracts located within the study area were selected and the occupants per residence calculated per tract. An overall average level of 2.5 occupants per residence was determined with a standard deviation of 0.6.

This 2.51 level of occupancy was applied to the number of equivalent residences determined from the tax parcel data to estimate the population. This population estimate, determined for each of the 12 census tracts based on the number of housing equivalents, was then compared to the population reported by the 2000 Census. The method provided a reasonable fit with a coefficient of variation of 0.91 (refer to Figure A4 in Appendix A).

The reason for these gyrations is that the application of the tax parcel information yields more information, providing a more rigorous spatial analysis approach (provides location of on-site systems), in relation to solely applying the Census tract data. Also, Census tracts (or blocks) extend, in many cases, beyond the study area boundary requiring an area weighting method which may not be appropriate as it assumes an equivalent residence and population distribution throughout the tract. Ultimately, all tax parcels situated beyond the monitored catchments and municipal wastewater service areas (exclusive area) were grouped by water resource inventory area (WRIA) and then sorted by land use (residential-type designation). For each WRIA, an enumeration of the various housing types was conducted and a residential housing equivalent determined. Based on the residential housing equivalent, the associated population was determined by applying the 2.5 capita per residence factor determined from the 2000 Census information.

Estimate of Residential Water Use

The relationship between average July/August municipal wastewater treatment flow levels observed at municipal wastewater treatment plants and the residential population served by the plant was used to estimate typical residential wastewater flow levels. Eight wastewater treatment plants situated within the study area were evaluated. The July/August period was chosen because it represents a time when precipitation is at an annual low minimizing the influence of inflow and infiltration. It is assumed that for the plants examined the primary inflow source is residential-based with minor industrial inflow. The service area delineation was used to identify all residential parcels presumed connected to the treatment plant system. The enumeration of residential parcels allowed an estimate of the population served by each plant. Based on this assessment, the median per capita wastewater flow is 93 gallons per day (Table 1). This estimate is on the higher range of reported per capita residential wastewater flows which tend to have a range between 40 and 80 gallons per day (Metcalf and Eddy, 1991). An analysis of daily in-door residential water use in the United States was found to average 69 gallons per

day with a standard deviation of 40 (EPA, 2002). Given the wastewater flow approach appears to estimate toward the higher end of typically reported values, this analysis will assume the reported 69 gallons per capita per day average indoor water use.

Table 1. Several greater study area municipal wastewater treatment plants, their average July/August flow levels, estimated population served, and estimated per capita wastewater flows.

Plant Name	Permit No.	Avg. July/August Flow (million gallons per day)	Residences/Population	Wastewater Flows (gallons/capita-day)
Vashon	22527	0.078	282 / 620	126
Duvall	29513	0.390	1,946 / 4,281	91
Port Orchard	20346	1.371	6,518 / 14,340	96
Central Kitsap	30520	3.210	15,763 / 34,679	93
Puyallup	37168	3.050	15,000 / 33,000	92
Bremerton	29289	3.830	17,747 / 39043	98
Redondo/Lakota (grouped)	23451	6.329	32,559 / 71,630	88
LOTT (Olympia)	37061	8.800	44,611 / 98144	90

On-Site Effluent DIN

Typical total nitrogen (TN) wastewater loading rates, on a per capita basis, is about 4.8 kg N/capita – year (Bowen, 2001). Based on an average daily per capita in-door domestic water use of 69 gallons per day (262 liters per day), this works out to an average influent TN concentration of 50 mg/L. Literature values for the TN concentration of raw domestic wastewater (influent) tend to range between 35 to 80 mg/L with the on-site system effluent concentrations between 25 to 60 mg/L (Metcalf and Eddy, 1991). A survey of on-site system effluent found an average TN concentration of 45 mg N/L with a standard deviation of 18 mg/L (University of Wisconsin, 1978 in Cantor and Knox, 1988). That study determined that about 30% of the nitrogen is in an organic form with the primary nitrogen form ammonia-N which averaged 31 mg/L (standard deviation=14 mg/L). Typical values for total Kjeldahl nitrogen (TKN =organic-N + DIN) is 70.4 mg/L, with ammonia–N comprising 41.2 mg/L of that total with the remainder, or 29.1 mg/L, (41% of TKN) organic-N (Crites, 1998). Once introduced to the soil matrix effluent ammonia-N is oxidized to nitrate which then typically becomes the dominant inorganic form of nitrogen within surface and groundwater. Based on an average TN effluent concentration of approximately 50 mg/L and assuming that 35% is in an organic form, then the ammonia-N concentration is around 33 mg/L. This sets the ammonia-N concentration at a level close to that reported based on a more extensive analysis of on-site effluent (μ=31 mg/L, α=14 mg/L) (Canter and Knox, 1988). For this reason, this analysis will apply the 31 mg/L ammonia-N level for estimating on-site DIN loading.

Estimate of DIN loss

Following discharge to sub-surface soil layers, there are a number of potential pathways that wastewater-related DIN can take including de-nitrification, or the loss of nitrogen to its elemental gas form (N_2), and that lost through incorporation into organic (plant) growth. DIN loss occurring through the latter pathway can be substantial if the groundwater flow path is bisected by dense riparian growth prior to surface water discharge. Though site specific, de-nitrification tends to occur as nitrate migrates through the interface between the soil matrix and the water table where anaerobic conditions

are present. This process may also be repeated as nitrate, present in the groundwater, is discharged to surface water further afield. The number of environmental variables determining the level of de-nitrification is large and though relatively well studied continues to be poorly defined. This is because environmental characteristics such as soil (organic and mineral composition), underlying geology (depth to bedrock), and water table flow pathways are all highly variable. Based on a review of reported de-nitrification rates (first order) the median level was found to be 0.025/day (approximately 2.5%/day) with a range of 0.004-2.27/day (McCray, 2005). An analysis of de-nitrification rates associated with on-site effluent in Mason County (Hood Canal) determined a median level of 0.06 mg/L-day (zero order) (Horowitz, 2008). The USGS applied a de-nitrification loss rate of 10% to its assessment of DIN loading associated with shoreline-based on-site systems in Hood Canal (Paulson, 2006). Analyses of nitrate attenuation conducted further afield of on-site drain fields reported levels as high as 90% (Horowitz, 2008).

This study examined end-of-pathway DIN loading within 19 primarily residentially developed catchments within the study area that solely utilize on-site wastewater treatment. These catchments tend to be suburban to rural with lower development levels. The range in the number of residences per hectare was 0.01 to 1.1, with a median level of 0.2 (residences/hectare). The median catchment area was 2901 hectares with a range of 124 to 8,576 hectares. The catchments tended to have well established riparian corridors.

For each catchment, average flow and nitrate concentrations were determined based on measurements collected during July and August. From this information, a low-flow nitrate load was determined. The reason for examining the low flow condition is that it is a period when groundwater discharge is the primary source of flow and the nitrate concentrations associated with it more accurately characterize the long-term nitrogen loading to groundwater within the catchment. During the winter months, more flow within the stream is derived from overland flow bringing with it nitrate from a greater variety of sources (i.e. fertilizer, animal wastes etc.). It is assumed that within these residentially developed catchments, nitrate from on-site systems is the primary source to groundwater because it is directly delivered to the sub-surface soil matrix whereas the pathway of surface-based nitrate sources (animal waste, fertilizer) within the environment is primarily overland flow with lower penetration to groundwater. It is recognized that there are naturally occurring background sources in these catchments though it is assumed that their contributions to stream concentrations are insignificant. (Median July-August DIN levels in the relatively un-impacted upper Mashel River catchment (a tributary to the Nisqually River) was observed at 43 ug/L (Whiley, 1994) , 86% lower than the median level (300 ug/L) observed in the assessment streams.)

Once determined, the catchment nitrate loads were compared to those calculated based on the number of residences present within each catchment and assumed wastewater characteristics. In calculating the on-site loads it was assumed that the average per capita water usage was 69 gallons per day (gpd), the DIN concentration within the associated wastewater was 31 milligrams per liter (mg/L) (Canter and Knox, 1988), and the average capita per residence was 2.51. Based on these characteristics, the annual DIN load delivered to the soil matrix is around 2.96 kilograms per capita.

Overall, among the catchments, the median residential-based DIN load was estimated at 8.51 kg/d (refer to Table A2 in Appendix A). In comparison, the median catchment base-flow DIN load was 2.32 kg/d, indicating an overall loss of about 70%. As expected, these attenuation rates are highly variable with the inner quartile range between 43-88%. (Assuming a background DIN concentration of 0.04 mg/L, the median attenuation level increases slightly to 73%.)

These results indicate that DIN loss can be substantial if the on-site effluent travels a complex flow path encountering organic/anaerobic interfaces, allowing for more extended de-nitrification. Incorporation into organic growth (plant-animal) as groundwater up-wells and discharges through the riparian corridor is another route of attenuation. Unfortunately, much of the residential development within the exclusive area is situated along the marine shoreline characterized by relatively short flow transit prior to surface water discharge, providing a reduced opportunity for de-nitrification.

Results

Housing and Population within the Exclusive Area

Among the residential land use types identified in the exclusive area, single family residences are the most highly represented at 88% of the total, followed by 2-4 units (3.5%), condominiums (2.4%) and other residential (2.1%). The remainder of the residential types are represented at approximately 1% each (Table 2).

The exclusive area includes the following water resource inventory areas: Chambers-Clover, Deschutes, Duwamish-Green, Kennedy-Goldsborough, Kitsap, Nisqually, and Puyallup-White (refer to Figure A1). (Though present within the study area, the Cedar-Sammamish WRIA was not represented in this assessment due to catchment monitoring and extensive municipal wastewater service coverage.) Among the 80,702 residences occurring within the exclusive area, 69% or 55,863 occur in the Kitsap WRIA. The next highest WRIA represented is the Deschutes with 10% (8,065 residences) followed by Kennedy-Goldsborough at 8% (6,283 residences) and Puyallup-White at 8% (6,184 residences). The total population within the exclusive area was estimated at 202,562.

Table 2. Total accounting of residential-type housing occurring within the exclusive area, by WRIA; along with the assessment of housing equivalents and their associated populations.

Housing Description	Water Resource Inventory Area							
	Chambers-Clover	Deschutes	Duwamish-Green	Kennedy-Goldsborough	Kitsap	Nisqually	Puyallup-White	Total
Single Family	130	6,910	2,769	4,067	51,243	668	4,888	70,675
2-4 Units	5	151	31	26	517	29	186	945
>5 Units		12	13	3	140	6	29	203
Condominium		98	3		418	282	156	957
Mobile Home		66		9	34	9	31	149
Hotel/Motel				1	9			10
Inst. Lodging				5				5
Other Residential	5	463		4,489	1,701	131	106	6,895
Cabin/Vacation				1,029	151			1,180
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Residential Equivalents	146	8,065	2,933	6,184	55,863	1,427	6,084	80,702
Associated Population	367	20,243	7,362	15,522	140,216	3,582	15,271	202,562

Of this larger data set, residences were grouped by both WRIA and proximity to shoreline: residences within 150-meters of the shoreline and those beyond 150-meters of the shoreline. The 150-meter distance was selected because it marked an inflection point in the density of housing in proximity to the shoreline (refer to Figure A6 in Appendix A). This separation is used later in determining the annual DIN loading rate because it identifies residences situated closest to the shoreline that have the least possibility of DIN attenuation. (Figure A2 provides a detail of this analysis approach.)

Of the total residences situated within the exclusive area, approximately 20% are within 150-meters of the shoreline (Table 3; Figure A7). Among the WRIAs, 22% (14,274) of the Kitsap residences are situated within 150-meters of the marine shoreline. The Kennedy-Goldsborough WRIA also shares a similar representation of shoreline-based residential development (1,565) in relation to its total number of residences.

Table 3. Enumeration of marine shoreline-based residential-type housing (within 150-meters of shoreline) included within the exclusive area, by WRIA; along with the assessment of housing equivalents and their associated populations. (This is a subset of the total housing and population data presented in Table 2.)

Housing Description	Water Resource Inventory Area							
	Chambers-Clover	Deschutes	Duwamish-Green	Kennedy-Goldsborough	Kitsap	Nisqually	Puyallup-White	Total
Single Family	115	1,469	178	906	11,062	19	85	13,834
2-4 Units	4	6		2	75			87
>5 Units		1	1	2	68			72
Condominium		13			98			111
Mobile Home		1		3				4
Hotel/Motel					3			3
Inst. Lodging								
Other Residential	4	69		2,033	642	2		2,750
Cabin/Vacation				478	78			556
	---	---	---	---	---	---	---	---
Residential Equivalents	128	1,540	183	1,565	12,303	20	85	15,824
Associated Population	321	3,866	459	3,928	30,881	49	213	39,717

Estimate of DIN load from Exclusive Area

Assumptions used to calculate the DIN load for the exclusive area include:

- DIN load associated with residences within 150-meters of the marine shoreline has a loss rate of 10% due to de-nitrification (Paulson, 2006).
- DIN load associated with residences beyond 150-meters of the marine shoreline has an overall loss rate of 70% due to de-nitrification and organic growth.
- Residential occupancy rate of 2.51 people.
- Wastewater discharge rate of 69 gallons per person per day.
- An on-site effluent DIN concentration of 31 mg/L.

- On-site system DIN loading to shallow groundwater has remained relatively steady, occurring over a sufficient period to have reached steady state. Therefore, the DIN load associated with on-site effluent discharged to surface soils annually within the exclusive area has reached equilibrium in relation to that assumed entering Puget Sound.

The base loading equation along with a summary of the underlying assumptions is provided in Tables 4 and 5, respectively.

Table 4. DIN load equation applied.

$$\boldsymbol{DIN\ Load}\left(\frac{\boldsymbol{tonnes}}{\boldsymbol{WRIA-year}}\right)=$$

$$Number\ residences\ \left(\frac{No.\ Residence}{WRIA}\right)*Capita\ per\ residence\ \left(\frac{capita}{residence}\right)*Wastewater\ generation\left(\frac{gallons}{capita-day}\right)*$$
$$DIN\ effluent\ concentration\left(\frac{mg}{liter}\right)*Attenuation\ Factor$$

Unit Conversion: gallons to liters $\left(\frac{0.00379\ m\text{^}3}{gallon}\right)*\left(\frac{1000l}{m\text{^}3}\right)$; mg to tonne $\left(\frac{g}{1000mg}\right)*\left(\frac{kg}{1000g}\right)*\left(\frac{tonne}{1000kg}\right)$; $days\ to\ year\ \left(\frac{365d}{year}\right)$

Table 5. Load calculation assumptions based on proximity to shoreline.

Loading Assumption Applied	Proximity of Onsite System to Shoreline	
	<=150m	>150m
DIN Effluent Concentration (to drainfield)	31 milligrams per liter	
Capita per Residence	2.51 capita per residence	
Attenuation Factor (loss)	10%	70%
Wastewater generation	69 gallons per capita	

Based on these assumptions, the annual DIN inflow to the Puget Sound from on-site systems located in the exclusive area is 250 tonnes or 1.24 kg DIN/capita-yr (Table 6). Of that total, 106 tonnes or 42% of the annual area-wide loading total is derived from systems located within 150-meters of the marine shoreline. The DIN loading yield for the shoreline based residences is estimated at 2.67 kg/capita-yr. A similar yield (2.95 kg/capita-yr) was found for shoreline-based DIN loading associated with onsite systems for Hood Canal (Paulson, 2006). In comparison, the estimated DIN loading associated with on-site systems further removed (greater than 150-meters from shoreline) was 145 tonnes, 58% of the area total. While the DIN loading associated with onsite systems beyond 150-meters of the shoreline was greater due to an approximately four times greater population, the assumed higher attenuation rate significantly reduced the estimated loading to Puget Sound. The DIN loading yield associated with onsite systems greater than 150-meters of the shoreline was estimated at 0.89 kg/capita-yr. The three-fold decrease reflecting the assumption that for onsite systems located within 150-meters of the shoreline that 90% of the loading eventually migrates to Puget Sound while on-site systems further removed, 30% is assumed migrating to Puget Sound.

Assuming no attenuation in DIN associated with onsite effluent results in a total annual load of 599 tonnes or 2.96 kg/capita-yr. Therefore, the net attenuation rate assumed for the area is 58%. (Table A1 presents these annual loads at a daily rate.)

Table 6. Estimated annual DIN loads to Puget Sound from on-site wastewater system located within the exclusive area (loads are in units of tonnes per year).

Base Assumptions		Water Resource Inventory Area							Annual Load Total (t/yr)
		Chambers-Clover	Deschutes	Duwamish-Green	Kennedy-Goldsborough	Kitsap	Nisqually	Puyallup-White	
With loss assumptions	x<150-m	0.86	10.30	1.22	10.46	82.24	0.13	0.57	105.78
	x>150-m	0.04	14.54	6.13	10.29	97.06	3.14	13.37	144.57
	Total=	0.90	24.84	7.35	20.75	179.3	3.27	13.94	250.35
Without loss assumptions	x<150-m	0.95	11.44	1.36	11.62	91.38	0.14	0.63	117.52
	x>150-m	0.14	48.46	20.42	34.31	323.52	10.45	44.56	481.86
	Total=	1.09	59.90	21.78	45.93	414.90	10.59	45.19	599.38

DIN loading considering attenuation and parameter variability

The previous DIN loading estimates were based on the application of median parameter values. However, there is considerable variability for many of these parameters which can have a significant effect on the loading estimates. In addition, while this analysis used both reported and determined estimates of net DIN attenuation, it is recognized that this parameter has high variability reflecting the varied physical and environmental factors encountered. To account for these various uncertainties, a Monte Carlo-type analysis approach was applied.

The analysis took the form of generating results for 1000-iterations of loading estimates, for varying DIN attenuation levels, through the application of the Excel formula: NORMINV(rand(), mean, standard deviation). The formula generates a random parameter value based on its sample mean and standard deviation. The underlying assumption in the use of this formula is that the parameter distribution is normal. The NORMINV() function was applied to the parameters: population per residence (μ=2.51, α=0.61; U.S Census), on-site effluent DIN concentration (μ=31 mg/L, α=14 mg/L; Canter and Knox, 1988), and wastewater generation per capita (μ=68 gal., α=40 gal.; EPA, 2002).

In addition to applying the NORMINV() function, to examine how loading varied based on different attenuation rates, a data table was applied. Within the data table, attenuation rates varied from 0% (no loss) to 100% (complete loss). These attenuation levels therefore are net levels, reflecting an overall average because the shoreline and upland based residences were not separated. For each attenuation level, percentiles were generated from the approximately 1000 associated loading estimates and a box plot graphic generated.

Regarding the interpretation of the box plot graphic: the upper and lower sides of the central box indicate the 75th and 25th percentiles of the data set; the dot and horizontal line within the box are the median (50th percentile) and average; while the upper and lower small squares (at end of upper and lower whisker extensions) are the 90th and 10th percentile of the DIN load estimates.

The utility of this type of analysis is that it provides an assessment of variability to the loading estimates. However, the difficulty in application is that the actual attenuation level attributed to on-site DIN loading is not known. This study assumed that the shoreline-based residences (those located

within 150-meters of the shoreline) had a DIN attenuation level of 10% while those further removed from the shoreline (located beyond 150-meters) have an attenuation level of 70%. Referring to Figure 1, a worst case scenario (0% attenuation) has 75th, 50th, and 25th percentiles of 872, 496, and 219 tonnes per year in DIN loading, respectively. As observed, overall loading variability increases with reduced DIN environmental attenuation. (The average loads depicted in Figure 1 by the horizontal bar are those presented Table 6.) Previously, the net attenuation level, considering both that attributed to the shoreline and upland-based residences, was assumed to be 58%; close to the 60% level depicted in Figure 1. At the 60% attenuation level, the median loading estimate is 194 tonnes per year with the 75th and 25th percentiles 345 and 99 tonnes per year, respectively.

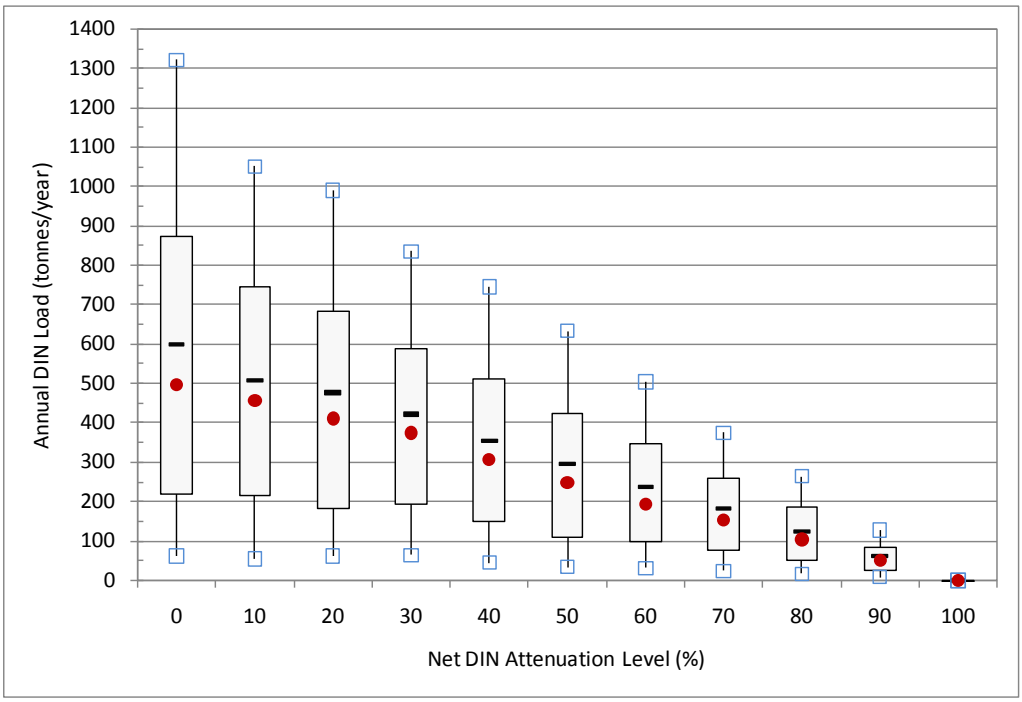

Figure 1. Box plots of predicted DIN loading for entire exclusive area provided varying attenuation levels.

Figure 2 presents box plots of the estimated annual DIN loads for the shoreline-based residences, those located more distant, and for the entire exclusive area. In review, the loading estimates are based on an assumed 10% attenuation level for the shoreline-based residences (those located within 150-meters of the shoreline) and 70% for those located more distant. A weighted average attenuation level for the entire exclusive area, based on the number of residences situated within each designation, was determined to be 58%.

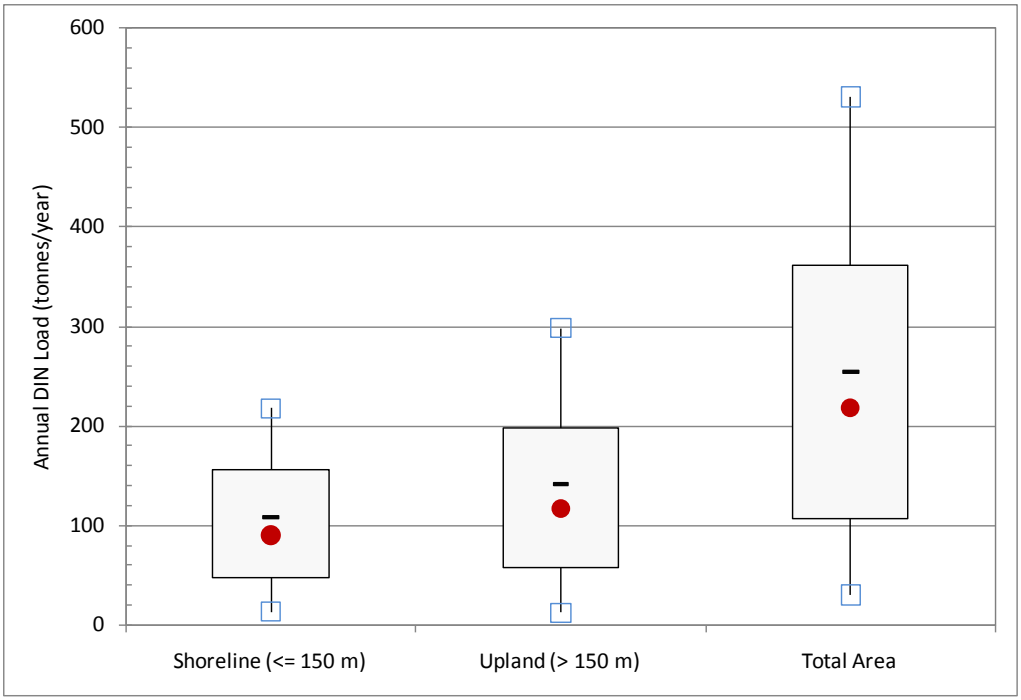

Figure 2. Box plots of the estimated annual DIN load (t/yr) associated with shoreline-based residences, those located upland, and their combined effect within the exclusive area.

Table 7. Annual DIN loading (t/yr) percentiles based on proximity to the marine shoreline and for the entire exclusive area.

Area Designation	Annual DIN Load (t/yr) Percentiles		
	25th	50th	75th
Total Area	107	218	362
Shoreline (<150 m)	48	90	157
Up-land (>150 m)	57	117	198

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Appendix A - Additional Figures and Tables

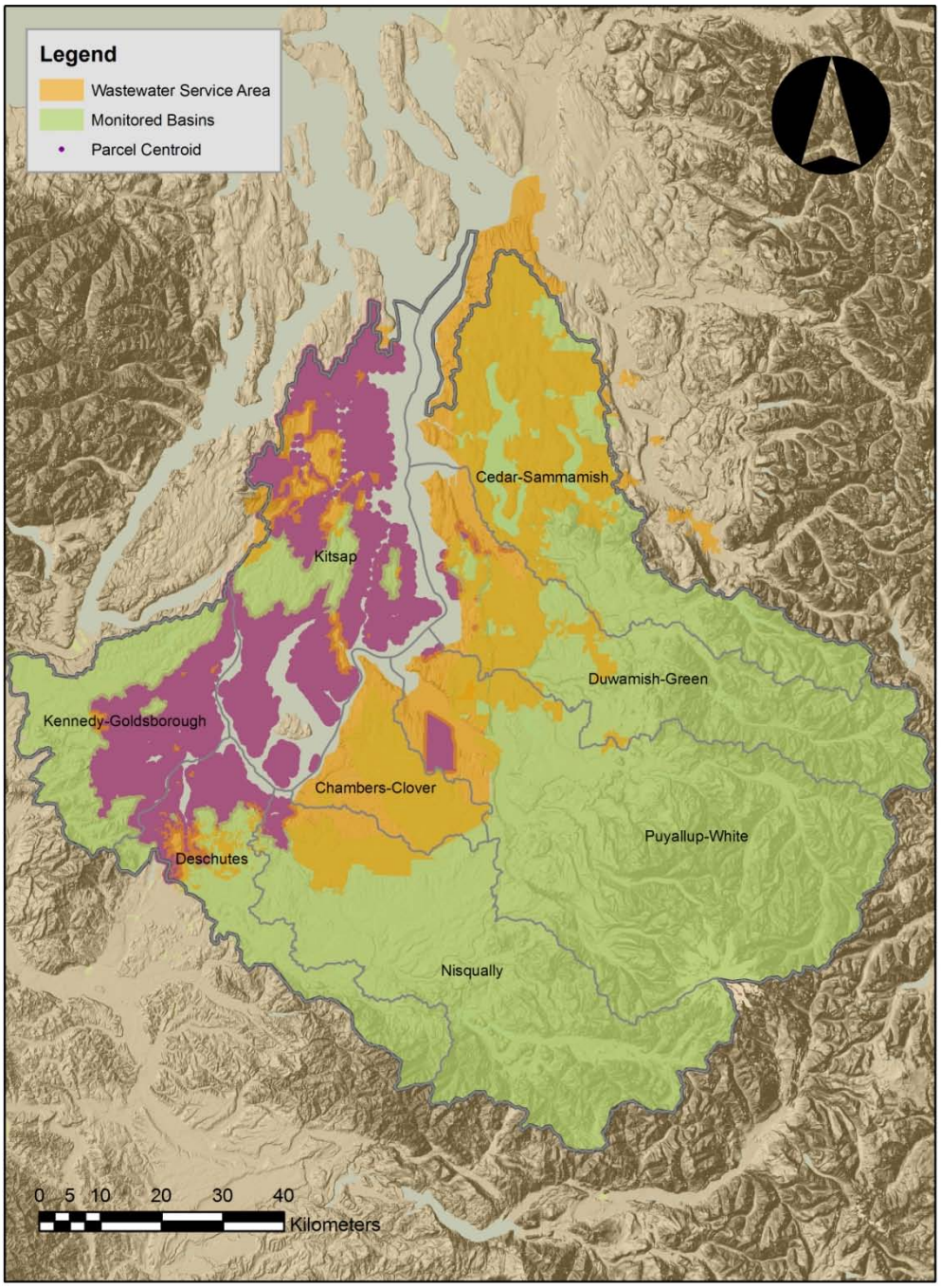

Figure A1. Study area defined by water resource inventory areas, monitored catchments (green), wastewater service areas (orange), and exclusive area (purple).

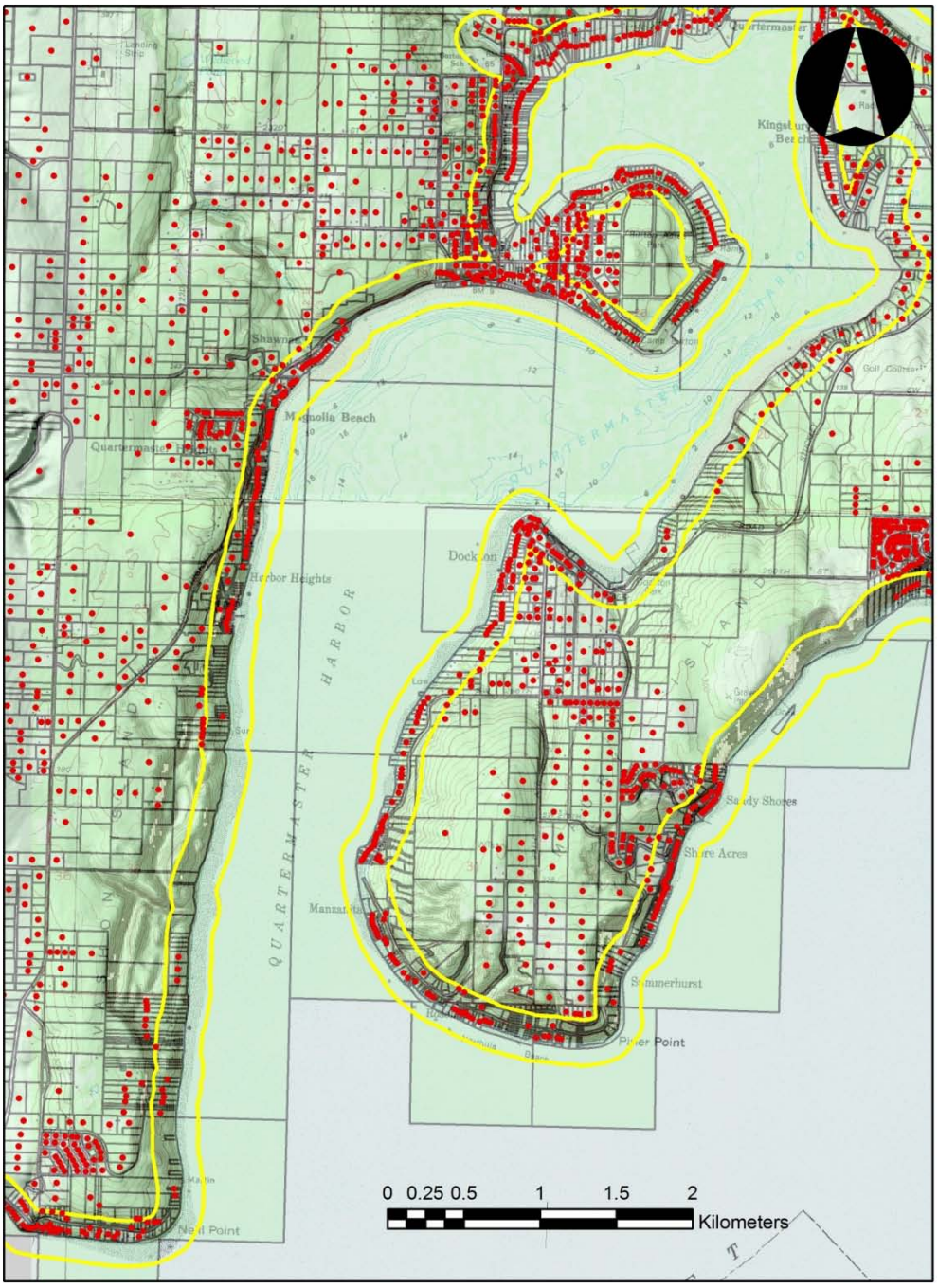

Figure A2. Study area detail (Quartermaster Harbor, Vashon Island) displaying parcels, parcel centroids identified as primary residential, and the 150-meter shoreline buffer.

Table A1. Estimated daily DIN loads to Puget Sound from on-site wastewater systems located within the exclusive area (loads are in units of kilograms per day).

Base Assumptions		Water Resource Inventory Area							Daily Load Total (kg/d)
		Chambers-Clover	Deschutes	Duwamish-Green	Kennedy-Goldsborough	Kitsap	Nisqually	Puyallup-White	
w/loss assumptions	x<150-m	2.36	28.22	3.34	28.66	225.32	0.36	1.56	289.82
	x>150-m	0.11	39.84	16.79	28.19	265.92	8.60	36.63	396.08
	Total=	2.47	68.06	20.13	56.85	491.24	8.96	38.19	685.90
w/o loss assumptions	x<150-m	2.60	31.34	3.73	31.84	250.36	0.38	1.73	321.97
	x>150-m	0.38	132.77	59.95	94.00	886.36	28.63	122.08	1320.16
	Total=	2.99	164.11	59.67	125.84	1136.71	29.01	123.81	1642.14

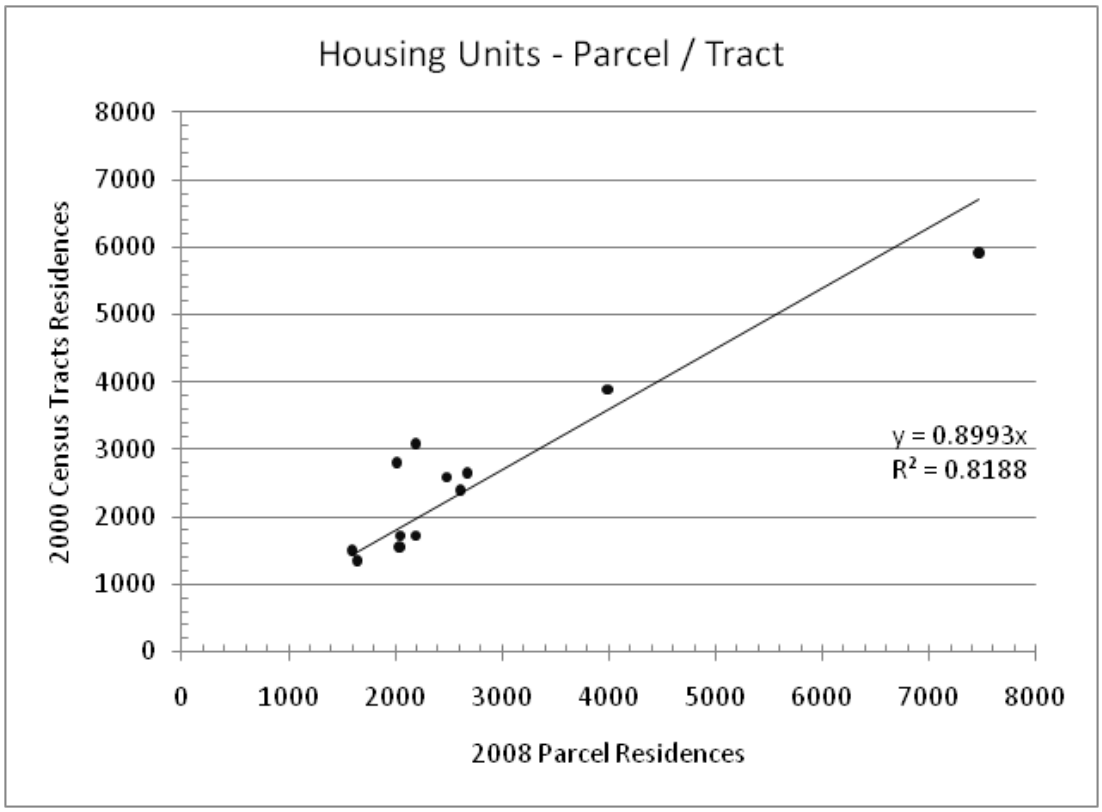

Figure A3. The number of residences estimated by the U.S. Census in relation to those estimated by county assessor parcel data based on several Census tracts within the study area.

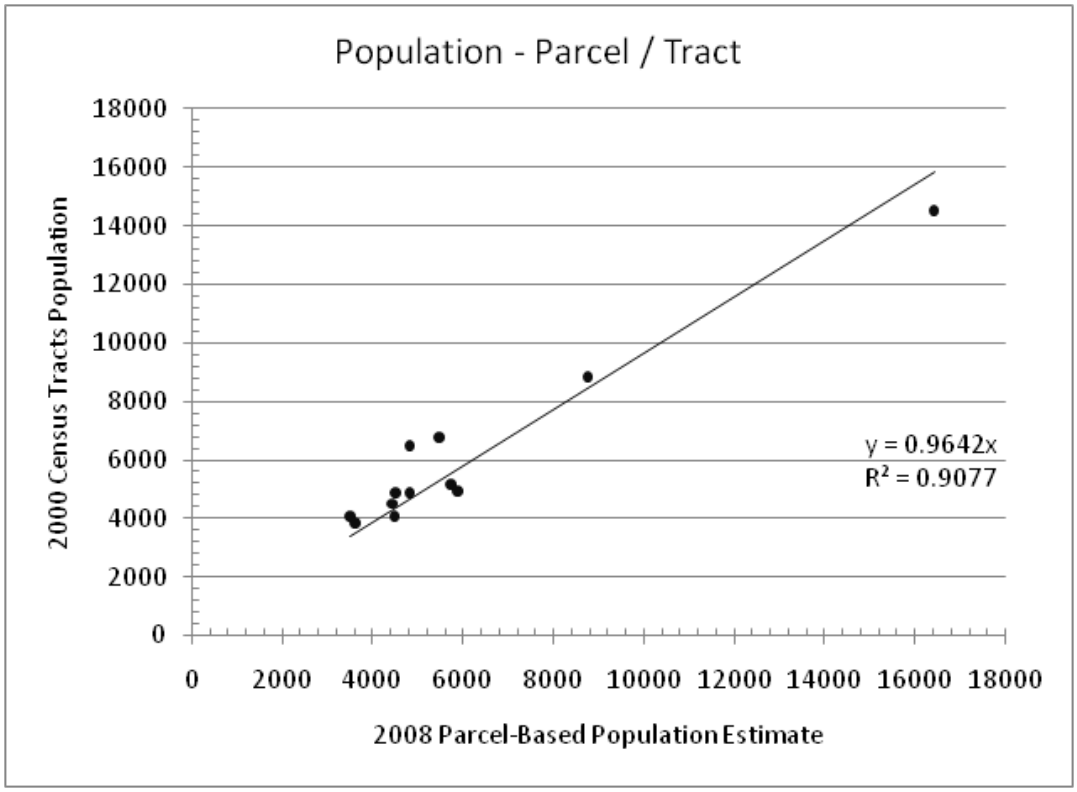

Figure A4. The population estimated by the U.S. Census in relation to estimates by application of county assessor parcel data, based on several Census tracts within the study area.

Figure A5 presents the relationship between the number of residences per hectare and median July/August nitrate concentrations observed in the monitored catchments. The majority of the monitored catchments are rural where maximum residential densities are typically set at 0.5 residences per hectare. From Figure A5, based on this residential density level, a median low-flow nitrate concentration of 0.610 mg/L is predicted. From the relationship, and assuming no residential development (y-intercept), a rough assessment of a "background" nitrate concentration can be determined for these catchments. The y-intercept based is 0.116 mg/L (116 ug/L). While in comparison, the July/August median nitrate concentrations of relatively un-impacted rivers (minimal residential and agricultural influences present) monitored as part of Washington State Department of Ecology's ambient monitoring such as the North Fork Stillaguamish River at Darrington (73 ug/L) and Green River at Kanaskat (62 ug/L). To be sure, there are other influences on groundwater nitrate concentrations in the monitored catchments other than on-site systems but this relationship suggests that their influence is a significant one.

Referring to Table A2 (below) within the monitored catchments the median residential density is 0.21 residences per hectare. From the relationship in Figure A5, this results in a stream concentration of 0.323 mg/L. If a background concentration of 0.116 mg/L is assumed, then the net residential contribution to stream nitrate concentration is 0.207 mg/L. Applying the median flow (0.11 m^3/s), this concentration results in a July/August nitrate load of 1.97 kg/d. In comparison, the median on-site nitrate load is estimated at 8.51 kg/d. This would indicate that the retention level is around 77%. To be sure, there is high variability in each component of this estimate, but it indicates overall that high nitrate retention is possible provided a complex flow path that encounters aerobic/anaerobic transitions, conducive to de-nitrification, along with biological uptake opportunities.

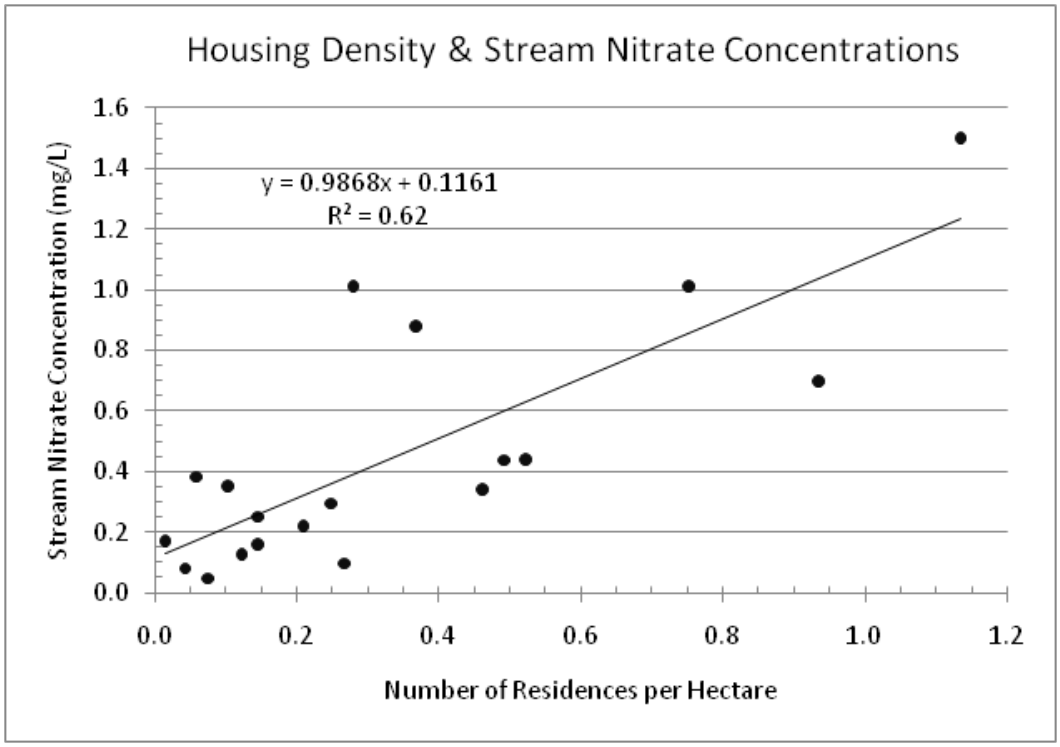

Figure A5. The relation between housing density (no./ha) and the median July/August nitrate concentration for several catchments within the study area.

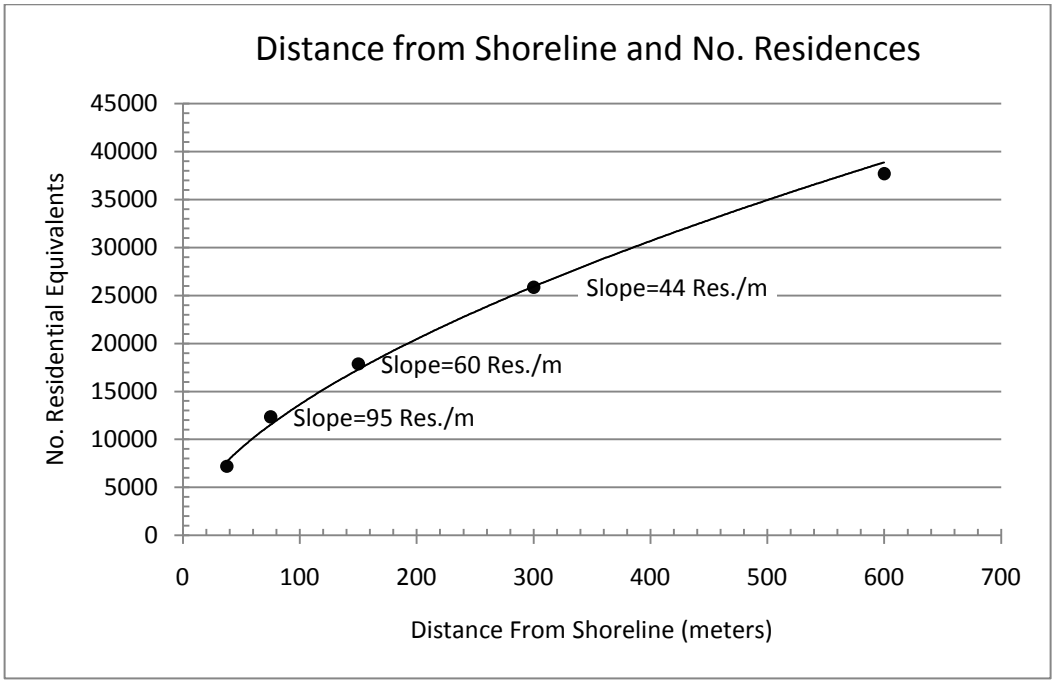

Figure A6. The relation between the distance from shoreline (meters) and the number of residences (exclusive area).

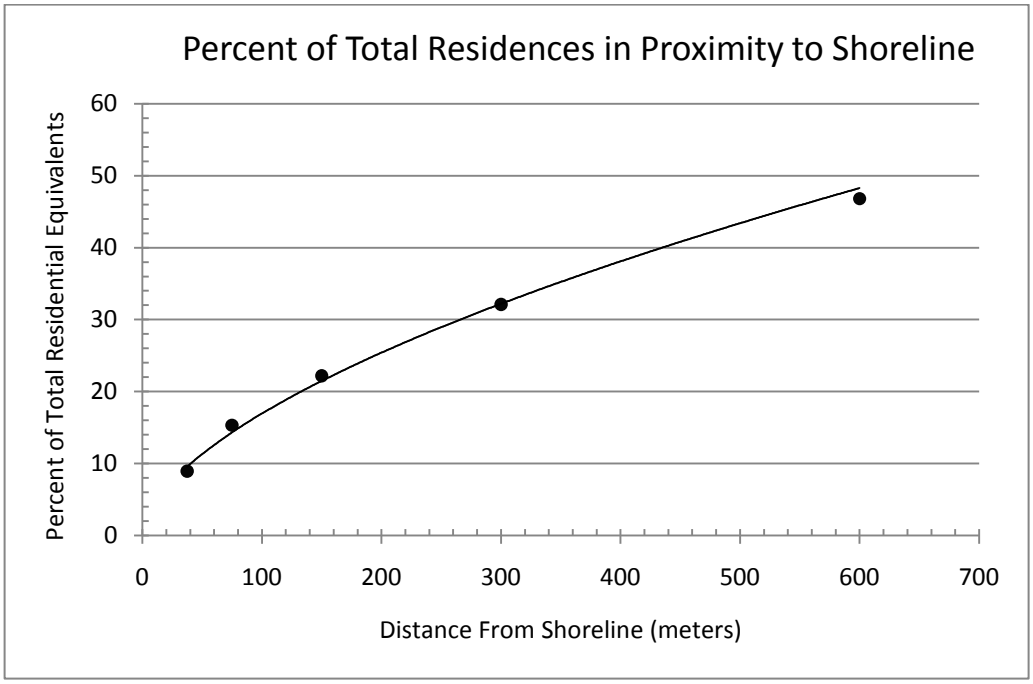

Figure A7. The percent representation of total residential equivalents (within exclusive area) based on distance from shoreline.

Table A2. Stream and residential-based nitrate loads for several catchments within the study area.

Catchment	Median July/August Discharge (ft3/s)	Median Nitrate Concentration (mg/L)	Catchment Area (ha)	Residences (No.)	Res./Ha	Stream Nitrate Load (kg/d)	On-Site System Load (kg/d)	Nitrate Attenuation (%)
Burley	14.17	0.697	2566	2398	0.93	24.16	48.85	51
Butler	0.04	1.500	124	141	1.13	0.16	2.87	94
Cranberry	9.93	0.096	3645	970	0.27	2.32	19.76	88
Deer	17.41	0.079	3748	161	0.04	3.36	3.28	0
Johns	11.95	0.220	2631	551	0.21	6.43	11.22	43
Judd	1.80	1.011	1212	339	0.28	4.45	6.91	36
Kennedy	5.40	0.351	5034	516	0.10	4.64	10.51	56
McAllister	==	1.010	6718	5047	0.75	==	102.81	==
McLane	3.90	0.158	2901	418	0.14	1.51	8.51	82
Mill	11.36	0.047	5207	388	0.07	1.31	7.90	83
Minter	==	0.438	3921	1929	0.49	==	39.29	==
Olalla	5.75	0.441	1283	669	0.52	6.20	13.63	54
Perry	0.62	0.383	1637	96	0.06	0.58	1.96	70
Purdy	1.91	0.340	938	433	0.46	1.59	8.82	82
Rocky	3.29	0.295	4763	1178	0.25	2.37	24.00	90
Schneider	1.20	0.127	1997	245	0.12	0.37	4.99	93
Sherwood	0.54	0.251	8576	1243	0.14	0.33	25.32	99
Shingle	2.09	0.880	805	296	0.37	4.50	6.03	25
Skookum	3.89	0.170	4084	61	0.01	1.62	1.24	0
Median	**3.89**	**0.30**	**2631**	**418**	**0.21**	**2.32**	**8.51**	**70**

*Shaded catchments were excluded from calculation of medians due to lack of flow measurements.

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Appendix D. Rivers: Predicted and Observed Nutrient Concentrations and Loads

Figures D-1 through D-3 compare observed and predicted concentrations and loads of various parameters for the Deschutes River.

Figure D-1. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the Deschutes River.

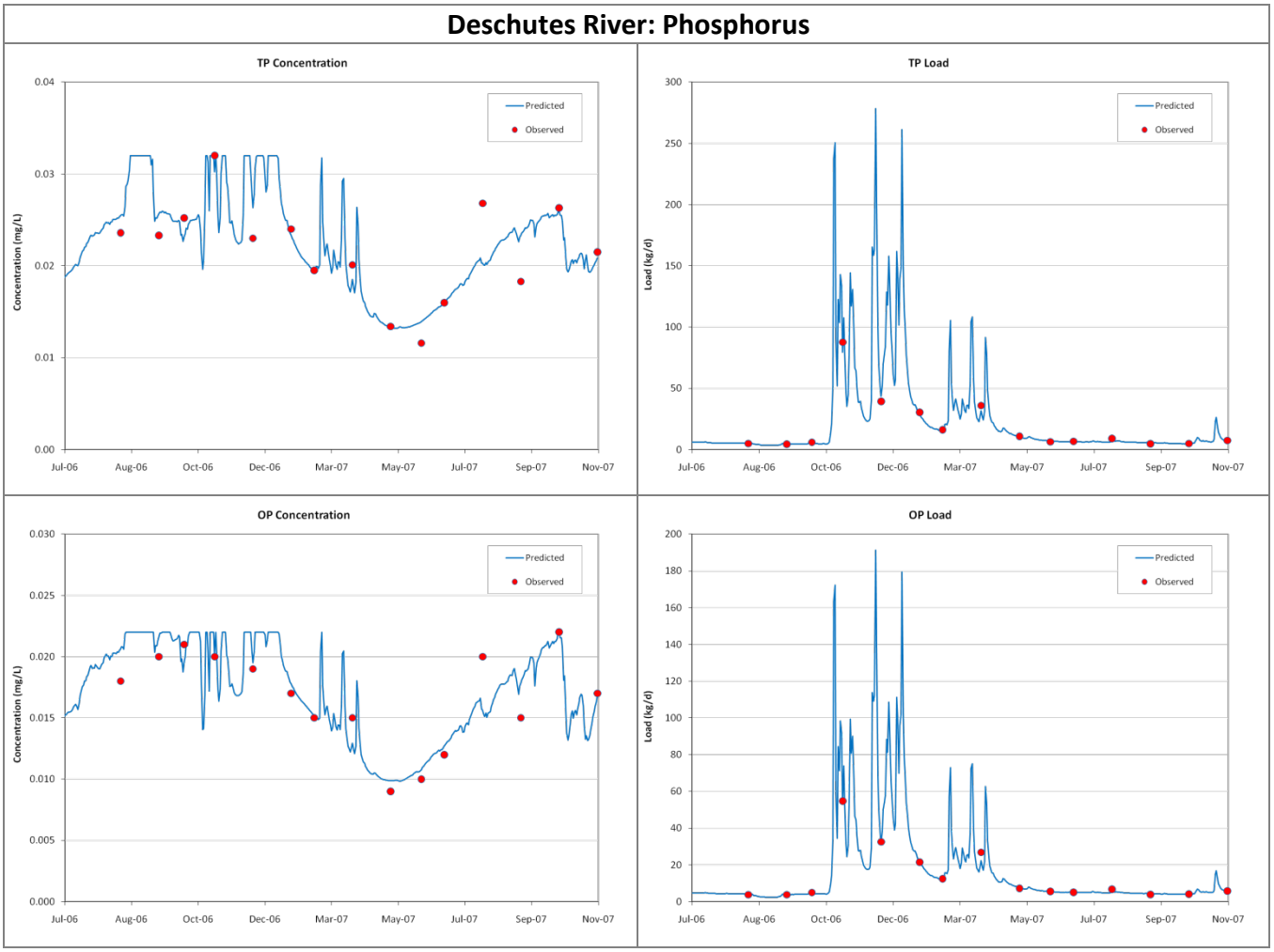

Figure D-2. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the Deschutes River.

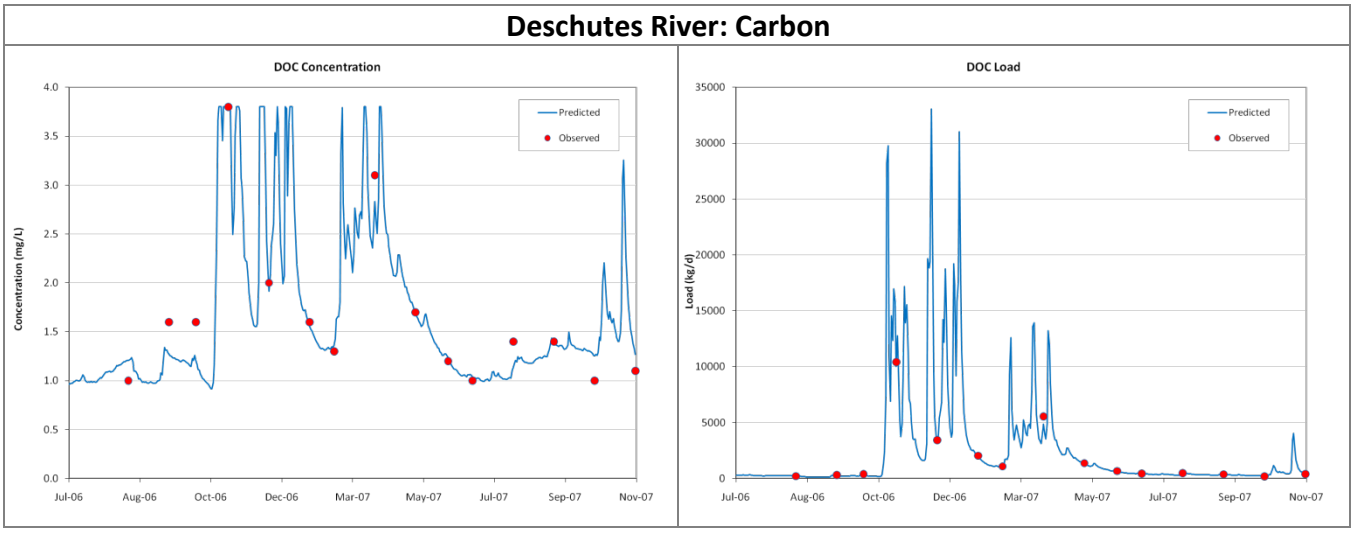

Figure D-3. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon (DOC) for the Deschutes River.

Figures D-4 through D-6 compare observed and predicted concentrations and loads of various parameters for the Green River.

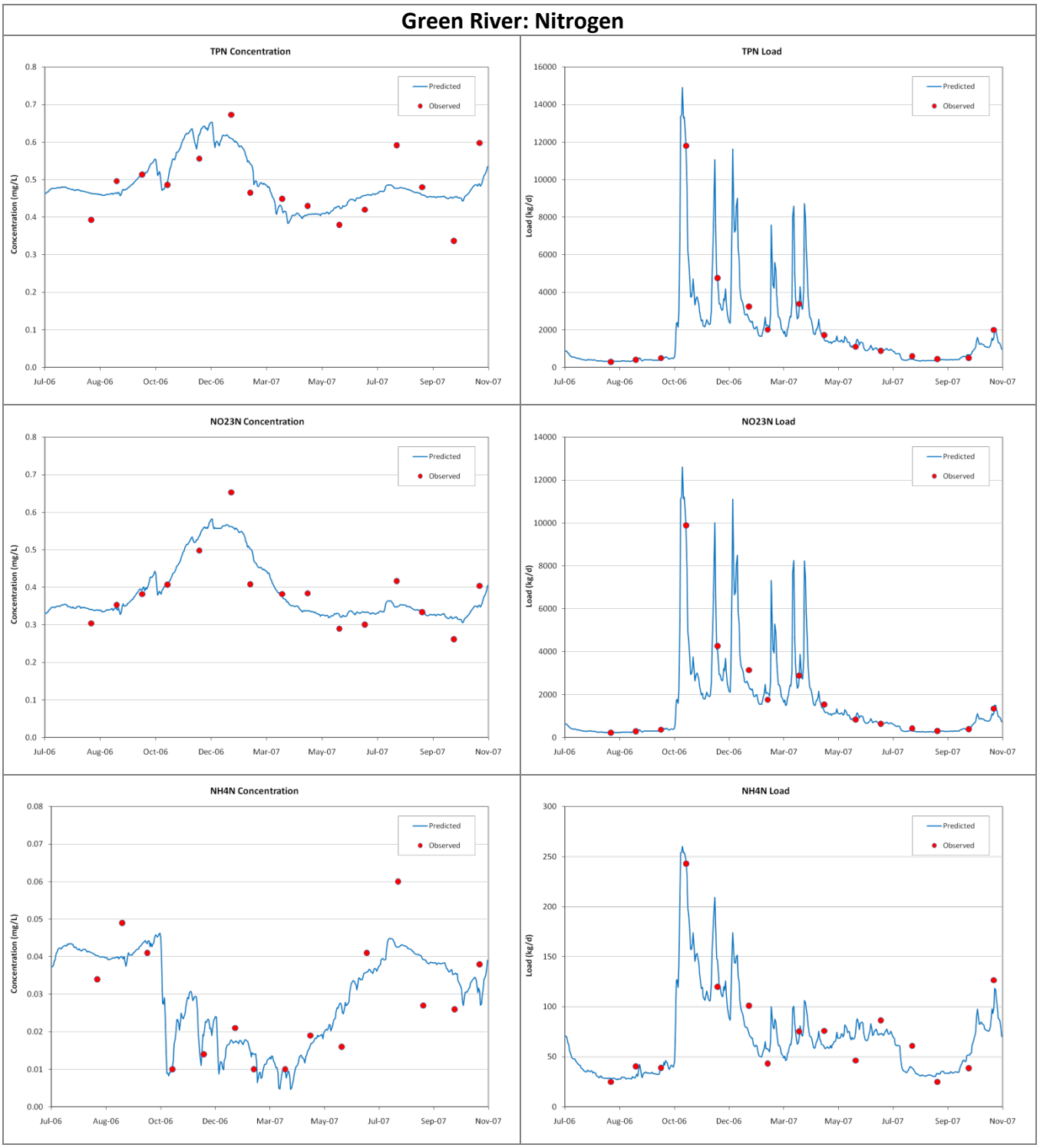

Figure D-4. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the Green River.

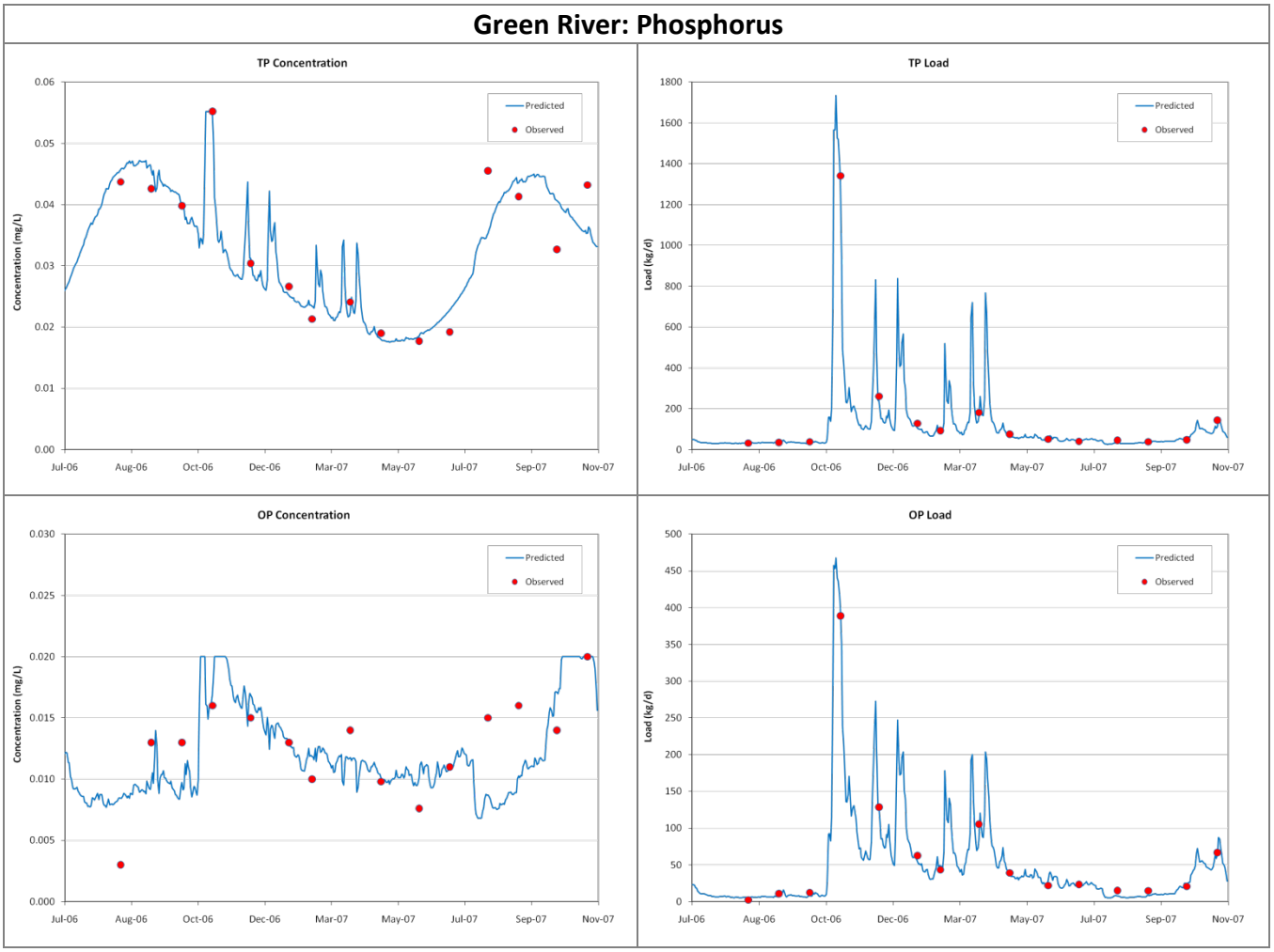

Figure D-5. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the Green River.

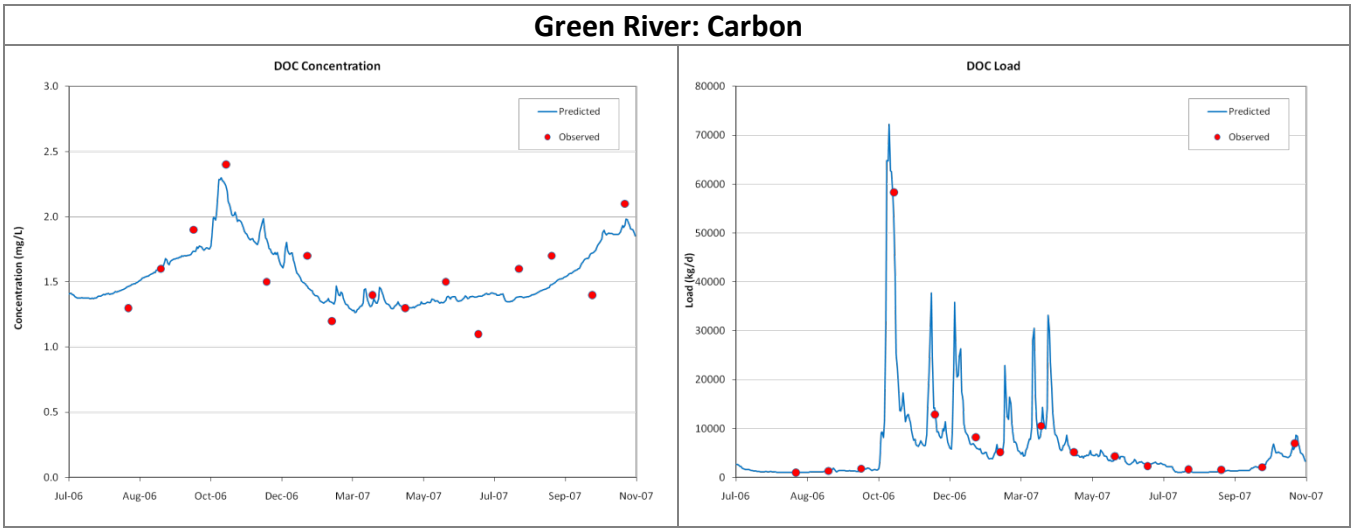

Figure D-6. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon (DOC) for the Green River.

Figures D-7 through D-9 compare observed and predicted concentrations and loads of various parameters for the Nisqually River.

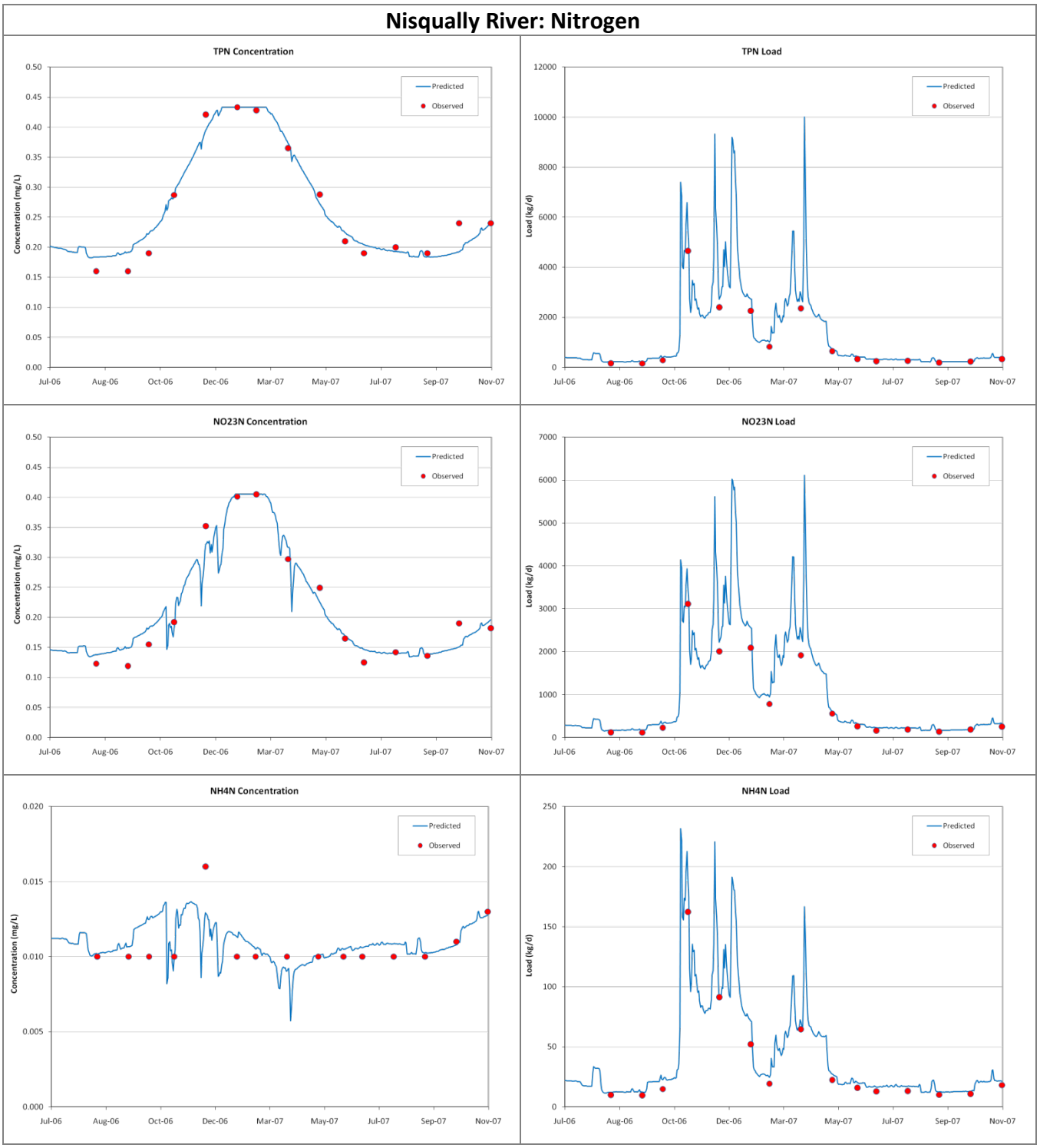

Figure D-7. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the Nisqually River.

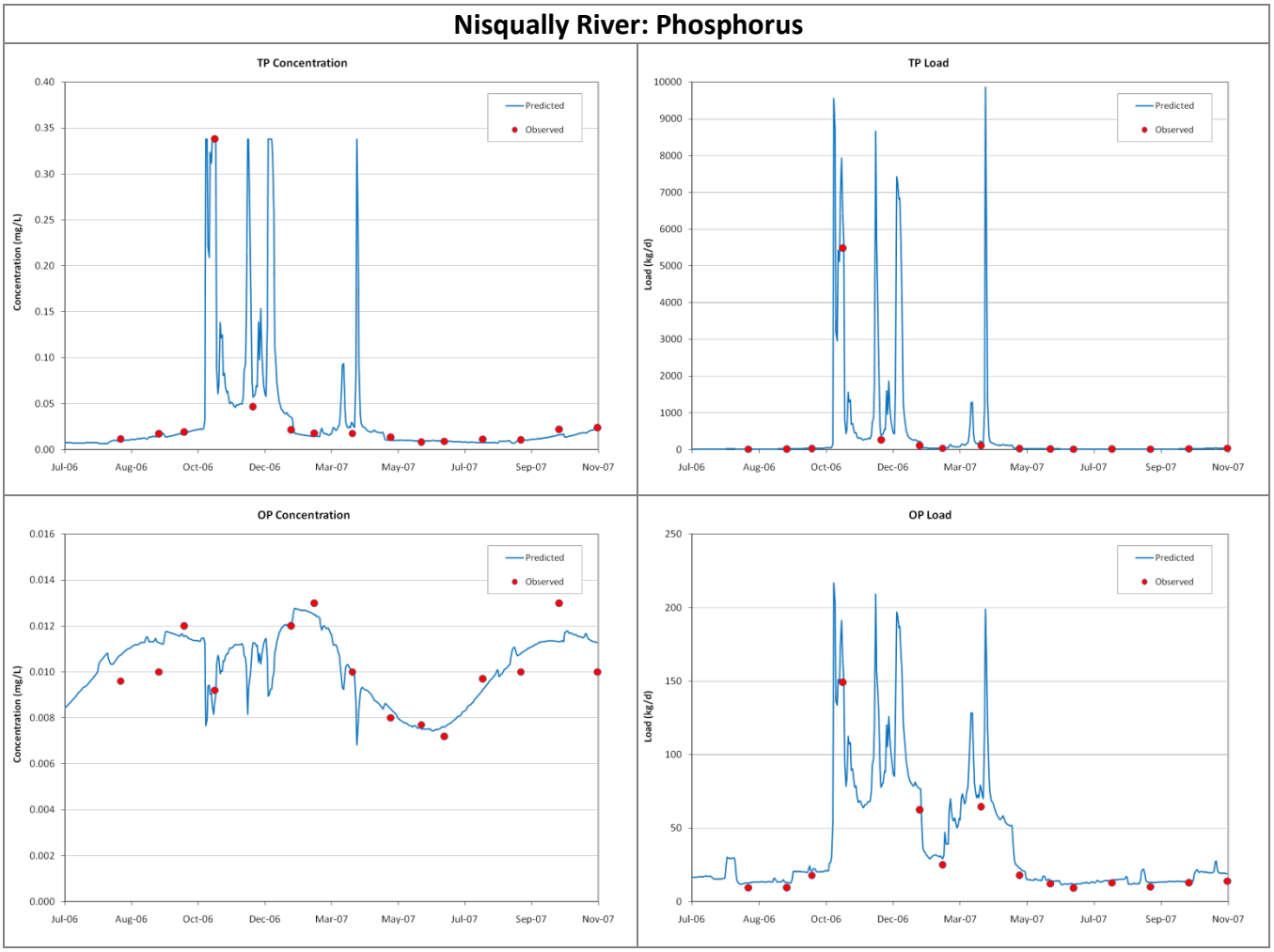

Figure D-8. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the Nisqually River.

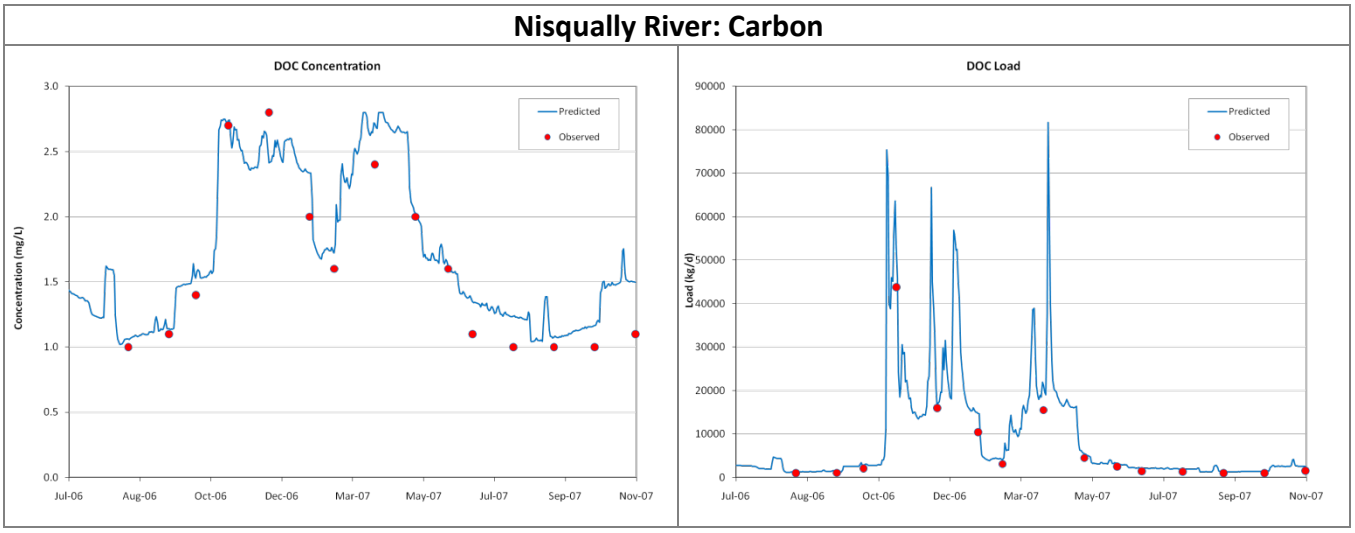

Figure D-9. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon (DOC) for the Nisqually River.

Figures D-10 through D-12 compare observed and predicted concentrations and loads of various parameters for the Puyallup River.

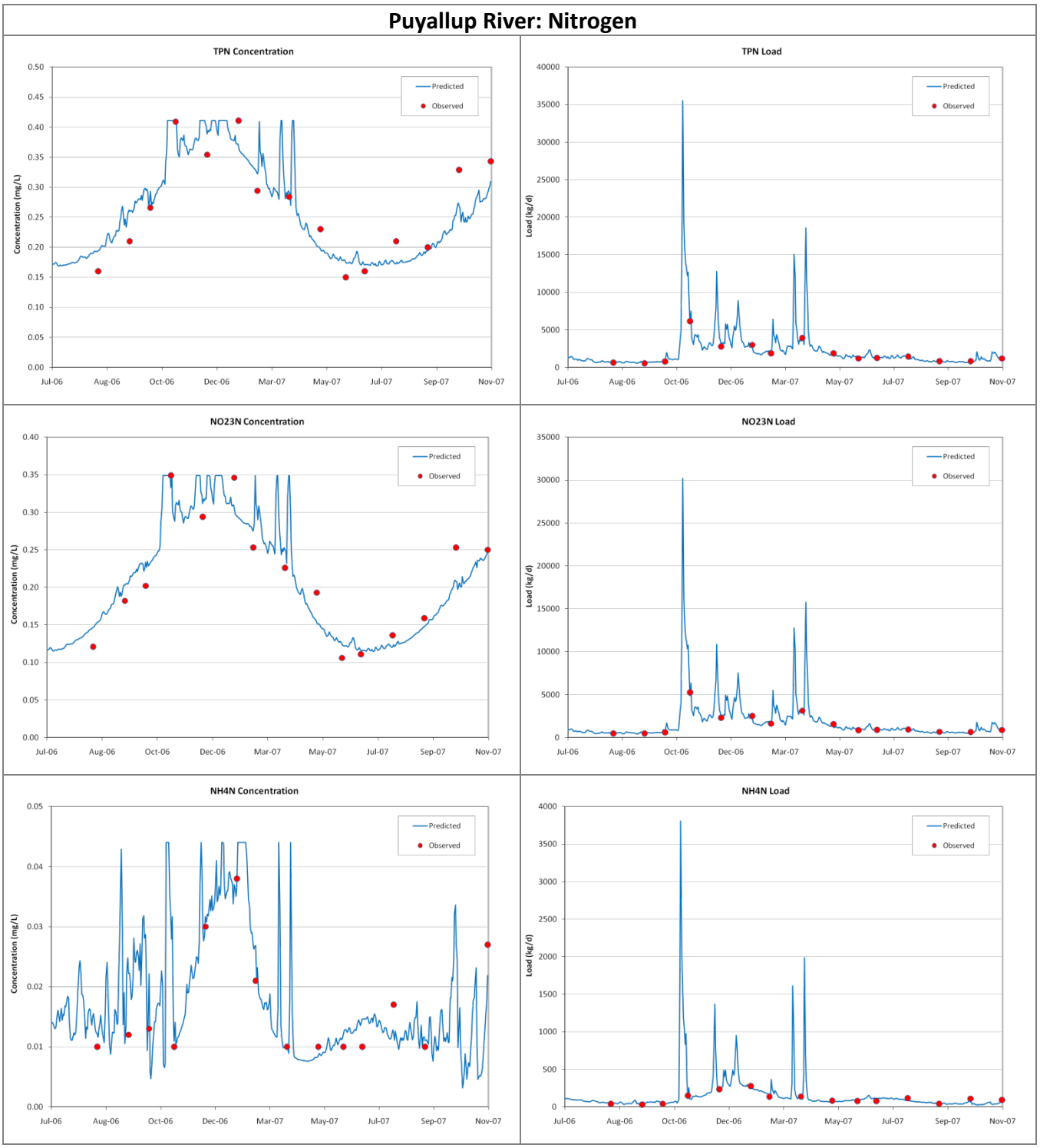

Figure D-10. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the Puyallup River.

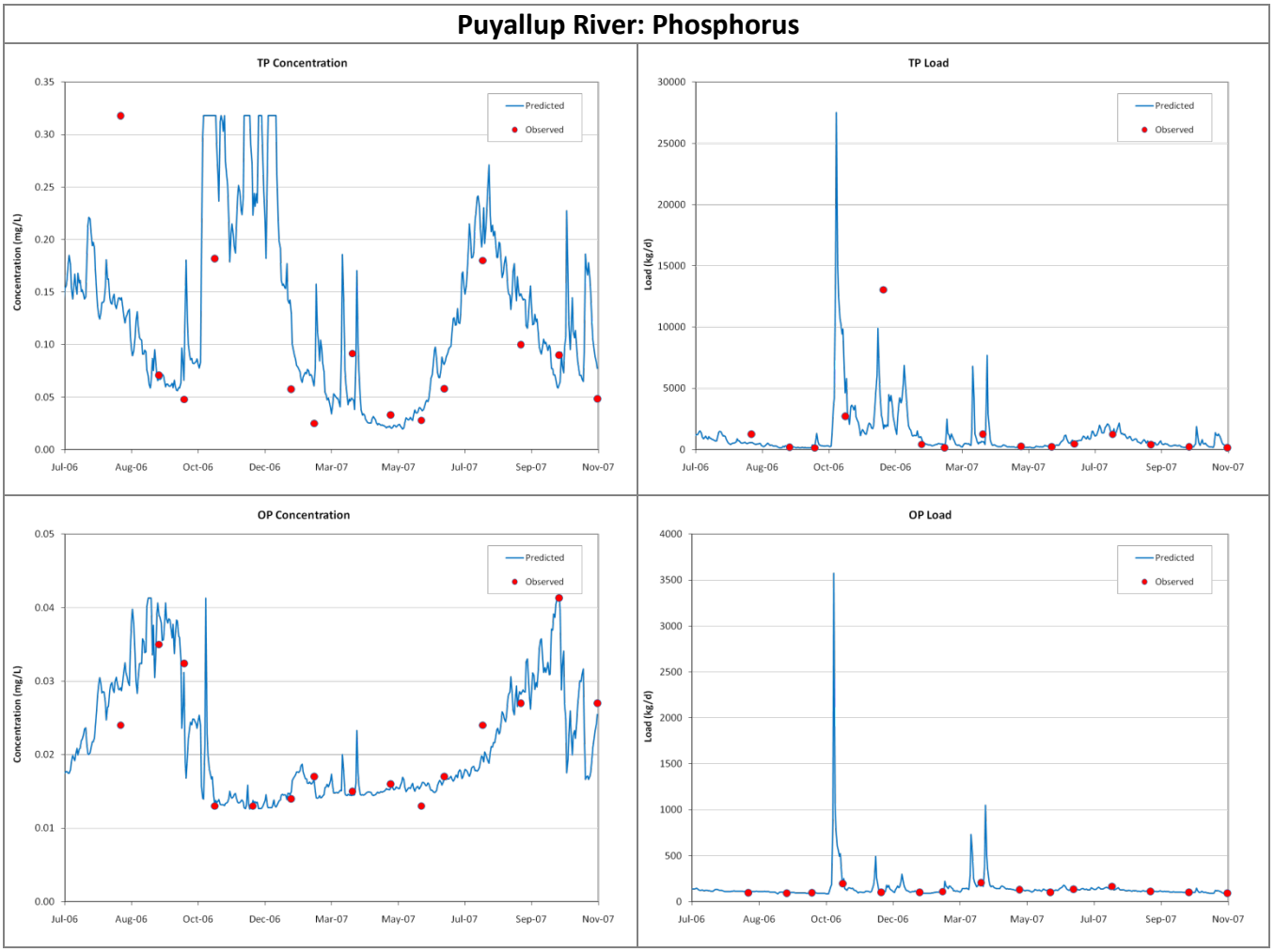

Figure D-11. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the Puyallup River.

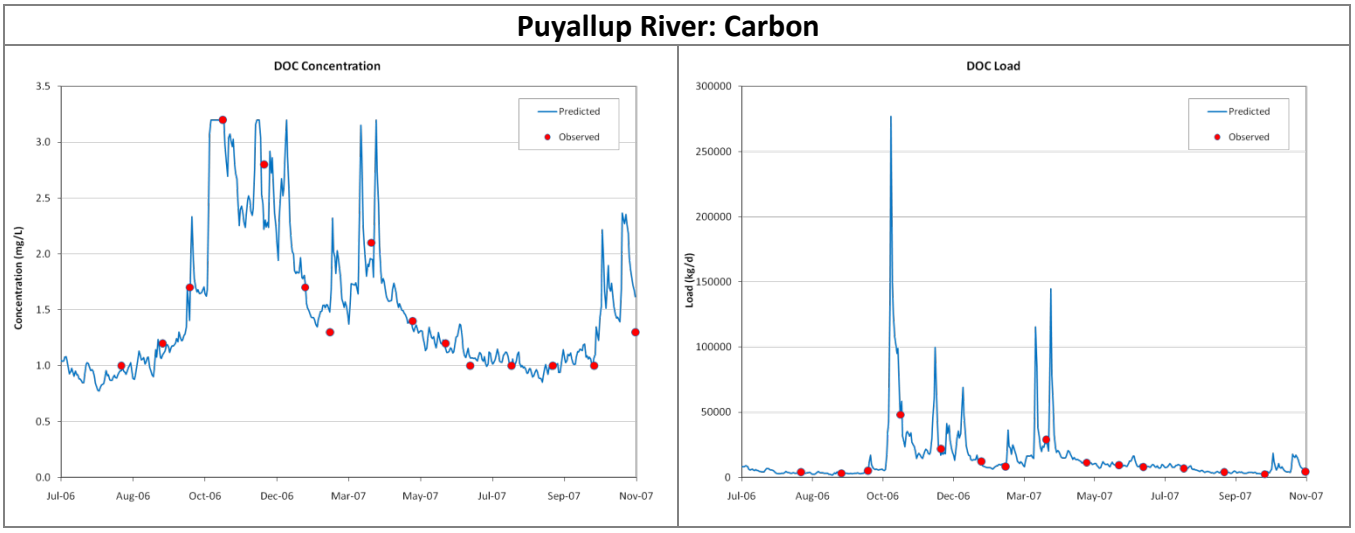

Figure D-12. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon (DOC) for the Puyallup River.

Table D-1 presents the average difference and average root mean square error (RMSE) between predicted and observed concentrations of various parameters for each river and stream where monitoring took place for 15 or four months.

Table D-1. Average difference and average RMSE between predicted and observed concentrations of various parameters for stations that were monitored for 15 months and stations that were monitored for 4 months.

Difference between Predicted and Observed Concentrations						
Stream/River Name	**NO23N** mg/L	**NH4N** mg/L	**TPN** mg/L	**OP** mg/L	**TP** mg/L	**DOC** mg/L
15 Month Stations						
Burley	-0.017	-0.003	-0.031	0.002	0.004	-0.974
Chambers	0.000	0.000	0.001	0.000	0.000	0.000
Coulter	-0.007	0.008	-0.007	0.001	0.001	-0.084
Deschutes	0.015	0.000	0.010	0.000	0.000	-0.043
Goldsborough	0.000	0.000	0.000	0.000	0.000	0.274
Green	0.002	0.000	0.002	0.000	0.000	-0.008
Kennedy	-0.001	-0.013	-0.018	-0.003	-0.004	0.023
Lake Washington	-0.005	0.001	0.007	0.000	0.001	-0.052
McAllister	0.000	0.000	-0.006	-0.001	0.000	-0.013
McLane	0.035	0.001	0.032	0.000	0.000	-0.566
Minter	0.000	-0.005	0.000	0.000	0.000	0.010
Nisqually	0.002	0.000	0.002	0.000	0.001	0.122
Perry	0.064	0.003	0.082	0.001	0.004	-1.316
Puyallup	0.000	0.001	0.000	0.000	0.009	-0.040
Rocky	0.025	-0.003	0.050	-0.004	-0.001	0.186
Sherwood	-0.033	-0.014	-0.051	-0.008	-0.001	0.267
Sinclair Dyes	0.000	0.000	-0.001	0.000	0.000	-0.003
Skookum	0.076	0.000	0.041	0.000	0.001	-0.161
Woodard	-0.076	0.000	0.039	0.000	0.003	0.063
Woodland	-0.006	0.001	0.007	0.000	0.000	0.023
Avg. Difference	**0.004**	**-0.001**	**0.008**	**-0.001**	**0.001**	**-0.115**
4 Month Stations						
Butler	-1.192	0.010	-1.158	-0.022	-0.006	-2.140
Campbell	0.203	0.010	0.187	0.000	0.009	-3.473
Cranberry	0.162	0.003	0.156	-0.005	0.007	-0.911
Curley	0.105	0.009	0.047	0.005	0.013	-3.066
Des Moines	-0.534	0.006	-0.601	-0.048	-0.037	-3.477
Ellis	-0.676	0.006	-0.674	-0.027	-0.020	-2.466
Goodnough	-2.451	0.010	-2.334	0.001	0.007	-1.366
Hylebos	-0.655	-0.053	-0.774	-0.073	-0.081	-5.027
Johns	0.031	-0.006	0.021	-0.008	0.006	-1.123
Judd	-0.684	0.010	-0.715	-0.025	-0.012	-3.940
Mill	0.231	0.010	0.220	0.006	0.018	-1.798
Miller	-0.813	0.010	-0.849	-0.041	-0.032	-3.902
Mission	-0.960	0.003	-1.026	-0.081	-0.085	-3.391
Moxlie	-0.472	0.000	-0.445	-0.041	-0.037	-1.491
Olalla	-0.148	0.010	-0.137	-0.011	0.001	-2.591
Purdy	-0.015	0.010	-0.017	-0.014	-0.001	-2.116
Shingle Mill	-0.604	0.010	-0.564	-0.037	-0.021	-2.152
Avg. Difference	**-0.498**	**0.004**	**-0.510**	**-0.025**	**-0.016**	**-2.614**

Root Mean Square Error between Predicted and Observed Concentrations						
Stream/River Name	**NO23N** mg/L	**NH4N** mg/L	**TPN** mg/L	**OP** mg/L	**TP** mg/L	**DOC** mg/L
15 Month Stations						
Burley	0.039	0.007	0.057	0.004	0.013	2.327
Chambers	0.137	0.003	0.105	0.005	0.003	0.249
Coulter	0.010	0.014	0.018	0.004	0.004	0.828
Deschutes	0.041	0.001	0.048	0.002	0.003	0.165
Goldsborough	0.008	0.000	0.021	0.001	0.001	1.059
Green	0.048	0.007	0.062	0.003	0.004	0.195
Kennedy	0.022	0.045	0.046	0.005	0.007	0.053
Lake Washington	0.014	0.006	0.058	0.000	0.006	0.316
McAllister	0.051	0.011	0.304	0.007	0.015	0.176
McLane	0.066	0.013	0.070	0.001	0.004	1.578
Minter	0.017	0.037	0.052	0.007	0.010	1.012
Nisqually	0.020	0.001	0.021	0.001	0.006	0.218
Perry	0.123	0.006	0.145	0.002	0.006	1.767
Puyallup	0.025	0.006	0.033	0.002	0.067	0.200
Rocky	0.037	0.006	0.068	0.005	0.002	0.252
Sherwood	0.052	0.043	0.091	0.014	0.009	0.859
Sinclair Dyes	0.022	0.003	0.024	0.001	0.004	0.152
Skookum	0.133	0.002	0.085	0.001	0.002	0.370
Woodard	0.111	0.001	0.108	0.001	0.005	3.772
Woodland	0.229	0.012	0.177	0.002	0.002	0.243
Avg, RMSE	**0.060**	**0.011**	**0.080**	**0.003**	**0.009**	**0.790**
4 Month Stations						
Butler	1.195	0.012	1.160	0.022	0.010	4.812
Campbell	0.204	0.013	0.188	0.003	0.009	4.584
Cranberry	0.164	0.018	0.157	0.005	0.007	1.312
Curley	0.123	0.010	0.075	0.005	0.013	3.659
Des Moines	0.592	0.012	0.655	0.049	0.038	5.269
Ellis	0.691	0.009	0.685	0.028	0.021	4.414
Goodnough	2.454	0.012	2.339	0.002	0.018	2.951
Hylebos	0.665	0.054	0.775	0.074	0.081	8.282
Johns	0.036	0.033	0.056	0.008	0.008	2.259
Judd	0.693	0.013	0.718	0.026	0.013	5.640
Mill	0.234	0.013	0.222	0.007	0.018	2.647
Miller	0.865	0.012	0.900	0.042	0.033	5.710
Mission	0.980	0.009	1.038	0.081	0.086	5.829
Moxlie	0.475	0.008	0.448	0.041	0.037	3.620
Olalla	0.157	0.012	0.141	0.011	0.002	3.924
Purdy	0.104	0.012	0.127	0.014	0.004	3.805
Shingle Mill	0.604	0.012	0.564	0.037	0.022	4.017
Avg. RMSE	**0.602**	**0.016**	**0.603**	**0.027**	**0.025**	**4.279**

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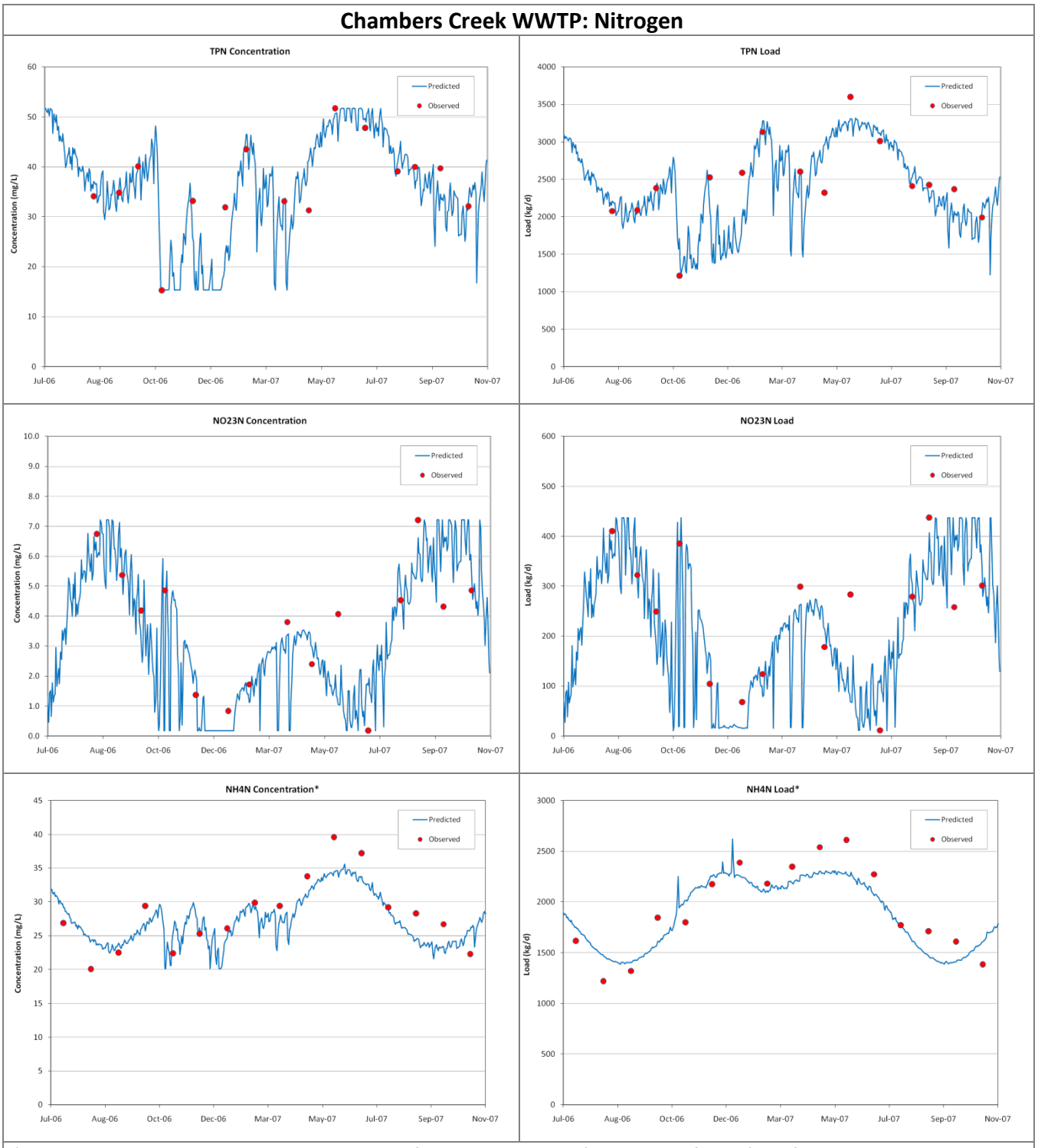
Appendix E. Wastewater Treatment Plants: Predicted and Observed Nutrient Concentrations and Loads

Figures E-1 through E-4 compare observed and predicted concentrations and loads of various parameters for the Chambers Creek WWTP.



* Observed NH4N concentrations and load data for Chambers Creek (bottom two figures) are from 2006-07 DMR data. These data were used to develop the NH4N regression estimates instead of the data Ecology collected at this plant.

Figure E-1. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the Chambers Creek WWTP.

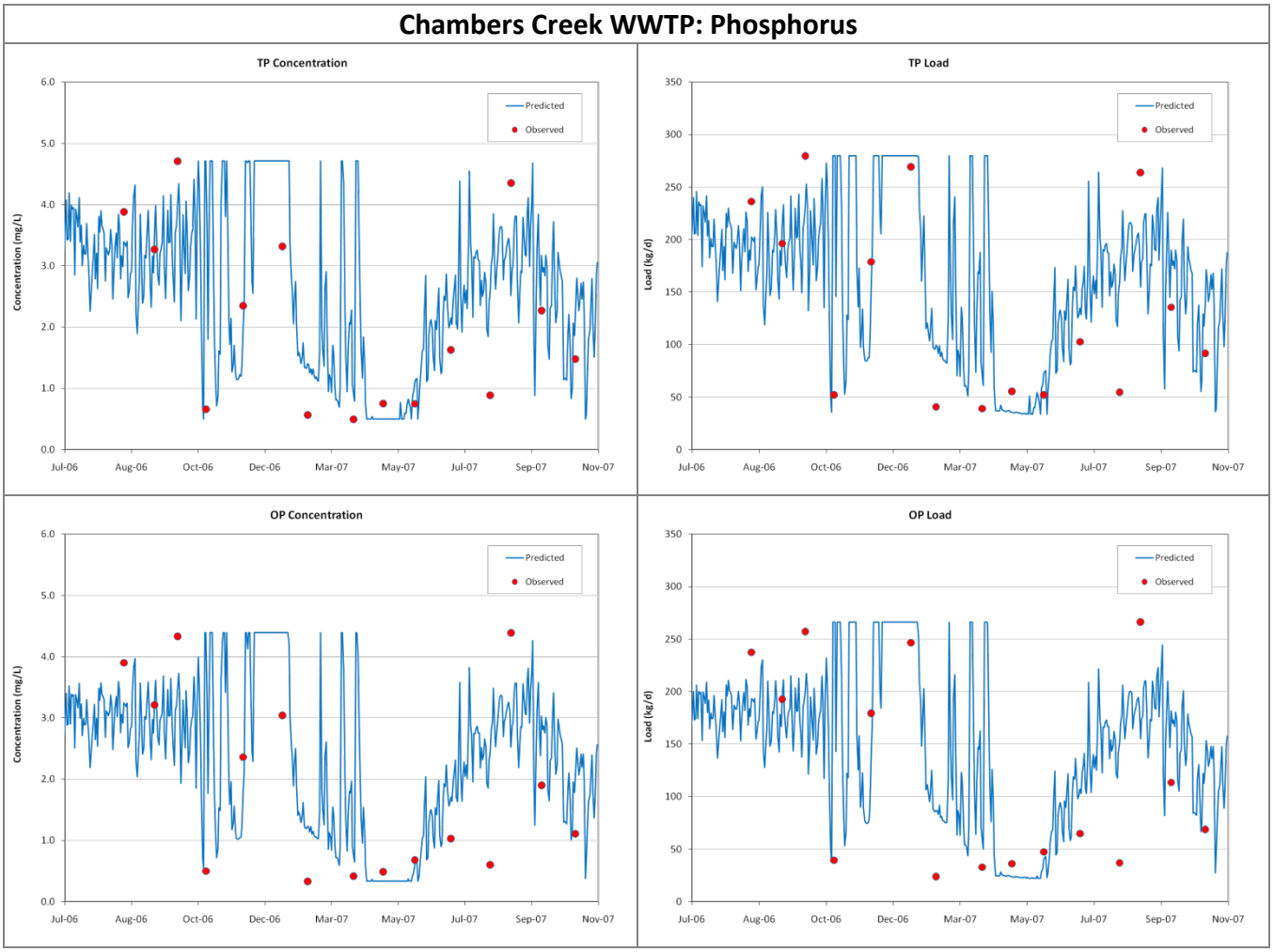


Figure E-2. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the Chambers Creek WWTP.

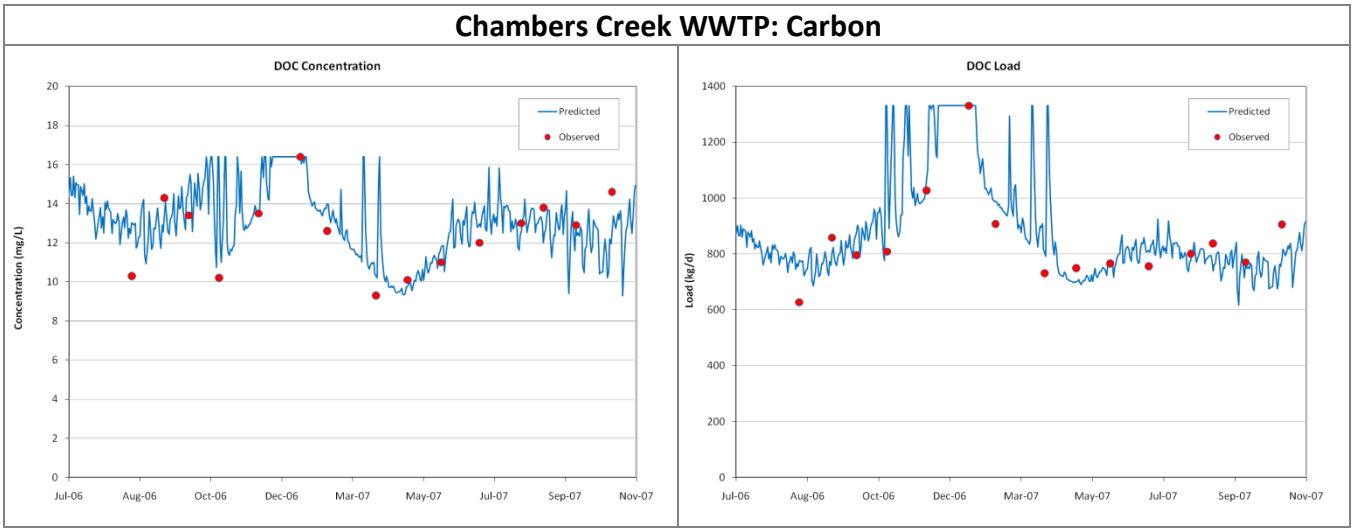


Figure E-3. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon (DOC) for the Chambers Creek WWTP.

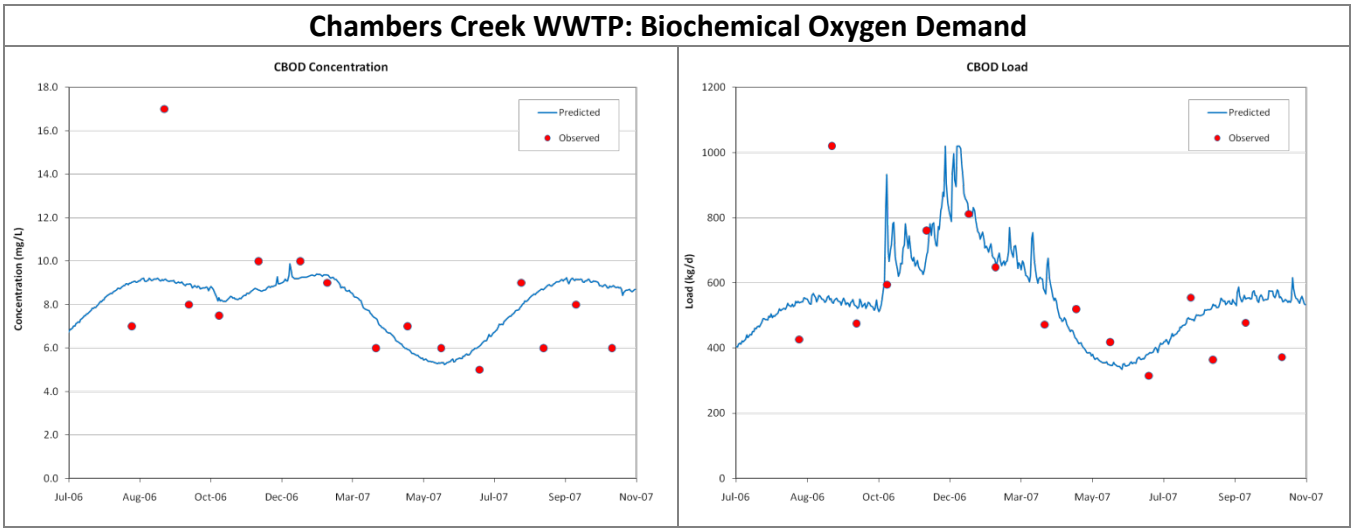
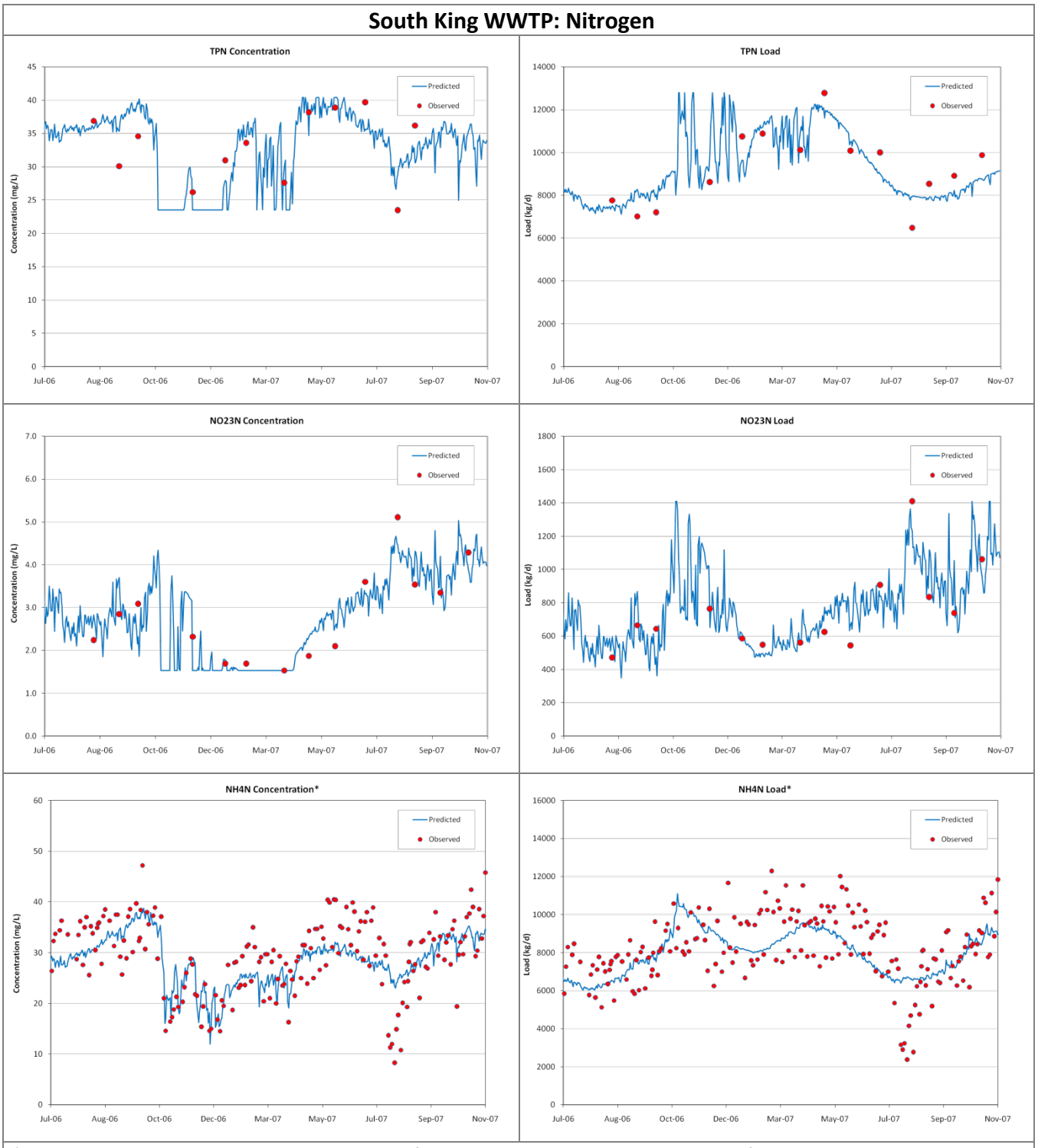


Figure E-4. Predicted and observed concentrations (left column) and loads (right column) of CBOD for the Chambers Creek WWTP.

Figures E-5 through E-8 compare observed and predicted concentrations and loads of various parameters for the South King WWTP.



* Observed NH4N concentrations and load data from 2006-07 shown in the bottom two figures were sent to Ecology by the South King WWTP, and were used to develop the NH4N regression estimates instead of the data Ecology collected at this plant.

Figure E-5. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the South King WWTP.

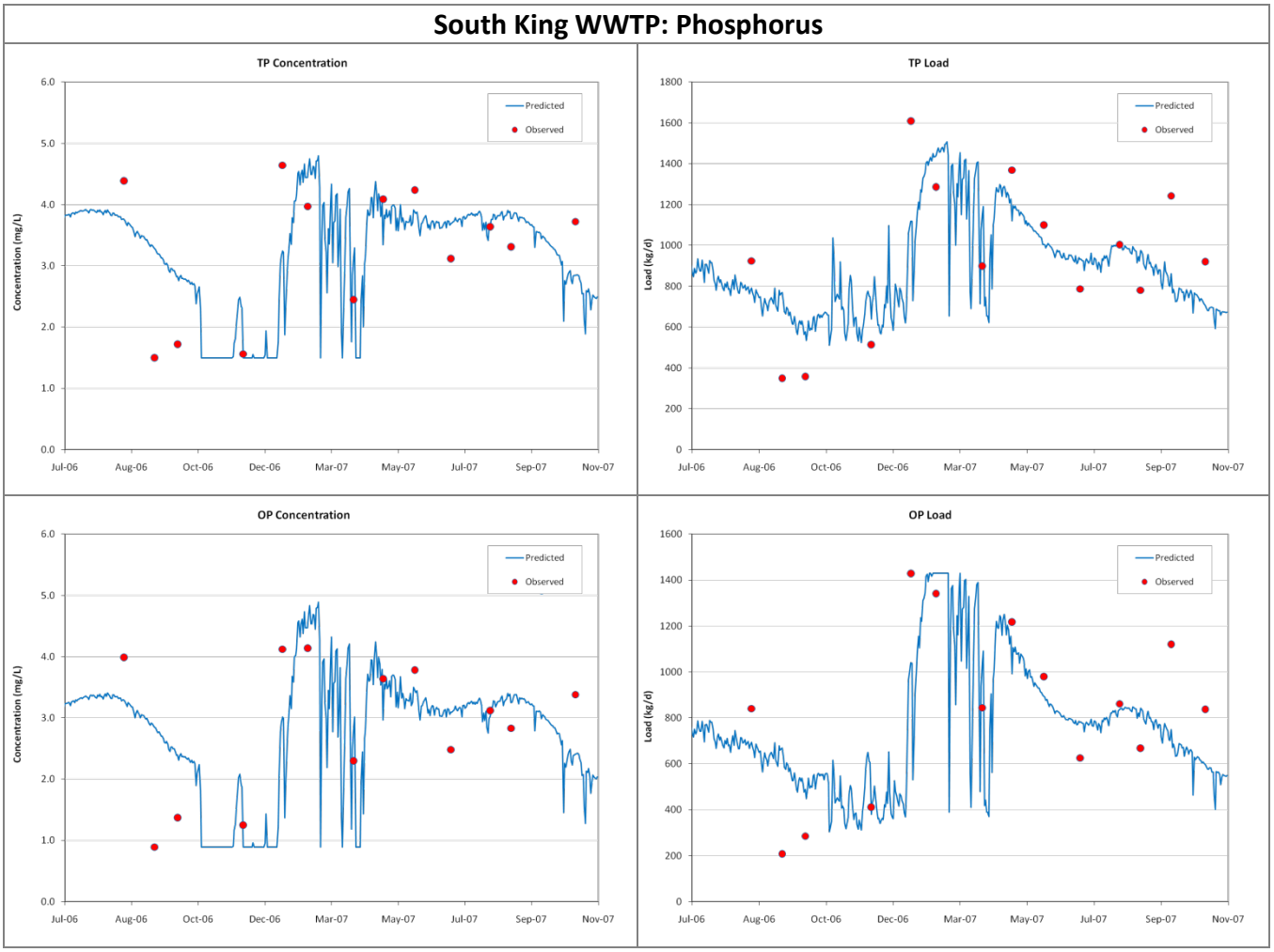


Figure E-6. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the South King WWTP.

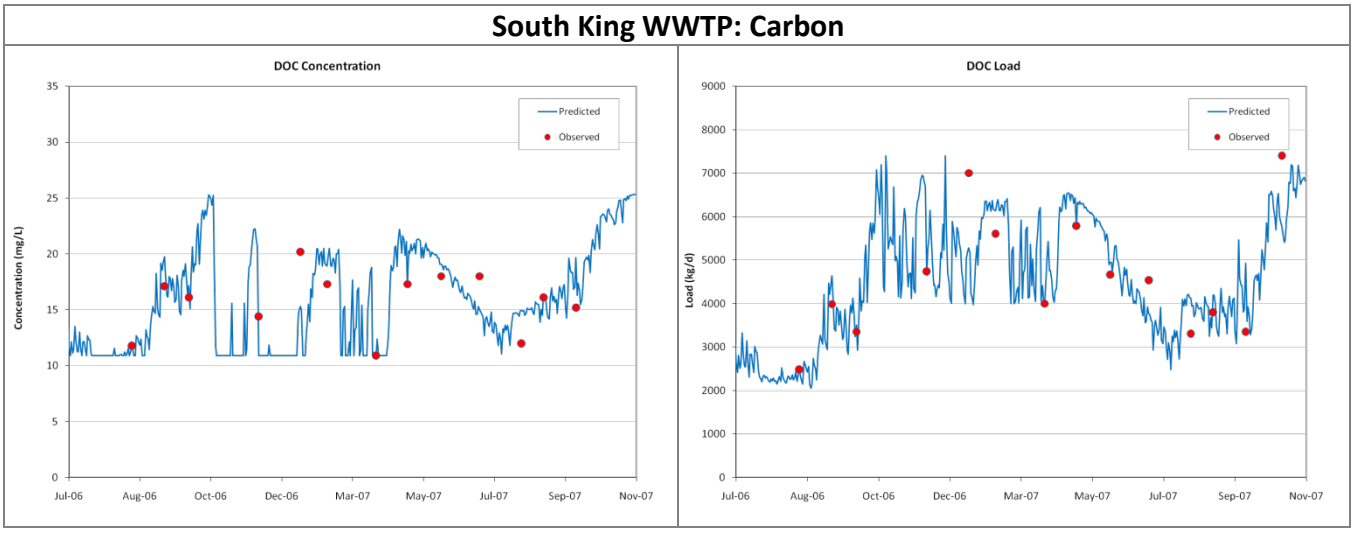


Figure E-7. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon for the South King WWTP.

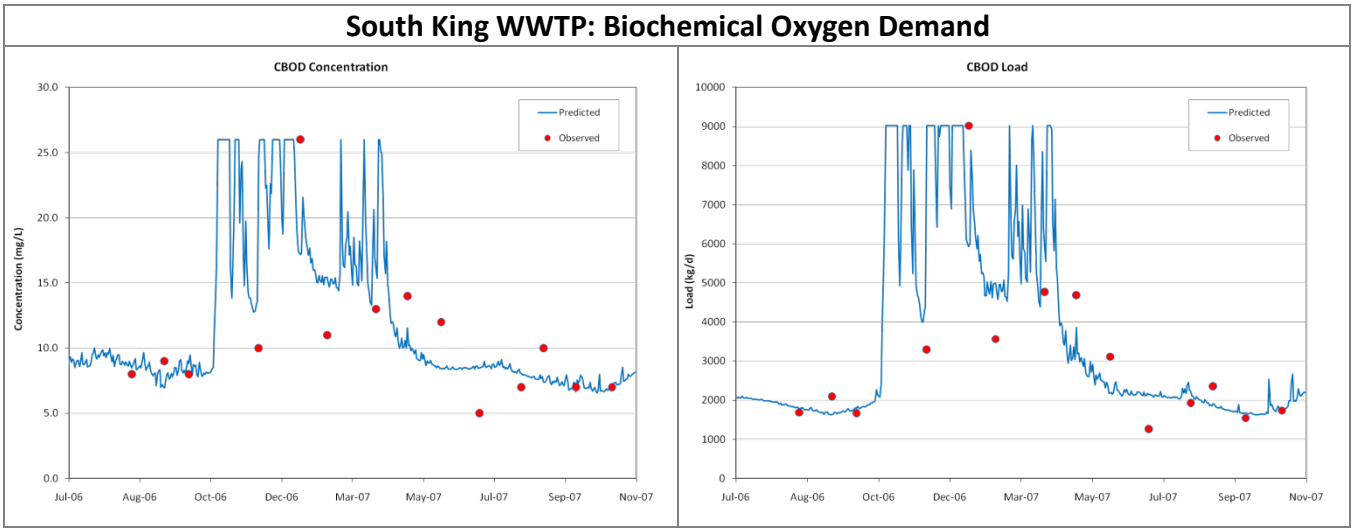


Figure E-8. Predicted and observed concentrations (left column) and loads (right column) of CBOD for the South King WWTP.

Figures E-9 through E-12 compare observed and predicted concentrations and loads of various parameters for the Tacoma-Central WWTP.

Figure E-9. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the Tacoma-Central WWTP.

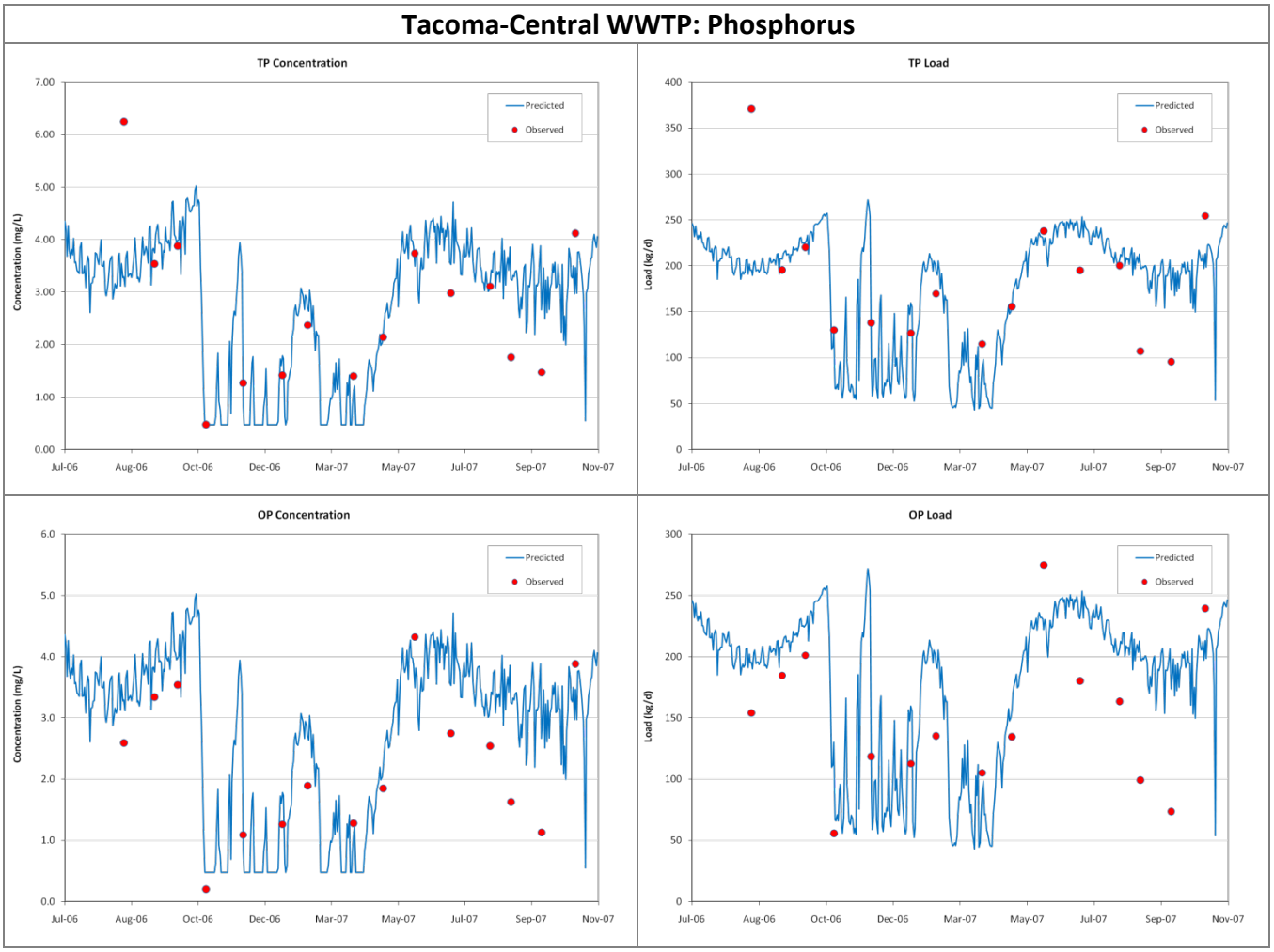


Figure E-10. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the Tacoma-Central WWTP.

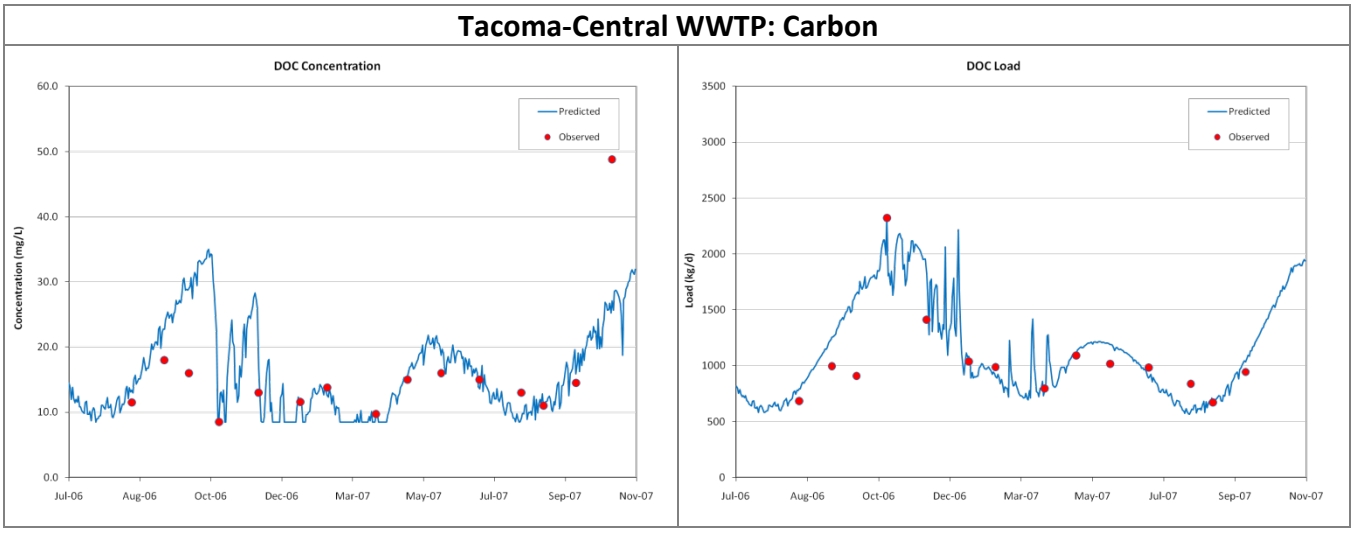


Figure E-11. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon (DOC) for the Tacoma-Central WWTP.

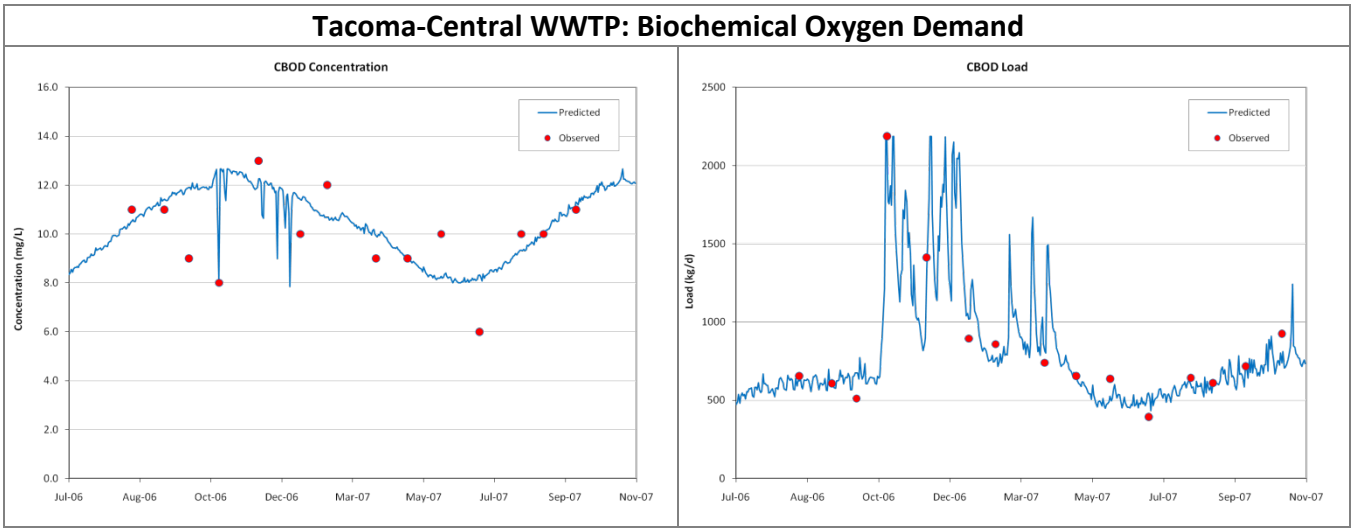


Figure E-12. Predicted and observed concentrations (left column) and loads (right column) of CBOD for the Tacoma-Central WWTP.

Figures E-13 through E-16 compare observed and predicted concentrations and loads of various parameters for the West Point WWTP.

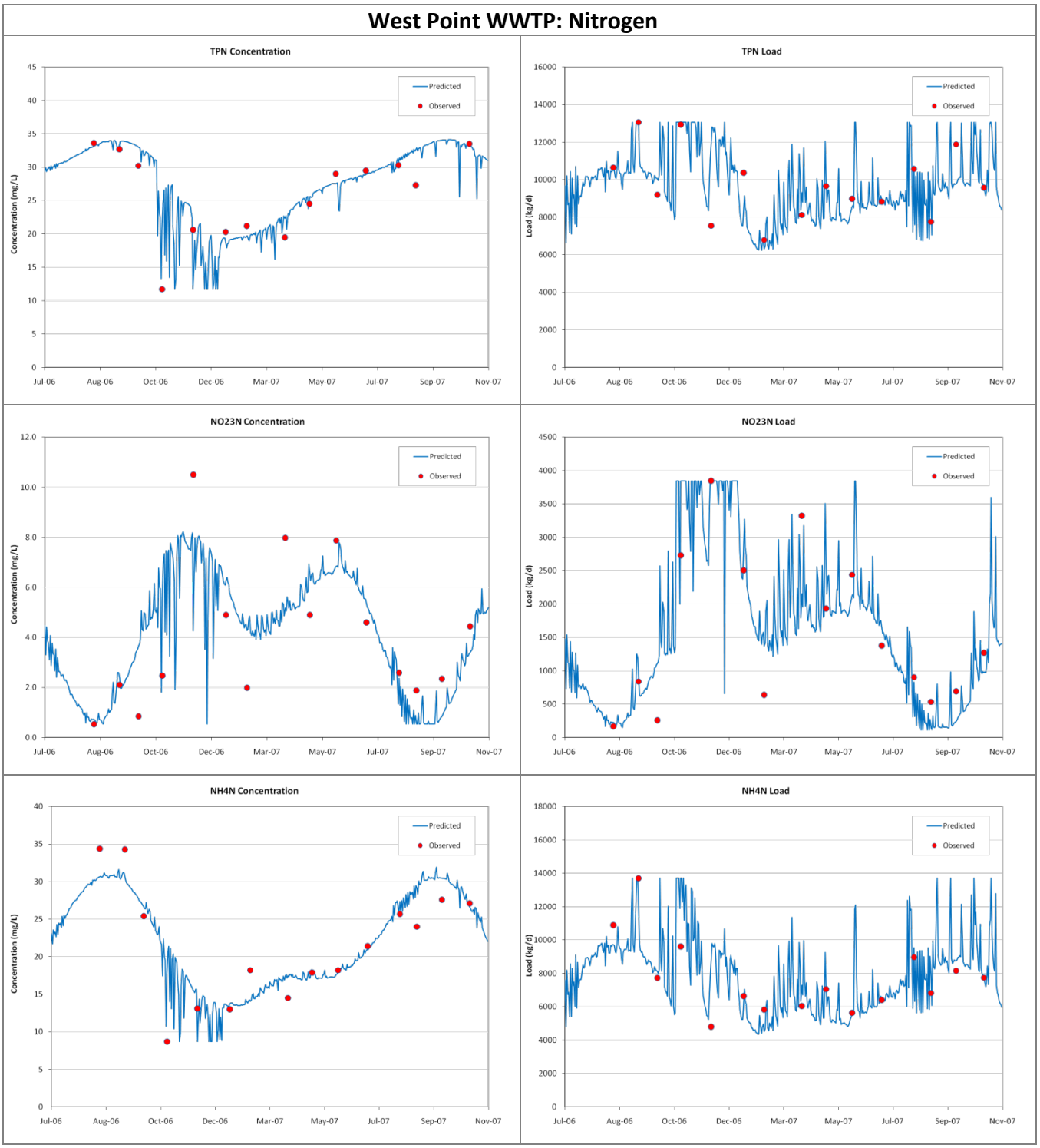


Figure E-13. Predicted and observed concentrations (left column) and loads (right column) of nitrogen for the West Point WWTP.

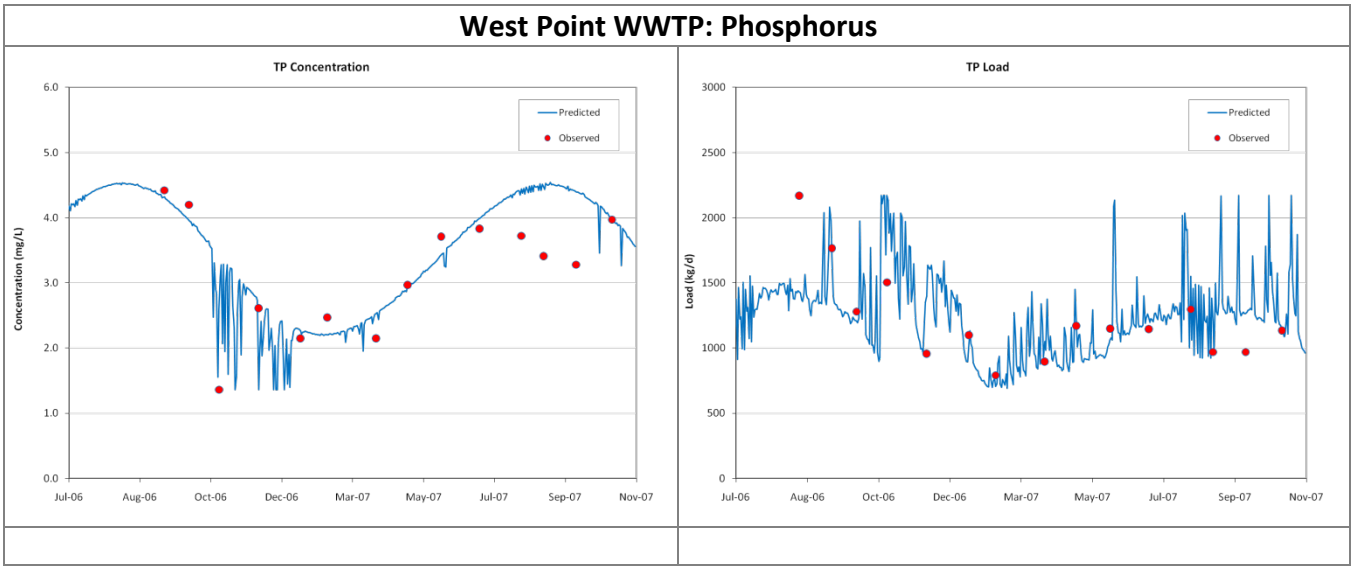


Figure E-14. Predicted and observed concentrations (left column) and loads (right column) of phosphorus for the West Point WWTP.

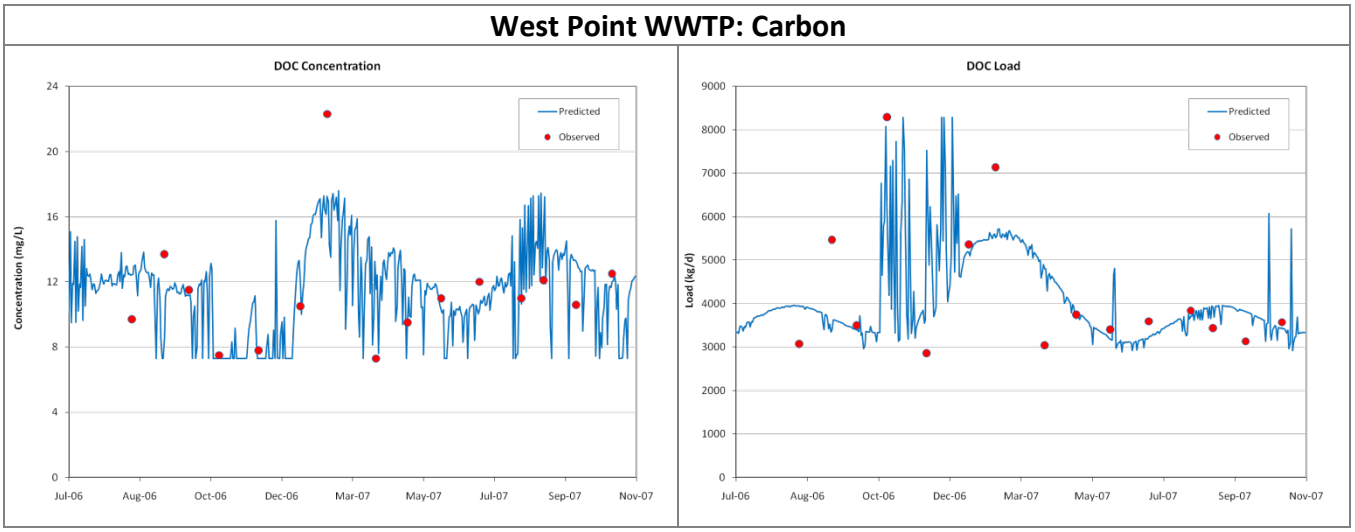


Figure E-15. Predicted and observed concentrations (left column) and loads (right column) of dissolved organic carbon (DOC) for the West Point WWTP.

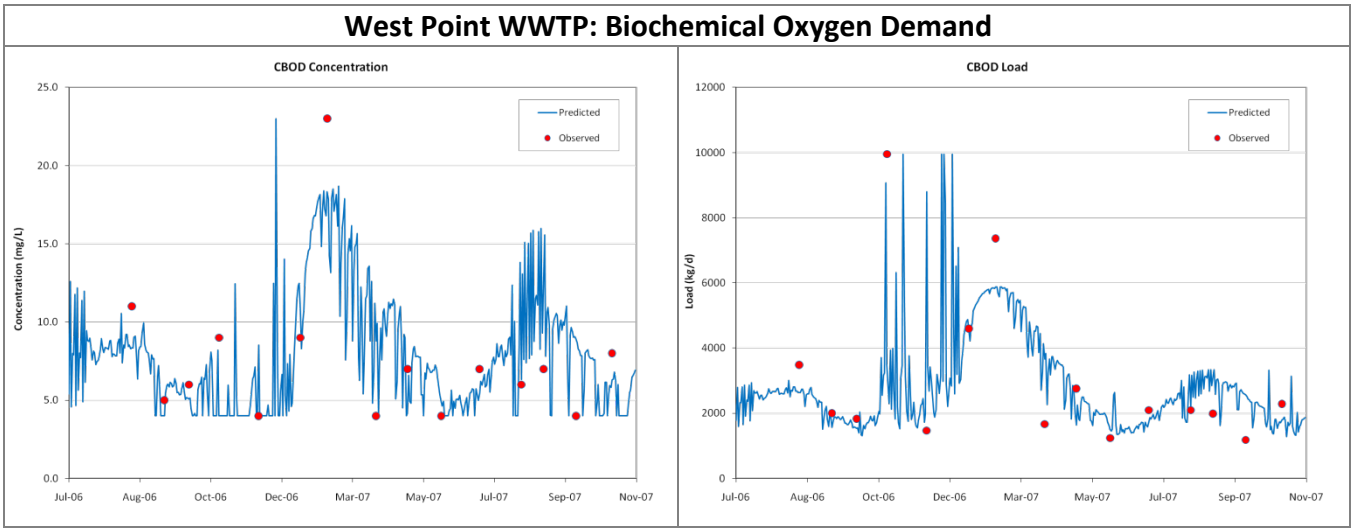


Figure E-16. Predicted and observed concentrations (left column) and loads (right column) of CBOD for the West Point WWTP.

Table E-1 presents the average difference and average root mean square error (RMSE) between predicted and observed concentrations of various parameters for each WWTP where monitoring took place for either 15 or three months.

Table E-1. Average difference and average RMSE between predicted and observed concentrations of various parameters for WWTPs that were monitored for 15 months and WWTPs that were monitored for 4 months.

Difference between Predicted and Observed Concentrations

WWTP Name	NO23N mg/L	NH4N mg/L	TPN mg/L	OP mg/L	TP mg/L	DOC mg/L	CBOD mg/L
15 Month WWTPs							
Boston Harbor	1.438	-0.061	1.170	-0.205	0.191	0.008	-0.612
Bremerton	0.172	-1.016	-0.337	-0.027	0.026	0.045	0.102
Chambers	-0.416	0.000*	-0.291	0.468	0.506	0.608	0.040
Gig Harbor	-0.004	0.378	0.296	0.251	0.318	1.472	0.826
Lakota	0.023	-0.453	-0.627	-0.259	-0.338	0.098	-0.623
LOTT	-0.172	-0.079	-0.398	0.163	0.020	0.025	0.058
Manchester	-0.131	0.098	-0.080	-0.037	-0.037	-0.165	-0.081
Midway	-0.247	-0.369	-0.246	-0.016	-0.061	0.231	0.267
Port Orchard	0.553	-0.433	-0.012	-0.077	-0.036	0.024	0.270
Redondo	-0.478	-0.148	-0.466	-0.046	-0.074	-0.246	0.286
Shelton	0.076	0.373	0.181	0.116	0.043	0.528	0.505
South King	0.072	0.000*	-0.861	-0.102	-0.083	-0.273	0.586
Tacoma-Central	0.007	-0.175	-0.125	-0.030	-0.015	-0.004	0.036
Tacoma-North	0.009	-0.648	-0.161	0.001	0.000	-0.398	-0.713
Tamoshan	0.276	-0.319	0.038	-0.298	-0.001	0.236	-0.028
West Point	-0.122	0.433	0.046	0.045	0.020	-0.080	0.091
Avg. Difference	**0.066**	**-0.151**	**-0.117**	**-0.003**	**0.030**	**0.132**	**0.063**
3 Month WWTPs - Medium Template							
Fort Lewis	-0.061*	-0.248*	3.876	-1.319	-0.465	-5.856	-3.075
Miller	7.093	-6.229	-0.190	0.106	0.313	-9.239	-1.741
Salmon	-1.184	-6.229	11.79	0.106	0.313	-2.156	1.425
Avg. Difference	**1.950**	**-4.235**	**5.160**	**-0.369**	**0.053**	**-5.750**	**-1.130**
3 Month WWTPs - Small Template							
Bainbridge Kitsap	-21.75	2.617	-19.98	-0.719	-0.555	5.947	0.807
Hartstene	2.782	1.276	5.565	-0.467	1.153	4.935	2.361
Kitsap Kingston	-6.252	2.341	-3.712	1.163	1.806	2.268	2.361
Rustlewood	5.027	-8.745	-3.378	0.567	0.856	4.935	2.361
Seashore Villa	-4.487	-6.694	-12.63	1.209	-0.840	-4.853	-3.193
Suquamish	5.069	-25.60	-20.88	3.744	4.251	-0.398	2.361
Vashon	-7.742	2.697	-4.392	-1.430	-0.841	-0.198	2.361
Avg. Difference	**-3.908**	**-4.587**	**-8.488**	**0.581**	**0.833**	**1.805**	**1.345**
3 Month WWTPs - Other							
Carlyon	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Simpson Kraft	0.047	-0.004	0.042	0.114	0.215	0.941	--

Root Mean Square Error between Predicted and Observed Concentrations

WWTP Name	NO23N mg/L	NH4N mg/L	TPN mg/L	OP mg/L	TP mg/L	DOC mg/L	CBOD mg/L
15 Month WWTPs							
Boston Harbor	4.764	8.364	6.648	1.672	0.688	1.106	4.441
Bremerton	1.927	8.476	7.424	0.960	0.746	1.040	2.219
Chambers	1.667	2.856*	4.583	1.392	1.375	2.017	2.478
Gig Harbor	2.783	4.714	3.473	1.263	1.386	4.813	3.415
Lakota	0.399	4.523	4.528	0.959	0.878	2.062	2.611
LOTT	0.615	0.702	1.467	1.227	0.573	1.603	0.284
Manchester	3.054	1.732	2.672	0.886	0.407	1.029	1.219
Midway	1.716	1.467	1.476	0.604	0.289	1.734	0.900
Port Orchard	2.184	8.623	8.130	1.837	1.764	2.390	4.490
Redondo	2.570	2.010	4.108	0.402	0.246	1.749	2.022
Shelton	1.712	2.988	4.037	0.720	0.823	6.261	4.300
South King	0.581	4.942*	4.156	0.984	1.009	3.051	5.126
Tacoma-Central	1.071	4.010	5.645	0.409	0.955	6.869	1.457
Tacoma-North	0.128	3.561	3.406	0.007	0.029	4.558	5.749
Tamoshan	1.489	2.025	1.879	1.608	0.799	1.989	1.640
West Point	2.317	3.590	4.073	0.846	0.889	2.530	3.290
Avg. RMSE	**1.811**	**4.036**	**4.232**	**0.986**	**0.803**	**2.800**	**2.852**
3 Month WWTPs - Medium Template							
Fort Lewis	4.884*	0.603*	5.663	1.620	0.536	5.967	7.572
Miller	7.101	7.203	6.088	0.234	0.331	12.01	2.312
Salmon	2.551	7.203	12.410	0.234	0.331	2.354	2.448
Avg. RMSE	**4.845**	**5.003**	**8.054**	**0.696**	**0.399**	**6.777**	**4.110**
3 Month WWTPs - Small Template							
Bainbridge Kitsap	21.86	2.621	20.13	1.593	1.729	6.160	2.798
Hartstene	3.712	1.839	6.051	1.764	1.338	5.139	2.506
Kitsap Kingston	6.254	2.350	4.054	1.534	2.011	3.566	2.506
Rustlewood	5.030	12.06	8.697	0.612	0.875	5.139	2.506
Seashore Villa	6.757	10.579	13.38	2.533	0.869	5.373	5.373
Suquamish	5.070	26.33	21.18	3.766	4.269	1.405	2.506
Vashon	9.323	2.702	6.896	1.457	0.905	2.713	2.506
Avg. RMSE	**8.287**	**8.356**	**11.484**	**1.894**	**1.714**	**4.214**	**2.957**
3 Month WWTPs - Other							
Carlyon	0.492	0.406	1.374	1.012	0.460	1.634	1.700
Simpson Kraft	0.063	0.040	0.085	0.182	0.290	3.868	--

*These values are based on plant-specific regressions developed using observed data sent by the WWTP or uploaded from DMR reports (not using the concentration templates or from regressions developed using data that Ecology collected at WWTPs).

Appendix F. Rivers: Nutrient Estimates

The nutrient estimates presented in this appendix are based on the multiple linear regression method described in the “Methods” section of the report.

Table F-1 includes a summary of summer and annual dissolved inorganic nitrogen (DIN) loads from all watersheds into South and Central Puget Sound.

Figures F-1 through F-7 present concentration box plots of various nutrients (nitrogen, phosphorus, and carbon) for all rivers in the study area.

Table F-1. Mean summer (July-September) and annual DIN loads from all watersheds into South and Central Puget Sound for 2006-07.

Watershed Name	Summer DIN Load (kg/d)	Annual DIN Load (kg/d)
South Puget Sound		
Anderson east	5.8	10
Anderson west	17	30
Artondale	12	38
Burley Cr	38	51
Butler Cr	0.9	6.7
Campbell Cr	2.0	7.6
Chambers Cr	118	389
Coulter Cr	2.1	11
Cranberry Cr	11	42
Dana Passage	6.9	19
Deer Cr	2.6	15
Deschutes R	248	993
Dutcher Cove	2.5	6.2
Ellis_Mission Cr	3.7	10
Filucy Bay	4.6	15
Frye Cove	2.2	6.4
Gallagher Cove	2.5	17
Glen Cove	4.6	15
Goldsborough Cr	8.3	80
Goodnough Cr	4.9	16
Grant	1.3	5.0
Green Cove	2.7	21
Gull Harbor	5.3	14
Hale Passage	6.7	22
Henderson Inlet	5.4	13
Herron	2.0	4.9
Jarrell Cove	2.8	11
Johns Cr	4.2	17

Watershed Name	Summer DIN Load (kg/d)	Annual DIN Load (kg/d)
South Puget Sound		
Kennedy_Schneider	16	110
Ketron	3	9
Mayo Cove	2	8
McAllister Cr	110	295
McLane Cr	5.3	39
McNeil Isl	20	34
Mill Cr	22	125
Minter Cr	15	50
Moxlie Cr	8	23
Nisqually R	394.2	1748
Peale Passage	1.8	7
Perry Cr	6	18
Purdy Cr	4.6	14.8
Rocky Cr	13	33
Rosedale	7.7	25
Schneider Cr	0.3	2.0
Sequalitchew Cr	64	210
Sherwood Cr	12	45
Skookum Cr	15	86
Snodgrass Cr	0.9	6
Sun Pt	0.9	3.5
Tolmie	15	38
Van Gelden	6.1	20
Vaughn	3.1	8
Whitman Cove	3.7	9
Wilson Pt	1.5	5.5
Woodard Cr	15	40
Woodland Cr	74	183

Watershed Name	Summer DIN Load (kg/d)	Annual DIN Load (kg/d)
Central Puget Sound		
Buenna	4.9	16
Curley Cr	23	75
Des Moines Cr	9.2	30
Ellisport	3.9	13
Federal Way	6.7	22
Gig Harbor	15	48
Green R	368	1942
Hylebos Cr	39	130
Judd Cr	7.0	23
Lake Washington	26	580
Magnolia Bch	6.3	21
Miller Cr	25	81
Olalla Cr	18	58
Puyallup R*	762	2420
Saltwater St Pk	3.9	13
Shingle Mill Cr	6.1	20
Sinclair Dyes	50	280
Tahlequah	4.6	15
University Place	7.8	26

	Summer DIN Load (kg/d)	Annual DIN Load (kg/d)
South Puget Sound Subtotal	1370	5080
Central Puget Sound Subtotal	1387	5814
TOTAL	2757	10894

*The Puyallup R load does not include loads from the Puyallup WWTP since this WWTP was located downstream of the river monitoring station. However, the load from this WWTP will be included in the model. Based on the medium plant template and plant-specific monthly average flows, the Puyallup WWTP had an average annual DIN load of 130 kg/d for 2006-2007.

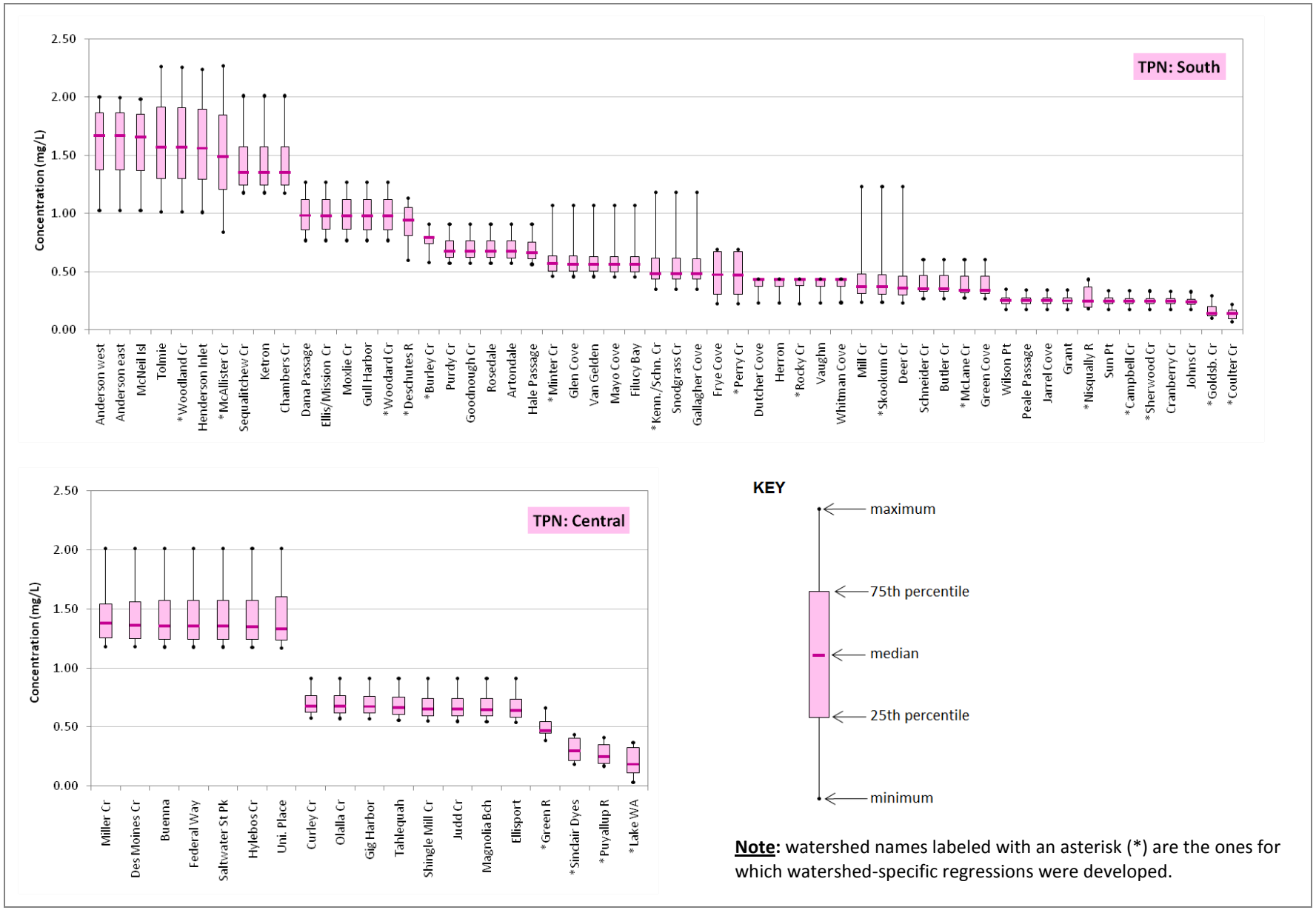
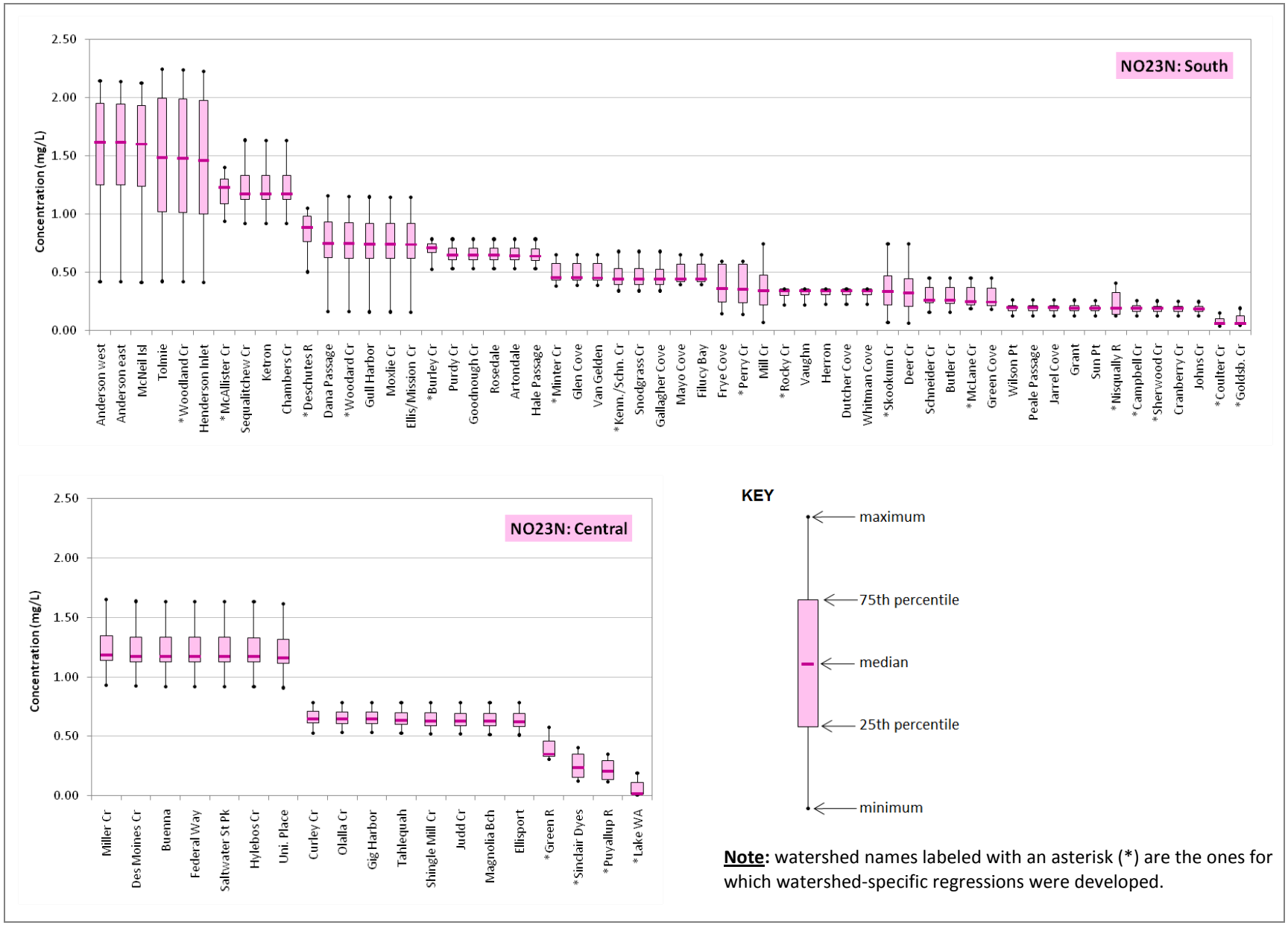


Figure F-1. Box plots of total persulfate nitrogen concentrations for 2006-07 for watersheds in South (top) and Central (bottom) Puget Sound.



Note: watershed names labeled with an asterisk (*) are the ones for which watershed-specific regressions were developed.

Figure F-2. Box plots of nitrate + nitrite concentrations for 2006-07 for watersheds in South (top) and Central (bottom) Puget Sound.

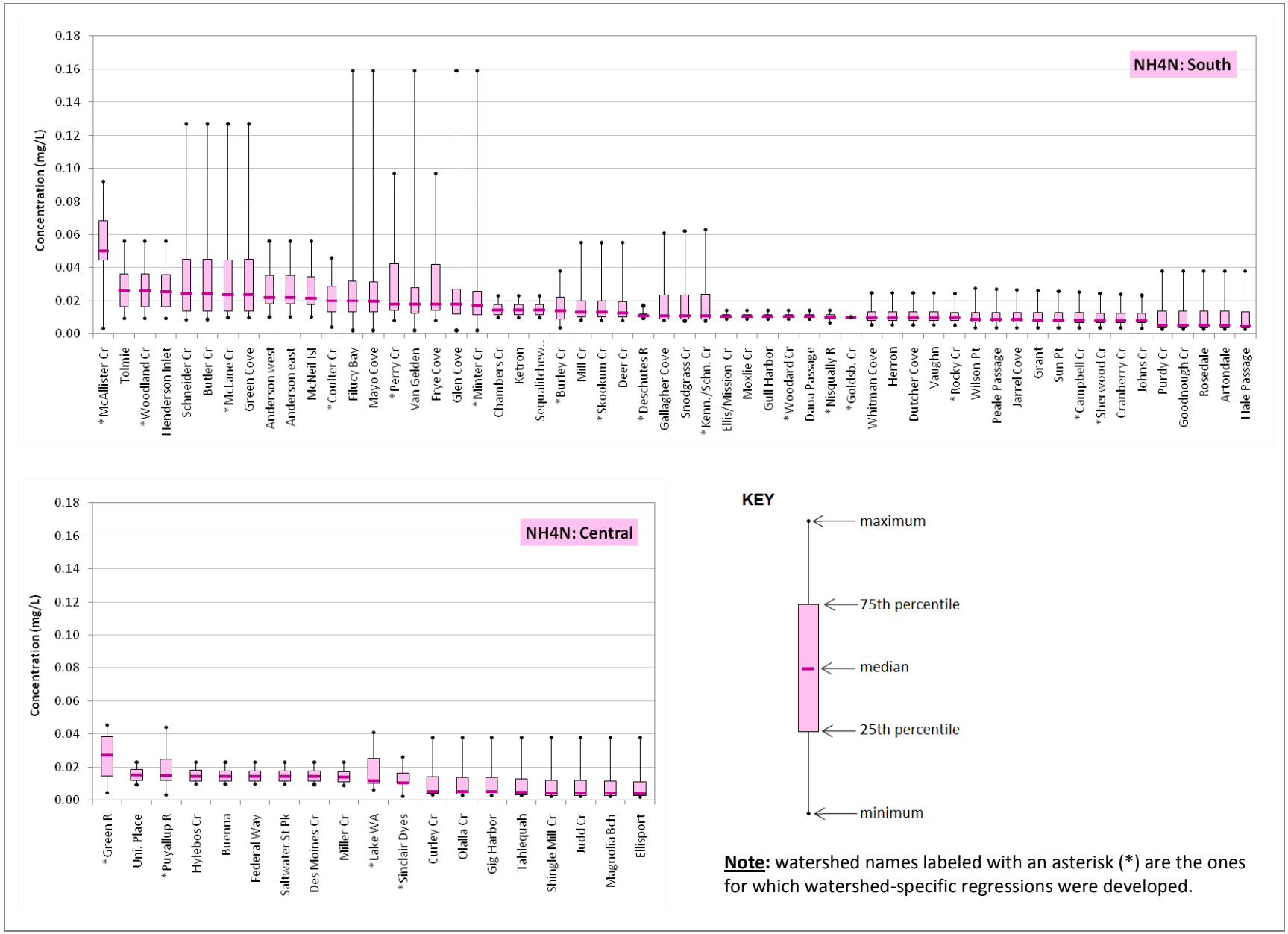


Figure F-3. Box plots of ammonium concentrations for 2006-07 for watersheds in South (top) and Central (bottom) Puget Sound.

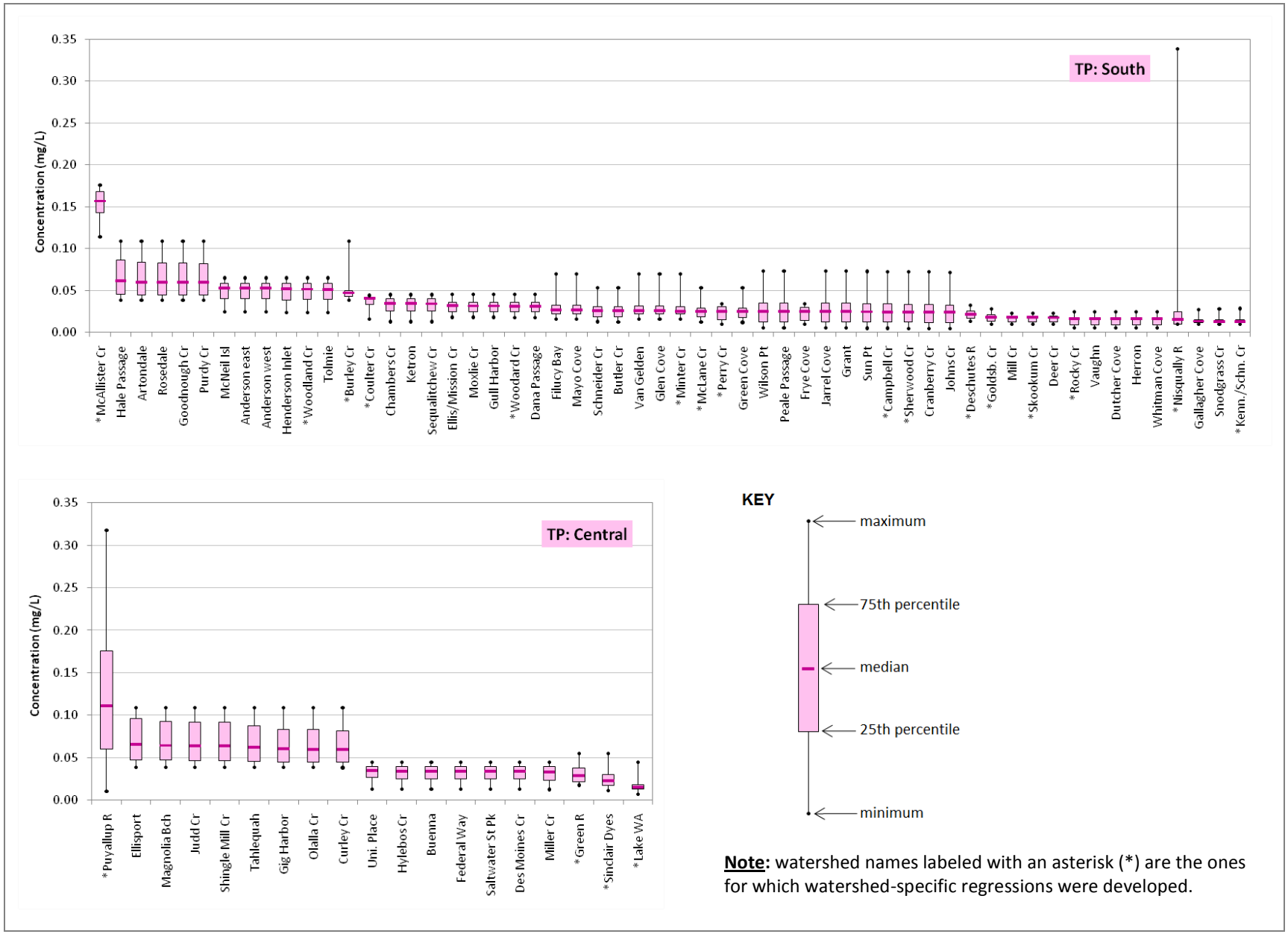


Figure F-4. Box plots of total phosphorus concentrations for 2006-07 for watersheds in South (top) and Central (bottom) Puget Sound.

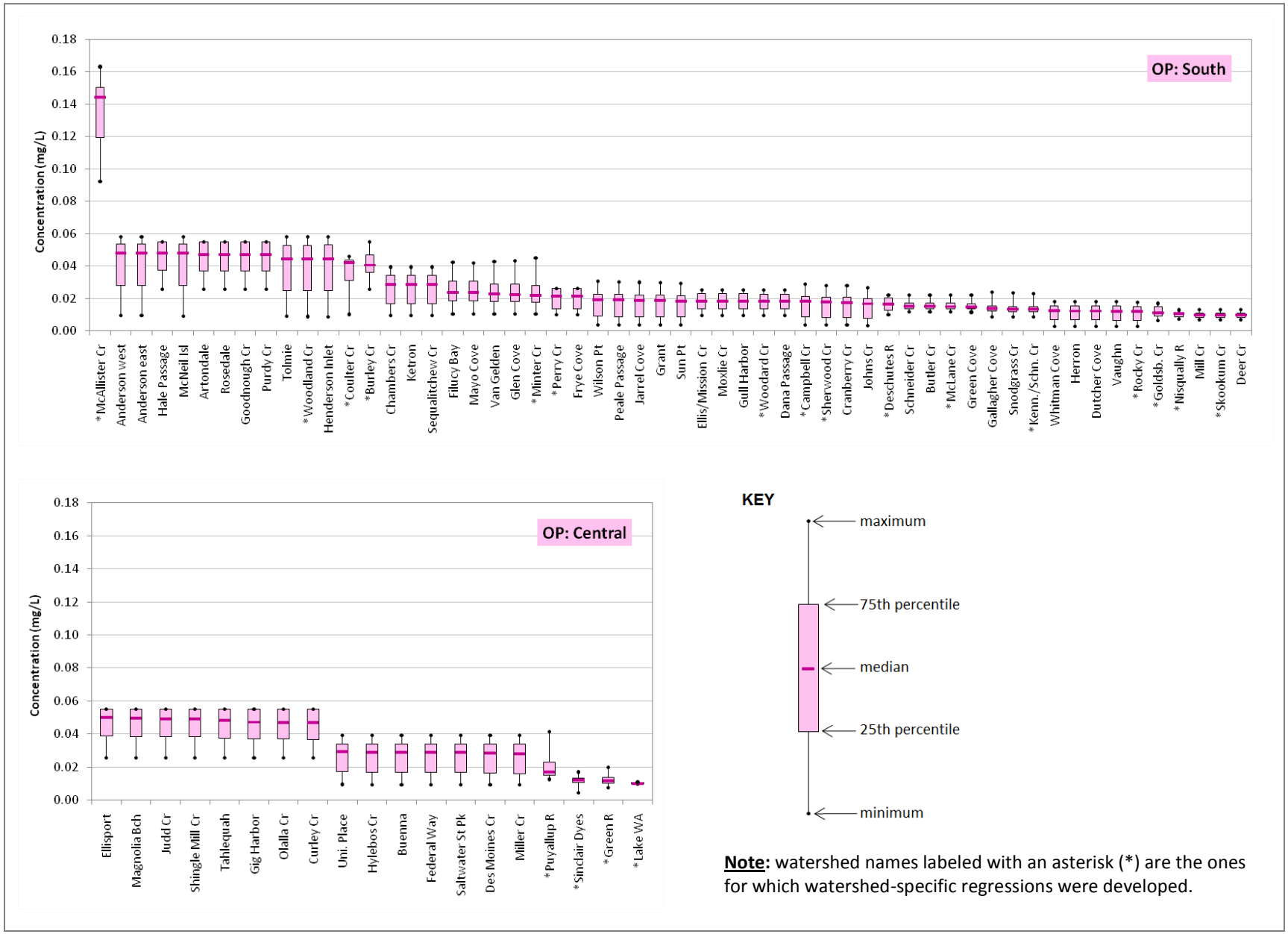


Figure F-5. Box plots of ortho-phosphate concentrations for 2006-07 for watersheds in South (top) and Central (bottom) Puget Sound.

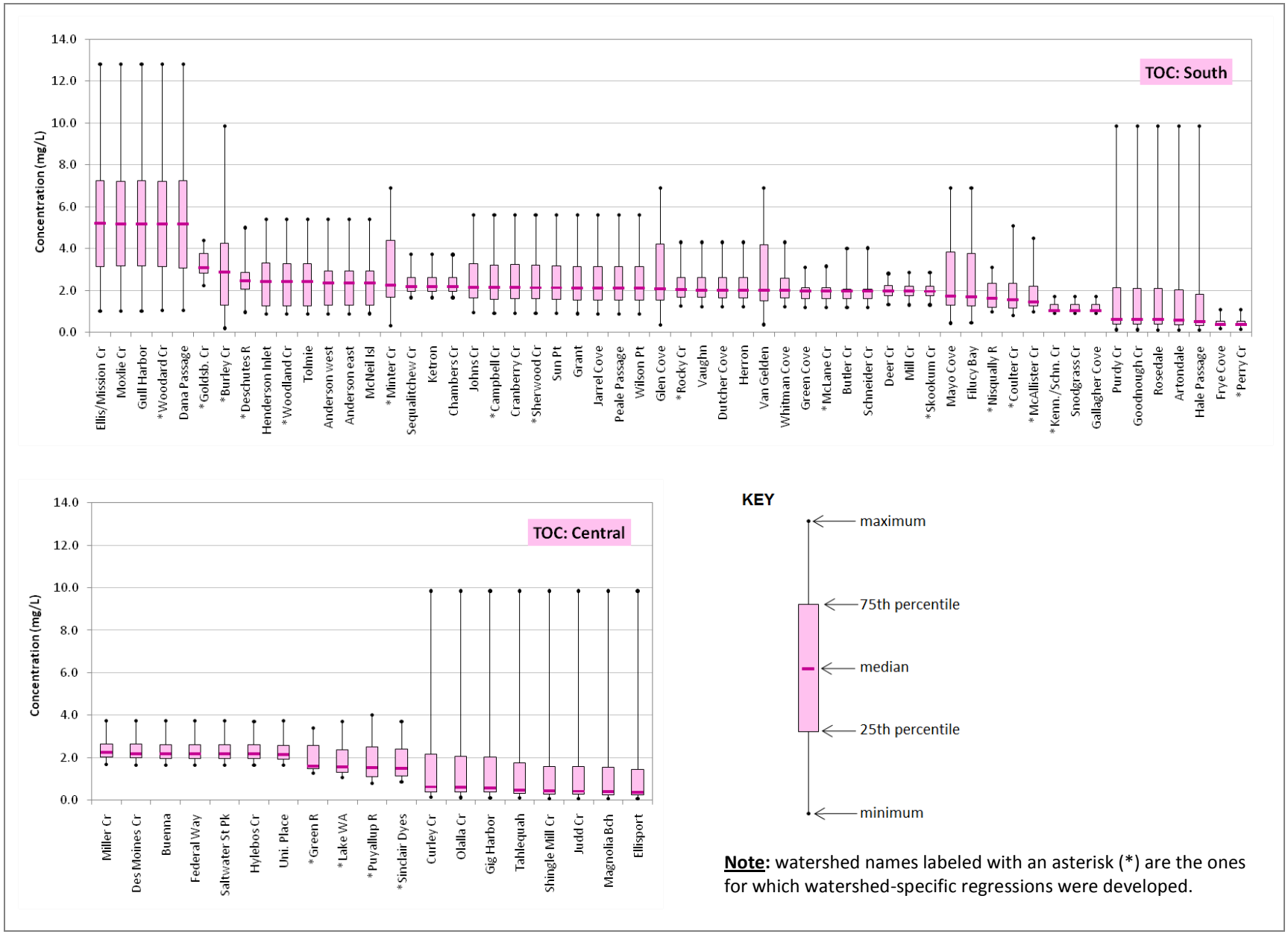


Figure F-6. Box plots of total organic carbon concentrations for 2006-07 for watersheds in South (top) and Central (bottom) Puget Sound.

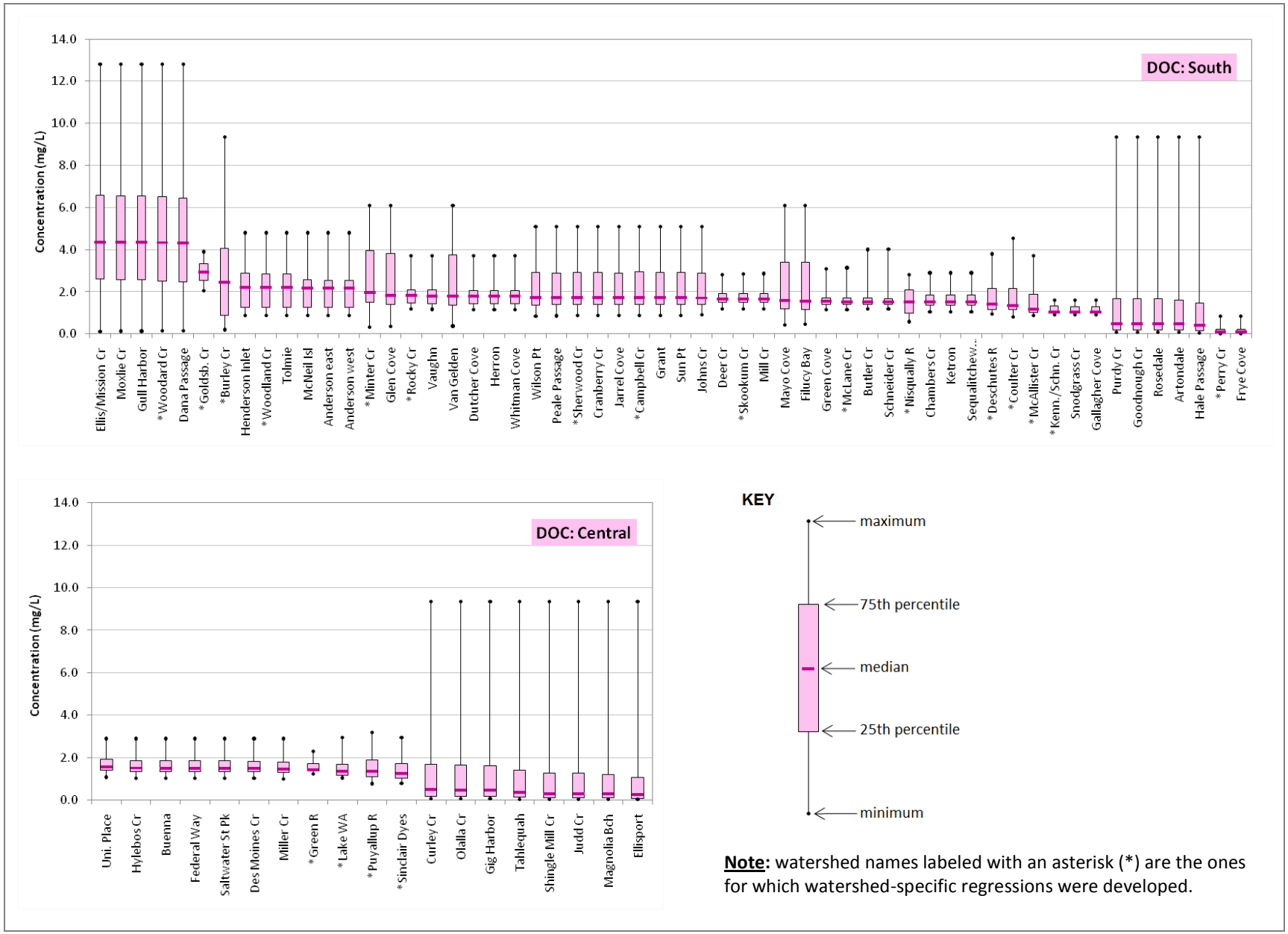


Figure F-7. Box plots of dissolved organic carbon concentrations for 2006-07 for watersheds in South (top) and Central (bottom) Puget Sound.

Figures F-8 through F-14 present dot plots of nutrient loads for various parameters from all rivers in the study area.

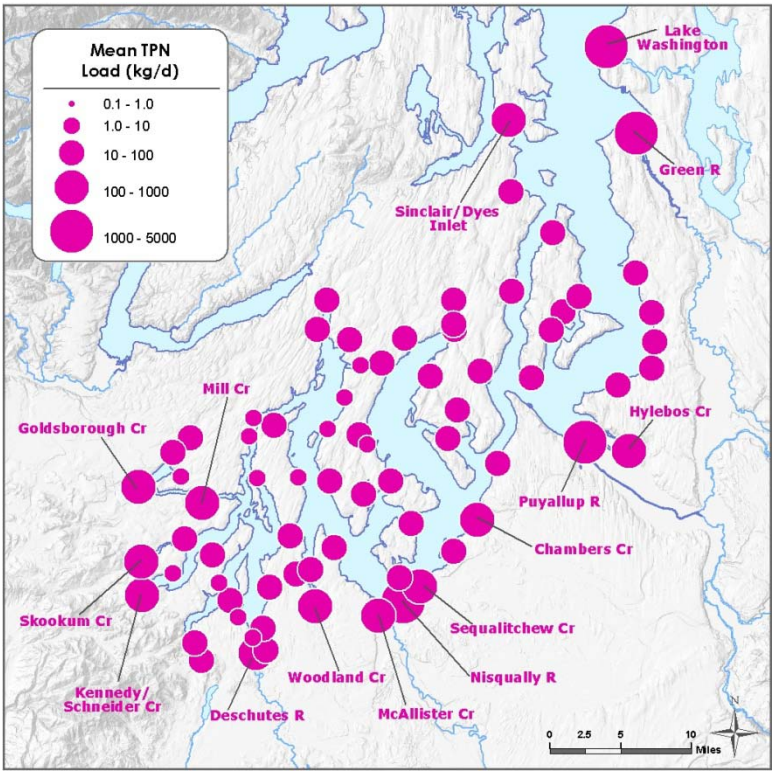


Figure F-8. Mean total persulfate nitrogen loads from watersheds during 2006-07.

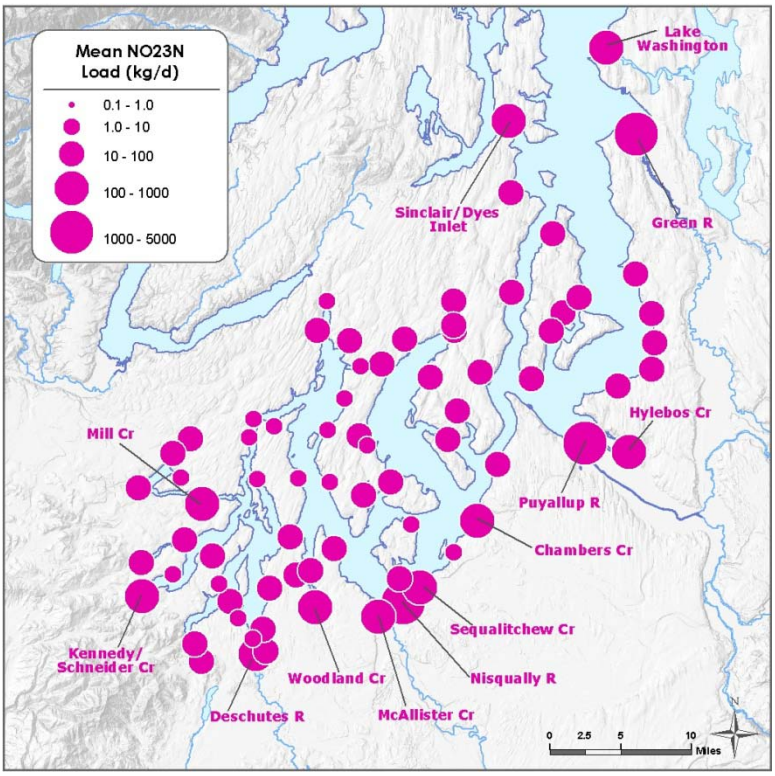


Figure F-9. Mean nitrate + nitrite loads from watersheds during 2006-07.

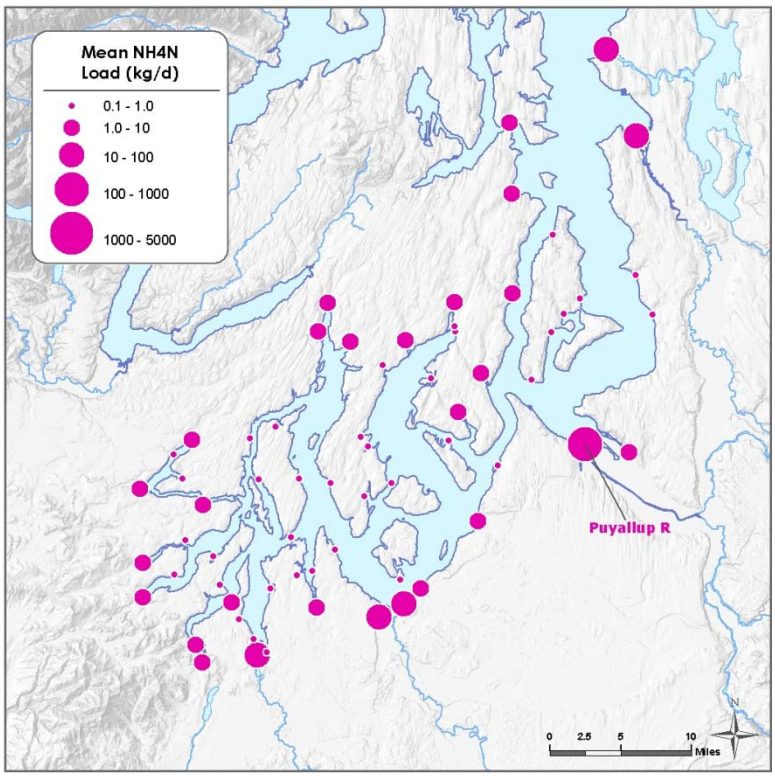


Figure F-10. Mean ammonium loads from watersheds during 2006-07.

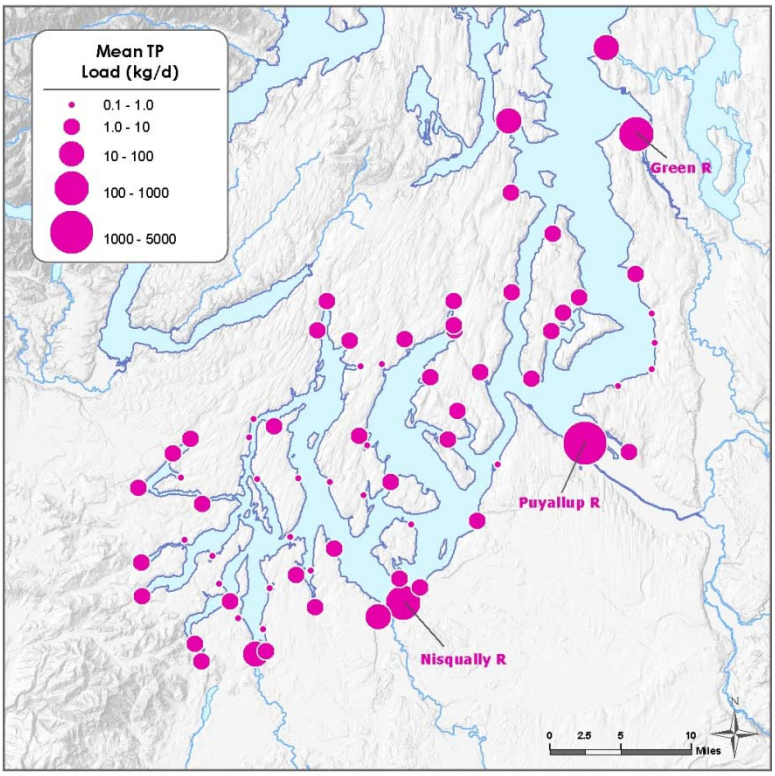


Figure F-11. Mean total phosphorus loads from watersheds during 2006-07.

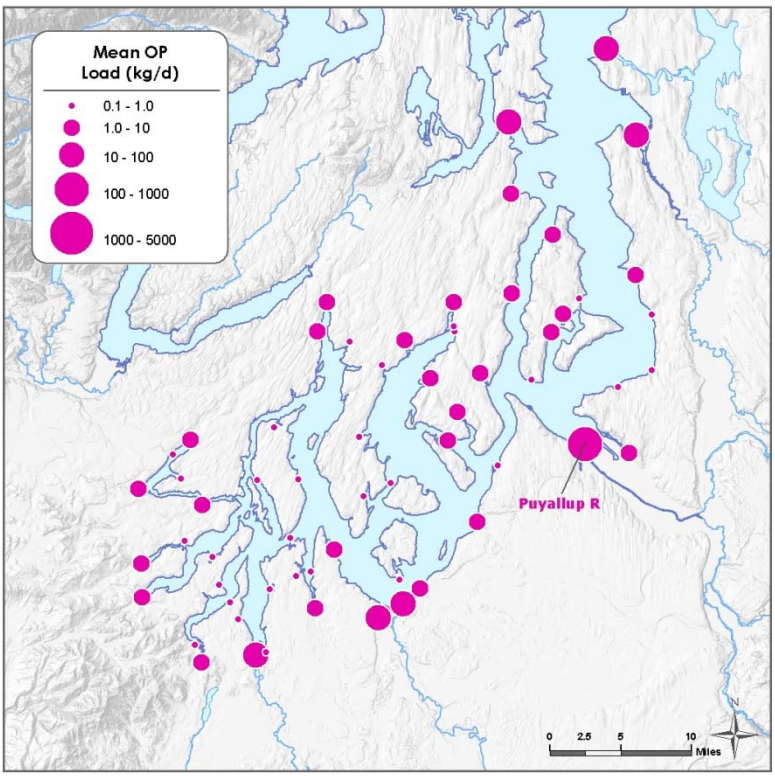


Figure F-12. Mean ortho-phosphate loads from watersheds during 2006-07.

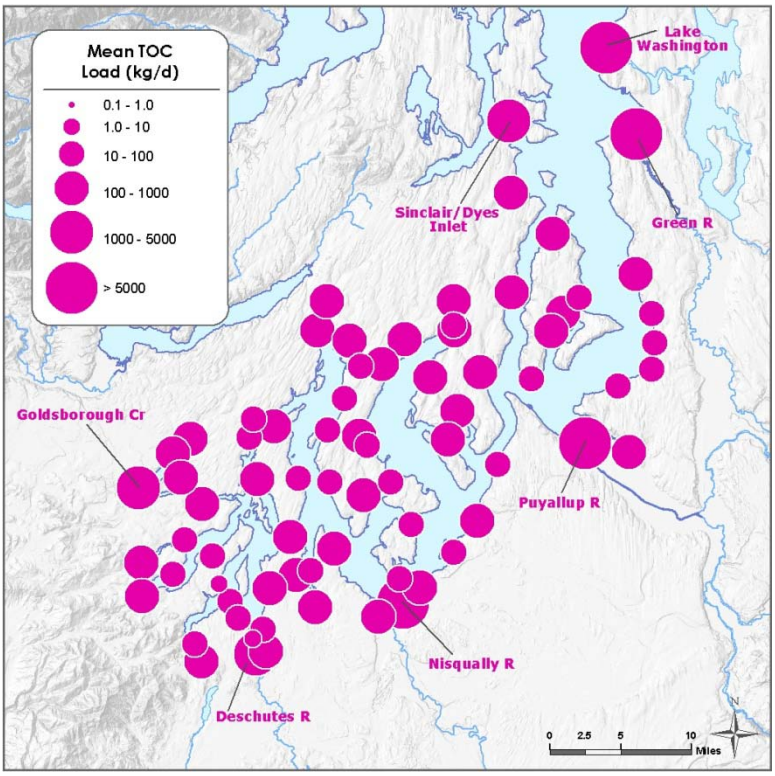


Figure F-13. Mean total organic carbon loads from watersheds during 2006-07.

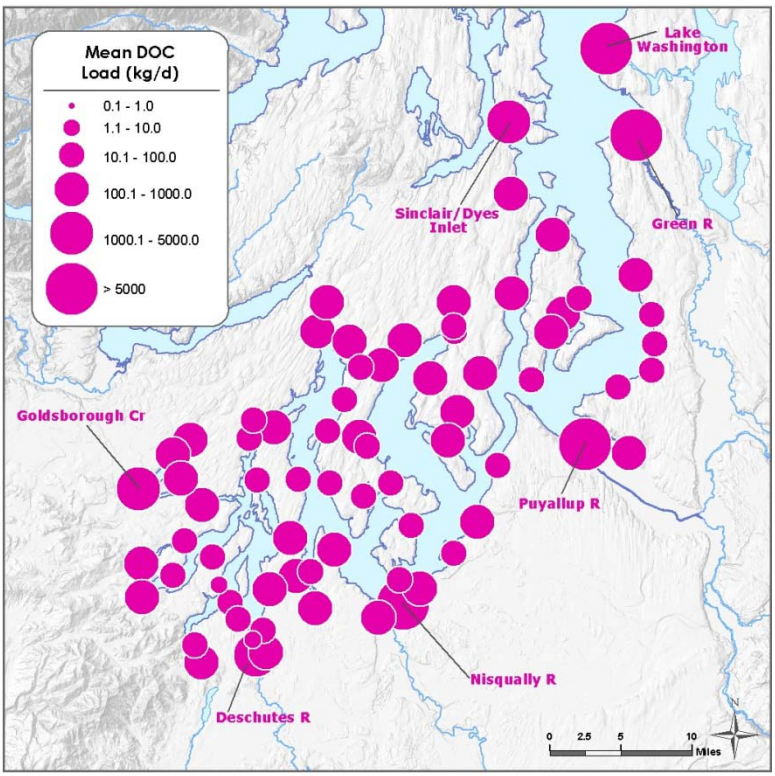


Figure F-14. Mean dissolved organic carbon loads from watersheds during 2006-07.

Figures F-15 through F-17 present mean monthly nitrogen, phosphorus, and organic carbon loads totaled by the different regions in South and Central Puget Sound into which they drain.

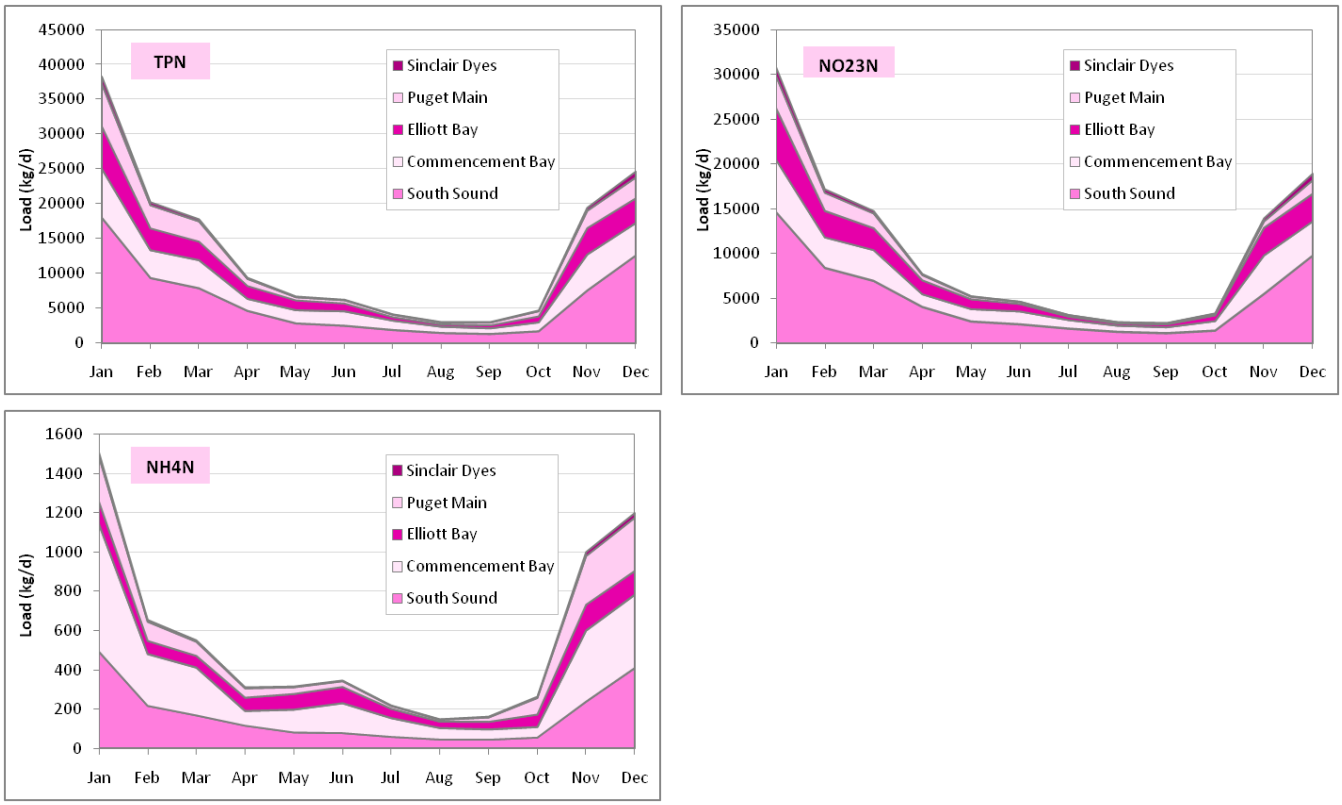


Figure F-15. Mean 2006-07 monthly nitrogen loads from watersheds totaled according to the regions in South and Central Puget Sound into which they drain.

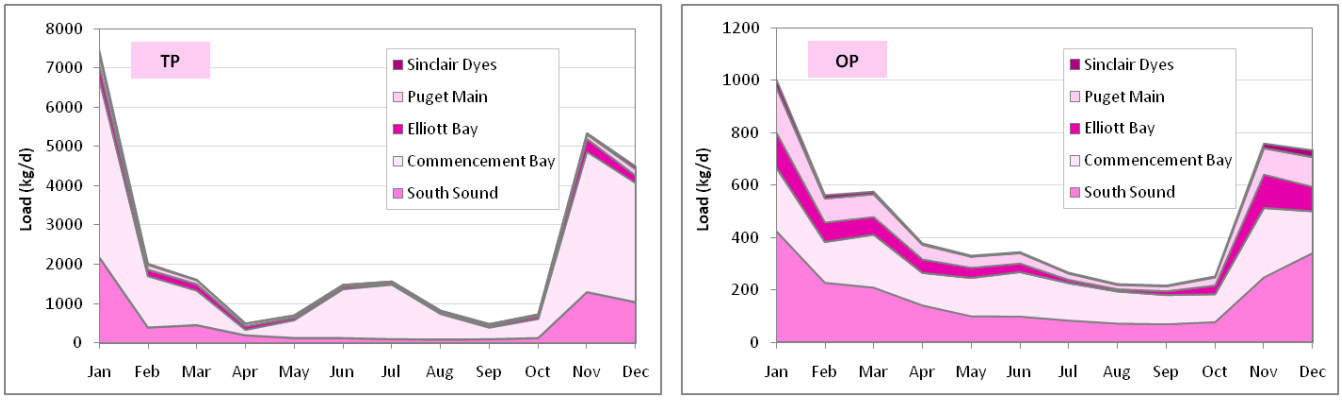


Figure F-16. Mean 2006-07 monthly phosphorus loads from watersheds totaled according to the regions in South and Central Puget Sound into which they drain.

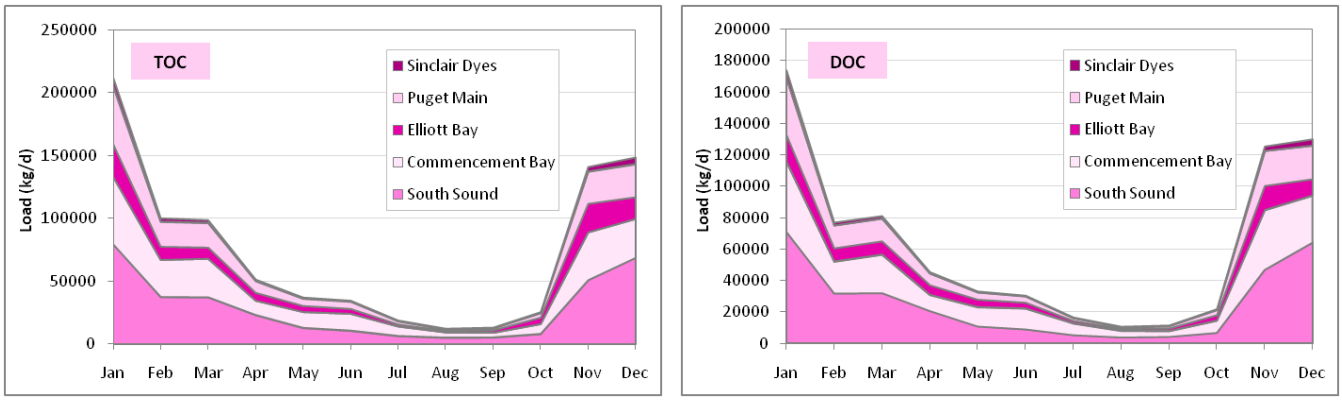


Figure F-17. Mean 2006-07 monthly organic carbon loads from watersheds totaled according to the regions in South and Central Puget Sound into which they drain.

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Appendix G. Wastewater Treatment Plants: Nutrient Estimates

The nutrient estimates presented in this appendix are based on the multiple linear regression method described in the "Methods" section of the report.

Table G-1 includes a summary of summer and annual DIN loads from all WWTPs in the South and Central Puget Sound study area.

Table G-1. Mean summer (July-September) and annual DIN loads from all WWTPs into South and Central Puget Sound for 2006-07.

WWTP Name	Summer DIN Load (kg/d)	Annual DIN Load (kg/d)
South Puget Sound		
Boston Harbor	1.3	2.5
Carlyon	4.2	4.2
Chambers Creek	1880	2142
Fort Lewis	344	329
Hartstene Pointe	1.0	2.5
LOTT	62	159
McNeil Is	6.2	7.7
Rustlewood	0.4	1.0
Seashore Villa	0.3	0.4
Shelton	19	57
Tamoshan	0.8	0.8
Taylor Bay	0.3	0.3

	Summer DIN Load (kg/d)	Annual DIN Load (kg/d)
South Puget Sound Subtotal	2320	2705
Central Puget Sound Total	21999	24047
TOTAL	24318	26752

WWTP Name	Summer DIN Load (kg/d)	Annual DIN Load (kg/d)
Central Puget Sound		
Bainbridge Is (City)	14	19
Bainbridge Kitsap Co 7	2.1	3.0
Bremerton	175	361
Central Kitsap	435	453
Gig Harbor	29	38
Kitsap Co Kingston	3.0	3.8
Lakota	745	797
Manchester	4.9	6.8
Midway	390	422
Miller Creek	308	336
Port Orchard	149	131
Redondo	189	238
Salmon Creek	214	284
Simpson Kraft	13	15
South King	7576	8814
Suquamish	4.6	7.2
Tacoma Central	1984	2056
Tacoma North	359	388
US Oil & Refining	0.4	0.6
Vashon	2.4	5.1
West Point	9401	9669

Figures G-1 through G-8 present concentration box plots of various nutrients (nitrogen, phosphorus, carbon, and biochemical oxygen demand) for all WWTPs in the study area.

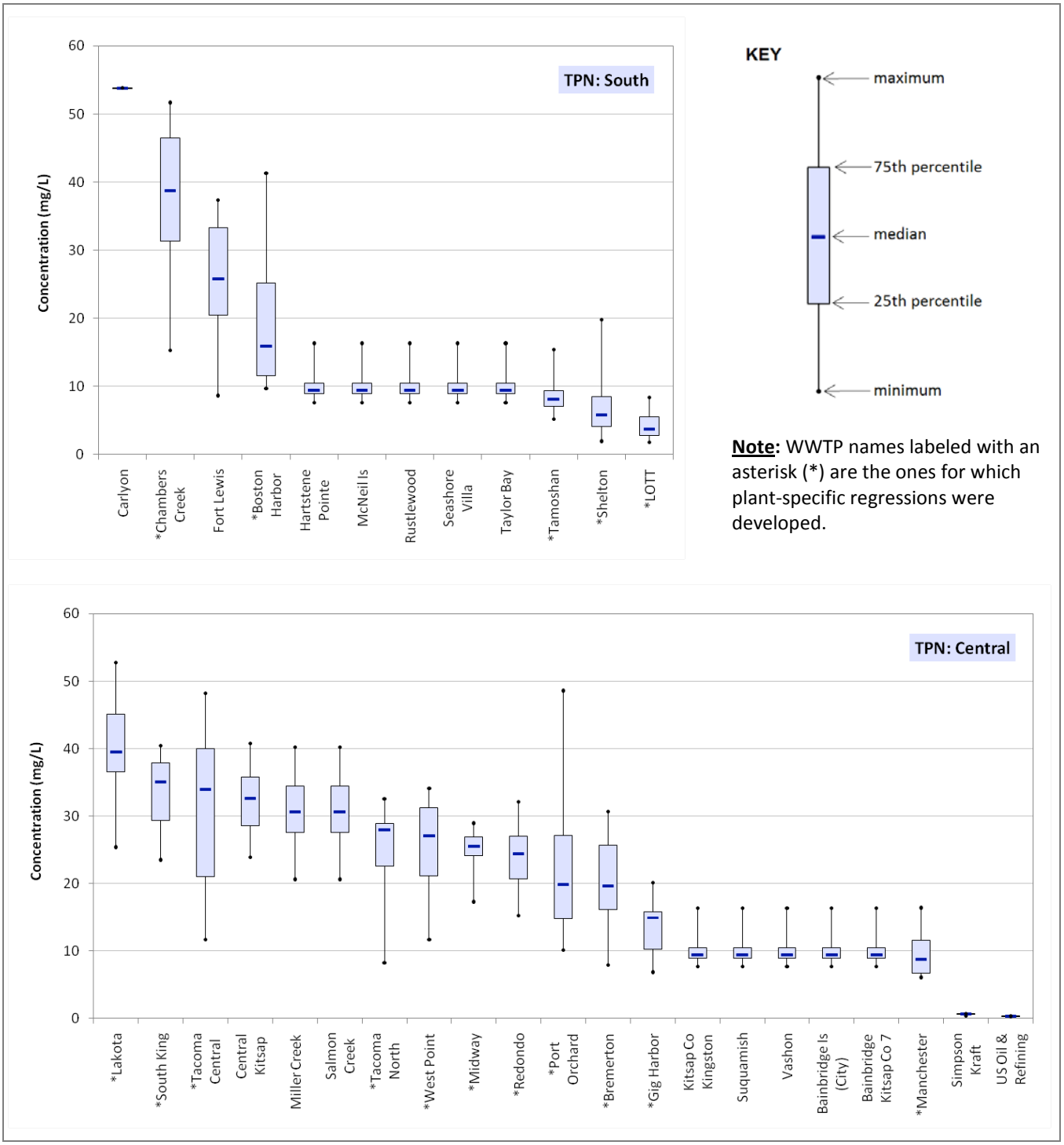


Figure G-1. Box plots of total persulfate nitrogen concentrations for 2006-07 for WWTPs in South (top) and Central (bottom) Puget Sound.

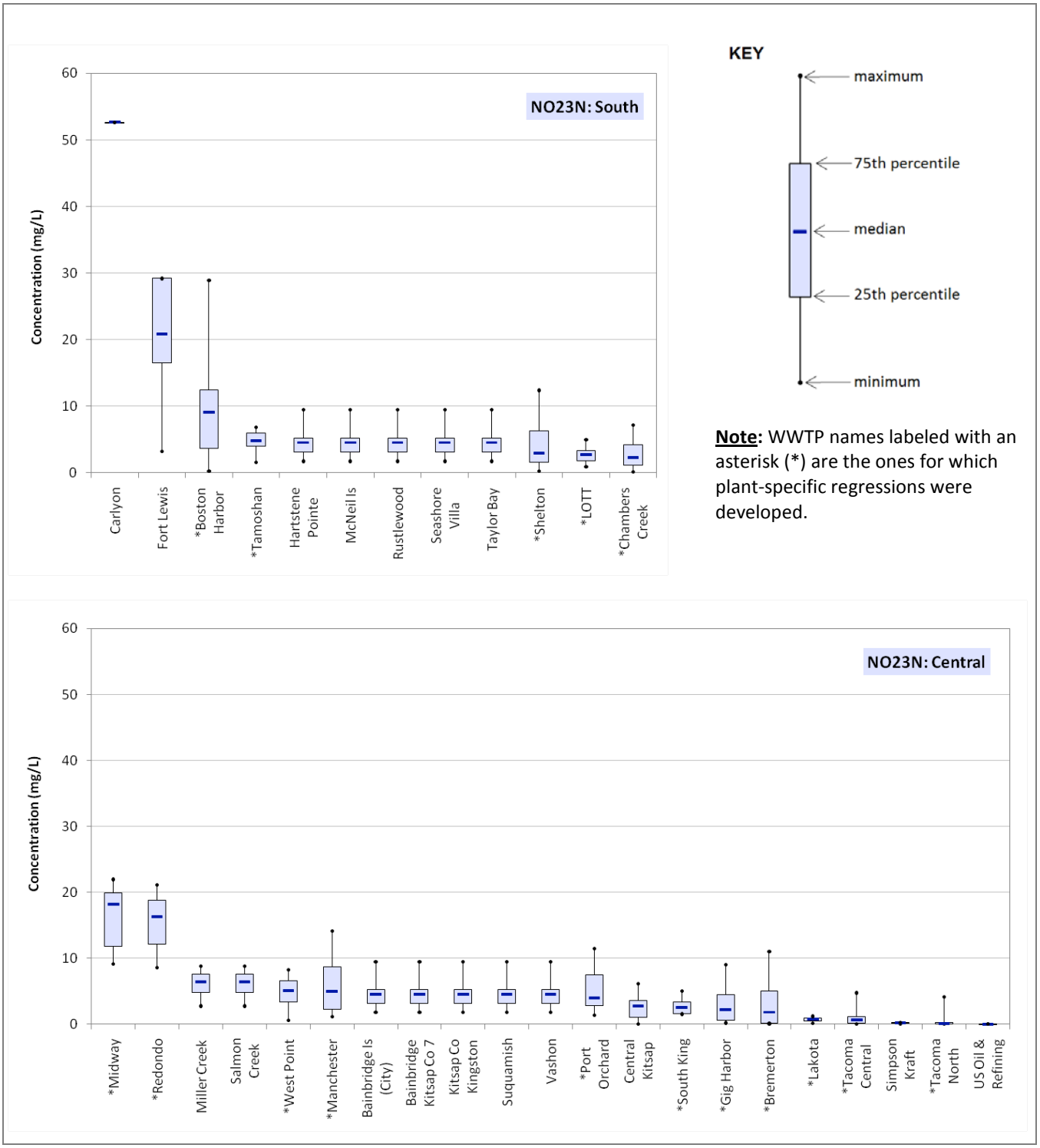


Figure G-2. Box plots of nitrate + nitrite concentrations for 2006-07 for WWTPs in South (top) and Central (bottom) Puget Sound.

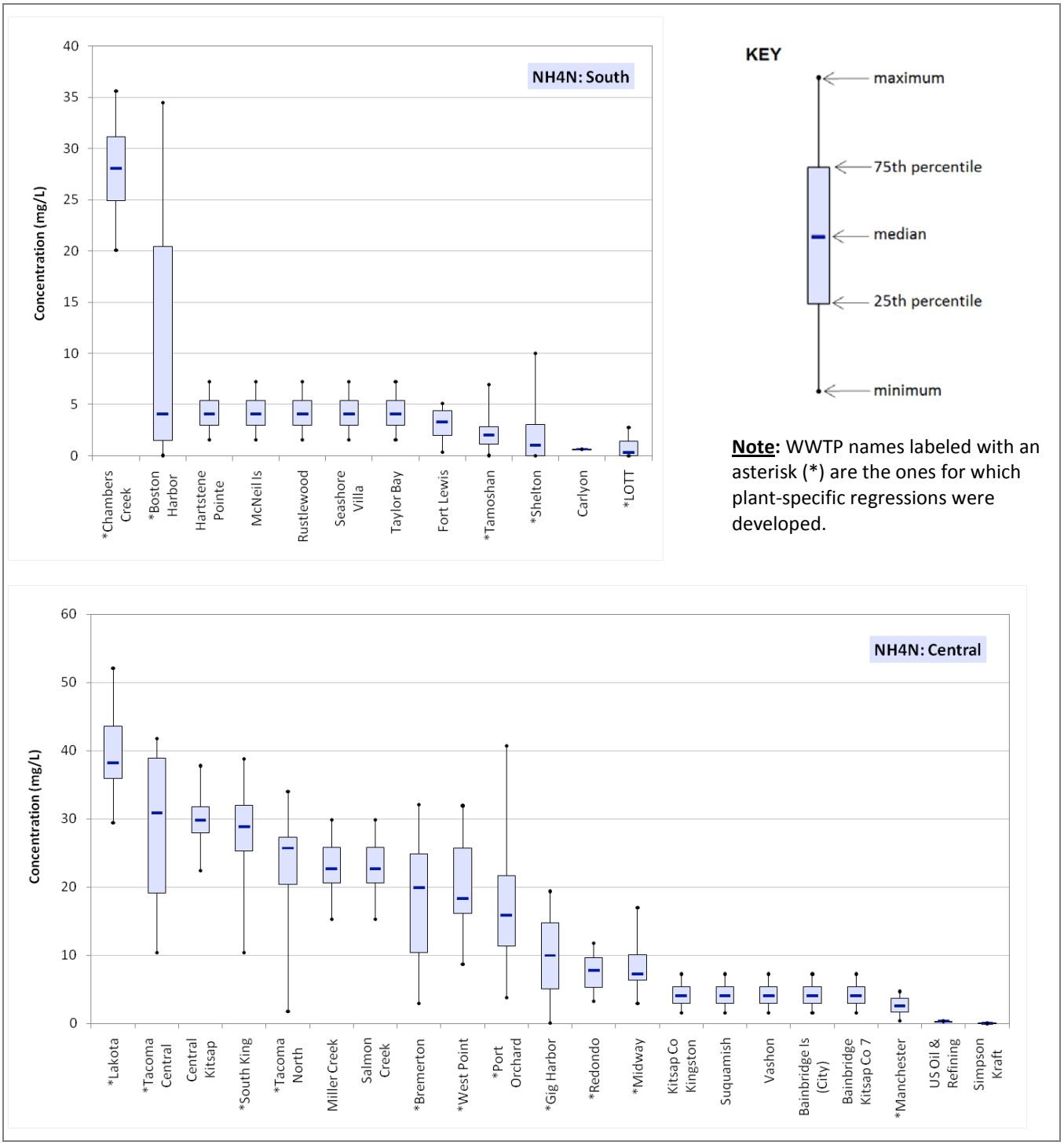


Figure G-3. Box plots of ammonium concentrations for 2006-07 for WWTPs in South (top) and Central (bottom) Puget Sound.

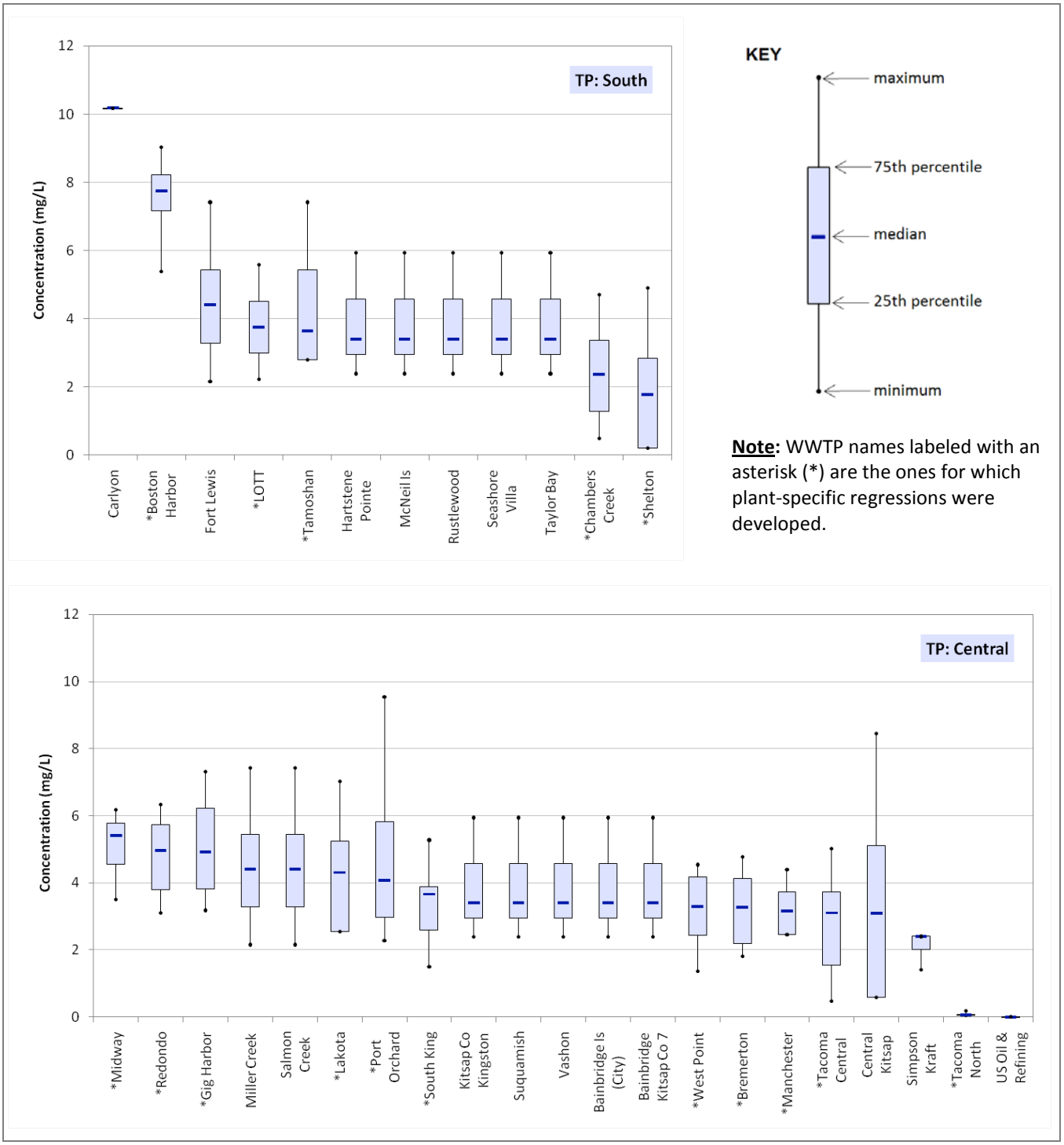
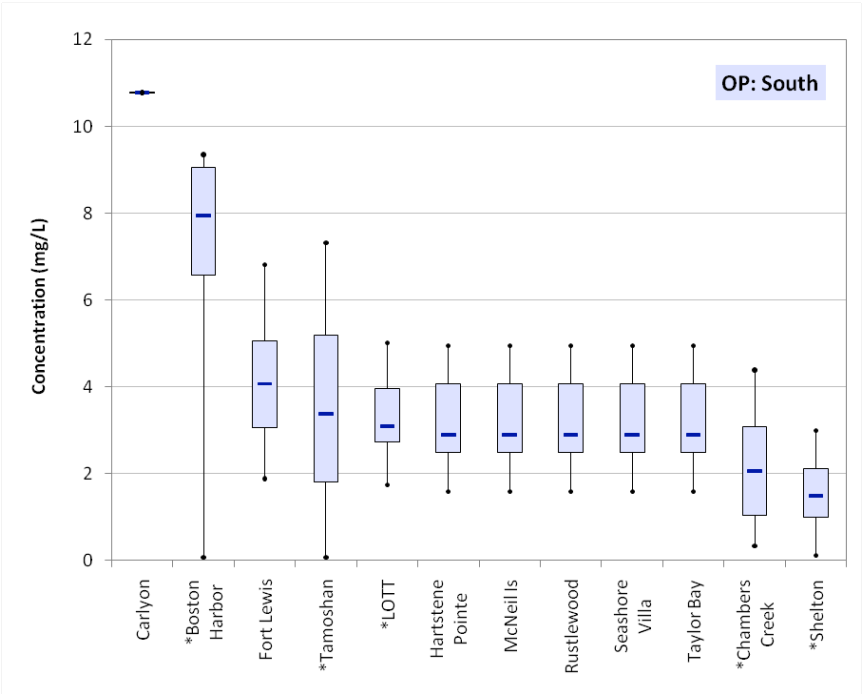
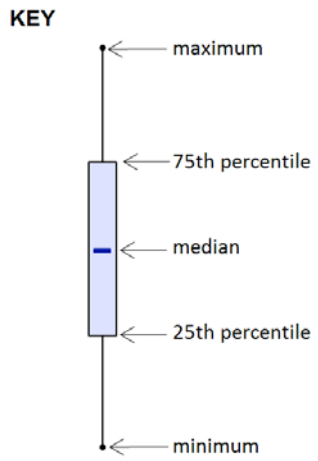


Figure G-4. Box plots of total phosphorus concentrations for 2006-07 for WWTPs in South (top) and Central (bottom) Puget Sound.





Note: WWTP names labeled with an asterisk (*) are the ones for which plant-specific regressions were developed.

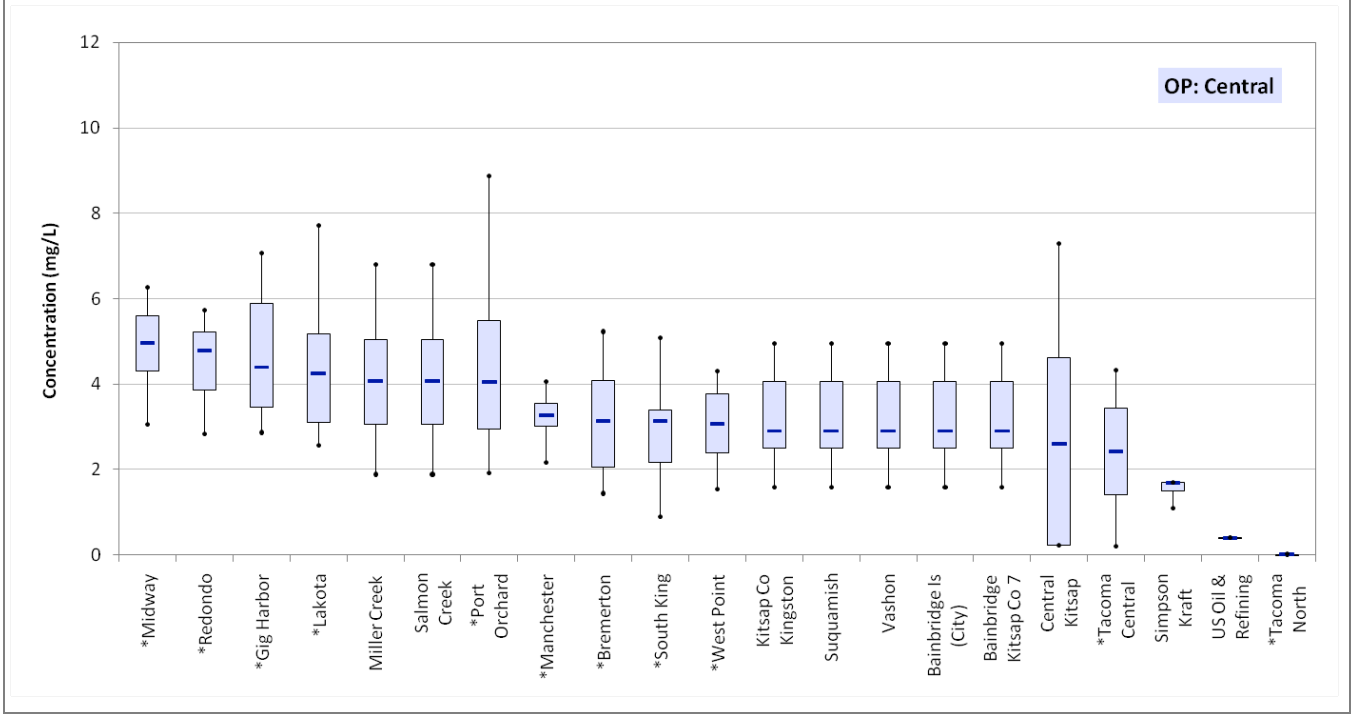


Figure G-5. Box plots of ortho-phosphate concentrations for 2006-07 for WWTPs in South (top) and Central (bottom) Puget Sound.

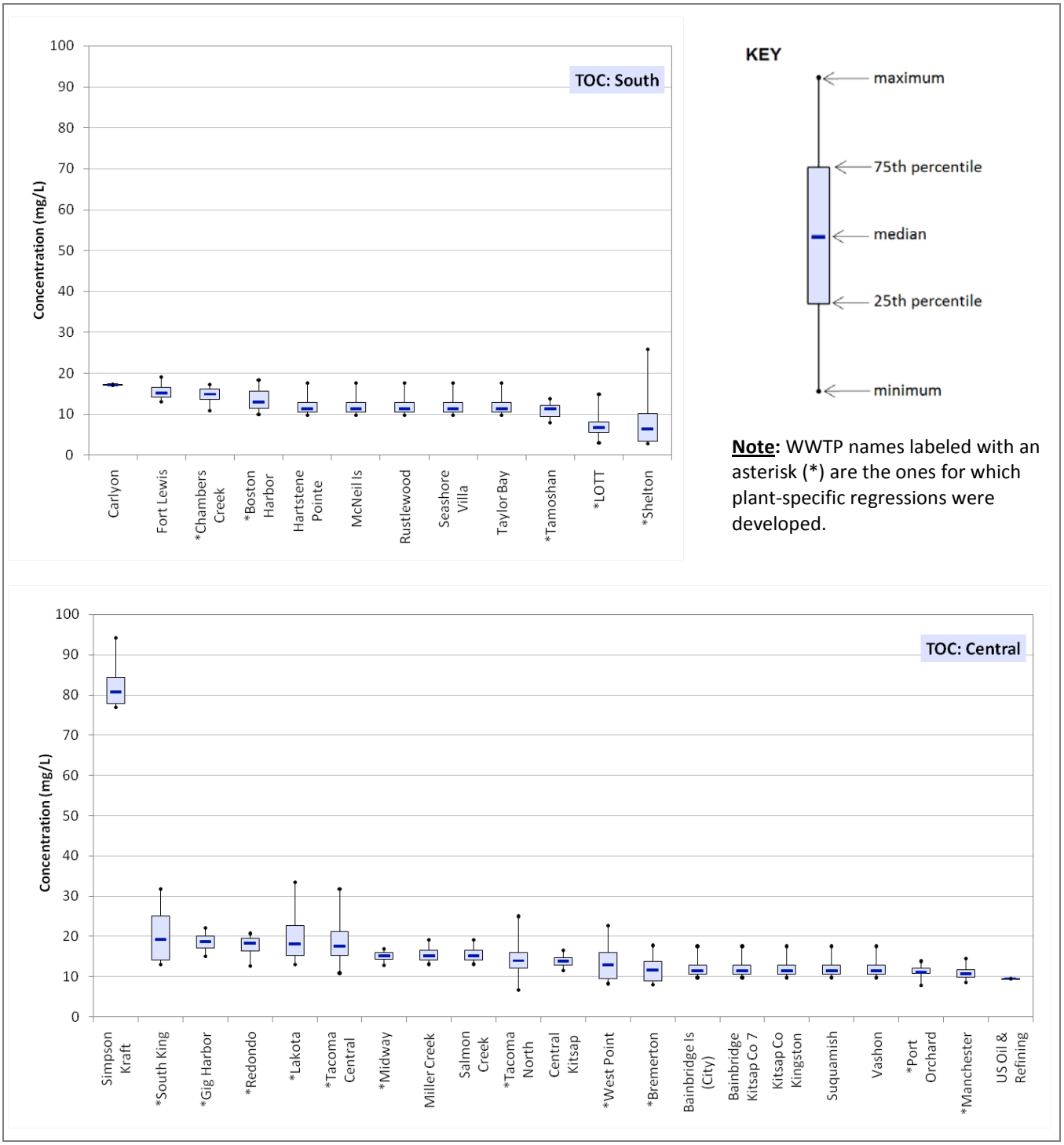


Figure G-6. Box plots of total organic carbon concentrations for 2006-07 for WWTPs in South (top) and Central (bottom) Puget Sound.

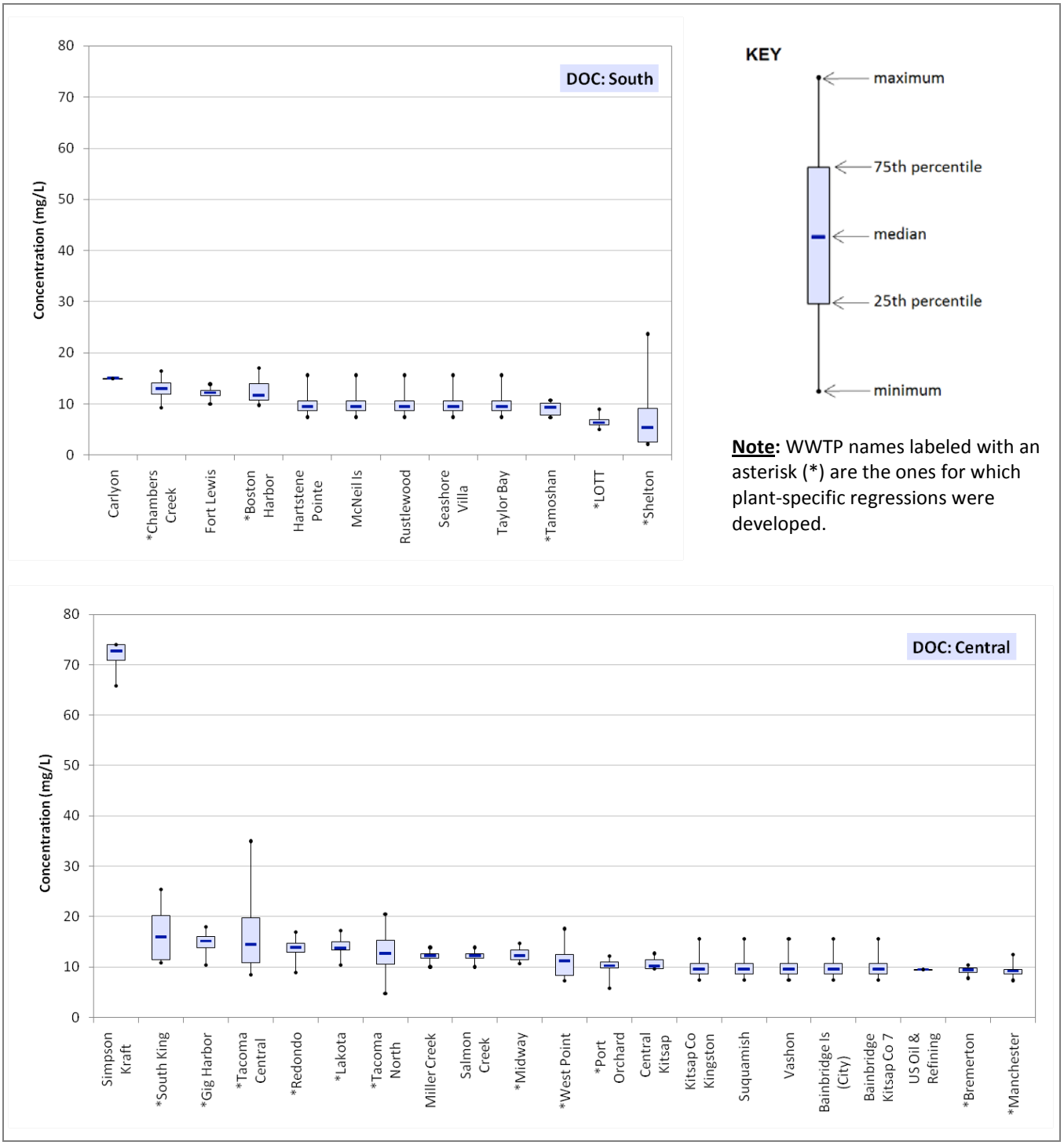


Figure G-7. Box plots of dissolved organic carbon concentrations for 2006-07 for WWTPs in South (top) and Central (bottom) Puget Sound.

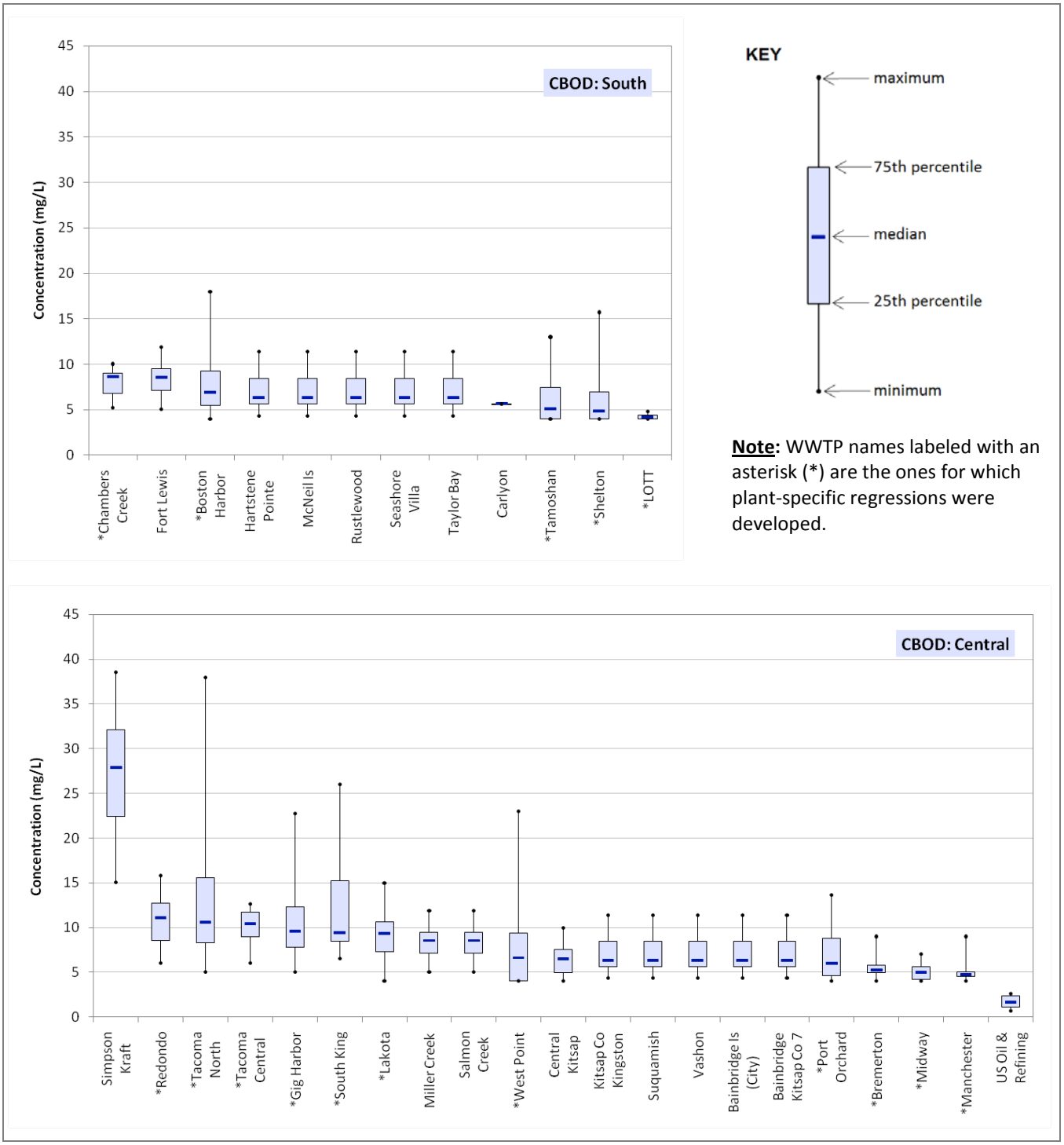


Figure G-8. Box plots of carbonaceous biochemical oxygen demand concentrations for 2006-07 for WWTPs in South (top) and Central (bottom) Puget Sound.

Figures G-9 through G-16 present dot plots of nutrient loads for various parameters from all WWTPs in the study area.

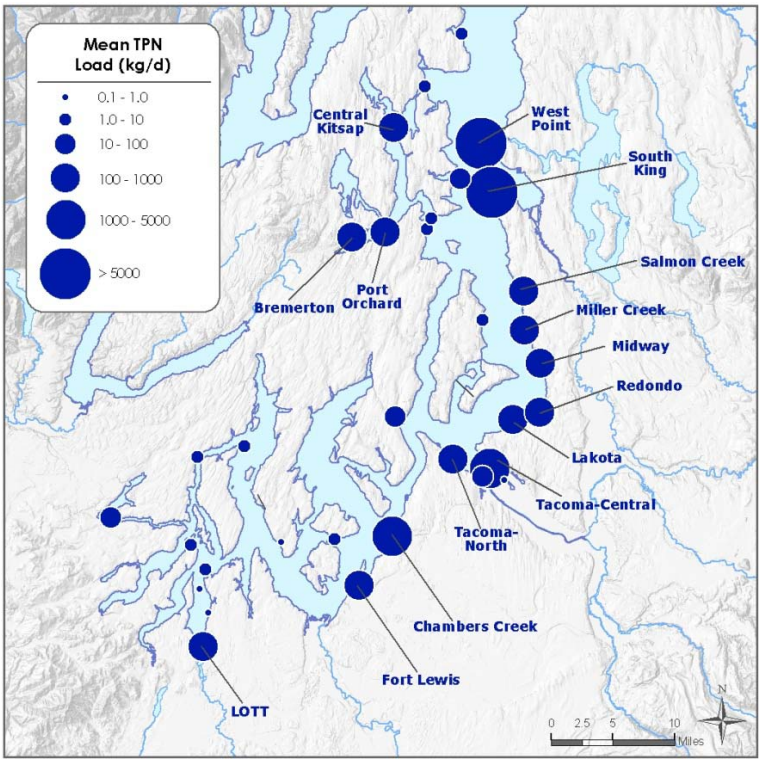


Figure G-9. Mean total persulfate nitrogen loads from WWTPs during 2006-07.

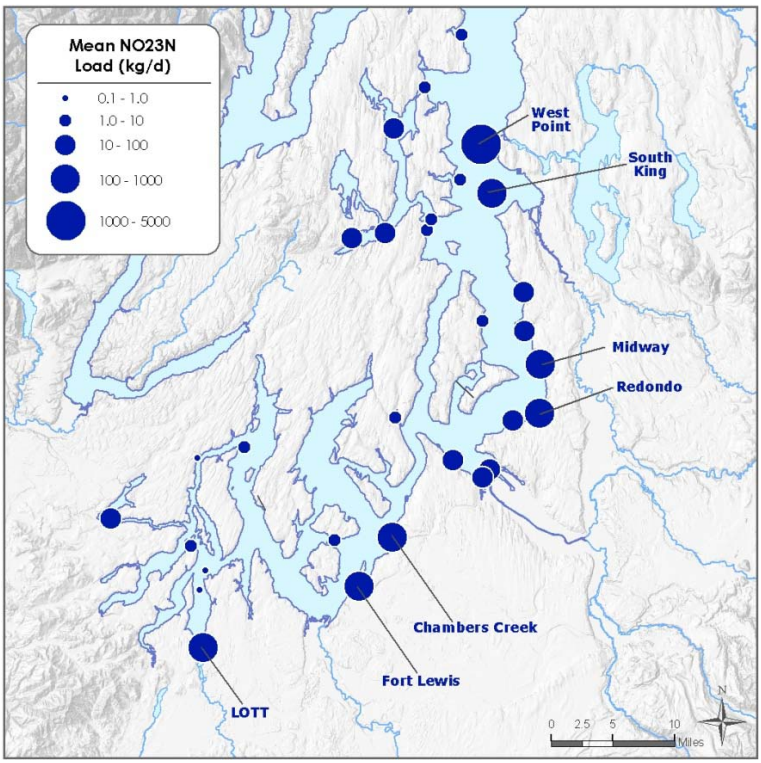


Figure G-10. Mean nitrate + nitrite loads from WWTPs during 2006-2007.

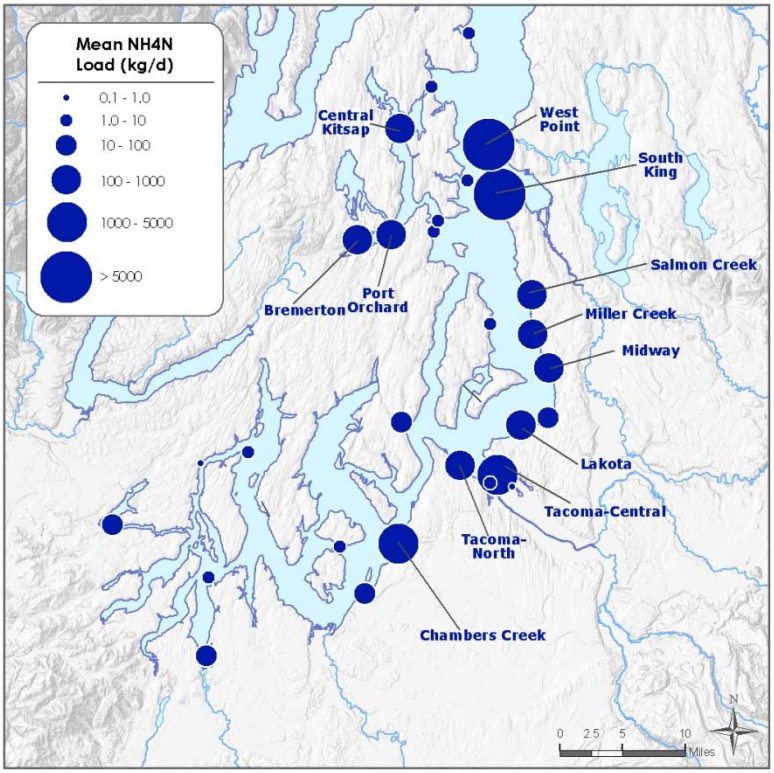


Figure G-11. Mean ammonium loads from WWTPs during 2006-07.

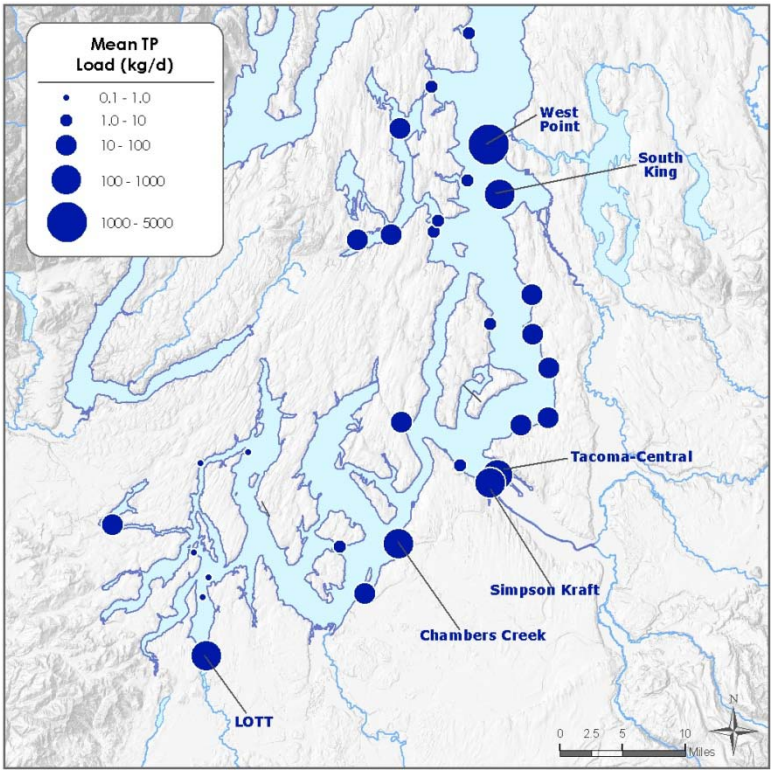


Figure G-12. Mean total phosphorus loads from WWTPs during 2006-07.

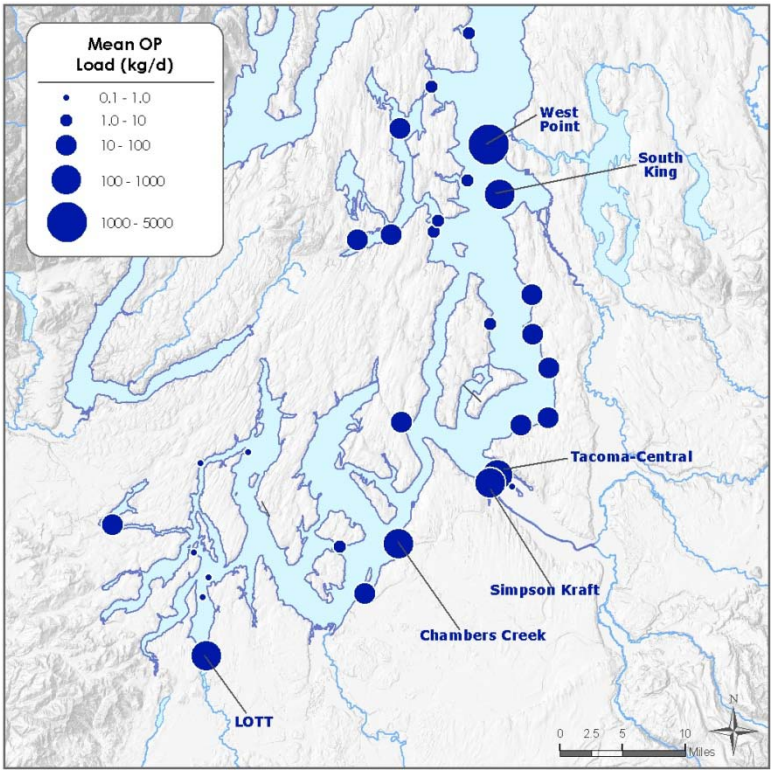


Figure G-13. Mean ortho-phosphate loads from WWTPs during 2006-07.

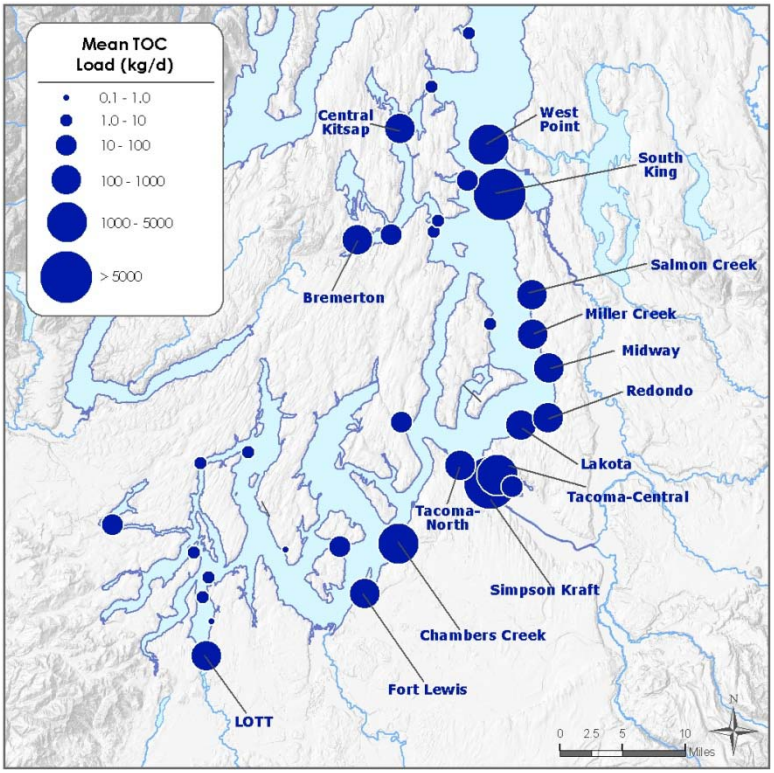


Figure G-14. Mean total organic carbon loads from WWTPs during 2006-07.

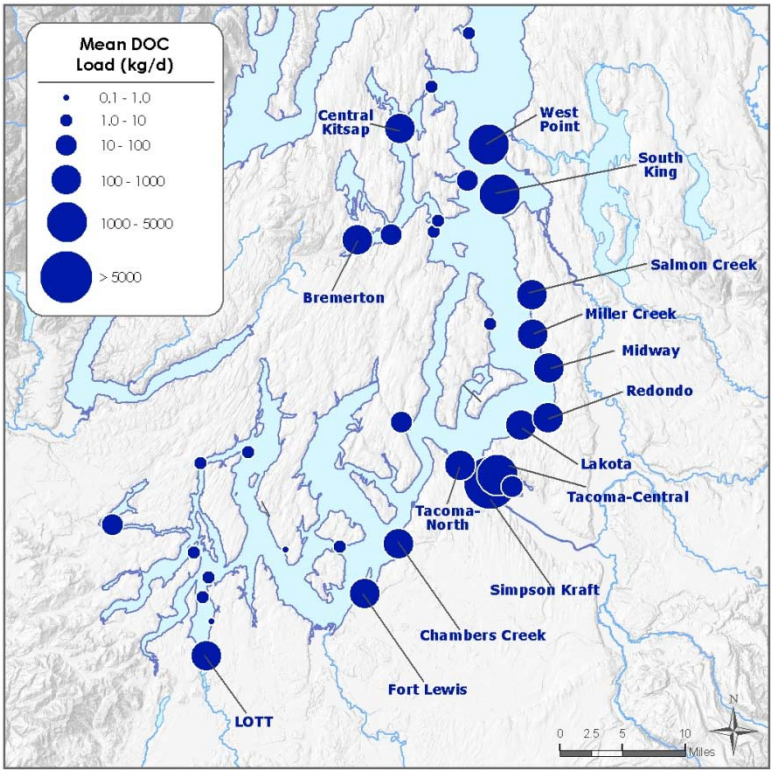


Figure G-15. Mean dissolved organic carbon loads from WWTPs during 2006-07.

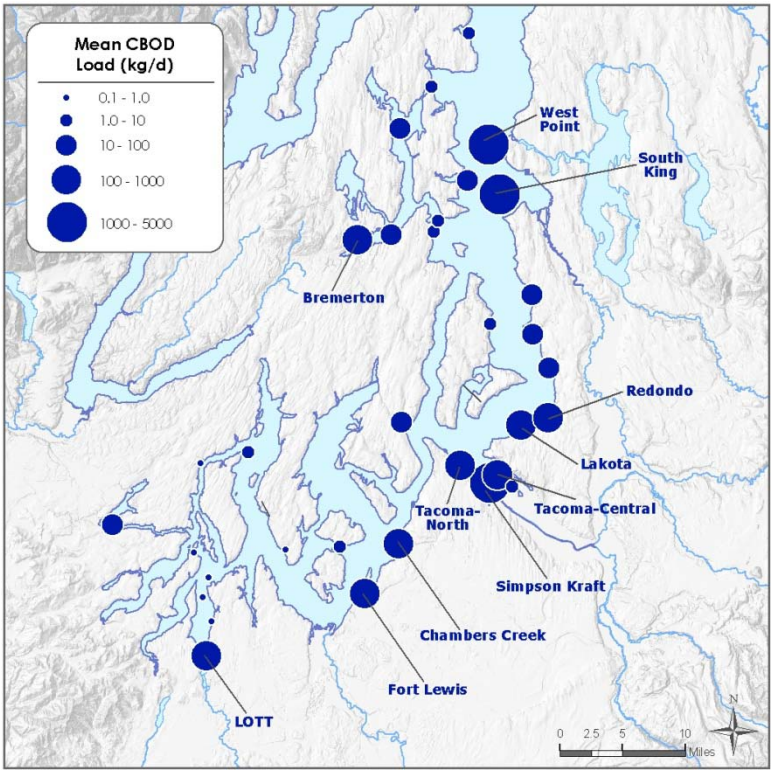


Figure G-16. Mean dissolved organic carbon loads from WWTPs during 2006-07.

Figures G-17 through G-20 present mean monthly nitrogen, phosphorus, and organic carbon loads from WWTPs totaled by the different regions in South and Central Puget Sound into which they drain.

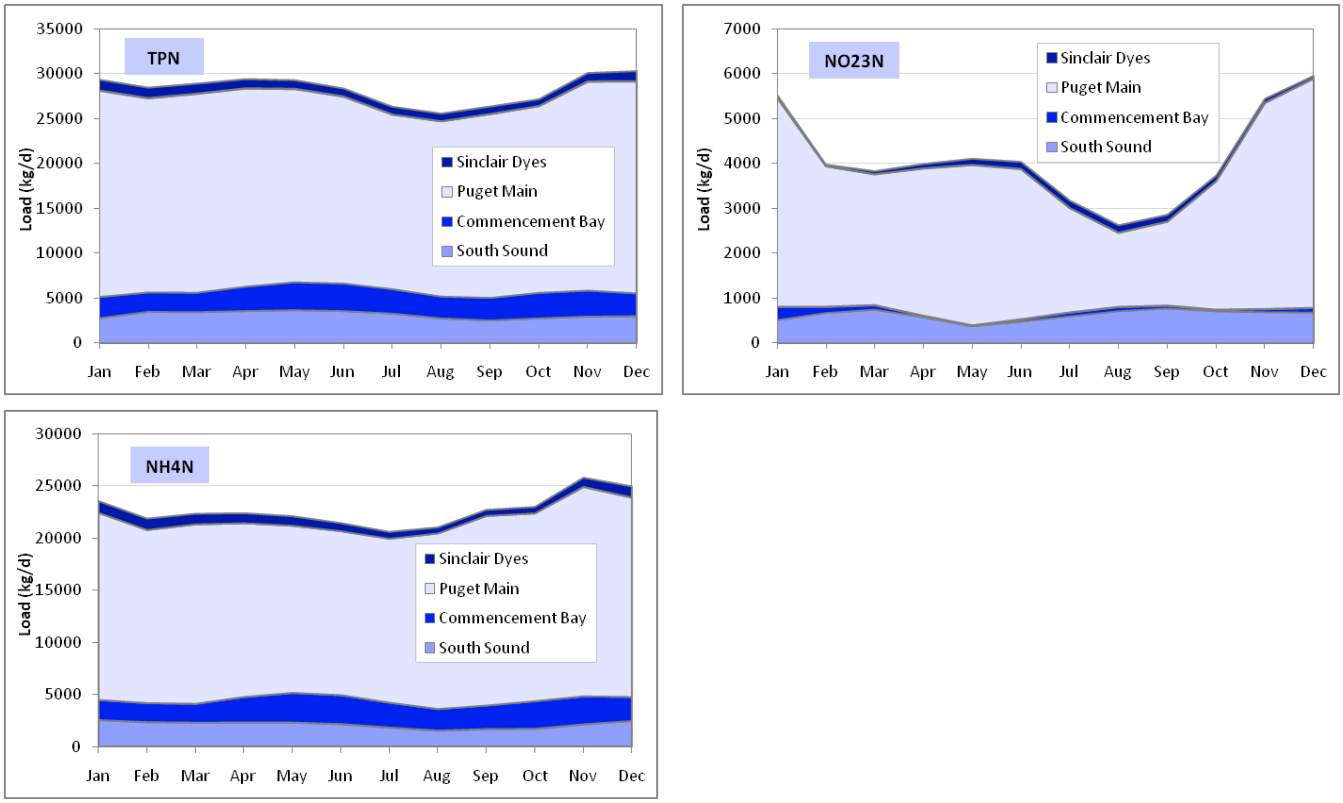


Figure G-16. Mean 2006-07 monthly nitrogen loads from WWTPs totaled according to the regions in South and Central Puget Sound into which they drain.

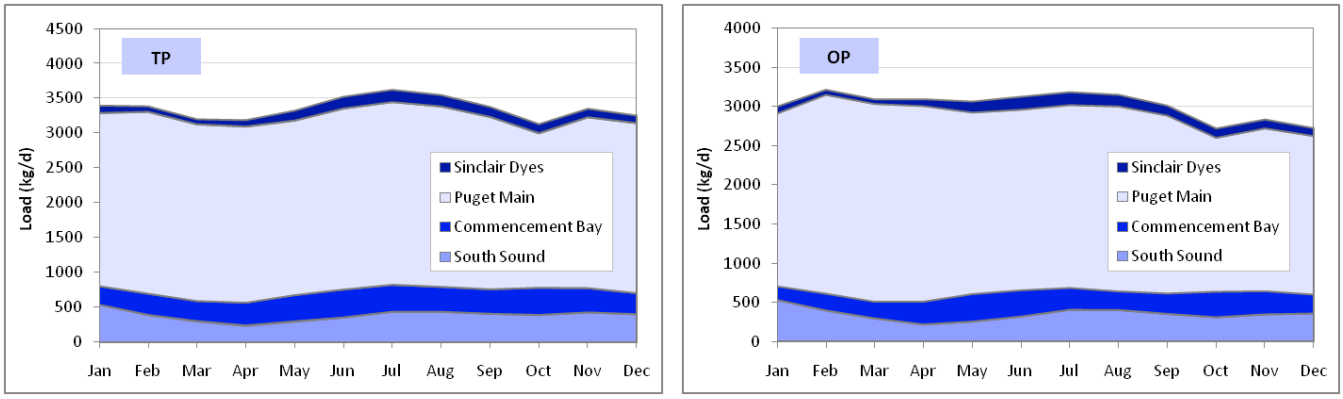


Figure G-17. Mean 2006-07 monthly phosphorus loads from WWTPs totaled according to the regions in South and Central Puget Sound into which they drain.

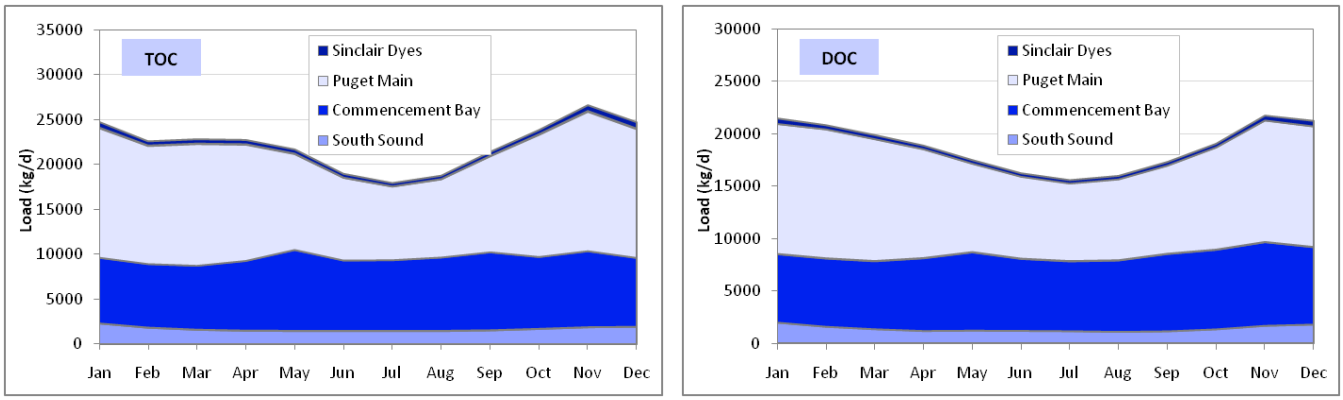


Figure G-18. Mean 2006-07 monthly organic carbon loads from WWTPs totaled according to the regions in South and Central Puget Sound into which they drain.

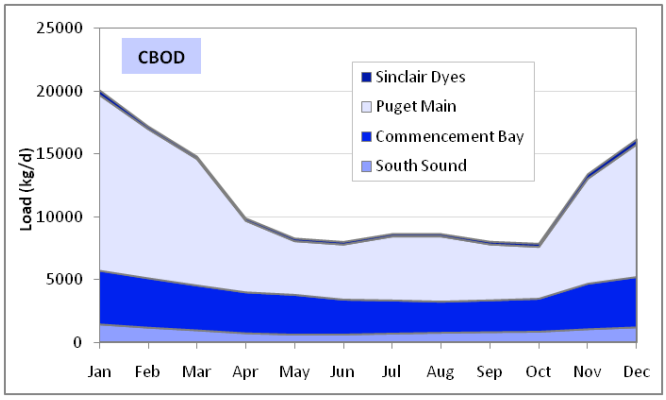


Figure G-19. Mean 2006-07 monthly carbonaceous biochemical oxygen demand loads from WWTPs totaled according to the regions in South and Central Puget Sound into which they drain.

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Appendix H. Waterbody Numbers

Table H-1 and H-2 list the marine and freshwater Waterbody Numbers (WBID) and names relevant to this study.

Table H-1. List of marine WBID names and numbers within the South and Central Puget Sound marine study area.

Waterbody ID	Waterbody Name
WA-09-0010	Elliott Bay
WA-10-0010	Commencement Bay (outer)
WA-10-0020	Commencement Bay (inner)
WA-10-0030	Thea Foss (City) Waterway
WA-13-0010	Henderson Inlet
WA-13-0020	Budd Inlet (outer)
WA-13-0030	Budd Inlet (inner)
WA-14-0010	Squaxin, Peale, and Pickering passages
WA-14-0020	Eld Inlet
WA-14-0050	Shelton Harbor (inner)
WA-14-0100	Hammersley Inlet
WA-14-0110	Oakland Bay
WA-14-0120	Little Skookum Inlet
WA-14-0130	Totten Inlet
WA-15-0010	Port Madison
WA-15-0020	Eagle Harbor
WA-15-0030	Port Orchard, Agate and Rich Passage
WA-15-0040	Sinclair Inlet
WA-15-0050	Dyes Inlet and Port Washington Narrows
WA-15-0060	Carr Inlet
WA-15-0070	Henderson Bay
WA-15-0100	Liberty Bay
WA-15-0110	Colvos Passage
WA-15-0120	Quartermaster Harbor
WA-15-0130	Hale Passage (south)
WA-PS-0070	Tacoma Narrows
WA-PS-0090	Case Inlet and Dana Passage
WA-PS-0240	Puget Sound (central)
WA-PS-0270	Puget Sound (s-central) and East Passage
WA-PS-0280	Dalco Passage/Poverty Bay
WA-PS-0290	Nisqually Reach/Drayton Passage
WA-PS-0300	Balch and Cormorant Passages

Table H-2. List of freshwater WBID names and numbers within the South and Central Puget Sound watershed areas.

Waterbody ID	Waterbody Name	Waterbody ID	Waterbody Name
WA-08-1000	Pipers Creek	WA-09-1025	Rock Creek
WA-08-1003	Deer Creek	WA-09-1026	Soos Creek System
WA-08-1010	Juanita Creek	WA-09-1027	Ravensdale Creek
WA-08-1012	Forbes Creek	WA-09-1028	Newaukum Creek
WA-08-1014	Yarrow Bay Creek	WA-09-1029	Stone Quarry Creek
WA-08-1016	Fairweather Bay Creek	WA-09-1030	Green River
WA-08-1018	Kelsey Creek	WA-09-1032	Icy Creek
WA-08-1020	Thornton Creek	WA-09-1040	Green River
WA-08-1021	Maple Leaf Creek	WA-09-1041	Gale Creek
WA-08-1030	McAleer Creek	WA-09-1050	Smay Creek
WA-08-1040	Lyon Creek	WA-09-2000	Des Moines Creek
WA-08-1050	Sammamish River	WA-09-2005	Miller Creek
WA-08-1060	Swamp Creek	WA-09-2010	Cold Springs Creek
WA-08-1065	North Creek	WA-09-2020	Redondo Creek
WA-08-1070	Sammamish River	WA-10-0000	Unnamed Creek
WA-08-1080	Sammamish River	WA-10-1010	Puyallup River
WA-08-1085	Little Bear Creek	WA-10-1011	Hylebos Creek
WA-08-1087	Oil Spill Creek	WA-10-1012	Fife Ditch
WA-08-1090	Sammamish River	WA-10-1013	Hylebos Creek, W.F.
WA-08-1095	Bear-Evans Creeks	WA-10-1015	Wapato Creek
WA-08-1100	Sammamish River	WA-10-1020	Puyallup River
WA-08-1110	Issaquah Creek	WA-10-1021	Clear Creek
WA-08-1111	Issaquah Creek, N.F.	WA-10-1022	Swan Creek
WA-08-1112	Issaquah Creek, E.F.	WA-10-1025	Clarks Creek
WA-08-1114	Carey Creek	WA-10-1026	Unnamed Creek
WA-08-1115	Tibbetts Creek	WA-10-1027	Diru Creek
WA-08-1116	Laughing Jacob's Creek	WA-10-1028	Meeker Ditch
WA-08-1117	Pine Lake Creek	WA-10-1030	White (Stuck) River
WA-08-1118	Eton Creek	WA-10-1031	Unnamed Creek
WA-08-1120	Coal Creek	WA-10-1032	Boise Creek
WA-08-1130	May Creek	WA-10-1033	Strawberry (Salmon) Creek
WA-08-1143	Cedar River	WA-10-1035	Lake Tapps Outflow Canal
WA-08-1145	Cedar River	WA-10-1036	Bowman Creek
WA-08-1150	Cedar River	WA-10-1038	Unnamed Creek
WA-08-1160	Cedar River	WA-10-1040	White River
WA-08-2100	Mercer Slough	WA-10-1041	Scatter Creek
WA-09-1000	Longfellow Creek	WA-10-1043	Clearwater River
WA-09-1005	Fauntleroy Creek	WA-10-1046	Greenwater River
WA-09-1010	Duwamish Waterway and River	WA-10-1050	Puyallup River
WA-09-1015	Springbrook (Mill) Creek	WA-10-1055	Unnamed Creek
WA-09-1019	Black River	WA-10-1060	Puyallup River
WA-09-1020	Green River	WA-10-1061	Fennel Creek
WA-09-1022	Hill (Mill) Creek	WA-10-1062	Canyonfalls Creek
WA-09-1023	Mud Lake Creek	WA-10-1070	Puyallup River
WA-09-1024	Unnamed Creek	WA-10-1080	Carbon River
WA-10-1081	Voight Creek	WA-14-1410	McDonald Creek
WA-10-1085	South Prairie Creek	WA-14-1450	Lynch Creek
WA-10-1087	Wilkenson Creek	WA-14-1500	Mill Creek
WA-10-1090	Lily Creek	WA-14-1600	Goldsborough Creek
WA-10-2040	Joes Creek	WA-14-1650	Shelton Creek
WA-11-1010	Nisqually River	WA-14-1700	Johns Creek
WA-11-1020	Nisqually River	WA-14-1750	Deer Creek
WA-11-1024	Ohop Creek	WA-14-1800	Uncle John Creek

Table H-2 continued. List of freshwater WBID names and numbers within the South and Central Puget Sound watershed areas.

Waterbody ID	Waterbody Name	Waterbody ID	Waterbody Name
WA-11-1025	Mashel River	WA-14-1850	Campbell Creek
WA-11-1030	Nisqually River	WA-14-1900	Sherwood Creek
WA-11-1040	Big Creek	WA-15-1015	Purdy Creek
WA-11-1050	Catt Creek	WA-15-1100	Rocky Creek
WA-11-2000	McAllister Creek	WA-15-1130	Unnamed Creek
WA-12-1110	Chambers Creek	WA-15-1190	North Bay Creek
WA-12-1115	Clover Creek	WA-15-1200	Coulter Creek
WA-13-1010	Deschutes River	WA-15-1290	Anderson Creek
WA-13-1012	Percival Creek	WA-15-1300	Minter Creek
WA-13-1014	Chambers Creek	WA-15-1350	Little Minter Creek
WA-13-1015	Ayer (Elwanger) Creek	WA-15-1400	Burley Creek
WA-13-1016	Spurgeon Creek	WA-15-1450	Bear Creek
WA-13-1020	Deschutes River	WA-15-1451	Unnamed Creek
WA-13-1022	Riechel Creek	WA-15-2030	Dogfish Creek
WA-13-1024	Huckleberry Creek	WA-15-2033	Grovers Creek
WA-13-1026	Thurston Creek	WA-15-2034	Steele Creek
WA-13-1028	Little Deschutes River	WA-15-2035	Unnamed Creek
WA-13-1030	Lincoln Creek	WA-15-2036	Johnson Creek
WA-13-1031	Buck Creek	WA-15-2037	Unnamed Creek
WA-13-1032	Ware Creek	WA-15-3000	Mayo Creek
WA-13-1034	Hard Creek	WA-15-3010	Unnamed Creek
WA-13-1100	McLane Creek	WA-15-3020	Ravine Creek
WA-13-1200	Green Cove Creek	WA-15-3030	Private Creek
WA-13-1300	Indian Creek	WA-15-3040	Lagoon Creek
WA-13-1350	Moxlie Creek	WA-15-3050	Picnic Creek
WA-13-1380	Mission Creek	WA-15-4000	Gorst Creek
WA-13-1400	Dobbs Creek	WA-15-4002	Parish Creek
WA-13-1500	Woodland Creek	WA-15-4200	Blackjack Creek
WA-13-1600	Woodard Creek	WA-15-4300	Ross Creek
WA-13-1700	Sleepy (Libbey) Creek	WA-15-4400	Annapolis Creek
WA-14-1100	Perry Creek	WA-15-4500	Wilson Creek
WA-14-1110	Madrona Beach Creek	WA-15-4800	Curley Creek
WA-14-1190	Pierre Creek	WA-15-4900	Beaver Creek
WA-14-1195	Burns Creek	WA-15-5100	Barker Creek
WA-14-1200	Schneider Creek	WA-15-5200	Strawberry Creek
WA-14-1300	Kennedy Creek	WA-15-5210	Unnamed Creek
WA-14-1400	Skookum Creek	WA-15-6000	Fern Creek