Water-Quality Assessment of the Puget Sound Basin, Washington, Nutrient Transport in Rivers, 1980-93

By S. S. Embrey and E. L. Inkpen

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 97-4270

Tacoma, Washington
1998

U.S. DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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<URL:http://wwwrvares.er.usgs.gov/nawqa/nawqa_home.html>

FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

•Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.

•Describe how water quality is changing over time.

•Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Mass	
pound (lb)	0.4536	kilogram
tons (T)	907.18486	kilogram
	Area	
acre	4,047	square meter
	0.4047	hectare
square feet (ft^2)	0.0929	square meter
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
	3,785	milliliter
	Flow	
cubic feet per second (ft^3/s)	0.028317	cubic meter per second

Physical and Chemical Water-Quality Units

Temperature: Water and air temperature are given in degrees Celsius (^{o}C), which can be converted to degrees Fahrenheit (^{o}F) by use of the following equation: $^{o}F = 1.8 \times (^{o}C) + 32$.

Milligrams per liter (mg/L): Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water.

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

The Puget Sound Basin study team compiled historical nutrient data to evaluate the transport of nutrients in the major rivers of the Puget Sound Basin study unit of the National Water Quality Assessment program. The rivers included in this retrospective analysis carry an average nutrient load of about 11,000 tons of inorganic nitrogen, 9,900 tons of organic nitrogen, and 2,100 tons of total phosphorus to Puget Sound and its adjacent marine waters each year. Rivers with the largest watersheds and streamflows transport the greatest nutrient loads.

Nutrient transport from basins was normalized by drainage areas and expressed as a nutrient yield in tons per square mile per year. The smallest yields are from rivers in the Olympic Mountains. These rivers generally yield less than 1 ton per square mile per year of inorganic nitrogen and less than 0.1 ton per square mile per year of phosphorus. The largest yields are from rivers draining the east side of the Puget Sound Basin. These rivers generally yield more than 1 ton per square mile per year of inorganic nitrogen and more than 0.1 ton per square mile per year of phosphorus.

Estimates of nutrient-source loading rates to the watersheds help explain, in part, stream loads and river basin yields. Because they are among the least developed and populous watersheds, annual loading rates to western Puget Sound Basin watersheds from animal manures, agricultural fertilizers, and precipitation are small (typically less than 1 ton per square mile). To the more densely populated and agricultural eastern Puget Sound Basin watersheds, the loading rates are generally greater than 2 tons per square mile, which correspond to the higher east-side stream nutrient loads and basin yields.

To eight of the major watersheds, more than half of the annual nitrogen loading is from animal manures. Agricultural fertilizers make up from 9 to 33 percent of the nitrogen loading to these eight basins. Each year, animal manures, agricultural fertilizers, and precipitation contribute 10 tons of nitrogen per square mile to the Samish River Basin and 9 tons per square mile to the Nooksack River Basin. In response, nutrient yields from these two basins (up to 2.8 tons of nitrogen per square mile per year and up to 0.3 ton of phosphorus per square mile per year) are among the highest rates for watersheds of the Puget Sound Basin. Fertilizer is the principal nutrient source to the Samish River Basin, which might account for the relatively low phosphorus yield compared to the yield from the Nooksack River Basin, where animal manures are the principal source.

Nutrients from precipitation and domestic-applied fertilizers are of interest for the populous Green, Lake Washington, and Snohomish River Basins. Precipitation is estimated to contribute from 1 to 2 tons of nitrogen per square mile each year and from 0.10 to 0.2 ton of phosphorus per square mile each year to these three basins. In addition, if it is assumed that one-eighth of the urban area is fertilized on an annual basis, a watershed the size of Lake Washington might receive nearly 3 tons of nitrogen per square mile. The total annual nitrogen loading rate to a watershed similar to that of Lake Washington would nearly double with the additional contribution from urban fertilizer applications.

INTRODUCTION

In 1991, the U.S. Geological Survey (USGS) began the National Water-Quality Assessment Program (NAWQA) to describe the status and trends in the quality of the Nation's surface- and ground-water resources and to identify the major natural and human factors that affect the quality of these resources. When fully implemented, about 60 study units nationwide will constitute the NAWQA program. Approximately 60 to 70 percent of the Nation's water use and the population served by public water supplies will be represented in the program. In 1991, hydrologic studies began in 20 study units; in 1994, studies began in another 16 study units, one of which is the Puget Sound Basin.

Designed as a long-term, multiphase investigation, the Puget Sound Basin study will address water-quality issues in the Puget Sound Basin consistent with the NAWQA focus. The first phase of the Puget Sound Basin assessment is a high-intensity phase and spans a 6-year period when surface- and ground-water-quality data will be collected and aquatic ecological surveys will be conducted. Data analyses and report writing will be completed during 1999-2000, at which time the assessment will shift into a low-intensity phase of limited data collection. The low-intensity phase is designed to track long-term trends (or lack of trends) and identify emerging water-quality issues before a second high-intensity phase begins in 2005.

Compilation and analysis of historical water-quality data are important initial tasks for each study-unit team of the NAWQA program. The analyses provide a basis upon which water-quality trends can be evaluated and for comparing the water-quality characteristics of individual basins. The Puget Sound Basin team focused on compiling and analyzing historical nutrient data to evaluate the transport of nutrients in the rivers of the Puget Sound Basin. This nutrient retrospective focus represents the first time an attempt has been made to calculate comprehensive estimates of nitrogen and phosphorus loads transported each year from the major watersheds to Puget Sound and its adjacent marine waters.

Purpose and Scope

This report summarizes existing nitrogen and phosphorus data collected from Puget Sound Basin rivers and describes the results of calculations made with these nutrient data to estimate nutrient loads. Data from a total of 24 rivers and streams were used in this analysis. Also included in the report are estimates of the major non-point and wastewater-treatment-plant point sources of nutrients to selected watersheds and rivers.

Description of the Puget Sound Basin Study Unit

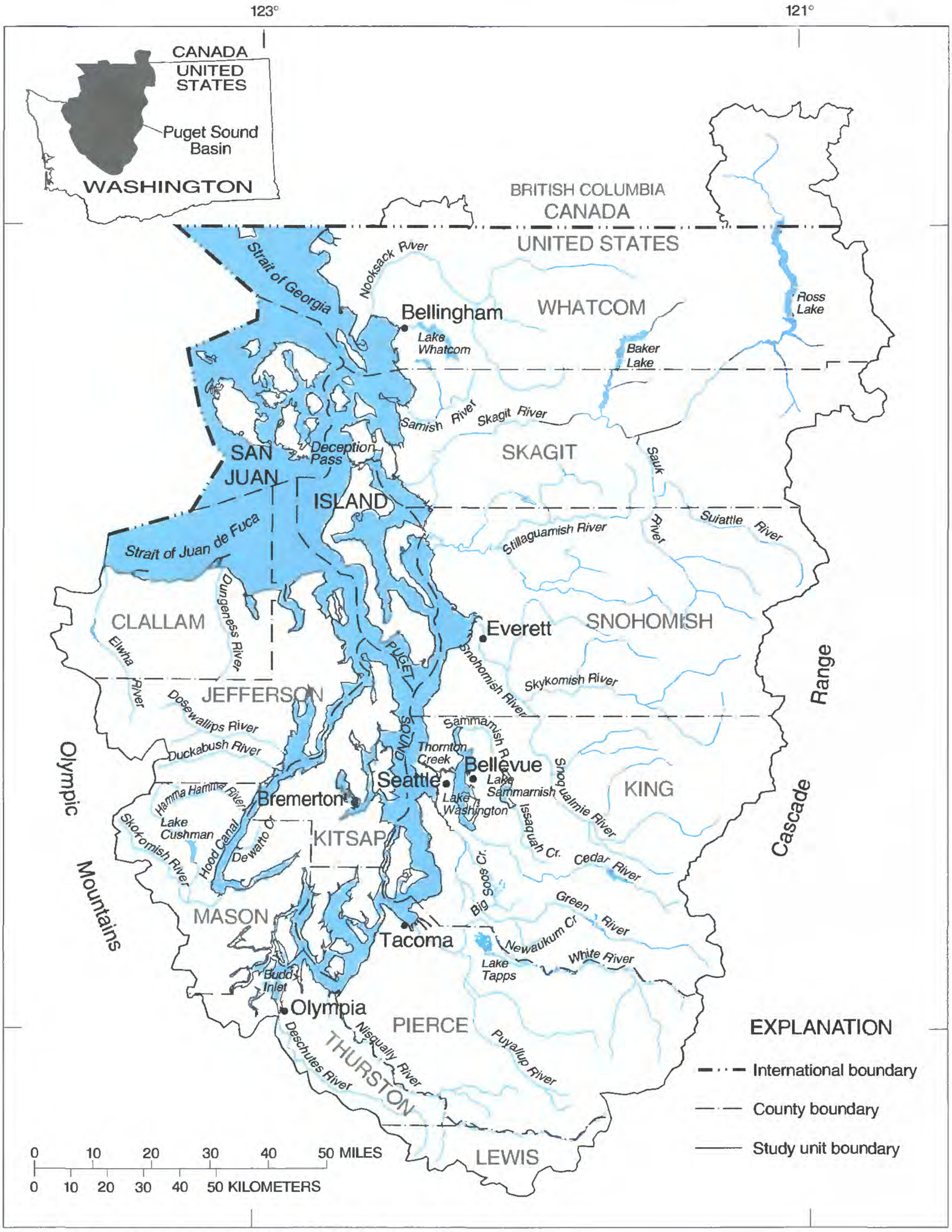
The Puget Sound Basin study unit encompasses the 13,700-mi^2 (square mile) area that drains to the Puget Sound and its adjacent waters (fig. 1). It includes all or part of 13 counties in western Washington and the headwaters of the Skagit River and part of the Nooksack River Basin in Canada. The Cascade Range bounds the study unit on the east and the Olympic Mountains of the Coastal Range bound the study unit on the west. Fourteen major and numerous minor tributaries drain to Puget Sound and adjoining waters. The major tributaries, with their headwaters in the Olympic Mountains and Cascade Range, account for more than 91 percent of the 52,500 ft^3/s (cubic feet per second) of mean annual surface-water inflow to Puget Sound and adjacent waters (Williams, 1981; Staubitz and others, 1997).

The Puget Sound Basin has a Pacific Coast marine climate that is characterized by cool, wet winters and warm, dry summers. Precipitation ranges from about 16 to 47 in/yr (inches per year) in the lowlands, and from 60 to more than 200 in/yr in the mountains (Staubitz and others, 1997). Most of this precipitation falls during the period from October to March.

About 3.7 million people, or 70 percent of the population of Washington State, live in the Puget Sound Basin study unit, mainly in the metropolitan areas of Seattle, Tacoma, Everett, Bellingham, and Olympia. Most of the population lives near the shores of Puget Sound and adjacent waters and in the alluvial valleys of major rivers. In 1970, urban areas covered approximately 8 percent of the basin, but increased to about 11 percent by 1996. About 75 percent of the Puget Sound Basin remains forested, and about 6 percent of the basin is farmed. The balance is covered by lakes, reservoirs, glaciers, and shorelands (Staubitz and others, 1997).

The Importance of Nitrogen and Phosphorus in the Aquatic Environment

Aquatic plants and animals require nitrogen and phosphorus to grow and sustain life. In an aquatic system, a balance exists between the input of these nutrients and



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic Projection
Standard parallels 47° and 49°, central meridian 122°

Figure 1. Puget Sound Basin NAWQA study unit.

the numbers of aquatic plants and animals. Natural events and human activities can alter the balance by contributing large amounts of nitrogen or phosphorus. The result is nutrient enrichment that can cause excessive plant growth or eutrophication. This excessive plant growth, especially of algae, can cause aesthetically unpleasant water-quality conditions, such as taste and odor problems, and can lead to dissolved-oxygen depletion. Low dissolved-oxygen levels adversely affect certain desirable fish species and can increase the solubility of metals, some of which are toxic.

Puget Sound, its adjacent waters, and Puget Sound Basin rivers are the receiving waters for natural and human inputs of nitrogen and phosphorus and are therefore subjected to potential nutrient enrichment and accompanying water-quality problems. Although the quality of surface water in Puget Sound and its rivers is generally good, there are some areas of documented problems. Natural conditions contribute to some of the observed water-quality problems, but human presence and activities are also factors in some areas. In areas of intensive agriculture and near population centers, some river reaches and lakes are known to have elevated total phosphorus, total nitrogen, and ammonia concentrations (Butkus and Lynch, 1996). In addition, a few Puget Sound embayments have some water-quality problems, notably low dissolved-oxygen concentrations (Newton and others, 1994). Puget Sound embayments with observed water-quality problems are typically near urban areas and where persistent or seasonal stratification of the water column exists (Newton and others, 1994). In south Puget Sound near Olympia, Budd Inlet undergoes water-quality problems such as excessive phytoplankton growth and low levels of dissolved oxygen caused by nutrient enrichment (Eisner and others, 1994).

Nutrient Water-Quality Criteria

In natural water, the common forms of nitrogen are nitrite, nitrate, ammonia, and organic nitrogen (Hem, 1985). The nitrogen forms dissolve easily in water and are readily transported in surface water. Nitrite nitrogen typically occurs in natural water in such low concentration that it is unimportant. Conversely, nitrate nitrogen can be present in water in relatively high concentrations. Nitrate nitrogen in drinking water can pose a health risk for human infants because it has been related to methemoglobinemia or blue baby syndrome. To protect young children, the U.S. Environmental Protection Agency (USEPA) established a maximum contaminant level (MCL) of 10 mg/L (milligrams per liter) for nitrate in drinking water (U.S. Environmental Protection Agency, 1996).

Of the other forms of nitrogen, ammonia can be harmful to aquatic organisms. The USEPA (1986) has established criteria for maximum ammonia concentrations in surface water to protect aquatic life. Within the ranges of pH (6.5 to 9.0) and temperature (0 to 30^{o}Celsius) typical of most natural surface waters, total ammonia concentrations from 0.1 mg/L to about 2.1 mg/L as N can exceed USEPA chronic criteria (Mueller and others, 1995).

Phosphorus is only moderately soluble in water and in natural water is mostly associated with suspended sediment. The common forms of phosphorus dissolved in natural water are phosphates, such as orthophosphate (Hem, 1985). Phosphorus can be especially troublesome in freshwater lakes and river systems. To reduce the risk of eutrophication, MacKenthun (1973) suggests:

(1) total phosphate as phosphorus should not exceed 0.05 mg/L in a stream at the point where it enters a lake or reservoir, and

(2) total phosphorus should not exceed 0.1 mg/L in flowing waters that do not discharge directly into lakes or impoundments.

APPROACH AND METHODS

The calculation of stream loads requires both constituent-concentration data and streamflow data. Nutrient-concentration data were compiled from databases maintained by agencies operating water-quality monitoring stations in the Puget Sound Basin. Streamflow data were obtained from gaging station records or from measurements made at the time of water-quality sample collection. Nutrient-concentration data and streamflow data were entered into a computer program to calculate loads transported by Puget Sound Basin rivers and streams. For some rivers, however, the minimum data requirements for using the computer program could not be met, so arithmetic methods were used to estimate instream loads.

Long-term water-quality monitoring programs by Washington State Department of Ecology (Ecology), King County Department of Metropolitan Services (METRO), and the U.S. Geological Survey provided data collected since the 1970s. Ecology currently samples near the mouths of 12 major rivers (Hallock and Hopkins, 1994), and METRO samples at several sites in the Green River, Sammamish River, and Lake Washington Basins (King County Department of Metropolitan Services, 1994). The USGS has sampled near the mouths of the Skagit, Puyallup, and Elwha Rivers (fig. 2). Stream nutrient loads at most stations were calculated by the USGS for the period 1980-93. At some water-quality stations, data were available only from the 1970s or earlier. Even though the primary period for load calculations was 1980-93, loads were estimated for the few stations with earlier data. The periods of record used in all loading calculations and the agencies responsible for data collection are listed in table 1.

Streamflow data were available from gaging station records or were measured at the time of sample collection at water-quality monitoring stations. Using the computer model requires data sets of daily streamflows for each water-quality station over the period of time for which loads are to be calculated. These data sets were constructed from gaging stations equipped with continuous streamflow monitors and operated mostly by USGS.

The computer program Estimator was used for calculations of nutrient loads. Estimator calculates instream constituent loads by relating constituent concentrations to streamflow and other parameters. The following sections describe in detail the methods used in this study to construct nutrient and streamflow data sets, calculate instream nutrient loads, and estimate the major sources of nutrient loadings to the watersheds.

Nutrient Data-Set Construction

Since the 1970s, data-collection strategies and needs, sample handling, and sample preservation varied among the agencies, and analytical techniques have changed. Thus, the data sets consist of nutrient concentrations determined and reported in different ways. Some water samples collected from rivers in the Puget Sound Basin were unfiltered, analyzed as whole water, and the results reported as totals. Others were filtered and the results reported as dissolved. Data sets were made as complete over time as possible by considering whole-water and filtered-water results for nitrite, nitrate, nitrite-plus-nitrate, and ammonia nitrogen to be equivalent. For the three USGS water-quality stations, less than 25 percent of ammonia nitrogen values resulted from merging dissolved ammonia values with total ammonia nitrogen, and less than 20 percent of nitrite-plus-nitrate nitrogen values were from dissolved nitrite-plus-nitrate nitrogen.

All nitrogen forms were expressed as N (nitrogen) and all phosphorus forms were expressed as P (phosphorus). Values for inorganic nitrogen in the data sets were created by summing concentrations of nitrite-plus-nitrate and ammonia nitrogen; values for organic nitrogen were created by subtracting ammonia concentrations from concentrations of organic nitrogen-plus-ammonia (Kjeldahl nitrogen). Hereafter in this report, nitrite-plus-nitrate nitrogen is referred to as nitrate and ammonia nitrogen is referred to as ammonia.

Streamflow Data Sets

Nineteen active gaging stations were available to construct data sets of daily streamflows for most all of the water-quality stations used in this study (table 1). Data sets of daily streamflows included the 1980-93 period for which nutrient loads were calculated, as well as any additional period of historical water-quality record used by Estimator to develop the nutrient load equations. USGS gaging stations were used to create daily streamflow data sets for all but one water-quality station. The Corps of Engineers, Seattle District provided 1980-93 daily values for the outflow through the Lake Washington Ship Canal.

Active streamflow gaging stations corresponding to a water-quality station were not always present. For the water-quality station Stillaguamish River at Silvana, daily streamflows were estimated using historical streamflows and streamflows at active gaging stations (stations 21-23) upstream in the basin (table 2 and fig. 2). Statistical regression equations between the historical and active-station streamflows were developed and used to extend the historical daily-flow record into the 1980-93 time period. For three stations on the Green River (at Fort Dent Bridge, at Renton Junction, and at 212th Street near Kent), daily streamflows were estimated with statistical regression between streamflows at gaging stations Green River at Tukwila and near Auburn. For the stations Green River above Big Soos Creek and near Newaukum Creek, daily streamflows were estimated by subtracting gaged tributary streamflows from streamflows in the Green River as measured at the nearby gaging station Green River near Auburn.

In some cases, data sets of daily streamflows could not be constructed. Instead, historical streamflows and statistical summaries of streamflow data published by the USGS (Williams and others, 1985a and 1985b) were used for seven water-quality stations, mostly on rivers draining the east slopes of the Olympic Mountains. The seven

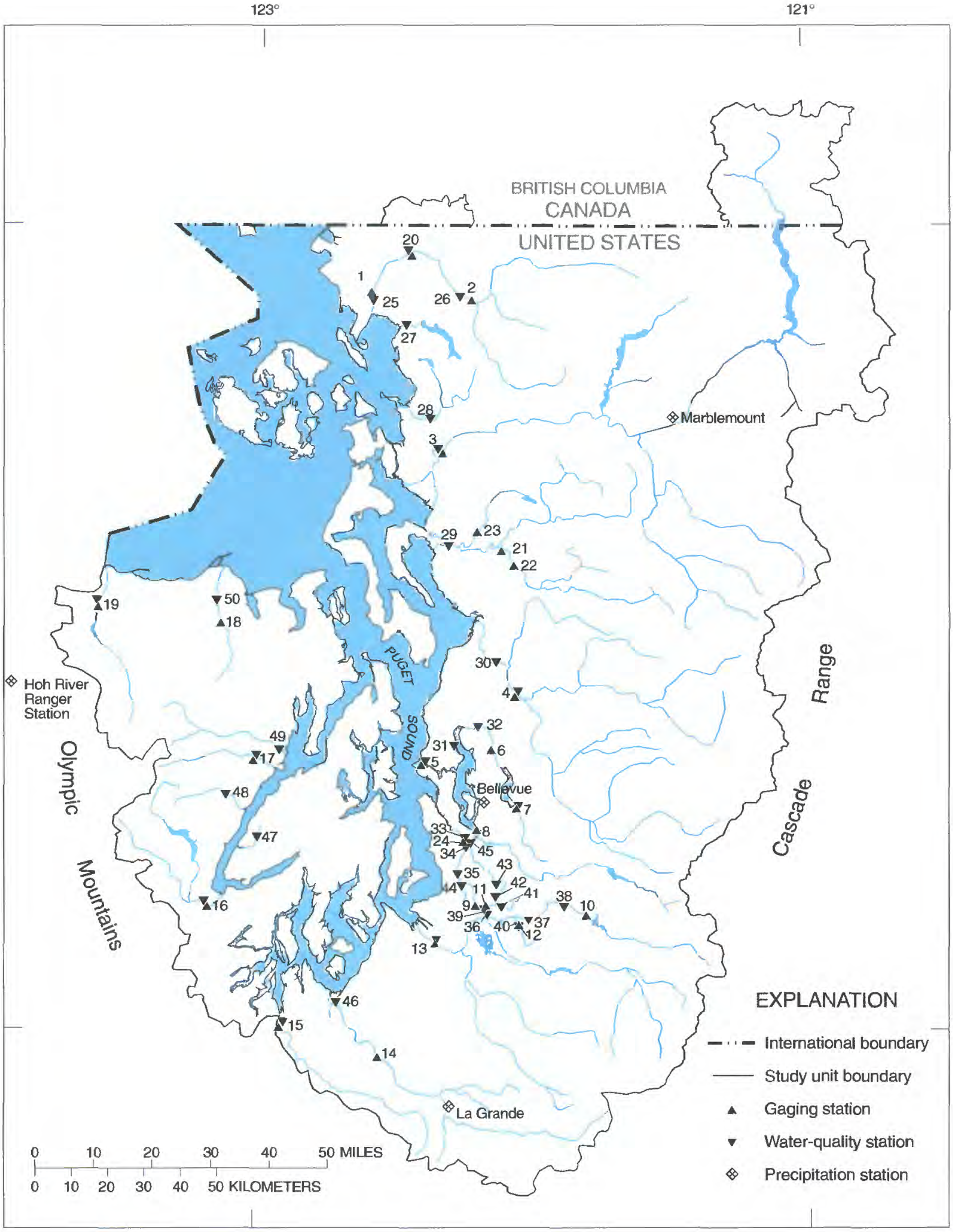


Figure 2. Location of gaging stations and water-quality stations from which data were used for load calculations. The corresponding numbers are related to station names in tables 1 and 2.

Table 1.--*Active streamflow gaging stations, water-quality stations, collection agencies, and period of record used to estimate nutrient loads*

[Ecology, Washington State Department of Ecology; METRO, King County Department of Metropolitan Services; USGS, U.S. Geological Survey; [a], approximate value]

Streamflow Gaging Station			Associated Water-Quality Station				
Map identifier (figure 2)	Name (station number)	Drainage area at gage, in square miles	Map identifier (figure 2)	Name	Drainage area at station	Period of water-quality record	Collection agency
1	Nooksack River at Ferndale (12213100)	786	25	Nooksack River at Brennan	790[a]	1970-93	Ecology
2	Nooksack River at Deming (12210500)	584	20	Nooksack River near Lynden	648	1974, 1977	Ecology
			26	Nooksack River at North Cedarville	596	1970-71, 1973-74, 1977-93	Ecology
			27	Whatcom Creek at Bellingham	55.4	1972-73, 1976-77	Ecology
			28	Samish River near Burlington	87.8	1970-71, 1973-74, 1976-93	Ecology
3	Skagit River near Mount Vernon (12200500)	3,093	3	Skagit River at Mount Vernon	3,093	1970-93	USGS
			29	Stillaguamish River at Silvana	609[a]	1970-93	Ecology
4	Snohomish River near Monroe (12150800)	1,537	30	Snohomish River at Snohomish	1,729	1970-93	USGS Ecology
5	Lake Washington Ship Canal (METRO 0512)	600[a]	5	Lake Washington Ship Canal	600[a]	1980-93	METRO
			31	Thornton Creek near Seattle	12.1	1974, 1976, 1979-92	METRO
6	Sammamish River near Woodinville (12125200)	159	32	Sammamish River at Bothell	212	1970-93	Ecology
7	Issaquah Creek near mouth near Issaquah (12121600)	56.6	7	Issaquah Creek at gaging station	56.6	1975-93	Ecology

Table 1.--*Active streamflow gaging stations, water-quality stations, collection agencies, and period of record used to estimate nutrient loads--Continued*

Streamflow Gaging Station			Associated Water-Quality Station				
Map identifier (figure 2)	Name (station number)	Drainage area at gage, in square miles	Map identifier (figure 2)	Name	Drainage area at station	Period of water-quality record	Collection agency
8	Cedar River at Renton (12119000)	184	8	Cedar River at Renton	184	1970-93	Ecology
9	Green River near Auburn (12113000)	399	33	Green River at Fort Dent Bridge	460[a]	1987-93	METRO
			34	Green River at Renton Junction	440[a]	1970-93	METRO
			35	Green River at 212th Street near Kent	435	1970-71, 1974-76, 1980-91	Ecology
			36	Green River above Big Soos Creek	327	1972-93	METRO
			37	Green River near Newaukum Creek	285	1972-93	METRO
10	Green River at purification plant near Palmer (12106700)	231	38	Green River at Kanaskat	240	1975-93	Ecology
11	Big Soos Creek above hatchery near Auburn (12112600)	66.7	39	Big Soos Creek near mouth	66.7	1972-93	METRO
12	Newaukum Creek near Black Diamond (12108500)	27.4	40	Newaukum Creek near mouth	27.4	1972-93	METRO
			41	Covington Creek	21.6	1977-86	METRO
			42	Jenkins Creek	15.5	1977-84, 1987-92	METRO
			43	Little Soos Creek	6.08	1977-84, 1987-88	METRO
			44	Mill (Hill) Creek	10.5	1977-91	METRO
			45	Springbrook Creek	21.4	1977-92	METRO

Table 1.--*Active streamflow gaging stations, water-quality stations, collection agencies, and period of record used to estimate nutrient loads--Continued*

Streamflow Gaging Station			Associated Water-Quality Station				
Map identifier (figure 2)	Name (station number)	Drainage area at gage, in square miles	Map identifier (figure 2)	Name	Drainage area at station	Period of water-quality record	Collection agency
13	Puyallup River at Puyallup (12101500)	948	13	Puyallup River at Puyallup	948	1970-93	USGS
14	Nisqually River at McKenna (12089500)	517	46	Nisqually River at Nisqually	640[a]	1977-93	Ecology
15	Deschutes River at E Street Bridge at Tumwater (12080010)	162	15	Deschutes River at E Street Bridge at Tumwater	162	1990-93	Ecology
			47	Dewatto River near Dewatto	18.4	1971-74	Ecology
16	Skokomish River near Potlatch (12061500)	227	16	Skokomish River near Potlatch	227	1971-74, 1977, 1978-80, 1983-93	Ecology
			48	Hamma Hamma River near Eldon	51.3	1972-74	Ecology
17	Duckabush River near Brinnon (12054000)	66.5	17	Duckabush River near Brinnon	66.5	1972-74	Ecology
			49	Dosewallips River near Brinnon	93.5	1971-74	Ecology
18	Dungeness River near Sequim (12048000)	156	50	Dungeness River at Highway 101 near Sequim	156	1971-74	Ecology
19	Elwha River at McDonald Road Bridge near Port Angeles (12045500)	269	19	Elwha River at McDonald Road near Port Angeles	269	1974-86	USGS

Table 2.--*Streamflow gaging stations used to extend the period of record to estimate daily streamflows at water-quality stations not associated with an active streamflow gage*

Water-quality station	Historical streamflow gaging station and station numbers	Gaging station map number (figure 2)	Period of historical record, water years	Gaging station used to extend the periods of record or to estimate daily flows and station numbers
Nooksack River near Lynden	Nooksack River near Lynden, 12211500	20	1945-67; 1974; 1977[a]	
Stillaguamish River at Silvana	South Fork Stillaguamish River near Arlington, 12164500;	21	1929-36; 1937-57; 1930-75	North Fork Stillaguamish River near Arlington, 12167000
	South Fork Stillaguamish River above Jim Creek near Arlington, 12162500;	22		
	Pilchuck Creek near Bryant, 12168500	23		
Green River at Fort Dent Bridge	Green River at Tukwila, 12113350	24	1961-79	Green River near Auburn, 12113000
Green River at Renton Junction	Green River at Tukwila, 12113350	24	1961-79	Green River near Auburn, 12113000
Green River at 212th Street near Kent	Green River at Tukwila, 12113350	24	1961-79	Green River near Auburn, 12113000
Green River above Big Soos Creek				Green River near Auburn (12113000) minus Big Soos Creek above hatchery near Auburn (12112600)
Green River near Newaukum Creek				Green River near Auburn (1211300) minus Big Soos Creek above hatchery near Auburn (12112600) minus Newaukum Creek near Black Diamond (12108500)

[a] Instantaneous streamflow at time of sample collection is included in the water-quality database.

water-quality and corresponding streamflow stations are

Duckabush River near Brinnon (gage 12054000),
Dosewallips River near Brinnon (gage 12053500),
Dungeness River at Highway 101 near Sequim (gage 12048600),
Dewatto River near Dewatto (gage 12068500),
Hamma Hamma River near Eldon (gage 12054500),
Whatcom Creek at Bellingham (gage 12203550), and
Samish River near Burlington (gage 12201500).

Along with the water-quality data, instantaneous streamflows provided by METRO were used for calculations at six more water-quality stations: Thornton Creek, Little Soos Creek, Covington Creek, Jenkins Creek, Mill (Hill) Creek, and Springbrook Creek (see figure 7).

Nutrient-Load Calculations

Nutrient data from the monitoring programs, along with daily streamflow data, were entered into the Estimator computer program to calculate average annual nutrient loads transported by Puget Sound Basin rivers. Estimator was developed in 1988 as part of a USGS study to estimate stream nutrient loads entering Chesapeake Bay (Cohn and others, 1989; Cohn and others, 1992). The program uses a multiple regression model to relate logarithms of constituent concentration with logarithms of streamflow and with time and seasonality parameters and then to predict constituent concentrations. Daily loads, computed by multiplying predicted concentrations by daily mean streamflows, are summed for an estimate of annual loads. The program is capable of handling censored data (values less than the reporting or method detection limit). Typically, a regression model consisting of seven parameters describing flow dependence, time trends, and seasonality accounts for 10 to 50 percent of variability observed in the logarithms of constituent concentration data (Cohn and others, 1992).

Data were not available to use Estimator at all the water-quality stations. At some stations, water-quality data were too few (less than 12 observations per year) to use the model. Other stations had a sufficient amount of water-quality data, but the required sets of daily streamflows were not available or could not be constructed. For these stations, nutrient loads were estimated as a simple product of concentration times streamflow and extrapolated to an annual load according to the following steps. The method of calculation varied only in the first step depending on the type of streamflow data available for the calculations.

Step 1: Method A--If instantaneous streamflows (streamflow at the time of sample collection) were available, monthly loads were calculated by multiplying sample concentration by instantaneous streamflow and by the number of days in the corresponding sampling month. This method was used for the Nooksack River near Lynden, Covington Creek, Jenkins Creek, Little Soos Creek, Mill (Hill) Creek, Springbrook Creek, and Thornton Creek.

Step 1: Method B--If instantaneous flows were not available, average streamflow for the same month and year (monthly mean) in which the water sample was collected was used to calculate monthly load as in Method A. Method B was used for the Duckabush River, the Dungeness River, and Whatcom Creek.

Step 1: Method C--If no streamflow data were available for the month and year of sample collection, the average flow for that month over the entire period of record (the mean monthly flow) was used to calculate monthly load as in Method A. Method C was used for the Dosewallips River, the Hamma Hamma River, the Dewatto River, and the Samish River.

Step 2: Monthly loads were summed to obtain annual loads. If less than 12 months of data existed in a particular year, the monthly loads were averaged and the average multiplied by 12 to obtain annual loads.

Step 3: Annual loads from Step 2 were averaged to estimate the average annual load at the station.

As with all estimation methods, loads calculated by the product method are subject to errors, one of which is related to sampling frequency. Depending on the constituent, load estimates can be underestimated or overestimated by data collection strategies targeting only low-flow or high-flow seasonal conditions. For the sites listed above, water-quality data were collected at fixed intervals (monthly, every other month, or quarterly), which reduces some of the potential bias due to sampling. However, even though fixed-interval sampling can represent seasonal aspects of the hydrograph, it does not necessarily represent high streamflow events that can occur during storms or snowmelt. Without representative samples over the range of a stream's hydrograph, the error in using the product method to estimate stream loads could be large. Of the 14 sites listed above, fixed-interval sampling without targeted high-streamflow sampling might affect load estimates at Nooksack River near Lynden, Whatcom Creek, Dosewallips River, Dungeness River, Duckabush River, Dewatto River, and Hamma Hamma River.

Estimating Sources of Nitrogen and Phosphorus to Puget Sound Basin Watersheds

Nitrogen and phosphorus can enter surface water systems from natural geologic and biological sources. Nitrogen and phosphorus are also major components of commercial fertilizers and are present in high concentrations in sewage and animal wastes. Point-source wastewater treatment or industrial facilities discharge these nutrients directly to Puget Sound and its adjacent waters, and to Puget Sound Basin rivers. In addition, non-point sources such as stormwater runoff from urban areas and drainage from agricultural croplands and livestock operations can transport nitrogen and phosphorus into Puget Sound Basin rivers, lakes, and estuaries. Precipitation can also contribute large amounts of nitrogen to river basins. In the United States, more than 3.2 million tons of nitrogen are deposited each year from the atmosphere (Mueller and Helsel, 1996). As an example at the local scale, atmospheric deposition of nitrogen to the 11,200 square mile Willamette River Basin, Puget Sound's neighboring NAWQA study unit in Oregon, amounts to about 4,100 tons per year (Bonn and others, 1995).

Because the nature and intensity of land use and human population densities differ greatly among the study unit's river basins, widely varying amounts of nutrients are deposited in or applied to the basins. Several mechanisms, such as adsorption, volatilization, and plant uptake, prevent some fraction of the nutrients deposited in a river basin from entering surface waters. This study does not attempt to quantify the amount of nitrogen or phosphorus that actually enters surface waters to become part of the nutrient load transported by the rivers. Rather, this study uses the estimates of the amounts of nutrients deposited over a basin's landscape only as an indicator of the potential for nutrients to enter surface waters. Because of the nature of the data, or the lack of data, and the need to make certain assumptions, large errors can be associated with the approximations of source amounts.

Various data sets, including farm-animal censuses, agricultural fertilizer sales, precipitation chemistry data, and wastewater-treatment plant discharges, were compiled and used to estimate the amounts of nitrogen and phosphorus entering a watershed or a river. The following methods were used to estimate the amounts of these nutrients distributed within a river basin.

Agricultural Fertilizers and Animal Manure

The contributions of nitrogen and phosphorus in animal manures and agricultural fertilizer applications were estimated from county-based data on animal populations during the years 1982, 1987, and 1992 (L.J. Puckett, U.S. Geological Survey, written commun., 1995; R.B. Alexander, U.S. Geological Survey, written commun., 1992) and commercial fertilizer sales during the period 1985-91 (Bill Battaglin, U.S. Geological Survey, written commun., 1992). The manure and fertilizer contributions were averaged over the number of years for which data were available and allocated to agricultural land-use areas in the river basins. The percentage of a county's agricultural area within a river basin was multiplied by the county's nutrient loading rates from animal manure and fertilizer. For the Elwha and Dungeness Rivers, it was necessary to estimate agricultural area because the basins' boundaries were not available in a GIS (Geographical Information System) coverage. From manual measurements of maps, it was estimated that about 10 percent of Clallam County's agricultural area was situated in the Elwha Basin and about 70 percent in the Dungeness Basin.

Urban-Suburban Fertilizer

The amounts of nitrogen and phosphorus purchased and applied by urban and suburban homeowners in the Puget Sound Basin are unknown. Homeowner and commercial-service applications of fertilizers could be an important component of the total nutrient loads to the watersheds in the populated regions of Snohomish, King, and Pierce Counties. For example, commercial applications in the Puget Sound Basin study unit typically amount to about 4 to 6 pounds of nitrogen and 0.06 pounds of phosphorus per 1,000 square feet per year. Fertilizer applications by homeowners can vary widely depending on adherence to recommended application rates and the frequency of applications; however, typical average application rates to lawns are from about 3 to 4 pounds of nitrogen per 1,000 square feet per year (Crockett, 1971). Rates from 3 to 4 pounds of nitrogen per 1,000 square feet per year are equivalent to about 130 to 170 pounds of nitrogen per acre. These rates are higher than typical agricultural rates of about 83 pounds of nitrogen per acre to land planted in raspberries, 50 pounds of nitrogen per acre to pasture land, and 65 pounds of nitrogen per acre to land planted in winter wheat (Washington Agricultural Statistics Service, 1994).

Precipitation

Average annual wet deposition loads of nitrogen and phosphorus were estimated from deposition rates at precipitation-collection sites within and near the study unit (fig. 2). Estimates of nitrogen loadings to river basins used the wet deposition rates calculated from 1980-90 precipitation chemistry data from three sites in the eastern part of the Puget Sound Basin and one site in the Olympic Mountains in the western part. All except the Bellevue site are operated as part of the National Trends Network (NTN) of the National Atmospheric Deposition Program (NADP) (Coordination office, National Trends Network, written commun., 1995). The Bellevue site was operated as part of the National Urban Runoff program, which was a 5-year national program beginning in 1978. Estimates of phosphorus loads used a deposition rate averaged from values determined for the Bellevue area by Ebbert and others (1985).

For nitrogen estimates in each basin, one to three NTN sites were chosen to represent the basins' precipitation chemistry and physiography. The selection of the sites also depended on how well they represented precipitation amounts during the time of year when prevailing southwesterly storm systems moving in from the Pacific Ocean bring the greatest rainfall. Only one NTN precipitation-collection site was used for deposition calculations in some basins. The Hoh River Ranger Station site was used for the Hamma Hamma, Duckabush, Dosewallips, Dungeness, Skokomish, and Elwha Rivers. The LaGrande site was used for the Puyallup, Deschutes, and Nisqually Rivers. Wet deposition to the remaining study unit river basins used all three Puget Sound Basin NTN sites.

When only one NTN site was used to represent a basin, the corresponding deposition rate was applied to the entire basin area. This included all the phosphorus wet-deposition calculations as the data available are from only the Bellevue site. For basins that used more than one NTN site, the deposition rates were averaged by an inverse-distance-squared weighting method (L.J. Puckett, U.S. Geological Survey, written commun., 1992).

Average annual dry deposition rates were estimated from wet deposition rates using a wet-to-dry ratio and a correction factor for urban effects according to Sisterson (1990). A geographic information system was used to determine distances from the NTN sites to basin centers, basin areas, and the amount of urban area in each basin.

Wastewater-Treatment Plant Discharges

Few data are available in the Washington State's Water Permit Life Cycle System (WPLCS) database to calculate nutrient loadings to Puget Sound Basin rivers from wastewater-treatment plants. Most plants do not monitor for nutrients in the effluent, or they monitor only for total ammonia. WPLCS contains some effluent flow data for miscellaneous periods of time, but for only 19 of 35 plants of interest. For nutrient concentrations, a study by Ebbert and others (1987) and class II plant inspections and total maximum daily load (TMDL) studies by Ecology provided chemical data to estimate nutrient loadings from wastewater-treatment plants.

Ebbert and others (1987) collected effluent samples from two plants in the lower Puyallup River Basin. Class II inspections, mostly involving only one of several plants within a river basin, have been made in the Skagit River Basin (Golding, 1992), the Stillaguamish River Basin (Kendra, 1987; Heffner, 1993), the Nooksack River Basin (Jeane, 1973; Chase, 1981; Ruiz, 1989), Snoqualmie River Basin (tributary to the Snohomish River) (Das, 1992), Snohomish River Basin (Stasch, 1993; Glenn, 1994), and Puyallup River Basin (Heffner, 1992). TMDL studies have been done in the Snoqualmie River Basin (Joy, 1994) and the Puyallup River Basin (Pelletier, 1993). As a result, these are the only two basins having some chemical information for most wastewater-treatment plants discharging to the tributaries and mainstem rivers in the basins.

Because little or no nutrient data were available for individual plants, this study calculated a regional value for the nitrogen and phosphorus content in wastewater-treatment plant effluent. From the 21 effluent samples collected and analyzed for nutrient concentrations during the studies by Ebbert and others (1987) and by Ecology, the median concentrations were used as the regional value. Nitrogen concentrations ranged from 2.60 to 29.7 mg/L, with a median of 16.7 mg/L, and total phosphorus concentrations ranged from 1.4 to 8.52 mg/L, with a median of 4.2 mg/L.

For those plants with flow data (table 3), daily nutrient loads in effluent were calculated by multiplying the reported average daily flow by the median regional nitrogen and phosphorus concentrations. Daily loads were averaged and multiplied by 365 for an estimated annual load. For plants with no flow data (table 4), loads could only be estimated by multiplying the flow observed at the time of plant inspection or TMDL study by the median regional nutrient concentrations.

Table 3.--*Wastewater-treatment plants with daily flow data, and the number of observations available to estimate effluent nutrient loads*

Wastewater-treatment plant	River basin	Average flow, in million gallons per day	Range, in million gallons per day	Number of observations
Burlington	Skagit	0.968	0.510-2.47	72
Granite Falls	Snohomish	0.176	0.120-0.233	14
Echo Glen	Snohomish	0.031	0.018-0.051	28
Marysville	Snohomish	3.108	1.85-4.08	28
Monroe Honor Farm	Snohomish	0.003	0.0018-0.00498	8
Monroe	Snohomish	0.9295	0.747-1.171	18
North Bend	Snohomish	0.693	0.450-1.07	9
Snohomish	Snohomish	0.835	0.500-1.30	11
Snoqualmie	Snohomish	0.278	0.149-0.521	18
Buckley	Puyallup	0.500	0.213-0.995	53
Carbonado	Puyallup	0.034	0.013-0.321	56
Enumclaw	Puyallup	1.216	0.600-2.50	216
Orting	Puyallup	0.439	0.191-0.901	51
Puyallup	Puyallup	4.426	2.822-7.306	53
Rainier School	Puyallup	0.1675	0.0-1.40	65
South Prairie	Puyallup	0.022	0.003-0.039	33
Sumner	Puyallup	1.32	0.980-1.78	44
Wilkeson	Puyallup	0.033	0.014-0.078	53
Eatonville	Nisqually	0.127	0.071-0.249	38

Table 4.--Wastewater-treatment plants with no available flow data and plants with at least one flow value observed during Washington State Department of Ecology class II inspections or total maximum daily load studies

Wastewater-treatment plant	River basin	Effluent, in million gallons per day	Data sources
Concrete	Skagit	No data	
Seattle City Light-Diablo	Skagit	No data	
Seattle City Light-Newhalem	Skagit	No data	
Sedro Wooley	Skagit	No data	
Skagit County #2	Skagit	No data	
Mount Vernon	Skagit	4.57	Golding, 1992
Arlington	Stillaguamish	0.46	Kendra, 1987
Stanwood	Stillaguamish	0.5	Heffner, 1993
Indian Ridge	Stillaguamish	No data	
Everson	Nooksack	0.065	Jeane, 1973
Ferndale	Nooksack	0.642	Ruiz, 1989
Lynden	Nooksack	1.1	Chase, 1981
Duvall	Snohomish	0.17; 0.26	Joy, 1994; Das, 1992
Monroe Reformatory	Snohomish	No data	
Sultan	Snohomish	about 0.1	Glenn, 1994
McAlder Elementary	Puyallup	0.008	Pelletier, 1993

NUTRIENT CONCENTRATIONS IN PUGET SOUND BASIN RIVERS

Boxplots of nutrient data show the variability and ranges in concentrations of nitrate, ammonia, organic nitrogen (fig. 3), phosphorus and orthophosphorus (fig. 4) at 24 water-quality stations. To compare the water quality of Puget Sound Basin rivers with other rivers at a national scale, USEPA criteria and a statistical summary of 1992 data collected as part of the NAWQA program are also shown in figures 3 and 4. Nutrient data collected in 20 NAWQA study units and summarized by Mueller and others (1995) provide national background values of 0.7 mg/L for nitrate and 0.1 mg/L for ammonia and for total phosphorus. The NAWQA values, referred to as background levels, were derived from sites grouped as Undeveloped based on the dominant upstream land use.

For nitrate, none of the samples from any of the 24 rivers exceeds the MCL of 10 mg/L. Eighty percent of the samples from Thornton Creek, Big Soos Creek, and Newaukum Creek are greater than 0.7 mg/L, the NAWQA background level, and about 60 percent of the samples from Samish River and Issaquah Creek are greater than 0.7 mg/L (fig. 3). Of the rivers in the eastern part of the study unit, only samples from the Skagit River and the outflow from Lake Washington at the Ship Canal all fall below the NAWQA background level of 0.7 mg/L. Median nitrate concentrations range from 0.2 mg/L in samples from the Elwha River to 1.7 mg/L in Newaukum Creek. On the basis of median values, nitrate is the dominant form of nitrogen in samples from 13 of the 24 rivers.

For ammonia, most sample concentrations are less than the NAWQA background level of 0.1 mg/L (fig. 3). No sample from any of the rivers shown in figure 3 contains ammonia in concentrations exceeding the maximum chronic criterion of 2.1 mg/L. On occasion, water samples from all rivers except the Hamma Hamma and Duckabush Rivers exceed the NAWQA background level of 0.1 mg/L. Median ammonia concentrations range from 0.01 mg/L in samples from Big Soos Creek and Skokomish River to 0.09 mg/L in the lower Puyallup River. The higher ammonia concentrations in the Puyallup River might be due to upstream wastewater-treatment plant discharges.

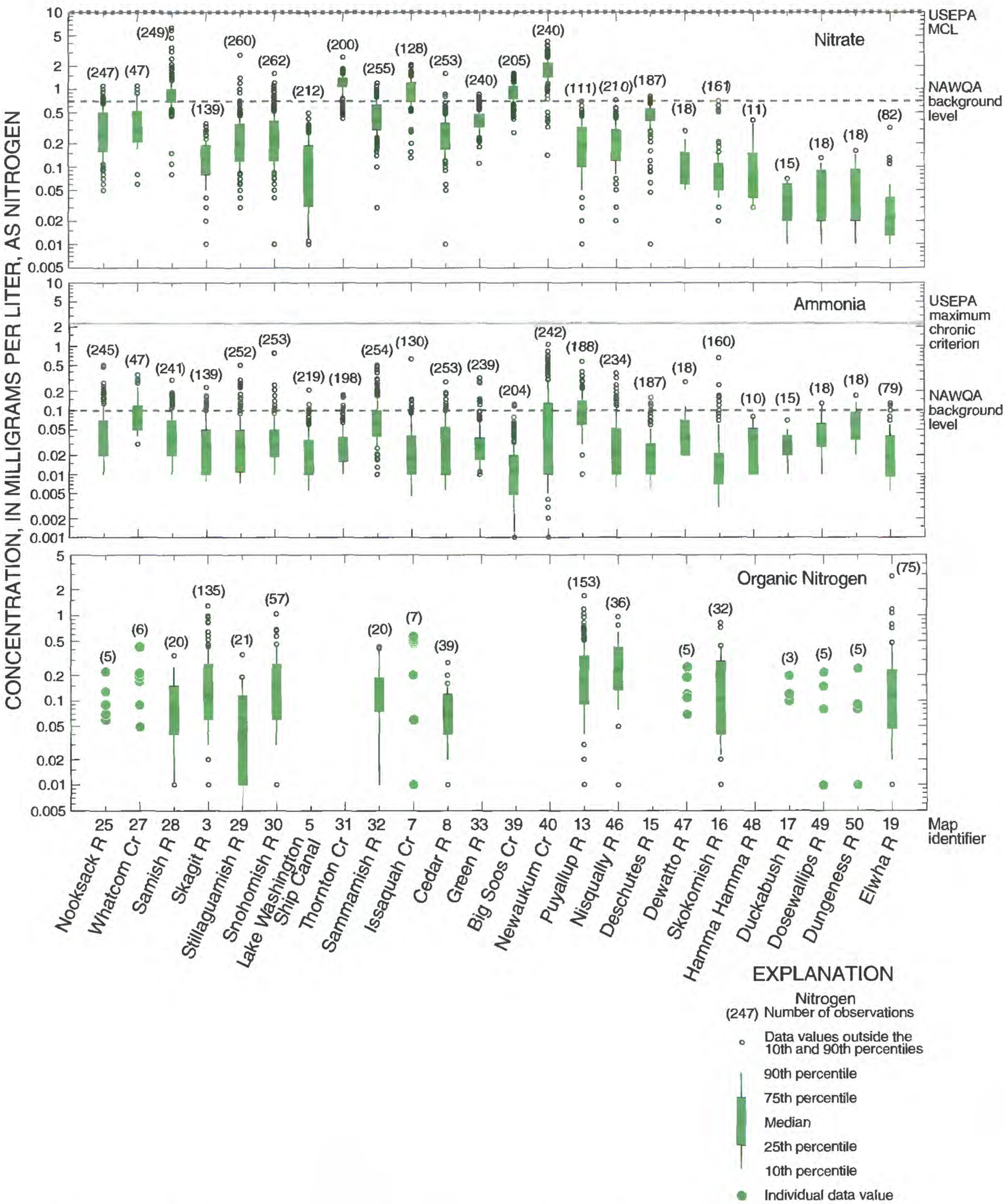


Figure 3. Concentrations of nitrate, ammonia, and organic nitrogen in samples from selected rivers in the Puget Sound Basin. USEPA MCL is maximum contaminant level for drinking water; USEPA maximum chronic criterion is for the protection of aquatic life; and the NAWQA background level is the 90th percentile value for undeveloped sites in 20 NAWQA study units.

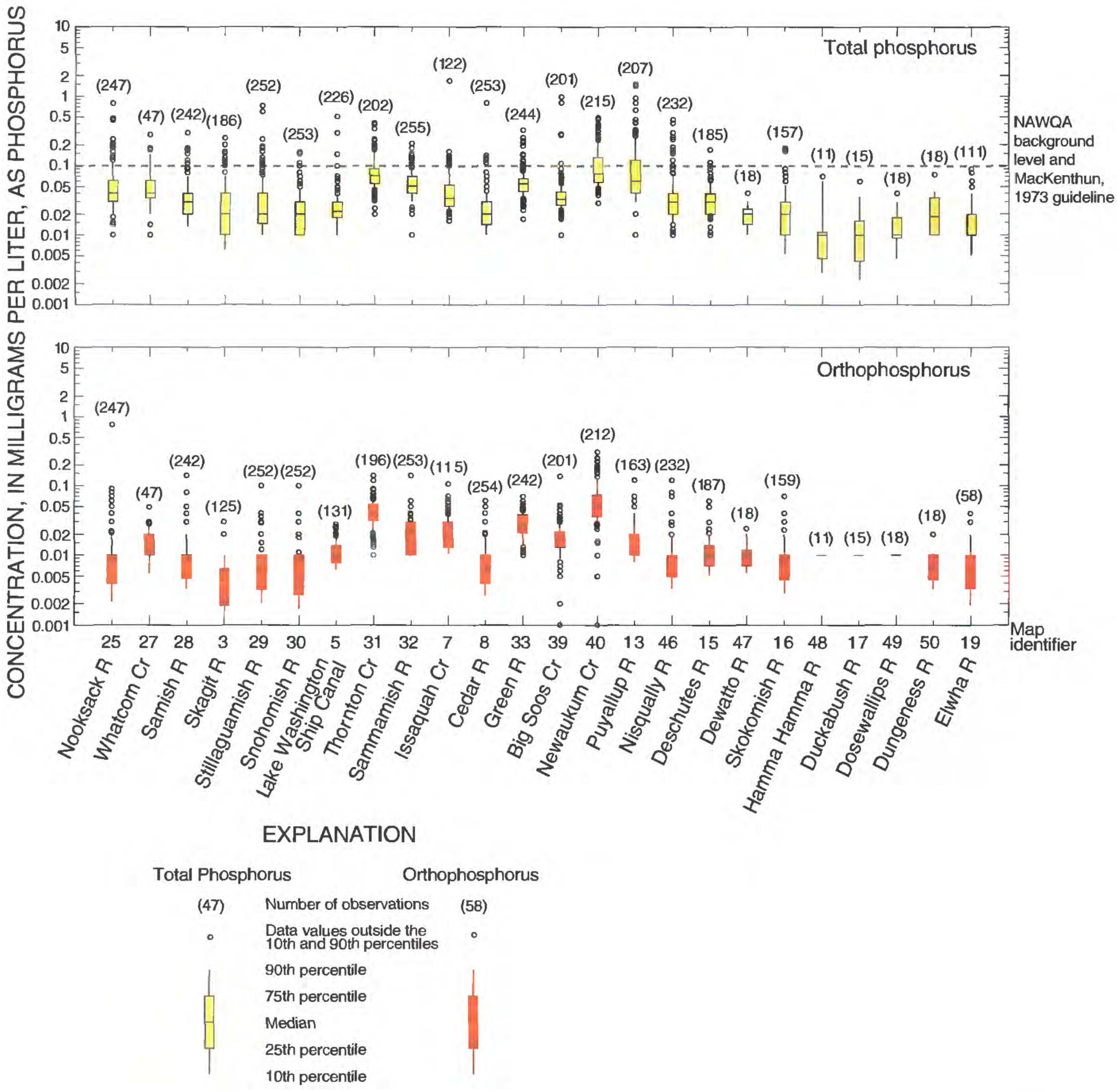


Figure 4. Concentrations of total phosphorus and orthophosphorus in samples from selected rivers in the Puget Sound Basin. NAWQA background level is the 90th percentile for undeveloped sites in 20 NAWQA study units, and MacKenthun, 1973 guideline is to protect freshwaters from eutrophication.

For organic nitrogen, most of the concentrations are between about 0.05 to 0.3 mg/L (fig. 3). The highest concentration, 3.0 mg/L, is a sample from the Elwha River. Median concentrations, however, are as low as 0.07 mg/L in the Stillaguamish and Cedar Rivers and as high as 0.5 mg/L in Issaquah Creek. In rivers draining the Olympic Mountains and in the Skagit, Puyallup, and Nisqually Rivers, the median organic nitrogen concentration is nearly equal to or greater than the median nitrate concentration. This implies that organic nitrogen is an important part of the total nitrogen transported by the study unit's rivers to Puget Sound and its adjacent waters. In fact, the median concentrations suggest that the organic-nitrogen fraction of the total nitrogen load could, in some cases, be as much as or greater than the inorganic fraction.

For total phosphorus, concentrations in samples from most of the rivers rarely exceed the USEPA freshwater guideline and the NAWQA background level of 0.1 mg/L (fig. 4). Exceptions include Newaukum Creek and the Puyallup River, in which more than 15 percent of the samples are above 0.1 mg/L. In several of the Olympic Mountain rivers and in the Dewatto River, Skagit River, and Lake Washington Ship Canal, no sample concentration exceeds 0.1 mg/L.

Summary values from other studies or regulatory values were not available to compare orthophosphorus data collected at Puget Sound Basin sites. Most of the orthophosphorus-concentration data for Puget Sound Basin streams and rivers is below 0.02 mg/L (fig. 4). Median values for samples from Thornton Creek, Green River, and Newaukum Creek, however, are higher than 0.02, ranging from about 0.03 to 0.05 mg/L.

NUTRIENT TRANSPORT IN PUGET SOUND BASIN RIVERS

The following sections discuss nutrient loads and yields transported by major rivers to Puget Sound and its adjacent waters, and sources of nutrients to the watersheds. The rivers for which nutrient loads were estimated (see fig. 5) have a combined drainage area of 10,247 square miles, or about 75 percent of the area that drains to Puget Sound and adjacent waters. The remaining 25 percent of the Puget Sound Basin is drained by dozens of small streams that discharge directly from coastal areas to the marine waters of the Puget Sound Basin. To compare the amounts of nutrients transported by rivers with greatly different drainage areas, the nutrient loads were normalized by the size of their respective basin areas. The result is average annual nutrient yields expressed in tons per square mile per year (tons/mi^2)/yr of drainage area.

In this retrospective analysis, Estimator was used for load calculations at 22 water-quality stations. Table 5 lists the number of observations in each station's data set, the number of remarked values, and the coefficient of determination (R^2) for the nitrogen and phosphorus concentration models. For the nitrate, ammonia, inorganic nitrogen (calculated with the sums of nitrate and ammonia concentrations in each data set), and total phosphorus models developed for each site, the R^2 values ranged from 5 to 78 percent. For the eight organic nitrogen models that could be developed, R^2 values ranged from 2 to 46 percent. Table 6 lists the estimated loads of inorganic nitrogen, organic nitrogen, and total phosphorus for all water-quality stations, including the 14 stations for which loads were estimated by the product method. For those loads calculated with Estimator, the 95-percent confidence limits are provided in table 6.

Stream Nutrient Loads and Yields

The rivers included in this retrospective analysis carry an average nutrient load of 11,000 tons of inorganic nitrogen and 2,100 tons of total phosphorus to Puget Sound and adjacent waters each year. Approximately 9,900 tons of organic nitrogen are transported to the marine waters of the study unit by eight of the largest rivers of Puget Sound Basin--the Skagit, Stillaguamish, Snohomish, Green, Puyallup, Nisqually, Skokomish, and Elwha Rivers. As expected, the greatest nutrient loads are carried by the rivers with the largest watersheds and streamflows (fig. 5). The Skagit and Snohomish Rivers, which together constitute about 47 percent of the drainage area included in this analysis, carry about 49 percent of the inorganic nitrogen, 66 percent of the organic nitrogen, and 45 percent of the total phosphorus load.

In the Lake Washington Basin, the Sammamish River, Cedar River, and Thornton Creek transport each year about 380 tons (tons/yr) of inorganic nitrogen and 32 tons/yr of total phosphorus to Lake Washington. Through the Ship Canal, 250 tons/yr of inorganic nitrogen and 29 tons/yr of total phosphorus are transported out of the basin. Several other streams, for which loads were not calculated, empty into Lake Washington. The additional loads transported by these streams would likely increase the estimates of nitrogen and phosphorus transported into the lake, but the extent of that increase is unknown.

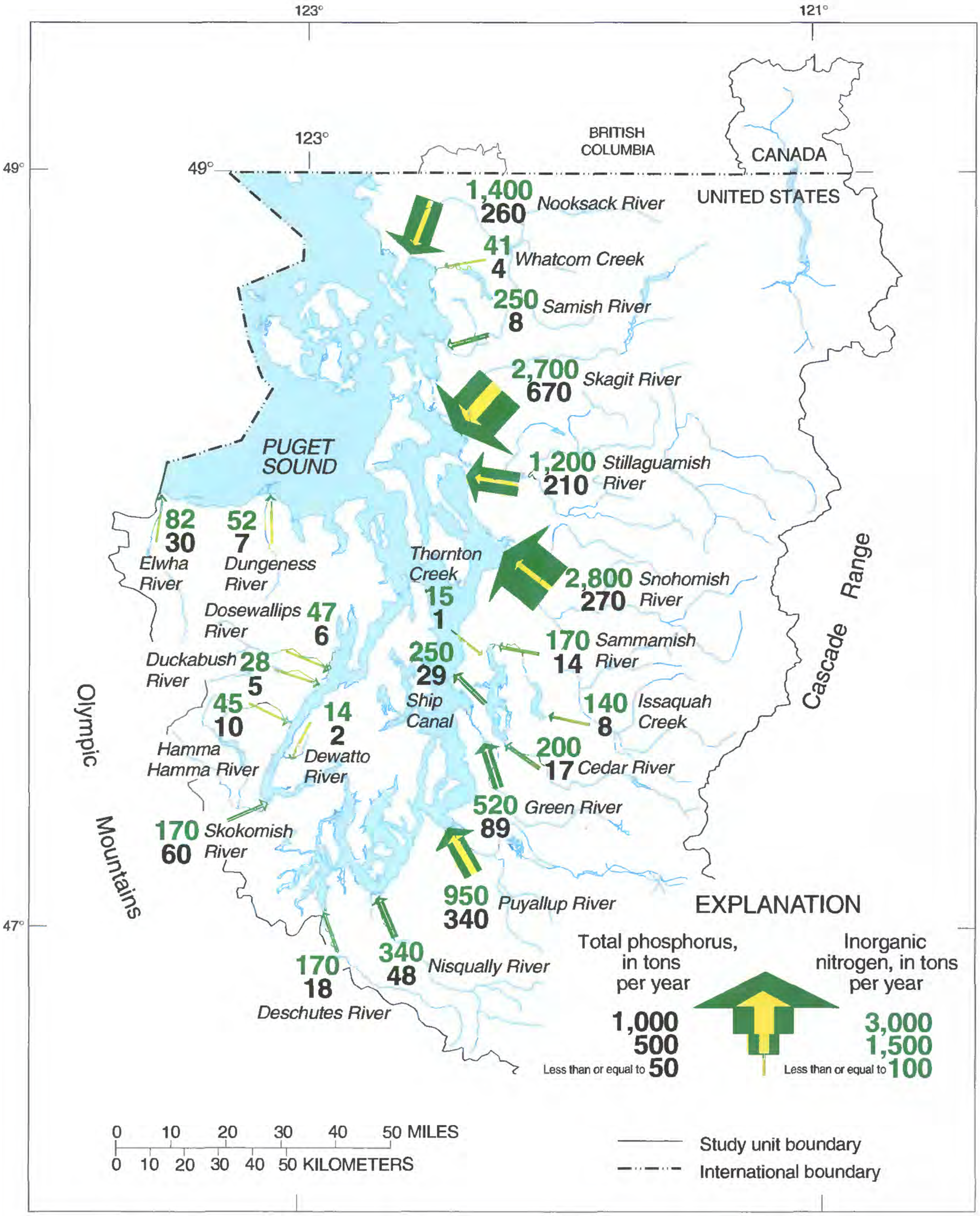


Figure 5. Annual nutrient loads transported by Puget Sound Basin rivers and streams. Total phosphorous loads are represented by yellow arrows: inorganic nitrogen loads by green arrows.

Table 5.--*Selected regression statistics for the streamflow-concentration models of the Estimator computer program*
[N, number of observations in the data set; N_c, number of remarked observations in the data set; R^2, coefficient of determination for the concentration model; inorganic nitrogen is the sum of nitrite, nitrate, and ammonia concentrations; organic nitrogen is Kjeldahl nitrogen concentrations minus ammonia concentrations; --, no data]

	Nitrogen												Total phosphorus		
	Nitrate			Ammonia			Inorganic			Organic					
Basin name	N	N_c	R^2, in per-cent	N	N_c	R^2, in per-cent	N	N_c	R^2, in per-cent	N	N_c	R^2, in per-cent	N	N_c	R^2, in per-cent
Nooksack River near Brennan	247	0	77	245	18	19	247	0	78	--	--	--	247	3	22
Nooksack River at North Cedarville	120	0	77	217	32	30	120	0	74	--	--	--	216	8	17
Skagit River	195	28	48	168	23	11	168	27	37	168	39	46	186	21	13
Stillaguamish River	252	1	66	252	30	21	252	1	66	--	--	--	252	15	24
Snohomish River	262	5	62	253	25	22	253	3	67	59	6	12	253	13	21
Lake Washington Ship Canal	142	6	76	145	32	34	131	4	68	--	--	--	161	9	9
Sammamish River	255	0	66	254	3	35	254	0	64	--	--	--	255	0	12
Issaquah Creek	207	0	59	192	3	35	189	0	66	--	--	--	202	0	45
Cedar River	253	0	52	252	46	42	252	0	59	40	3	22	252	14	29
Green River at Fort Dent	121	0	32	119	6	13	125	0	31	--	--	--	122	0	33
Green River at Renton Junction	615	0	20	615	3	24	612	0	22	--	--	--	501	1	37
Green River at 212th Street	197	0	42	197	5	29	195	0	38	39	2	19	198	1	30
Green River above Big Soos Creek	227	1	36	225	18	16	225	0	39	--	--	--	224	0	34
Green River near Newaukum Creek	276	1	26	276	39	10	275	1	24	--	--	--	249	1	35
Green River at Kanaskat	209	3	51	209	46	38	209	1	53	--	--	--	208	24	27
Big Soos Creek	201	0	32	200	27	12	198	0	36	--	--	--	197	1	37
Newaukum Creek	236	0	51	238	15	58	234	0	54	--	--	--	211	0	67
Puyallup River	209	11	48	208	4	11	205	5	35	177	7	33	207	2	31
Nisqually River	185	0	77	186	26	27	186	0	72	35	0	2	184	4	26
Deschutes	36	0	37	36	11	23	36	0	35	--	--	--	36	2	68
Skokomish River	160	0	44	160	40	31	160	0	43	32	2	2	157	23	28
Elwha River	111	51	22	103	30	5	103	47	8	106	15	29	140	16	26

Table 6.--*Nutrient loads in Puget Sound Basin rivers and the 95-percent confidence limits for loads calculated using the streamflow-concentration models of the Estimator computer program*
[CL, confidence limits; [a], loads calculated with product method; inorganic nitrogen is the sum of nitrite, nitrate, and ammonia concentrations; organic nitrogen is Kjeldahl nitrogen concentrations minus ammonia concentrations; --, no data]

River name	Average inorganic load, in tons per year	95-percent CL about the average annual inorganic load, in tons per year	Average organic load, in tons per year	95-percent CL about the average annual organic load, in tons per year	Average total phos-phorus load, in tons per year	95-percent CL about the average annual load, in tons per year
Nooksack River at Brennan	1,400	1,200 - 1,700	--	--	260	140 - 370
Nooksack River near Lynden	[a]1,400	--	--	--	[a]260	--
Nooksack River at North Cedarville	750	580 - 910	--	--	160	77 - 250
Whatcom Creek at Bellingham	[a]41	--	--	--	[a]4	--
Samish River near Burlington	[a]250	--	[a]27	--	[a]8	--
Skagit River at Mount Vernon	2,700	1,900 - 3,500	4,800	2,300 - 7,200	670	190 - 1,100
Stillaguamish River at Silvana	1,200	990 - 1,500	[a]1,100	--	210	86 - 340
Snohomish River	2,800	2,300 - 3,400	1,700	480 - 2,900	270	170 - 370
Lake Washington Ship Canal	250	170 - 330	--	--	29	19 - 39
Thornton Creek	[a]15	--	--	--	[a]1	--
Sammamish River	170	150 - 190	[a]74	--	14	11 - 17
Issaquah Creek	140	120 - 160	--	--	8	5 - 12
Cedar River	200	160 - 230	41	18 - 63	17	11 - 23
Green River at Fort Dent	520	300 - 750	--	--	89	34 - 140
Green River at Renton Junction	620	500 - 730	--	--	97	70 - 120
Green River at 212th Street	640	530 - 760	250	84 - 420	72	48 - 95
Green River above Big Soos Creek	420	320 - 530	--	--	53	29 - 77
Green River near Newaukum Creek	240	180 - 300	--	--	36	14 - 57
Green River at Kanaskat	130	97 - 170	--	--	26	13 - 39
Big Soos Creek	110	97 - 120	--	--	6	4 - 8
Newaukum Creek	120	99 - 140	--	--	12	8 - 17
Puyallup River	950	610 - 1,300	1,400	580 - 2,300	340	140 - 540
Nisqually River	340	280 - 390	290	100 - 470	48	26 - 70
Deschutes River	170	72 - 270	--	--	18	8 - 28
Skokomish River	170	110 - 230	180	0 - 400	60	12 - 110
Dewatto Creek	[a]14	--	--	--	[a]2	--
Hamma Hamma	[a]64	--	--	--	[a]13	--
Duckabush	[a]28	--	--	--	[a]5	--
Dosewallips	[a]47	--	--	--	[a]6	--
Dungeness	[a]52	--	--	--	[a]7	--
Elwha River	82	11 - 154	220	45 - 390	30	7 - 52

In this report, yields are the amounts of inorganic nitrogen and total phosphorus transported each year from one square mile of river basin. The smallest nutrient yields are from Olympic Mountain river basins, which are among the least developed and populated areas of the Puget Sound Basin. These river basins generally yield less than 1 ton per square mile per year (ton/mi^2)/yr of inorganic nitrogen and 0.1 (ton/mi^2)/yr of phosphorus (fig. 6). Major river basins located in the south and the east side of the study unit with similarly low yields include the Nisqually River, the Deschutes River, and, most notably, the Skagit River Basins. Because of the volume of streamflow, the Skagit River transports the second highest amount of inorganic nitrogen (2,700 tons/yr) and the highest amount of total phosphorus (670 tons/yr). However, yields from the basin are only 0.9 (ton/mi^2)/yr of inorganic nitrogen and 0.2 (ton/mi^2)/yr of total phosphorus.

The largest yields are from river basins draining to the east side of the Puget Sound Basin, where about 2.7 million of the study unit's 3.7 million people reside, and from the northeast part of the study unit, where agriculture is an important land use in the watersheds. These river basins generally yield more than 1 (ton/mi^2)/yr of inorganic nitrogen and 0.1 (ton/mi^2)/yr of phosphorus. The Samish, Nooksack, and Stillaguamish River Basins, all located in the northeastern agricultural areas of the study unit, and the Issaquah Creek Basin, located in an urbanizing area of King County, each year yield 2 (tons/mi^2)/yr or more of inorganic nitrogen. The Snohomish, Sammamish, Cedar, Green, and Puyallup River Basins each year yield 1.0 (ton/mi^2)/yr or more of inorganic nitrogen. The Puyallup River and Stillaguamish River Basins yield the largest amount of total phosphorus, 0.4 (ton/mi^2)/yr, followed by the Nooksack and Skokomish Basins, which yield 0.3 (ton/mi^2)/yr total phosphorus.

Because most settlement and development are concentrated in the Puget Sound Basin lowlands, most of the non-point source loadings happen within the lower 10 to 20 miles of the rivers. Consequently, most of the nutrient yield is from the lower reaches of the basins, as illustrated by the inorganic nitrogen yields from the Nooksack and Green River Basins (fig. 7). In the Nooksack River, much of the inorganic nitrogen yield is from the lower basin near Lynden where the river passes through agricultural area. Similarly, inorganic nitrogen yields from the lower Green River Basin increase as the river passes through the urbanized and populous Green River Valley below the tributaries, Newaukum Creek and Big Soos Creek. Tributary basins of the Green River, located in urbanizing (such as Big Soos Creek) or agricultural (such as Newaukum Creek) areas, yield from 1.4 to 4.3 (tons/mi^2)/yr of inorganic nitrogen to the lower Green River.

Major Sources and River Basin Yields

In many of the study unit river basins (8 out of 16), much of the loading is from animal manures, contributing up to 5 (tons/mi^2)/yr of nitrogen and composing from 54 to 71 percent of the nitrogen loading to the basins. Agricultural fertilizer accounts for about 9 to 33 percent of the annual nitrogen loadings to these eight basins. Precipitation contributes from 0.43 to 1.8 (tons/mi^2)/yr of nitrogen to watersheds in the eastern part of the Puget Sound Basin (from the Nooksack River south to the Deschutes River) and from 0.17 to 0.39 (ton/mi^2)/yr of nitrogen to watersheds in the Olympic Mountains in the western part of the Puget Sound Basin (table 7).

Nutrient yields transported by Puget Sound Basin rivers tend to correspond to rates of nutrient source-loadings. For example, nitrogen and phosphorus loading rates that could be estimated for this study for the major nutrient contributors, animal manures, agricultural fertilizer, and precipitation, are considerably lower to the less developed watersheds in the Olympic Mountains than to watersheds in the eastern part of the Puget Sound Basin. These western river basins (excluding the more agricultural Dungeness River Basin) receive only 0.2 to 0.6 (ton/mi^2)/yr of nitrogen and 0.08 to 0.19 (ton/mi^2)/yr of phosphorus (table 7) and have correspondingly low nutrient yields (see fig. 6). Nitrogen and phosphorus loading rates from the major sources are much higher to watersheds in the more developed and populous eastern Puget Sound Basin than to watersheds draining the Olympic Mountains (table 7). The eastern watersheds all receive 2.0 or more (tons/mi^2)/yr of nitrogen and more than 0.25 (ton/mi^2)/yr of phosphorus from the major sources.

In the northeastern part of the Puget Sound Basin, nutrient source-loading rates to the Samish and Nooksack River Basins are the highest of the loading rates estimated for watersheds in this study. Animal manures, agricultural fertilizer, and precipitation contribute 10 (tons/mi^2)/yr of nitrogen to the Samish River Basin and 9 (tons/mi^2)/yr to the Nooksack River Basin. Together, animal manures and fertilizer make up 90 percent of the annual nitrogen loadings to the Samish River Basin and 91 percent to the Nooksack River Basin. Animal manures, agricultural fertilizer, and precipitation also contribute the highest phosphorus loadings to the Samish River Basin, 1.5 (tons/mi^2)/yr, and to the Nooksack River Basin, 1.3 (tons/mi^2)/yr (table 7). In response, the nutrient yields from these two basins are among the highest yields calculated in this study.

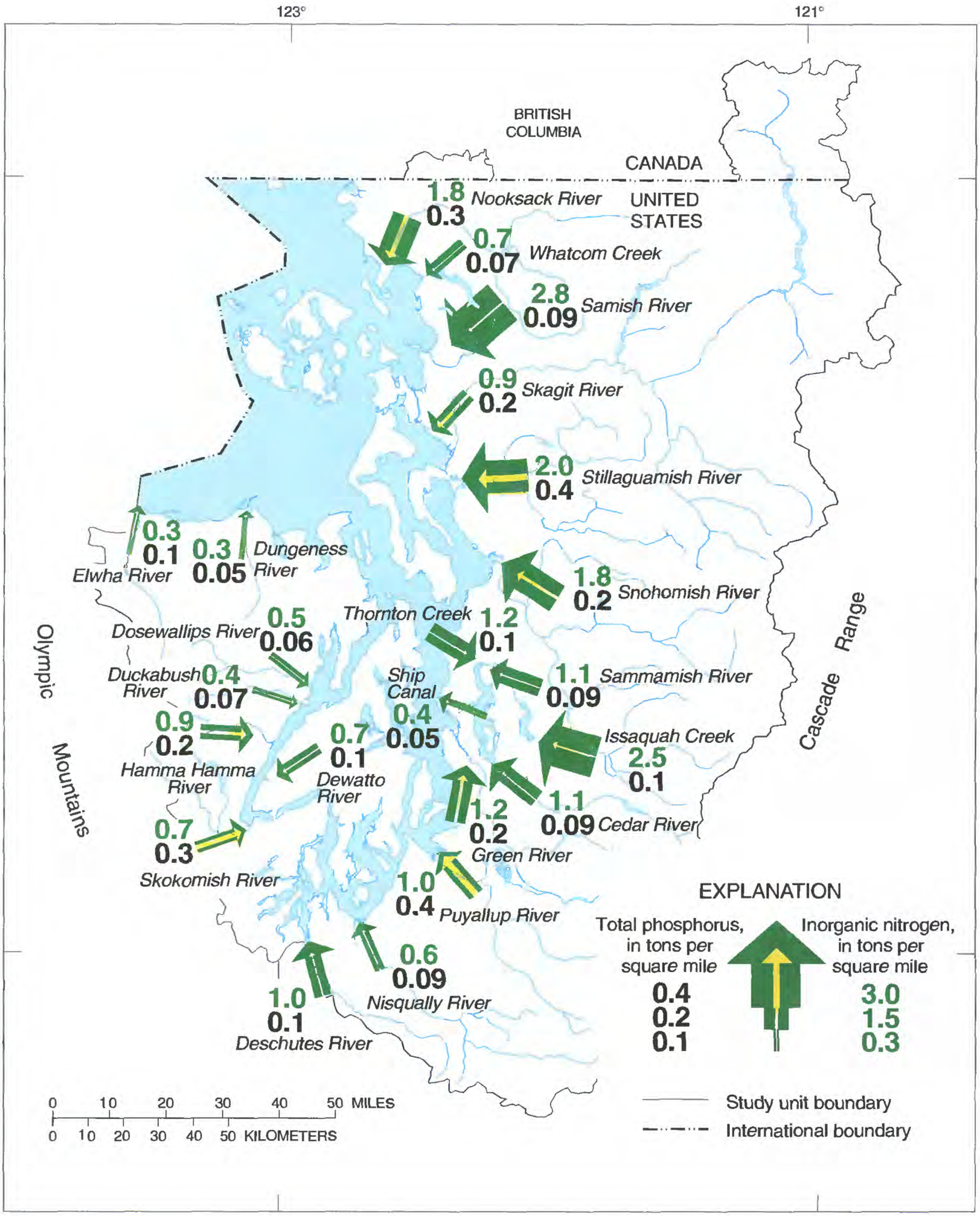


Figure 6. Annual nutrient yields from Puget Sound Basin watersheds. Total phosphorus yields are represented by yellow arrows; inorganic nitrogen yields by green arrows.

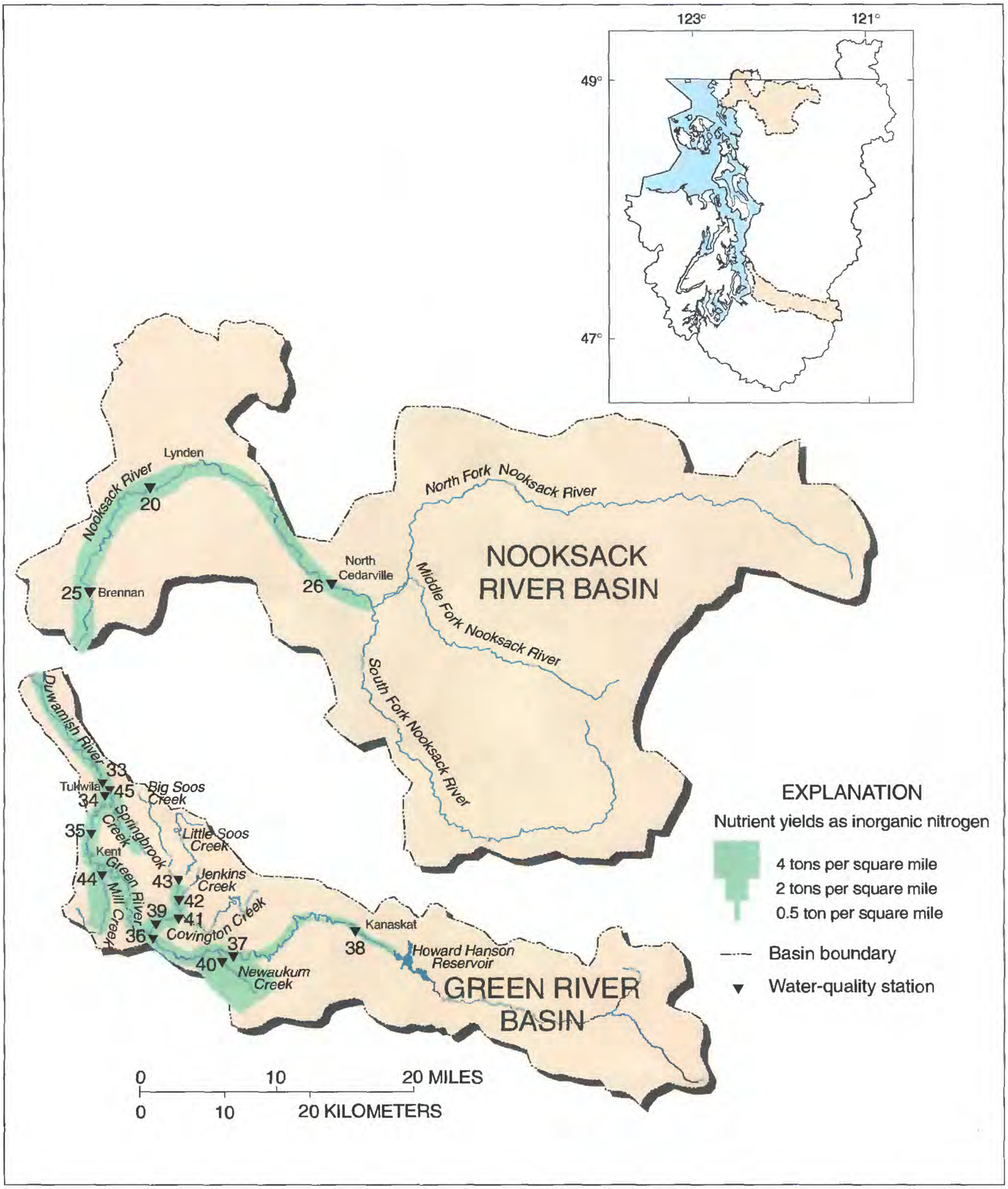


Figure 7. Annual inorganic nitrogen yields from the lower Nooksack River Basin, Whatcom County, Washington, and the Green River Basin and selected tributary basins, King County, Washington. Numbers corresponding to stations are related to station names in tables 1 and 2.

Table 7.--*Sources of nutrients to selected Puget Sound Basin watersheds and point-source loadings to rivers from wastewater-treatment plants*
[Values are in tons per square mile per year; differences in totals are due to rounding; --, no wastewater-treatment plant or no data]

Basin	Animal manures	Agricultural fertilizers	Precipitation	Total	Point-source loadings from wastewater-treatment plants
		TOTAL NITROGEN LOADING TO BASIN			
Nooksack	5.3	3.0	0.77	9.1	0.06
Samish	3.4	5.6	0.96	10.0	--
Skagit	0.48	0.79	0.70	2.0	0.05
Stillaguamish	2.2	0.87	0.86	3.9	0.04
Snohomish	2.5	0.69	1.2	4.4	0.10
Lake Washington	0.43	0.15	1.8	2.4	--
Green	2.5	0.88	1.1	4.5	--
Puyallup	0.98	0.35	0.44	1.8	0.22
Nisqually	2.5	0.79	0.48	3.8	0.006
Deschutes	1.5	0.18	0.43	2.1	--
Skokomish	0.11	0.04	0.27	0.42	--
Hamma Hamma	0	0	0.37	0.37	--
Duckabush	0	0	0.17	0.17	--
Dosewallips	0	0	0.39	0.39	--
Dungeness	1.4	0.67	0.39	2.5	--
Elwha	0.18	0.09	0.38	0.64	--
		PHOSPHORUS LOADING TO BASIN			
Nooksack	0.90	0.33	0.09	1.3	0.02
Samish	0.65	0.73	0.11	1.5	--
Skagit	0.09	0.10	0.08	0.27	0.01
Stillaguamish	0.45	0.11	0.09	0.65	0.01
Snohomish	0.51	0.09	0.10	0.70	0.03
Lake Washington	0.08	0.02	0.15	0.25	--
Green	0.45	0.12	0.12	0.69	--
Puyallup	0.22	0.05	0.09	0.36	0.05
Nisqually	0.57	0.10	0.10	0.77	0.002
Deschutes	0.38	0.02	0.09	0.49	--
Skokomish	0.03	0.08	0.08	0.19	--
Hamma Hamma	0	0	0.08	0.08	--
Duckabush	0	0	0.09	0.09	--
Dosewallips	0	0	0.09	0.09	--
Dungeness	0.33	0.09	0.09	0.51	--
Elwha	0.04	0.01	0.08	0.13	--

Although total source loadings to the Samish and Nooksack River Basins are nearly the same, the phosphorus yield, 0.09 (ton/mi^2)/yr, from the Samish River Basin is considerably less than the yield, 0.3 (ton/mi^2)/yr, from the Nooksack River Basin. Conversely, the nitrogen yield of 2.8 (tons/mi^2)/yr from the Samish River Basin is larger than the nitrogen yield of 1.8 (tons/mi^2)/yr from the Nooksack River Basin. The differences in yields might be explained by the differences in the principal source loadings. Agricultural fertilizer is the greatest source of nitrogen, 6 (tons/mi^2)/yr, to the Samish River Basin, followed by 3 (tons/mi^2)/yr nitrogen from animal manures. Fertilizer, which is rich in nitrogen but relatively low in phosphorus as indicated by a phosphorus-nitrogen ratio of about 0.1, is the principal nutrient source to the Samish River Basin and would relate to its low phosphorus yield and high nitrogen yield relative to the Nooksack River Basin. Animal manures account for most of the nitrogen loading, 5 (tons/mi^2)/yr, to the Nooksack River Basin, followed by fertilizers, which contribute 3 (tons/mi^2)/yr. Animal manures, with a phosphorus-nitrogen ratio of about 0.2, are richer than fertilizers in phosphorus and would help explain the high phosphorus yield and low nitrogen yield (relative to the Samish River Basin) from the Nooksack River Basin.

The next highest nitrogen loading rate, 4.5 (tons/mi^2)/yr, is to the Green River Basin and is only about half the nitrogen loading rates to the Samish and Nooksack River Basins. The Green and the Nisqually River Basins receive the next highest phosphorus loading rates 0.7 to 0.8 (ton/mi^2)/yr, respectively. Manures and fertilizers together account for 83 to 87 percent of the phosphorus loading rates to these two basins. But, for any of the river basins in the counties of King, Pierce, Snohomish, and Thurston having extensive urban-suburban development, such as the Green River Basin, the nitrogen and phosphorus loading rates shown in table 7 might be somewhat underestimated because of unknown quantities of commercial and homeowner-applied fertilizers and contributions from septic systems.

In the highly urbanized (42 percent urban land use) Lake Washington Basin, agricultural activities contribute less than 25 percent of the 2.4 (tons/mi^2)/yr of nitrogen loadings and only 40 percent of the 0.25 (ton/mi^2)/yr of phosphorus loadings to the basin. For this basin, the missing elements of nutrient sources that could not be estimated, such as on-site septic systems and, particularly, the amounts of commercial and homeowner-applied fertilizers, might be important. The total nutrient loading rates per year would likely increase to some extent, which in turn, would further reduce the proportion of nutrient loadings from agriculture and precipitation. For example, in a hypothetical watershed of approximately 600 mi^2 and 40-percent urban area, if one eighth of the urban area (30 mi^2) received fertilizer applications of up to 4 pounds per 1,000 square feet per year, 2.8 (tons/mi^2)/yr of nitrogen would be added. The total annual nitrogen loading rate to a watershed similar in size to Lake Washington would nearly double with the additional contribution from urban fertilizer applications.

East-side basins receiving the lowest source loadings include the Skagit River and Puyallup River (table 7). Nitrogen:P loadings to the Skagit River are about 2.0 (tons/mi^2)/yr and 0.27 (ton/mi^2)/yr, respectively. Source loadings to the Puyallup River are about 1.8 (tons/mi^2)/yr of nitrogen and 0.36 (ton/mi^2)/yr of phosphorus. The low nutrient yields for the Skagit River Basin discussed earlier might be due in part to these relatively low nutrient source loading rates.

Of the other nutrient sources (precipitation and wastewater-treatment plant discharges) for which estimates of loading rates could be made, precipitation contributes an important share of nitrogen and phosphorus to watersheds located in the densely populated lowlands of King and Snohomish Counties and downwind of prevailing southwesterly storm systems. The Green, Lake Washington, and Snohomish River Basins receive from 1 to 2 (tons/mi^2)/yr of nitrogen and 0.1 to 0.2 (ton/mi^2)/yr of phosphorus from precipitation.

From wastewater-treatment plants, point discharges contribute from less than 0.01 (ton/mi^2)/yr of nitrogen into the Nisqually River to 0.2 (ton/mi^2)/yr into the Puyallup River. A comparison of point-source loadings in table 7 with nutrient yields in figure 6, shows that point-source loadings amount to from less than 1 percent of the load transported by the Nisqually River up to 22 percent transported by the Puyallup River. Point-source loading rates from wastewater-treatment plants for phosphorus range from less than 0.01 (ton/mi^2)/yr into the Nisqually River to 0.05 (ton/mi^2)/yr into the Puyallup River. For phosphorus, the point-source discharges amount to 12 percent of the load transported by the Puyallup River and 15 percent of load transported by the Snohomish River. Less than 7 percent of the inorganic nitrogen and total phosphorus transported by the Nooksack, Skagit, Stillaguamish, and Nisqually Rivers is from wastewater-treatment plant discharges.

SUMMARY AND CONCLUSIONS

The Puget Sound Basin study team compiled historical nutrient data for evaluating nutrient transport in the major rivers of the Puget Sound Basin study unit of NAWQA (National Water-Quality Assessment program). This retrospective analysis represents a first-time effort to quantify, to the extent possible, nitrogen and phosphorus transport from the major rivers to Puget Sound and its adjacent waters. As the receiving waters for natural and human sources of nutrients, the quantities of nitrogen and phosphorus transported by surface waters have implications for the quality of water in rivers, streams, lakes, Puget Sound, and its adjacent waters.

Long-term water-quality monitoring programs by the Washington State Department of Ecology (Ecology), the King County Department of Metropolitan Services (METRO), and the U.S. Geological Survey (USGS) provided water-quality data for this effort. Streamflow data collected by USGS, METRO, and the Seattle District Corps of Engineers were used in the nutrient-load calculations. Nutrient data, along with daily streamflows, were entered into Estimator, a computer program to calculate nutrient loads. With Estimator, nitrate, ammonia, inorganic nitrogen (nitrate plus ammonia), and total phosphorus loads were calculated at 22 water-quality stations. Also with Estimator, organic nitrogen (Kjeldahl nitrogen minus ammonia) loads were calculated at eight stations. For sites where Estimator could not be used because water-quality data were too few or a data set of daily streamflows was not available, nutrient loads were estimated as a simple product of concentration multiplied by streamflow and extrapolated to an annual load.

Nutrient concentration data from samples collected at 24 water-quality stations were compared with USEPA criteria and NAWQA background levels derived from a statistical summary of data collected in 20 other study units at sites in the undeveloped land-use category. Of the river basins in the eastern part of the study unit, only samples from the Skagit River and the outflow from Lake Washington are all below the NAWQA background level of 0.7 mg/L. Eighty percent of samples from three relatively small streams located in the populous Lake Washington and Green River Basins, Thornton Creek, Big Soos Creek, and Newaukum Creek, have nitrate concentrations greater than the NAWQA background level. For all rivers and streams in the study unit, ammonia concentrations are mostly less than the NAWQA background level of 0.1 mg/L, and no samples have ammonia in concentrations exceeding the USEPA maximum chronic criterion of 2.1 mg/L. For total phosphorus, sample concentrations occasionally exceed MacKenthun's (1973) freshwater guidelines and the NAWQA background level of 0.1 mg/L. In Newaukum Creek and the Puyallup River, more than 15 percent of the samples have total phosphorus concentrations above 0.1 mg/L.

The rivers included in this retrospective analysis carry a total nutrient load of about 11,000 tons/yr of inorganic nitrogen and 2,100 tons/yr of total phosphorus to Puget Sound and adjacent waters. Approximately 9,900 tons/yr of organic nitrogen are transported by eight of the largest rivers--the Skagit, Stillaguamish, Snohomish, Green, Nisqually, Skokomish, and Elwha Rivers. The Skagit and Snohomish Rivers carry the two largest nutrient loads, transporting 49 percent of the inorganic nitrogen, 66 percent of the organic nitrogen, and 45 percent of the total phosphorus load each year to Puget Sound and adjacent waters. As expected, the greatest nutrient loads are carried by the rivers with the largest watersheds and streamflow. With more than 3,000 mi^2 in the Skagit River Basin and 1,700 mi^2 in the Snohomish River Basin, the drainage area of these two basins makes up about 47 percent of the watershed area included in this analysis.

Nutrient loads were normalized by watershed area and expressed as a nutrient yield in $(tons/mi^2)/yr$ in order to compare the amounts of nutrients transported by watersheds of greatly different size. The smallest yields are from the Olympic Mountain watersheds, which are among the least developed and least populous watersheds of the Puget Sound Basin. These river basins generally yield less than 1 $(ton/mi^2)/yr$ of inorganic nitrogen and 0.1 $(ton/mi^2)/yr$ of phosphorus. The largest yields are from basins draining the east side of the study unit, where population is most dense and agriculture is an important land use. These river basins generally yield more than 1 $(ton/mi^2)/yr$ of inorganic nitrogen and 0.1 $(ton/mi^2)/yr$ of phosphorus. An exception to the east-side basins is the Skagit River Basin. Even though the Skagit River transports the second highest amount of inorganic nitrogen (2,700 tons/yr) and the highest amount of total phosphorus (670 tons/yr), the basin yields only 0.9 $(ton/mi^2)/yr$ of inorganic nitrogen and 0.2 $(ton/mi^2)/yr$ of total phosphorus. The low nutrient yields from the Skagit River Basin might be due in part to relatively low (for east-side basins) nutrient-source loading rates of 2.0 $(tons/mi^2)/yr$ of nitrogen and 0.27 $(ton/mi^2)/yr$ of phosphorus to the basin.

Estimates of nutrient loading rates to the basins and of point-source loads from wastewater-treatment plants can explain, in part, nutrient loads and yields transported by Puget Sound Basin rivers. Nitrogen and phosphorus annual loading rates to west-side watersheds from animal manures, agricultural fertilizers, and precipitation are typically less than 1 (ton/mi^2)/yr, whereas the rates are generally greater than about 2 (tons/mi^2)/yr to the populous and agricultural watersheds in eastern and southern Puget Sound Basin. These higher loading rates to southern and east-side watersheds correspond to considerably higher stream loads and river basin yields than for river basins in the much less developed western Puget Sound Basin.

In about half the river basins in this analysis, much of the nitrogen loading (from 54 to 71 percent) is from animal manures; agricultural fertilizers account for 9 to 33 percent of annual nitrogen loadings. Animal manures, agricultural fertilizers, and precipitation contribute 10 (tons/mi^2)/yr of nitrogen to the Samish River Basin and 9 (tons/mi^2)/yr to the Nooksack River Basin. In response, nitrogen and phosphorus yields from these two basins (up to 2.8 (tons/mi^2)/yr nitrogen and 0.3 (ton/mi^2)/yr phosphorus) are among the highest rates for river basins in the study unit. Although the nitrogen yields are high for both river basins, the phosphorus yield from the Samish River Basin is much lower than the yield from the Nooksack River Basin possibly because the principal source loadings are different. Fertilizer, rich in nitrogen, but relatively low in phosphorus (the phosphorus-nitrogen ratio is about 0.1), is the principal nutrient source to the Samish River Basin, whereas animal manures, with a phosphorus-nitrogen ratio of about 0.2, account for most of the nutrient loading to the Nooksack River Basin.

Precipitation and domestic-applied fertilizers are source loadings of interest for river basins in the urban and suburban regions of the study unit. To basins located in the densely populated lowlands of King and Snohomish Counties and downwind of prevailing southwesterly storm systems, precipitation is estimated to contribute a large share of the total source loadings. From 1 to 2 (tons/mi^2)/yr of nitrogen and from 0.1 to 0.2 (ton/mi^2)/yr phosphorus are deposited on the Green, Lake Washington, and Snohomish River Basins from precipitation. Missing from the potential sources to these lowland basins, however, is the contribution from homeowner-and commercially applied fertilizers. At typical application rates of nitrogen (about 4 pounds per 1,000 square feet per year), a watershed the size of Lake Washington might receive 2.8 (tons/mi^2)/yr of nitrogen if one eighth of the urban area were routinely fertilized. The total annual nitrogen loading rate to a watershed similar to that of Lake Washington would nearly double with the additional contribution from urban fertilizer applications.

Point-source discharges to rivers from wastewater-treatment plants account for small fractions of the stream loads. Loads from the plants amount to less than 7 percent of the inorganic nitrogen and total phosphorus loads in the Nooksack, Skagit, Stillaguamish, and Nisqually Rivers. Wastewater-treatment plants are a more important part of nutrient loads transported by the Puyallup River, amounting to about 22 percent of the inorganic nitrogen load and 12 percent of the total phosphorus load.

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