Analysis of Nutrient and Ancillary Water-Quality Data for Surface and Ground Water of the Willamette Basin, Oregon, 1980–90

By Bernadine A. Bonn, Stephen R. Hinkle, Dennis A. Wentz, *and* Mark A. Uhrich

Prepared as part of the National Water-Quality Assessment Program

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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

SPECIAL ACKNOWLEDGEMENT

The Willamette Basin National Water-Quality Assessment (NAWQA) staff appreciates the contributions of Julija "Julie" M. Laenen, who lived almost one-quarter of her life with cancer and its complications and who died on February 14, 1995.

Julie began her career with the U.S. Geological Survey in 1966 as an entry-level hydrologic technician in the Oregon District Water-Quality Laboratory, which served the Pacific Northwest and Pacific Islands. Later, she became laboratory manager. In this role, her commitment to quality was clearly demonstrated in her strong work ethic, her hiring of exceptional support personnel, and her thorough training of new employees with regard to water-quality instrumentation and data-collection techniques

In 1969, Julie took a leave of absence to start a family, but she returned to her Survey friends in 1976. Shortly thereafter, in 1980, she coordinated a sediment data-collection program on the Columbia River following the eruption of Mt. St. Helens, and she was an integral part of a team that produced one of the early reports on the effects of the eruption on sediment transport. She was instrumental in the network design and operation, and the quality assurance and publication of data collected under Oregon's atmospheric-deposition program; she became the District's expert in this area. Julie's talent and dedication to working with others were evident in her coordination and supervision during 1987 of the streambed sampling program for trace elements in the Yakima Basin NAWQA. In 1993, she was selected as an instructor for a field water-quality methods course required of all new Water Resources Division technical employees.

Throughout her career, Julie's unwavering commitment to accomplishing the mission of the Survey made her one of the most sought after and trusted employees in the Oregon District. Her professional attitude, dedication to excellence, attention to detail, and unselfish willingness to share her talents have been an inspiration to her co-workers.

Julie's official position with the Willamette Basin NAWQA was database manager, a role she began in 1990. As such, she was the sentinel whose watchful eye guaranteed that our data were of the highest possible quality. She was, however, much more than a database manager. She was a teacher who took responsibility for training those in need with regard to the vagaries of water-quality sampling. She was a team member who never hesitated to accept the challenge of any task presented to her. She was a pragmatist who often found an easier, more efficient way to complete that task, and she was an idealist whose guiding principle was to do the best job possible regardless of how trivial a request may have seemed. She was a consummate optimist who always found a way to accomplish what was asked of her, regardless of how impossible it might have appeared to the rest of us. She was a wife, a mother, and, recently, a grandmother. She was a dear friend and colleague, and she was, perhaps, the most dedicated employee we have known. She will be sorely missed.

Bernadine A. Bonn — Antonius Laenen
Kurt D. Carpenter — [illegible]
Neil Gates — Frank A. Rinella III
Stephen R. Hinkle — [illegible] M. Rios-Huston
Mary Janet — Mark Uhrich
Martell Kiefer — Ian R. Waite
Dennis A. Wentz

Photograph of Julie Laenen by Kenneth A. Skach, U.S. Geological Survey

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TRANSPARENCY

[Transparency is in pocket.]

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter
inch (in.)	0.0254	meter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.004047	square kilometer
square mile (mi^2)	259	hectare
square mile (mi^2)	2.59	square kilometer
	Volume	
acre-feet (acre-ft)	1233	cubic meter
cubic feet (ft^3)	0.02832	cubic meter
gallon (gal)	3.785	cubic decimeter (liter)
	Discharge	
cubic feet per second (cfs)	0.02832	cubic meter per second
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram
ton, short (ton)	0.9072	metric ton
pound per acre (lb/acre)	1.121	kilogram per hectare
ton per acre (ton/acre)	2.242	metric ton per hectare

Temperature

Degrees Fahrenheit (°F) and Degrees Celsius (°C) are related by the equation: $°F = 1.8\ (°C) + 32$

Abbreviation	Chemical constituent(s)
DO	dissolved oxygen
NH_4-N	total ammonia
NO_2-N	nitrite nitrogen
NO_3-N	nitrate nitrogen (pooled data for dissolved and total, nitrate and nitrite plus nitrate)
SRP	soluble reactive phosphorus or dissolved orthophosphate
total N	total nitrogen (sum of nitrite, nitrate, and total reduced nitrogen)
total P	total phosphorus
TRN	total reduced nitrogen (ammonia plus organic nitrogen, or total Kjeldahl nitrogen)
	Water-quality units
mg/L	milligrams per liter
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius

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

An analysis of historical water-quality data for surface and ground water collected in the Willamette and Sandy River Basins during the 1980–90 water years was performed. For surface water, most data were concentrated at sites on the main stem Willamette River or near the mouths of major tributaries. All seasons were represented. Data for nitrogen and phosphorus species were readily available, but simultaneously collected discharge measurements frequently were not. Seven primary sites were used for a quantitative analysis of nutrient data in surface water.

At six of the seven primary sites, median concentrations of nitrite plus nitrate and total phosphorus were less than 0.5 milligrams per liter (mg/L) as nitrogen (N) and 0.1 mg/L as phosphorus (P), respectively. These concentrations were lower than national median concentrations for basins with similar land uses. At the Pudding River site, which received significant point-source and agricultural nonpoint-source inputs, median values for nitrite plus nitrate and total phosphorus were 1.4 mg/L as N and 0.2 mg/L as P, respectively. Nitrite-plus-nitrate concentrations at this site were seasonally dependent, with the highest concentrations occurring during winter. Forested sites had significantly lower water temperatures and nutrient concentrations than urban or agricultural sites. Evidence of diel variations in dissolved oxygen concentrations and pH values suggest that, at some sites, low dissolved oxygen concentrations may be a problem during early morning hours in the summer.

Historical nutrient data for ground water were limited primarily to nitrate and nitrite-plus-nitrate determinations for wells completed in the basin-fill and alluvial aquifer. Nitrate and nitrite-plus-nitrate concentrations in this aquifer showed a weak inverse relationship with depth.

INTRODUCTION

The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) is designed to characterize the current status and long-term trends in water quality of most (60–70 percent) of the Nation's utilized surface- and ground-water resources and to provide a solid, scientific foundation for evaluating natural and anthropogenic impacts on these resources (Leahy and others, 1990). The program began full implementation during water year 1991 (October 1, 1990 – September 30, 1991) when investigations began nationwide in 20 study units—combinations of river basins and associated aquifer systems—including the Willamette Basin.

The watershed concept is the cornerstone of the NAWQA design, which emphasizes integration of surface- and ground-water systems using a nationally consistent, multidisciplinary approach involving the sampling and analysis of water, sediment, biota, and habitat to provide converging lines of evidence with regard to the assessment of water quality (Leahy and others, 1993). To accomplish the design, the program contains two components, each encompassing different spatial scales. The national synthesis component, which includes studies of pesticides and nutrients, emphasizes comparisons among study units at national and regional levels. The study-unit component focuses more effort on water-quality issues at the basin and subbasin (local) levels.

Purposes And Scope

The purposes of this report are (1) to describe the spatial and temporal distributions of nutrient (nitrogen and phosphorus) concentrations and water-quality indicators (temperature, specific conductance, pH, dissolved oxygen concentration, and suspended sediment concentration) in surface and ground water of the Willamette and Sandy River Basins and (2) to present preliminary conceptual models to explain these distributions. To the extent possible, constituent concentrations are compared to water-quality standards established by the State of Oregon or by the U.S. Environmental Protection Agency (USEPA), and to concentrations that are associated with adverse biological effects. The review period is October 1, 1979 through September 30, 1990, that is, water years 1980–90.

Acknowledgments

This report synthesizes the work from many scientific and regulatory agencies. The following people were especially helpful. Doug Bloom (Portland Water Bureau [PWB]) provided surface-water data, and Alberta Seierstad (PWB) provided information concerning the methods used to obtain those data. Patrick Meyer (Oregon Department of Human Resources-Health Division [OHD]) and Greg Pettit (Oregon Department of Environmental Quality [ODEQ]) provided ground-water data and guidance in the interpretation of those data.

DESCRIPTION OF THE WILLAMETTE BASIN STUDY UNIT

The Willamette Basin study unit is one of 20 study units initiated as part of the NAWQA Program during water year 1991. It is comprised of the Willamette and Sandy River Basins (fig. 1), and is referred to as the Willamette Basin throughout this report. Both rivers are tributaries of the Columbia River.

Water-quality issues of primary concern in the Willamette Basin include biological degradation of the aquatic ecosystems, soil erosion from changing land use, and elevated concentrations of nutrients, synthetic organic compounds (including pesticides), and trace elements (Wentz and McKenzie, 1991). In addition, the management of surface- and ground-water resources influences water-quality conditions and continues to be a concern in the basin. These issues are consistent with the national synthesis concerns described previously.

Geographic Setting

The Willamette Basin occupies about 12,000 mi^2 in northwestern Oregon. It includes portions of five ecoregions and subregions (fig. 2) that are defined primarily on the basis of land use, land surface form, potential natural vegetation, and soils (Omernik and Gallant, 1986; Clarke and others, 1991). The ecoregions of the Willamette Basin are similar in areal extent to the physiographic provinces of Fenneman (1931).

The ecoregions of the Willamette Basin can be aggregated into three topographic units: (1) the Cascade Range (comprising the Western and High Cascades ecoregions) on the east, (2) the Coast Range on the west, and (3) the interlying Willamette Valley (which includes the Willamette Valley Plains and Foothills ecoregions). The Cascade Range, which is composed of basalt, andesite, and volcanic debris, reaches elevations of over 10,000 ft. Marine sedimentary and associated volcanic rocks form the Coast Range, which exceeds elevations of 4,000 ft. The Willamette Valley is an elongated, structural and erosional lowland surrounded by resistant volcanic and sedimentary rocks. The valley fill consists of clastic sediment of Tertiary and Quaternary age primarily of alluvial and lacustrine origin.

Hydrogeology

The Willamette Basin can be divided into five aquifer units: Tertiary and Quaternary sedimentary deposits (basin-fill and alluvial aquifer), Columbia River Basalt Group, Tertiary and Quaternary volcanic rocks of the High Cascade Range, Tertiary volcanic rocks of the Western Cascade Range, and Tertiary rocks of the Coast Range (McFarland, 1983). For purposes of this report, these units are classified into three simpler groups (fig. 3): (1) basin-fill and alluvial aquifer, (2) Columbia River basalt aquifer, and (3) other bedrock aquifers. In the northern Willamette River Basin, structural basins of Columbia River Basalt Group contain portions of the basin-fill and alluvial aquifer; the Columbia River basalt aquifer is exposed near the edges of these structural basins.

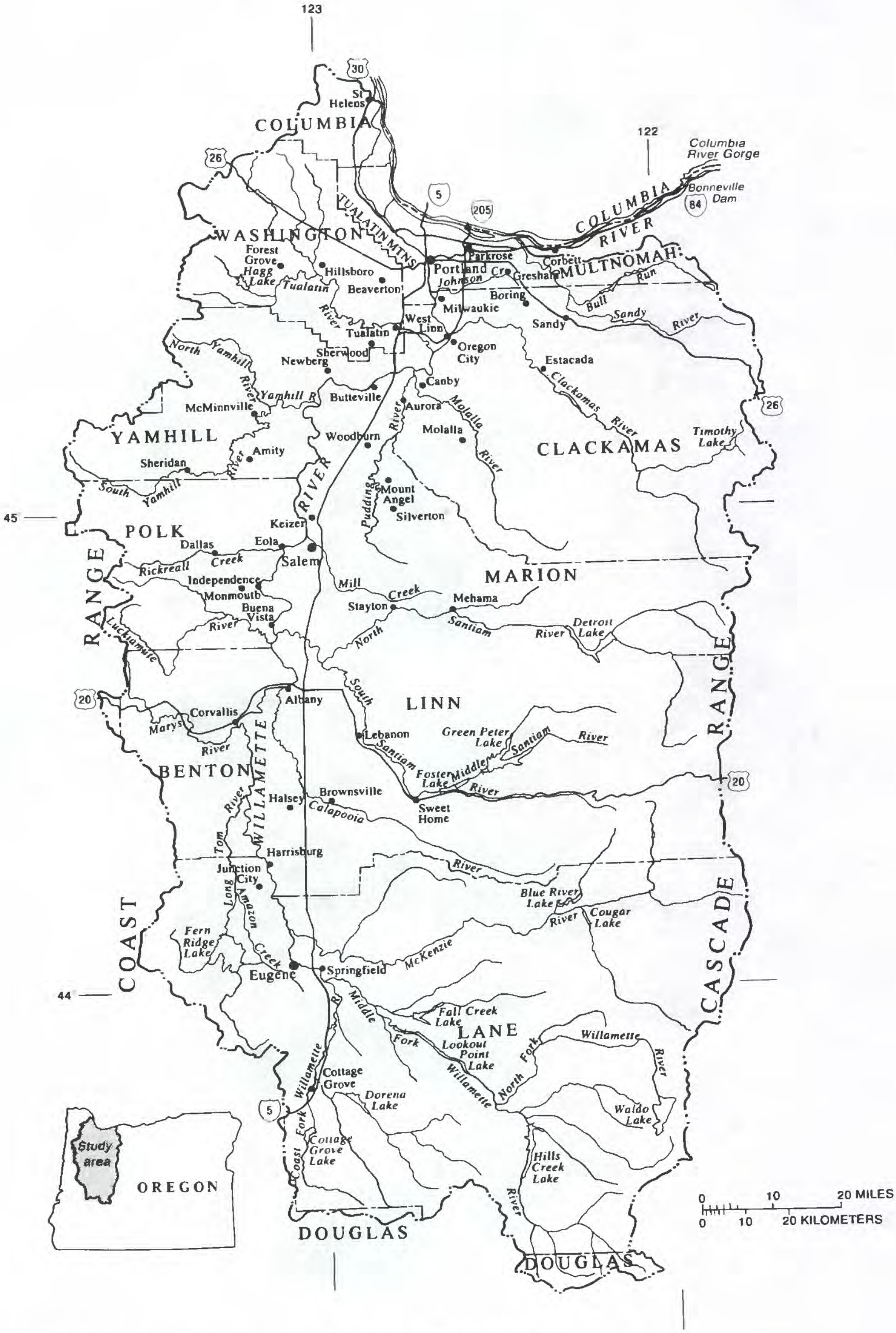


Figure 1. Location of the Willamette and Sandy River Basins, Oregon.

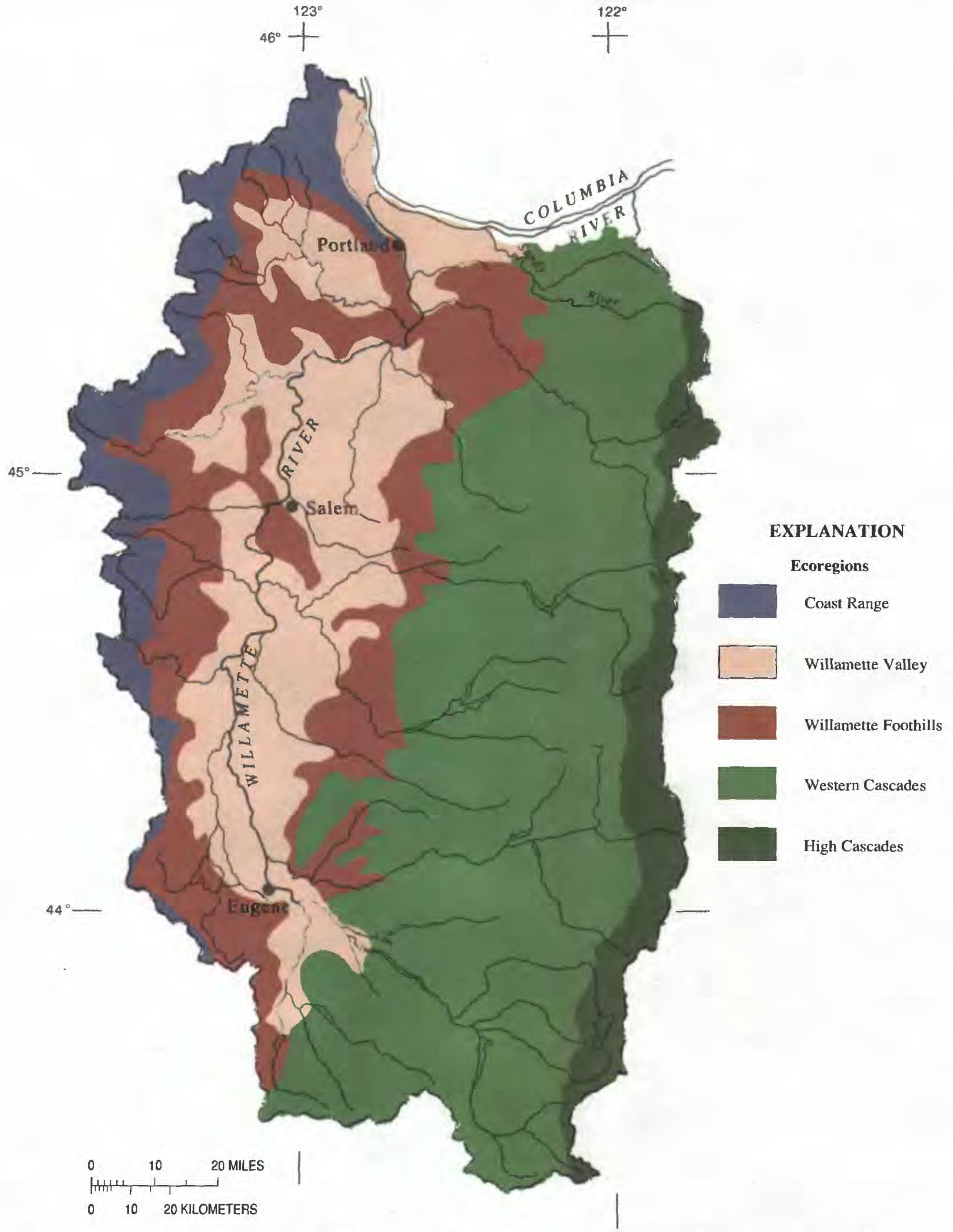


Figure 2. Ecoregions of the Willamette and Sandy River Basins, Oregon. (Modified from Clarke and others, 1991.)

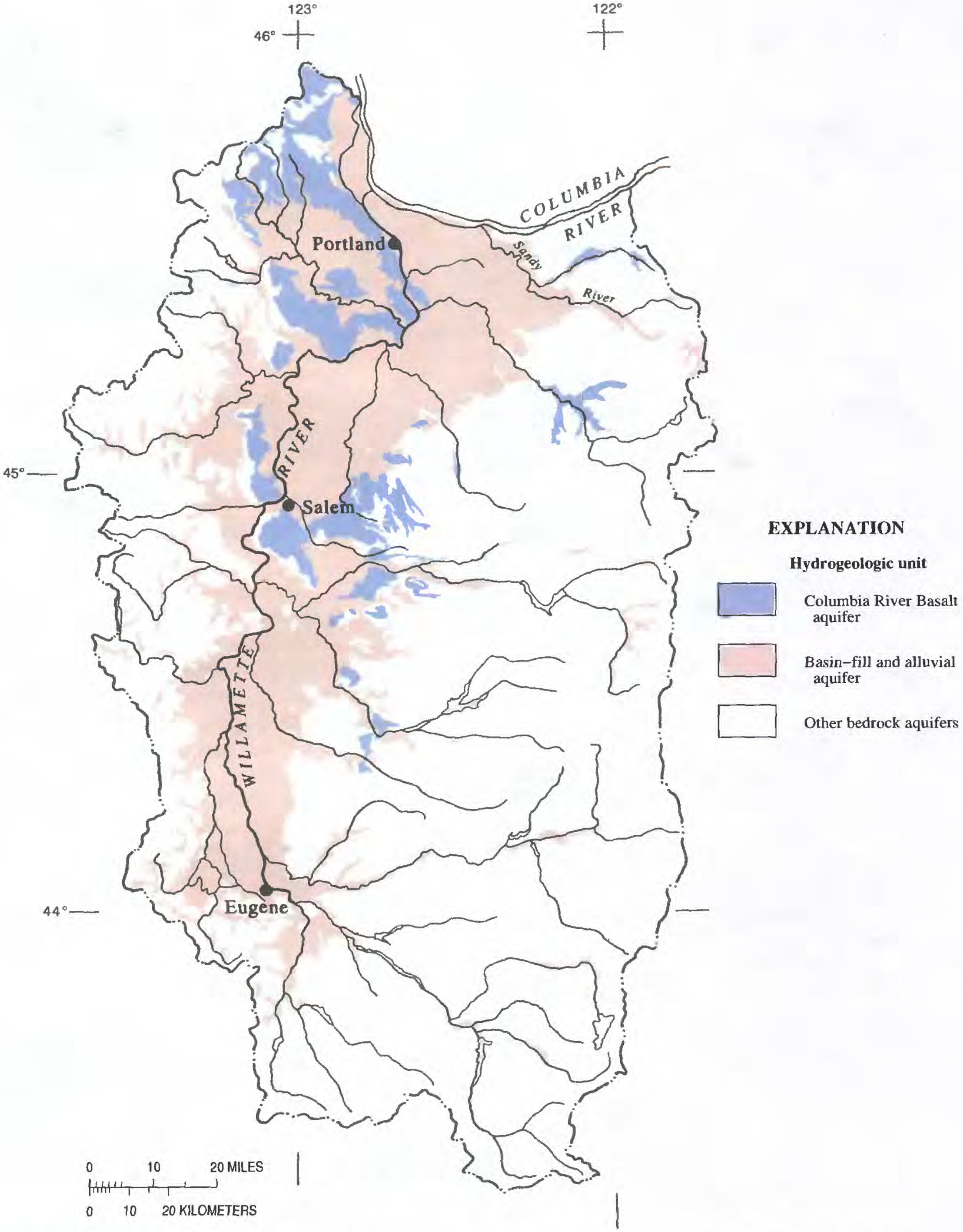


Figure 3. Surface expressions of the major hydrogeologic units in the Willamette and Sandy River Basins, Oregon. (Modified from McFarland, 1983.)

The principal aquifers in the Willamette River Basin are the basin-fill and alluvial aquifer and the Columbia River basalt aquifer (Gonthier, 1985, p. 357). Of these two, the basin-fill and alluvial aquifer is considered the more important ground-water resource (Gonthier, 1985, p. 356–358; Willamette Basin Task Force, 1969, p. IV–58). This aquifer is a heterogeneous mixture of unconsolidated and semi-consolidated clay, silt, sand, and gravel. Water levels tend to be shallow, usually within 50 ft of land surface. The Columbia River basalt aquifer contains permeable interflow zones and fractures that readily transmit water. Water levels in this aquifer tend to be deeper than those in the basin-fill and alluvial aquifer, except in areas overlain by the basin-fill and alluvial aquifer (McFarland, 1983, p. 34). In general, well depths in the basin-fill and alluvial aquifer are less than those in the Columbia River basalt aquifer. Although the water quality in both aquifers generally is adequate for most uses, the basin-fill and alluvial aquifer "may be very sensitive to contamination in areas where the water table is shallow" (Gonthier, 1985, p. 356).

Climate

Because of the proximity of the Willamette Basin to the Pacific Ocean and its exposure to prevailing westerly winds, the area is characterized by cool, wet winters and warm, dry summers. This is illustrated by data from six representative index stations (table 1; fig. 4) for the 1940–91 calendar years or closest available period of record. Almost half of the annual precipitation occurred between November and January; less than 5 percent occurred during July and August (fig. 5). Mean annual precipitation ranged from 41 inches at Fern Ridge Dam to 82 inches at Headworks in the Bull Run watershed. December and January were the coolest months, with mean air temperatures ranging from 2.2 °C (degrees Celsius) at Cascadia to 3.9 °C at Corvallis. During the warmest months (July and August), mean air temperatures ranged from 17.7 °C at Cascadia to 18.9 °C at Corvallis.

Topography strongly affects the areal distribution of precipitation within the Willamette Basin (fig. 6). Mean annual amounts for 1961–90 range from about 40 inches on the valley floor to values as high as 175 inches in the Coast and Cascade Ranges. Basinwide mean annual precipitation for the 1961–90 period was 62 inches (based on data from Taylor, 1993).

Climate data from 1980–90 (the period used for the analysis of water-quality data in this report) were compared to data from 1940–91 to assess whether the 1980–90 period was representative of average long-term conditions. The percent differences between the mean annual precipitation values for these two time periods are small and bracket zero (table 1). Boxplots of annual precipitation values for 1980–90 and the index period also indicate that the two time periods experienced similar precipitation (fig. 7).

Table 1. National Oceanic and Atmospheric Administration index stations for climate data in the Willamette and Sandy River Basins, Oregon
[See fig. 4 for site locations.]

Site number	Name	Elevation (feet)	Index period (calendar years)	Mean annual precipitation (inches/year)		
				Index period	1980–90	Percent difference
1433	Cascadia	900	1940–91	61	63	+3.2
1862	Corvallis (Oregon State University)	250	1940–91	41	41	.0
2325	Dilley	200	1949–91	45	42	-6.7
2867	Fern Ridge Dam	400	1944–91	41	43	+4.9
3770	Headworks (Bull Run)	750	1940–91	82	77	-5.7
6213	Oakridge	1,300	1949–91	44	43	-2.3

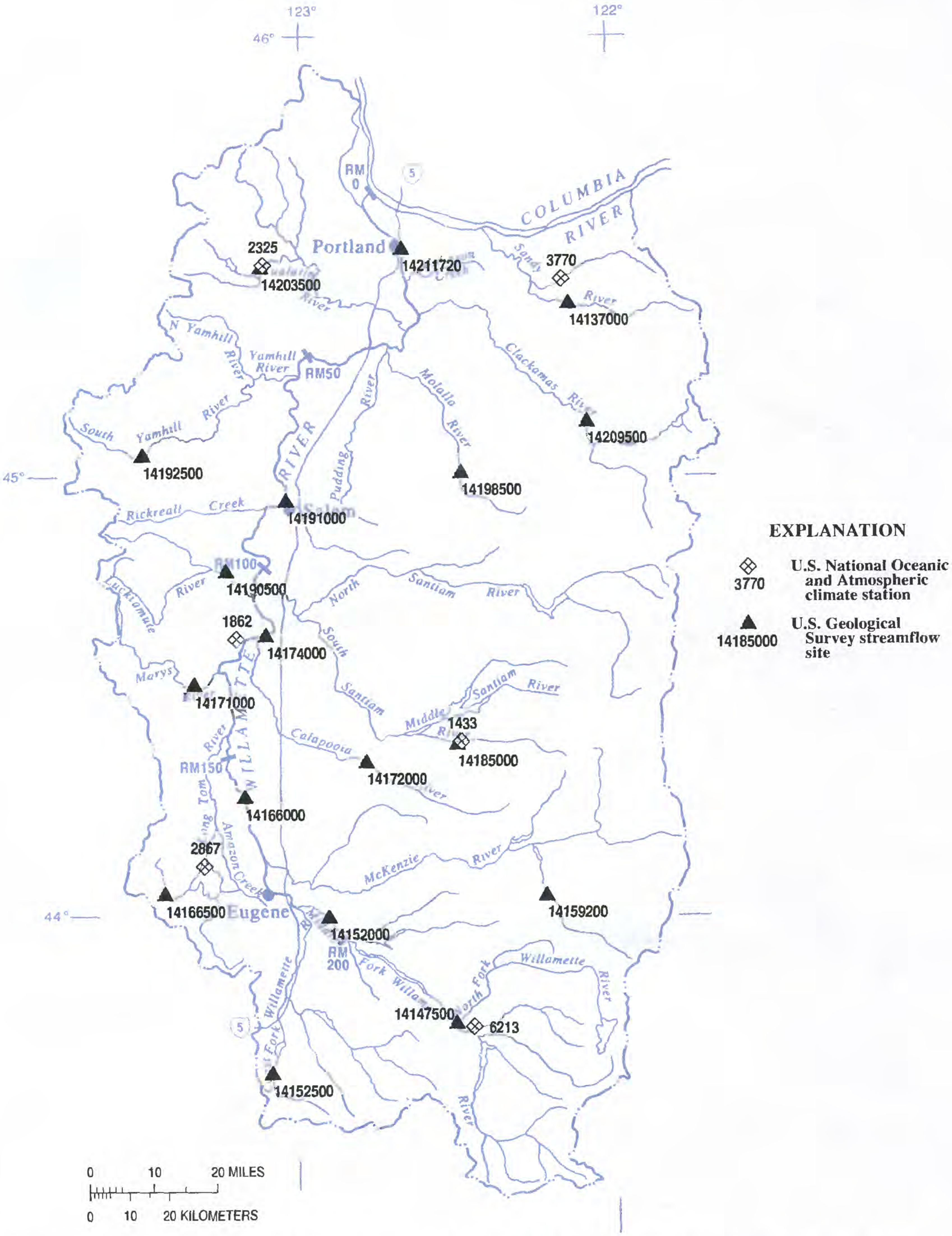
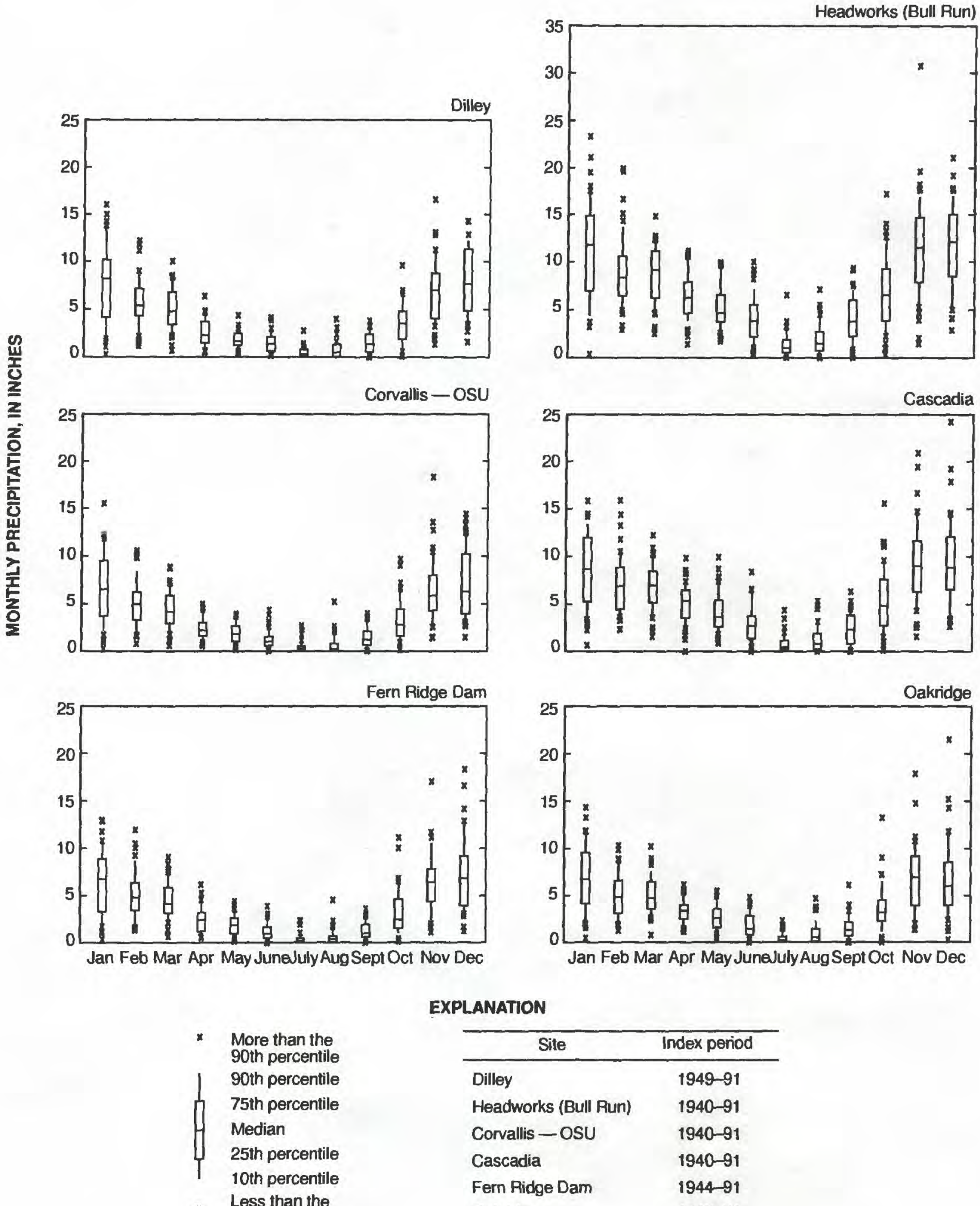


Figure 4. Locations of index stations for climate and streamflow in the Willamette and Sandy River Basins, Oregon. (See tables 1 and 2 for site names and other details.)



Site	Index period
Dilley	1949–91
Headworks (Bull Run)	1940–91
Corvallis — OSU	1940–91
Cascadia	1940–91
Fern Ridge Dam	1944–91
Oakridge	1949–91

Figure 5. Monthly precipitation at selected locations in the Willamette and Sandy River Basins, Oregon. (See table 1 and fig. 4 for site locations and other details.)

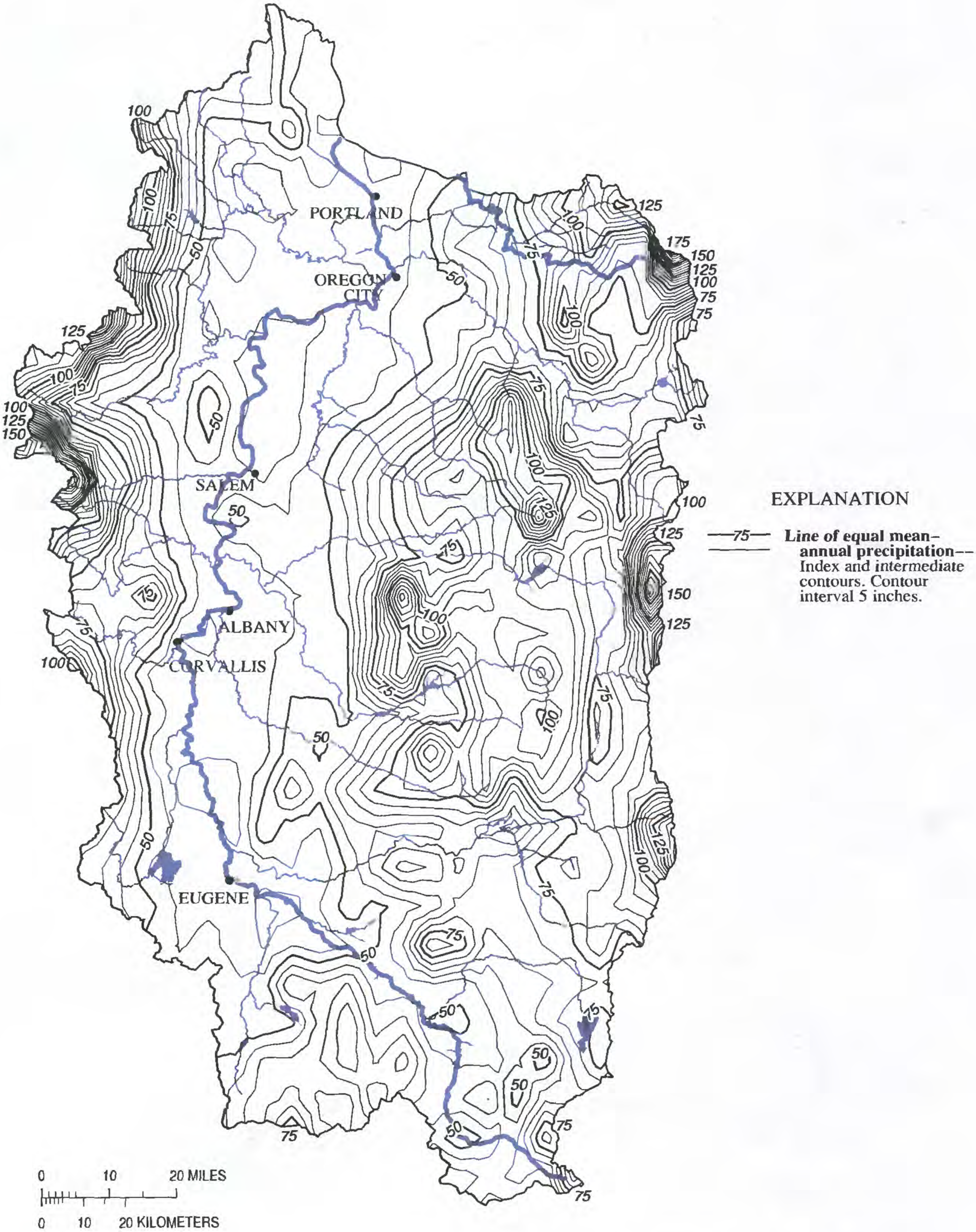
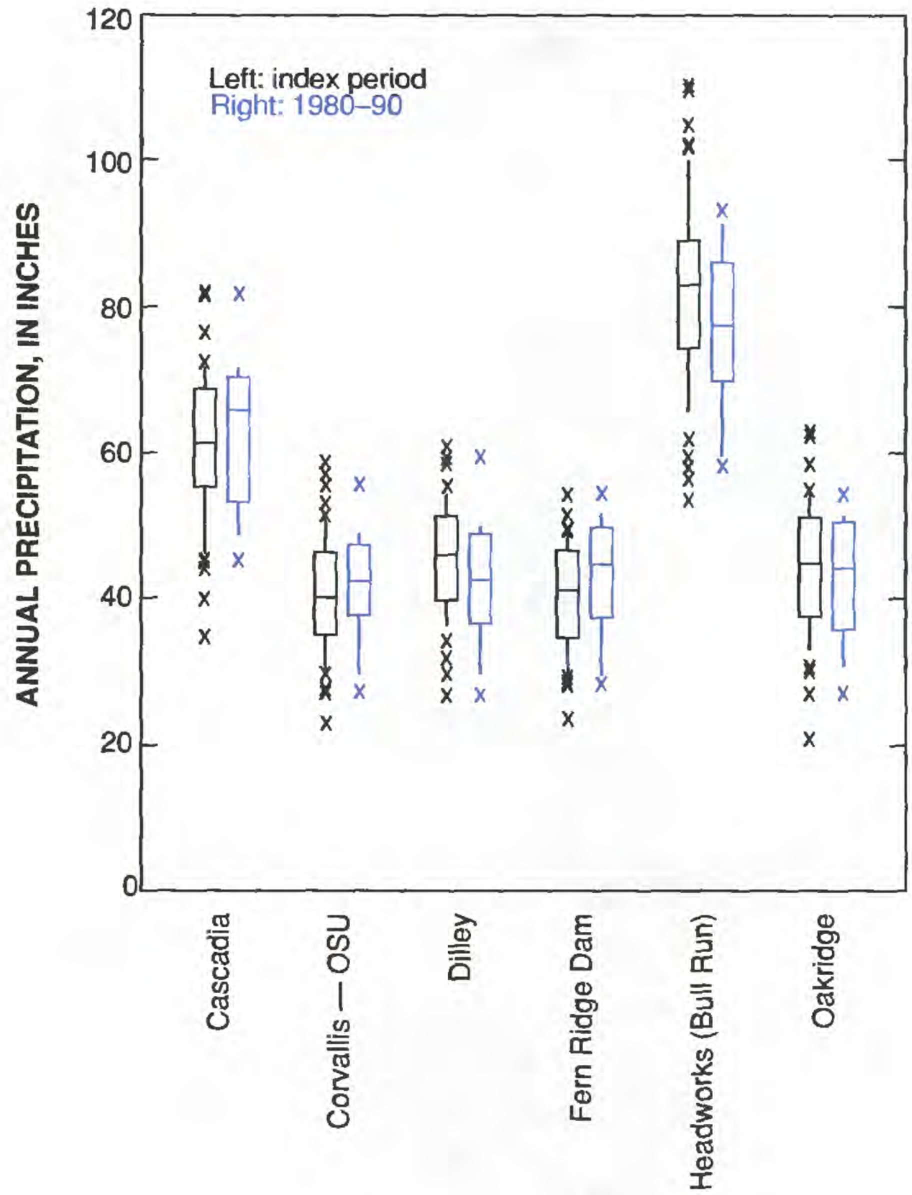
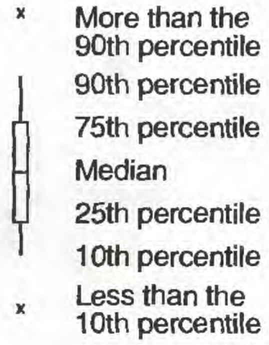


Figure 6. Mean-annual precipitation in the Willamette and Sandy River Basins, Oregon, 1961–90. (Modified from Taylor, 1993.)



EXPLANATION



Site	Index period
Dilley	1949–91
Headworks (Bull Run)	1940–91
Corvallis — OSU	1940–91
Cascadia	1940–91
Fern Ridge Dam	1944–91
Oakridge	1949–91

Figure 7. Comparison of annual precipitation amounts during 1980–90 with those during the index period at selected locations in the Willamette and Sandy River Basins, Oregon. (See table 1and fig. 4 for site locations and other details.)

Surface-Water Hydrology

Streamflow in the Willamette Basin is driven largely by rainfall. This is illustrated by data from six streamflow index stations that are located near the previously discussed climate stations (table 2; fig. 4). Highest flows occur December through March (fig. 8). Streams draining the Cascades (east side of the basin) also receive snowmelt, which extends the high flow period through May and augments flow during the summer months. Low flow occurs during August and September and accounts for less than 2 percent of the total annual streamflow for west-side streams and an average of five percent for east-side streams.

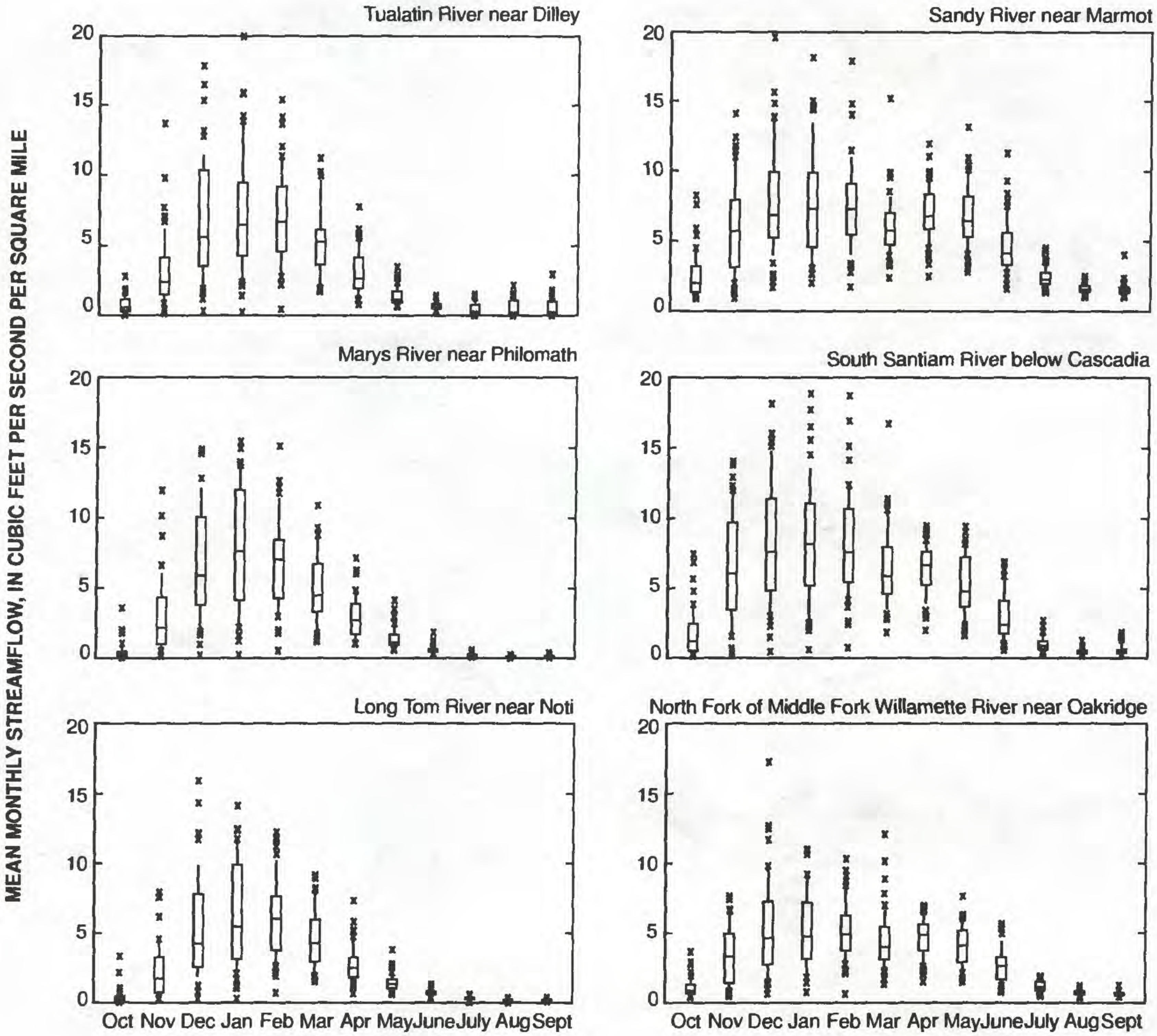
Streamflow records for the Willamette River at Albany (table 2, fig. 4) were examined to compare the 1980–90 period with long-term conditions. This site has the longest continuous record of streamflow measurements in the Willamette Basin: 1896–present (1995) water years. Its drainage area encompasses 40 percent of the total basin area. Neither the historic maximum annual streamflow (24,100 ft^3/s in 1956), nor the historic minimum annual streamflow (5,830 ft^3/s in 1977) occurred during the review period for this report (fig. 9a).

Comparisons of annual mean streamflows for water years 1896–1992, 1940–92, and 1980–90 (fig. 9b) show that the distributions for the 1940–92 index period and the period of record are similar: medians are 14,300 and 14,200 ft^3/s, respectively, and ranges are identical. The 1980–90 period, however, had three years of relatively high flow (1982–84) and eight years of below-average flow. The median value for the 1980–90 period (13,100 ft^3/s) is 7 percent lower than that for the period of record.

The distributions of annual mean streamflow per unit drainage area for 18 index stations for 1940–92 and 1980–90 are similar to the distribution for the Willamette River at Albany site. Throughout the basin, mean (table 2) or median (fig. 10) annual streamflows during 1980–90 were typically less than those during 1940–92. Annual streamflow ranges during 1980–90, however, were not consistently lower than those during the index period (fig. 10). These data indicate that except for a few years of relatively high flow, most years during 1980–90 experienced below-average flow. Interpretations of water-quality conditions for 1980–90 are not expected to be compromised by this distribution of streamflows.

Table 2. U.S. Geological Survey index stations for streamflow in the Willamette and Sandy River Basins, Oregon
[See fig. 4 for site locations.]

Site number	Name	Drainage area (square miles)	Index period (water years)	Mean annual streamflow (cubic feet per second per square mile)		
				Index period	1980–90	Percent difference
14137000	Sandy River near Marmot	262	1940–92	5.2	4.9	-5.8
14147500	North Fork of Middle Fork Willamette River near Oakridge	246	1940–92	3.2	3.1	-3.1
14152000	Middle Fork Willamette River at Jasper	1,340	1953–92	3.1	3.0	-3.2
14152500	Coast Fork Willamette River at London	72	1940–87	2.8	2.7	-3.6
14159200	South Fork McKenzie River above Cougar Lake near Rainbow	160	1958–87	4.0	3.9	-2.5
14166000	Willamette River at Harrisburg	3,420	1945–92	3.5	3.2	-8.6
14166500	Long Tom River near Noti	89	1940–91	2.6	2.4	-7.7
14171000	Marys River near Philomath	159	1941–85	2.9	3.1	+6.9
14172000	Calapooia River at Holley	105	1940–90	4.1	3.8	-7.3
14174000	Willamette River at Albany	4,840	1940–92	3.0	2.8	-6.7
14185000	South Santiam River below Cascadia	174	1940–92	4.7	4.5	-4.3
14190500	Luckiamute River near Suver	240	1941–91	3.6	3.4	-5.6
14191000	Willamette River at Salem	7,280	1940–92	3.3	3.1	-6.1
14192500	South Yamhill River near Willamina	133	1940–91	4.6	4.3	-6.5
14198500	Molalla River above Pine Creek near Wilhoit	97	1940–92	5.5	5.0	-9.1
14203500	Tualatin River near Dilley	125	1941–91	3.1	2.8	-9.7
14209500	Clackamas River above Three Lynx Creek	479	1940–92	4.2	4.0	-4.8
14211720	Willamette River at Portland	11,200	1973–92	2.9	2.9	0



EXPLANATION

Site	Index period
Tualatin River near Dilley	1941–91
Sandy River near Marmot	1940–92
Marys River near Philomath	1941–85
South Santiam River below Cascadia	1940–92
Long Tom River near Noti	1940–91
North Fork of Middle Fork Willamette River near Oakridge	1940–92

Figure 8. Mean monthly streamflow at selected locations in the Willamette and Sandy River Basins, Oregon. (See table 2 and fig. 4 for site locations and other details.)

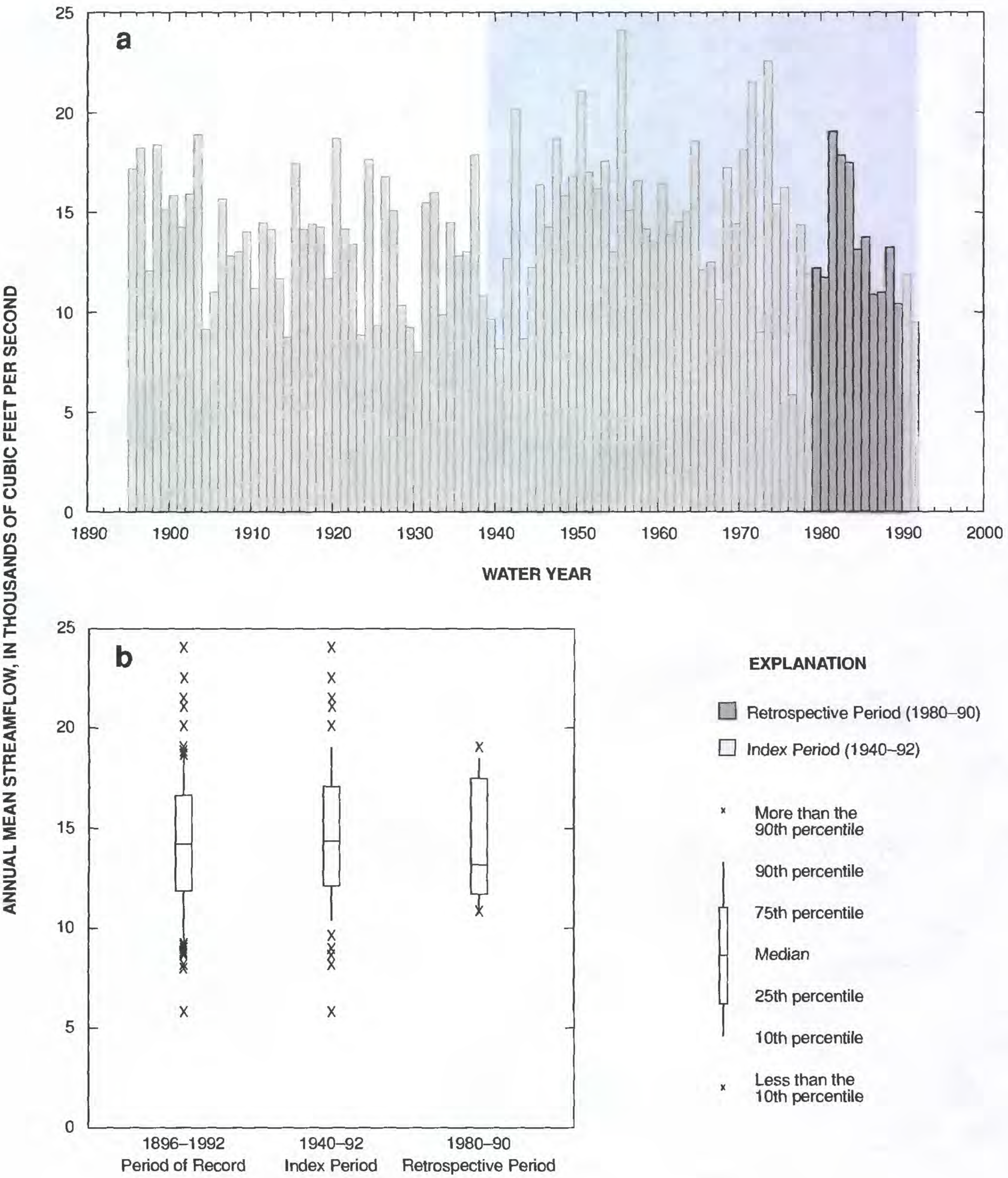


Figure 9. Annual mean streamflows at the Willamette River at Albany, Oregon: (a) streamflow by year, (b) streamflow distributions for period of record, index period, and retrospective period.

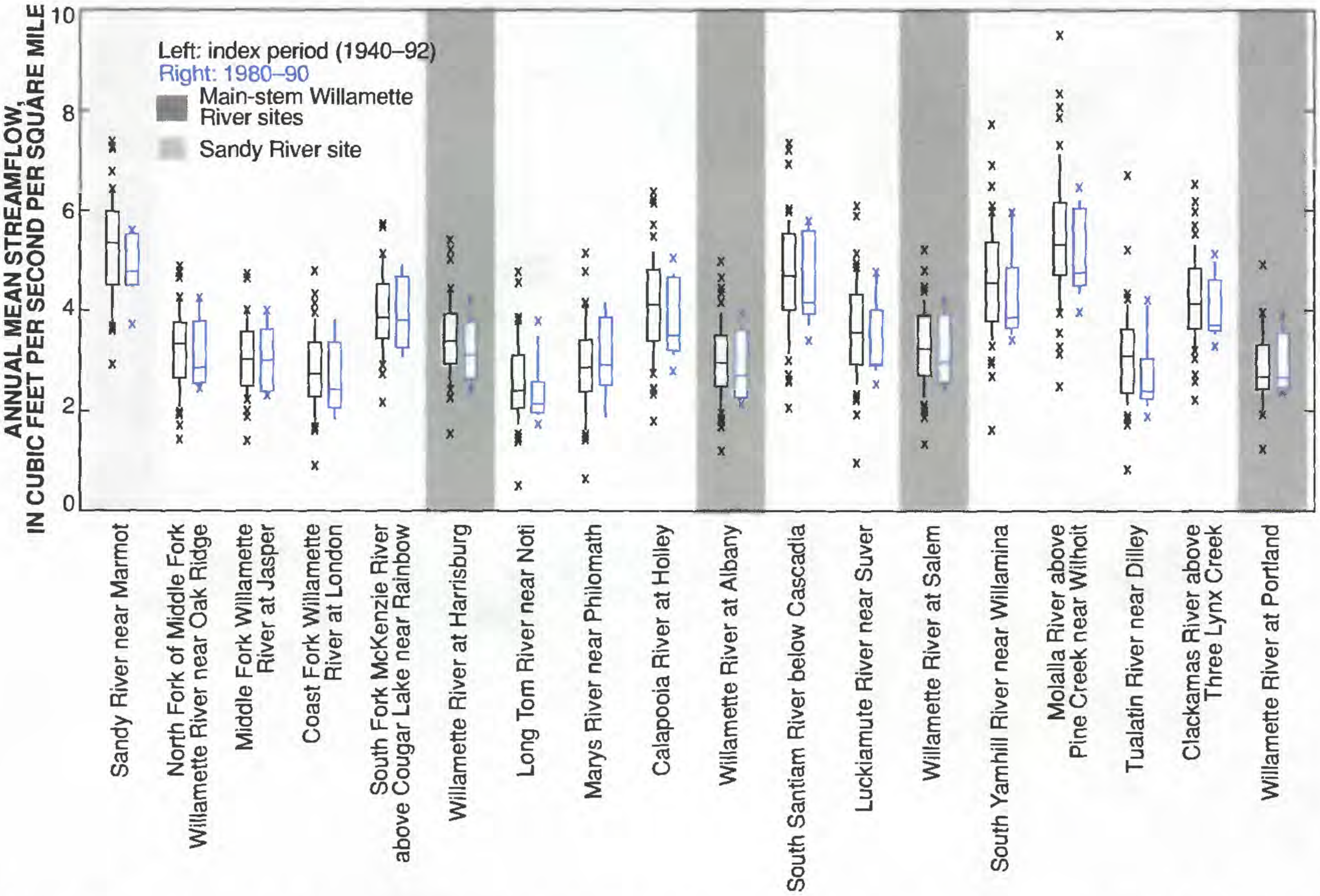


Figure 10. Comparison of annual mean streamflows during 1980–90 with those during the index period at selected locations in the Willamette and Sandy River Basins, Oregon. (See table 2 and fig. 4 for site locations and other details. See fig. 5 on previous page for explanation of boxplots)

Land Use and Population

The major land uses in the Willamette Basin were determined using data from the Geographic Information Retrieval and Analysis System (GIRAS) (Fegeas and others, 1983; Mitchell and others, 1977) and are shown on figure 11. These data were collected during the 1970s.

Most of the agricultural land, which comprises 22 percent of the basin, is located in the Willamette Valley. In contrast, forest land (70 percent of the basin) dominates the foothills and mountains of the Coast and Cascade Ranges. Most urban centers are located along the main stem of the Willamette River; they account for 5 percent of the basin area.

Population statistics for Oregon show that 11 of the 12 largest cities, including the 5 largest, lie within the Willamette Basin (Center for Population Research and Census, 1992). The Portland metropolitan area, located near the northern boundary of the basin (fig. 1), accounts for about 44 percent of the State's population. The Willamette River Basin includes parts of 13 counties, 9 of which lie entirely, or almost entirely, within the basin boundary. Because most of the population within these nine counties is also within the basin, county population data were used to estimate the basin population. Between 1980 and 1990, the population of these nine counties increased by 13 percent, from 1.8 million to 2.0 million. Although most of this population growth occurred within Portland and its suburbs, all major cities in the basin increased in population during the 1980–90 period (Center for Population Research and Census, 1992). The population increases generally resulted in conversion of agricultural and forest land to urban land.

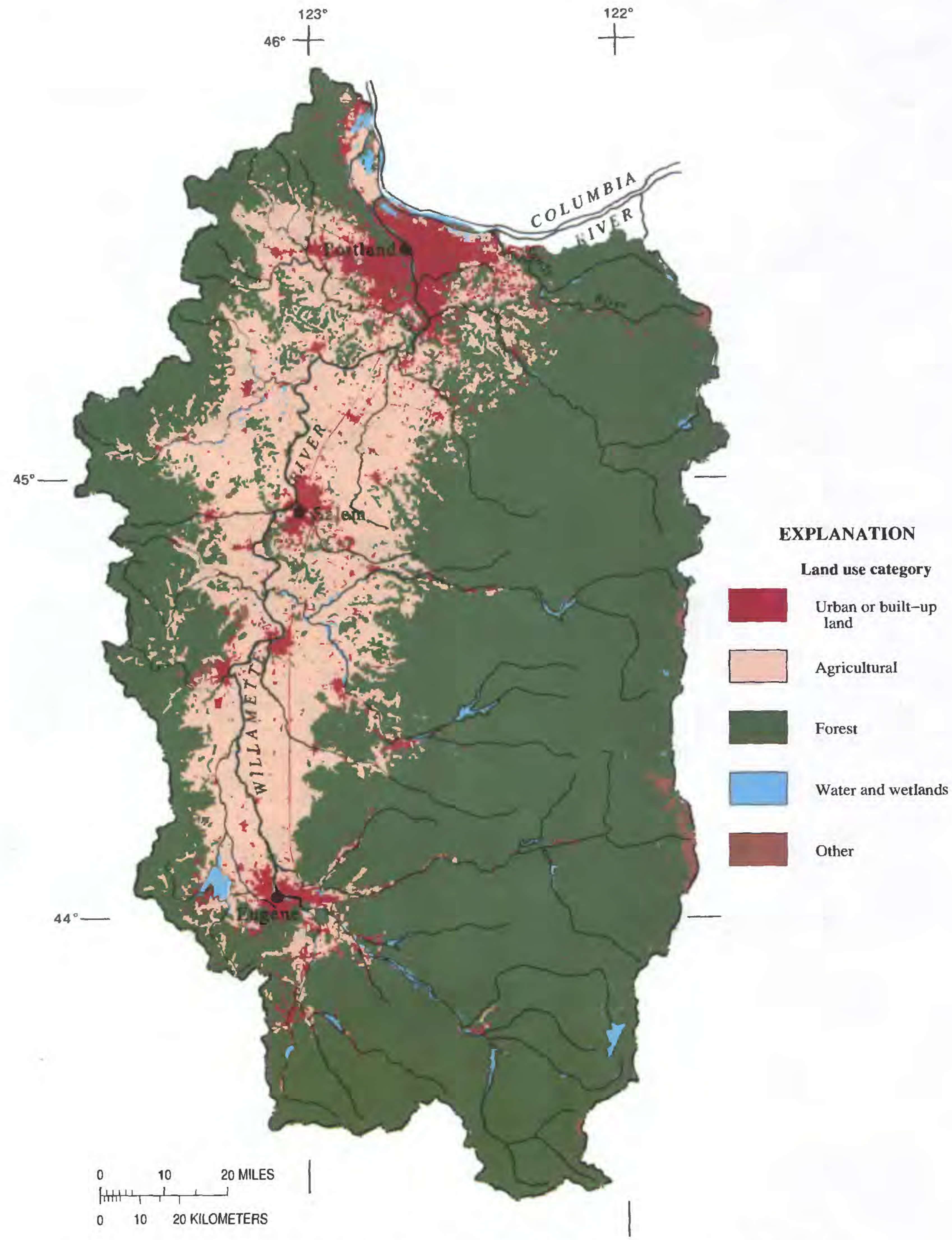


Figure 11. Major land uses in the Willamette and Sandy River Basins, Oregon. (Modified from Fegeas and others, 1983.)

Water Use

Estimated surface-water use in the Willamette River Basin for 1985 is shown on figure 12. Estimates of surface-water use in the Sandy River Basin were not available. Estimates of ground-water use were not available for either basin.

The locations of sites where major withdrawals (exceeding 1 million gallons per day) of surface or ground water occur are shown on figure 13. Major surface-water withdrawals are distributed along the main stem of the Willamette River and its tributaries. Major ground-water withdrawals are concentrated in areas associated with the basin-fill and alluvial aquifer—the valley floor and along the Columbia River at the northern basin boundary.

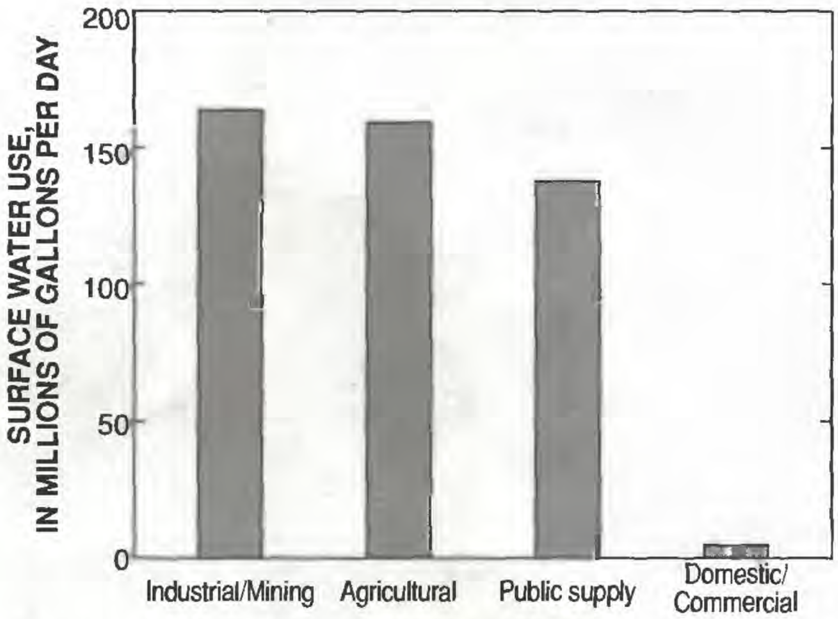


Figure 12. Estimated major surface-water uses in the Willamette River Basin, Oregon for 1985. (Data from Broad and Nebert, 1990.)

Sources of Nutrients

Atmosphere—Estimated annual atmospheric deposition rates of nitrogen to selected subbasins are shown in table 3. (Characteristics of these subbasins are discussed under "Description of surface-water sites," p. 24). Average total atmospheric inputs (wet plus dry deposition) of ammonia and nitrate to each subbasin were estimated using data from the National Trends Network of the National Atmospheric Deposition Program (NADP/NTN) for the 1980–90 period (L.J. Puckett, USGS, written commun., 1992). NADP/NTN annual wet deposition rates were available for four sites, three in the Willamette Basin and one 8 miles west of the basin divide (fig. 14). Average annual wet deposition rates for each subbasin were obtained by averaging the NADP/NTN data using inverse-distance-squared weighting methods. The method of Sisterson (1990) was applied to estimated mean annual wet-deposition rates in order to estimate average annual dry deposition and to correct for the proximity of urban areas. The calculated values

Table 3. Estimated non-point source inputs of nitrogen and phosphorus to primary subbasins in the Willamette and Sandy River Basins, Oregon

[Atmospheric deposition data for 1980–90 from National Atmospheric Deposition Program/National Trends Network; fertilizer data for 1985 and manure data for 1982 (R.B Alexander, U.S. Geological Survey, written commun., 1992); see table 6 for subbasin characteristics]

Site	Nitrogen input (tons/year)			Phosphorus input (tons/year)	
	Atmospheric deposition	Fertilizer	Manure	Fertilizer	Manure
Fir Creek	5	0	0	0	0
Middle Fork Willamette River	500	180	80	20	20
Long Tom River	34	2,100	1,000	260	260
South Yamhill River	60	3,300	950	400	250
Pudding River	240	4,900	2,300	590	610
Willamette River at Portland	4,100	51,000	19,000	6,200	4,800

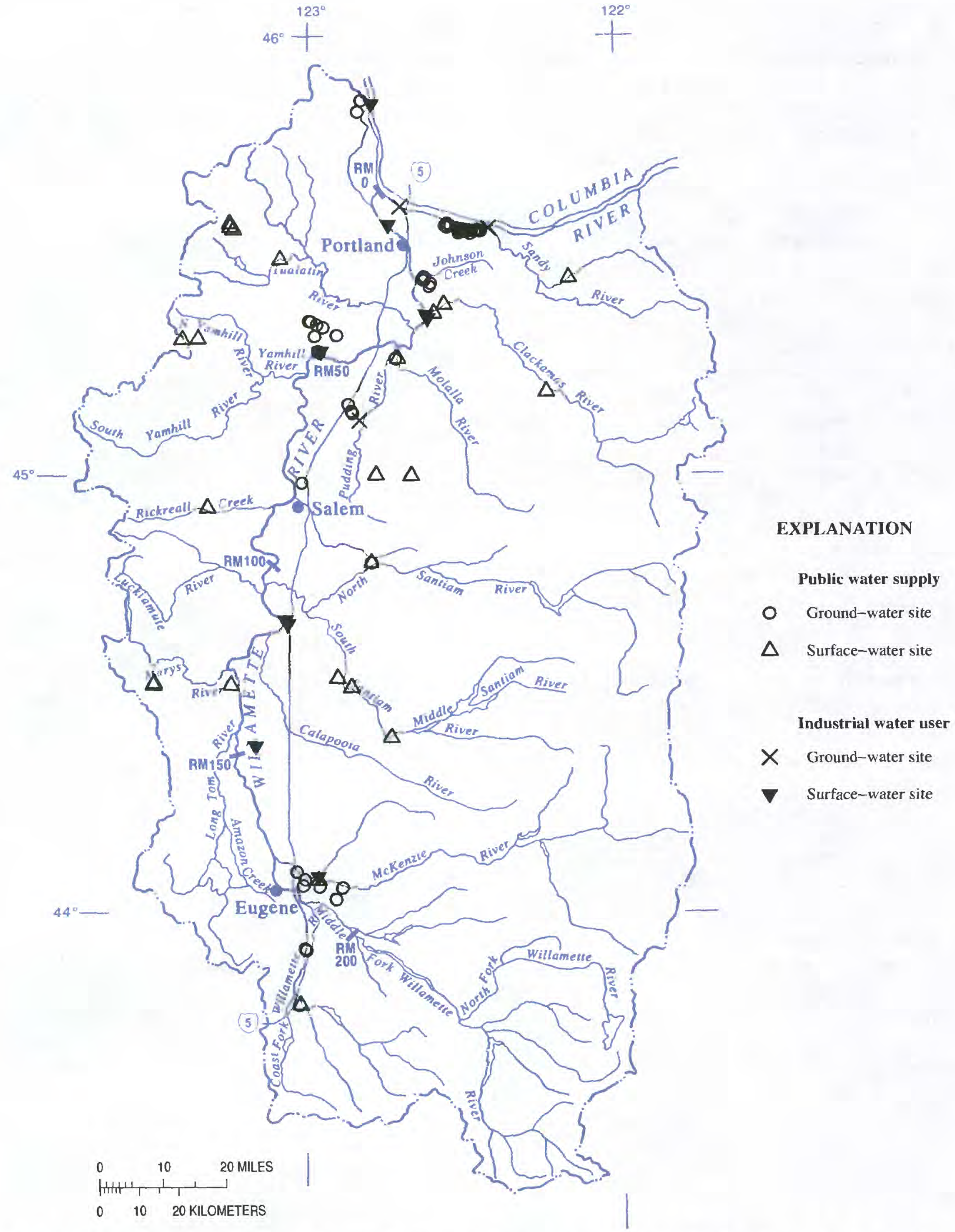


Figure 13. Locations of sites in the Willamette River Basin, Oregon, where withdrawals of surface water or ground water exceed 1,000,000 gallons per day. (Data from Oregon Health Division and U.S. Environmental Protection Agency.)

are estimates of deposition to the entire subbasin area; an unknown fraction of this deposition would be expected to contribute to the stream load.

Fertilizer and manure—Estimated loading of nitrogen and phosphorus from fertilizer and manure are shown in table 3 for selected subbasins. (Characteristics of these subbasins are discussed under "Description of surface-water sites," p. 24). The values were calculated for each subbasin from county-based data (R.B. Alexander, USGS, written commun.,1992). The county contribution to each subbasin was calculated by multiplying the county application rate for agricultural land by the amount of agricultural land in the county that was also within the subbasin. The county contributions were summed to obtain an estimate for the entire subbasin. These estimates constitute an upper bound of the nutrient load from fertilizer and manure. Plant uptake and harvest, denitrification, and volatilization of ammonia will reduce the actual input to streams and ground water.

Landfill sites—Landfill sites are potential sources of nutrients to both ground and surface water. Known landfill sites in the Willamette Basin are shown on figure 14.

National Pollutant Discharge Elimination System (NPDES) sites—Thirty-three major NPDES permittees and 320 minor NPDES permittees discharge effluent into the Willamette River or its tributaries (fig. 14) (Tetra Tech, 1992). Relatively little information is available, however, concerning the nutrient inputs associated with these discharges. Of the 21 major NPDES permittees that discharge domestic wastes, only 2 report the concentrations of nutrients (ammonia, nitrite plus nitrate, total Kjeldahl nitrogen, and total phosphorus) in their effluent on a monthly basis. Seven others report concentrations of some of these constituents, but only during the summer months (May through October). Three industrial dischargers and one wastewater treatment plant report effluent ammonia concentrations monthly. The remainder of the major NPDES permittees and all of the minor NPDES permittees do not report effluent nutrient concentrations. The available data did not permit estimation of point-source inputs; such estimates are, therefore, not included in this report.

Other sources—A variety of other sources also contribute nutrients to the Willamette Basin, including runoff from highways and urban areas, leachate from septic tanks, combined sewer overflows, and irrigation return flows. In addition, nitrogen contributions from leguminous plants (used as cover crops or cash crops) and from alder may be important in agricultural and forested areas, respectively. Estimates of the basin loadings from these sources were not available.

APPROACH AND METHODS

Analysis of historical data is complicated by the fact that data obtained from different agencies or studies are not necessarily comparable. Because the data were collected for different purposes, they usually will not constitute an unbiased or detailed representation of water quality throughout a basin. Factors that must be considered when analyzing historical data include constituents measured, sampling frequency and duration, spatial distribution of sites, sampling procedures, analytical methods, quality-assurance methods, and the extent and type of ancillary data available.

The data and analyses in this report were not designed to provide an exhaustive and unequivocal description of past conditions. Rather, they will be used to formulate hypotheses, develop questions, guide future data collection, and indicate general patterns that may exist in the basin as a whole. Therefore, statistical methods that emphasize broad patterns, such as boxplots and smoothing techniques, were utilized for most of the data analyses.

Data Sources

Many agencies have collected and analyzed surface water or ground water in the Willamette Basin, including the USGS, ODEQ, OHD, Bureau of Reclamation, U.S. Forest Service, USEPA, and the Washington Department of Ecology. The data collected by the USGS reside in the National Water Information System (NWIS) data base. Much of the data collected by other agencies reside in USEPA's water-quality data base (STORET). These two data bases, NWIS and STORET, were the primary sources of surface-water data for this report. Ground-water data were obtained from ODEQ (G. Pettit, ODEQ, written commun., 1992) and OHD (D. Nelson, OHD, written commun., 1992). Most data were received in electronic format.

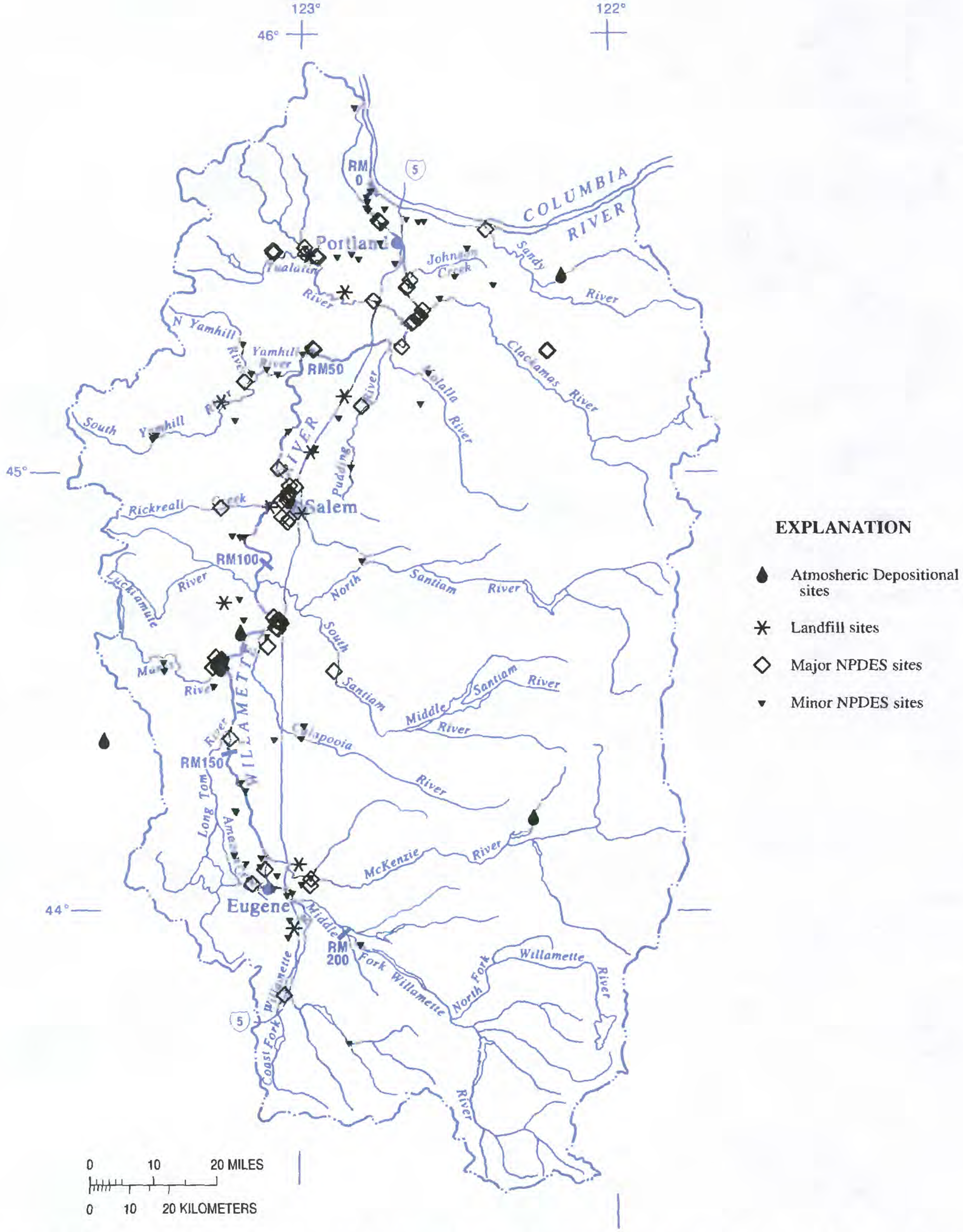


Figure 14. Locations of National Atmospheric Deposition Program/National Trends Network sites, landfill sites, and major and minor National Pollutant Discharge Elimination System sites within or near the Willamette and Sandy River Basins, Oregon. (Digital data from National Atmospheric Deposition Program/National Trends Network, and D. Terra [Oregon Department of Environmental Quality, written commun., 1993])

Retrospective period—The retrospective period (primary review period for this report) is defined as water years 1980 through 1990. (A water year is the 12-month period beginning on October 1, ending on September 30, and designated by the calendar year in which it ends). This period was chosen to coincide with the needs of the national synthesis component of the NAWQA program. In addition, data obtained prior to the 1980s may not be comparable to more recent data because analytical methods have changed over time.

In June 1992, STORET records for the basin were obtained for the period October 1, 1979, through September 30, 1990. Any additions or changes to the STORET data base after June 1992 are not included in this report.

Constituents—All records that contained surface-water or ground-water data for ammonia, nitrite, nitrate, total reduced nitrogen (organic nitrogen plus ammonia), total nitrogen, soluble reactive phosphorus, total phosphorus, suspended sediment, and other related constituents were retrieved from the NWIS and STORET data bases. Ancillary data, including streamflow, pH, dissolved oxygen concentration, specific conductance, and water temperature also were obtained, if available.

National Conditions—Data from sites in the Willamette Basin were compared with a national composite of surface-water data compiled by Smith and others (1993). The national sites were grouped by representative land use. To be classified as an agricultural site in the national composite, more than 40 percent of the upstream drainage area must have been used as cropland or pasture. In addition, the proportions of forest and urban land could not have exceeded 40 percent and 10 percent, respectively. Drainage basin areas for the national data ranged from 1,000 to 3,000 mi^2. The water-quality data were collected during the 1980s. No sites within the Willamette Basin meet all the criteria that were used to classify the national sites. The drainage areas of most of the major Willamette River tributaries are less than 1,000 mi^2. The Willamette River near the mouth drains a much larger area (about 11,000 mi^2). The Pudding River Basin is the only subbasin discussed in this report that meets Smith and others' land-use percentage criteria for agricultural basins.

Statistical Methods

Boxplots—Boxplots (for example, fig. 20) are used to graphically represent much of the data in this report (Helsel and Hirsch, 1992). The boxplot displays the 10th, 25th, 50th (median), 75th, and 90th percentiles. A rectangle (the box) represents the data range between the 25th and 75th percentiles. The median is represented by a horizontal line within the box. Two vertical lines (the whiskers) extend above and below the box to the 10th and 90th percentiles. Data that fall outside of the 10th to 90th percentile range are shown as individual points. All boxplots in this report represent a minimum of 10 values. If fewer than 10 values were available, then the individual data points are shown.

Comparisons Between Groups—Statistical comparisons between groups were performed using multiple unbalanced analysis of variance (ANOVA) on rank-transformed data (Helsel and Hirsch, 1992). Rank transformation minimizes problems associated with data that are not normally distributed. Differences between groups were evaluated using Tukey's Honestly Significant Difference test on rank-transformed data with an alpha value of 0.05 (Helsel and Hirsch, 1992, p. 195–202; SAS Institute, 1989, p. 941–945). Groups which were found to be significantly different from one another are shown with different letter designations on the boxplots; groups with the same letter designation were not statistically different. All analyses were performed using the General Linear Models procedure of the SAS/STAT® software (SAS Institute, 1989).

Smooths—LOcally WEighted Scatterplot Smoothing (LOWESS) (Cleveland, 1979; Helsel and Hirsch, 1992) was applied to surface-water data to investigate and illustrate relations between variables. These plots, known as smooths, highlight trends in the data that are difficult to discern in a simple scatterplot. Smoothing is an attractive technique because no assumptions about the form of the relation (for example, linearity) are required. In smoothing procedures, nearby data points are used to calculate a 'smoothed value' for every data point. Each nearby data point is weighted so that more distant points influence the smoothed value less than points that are closer. The number of nearby points used to calculate the smoothed value is controlled by a smoothness factor. A smoothness factor of 0.5 was used for all smooths presented in this report. This means that the nearest 50 percent of all the data points were used to calculate each smoothed value.

Trend Analysis—The potential existence of temporal trends was explored graphically by smoothing flow-adjusted concentration data with respect to time. Flow-adjustment removes the variability in the concentration that is associated with a change in streamflow. Flow-adjusted concentrations were calculated as the difference between the measured concentrations and values obtained from a LOWESS smooth of concentration with respect to streamflow. The median measured concentration was then added to this difference to correctly center the flow-adjusted data. To summarize the procedure, two LOWESS smooths were used: the first to correct for any relation with flow, and the second to highlight any changes with time (fig. 15). Even this exploratory analysis of temporal trends was compromised by lapses in the data and uneven sampling intervals. Smoothed lines were broken for data lapses of 4 or more months. Statistical tests to detect long-term temporal trends in surface-water nutrient concentrations were not performed because sampling frequencies were not regular and because possible changes in collection and/or analysis techniques over time typically were unknown.

Load Calculations—Annual nutrient loads (in tons per year) were estimated using daily mean streamflow data from the USGS and estimated daily concentrations. Multiple linear regression was used to estimate daily nutrient concentrations. The regressor variables included the logarithm of streamflow, the sine and cosine of time (to model seasonal variations), and decimal time (to model long-term trends). Both sine and cosine terms were included because the seasonal phase shift was unknown. The logarithm of streamflow was used because distributions of daily streamflow values were approximately log-normal. The model having the smallest value of Mallow's C_p statistic (Draper and Smith, 1981) was chosen. This criterion is designed to simultaneously minimize error and the number of explanatory variables.

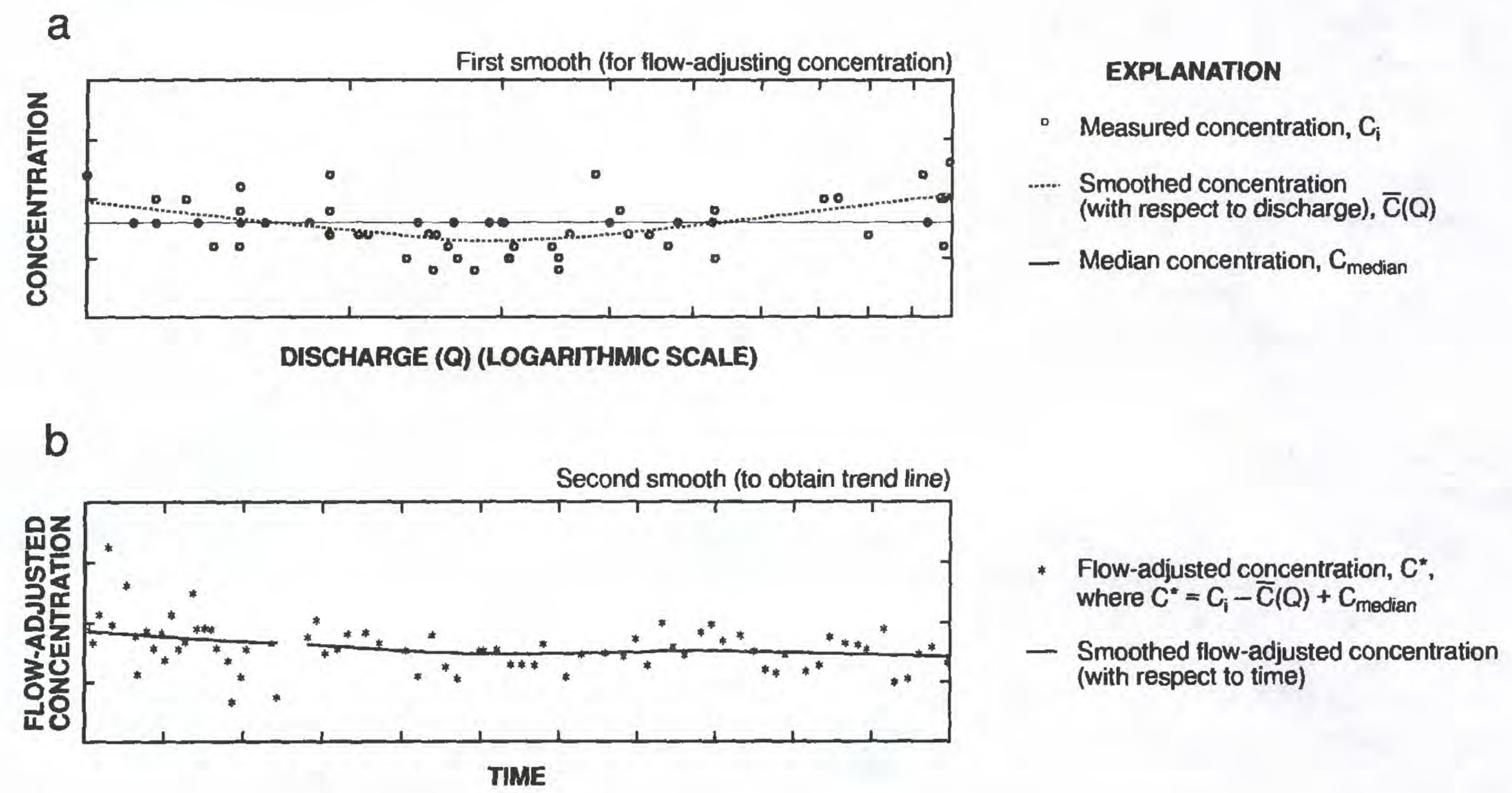


Figure 15. Example of procedure used to obtain trend lines: (a) concentration data are smoothed with respect to discharge to obtain flow-adjusted concentration; (b) then flow-adjusted concentrations are smoothed with respect to time to obtain trend line. (Trend line is broken for long lapses in data. Units on graph are arbitrary.)

SURFACE WATER

Data Selection and Description

The results of the initial data retrieval are summarized in table 4. Site locations are shown on figure 16a; the seasonal distribution is shown on figure 16b. The available data are generally skewed toward the summer season and toward sites located on the main stem of the Willamette River or at the mouths of its major tributaries.

Evaluation of Data

Data screening— The data were screened for duplicate entries and for inconsistencies before any analyses were performed. In all, approximately 0.5 percent of the nutrient data were eliminated due to inconsistencies. The screening procedures that were used are summarized below.

For some records, the concentration of an individual nutrient was reported under more than one name (parameter code). Different parameter codes were often associated with different units (for example, soluble reactive phosphorus [SRP] in mg/L [milligrams per liter] as P or in mg/L as PO_4). Both values were deleted if they differed by more than 10 percent when expressed in the same units.

Occasionally, a site had been sampled more than once on a given day. Data that were obtained within 4 hours of each other were replaced by their mean. If morning and evening samples had been taken, both values were retained so that the characteristics of diel variation would not be lost

The concentrations of related species were compared to uncover any inconsistencies. For example, if the SRP concentration exceeded the total phosphorus (total P) concentration by more than 10 percent, both values were deleted. Similar comparisons were made between total ammonia (NH_4-N) and total reduced nitrogen (TRN).

Data manipulation— Although many nutrient analyses were performed, data for some constituents were rare. In addition, different agencies did not always collect comparable data. Some data represented the concentrations of constituents that were dissolved; other data represented total concentrations. Similar data were combined when possible. The procedures used to combine data are summarized below.

Table 4. Summary of surface-water data retrieved for sites in the Willamette and Sandy River Basins, Oregon, 1980-90 water years.
[The databases are identified as follows: STORET, STOrage and RETrieval— U.S. Environmental Protection Agency database; NWIS, National Water Information System— U.S. Geological Survey database; PWB, Portland Water Bureau database]

Database	Number of sites	Number of measurements: Nutrients	Number of measurements: Suspended sediment
STORET	723	42,566	3,063
NWIS	64	2,560	1,551
PWB	4	2,703	858

Data for dissolved NH_4-N were not available at most sites. Data for total NH_4-N, however, were more common. Only data for total NH_4-N were analyzed. Data for total and dissolved NH_4-N were not combined because an examination of paired NH_4-N data (dissolved and total) from one USGS site showed that total NH_4-N concentrations exceeded dissolved concentrations by a small, but statistically significant, amount (mean relative difference 12%; n=47, α<0.01).

Similarly, suspended-sediment data (STORET parameter code 80154) were available only for USGS and PWB sites. For the ODEQ sites, only suspended-solids data (STORET parameter code 00530) were available. No paired data were available at any individual site. Limited data from two sites on the main stem Willamette River separated by 5.8 miles showed that the suspended-solids concentrations were approximately half the suspended-sediment concentrations. These data were not combined. Both types of data are shown in this report, but should be compared only qualitatively.

Three different measures of nitrate-related species were retrieved from the different databases: total nitrite plus nitrate (STORET and NWIS), total nitrate (PWB), and dissolved nitrite plus nitrate (NWIS). Data for these three constituents were combined and will be referred to in this report as NO_3-N. Nitrate and nitrite-plus-nitrate concentrations are expected to be nearly identical in well-oxygenated water samples, an assumption that is supported by the very low nitrite (NO_2-N) concentrations found at all sites. No statistically significant difference was found between total and dissolved nitrite-plus-nitrate concentrations (22 data pairs). If values for both dissolved and total

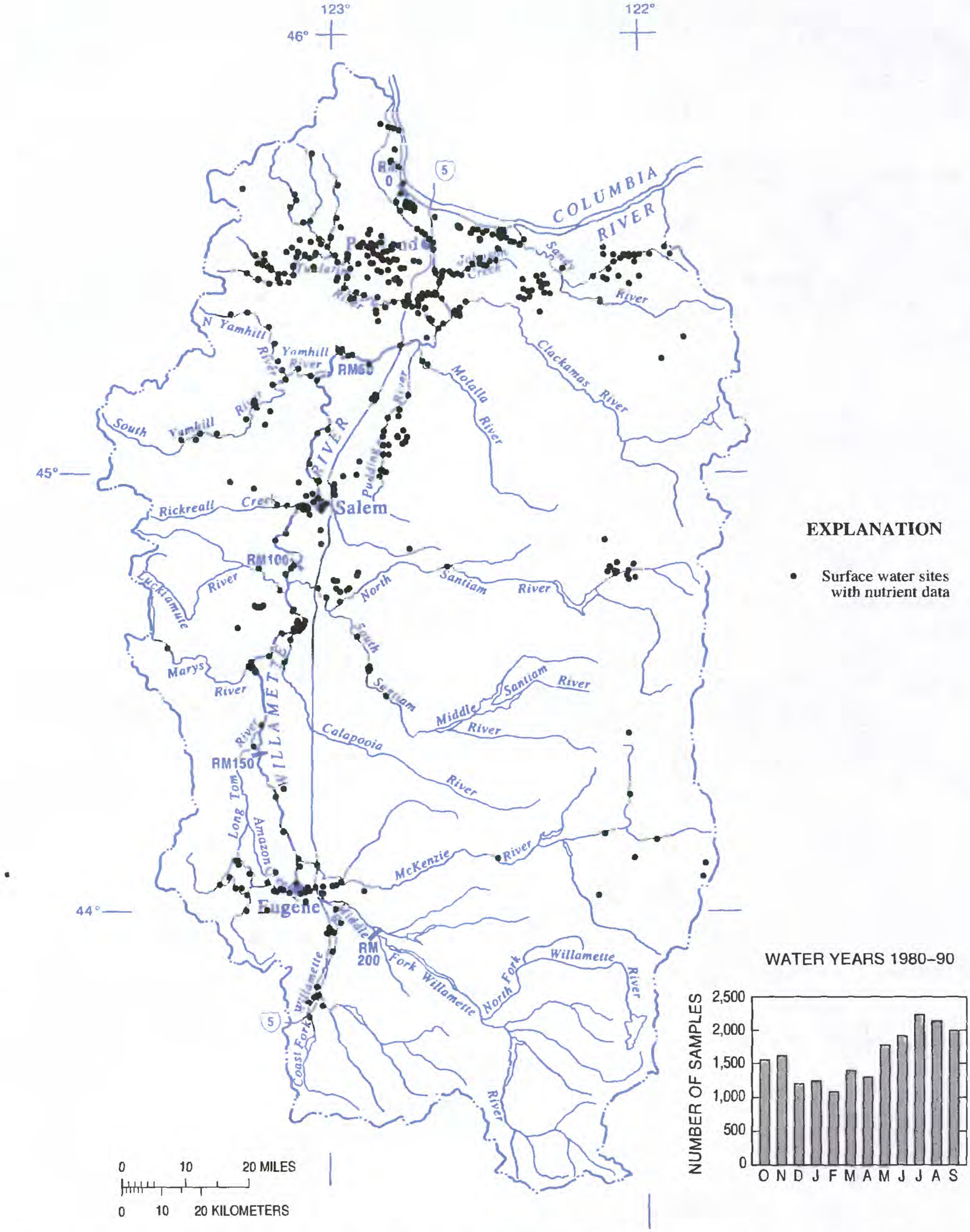


Figure 16. Locations of all surface-water sites with nutrient data in the Willamette and Sandy River Basins, Oregon, 1980–90 water years; graph showing seasonal distribution of the data. (Data from STORET, STOrage and RETrieval— U.S. Environmental Protection Agency database; NWIS, National Water Information System—U.S. Geological Survey database; and Portland Water Bureau database.)

nitrite plus nitrate were available, the value for dissolved nitrite plus nitrate was used.

Total nitrogen (total N) could not be directly retrieved from the STORET, NWIS, or PWB data bases and was calculated as the sum of NO_3-N and TRN. A consistent, albeit somewhat arbitrary, method was devised to calculate this constituent. Four cases were considered in the calculation: (1) both NO_3-N and TRN were greater than their respective detection limits, (2) both values were less than their detection limits, (3) NO_3-N was less than its detection limit, and TRN was detected, and (4) NO_3-N was detected, and TRN was less than its detection limit. A simple sum was used for case 1. For the remaining cases, the relative magnitudes of the detection limits had to be considered. The detection limits for NO_3-N and TRN determinations usually differed by an order of magnitude (0.02 and 0.2 mg/L as N, respectively, were common). The algorithms are summarized in table 5

Detection limits—Multiple detection limits are often associated with data obtained from different sources, and the data evaluated in this report were no exception. No effort was made to obtain a set of detection limits that applied for all of the surface-water data. Rather, detection limits were treated on a site-by-site basis. The reported detection limits did not vary among the records for an individual site.

Selection of Surface-Water Sites

Because the entire collection of surface-water records was large and because details concerning the nature of individual studies and the methods used for sampling and analysis generally were unavailable, a subset of the available data was created that was more suitable for statistical analysis. In choosing this subset, preference was given to data obtained from sites that were sampled repeatedly throughout the retrospective period. Fifty-five percent of the sites had been sampled 10 times or fewer; these records were not considered further. The remaining sites were evaluated with respect to the following criteria: (1) seasonal sampling frequency (monthly preferred), (2) length of data-record (entire retrospective period preferred), (3) location within the basin, (4) availability of streamflow data, and (5) proximity of major point sources. Based upon these criteria, a subset of the data (called the surface-water data set) was selected to represent the Willamette Basin and was used for all analyses discussed in this report.

Description of Surface-Water Sites

The surface-water data set is comprised of data from 10 sites (fig. 17; transparency† 1). Characteristics of the surface-water sites are summarized in table 6. Seven of the surface-water sites were classified as

Table 5. Calculation of total nitrogen
[Variables are defined as follows: $value_{NO3}$, nitrite-plus-nitrate concentration; $value_{TRN}$, total reduced nitrogen concentration; DL_{NO3}, detection limit for the nitrite-plus-nitrate determination; DL_{TRN}, detection limit for the total reduced nitrogen determination. All values and detection limits expressed in units of milligrams per liter as nitrogen; case frequency expressed as percent]

Case	Nitrite+nitrate value	Total-reduced-nitrogen value	Condition	Total nitrogen calculation	Case frequency
1	$value_{NO3}$	$value_{TRN}$	none	$value_{NO3} + value_{TRN}$	84
2	$< DL_{NO3}$	$< DL_{TRN}$	$DL_{NO3} \leq 0.1\ DL_{TRN}$	$< DL_{TRN}$	5
3	$< DL_{NO3}$	$value_{TRN}$	$DL_{NO3} \leq 0.1\ value_{TRN}$	$value_{TRN}$	3
4a	$value_{NO3}$	$< DL_{TRN}$	$value_{NO3} < 0.5\ DL_{TRN}$	$< DL_{TRN}$	7
4b	$value_{NO3}$	$< DL_{TRN}$	$value_{NO3} \geq 0.5\ DL_{TRN}$	$value_{NO3} + 0.5\ DL_{TRN}$	1

†A transparency of the site-location map is provided to facilitate comparisons to maps of land use, geology, and other ancillary data.

Table 6. Characteristics of primary and nested subbasin surface-water sites in the Willamette and Sandy River Basins, Oregon

[Abbreviations are defined as follows: mi^2, square miles; PWB, Portland Water Bureau; EWI, samples obtained by isokinetic, depth- and width-integrated method; Grab, samples obtained at the center of flow at about one meter below the surface; NPDES, National Point Discharge Elimination System— major and minor point sources that are registered with the U.S. Environmental Protection Agency; ODEQ, Oregon Department of Environmental Quality; WWTP, municipal wastewater treatment plant; USGS, United States Geological Survey; NASQAN, National Stream Quality Accounting Network— an ambient monitoring program of the USGS; TMDL, Total Maximum Daily Load]

Site [Site number]	Basin area (mi^2)	Land use: Land-use percent		Land use: Upstream influences	Land use: Designated land use	Data collection: Collecting agency	Data collection: Sampling method	Data collection: Purpose, Frequency and duration
Primary Sites								
Fir Creek near Brightwood [14138870]	5.8	Forest	100		Forest	PWB	EWI, Grab	Ambient monitoring Biweekly: 7/1/85 – 9/30/90
Middle Fork Willamette River at Jasper Bridge [435959122543401]	1,340	Agriculture Forest Urban Water/wetland	1 96 1 2	4 reservoirs; minor NPDES	Forest	ODEQ	Grab	Ambient monitoring Monthly: 10/1/79 – 10/31/89 Intermittent: 11/1/89 – 9/30/90
Long Tom River at White Bridge [442020123174401]	394	Agriculture Forest Urban Water/wetland	28 58 9 5	1 reservoir; minor NPDES	Agriculture (Urban)	ODEQ	Grab	Ambient monitoring Intermittent: 4/1/82 – 9/30/90
South Yamhill River at US Hwy 99W [451010123124301]	464	Agriculture Forest Urban Water/wetland	35 63 1 1	minor NPDES	Agriculture	ODEQ	Grab	Ambient monitoring Monthly: 10/1/79 – 9/30/90
Pudding River at US Hwy 99E [451408122445201]	480	Agriculture Forest Urban	59 37 4	1 major NPDES (WWTP); minor NPDES	Agriculture	ODEQ	Grab	Ambient monitoring Intermittent: 10/1/79 – 9/30/84 Monthly: 10/1/84 – 9/30/90
Willamette River at Portland (RM 12.8) [14211720]	11,200	Agriculture Forest Urban Water/wetland	24 70 5 1	20 major NPDES; minor NPDES	Mixed	USGS	EWI	NASQAN program Bimonthly: 10/1/79 – 9/30/90
Willamette River at SPS Bridge (RM 7.0) [453446122444201]	11,200	Agriculture Forest Urban Water/wetland	24 70 5 1	22 major NPDES; minor NPDES	Mixed	ODEQ	Grab	Ambient monitoring Monthly: 10/1/79 – 9/30/90
Nested Subbasin Sites								
Dairy Creek at Hwy 8 [453114123004301	227	Agriculture Forest Urban	39 58 3		Agriculture	ODEQ	Grab	TMDL study Monthly: 1/1/88 – 9/30/90 Weekly: May-Sept, 1989–90
Fanno Creek at Durham [452413122451301]	31	Agriculture Barren Forest Urban	14 2 12 72		Urban	ODEQ	Grab	TMDL study Monthly: 7/1/87 – 9/30/90 Weekly: May-Sept, 1989–90
Tualatin River at Weiss Bridge [452023122391401]	714	Agriculture Forest Urban	38 49 13	2 major NPDES (WWTP); minor NPDES	Mixed	ODEQ	Grab	TMDL study Monthly: 7/1/88 – 9/30/90 Weekly: May-Sept, 1989–90

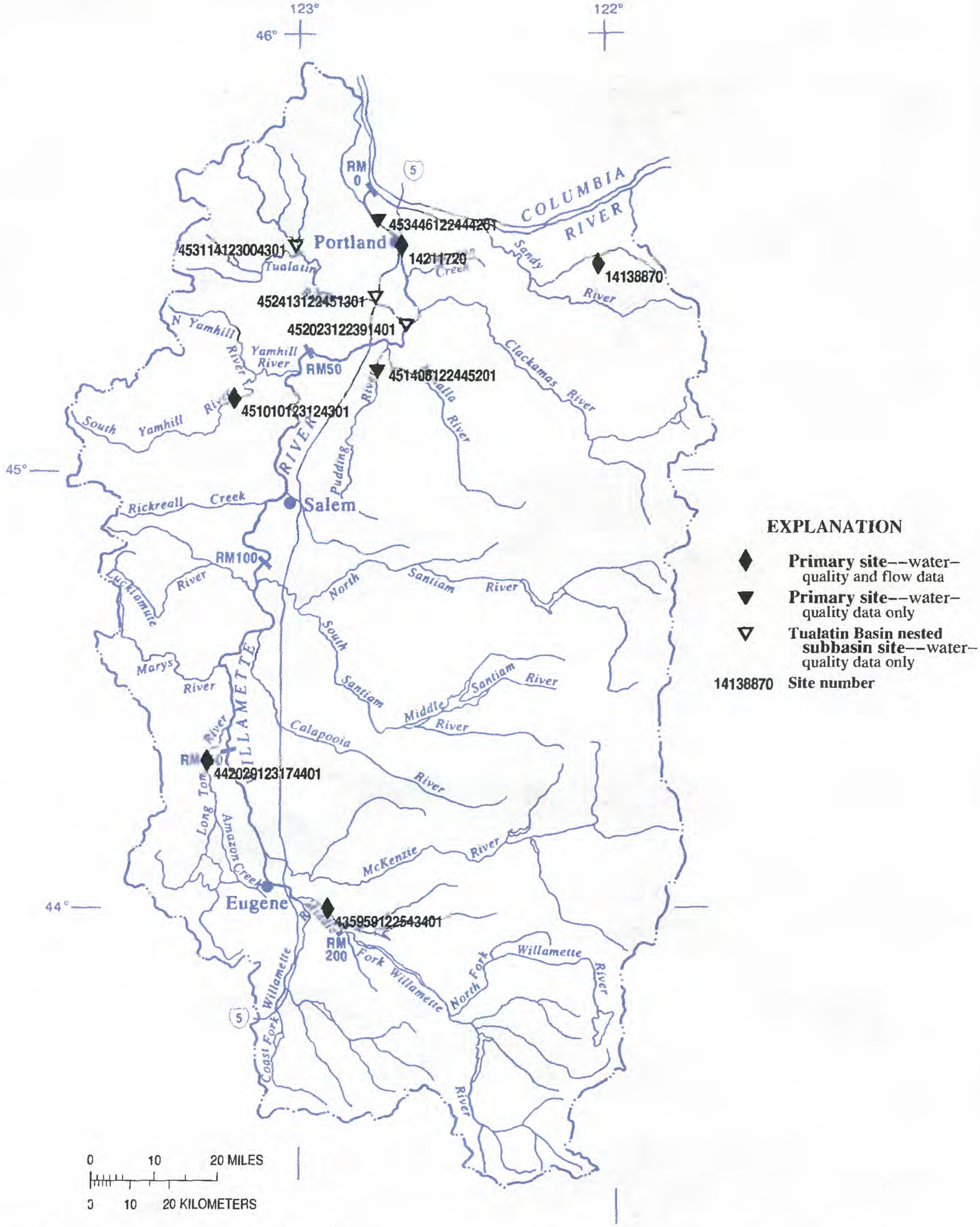


Figure 17. Locations of primary and nested-subbasin surface-water sites in the Willamette and Sandy River Basins, Oregon.

primary sites; data from these sites were used for most of the analysis presented in this report. The northern and southern regions of the Willamette Basin are represented by the seven primary sites, as are basins draining the Cascades and basins draining the Coast Range. The three other sites in the surface-water data set are located in the Tualatin River Basin and are classified as nested subbasin sites. These sites allow lower-order streams within the same subbasin (Fanno and Dairy Creeks) to be compared to each other and to a common, and much larger, receiving stream (Tualatin River). A brief description of each site follows. Summary statistics for the surface-water-quality data are provided in table 12 in the Supplemental Data section.

Fir Creek (river mile [RM] 0.6; site elevation, 1440 ft)—Fir Creek, a small mountain stream that is fed primarily by rainfall and local ground water, is the most pristine of all sites in the surface-water data set. The Fir Creek drainage is part of the Bull Run Reserve, a 102 mi^2 watershed that is protected from human activity because it is the primary drinking-water source for the City of Portland. The drainage basin is entirely forested; most of it has never been logged. The primary anthropogenic input to the Fir Creek Basin is atmospheric deposition.

Fir Creek is the only site located in the Sandy River Basin; as such, it may not be representative of small Willamette River Basin streams.

Middle Fork Willamette River (RM 8.0; site elevation, 514 ft)—The Middle Fork Willamette River, whose basin encompasses the southeastern part of the Willamette Basin, is generally considered to be the source of the main stem Willamette River (fig. 1). The upper portions drain the mountainous terrain of the Cascades. The basin is mostly forested and is actively logged. Three reservoirs regulate the flow of the Middle Fork Willamette River (RM 16.8, 20.0, and 45.8); an additional reservoir regulates flow on Fall Creek, a tributary of the Middle Fork Willamette River. No major NPDES permittees are located in this basin. Half of the six minor NPDES permittees in this basin discharge upstream of at least one reservoir. A fish hatchery and a small municipality discharge below the reservoirs.

Long Tom River (RM 6.7; site elevation, 271 ft)—The Long Tom River is regulated by Fern Ridge Reservoir (RM 25.8). The drainage area encompasses agricultural land, forests, and much of the City of Eugene (population 117,155 [Center for Population Research and Census, 1992]). The forested areas in the basin are located primarily above the reservoir, in the foothills of the Coast Range, and have been heavily logged. Below the reservoir, agriculture predominates; much of the river in this section lacks riparian cover. Urban runoff from the City of Eugene enters the Long Tom River both above and below the reservoir. Although no major NPDES permittees discharge into the Long Tom River or its tributaries, a number of minor NPDES permittees do, including 2 municipalities (domestic waste) and 10 dischargers of industrial waste. Most of the industrial dischargers are forest products industries (plywood mills and wood preserving facilities). All but one of these point sources discharge below the reservoir.

South Yamhill River (RM 17.0; site elevation, 82 ft)—The South Yamhill River drains the Coast Range and meanders through farm and grazing land in the coastal foothills. A substantial portion of the basin is forested, almost entirely as second growth, and is actively logged. In addition to field crops, the South Yamhill Basin supports numerous orchards, vineyards, and caneberry fields. No major NPDES permits have been issued in this basin; 11 minor NPDES permittees are present. Minor dischargers include four municipalities (domestic and industrial wastes), four forest products industries, and a steel rolling mill. In addition to these point sources, leachate from a landfill in the basin is a suspected source of contamination to the South Yamhill River.

Pudding River (RM 8.1; site elevation, 72 ft)—The Pudding River drains the most intensive agricultural region represented in the surface-water data set. Most of the main stem (about 50 of 63 miles) of the Pudding River meanders slowly through the valley floor. Farms in this basin tend to be relatively small and highly diversified. Much of the agriculture is intensively managed. The basin is dotted with small- to medium-sized towns. The largest town, Woodburn (population 13,525 [Center for Population Research and Census, 1992]), discharges effluent from its wastewater treatment facility into the Pudding River and is the only major NPDES permittee in the basin. A number of minor NPDES permittees discharge into the Pudding River Basin, including two poultry farms, two food processing plants, a meat processing plant, and four municipalities.

Willamette River at Portland (RM 12.8; site elevation, 1.5 ft) and at SPS Bridge (RM 7.0)—Both of these sites are located in the Portland Harbor area in the center of urban Portland. This lower section of the Willamette River is separated from the upstream portion of the river by Willamette Falls (RM 26.5), and is tidally influenced by colder Columbia River water, which moves along on the channel bottom. The channel is dredged to a depth of 40 ft. In addition to receiving input from all upstream Willamette Basin sources, these sites are influenced by urban runoff, industrial discharges, and combined sewer overflows from the City of Portland. A number of point sources (2 major and 18 minor NPDES permittees, as well as 14 combined sewer overflows) discharge into the Willamette River between the two sites, and could account for water-quality differences between the sites.

Nested subbasin sites—The Dairy Creek (RM 1.8), Fanno Creek (RM 1.2), and Tualatin River (RM 0.2) sites are all located in the Tualatin River Basin. Dairy Creek drains agricultural and forested areas. Fanno Creek drains urban areas. The Tualatin River site is located near the mouth of the river and drains an area of mixed land use. Several NPDES permittees, including two major municipal wastewater treatment plants, discharge into the Tualatin River upstream of this site.

Land Use

The land uses associated with each site were determined by superimposing GIRAS land-use data on the drainage basin for each site. The subbasin drainage areas and land-use data are summarized in table 6. Clearly, the Fir Creek and Middle Fork Willamette River sites represent forested basins. For the other sites in this data set, however, identifying a dominant land use is more subjective. Several sites are influenced by the presence of upstream point sources and(or) flow regulation. Although the major tributaries drain large areas and integrate the effects of all upstream land uses and point sources, only the main stem sites (Willamette River at Portland and Willamette River at SPS Bridge) and the Tualatin River site were designated as mixed land-use sites. The remaining sites were designated as agricultural if at least 25 percent of the drainage basin area was agricultural land and if the percentage of urban land was small. Urban sites were similarly identified. The Long Tom River site was assigned a secondary urban land use because the proportion of urban land in this drainage area is probably too great to be ignored. The land-use designations should be considered approximate.

Temporal Considerations

Because nutrient concentrations may vary seasonally and with flow, distributions of data with respect to time are important. As might be expected for historical data, not all sites were sampled with the same frequency. Furthermore, at an individual site, the frequency of sampling varied among the constituents. For example, NO_2-N determinations were rare, while NO_3-N determinations were relatively frequent and occurred at approximately regular intervals. Generalized temporal distributions of nutrient data were defined using dates for which both total N and total P data were available (fig. 18). Note that for all sites, sampling schedules changed over time and lapses in sampling were common. In general, sampling frequencies increased during summer months. Despite the irregularities in sampling frequency, the data were reasonably well-distributed seasonally; seasonal trends probably were captured by these data. Long-term trends were more difficult to assess because of the data lapses and irregular sampling intervals.

Data distributions with respect to streamflow are shown on figure 19. (Daily streamflow data were unavailable for the Pudding River, Dairy Creek, Fanno Creek, and Tualatin River sites.) Flow percentile ranks were obtained by comparing daily mean streamflow on the sampling date to the distribution of all the daily mean streamflow values for water years 1980 through 1990 (table 7). Ideally, the distributions shown on figure 19 would be uniform (the same number of samples would be represented by each equal range of percentiles). None of the distributions were perfectly uniform, but the irregularities in the distributions for three sites (Middle Fork Willamette River, Willamette River at Portland, and Fir Creek) appeared to be random. Sampling distributions are skewed toward low flow at the South Yamhill River and the Long Tom River sites. In addition, the Long Tom River site had few samples representing high flows.

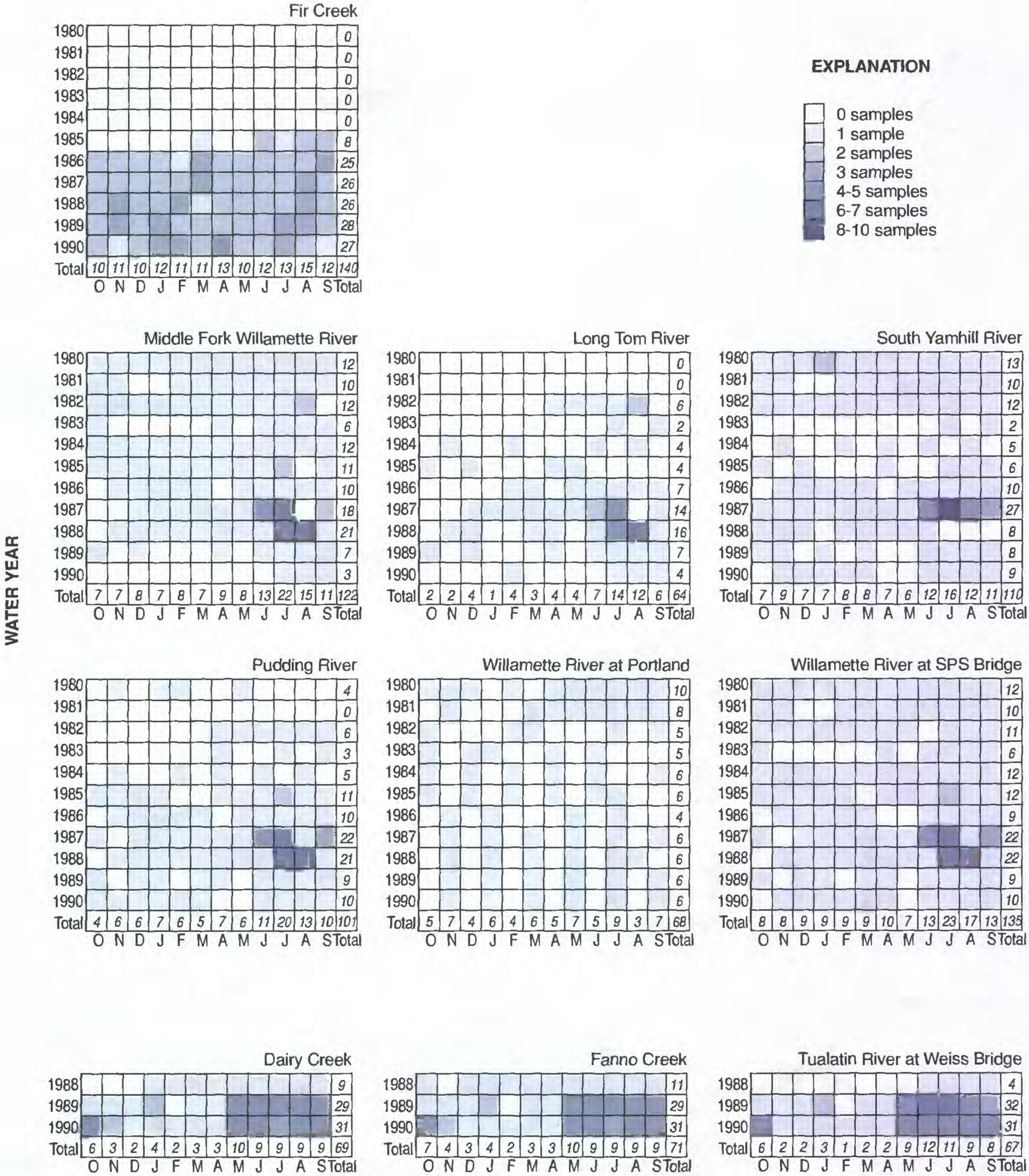


Figure 18. Seasonal and long-term distributions of data (total nitrogen and total phosphorus) from primary surface-water sites in the Willamette and Sandy River Basins, Oregon. (Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

Table 7. Streamflows corresponding to the indicated percentile ranks for primary surface-water sites in the Willamette and Sandy River Basins, Oregon
[Values expressed in cubic feet per second; ranks based on daily data for 1980–90 water years]

Site	Percentile ranks										
	Minimum	10th	20th	30th	40th	50th	60th	70th	80th	90th	Maximum
Fir Creek	8	39	59	10	16	23	29	37	49	71	536
Middle Fork Willamette River	1,030	1,540	1,730	1,990	2,460	3,085	3,770	4,640	5,370	7,450	20,900
Long Tom River	17	34	42	64	129	224	385	763	1,090	2,000	7,130
South Yamhill River	4	36	64	139	318	601	951	1,480	2,440	4,450	27,500
Willamette River at Portland	6,700	8,200	10,100	13,200	17,000	21,800	27,000	35,900	47,000	72,400	213,000

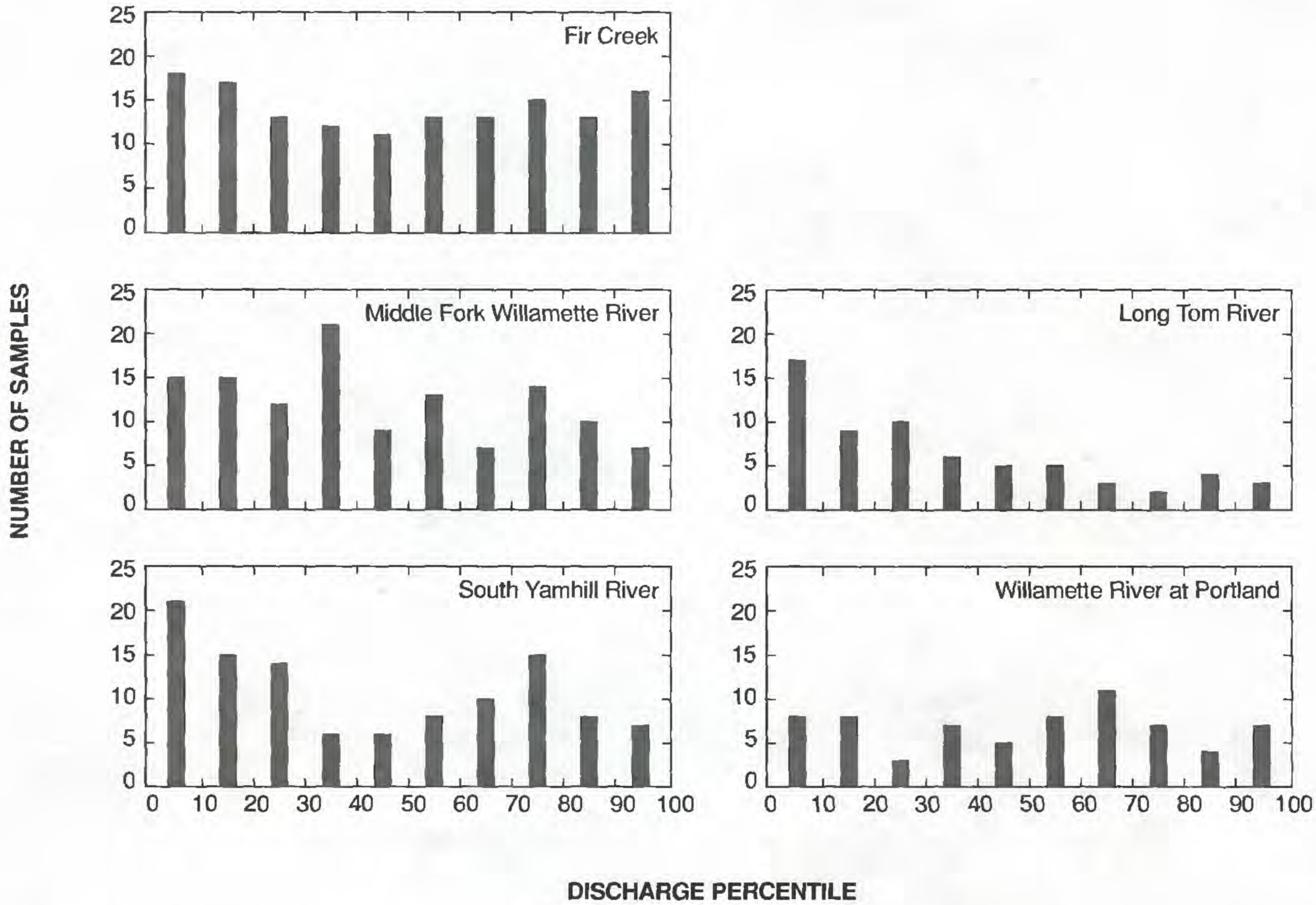


Figure 19. Frequency distributions of total nitrogen and total phosphorus determinations as a function of discharge for primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

Data Acquisition Methods

Sampling and analytical methods—Eight sites in the surface-water data set were sampled by ODEQ. Five of the eight sites were part of a long-term ambient water-quality monitoring program. The remaining three ODEQ sites (the nested Tualatin Basin sites) were used in a study of nutrient loads (G. A. Pettit, ODEQ, oral commun., 1993). At all ODEQ sites, grab samples were taken in the center of flow, at a depth of 3 ft below the water surface. Samples for SRP analysis were filtered through a 0.45-µm (micrometer) membrane filter in the field. NO_3-N determinations were performed using automated cadmium reduction (U.S. Environmental Protection Agency, 1979, EPA Method 353.2). TRN determinations were performed by the automated phenate method (U.S. Environmental Protection Agency, 1979, EPA Method 351.1). Total P and SRP were determined by colorimetric ascorbic acid reduction, with and without persulfate digestion, respectively (U.S. Environmental Protection Agency, 1979, EPA Method 365.2). Suspended solids were operationally defined as the mass that was retained on a 0.45-µm filter.

Data for the Willamette River at Portland were collected by the USGS as part of the National Stream-Quality Accounting Network (NASQAN) program. A depth- and width-integrated sampling method was used, and samples were collected isokinetically. In isokinetic sampling, water undergoes no change in speed or direction as it enters the sampling device. This method is designed to avoid errors associated with incomplete mixing within the river and to ensure the representative sampling of suspended sediment (Edwards and Glysson, 1988). Samples to be analyzed for dissolved nutrient species were filtered through 0.45-µm membrane filters. Samples were preserved according to standard USGS procedures (Ward and Harr, 1990). NO_3-N determinations were performed by the automated cadmium reduction procedure (Fishman and Friedman, 1989, USGS Method I-2545-78). TRN determinations were performed by block digestion with an automated colorimetric salicylate-hypochlorite method (Fishman and Friedman, 1989, USGS Method I-4552-78). Colorimetric phospho-molybdate methods were used for total P and for SRP (Fishman and Friedman, 1989, USGS Methods I-4600-78 and I-2601-78, respectively).

Data for Fir Creek were collected by the PWB and the USGS as part of an ongoing effort to monitor water quality in the Bull Run watershed— the primary source of drinking water for the City of Portland. Both grab sampling and depth- and width-integrated sampling techniques were used. Approximately half of the nutrient samples from Fir Creek are known to have been collected using depth- and width-integrated methods. Suspended-sediment samples were collected isokinetically using depth- and width-integrated methods. The sampling methods used for the remaining samples are unknown. NO_3-N determinations were performed on unfiltered samples using the brucine colorimetric method (U.S. Environmental Protection Agency, 1979, EPA method 352.1). TRN was determined with an ion-selective ammonium electrode after mercury-catalyzed acid digestion (U.S. Environmental Protection Agency, 1979, EPA Method 351.4). The acid-digested samples also were analyzed for total P by the stannous chloride method (American Public Health Association and others, 1989, Method 4500-P D). SRP was determined on unfiltered samples using the same stannous chloride method. Turbidity corrections were applied to the SRP determinations (Alberta Seierstad, PWB, oral commun., 1993).

Quality assurance of nutrient data—The ODEQ laboratory is certified by the USEPA and is the USEPA certification laboratory for non-bacteriological analyses for the State of Oregon. The laboratory maintains an extensive in-house quality assurance program, including analyses of replicate samples and laboratory spikes. They also participate in multi-laboratory comparison studies. Determinations for total P by the ODEQ laboratory before 1982 are thought to have a negative bias (Oregon Department of Environmental Quality, 1992a, p. 3–48). No other analytical problems are known for the ODEQ nutrient data used in this report (Claude Shin, ODEQ, oral commun., 1993).

The USGS samples were analyzed by the National Water Quality Laboratory (NWQL) in Denver, Colorado. The quality assurance program at the NWQL includes replicate analyses and laboratory spikes. Annual reports (starting in 1983) describing the performance of the NWQL are available from the USGS Branch of Quality Assurance (T. Maloney, USGS, oral commun., 1993). The NWQL experienced ammonia contamination problems during water years 1980 through 1982, resulting in a positive analytical bias in NH_4-N and TRN concentrations during that time. Other analytical problems during the same 1980–82 time period resulted in positively biased phosphorus determinations.

The PWB laboratory follows the USEPA's quality assurance guidelines (U.S. Environmental Protection Agency, 1982). Replicates and spiked samples each account for 10 percent of all laboratory analyses. Reference samples are analyzed daily. There are no known analytical problems for the PWB data used in this report (Alberta Seierstad, PWB, oral commun., 1993).

Streamflow data—Few streamflow data were available from the STORET data base for the ODEQ sites. Four of these sites were near USGS stream gaging stations, and daily mean streamflows at these gaging stations were used in this report (table 8) Both instantaneous streamflow measurements and daily mean streamflow values were available for Willamette River at Portland and Fir Creek. The two streamflow measurements were similar in almost all instances; the daily mean values were used in this report to maintain consistency among sites. Daily streamflow data were unavailable for the Pudding River site and the nested Tualatin Basin sites.

Suitability of Data for Analysis

The surface-water data set is not fully representative of the Willamette Basin. Most of the sites are located on the main stem of the Willamette River or near the mouths of its major tributaries. It is unlikely that data from these sites represent any 'hot spots' of contamination because of the dilution that occurs in rivers of this size. Two of the nested subbasin sites, Dairy and Fanno Creeks, represent low-order streams draining small basins; they should be more directly influenced by land use than are the larger, higher-order rivers. Data from Dairy and Fanno Creeks will be compared with those from the Tualatin River in order to investigate the relation between upstream sites with dominant land-use and a downstream site that integrates the upstream influences. The data from Dairy Creek and Fanno Creek were limited to 1988–90 water years, and therefore, cannot be directly compared with the remainder of the data.

Because data were collected by different agencies, care must be taken to avoid conclusions that could be due to differences in sampling methods, analytical methods, and sampling frequencies. A comparison of data collected at a USGS site and an ODEQ site within 6 mi of each other (Willamette River at Portland and Willamette River at SPS Bridge, respectively) will be used to identify differences that may be attributed to the different sampling and analytical methods used by these agencies. As discussed previously, some of the data analyzed in this report are compromised by problems with analytical methods and laboratory contamination. Although the errors were not large, they were time-dependent, and therefore could create small spurious temporal trends in the data or mask small existing trends. Similarly, the inevitable changes and refinements in laboratory procedures that occur over a 10-year period could result in spurious temporal trends. For these reasons, small temporal trends in these data should be interpreted with caution.

Table 8. Correspondence of Oregon Department of Environmental Quality (ODEQ) sampling sites with U.S. Geological Survey (USGS) stream-gaging stations
[RM, river mile]

ODEQ Sampling site		USGS stream-gaging station	
Site name	Location	Station name	Location
Long Tom River at White Bridge	RM 6.7	Long Tom River at Monroe	RM 6.8
Middle Fork Willamette River at Jasper Bridge	RM 8.0	Middle Fork Willamette River at Jasper	RM 8.0
South Yamhill River at US Hwy 99W	RM 17.0	South Yamhill River Near Whiteson	RM 16.7
Willamette River at SPS Bridge	RM 7.0	Willamette River at Portland	RM 12.8

Analysis of Ancillary Data

Several general physical and chemical measures are important because they indicate and influence water quality. Four such measures are streamflow, water temperature, specific conductance, and pH.

Streamflow directly affects the total mass of constituent transported per unit time (instream load). Streamflow also influences the concentrations of both dissolved and suspended constituents, but the relation between concentration and streamflow is not straightforward. For example, high flows can reduce concentrations by diluting point-source inputs, or, conversely, they can be associated with additional inputs, such as nonpoint-source contaminants in surface runoff. Because streamflows vary among sites and at an individual site, these effects should be considered whenever concentrations are compared.

Water temperature influences the entire aquatic ecosystem, including the composition of the biological community and the chemical behavior of the system. Most living organisms have adapted to and tolerate only limited temperature ranges (U. S. Environmental Protection Agency, 1986; Lagler, and others, 1977). For example, water temperatures exceeding 20°C have been reported as limiting for salmonid species, and temperatures exceeding 25°C can be lethal. Temperature also influences the chemical behavior of many dissolved constituents. These effects are usually subtle, except for a few cases, such as the solubilities of gases, which decrease with increasing temperature. This effect is particularly important for dissolved oxygen (DO), and is one cause of the seasonal variation in the DO concentration.

Specific conductance is a measure of the ability of water to conduct electricity. Because ions (charged chemical species) are directly responsible for the electrical conductance of a water sample, specific conductance is a rough indicator of the total concentration of ions. Dissolved ions may originate from the natural dissolution of minerals, as well as from point and nonpoint sources. Specific conductance measurements are useful for comparing water from different sites, but cannot be used to determine ion concentrations.

Water chemistry and, in turn, water quality, are profoundly affected by the relative acidity, or hydrogen ion (H^+) activity, of the water, which is usually expressed using the pH scale. Hydrogen ions participate in many equilibrium reactions in natural waters. Consequently, the H^+ activity or pH can be used to indicate which chemical species predominate.

Distinctions among different chemical species can be very important, especially when considering the toxicity of a weak acid or base. In the case of ammonia, the non-toxic, ionized form (NH_4^+) is dominant when the pH is low (<9.3); but when the pH is high (>9.3), the toxic, neutral form (NH_3) is dominant. The H^+ activity also affects the dissolution and precipitation of solids, and the rates and products of oxidation-reduction reactions.

A pH standard for the Willamette River and its tributaries has been established by ODEQ as the range 6.5–8.5 (Oregon Department of Environmental Quality, 1992b, p. 30). Water having a pH value outside of this range can be toxic to freshwater aquatic organisms (Wiederholm, 1984; U. S. Environmental Protection Agency, 1986).

Site Comparisons

Comparisons among the seven primary sites in the Willamette Basin with respect to streamflow, water temperature, specific conductance, and pH are shown on figure 20.

Except for the Long Tom River site, the distributions of streamflow associated with the water-quality data closely resemble the distributions of all streamflow data for water years 1980–1990. The water-quality data for the Long Tom River site is biased toward low flow (see also fig. 19). Among all sites, daily mean streamflows spanned more than five orders of magnitude. Even at an individual site, streamflows varied by at least an order of magnitude, and at some sites they varied by much more. The greatest relative streamflow range, about four orders of magnitude, occurred at the South Yamhill River site.

The agricultural sites generally were associated with slightly elevated water temperatures and the largest values of specific conductance. Temperatures exceeding 25°C occurred only at the agricultural basin sites. The specific conductance values at the agricultural sites were generally two or more times greater than those measured at the forested basin sites. Although the forested basin sites had lower water temperatures and specific-conductance values than did either the agricultural basin or mixed-use sites, the forested basin sites also differed from one another. The

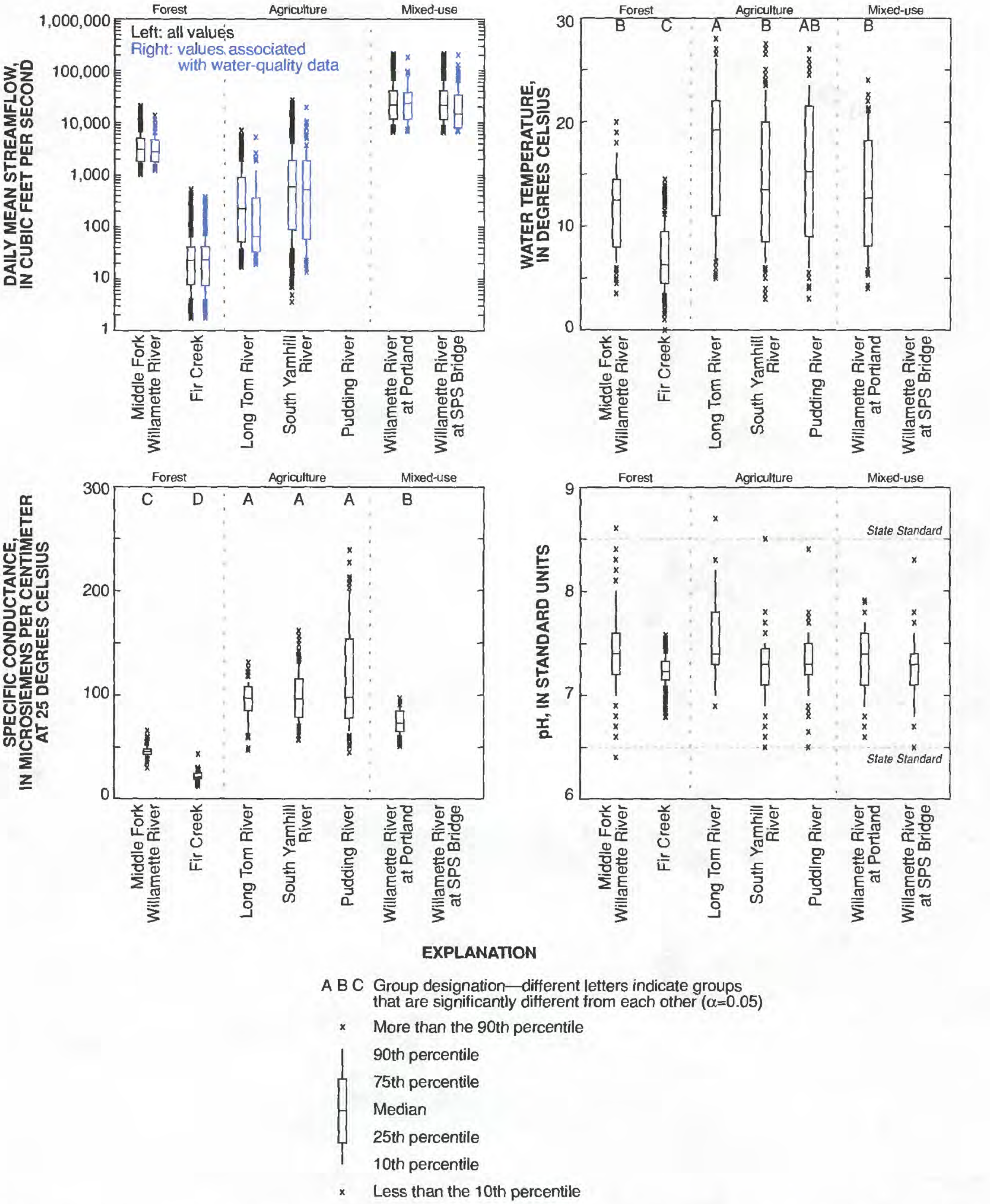


Figure 20. Streamflow, water temperature, specific conductance, and pH at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey. Streamflow data were not available for the Pudding River site. Water temperature and specific conductance data were not available for the Willamette River at SPS Bridge site.)

consistently lower water temperatures at Fir Creek may have been due to the higher elevation of the Fir Creek site and (or) the lack of impoundments; the lower specific conductance values may have been related to the lack of human activity or to the geology of the Fir Creek Basin. The pH values were similar for all sites and only rarely fell outside of ODEQ limits (4 of 1,200 measurements)

Seasonality

Streamflow, water temperature, specific conductance and pH all exhibit seasonal variability (figs. 21—24). Maximum streamflows occur in winter; minimum flows occur in summer (fig. 21). This pattern parallels the annual precipitation pattern (fig. 5). In general, the monthly distributions of daily mean streamflows associated with water-quality data (fig. 21, in blue) closely resemble the distributions of all daily mean streamflows (in black).

Water-temperature ranges at the forested sites were generally smaller than those at either the agricultural or mixed land-use sites (fig. 22). Summer water temperatures, in particular, were elevated at the agricultural sites. From June through September, water temperatures exceeding 20°C occurred with frequencies of 70, 67, and 55 percent at the agricultural sites (Long Tom, Pudding, and South Yamhill Rivers, respectively). In contrast, water temperatures at the two forested sites (Middle Fork Willamette River and Fir Creek) never exceeded 20°C; those at the mixed land-use site, Willamette River at Portland, exceeded 20°C during 42 percent of the time. The higher summer water temperatures at agricultural sites may be related to the relative lack of riparian areas, and the resulting lack of shade, associated with agricultural watersheds. Differences in elevation also may have affected the water temperature; relative to forested basins, greater proportions of the agricultural basins are at low elevation.

At the Fir Creek site and all three agricultural sites, specific conductance varied seasonally and appeared to be inversely related to streamflow (fig. 23). Low specific conductance values coincided with the winter high-flow period; high values coincided with low flow near the end of the summer. This relation with streamflow is characteristic of systems in which the primary sources of ions are diluted upon mixing with runoff. The magnitude of the seasonal variation was greatest for two of the agricultural sites, South Yamhill River and Pudding River. Decreased dilution of the effluent from a wastewater treatment plant (major NPDES permittee) may explain some of the summer increase in specific conductance at the Pudding River site. Several small wastewater treatment plants discharge into the South Yamhill River, but all of these are minor NPDES permittees. The South Yamhill River does, however, exhibit particularly low streamflow during summer. Because both the Pudding and South Yamhill Rivers are in agricultural areas, the return of water from irrigated fields could constitute an important additional source of ions during summer.

The seasonal variation in pH was small, similar for all sites, and characterized by generally lower pH values during winter and higher pH values during summer (fig. 24). The summer increase may have been due to the consumption of carbon dioxide (CO_2) by algae engaged in photosynthesis. As CO_2 becomes depleted, the water becomes less acidic (higher pH). Increases in pH may be particularly pronounced in the uppermost water layers of larger, slow-moving rivers during summer daylight hours.

Analysis of Suspended-Sediment and Suspended-Solids Data

Suspended material is usually of interest because a variety of other constituents, including metal ions, organic compounds, and bacteria, adhere to it. Many of these constituents have low water solubilities, and are transported primarily with suspended material. In addition to its role in the transport of other constituents, suspended material also may affect the quality of an ecosystem by depositing on stream beds, thereby degrading benthic-invertebrate habitat and fish spawning grounds. High concentrations of suspended material typically are associated with storms. Suspended material is contributed from the watershed by surface runoff, from the channel bed and bank by erosion and resuspension.

Measurements of the concentration of suspended material are highly variable and depend upon the sampling and analytical methods used. Not all of the data presented in this report were collected or analyzed by the same methods and, therefore, may not be comparable. In particular, suspended-solids concentrations from grab samples (ODEQ) may be less than

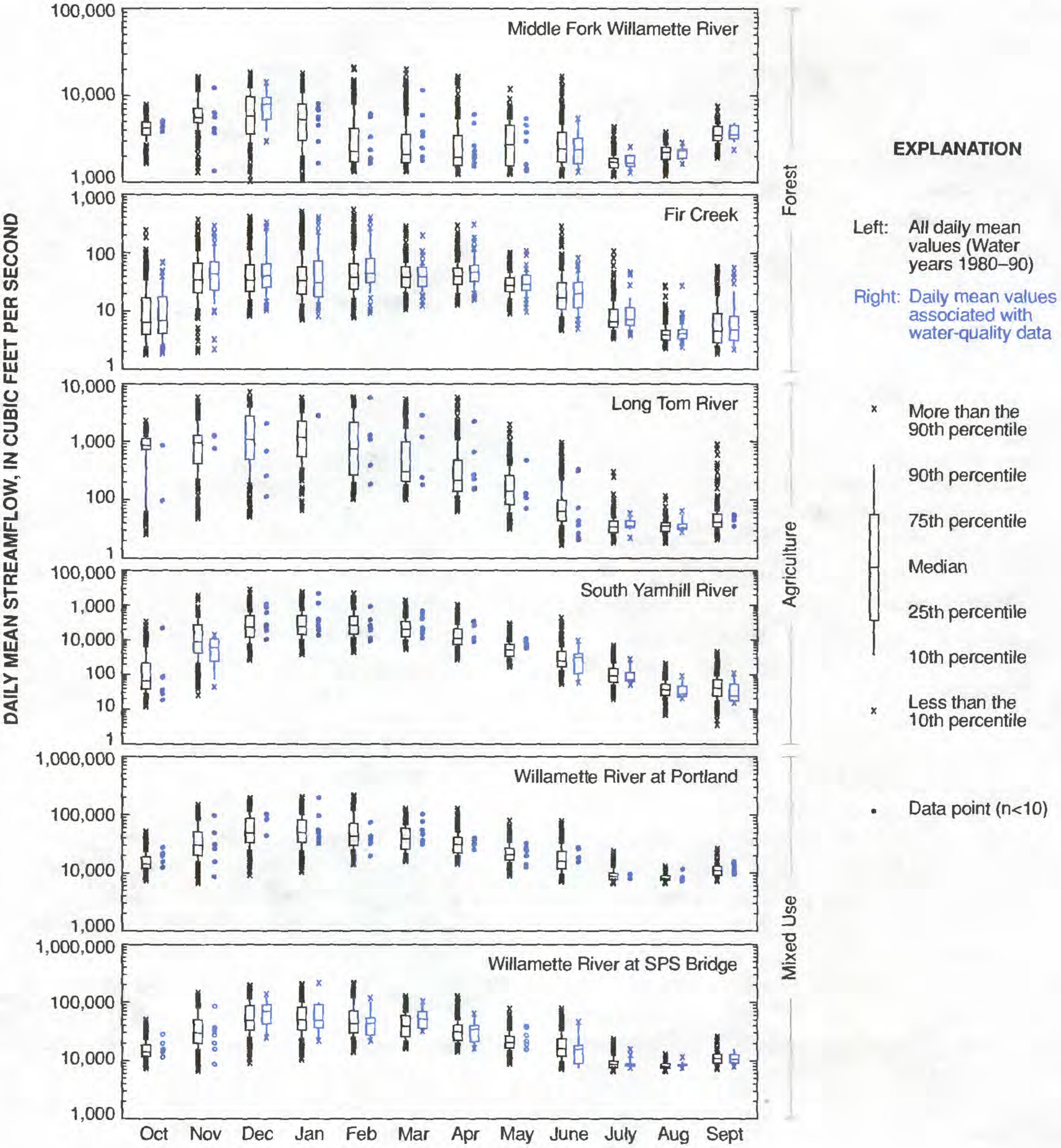


Figure 21. Seasonal variations of streamflow at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Note different ordinate scales. Data from U.S. Geological Survey.)

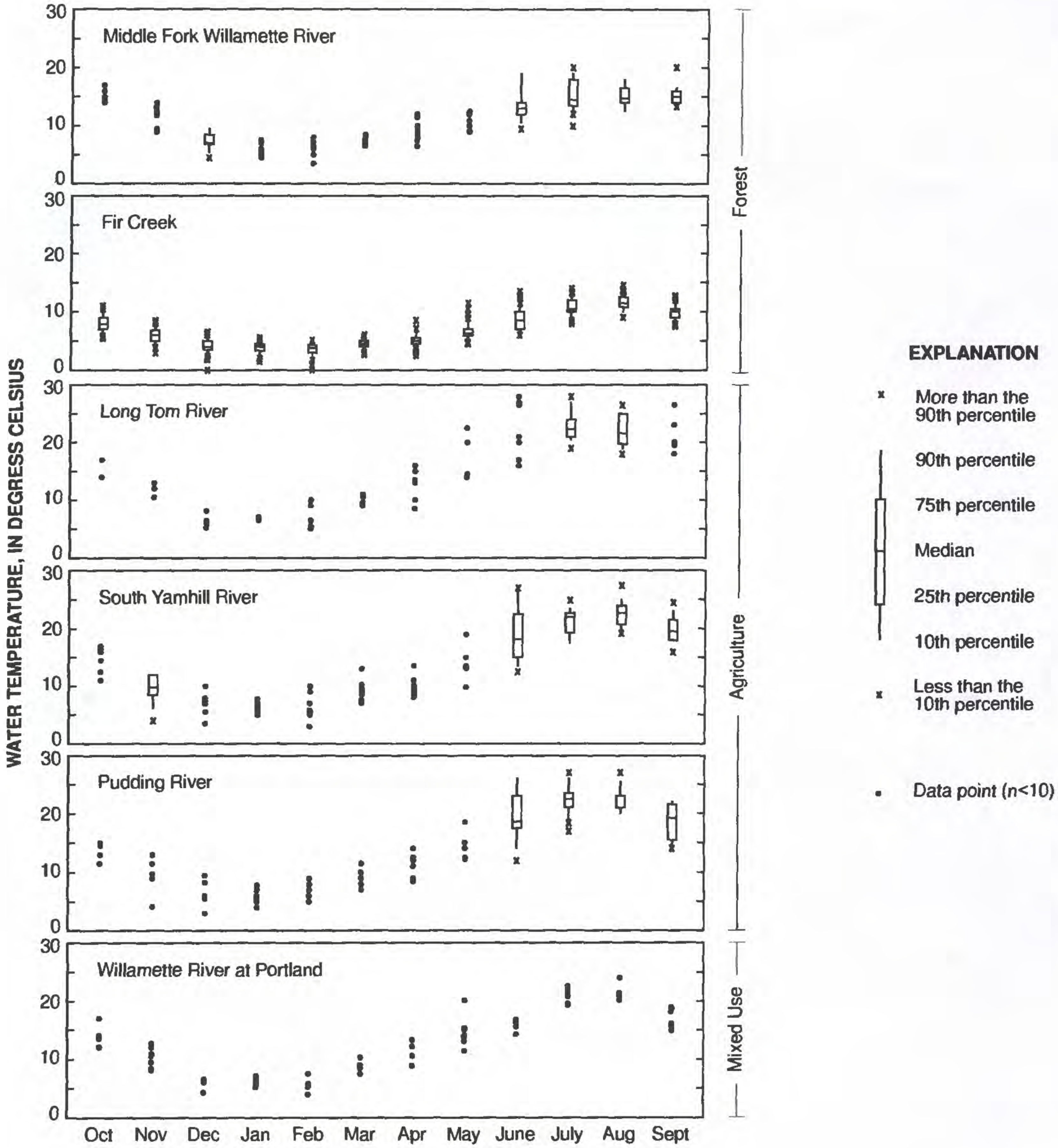


Figure 22. Seasonal variations of water temperature at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

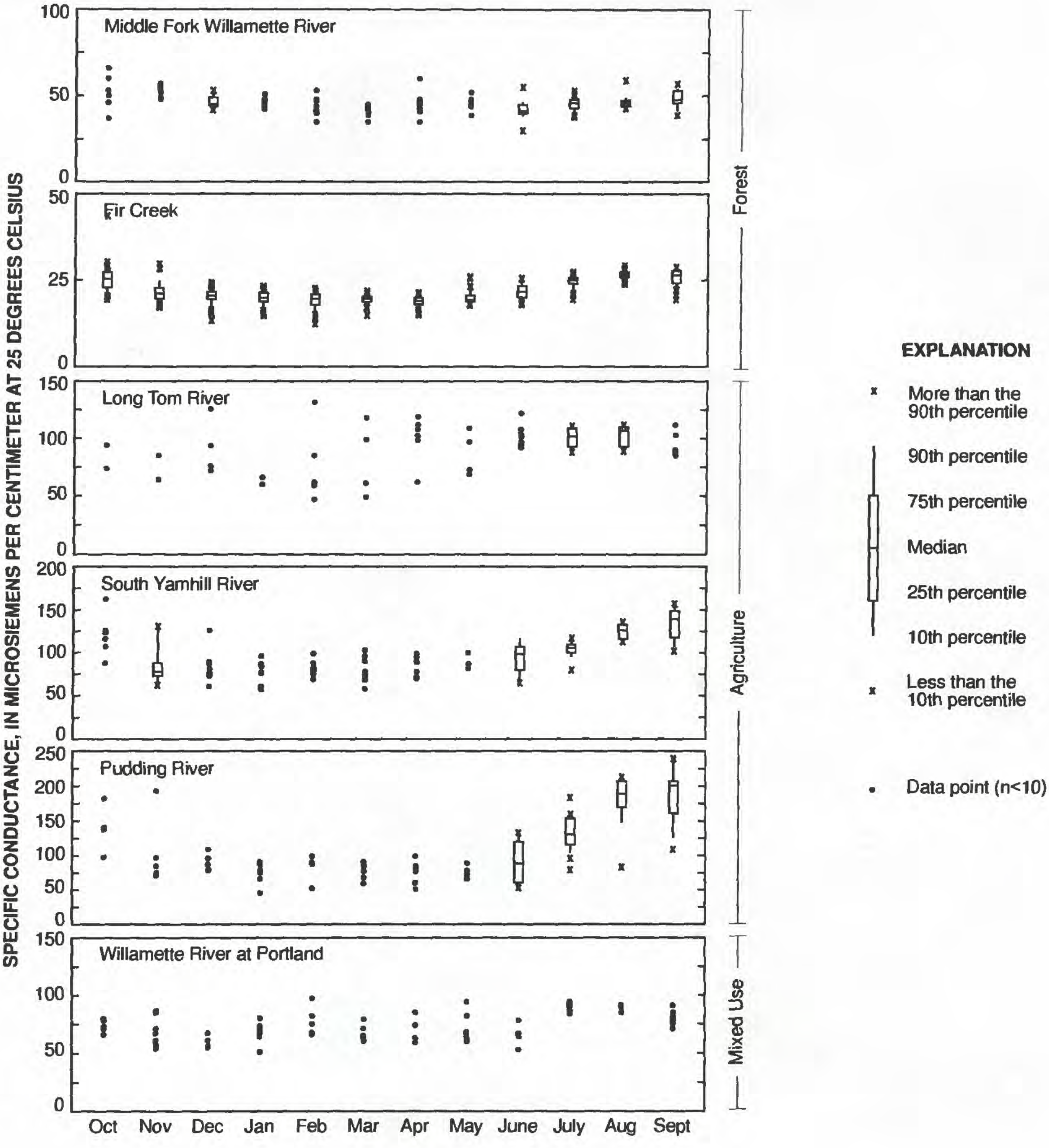


Figure 23. Seasonal variations of specific conductance at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Note different ordinate scales. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey)

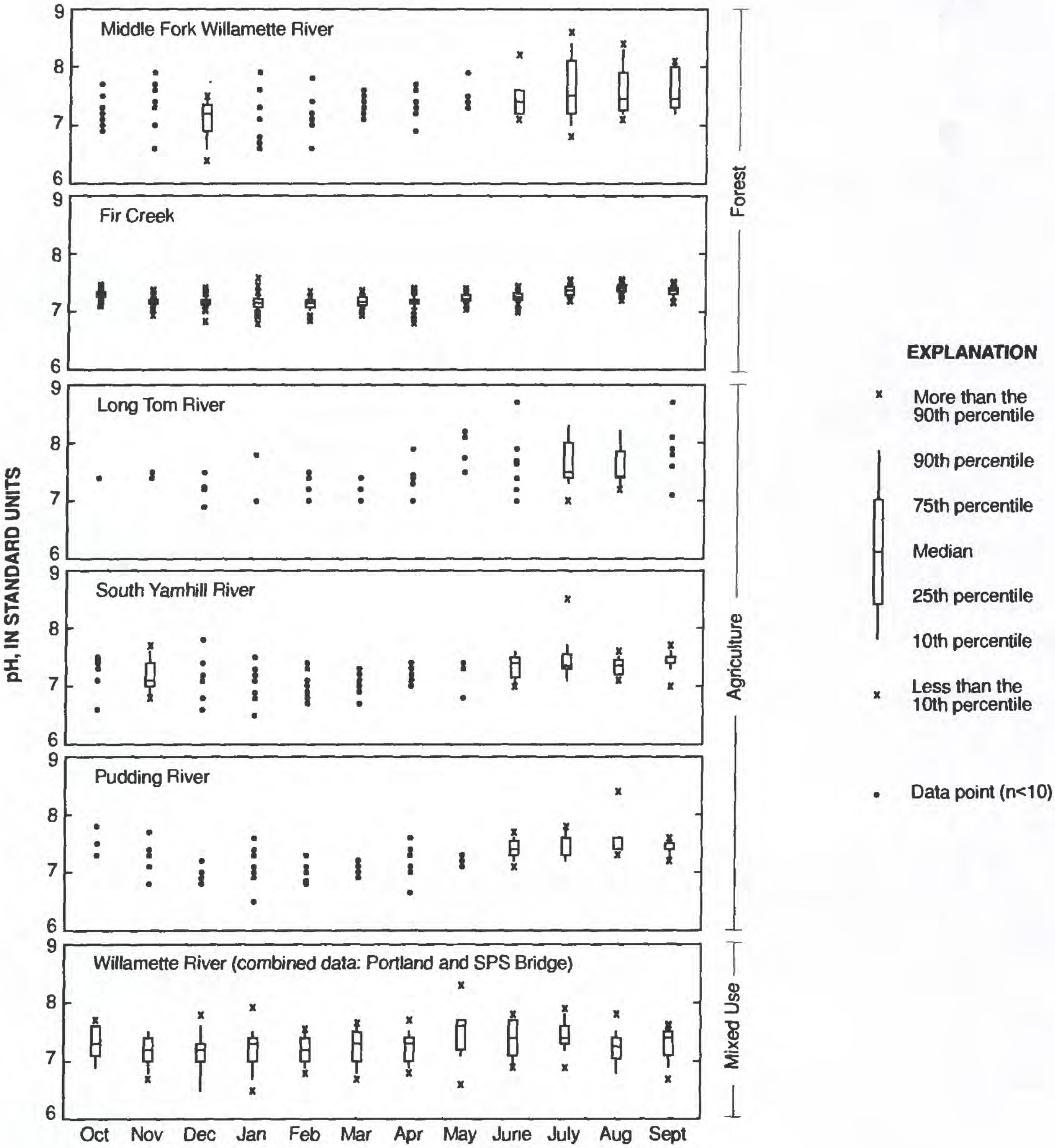


Figure 24. Seasonal variations of pH at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

suspended-sediment concentrations from isokinetically obtained, depth- and width-integrated samples (USGS and PWB) solely because of the different sampling methods employed. For this reason, no statistical comparisons will be performed between the suspended-sediment and suspended-solids data in this report. The data are presented to provide general comparisons only.

Site comparisons

Among sites—The lowest concentrations of suspended material were found at the two forested sites (Fir Creek and Middle Fork Willamette River; fig. 25). The suspended-solids concentrations at Middle Fork Willamette River were about five times higher than the suspended-sediment concentrations at Fir Creek and may be related to increased human activity in the Middle Fork Willamette River watershed. No obvious differences in suspended-solids concentrations were evident among the agricultural basin sites or between those sites and the mixed-use site (Willamette River at SPS Bridge).

Comparisons of the two Portland Harbor sites can provide some indication of the differences associated with different sampling methods. As expected, the grab samples (ODEQ, Willamette River at SPS Bridge) had lower concentrations than did the depth- and width-integrated samples (USGS, Willamette River at Portland). The data set was searched for dates on which samples were obtained at both sites. This situation occurred on five occasions. Based upon these five date-matched data pairs, the suspended-solids concentration in an ODEQ grab sample was about half the suspended-sediment concentration in a USGS depth- and width-integrated sample.

Relation to national conditions—All of the Willamette Basin sites had median concentrations of suspended material that were much lower (at least 50 times less) than the median concentrations of suspended-sediment concentrations for national sites with comparable land uses. It is unlikely that sampling methods could account for such large differences.

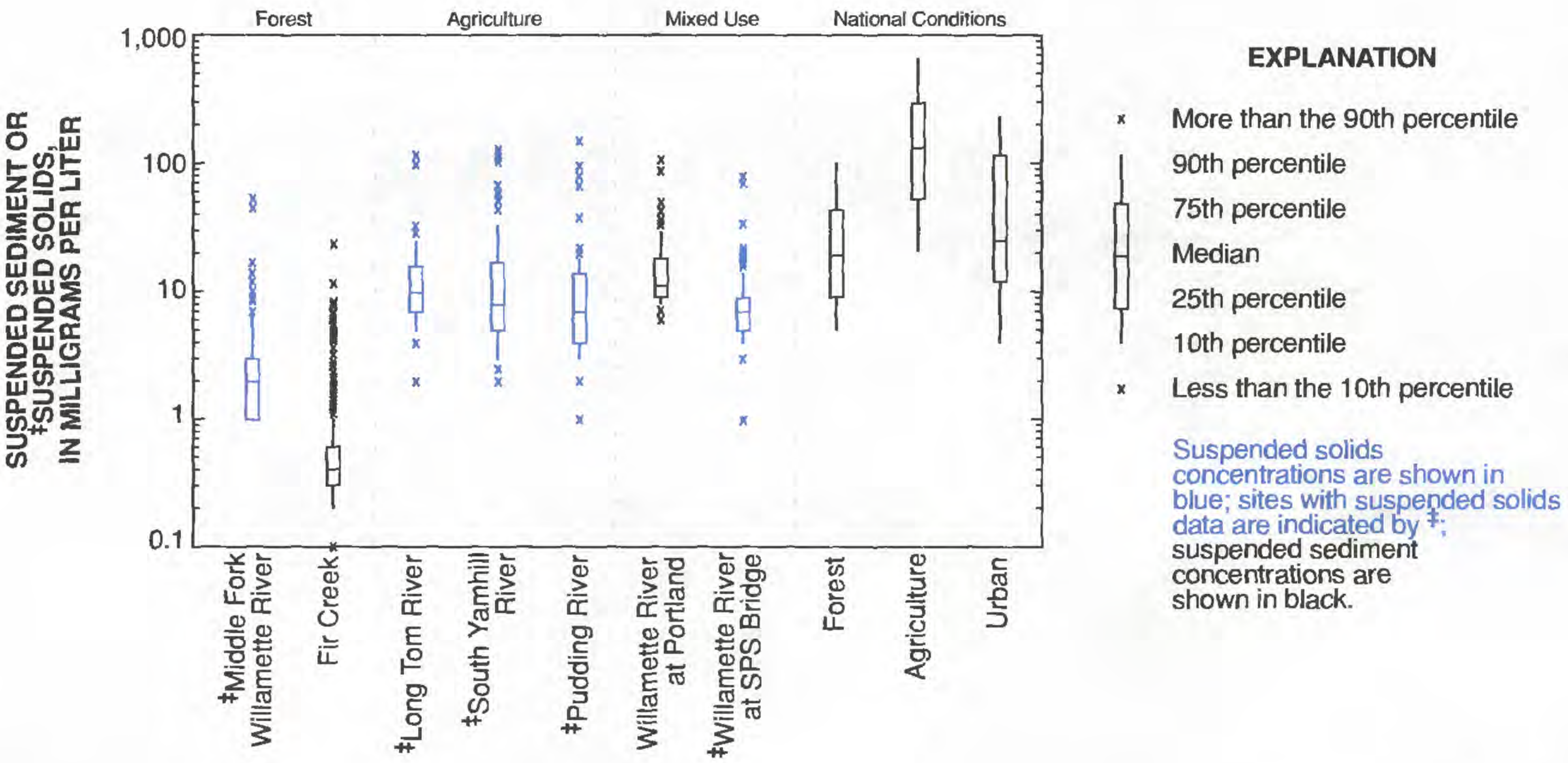


Figure 25. Concentrations of suspended sediment or suspended solids at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Suspended sediment data were obtained using isokinetic, depth- and width-integrated sampling methods; suspended solids data were obtained from grab samples. Data from Oregon Department of Environmental Quality, Portland Water Bureau, U.S. Geological Survey, and Smith and others [1993])

Seasonality

Seasonal variations in suspended-solids concentrations were evident at all sites and were consistent with increased concentrations during winter high flows (fig. 26). Concentrations in the winter were not only higher than those during the summer, but also showed greater variability. In general, suspended-solids concentrations in the winter were no more than 10 times the summer values. Baseline summer suspended solids concentrations at agricultural sites were typically 5–10 mg/L, while those at the Middle Fork Willamette River site were 1–2 mg/L. At the Fir Creek site, the suspended-sediment concentrations were even lower and probably reflect the geology and protected status of that watershed.

Relation between Concentration and Streamflow

Two distinct regimes are apparent in the relation between suspended-solids concentrations and streamflow (fig. 27). Under low-flow conditions, suspended-solids concentrations appear to be random; at high flows, the relation seems to approximate a power law (log-log plots are roughly linear). This type of relation suggests that a minimum energy is required to cause significant erosion, resuspension, and transport. The relation is similar for all sites. The point at which suspended-sediment or suspended-solids concentrations become a function of streamflow, however, is unique for each site. At the Long Tom River and Middle Fork Willamette River sites, the relation is less pronounced, possibly due to the presence of upstream reservoirs. In addition, the high-flow data required to characterize this relation is relatively sparse for the Long Tom River site.

Analysis of Nitrogen Data

Nitrogen species are of interest primarily because they contribute to algal growth and eutrophication. Both reduced (ammonia and organic nitrogen) and oxidized (nitrate and nitrite) forms of nitrogen can be utilized as nutrients and can stimulate increased algal productivity, especially during summer months. Some nitrogen species are also potentially toxic. Freshwater fish are highly sensitive to un-ionized ammonia (NH_3); the concentration of NH_3 increases with temperature, pH, and the total ammonia concentration (NH_4-N=NH_3 + NH_4^+). USEPA has tabulated toxic concentrations of total ammonia as a function of pH and temperature (U.S. Environmental Protection Agency, 1986). Nitrite and nitrate can be a concern for warm-blooded animals. Nitrite interferes with respiration by inhibiting the ability of hemoglobin to transport oxygen. Nitrite concentrations exceeding 1 mg/L as N may be harmful to infants and children (U. S. Environmental Protection Agency, 1986). Nitrate itself is not toxic, but it can be converted to nitrite in the gut. The USEPA maximum contaminant level (MCL) for nitrate in drinking water is 10 mg/L as N (U. S. Environmental Protection Agency, 1986). Common sources of ammonia and organic nitrogen include sewage treatment plant wastes, food processing plant wastes, and manure. In some cases, sewage treatment facilities convert reduced forms of nitrogen to nitrate before discharge. Commercial fertilizers can be a source of organic nitrogen, nitrate, and(or) ammonia.

Site Comparisons

Among sites—Nitrite was infrequently measured by agencies collecting data in the Willamette Basin. The number of NO_2-N detections are shown on figure 28. Although NO_2-N was detected at four of the seven sites, the concentrations never exceeded the detection limit. Low NO_2-N concentrations would be expected in well-oxygenated surface water.

Statistically significant differences existed among the total NH_4-N concentrations at different sites (fig. 29). The highest NH_4-N concentrations were found at the two Portland Harbor sites and the Pudding River site— the only sites located downstream from major NPDES permittees. The lowest NH_4-N concentrations were found at the forested sites (Middle Fork Willamette River and Fir Creek). Interestingly, NH_4-N concentrations at the two forested sites were significantly different from each other, with the Middle Fork Willamette River site generally having higher values. NH_4-N concentrations at the Fir Creek site never exceeded the detection limit of 0.02 mg/L as N (103 samples). The Middle Fork Willamette River receives effluent from minor NPDES permittees; no point sources discharge into Fir Creek. In general, NH_4-N concentrations appeared to increase with the number and size of upstream point sources. Unfortunately, effluent ammonia concentrations

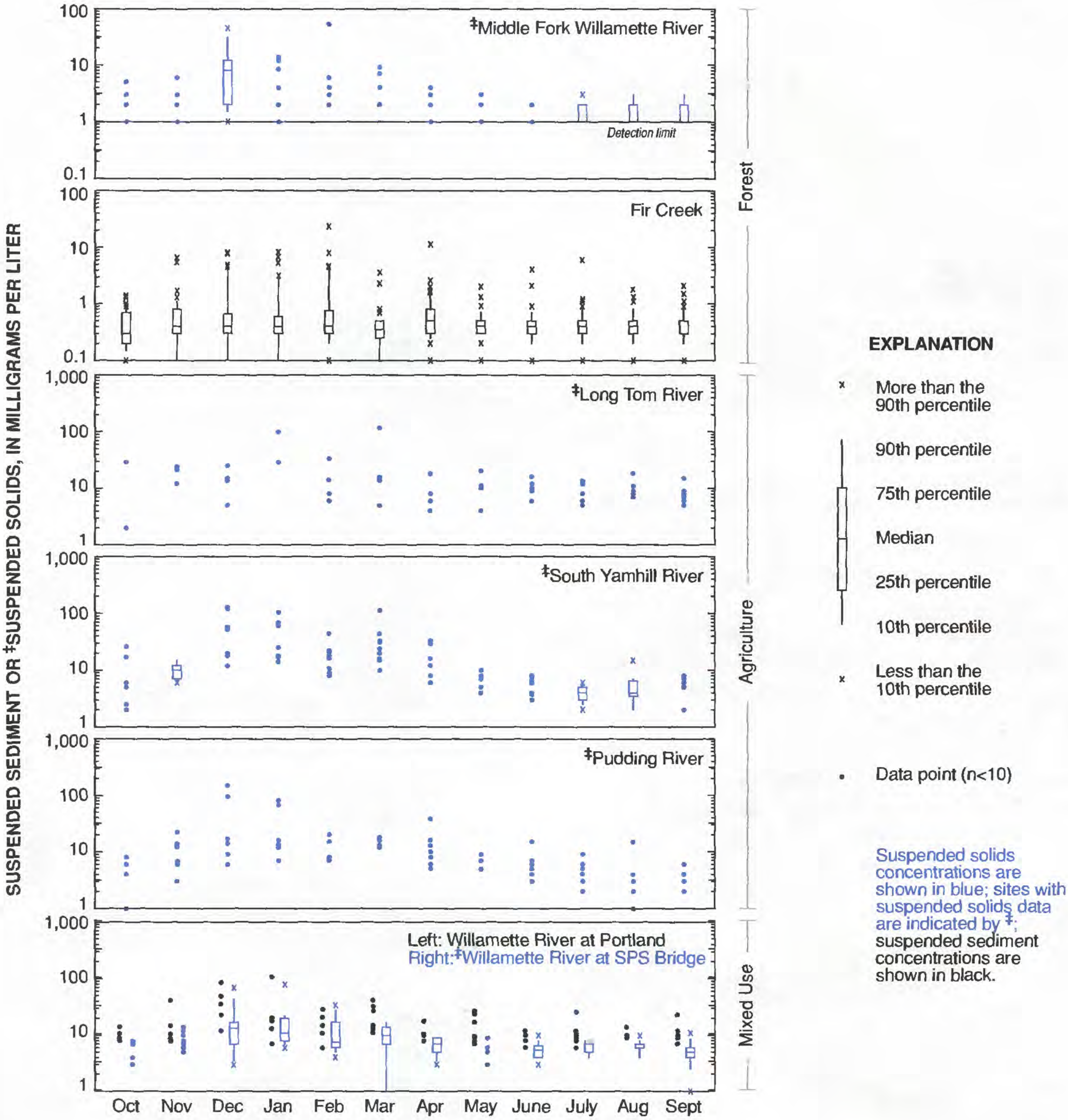


Figure 26. Seasonal variations of suspended sediment or suspended solids at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Suspended sediment data were obtained using isokinetic, depth- and width-integrated sampling methods; suspended solids data were obtained from grab samples. Note different ordinate scales. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey)

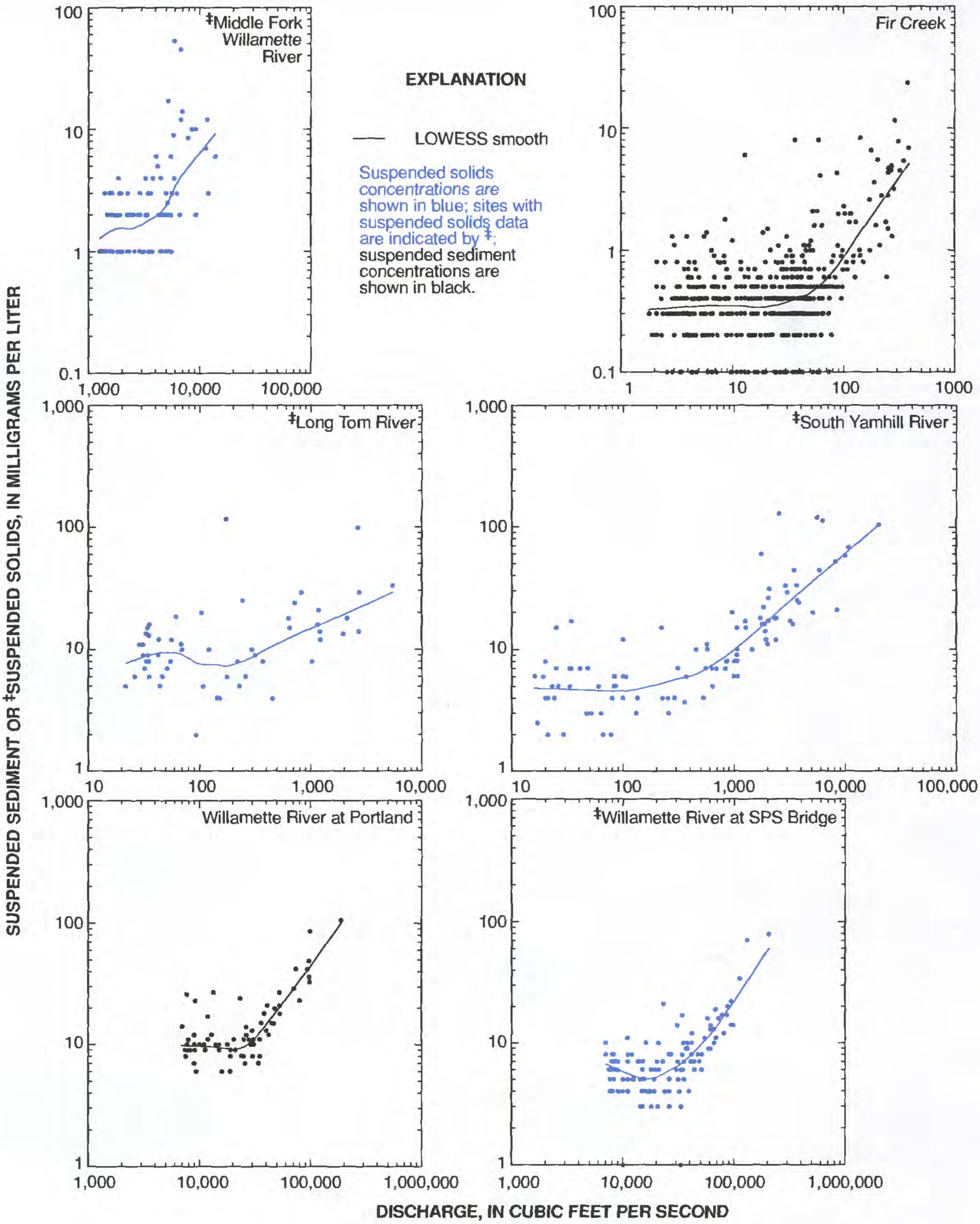


Figure 27. Relation between suspended-sediment or suspended-solids concentration and streamflow at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980-90 water years. (Suspended sediment data were obtained using isokinetic, depth- and width-integrated sampling methods; suspended solids data were obtained from grab samples. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey)

currently are available for only a small fraction of the NPDES permittees, so the loading from point sources cannot be adequately assessed. NH_4-N concentrations at the primary surface-water sites never exceeded concentrations considered toxic to freshwater fish by USEPA for the appropriate pH and temperature.

Concentration distributions of TRN for each site are shown in figure 29. In general, TRN concentrations were low. For the ODEQ sites (Middle Fork Willamette River, Long Tom River, South Yamhill River, Pudding River, and Willamette River at SPS Bridge), 42 percent of the TRN concentrations were at or below the detection limit of 0.2 mg/L as N; 50 percent of the values that exceeded the detection limit were 0.5 mg/L as N or less. The forested sites had TRN values that were significantly lower than those of the other sites.

TRN values for the Willamette River at Portland site (upstream) were significantly higher than those for the Willamette River at SPS Bridge site (downstream) despite the fact that several point sources and combined sewer overflows discharge into the Willamette River between the two sites. NH_4-N concentrations at these two sites were virtually identical (fig. 29), indicating that TRN differences are due to organic nitrogen. Because organic nitrogen is frequently associated with particles, the differences between the two Portland Harbor sites may be related to the concentration of suspended material. Samples collected using the depth- and width-integrated, isokinetic sampling method (Portland site) have higher concentrations of particles and therefore may have higher TRN concentrations than do grab samples (from SPS Bridge site). The previously discussed laboratory analytical problems (Quality assurance of nutrient data, page 31) also could have contributed to this difference.

Comparisons among the ODEQ sites (Middle Fork Willamette River, Long Tom River, South Yamhill River, Pudding River, and Willamette River at SPS Bridge) should be relatively free of sampling artifacts because the same sampling method was used at all of these sites. TRN values at the Pudding River and Long Tom River sites were slightly greater than those at the South Yamhill River and Willamette River at SPS Bridge sites. The differences, although statistically significant, were quite small, (approximately equal to the detection limit) and may be spurious.

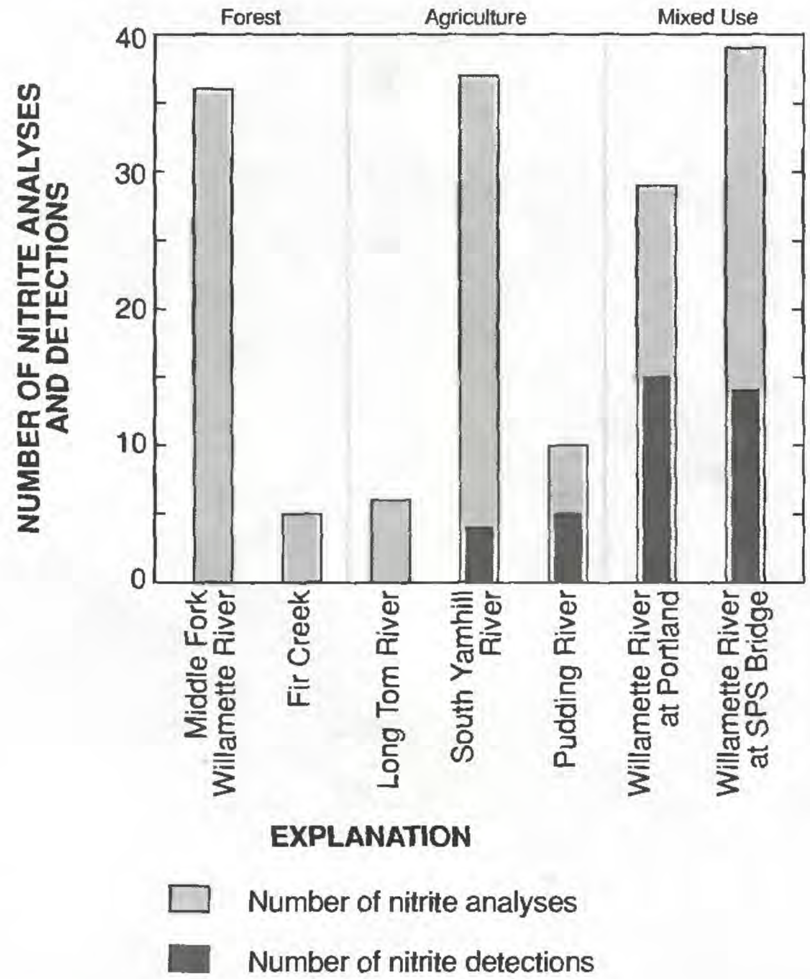


Figure 28. Detections of nitrite at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980-90 water years.(Detection limits at the sites varied as follows: Middle Fork Willamette River, Long Tom River, South Yamhill River, Pudding River, and Willamette River at SPS Bridge— 0.02 mg/L as N; Fir Creek— 0.001 mg/L as N; Willamette River at Portland— 0.01 mg/L as N. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

Concentrations of NO_3-N were much larger at the Pudding River site (an agricultural site) than at all other sites (fig. 29). With the exception of the Pudding River site, however, differences between agricultural and mixed-use sites were small. The concentration distributions at the two Willamette River sites were essentially the same. The two forested sites had the lowest NO_3-N concentrations.

The causes of the high NO_3-N concentrations in the Pudding River are not known. Although nitrate sources in the Pudding Basin are readily identifiable (a relatively large municipal wastewater treatment plant and the application of fertilizers), the sources alone do not explain the high NO_3-N concentrations. Effluent from the wastewater treatment plant does not undergo complete nitrification (conversion of reduced nitrogen species to nitrate) before discharge to the Pudding River, yet elevated TRN values were not observed.

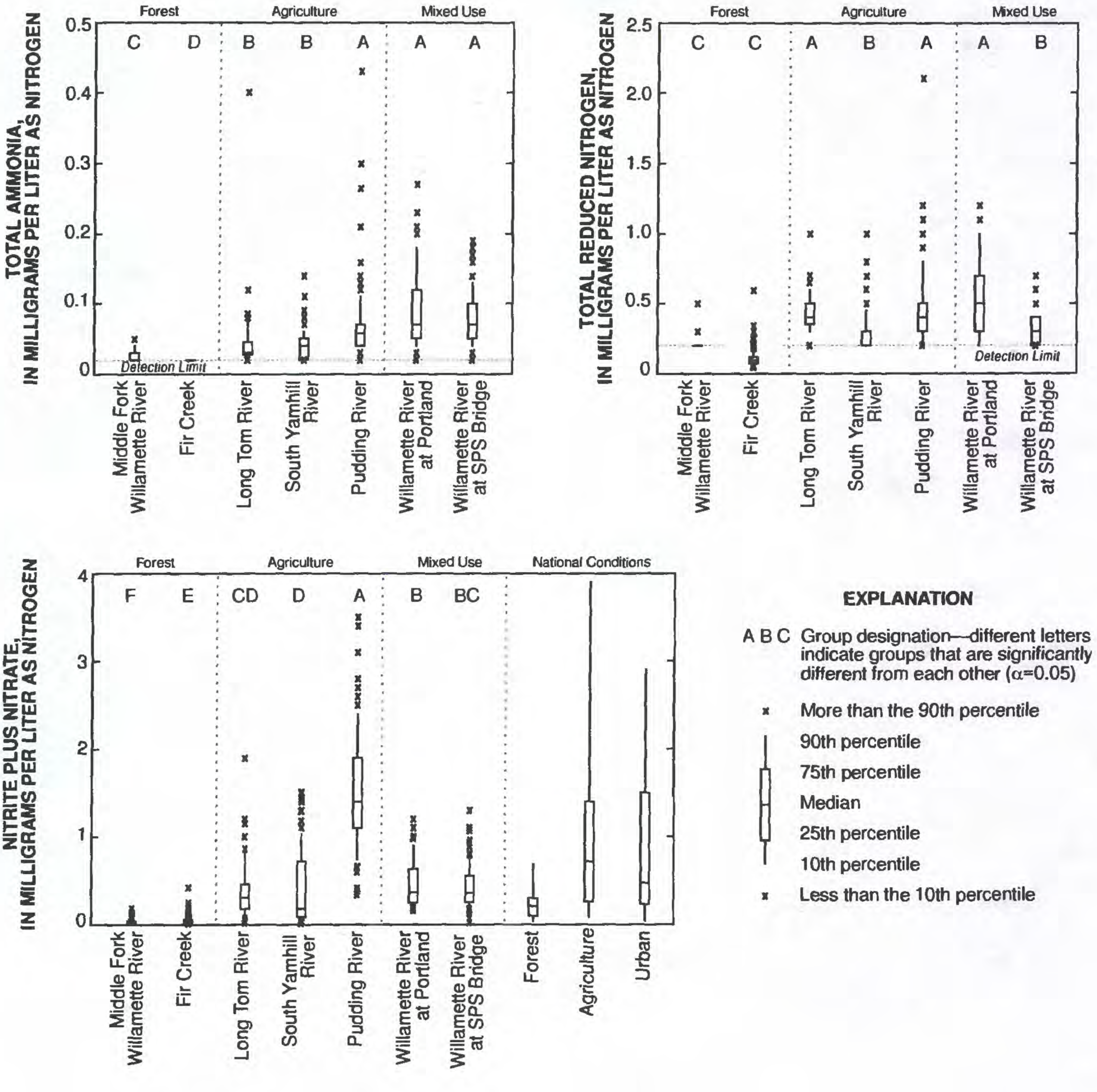


Figure 29. Total ammonia, total-reduced-nitrogen, and nitrite-plus-nitrate concentrations at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Ammonia concentrations for Fir Creek never exceeded the detection limit.Data from Oregon Department of Environmental Quality, Portland Water Bureau, U.S. Geological Survey, and Smith and others [1993].)

Fertilizer application also occurred in the other agricultural basins (South Yamhill and Long Tom Basins), yet NO_3-N concentrations at those sites were much less than the concentrations at the Pudding River site. Identifying the factors that lead to high NO_3-N concentrations in the Pudding River will require further investigation.

Compared to national conditions—The NO_3-N concentrations at primary sites in the Willamette Basin were generally less than the national median values. The Pudding River site was an exception: 90 percent of the NO_3-N concentrations measured at the Pudding River site exceeded the national median value for agricultural basins.

Seasonality

Primary sites—Neither NH_4-N nor TRN concentrations showed much seasonal variation (figs. 30 and 31). Although the data suggest the existence of small seasonal variations at some sites, more data are necessary before seasonal patterns for the reduced nitrogen species can be identified or discounted with reasonable certainty.

Clear seasonal patterns were evident in the NO_3-N concentrations at all sites (fig. 32). The total variation, however, was smallest at the two forested sites. Maximum concentrations occurred during the winter months at all sites except Fir Creek. The winter NO_3-N concentration peak may have been due to increased surface runoff or short-path ground-water flow associated with winter rain, both of which may leach nitrate from the soil. Alternatively, the winter peak may have resulted from decreased uptake by algae or higher plants. At Fir Creek, the maximum NO_3-N concentrations occurred during autumn. A late-summer peak occurred at the Pudding River site, although it was smaller than the winter peak. The peaks during late-summer and autumn were probably due to lack of dilution during low-flow periods. This is especially likely in the Pudding River, where effluent from the wastewater treatment plant received less dilution during low-flow conditions. At the Fir Creek site, nitrogen fixation by alder coupled with low flow conditions may have been the cause of the autumn peak. Interestingly, a low-flow-coincident maximum did not occur at all sites. Despite very low summer flows at the South Yamhill River site, summer NO_3-N concentrations were about five times lower than winter concentrations. These low NO_3-N concentrations may result from algal uptake coupled with the lack of major point sources in the South Yamhill Basin.

The relative contributions of TRN and NO_3-N to the total N concentration also exhibited seasonal patterns (fig. 33). At the Long Tom River, South Yamhill River, and Willamette River sites during winter, most of the total N was in the oxidized form (NO_3-N); during the summer, the reduced form (TRN) predominated. This pattern was not evident, however, at the forested sites or the Pudding River site. At the forested sites (Fir Creek and Middle Fork Willamette River), the proportions of reduced and oxidized nitrogen remained relatively constant throughout the year with the reduced forms predominating. At the Pudding River site, the proportions also were relatively constant, but the oxidized forms accounted for nearly 80 percent of the total N. The sources and(or) processes responsible for these various distributions of nitrogen species are not yet identified.

Nested subbasin sites—Seasonal nitrogen variations at the Fanno Creek and Dairy Creek sites were similar to those at the primary sites (fig. 34). Little seasonal variation was evident in the TRN concentrations. At the Dairy Creek and Fanno Creek sites, maximum NO_3-N concentrations occurred during the winter; the winter peak, however, was substantially greater at Dairy Creek. The winter NO_3-N concentrations at the Dairy Creek site were large, similar to those found at the Pudding River site. Interestingly, the concentrations and seasonal variation observed at the downstream mixed-use site (Tualatin River) bore little resemblance to those at either tributary site. Contributions from point sources or other tributaries appear to influence the nitrogen concentrations at the Tualatin River site more than the inputs from either Dairy Creek or Fanno Creek.

Relation between Concentration and Streamflow

The relation between streamflow and concentrations of NH_4-N, TRN, or NO_3-N was site dependent; it did not, however, appear to be related to land use (figs. 35-37). The most pronounced flow dependence for all three species occurred at the South Yamhill River site— the site with the largest relative range of streamflow (four orders of magnitude). At the South Yamhill site, NH_4-N and TRN concentrations increased with high flow and also were slightly elevated at low flow, but the relation was weak. NO_3-N was more strongly related to streamflow; NO_3-N concentrations increased with flow at all sites except Fir Creek. The most pronounced relation occurred at the South Yamhill River site, the weakest at the Middle Fork Willamette River site.

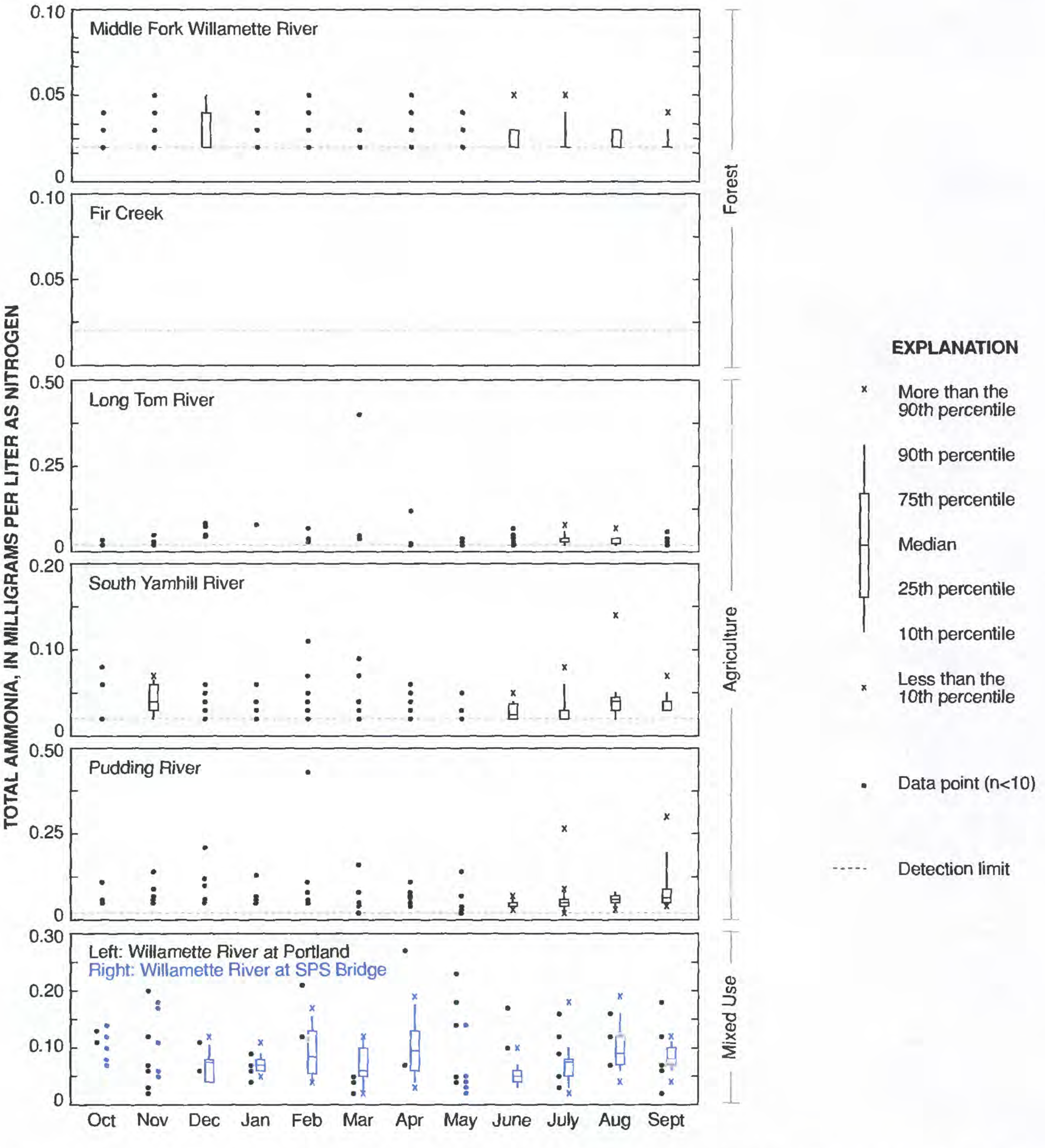


Figure 30. Seasonal variations of total ammonia at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Note different ordinate scales. Ammonia concentrations for Fir Creek site never exceeded the detection limit. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

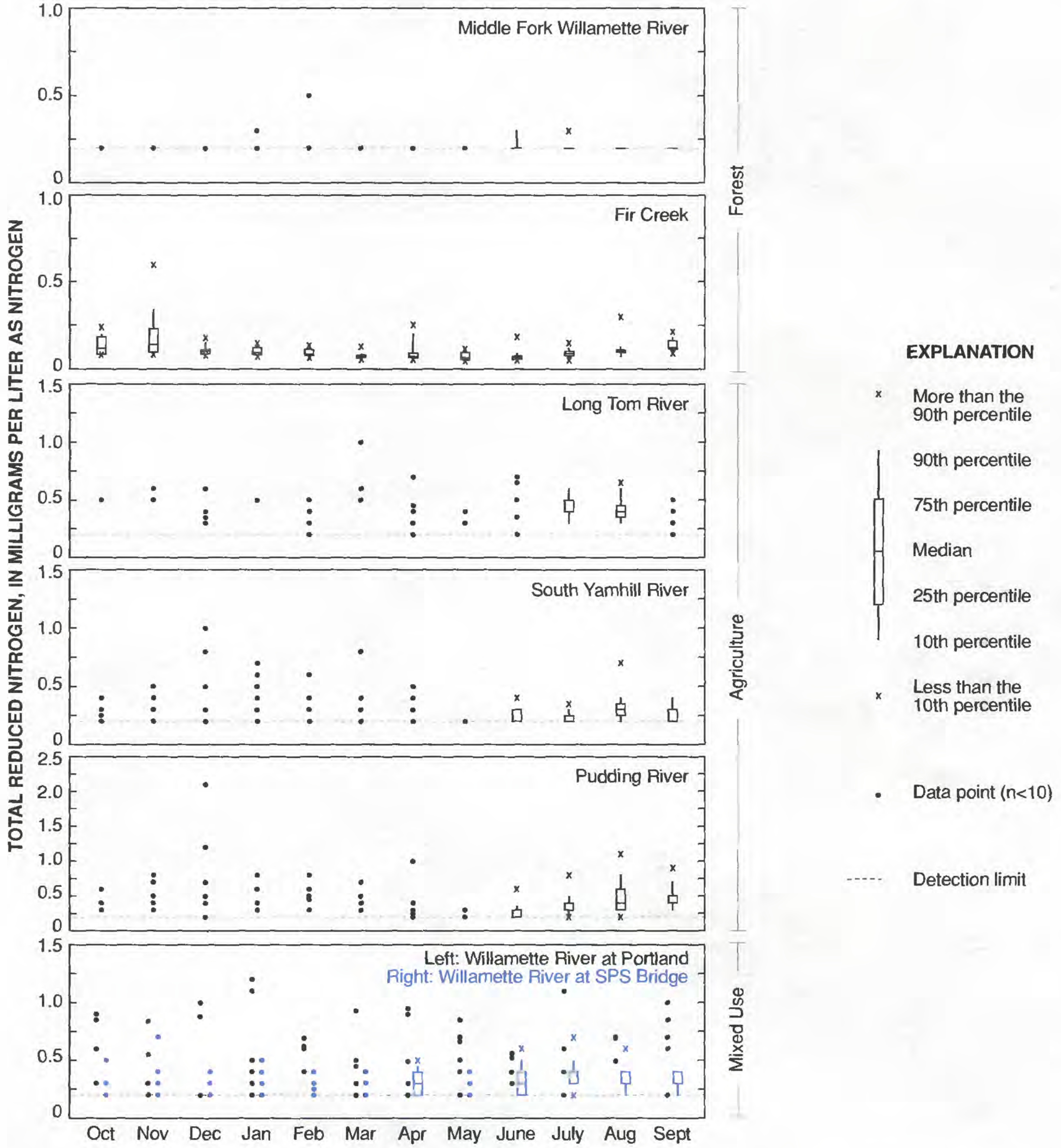


Figure 31. Seasonal variations of total reduced nitrogen at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980-90 water years. (Note different ordinate scales. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

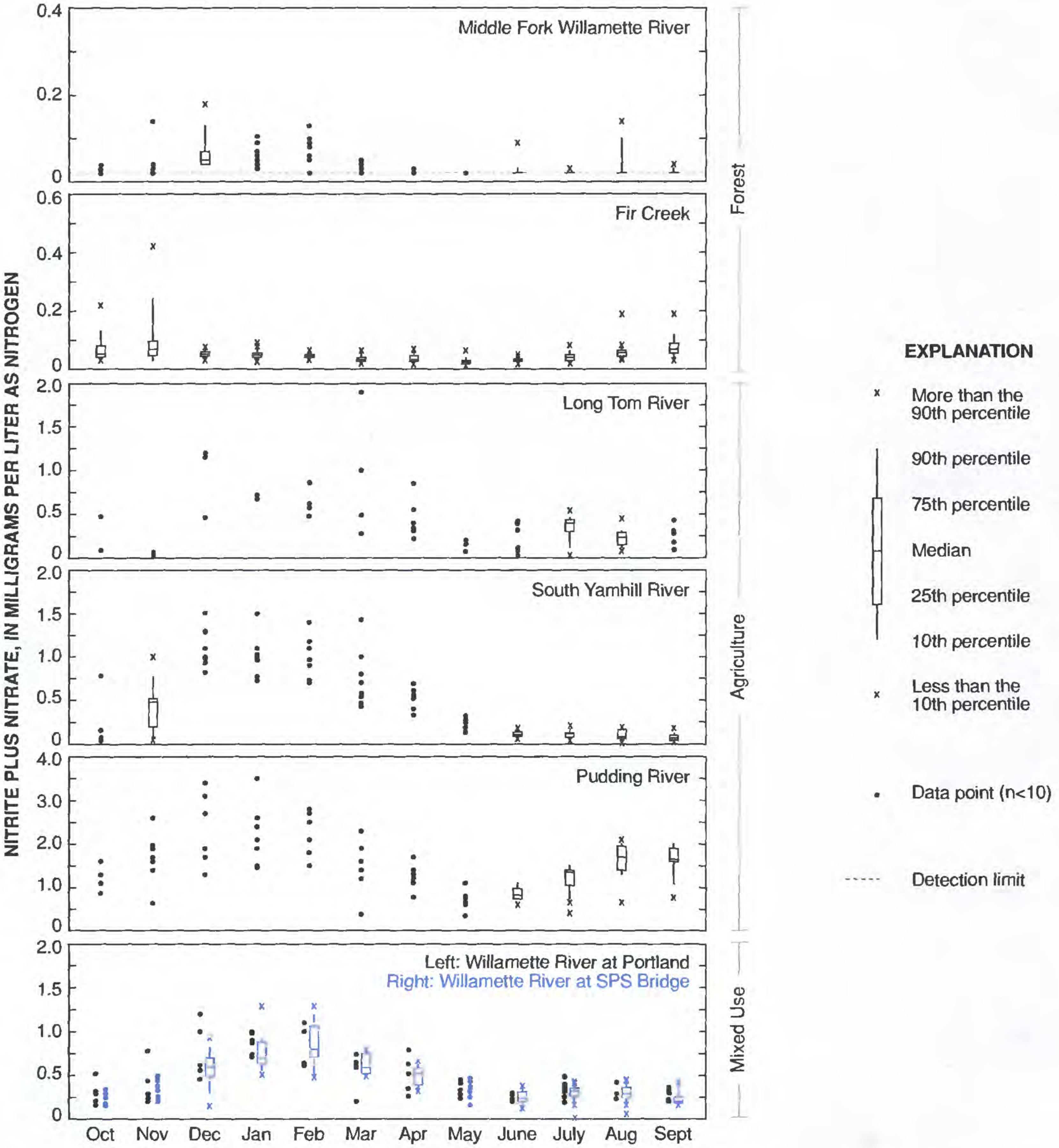


Figure 32. Seasonal variations of nitrite plus nitrate at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Note different ordinate scales. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

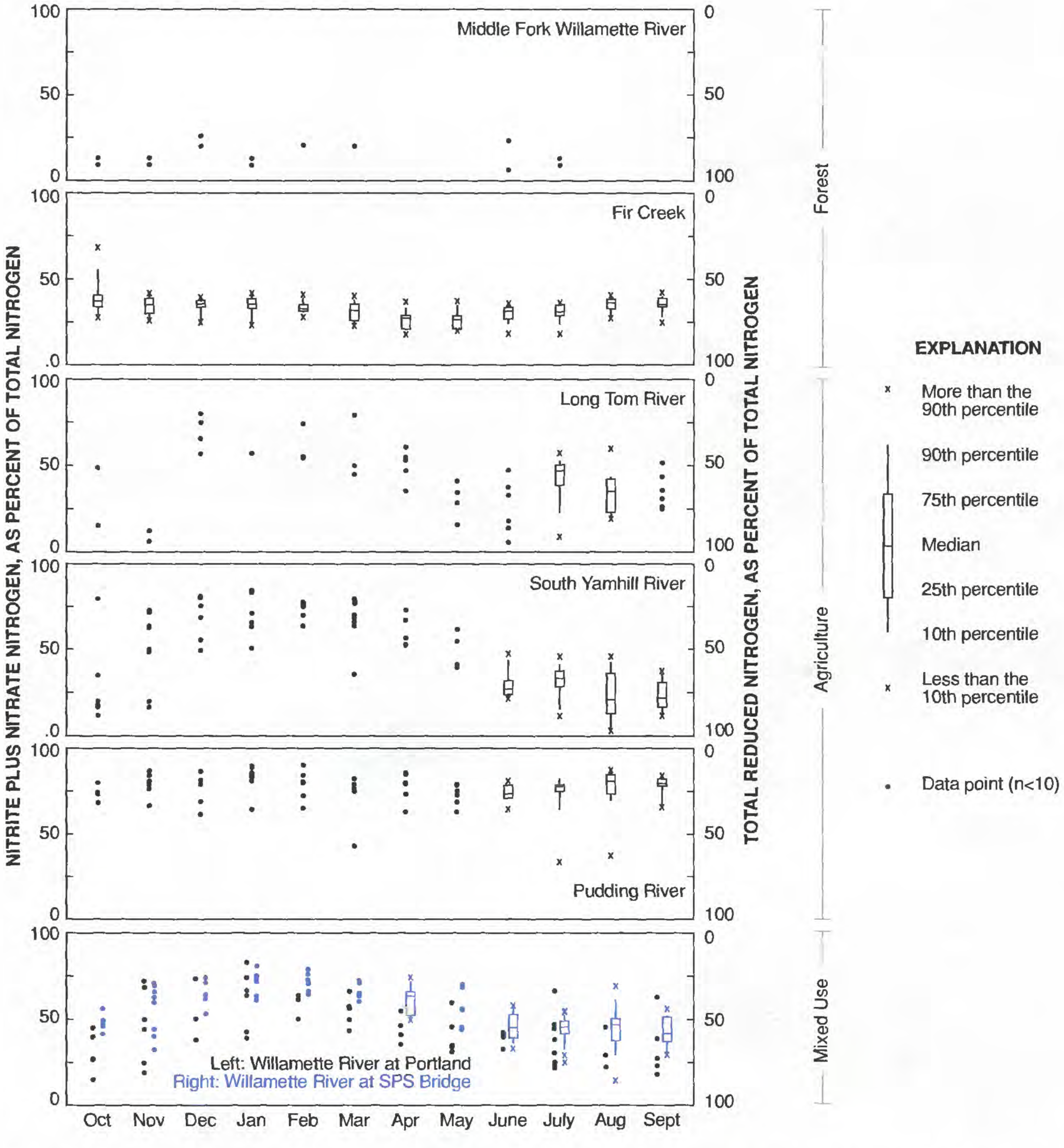


Figure 33. Seasonal variations of percent nitrite plus nitrate or percent total reduced nitrogen at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

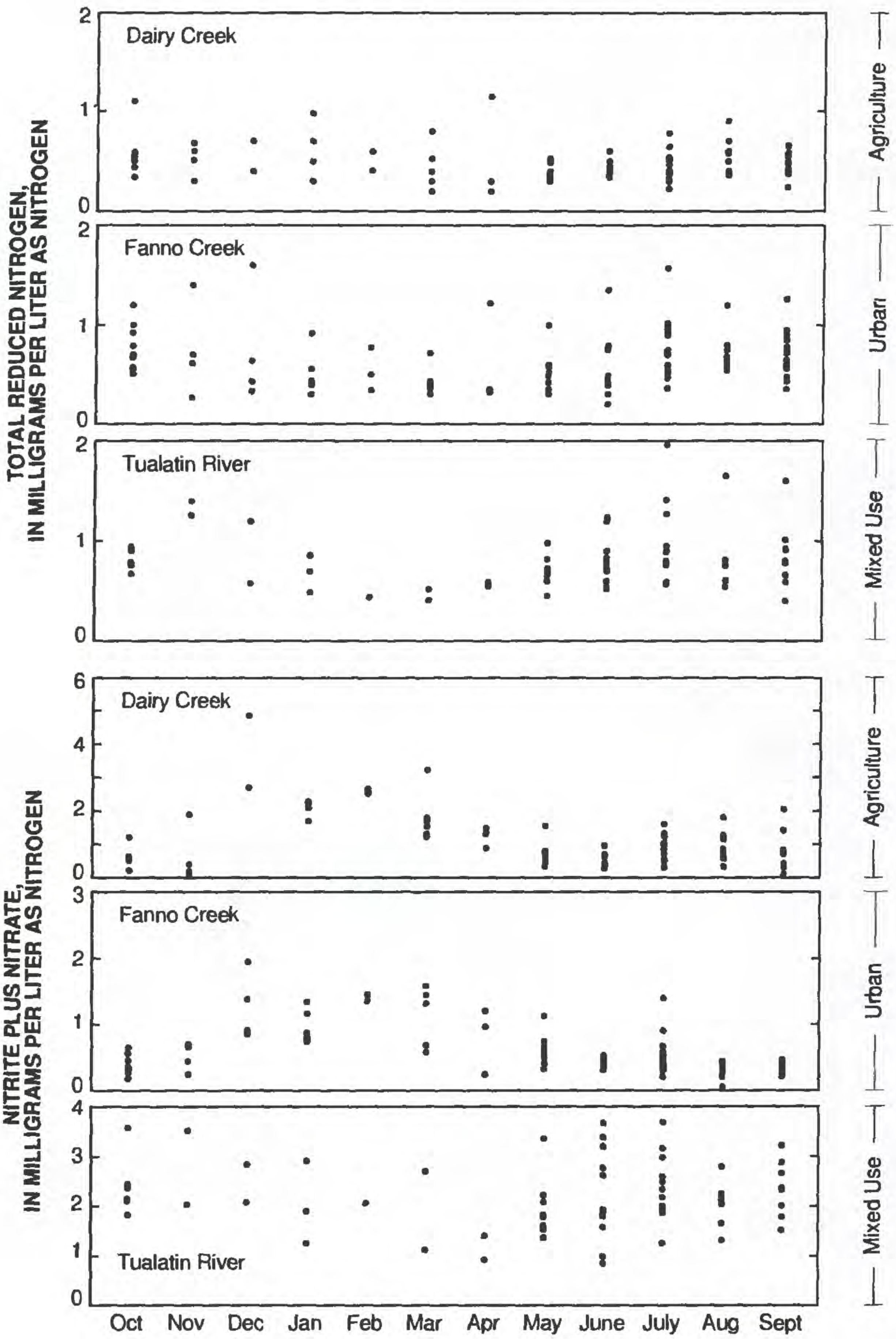


Figure 34. Seasonal variations of total reduced nitrogen and nitrite plus nitrate at sites in the Tualatin River Basin, Oregon, 1988–90 water years. (Note different ordinate scales. Data from Oregon Department of Environmental Quality.)

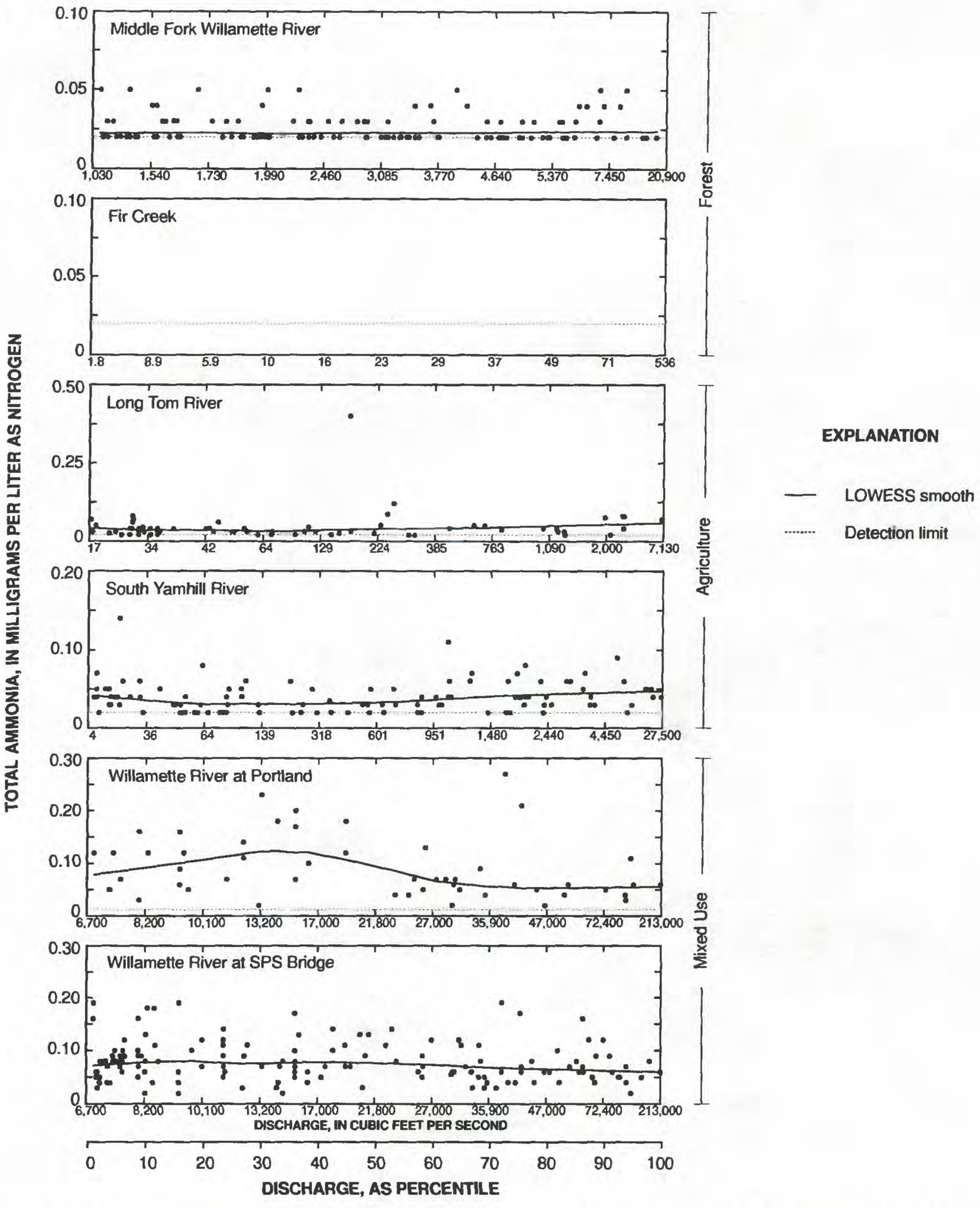


Figure 35. Relation between total ammonia and streamflow at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Note different ordinate scales. Ammonia concentrations for Fir Creek site never exceeded the detection limit. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

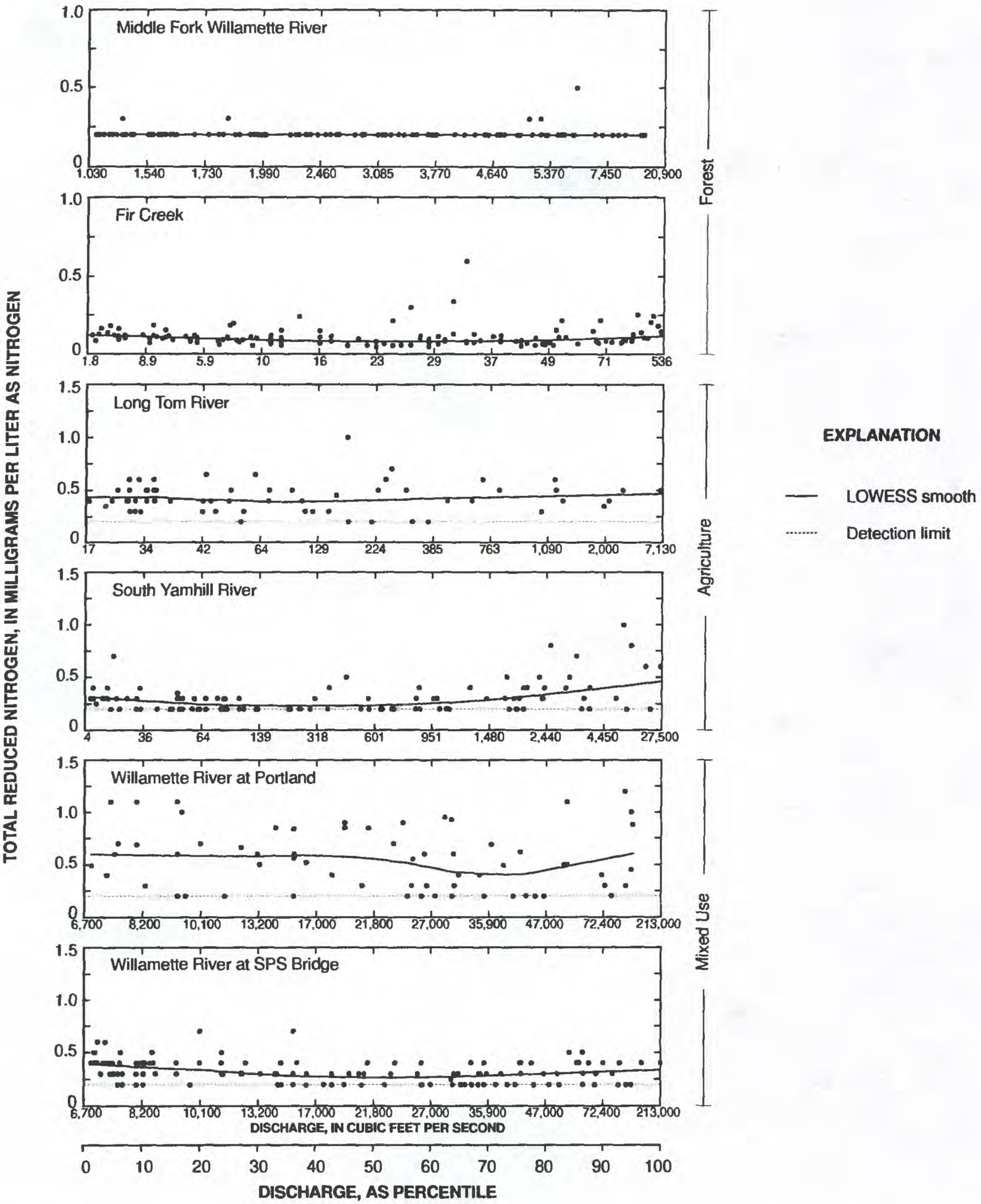


Figure 36. Relation between total reduced nitrogen and streamflow at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Note different ordinate scales. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

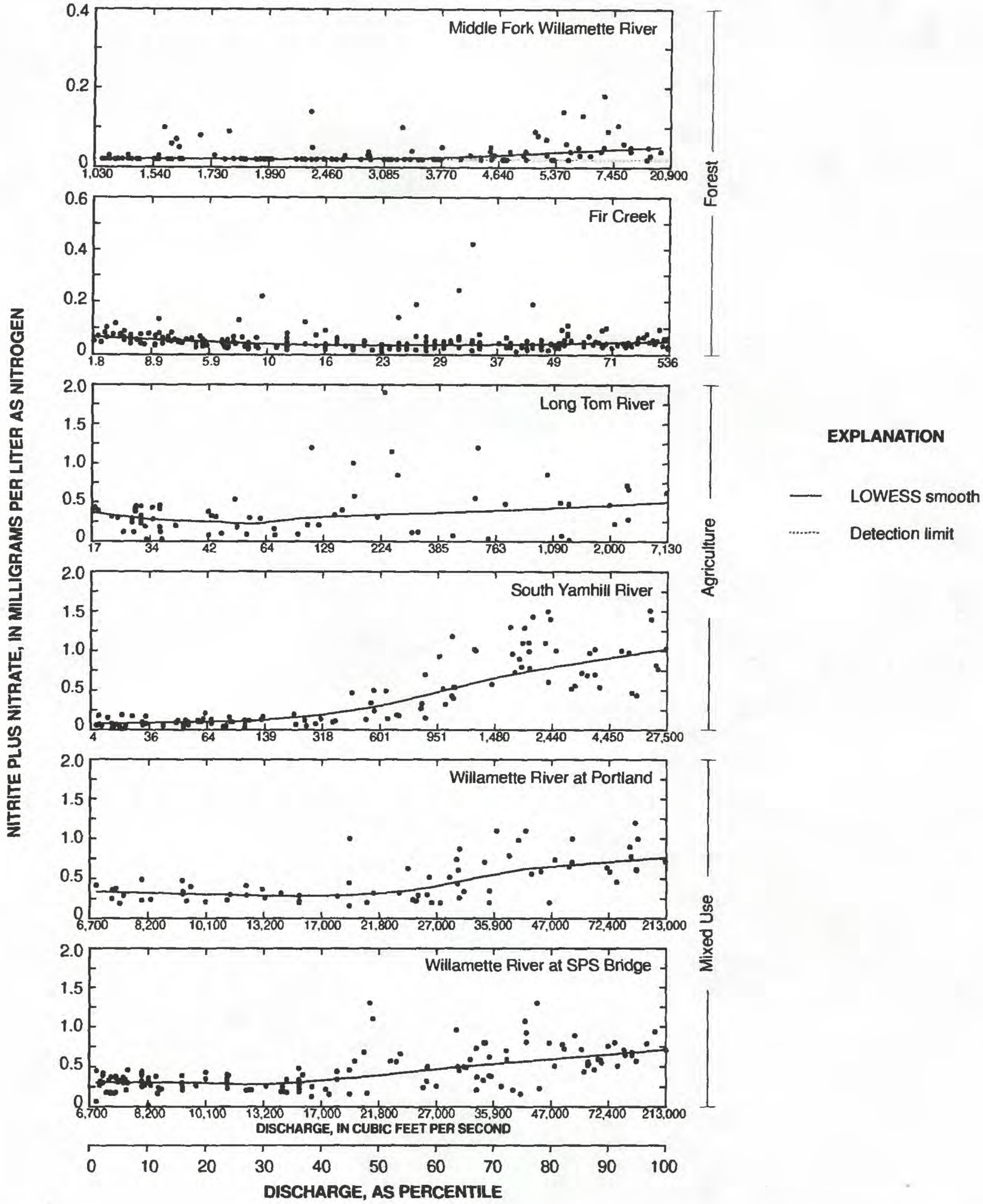


Figure 37. Relation between nitrite plus nitrate and streamflow at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Note different ordinate scales. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

Analysis of Phosphorus Data

Like nitrogen, phosphorus is an essential nutrient for plant growth; high concentrations of phosphorus promote eutrophication. To prevent the excessive growth of aquatic plants in streams, USEPA recommends that total phosphorus concentrations not exceed 0.1 mg/L as P (U. S. Environmental Protection Agency, 1986). A significant fraction of the total phosphorus often is associated with suspended particles. The soluble forms of phosphorus, however, are the most readily available. Sources of phosphorus include sewage treatment plants, sediment-laden surface runoff, and fertilizers. Dissolution of phosphate-containing minerals can be a natural source of phosphorus; such minerals have been found in the Tualatin Basin (C.D. Palmer, Oregon Graduate Institute, oral commun., 1993).

Site Comparisons

Among sites— The largest concentrations of SRP (soluble reactive phosphorus) were found at the Pudding River site (fig. 38). Concentrations at the other two agricultural basin sites (South Yamhill and Long Tom Rivers) were much less. SRP concentrations at the two Willamette River sites, which received localized urban inputs, were greater than those at the South Yamhill River and Long Tom River sites. Forested sites had the lowest SRP concentrations. Differences in total P concentrations among sites were similar to those for SRP, but less pronounced (fig. 38). At the Pudding River site, total P concentrations routinely exceeded the recommended maximum for the prevention of eutrophication. The small difference between total P concentrations for the Willamette River at Portland and Willamette River at SPS Bridge sites could be due to inputs from combined sewer overflows or from point sources between the two sites, or the difference may be related to analytical bias (see Quality assurance of nutrient data, p.31).

SRP accounted for half or more of the total P at most sites (fig. 38). The relative fraction of SRP was significantly less, however, at the South Yamhill River and Long Tom River sites. The smaller proportion of SRP at these sites may indicate a lack of sources of soluble phosphorus, such as point sources or ground-water inputs. Sediment-laden runoff may be the most important source of phosphorus at these two agricultural sites.

Compared to national conditions— Except for the Pudding River site, total P concentrations at the Willamette Basin sites were much less than median national concentrations for comparable land uses. Although total P concentrations at the Pudding River site were large relative to the other Willamette Basin sites, they were similar to national concentrations for agricultural sites. Total P concentrations at the other two agricultural sites (South Yamhill and Long Tom Rivers) were considerably lower than the national composite of agricultural sites; 75-percent of the national values exceeded 90-percent of the total P concentrations at the South Yamhill River and Long Tom River sites combined. Similarly, total P concentrations at Fir Creek were very low compared to the national data for forested sites. Of the 166 total P determinations for Fir Creek, all but one were less than the 10th percentile for the national data.

Seasonality

Primary sites— No clear seasonal patterns were evident in the SRP concentrations at the Fir Creek, Long Tom River, or South Yamhill River sites (fig. 39). At the Pudding River site, SRP concentrations increased during summer and early autumn. Similar, but smaller, increases occurred during summer at both Willamette River sites. This pattern of seasonal dependence can be caused by lack of dilution during low-flow periods and may be indicative of point sources or ground-water sources in these basins. A wastewater treatment plant (major NPDES permittee) discharges directly into the Pudding River and may be an important source of soluble phosphorus in that basin. At the Middle Fork Willamette River site, SRP concentrations peaked during late winter and early spring. The highest concentrations of total P typically occurred during winter (fig. 40). In addition, the variability of the total P concentrations increased during the winter. The winter peaks coincide with increases in suspended-sediment concentrations (fig. 26), and probably represent phosphorus that is associated with particles. The increase in total P concentration during summer months at the Pudding River site reflects increased SRP.

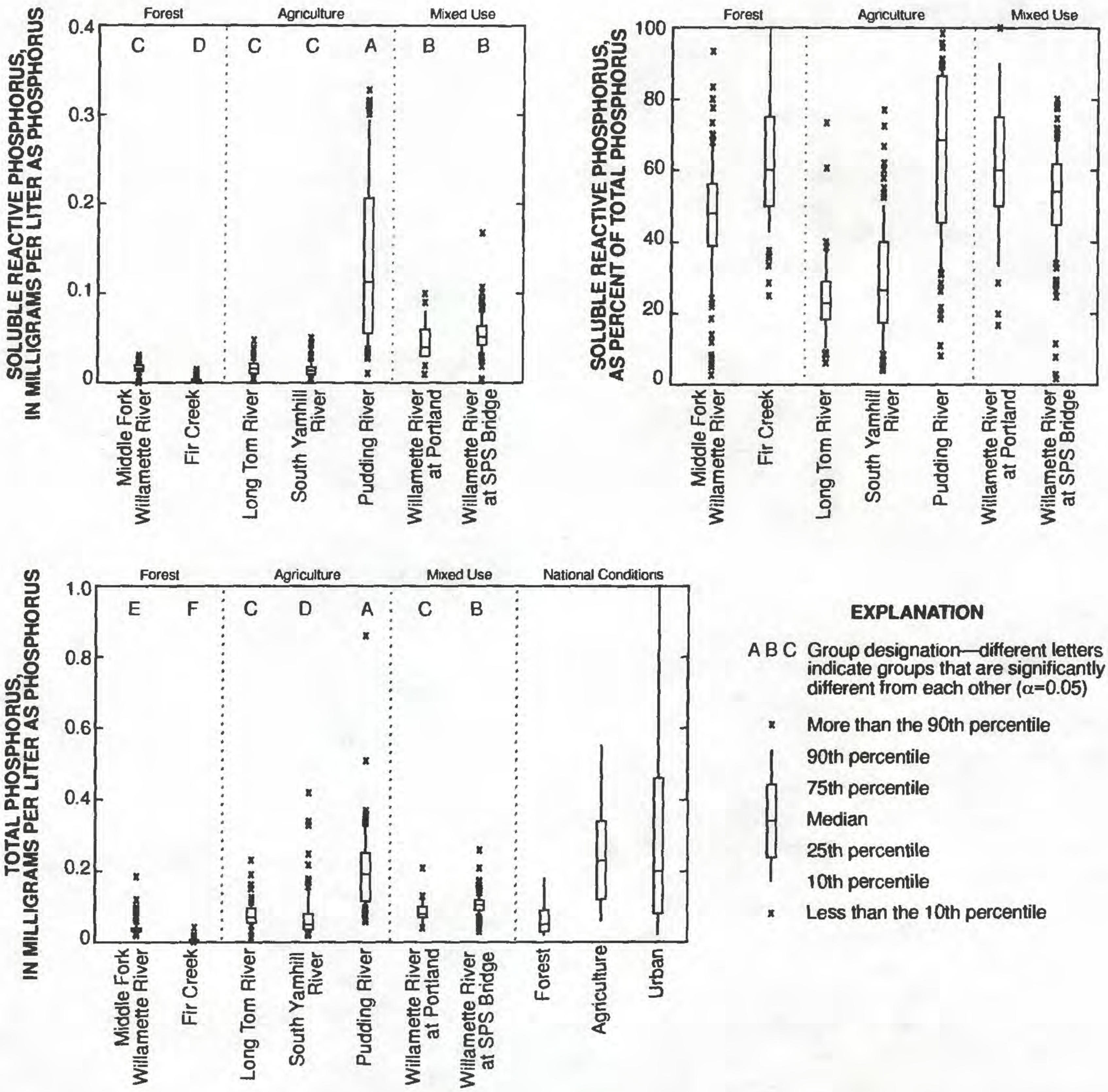


Figure 38. Concentrations of soluble reactive phosphorus and total phosphorus, and percent soluble reactive phosphorus at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

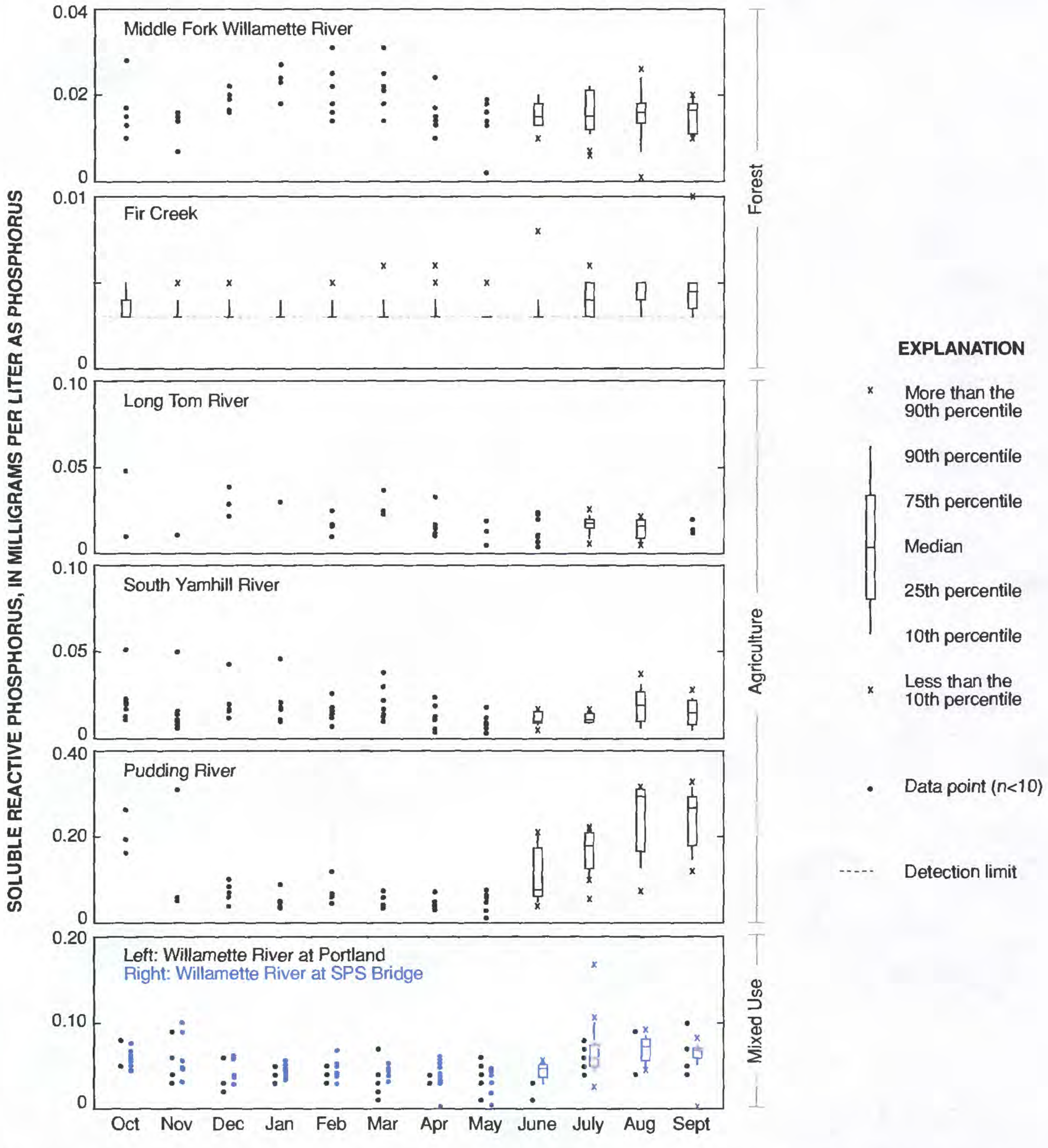


Figure 39. Seasonal variations of soluble reactive phosphorus at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Note different ordinate scales. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

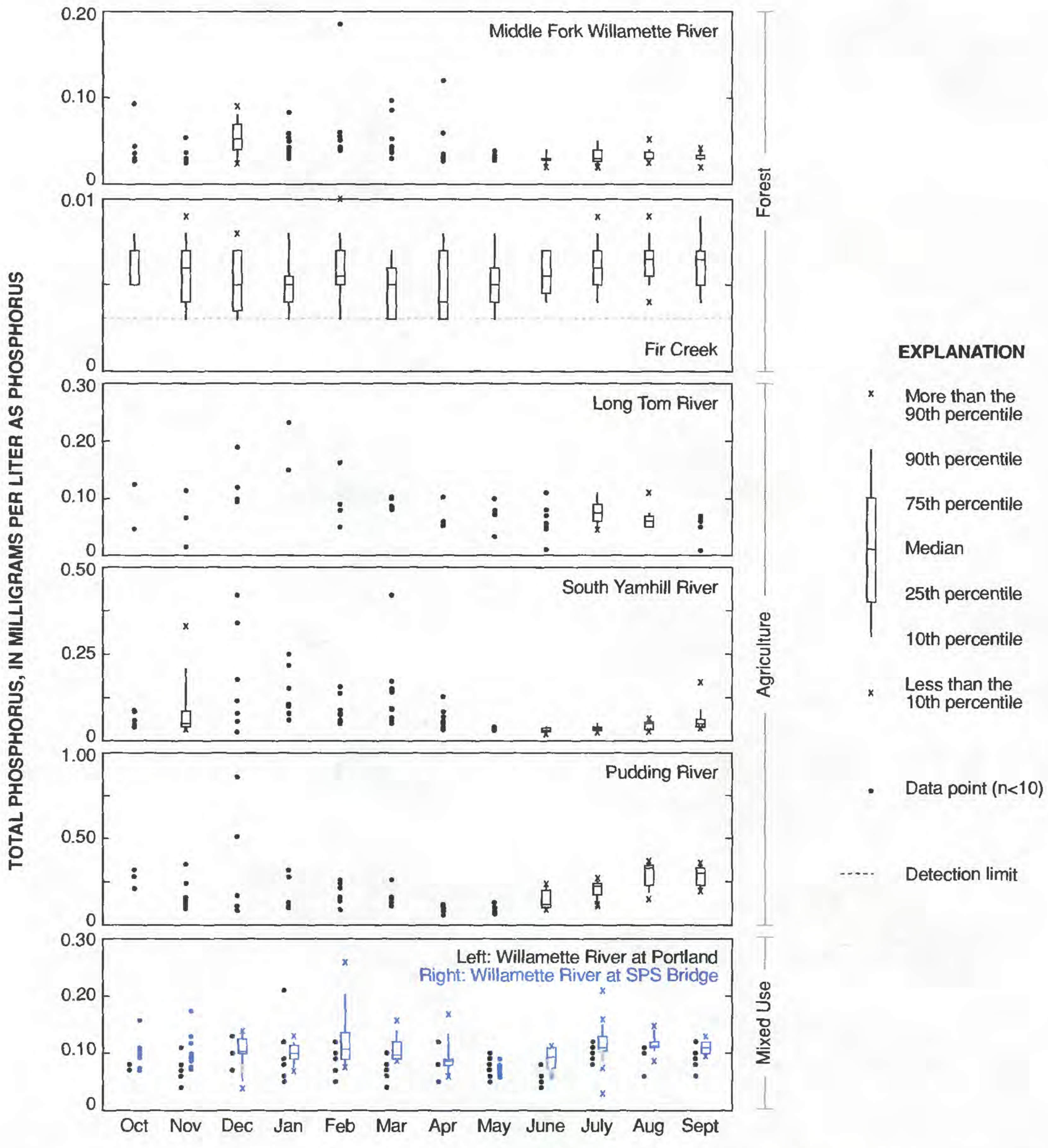


Figure 40. Seasonal variations of total phosphorus at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Note different ordinate scales. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

Nested subbasin sites— SRP concentrations at the nested subbasin sites were generally greater than those found at the primary sites, except the Pudding River site. SRP concentrations and seasonal variations at the agricultural (Dairy Creek) and urban (Fanno Creek) sites were similar; concentrations at the mixed-use site (Tualatin River), however, were greater than those at either of the tributary sites (fig. 41). SRP concentrations increased during the low-flow period (summer-autumn), indicating that point sources or ground-water inputs may be important. Elevated phosphorus concentrations have been detected in ground water in the Tualatin Basin (S.A. Rounds, USGS, oral commun., 1993). Total P concentrations were greatest at the mixed-use site and least at the agricultural site.

Relation between Concentration and Streamflow

SRP concentrations increased during low flow at three sites (Fir Creek and the two Willamette River sites), indicating that soluble phosphorus was diluted as streamflow increased. (fig. 42). Sources of SRP could include point sources and ground-water inputs. Total P concentrations, in contrast, increased during high flow at all sites (fig. 43). This relation is consistent with a surface-runoff source of suspended sediment. At sites where SRP accounted for most of the phosphorus (Fir Creek and the two Willamette River sites, fig. 38), the inverse relation between SRP and streamflow at low flows was also evident in the total P relation.

The relation between phosphorus concentration and flow was site dependent. At the South Yamhill site, for example, a strong relation existed between total P and flow; the relation between SRP and flow, however, was weaker. The dependence of either the SRP or total P concentration on flow was minimal at sites that were regulated by upstream reservoirs (Long Tom and Middle Fork Willamette Rivers).

Analysis of Dissolved Oxygen Data

DO concentration is one of the most commonly used indicators of water quality. Almost all aquatic organisms require dissolved oxygen to survive. The minimum concentration that can be tolerated varies; fish generally require higher DO concentrations than do invertebrates, and salmonids require higher DO concentrations than do warm-water fish species. The minimum DO standards set by ODEQ for the Willamette River tributaries are 6 mg/L in non-salmonid producing waters, and 90 percent of the saturation concentration in salmonid producing waters (95 percent in salmonid spawning areas). At Portland Harbor, the DO standard is 5 mg/L (Oregon Department of Environmental Quality, 1992b). Although not all Willamette Basin tributaries are identified as salmonid producing, for the purposes of this report, DO concentrations will be compared to 90 percent saturation.

The DO concentration is highly dependent on many factors, including physical stream conditions, chemical constituents, and biological activity. Fundamentally, the DO concentration is limited by the solubility of oxygen in water, which is determined by water temperature, atmospheric pressure, and the concentrations of other dissolved constituents. The solubility limit, therefore, varies with location and time of year. For this reason, DO is often expressed as "percent saturation" (the absolute concentration divided by the solubility, expressed as a percent). The DO concentration will not necessarily, or even usually, equal the solubility. Differences, either positive or negative, between the measured DO concentration and the solubility may be due to abiotic processes, but more frequently are caused by biological activity.

Effects of biota on the DO concentration are complex. Oxygen is produced during photosynthesis and consumed during respiration. Consequently, any factor that affects organisms involved in either photosynthesis or respiration also may affect the DO concentration.

Interpretation of DO measurements should include all of the processes that affect DO concentrations; physical, chemical, and biological conditions of the site should be taken into account. Consider the following example: The absolute DO concentration in a cool stream would be greater than that in a warm stream if both streams were well-aerated and undisturbed by other processes. The percent saturation measurements, however, could be the same. If the warm stream received direct sunlight and began to build up a significant algal population, and if the DO measurements were taken during daylight hours, then both the absolute DO concentration and the percent saturation could exceed those of the cool stream because of photosynthetic oxygen production.

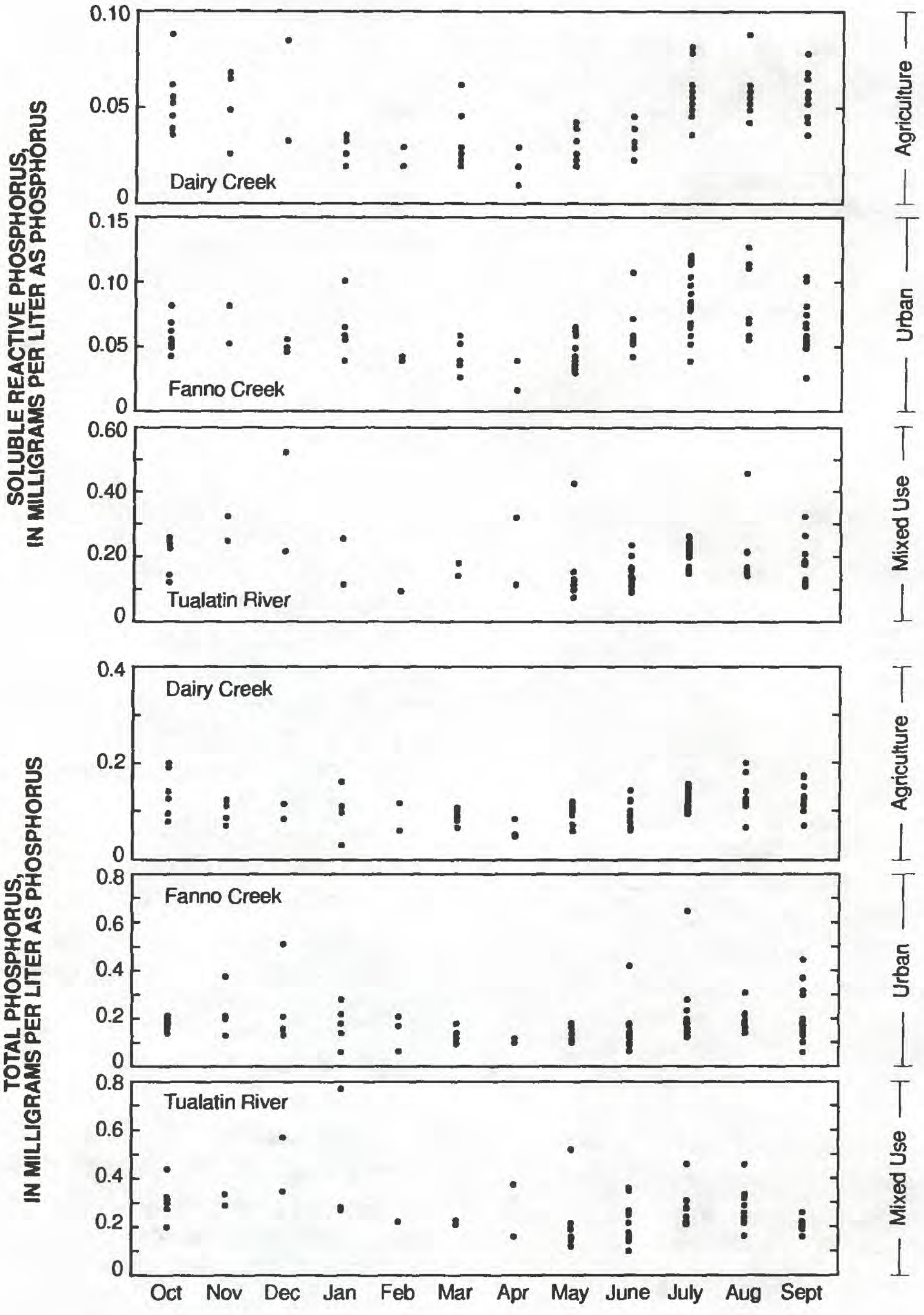


Figure 41. Seasonal variations of soluble reactive phosphorus and total phosphorus at sites in the Tualatin River Basin, Oregon, 1988–90 water years. (Note different ordinate scales. Data from Oregon Department of Environmental Quality.)

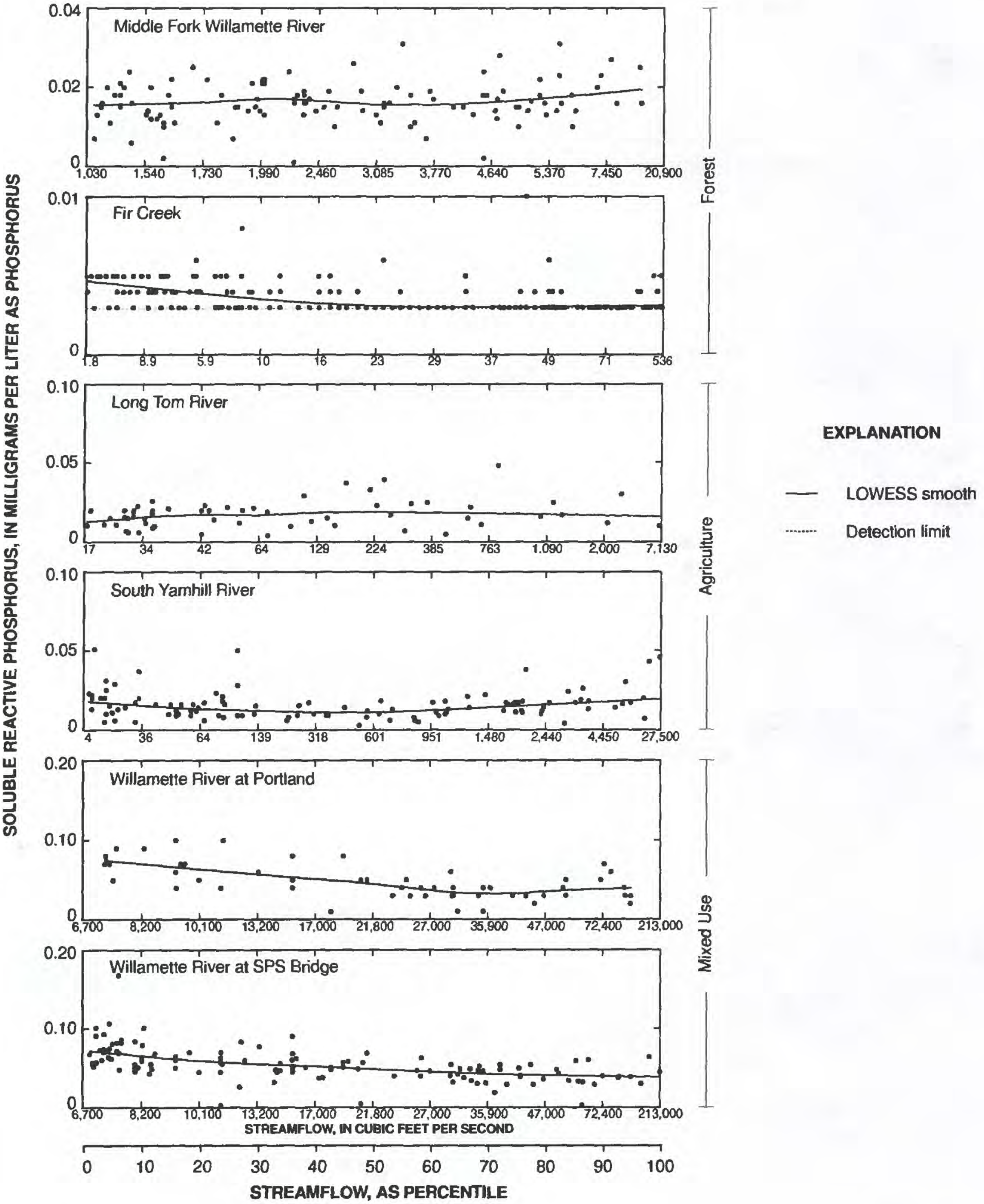


Figure 42. Relation between soluble reactive phosphorus and streamflow at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Note different ordinate scales. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

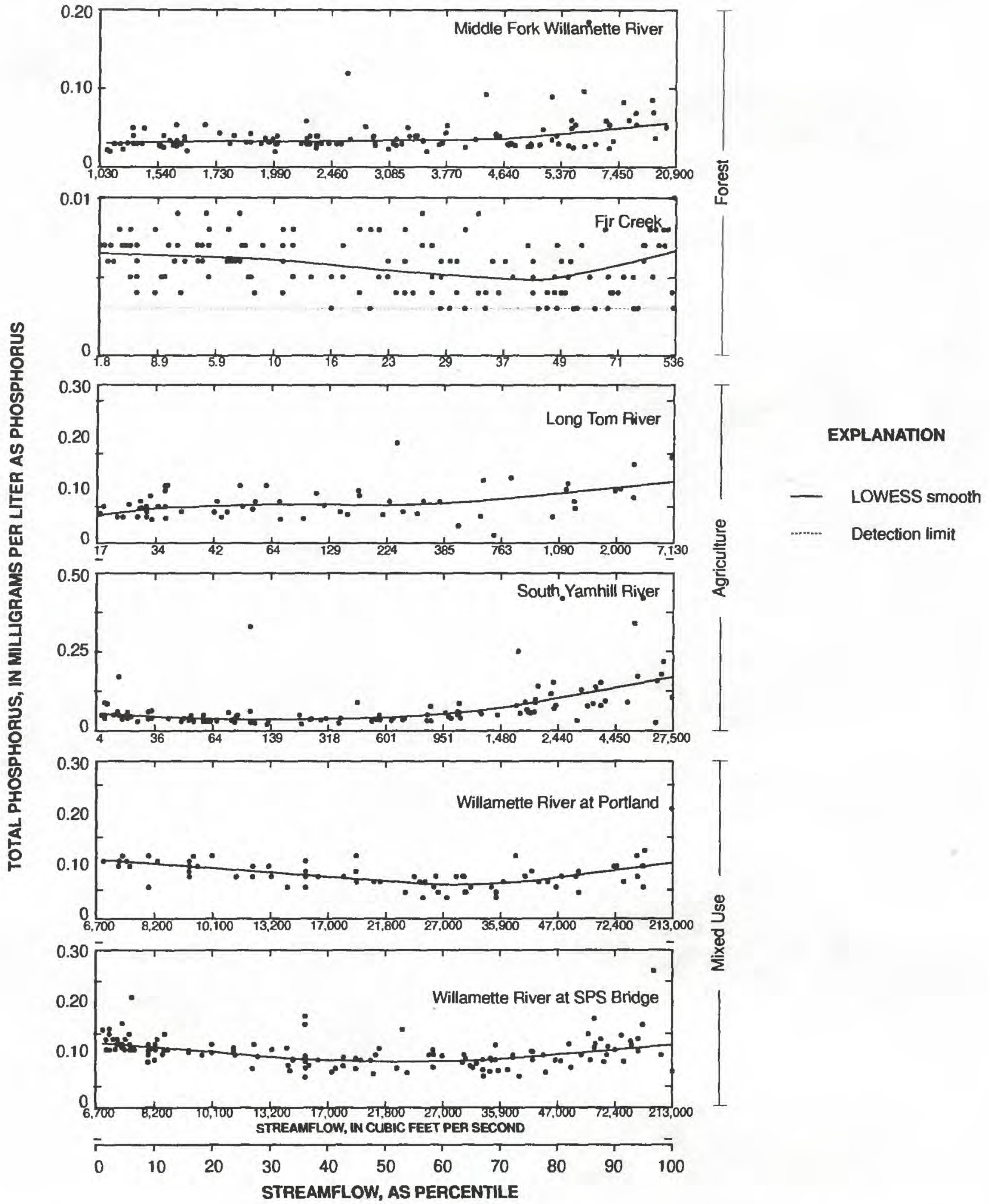


Figure 43. Relation between total phosphorus and streamflow at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Note different ordinate scales. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

Site Comparisons

Among sites—Absolute DO concentrations and percent saturation concentrations were generally lowest at the Pudding River site (fig. 44). The median DO concentration at the Pudding River site (9.1 mg/L) was almost a full unit less than the median DO concentration at any of the other sites. Half of the DO concentrations at this site were less than 90-percent saturation. At least 10 percent of the measurements at the other agricultural sites and at the mixed-use sites also were less than 90-percent saturation (fig. 44). At the forested site (Middle Fork Willamette River), however, only 2 of 130 measurements were less than 90-percent saturation. Although the absolute DO concentrations at the Long Tom River and South Yamhill River sites were similar, the percent saturation concentrations were greater at the Long Tom River site (fig. 44). Recall that water temperatures at the Long Tom River site were higher than those at the South Yamhill River site (fig. 20). High water temperatures are associated with decreased oxygen solubility, thereby resulting in increased values of percent saturation for similar absolute concentrations.

Seasonality and Diel Variation

At all sites, absolute DO concentrations followed an expected seasonal pattern driven by temperature (higher concentrations in winter and lower concentrations in summer) (fig. 45a). When this temperature effect is removed by expressing the data as percent saturation, however, a different seasonal pattern emerges (fig. 45b). Through winter and early spring, percent saturation values remained relatively

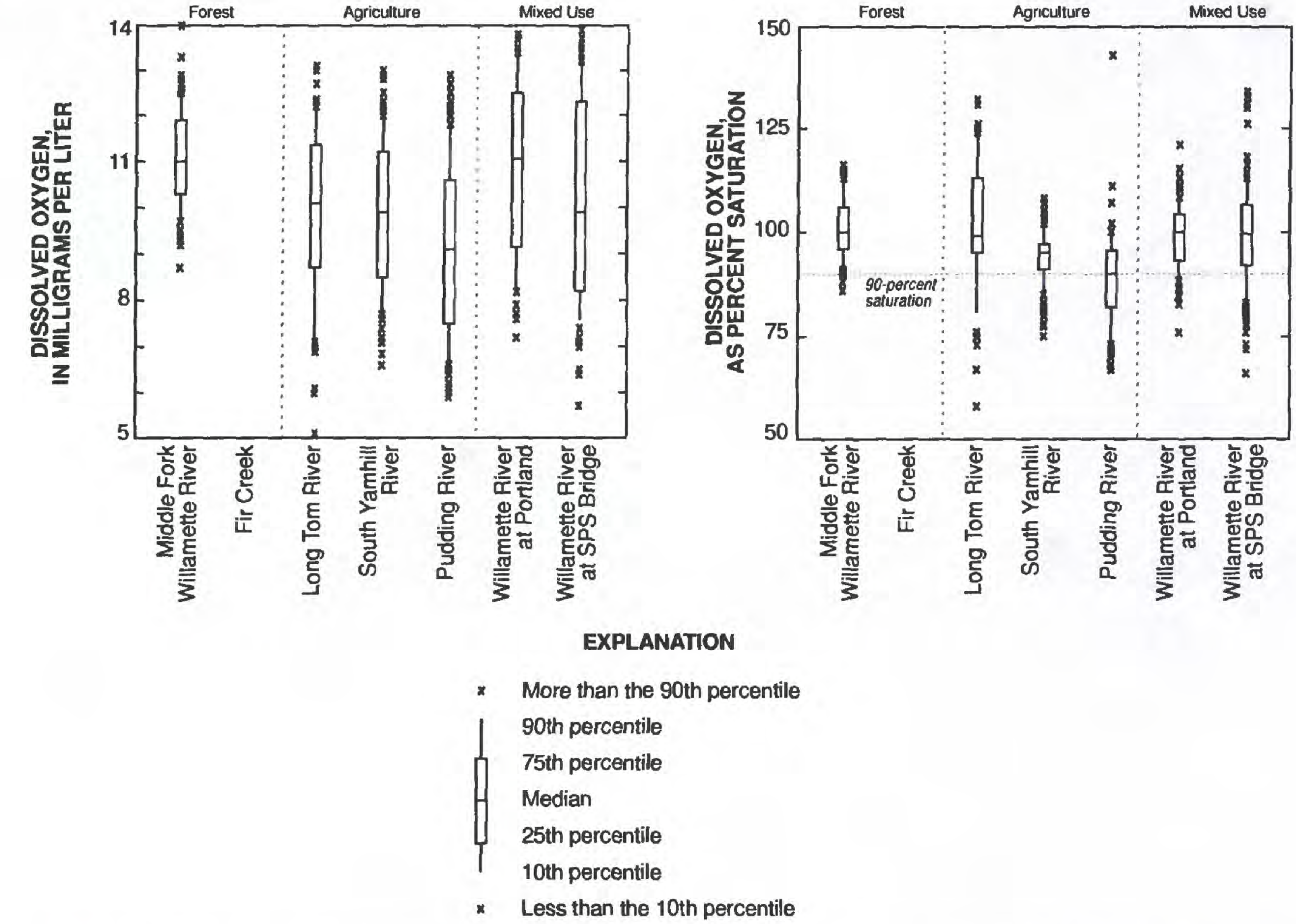


Figure 44. Dissolved oxygen concentrations at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980-90 water years. (Dissolved oxygen concentrations were not available for the Fir Creek site. Data from Oregon Department of Environmental Quality, and U.S. Geological Survey.)

a

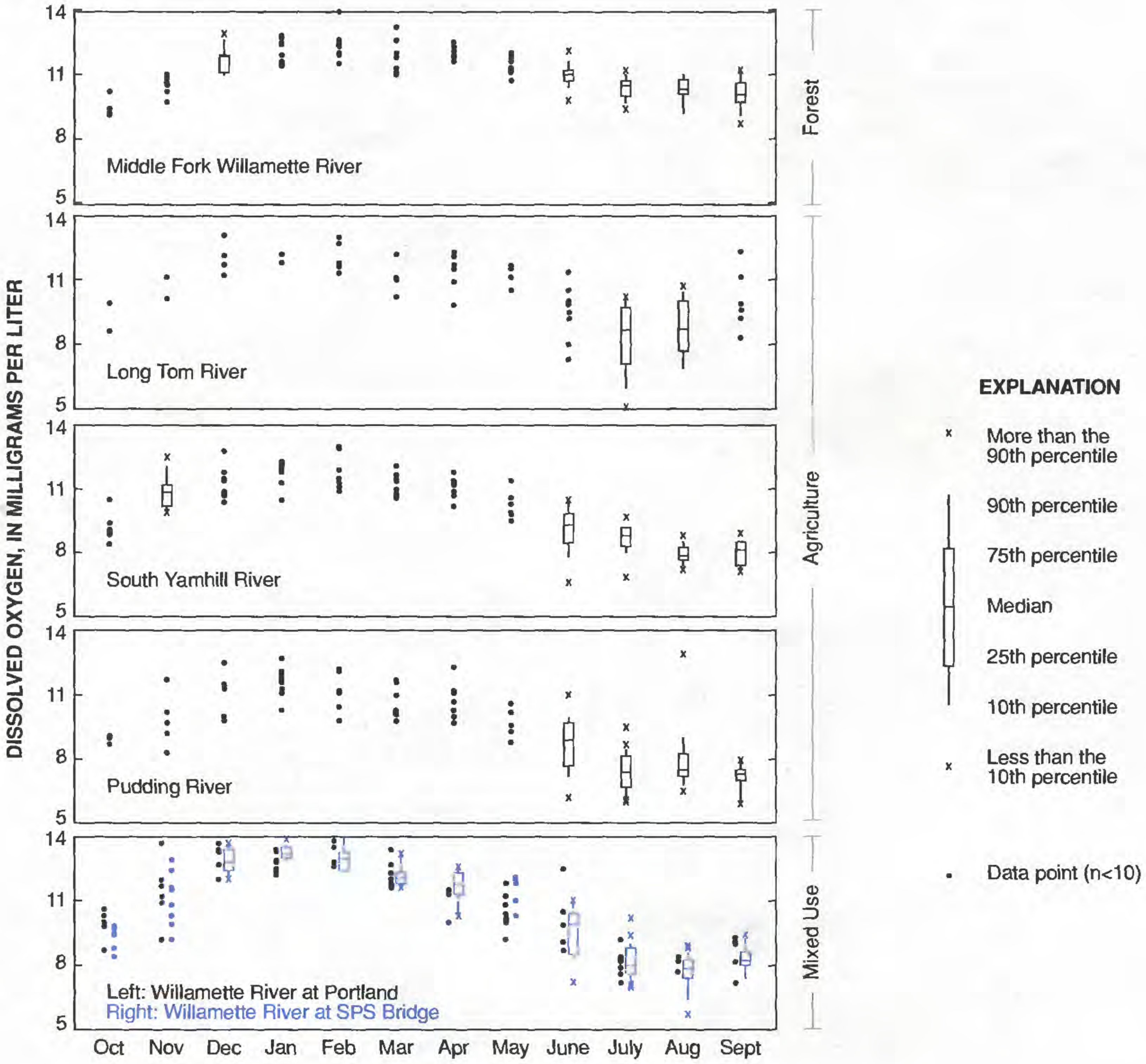


Figure 45. Seasonal variations of dissolved oxygen at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980-90 water years: (a) expressed in milligrams per liter. (Data from Oregon Department of Environmental Quality, andU.S. Geological Survey.)

b

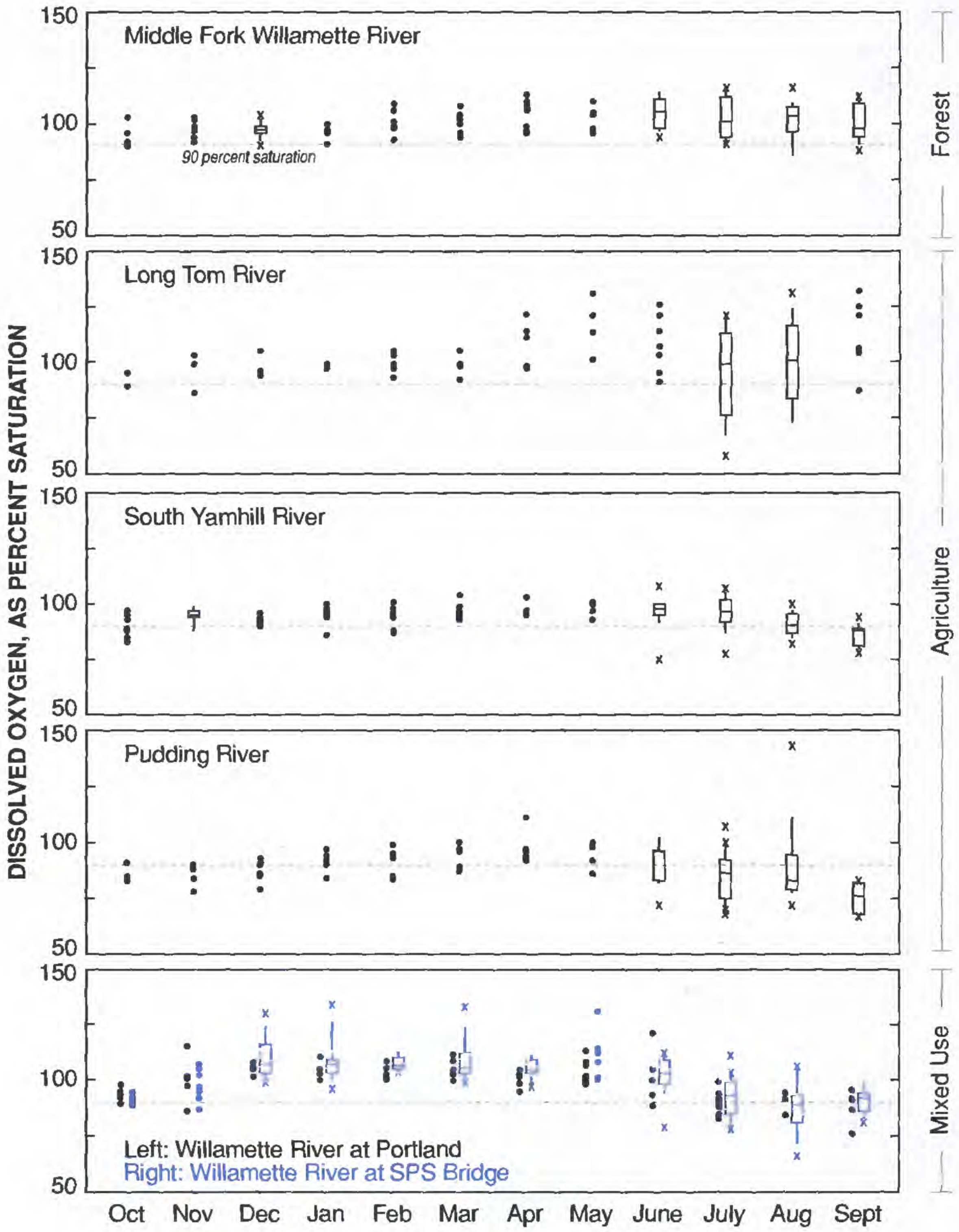


Figure 45.— continued (b) expressed as percent saturation.

constant and were not highly variable. During summer, the variability tended to increase; the variability increase was especially pronounced at the Long Tom River site. At the Willamette River at Portland, Willamette River at SPS Bridge, Pudding River, and South Yamhill River sites, percent saturation concentrations decreased in late summer.

Although minimal diel data were available, those data suggest that photosynthetic activity affected the DO at all sites. During the day, photosynthetic organisms consume carbon dioxide (causing an increase in pH) and produce oxygen in excess of that consumed by respiration. At night, photosynthesis ceases, but respiration continues to consume oxygen. The data show lower pH values and DO concentrations in the early morning (6:00–9:00 a.m.) than in the afternoon (1:00–6:00 p.m.) (fig. 46). The ranges of the diel variation for DO and pH were particularly large at the Long Tom River site and may have been related to the lack of shade in the lower reaches of the river. The early morning DO concentrations at this site were low (60–80 percent of saturation). If these values are typical for the Long Tom River during summer months, then DO concentrations should be of concern. Most of the data shown for this site on figures 44 and 45 were collected during the mid-day, when DO values were near their daily maximum, and do not accurately represent a 24-hour period.

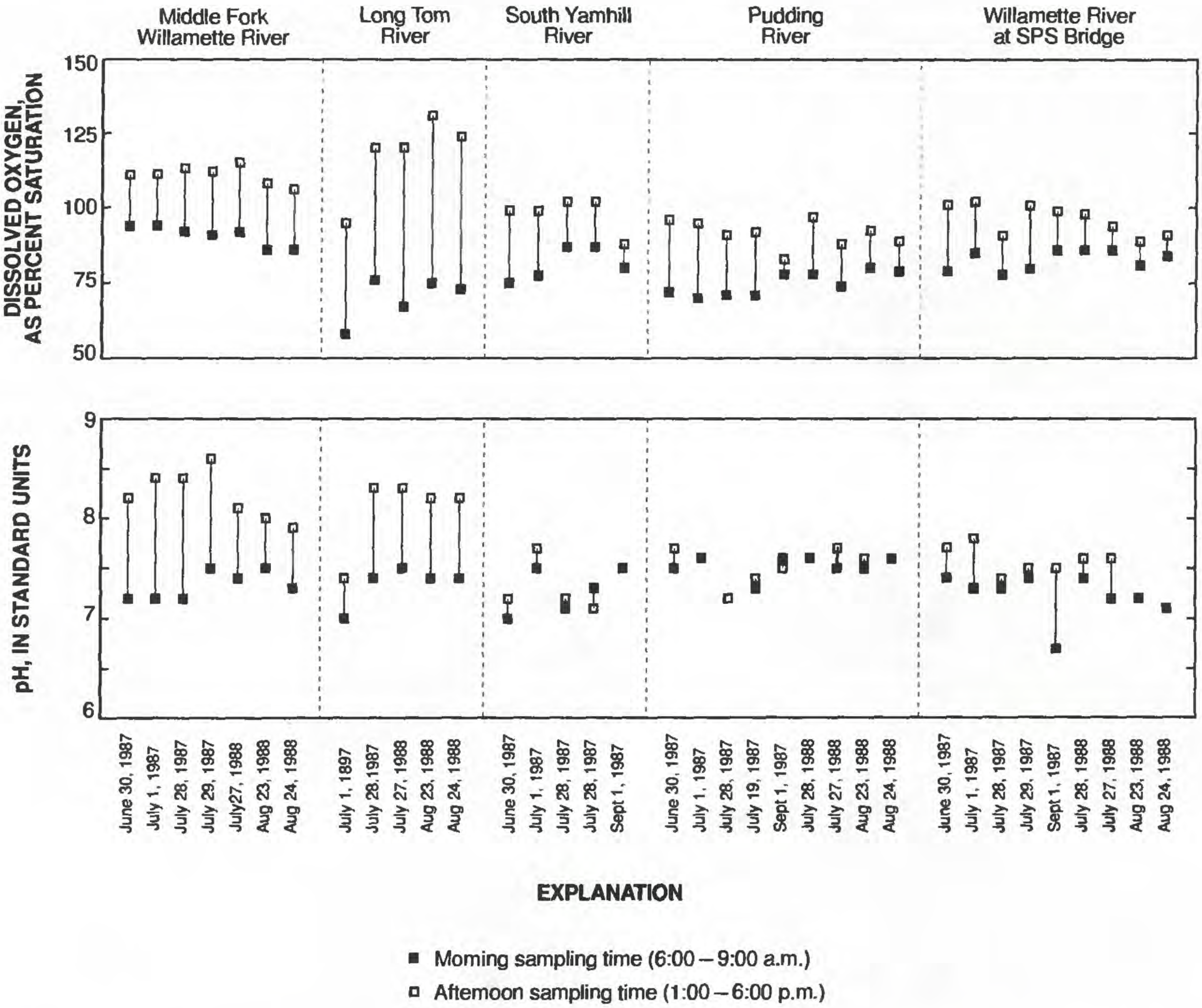


Figure 46. Diel variation of dissolved oxygen and pH at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1987–88. (Data from Oregon Department of Environmental Quality, and U.S. Geological Survey.)

At the Pudding River site, DO concentrations never exceeded 100-percent saturation and, on some days, diel pH changes were not observed (fig. 46). Why DO concentrations were suppressed at the Pudding River site is unknown. Photosynthesis may have been light-limited; much of the Pudding River is turbid. Periphyton growth may have been limited by lack of suitable substrate. Oxygen may have been consumed by the decomposition of organic material; inputs from the sewage treatment plants or from food processing plants in the basin may contribute a significant oxygen demand. In addition, photosynthetic organisms may have been affected by toxic substances such as herbicides and pesticides from agricultural applications. The sparse data available suggest that diel variations in pH values and DO concentrations have an important influence on the overall water quality within the Willamette Basin.

Temporal Trends for Nutrients

No strong temporal trends were evident for flow-adjusted nutrient data at the primary sites (figs. 47–51). Weak increasing trends between 1981 and 1987 were noticeable at the Long Tom River site for TRN, NO_3-N, SRP, and total P. Because the data for the Long Tom River site during this time period were sparse with several temporal gaps, the apparent weak trends at this site should be interpreted cautiously. During the early 1980's, TRN values for the Willamette River at Portland site were greater than those for the SPS Bridge site. During the late 1980s, TRN values at the two sites were similar. The abrupt decrease in reported TRN concentrations in 1983 for the Willamette at Portland site was probably due to the correction of an ammonia contamination problem at the USGS NWQL (see Quality assurance of nutrient data, p. 31).

Statistical tests for temporal trends at sites in the Willamette Basin have been reported elsewhere. Laenen (1993) reported the results of seasonal Kendall tests (Hirsh and others, 1982; Hirsh and Slack, 1984) on data from two sites (Willamette River at Portland, and Tualatin River at West Linn, RM 1.8). No trends in NO_3-N (1980–1989), dissolved phosphorus (1982–1989), or DO (1975–1989) were detected for the Willamette River at Portland site. Dissolved phosphorus showed an increasing trend, and DO showed a decreasing trend for the Tualatin River at West Linn site. Laenen (1993) suggested that these trends may have been due to increased use of phosphorus-containing fertilizers, increased urbanization, and increased input from sewage treatment plants. The trends, however, may not have continued beyond 1991, when tertiary treatment for phosphate removal was established at the two major sewage treatment plants that discharge directly into the Tualatin River.

ODEQ (1992a) reported results of seasonal Kendall tests on data from three sites on the main stem Willamette River (SPS Bridge; Newberg Pool, RM 48.6; and Salem, RM 83.9). NH_4-N concentrations showed a significant decrease at the SPS Bridge (1971–1990) and Newberg Pool (1977–1990) sites. ODEQ attributed the decrease to a reduction in ammonia point sources (the closure of two paper mills and reduced ammonia loads from a metals-processing plant). A decreasing trend in inorganic nitrogen was reported for the SPS Bridge site (1971–1990), but an increasing trend was reported for the Salem site (1985–1990). No significant trends were reported for SRP or total P.

Mass Transport of Nutrients

Annual loads were calculated from daily mean flow values and regression-based estimates of concentration (see Load calculations, p. 21). The regression models are summarized in table 9. Regression results were generally poor, and consequently, load estimates could be in error by 100 percent or more (based on 95-percent confidence limits of regression-based concentration estimates). This lack of fit indicates that the important processes controlling the concentrations of nitrogen or phosphorus have not been well modeled by the regression.

Despite the inherent errors in these loads, a qualitative comparison between the estimated instream loads and the estimated annual nutrient input loadings to the watershed can be made. Estimated annual instream loads for representative high-flow, low-flow, and moderate-flow years are shown in table 10. In general, the annual load estimates parallel the annual streamflows. Annual nutrient inputs to the watershed

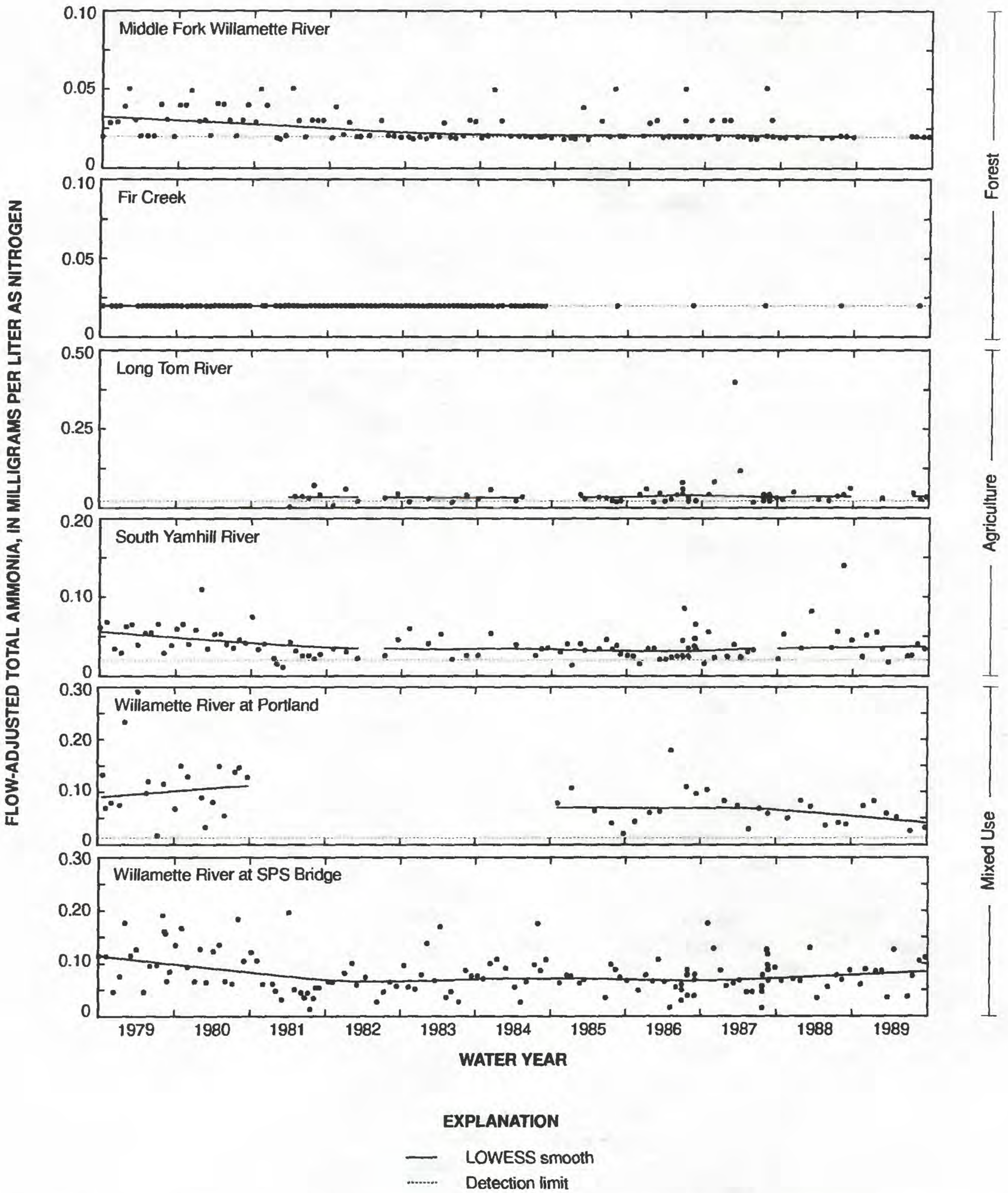


Figure 47. Temporal trends for total ammonia at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Smooth lines are broken for data lapses of 4 or more months. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

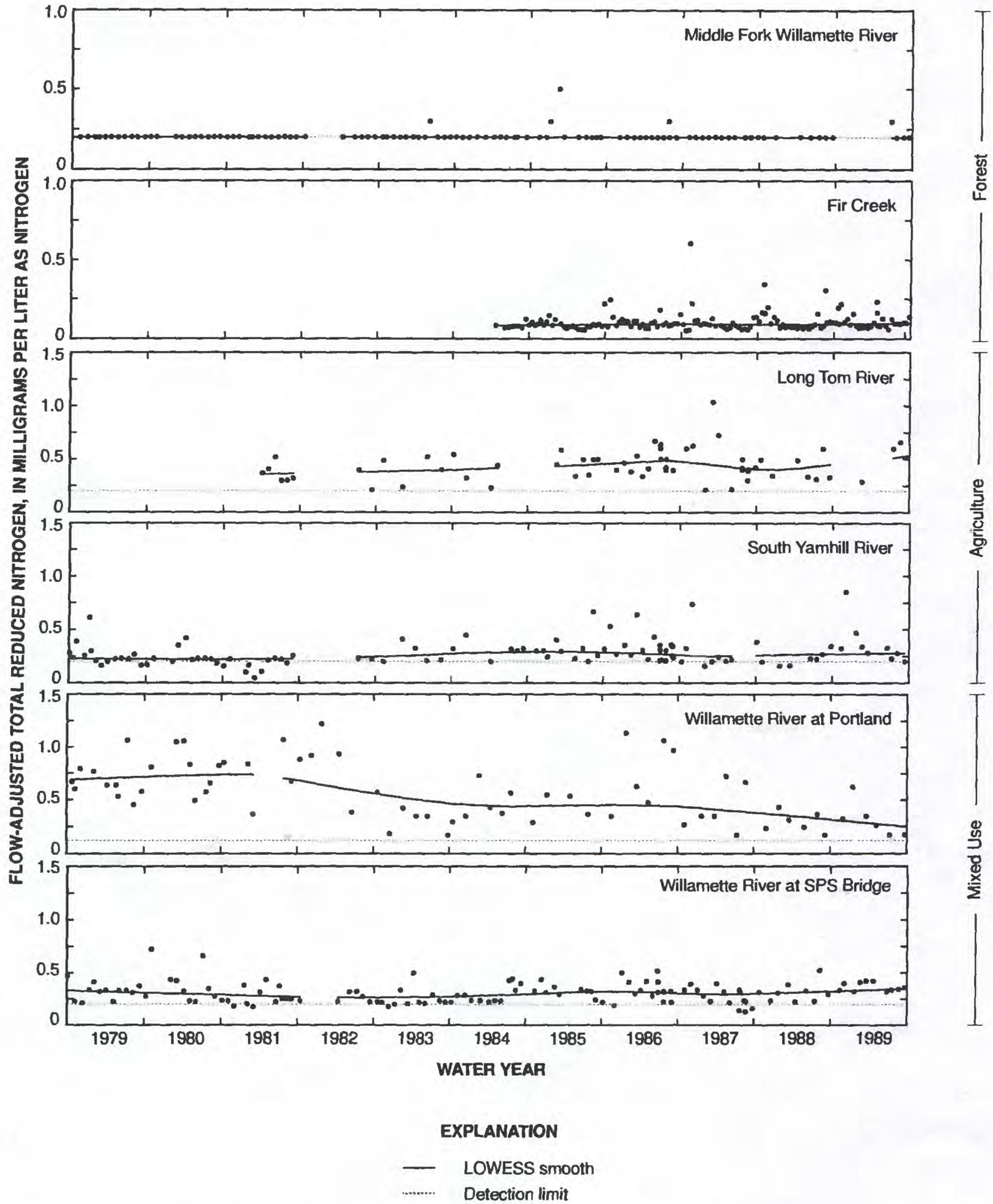


Figure 48. Temporal trends for total reduced nitrogen at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Smooth lines are broken for data lapses of 4 or more months. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

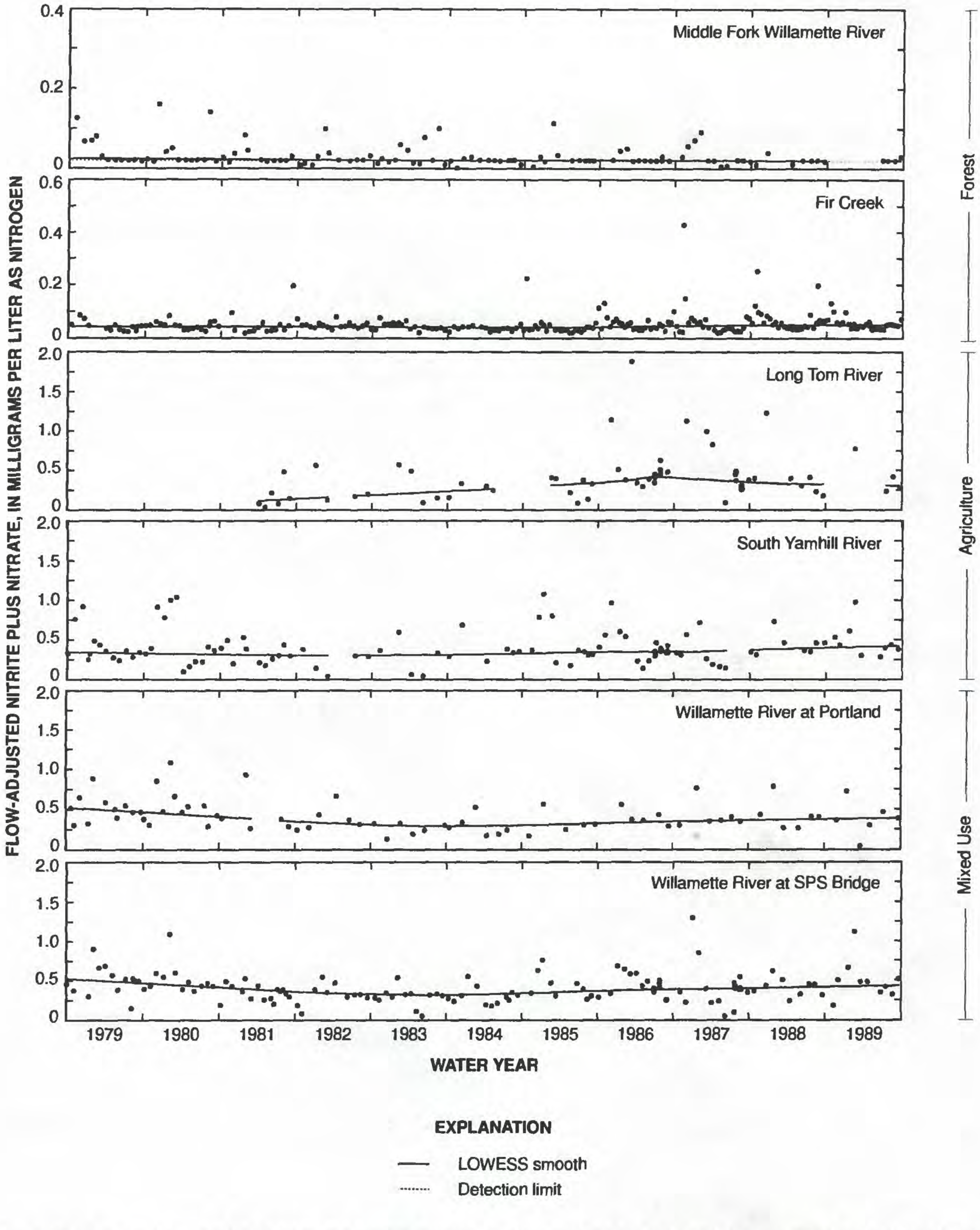


Figure 49. Temporal trends for nitrite plus nitrate at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Smooth lines are broken for data lapses of 4 or more months. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

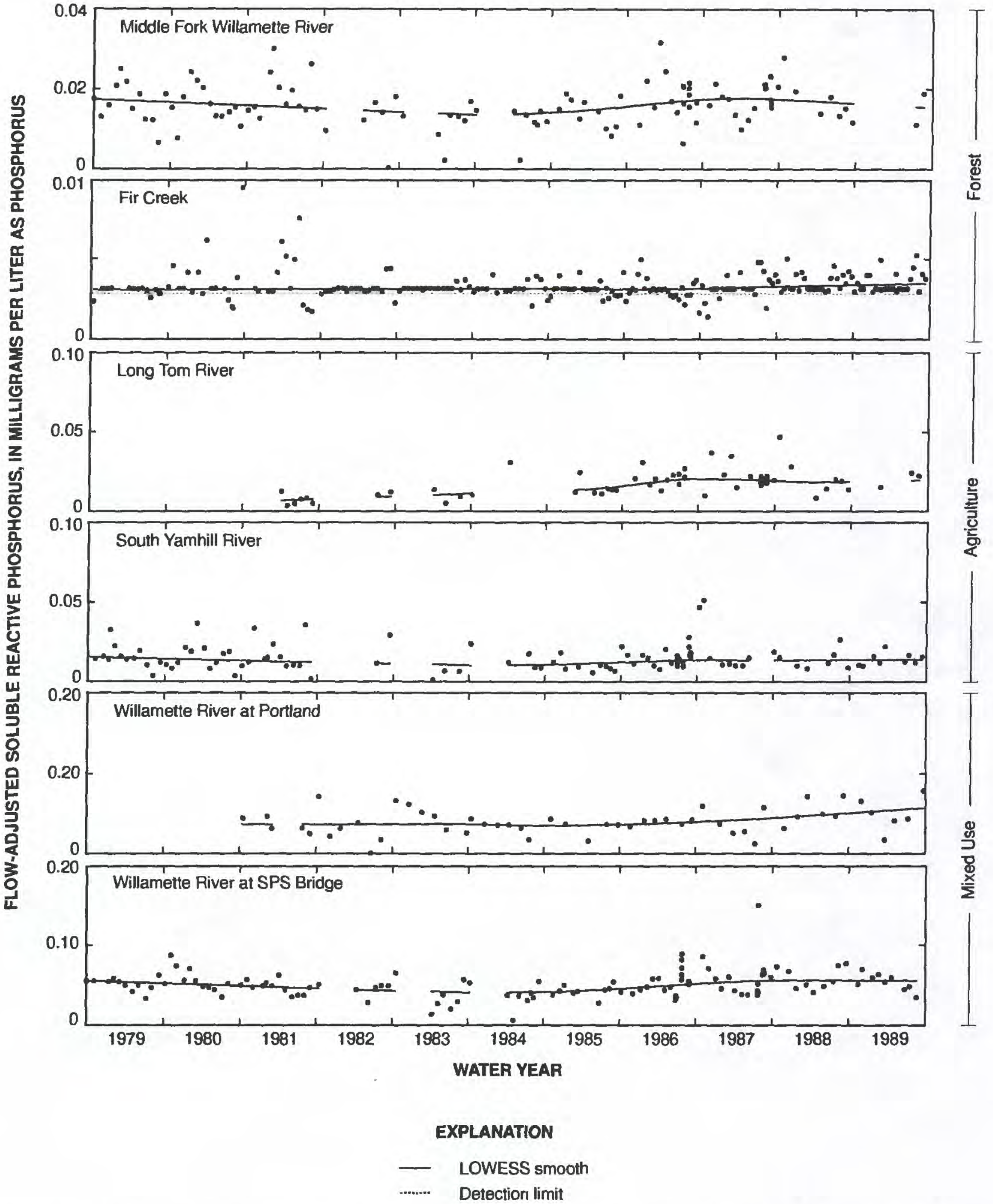


Figure 50. Temporal trends for soluble reactive phosphorus at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980-90 water years. (Smooth lines are broken for data lapses of 4 or more months. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

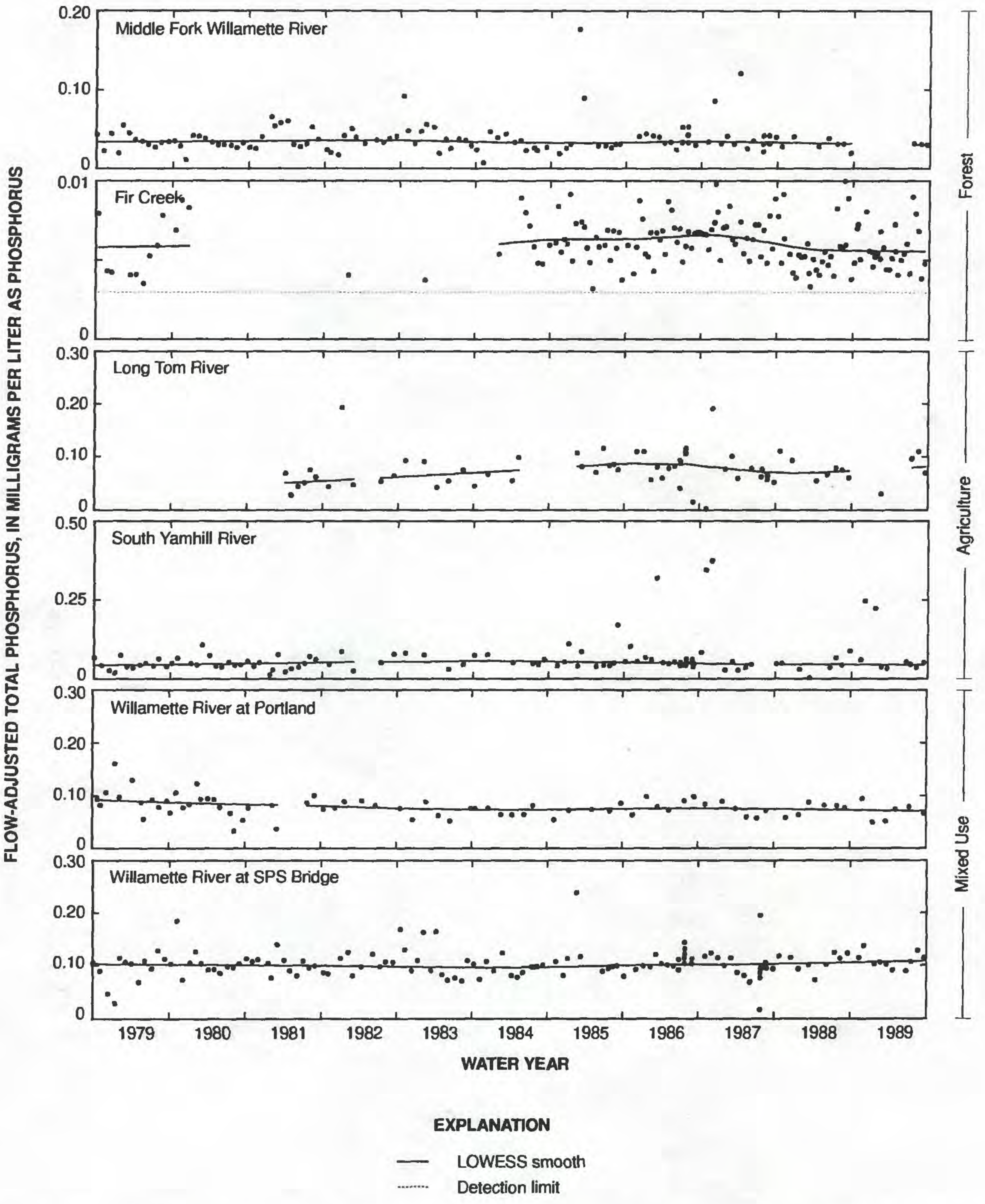


Figure 51. Temporal trends for total phosphorus at primary surface-water sites in the Willamette and Sandy River Basins, Oregon, 1980–90 water years. (Smooth lines are broken for data lapses of 4 or more months. Data from Oregon Department of Environmental Quality, Portland Water Bureau, and U.S. Geological Survey.)

from fertilizer, manure, and the atmosphere (table 3, p. 16) substantially exceed the instream nutrient loads at all sites except Fir Creek and Middle Fork Willamette River (the two forested sites and the sites with the lowest nutrient concentrations). The differences between watershed inputs and instream loads indicate that a significant fraction of nitrogen and phosphorus applied to the landscape as fertilizer and manure is not transported to surface water, but is taken up by plants, bound to soil, undergoes denitrification or mineralization, or is transported to the ground-water system. The fraction that is not transported to surface water will increase further if additional inputs are considered in the calculations. Point-source inputs and other nonpoint-source inputs (such as nitrogen fixation by legumes) were not included in the present calculations because the necessary data were not available.

Table 9. Summary of regression models used to estimate constituent concentrations for load estimates
[The regression model is of the form: $C = a\ln(Q) + b\sin(2\pi t) + c\cos(2\pi t) + dt + e$, where C is the constituent concentration in milligrams per liter; Q is the streamflow in cubic feet per second, and t is the decimal time calculated as the number of elapsed days since October 1, 1979 divided by 365.25; a '—' indicates a regressor that was not included in the model as determined by Mallow's C_p test; CV is the coefficient of variation, defined as the root mean square error of the regression divided by the mean and expressed as a percent; r^2 is the adjusted coefficient of determination. Estimates of the regression parameters (*a*, *b*, *c*, *d*, *e*) are given to the number of significant digits warranted by their standard errors]

Site	Estimated regression parameters					Regression statistics	
	e	b	c	d	e	r^2	CV
			Total Nitrogen as Nitrogen				
Fir Creek	0.029	0.01	0.09	0.009	0	0.28	55
Long Tom River	-.13	.5	-.23	.05	1.2	.40	37
South Yamhill River	.12	.34	.03	.020	-.1	.74	36
Willamette River at Portland	—	.20	-.11	—	.80	.13	46
			Total Phosphorus as Phosphorus				
Fir Creek	.0013	-.0011	.0019	-.0002	.004	.10	57
Middle Fork Willamette River	.010	.007	-.008	.0008	-.04	.22	47
Long Tom River	.011	—	—	—	.02	.21	42
South Yamhill River	.016	.03	.02	.005	-.04	.28	83
Willamette River at Portland	—	—	—	-.0020	.094	.05	32

Table 10. Estimates of annual instream loads of nitrogen and phosphorus for representative low-, medium-, and high-flow years

[Ranks based on annual streamflows during 1980–90 water years, where rank=1 indicates lowest annual flow year and rank=11 indicates highest annual flow year during 1980–90; nitrogen loads at Middle Fork Willamette River could not be estimated because nitrogen concentrations at this site were frequently less than the detection limit]

Site	Water year (rank)	Streamflow (thousand acre-feet/year)	Nitrogen load (tons/year)	Phosphorus load (tons/year)
Fir Creek	1987 (1)	19.4	4.3	0.17
	1985 (4)	23.7	5.3	0.25
	1990 (10)	28.1	7.4	0.25
Long Tom River	1988 (2)	327	570	53
	1985 (6)	462	500	67
	1982 (11)	869	820	130
Middle Fork Willamette River	1988 (3)	2320	—	150
	1985 (6)	2,910	—	190
	1982 (10)	3,810	—	260
South Yamhill River	1988 (1)	856	1,470	150
	1985 (6)	911	1,600	160
	1982 (11)	1,700	2,800	260
Willamette River at Portland	1988 (1)	19,500	23,000	2,100
	1985 (7)	28,800	26,000	2,500
	1982 (11)	31,700	40,000	3,900

GROUND WATER

Data Selection and Description

The ground-water data discussed in this report were obtained from ODEQ (Oregon Department of Environmental Quality) and OHD (Oregon Department of Human Resources Health Division) (table 11). The ODEQ data consisted primarily of nitrite-plus-nitrate determinations from domestic and irrigation wells. Other nutrient constituents were reported in the ODEQ data base, but the amount of available data was insufficient for analysis. The OHD data were limited to nitrate determinations in water from public drinking-water-supply wells. Although limited, these data are particularly useful because they are spatially comprehensive. Summary statistics are provided in table 13 at the back of this report.

The USGS and USEPA databases (NWIS and STORET, respectively) were also searched, but failed to provide ground-water data that were suitable for analysis. The NWIS data base contained very little ground-water data. Most of the records obtained from the STORET data base were either from monitoring wells associated with landfill sites or from wells located in areas associated with ground-water-quality problems. These data, therefore, could not be used to assess the overall ground-water quality in the Willamette Basin. Ground-water data from these two data bases will not be discussed in this report.

Evaluation of Data

Data screening— The ground-water data were given minimal screening. OHD records that lacked well latitude and longitude were excluded. Samples from multiwell water-supply systems were also excluded. For both the OHD and ODEQ data, if more than one chemical analysis for a well was available, the most recent analysis within the 1980–90 water-year period was used; older analyses were removed to avoid creating bias towards frequently sampled sites. Insufficient time-series data prevented trend analyses.

Detection limits— A single detection limit for nitrate was reported for the OHD data (0.01 mg/L as N) (P. Meyer, OHD, oral commun., 1993). Variable detection limits for nitrite plus nitrate were reported for the ODEQ data. For statistical purposes, the greatest detection limit reported by ODEQ (0.10 mg/L as N) was used. All values between 0 and 0.10 mg/L as N were arbitrarily treated as if they had been reported as less than 0.10 mg/L as N.

Hydrogeology and Land Use

The locations of OHD wells are shown on figure 52 and on transparency[†] 1. Information concerning the hydrogeologic unit sampled was not available for the OHD wells. Superposition of the well locations on a map of the surface expressions of the basin-fill and alluvial and Columbia River basalt aquifers, however, shows that most wells were associated with the surficial expressions of these two units (fig. 52). For the purposes of this report, a well was assumed to be finished in the same hydrogeologic unit that was present at the land surface. This assumption may be incorrect in some cases. In particular, some wells in the Willamette Basin are developed in both the basin-fill and alluvial aquifer and the Columbia River basalt aquifer.

[†]A transparency of the site-location map is provided to facilitate comparisons to maps of land use, geology, and other ancillary data.

Table 11. Characteristics of the ground-water data
[Agencies are identified as follows: ODEQ, Oregon Department of Environmental Quality; OHD, Oregon Department of Human Resources Health Division]

Collecting agency	Purpose	Well type	Number of sites	Samples per site	Period of record
OHD	Drinking water monitoring	Public supply	312	1	10/01/79 – 05/31/90
ODEQ	Ground-water-quality assessment	Shallow domestic and irrigation	123	1	10/01/79 – 05/31/90

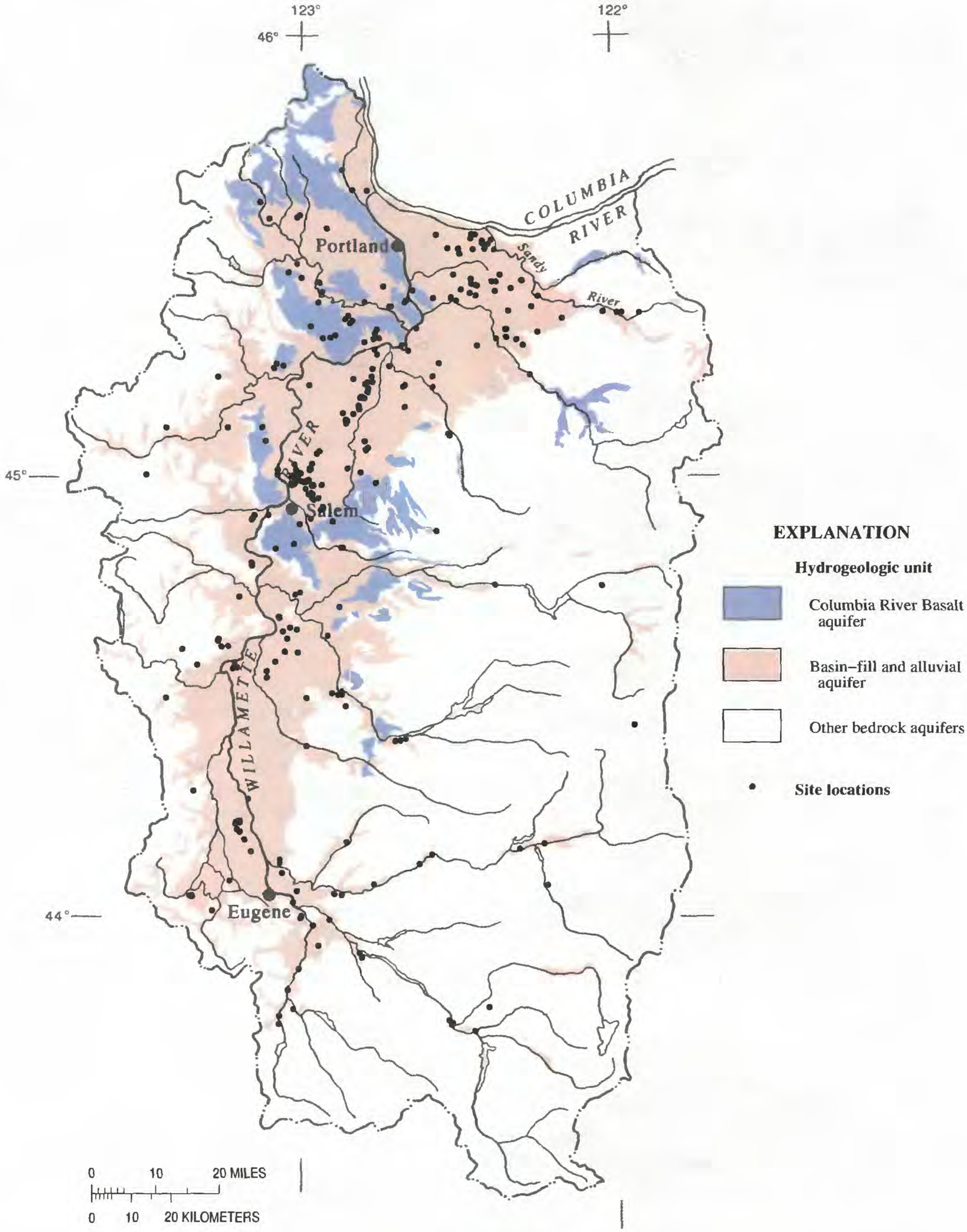


Figure 52. Locations of ground-water wells in the Willamette and Sandy River Basins, Oregon, that have nitrate data.

Precise locations and specific hydrogeologic information were unavailable for the ODEQ wells. More than 90 percent of these wells, however, were located in the basin-fill and alluvial aquifer (G.A. Pettit, ODEQ, oral commun., 1993).

The land-use designation of a well should represent the well's zone of contribution, which may be extensive and distant. The zones of contribution for the ODEQ and OHD wells are unknown. The land use at the well location was used as a first approximation of the land use for the zone of contribution. All of the ODEQ wells were known to be located in agricultural areas. For the OHD wells, the land use at the well was obtained by superimposing well locations on a map of GIRAS land-use data (Mitchell and others, 1977; Fegeas and others, 1983). The distribution of the wells with respect to hydrogeologic unit and land use is shown on figure 53.

Well Depth and Well Type

Not all of the ODEQ or OHD records included well depth (fig. 53). The well-depth distributions (fig. 54) show that wells finished in the basin-fill and alluvial aquifer tend to be shallower than those finished in the Columbia River basalt aquifer. The ODEQ study specifically targeted shallow wells; 86 percent of the wells with known depths were less than 100-ft deep.

All of the OHD wells were public-water-supply wells. Most of the ODEQ wells were domestic wells; a small number were used for irrigation. The information regarding well type was insufficient to investigate any potential effect of well type.

Data Acquisition Methods

Sampling and analytical methods— The OHD data were collected as part of routine monitoring of public drinking-water supplies in Oregon. Samples were not filtered and were analyzed using a nitrate electrode (American Public Health Association and others, 1989, Method 4500–NO_3 D).

The ODEQ data were collected during a study of nonpoint-source agricultural pollution in the Willamette Valley. Wells that were considered vulnerable to contamination from surface activities were targeted. These wells were shallow, located in areas of intensive agriculture, and completed in geologic media that lacked relatively impermeable strata (S. M. Fortuna and others, ODEQ, written commun., 1988). Most were domestic wells, but some irrigation wells also were sampled (G. A. Pettit, ODEQ, oral commun., 1993). Samples were not filtered. Automated cadmium reduction was used to determine nitrite-plus-nitrate concentrations (U.S. Environmental Protection Agency, 1979, EPA Method 353.2).

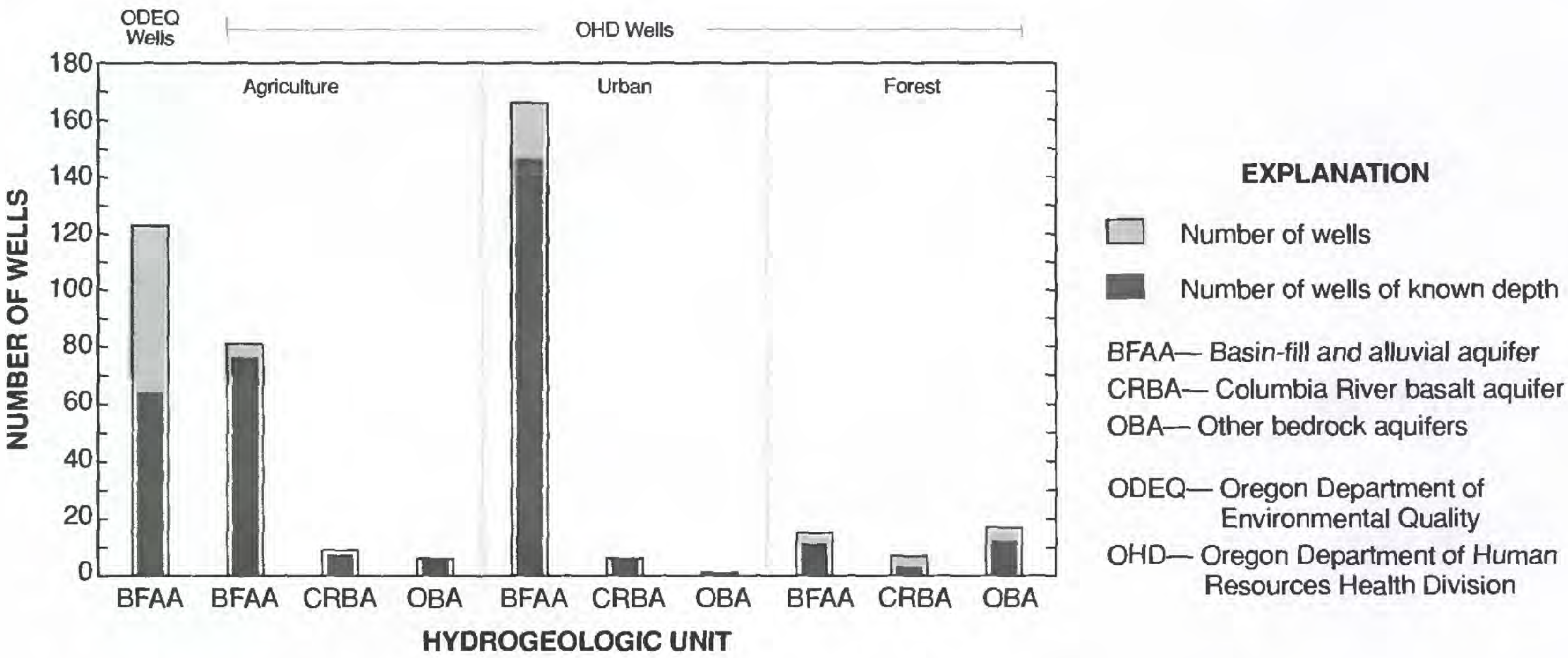


Figure 53. Distribution of wells in the Willamette and Sandy River Basins, Oregon by hydrogeologic unit and land use.

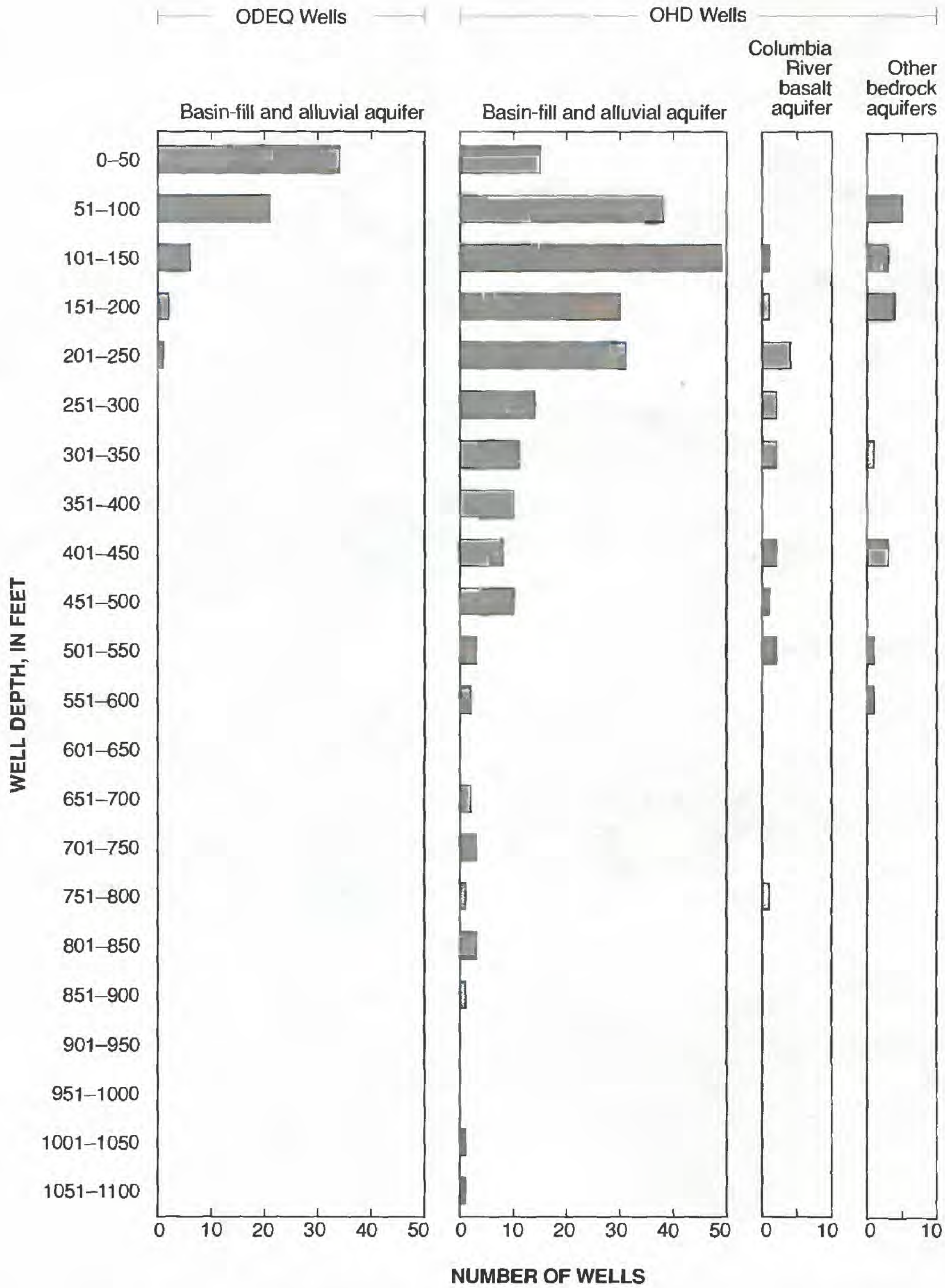


Figure 54. Distribution of well depths (measured with respect to land surface) for wells in the Willamette and Sandy River Basins, Oregon. (Agencies are identified as follows: ODEQ, Oregon Department of Environmental Quality; OHD, Oregon Department of Human Resources Health Division)

ODEQ and OHD used different analytical methods to assay for slightly different constituents: ODEQ assayed for nitrite plus nitrate, OHD assayed for nitrate. Nitrite concentrations usually are negligible in water that was well-oxygenated somewhere along its flow path. Relatively shallow ground water, such as that sampled by ODEQ, usually contains little nitrite. For this report, NO_3-N will be used to represent both nitrate and nitrite plus nitrate.

Quality assurance of nutrient data— The OHD used third-party certification for their laboratories prior to 1982 (P. Meyer, OHD, oral commun., 1993). From 1982 until 1990, OHD followed published quality-assurance guidelines (U.S. Environmental Protection Agency, 1982). ODEQ used in-house quality-assurance methods as previously described for the surface-water data (page 31).

Suitability of Data for Analysis

The ground-water data set may not be representative of basinwide ground-water quality for several reasons. Wells were not randomly distributed throughout the Willamette Basin. Wells located in forested areas or completed in the Columbia River Basalt or other bedrock aquifers are not well represented in this data set. Only already existing wells were sampled. No new wells were drilled. Water from already existing wells could be affected by local contamination because such wells often are located near residences and, therefore, near possible sources of septic contamination. In general, these data best characterize the local ground-water quality of the basin-fill and alluvial aquifer for wells located in relatively populated areas.

Care must be exercised when comparing OHD data with ODEQ data because these agencies collected data for different purposes. The OHD data are representative of ground water that is used as drinking water. Public-water-supply wells (such as those sampled by OHD) are usually not sited in areas of suspected contamination and may be abandoned if they fail to meet water-quality standards. Incidences of contamination, therefore, may be underrepresented in the OHD data. For the same reason, differences associated with land use or hydrogeologic unit may be minimized in this data. In contrast, the ODEQ data are representative of shallow ground water underlying agricultural areas. Because ODEQ targeted wells with an increased risk of contamination, incidences of contamination may be frequent in the ODEQ data.

The assumption that the land use at the well represents the land use for the zone of contribution introduces a potentially significant error. Recharge zones for public-water-supply wells, such as those monitored by OHD, are frequently large and may include multiple land uses. The land use of the zone of contribution also may have changed significantly since the ground water produced by a well entered the ground. The relations between ground-water quality and land use presented in this report should be considered in light of these potential spatial and temporal ambiguities in land use identification.

Analysis of Nitrate Data

Relations to Hydrogeology and Land Use

No significant differences in median NO_3-N concentrations were observed among hydrogeologic units or land uses for the OHD wells (fig. 55). Although the median concentrations were similar among these groups, the concentration ranges were larger for wells in the basin-fill and alluvial aquifer. NO_3-N concentrations exceeding 1 mg/L as N occurred less frequently in the Columbia River basalt aquifer and the other bedrock aquifers than in the basin-fill and alluvial aquifer. A greater incidence of high NO_3-N concentrations was evident at wells in the basin-fill and alluvial aquifer, and may indicate greater nitrate loadings to this hydrologic unit or an increased susceptibility to contamination. Alternatively, the different concentration distributions could be an artifact due to the different sample sizes of groups in this data set. Some extreme concentrations would be expected for a group with a large sample size, such as the basin-fill and alluvial aquifer group. Because extreme concentrations are rare, they would not necessarily occur in groups with fewer data.

The ODEQ data provide an interesting contrast with the OHD data. The median NO_3-N concentration for the ODEQ wells (4.9 mg/L as N) was more than an order of magnitude greater than the median concentration for similar (agricultural land use; basin-fill and alluvial aquifer) OHD wells (0.3 mg/L as N). Twenty-one percent of the ODEQ data exceeded the MCL. Although the ODEQ data are not representative

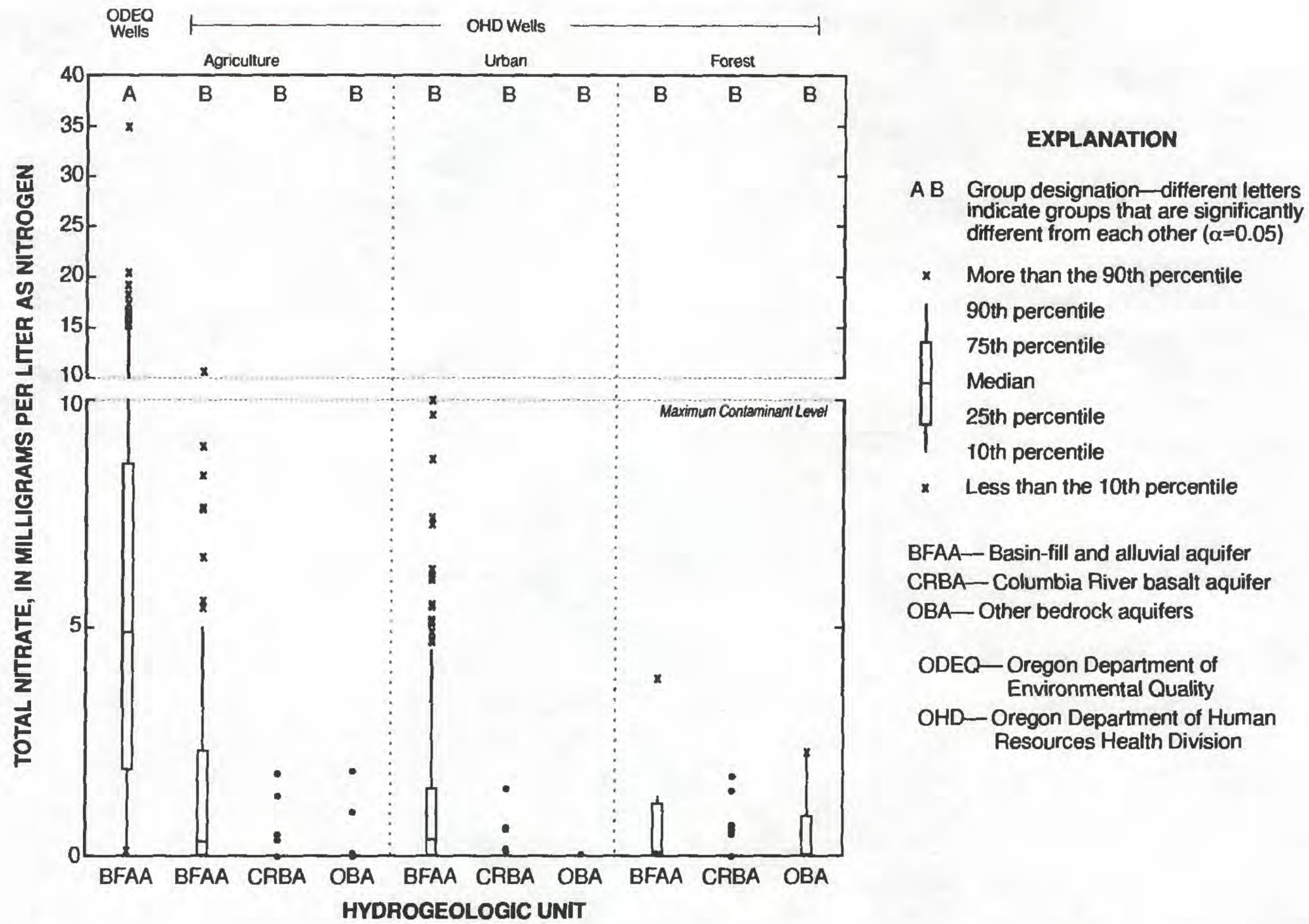


Figure 55. Relation between nitrate in ground water and hydrogeologic unit and land use for wells in the Willamette and Sandy River Basins, Oregon, October 1, 1979 – May 31, 1990.

of ground water in all agricultural settings, they do show that high NO_3-N concentrations can occur in shallow ground water near intensive agricultural areas of the Willamette Basin.

Relation to Well Depth

NO_3-N concentrations show a weak inverse relation with well depth that appears to be independent of land use and hydrogeologic unit (fig. 56). This relation may be due to slow vertical advection and diffusion, denitrification along flow paths, or different recharge zones of the water. Comparisons of NO_3-N concentrations along flow paths is not possible with these data.

Some of the difference between the median NO_3-N concentration for the ODEQ wells and that for similar OHD wells (agricultural land use; basin-fill and alluvial aquifer) may have been due to well depth. Median well depths for these two groups were 48 and 199 ft, respectively. To minimize the influence of well depth, data from the 25 shallowest wells in the OHD group (agricultural land use; basin-fill and alluvial aquifer) were selected and compared with the ODEQ data. The median well depth for this subset was 67 ft. The median NO_3-N concentration for this subset was 3.0 mg/L as N, 10 times the value for the entire group (0.3 mg/L as N), and more closely approached the ODEQ value (4.9 mg/L as N).

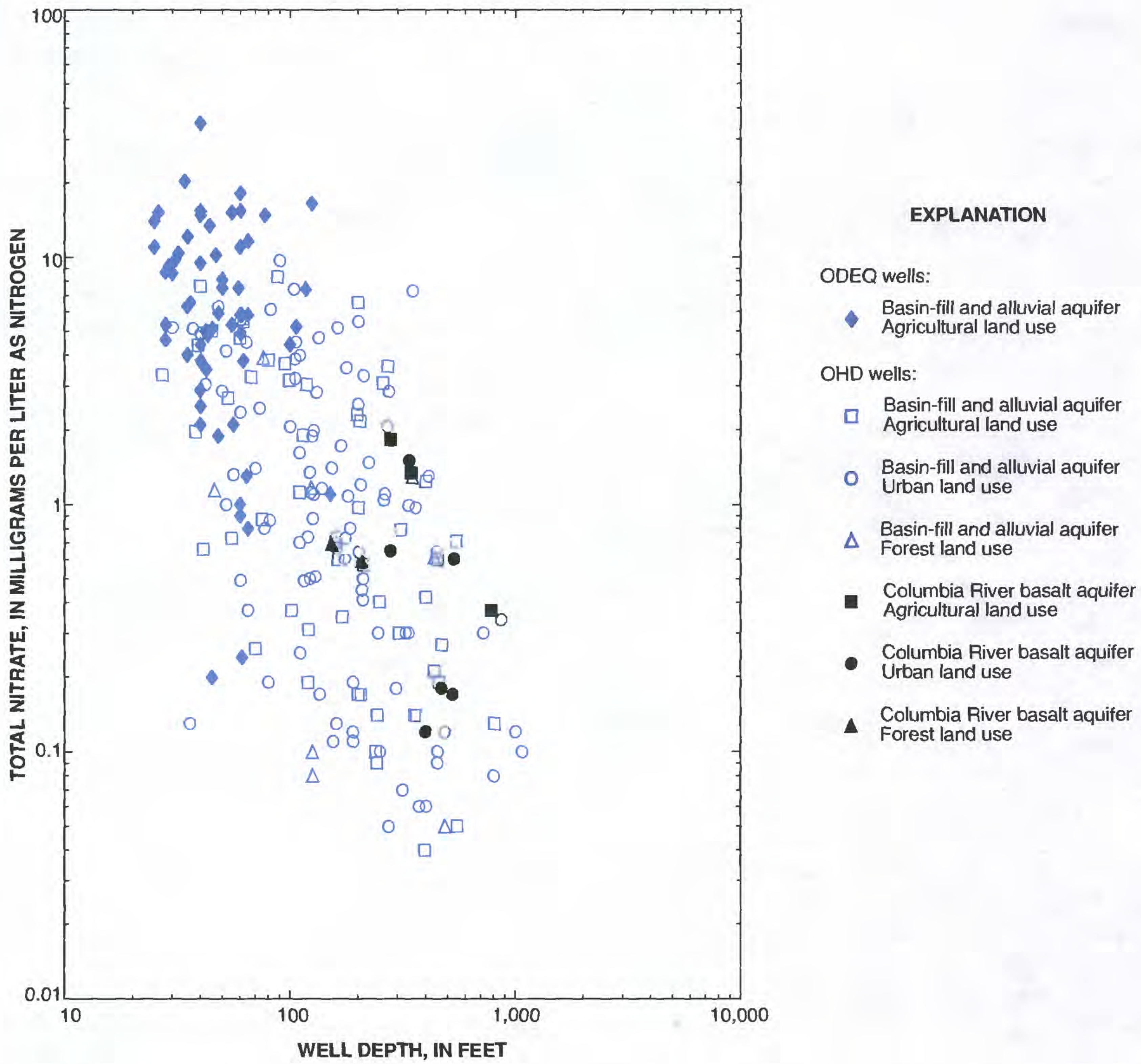


Figure 56. Relation between nitrate in ground water and well depth, for wells in the Willamette and Sandy River Basins, Oregon, October 1, 1979 – May 31, 1990. (Well depth measured with respect to land surface. Data below the detection limit [0.1 mg/L as N for ODEQ wells; 0.01 mg/L as N for OHD wells] not shown. Agencies are identified as follows: ODEQ, Oregon Department of Environmental Quality; OHD, Oregon Department of Human Resources Health Division)

SUMMARY

Surface water — As part of the National Water-Quality Assessment Program (NAWQA), data from 10 sites (7 primary sites and 3 nested subbasin-sites) were used to analyze the general water quality within the Willamette and Sandy River Basins (the Willamette Basin). Three agencies collected the data: Oregon Department of Environmental Quality (ODEQ), Portland Water Bureau, and the United States Geological Survey (USGS). All data were collected as part of ambient water-quality monitoring programs or in conjunction with multiyear studies of nutrient loads.

Most of the available water-quality data for surface water were obtained at sites on the main stem Willamette River or near the mouths of major tributaries. A clear identification of land use was possible only for two forested sites. Three of the remaining sites were classified as agricultural sites because large proportions of their drainage areas were agricultural, but that classification was somewhat subjective. The agricultural sites were located near the mouths of major tributaries and integrated many upstream effects, including municipal wastewater treatment plants, industrial point sources, and urban centers. Information concerning inputs from upstream point sources essentially was nonexistent. Water-quality data for smaller basins with more homogeneous land use were not available. Instantaneous streamflow measurements were available for only two sites. Therefore, daily mean streamflow values from nearby USGS gaging stations were used.

In general, data were collected at monthly intervals. All seasons were represented; however, more data were collected during summer months. Processes that occur on time scales smaller than a month were not captured by these data. A few measurements of DO concentration and pH were obtained in both morning and afternoon, but those data were not sufficient to fully characterize diel variations. Both high- and low- flow conditions were represented to some extent; at some sites, few data were available for high-flow conditions.

Concentrations of NO_3-N, total P, and suspended sediment measured at sites in the Willamette Basin generally were less than national median values for sites with similar land uses. No trends in nutrient concentrations during the retrospective period (water years 1980–90) were observed. Forested sites in the basin had the lowest water temperatures and nutrient concentrations and the most stable DO concentrations. Elevated water temperatures may be a problem in some tributaries in the basin. Water temperatures at the Long Tom River site (an agricultural site) were particularly high and might have been associated with lack of riparian cover.

Nitrite was never detected at concentrations greater than its detection limit, indicating that elevated nitrite concentrations are probably not a problem. NH_4-N concentrations were greatest at the two mixed-use sites, both of which were located in the Portland Harbor near the mouth of the Willamette River. NH_4-N concentrations tended to be greatest at sites with upstream point sources. NH_4-N concentrations never exceeded U.S. Environmental Protection Agency (USEPA) guidelines for fish toxicity. TRN values at agricultural and urban sites were low (76 percent of the values were less than 0.5 mg/L [milligrams per liter] as N), but nonetheless were significantly greater than those at forested sites (where only 2 of 267 values were 0.5 mg/L as N or greater). The highest NO_3-N concentrations occurred at agricultural sites. The USEPA maximum contaminant level (MCL) for nitrate (10 mg/L as N) was not exceeded at any of the sites. NO_3-N concentrations were less than national median values, except at the Pudding River site, where 90 percent of the NO_3-N determinations exceeded the national median value (0.72 mg/L as N) for agricultural sites. NO_3-N concentrations at the Pudding River site were about three times greater than those at the other agricultural sites in the Willamette Basin; NO_3-N accounted for nearly 80 percent of the total N at this site— a greater proportion than that found for the other sites. At the forested sites, NO_3-N accounted for 40 percent or less of the total N. The elevated NO_3-N concentrations at the Pudding River site may have been due, in part, to effluent from a wastewater treatment facility, or to agricultural activity in the Pudding Basin. At all sites in the Willamette Basin, NO_3-N concentrations exhibited a clear seasonal pattern characterized by a winter maximum. The cause of the seasonal cycle is not clear at this time. The winter maximum may be related to increased inputs associated with runoff or decreased uptake by biota during the cooler and darker winter months.

The greatest concentrations of SRP and total P also occurred at the Pudding River site. The median total phosphorous concentration at that site was 0.19 mg/L as P, a value comparable to the national median value for agricultural sites (0.23 mg/L as P). Total P concentrations at the other sites were considerably less than national median values. Although seasonal variations in phosphorus concentrations were observed, they were more site specific than the seasonal pattern for NO_3-N. In general, SRP concentrations exhibited maximum values during low-flow conditions; maximum total P concentrations occurred during high flows.

DO concentrations at the Pudding River site were less than those at the other sites. Sparse data indicated diel variations in DO and pH at several sites, including the Pudding River site. The diel variation was particularly large at the Long Tom River site, where low DO concentrations during early summer mornings may be a water-quality problem.

Ground water— Historical ground-water nutrient data were largely limited to NO_3-N concentrations. Data were obtained from ODEQ (123 wells in agricultural areas) and the Oregon Department of Human Resources Health Division (OHD; 312 public water-supply wells). One NO_3-N determination was associated with each well. The land uses at the recharge zones of the OHD wells were unknown and assumed to be the same as the land uses at the well locations. These land-use assignments were subject to significant error.

Most of the wells were completed in the basin-fill and alluvial aquifer and consequently were located in the Willamette Valley. Wells in other hydrogeologic units were only minimally represented by the data. Few data were available for forested areas. No significant differences related to land use or hydrogeologic unit were found in the OHD NO_3-N data. Elevated NO_3-N concentrations generally were associated with shallow wells; NO_3-N concentrations exhibited a weak inverse relation with depth. The greatest NO_3-N concentrations occurred in wells sampled by ODEQ in a study that targeted shallow wells in agricultural areas. The MCL for NO_3-N was exceeded at 26 of 123 ODEQ wells. The ODEQ data, however, were not significantly different from a comparable subset of the OHD data (shallow wells completed in basin-fill and alluvial aquifer and identified as agricultural land use).

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Supplemental Data

Table 12. Summary statistics for the surface-water data set
[DL, detection limit. Concentrations are expressed using the following units: ammonia, total reduced nitrogen (ammonia-plus-organic nitrogen), nitrite, nitrate, and nitrite plus nitrate, milligrams per liter as nitrogen; soluble reactive phosphorus and total phosphorus, milligrams per liter as phosphorus; specific conductance, microsiemens per centimeter at 25 degrees Celsius; dissolved oxygen, milligrams per liter; pH, standard units; suspended solids and suspended sediment, milligrams per liter; water temperature, degrees Celsius. Suspended sediment values were determined using isokinetic, depth-width integrated sampling methods; suspended solids values were determined for grab samples]

Constituent	Total number	Number less than DL	DL	Value at indicated percentile					Sampling period
				10th	25th	50th	75th	90th	
Fir Creek near Brightwood—forest land use									
Ammonia (total)	103	103	0.020	—	—	—	—	—	10/79 – 8/90
Total reduced nitrogen	143	0		0.062	0.073	0.097	0.118	0.178	4/85 – 9/90
Nitrite (total)	5	5	.001	—	—	—	—	—	2/82 – 8/87
Nitrate (total)	234	0		.025	.031	.044	.058	.079	10/79 – 9/90
Soluble reactive phosphorus	231	90	.003	—	<.003	.003	.004	.005	10/79 – 9/90
Total phosphorus	166	8	.003	.003	.004	.006	.007	.009	10/79 – 9/90
Specific conductance	567	0		18.1	19.3	21.1	25.0	27.1	10/79 – 9/90
pH	567	0		7.08	7.15	7.23	7.33	7.42	10/79 – 9/90
Suspended sediment	574	14	.1	.2	.3	.4	.6	1.0	10/79 – 9/90
Water temperature	568	0		3.5	4.5	6.3	9.5	11.0	10/79 – 9/90
Middle Fork Willamette River at Jasper Bridge—forest land use									
Ammonia (total)	132	44	.02	—	<.02	.02	.03	.04	10/79 – 9/90
Total reduced nitrogen	124	91	.20	—	—	—	<.20	.20	10/79 – 9/90
Nitrite (total)	36	36	.02	—	—	—	—	—	10/79 – 8/82
Nitrite plus nitrate (total)	132	55	.02	—	<.02	.02	.04	.07	10/79 – 9/90
Soluble reactive phosphorus	116	0		.010	.014	.016	.020	.023	10/79 – 8/90
Total phosphorus	129	0		.027	.030	.032	.040	.059	10/79 – 9/90
Specific conductance	131	0		40	43	46	48	53	10/79 – 9/90
Dissolved oxygen	130	0		9.8	13	11.0	11.9	12.4	11/79 – 9/90
pH	128	0		7.0	7.2	7.4	7.6	8.0	10/79 – 9/90
Suspended solids	110	17	1.0	1.0	1.0	2.0	3.0	6.5	10/79 – 9/90
Water temperature	132	0		6.5	8.0	12.5	14.5	17.0	10/79 – 9/90

Table 12. Summary statistics for the surface-water data set— Continued

Constituent	Total number	Number less than DL	DL	Value at indicated percentile					Sampling period
				10th	25th	50th	75th	90th	
Long Tom River at White Bridge—agricultural land use									
Ammonia (total)	69	4	.02	.02	.03	.03	.04	.08	4/82 – 9/90
Total reduced nitrogen	65	1	.20	.30	.35	.40	.50	.60	4/82 – 9/90
Nitrite (total)	6	6	.02	—	—	—	—	—	4/82 – 8/82
Nitrite plus nitrate (total)	69	0		.08	.18	.31	.46	.85	4/82 – 9/90
Soluble reactive phosphorus	60	0		.007	.011	.016	.022	.028	4/82 – 8/90
Total phosphorus	70	0		.048	.055	.070	.095	.112	4/82 – 9/90
Specific conductance	69	0		62	85	97	108	112	4/82 – 9/90
Dissolved oxygen	70	0		7.2	8.7	10.1	11.4	12.2	4/82 – 9/90
pH	70	0		7.0	7.3	7.4	7.8	8.2	4/82 – 9/90
Suspended solids	55	0		7	7	10	16	25	4/82 – 9/90
Water temperature	70	0		6.8	11.0	19.2	22.0	26.0	4/82 – 9/90
South Yamhill River at US Hwy 99W—agricultural land use									
Ammonia (total)	115	8	.02	.02	.02	.04	.05	.06	10/79 – 9/90
Total reduced nitrogen	110	15	.20	.20	.20	.30	.30	.45	10/79 – 9/90
Nitrite (total)	37	33	.02	—	–	—	<.02	.02	10/79 – 9/82
Nitrite plus nitrate (total)	115	1	.02	.05	.09	.18	.72	1.03	10/79 – 9/90
Soluble reactive phosphorus	109	0		.007	.010	.014	.018	.026	10/79 – 9/90
Total phosphorus	115	0		.030	.036	.050	.080	.152	10/79 – 9/90
Specific conductance	114	0		71	79	96	116	132	10/79 – 9/90
Dissolved oxygen	115	0		7.8	8.5	9.9	11.2	11.9	10/79 – 9/90
pH	115	0		6.9	7.1	7.3	7.4	7.5	10/79 – 9/90
Suspended solids	102	0		3	5	8	17	33	10/79 – 9/90
Water temperature	115	0		6.5	8.5	13.5	2.0	23.0	10/79 – 9/90
Pudding River at US Hwy 99E—agricultural land use									
Ammonia (total)	104	1	.02	.04	.04	.06	.07	.11	11/79 – 9/90
Total reduced nitrogen	101	3	.20	.20	.30	.40	.50	.80	11/79 – 9/90
Nitrite (total)	10	5	.02	—	—	—	—	<.02	11/79 – 9/82
Nitrite plus nitrate (total)	104	0		.7	1.1	1.4	1.9	2.4	11/79 – 9/90
Soluble reactive phosphorus	95	0		.039	.056	.113	.206	.294	11/79 – 9/90
Total phosphorus	104	0		.10	.12	.19	.25	.33	11/79 – 9/90
Specific conductance	103	0		66	78	98	154	200	11/79 – 9/90
Dissolved oxygen	103	0		6.7	7.5	9.1	1.6	11.7	11/79 – 9/90
pH	102	0		7.0	7.2	7.3	7.5	7.6	11/79 – 9/90
Suspended solids	83	0		3.0	4.0	7.0	14.0	18.0	11/79 – 9/90
Water temperature	104	0		6.0	9.0	15.2	21.5	23.5	11/79 – 9/90

Table 12. Summary statistics for the surface-water data set— Continued

Constituent	Total number	Number less than DL	DL	Value at indicated percentile					Sampling period
				10th	25th	50th	75th	90th	
Willamette River at Portland—mixed land use									
Ammonia (dissolved)	71	0		.03	.05	.07	.11	.15	10/79 – 9/90
Ammonia (total)	51	0		.04	.05	.07	.12	.18	10/79 – 9/90
Total reduced nitrogen	68	7	.20	.20	.30	.50	.70	1.00	10/79 – 9/90
Nitrite (total)	29	14	.01	—	—	<.01	.01	.01	11/85 – 9/90
Nitrite plus nitrate (dissolved)	74	0		.20	.25	.36	.63	.90	10/79 – 9/90
Nitrite plus nitrate (total)	23	0		.28	.34	.51	.79	1.10	10/79 – 9/90
Soluble reactive phosphorus	52	2	.01	.03	.03	.04	.06	.08	10/81 – 9/90
Total phosphorus	74	0		.05	.07	.08	.10	.12	10/79 – 9/90
Specific conductance	75	0		60	65	73	85	91	10/79 – 9/90
Dissolved oxygen	72	0		8.2	9.2	11.0	12.5	13.3	10/79 – 7/90
pH	75	0		6.9	7.0	7.4	7.6	7.7	10/79 – 9/90
Suspended sediment	71	0		8.0	9.0	11.0	18.0	29.0	10/79 – 9/90
Water temperature	75	0		6.0	8.1	12.7	18.2	21.0	10/79 – 9/90
Willamette River at SPS Bridge—mixed land use									
Ammonia (total)	148	1	.02	.04	.05	.07	.10	.13	10/79 – 9/90
Total reduced nitrogen	138	7	.20	.20	.20	.30	.40	.40	10/79 – 9/90
Nitrite (total)	39	25	.02	—	—	<.02	.02	.02	10/79 – 9/82
Nitrite plus nitrate (total)	148	1	.02	.19	.26	.36	.56	.78	10/79 – 9/90
Soluble reactive phosphorus	126	0		.032	.043	.052	.064	.082	10/79 – 9/90
Total phosphorus	142	0		.072	.090	.105	.119	.137	10/79 – 9/90
Dissolved oxygen	146	0		7.6	8.2	9.9	12.3	13.1	10/79 – 9/90
pH	145	0		6.8	7.1	7.3	7.4	7.6	10/79 – 9/90
Suspended solids	124	1	1	4	5	7	9	14	10/79 – 9/90
Dairy Creek at Hwy 8—agricultural land use									
Total reduced nitrogen	85	0		.30	.39	.49	.58	.70	7/80 – 9/90
Nitrite plus nitrate (total)	85	0		.33	.51	.72	1.32	2.05	7/80 – 9/90
Soluble reactive phosphorus	83	0		.023	.029	.046	.059	.069	7/80 – 9/90
Total phosphorus	84	0		.066	.089	.11	.13	.16	7/80 – 9/90
Fanno Creek at Durham—urban land use									
Total reduced nitrogen	100	0		.35	.46	.60	.79	1.00	7/80 – 9/90
Nitrite plus nitrate (total)	101	0		.28	.33	.44	.66	1.20	7/80 – 9/90
Soluble reactive phosphorus	99	0		.039	.049	.059	.072	.10	7/80 – 9/90
Total phosphorus	100	0		.10	.13	.16	.20	.29	7/80 – 9/90
Tualatin River at Weiss Bridge—mixed land use									
Total reduced nitrogen	68	0		.52	.60	.77	.91	1.26	6/88 – 9/90
Nitrite plus nitrate (total)	68	0		1.3	1.8	2.1	2.7	3.2	6/88 – 9/90
Soluble reactive phosphorus	67	0		.11	.13	.17	.23	.32	6/88 – 9/90
Total phosphorus	68	0		.15	.19	.23	.31	.38	6/88 – 9/90

Table 13. Summary statistics for the ground-water data set

[Abbreviations and units are as follows: DL, detection limit; BFAA, Basin-fill and alluvial aquifer; CRBA, Columbia River Basalt aquifer; OBA, other bedrock aquifers; nitrate and nitrite-plus-nitrate concentrations (total), milligrams per liter as nitrogen; well depth, feet below ground surface. If fewer than 10 data points were available, only the median statistic is shown]

Constituent	Hydrogeologic unit	Land use	Total number	Number less than DL	DL	Value at indicated percentile				
						10th	25th	50th	75th	90th
Oregon Department of Environmental Quality Data										
Nitrite plus nitrate	BFAA	agriculture	123	7	0.1	0.15	1.9	4.9	8.6	14.8
Well depth			64	—	—	29	40	47.5	61	110
Oregon Department of Human Resources — Health Division Data										
Nitrate	BFAA	forest	15	6	.01	<.01	<.01	.08	1.14	1.29
Well depth			11	—	—	46	57	125	350	435
Nitrate	BFAA	agriculture	81	23	.01	<.01	<.01	.31	2.3	5.0
Well depth			76	—	—	53	97	199	320	470
Nitrate	BFAA	urban	166	54	.01	<.01	<.01	.36	1.48	4.5
Well depth			146	—	—	65	110	164	263	450
Nitrate	CRBA	forest	7	1	.01	—	—	.7	—	—
Well depth			3	—	—	—	—	208	—	—
Nitrate	CRBA	agriculture	9	5	.01	—	—	<.01	—	—
Well depth			7	—	—	—	—	280	—	—
Nitrate	CRBA	urban	6	0	—	—	—	.39	—	—
Well depth			6	—	—	—	—	435	—	—
Nitrate	OBA	forest	17	6	.01	<.01	<.01	.02	.87	2.2
Well depth			12	—	—	280	339	435	526	535
Nitrate	OBA	agriculture	6	2	.01	—	—	.045	—	—
Well depth			5	—	—	—	—	135	—	—
Nitrate	OBA	urban	1	0	—	—	—	.06	—	—
Well depth			1	—	—	—	—	70	—	—

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Location of primary and nested-subbasin surface-water sites, and ground-water wells that have nitrate data, in the Willamette and Sandy River Basins, Oregon.