WATER-QUALITY CHARACTERISTICS OF THE COLUMBIA PLATEAU REGIONAL AQUIFER SYSTEM IN PARTS OF WASHINGTON, OREGON, AND IDAHO

By William C. Steinkampf

A Contribution of the
Regional Aquifer-System
Analysis Program

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For use of readers who prefer to use metric (International System) units, rather than the inch-pound units used in this report, the following conversion factors may be used:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km°)
acre	4,047	square meter (m^2)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)

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

Data from 824 ground-water samples collected from about 350 wells in three Miocene basaltic units of the Columbia Plateau regional aquifer system indicate that ground waters generally are of good quality and are suitable for most uses. The chemical composition of water in the shallowest units is predominantly calcium-magnesium bicarbonate type and evolves toward sodium bicarbonate type in the deepest unit. Calcium-magnesium sulfate-chloride type waters occur less commonly and are associated with water in shallow wells, areas with thin overburden cover, and areas under agricultural land use. Dissolved-solids concentrations generally are less than 500 milligrams per liter (mg/L).

The Saddle Mountains unit is the shallowest and least extensive unit in the regional geohydrologic system. Calcium-magnesium bicarbonate type waters are most abundant and reflect a less geochemically evolved water type. Sodium bicarbonate type waters are usually found in downgradient locations and in the deepest wells sampled. Calcium-magnesium sulfate-chloride waters generally occur where dissolved-oxygen concentrations are greater than 5 mg/L, where the overburden is less than 100 feet thick, and where surface-water irrigation occurs. The mean dissolved-solids concentration for 131 samples is 340 mg/L. Dissolved-nitrogen species, and to a lesser extent sulfate, concentrations also are influenced by overburden thickness and land use.

The distribution of water types in the Wanapum unit, which underlies the Saddle Mountains unit, appears to be affected by the same factors as that of the Saddle Mountains. The mean dissolved-solids concentration (410 samples) is 270 mg/L. Elevated nitrogen concentrations occur mostly in the central part of the plateau, and are associated with wells that have depths less than 300 feet and that are in areas with a thin or no overburden.

The Grande Ronde unit, which is below the Wanapum, has water that is dominantly calcium-magnesium bicarbonate in type and has sodium bicarbonate water in downgradient areas and in the central plateau near the Columbia River. Based on 283 samples, the waters from this unit have the lowest mean dissolved-solids concentrations, 234 mg/L, and most nitrogen concentrations are less than 2 mg/L.

INTRODUCTION

A study of the Columbia Plateau regional aquifer system was begun in 1982 as one of 28 studies by the U.S. Geological Survey under the Regional Aquifer-System Analysis (RASA) program. This RASA project was designed to aid in the effective management of the ground-water resources of the plateau by providing information on the geohydrology and geochemistry of the aquifer system. A complete discussion of the purpose, background, and scope of the project is documented in the planning report by Vaccaro (1986). The objective of this report was to describe the water-quality characteristics of the basalt part of the Columbia Plateau aquifer system based on data collected from 1982 to 1985. The report presents and discusses the distribution of selected chemical and physical characteristics relative to the regional geohydrologic system, geochemical processes, and land use.

The Columbia Plateau aquifer system consists of part of the Columbia River Basalt Group, intercalated sediments, and the overlying water-bearing unconsolidated sediments. The basalts cover about 63,000 square miles in central and eastern Washington, north-central and eastern Oregon, and a small part of northwestern Idaho (fig. 1). The stratigraphic nomenclature for the Columbia River Basalt Group, intercalated sediments, and the overlying water-bearing unconsolidated sediments is shown in figure 2, along with the nomenclature for the Columbia Plateau aquifer system. The aquifer system is a major source of water for irrigation, municipal, industrial, and domestic uses. Concurrent with ground-water usage, imported and local surface water is used for irrigation in several areas of the plateau. The Columbia and Yakima Rivers are the major surface-water sources for this irrigation.

Agriculture and related industries are the dominant economic activities on the plateau. There are about 1.8 million acres of irrigated croplands, of which about 30 percent is irrigated with ground water (0.9 million acre-feet per year) and the remainder with surface water. The surface-water supply in the existing distribution systems is almost fully appropriated and the demand for irrigation water is increasing. Irrigation has caused ground-water levels to rise in areas of surface-water irrigation (Tanaka and others, 1974), and to decline in areas of ground-water pumpage (Cline, 1984). Changes in the chemical quality of the ground water have also been attributed to agricultural activities (Bortleson and Cox, 1986).

The figures, maps, and tables presented in this report are not intended to provide the means whereby one can precisely and specifically predetermine a ground-water chemical composition. They are, instead, one facet of the characterization of the regional ground-water system. Their intended use is to demonstrate or infer the significance of various attributes of the system: areal variations of geohydrologic characteristics, geochemical processes, and changes induced by man.

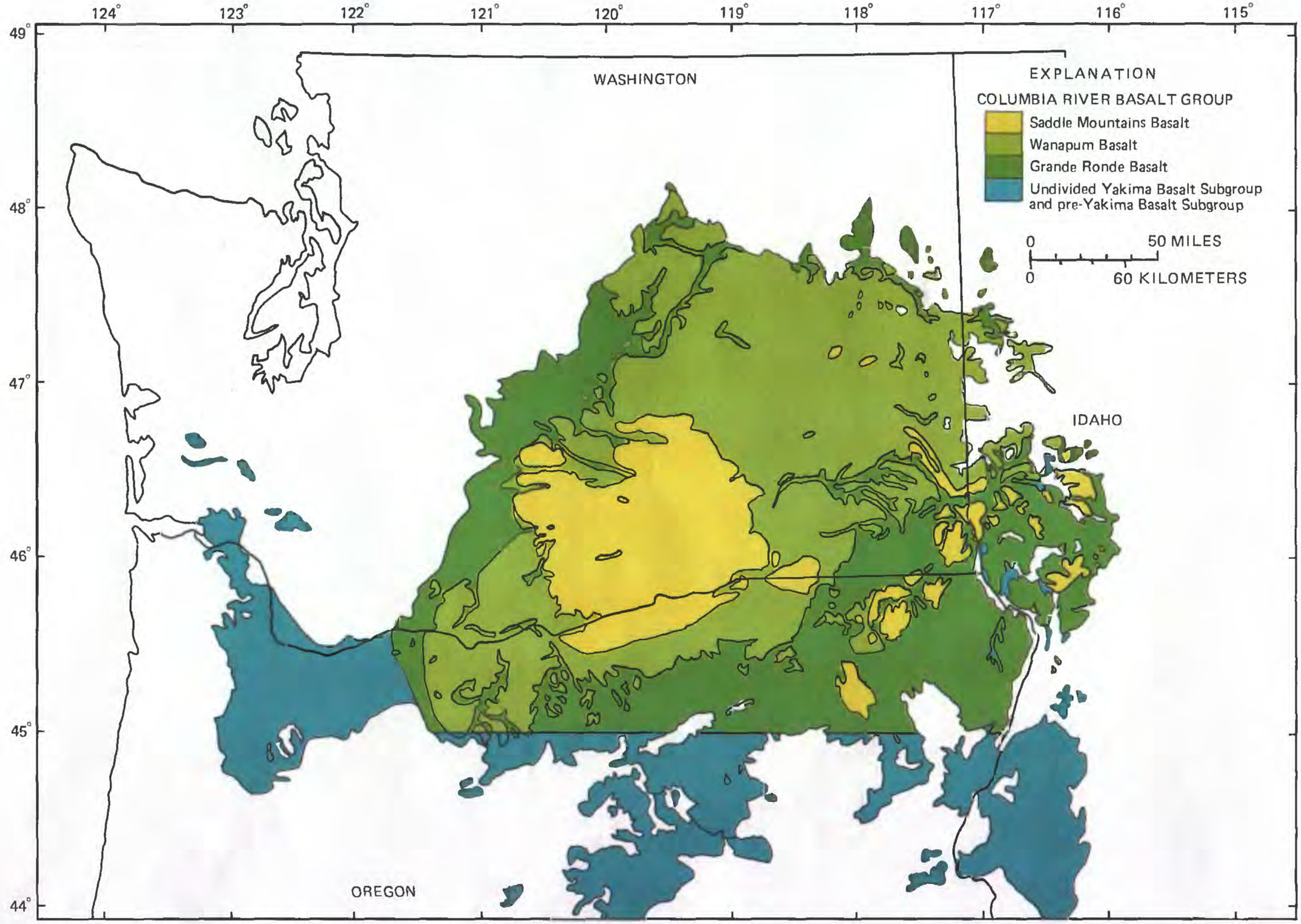


Figure 1.–Generalized extent of the Columbia River Basalt Group

GEOLOGIC FRAMEWORK								HYDROLOGIC FRAMEWORK
BASALT STRATIGRAPHY						SEDIMENT STRATIGRAPHY		STUDY UNIT
						Sediments of Miocene through Holocene age (glaciofluvial, fluvial, lacustrine, eolian, and ash fall materials). Locally includes sediments of the Palouse, Latah, Ringold, and Ellensburg Formations, and the Dalles Group	Columbia Plateau Aquifer System	Overburden Aquifer
MIOCENE	Upper / Middle	COLUMBIA RIVER BASALT GROUP	YAKIMA BASALT SUBGROUP	Saddle Mountain Basalt	Lower Monument Member Ice Harbor Member Buford Member Elephant Mountain Member Pomona Member Esquatzel Member Weissenfels Ridge Member Asotin Member Wilbur Creek Member Umatilla Member		Columbia Plateau Aquifer System	Saddle Mountain Unit
MIOCENE	Middle	COLUMBIA RIVER BASALT GROUP	YAKIMA BASALT SUBGROUP			Saddle Mountains - Wanapum Interbed	Columbia Plateau Aquifer System	Confining Unit
MIOCENE	Middle	COLUMBIA RIVER BASALT GROUP	YAKIMA BASALT SUBGROUP	Wanapum Basalt	Priest Rapids Member Roza Member Frenchman Springs Member Eckler Mountain Member		Columbia Plateau Aquifer System	Wanapum Unit
MIOCENE	Middle	COLUMBIA RIVER BASALT GROUP	YAKIMA BASALT SUBGROUP			Wanapum - Grande Ronde Interbed	Columbia Plateau Aquifer System	Confining Unit
MIOCENE	Middle / Lower	COLUMBIA RIVER BASALT GROUP	YAKIMA BASALT SUBGROUP	Grande Ronde Basalt	N_2 R_2 N_1 R_1 T		Columbia Plateau Aquifer System	Grande Ronde Unit
MIOCENE	Lower	COLUMBIA RIVER BASALT GROUP	Picture Gorge Basalt				Columbia Plateau Aquifer System	Grande Ronde Unit
MIOCENE	Lower	COLUMBIA RIVER BASALT GROUP	Imnaha Basalt		N_0 R_0		Columbia Plateau Aquifer System	Grande Ronde Unit
"Basement" rocks (pre-Columbia River Basalt Group rocks)								Basement Confining Unit

Figure 2.--Generalized stragraphy of the Columbia Plateau.

DESCRIPTION OF THE STUDY AREA

Physiography

The Columbia Plateau aquifer system is in the Columbia intermontane physiographic province (Freeman and others, 1945). The aquifer system within the study area underlies about 51,000 square miles and is bordered by the Cascade Range on the west, the Okanogan Highlands on the north, and the Rocky Mountains on the east, and extent of the Grande Ronde Basalt on the south (fig. 3). The plateau is a complex structural basin containing smaller structural basins that commonly are partially filled with unconsolidated sediments.

The study area is within the drainage of the Columbia River and its major tributaries, including the Snake, Yakima, John Day, and Deschutes Rivers. These rivers and their associated tributaries drain the bordering mountainous areas, which locally receive more than 80 inches of precipitation per year. Forests dominate at these higher altitudes (greater than 3,000 feet). At intermediate altitudes (about 2,000 to 3,000 feet) annual precipitation ranges from 15 to 25 inches, and vegetations of both grasslands and forest are more typical of semiarid climates. Precipitation in the lower, central part of the plateau ranges from 7 to 15 inches per year. The lower precipitation in this part of the plateau results in an arid environment characterized by sage and grasslands and the presence of few perennial streams.

Geology

The Columbia River Basalt Group comprises a series of tholeiitic flood basalts of Miocene age that were extruded primarily from a system of northwest-trending linear fissures in northeast Oregon and southeast Washington. The lavas flowed generally westward into a structural and topographic basin, some flows reaching the Pacific Ocean. The basalts are essentially horizontal, with minor amounts of interbedded Miocene sediments of various lithologies. Interbeds tend to be thicker and occur more commonly in successively younger basalt formations, largely reflecting the time interval over which the formations were emplaced and the magnitudes and extents of contemporaneous uplifts in and around the plateau. Overlying the basalts are fluvial, glaciofluvial, and volcaniclastic sediments, and loess of Pliocene to Holocene age. The average total thickness of basalt in the study area is about 2,500 feet; individual flow thicknesses range from several inches to more than 300 feet and average about 100 feet. Hooper (1982, p. 1464) estimated the total volume of basalt at more than 48,000 cubic miles.

The Imnaha and Picture Gorge Basalts are the lowermost formations in the Columbia River Basalt Group. They underlie the Yakima Basalt Subgroup and are of limited extent, occurring only in parts of southeast Washington and north-east Oregon.

The Yakima Basalt Subgroup of the Columbia River Basalt Group comprises tne Saddle Mountains, Wanapum, and Grande Ronde Basalts, the geologic formations of primary interest in this study. The Grande Ronde Basalt is the lowermost formation in the subgroup. It underlies virtually all of the study area and makes up about 85 percent of the total basalt volume in the Columbia Plateau.

Figure 3.--Selected physiographic and cultural features of the Columbia Plateau.

Its thickness ranges from a few feet in marginal areas to more than 10,000 feet in the center of the basin near Pasco, Wash. (Drost and Whiteman, 1986). Thirty to several hundred flows make up the Grande Ronde Basalt.

A sedimentary interbed that separates the Grande Ronde Basalt and the overlying Wanapum Basalt occurs in much of the plateau. This interbed, called the Wanapum-Grande Ronde interbed, has an average thickness of about 25 feet, ranging from 0 to 100 feet (Drost and Whiteman, 1986). The Wanapum Basalt underlies most of the study area, but is less extensive than the Grande Ronde. It comprises about 10 flows and has an average thickness of about 400 feet. Its thickness ranges from a few feet to more than 1,000 feet in the central plateau (Drost and Whiteman, 1986).

The Saddle Mountains Basalt is the uppermost formation of the subgroup and the least extensive. It occurs chiefly in the central part of the basin and in ancestral drainages. Its thickness exceeds 800 feet in places and averages about 400 feet (Drost and Whiteman, 1986). It overlies the Saddle Mountains-Wanapum interbed, which consists of sedimentary materials of the Ellensburg Formation, over much of its extent.

Hydrology

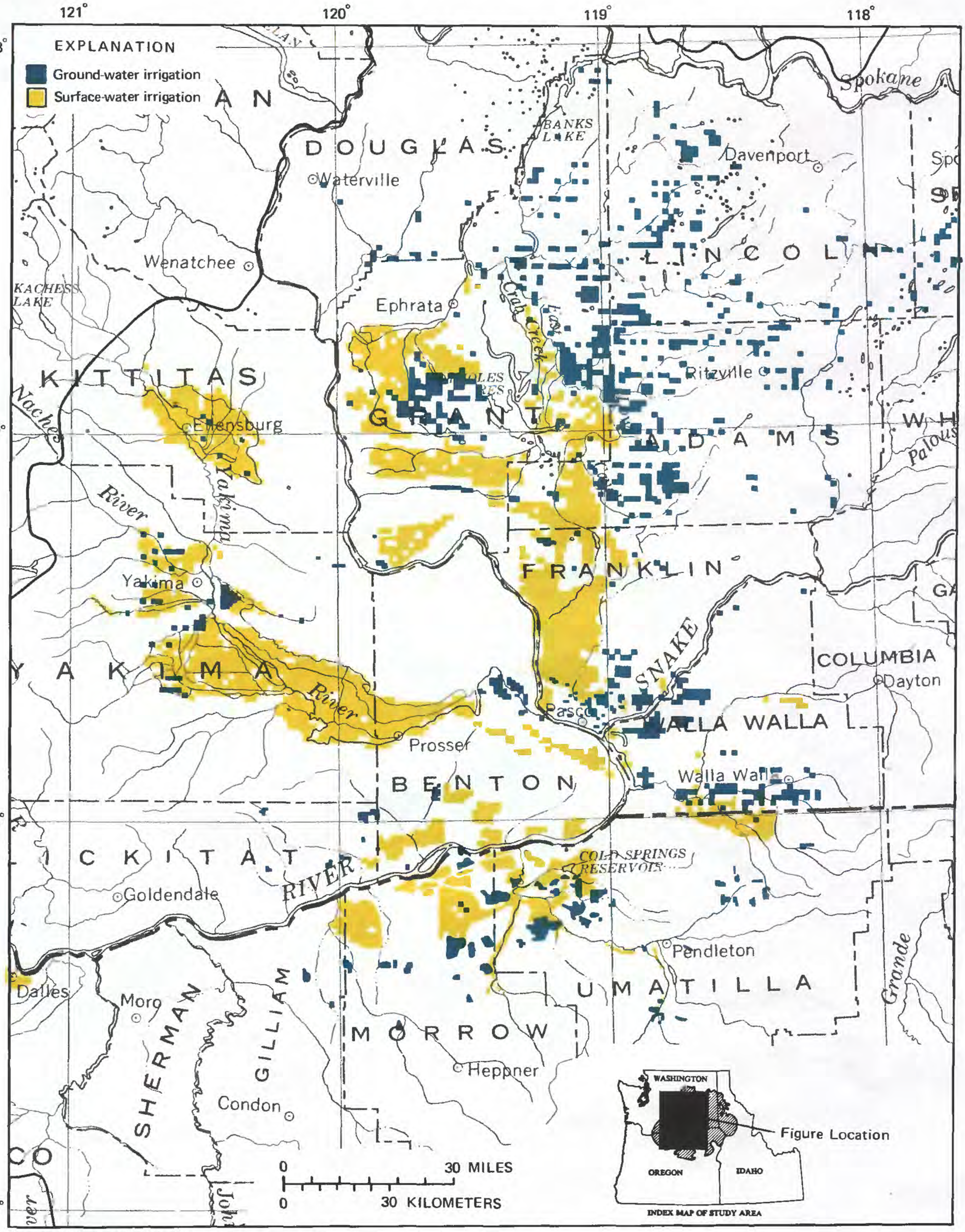
The conceptual regional geohydrologic system comprises seven units, four aquifer units and three confining units. The aquifer units are, in descending order, the unconsolidated sediments (herein called overburden), which overlie the basalts, and the Saddle Mountains, Wanapum, and Grande Ronde Basalt formations and their associated interbeds (intercalated sedimentary materials). On a regional scale, the Saddle Mountains-Wanapum and Wanapum-Grande Ronde interbeds between the formations are considered to function as confining units and the pre-basalt "basement" rocks, the Basement confining unit, are considered the base of the regional flow system (fig. 2).

In this report, the terms Saddle Mountains, Wanapum, and Grande Ronde units are used when referring to the three basaltic aquifer units. This distinguishes them from the geologic formations and defines them to include any interbeds within the respective formations. The Grande Ronde unit is underlain by the Precambrian to lower Tertiary "basement" rocks of mostly volcanic and metamorphic origin. In the extreme southeastern part of the study area, a small part of the Imnaha Basalt is included with the Grande Ronde unit. The areal extents of the basaltic units are shown in figure 1.

The basalts are recharged naturally throughout the plateau; recharge quantities range from zero to about 30 inches per year with a median value of about 0.56 inch per year (H. H. Bauer, U.S. Geological Survey, written commun., 1986). Artificial recharge occurs in areas of surface-water application (in some locations it exceeds 40 inches per year), and in areas where water-level declines caused by ground-water pumpage facilitate movement of water from an underlying or overlying unit. Areas where surface water and ground water are used for irrigation are shown in figure 4.

Water enters the basalts and flows horizontally and vertically through vesicles, joints, fractures, and the intraflow structures that create permeable zones. Flow is mainly horizontal in the interflow zones composed of the commonly rubbly and vesicular bases and tops of adjacent lava flows, and is mainly vertical in the less permeable central parts. Regional features that influence the directions of ground-water movement in each unit are major streams, geologic structures, geologic dip, and the presence and thicknesses of overlying unconsolidated materials and (or) basalts. These controls are discussed in reports describing regional water levels in each of the major aquifers (Bauer and others, 1985; Whiteman, 1986). In general, ground water flows toward major streams, away from anticlinal axes, and in the direction of regional geologic dip. Generalized directions of ground-water flow in each of the respective basaltic units are shown in figures 5, 6, and 7. The flow directions are based on maps of 1984 ground-water levels in each of the units (Whiteman, 1986). Interformational movement is downward over much of the region, with upward flow from or within the Grande Ronde Basalt in the vicinity of the Columbia and Snake Rivers, Crab Creek, and other major surface-water bodies.

Agricultural water uses have noticeably affected the ground-water system. Extensive large-scale ground-water withdrawals in the region adjacent to the east boundary of the Columbia Basin Irrigation Project have caused water-level declines of as much as 165 feet (Cline, 1984), whereas water levels beneath surface-water irrigation areas had risen as much as 310 feet by 1971 (Tanaka and others, 1974). Numerous uncased wells also greatly affect the hydrologic system by allowing the rapid vertical movement of ground water. The amount of this flux depends, in part, on the hydraulic head difference between the connected flows, and is likely locally significant compared to the natural flux.



Base from U.S. Geological Survey
State base map, 1:500 000

Figure 4.--Distribution of ground-water and surface-water irrigation areas.

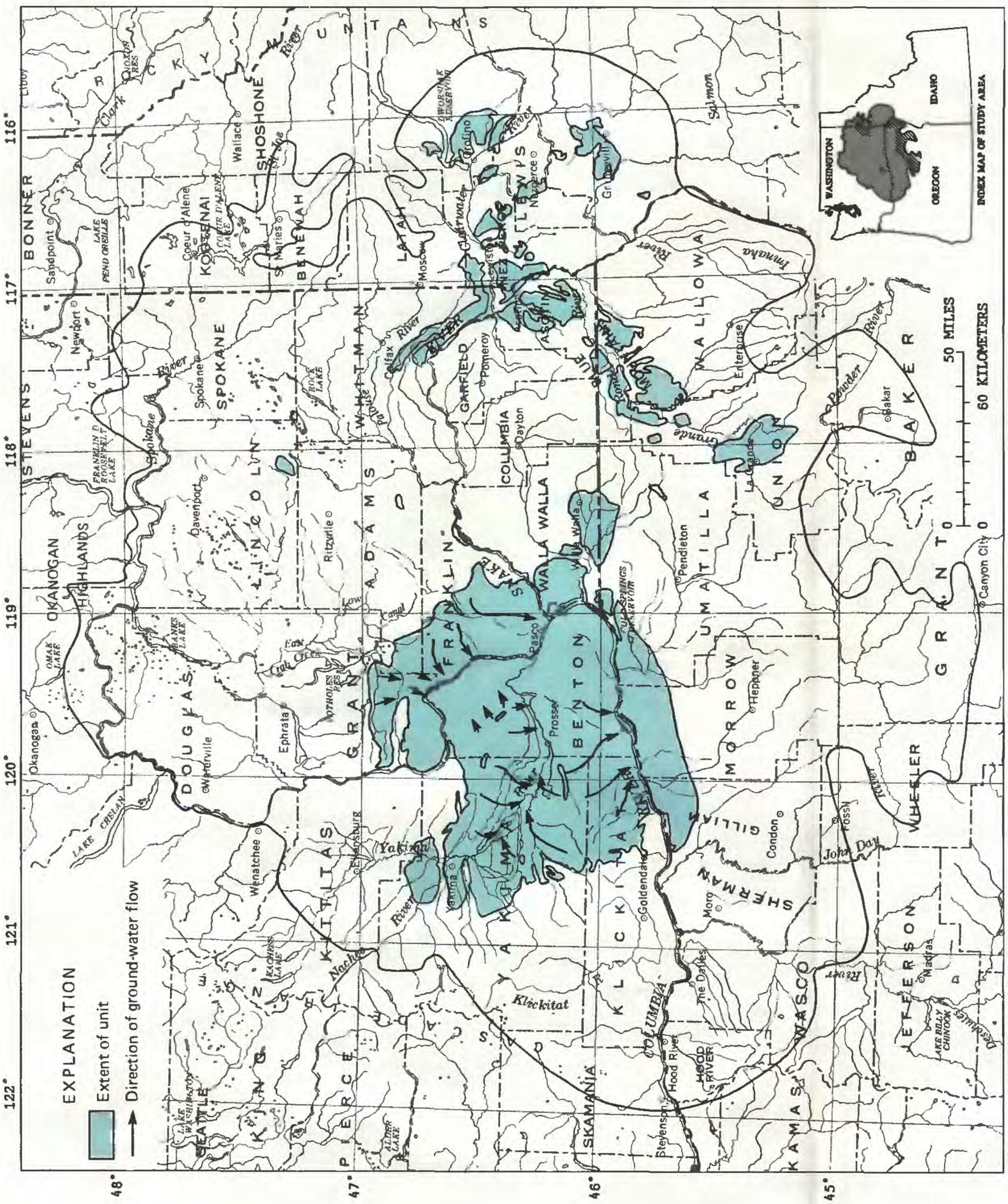


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Figure 5.--General horizontal directions of ground-water flow in the Saddle Mountains unit, 1984.

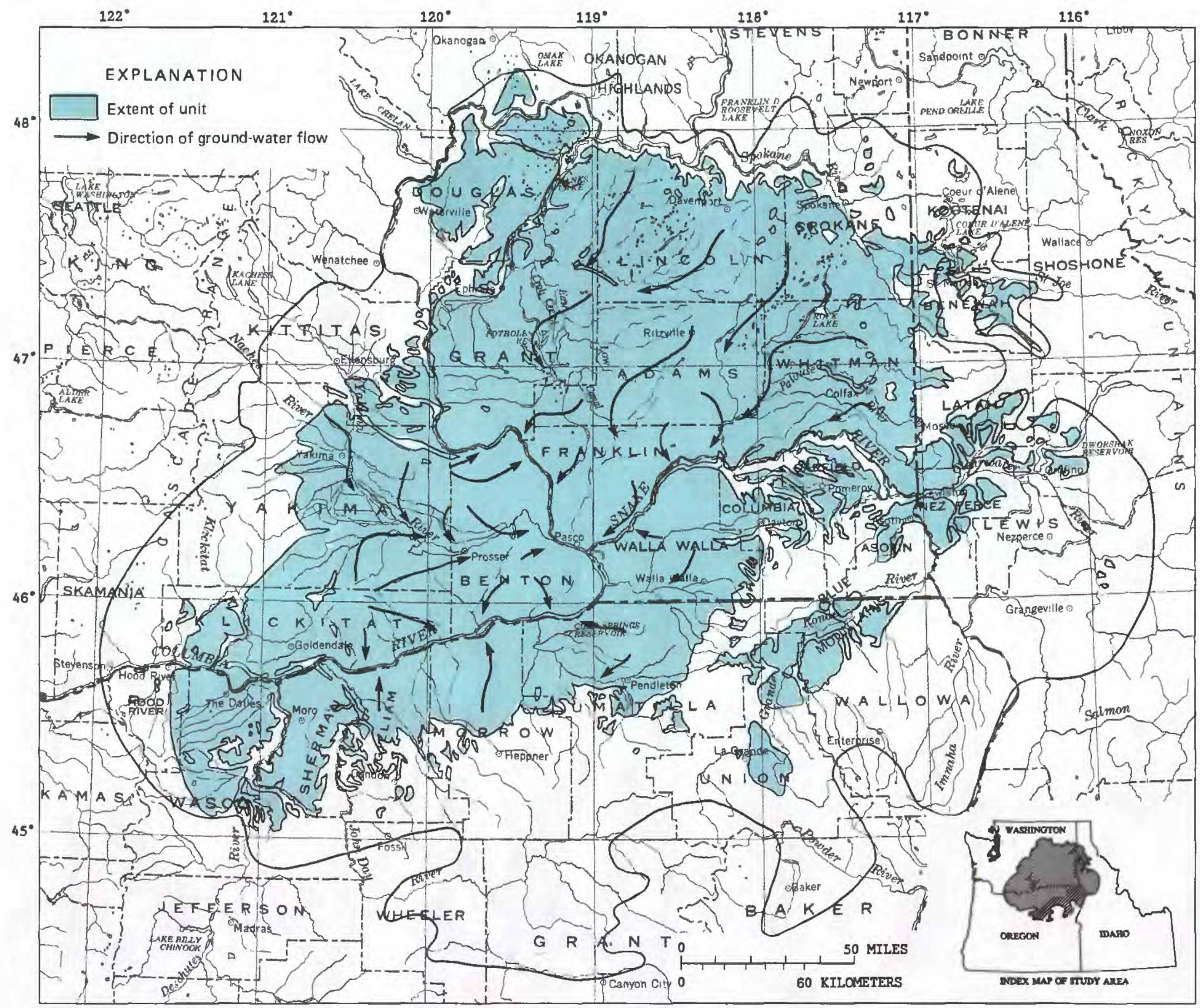

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Figure 6.--General horizontal directions of ground-water flow in the Wanapum unit, 1984.

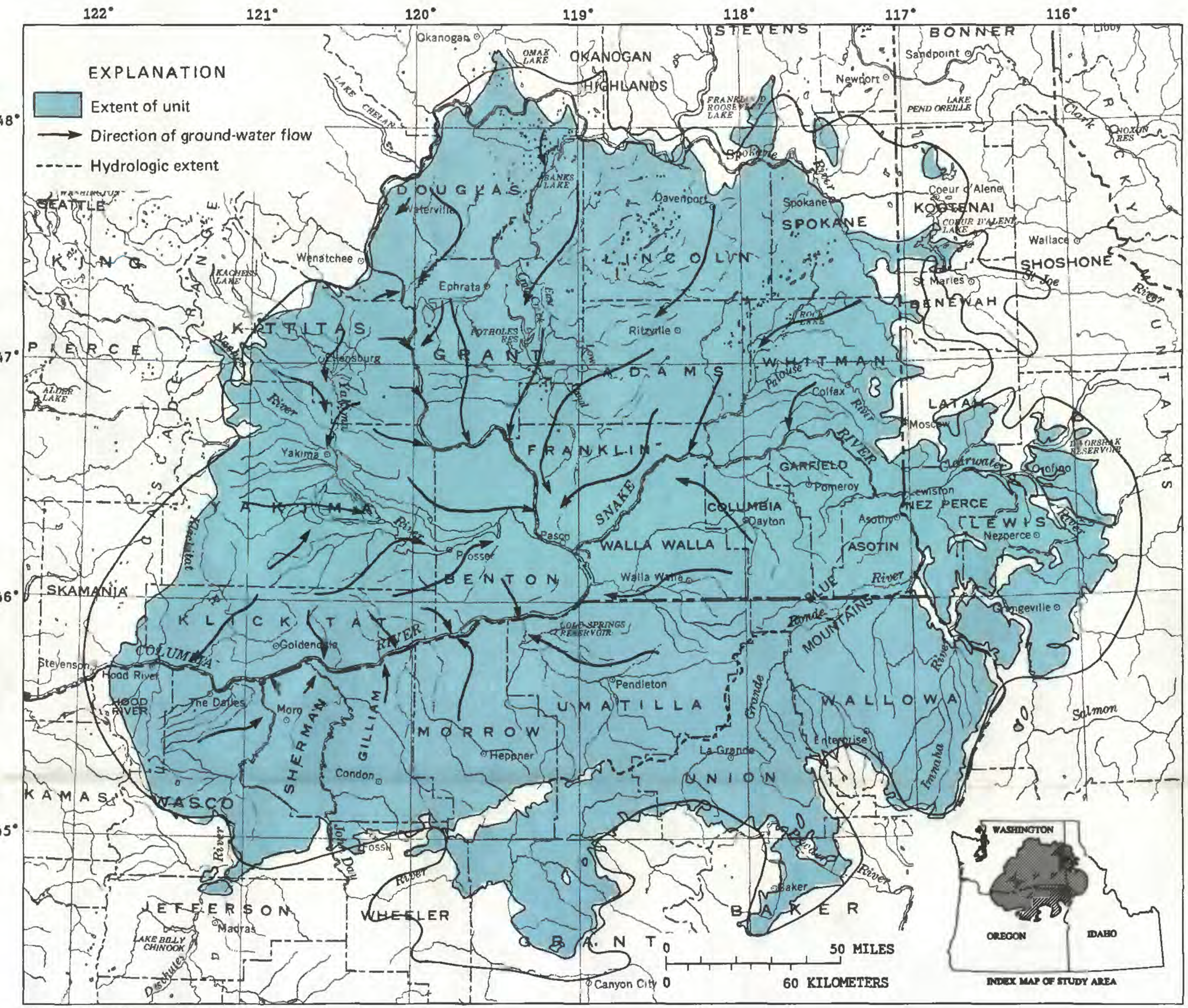

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Figure 7.--General horizontal directions of ground-water flow in the Grande Ronde unit, 1984.

WATER CHEMISTRY

The primary control of ground-water chemistry in the basaltic units is the reaction of water with the rocks that make up the units. Dissolution of the soluble solid phases puts dissolved materials into the ground-water system. The concentrations in which these materials can accumulate in solution are essentially determined by the facility with which new solid phases, which are not components of the basaltic rocks, can form from solution and the rates at which they do so. As the rock materials dissolve, the chemical characteristics of the ground waters change, and the waters can be described by the relative amounts of specific dissolved materials. These amounts are controlled by dissolution, precipitation, and other chemical processes that occur in the system. The relative significance of the different chemical processes varies with the amount of time that the waters are in contact with the basaltic units. As residence time and dissolved concentrations increase, different chemical reactions can begin to affect ground-water chemistry.

Over millions of years, the general geochemical processes referred to above have established distinct water compositions that can be related to the chemical and mineralogical compositions of the basaltic units, and to the residence time of the observed waters in the geohydrologic system. Land-use activities can superpose effects on these ground-water compositions over much shorter time spans. These influences are evinced by ground-water chemical compositions that do not fit the pattern of geochemical evolution demonstrated by examination of water chemistry on a regional scale.

Chemical data used in preparing this report are average or single values of the results of analyses of one to three individual samples collected from about 350 wells in the Columbia Plateau. Nearly all of the sites are within the hydrologic boundaries of the regional ground-water system studied by this RASA project. The exceptions are samples from the Grande Ronde unit south and southeast of the Grande Ronde River and the crest of the Blue Mountains. Most of the wells sampled are irrigation or municipal wells and each well is completed in a single basaltic unit. The samples were collected and analyzed in 1982-85 by the U.S. Geological Survey. The field and analytical data are in the Survey's WATSTORE data base.

In general, ground waters in the basaltic units are of a quality suitable for most uses. The waters are commonly either calcium-magnesium bicarbonate type or sodium bicarbonate type, with dissolved-solids concentrations generally less than 500 milligrams per liter (mg/L). Figure 8 is a graph of the relation between specific conductance and calculated dissolved-solids concentrations for waters from all of the sampled basaltic units. The observed relation enables the estimation of dissolved-solids concentration from conductance information, using either the graph or the following equation for a straight line fitted to the data:

$$\text{dissolved solids (in mg/L)} = [0.554 * \text{conductance} + 50].$$

The dominant dissolved species are sodium, calcium, magnesium, bicarbonate, silica, sulfate, and chloride; the means and ranges of these and other species and selected physical properties are listed in table 1. Dissolved concentrations of these species cannot be estimated as readily or as accurately as with the above relation for dissolved solids, because individual species concentrations do not consistently increase linearly with other concentrations or with physical properties.

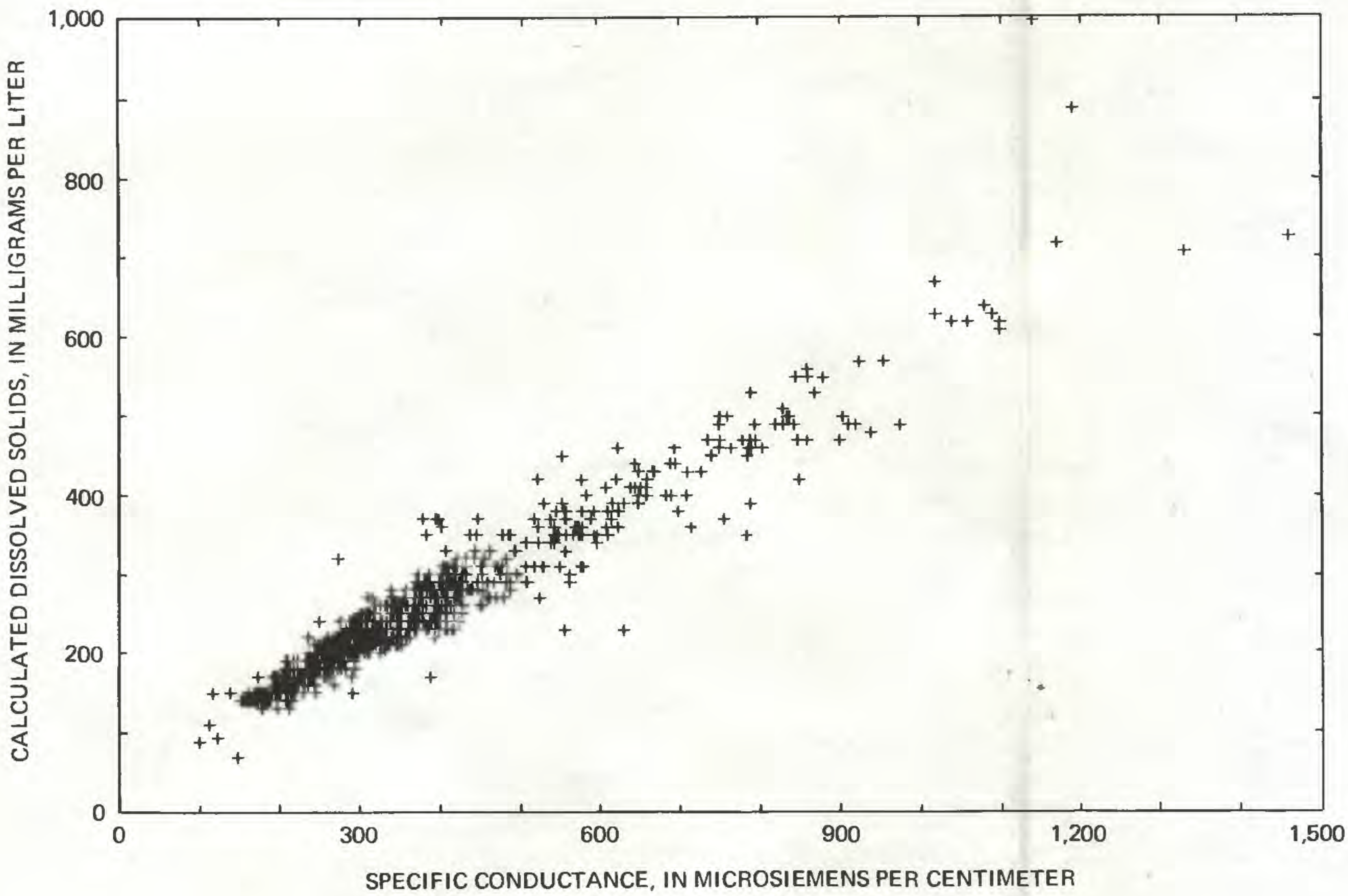


Figure 8.--Relation between specific conductance and calculated dissolved-solids concentrations.

Table 1.--Summary of water-quality data for the three basalt units, 1982-1985

[Number of samples is 824; concentration units are milligrams per liter unless otherwise indicated]

Water-quality property	Maximum	Minimum	Mean
Specific conductance (microsiemens per centimeter at 25 °Celsius)	1,970	85	385.6
Calculated dissolved solids	1,100	69	243
Sodium (Na)	130	2.4	40.4
Chloride (Cl)	300	.5	14.9
Nitrate + nitrite (NO_3+NO_2, as N)	54	.1	2.9
Silica (SiO_2)	110	10	52.3
Sulfate (SO_4)	490	.2	30.1
Temperature (°Celsius)	43.4	6.2	16.7
Dissolved oxygen (DO)	10.6	.1	4.5
Calcium (Ca)	180	.8	30.8
Magnesium (Mg)	75	.01	14.1
Fluoride (F)	4.9	.1	.53
Bicarbonate (HCO_3)	455	43	166.2
Iron (Fe)	10	.003	.05
Potassium (K)	22.0	.9	5.1
pH (units)	9.4	6.1	[a]7.5

[a]Mean value is the negative log of the average hydrogen ion concentration.

Saddle Mountains Unit

A summary of the means and ranges of the major solutes in, and physical properties of, water samples from the Saddle Mountains unit are listed in table 2. Calcium and magnesium are the dominant cations and bicarbonate is the dominant anion. These three ions characterize the most common water type, calcium-magnesium bicarbonate, in the unit (fig. 9). Sodium bicarbonate waters occur farther downgradient in the flow system (adjacent to the Columbia River) and generally deeper in the unit than calcium-magnesium bicarbonate waters (fig. 10). This suggests that sodium increases with residence time in the system, as was proposed by Hearn and others (1985). All occurrences of calcium-magnesium sulfate-chloride waters are associated with overburden thicknesses of less than 100 feet (fig. 11) and dissolved-oxygen concentrations greater than 5 mg/L, suggesting that these waters or some fraction of them were recharged fairly recently. Additionally, they occur almost exclusively in areas where surface water is used for irrigation. These relations suggest that the occurrence of the calcium-magnesium sulfate-chloride waters in this unit is related to land-use activities and the absence of a thick overburden layer.

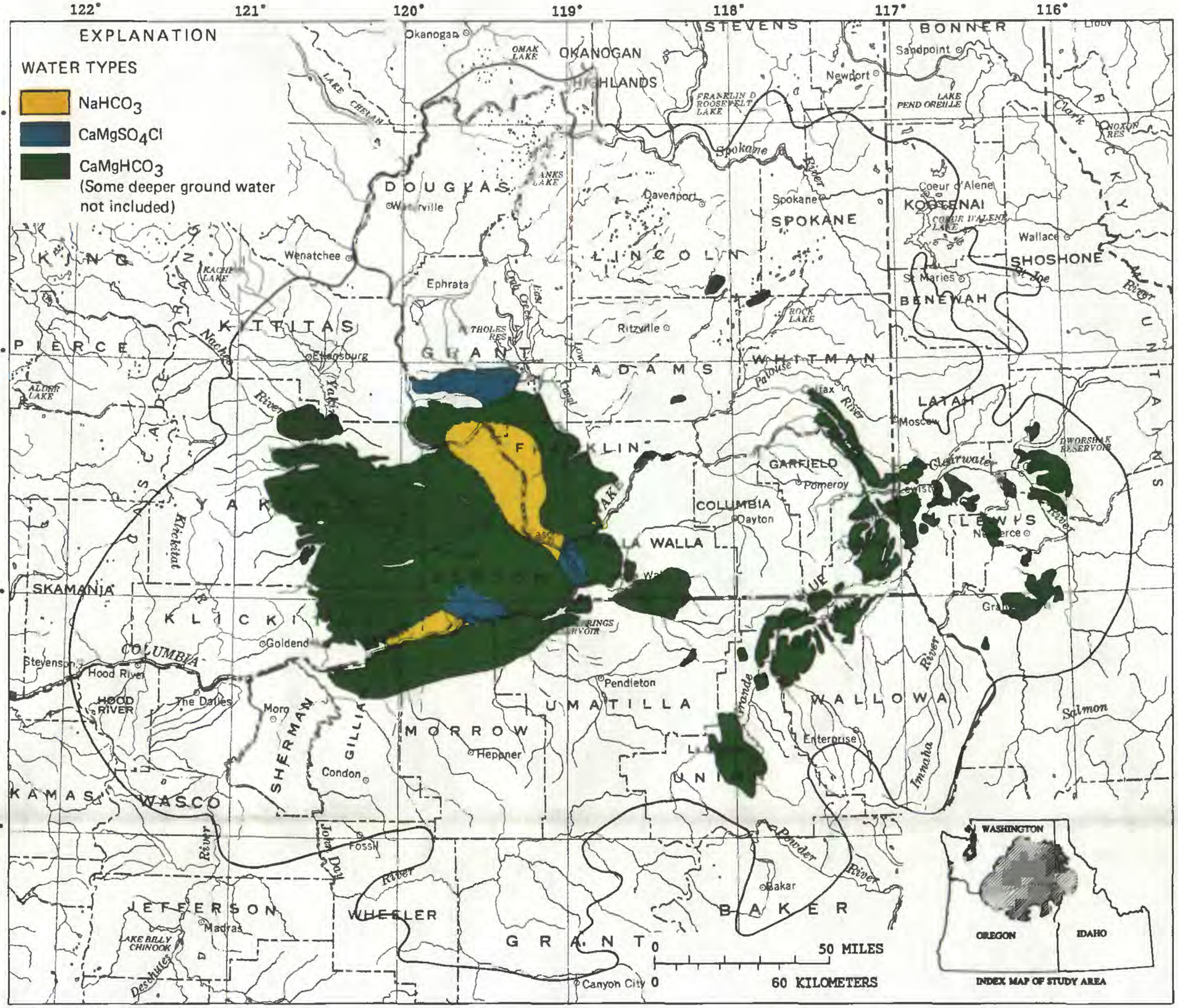
Table 2.--Summary of water-quality data for the Saddle Mountains unit, 1982-1985

[Number of samples is 131; concentration units are milligrams per liter unless otherwise indicated]

Water-quality property	Maximum	Minimum	Mean
Specific conductance (microsiemens per centimeter at 25 °Celsius)	1,460	175	498.2
Calculated dissolved solids	890	140	340.2
Sodium (Na)	100	7.3	34.5
Chloride (Cl)	130	1.3	24.3
Nitrate + nitrite (NO_3+NO_2, as N)	54	.1	4.8
Silica (SiO_2)	72	36	55.6
Sulfate (SO_4)	490	.2	53
Temperature (°Celsius)	25.5	8.6	18.36
Dissolved oxygen (DO)	10.1	.1	4.5
Calcium (Ca)	98	1.9	38.28
Magnesium (Mg)	62	.28	19.4
Fluoride (F)	2.9	.2	.58
Bicarbonate (HCO_3)	392	108	195.4
Iron (Fe)	.79	.003	.03
Potassium (K)	13.0	1.5	6.9
pH (units)	8.7	7.0	[a]7.7

[a]Mean value is the negative log of the average hydrogen ion concentration.

The areal variation of calculated (summation) values of dissolved-solids concentration is shown in figure 12. Downgradient waters in the unit have the highest values, generally reflecting a longer residence time in the aquifer system than upgradient waters. The increases are not regular, however, and appear to be significantly influenced by agricultural activities, since the highest concentrations tend to occur in areas where surface water is used for irrigation (fig. 4). The distribution of dissolved sodium differs from that of total solutes in that there is a discernible progressive sodium increase, but the dissolved-solids concentration does not increase at the same rate. This largely reflects the geochemical evolution of the waters (Steinkampf and others, 1985, p. 16). Whereas dissolved solids are highest in the eastern half of that part of the unit east of the Columbia River, sodium concentrations are highest in the western half, along the Columbia River (fig. 13).



Base from U.S. Geological Survey
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Figure 9.--Water types in the Saddle Mountains unit, 1982-1983.

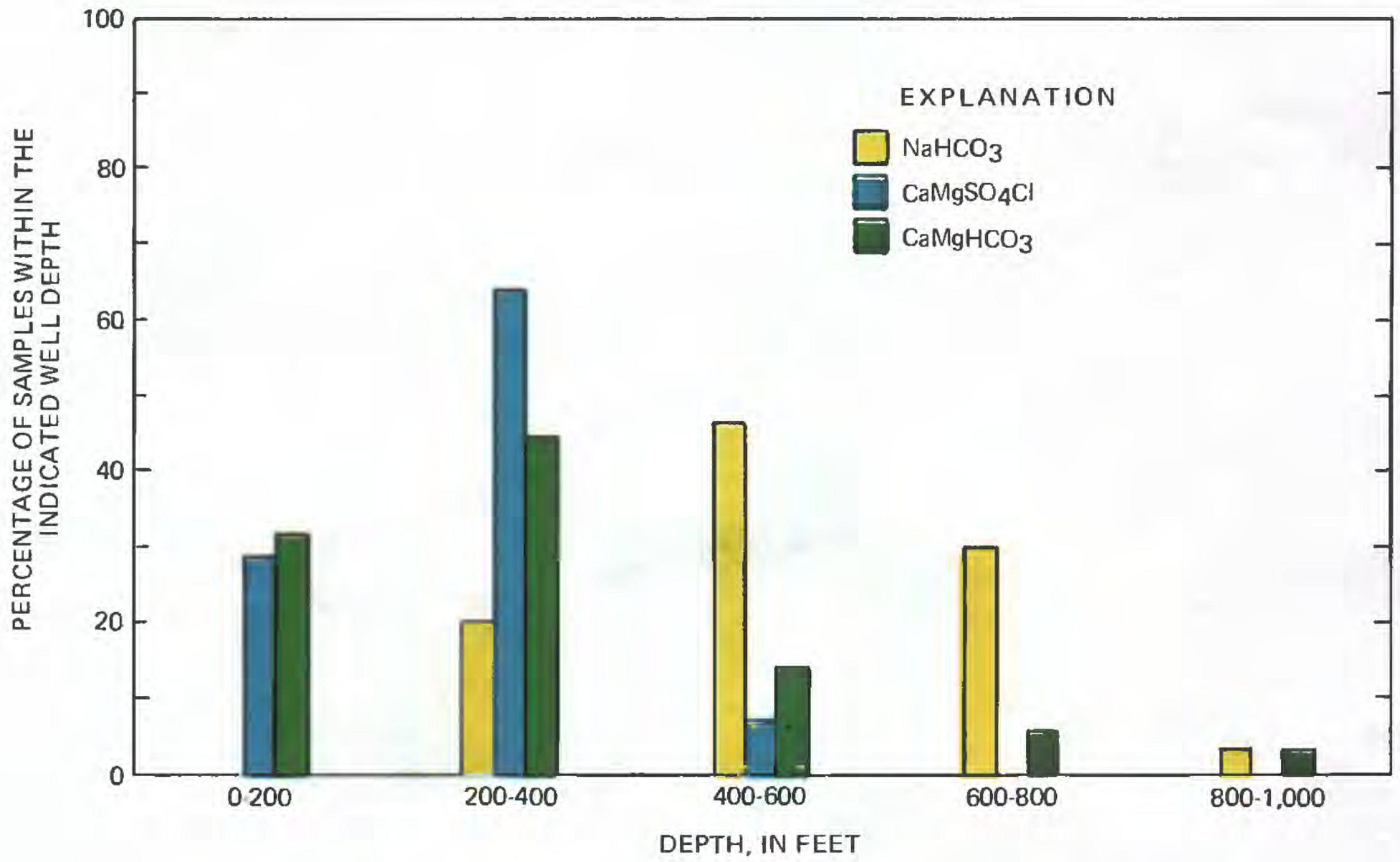

Figure 10.--Distribution of water types related to well depth in the Saddle Mountains unit.

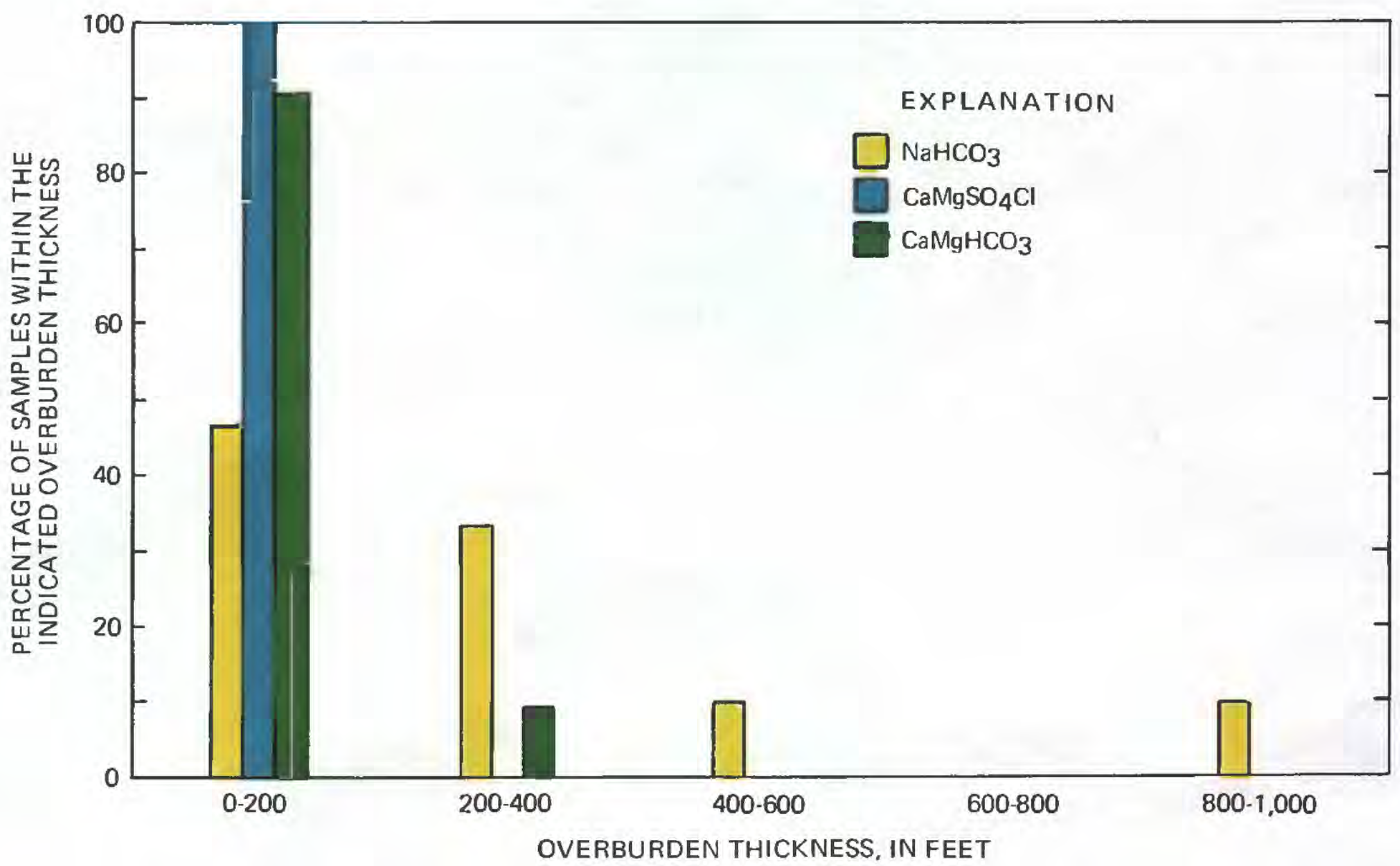

Figure 11.--Distribution of water types related to overburden thickness in the Saddle Mountains unit.

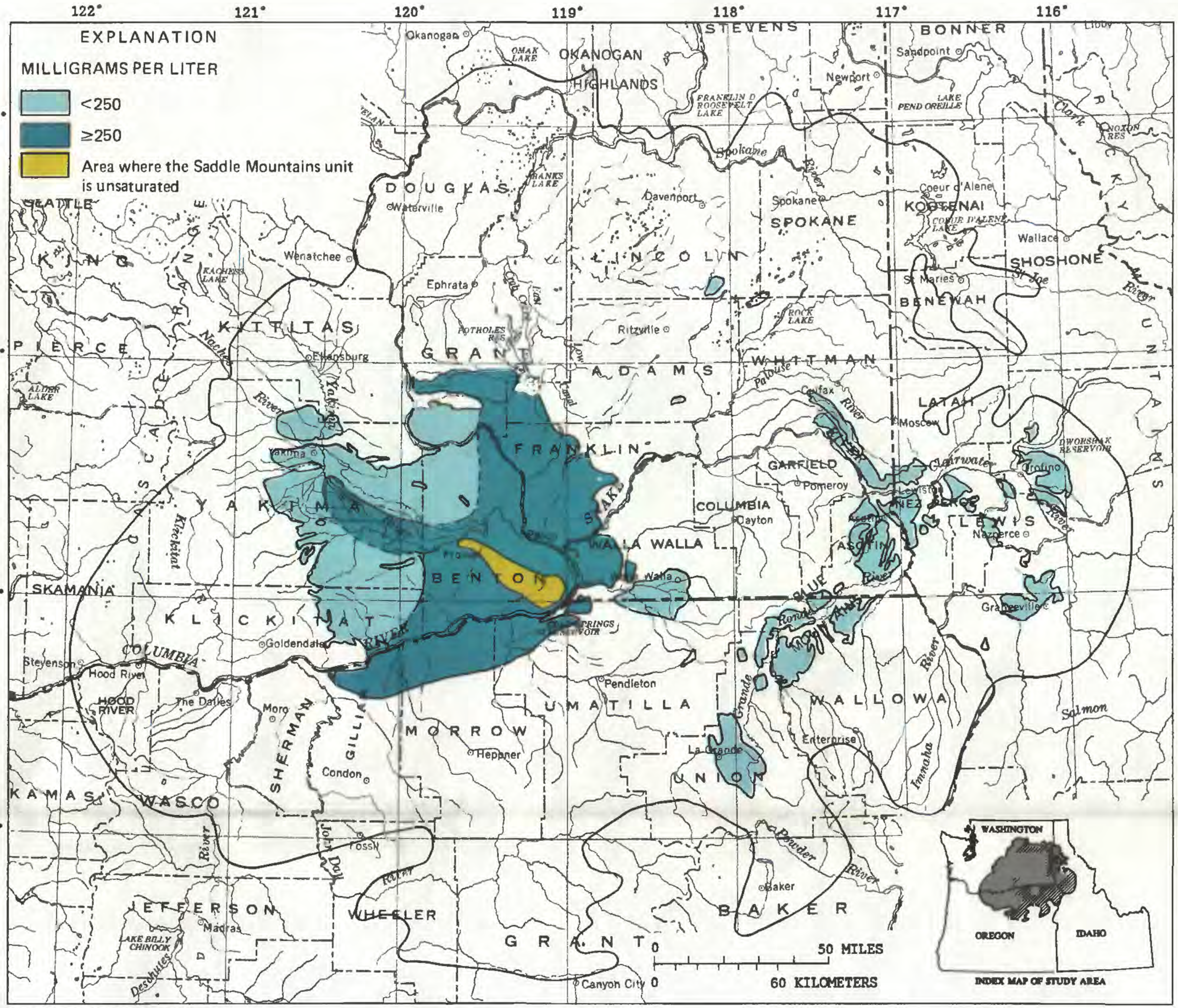

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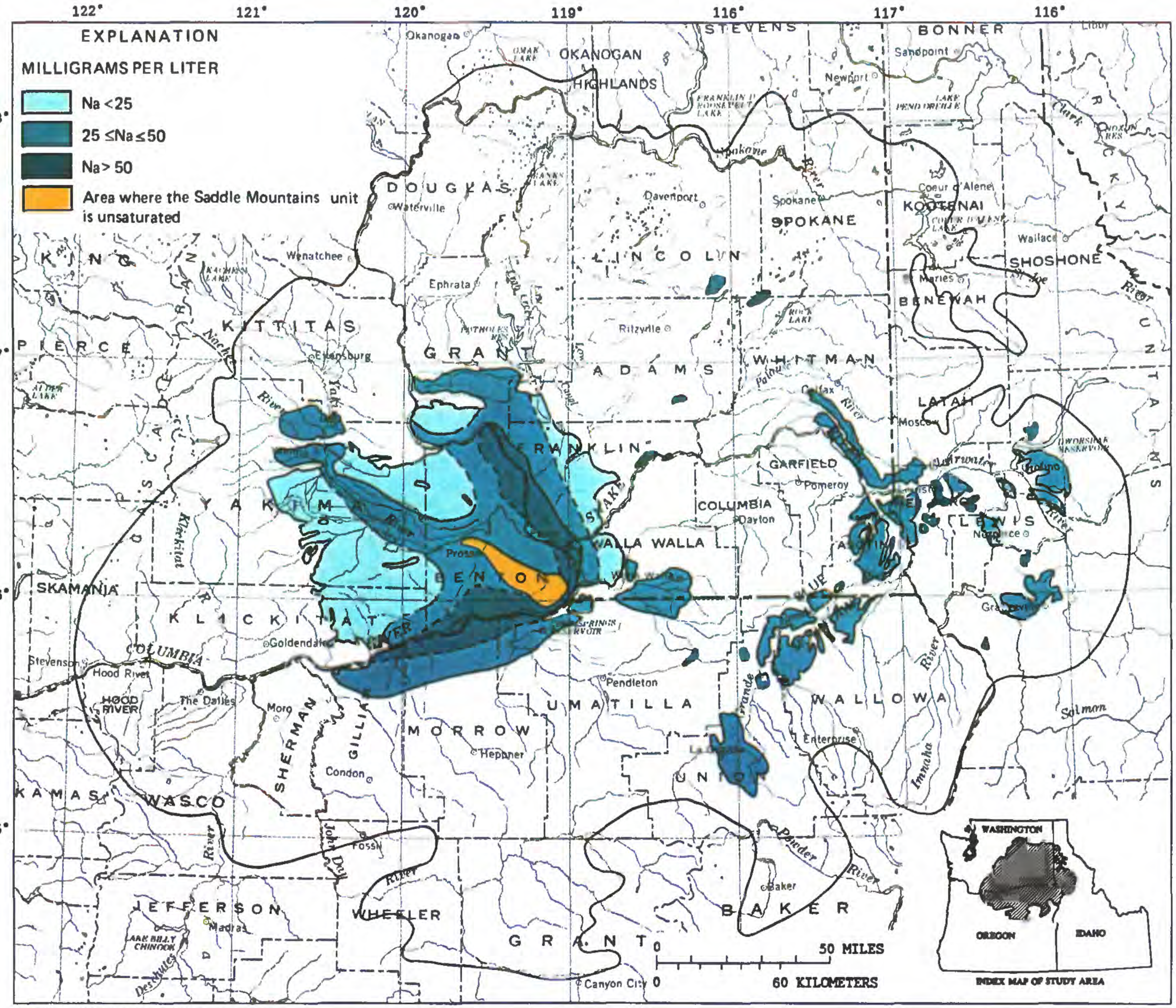
Figure 12.--Calculated dissolved-solids concentrations in the Saddle Mountains unit, 1982-1983.



Base from U.S. Geological Survey
State base map, 1:500 000

Figure 13.--Sodium concentrations in the Saddle Mountains unit, 1982-1983.

The highest nitrogen concentrations, as nitrate-plus-nitrite, occur largely where there is an absence of a significant thickness of overburden (fig. 14; see fig. 15 for areal distribution in the unit). More than half of the sample sites with 100 feet or less of overburden yielded waters with nitrogen concentrations of 2.0 mg/L or higher. This concentration is used in this report as a comparative value; concentrations higher than this likely represent anthropogenic input to the ground-water system. The nitrogen data used in this study essentially represent dissolved nitrate concentrations. Nitrite is much less stable and readily oxidizes to nitrate. On the basis of analyses of nitrogen species in waters from selected wells in the eastern part of the Pasco Basin (S. E. Cox, U.S. Geological Survey, oral commun., 1986), nitrite can be expected to be present in insignificant concentrations.

About one-fifth of the samples from sites with relatively thin overburden have nitrogen concentrations above the recommended nitrate limit of 10 mg/L, as nitrogen (U.S. Environmental Protection Agency, 1976). Of 51 sites with sulfate data (see fig. 16 for areal distribution of sulfate), 31 have nitrogen concentrations less than 2.0 mg/L. Twenty-four of these sites with low nitrogen concentrations also have sulfate concentrations lower than 25 mg/L. This, together with the fact that the higher concentrations are primarily in areas of surface-water irrigation, suggests that the higher nitrogen and sulfate concentrations are related both to overburden thickness and land use. Higher sulfate concentrations are more extensive than those of nitrogen in south-central Washington near the Columbia River (figs. 15 and 16). This is due in part to the upward flux of deeper, more saline water in this area (Steinkampf and others, 1985, p. 18). Possible sources of sulfate include agricultural chemicals and metallic sulfide accessory minerals in the basalts.

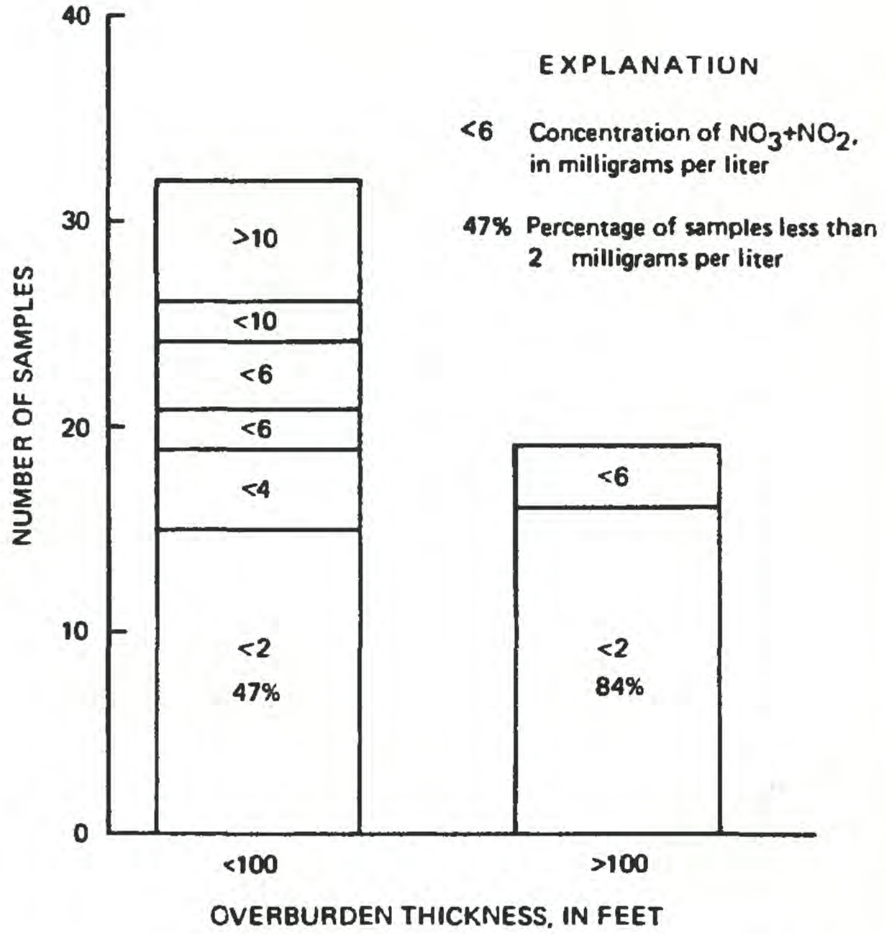
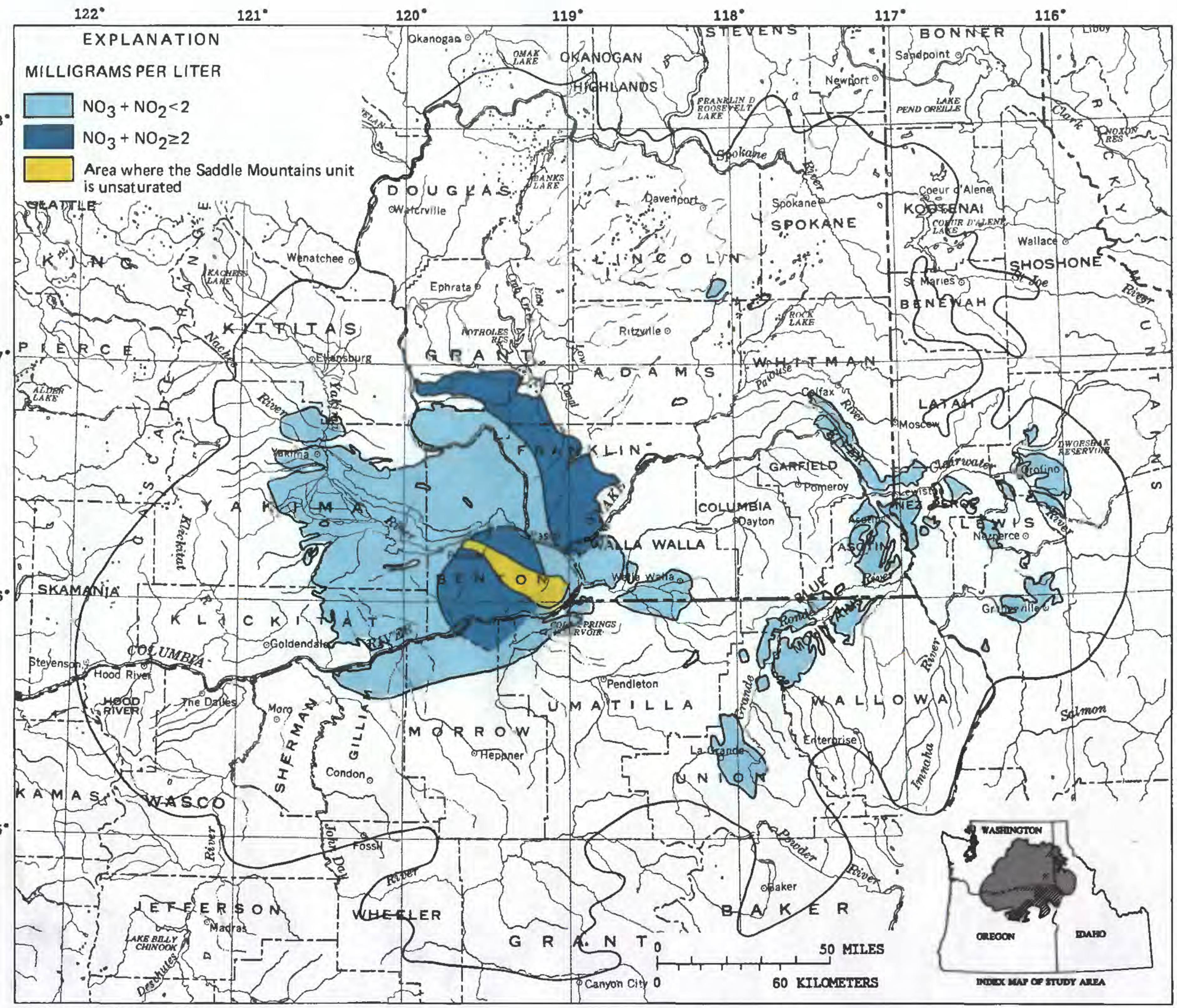


Figure 14.--Distribution of nitrate-plus-nitrite concentrations (in milligrams per lite as nitrogen) in the Saddle Mountains unit related to overburden thickness.



Base from U.S. Geological Survey
State base map, 1:500 000

Figure 15.--Nitrate-plus-nitrite concentrations in the Saddle Mountains unit, 1982-1983.

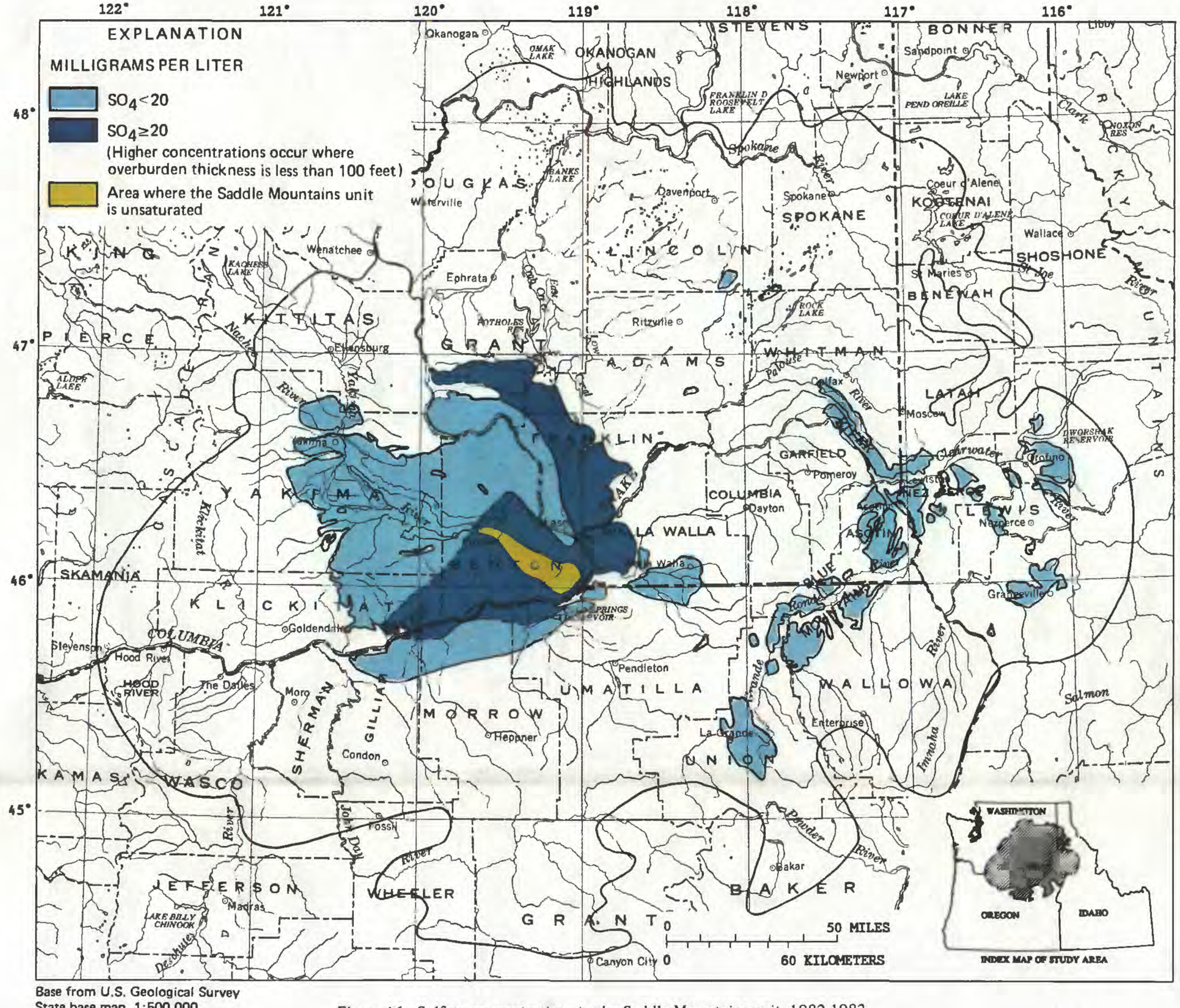


Figure 16.--Sulfate concentrations in the Saddle Mountains unit, 1982-1983.

Wanapum Unit

A summary of the maximum, minimum, and mean values for samples from the Wanapum unit are listed in table 3. As in the Saddle Mountains unit, the dominant water composition is calcium-magnesium bicarbonate, followed by sodium bicarbonate and calcium-magnesium sulfate-chloride. The distribution and occurrence of the latter types in the Wanapum unit appear to have the same causal relations as in the Saddle Mountains unit. Sodium bicarbonate waters occur primarily in downgradient regions and in deeper wells. Calcium-magnesium sulfate-chloride waters are the least common in the unit. They almost invariably: 1) are found in wells shallower than 300 feet (fig. 17); 2) have dissolved-oxygen concentrations greater than 4.0 mg/L (fig. 18); and 3) are found in areas with less than 100 feet of overburden (fig. 19). The areal distribution of the individual types cannot be mapped in a systematic or regular fashion because of variations in the density and distribution of sample sites.

Calculated dissolved-solids concentrations in the Wanapum unit range from 69 to 1,100 mg/L with a mean of 270 mg/L. More than 95 percent of the concentrations are less than 500 mg/L. The location of the approximate 250-mg/L isoline (line of equal concentrations; fig. 20) shows that concentrations greater than 250 mg/L are found beneath lands irrigated with surface waters and are primarily in downgradient locations in the flow system. The isoline configuration may also reflect, in some parts of downgradient areas, the fact that water-level elevations in the underlying Grande Ronde unit are higher than those in the Wanapum unit, particularly in the vicinity of the Pasco Basin. These water-level differences result in upward flow of ground water from the Grande Ronde to the Wanapum in such areas.

Table 3.--Summary of water-quality data for the Wanapum unit, 1982-1985

[Number of samples is 410; concentration units are milligrams per liter unless otherwise indicated]

Water-quality property	Maximum	Minimum	Mean
Specific conductance (microsiemens per centimeter at 25 °Celsius)	1,970	102	402.5
Calculated dissolved solids	1,100	69	269.5
Sodium (Na)	130	2.4	28
Chloride (Cl)	300	7	17.2
Nitrate + nitrite (NO_3+NO_2, as N)	35	.1	3.7
Silica (SiO_2)	100	10	48.3
Sulfate (SO_4)	290	.2	29.3
Temperature (°Celsius)	43.4	6.2	15.5
Dissolved oxygen (DO)	10.6	.1	5.2
Calcium (Ca)	180	.S	32.8
Magnesium (Mg)	75.0	.1	14.8
Fluoride (F)	3.4	.1	.5
Bicarbonate (HCO_3)	406	53	178.1
Iron (Fe)	1.1	.003	.03
Potassium (K)	22.0	.9	4.9
pH (units)	9.4	6.1	[a]7.4

[a]Mean value is the negative log of the average hydrogen ion concentration.

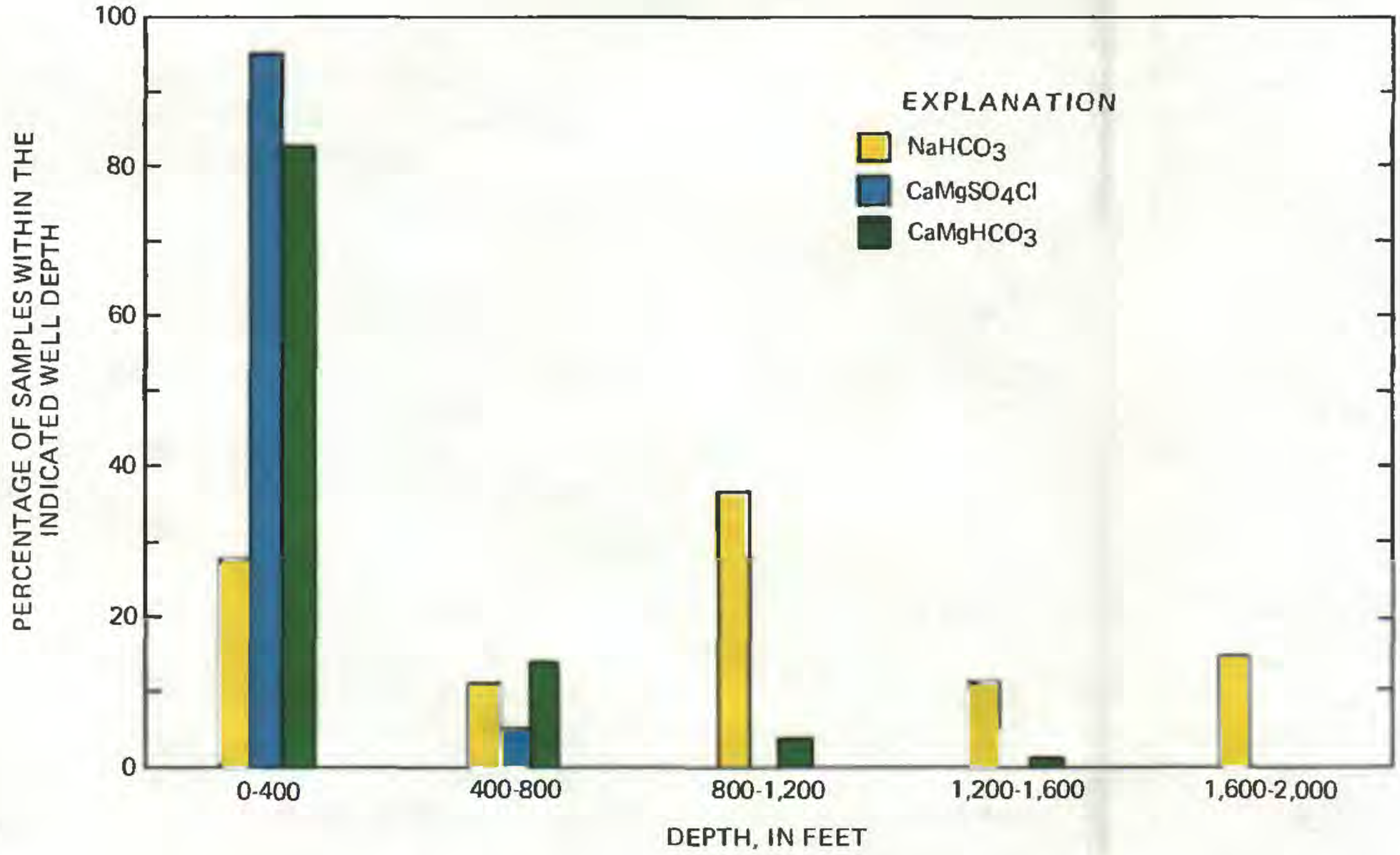


Figure 17.--Distribution of water types related to well depth in the Wanapum unit.

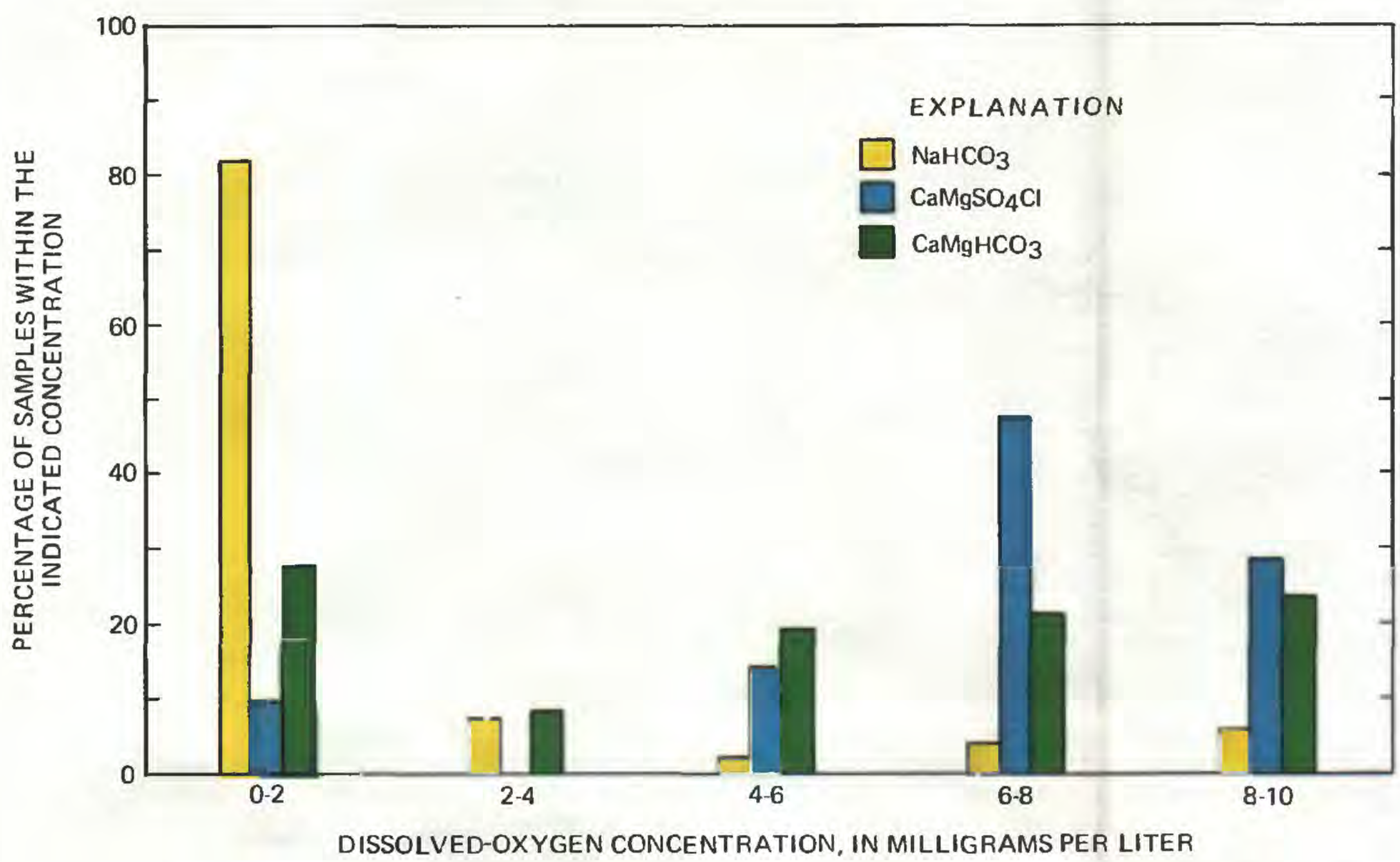


Figure 18.--Distribution of water types related to dissolved-oxygen concentration in the Wanapum unit.

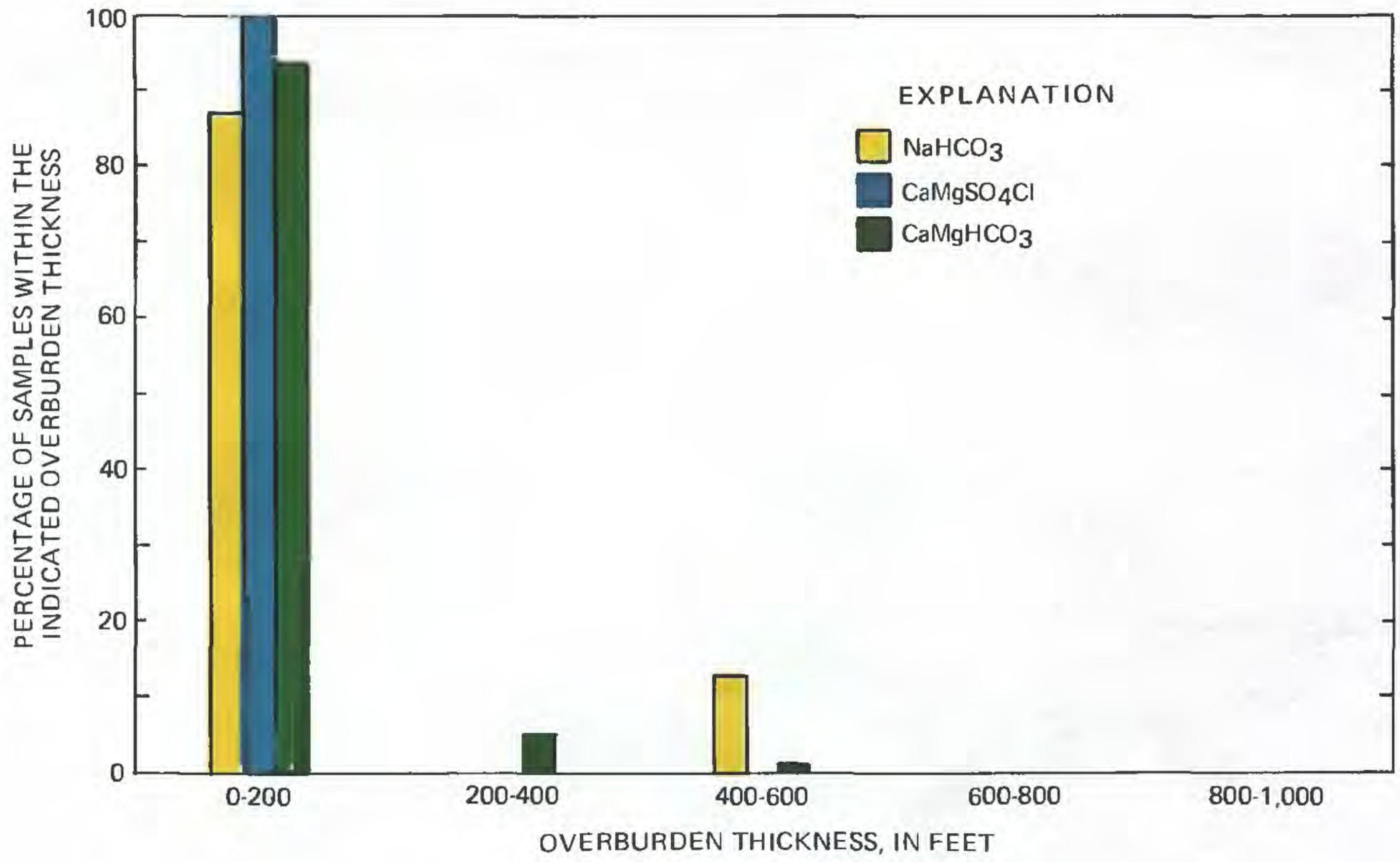


Figure 19.--Distribution of water types related to overburden thickness in the Wanapum unit.

The sodium distribution in the Wanapum unit (fig. 21) resembles that of the dissolved-solids distribution. Sodium concentrations greater than 25 mg/L are found largely in downgradient and discharge areas, and in the central part of the plateau. The prominent southwest-trending tongue of lower sodium water in the central part of the plateau generally coincides with a similarly oriented feature in the dissolved-solids configuration. It also partly coincides with a similar feature in the distribution pattern of sulfate (not illustrated). These features do not appear to be functions of the directions of ground-water flow, based on examinations of 1983 and 1984 ground-water levels (Bauer and others, 1985; Whiteman, 1986).

The distribution of nitrogen (nitrate-plus-nitrite, as nitrogen) in ground water in the Wanapum unit is shown in figure 22. Concentrations greater than 2.0 mg/L were not found in the southwest half of the study area. Essentially none of the samples that did have greater concentrations came from wells deeper than about 500 feet, and most were from wells shallower than 400 feet (fig. 23). The shallowest wells are generally found in the areas northwest of Banks Lake, east of a north-south line through the junction of the Palouse and Snake Rivers, and in a smaller area north of Crab Creek in Lincoln County, Washington. Of the 36 samples with nitrogen concentrations greater than 10 mg/L, 32 are from wells shallower than about 300 feet. The greatest concentrations tend to be found in the central part of the plateau, and in areas with little or no overburden present. With the notable exception of the area north of Lower Crab Creek and west of the East Low Canal, greater concentrations in the Wanapum do not correspond to surface-water irrigation areas.

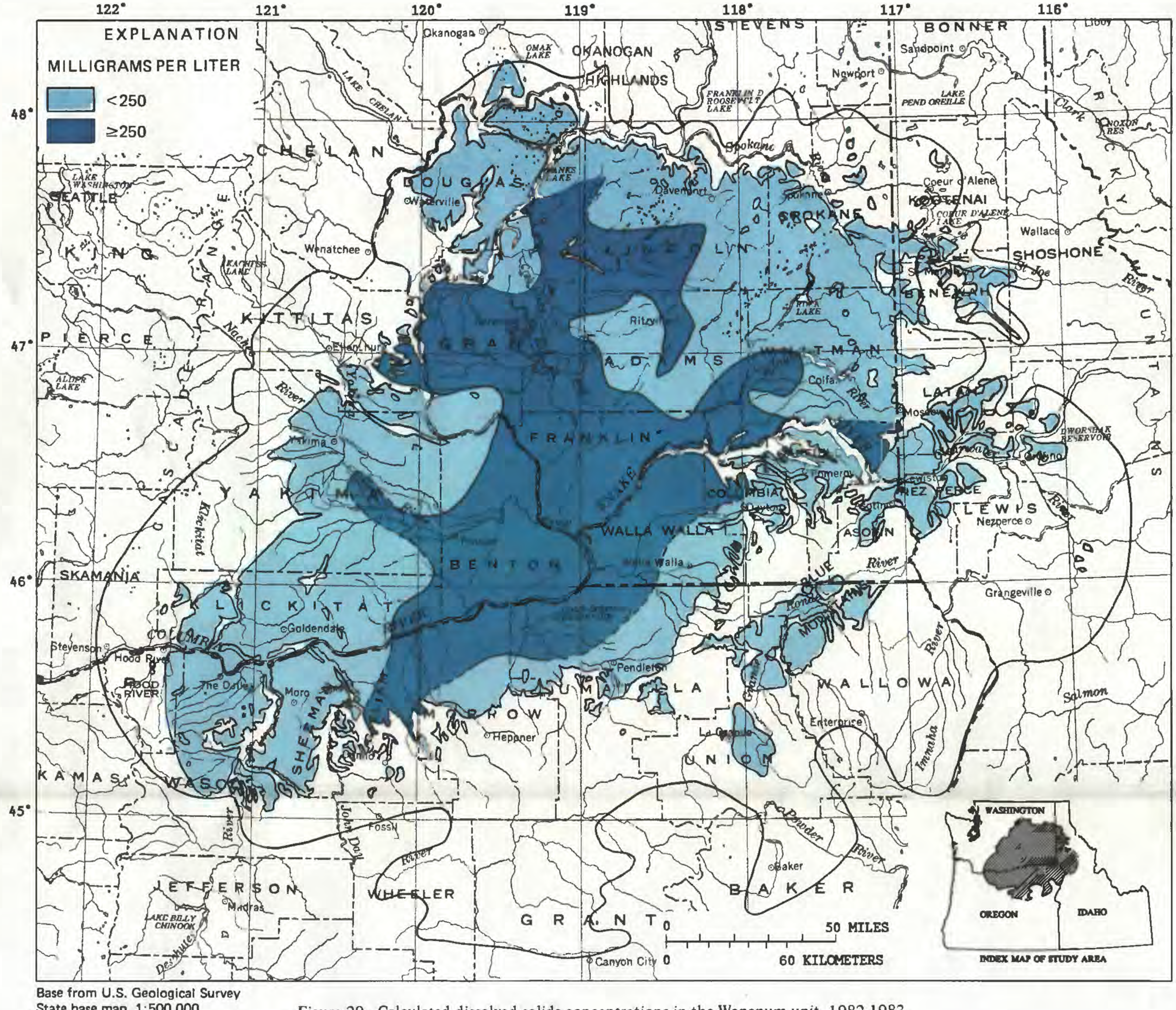
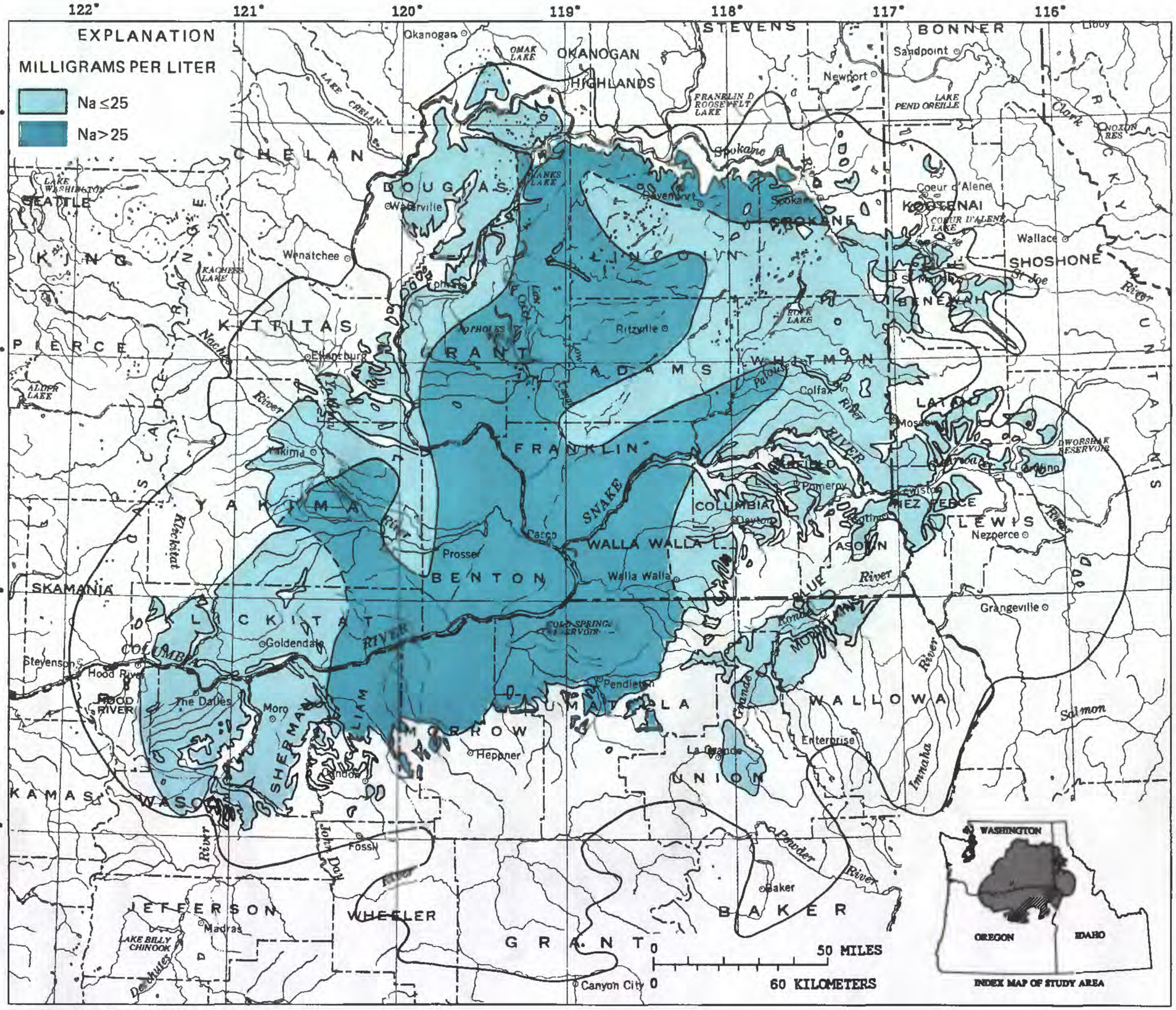
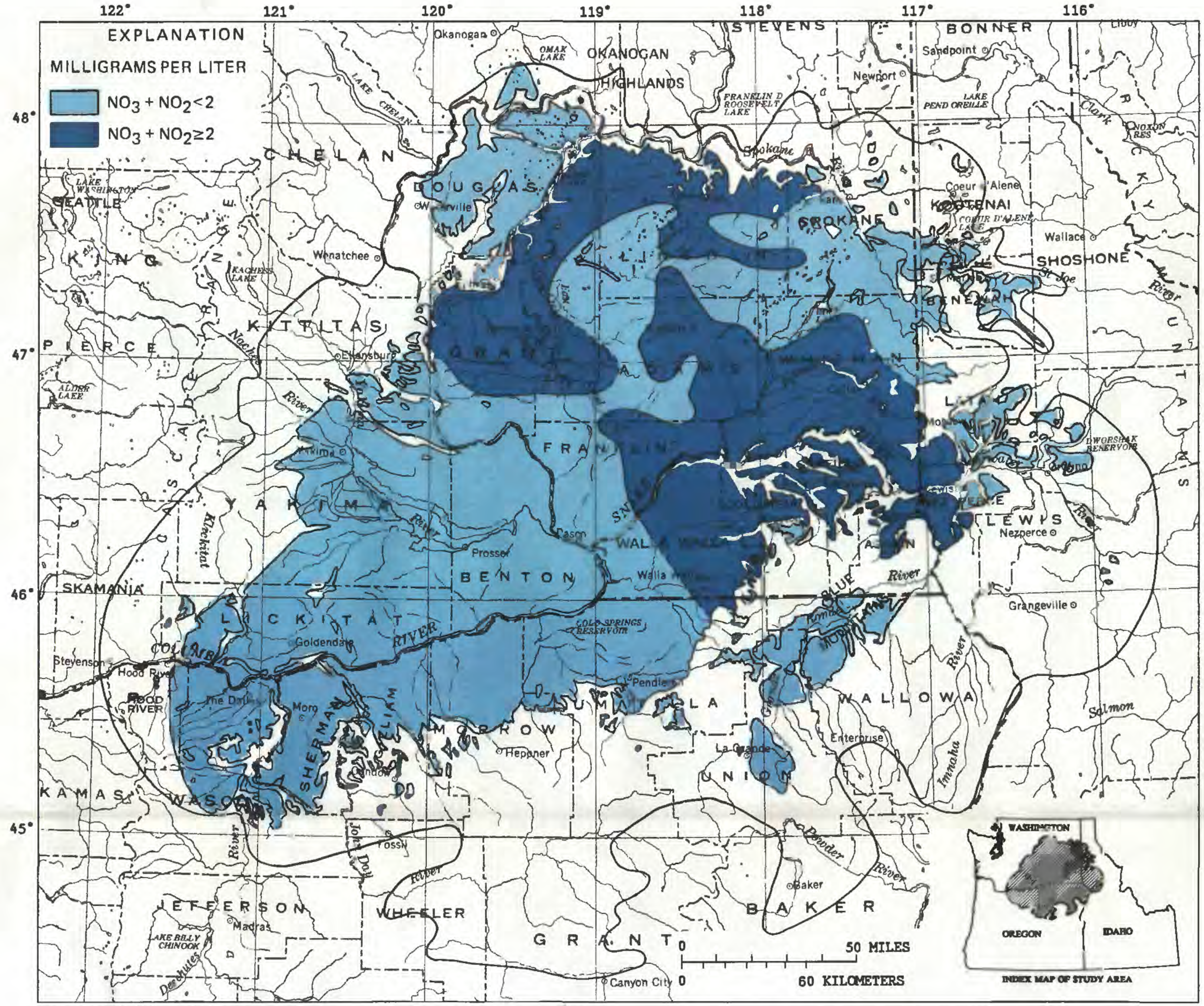


Figure 20.--Calculated dissolved-solids concentrations in the Wanapum unit, 1982-1983.



Base from U.S. Geological Survey
State base map, 1:500 000

Figure 21.--Sodium concentrations in the Wanapum unit, 1982-1983.



Base from U.S. Geological Survey
State base map, 1:500 000

Figure 22.--Nitrate-plus-nitrite concentrations in the Wanapum unit, 1982-1983.

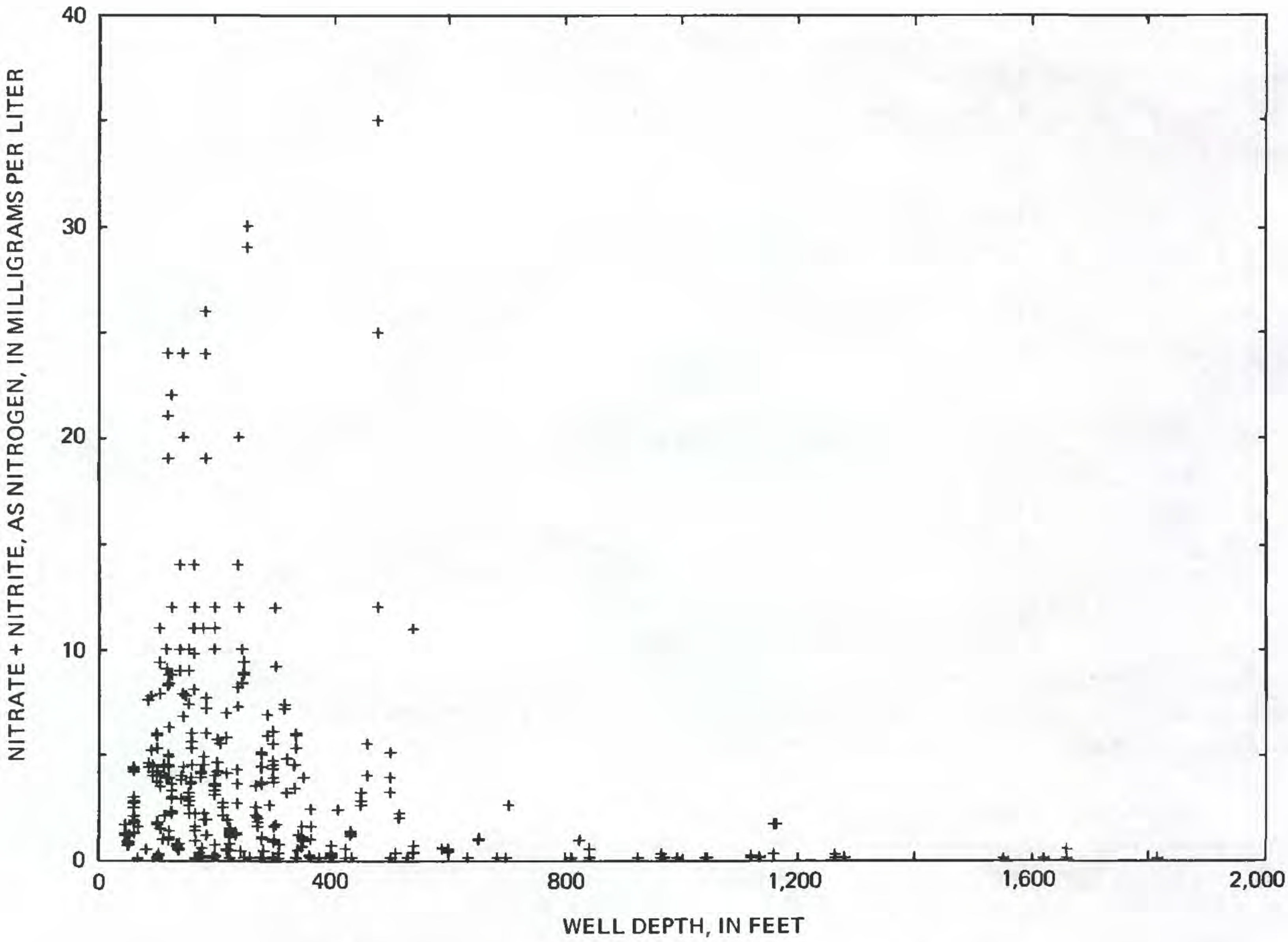


Figure 23.--Relation between nitrogen species and well depth in the Wanapum unit.

Grande Ronde Unit

The paucity of Grande Ronde sample sites in the central part of the plateau precludes a complete discussion of overall areal variations. However, some inferences can be and have been made for some areas, using data from wells that withdraw water from more than one unit and from the flow directions shown in figure 7.

A summary of selected means and ranges of chemical concentrations and physical properties of water samples from the Grande Ronde unit are listed in table 4. As in the other units, the dominant water type is calcium-magnesium bicarbonate, and sodium bicarbonate water tends to be found in downgradient areas, in deeper wells (fig. 24), and in the central parts of the plateau (fig. 25).

The 250-mg/L dissolved-solids isoline (fig. 26) reflects the general configuration of the ground-water levels and the resultant directions of ground-water flow. The only exception to this is in the Yakima River valley, as shown by the northwest part of the region of greater dissolved solids. The elevated concentrations likely result from agricultural activities in an area where the Grande Ronde is at or very near land surface.

The sodium distribution is similar to that of dissolved solids (fig. 27). Concentrations increase downgradient, reflecting increasing residence time in the flow system. The east-projecting area within the 25 mg/L isoline, between the Snake and Palouse Rivers, likely is due to the presence of a significant mantle of unsaturated loess. The highest sodium concentrations noted in the study area are from the deepest wells sampled, and are in the vicinity of the East Low Canal, south of Crab Creek.

Dissolved nitrogen is not a regionally significant component of ground water in this unit; few samples were reported to contain more than 2.0 mg/L.

Table 4.--Summary of water-quality data for the Grande Ronda unit, 1982-1985

[Number of samples is 283; concentration units are milligrams per liter unless otherwise indicated]

Water-quality property	Maximum	Minimum	Meen
Specific conductance (microsiemens per centimeter et 25 °Celsius)	830	85	311.8
Calculated dissolved solids	510	94	234.1
Sodium (Na)	90	4	24.9
Chloride (Cl)	45	.5	7.1
Nitrate + nitrite (NO_3+NO_2, es N)	15	.1	.96
Silica (SiO_2)	110	29	56.5
Sulfete (SO_4)	100	.2	21.8
Tempereture (°Celsius)	36.7	7.6	18
Dissolved oxygen (DO)	10.2	.1	3.3
Celcium (Ca)	88	.95	24.5
Magnesium (Mg)	38	.13	10.7
Fluoride (F)	4.9	.1	.6
Bicerbonete (HCO_3)	455	43	170.3
Iron (Fe)	10	.003	.098
Potassium (K)	13	1.1	4.7
pH (units)	9.4	6.7	[a]7.6

[a]Mean value is the negative log of the average hydrogen ion concentretion.

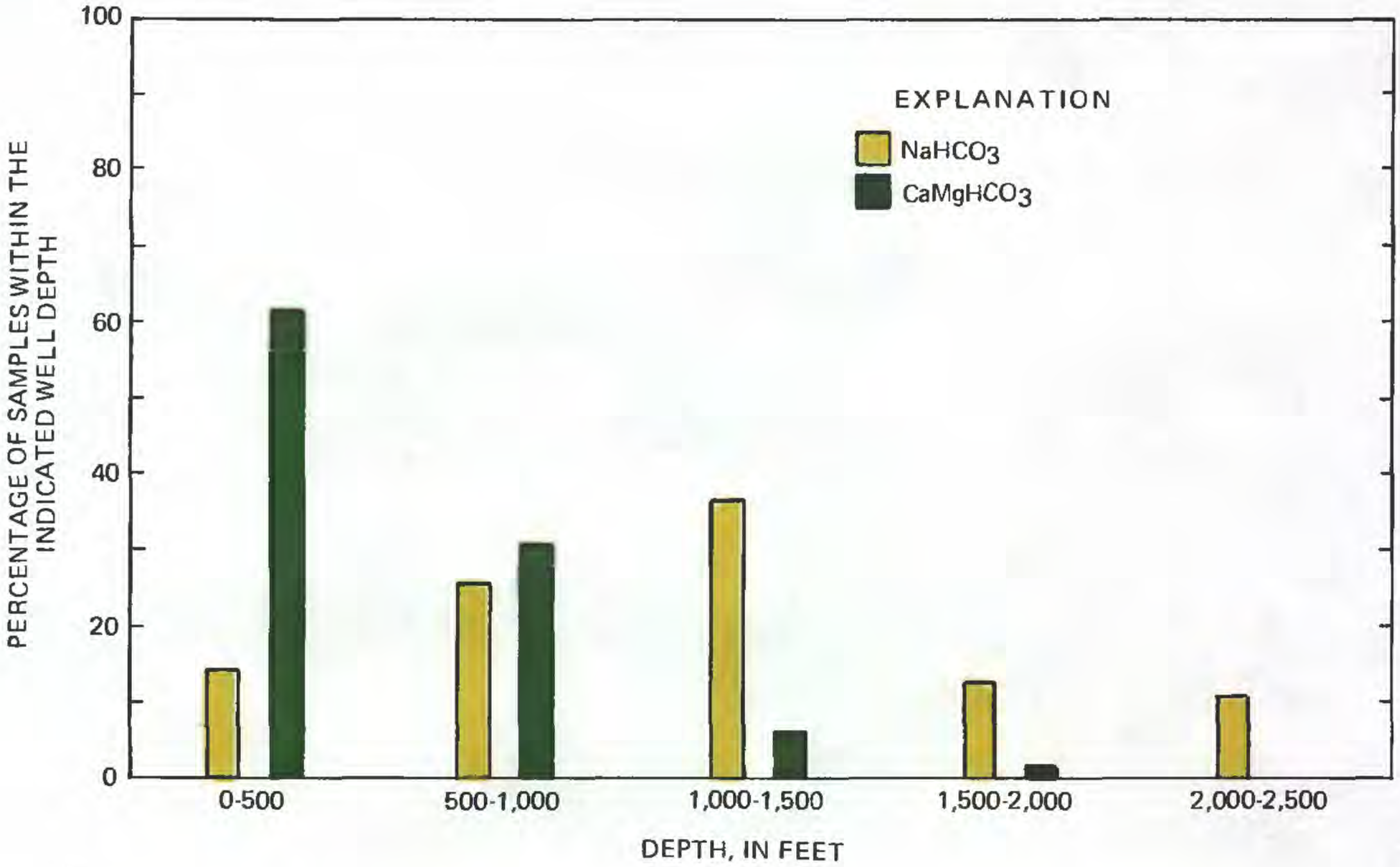


Figure 24.--Distribution of water types related to well depth in the Grande Ronde unit.

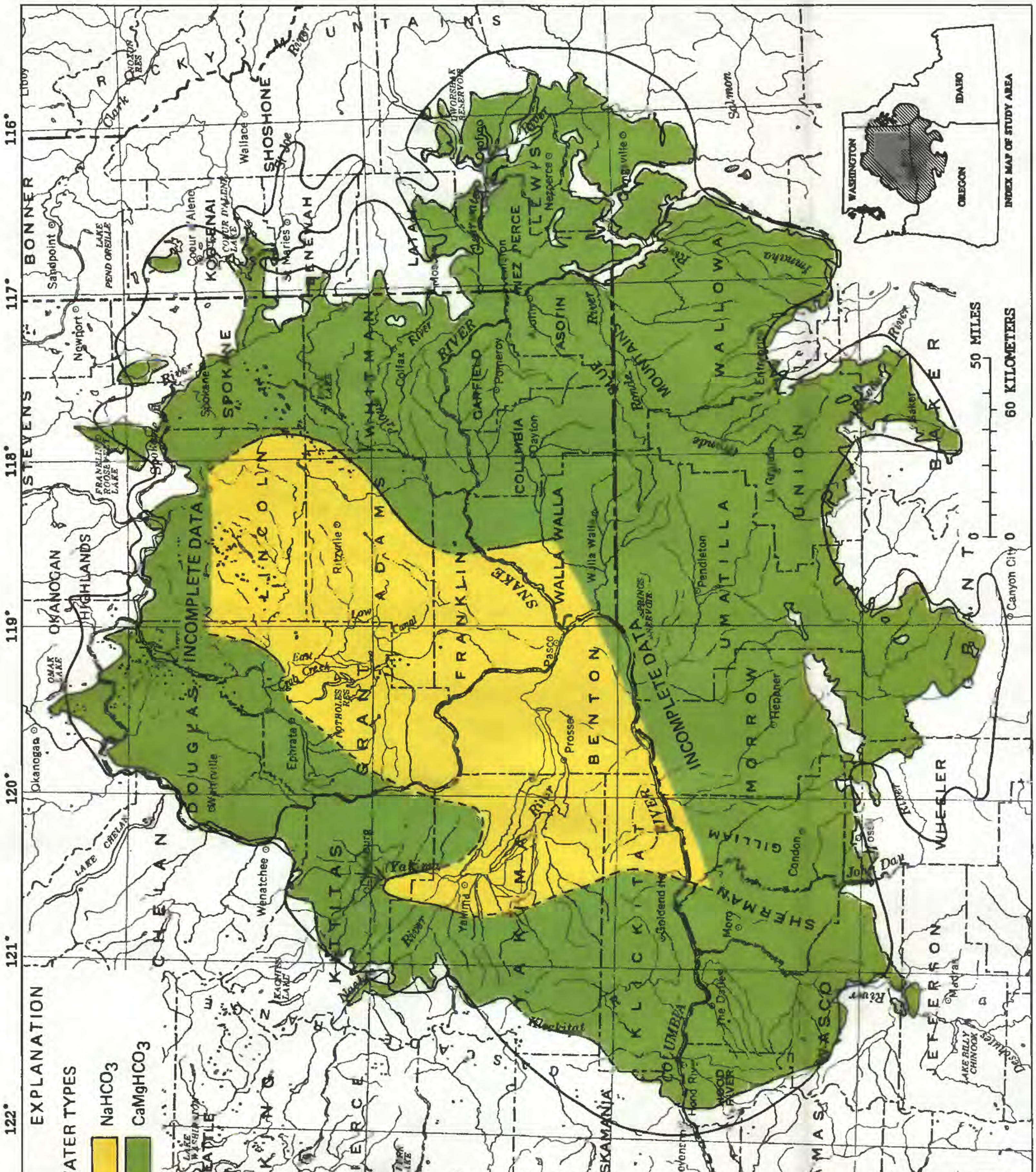
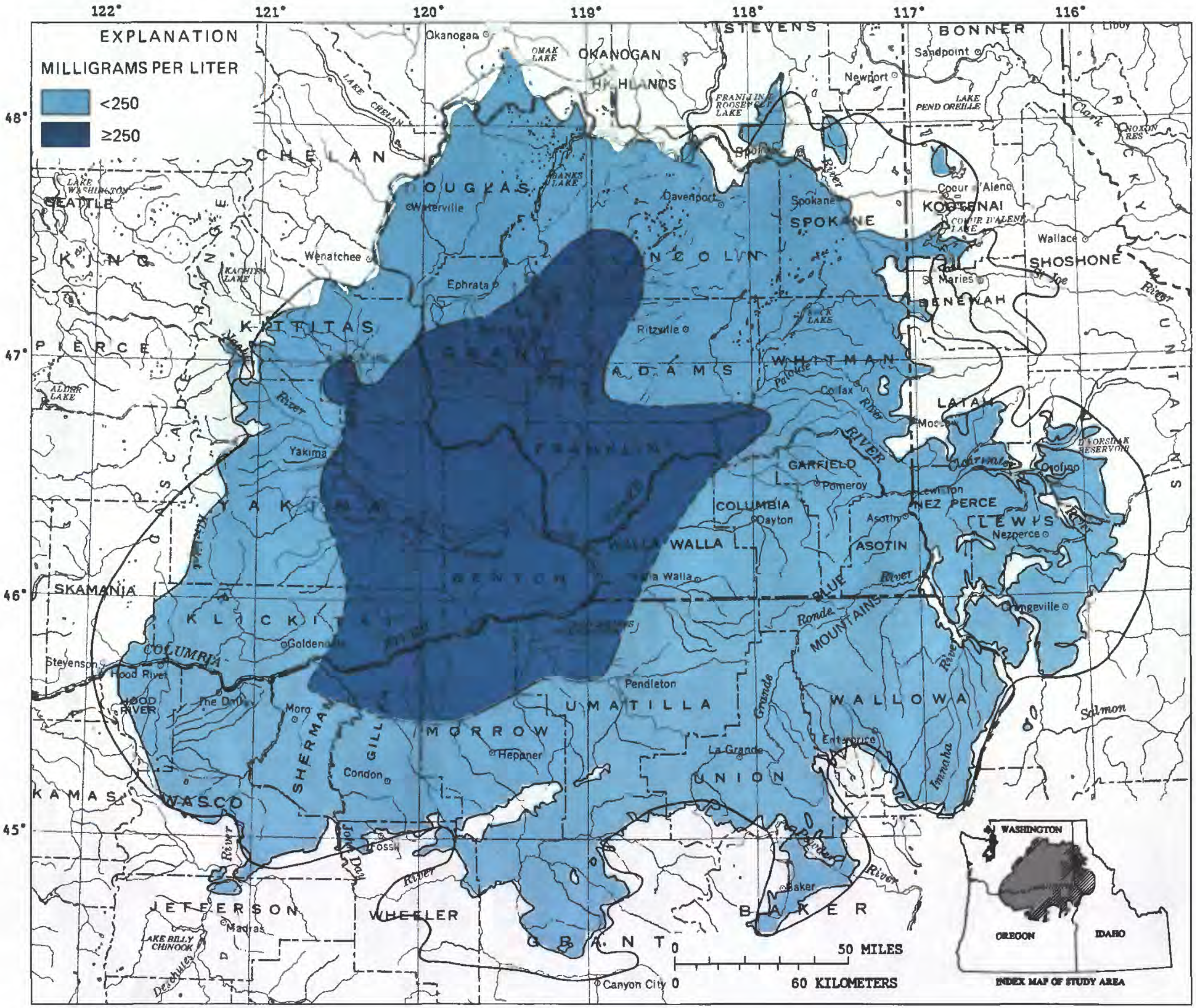


Figure 25.--Water types in the Grande Ronde unit, 1982-1983.



Base from U.S. Geological Survey
State base map, 1:500 000

Figure 26.--Calculated dissolved-solids concentrations in the Grande Ronde unit, 1982-1983.

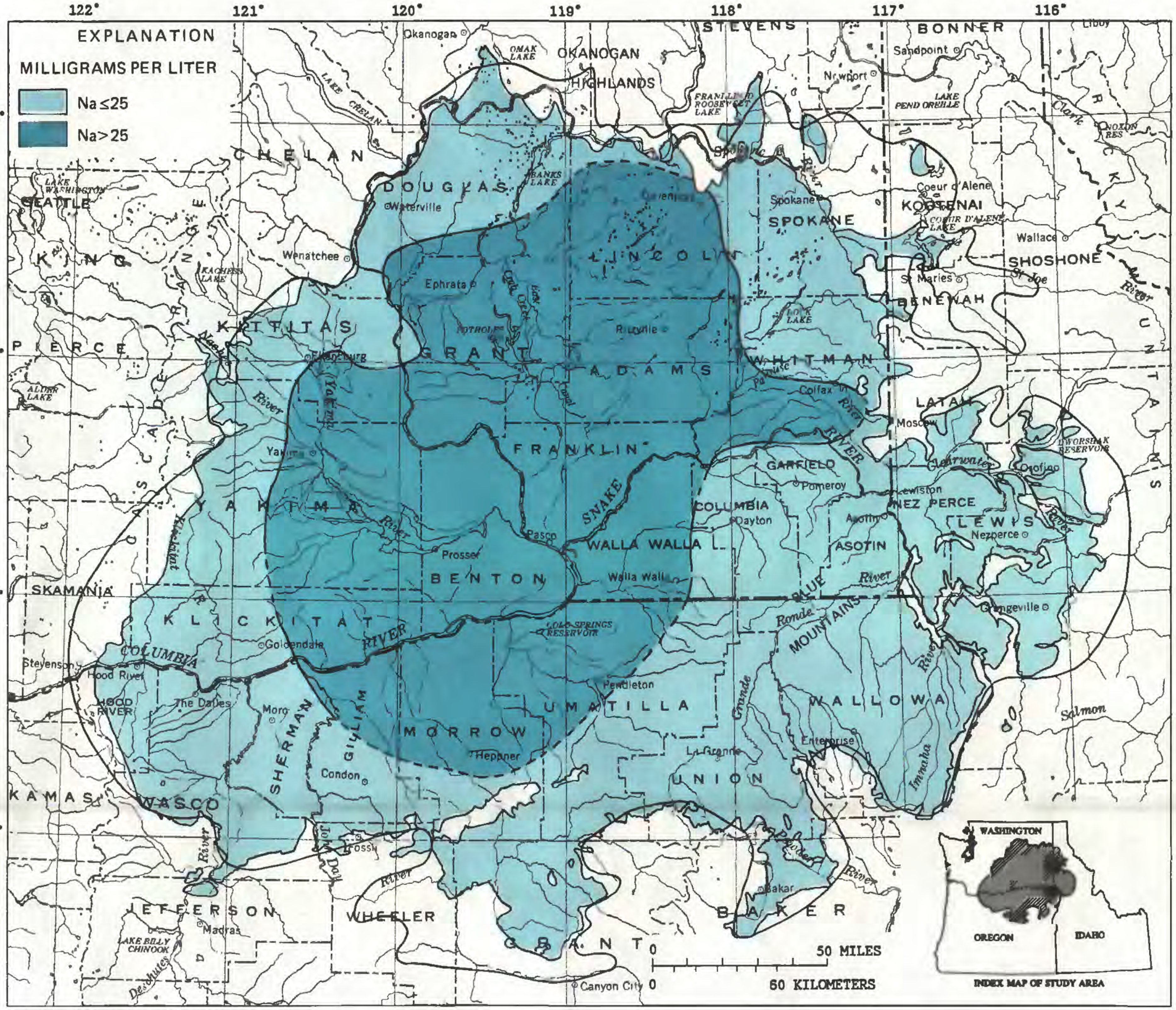


Figure 27.--Sodium concentrations in the Grande Ronde unit, 1982-1983.

SUMMARY

A total of 824 ground-water samples collected from 1982 through 1985 from about 350 wells were analyzed for water-quality characteristics as part of the Columbia Plateau regional aquifer system study. The wells are in three Miocene basalt units of the Columbia Plateau regional aquifer system--the Saddle Mountains, Wanapum, and Grande Ronde units. These units are the principal geohydrologic units of the aquifer system. The water-quality characteristics of the fourth aquifer unit of the aquifer system, the unconsolidated sediments which overlie the basalts, were not analyzed in this report. The analysis consisted of describing the water-quality characteristics of the three units by mapping areal distributions of selected water-quality characteristics and discussion and comparison of the analytical data and the distributions. The analytical data used in preparing this report are average or single values of the results of analyses of one to three individual samples. The data indicate that ground water in the basalts generally is of good quality and is suitable for most uses. The chemical composition of water in the shallowest unit is predominantly calcium-magnesium bicarbonate in type and evolves toward sodium bicarbonate type in the deepest unit. Calcium-magnesium sulfate-chloride waters occur less commonly and are associated with water in shallow wells, areas with thin or no overburden cover, and areas under agricultural land use. Dissolved-solids concentrations in ground water generally are less than 500 mg/L.

A statistical relation between specific conductance and calculated dissolved-solids concentrations, useful for estimating dissolved-solids concentration from specific-conductance data, was developed for waters from all of the basalt units. The major dissolved species in the ground water are sodium, calcium, magnesium bicarbonate, silica, sulfate, and chloride. The largest observed mean concentrations were for bicarbonate (166 mg/L), silica (52 mg/L), sodium (40 mg/L), calcium (31 mg/L), and sulfate (30 mg/L). Dissolved-oxygen concentrations ranged from about 0.1 to 11 mg/L, whereas nitrate-plus-nitrite concentrations ranged from about 0.1 to 54 mg/L. The mean temperature of the ground water is about 17 degrees Celsius, but ranges from about 6° to 43° Celsius.

The Saddle Mountains unit is the shallowest and least extensive unit in the regional geohydrologic system. Calcium and magnesium are the dominant cations and bicarbonate is the dominant anion. As such, calcium-magnesium bicarbonate waters are most abundant and reflect a less geochemically evolved water type. Sodium bicarbonate waters are usually found downgradient in the flow system, adjacent to the Columbia River, and in the deepest wells sampled. Calcium-magnesium sulfate-chloride waters generally occur where dissolved-oxygen concentrations are greater than 5 mg/L, where the overburden is less than 100 feet thick, and where surface-water irrigation occurs. This indicates that these waters, or at least a part of them, were recharged recently and that quality of these waters is influenced by land-use activities and by the absence of a thick overburden. The mean dissolved-solids concentration for 131 samples is 340 mg/L; however, waters near the discharge locations generally have higher values and reflect a larger residence time in the aquifer system. Dissolved-sodium concentrations increase in a downgradient direction in a manner similar to that of dissolved solids. Dissolved nitrogen species, and to a lesser extent sulfate, concentrations are also influenced by overburden thickness and land use.

The distribution of water types in the Wanapum unit, which underlies the Saddle Mountains unit, appears to be affected by the same factors as that of the Saddle Mountains unit. The dominant water type is calcium-magnesium bicarbonate, followed by sodium bicarbonate and calcium-magnesium sulfate-chloride. Sodium bicarbonate waters occur in deeper wells and in downgradient locations, and calcium-magnesium sulfate-chloride waters are associated with thin overburden, shallow wells, and dissolved-oxygen concentrations greater than 4 mg/L.

The mean dissolved-solids concentration (410 samples) of water in the Wanapum unit is 270 mg/L and ranges from 69 to 1,100 mg/L. Larger concentrations of dissolved solids generally occur in areas irrigated with surface waters and in areas where the water-level altitudes in the Grande Ronde unit are higher than those in the Wanapum unit. Similarly, sodium concentrations greater than 25 mg/L occur in downgradient and discharge areas. High nitrogen concentrations occur mostly in the central part of the plateau, and are associated with wells that have depths less than 300 feet and that are in areas with a thin or no overburden.

The Grande Ronde unit, which underlies the Wanapum unit, has water that is dominantly calcium-magnesium bicarbonate in type and has sodium bicarbonate water in downgradient areas and in the central plateau near the Columbia River. The waters from this unit have the lowest mean dissolved-solids concentrations (234 mg/L); most nitrogen concentrations are less than 2 mg/L.

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