OREGON GROUND-WATER QUALITY AND ITS RELATION TO HYDROGEOLOGIC FACTORS ---A STATISTICAL APPROACH

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CONTENTS

ILLUSTRATIONS

TABLES

OREGON GROUND-WATER QUALITY AND ITS RELATION TO HYDROGEOLOGIC FACTORS - A STATISTICAL APPROACH

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ABSTRACT

An appraisal of Oregon ground-water quality was made using existing data accessible through the U.S. Geological Survey computer system. Currently, these data represent a majority of the computer accessible ground-water quality data for Oregon. The U.S. Geological Survey data available for about 1,000 sites were separated by aquifer units and hydrologic units. Selected descriptive statistics are given for 19 constituents including major ions. Analyses of hazardous substances (complex organics and metals) are generally not available as part of this data set, but a small number (less than 50) of samples were analyzed for lead or mercury. About 96 percent of all sites in the current U.S. Geological Survey data base were sampled only once, thus eliminating the opportunity to determine time trends. The sample data were classified by aquifer unit and hydrologic unit, and analysis of variance was run to determine if significant differences existed between the units within each of these two classifications for the same 19 constituents on which descriptive statistics were determined. Results of the analysis of variance indicated both classification variables performed about equally well in grouping samples into distinctive subsets, but the aquifer unit classification provided a better opportunity to explain the statistical results because these units are related to the lithology. Therefore aquifer unit classification is a more useful tool in relation to ground-water quality variation.

Samples from the Rogue River basin were classified by location within the flow system and the type of flow system. The samples were then analyzed using analysis of variance on 14 constituents to determine if there were significant differences between the subsets classified by flow path. Results of this analysis were not definitive, but classification as to the type of flow system did indicate potential for segregating water-quality data into distinct subsets.

INTRODUCTION

For years, ground water has been considered an excellent source of potable water, less susceptible to contamination than surface waters. This public perception has changed in recent years with the recognition of ground-water sites, such as the Love Canal in New York, that have been contaminated by hazardous waste. Concurrent with this new concern about ground-water contamination has been a rapid increase in ground-water use. Solley and others (1983), indicate a 22 percent increase in ground-water withdrawals in the United States between 1970 and 1975, and a 7 percent increase between 1975 and 1980. According to Solley and others (1983), about 95 percent of all rural domestic water and 35 percent of public-supplied fresh drinking waters are obtained from ground-water sources.

In Oregon, about 30 percent of the public-supplied fresh water and about 85 percent of the rural domestic water come from ground-water sources (Solley and others, 1983; Murray, C. R., and Reeves, E. B., 1977). Because many of the wells in Oregon are shallow lowland wells in alluvial deposits, they may be particularly susceptible to contamination from surface sources. Potential sources of ground-water contamination include natural sources such as elements dissolved from rock and soil, and man-made sources such as landfills, hazardous waste disposal sites, agricultural products including fertilizers and pesticides, and subsurface sewage disposal systems. The naturally-occurring contaminants that have been detected locally are arsenic, iron, and high concentrations of dissolved solids (saline water); recognized man-induced contaminants are nitrate and some organic compounds.

Purpose

This report summarizes Oregon ground-water quality conditions and determines if these conditions are related to hydrogeologic factors. The summary and analysis was done as part of the U.S. Geological Survey's national program to assess the impact of hazardous wastes on ground-water quality. Data are related to aquifer units, hydrologic units, and flow systems in an attempt to explain variations in the data. Areas where known natural or man-induced causes have affected ground-water quality are identified.

Scope

In order to produce results quickly, only existing data were used; no new data were collected. The requirement for the statistical analysis and mapping was that the data be computer accessible. No attempt was made to use data not accessible to the Geological Survey Oregon District computer.

Approach

Oregon's ground-water quality was appraised by using descriptive statistics computed from computer accessible data contained in the Geological Survey National Water Data Storage and Retrieval System (WATSTORE). Ground-water quality variations were explained by assigning water samples to a geologic unit source and these units were grouped into broader aquifer units. The aquifer units were used as class variables in an analysis of variance. Samples also were assigned hydrologic unit codes (drainage basin source) and similar statistical analyses were performed using hydrologic units as class variables.

One basin was singled out for application of an analytical approach dependent on the ground-water flow system. In the Rogue River basin, sites were classified according to type of flow system (local, intermediate, regional, or unknown), and according to position within a flow system (recharge area, intermediate area, discharge area, or unknown area). Analysis of variance was then used to determine whether these designations helped explain observed variations of the ground-water quality.

Indication of man's impact on ground-water quality was provided by an Oregon Department of Environmental Quality (DEQ) summary (1980) of areas with identified water-quality problems. The Geological Survey data were examined to see if the accessible data could substantiate identified problem areas, and to determine if analyses had been done for hazardous substances (complex organics and metals).

INFLUENCES ON GROUND-WATER QUALITY IN OREGON

Natural Factors

Some of the obvious factors that influence ground-water quality are: the chemical composition and physical characteristics of precipitation; the mineral and organic composition of the soils and rocks; the quantity and type of gasses present; and the pH and temperature in the host environment. Other natural factors that impact ground-water quality are climate, physiography, geology and flow system geometry (fig. 1); brief discussions of some of these factors are presented below. More detailed discussions can be found in Freeze, R. A. and Cherry, J. A. (1979).

Most ground water originates as precipitation (fig. 2) which has infiltrated through a soil zone and eventually reaches a flow system in the subsurface. As this meteoric ground water moves from the recharge area to a discharge area it reacts with organic material and rocks in the subsurface and is chemically altered through a variety of geochemical processes.

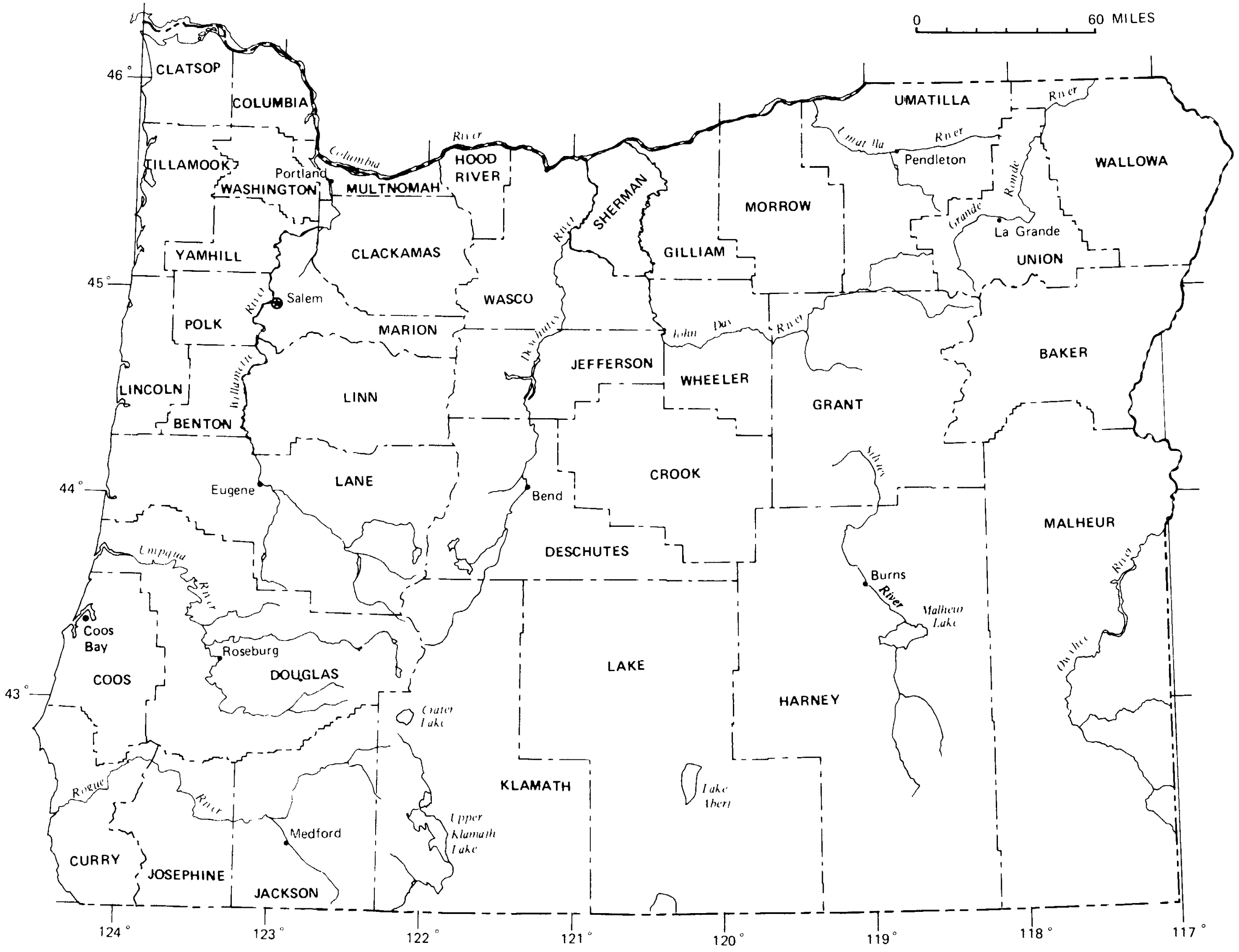


Figure 1.--State of Oregon.

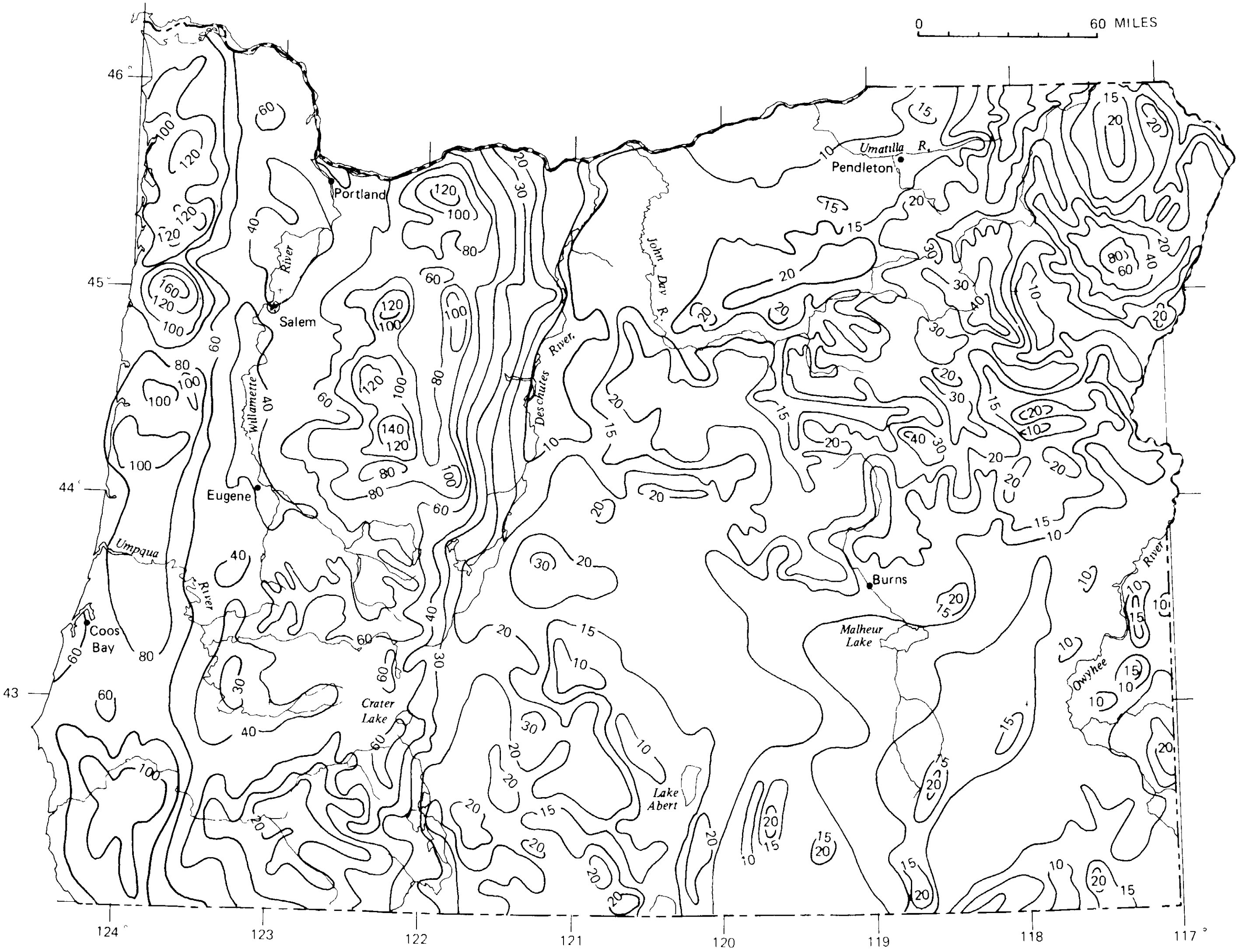


Figure 2.--Mean annual precipitation 1930-57.

Some ground waters originate as water trapped in the formations at the time of deposition. This water, referred to as connate ground water, could be the source of some saline ground waters found in areas underlain by marine formations in western Oregon. Connate water is gradually being flushed from low-permeability marine formations by fresh meteoric ground waters circulating at shallow depths through these same formations.

In simple ground-water flow systems, that is, systems consisting of geologic materials that do not vary appreciably in permeability or in mineral composition with depth, the ground water should be characterized by higher concentrations of dissolved solids with increased depth in a flow system. This occurs because ground water, which has moved further along the flow path, generally has been in the flow system longer. Consequently, the deeper water has had more time to react chemically with the minerals and environment in the host rocks.

The highest concentrations of dissolved solids in a particular flow system generally will be found in the discharge area of that system, an area where all flow lines from different systems, deep and shallow, tend to converge within a relatively narrow distance. The convergence of flow lines in the discharge area may result in wide dissolved solids variation between wells that are geographically close but tap different systems.

In complex ground-water flow systems, waters of more than one chemical type may be found in discharge areas. The chemical type indicates the major (greater than 50 percent of the milliequivalents per liter) cations and anions, such as calcium bicarbonate and sodium-chloride type waters. This may be due to the merging of ground waters of different chemical composition derived from cross-formational flow between different geologic formations within the flow system.

Because the topography in Oregon is generally characterized by high local relief, the authors believe that most of Oregon ground-water flow system boundaries coincide with the overlying surface-water drainage basin boundaries. This implies that most ground water infiltrates the subsurface and eventually is discharged downgradient to surface water within the same basin. The length of time for ground water to move from the point of recharge to the point of discharge may range from a few days to several millenia depending upon the length and character of the flow path. The water may pass through several different formations or rock types. Reaction of the water with solutes in the unconsolidated material or reaction with consolidated rock will gradually change its composition. Coincidence of the surface-water basin boundaries with ground-water flow system boundaries at the subregional hydrologic unit level (fig. 3) allowed use of hydrologic unit as a classification variable for statistical analyses.

The selected Oregon hydrologic unit boundaries shown on figure 2 are the surface-water drainage divides which generally include several major surface-water subbasins; therefore, within each of the hydrologic units there may be many separate ground-water flow systems.

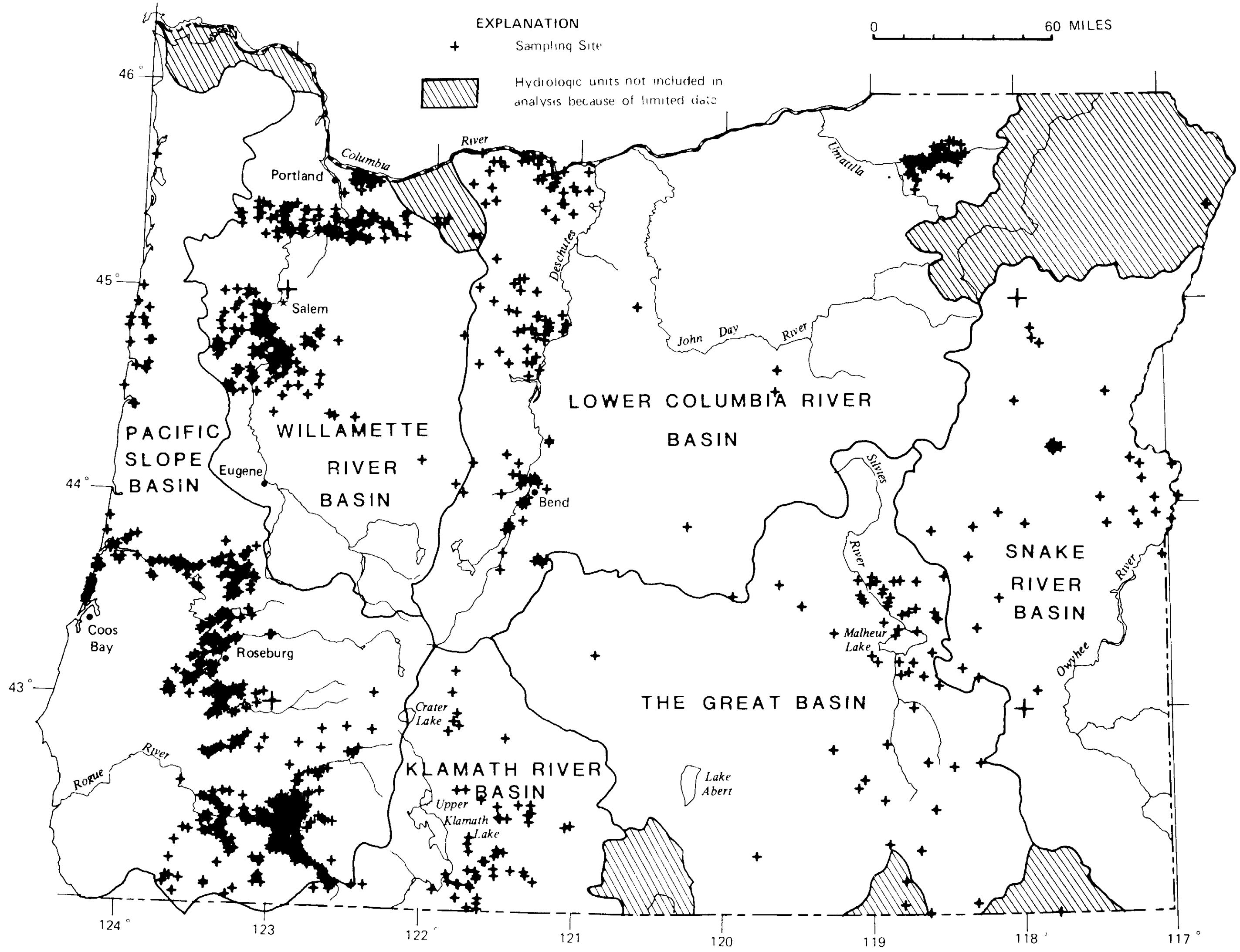


Figure 3.--Location of surface-water divides (hydrologic units) and sampling sites for all WATSTORE data used in this study.

The above concept of Oregon ground-water flow systems probably is most accurate in regions similar to the Coast Range or the western Cascades which have naturally eroded, have large local relief, and are underlain by low permeability formations to great depths. In both regions, surface drainage basins as small as a few square miles probably are underlain by similar sized ground-water flow systems. These systems are characterized by areas of local, intermediate, and regional flow each with recharge and discharge areas.

The boundaries of ground-water flow systems in Oregon are least likely to conform with overlying surface-water basins in the High Lava Plains of central Oregon (fig. 4), an area with small local topographic relief underlain by formations having extremely variable permeability. It is believed that in this area the major ground-water flow systems are at least several hundred square miles in extent, having boundaries that do not conform exactly with the overlying surface-water drainage basins. In places, ground-water underflow between adjacent basins occurs.

Another region where ground-water flow system boundaries may not conform with the overlying surface-water drainage basin boundaries is the High Cascades (fig. 4). The High Cascade Range is a poorly dissected plateau-like mountain range dominated by several strato volcanoes and underlain by thick basaltic and andesitic lavas, and pyroclastic debris. Recharge to the ground-water system is large, principally by direct infiltration of snowmelt runoff. Because of the great local variation in permeability of the volcanic rocks, flow paths and directions are complex, and subsurface underflow between small and medium sized drainage basins probably is large. Several major springs dot the region and most of the ground water is eventually discharged to the Klamath and Deschutes River basins on the east or to western Oregon streams.

Ground-water pumpage from the Columbia River Basalt Group, in portions of the Deschutes-Umatilla Plateau (fig. 4), probably has significantly altered the positions of the ground-water basin boundaries from their natural predevelopment location. In that region some ground-water flow system boundaries therefore differ from the overlying surface-water basin boundaries because they have been altered by man's development of the aquifer system.

Folding and faulting of geologic formations can markedly affect the directions of ground-water flow. Folds and faults form barriers to flow or compartmentalize flow systems, and thereby indirectly affect ground-water quality. The tectonic map (fig. 5) shows the major geologic structures in the State.

In southeastern Oregon, the arid climate and the closed topographic basins of the Basin and Range region combine to create conditions where evaporation has resulted in the deposition of thin, soluble evaporite beds or concentrations of salts in shallow saline lakes in the numerous playas dotting the region.

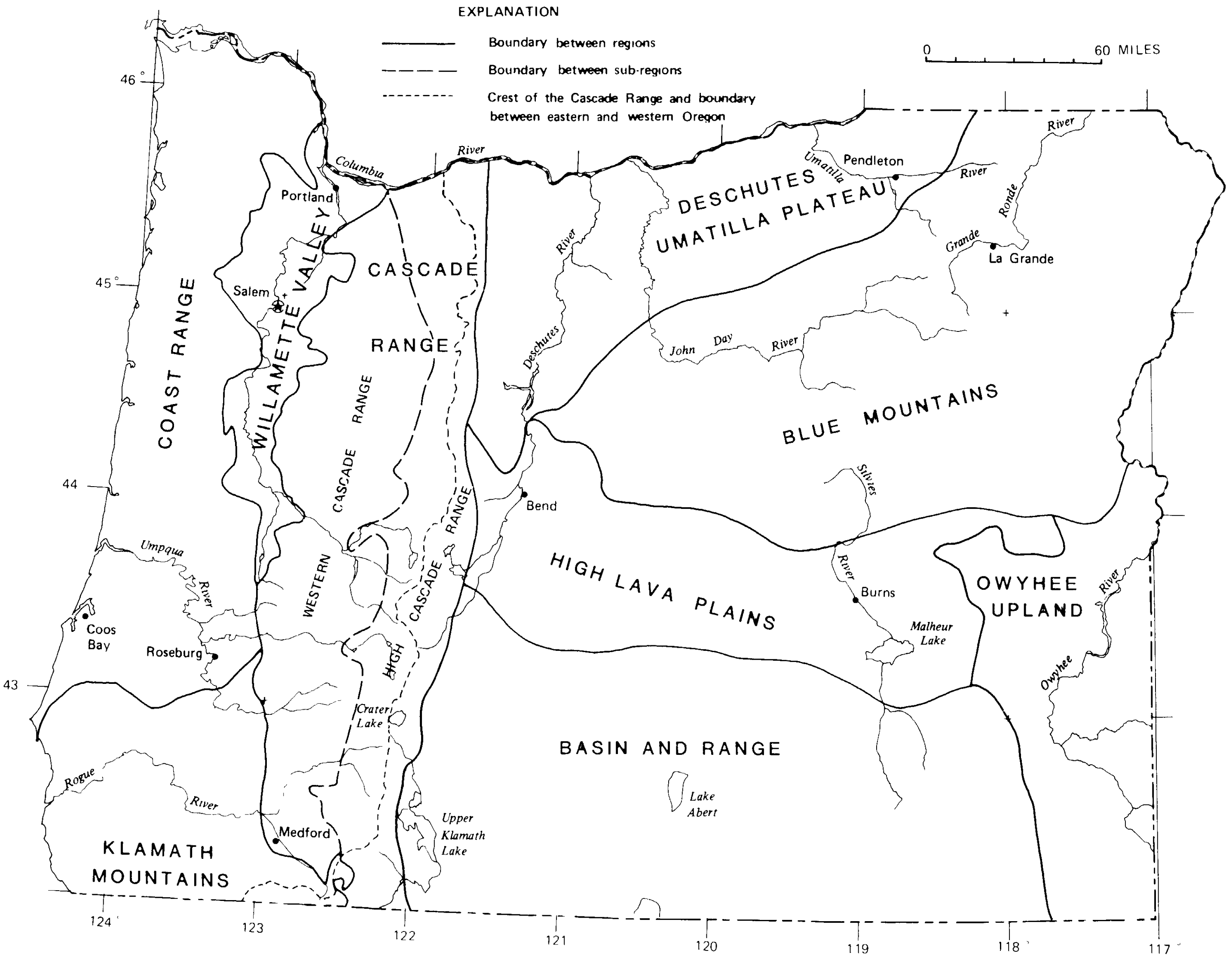


Figure 4.--Physiographic regions of Oregon (modified from Dicken, 1950).

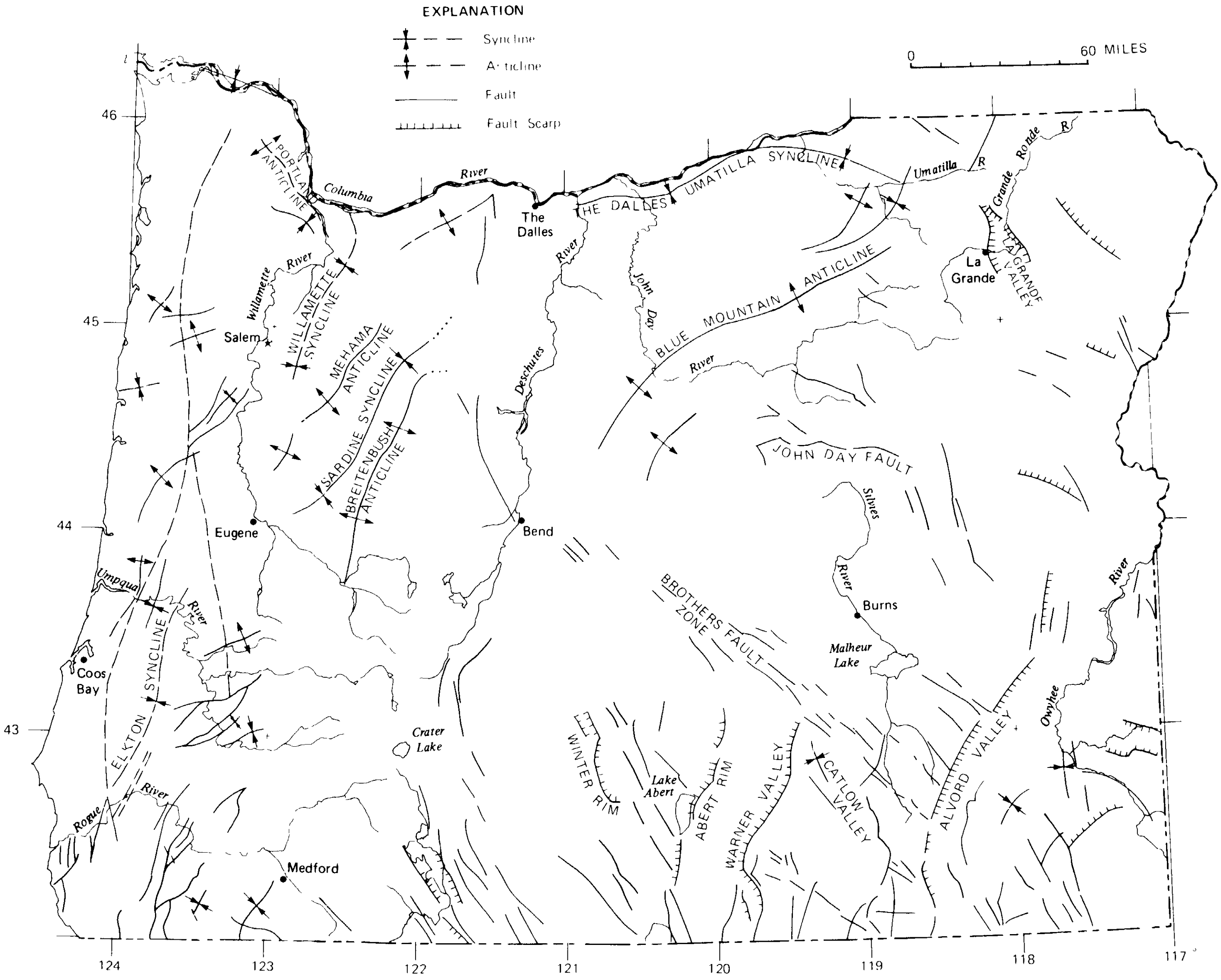


Figure 5.--Major tectonic features of Oregon (modified from Walker, 1977; Wells and Peck, 1961).

Man's Activities

The chemical quality of ground water can be altered directly or indirectly by man's activities and land-use practices. Such activities may include silviculture; construction; mining; agriculture; irrigation; industrialization; urbanization; injection of liquid wastes; burial of solid wastes and domestic wastes; application of fertilizers, herbicides, and pesticides; construction of waste lagoons, tailing piles, canals, and pipelines.

In addition to these types of activities, man can also alter ground-water flow patterns with ground-water pumpage or injection of liquids into the subsurface. These activities may result in the mixing of natural ground waters of different chemical composition or the addition of liquids that can improve or degrade ground-water quality. Pumping ground water can also induce flow from overlying or underlying aquifers or from surface waters. One example of this latter type of process is saltwater intrusion in coastal aquifers.

Man's influence on ground-water quality has been indentified and documented by the DEQ in several areas. The DEQ (1980) has described the following areas as having contamination problems:

(1) Clatsop Plains in coastal Clatsop County -- The DEQ sampled wells in the area between 1969 and 1976. Though most wells had nitrate (as N) concentrations below 10 mg/L, there appeared to be a correlation between nitrate concentrations and housing density.

(2) East Multnomah County -- Water from wells in unsewered areas in the central part of the county have nitrate levels considerably higher than water from wells in sewered areas. Higher nitrate concentrations were found in shallower wells.

(3) River Road - Santa Clara, Lane County -- Subsurface sewage-disposal systems are suspected of degrading water quality in a shallow aquifer.

(4) La Pine, Deschutes County -- Degradation of shallow aquifers by suspected subsurface sewage disposal. A limited number of samples show high nitrate concentrations.

(5) Milton-Freewater, Umatilla County -- A sand and gravel operation utilizing wash-water disposal ponds caused increased turbidity in downgradient domestic wells.

(6) La Grande, Union County -- Owners of shallow domestic wells have complained of oil contamination. Sources of contamination are dry wells receiving storm water from shopping areas, subdivisions, and railroad refueling facilities.

(7) Turner, Marion County -- A lumber company disposed of wood waste in an abandoned gravel pit. Leachates from the pit caused contamination of downgradient domestic wells. Lignin - tannin concentrations were as high as 7.5 mg/L, and the organic acids caused iron and manganese concentrations to be as high as 13 mg/L and 106 mg/L, respectively.

These examples are some of the known and documented contamination problems that have resulted from different land-use activities. In almost every case, the greatest impact has been on ground waters in shallow alluvial deposits.

HYDROGEOLOGY

Most geologic formations in Oregon are capable of yielding at least small quantities of potable water to wells provided the formation is saturated and sufficiently thick. Recently, McFarland (1982) and Gonthier (in press, 1984) have grouped geologic units in Oregon into ten principal aquifer units. Each principal aquifer unit generally includes a few to several separate geologic formations that are logically grouped according to similarities in lithologic, hydrogeologic, and geologic characteristics. Water wells in most of Oregon average less than 200 feet in depth and they tend to exhibit a clumpy areal distribution; consequently, in many parts of the State there is little hydrogeologic information for most geologic formations.

The major aquifer units delineated by McFarland (1982) and informally named in western Oregon are the; Mesozoic-Paleozoic rocks of the Klamath Mountains, Tertiary marine rocks of the Coast Ranges, Columbia River Basalt Group, Tertiary volcanic rocks of the Western Cascades, Quaternary-Tertiary volcanics of the High Cascades, and Quaternary-Tertiary sedimentary rocks. East of the crest of the Cascade Range in eastern Oregon, Gonthier (in press, 1984) similarly grouped the geologic units into the: Igneous and metamorphic aquifers; Older volcanic aquifers; Basalt aquifers; Volcanic and sedimentary aquifers; Sedimentary aquifers; and the Basin-fill alluvial aquifers. McFarland's Columbia River Basalt Group unit and Gonthier's Basalt aquifers in the north half of the State are stratigraphically equivalent. In the southeastern corner of the State, geologic units included Gonthier's Basalt aquifer are probable time equivalents, but are not as uniform lithologically as they are in the north. The Volcanic and sedimentary aquifers and the Quaternary-Tertiary volcanics of the High Cascades are also more or less equivalent stratigraphically and lithologically. Tables 1 and 2 give a general description of each aquifer in western and eastern Oregon, respectively. Table 3 summarizes physiographic information for these regions.

Table 1.--Aquifer units of western Oregon

[Modified from McFarland, 1982]

Aquifer unit	Lithologic description	Exposure	Water-bearing characteristics
Quaternary-Tertiary Sedimentary deposits (I)	Sand, gravel, and silt, unconsolidated to consolidated; some weathered basalt and pyroclastic rocks are also included.	Alluvium occurs along streams and rivers, most extensively in the Willamette Valley. Beach and dune sand occur along the Pacific coast, and volcanic rocks are localized around source vents near Portland.	Permeability generally high; however, less permeable fine material is commonly interlayered with good aquifers. Wells yield more than 2,000 gal/min in some areas, but average less than 300 gal/min. Most productive aquifer unit in western Oregon.
Volcanic rocks of the High Cascade Range (II)	Andesite and basalt, flow and pyroclastic rocks.	Form the crest of the Cascade Range.	Largely unknown. Available data indicate variable permeability. Well yields range from a few gallons per minute to 300 gal/min. Springs issuing from the unit are commonly large.
Volcanic rocks of the Western Cascade Range (III)	Andesite, basalt, and dacite; older rocks are dominantly volcaniclastic and younger rocks are almost entirely flow material.	Form the western slope of Range.	Permeability is generally low; however, fracturing may form localized permeable zones. Well yields may reach 100 gal/min, but average less than 20 gal/min.
Columbia River Basalt Group (IV)	Basalt; distinctive columnar jointing and fractured interflow zones.	Crops out along the western and eastern edges of the northern Willamette Valley and along the Columbia River as far west as the Pacific Ocean. Forms Structual basins beneath the northern Willamette Velley.	Overall permeability low, but interflow zones and scoriaceous flow tops are relatively permeable. Dense, poorly permeable flow centers may limit recharge. Yields may exceed 1,000 gal/min, but are typically less than 100 gal/min.
Marine rocks of the Coast Range (V)	Sandstone, siltstone, and mudstone, commonly tuffaceous; intrusive rocks.	Marine sedimentary rocks form most of the Coast Range. Marine volcanic rocks are abundant in the northern part of the range. Intrusive rocks form some of the highest peaks in the Coast Range.	Permeability low. Well yields are generally less than 10 gal/min.
Granite saprolite of the Klamath Mountains (VI)	Saprolite derived from granite intrusive rocks; degree of weathering variable.	Saprolite occurs most extensively near Grants Pass, Oregon and Evans Creek in the Klamath Mountains. Extent of weathering variable. Granitic rocks crop out as irregular masses throughout the Klamath Mountains.	Permeability is high relative to surrounding geologic units. The quantity of water available is dependent on the extent of weathering and fracturing. Wells may yield as much as 50 gal/min.
Mesozoic-Paleozoic bedrock of the Klamath Mountains (VII)	Sandstone, siltstone, graywacke, conglomerate, and shale with some andesitic flows, agglomerate, and tuff. Metasedimentary and metavolcanic rocks are common.	Underlie entire Klamath Mountain area, with the exception of the saprolite mentioned above.	Permeability is low. Well yields are typically less than 10 gal/min.

Table 2.--Aquifer units of eastern Oregon

[Modified from Gonthier, 1984]

Aquifer unit	Lithologic description	Exposure	Water-bearing characteristics
Basin-fill and alluvial aquifers	Clay, silt, gravel, pumice, ash, diatomite, some evaporite and basalt; unconsolidated to semiconsolidated. Includes alluvial lacustrine aeolian, pyroclastic, and pediment deposits. Not readily differentiated from older Cenozoic versus playa deposits (Qp) included.	Delineated in south half of area where it underlies and outlines floors of structual and topographic basins of the Basin and Range region (fig. 4). Lowest parts of some basins have playas where soluble evaporite deposits may have accumulated.	Beds of sand, gravel, cinders or porous basalt interflow zones are highly permeable and are excellent aquifers. Major aquifer unit in Harney Basin, Fort Rock-Christmas Valley, Klamath Falls and Lakeview areas.
Sedimentary aquifers	Clay, silt, sand, gravel, conglomerate, pumice, pyroclastic deposits some basalt and andesite. Unconsolidated to consolidated. Include alluvial, lacustrine, aeolian, glacial and pyroclastic debris deposits.	Mapped in north half of area in Deschutes-Umatilla Plateau where it generally overlies Columbia River Basalt Group. In northeast Oregon near Flora some unsaturated basalt of the Columbia iver Basalt Group is included in unit.	Significant aquifer unit where extensive saturated coarse grained deposits are present. Hydraulic connection with overlying surface water generally excellent. Good aquifer in Hermiston-Boardman area, Milton-Freewater, Grande Ronde Valley, Baker Valley, Enterprise, Tygh Valley and Prineville.
Volcanic and sedimentary aquifers	Basalt, andesite, tuff, tuffaceous sediments, clay, silt, sand, gravel, diatomite, pyroclastic, deposits and intrusive rocks. Unconsolidated to consolidated. In uplands such as Cascades flow rocks predominate whereas in lowlands volcaniclastic materials generally are predominant.	High Cascades and southern half of area. Includes rocks derived from numerous volcanic vent systems. Individual deposits commonly local to subregional in extent.	Significant aquifer unit, especially in structural and topographic basins where this unit and overlying Qs are present and hydraulically interconnected.
Tcr - Basalt aquifers	Basalt and basaltic andesite, some sedimentary interbeds, tuff and flow breccia. In southeastern Oregon unit also includes rhyolite and dacite flows and breccia.	In southeastern quarter of area several formations, probable equivalents of the Columbia River Basalt Group of northern Oregon, are included in this unit.	In northeastern Oregon the Columbia River Basalt Group is a major interstate regional aquifer system. In Morrow and Umatilla Counties pumpage for irrigation has resulted in regional water level declines. Largely undeveloped in remainder of area.
Tjc - Older volcanic aquifers	Andesite and dacite flows, breccia and volcaniclastic rock; tuffaceous mudstone, siltstone, sandstone and conglomerate, rhyolitic to dacitic tuffs. Semi-consolidated to consolidated.	Central part of area, Blue Mountains, Lakeview area. Paisley Hills, Alvord Valley. Exposures mapped as Tcj in southern part of area are probably equivalent to Clarno-John Day Formation of Central Oregon.	Generally a poor aquifer unit capable of yielding small amounts of water suitable for domestic or stock use.
Igneous and metamorphic aquifers	Sediments, volcanic and igneous rocks; mostly metamorphosed. Large variety of rock types and numerous separate formations.	Blue Mountains, Wallowa Mountains, Snake River Canyon and Pueblo Mountains.	Generally a poor aquifer unit capable of yielding small quantities of water. Largely unused because it outcrops only in sparsely populated mountainous terrain.

Table 3.--Summary of features of physiographic regions of Oregon

Physiographic subdivisions	Landforms	Altitude (range and feet)	Relief (local) feet	Rock types	Geologic structures	Vegetation cover	Boundaries of subdivision
Coast Range	Maturely dissected humid low mountains	Max 4,098 Min 0 Avg crest 1,475	Typical 650	Tertiary marine sediments, siltstone, sandstone, some shale, submarine basalt.	Gently folded anticlinorium, locally faulted.	Heavily forested	Willamette Valley, Coastal lowlands and Pacific Ocean.
The Willamette Valley	Broad alluvial plain in southern part. Plains in northern part cut by gently rolling hills.	Max 394 at southern end, slopes gently northward to less than 30	Local 15 160 to 330 at margins	Unconsolidated to to semiconsolidated alluvium underlain by sandstone and mudstones. Some basalt included in northern half of valley.	Large structural basin in south; north part can be subdivided into at least four subbasins separated by narrow anticlinal ridges.	Farmlands, mostly small grains.	Foothills of Coast Range and western Cascades Range.
Klamath Mountains	Rugged maturely dissected humid mountains, ridges trend northeast to southwest.	Max 7,530 Min 0	Local 1,900 to 4,900	Mesozoic igneous, volcanic and sedimentary rock, mostly metamorphosed, some granite and alluvium.	Bedrock units are steeply dipping and cut by major west dipping thrusts.	Heavily forested.	Merge gradually with Coast Range and with western Cascades in north and northeast. Boundary with Cascades at south is abrupt.
Cascade Range	Rugged north-south volcanic range subdivides Oregon into east and west parts. Western Cascades are maturely dissected. High Cascades are have several young strato-volcanoes that rise above an undissected rolling lava covered platform.	Max 11,235 general level 2,950 to 4,900	Western Cascades 650 to 1,600 High Cascades 4,900 and more locally	Western Cascades have Tertiary volcanic rocks including andesite and basalt with tuff and agglomerates hydrothermally altered. High Cascades are mostly Cenozic volcanic and pyroclastic rocks of andesitic and basaltic composition.	Western Cascades are gently folded, locally faulted. High Cascades appear to be major graben, filled with lava and pyroclastic rocks. Rocks dip away from source vents.	Western Cascades are heavily forested. Highest peaks are above timberline. Forests are less dense on eastern slopes which receive smaller precipitation.	Abrupt topographic break with Willamette Valley. Mature topography contrasts sharply with higher less dissected High Cascades. Boundary of High Cascades with eastern physiographic provinces are neither sharp nor distinct in east central edge of High Cascades.
Deschutes-Umatilla Plateau	Plateau slopes gently northward and is deeply dissected at irregular intervals by north flowing streams.	Max 2,950 Min 330	Local relief low except in deep canyons where it may reach 980 or more	Basalt with alluvial cover in lowland basins some sedimentary interbeds also present in basalt.	Dips gently northward, cut by numerous normal faults and joints, a few low angle small displacement thrusts and gentle folds.	Mostly grasslands and croplands with grazing lands in steeper dissected valley.	Blue Mountain anticline on south, but east part is dissected plateau and considered part of Blue Mountains.
The Blue Mountains	Includes deeply dissected plateaus, alluvial basins, rugged mountains; generally is steeply sloping.	Max 9,840 Min 1,300 general 3,200	4,900 and more	Metamorphosed Mesozoic-Paleozoic volcanic and sedimentary rock, platonic rocks, andesite, basalt, tuff, and agglomerate. Valley fill sediments and alluvium.	Mesozic-Paleozoic rocks are mostly highly folded and faulted, younger units are gently folded or flat-lying.	Highest areas are above timberline; open forest and grasslands cover remainder.	Boundaries of region are poorly defined topographically except at south edge along High Lava Plains.
The High Lava Plain	Plain broken by low buttes or low fault scarps. Few perennial streams.	Max 7,986 Min 3,280	Small 320 to 1,000	Cenozic volcanics, pyroclastics and sediments. Mostly andesitic and basaltic minor acidic volcanics. Many volcanic vents present.	Flat to gently folded and broken by numerous northwest trending en echelon normal faults and vents. Region coincides with Brother's Fault Zone.	Forest covered at west edge, desert vegetation elsewhere.	West boundary merges gradually into High Cascades; south boundary not distinct due to gradual merging into basin and range landforms.
The Basin and Range	Long, narrow, asymmetrical ridges bounded by steep high fault scarps and bordered by flat-floored sediment filled basins and playas. Closed basins and internal drainages are common.	Max 8,850 Min 3,930	Local relief 3,200 to 4,900	Cenozoic volcanics pyroclastics, and sediments, some metamorphosed Mesozic rocks volcanic vents present. Basalt and andesite predominate in uplifted blocks.	Tilted block faulted ranges, gently dipping; gentle folds locally. Basin floors filled with flat lying sediments.	Some forested areas most is covered by desert vegetation.	North and east boundaries are not distinct; extends southward to Mexico.
The Owyhee Upland	Plateau, rough and uneven, locally deeply dissected.	Max 6,390 Min 2,100	Local relief in Canyons 950	Cenozic volcanics and sediments. Rhyolite and basalt common.	Gently folded southeast and northeast portions are more dissected than central.	Mostly sage and other desert vegetation	Boundaries indistinct except along Steens Mountain scarp.

The U.S. Geological Survey has adopted a policy for naming aquifers that discourages the use of formal rock-stratigraphic terms and geologic-age designations. Therefore, we have revised the informal aquifer names used by McFarland and substituted the following informal names for his units in this report. McFarland's Mesozoic-Paleozic rocks of the Klamath Mountains will be called the Igneous and metamorphic rocks of the Klamath Mountains; the Tertiary volcanic rocks of the western Cascade Range are changed to the Volcanic rocks of the western Cascade Range; the Tertiary marine rocks of the Coast Ranges are called the Marine rocks of the Coast Ranges; the Quaternary-Tertiary sedimentary rocks are referred to as the Basin-fill and alluvial aquifers; and the Columbia River Basalt Group will be called the Columbia River Basalt aquifer. Although these changes may result in confusion, it should be remembered that the names are strictly informal and that with future studies more formal aquifer names will be given, and their lateral and vertical boundaries more accurately defined. The maps that accompany this report show the extent and outcrop for each of the aquifers.

In western Oregon, the Igneous and metamorphic rocks of the Klamath Mountains, the Marine rocks of the Coast Ranges, and the Volcanic rocks of the western Cascade Range each consist of low-permeability rocks generally capable of yielding only small quantities of water to wells. These units are important aquifer units, however, because in the areas where they outcrop, they may be the only source of potable water available for domestic use by the rural population. The remaining units have permeable materials or zones interlayered with less-permeable rocks. In places, the permeable beds may be capable of yielding up to several hundred gallons per minute.

Similarly in eastern Oregon, the Igneous and metamorphic aquifers and the Older volcanic aquifers consist of low-permeability rocks; whereas, the remaining units contain some very productive layers within them.

The rocks at the surface in most of Oregon are Cenozoic age (Tertiary and Quaternary) formations derived from or consisting of andesite or basalt of volcanic origin. Of these two chemically similar and closely related mafic (dark colored) volcanic rocks, basalt probably is the more voluminous. Other types of Cenozoic igneous and volcanic rocks are found in the State, but they make up a relatively small percentage of the total volume of igneous rocks present. Areas of Oregon covered by older rocks also include large volumes of mafic igneous and volcanic rocks and the clastic rocks derived from them. As a consequence of this rather uniform composition of the rock, one would anticipate that the chemical composition of Oregon ground waters would also be relatively uniform or at least contain similar ionic ratios if mineral composition of the rocks is the major factor determining chemical composition of ground water. The trilinear diagrams presented later in the text support that supposition, with many samples having similar ionic ratios.

Marine sediments derived, in part, from Tertiary andesitic volcanic rocks in the Western Cascades were deposited in marine embayments located near the present Coast Ranges. They probably contained seawater when they were subsequently uplifted and partially eroded. These events have affected the evolution of the ground-water quality in these rocks.

Geologic-unit codes were established for 86 Oregon formations in the 1960s using a system devised for computer coding of geologic data by the American Association of Petroleum Geologists. The codes reflected the status of geologic mapping in Oregon at that time. New codes were not added as geologic mapping of the State improved until after this study began. Some earlier well-water samples collected for chemical analyses were probably assigned geologic formation codes that either did not fit the sample site precisely or, in some situations, may have been somewhat arbitrary. Assigned geologic unit codes were checked in the five areas of the state for which published Geological Survey data were added to the computer data base. About one-third of the earlier samples in those areas could be recoded with more specific codes than the general codes originally assigned. Insufficient time prevented checking assigned geologic codes for other samples.

GROUND-WATER QUALITY DATA BASE

Existing Data

The ground-water quality data base used in this report (limited to Geological Survey WATSTORE computer accessible data) is small when compared to data bases available for states such as California, Florida, or Arizona where ground-water pumpage is much greater. Table 4 indicates that the ground-water quality data base for Oregon has over 9,000 samples from more than 2,000 sites.

The Geological Survey ground-water data in Oregon consists of over 3,400 samples from more than 1,500 sites. Over half of the Geological Survey data have been computerized on WATSTORE and STORET. Many of the samples are from areas where areal ground-water appraisals have been done. The samples were generally analyzed for major ions, nutrients, physical properties, and some metals such as iron. The Geological Survey samples have not been analyzed for complex organic substances and few analyses were made for trace metals such as mercury or lead. In the Geological Survey computerized data base only 47 samples were analyzed for total phenols, and 18 samples for organic carbon.

Oregon DEQ also has a sizeable data base with almost 5,000 samples from over 450 sites. Much of these data have not been computerized, but will soon be entered into a computerized data base (Andrew Schaedel, oral commun., 1982). Many of the samples are from monitoring wells near sanitary landfills with some wells being sampled from multiple depths. Some samples came from areas of known contamination (DEQ 208 studies) and some are from wells near two hazardous waste sites. Generally the analyses are for major ions, nutrients, and physical properties, and few samples have extensive organic analyses.

Table 4.--Oregon ground-water quality data

Data source	No. samples/sites	Constituents	Condition of data	Remarks
USGS	1900+/1000+	110+ constituents including major ions nutrients and iron. Ionic balances can be calculated for about 590 samples.	These data have been stored on the Oregon USGS minicomputer.	These data are from many studies including areal appraisals, and some studies that were begun to examine areas of high arsenic or iron. The data used for analysis in this study were taken from this data set.
USGS	1500+/500+	About 100+ constituents. These data are generally older analyses than the set in the computer.	These data are mostly in published reports, and are pre-1960 data, usually.	More data from areal appraisals and other special studies. Generally sites have been sampled only once.
Oregon DEQ	4000+/350+	Constituents include pH COD Alk Cond. C1 SO4 Fe NH4 TOC NO2+ NO3 and Hardness.	Some of these data are in STORET, but most have been archived on data cards.	Samples collected by DEQ around major landfills in western Oregon. There are between 30 and 50 landfills with 3 to 4 wells each, with samples taken once or twice per year. Some samples are from multiple levels.
Oregon DEQ	100+/2	Generally the same list as for the landfill sites, but with some organics also.	These data are on data cards; with none of it in STORET.	DEQ has collected data at two hazardous waste sites. Sample analyses for organic substances are not extensive.
Oregon DEQ 208 studies	300+/?	Analyses include pH Alk COD Cond Fe Cl NH4 SO4 and Hardness.	Data are stored on data cards, none is computer accessible.	Data was collected in areas of known ground-water problems. Most areas have high nitrate problems, such as Clatsop plains, La Pine, and East Multnomah County.
U.S. Forest Service	700+/60+	Most of the samples were only analyzed for bacteria.	These data are stored in STORET.	Most of the sampling sites appear to be USFS campgrounds and the like. Some samples (5%) were analyzed for ions, nutrients, pH and Cond.
Oregon DEQ	500+/50+	Analyses include pH ions nutrients and bacteria.	These data are stored in STORET.	These samples are from wells around landfills and other private wells. These samples could be included in the first DEQ entry shown above.
U.S. EPA	175+/50+	Analyses include the major constituents listed above.	These data are stored in STORET.	Samples are from landfills and public drinking supplies. Six samples include extensive organic analyses; three samples are from landfills, two from a chemical co., and one public water well.

USGS = United State Geological Survey / Oregon DEQ = Oregon Department of Environmental Quality
U.S. EPA = United States Environmental Protection Agency / 208 studies = Nonpoint pollution source studies.

The U.S. Forest Service data was located in STORET. Most samples appear to have come from wells at ranger stations on Forest Service land. Only about five percent of the samples were analyzed for major ions, nutrients, and physical properties. The remaining samples were only analyzed for bacteria.

The U.S. Environmental Protection Agency data located in STORET includes samples from monitoring wells near landfills and public drinking supply wells. Six of the 175 samples have been analyzed extensively for complex organic substances.

The data described in table 4 indicate that there has not been any specific sampling done to determine background concentrations of organic compounds in ground water. Further, the purpose for most of the studies responsible for collecting ground-water quality data have required samples be collected near population centers, so geographical coverage is not uniform.

Data Selected for Analysis

The principal criterion for selecting data to be analyzed in this report was that the data needed to be accessed through the Geological Survey Oregon District computer system. Most of these data were part of Geological Survey WATSTORE. Some data from published reports were added to the data base to improve the geographical distribution of data. The map in figure 3 (p. 7) shows the locations of the sampled sites; most of the sites are in the populous western half of the State, and generally the samples were collected and analyzed between 1970 and 1981. Data from Oregon DEQ, USFS, and USEPA were not used as part of this study because they were not accessible to the Geological Survey computer.

Most of the wells (96 percent) in the Geological Survey data base were sampled only once. Samples from about 10 wells near Coos Bay on the central Oregon Coast were deleted from the data base because the wells were sampled frequently at various depths and were not compatible with the rest of the data. A separate report describing the geochemistry of that area is in preparation. Deleting these samples reduced the data base from about 1,950 to about 1,080 samples. The number of sites remained about 1,000 and did include a few sites in the Coos Bay area that were sampled in a manner consistent with the rest of the data base. Because most of the sites in the data base were sampled once, the data were not suitable for time-trend analysis.

Information in the WATSTORE Quality of Water (QW) file includes location, collection date and time, geologic and hydrologic unit data for each site, and also contains analytical data for each water sample. In addition, a separate WATSTORE data base, the Ground-Water Site Inventory file (GWSI), contains information on well ownership, construction, lithology, ground-water levels, and aquifer hydraulics. When this study began, merging the two data bases was not possible. In addition, the GWSI file contains about five times as many sites as in the QW file, but not all QW sites are in the GWSI file. For these reasons, it was impractical to merge the GWSI information with the QW file data for this study.

Most ground-water quality data used in this study are from wells in project areas that were selected to give good areal coverage by geologic unit source and by range of specific conductance. Specific conductance had been previously measured at about 50 percent of the inventoried wells in an area. This selection process does not eliminate bias that occurs because of factors that can not be controlled. For example, most wells in mountainous regions such as those found in southwestern Oregon are in lowland valley sites where the population lives. These lowlands represent a small portion of the total land area and the wells are shallow compared to the total thickness of the geologic formation or to the flow system which they tap. A wide range of ground-water quality variations are often observed because the lowlands tend to be discharge areas for flow systems where both shallow and deep flow lines converge within short distances.

Ground-water samples may represent water from a point source or a composite source within an aquifer. The point source might be a small-capacity well or piezometer open to a few feet of the aquifer; the composite samples commonly are from large-capacity wells open to a thick zone of the source aquifer. The large-capacity well generally will yield a sample that integrates the quality of water from a large segment of the flow system near the well, and may in fact be drawing water from multiple aquifer units. The result often is that insufficient data is available to account for observed variations in ground-water quality.

When this study began, there was no option in the WATSTORE water-quality data base to code more than one geologic source for samples from wells tapping more than one formation or multiple depths within the same formation. At each sampling site, the principal source was recorded; secondary sources were listed separately under remarks, and could not be retrieved for computer analysis.

A few samples included in this data base were collected for geothermal studies and cannot be considered representative samples. Geothermal areas exhibit abnormally high heat flows which may result in accelerated geochemical processes. Because the number of samples are small compared to size of the data base and to the subsets in which they are included, the impact of these data on the nonparametric statistics should be negligible, and to identify and remove these samples would require considerable effort.

In the section on descriptive statistics that follows, for each of the aquifer units examined, the reader should refer to tables 1 and 2, (p. 13,14) for a brief description of the aquifer units.

STATISTICAL ANALYSIS OF WATSTORE GROUND-WATER DATA

Before reviewing the statistical analyses, the reader should be aware that the results of the statistical analysis in this report fall outside the realm of classical statistics because the analyst had no control over sample design (Davis, J. C., 1973). Thus the data analyzed were not collected specifically to test the hypotheses of interest; but statistical tests were applied to the available data anyway for that purpose. Some consequences of this situation will become evident as the analysis of variance results are examined. As an example, data for many constituents from the Older volcanic aquifers are not significantly different from other aquifer units according to the statistical results of this study. This result though is probably due more to the fact that only 20 samples were available for analysis (sample design not controlled by this study) than to actual similarities between the Older volcanic aquifers and other aquifer units.

Statistical analyses are tools developed to enhance our understanding of relationships that may be present in the examined data. The validity of the conclusions drawn from the results of statistical analyses will depend on: (1) the consistent use of proper methods of sample collection, preservation, and chemical analyses; (2) good judgement in grouping and assigning classification variables such as geologic source of the water; and (3) use of the appropriate methods of statistical analysis for the data being analyzed. For this study, the assignment of the classification variables may have the greatest impact on the statistical results.

Descriptive Statistics

The statistics used to describe the ground-water quality data are; minimum, maximum, and the 25, 50, and 75 percentiles. The 50-percentile value is the median value. These statistics were selected because most of the data are not from a normal or log-normal distribution; therefore, the quartile (25, 50, and 75 percentile) values should be better descriptors of the distribution than the mean and standard deviation. Descriptive statistics are provided for 19 constituents or properties (plus well depth) including calcium, magnesium, sodium, potassium, sulfate, chloride, nitrite plus nitrate dissolved as N, alkalinity, specific conductance, hardness, temperature, dissolved solids, pH, bicarbonate, iron, arsenic, flouride, boron, and silica. The Oregon data base taken from the WATSTORE files contains analyses for another 97 constituents, some of which are calculated from other analytical results. Table 5 lists 85 constituents and properties and shows the number of samples for each constituent. The 19 constituents were

Table 5.--Constituent analyses available for WATSTORE samples selected for this study

[Only constituents with five or more analyses are included. Units are mg/L except where noted otherwise.]

Analysis	Number	Minimum	Maximum
Alkalinity, total Lab as $CaCO_3$	7	10	210
Alkalinity, total as $CaCO_3$	903	0	3,570
Ammonia, total as N	31	0	.32
Ammonia, dissolved as N	9	0	.32
Ammonia, total as NH_4	6	0	.06
Ammonia, dissolved as NH_4	10	0	.41
Arsenic, dissolved (ug/L as As)	373	0	340
Arsenic, total (ug/L as As)	126	0	20
Barium, total (ug/L as Ba)	27	0	5,200
Bicarbonate as HCO_3	837	0	4,353
Boron, dissolved (ug/L as B)	675	0	16,000
Boron, total (ug/L as B)	15	30	2,300
Cadmium, total (ug/L as Cd)	24	0	4
Calcium, dissolved	989	.3	5,000
Calcium, total	44	3.2	26
Carbon dioxide	682	0	2,170
Carbonate as CO_3	627	0	144
Carbon, total organic	6	0	11
Chloride, dissolved	1,032	0	14,000
Chromium, total (ug/L as Cr)	18	0	20
Coliform, fecal (colonies/100 ml)	15	0	10
Color (platinum-cobalt units)	39	0	50
Conductance (micromhos/cm at 25 deg. C)	1,045	2.06	35,000
Copper, total (ug/L as Cu)	5	20	40
Depth collection (feet)	542	5	1,128
Discharge (ft^3/sec)	132	.001	2.0
Discharge, instantaneous (ft^3/sec)	75	.001	4.0
Dissolved solids at 180 deg. F	264	32	6,730
Dissolved solids sum	903	23	22,400
Dissolved solids tons per day	77	0	4.53
Dissolved solids tons per acre-foot	647	.03	30.5
Flouride, dissolved	944	0	27
Hardness, total as $CaCO_3$	993	1	13,000
Hardness, noncarbonate as $CaCO_3$	826	0	13,000
Iron, dissolved (ug/L as Fe)	667	0	32,000
Iron, total (ug/L as Fe)	157	0	13,400
Lead, total (ug/L as Pb)	42	1	45
Magnesium, dissolved	979	0	210
Magnesium, total	44	.6	12
Manganese, dissolved (ug/L as Mn)	381	0	36,000
Manganese, total (ug/L as Mn)	42	0	380
Mercury, total (ug/L as Hg)	25	0	4.3
Methylene-blue-active substance	44	0	2.0
Nitrate, dissolved as N	22	0	5.3
Nitrate, total as N	269	0	163
Nitrate, dissolved as NO_3	28	0	205
Nitrite, dissolved as N	15	0	.01
Nitrite, total as N	5	.01	.02
Nitrite plus nitrate, total as N	53	0	7.9
Nitrite plus nitrate, dissolved as N	581	0	24
Nitrite, dissolved as NO_2	23	0	.03
Nitrogen, total as N	57	.08	8.0
Nitrogen, dissolved as N	6	.1	.43
Nitrogen, total organic as N	53	0	.74
Nitrogen, dissolved organic as N	6	.1	.43
Nitrogen, Kjeldahl, total as N	47	.01	.79
Nitrogen, Kjeldahl, dissolved as N	6	.1	.43
Nitrogen, Kjeldahl, suspended as N	6	.01	.37
Nitrogen, total as NO_3	54	.35	35
Oxygen, dissolved	10	.1	4.1
pH (standard units)	1,024	3.4	10.6
pH Lab (standard units)	7	7.2	8.6
Phenols (ug/L)	47	0	8
Phosphate, ortho, dissolved as PO_4	407	0	3.4
Phosphate, total as PO_4	42	.03	3.5
Phosphorus, ortho, total as P	61	.02	7.0
Phosphorus, total as PO_4	10	.06	.31
Phosphorus, total as P	59	.02	.39
Phosphorus, dissolved as P	47	0	.74
Phosphorus, ortho, dissolved as P	381	0	1.1
Potassium, dissolved	946	0	73
Potassium, total	44	.6	4.1
Selenium, dissolved ((ug/L as Se)	8	0	0
Selenium, total (ug/L as Se)	24	0	0
Silica, dissolved as SiO_2	971	.9	370
Silver, total (ug/L as Ag)	24	0	2.0
Sodium, dissolved	963	1.5	5,000
Sodium, total	33	1.2	12
Sodium absorption ratio	962	.01	120
Sodium, percent	874	3	100
Sulfate, dissolved	981	0	1,550
Temperature, water (Deg. C)	882	1	84
Turbidity (NTU)	7	.2	37.5
Well depth	89	12	2,812
Zinc, total (ug/L as Zn)	29	.53	2,900

selected to characterize the ground-water quality because analyses of more than 30 samples were available for each constituent. Constituents of particular interest are nitrite plus nitrate and arsenic, because some concentrations of each have been high enough for the State to deny some identified beneficial water use such as livestock watering.

The ground-water quality data exhibit considerable concentration variability for most of the constituents analyzed. Descriptive statistics for constituents in each aquifer and hydrologic unit are presented in tables 6 through 19. Units with fewer than 20 analyses were not included. The location of sampling sites for each aquifer unit is shown on figures 10 through 16. These maps show the irregular distribution of sampling sites for each unit.

Tables of descriptive statistics are presented for two classification variables; aquifer units and hydrologic units. Analyses for aquifer units examine how variations in ground-water quality are related to geology. Analyses for hydrologic units examine similarities or variations in ground-water quality between units or regional aquifer systems.

All Selected WATSTORE Data

Descriptive statistics presented in table 6 were calculated using all the Oregon data from WATSTORE combined with the data entered for this study, a total of 1,077 samples. The number of analyses for each constituent varied from 519 for arsenic to 1,045 for specific conductance. Each constituent shows a wide range of values, with infrequently occurring high values producing positive positive skew. This skewness is particularly noticeable for calcium, sodium, specific conductance, hardness, arsenic, chloride, iron, and boron. As each succeeding table is examined, the expectation is that variability and skewness will decrease because the data in each tabulation will be from smaller more uniform areas. The range of concentrations are large because these samples come from many different formations and locations including local recharge to regional discharge areas. In addition, some samples are of connate waters and marine-sedimentary formations yielding relatively high concentrations.

High values of nitrite plus nitrate, chloride, hardness, temperature, iron, arsenic, and boron show that some waters have constituents in concentrations or characteristics sufficient to impair the use of the water for purposes such as irrigation, livestock, and domestic supply. Generally fewer than 25 percent of the water samples analyzed have concentrations of constituents that may limit water use for selected purposes. Some examples are nitrite plus nitrate for which the 75-percentile value (0.73 mg/L) is below the EPA (1976) criteria for domestic supply of 10 mg/L, but the maximum is above the criteria level. This is also the case for boron in irrigation waters (criteria 750 ug/L), and iron in domestic supplies (criteria 300 ug/L).

Basin-fill and Alluvial Aquifers

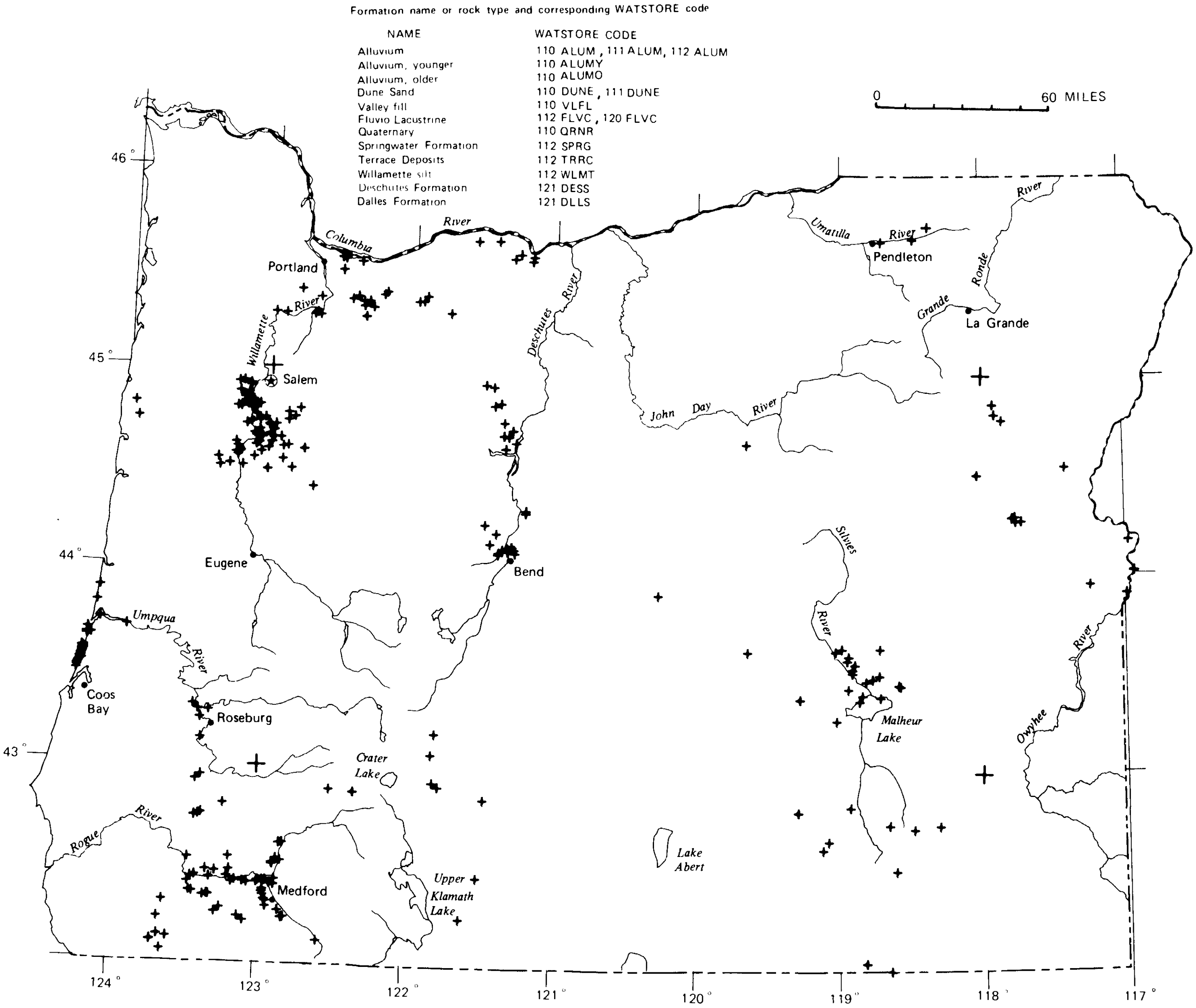
The Basin-fill and alluvial aquifer as defined here consists of all the formations in western Oregon grouped into McFarland's (1982) Unit I, the Quaternary-Tertiary sedimentary deposits, the formations grouped into the Basin-fill and alluvial aquifers, and the Sedimentary aquifers defined by Gonthier (in press, 1984) in eastern Oregon. A brief description of each of these separate units can be found in table 1 and 2; figure 6 shows the major outcrops and figure 7 shows the sampling sites and the aquifer codes of the units grouped under this classification. The scale of figure 6 prevents showing stream alluvial deposits which are included in this aquifer unit.

The range of values for many of the constituents analyzed in samples from the Basin-fill and alluvial aquifers (table 7) is nearly as large as it is for the combined Oregon data set. This is due in part to the fact that this aquifer unit is widely distributed and because it overlies older aquifer units in most lowland areas. In western Oregon, for example, it commonly overlies older marine formations, and in some of these areas, water from the older marine rocks discharges to the Basin-fill and alluvial aquifer, resulting in localized occurrences of saline water. As expected, the range of nitrite plus nitrate is large and the 25- and 50-percentile concentrations are nearly three times greater than the same percentiles for all data combined (table 6). The maximum nitrite plus nitrate concentration observed occurs in this aquifer unit. Nitrate could be due to man's influences, such as fertilizers or from domestic sewage-disposal systems. Surface sediments in this unit commonly are permeable and the water table generally is shallow; these factors combine to make it more sensitive to water-quality degradation than each of the other units examined.

The 50- and 75-percentile arsenic concentrations are two to three times those for all the combined Oregon data. The 75-percentile concentration is 10 ug/L and the maximum concentration is 240 ug/L. The U.S. Environmental Protection Agency (EPA) suggested limits for arsenic is 50 ug/L domestic supply, and 100 ug/L for irrigation (EPA, 1976). The interquartile range (between 25th and 75th percentile) for all other constituents is similar to that of all the combined Oregon data. The high arsenic values may be due to samples from arid eastern Oregon basins where the source rocks are young volcanic rocks and high evapotranspiration rates tend to concentrate arsenic in the ground waters of some areas.

Samples with complete analyses of all major ions are plotted on a trilinear diagram (fig. 8). Trilinear plots display only the major ionic constituents in milliequivalents per liter. Cations are calcium, magnesium, and sodium plus potassium, and anions are sulfate, chloride plus nitrate, and alkalinity (which was used to represent bicarbonate), and carbonate. Plotted values are expressed as percentages of the total milliequivalents per liter of cations and anions. Two triangles are used -- one for cations and one for anions. Each vertex of the triangle represents 100 percent of a particular ion or group of ions.

Figure 6.--Distribution of Basin-fill and alluvial aquifers (modified from Walker, 1977; Wells and Peck, 1961).



Formation name or rock type and corresponding WATSTORE code

NAME	WATSTORE CODE
Alluvium	110 ALUM, 111 ALUM, 112 ALUM
Alluvium, younger	110 ALUMY
Alluvium, older	110 ALUMO
Dune Sand	110 DUNE, 111 DUNE
Valley fill	110 VLFL
Fluvio Lacustrine	112 FLVC, 120 FLVC
Quaternary	110 QRNR
Springwater Formation	112 SPRG
Terrace Deposits	112 TRRC
Willamette silt	112 WLMT
Deschutes Formation	121 DESS
Dalles Formation	121 DLLS

Figure 7.--Location of sampling sites for Basin-fill and alluvial aquifers.

Table 6.--Descriptive statistics of ground-water quality for all selected WATSTORE data (1,077 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
989	Calcium, dissolved	0.3	8.2	19	37	5,000
979	Magnesium, dissolved	.1	2.9	6.5	13	210
963	Sodium, dissolved	1.5	9.4	21	66	5,000
944	Potassium, dissolved	.1	.8	1.5	3.3	73
985	Sulfate, dissolved	.1	2.4	6.4	16	690
620	Nitrite + Nitrate, dissolved (as N)	.01	.06	.15	73	24
1002	Chloride, dissolved	1	2	6	23	14,000
909	Alkalinity, total (as $CaCO_3$)	1	62	112	171	3,570
1022	pH (units)	3.4	7.0	7.5	8.0	10.6
1045	Specific conductance (micromhos/cm at 25°C)	2	175	288	536	35,000
994	Hardness, total (as $CaCO_3$)	1	37	78	144	13,000
899	Dissolved solids (sum of constituents)	23	138	204	342	7,050
880	Temperature (°Celsius)	1	12	13	15	84
834	Bicarbonate (as HCO_3)	1	80	137	218	4,353
699	Iron, dissolved (ug/L)	3	20	60	220	32,000
519	Arsenic, dissolved (ug/L)	1	1	1	3	340
711	Boron, dissolved (ug/L)	1	20	40	220	16,000
976	Fluoride, dissolved	.1	.1	.2	.4	27
971	Silica, dissolved (as SiO_2)	.9	21	35	49	370
542	Collection depth (feet)	5	76	128	276	1,128

Table 7.--Descriptive statistics of ground-water quality for the Basin-fill and alluvial aquifers (300 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
269	Calcium, dissolved	0.5	7.8	18	32	600
269	Magnesium, dissolved	.1	4.3	8.2	14	177
264	Sodium, dissolved	1.5	8.0	13	28	1,400
261	Potassium, dissolved	.1	.8	1.6	3.0	33
268	Sulfate, dissolved	.1	2.2	5.4	15	680
142	Nitrite + Nitrate, dissolved (as N)	.01	.16	.46	1.7	24
280	Chloride, dissolved	1	3	6	19	3,100
213	Alkalinity, total (as $CaCO_3$)	1	49	80	142	379
279	pH (units)	5.4	6.7	7.3	7.7	9.6
284	Specific conductance (micromhos/cm at 25°C)	2	144	246	424	11,550
271	Hardness, total (as $CaCO_3$)	2	41	80	140	1,500
237	Dissolved solids (sum of constituents)	35	107	172	268	5,630
246	Temperature (°Celsius)	5	12	13	14	46
225	Bicarbonate (as HCO_3)	4	58	95	190	2,000
193	Iron, dissolved (ug/L)	3	30	80	355	32,000
136	Arsenic, dissolved (ug/L)	1	1	2	10	240
188	Boron, dissolved (ug/L)	1	20	30	90	8,900
258	Fluoride, dissolved	.1	.1	.1	.3	19
264	Silica, dissolved (as SiO_2)	3.6	25	36	51	98
132	Collection depth (feet)	5	38	72	122	819

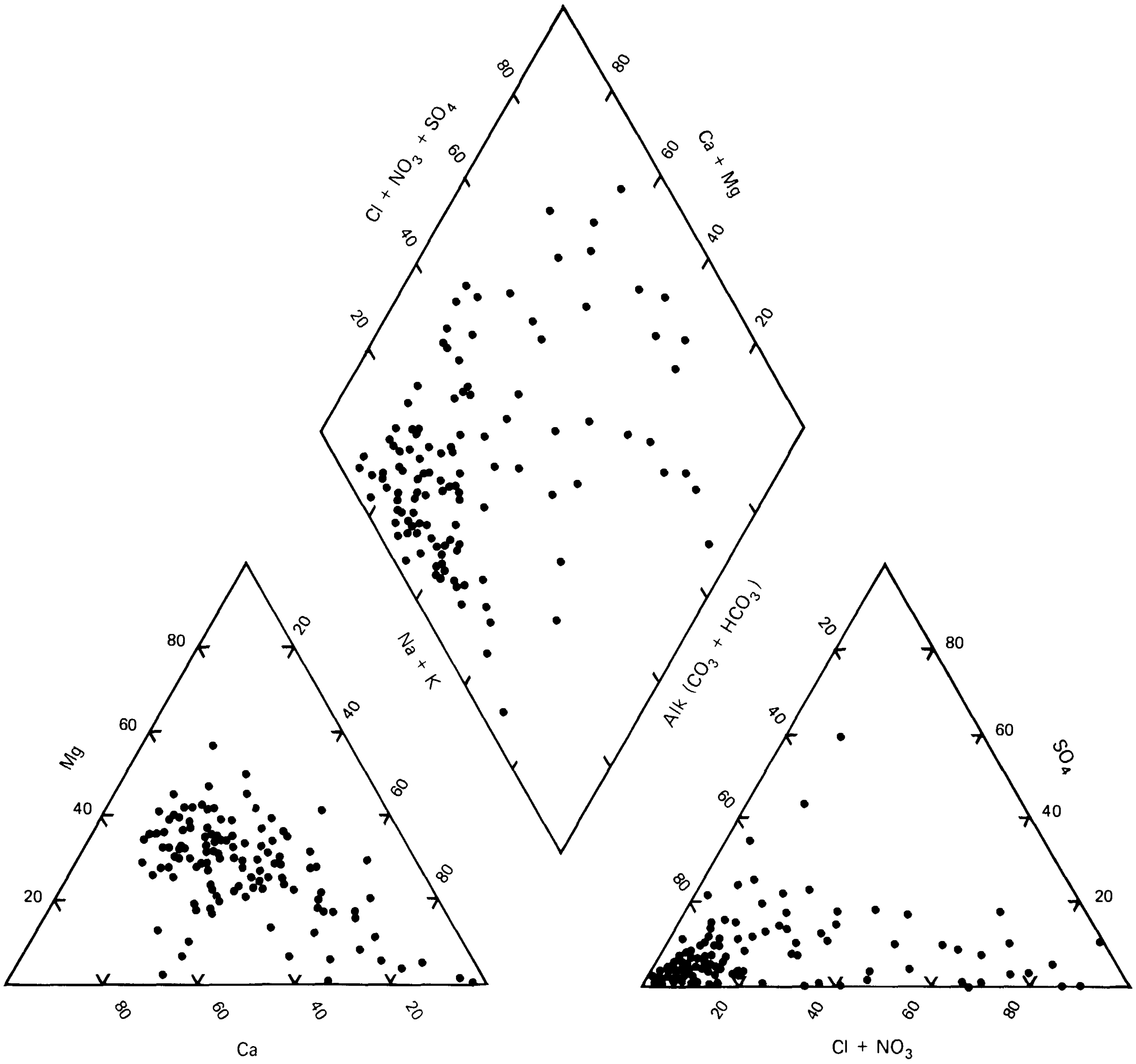


Figure 8.--Percentage composition of ions for Oregon ground-water quality sites in the Basin-fill and alluvial aquifers.

For each point, the coordinates add to 100 percent. The diamond plot provides a single point for each sample by projection of the points in each triangle to an intersection. Alkalinity accounts for the predominant anions in most waters; however, chloride was high in some samples. Sulfate generally was low, less than 20 percent of the total anions. Cations tend to cluster near the center of the cation triangle, but a few samples have sodium as the predominant cation. Samples with high sodium also have high chloride. The diamond plot shows considerable scatter, but the majority of waters indicate high percentages for calcium and magnesium, and alkalinity.

Marine Rocks of the Coast Ranges

Figure 9 shows the distribution of the Marine rocks and figure 10 shows the locations of sampling sites and a list of the geologic unit codes included in this aquifer grouping. Water samples from Cretaceous sedimentary rocks found in the Klamath Mountains are included with the Marine rocks because their lithology and depositional environment appears to be more closely related to the Marine rocks of the Coast Ranges than to the underlying metamorphosed Mesozoic-Paleozic rocks.

Water from the Marine rocks (table 8) generally contains higher concentrations of chloride and sodium ions than water from other aquifer units (table 6). This is believed to be due in part to interception by wells of upward moving older, possibly connate ground waters, to principal streams in lowlands.

Chloride concentrations are about three times higher for the 25- and 50-percentile concentrations, and five times higher for the 75th percentile than for the combined data, and are generally higher than for any other aquifer unit examined (table 8). The sodium quartiles are about three times higher than for the combined Oregon data set. Nitrite plus nitrate and silica quartiles are about half those of the entire data set.

The Marine rocks have boron concentrations considerably above the median concentrations for all combined Oregon data and the maximum boron concentration for the entire data set occurs in this unit. The high boron concentrations generally occur in samples containing high dissolved-solids concentrations that generally make the water unusable for repeated irrigation or domestic use.

The trilinear diagrams (fig. 11) indicate the predominant anions are either the constituents that comprise alkalinity or chloride. The cation triangle has a band of points across the bottom which indicates that either sodium or calcium is the predominant cation. The diamond plot shows wide variation, indicating several types of water are present in this unit.

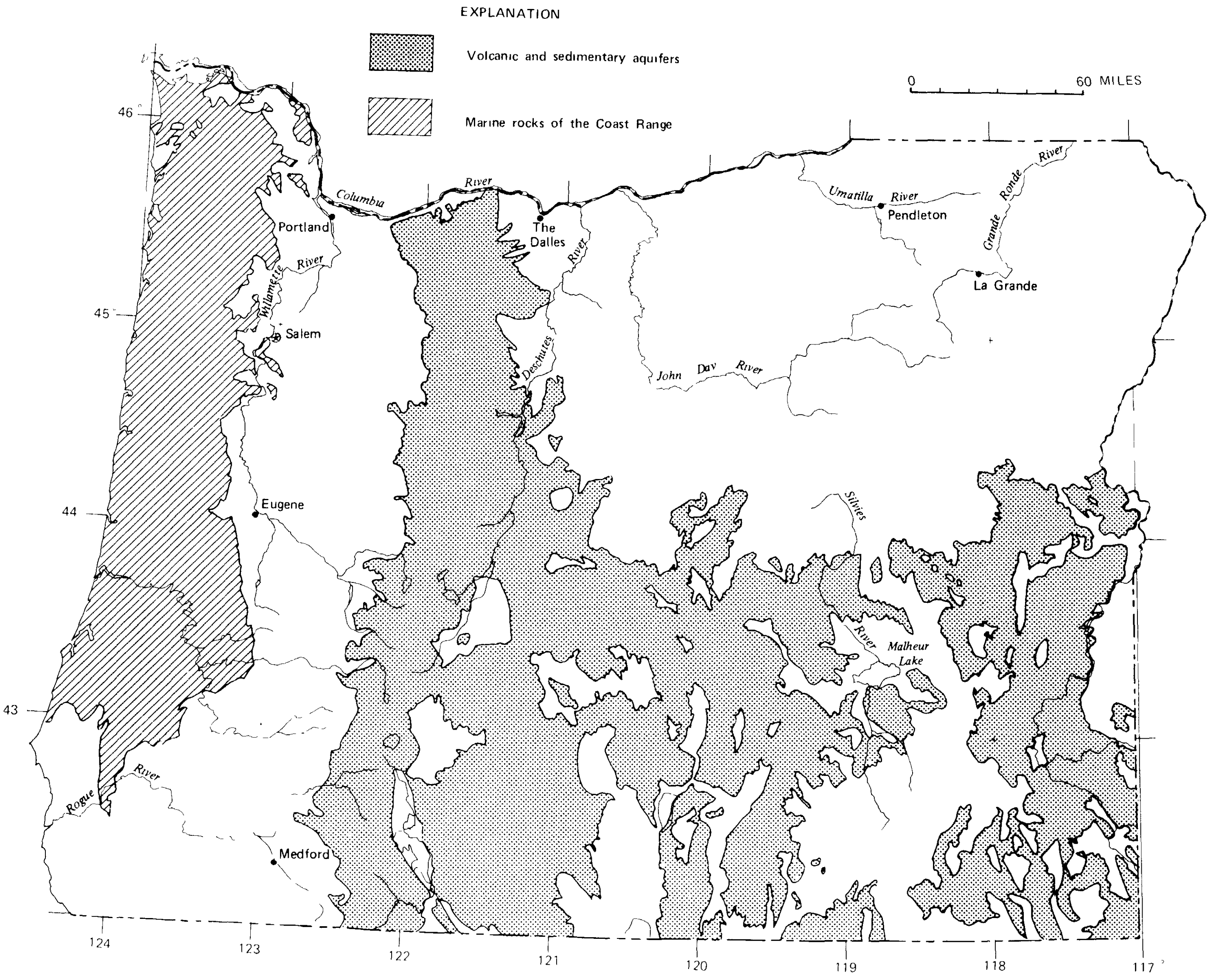
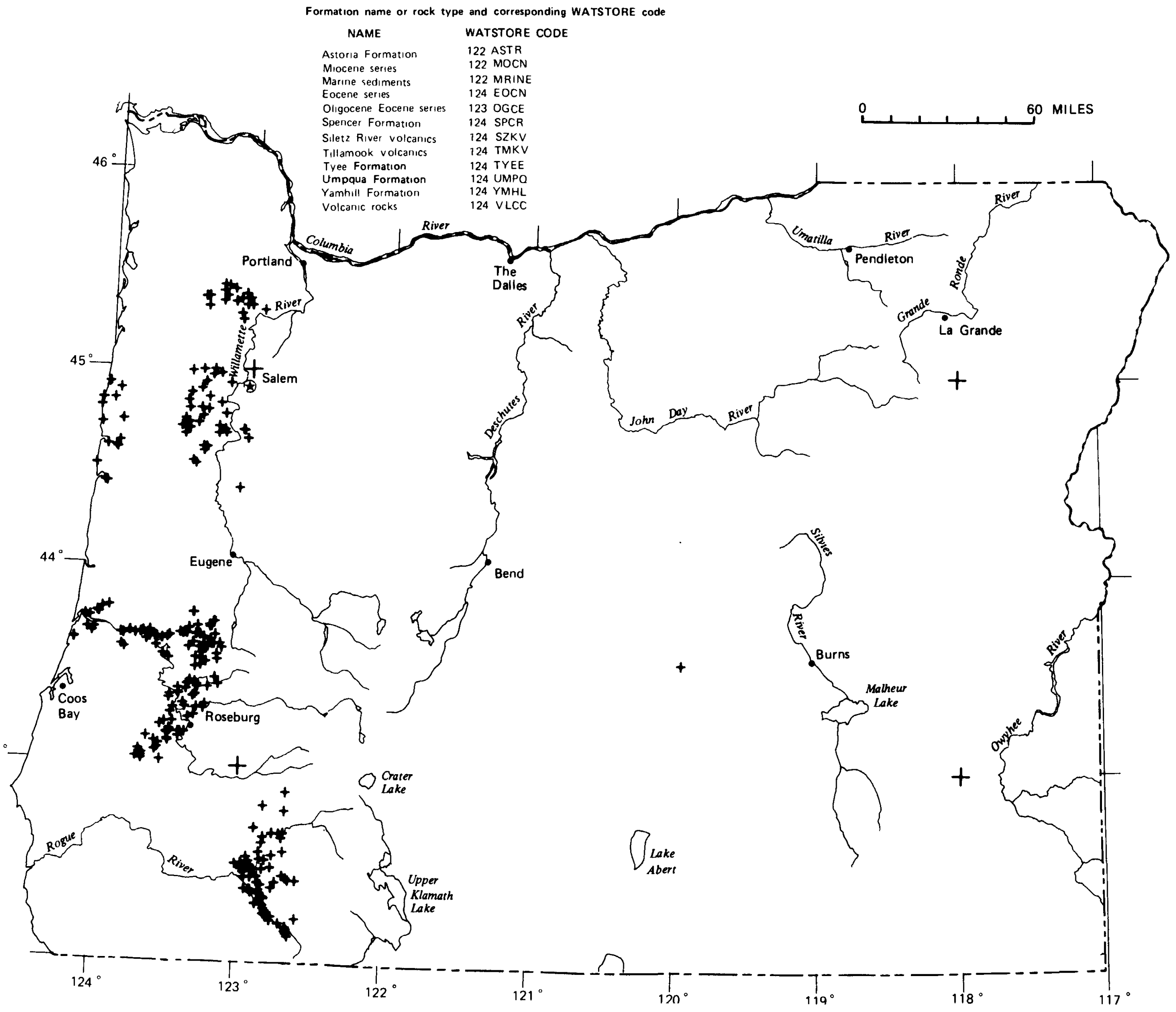


Figure 9.--Distribution of outcrops of the Marine rocks of the Coast Ranges and the Volcanic and sedimentary aquifers. The Volcanic and sedimentary aquifers as used here includes and is equivalent to the Tertiary-Quaternary volcanics of the High Cascades (McFarland, 1983) and the Volcanic and sedimentary aquifers (Gonther, in preparation). Modified from Walker, 1977; Wells and Peck, 1961).



Formation name or rock type and corresponding WATSTORE code

NAME	WATSTORE CODE
Astoria Formation	122 ASTR
Miocene series	122 MOCN
Marine sediments	122 MRINE
Eocene series	124 EOCN
Oligocene Eocene series	123 OGCE
Spencer Formation	124 SPCR
Siletz River volcanics	124 SZKV
Tillamook volcanics	124 TMKV
Tyee Formation	124 TYEE
Umpqua Formation	124 UMPQ
Yamhill Formation	124 YMHL
Volcanic rocks	124 VLCC

Figure 10.--Location of sampling sites for Marine rocks of the Coast Ranges.

Table 8.--Descriptive statistics of ground-water quality for the Marine rocks of the Coast Ranges (271 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
267	Calcium, dissolved	0.3	6.7	20	48	5,000
263	Magnesium, dissolved	.1	1.1	3.3	9.5	210
260	Sodium, dissolved	2.4	24	66	160	3,000
253	Potassium, dissolved	.1	.6	.9	1.5	73
248	Sulfate, dissolved	.1	3.9	8.6	20	395
178	Nitrite + Nitrate, dissolved (as N)	.01	.02	.10	.37	5.0
259	Chloride, dissolved	1	5	17	120	11,000
256	Alkalinity, total (as $CaCO_3$)	2	78	148	230	3,570
266	pH (units)	5.3	7.3	7.8	8.3	10.6
268	Specific conductance (micromhos/cm at 25°C)	9	263	460	849	24,300
266	Hardness, total (as $CaCO_3$)	1	24	68	161	13,000
252	Dissolved solids (sum of constituents)	30	170	282	487	7,050
204	Temperature (°Celsius)	8	12	14	16	63
222	Bicarbonate (as HCO_3)	3	103	180	274	4,353
184	Iron, dissolved (ug/L)	9	30	60	278	19,000
130	Arsenic, dissolved (ug/L)	1	1	1	2	150
197	Boron, dissolved (ug/L)	1	40	230	705	16,000
256	Fluoride, dissolved	.1	.2	.3	.6	10
259	Silica, dissolved (as SiO_2)	3.2	13	21	30	110
161	Collection depth (feet)	14	80	112	173	735

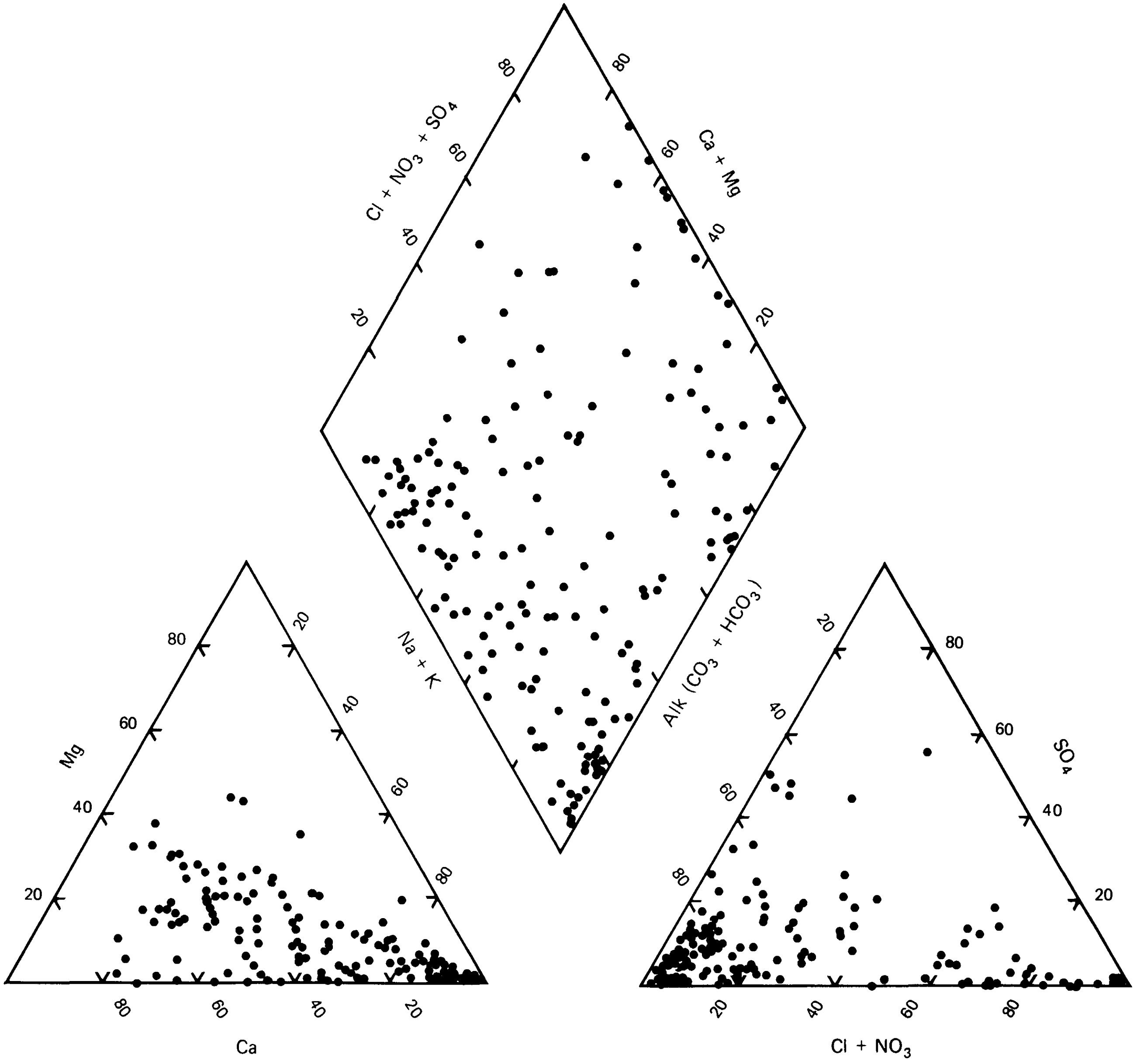


Figure 11.--Percentage composition of ions for Oregon ground-water quality sites in the Marine rocks of the Coast Ranges.

Igneous and Metamorphic Rocks of the Klamath Mountains

This aquifer unit is complex and includes a wide range of rock types and individual formations. Figures 12 and 13 show the geologic units and the distribution of sampling sites included in this unit.

The percentile values for this aquifer unit exhibit concentration ranges higher for calcium, sulfate, and hardness compared to the combined data set, but nitrite plus nitrate and potassium values are about half the values for combined data (table 9). Maximum data base values for sodium, sulfate, chloride, and specific conductance were from this aquifer. Higher calcium values may reflect the abundance of mafic and ultramafic igneous rocks as well as lenses of marble in these rocks locally. Sulfate may be from widespread occurrences of metallic sulfides and sodium and chloride may be from connate waters as in the marine rocks.

The trilinear diagrams (fig. 14) indicate alkalinity is generally predominant among the anions with some waters containing high percentages of chloride. Calcium is generally the dominant cation and magnesium content is significant probably due to high magnesium in the ultramafic rocks. Although the samples come from a small area in western Oregon, the ions show a pronounced scatter on the diamond plot mostly due to some high concentrations of sodium and chloride ions.

Volcanic and Sedimentary Aquifers

Location of the sampling sites in the Volcanic and sedimentary aquifer, and geologic units grouped under this aquifer unit are shown in figure 15, and the outcrop areas are shown on figure 9. This classification includes all the formations in Unit II, the Quaternary-Tertiary volcanic rocks of the High Cascades (McFarland, 1982), and those included in the Volcanic and sedimentary aquifers identified by Gonthier (in press, 1984). These geologic units are correlative units in the High Cascades but elsewhere actual correlations are less certain.

The percentile values in table 10 were, in general, equal or lower than those for the entire combined Oregon data set, and all maximum values were lower than data set maximum values. Percentile values for potassium, arsenic, and silica were higher than for the entire combined data set.

As in other aquifer units examined, the trilinear plot (fig. 16) shows that the constituents comprising alkalinity predominate the anions. Sulfate was the principal anion in two samples, but there were no samples with high percentages of chloride. The cations are rather variable with a few samples showing high sodium percentages.

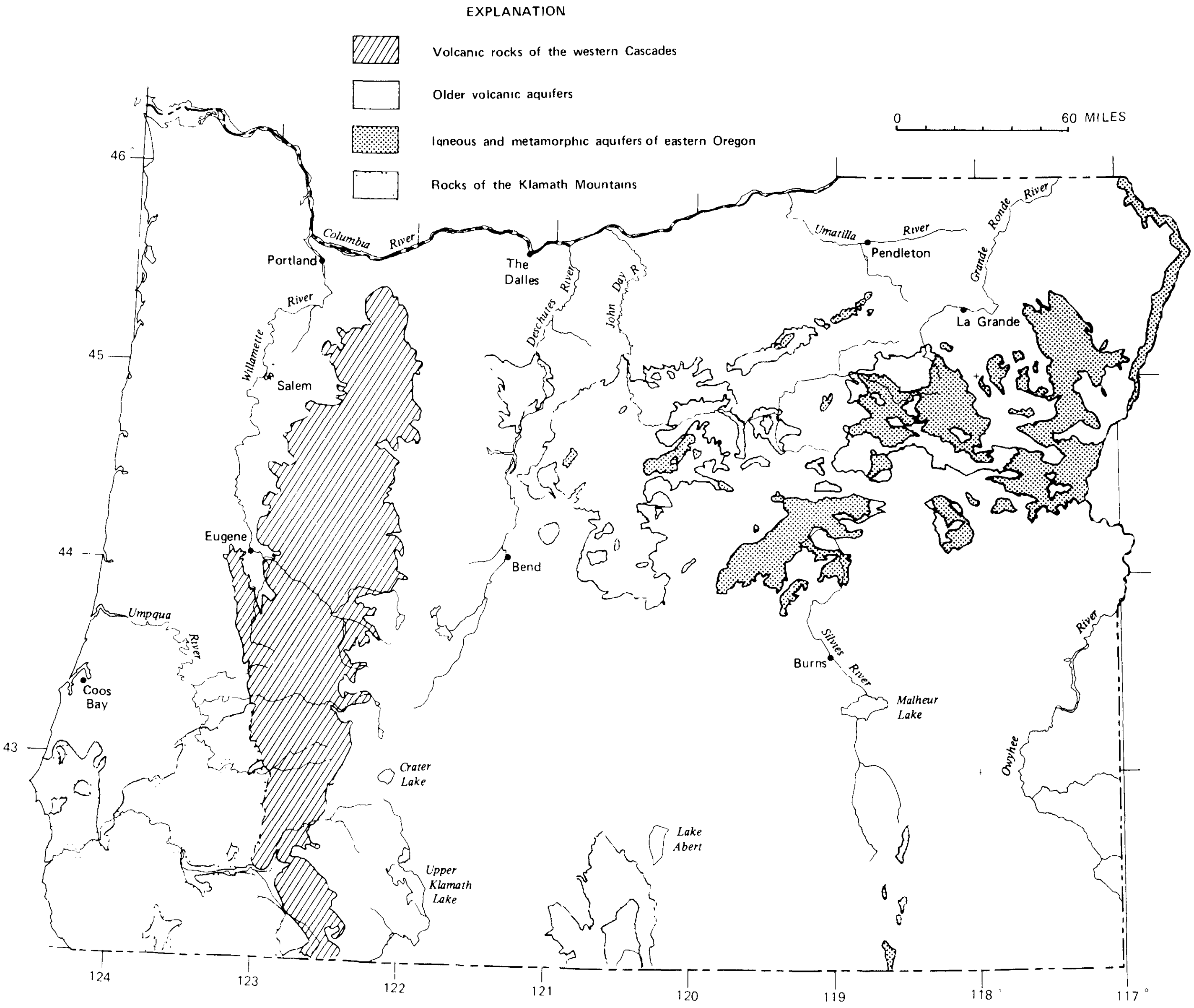


Figure 12.--Distribution of outcrops of the Igneous and metamorphic rocks of the Klamath Mountains, Igneous and metamorphic aquifers of eastern Oregon, Older volcanic aquifers and the Volcanic rocks of the western Cascades (modified, from Walker, 1977; Wells and Peck, 1961).

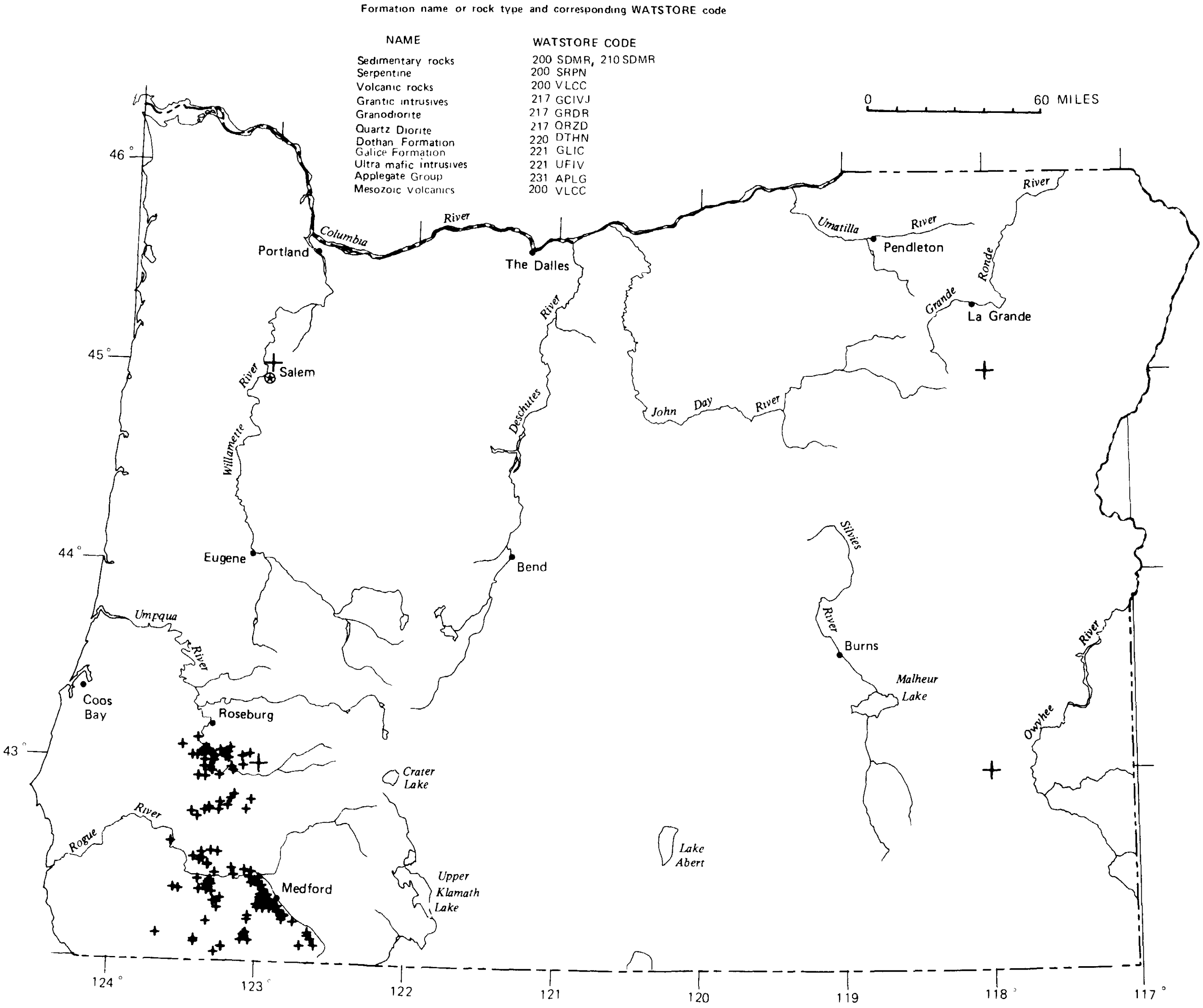


Figure 13.--Location of sampling sites for Igneous and metamorphic rocks of the Klamath Mountains.

Table 9.--Descriptive statistics of ground-water quality for Igneous and metamorphic rocks of the Klamath Mountains (135 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
132	Calcium, dissolved	1	21	35	62	3,300
128	Magnesium, dissolved	.1	5.9	12	19	78
127	Sodium, dissolved	2.5	8.1	16	83	5,000
116	Potassium, dissolved	.1	.4	.8	1.7	11
120	Sulfate, dissolved	.2	5.2	10	24	690
61	Nitrite + Nitrate, dissolved (as N)	.01	.05	.10	.37	4.8
123	Chloride, dissolved	1	3	8	33	14,000
132	Alkalinity, total (as $CaCO_3$)	16	110	150	203	530
128	pH (units)	5.5	6.7	7.3	7.9	9.9
131	Specific conductance (micromhos/cm at 25°C)	3	291	400	608	35,000
132	Hardness, total (as $CaCO_3$)	3	90	150	236	8,400
122	Dissolved solids (sum of constituents)	39	194	256	399	6,290
91	Temperature (°Celsius)	4	12	14	15	22
109	Bicarbonate (as HCO_3)	1	138	190	256	570
63	Iron, dissolved (ug/L)	10	20	40	110	13,000
35	Arsenic, dissolved (ug/L)	1	1	1	1	189
78	Boron, dissolved (ug/L)	1	12	45	280	14,000
122	Fluoride, dissolved	.1	.1	.2	.4	13
125	Silica, dissolved (as SiO_2)	2.7	19	29	38	60
49	Collection depth (feet)	32	96	126	178	447

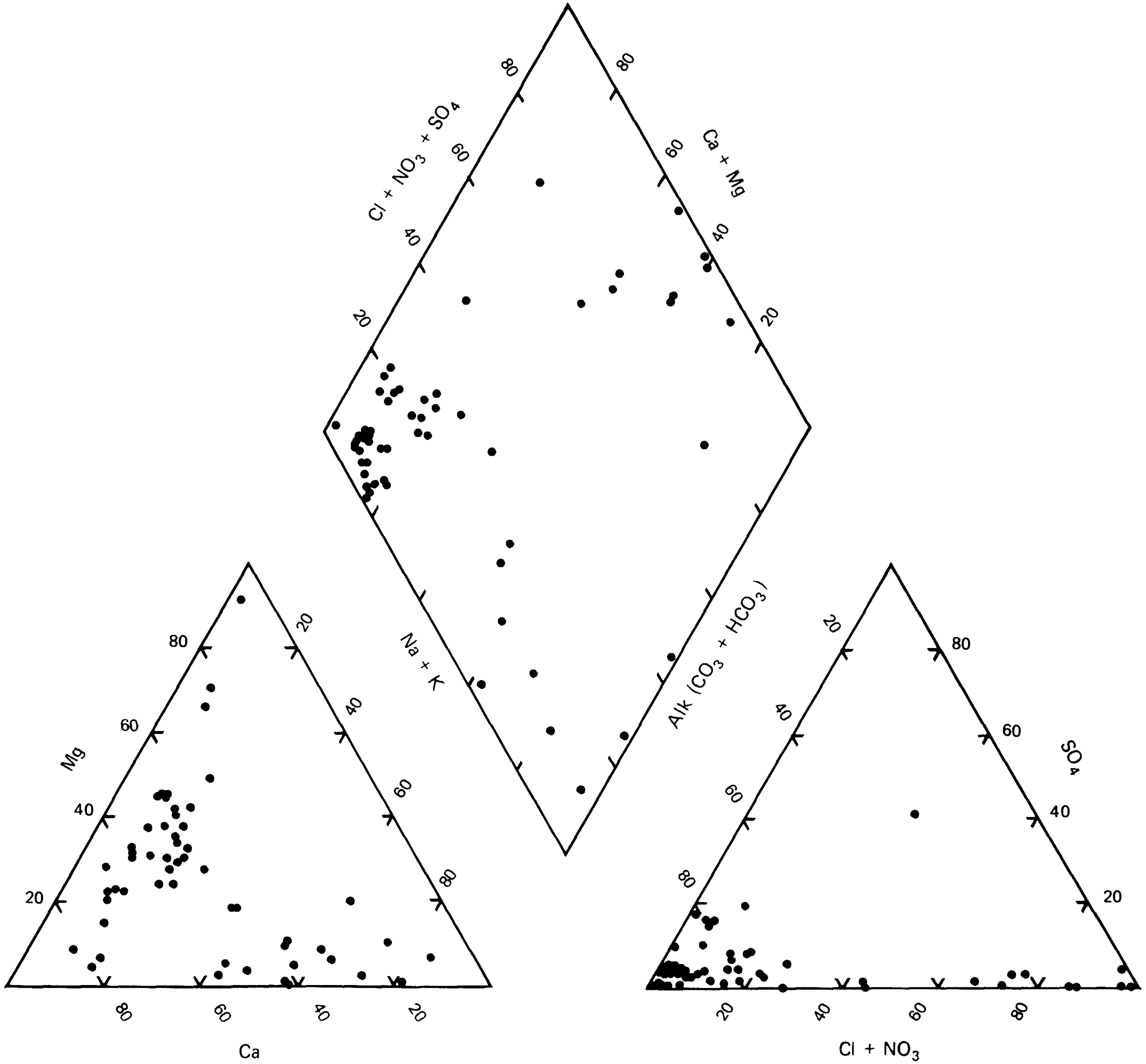


Figure 14.--Percentage composition of ions for Oregon ground-water quality sites in the Igneous and metamorphic rocks of the Klamath Mountains.

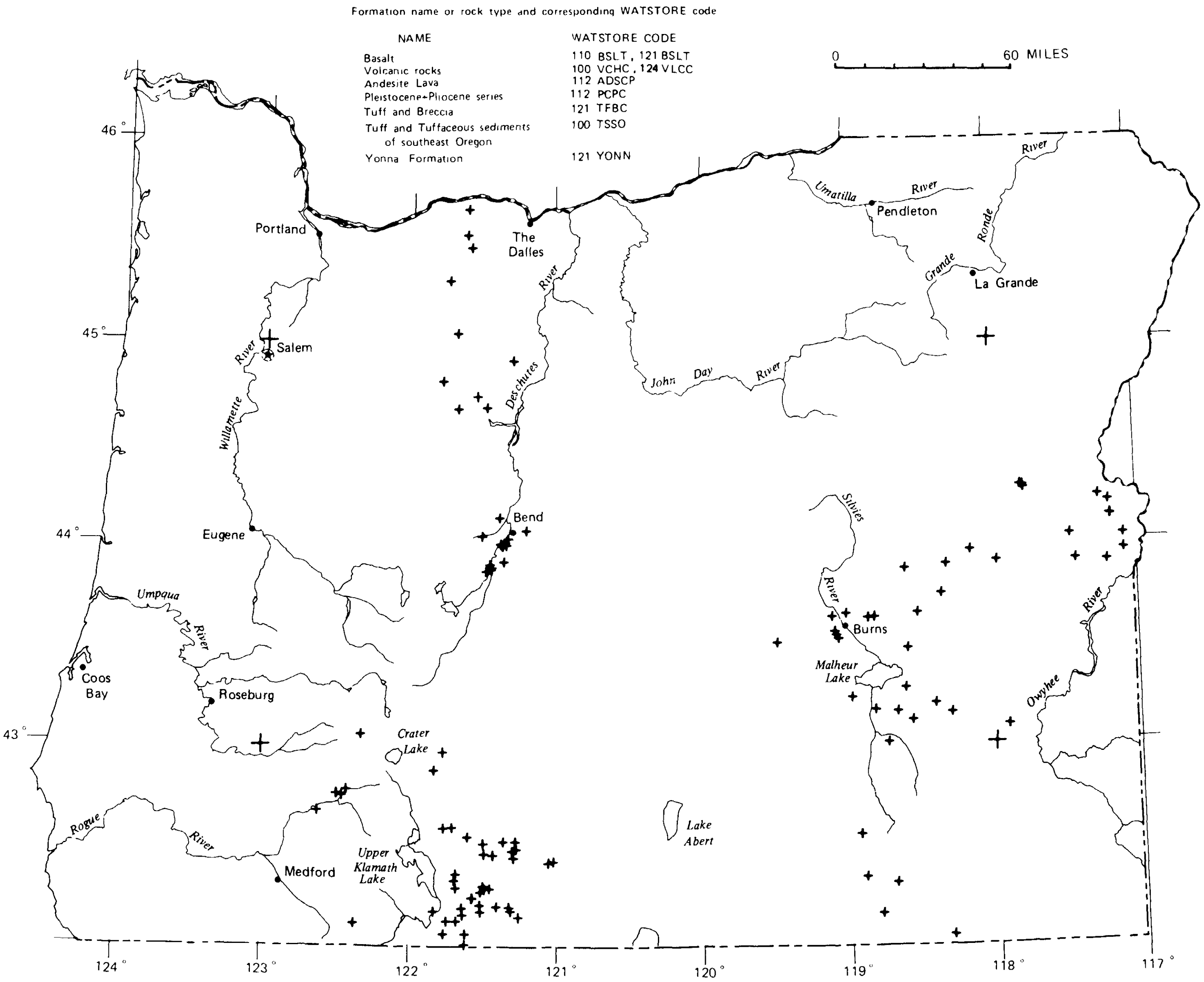


Figure 15.--Location of sampling sites for the Volcanic and sedimentary aquifers.

Table 10.--Descriptive statistics of ground-water quality for the Volcanic and sedimentary aquifers (119 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
114	Calcium, dissolved	1.0	5.8	11	18	180
113	Magnesium, dissolved	.1	2.8	4.9	9.0	47
108	Sodium, dissolved	1.7	8.7	16	38	706
107	Potassium, dissolved	.1	1.7	2.6	5.4	28
112	Sulfate, dissolved	.1	1.7	4.5	12	460
58	Nitrite + Nitrate, dissolved (as N)	.02	.09	.14	.58	7.1
108	Chloride, dissolved	1	1	3	7	975
71	Alkalinity, total (as $CaCO_3$)	15	47	68	119	1,190
109	pH (units)	5.6	7.2	7.6	8.1	9.5
117	Specific conductance (micromhos/cm at 25°C)	32	108	192	317	4,000
113	Hardness, total (as $CaCO_3$)	3	28	49	80	640
84	Dissolved solids (sum of constituents)	38	119	158	221	2,350
106	Temperature (°Celsius)	1	10	14	19	72
74	Bicarbonate (as HCO_3)	18	76	112	154	1,449
64	Iron, dissolved (ug/L)	10	20	50	160	2,100
61	Arsenic, dissolved (ug/L)	1	1	3	11	180
87	Boron, dissolved (ug/L)	6	20	40	110	4,800
110	Fluoride, dissolved	.1	.1	.1	.3	9.8
113	Silica, dissolved (as SiO_2)	4	36	43	54	130
46	Collection depth (feet)	42	144	272	437	916

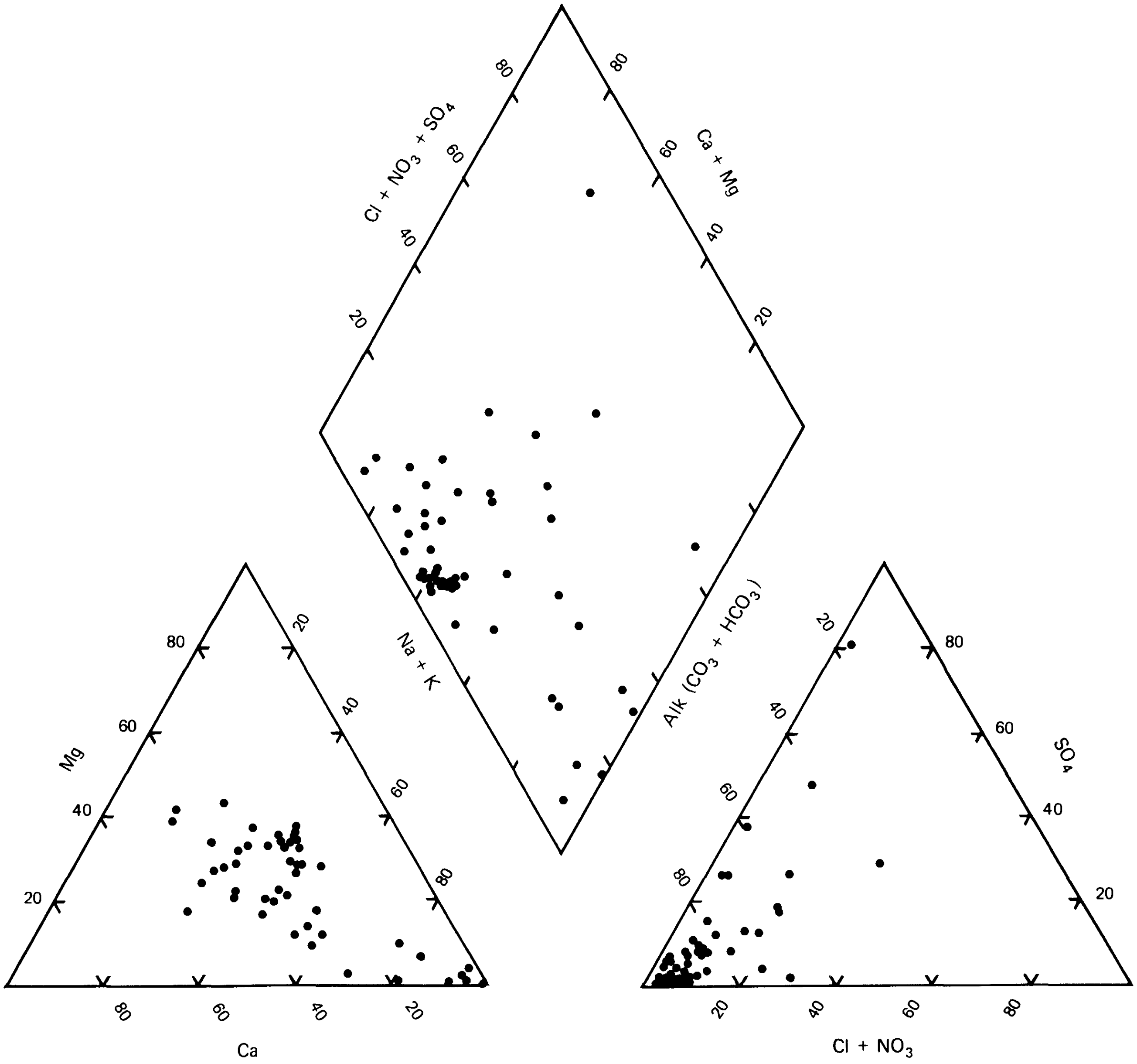


Figure 16.--Percentage composition of ions for Oregon ground-water quality sites in the Volcanic and sedimentary aquifers.

Columbia River Basalt Aquifer

The Columbia River basalt aquifer occurs in both eastern and western Oregon (fig. 17). Figure 18 shows the location of the sampling sites. The relatively low concentration of most constituents is noteworthy. The maximum concentration of arsenic and boron were 4 and 140 ug/L, respectively, and the highest observed temperature was 30 degrees Celsius (table 11). Maximum dissolved solids and specific conductance values were low compared to other aquifer units. This aquifer consists almost entirely of a single rock type, basalt, and the statistics reflect this uniform composition. Nitrite plus nitrate had a maximum of 19 mg/L, and dissolved iron of 8,100 ug/L. The wells in this unit were the deepest of any of the aquifer units examined. The median depth of the sampled wells was 315 feet. The interquartile range was much less than for the entire combined Oregon data set, with the exception of nitrite plus nitrate which was wider.

Sampling sites in this aquifer were clustered in three separate areas. In northeastern Oregon, the aquifer is extensive, thick, and heavily developed consisting of several individual subunits which were not subdivided for this study. It is believed that there are subtle systematic changes in water quality with depth in the unit that are related to stratigraphy, structure, flow system geometry, and withdrawals from the aquifer system. However, knowledge of the subsurface geology and the geographic distribution of sample sites are both inadequate to describe these subtle variations.

The trilinear plot for this unit exhibits well defined clustering (fig. 19). The constituents comprising alkalinity clearly dominate the anions. Cations are variable with a few samples having high sodium percentages. The diamond plot shows predominance of calcium and magnesium, and alkalinity.

Volcanic Rocks of the Western Cascade Range

Locations of sampling sites and a list of geologic unit codes included in this classification are shown in figure 20. Figure 12 shows the outcrop areas for the Volcanic rocks included in this aquifer. Percentile values (table 12) are generally lower compared to the set of all combined Oregon data, and major ions and dissolved solids are about one-third lower.

The constituents comprising alkalinity dominate the anions in samples from the Volcanic rocks of the western Cascades (fig. 21) and calcium and magnesium together are the predominant cations. A few samples from this aquifer represent the sodium-chloride type water. In places, these rocks interfinger with marine rocks which may be the source of the sodium-chloride waters.

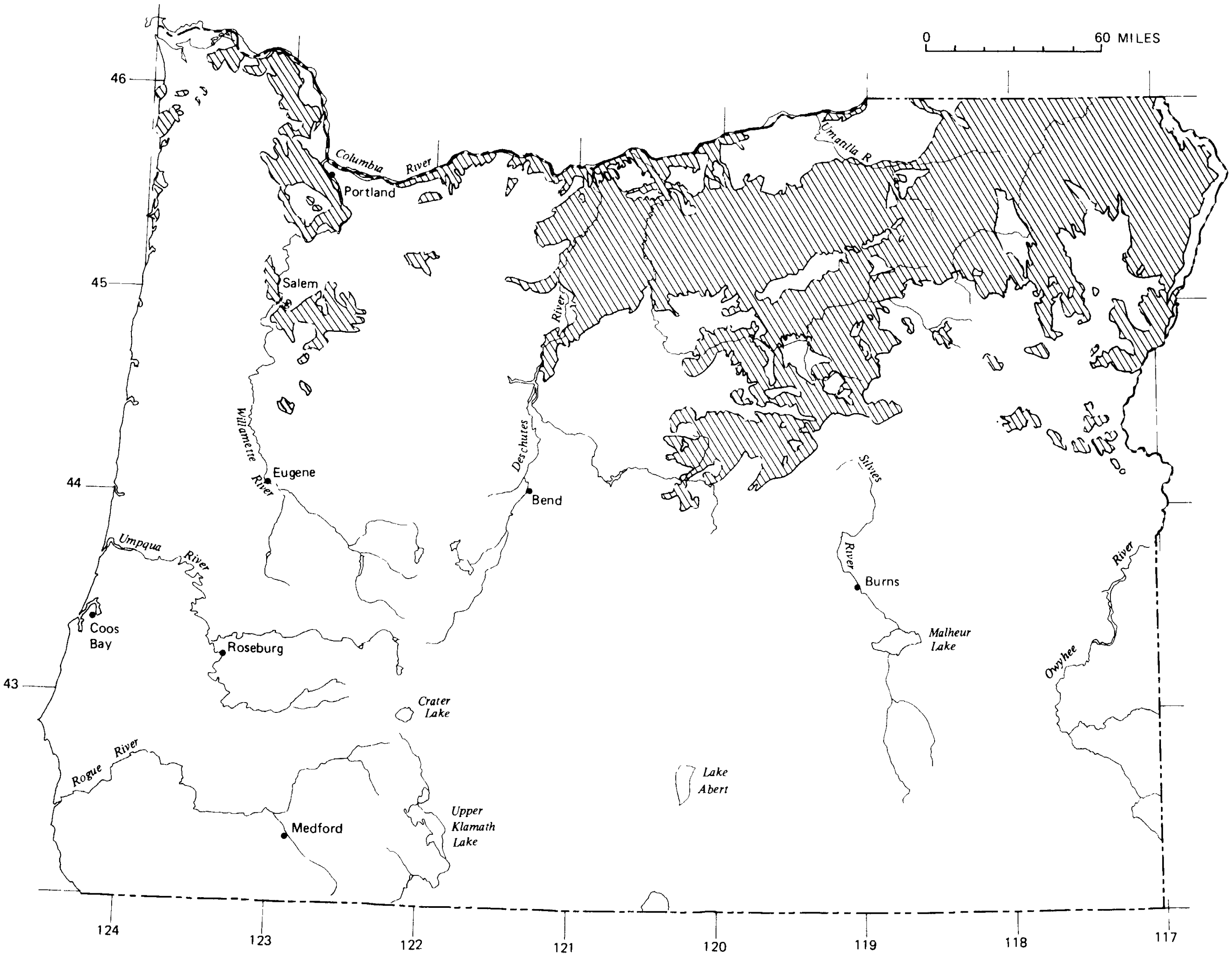


Figure 17.--Distribution of outcrops of the Columbia River Basalt aquifer.

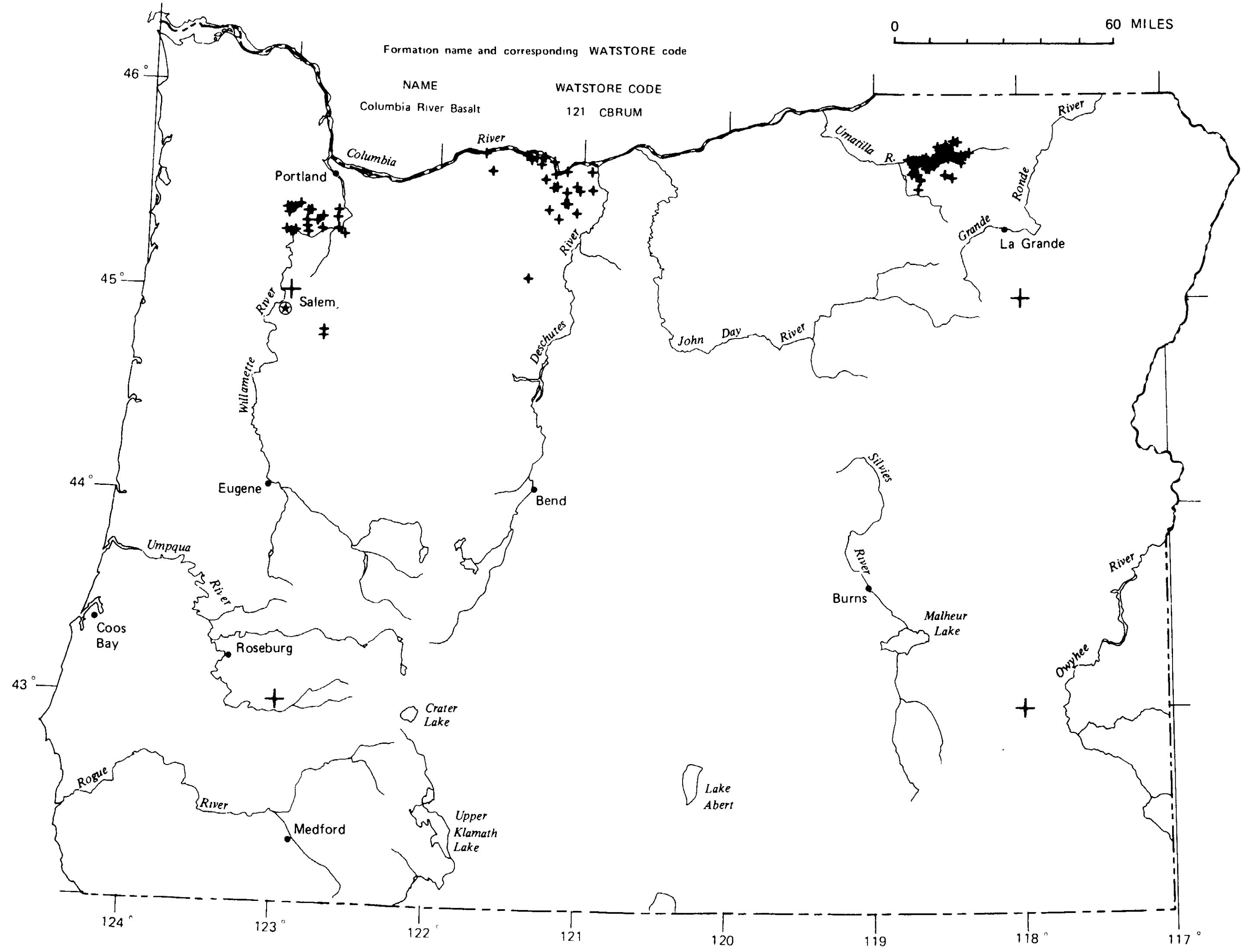


Figure 18.--Location of sampling sites in the Columbia River Basalt aquifer.

Table 11.--Descriptive statistics of ground-water quality for the Columbia River basalt aquifer (95 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
91	Calcium, dissolved	0.4	14	19	27	140
90	Magnesium, dissolved	1.0	5.4	7.8	12	36
89	Sodium, dissolved	3.6	9.2	16	32	100
92	Potassium, dissolved	.8	2.5	3.8	5.1	18
95	Sulfate, dissolved	.1	2.6	6.0	11	150
90	Nitrite + Nitrate, dissolved (as N)	.01	.08	.18	1.1	19
92	Chloride, dissolved	1	2	3	7	400
93	Alkalinity, total (as $CaCO_3$)	11	92	115	144	234
91	pH (units)	5.9	7.2	7.8	8.0	8.6
93	Specific conductance (micromhos/cm at 25°C)	69	187	261	333	1,200
91	Hardness, total (as $CaCO_3$)	1	57	82	120	430
89	Dissolved solids (sum of constituents)	51	156	200	238	768
93	Temperature (°Celsius)	8	12	14	16	30
71	Bicarbonate (as HCO_3)	14	104	132	170	285
91	Iron, dissolved (ug/L)	10	20	30	110	8,100
75	Arsenic, dissolved (ug/L)	1	1	1	1	4
86	Boron, dissolved (ug/L)	2	9	20	30	140
95	Fluoride, dissolved	.1	.1	.3	.6	1.7
95	Silica, dissolved (as SiO_2)	6.6	48	55	60	99
87	Collection depth (feet)	10	150	315	500	1,103

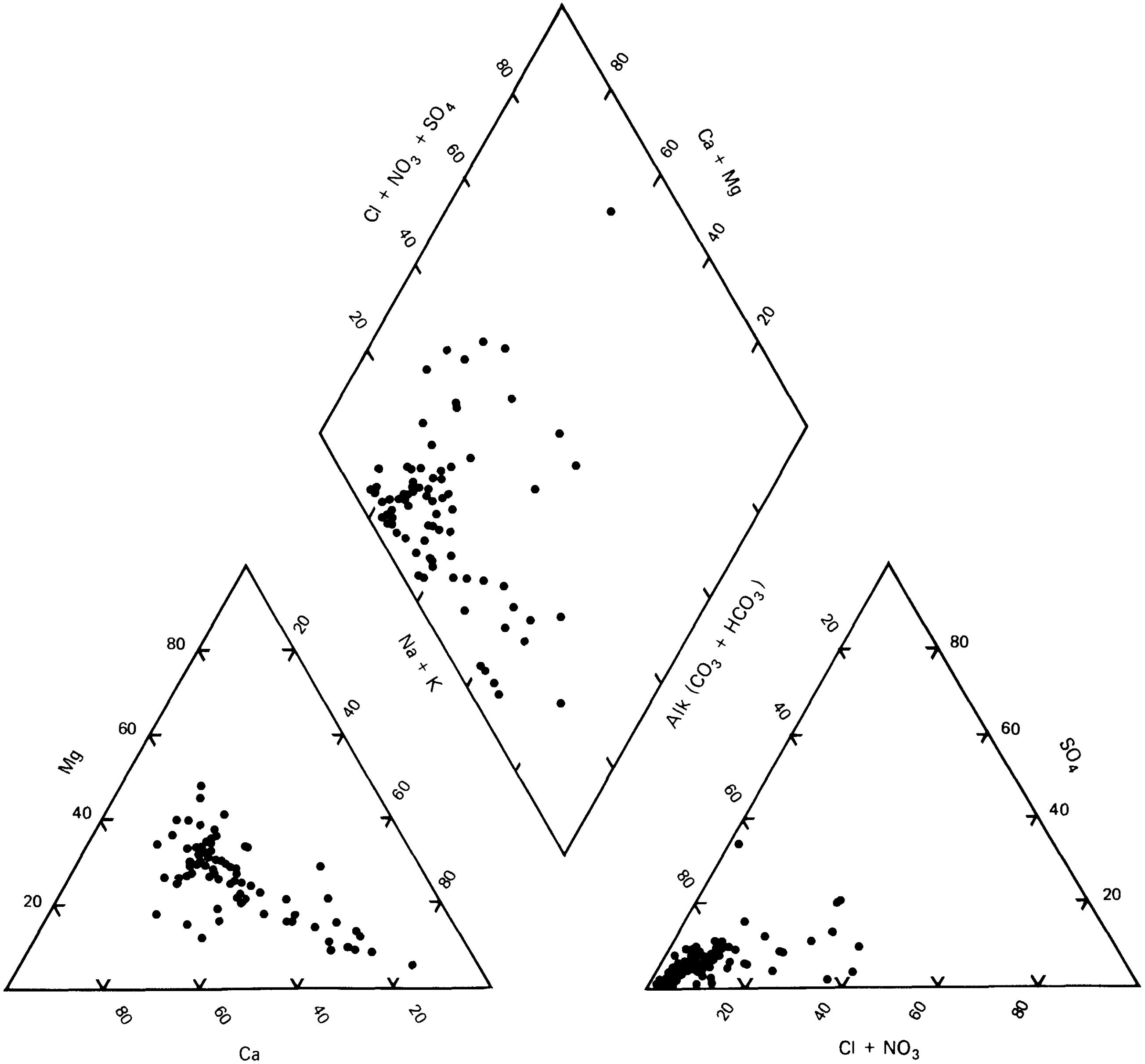
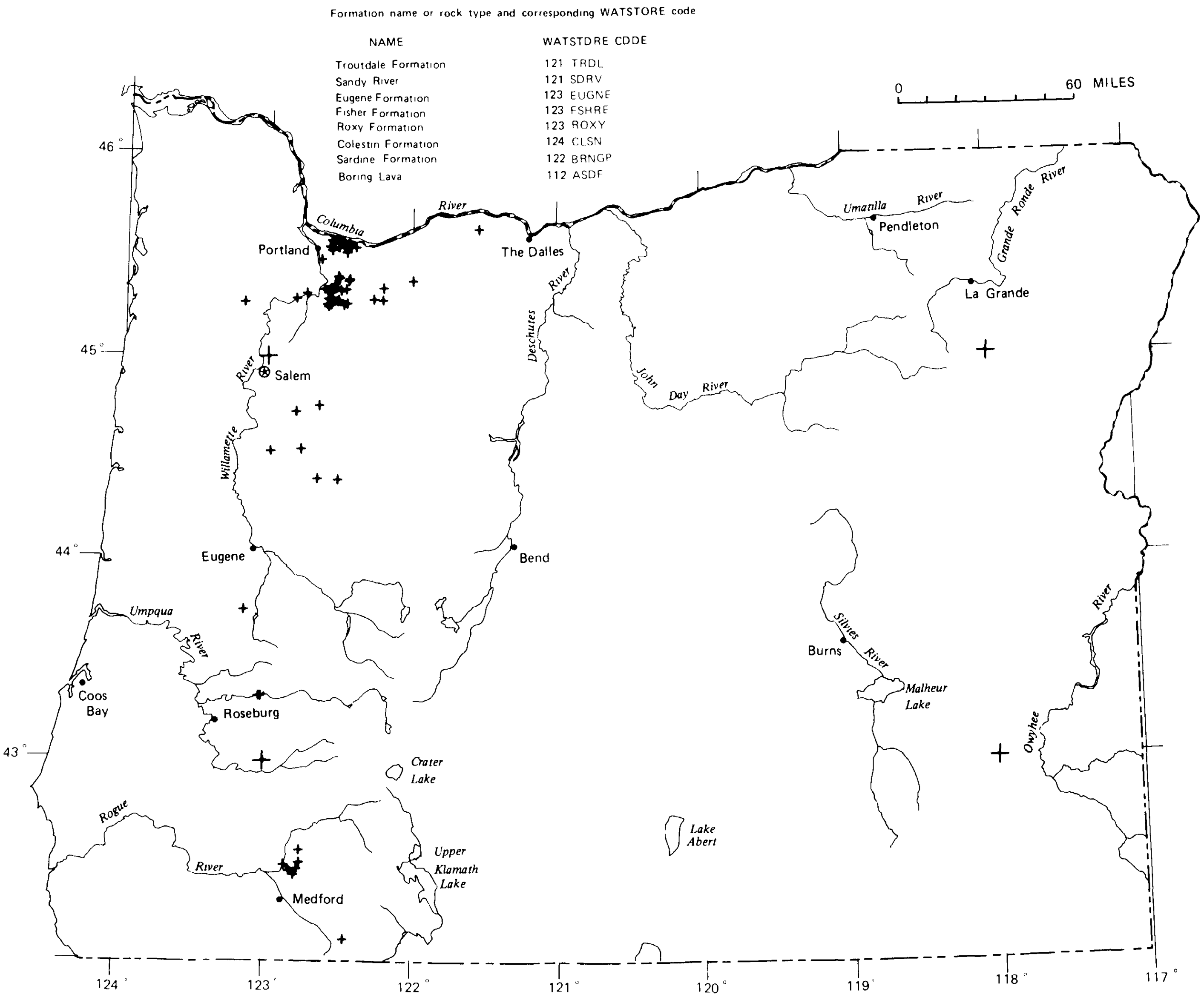


Figure 19.--Percentage composition of ions for Oregon ground-water quality sites in the Columbia River Basalt aquifer.


Formation name or rock type and corresponding WATSTORE code

NAME	WATSTDRE CDDE
Troutdale Formation	121 TRDL
Sandy River	121 SDRV
Eugene Formation	123 EUGNE
Fisher Formation	123 FSHRE
Roxy Formation	123 ROXY
Colestin Formation	124 CLSN
Sardine Formation	122 BRNGP
Boring Lava	112 ASDF

Figure 20.--Location of sampling sites for the Volcanic rocks of the western Cascades.

Table 12.--Descriptive statistics of ground-water quality for the Volcanic rocks of the Western Cascade Range (84 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
50	Calcium, dissolved	0.9	11	16	34	491
50	Magnesium, dissolved	.2	3.4	6.0	10	22
49	Sodium, dissolved	1.5	6.7	13	38	660
49	Potassium, dissolved	.2	.6	1.2	2.6	11
75	Sulfate, dissolved	.2	1.6	3.3	6.4	43
31	Nitrite + Nitrate, dissolved (as N)	.01	.04	.10	.22	7.1
78	Chloride, dissolved	1	2	3	7	1,850
77	Alkalinity, total (as $CaCO_3$)	8	62	75	108	419
83	pH (units)	6.0	6.9	7.3	7.6	9.0
83	Specific conductance (micromhos/cm at 25°C)	15	163	214	251	4,430
55	Hardness, total (as $CaCO_3$)	5	48	73	113	1,240
49	Dissolved solids (sum of constituents)	23	111	158	190	3,010
75	Temperature (°Celsius)	8	12	12	14	18
77	Bicarbonate (as HCO_3)	10	76	96	140	443
41	Iron, dissolved (ug/L)	10	10	40	170	1,600
33	Arsenic, dissolved (ug/L)	1	1	1	2	120
34	Boron, dissolved (ug/L)	20	20	20	98	9,900
73	Fluoride, dissolved	.1	.1	.1	.2	.9
49	Silica, dissolved (as SiO_2)	8.9	24	36	44	68
45	Collection depth (feet)	40	120	245	329	491

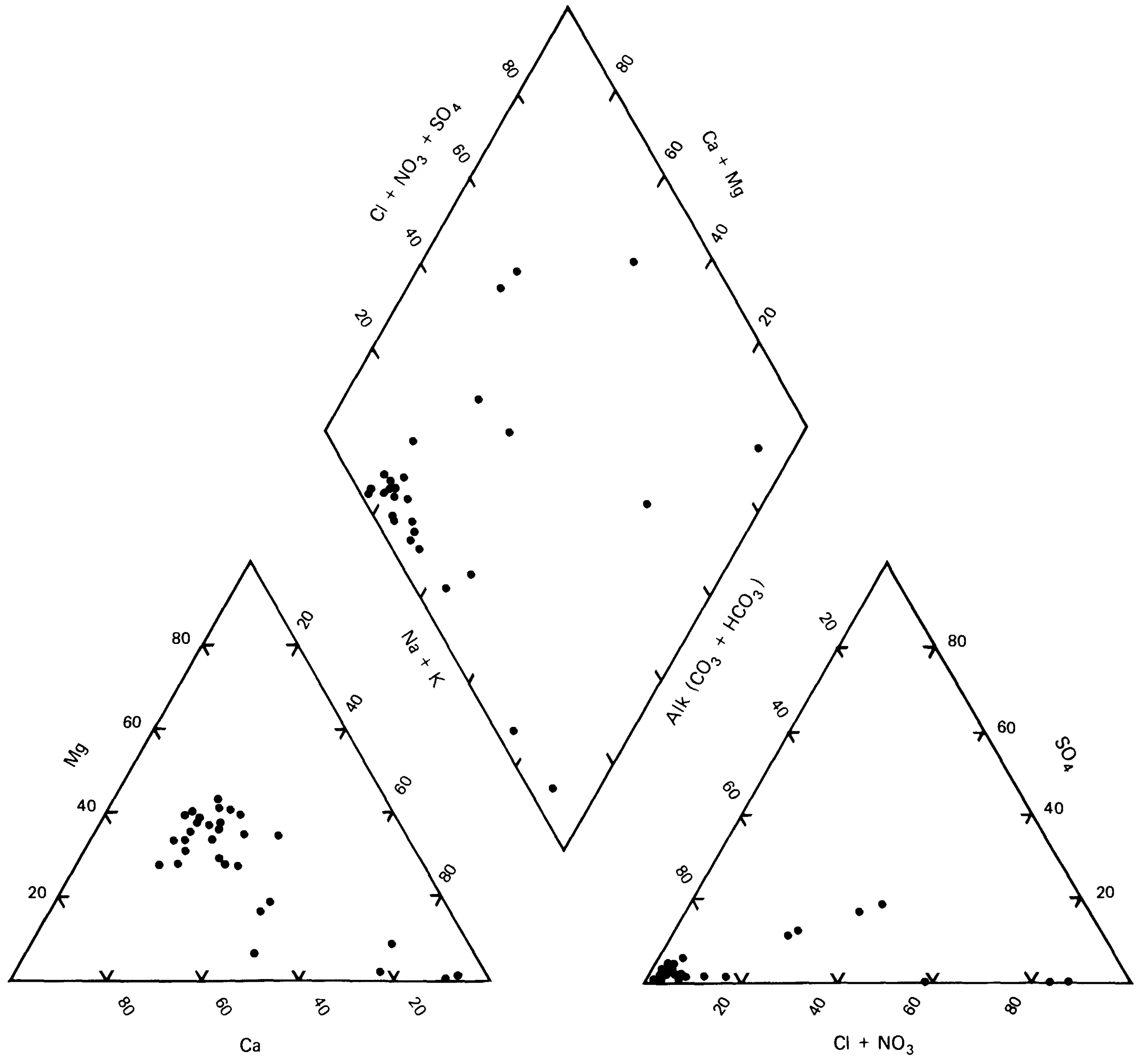


Figure 21.--Percentage composition of ions for Oregon ground-water quality sites in the Volcanic rocks of the western Cascades

Older Volcanic Aquifers

Figure 22 shows the locations of sampling sites and a list of geologic units included in this grouping. Areas where the Older volcanic rocks outcrop are shown in figure 12. Of the aquifer units discussed, this unit has the least number of samples (20), and all samples in this data set are from the Warm Springs Indian Reservation. They may not be representative of water quality in the rest of the outcrop area. The percentile values (table 13) are similar to the percentile values for the combined State data (table 6). One of the sites sampled is a hot spring; that sample had the maximum temperature for this unit and the maximum arsenic concentration for the combined Oregon data set.

The anions from the Older volcanic aquifer are also dominated by the constituents comprising alkalinity (fig. 23). The cation plot shows considerable scatter; sodium was the principal cation in water from about 50 percent of the sampling sites.

Pacific Slope Basins

The Pacific Slope Basins discussed below include all Oregon rivers draining to the Pacific Ocean except the Columbia River. Most of the samples included in this hydrologic unit were from the Rogue and Umpqua River basins. Table 14 shows that the percentile values for a large number of constituents are slightly higher than the same values for the combined Oregon data. For this hydrologic unit, the maximum values of calcium, sodium, potassium, sulfate, chloride, alkalinity, specific conductance, hardness, dissolved solids, bicarbonate, iron, and boron were also the maximum values of the entire combined Oregon data set. This is expected because the Marine rocks of the Coast Ranges and the Igneous and metamorphic rocks, which were examined earlier and are included in this hydrologic unit, were the aquifer units usually having the highest constituent concentrations and containing the most highly variable ground waters examined in this study. Potassium and silica were considerably lower in concentration than those found in the entire Oregon data set. This hydrologic unit also had the largest number of samples and the sampled wells generally were the shallowest wells of any unit examined.

The samples are from a large geographical area which includes several aquifer units. Constituents comprising alkalinity predominate the anions in most samples, but there are some samples that have high percentages of chloride (fig. 24). Cations show considerable scatter and calcium and sodium generally are the dominant cations. Data on the diamond plot have considerable scatter, but indicate a few samples were of the sodium-chloride type.

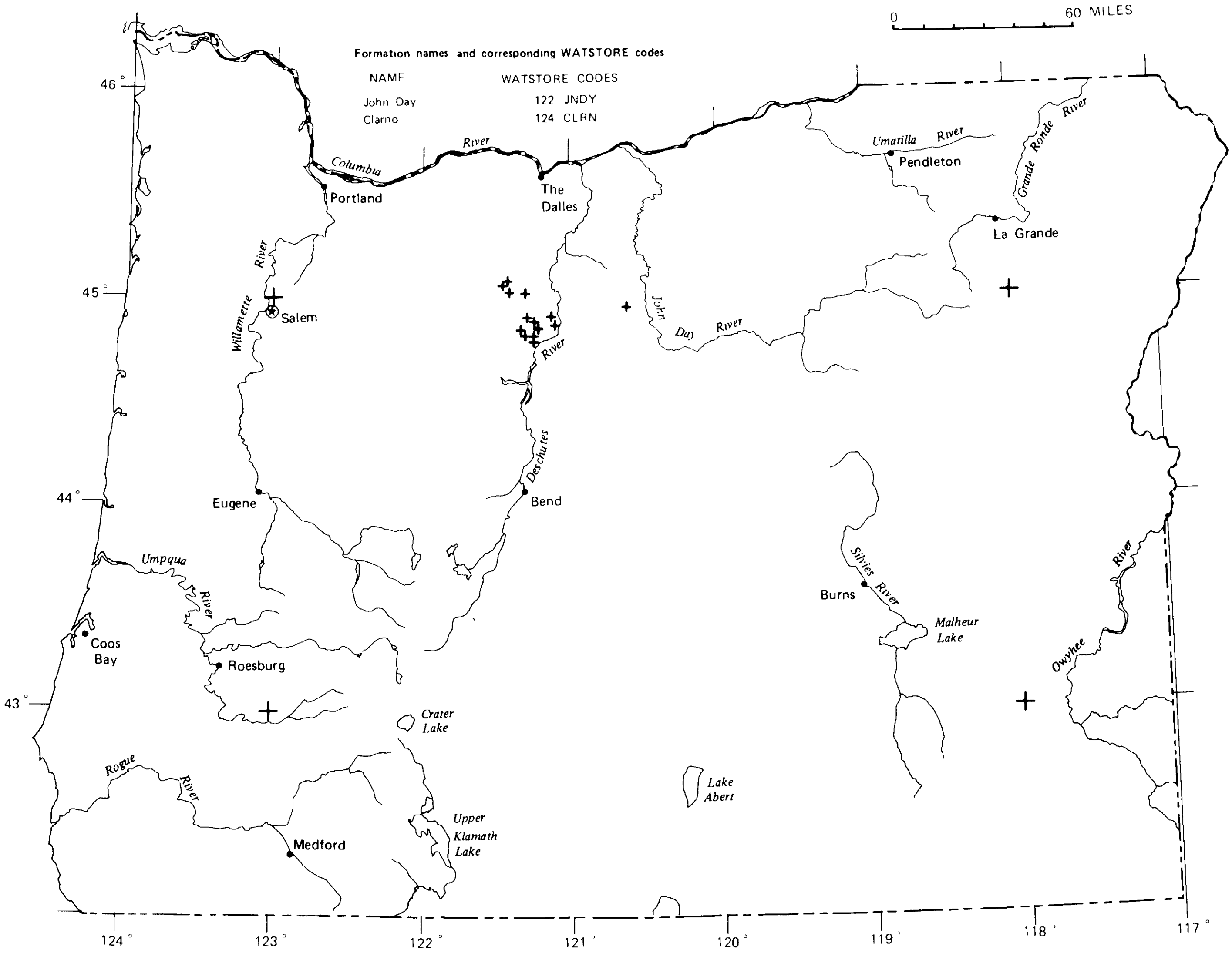


Figure 22.--Location of sampling sites for the Older volcanic aquifers.

Table 13.--Descriptive statistics of ground-water quality for the Older volcanic aquifers (20 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
16	Calcium, dissolved	5.2	8.7	12	22	41
16	Magnesium, dissolved	.2	2.2	4.2	6.1	8.4
16	Sodium, dissolved	4.7	12	16	67	400
16	Potassium, dissolved	.8	1.2	3.6	6.2	11
16	Sulfate, dissolved	1.0	2.0	6.2	15	39
16	Nitrite + Nitrate, dissolved (as N)	.03	.10	.19	.92	2.4
16	Chloride, dissolved	1	2	2	16	240
16	Alkalinity, total (as $CaCO_3$)	44	57	100	205	494
16	pH (units)	7.0	7.4	7.6	8.1	8.8
16	Specific conductance	104	126	252	462	1,790
16	(micromhos/cm at 25°C)					
16	Hardness, total (as $CaCO_3$)	14	36	54	74	140
16	Dissolved solids (sum of constituents)	96	115	212	329	1,100
17	Temperature (°Celsius)	6	12	16	17	84
16	Bicarbonate (as HCO_3)	54	69	122	250	603
16	Iron, dissolved (ug/L)	10	50	70	298	680
14	Arsenic, dissolved (ug/L)	1	--	2	--	340
6	Boron, dissolved (ug/L)	20	--	20	--	5,600
16	Fluoride, dissolved	.1	.1	.2	.8	27
16	Silica, dissolved (as SiO_2)	38	42	64	73	78
1	Collection depth (feet)	124	--	--	--	124

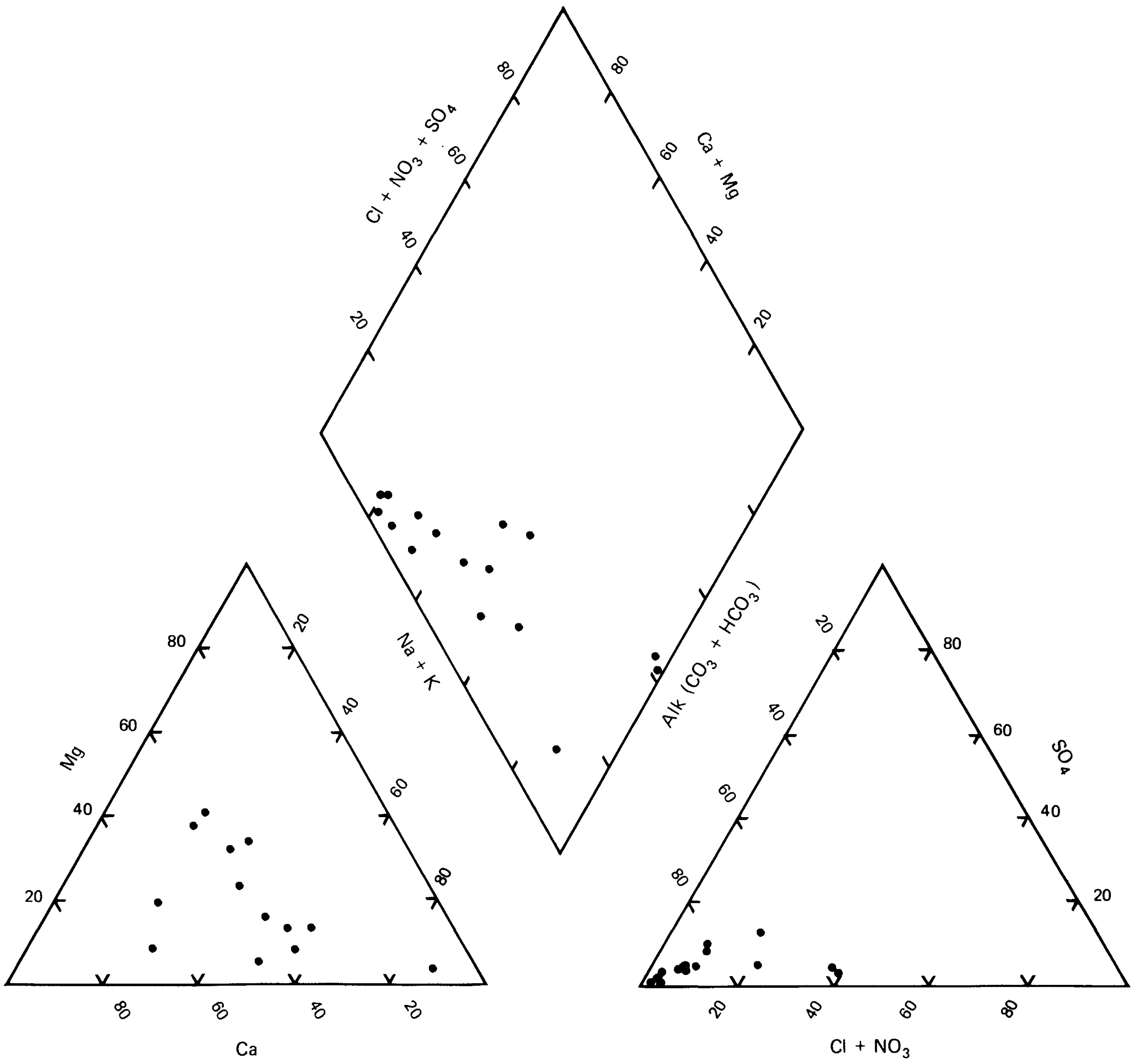


Figure 23.--Percentage composition of ions for Oregon ground-water quality sites in the Older volcanic aquifers.

Table 14.--Descriptive statistics of ground-water quality for th Pacific Slope Basins (458 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
458	Calcium, dissolved	0.3	8.7	26	49	5,000
451	Magnesium, dissolved	.1	2.3	6.4	14	156
439	Sodium, dissolved	1.5	11	29	98	5,000
418	Potassium, dissolved	.1	.5	.9	1.5	73
421	Sulfate, dissolved	.1	3.6	7.4	19	690
240	Nitrite + Nitrate, dissolved (as N)	.01	.03	.10	.40	15
435	Chloride, dissolved	1	4	13	45	14,000
458	Alkalinity, total (as $CaCO_3$)	1	78	140	207	3,570
453	pH (units)	5.4	6.9	7.5	8.0	10.0
457	Specific conductance (micromhos/cm at 25°C)	3	235	387	628	35,000
458	Hardness, total (as $CaCO_3$)	1	38	100	187	13,000
428	Dissolved solids (sum of constituents)	37	159	247	404	7,050
338	Temperature (°Celsius)	3.8	12	14	16	63
362	Bicarbonate (as HCO_3)	1	101	178	263	4,353
268	Iron, dissolved (ug/L)	3	20	60	220	32,000
159	Arsenic, dissolved (ug/L)	1	1	1	3	189
294	Boron, dissolved (ug/L)	1	20	80	410	16,000
429	Fluoride, dissolved	.1	.1	.2	.4	13
435	Silica, dissolved (as SiO_2)	2.7	16	24	35	110
234	Collection depth (feet)	10	66	102	156	735

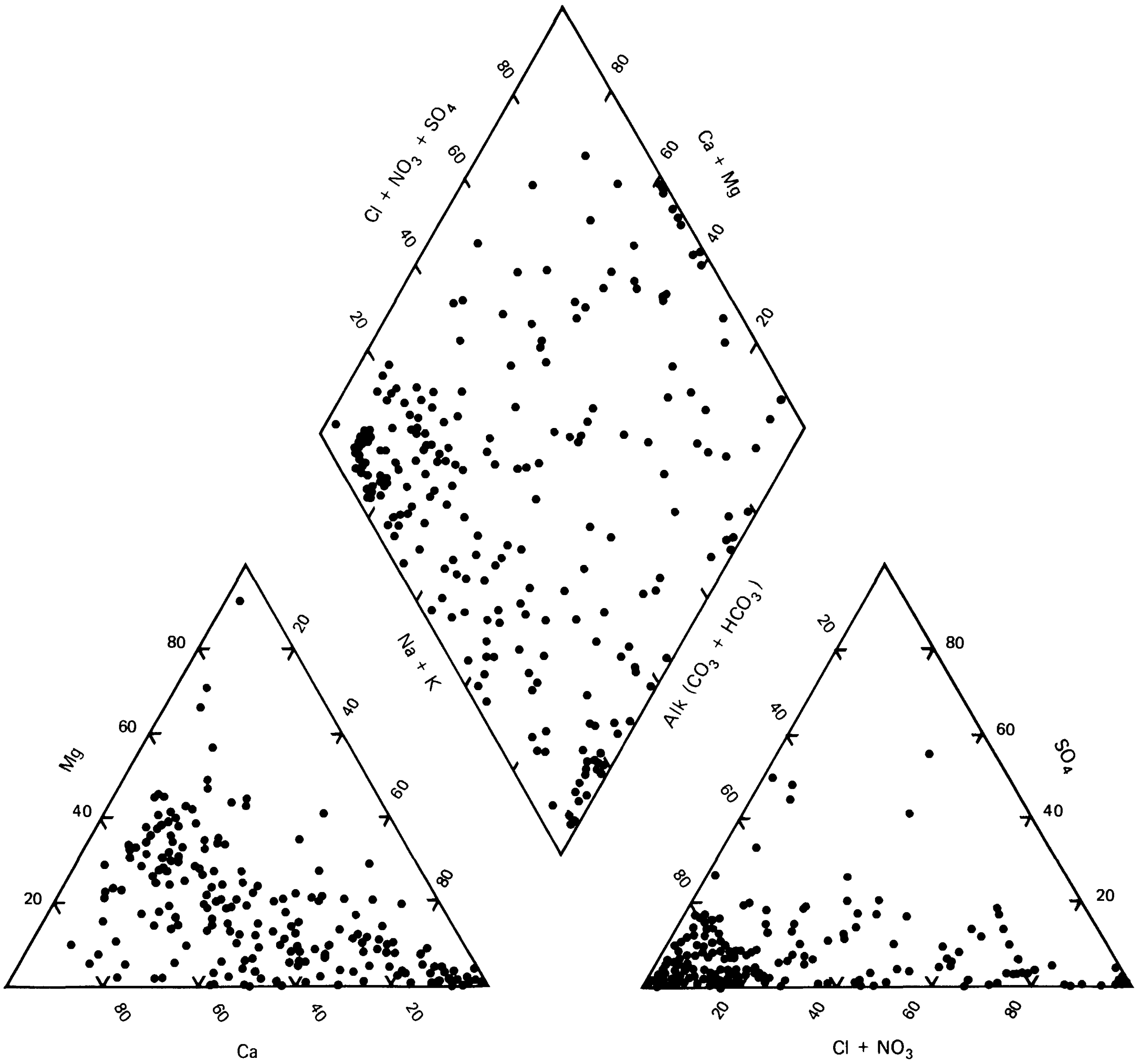


Figure 24.--Percentage composition of ions for Oregon ground-water quality sites in the Pacific Slope Basins.

Willamette River Basin

The Willamette River basin is the most populous in the State. Samples from this area include four of the aquifer units already examined. The units are Basin-fill and alluvial aquifers, Marine rocks of the Coast Range, Columbia River basalt aquifer, and Volcanic rocks of the Western Cascades with most of the samples coming from the first two units. The percentile values in table 15 are similar in magnitude to those for the entire combined Oregon data set. The maximum values in this data set for magnesium, nitrite plus nitrate, and pH are the highest values for the entire combined data set.

Constituents comprising alkalinity predominate the anions in samples from the Willamette Basin (fig. 25). Chloride was predominant in some samples. Cation data percentages cluster in an area where magnesium and sodium plus potassium ions range from 20 to 40 percent. A few samples had high sodium percentages and just less than half the samples are of sodium-chloride type water.

Lower Columbia River Basin

The Lower Columbia River basin in Oregon includes all rivers east of the Cascade Range that drain directly to the Columbia River. The statistical data in table 16 show percentile values generally much lower than those for the combined Oregon data set which probably results from many of the samples coming from the Columbia River Basalt aquifer. Noticeable is the low maximum chloride value of 240 mg/L. The 75th percentile for boron is only 40 ug/L. This hydrologic unit contains a hot spring (temperature 84 degrees Celsius) which also had the maximum observed arsenic value of 340 ug/L. Samples taken from this unit were from relatively deep wells with a median depth of 264 feet. When compared to the entire combined Oregon data set, specific conductance is lower, although dissolved solids showed almost no difference because of the increase in silica.

The trilinear plot (fig. 26) for the Lower Columbia Basin shows that the constituents comprising alkalinity dominate the anions. Calcium and magnesium are the principal cations but neither ion is dominant.

Klamath River Basin

Wells sampled in the Klamath River basin are some of the deeper wells in the data set and include the deepest well (1,128 feet). The concentrations of calcium, sodium, sulfate, and chloride are low while potassium and silica values are high (table 17) in relation to the combined Oregon data set. Only nine samples were analyzed for nitrite plus nitrate; the median concentration of these samples was more than twice that determined for the combined data. This may be the effect of small sample size and the site selection process.

Table 15.--Descriptive statistics of ground-water quality for the Willamette River basin (257 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
204	Calcium, dissolved	0.9	10	17	32	3,600
202	Magnesium, dissolved	.1	2.9	6.6	11	210
203	Sodium, dissolved	1.6	7.6	14	51	3,000
203	Potassium, dissolved	.1	.7	1.3	2.6	16
237	Sulfate, dissolved	.1	1.6	4.6	11	500
146	Nitrite + Nitrate, dissolved (as N)	.01	.06	.13	.86	24
246	Chloride, dissolved	1	2	5	13	8,600
196	Alkalinity, total (as $CaCO_3$)	2	53	76	117	709
249	pH (units)	5.3	6.8	7.2	7.7	10.6
249	Specific conductance (micromhos/cm at 25°C)	2	169	224	326	24,300
210	Hardness, total (as $CaCO_3$)	4	42	73	120	9,000
201	Dissolved solids (sum of constituents)	23	124	168	282	5,650
235	Temperature (°Celsius)	6.5	12	12	14	70
244	Bicarbonate (as HCO_3)	3	63	90	143	808
193	Iron, dissolved (ug/L)	10	20	60	315	19,000
139	Arsenic, dissolved (ug/L)	1	1	1	2	120
167	Boron, dissolved (ug/L)	2	20	30	250	2,800
228	Fluoride, dissolved	.1	.1	.1	.2	1.1
203	Silica, dissolved (as SiO_2)	3.2	24	34	45	85
136	Collection depth (feet)	15	78	130	300	1,005

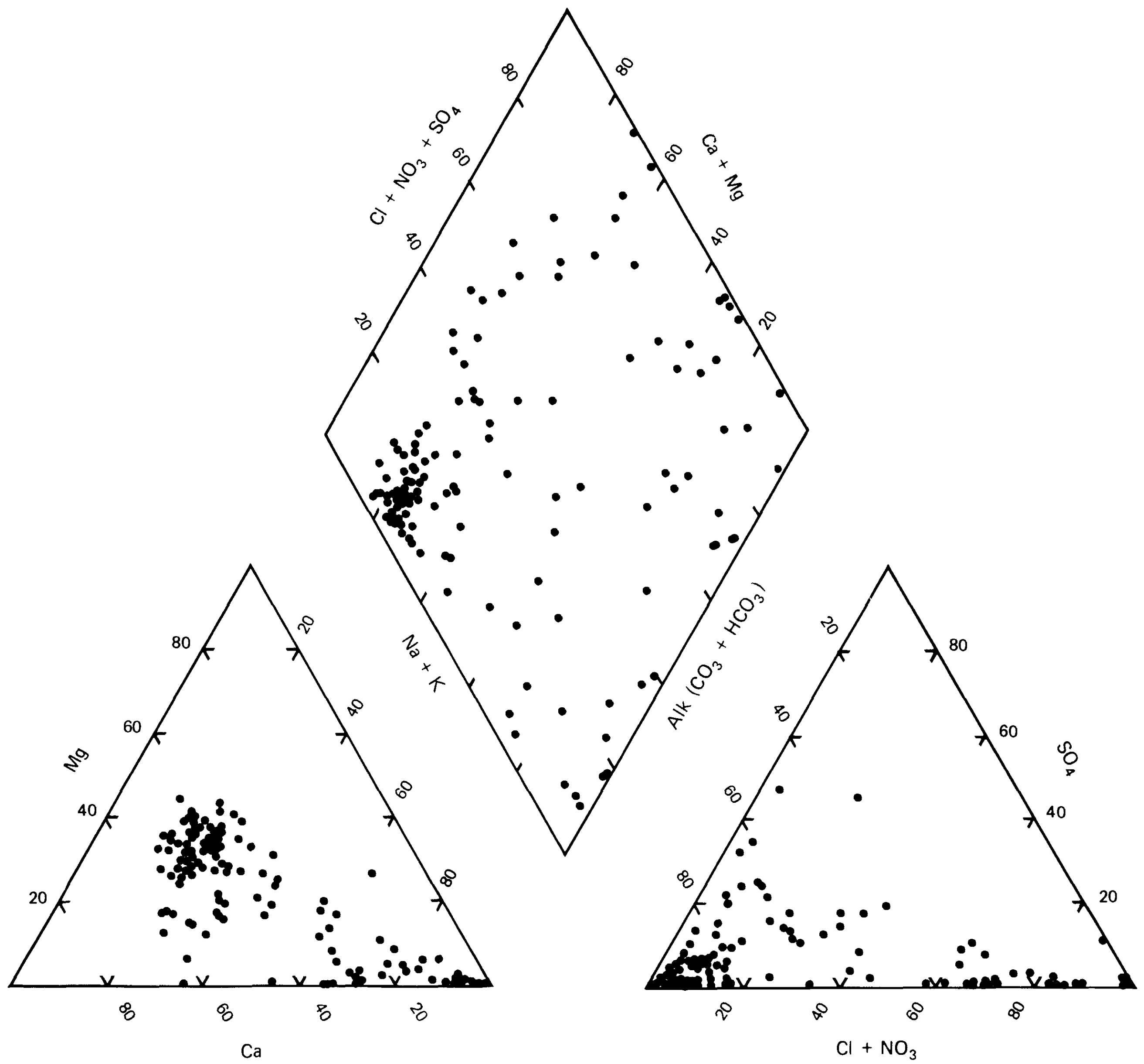


Figure 25.--Percentage composition of ions for Oregon ground-water quality sites in the Willamette River basin.

Table 16.--Descriptive statistics of ground-water quality for the Lower Columbia River basin (180 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
169	Calcium, dissolved	0.4	7.7	14	22	77
168	Magnesium, dissolved	.2	3.8	6.3	11	51
167	Sodium, dissolved	1.7	8.7	16	31	400
171	Potassium, dissolved	.1	1.8	3.0	4.8	18
175	Sulfate, dissolved	.3	1.9	4.1	11	200
166	Nitrite + Nitrate, dissolved (as N)	.01	.10	.24	.98	19
168	Chloride, dissolved	1	1	3	5	240
175	Alkalinity, total (as $CaCO_3$)	1	55	99	140	573
161	pH (units)	3.4	7.2	7.6	8.0	8.8
174	Specific conductance (micromhos/cm at 25°C)	32	118	228	330	1,790
169	Hardness, total (as $CaCO_3$)	1	36	63	99	350
134	Dissolved solids (sum of constituents)	24	146	201	246	1,100
168	Temperature (°Celsius)	3.0	10	13	15	84
102	Bicarbonate (as HCO_3)	21	100	138	182	698
133	Iron, dissolved (ug/L)	10	20	50	190	15,000
132	Arsenic, dissolved (ug/L)	1	1	1	3	340
136	Boron, dissolved (ug/L)	2	20	20	40	5,600
171	Fluoride, dissolved	.1	.1	.2	.5	27
175	Silica, dissolved (as SiO_2)	.9	38	51	59	190
120	Collection depth (feet)	5	114	264	447	1,103

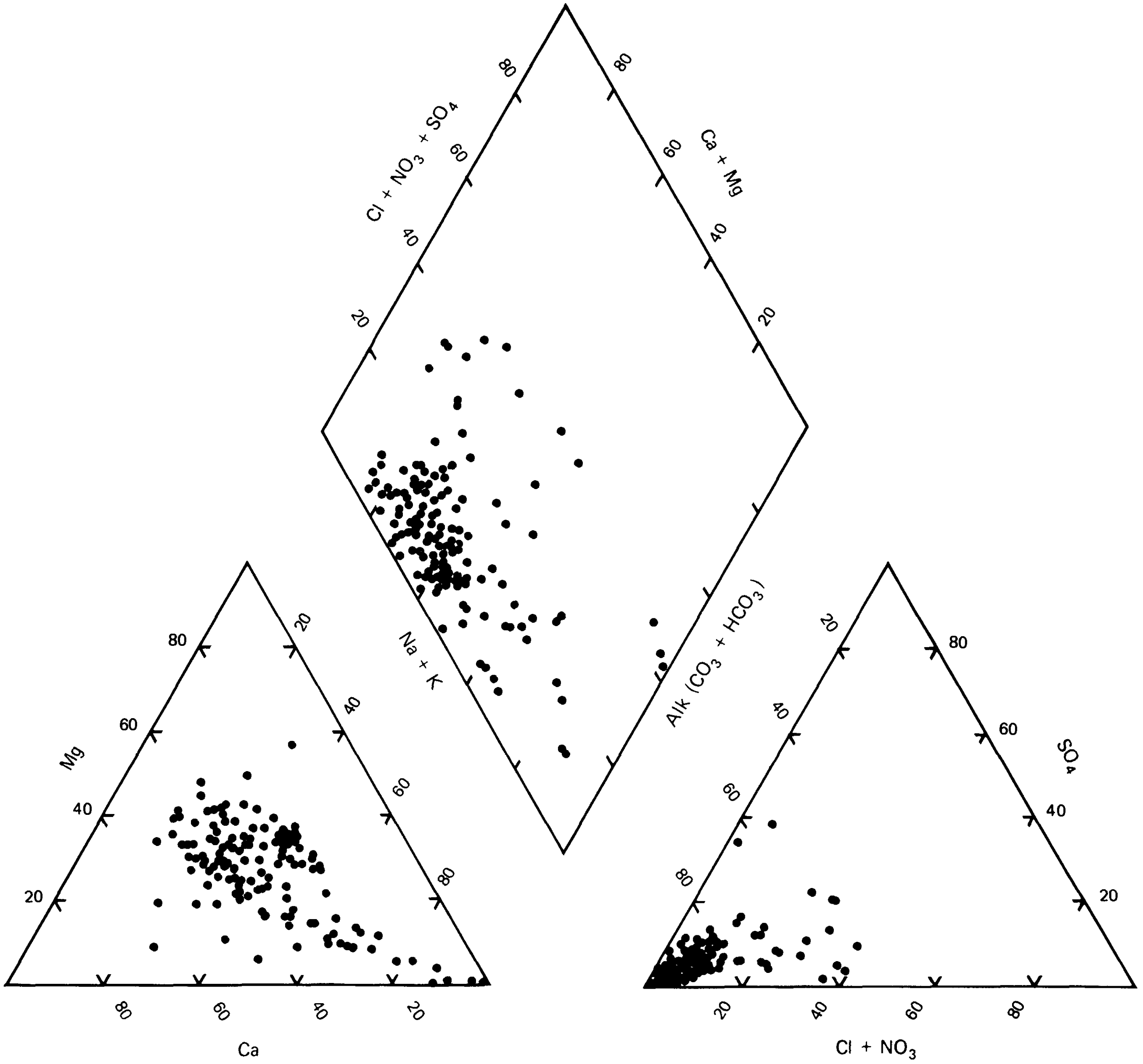


Figure 26.--Percentage composition of ions for Oregon ground-water quality sites in the Lower Columbia River basin.

Table 17.--Descriptive statistics of ground-water quality for the Klamath River basin (57 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
57	Calcium, dissolved	2.0	6.6	12	18	180
56	Magnesium, dissolved	.1	3.0	6.8	11	47
52	Sodium, dissolved	5.0	8.6	16	29	480
51	Potassium, dissolved	.5	1.6	2.4	4.0	18
56	Sulfate, dissolved	.1	2.2	3.7	9.5	300
9	Nitrite + Nitrate, dissolved (as N)	.03	--	.38	--	6.8
53	Chloride, dissolved	1	1	2	4	170
19	Alkalinity, total (as $CaCO_3$)	70	90	119	168	1,190
57	pH (units)	6.7	7.7	7.9	8.2	9.1
57	Specific conductance (micromhos/cm at 25°C)	56	144	192	270	2,700
56	Hardness, total (as $CaCO_3$)	9	28	61	88	640
57	Dissolved solids (sum of constituents)	60	116	150	202	2,000
45	Temperature (°Celsius)	1	12	16	22	35
57	Bicarbonate (as HCO_3)	31	77	111	152	1,449
34	Iron, dissolved (ug/L)	20	20	40	168	3,000
21	Arsenic, dissolved (ug/L)	1	1	2	4	20
39	Boron, dissolved (ug/L)	9	10	20	40	1,400
52	Fluoride, dissolved	.1	.1	.1	.2	1.4
55	Silica, dissolved (as SiO_2)	30	38	45	51	89
15	Collection depth (feet)	67	150	250	820	1,128

Only 8 samples in the Klamath Basin had data for each of the major ions. Even though the number of samples is small, figure 27 shows a pattern similar to other basins. Constituents comprising alkalinity dominate the anions. The cations are mixed showing no dominant species.

The Great Basin

This hydrologic unit is in south central Oregon and includes several closed basins (table 18). Percentile values generally are higher than those of the combined Oregon data, and the basin had the deepest median sampled well depth, 338 feet. Arsenic, boron and potassium percentile values were greater than those for the combined data set. Arsenic 50- and 75-percentile values were 5 and 37 ug/L, respectively, compared to 1 and 3 ug/L for the combined Oregon data. Boron percentile values were about three times higher, and the percentile values for potassium were two to three times greater than for the combined Oregon values shown.

The trilinear plot for The Great Basin data was similar to plots for other hydrologic units and indicates constituents comprising alkalinity dominate the anions (fig. 28). Cations, however, are mixed showing sodium possibly having dominance in a majority of samples.

Snake River Basin

This hydrologic unit includes the Oregon streams tributary to the Snake River system. The Snake River basin has the smallest number of ground-water samples (39) of all the hydrologic units examined. Maximum values for most constituents are low compared to other hydrologic units but, the 25-, 50-, and 75-percentile values generally were higher (table 19). All major ions have higher percentile values than the combined Oregon data and sulfate values were seven to ten times greater. Arsenic median and 75-percentile concentrations were 10 to 30 times higher than those found in any other hydrologic unit or aquifer unit. Boron values also tend to be high compared to other units, but similar to those in The Great Basin, and in the Marine rocks of the Coast Ranges. The preponderance of volcanic and volcaniclastic rocks along with the arid climate may partially explain the high concentrations of these ions in the Snake River basin and The Great Basin. Many of the samples are from the Volcanic and sedimentary aquifer and the Basin-fill and alluvial aquifers. High concentrations of these ions are reported in shallow ground waters beneath some playas in southeast Oregon. The maximum silica value for the combined data was from a hot spring in the Snake River basin.

Major ion data (fig. 29) indicate constituents comprising alkalinity dominate the anions for a majority of samples. Sodium is the dominant cation in a majority of samples.

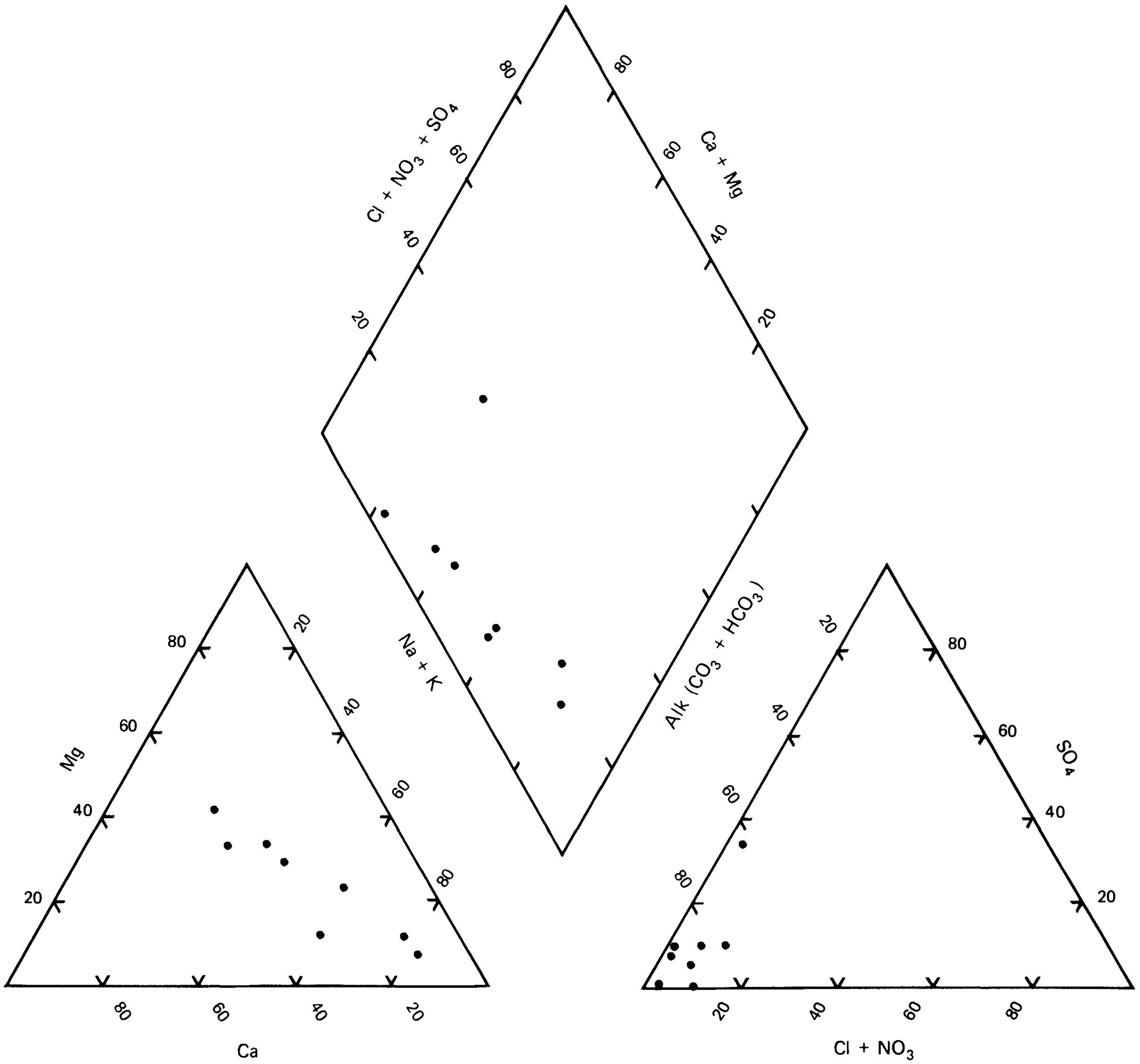


Figure 27.--Percentage composition of ions for Oregon ground-water quality sites in the Klamath River basin.

Table 18.--Descriptive statistics of ground-water quality for The Great Basin (54 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
51	Calcium, dissolved	0.5	6.4	16	25	97
51	Magnesium, dissolved	.1	3.7	6.3	14	177
51	Sodium, dissolved	2.2	22	37	135	835
51	Potassium, dissolved	.4	2.9	4.4	8.0	33
51	Sulfate, dissolved	.4	6.9	12	29	269
27	Nitrite + Nitrate, dissolved (as N)	.01	.08	.72	1.4	3.5
53	Chloride, dissolved	1	3	9	24	975
27	Alkalinity, total (as $CaCO_3$)	16	73	120	200	514
53	pH (units)	6.2	7.4	7.6	8.0	9.6
54	Specific conductance (micromhos/cm at 25°C)	50	225	342	692	4,000
51	Hardness, total (as $CaCO_3$)	2	32	75	120	374
51	Dissolved solids (sum of constituents)	40	180	263	419	3,090
51	Temperature (°Celsius)	4.4	12	14	18	72
34	Bicarbonate (as HCO_3)	49	123	180	480	2,000
39	Iron, dissolved (ug/L)	10	20	50	200	3,200
34	Arsenic, dissolved (ug/L)	1	2	5	37	240
43	Boron, dissolved (ug/L)	7	70	130	610	8,900
54	Fluoride, dissolved	.1	.3	.4	.8	19
54	Silica, dissolved (as SiO_2)	4	40	52	60	98
23	Collection depth (feet)	110	151	338	490	685

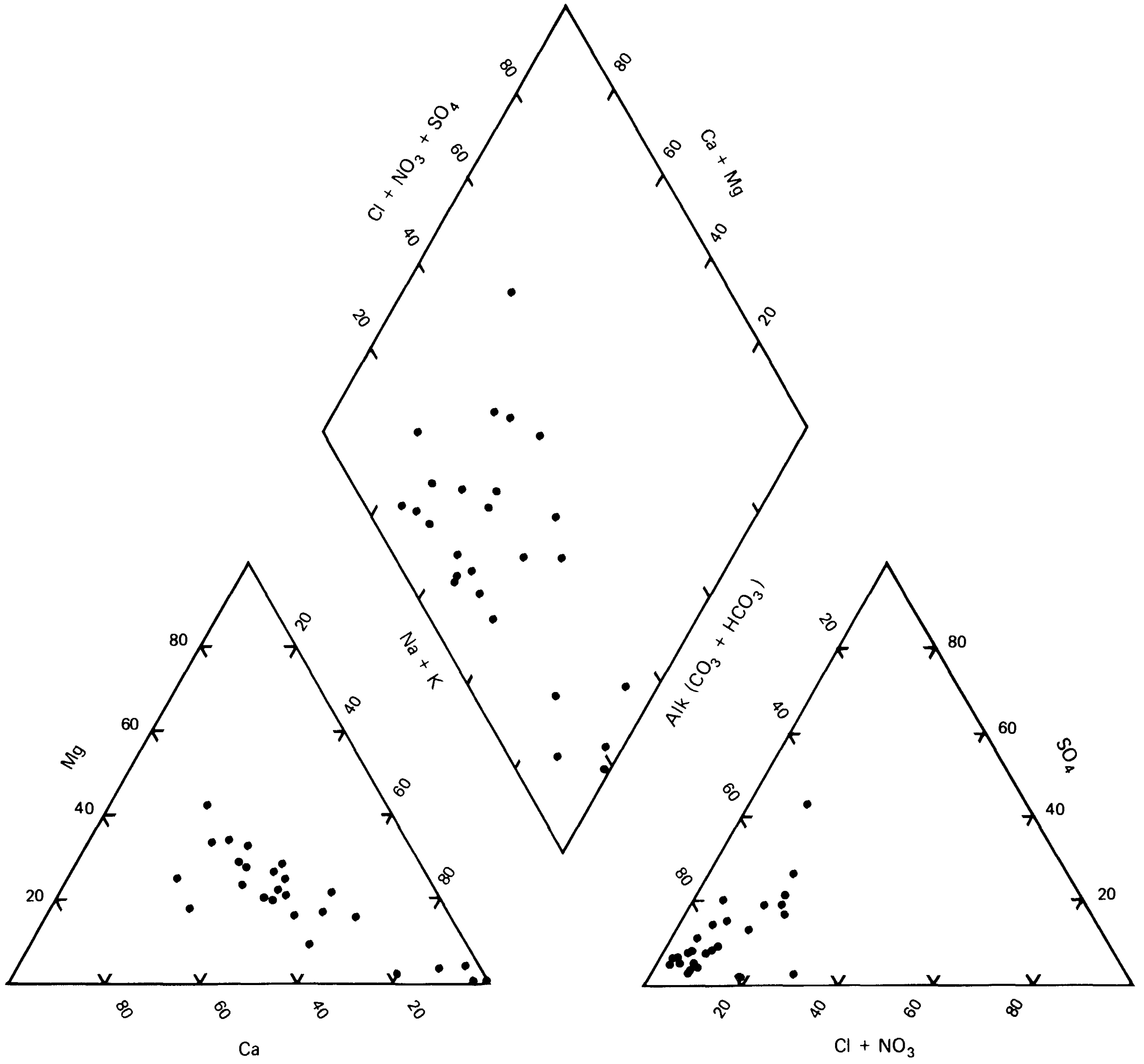


Figure 28.--Percentage composition of ions for Oregon ground-water quality sites in the Great Basin.

Table 19.--Descriptive statistics of ground-water quality for the Snake River basin (39 total analyses)

[Units are mg/L except as noted.]

Number of samples	Constituent analyzed	Minimum	25 percentile	Median-50 percentile	75 percentile	Maximum
37	Calcium, dissolved	2.7	18	29	54	109
38	Magnesium, dissolved	.1	4.2	11	18	109
38	Sodium, dissolved	2.7	21	56	84	470
37	Potassium, dissolved	1	4.8	6.2	12	28
32	Sulfate, dissolved	2.3	18	68	118	680
23	Nitrite + Nitrate, dissolved (as N)	.02	.11	.47	.96	16
36	Chloride, dissolved	1	5	10	34	120
21	Alkalinity, total (as $CaCO_3$)	15	95	140	275	890
35	pH (units)	6.1	7.1	7.6	8.2	9.1
39	Specific conductance (micromhos/cm at 25°C)	52	320	550	850	2,130
37	Hardness, total (as $CaCO_3$)	7	58	108	203	720
15	Dissolved solids (sum of constituents)	129	--	376	--	1,400
29	Temperature (°Celsius)	9.6	13	16	24	62
27	Bicarbonate (as HCO_3)	18	130	195	258	1,085
22	Iron, dissolved (ug/L)	10	30	75	212	1,500
27	Arsenic, dissolved (ug/L)	1	3	10	94	180
25	Boron, dissolved (ug/L)	7	70	130	720	4,400
29	Fluoride, dissolved	.1	.3	.4	.8	9.8
36	Silica, dissolved (as SiO_2)	13	44	53	74	370
13	Collection depth (feet)	55	84	150	462	718

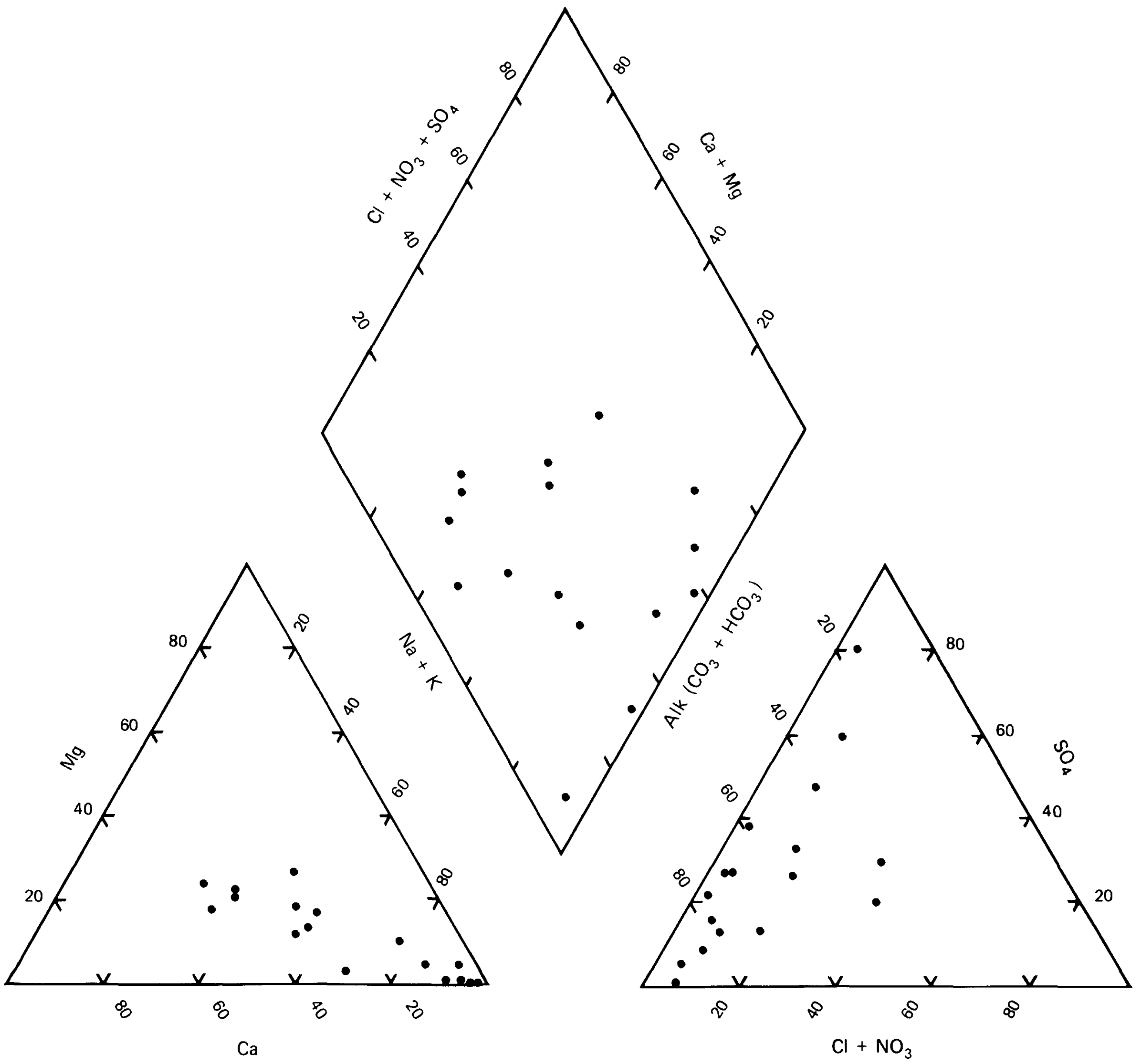


Figure 29.--Percentage composition of ions for Oregon ground-water quality sites in the Snake River basin.

Analysis of Variance

Examination of the descriptive statistics calculated for constituents in tables 6 through 19 indicates there are differences in concentrations among aquifer units and hydrologic units. The differences between percentile values in each unit are as much as one order of magnitude, although they generally are smaller. An analysis of variance (ANOVA) procedure was used to determine if the differences between units are significant. The test was performed independently on the data segregated in the first test by aquifer unit and in the second test by hydrologic unit. A significant difference between units within a classification then is dependent on the strength of the relationship between the class variable and the causes of variation in specific constituents. If the class variable is not related to the cause of variation for a specific constituent, then there should be no significant difference between units within a class for that constituent.

All statistical procedures used in this analysis were performed using the Statistical Analysis System (SAS), SAS Institute Inc., 1982a. One of the assumptions of the ANOVA procedure is that the data within classes are normally distributed. This assumption was tested using the modified Kolmogorv-Smirinov and Shapiro-Wilk methods (SAS Institute, Inc., 1982b, p. 580). The results indicated that many of the data subsets were not normally distributed. Log transformations of the data did not change the results for many of the subsets. Because much of the data did not meet the test assumptions of normality, procedures known as nonparametric or distribution-free tests were used (Conover, 1980). Data were ranked regardless of level within the class for each constituent, then the ranks were analyzed with ANOVA procedures.

ANOVA tests whether differences between units are due to chance or are due to the tested effect which, in this study, is the class variable. As an example, ANOVA tested the specific conductance values segregated by aquifer unit, and indicated if differences in the specific conductance values between the seven aquifer units occurred because of chance or because at least one unit has conductance values significantly different from the other aquifer units. The results of ANOVA are shown in table 20 for the two class variables, aquifer unit and hydrologic unit. Each test of the class variable was made independent of the other. Thus, the results in table 20 do not reflect interaction between the class variables. The table lists probabilities that differences between units within a class variable are due to chance instead of the tested effect. As an example, for specific conductance values segregated by aquifer units, there is a 0.0001 probability that differences between units were due to chance and not the tested effect.

Table 20.--Results of analysis of variance on ranks

[Shown are probabilities that observed differences are due to chance rather than the tested effect and percent variation explained (R^2).]

Water-quality constituent	Aquifer units		Hydrologic units	
	p level	R^2	p level	R^2
Calcium	0.0001	8	0.0001	5
Magnesium	.0001	12	.2304	1
Sodium	.0001	16	.0001	8
Potassium	.0001	25	.0001	35
Sulfate	.0001	6	.0001	10
Nitrite + Nitrate	.0001	12	.0001	6
Chloride	.0001	15	.0001	17
Alkalinity	.0001	13	.0001	7
pH	.0001	9	.0001	6
Specific conductance	.0001	16	.0001	12
Hardness	.0001	7	.0001	3
Dissolved solids	.0001	12	.0001	7
Temperature	.0001	4	.0001	9
Bicarbonate	.0001	10	.0001	11
Iron	.0012	4	.6336	1
Arsenic	.0001	16	.0001	14
Boron	.0001	16	.0001	13
Fluoride	.0001	13	.0001	15
Silica	.0001	35	.0001	33

Similarily, for iron segregated by hydrologic unit, there is a 0.6336 probability that the differences between units are due to chance. Thus, the tested affect results in significant differences between units for specific conductance, but not for iron because there is a 63 percent probability that differences between units based on iron values is due to chance. The probability values in the table indicate that for most constituents, at least one unit differs from the other units for each class variable. The exceptions are iron values and magnesium values classified by hydrologic units. Because the class variables affect most constituents, the results imply that both aquifer unit source and hydrologic unit source represent effects causing significant differences in constituent concentrations. The percent of variation in the data explained by the classification variable is represented (table 20) by R^2. Note for aquifer units, the variation explained ranged from 4 to 35 percent. For hydrologic units, the variation explained ranged from 1 to 35 percent. The ANOVA results do not directly indicate which class separation provides a better explanation of the variation.

As previously stated, use of the ANOVA procedure determines if at least one of the units within a classification is significantly different from the other units. ANOVA, however, does not indicate which unit is different. To provide that information, Tukey's studentized multiple range test was used (SAS, 1982a, p. 151).

The error rate for the test was set at 0.05 which yields an overall error probability of 5 percent for indicating that one or more unit means are significantly different from the others when they are actually not significantly different. The results are listed in tables 21 and 22. Note that in each table the units have been grouped so that those that are not significantly different have the same letter. The letters do not represent particular groups with specific attributes, but are labels for units that are not significantly different at the 0.05 level. For example, the specific conductance values for aquifer units in table 21 have been put into three groups. Four of the units (in group B) are indistinguishable from each other, but units in group A have significantly different specific conductance values from the conductance values in group B. The Older volcanic aquifers were placed in two groups indicating those specific conductance values are only significantly different from conductance values in units that do not have letters B or C (in this case, only Marine rocks of the Coast Ranges). Because specific conductance samples from the Igneous and metamorphic rocks of the Klamath Mountains were placed into groups A and C, these conductance values are significantly different from conductance values in units given only the letter B designation.

Table 21.--Results of Tukey's multiple range test on analysis of variance of aquifer units

[Units with the same letter are not significantly different, p = 0.05. Values are the order of mean ranks for the units, 1 = highest mean rank]

AUS average unit separation	Constituent analyzed	Basin-fill and alluvial	Rank	Marine rocks of the Coast Range	Rank	Igneous and metamorphic rocks of the Klamath Mountains	Rank	Volcanic and sedimentary aquifer	Rank	Columbia River basalt aquifer	Rank	Volcanic rocks of of the western Cascades	Rank	Older volcanic aquifers	Rank	AUS average unit separation without Older volcanic aquifers
4.3	Calcium, dissolved	B	4	B	2	A	1	C	7	B	3	BC	5	BC	6	5.3
4.8	Magnesium, dissolved	AB	2	C	6	A	1	C	5	AB	3	BC	4	C	7	4.7
2.4	Sodium, dissolved	B	6	A	1	B	3	B	4	B	5	B	7	AB	2	3.3
6.2	Potassium, dissolved	BC	4	D	6	D	7	A	2	A	1	CD	5	AB	3	6.7
4.3	Sulfate, dissolved	C	4	AB	2	A	1	CD	6	BC	3	D	7	ACD	5	6.0
2.4	Nitrite + Nitrate, dissolved (as N)	A	1	C	6	BC	5	AB	4	AB	3	BC	7	AC	2	3.3
5.7	Chloride, dissolved	B	3	A	1	B	2	C	7	C	5	C	6	BC	4	7.3
4.8	Alkalinity, total (as $CaCO_3$)	C	5	AB	2	A	1	C	7	B	4	C	6	ABC	3	6.7
3.8	pH (units)	C	7	A	1	BC	5	AB	4	A	3	C	6	AC	2	5.3
4.3	Specific conductance (micromhos/cm at 25°C)	B	4	A	1	AC	2	B	7	B	3	B	6	BC	5	5.3
4.3	Hardness, total (as $CaCO_3$)	B	3	B	4	A	1	C	7	B	2	BC	5	BC	6	5.3
3.8	Dissolved solids (sum of constituents)	B	5	A	2	A	1	B	6	B	4	B	7	AB	3	5.3
1.9	Temperature (° Celcius)	B	6	A	2	A	3	AB	5	AB	4	B	7	AB	1	2.7
3.8	Bicarbonate (as HCO_3)	B	6	A	2	A	1	B	5	B	4	B	7	AB	3	5.3
1.0	Iron, dissolved (ug/L)	A	2	A	3	AB	5	AB	4	B	7	AB	6	AB	1	1.3
4.8	Arsenic, dissolved (ug/L)	AB	3	C	5	C	6	A	1	C	7	BC	4	AB	2	4.7
4.3	Boron, dissolved (ug/L)	B	5	A	1	B	3	B	2	C	7	B	4	ABC	6	6.0
5.2	Fluoride, dissolved	D	6	A	1	BC	4	CDE	5	AB	2	E	7	ACD	3	6.7
8.1	Silica, dissolved (as SiO_2)	C	4	E	7	D	6	B	3	A	2	CD	5	AB	1	8.7

Table 22.--Results of Tukey's multiple range test on analysis of variance of hydrologic units

[Units with the same letter are not significantly different $\alpha = 0.05$. Values are the order of mean ranks for the units, 1 = rank of highest mean.]

Average unit separation	Constituent analyzed	Pacific Slope basin	Rank	Willamette River basin	Rank	Lower Columbia River	Rank	Klamath River basin	Rank	The Great Basin	Rank	Snake River Basin	Rank
4.7	Calcium, dissolved	AB	2	C	3	C	5	C	6	BC	4	A	1
0.0	Magnesium, dissolved	A	4	A	6	A	3	A	5	A	2	A	1
6.0	Sodium, dissolved	A	3	B	4	B	6	B	5	A	2	A	1
8.0	Potassium, dissolved	E	6	D	5	BC	3	C	4	AB	2	A	1
7.3	Sulfate, dissolved	B	3	C	4	C	5	C	6	A	2	A	1
2.0	Nitrite + Nitrate, dissolved (as N)	B	6	AB	5	A	4	AB	3	A	2	A	1
6.7	Chloride, dissolved	A	2	BC	4	D	5	D	6	AC	3	A	1
2.0	Alkalinity, total (as $CaCO_3$)	A	2	C	6	BC	5	ABC	3	ABC	4	AB	1
4.7	pH (units)	B	5	C	6	B	3	A	1	AB	2	BC	4
6.0	Specific conductance micromhos/cm at 25°C)	A	3	B	4	B	5	B	6	A	2	A	1
2.7	Hardness, total (as $CaCO_3$)	A	2	AB	3	B	5	B	6	AB	4	A	1
6.0	Dissolved solids (sum of constituents)	A	3	B	5	B	4	B	6	A	2	A	1
5.3	Temperature (°Celsius)	A	4	B	6	B	5	A	2	A	3	A	1
4.7	Bicarbonate (as HCO_3)	A	3	C	6	AB	4	BC	5	A	1	A	2
0.0	Iron, dissolved (ug/L)	A	3	A	2	A	5	A	4	A	6	A	1
4.7	Arsenic, dissolved (ug/L)	C	5	C	6	C	4	BC	3	AB	2	A	1
7.3	Boron, dissolved (ug/L)	B	3	C	4	D	6	CD	5	A	1	AB	2
8.0	Fluoride, dissolved	B	4	C	5	B	3	C	6	A	2	A	1
6.0	Silica, dissolved (as SiO_2)	C	6	B	5	A	2	A	4	A	3	A	1

Results shown in table 21 provide some insights to the analyzed ground-water quality data. While each constituent was not separated into aquifer units that are all significantly different, many of the results show significant differences between some specific aquifer units that can be explained. Results in table 21 of particular interest are constituents for which an aquifer unit was significantly different (higher or lower) from all the other units. An example is chloride for which the Marine rocks of the Coast Ranges had higher values that were significantly different from all the other aquifer units.

Calcium and hardness concentrations generally were low in all aquifer units, but the Igneous and metamorphic rocks of the Klamath Mountains had the highest average ranks of concentrations and the values were significantly different from the other aquifers. Lenses of marble are known to be present in some of the rocks of this unit but are not believed to be widespread. The most likely sources of calcium are the calcium-rich igneous and metamorphic rocks. Additionally, the widespread occurrence of magnesium ultramafic igneous rocks in this unit is a source of magnesium which contributes to the hardness. Sulfate values were also high for this aquifer and significantly different from several of the other units. As mentioned earlier, this may reflect the widespread occurrence of metallic sulfides in these rocks.

Results on sodium and chloride (table 21) indicate higher and statistically significant differences for the Marine rocks of the Coast Ranges. The sodium and chloride probably reflect the presence of altered connate waters at depth in these rocks. Boron was also indicated as significantly different for the Marine rocks, which again is reflective of the marine environment present during formation of the rocks included in this aquifer.

Potassium concentrations were generally low in all aquifer units, but potassium values from the Volcanic and sedimentary aquifer and the Columbia River basalt aquifer are higher and significantly different from the values of other aquifers. Possible sources of potassium are beds and lenses of illite-type clays present in these two aquifers.

Arsenic values were higher and significantly different from the other aquifers in the Volcanic and sedimentary aquifer and the Basin-fill and alluvial aquifers. Arsenic seems to be associated with the volcanic rocks and both of these units occur together in eastern Oregon, sometimes in areas where arsenic may be concentrated in the alkaline waters of the playas.

Silica was generally abundant in all the aquifer units, but table 21 indicates it was most abundant in the Columbia River basalt aquifer and least abundant in the Marine rocks of the Coast Ranges. The higher values in the basalt could be due to reactions with feldspar or clay in these rocks. Also a number of samples in the basalt aquifer are from deeper wells (highest median depth - table 11) where the average ground-water temperature may reflect in the higher silica concentrations. The low values in the Marine rocks may reflect the presence of connate water and the characteristically low silica concentrations in marine waters.

The results of comparisons between hydrologic units using the 19 constituents in table 22 are best explained in relation to the geologic units found within a specific hydrologic unit. Thus the results for the hydrologic units probably are strongly influenced by the aquifer units sampled most frequently within the hydrologic unit. As a consequence, single hydrologic units do not stand apart from all the other hydrologic units as frequently as aquifer units were singled out in table 21.

Generally higher calcium values were evident in the Snake River basin and the Pacific Slope Basins. The reason for significantly high values in the Snake River basin is unknown. Pacific Slope Basins are underlain in part by the Igneous and metamorphic rocks of the Klamath Mountains, the aquifer that exhibited the highest calcium concentrations.

Higher sodium and chloride concentrations were found in the Pacific Slope Basins, The Great Basin, and Snake River basin. The higher values are probably due to the Marine rocks of the Coast Ranges and the Igneous and metamorphic rocks of the Klamath Mountains, both of which are found in the Pacific Slope Basins and as mentioned earlier, exhibit high sodium and chloride concentrations. The higher concentration found in The Great Basin and Snake River basin reflect the arid climate in those regions where formation of evaporite deposits is common. Also in these three basin areas, concentrations of dissolved solids and specific conductance again were significantly higher than in other regions of the State. These two variables are strongly associated with the same sources noted for sodium and chloride in these basin areas.

Silica is also present in higher concentrations in the eastern Oregon Basins. This in part reflects the number of samples from the Columbia River basalt, the general presence of basaltic lavas throughout eastern Oregon, and in addition, the presence of diatomite beds and siliceous dacitic ash beds in the structural basins of southeastern Oregon. Distinctively low levels of silica in the Pacific Slope Basins probably reflect the presence of Marine rocks of the Coast Ranges as discussed previously.

To compare the two class variables, each table has a calculated value called the average unit separation (AUS) which indicates with a numerical value the number of units that are significantly different. The AUS is computed by making all one-way comparisons between units for each constituent. For each comparison between units in the same Tukey group, zero is assigned; if the units are in different Tukey groups, the comparison is assigned a value of ten. Values for comparisons are summed and divided by the total comparisons made. As an example, the AUS for sodium (table 22) is computed as follows: comparison between Pacific Slope Basins (group A) and Willamette River basin (group B) is assigned a value of 10. The next comparison, Pacific Slope to Lower Columbia, also is assigned 10, and the next three comparisons get 10, 0, and 0, respectively. Comparisons continue with Willamette River basin (group B) to the Lower Columbia (group B) assigned zero. The remaining Willamette River comparisons get 0, 10, and 10, respectively.

Assignment of values continues until all basin comparisons are completed. There are six separate units for the hydrologic class variable, so a total of 15 one-way comparisons can be made. Calculation of the sodium AUS working across table 22 from left to right is shown below:

$$\text{AUS}_{\text{(sodium)}} = \frac{10+10+10+0+0+0+0+10+10+0+10+10+10+10+0}{15}$$

$$\text{AUS (sodium)} = 6.0$$

Comparisons for the aquifers (table 21) are between seven aquifer units, therefore 21 one-way comparisons are possible. Computed AUS values range between zero and ten, zero indicating that the multiple range test found no significant difference between units at the probability level 0.05. An AUS value of 10 indicates the multiple range test found a significant difference between all units; therefore, each unit was placed in a separate group.

The AUS values in tables 21 and 22 indicate the degree to which constituents were separated by the classification variables. In comparing AUS values between tables, the classification variable with the highest AUS value for a particular constituent had more distinct units based on values for that constituent. Because the number of units is different for each classification variable, the AUS values are not directly comparable to two significant figures. Calcium AUS values of 4.3 and 4.7 from tables 21 and 22 indicate both class variables separated calcium values into equally many different units. For comparative purposes, the best AUS values in table 21 are those calculated without the effects of the Older volcanic aquifers included. Because of the wide variation and small sample size, this aquifer unit could not readily be distinguished from the others, which generally lowered the AUS values. Comparison of AUS values calculated using the six remaining aquifers to the AUS values for the hydrologic unit classification are quite similar.

AUS values below about 5.0 indicate that few units were dissimilar from others because less than half the comparisons were placed in different letter groups. The units which were different though may have been very different because the ANOVA results were significant. The hydrologic unit classification between units provided few significantly different units for magnesium, iron, nitrite plus nitrate, alkalinity, and hardness. The aquifer unit classification provided few significantly different units for iron, temperature, sodium, and nitrite plus nitrate. Aquifer unit as a class variable produced AUS greater than 5.0 for more than half the constituents: calcium, potassium, sulfate, chloride, alkalinity, pH, conductance, hardness, dissolved solids, bicarbonate, boron, fluoride, and silica (using all aquifer units except Older volcanic aquifers). The hydrologic unit classification also resulted in AUS greater than 5.0 for more than half the constituents: sodium, potassium, sulfate, chloride, conductance, dissolved soilds, temperature, boron, fluoride, and silica.

Results of the multiple range test were also used to make comparisons between pairs of aquifer units and between pairs of hydrologic units. When the two units compared were in the same group assigned by the multiple range test, a value of one was given, otherwise a value of zero was assigned. This was done for each of the 19 constituents used in the multiple range test. As an example, a comparison between two hydrologic units such as Pacific Slope Basins and Willamette River basins would have a value of 19 if each constituent was placed in the same group, or a value of zero if all constituents were placed in different groups. The results shown in table 23 indicate which units are most similar or dissimilar based on the 19 constituents used.

Because of the small sample size, it is apparent that quality of water in the Older volcanic aquifers is not distinctive from any of the other units. The two most dissimilar aquifer units are the Marine rocks of the Coast Ranges and Basin-fill and alluvial aquifers (value of 3); the Marine rocks, and the Volcanic and sedimentary aquifers also were very dissimilar (value of 4). For the hydrologic units, those most similar are the Snake River basin and The Great Basin. The most dissimilar were the Willamette River basin and Pacific Slope Basins (value of 5), and the Willamette River basin and the Snake River basin (value of 5).

Using the results of table 23, aquifer units could be separated into two groups that show similarities among the aquifers within the group and dissimilarities between the groups. Group I contains: Basin-fill and alluvial aquifers, Volcanic and sedimentary aquifers, Volcanic rocks of the western Cascades, and Columbia River Basalt aquifer. Group II contains: Marine rocks of the Coast Ranges, and Igneous and metamorphic rocks of the Klamath Mountains. The aquifer units in Group II exhibit many of the higher concentrations of constituents because of connate water or the particular minerals discussed previously. The units in Group I exhibited generally lower values because samples in these units may tend to be from shallower wells or in the Columbia River Basalt aquifer where concentrations were low.

A similar grouping can be established for the hydrologic units shown in table 23. The units in Group I (having lower concentrations) are: Willamette River basin, Lower Columbia River basin, and Klamath River basin. The units in Group II are: The Great Basin, Snake River basin, and Pacific Slope Basins. The basins in Group II tend to group together because the Pacific Slope Basins are strongly influenced by samples from the aquifer units in Group II. In addition, the arid climate and evaporite influences on The Great Basin and Snake River basin samples tend to put these three basins within the same grouping. The hydrologic units in Group I tend to be influenced by the Columbia River Basalt aquifer samples and samples from the Basin-fill and alluvial aquifers found in aquifer unit Group I. Thus there appears to be an association between aquifer and hydrologic units with the aquifer units accounting for the noted variations.

Table 23.--Pairwise (aquifer and hydrologic unit) comparison of constituents grouped by Tukey's multiple range test

[A value of 19 means all constituents for the two compared units were placed in the same group and were not significantly different at $\alpha = 0.05$.]

	Aquifer Units					
	Marine rocks of the Coast Ranges	Igneous and Metamorphic rocks of the Klamath Mountains	Volcanic and sedimentary aquifer	Columbia River basalt aquifer	Volcanic rocks of the Western Cascades	Older volcanic aquifers
Basin-fill and alluvial aquifers	3	6	12	10	15	17
Marine rocks of the Coast Ranges	--	10	4	8	7	14
Igneous and Metamorphic rocks of the Klamath Mountains	--	--	7	7	8	13
Volcanic and sedimentary aquifers	--	--	--	11	15	19
Columbia River basalt aquifer	--	--	--	--	12	17
Volcanic rocks of the Western Cascades	--	--	--	--	--	16

	Hydrologic Units				
	Willamette River basin	Lower Columbia River basin	Klamath River basin	The Great Basin	Snake River basin
Pacific Slope basins	5	6	6	12	13
Willamette River basin	--	12	14	7	5
Lower Columbia River basin	--	--	16	10	7
Klamath River basin	--	--	--	10	6
The Great Basin	--	--	--	--	18

Summary of Statistical Results

The purpose of statistically analyzing the Oregon ground-water quality data is to explain the observed variation in the data. Generally, the data have predominantly low values, with occasional high values for each constituent. The examined ground-water quality data are not normally or log-normally distributed. To a large extent, the methods discussed in the previous section to explain data variability are dependent on the availability of information to assign samples to the appropriate classification. One of the major weaknesses in the WATSTORE QW-file containing the ground-water quality data base is insufficient information on sample source. Sufficient information is not available to determine the source of the sample water or to distinguish between samples that originate from single or multiple water sources. Addition of information contained in the GWSI data base may improve ability to determine sample source.

ANOVA statistical tests used aquifer unit and hydrologic unit as class variables to explain ground-water quality variation. Aquifer unit provided a separation of variation which could be related to lithology. Because a relationship does exist between constituent values and the class variables, a refinement would combine the effects of both classes by using the Cascade Range as a boundary and segregating aquifer units found on both sides of the range. Both Columbia River Basalt aquifer and Cenozoic sedimentary aquifer could be split into east and west segments; all other units used occurred only on one side or the other of the Cascade Range.

Examination of the ANOVA results also indicated that sample size was significant. Only 20 samples were available for the Older volcanic aquifers, and generally Tukey's multiple range test did not detect a significant difference between this aquifer and the others for most constituents (table 23). Small sample size increased the amount of uncertainty about the mean so that it was indistinguishable from the means for other aquifer units at the 0.05 probability level. Sample size appeared sufficient for other aquifer and hydrologic units.

The results of this statistical analysis gave the following insights to variation in Oregon ground-water quality: (1) For each constituent measured, the range from smallest to largest value is generally more than one order of magnitude and frequently is three or more orders of magnitude, (2) variability in constituents can be separated by variables such as aquifer unit and hydrologic unit, though these variables are not equally effective with all constituents, and they do not account for a large percentage of the variation, (3) selection of classification variables or descriptors used to account for variation in the ground-water quality data influence the results (note magnesium variation did not segregate into distinct subsets using hydrologic units), and (4) aquifer units provided the best opportunity to interpret the results of the ANOVA test because constituents could be related to lithology.

ROGUE RIVER BASIN

The Setting

The Rogue River basin is an area of about 5,000 mi^2 drained by the Rogue River and its' tributaries with about 150 mi^2 of the basin in California; the remainder is in Oregon. Most of the basin is in the Klamath Mountains physiographic region; however, the eastern one-quarter is in the Cascade Range, and includes portions of the High Cascades and the Western Cascades. Crater Lake National Park is found in the High Cascades and is in the headwaters of the Rogue River.

The Rogue River basin can be divided roughly into three geographic areas--the eastern, central, and western sections. The eastern section is lightly populated, heavily forested, and is mostly within the rugged western slopes of the Cascade Range. The central section differs from the eastern and western sections in that its' river valleys are much broader; consequently, most of the basin's population, farming, and industrial activities are located in the valleys in this central section. The western section is rugged and mountainous and, like the eastern section, is lightly populated and heavily forested.

Geologic formations in the eastern section are chiefly Quaternary and Tertiary age andesitic lava, breccia, tuff, and tuffaceous sediments, and are assigned to the Volcanic rocks of the western Cascades. These rocks dip gently eastward toward the Cascade Range.

In the central and western sections of the basin, the bedrock formations consist mainly of Mesozoic age metamorphosed volcanic, sedimentary, and intrusive rocks and unaltered sediments and volcanic rocks. Most of these rocks are folded, faulted, and steeply dipping.

Ground water is obtained from most of the geologic formations in the basin. The best water-bearing formations are (1) the alluvial deposits found in the lowlands along principal streams in the central part of the basin, (2) weathered granitic intrusive rocks, and (3) volcanic and pyroclastic rocks of the Cascade Range. All other formations consist mainly of low-permeability rocks and typically yield only a few to several gallons of water per minute to wells. As many as 10 percent of the holes drilled in this area may yield little or no water. The low-permeability formations consist of a variety of rock types, including metamorphosed sediment, lava, tuff, intrusive rock, and serpentine; and unaltered siltstone, sandstone, tuff, and lava. In spite of their poor water-yielding properties, however, these rocks are very important sources of water because locally they may be the only source for rural use.

Classification of Sample Sites

Because the Rogue River basin had numerous ground-water quality samples in the data base, and the junior author was familiar with the basin geohydrology, an attempt was made to classify the basin's samples in two additional ways; (1) according to type of flow system, and (2) according to position within the flow system. Once classified, statistical analyses were performed on the data; the result of these analyses are discussed in the following section. Classification by type of flow system required that each sample site be designated as local, intermediate, regional, or unknown type of flow system. To accurately classify sampling sites in this manner requires that much information be available about the three-dimensional distribution of head within the system. Because these data were not available, the process of classifying sites was largely subjective.

All of the information used to classify sites by geologic or hydrologic units is needed to classify sites according to type of flow system, but more data about head distribution within the system near the sampling site is needed to accurately classify the site with regard to flow system. Because this data is generally lacking, one must frequently rely on personal judgement. In some areas, the process is fairly simple. For example, in an area of high topographic relief, similar high concordant ground-water mounds, rocks of uniform permeability and narrow V-shaped valleys, such as are commonly present in the Oregon Coast Range or portions of the Klamath Mountains, one would anticipate that only local ground-water flow systems are present.

If a wide valley floor covered by thin more permeable alluvium were added to the simple system just described, one would then classify flow in the shallow alluvium as a local flow system, and flow in the underlying rock as part of a regional flow system. The classification process becomes more difficult with increasing geological complexity, decrease in relief, or variable permeability of the geologic formations.

Classifying sampling sites according to position within the flow system required the hydrologist to designate location of the sampled well in a recharge area, an intermediate area, a discharge area, or an unknown area of the flow system. A ground-water recharge area by definition is an area in which there is a decrease in head with depth in the natural undeveloped flow system. Recharge areas typically are located beneath drainage basin divides and upland areas. An intermediate area by definition is one in which there is no change in head with depth in the system. If an intermediate area cannot be identified using head data, then in simple flow systems it occurs at some point between the recharge and the discharge area. A discharge area is an area where the head increases with depth in the flow system; if head data are not available, generally the discharge area is located in lowlands adjacent to streams.

In this study, sample location in the flow system was determined from sampling-site well records, large scale topographic, geologic, and potentiometric surface maps. Information on ground-water pumpage near the site and on the rate of pumpage during the sampling process also is necessary. Water-level data recorded by the driller during drilling and completion of the well are of critical importance in accurate site classification. These data along with knowledge of the site may be combined to appropriately classify the site as a recharge, intermediate, or discharge area.

Results of Analysis of Variance

The Rogue River basin data were analyzed twice using the ANOVA procedure described earlier in this report. ANOVA used the ranks of constituent values to determine if there were significant differences between the type of flow system (TYPF): regional, intermediate, or local. ANOVA was also used to determine if there were significant differences between positions within the flow system (TYPA); discharge, intermediate, or recharge affected constituent values. Results of the ANOVA are presented in table 24, and the results indicate the type of flow system (TYPF) was significant ($p \leq .05$) for 6 of the 14 constituents analyzed, while the area within the flow system (TYPA), was significant for only three of the analyzed constituents. Of the constituents that showed a significant difference between designations, only dissolved solids showed a significant effect for both class variables.

Tukey's multiple range test was used to determine where the significant differences were within each classification variable. The results of the multiple range test are presented in table 25. Units (areas) within each class variable (TYPF or TYPA) that did not have significantly different rank means were assigned the same letter designation. Of the two class variables, TYPF provided the better separation between flow system types for sodium, chloride, and dissolved solids. For all three variables, regional and intermediate flow systems rank means were not significantly different, and the local rank means were lower than the regional and intermediate values. The lower values for the local system are consistent with the expectation that lower residence time for water moving through a local system compared to a regional system should yield lower dissolved solids--possibly including chloride and sodium as in this case. Three other constituents (sulfate, pH, and conductance) had unit rank means significantly different from each other for class TYPF. For sulfate and conductance the differences were not physically justified, because regional flow was not distinct from local flow. The significant difference was between local and intermediate flow which indicates the statistical results were not consistent with our concept of the flow system. This inconsistency probably is due to the limited information and method for defining flow systems with field data.

Table 24.--Results of analysis of variance on ranks for Rogue River basin samples

[Shown are the probabilities that observed differences are due to chance rather than the tested effect.]

Water-quality constituent	Type flow system (TYPF)	Area in flow system (TYPA)
Calcium	0.2968	0.1463
Megnesium	.0548	.4394
Sodium	.0001[1/]	.0824
Potassium	.6133	.0106[1/]
Sulfate	.0050[1/]	.4582
Nitrite + nitrate	.2519	.0235[1/]
Chloride	.0006[1/]	.3108
Alkalinity	.9424	.4458
pH	.0011[1/]	.1448
Spedific conductance	.0121[1/]	.0909
Hardness	.1741	.2880
Dissolved solids	.0001[1/]	.0181[1/]
Temperature	.2248	.7119
Bicarbonate	.3996	.8220

[1/] Indicates significant difference at $p \leq 0.05$.

Table 25.--Results of Tukey's multiple range test on analysis of variance of Rogue River basin flow system

[Columns with the same letter are not significantly different, $\alpha = 0.05$]

Constituent analyzed	Type of flow system (TYPF)			Type of area in flow system (TYPA)		
	Regional	Intermediate	Local	Discharge	Intermediate	Recharge
Calcium, dissolved	A	A	A	A	A	A
Magnesium,, dissolved	A	A	A	A	A	A
Sodium, dissolved	A	A	B	A	A	A
Potassium, dissolved	A	A	A	A	AB	B
Sulfate, dissolved	AB	A	B	A	A	A
Nitrite + nitrate, dissolved (as N)	A	A	A	AB	A	B
Chloride, dissolved	A	A	B	A	A	A
Alkalinity, total (as $CaCO_3$)	A	A	A	A	A	A
pH (units)	A	AB	B	A	A	A
Specific conductance (micromhos/cm at 25°C)	AB	A	B	A	A	A
Hardness, total (as $CaCO_3$)	A	A	A	A	A	A
Dissolved solids (sum of constituents)	A	A	B	A	AB	B
Temperature (°Celsius)	A	A	A	A	A	A
Bicarbonate (as HCO_3)	A	A	A	A	A	A

Results for the class variable TYPA, area within the flow system, indicate distinguishable units for only potassium, nitrite plus nitrate, and dissolved solids. A similar inconsistency to that mentioned above resulted for nitrite plus nitrate in that the recharge and discharge area rank sample means were not significantly different, but a difference was detected between intermediate and recharge area with the intermediate area having higher values. These results may occur because recharge areas are generally topographically higher than the other two area types and therefore less likely (because of lower population density) locations for subsurface sewage-disposal systems -- the most common source of high nitrate values in the State. Potassium and dissolved solids however, had significant differences between recharge and discharge, but intermediate areas were not distinguishable from the the other areas. Rank mean values were highest for discharge areas and lowest for recharge areas for both potassium and dissolved solids. This was anticipated because younger more dilute waters should be present in recharge areas.

Refinement of Methodology

The results of the ANOVA tests on data segregated by flow system are not conclusive because problems associated with assignment of class variables are one of the key factors that determined the ANOVA outcome. It is necessary to improve the method to designate flow-system type and area. For example, if the data could be segregated by flow-system type then segregated by area within the flow system, the range of concentrations for each constituent probably would increase as the data from local, intermediate, and regional flow systems are examined. The data would be examined by areas where lithology is similar within each type of flow system. Such an examination should account for some of the variability noted in the data.

CONCLUSIONS

Ground-water quality data from the Geological Survey WATSTORE water-quality file examined in this study contained little data which would indicate the impact of hazardous waste or man's activities on the overall quality of ground water in Oregon. A few analyses for complex organic substances are contained in U.S. EPA or Oregon DEQ files from monitor wells near sanitary landfills or public drinking supplies, but these data were not part of the WATSTORE data files. Samples from such as these are not generally useful in determining background concentrations nor the extent of current contamination. The most widespread recognized ground-water contamination problem in the State is from subsurface sewage-disposal system leachates, which have resulted in elevated nitrate concentrations in some areas. Evidence for the general presence or absence of hazardous waste contamination in Oregon ground water is lacking in the examined data because no areal sampling has been done to determine the presence of these constituents.

Explanation of observed variations in ground-water quality statewide in this study is hampered by several factors: (1) Small numbers of samples for large areas with complex flow systems; (2) irregular distribution of samples, spatially, geologically, and temporally; (3) incomplete surface and subsurface geologic and hydrologic information at sampling sites; (4) incomplete knowledge of well construction and pumpage effects; (5) inadequate knowledge of the subsurface flow system at specific sites; and (6) incomplete analytical data on many samples.

Factors used to statistically explain the observed ground-water quality variations were aquifer unit source and hydrologic unit source of ground water. The aquifer unit source classification generally included several distinct geologic formations combined together as a single aquifer because of similarities in lithology, hydrology, and (or) hydraulic properties. The hydrologic unit classification was used because each hydrologic unit represented a few to several adjoining river basins that have surface-water divides that coincide fairly close with major ground-water divides.

As determined by ANOVA tests, each classification group performed equally well numerically in segregating the ground-water quality data into statistically distinguishable units. Aquifer unit classification was relatable to lithology which provided better explanation of results. Statistical results could be improved if the classification groups were subdivided into smaller subunits that are more geologically and climatologically homogeneous. For example, a single geologic unit such as the Eocene Tyee Formation found in the Marine rocks of the Coast Range is lithologically more uniform throughout its extent than is the larger grouping of marine rocks. This type of data segregation was not possible because of the small number of samples available for most small homogeneous units. Another possibility for classifying samples in this data set would be to combine the effects of the two classification variables. This could be done by combining aquifer units subdivided by a major physiographic boundary such as the Cascade Range.

The presence of large amounts of andesitic and basaltic volcanic rocks, and sedimentary rocks derived from them, suggests that similar ground-water quality may be expected in those parts of the State where these rocks occur. Although the water-quality variations are great, the trilinear diagrams of cation and anion ratios show patterns that support this generalization. Most of the diagrams showed the principal anions were the constituents that comprise alkalinity while no single cation was dominant. The plots also show some specific water types which include many samples with high percentages of chloride and sodium. These samples are believed to be older, mineralized, possibly connate water unrelated to the more typical waters of the state.

In the Rogue River basin, an attempt was made to classify samples by flow-system type and by area within the flow system. The results were not generally conclusive because the variability of most constituents was not reduced by these new classifications.

Data available to describe ground-water quality in Oregon are limited in quantity, analytical detail, geographic distribution, and are generally inadequate for time-trend analysis. Because of the large variation in constituent concentrations, with no direct method for explaining the variation, the data generally does not provide predictive capability to determine future concentrations or problem areas. The data are particularly inadequate for defining the impacts of hazardous substances including nonpoint application of herbicides and pesticides on Oregon ground-water quality. Monitoring in the immediate vicinity of some waste disposal sites is done, and may provide information on point sources of hazardous waste contamination. To improve the Oregon ground-water quality data base, all existing sample data should be made computer accessible. In addition, the usefulness of the sample data may be improved by combining it with more accurate descriptions of the source of the sampled water. Included should be information on primary and secondary formations yielding water to the well and location in the flow system. Along with improvements to existing data, new data from a network of monitoring wells could provide background data on different geologic and physiographic regimes. To address questions regarding hazardous waste contamination, sites need to be selected where effects are expected from both point and nonpoint sources.

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