DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS REPORT 88-4018
SHEET 1 OF 4

# GROUND-WATER LEVELS SPRING 1985, AND GROUND-WATER LEVEL CHANGES SPRING 1983 TO SPRING 1985, IN THREE BASALT UNITS UNDERLYING THE COLUMBIA PLATEAU, WASHINGTON AND OREGON

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## ABSTRACT

Ground-water-level contour maps for three basalt units of the Columbia Plateau regional aquifer system were constructed using water levels measured in 1,105 wells during spring 1985. These measurements were then compared with similar measurements from spring 1983 to assess the changes in ground-water levels over the 2-year period for each of the basalt units. Configuration of the ground-water contours and water-level changes reflect (1) recharge and discharge, (2) hydraulic conductivity, (3) use of imported surface water for irrigation, and (4) pumpage of ground water. The dominant pattern of ground-water movement within each basalt unit is controlled mainly by the major rivers, streams and coulees; whereas, variations in flow directions between units are related to the occurrence, extent, and hydraulic conductivity of the basalt units and sedimentary interbeds and to differences in the amounts of recharge to each unit.

## INTRODUCTION

A study was begun to define and analyze the geohydrology and geochemistry of the Columbia Plateau regional aquifer system as part of the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) Program in October 1982. The Columbia Plateau regional aquifer system is in part of the Columbia Plateau of central and eastern Washington, north-central and eastern Oregon, and a small part of northwestern Idaho (fig. 1). The basalt part of the aquifer system, as described in this report, is principally in the Yakima Basalt Subgroup of the Miocene Columbia River Basalt Group.

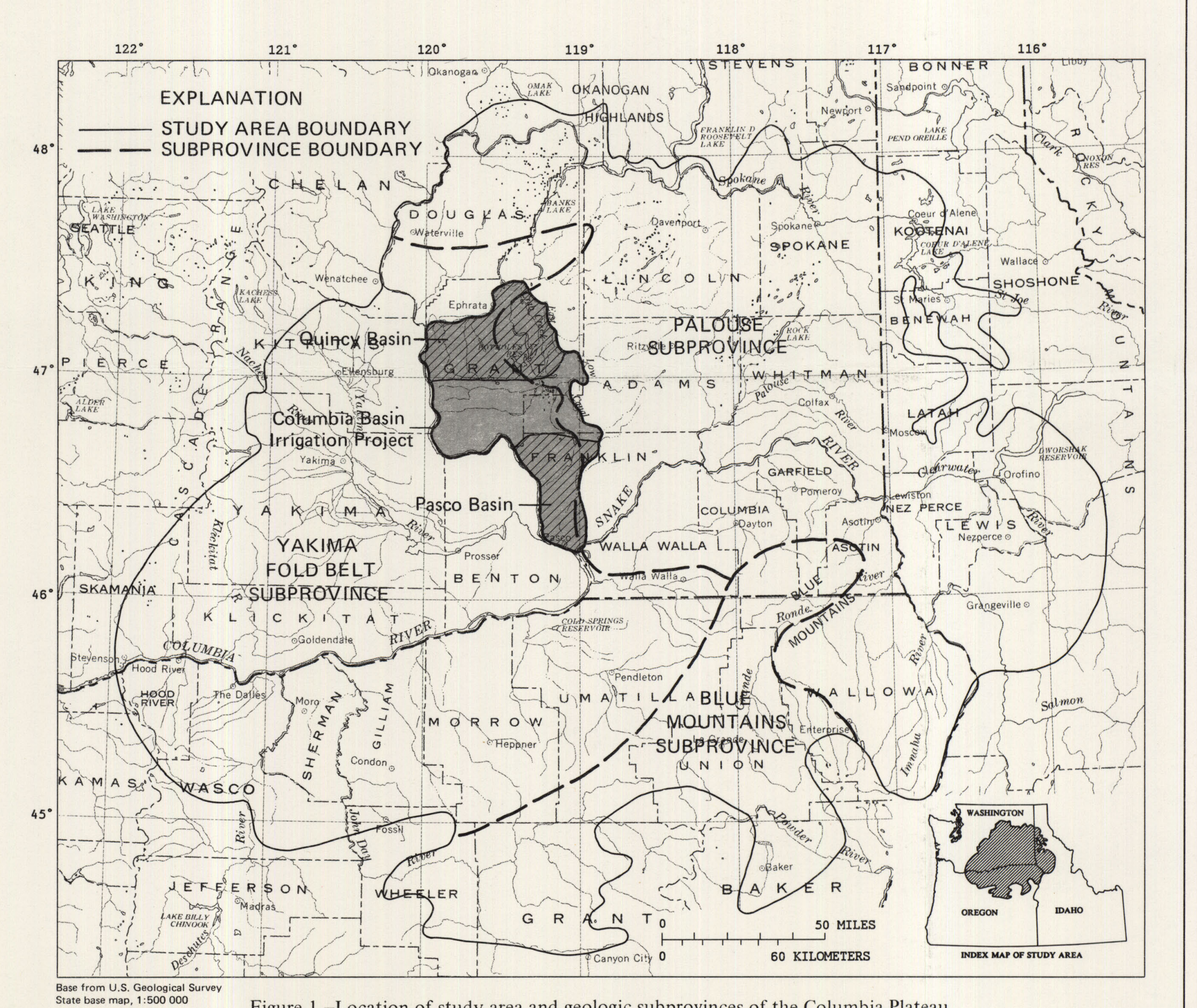

Figure 1.–Location of study area and geologic subprovinces of the Columbia Plateau.

The Columbia Plateau aquifer system is the area's major source of ground water for municipal, industrial, domestic, and irrigation uses. Concurrent with ground-water usage, imported surface water is used for irrigation in several parts of the plateau. Irrigation practices over the past 25 years have resulted in ground-water-level rises in areas of surface-water irrigation, in ground-water-level declines (locally by as much as 100 feet in Washington and 200 feet in Oregon) in areas of ground-water pumpage, and in changes in the chemical quality of ground water in irrigated areas (Cline, 1984).

### Purpose and Scope

The purpose of the RASA program is to aid in the effective management of the nation's ground-water resources by providing information on the geohydrology and geochemistry of regional aquifer systems. This report is one of several that will describe the geologic, hydrologic, and geochemical characteristics of the Columbia Plateau regional aquifer system. Specifically, this report describes the ground-water-level configuration in spring 1985, and changes in ground-water levels from spring 1983 to spring 1985 for three basalt units. In addition, brief overviews of the project area, the geologic framework, and the occurrence and movement of ground water have been included. This report contains the following map sheets.

| Sheet No. | Title |
|---|---|
| 1 | Text. |
| 2 | Generalized altitude of ground-water levels, spring 1985, and changes in ground-water levels, spring 1983 to spring 1985, in the Saddle Mountains unit, Washington and Oregon. |
| 3 | Generalized altitude of ground-water levels, spring 1985, and changes in ground-water levels, spring 1983 to spring 1985, in the Wanapum unit, Washington and Oregon. |
| 4 | Generalized altitude of ground-water levels, spring 1985, and changes in ground-water levels spring 1983 to spring 1985, in the Grande Ronde unit, Washington and Oregon. |

The water-level configurations presented in this report are of major importance to the understanding of the movement and availability of ground water in the aquifer system. The water-level-configuration maps are essential to the development of a ground-water model to simulate flow in the Columbia Plateau ground-water system. The development of a computer model is one of the major work elements of the current RASA program, and will establish a framework for more detailed local ground-water investigations.

### Acknowledgments

The cooperation of the well owners, tenants, and well drillers who supplied information and allowed access to wells is gratefully acknowledged. Special thanks are extended to the State of Washington Department of Ecology and the U.S. Bureau of Reclamation for collecting and supplying water-level data for this project. Water-level-change data for Oregon were computed and assessed by Joseph B. Gonthier, U.S. Geological Survey, Oregon State office.

## REGIONAL SETTING

The Columbia Plateau occupies an area of approximately 70,000 square miles in Washington, Oregon, and Idaho, part of which includes the study area (fig. 1). The region is drained by the Columbia River and its major tributaries: the Snake, Spokane, Yakima, Deschutes, John Day, and Umatilla Rivers. Average annual precipitation ranges from less than 8 inches in the central, low-lying part of the plateau to more than 25 inches on the surrounding mountain slopes.

The Columbia Plateau is an intermontane area bounded by the Cascade Range on the west, the Okanogan Highlands on the north, the Rocky Mountains on the east, and the Blue Mountains on the south and southeast. In the north, the plateau exhibits geomorphic features that are characteristic of channeled scablands, such as extensive exposure of the Columbia River Basalt Group, deep coulees, and paleochannels. To the east, the Palouse Hills overlie the basalt with a well-dissected mantle of windblown silts. In north-central Oregon the plateau is a moderately dissected basalt plateau, that rises steeply from the north to the south and abuts the Blue Mountains. The Yakima Fold Belt subprovince, in the west, is characterized by a series of east-west-trending anticlinal ridges and intervening synclinal valleys. In the center of the plateau is a major downwarp containing two structural basins, the Quincy and Pasco basins (fig. 1). In glacial times these basins functioned as sinks for outwash sediments carried by floodwaters from the northeast, and consequently the basalts in the central plateau are buried under a thick sequence of glaciofluvial and lacustrine sediments.

## GEOLOGIC FRAMEWORK

The following overview of the geology of the Columbia Plateau relies extensively on work done in recent years by other investigators. Previous studies that contributed to this study are those by Grolier and Bingham (1971), Swanson and others (1979a,b,c, and 1980) Myers and Price (1979 and 1981), and Drost and Whiteman (1986).

The part of the Columbia Plateau underlain by the Columbia River Basalt Group is both a structural and a topographic basin with a regional slope towards a low point near Pasco, Wash. The rocks of the plateau are primarily Miocene basalts with minor amounts of interbedded sediments of Miocene age and overlying sediments of Pliocene to Holocene age, herein called the overburden. Along the borders of the plateau, the basalts are underlain by "basement" rocks, mostly volcanic and metamorphic rocks of Precambrian to early Tertiary age. In the interior of the plateau, the nature of the rocks underlying the basalts is not well known. Recent tectonic studies of the Cascade Range and Columbia Plateau in Washington (Stanley, 1984), and petroleum exploration drilling, indicate that sediments of probable Tertiary age underlie the basalts in the center of the basin.

Myers and Price (1979) have subdivided the Columbia Plateau into three geologic subprovinces: the Yakima Fold Belt subprovince, the Palouse subprovince, and the Blue Mountains subprovince (fig. 1). Land-surface features tend to reflect the underlying geologic structure in the project area: the mountains are generally anticlines, the valleys synclines. The Yakima Fold Belt subprovince is characterized by long, narrow, tightly folded anticlines and broad-to-narrow intervening synclines trending in an easterly to southeasterly direction from the western margin of the plateau to its center. Most of the major faults associated with anticlinal fold axes are thrust or reverse faults and may be contemporaneous with the folding. In the Palouse subprovince, the basalts have a regional southwest dip of less than 5 degrees, and a small number of broad, gentle folds with a northeast-southwest orientation. The Blue Mountains subprovince is a broad, east- to northeast-trending anticline that extends from central Oregon into southeastern Washington. Beneath the basalts, the core of the anticline is composed of folded, faulted, and metamorphosed rocks of late Paleozoic and Mesozoic age (Myers and Price, 1979).

Individual basalt flows range in thickness from a few inches up to about 300 feet. The structure of an individual flow from bottom to top generally consists of three sections: the basal colonnade, the entablature, and the flow top (fig. 2). The basal colonnade, commonly 20 percent of the flow thickness, consists of nearly vertical three- to eight-sided columns formed by jointing during the slow cooling and contraction of the flow interior. The individual columns average about 3 feet in diameter and 25 feet in length, and are usually crosscut by horizontal joints. Porous pillow structures, caused by underwater cooling, are commonly present at the base of the colonnade, and a vesicular zone may be present above the pillow structures. The entablature, commonly 70 percent of the flow thickness, consists of small-diameter (averaging less than a foot) columns in fan-shaped arrangements. Within the entablature, irregular cross-jointing produces a hackly or friable structure, whereas the upper part of the entablature may be vesicular. The flow top generally consists of vesicular basalt and clinker, and when combined with the superposed flow base is called the interflow zone. The flow top averages about 10 percent of the total thickness of a single flow. The highest permeability in a lava flow is usually in the interflow zone, and the lowest permeability generally in the center, particularly the entablature.

The Columbia River Basalt Group has been stratigraphically divided into the Yakima Basalt Subgroup and the pre-Yakima basalts. Within the Columbia Plateau RASA study area the pre-Yakima basalts are of limited thickness and extent, and are found only in scattered locations in the southeastern part of the study area. Consequently, they have not been explored or developed, and will not be discussed further in this report. The Yakima Basalt Subgroup has been divided, in ascending order, into three basalt formations: the Grande Ronde, Wanapum, and Saddle Mountains Basalts. Each of these basalts, along with their sedimentary interbeds, comprise a geohydrologic unit named after the basalt formation. Figure 3 shows the generalized occurrence and extent of these three basalts within the study area.

The Grande Ronde Basalt, underlying virtually all of the study area, is the oldest of the three basalts, and is exposed along the plateau margins and in the canyons of the Columbia and Snake Rivers. Its thickness ranges from a few feet along the northern margin, where it pinches out against older rock, to at least 4,000 feet and perhaps as much as 10,000 feet in the central and southwest parts of the study area. Sedimentary interbeds are rare in the Grande Ronde Basalt and are generally only a few feet thick. These interbeds, as is common with virtually all the interbeds within the Columbia River Basalt Group, range in composition from clay to sand and gravel. A sedimentary interbed of light-colored, weakly cemented, incompetent sandstone and siltstone lies between the Grande Ronde Basalt and the overlying Wanapum Basalt in much of the study area. This interbed, the Wanapum-Grande Ronde interbed, averages 25 feet in thickness and ranges from nearly 0 to 100 feet or more.

The Wanapum Basalt is present in most of the study area and is exposed or is covered by a veneer of sedimentary or colluvial material throughout most of the northern half of the study area. In the southern half, it is generally covered by thick sequences of sediments and (or) by the Saddle Mountains Basalt. The Wanapum Basalt averages about 600 feet in thickness, and ranges from a few feet where it pinches out against exposures of the Grande Ronde Basalt, to more than 1,600 feet in the southwest part of the study area. Sedimentary interbeds are more common in the Wanapum Basalt than in the Grande Ronde Basalt, but still are relatively rare and only a few feet thick. A sedimentary interbed occurs between the Wanapum Basalt and the overlying Saddle Mountains Basalt in the southwest part of the study area. This interbed, the Saddle Mountains-Wanapum interbed, averages about 50 feet in thickness and varies from 0 to more than 150 feet.

The Saddle Mountains Basalt is the youngest of the three Yakima basalts and occurs only in the southwest part of the study area where it is either exposed at the land surface or is covered by sediments. This basalt unit averages 600 feet in thickness in the south-central part of the study area, with maximum thicknesses of over 800 feet near Pasco, Wash. Sedimentary interbeds in the Saddle Mountains Basalt are common and relatively thick (frequently 50 feet or more). One such interbed, located in north-central Oregon, is important stratigraphically and hydrologically, owing to its large extent and thicknesses in excess of 200 feet.

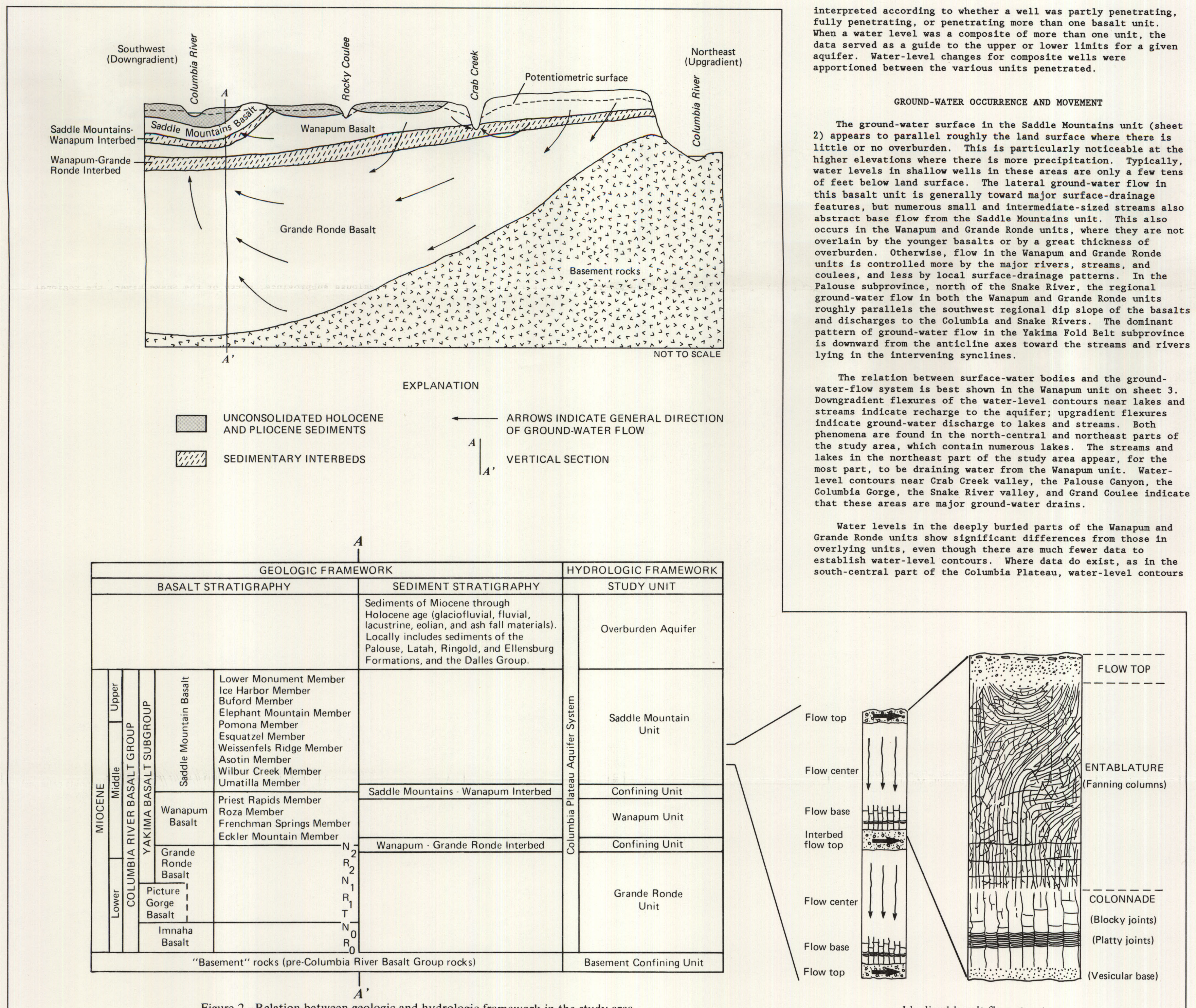

Figure 2.–Relation between geologic and hydrologic framework in the study area.

Idealized basalt flow structure.

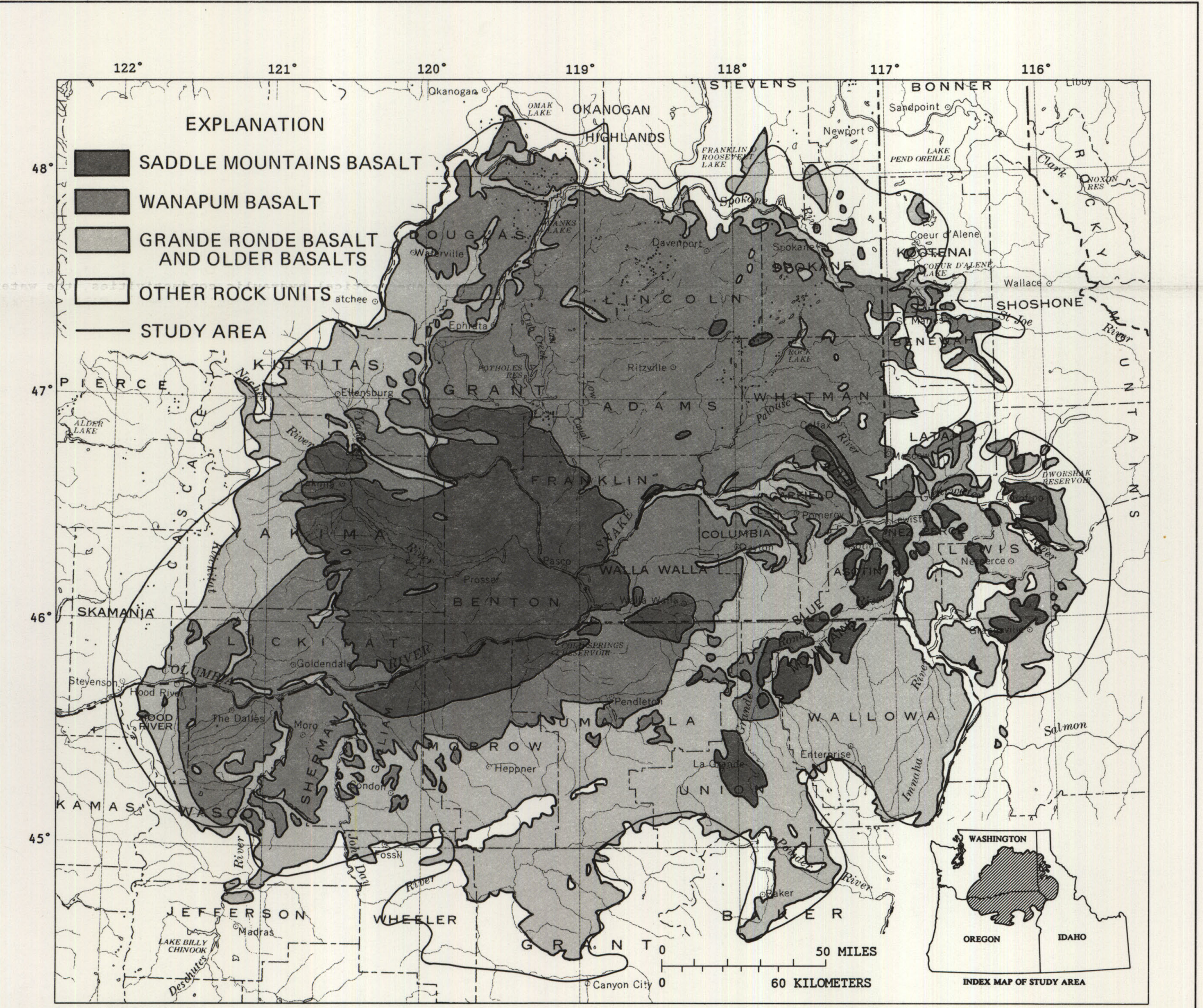

Figure 3.–Generalized extents of occurrence of three basalts underlying the study area.

## CONCEPTUAL MODEL OF AQUIFER SYSTEM

The basalts, sedimentary interbeds, and overburden compose the regional aquifer system of the Columbia Plateau. Ground water in basalt occurs in joints, vesicles, fractures, and other localized features that cause an increase in hydraulic conductivity. The highest hydraulic conductivities usually occur in flow tops, and relatively high hydraulic conductivities are found where the colonnades have vesicular bases. The entablature and much of the colonnade probably have lower hydraulic conductivities because they are more dense and coherent. The combination of a layered, jointed structure and the hydraulic conductivity distribution produce a ground-water-flow pattern with primarily lateral movement in the flow tops and vertical movement through the colonnade and entablature. Thus, the interflow zones in the basalt sequence include numerous small semiconfined aquifers. All interflow zones within a studied basalt formation have been combined with the intervening basalts and intercalated sediments to form study units.

Ground water also may be found in the sedimentary interbeds that occur between basalt formations. However, because of variations in lithology, thickness, and extent, these interbeds may serve as either aquifers or confining beds. These interbeds generally are composed of fine-grained materials and are considered confining units for the Columbia Plateau aquifer system. The pre-basalt "basement" rocks generally have much lower permeability than the basalts and are considered the base of the regional flow system. These rocks are called the Basement confining unit. The system has been conceptualized as consisting of seven study units corresponding to the three studied basalt formations, the two sedimentary interbeds, the sedimentary overburden materials, and the pre-basalt rocks (fig. 2). The four study units of importance in this project are called the Saddle Mountains unit, Wanapum unit, Grande Ronde unit, and the Overburden aquifer. The term "units" is used with the basalt study units to distinguish them from the basalt formations, because the formations do not include the intercalated sediments.

## METHOD OF ANALYSIS

In general, changes of hydraulic head occur with depth for any given location. The water-level contours drawn for a unit represent the vertically averaged areal hydraulic-head distribution for that unit insofar as the data permitted. The overburden material is in direct hydraulic connection with the immediately underlying basalt unit, and where thick enough constitutes a water-table aquifer. The ground-water-level configuration for the Overburden aquifer has not been included in this report, but has been constructed and published by Bauer, Vaccaro, and Lane (1985). The ground-water-level surfaces for the three basalt units during spring 1985 are shown on sheets 2 through 4.

Ground-water-level contours for each unit were based on water-level data obtained from 1,105 wells in spring 1985, prior to summer pumping. Water-level configurations drawn, but not shown, for spring 1984 in the Washington and Oregon part of the Columbia Plateau (Whiteman, 1986) provided a useful framework for analysis of the 1985 water-level data.

Water-level-change data were computed by subtracting spring 1983 water levels from spring 1985 water levels at the same wells. These changes then were contoured for each unit. In areas where no contours have been drawn, water-level changes of generally less than 5 feet were noted. These data did not lend themselves to the delineation of a zero-change contour line because of the interspersed nature of the water-level rises and declines.

The contours drawn for both the water levels and water-level changes are highly generalized because of the large-scale, regional nature of this RASA project, and they represent a simplified picture of the true, complex three-dimensional flow system. In areas where 1985 data were sparse or lacking, water-level configurations shown have been inferred. Data were interpreted according to whether a well was partly penetrating, fully penetrating, or penetrating more than one basalt unit. When a water level was a composite of more than one unit, the data served as a guide to the upper or lower limits for a given aquifer. Water-level changes for composite wells were apportioned between the various units penetrated.

## GROUND-WATER OCCURRENCE AND MOVEMENT

The ground-water surface in the Saddle Mountains unit (sheet 2) appears to parallel roughly the land surface where there is little or no overburden. This is particularly noticeable at the higher elevations where there is more precipitation. Typically, water levels in shallow wells in these areas are only a few tens of feet below land surface. The lateral ground-water flow in this basalt unit is generally toward major surface-drainage features, but numerous small and intermediate-sized streams also abstract base flow from the Saddle Mountains unit. This also occurs in the Wanapum and Grande Ronde units, where they are not overlain by the younger basalts or by a great thickness of overburden. Otherwise, flow in the Wanapum and Grande Ronde units is controlled more by the major rivers, streams, and coulees, and less by local surface-drainage patterns. In the Palouse subprovince, north of the Snake River, the regional ground-water flow in both the Wanapum and Grande Ronde units roughly parallels the southwest regional dip slope of the basalts and discharges to the Columbia and Snake Rivers. The dominant pattern of ground-water flow in the Yakima Fold Belt subprovince is downward from the anticline axes toward the streams and rivers lying in the intervening synclines.

The relation between surface-water bodies and the ground-water-flow system is best shown in the Wanapum unit on sheet 3. Downgradient flexures of the water-level contours near lakes and streams indicate recharge to the aquifer; upgradient flexures indicate ground-water discharge to lakes and streams. Both phenomena are found in the north-central and northeast parts of the study area, which contain numerous lakes. The streams and lakes in the northeast part of the study area appear, for the most part, to be draining water from the Wanapum unit. Water-level contours near Crab Creek valley, the Palouse Canyon, the Columbia Gorge, the Snake River valley, and Grand Coulee indicate that these areas are major ground-water drains.

Water levels in the deeply buried parts of the Wanapum and Grande Ronde units show significant differences from those in overlying units, even though there are much fewer data to establish water-level contours. Where data do exist, as in the south-central part of the Columbia Plateau, water-level contours appear to be less influenced by the surface-drainage features, and consequently have a smoother form. The "smoothing" is due, at least in part, to the fact that recharge to and discharge from the deeply buried basalts occur more through vertical leakage over broad areas to and from the overlying basalts than by direct physical contact with surface-water bodies or drainage features. An example of this can be seen in the Quincy basin (located in the northern part of the Yakima Fold Belt subprovince) on sheets 3 and 4, where ground-water movement in the Wanapum unit (which is at or near land surface) is towards Moses Lake and Potholes Reservoir. Ground-water movement in the underlying Grande Ronde unit, however, is relatively unaffected by these land-surface features, and flow is to the south toward the Columbia River.

In most of the study area, water-table conditions exist in the uppermost basalt flows, but owing to the difference between the horizontal and vertical hydraulic conductivities, the water in the deeper basalts is generally semiconfined. Fine-grained, tight interbeds and flow-center rock units compose the semiconfining beds of these deeper flows. The hydraulic connection between flows is sufficient to allow some continuous vertical movement of water between them. From the water-level data, it appears that over most of the plateau, the vertical component of flow is downward except near discharge areas. The exceptions to this pattern probably occur near unknown geologic structures or in areas of heavy pumpage. Newcomb (1961) cited lateral flow impediments resulting in upward flow caused by faulting in the basalts near Walla Walla and in the Cold Creek syncline east of Yakima in Washington, and southwest of The Dalles in Oregon. A subsequent study by the Survey of the Horse Heaven Hills in Washington revealed an area where wells tapping the Wanapum unit (sheet 3) are artesian, but approximately 2 miles downgradient to the southeast the water levels are about 340 feet lower. The vertical head gradient is upward northwest of the impediment and downward southeast of the impediment (Frank A. Packard, U.S. Geological Survey, written commun., 1984).

Steep water-level gradients are depicted on the flanks of the Blue Mountains, Horse Heaven Hills, Frenchman Hills, Rattlesnake Hills, and Saddle Mountains anticlines. Water-level data from locations on the flanks of anticlines and in other areas where the basalts are steeply dipping show lateral water-level gradients to be approximately equal to or slightly less than the structural gradients. This phenomenon was assumed to hold in similar areas where data were not available, and water-level contours were drawn accordingly.

In recent years, ground-water pumping for irrigation has disturbed the regional pattern. The effects of pumping on ground-water-level contours can be seen in the area of Connell, and north toward the Odessa-Lind area (sheet 3). This area shows a large upgradient bending or flexure of the contours, typical of lowered water levels. A similar upgradient contour flexure attributed to pumping is evident in the Umatilla River basin in Oregon.

The effects of man-induced recharge on the water-level configuration are shown on sheet 3 by the downgradient contour flexure just below Potholes Reservoir, between the 1,100- and 700-foot contours. The large East Low Irrigation Canal, which is part of the Columbia Basin Irrigation Project (CBIP), runs along the downgradient flexures.

## WATER-LEVEL CHANGES

The Columbia Plateau RASA study began water-level measurements in the spring of 1983 throughout the Columbia Plateau. A comparison of spring 1983 water-level data with the spring 1985 data summarized in this report indicates numerous areas where water levels have risen or fallen over that 2-year period. Water-level changes have been assessed for each basalt unit and are shown on sheets 2, 3, and 4. There was no apparent correlation between the amount and (or) direction of water-level change and whether a well was partly penetrating, fully penetrating, or penetrating more than one unit.

Water-level declines exceeding 20 feet did not extend over large areas, but occurred in all three basalt units. Such declines in the Saddle Mountains occurred in the Yakima River valley east of Donald. Declines exceeding 20 feet in the Wanapum unit occurred in the Horse Heaven Hills region, north of the Rattlesnake Hills along Dry Creek, in southern Adams County, and in Oregon south of The Dalles and west of Butter Creek. Declines exceeding 20 feet in the Grande Ronde unit occurred southeast of Othello in Adams County, and around Butter Creek in Oregon.

Water-level rises exceeding 20 feet occurred in the Saddle Mountains unit in two areas--the Horse Heaven Hills and the area north and west of Richland. In the Wanapum unit such rises were seen south of Connell in Franklin County, in a zone northeast of Potholes Reservoir, and in western Lincoln County. The only such water-level rises in the Grande Ronde unit were in Lincoln County south of Wilbur.

Water-level declines in western Lincoln and Adams Counties and northern Grant County were documented by Cline (1984) for the period from spring 1978 to spring 1981. During that 3-year period, Cline reported water-level declines ranging from 10 to more than 40 feet in the Wanapum unit in Adams County. For composite wells tapping both the Wanapum and Grande Ronde units, water-level declines covered a larger geographic area (western Adams County and extending into western Lincoln County) and ranged from 10 to 50 feet in magnitude.

During the 2-year period from 1983 to 1985, the rate of decline of water levels in the Wanapum unit in Adams County had decreased when compared to 1978-1981 rates. Much of the area outlined by Cline showed no net rise or decline in water levels from 1983 to 1985. Where declines were observed, they were generally less than 10 feet, with two wells exceeding 30 feet. In Lincoln County, where Cline noted large declines in composite wells in the Wanapum and Grande Ronde units, both the Wanapum and Grande Ronde units showed widespread water-level rises from 1983 to 1985. These rises ranged from 5 to more than 30 feet, but were generally less than 20 feet in magnitude.

Water-level rises and declines, which indicate changes in the amount of ground water in storage, occur in response to varying ground-water discharge and recharge rates. During this 2-year measurement period, recharge and discharge rates were affected by above-average precipitation during 1983 and 1984:

| Station | Long-term average annual precipitation (in inches) 1957-1977 | Departure from average (in inches) 1983 | 1984 |
|---|---|---|---|
| Connell 12 SE | 9.46 | +4.16 | +2.26 |
| Lind 3 NE | 9.21 | +4.15 | +2.40 |
| Ephrata FAA AP | 7.28 | +4.95 | +2.96 |
| Waterville | 10.87 | +12.05 | +3.79 |

In addition, the Federal Payment In Kind (PIK) program encouraged farmers not to plant and irrigate all their acreage, resulting in decreased ground-water discharge. Preliminary ground-water pumpage estimates for Adams and Lincoln Counties show approximately 20 and 27 percent overall decreases in pumpage rates from 1982 to 1983, respectively (D. R. Cline, U.S. Geological Survey, written commun., 1985). Franklin and Grant Counties also show rate decreases, but to a lesser degree. Ground-water-pumpage rates during 1984 increased by a small amount (approximately 2 percent overall), but did not return to the 1983 rates.

Throughout the period of record there have been large-scale water-level rises in the Columbia Plateau in response to surface-water importation from both the CBIP and the Yakima River Basin project, as well as large-scale water-level declines caused by high ground-water pumpage for irrigation. Figure 4 shows hydrographs of long-term water-level fluctuations for selected wells in the study area that illustrate these changes. Well 14N/29E-27E01, located in the CBIP area and completed in the Wanapum unit, shows a fairly steady rise in water level from 1958 to 1980, followed by a new equilibrium at a higher water-level elevation. The hydrographs of wells 21N/31E-10M02 (a composite well in the Wanapum and Grande Ronde units) and 24N/36E-16A08 (completed in the Grande Ronde) show declines in water levels throughout the 1970's and early 1980's in response to large ground-water withdrawal rates.

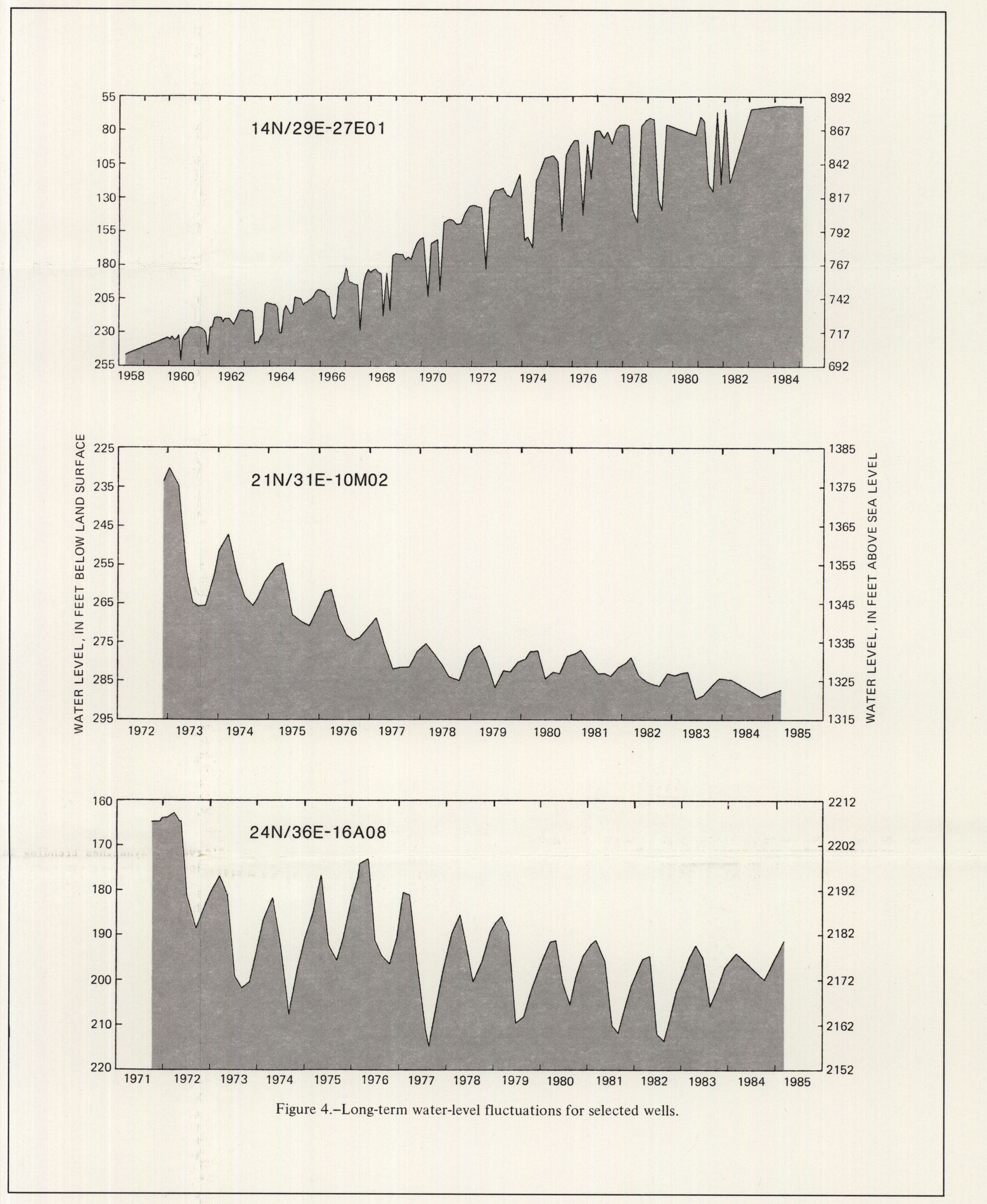

Figure 4.–Long-term water-level fluctuations for selected wells.

## SUMMARY

The dominant pattern of ground-water movement in all three basalt units indicates flow from higher elevations toward surface drainage features. Variations in flow direction from one unit to the next generally are related to the occurrence, extent, and hydraulic conductivity of the sedimentary interbeds and basalt units and the amount of recharge to each unit. Ground-water-flow patterns and water-level changes described in this report also indicate that water levels have risen as a result of the importation of surface water for irrigation, and that the water levels appear to be approaching equilibrium at the new, higher elevations. Conversely, in areas subject to large ground-water withdrawals, the water levels have declined as a result of prolonged pumpage.

## SELECTED REFERENCES

Barker, R.A., 1979, Computer similation and geohydrology of a basalt aquifer system in the Pullman-Moscow basin, Washington and Idaho: Washington State Department of Ecology Water-Supply Bulletin 48, 119 p.

Bauer, H.H., Vaccaro, J.J., and Lane, R.C., 1985, Ground-water levels in the Columbia River Basalt and overlying materials, spring 1983, southeastern Washington State: U.S. Geological Survey Water-Resources Investigations Report 84-4360, 4 sheets.

Brown, W.R., 1981, Results of the separations area ground-water monitoring network for 1980: Rockwell International, Inc., 77 p.

Cline, D.R., 1984, Ground-water levels and pumpage in east-central Washington, including the Odessa-Lind area, 1967 to 1981: Washington State Department of Ecology Water-Supply Bulletin 55, 34 p.

Drost, B.W., and Whiteman, K.J., 1986, Surficial geology, structure, and thickness of selected geohydrologic units in the Columbia Plateau, Washington: U.S. Geological Survey Water-Resources Investigations Report 84-4326, 10 sheets.

Grolier, M.J., and Bingham, J.W., 1971, Geologic map and sections of parts of Grant, Adams, and Franklin Counties, Washington: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-589, 6 sheets.

Luzier, J.E., and Skrivan. J.A., 1973, Digital simulation and projection of water-level declines in basalt aquifers of the Odessa-Lind area, east-central Washington: U.S. Geological Survey Open-File Report, 56 p.

MacNish, R.D., and Barker, R.A., 1976, Digital simulation of a basalt aquifer system, Walla Walla River basin, Washington and Oregon: Washington State Department of Ecology Water-Supply Bulletin 44, 51 p.

Myers, C.W., and Price, S.M., 1979, Geologic studies of the Columbia Plateau, a status report: Rockwell International, Rockwell Hanford Operations, RHO-BWI-ST-4.

-----1981, Subsurface geology of the Cold Creek syncline: Rockwell International, Rockwell Hanford Operations, RHO-BWI-ST-14.

Newcomb, R.C., 1961, Storage of ground water behind subsurface dams in the Columbia River Basalt, Washington, Oregon, and Idaho: U.S. Geological Survey Professional Paper 383-A, 15 p.

Prych, E.A., 1983, Numerical simulation of ground-water flow in lower Satus Creek basin, Yakima Indian Reservation, Washington: U.S. Geological Survey Water-Resources Investigations 82-4065, 78 p.

Stanley, W.D., 1984, Tectonic study of Cascade Range and Columbia Plateau in Washington State based upon magnetotelluric soundings: Journal of Geophysical Research, v. 89, no. B6, p. 4447-4460.

Swanson, D.A., Anderson, J.L., Bentley, R.D., Byerly, G.R., Camp, B.E., Gardner, J.N., and Wright, T.L., 1979a, Reconnaissance geologic map of the Columbia River Basalt Group in eastern Washington and northern Idaho: U.S. Geological Survey Open-File Report 79-1363, 26 p., scale 1:250,000, 12 sheets.

Swanson, D.A., Brown, J.C., Anderson, J.L., Bentley, R.D., Byerly, G.R., Gardner, J.N., and Wright, T.L., 1979b, Preliminary structure contour maps on the top of the Grande Ronde and Wanapum Basalts, eastern Washington and northern Idaho: U.S. Geological Survey Open-file Report 79-1364, scale 1:500,000, 2 sheets.

Swanson, D.A., Wright, T.L., Hooper, P.R., and Bentley, R.D., 1979c, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457-G, 59 p.

Swanson, D.A., Wright, T.L., Camp, V.E., Gardner, J.N., Helz, R.T., Price, S.M., Reidel, S.P., and Ross, M.E., 1980, Reconnaissance geologic map of the Columbia River Basalt Group, Pullman and Walla Walla quadrangles, southeast Washington and adjacent Idaho: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-1139, scale 1:250,000, 2 sheets.

Tanaka, H.H., Hansen, A.J., and Skrivan, J.A., 1974, Digital-model study of ground-water hydrology, Columbia Basin Irrigation Project area, Washington: Washington State Department of Ecology Water-Supply Bulletin 40, 60 p.

U.S. Geological Survey, 1975, Water resources of the Toppenish Creek basin, Yakima Indian Reservation, Washington: U.S. Geological Survey Water-Resources Investigations 42-74, 144 p.

Whiteman, K.J., 1986, Ground-water levels in three basalt hydrologic units underlying the Columbia Plateau in Washington and Oregon, Spring 1984: U.S. Geological Survey Water-Resources Investigations Report 86-4046, 4 sheets.

## CONVERSION FACTORS

For the convenience of readers who may prefer to use metric units rather than the inch-pound units used in this report, values may be converted by using the following factors:

| Multiply inch-pound unit | By | To obtain metric units |
|---|---|---|
| inch (in.) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |

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

degree Fahrenheit (°F) to
degree Celsius °C = 5/9 (°F -32)

# GROUND-WATER LEVELS, SPRING 1985, AND GROUND-WATER LEVEL CHANGES, SPRING 1983 TO SPRING 1985, IN THREE BASALT UNITS UNDERLYING THE COLUMBIA PLATEAU, WASHINGTON AND OREGON

By

R. C. Lane and K. J. Whiteman

1989