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Extent and Depth to Top of Basalt and Interbed Hydrogeologic Units, Yakima River Basin Aquifer System, Washington

Scientific Investigations Report 2008–5045

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph of Clark Well No. 1, located on the north side of the Moxee Valley in North Yakima, Washington. The well is located in township 12 north, range 20 east, section 6. The well was drilled to a depth of 940 feet into an artesian zone of the Ellensburg Formation, and completed in 1897 at a cost of $2,000. The original flow from the well was estimated at about 600 gallons per minute, and was used to irrigate 250 acres in 1900 and supplied water to 8 small ranches with an additional 47 acres of irrigation. (Photograph was taken by E.E. James in 1897, and was printed in 1901 in the U.S. Geological Survey Water-Supply and Irrigation Paper 55.)

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U.S. Department of the Interior
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Contents

Abstract.....1
Introduction.....1
    Purpose and Scope.....3
Description of Study Area.....3
    Location and Setting.....3
    Development of Water Resources.....5
    Overview of the Geology.....7
Methods of Investigation.....8
Hydrogeologic Framework.....10
    Saddle Mountains Hydrogeologic Unit.....11
    Mabton Hydrogeologic Unit.....11
    Wanapum Hydrogeologic Unit.....14
    Vantage Hydrogeologic Unit.....14
    Grande Ronde Hydrogeologic Unit.....14
Summary and Conclusions.....18
Acknowledgments.....18
Selected References.....18

Plates

[In pocket]

Plate 1. Map showing extent and depth to top of Saddle Mountains hydrogeologic unit, in Yakima River Basin aquifer system, Wahington

Plate 2. Map showing extent and depth to top of Mabton hydrogeologic unit, in Yakima River Basin aquifer system, Washington

Plate 3. Map showing extent and depth to top of Wanapum hydrogeologic unit, in Yakima River Basin aquifer system, Washinton

Plate 4. Map showing extent and depth to top of Vantage hydrogeologic unit, in Yakima River Basin aquifer system, Washington

Plate 5. Map showing extent and depth to top of Grande Ronde hydrogeologic unit, in Yakima River Basin aquifer system, Washinton

Figures

Figure 1. Map showing the Yakima River Basin, Washington 2

Figure 2. Map showing land use and land cover, Yakima River Basin, Washington, 1999 ... 4

Figure 3. Schematic diagram showing selected tributaries, diversion canals, return flows, and streamflow-gaging stations, Yakima River Basin, Washington 6

Figure 4. Map showing simplified surficial geology, Yakima River Basin, Washington 7

Figure 5. Map showing structure delineating Yakima River Basin aquifer system, Washington 9

Figure 6. Correlation chart showing the regional relation between generalized stratigraphy and hydrogeologic units for the Yakima River Basin, Washington 10

Figure 7. Map showing distribution of wells used to delineate the depth to top of Saddle Mountains unit, Yakima River Basin aquifer system, Washington 12

Figure 8. Map showing distribution of wells used to delineate the depth to top of Mabton unit, Yakima River Basin aquifer system, Washington 13

Figure 9. Map showing distribution of wells used to delineate the depth to top of Wanapum unit, Yakima River Basin aquifer system, Washington 15

Figure 10. Map showing distribution of wells used to delineate the depth to top of Vantage unit, Yakima River Basin aquifer system, Washington 16

Figure 11. Map showing distribution of wells used to delineate the depth to top of Grande Ronde unit, Yakima River Basin aquifer system, Washington 17

Conversion Factors, Datums, and Acronyms

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
inch per year (in/yr)	2.54	centimeter per year (cm/yr)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Altitude, as used in this report, refers to distance above the vertical datum.

Acronyms

CRBG	Columbia River Basalt Group
DEM	digital elevation model
DGER	Washington Division of Geology and Earth Resources
GIS	Geographic Information System
SOAC	System Operations Advisory Committee
TWSA	current available storage in the reservoirs, estimates of unregulated flow, and other sources that principally are return flows
USGS	U.S. Geological Survey
WaDOE	Washington State Department of Ecology
WRIA	Washington State Water Resources Inventory Area
YN	Yakama Nation
3D	Three dimensional
SMB	Saddle Mountains Basalt
WB	Wanapum Basalt
GRB	Grande Ronde Basalt

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Extent and Depth to Top of Basalt and Interbed Hydrogeologic Units, Yakima River Basin Aquifer System, Washington

By M.A. Jones and J.J. Vaccaro

Abstract

The hydrogeologic framework was delineated for the ground-water flow system of the three basalt formations and two interbeds in the Yakima River Basin, Washington. The basalt units are nearly equivalent to the Saddle Mountains, Wanapum, and Grande Ronde. The two major interbed units between the basalt formations generally are referred to as the Mabton and Vantage.

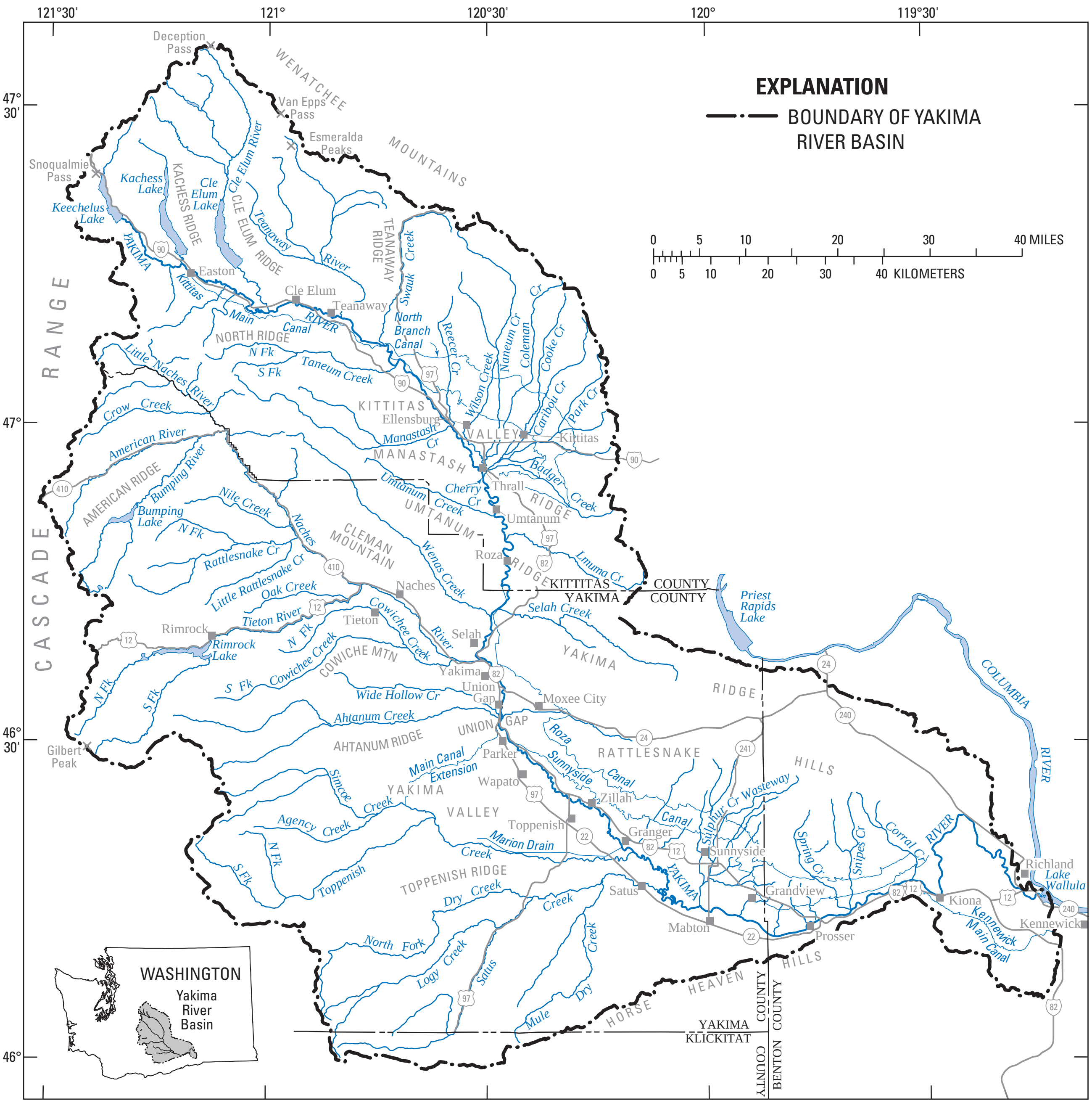
The basalt formations are a productive source of ground-water for the Yakima River Basin. The Grande Ronde unit comprises the largest area in the Yakima River Basin aquifer system. This unit encompasses an area of about 5,390 mi^2 and ranges in altitude from 6,900 ft, where it is exposed at land surface, to a depth of 2,800 ft below land surface. The Wanapum unit encompasses an area of 3,450 mi^2 and ranges in altitude from 5,680 ft, where exposed at land surface, to a depth of 2,050 ft below land surface. The Saddle Mountains unit, the least extensive, encompasses an area of 2,290 mi^2 and ranges from 4,290 ft, where exposed at the surface, to a depth of 1,840 ft below land surface.

Introduction

Surface water in the Yakima River Basin, in south-central Washington (fig. 1) is under adjudication and the amount of surface water available for appropriation is unknown, but there are increasing demands for water for municipal, fisheries, agricultural, industrial, and recreational uses. These demands must be met by ground-water withdrawals and/or by changes in the way water resources are allocated and used. On-going activities in the basin for enhancement of fisheries and obtaining additional water for agriculture may be affected by ground-water withdrawals and by rules implemented under the Endangered Species Act for salmonids that have been either listed or were proposed for listing in the late 1990s. An integrated understanding of the ground-water flow system and its relation to the surface-water resources is needed in order to implement most water-resources management strategies in the basin. In order to obtain this understanding, a study of the Yakima River Basin aquifer system began in June 2000. The study is a cooperative effort of the U.S. Geological Survey (USGS), Bureau of Reclamation (Reclamation), the Yakama Nation (YN), and the Washington State Department of Ecology (WaDOE).

The overall objectives of the study are to fully describe the ground-water flow system and its interaction with and relation to surface water, and to provide baseline information for a management tool—a numerical model. The conceptual model of the flow system and the results of the study will be used to guide and support actions taken by management agencies with respect to ground-water availability and to provide information to other stakeholders and interested parties. The numerical model will be developed as an integrated tool to assess short-term to long-term management activities, including the testing of potential management strategies.

The study includes three phases. The first phase includes (1) project planning and coordination, (2) compiling, documenting, and assessing available data, and (3) initial data collection. The second phase consists of data collection to support the following phase 2 work elements: (1) mapping of hydrogeologic units, (2) estimating ground-water pumpage, (3) developing estimates of ground-water recharge, (4) assessing ground water-surface water interchanges, and (5) constructing maps of ground-water levels. Together, these five elements provide the information needed to describe the ground-water flow system, the conceptual model, and provide the building blocks for the hydrogeologic framework. In the third phase, six structural basin models and one regional model of the ground-water flow system will be constructed in order to integrate the available information. The numerical models will be used to gain a further understanding of the flow system and its relation to surface water, and to test management strategies. The results from selected work elements will be described in a series of reports. This report defines the hydrogeologic framework of the three major basalt units, and the two major interbed units as described under the phase 2 work element, mapping of the hydrogeologic units.



Base modified from Fuhrer and others, 1994.

Figure 1. The Yakima River Basin, Washington.

Purpose and Scope

This report describes the depth to top of selected basalt and interbed hydrogeologic units that compose part of the Yakima River Basin aquifer system. This and other study information will be used to develop a conceptual model describing local and regional ground-water flow systems. Maps presented in this report provide the extents and the depth to the top of three basalt and two interbed hydrogeologic units within the study area. The three basalt units are nearly equivalent to the Grande Ronde, Wanapum, and Saddle Mountains Formations of the Columbia River Basalt Group (CRBG). The two major interbed units are between the Grande Ronde and Wanapum Formations and the Wanapum and Saddle Mountains Formations.

Description of Study Area

The location and setting of the study area, the development of water resources in the basin, and an overview of the geology are presented to provide a general background for understanding the study area.

Location and Setting

The Yakima River Basin aquifer system underlies about 6,200 mi^2 in south-central Washington (fig. 1). The Yakima River Basin produces a mean annual unregulated streamflow (adjusted for regulation and without diversions or returns) of about 5,600 ft^3/s (about 4.1 million acre-ft) and a regulated streamflow of about 3,600 ft^3/s (about 2.6 million acre-ft). The basin includes three Washington State Water Resource Inventory Areas (WRIA—numbers 37, 38, and 39), part of the Yakama Nation lands, and three ecoregions (Cascades, Eastern Cascades, and Columbia Basin—Omernik, 1987; Cuffney and others, 1997). The basin includes parts of four counties (Klickitat, Kittitas, Yakima, and Benton). Almost all of Yakima County and more than 80 percent of Kittitas County lie within the basin, and about 50 percent of Benton County is in the basin. Less than 1 percent of the basin, principally in an unpopulated upland area, lies in Klickitat County.

The headwaters of the basin are on the upper, humid east slope of the Cascade Range, where the mean annual precipitation is more than 100 in. The basin terminates at the confluence of the Yakima and Columbia Rivers in the low-lying, arid part of the basin, which receives about 6 in. of precipitation per year. Altitudes in the basin range from 400 to nearly 8,000 ft. Eight major rivers and numerous smaller streams are tributary to the Yakima River (fig. 1); the largest tributary is the Naches River. Most of the precipitation in the basin falls during the winter months as snow in the mountains. The mean annual precipitation over the entire basin is about 27 in. (about 12,000 ft^3/s or 8.7 million acre-ft). The spatial pattern of mean annual precipitation resembles the pattern of the basin's highly variable topography. The difference between the mean annual precipitation and mean annual unregulated streamflow is 6,400 ft^3/s (about 4.6 million acre-ft) or about 53 percent of the precipitation is lost to evapotranspiration under natural conditions.

The basin is separated into several broad valleys by large east-west trending anticlinal ridges. The valley floors are flat and slope gently towards the Yakima River. Few perennial tributary streams traverse these valleys. Most of the population and economic activity occurs in these valleys.

Agriculture is the principal economic activity in the basin. The average annual surface-water demand met by Reclamation's Yakima Project is about 2.5 million acre-ft; an additional 336,000 acre-ft of demand in the lower river basin is separate from the demand met by the project. Additional surface-water demand that is not met by Reclamation occurs in smaller tributaries and on the large rivers; this demand is based on State appropriated water. More than 95 percent of the surface-water demand is for irrigation of about 500,000 acres in the low-lying semiarid to arid parts of the basin (fig. 2). The demand is partially met by storage of nearly 1.1 million acre-ft of water in five Reclamation reservoirs. The major management point for Reclamation is the streamflow gaging station (12505000) at the Yakima River near Parker. Just upstream of this site, at Union Gap, is the location that is considered the dividing line between the upper (mean annual precipitation of 7 to 125 in.) and lower (mean annual precipitation of 6 to 45 in.) parts of the Yakima River Basin. About 45 percent of the water diverted for irrigation is eventually returned to the river system as surface-water inflows and ground-water discharge, but at varying time-lags (Bureau of Reclamation, 1999). During the low-flow period, these return flows, on average, account for about 75 percent of the streamflow below the Yakima River near Parker streamflow-gaging station. Much of the surface-water demand in the basin below Parker is met by these return flows and not by the release of water from the reservoirs. As a result of water use in the basin, the difference between mean annual unregulated and regulated streamflow in the basin is about 2,000 ft^3/s, suggesting that some 1.4 million acre-ft of water, or about 17 percent of the precipitation in the basin, is consumptively used—principally by irrigated crops through evapotranspiration.

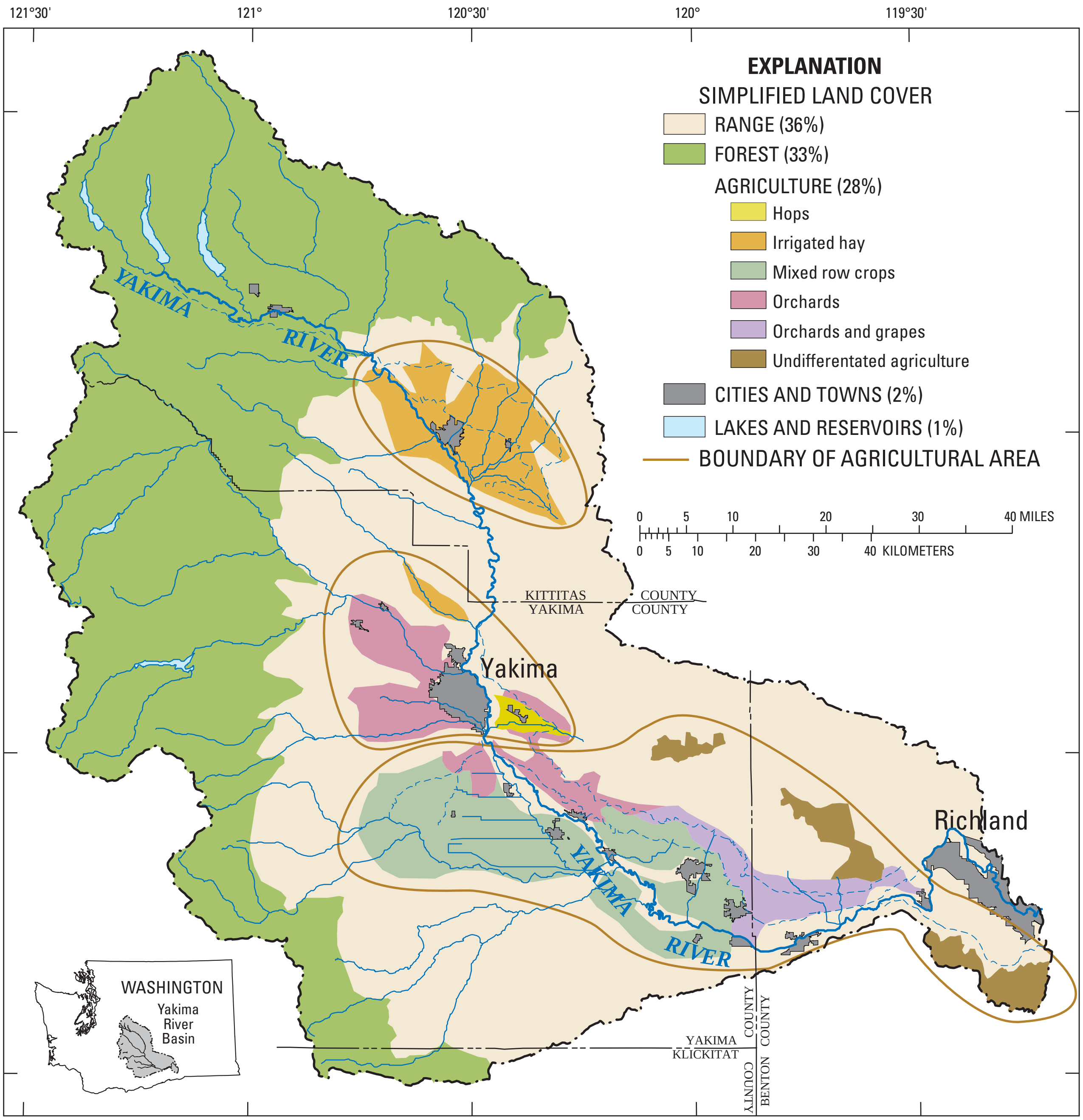


Figure 2. Land use and land cover, Yakima River Basin, Washington, 1999.

Development of Water Resources

Missionaries arrived in the basin in 1848 and established a mission in 1852 on Atanum (now Ahtanum) Creek. They were some of the first non-Indian settlers to use irrigation on a small scale. Miners and cattlemen immigrated to the basin in the 1850s and 1860s, which resulted in a new demand for water. With increased settlement in the mid-1860s, irrigation of the fertile valley bottoms began and the outlying areas were extensively used for stock raising. One of the first known non-Indian irrigation ditches was constructed in 1867 and diverted water from the Naches River (Parker and Storey, 1913; Flaherty, 1975). Private companies later delivered water through canal systems built between 1880 and 1904 for the irrigation of large areas. The development of irrigated agriculture was made more attractive by the construction of the Northern Pacific Railway that reached Yakima in December 1884, which provided a means to transport agricultural goods to markets; two years later, the completion of the railway to the Pacific coast provided new and easily accessible markets for agricultural products. The State of Washington was created in 1889, spurring further growth in the basin, especially because the cities of Ellensburg and Yakima were in contention for being the state capital. By 1902 there were about 120,000 acres under mostly surface-water irrigation in the basin (Parker and Storey, 1913; Bureau of Reclamation, 1999).

The Federal Reclamation Act was enacted in 1902 to enable the construction of Federal water projects in the western United States in order to expand the development of the West. In 1905, the Washington State Legislature passed the Reclamation Enabling Act and the Yakima Federal Reclamation Project was authorized to construct facilities to irrigate about 500,000 acres. As part of the 1905 authorization and extensions, all forms of further appropriation of unappropriated water in the basin were withdrawn (Parker and Storey, 1913). Six dams were constructed as part of the Yakima Project: Bumping Dam in 1910, Kachess Dam in 1912, Clear Creek Dam in 1914, Keechelus Dam in 1917, Tieton Dam (Rimrock Lake) in 1925, and Cle Elum Dam in 1933. The construction of the dams and other irrigation facilities resulted in an extremely complicated surface-water system (fig. 3). These Federal reservoirs provide water storage to meet irrigation requirements of the major irrigation districts at the time of year when the natural streamflow from unregulated streams can no longer meet demands; this time is referred to as the ‘storage control’ date. Several of the reservoirs also provide instream flows during the winter for the incubation of salmon eggs in the salmon redds (gravel spawning nests).

Legal challenges to water rights resulted in the 1945 Consent Decree (U.S. District Court, 1945) that established the framework of how Reclamation operates the Yakima Project to meet the water demands. The Decree determined two classes of rights—nonproratable and proratable. When the total water supply available (TWSA—defined as current available storage in the reservoirs, estimates of unregulated flow, and other sources that are principally return flows) is not sufficient to meet both classes of rights, the proratable (junior) rights are decreased according to the quantity of water available defined by the TWSA. This legally mandated method generally performs well in most years, but is dependent on the accuracy of the TWSA estimate. In some years, for example 1977, problems have arisen because of errors in the TWSA estimate (Kratz, 1978; Glantz, 1982). System management also accounts for defined instream flows at selected target points on the river, and for suggested changes in storage releases recommended by the Systems Operations Advisory Committee (SOAC)—the advisory board of fishery biologists representing the different stakeholders (Systems Operations Advisory Committee, 1999).

The drilling of numerous wells for irrigation was spurred by new (post 1945) well-drilling technologies, legal rulings, and the onset of a multi-year dry period in 1977 (Vaccaro, 1995, 2002). Population growth in the basin was, and still is, the driving force behind the increased drilling of shallow domestic wells and deeper public water supply wells. Currently, there are more than 20,000 wells in the basin. More than 70 percent of these wells are shallow, 10-250 ft deep, domestic wells. Based on the digital water-rights database provided by WaDOE (R. Dixon, Washington State Department of Ecology, written commun., 2001) and other information there are at least 2,874 active ground-water rights associated with the wells in the basin that can collectively withdraw an annual quantity of about 529,231 acre-ft during dry years. The irrigation rights are for the irrigation of about 129,570 acres. There are about 16,600 ground-water claims in the basin; these claims are for some 270,000 acre-ft of ground water (J. Kirk, Washington State Department of Ecology, written commun. 1998). ‘A water right claim is a statement of claim to water use that began before the state Water Codes were adopted, and is not covered by a water right permit or certificate. A water right claim does not establish a water right, but only provides documentation of one if it legally exists. Ultimately, the validity of claimed water rights would be determined through general water right adjudications’ (Washington State Department of Ecology, 1998). A ground-water claim means a user claims that they were using ground water continuously, for a particular use, prior to 1945 when the State legislature enacted the Ground Water Code.

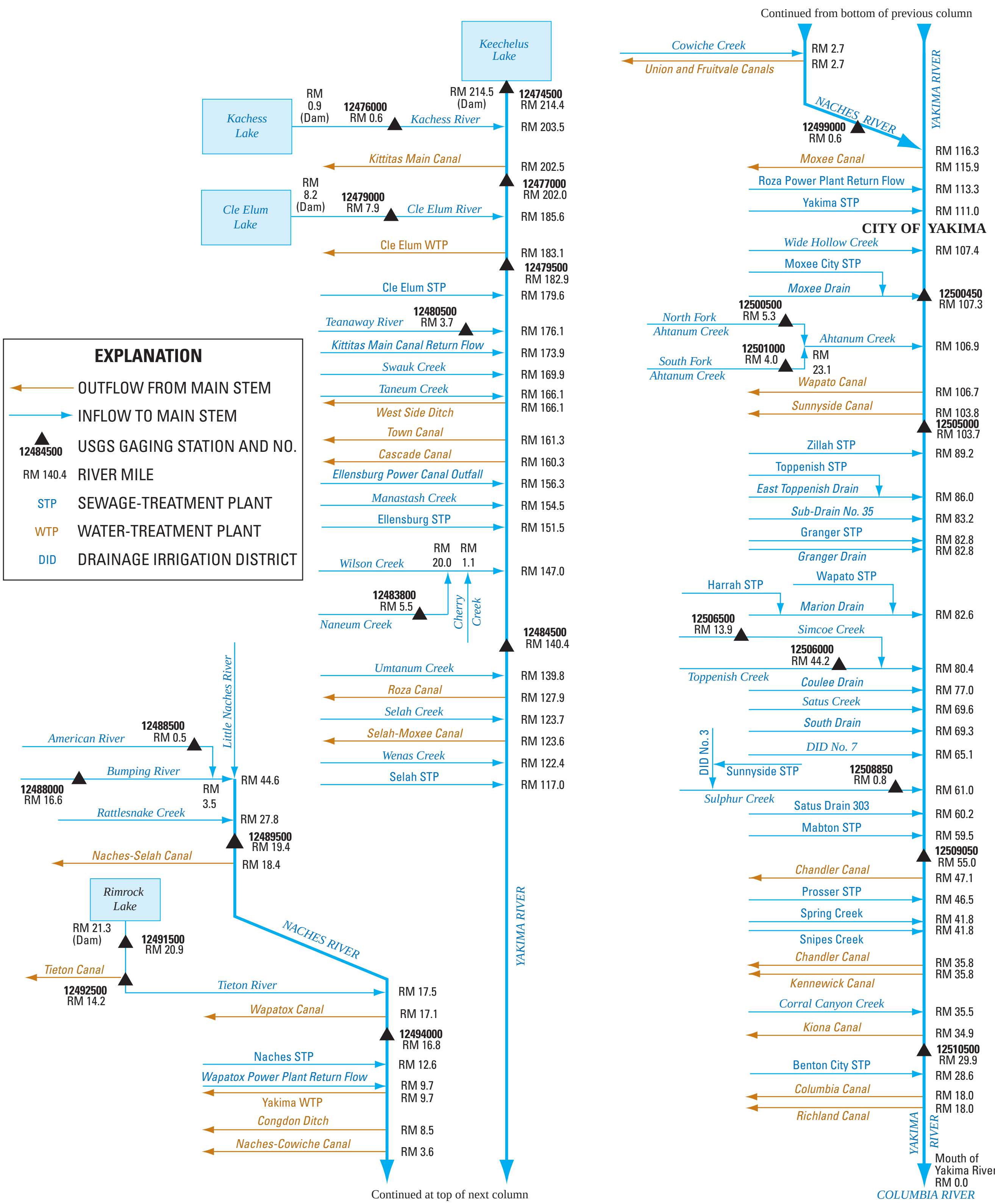


Figure 3. Selected tributaries, diversion canals, return flows, and streamflow-gaging stations, Yakima River Basin, Washington.

Overview of the Geology

The Columbia Plateau has been informally divided into three physiographic subprovinces (Meyers and Price, 1979). The western margin of the Columbia Plateau contains the Yakima Fold Belt subprovince and includes the Yakima River Basin. The Yakima Fold Belt is a highly folded and faulted region and within the study area part, it is underlain by various consolidated rocks, ranging in age from Precambrian to Tertiary, and unconsolidated materials and volcanic rocks of Quaternary age (fig. 4). In the Yakima River Basin, the headwater areas in the Cascade Range include metamorphic, sedimentary, and intrusive and extrusive igneous rocks.

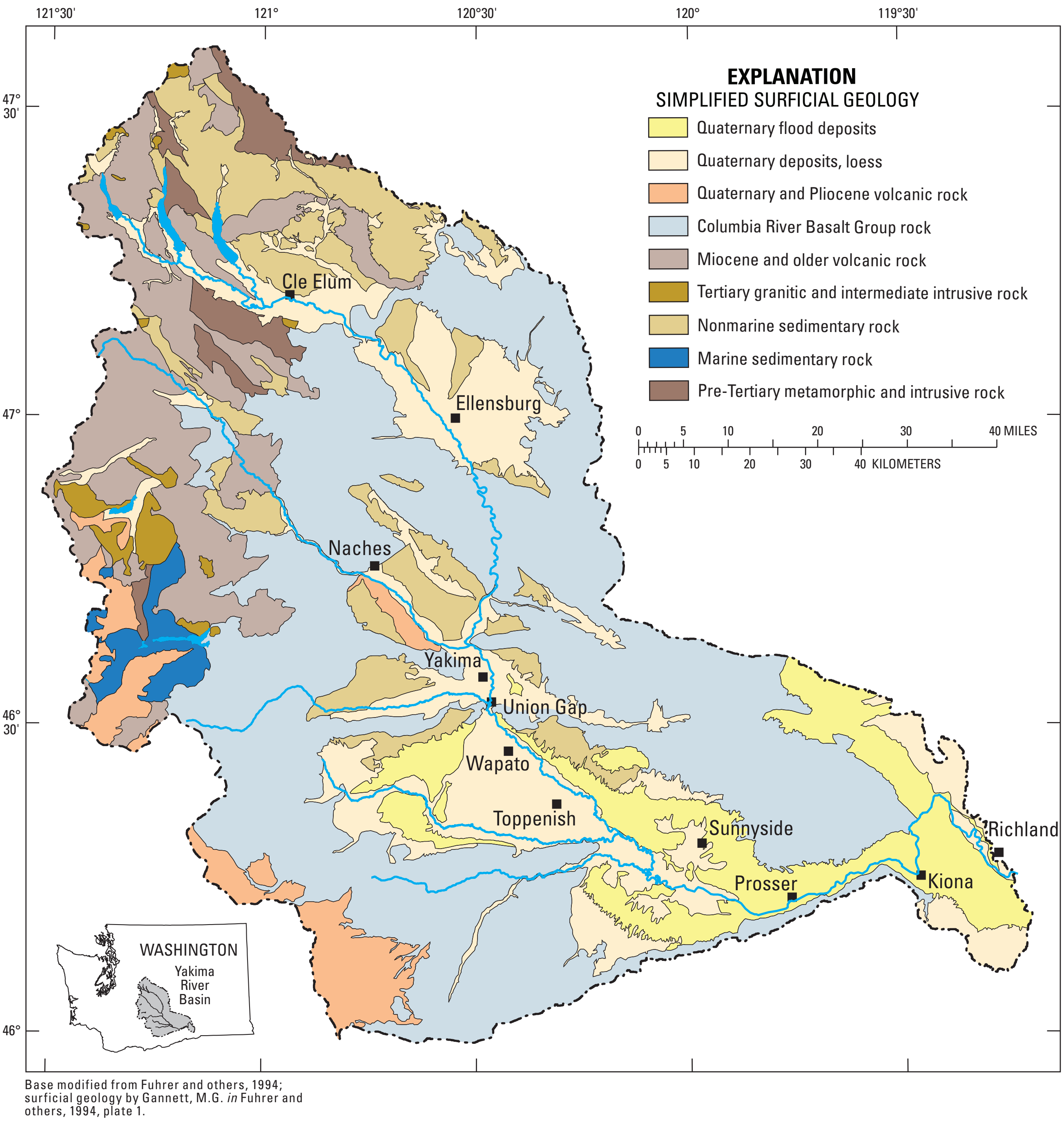


Figure 4. Simplified surficial geology, Yakima River Basin, Washington.

The central, eastern, and southwestern parts of the basin are composed of basalt lava flows of the Columbia River Basalt Group (CRBG) with some intercalated sediments that are discontinuous and weakly consolidated. The lowlands are underlain by unconsolidated and weakly consolidated valley-fill composed of glacial, glacio-fluvial, lacustrine, and alluvium deposits that in places exceed 1,000 ft in thickness (Drost and others, 1990). Wind-blown deposits, called loess, occur locally along the lower valley.

Valley-fill deposits and basalt lava flows are important for ground-water occurrence in the study area. The basalt consists of a series of flows erupted during various stages of the Miocene Age, ranging from 17 to 6 million years ago. Basalt erupted from fissures located in the eastern part of the Columbia Plateau and individual flows range in thickness from a few feet to more than 100 ft. The total thickness in the central part of the plateau is estimated to be greater than 10,000 ft (Drost and others, 1990) with a maximum thickness of more than 8,000 ft in the study area. Unlike most of the Columbia Plateau, the CRBG in the Yakima Fold Belt is underlain by sedimentary rocks. The valley-fill deposits were eroded from the Cascade Range and from the east-west-trending anticlinal ridges that were formed from the buckling of the basalt sequence during mid- to late-Miocene time. Much of these deposits are part of the Ellensburg Formation. This formation underlies, intercalates, and overlies the basalts along the western edge, and comprises most of the thickness of the unconsolidated deposits (informally called the overburden; Drost and others, 1990) in the basinal areas. The basins are narrow to large open synclinal valleys intervening between the numerous anticlinal ridges.

The deposition of a thick, upper sequence of sand, gravel, and some fine-grained material is the result of erosion by glacial ice and transport by meltwater streams. Damming of large lakes by glacial ice during the Pleistocene epoch resulted in the deposition of silt and clay beds in parts of the uplands. When the lakes drained, the fine sediments were exposed and subsequently eroded by wind and deposited over the lower, eastern parts of the study area. Thus, the unconsolidated materials in the basinal areas that are abutting and interbedded with the basalts range from Miocene to Holocene in age.

Methods of Investigation

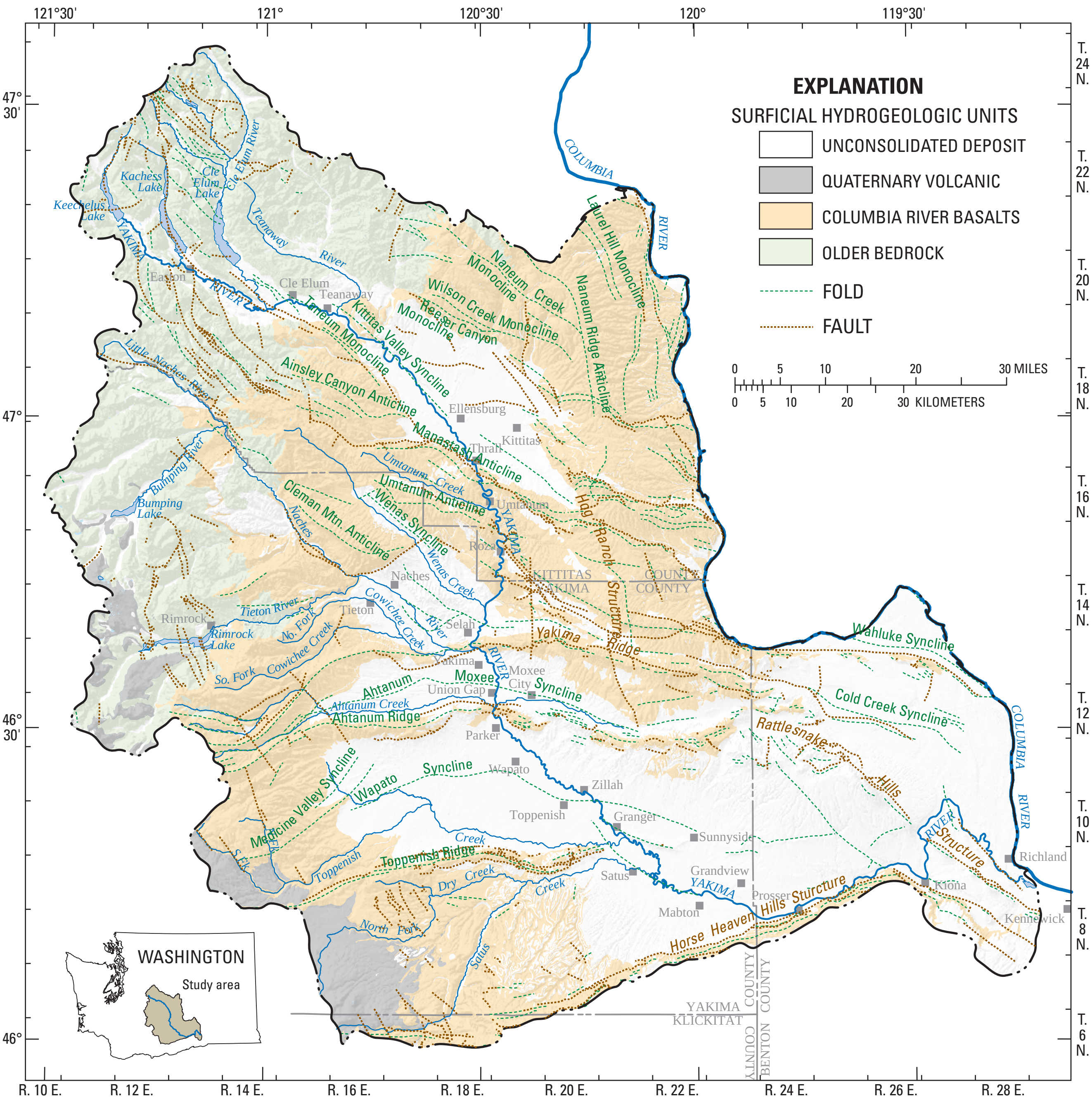
For this study, the area of interest was extended eastward to include an additional 700 mi^2 area beyond the Yakima River Basin to the Columbia River increasing the study area from 6,200 to 6,900 mi^2 (fig. 5). This extension to the Yakima River Basin was included to accommodate the larger Yakima River Basin aquifer system study area being used for the development of numerical ground-water flow models.

The hydrogeologic framework for the basalt and interbed units was compiled using information from multiple data types and data sources. Data types include well-log information from geochemical, geophysical, test hole, piezometer, and drillers' well-log records; and interpretative information from unit contour and geologic maps compiled from multiple sources. Sources of information include well records and maps from published and unpublished data and investigations. Previously published data and investigations include: Siems and others (1973), Swanson and others (1979), Meyers and Price (1979 and 1981), Tanaka and others (1979), Biggane (1982, 1983), Drost and Whiteman (1986), Drost and others (1989, 1990, 1997), U.S. Department of Energy (1988), Lane (1988), Whiteman and others (1994), Owens (1995), Sinclair (1998), Jones and others (2006), and Vaccaro and Sumioka (2006). Unpublished data were supplied by John Kirk (Washington Department of Ecology, written commun., 2006), Steve Reidel (unpub. report, Battelle, 2006), WaDOE well records web site (http://apps.ecy.wa.gov/welllog/index.asp), and the U.S. Geological Survey unpublished well records (or non-inventoried well records). Well-record information includes data from inventoried wells (well location verified by field personnel visit) and non-inventoried wells (well location not verified, used reported information). The non-inventoried, well records were selected to help refine the hydrogeologic framework in strategic areas where available well records were sparse. Their reported locations generally are accurate within a radius of 0.25 mi of their actual location. Locations of the inventoried wells generally are accurate within a radius of several hundred feet of their actual location.

A simplified surficial-geology map (Jones and others, 2006), based on the original mapping of 12 quadrangle maps available from the Washington State Division of Geology and Earth Resources (DGER), was used in this study to assist in delineating the hydrogeologic framework and extents of the basalt and interbed units. For the study area, the combined CRBG from the simplified map was subdivided and regrouped into three basalt units: Grande Ronde, Wanapum, and Saddle Mountains. No attempt was made to reconcile matching of the surficial geologic units across originally mapped quadrangle boundaries.

Extents and depth to the top of the basalt and interbed units were constructed for each unit based on information from the (1) simplified surficial-geology map, (2) unit interpretations from previously constructed contour maps, and (3) unit interpretations from about 3,000 well records. A given unit was assumed to be continuous within the boundaries of its extent, except where an underlying unit was present at the surface or where the interpreted data indicated the unit was absent.

Information from well records and available unit contour maps were converted to digital data layers and entered into a Geographic Information System (GIS) to facilitate data comparison and analysis and to construct layers representing the extents and tops of units. These unit layers were constructed from the top down using all available data for each individual unit so the layers for each successive unit were constrained by all the overlying layers.



Base from U.S. Geological Survey and (or) Washington Division of Geology and Earth Resources digital data, 1983, 1:100,000
Universal Transverse Mercator projection, Zone 10
Horizontal Datum: North American Datum of 1927 (NAD 27)
Vertical Datum: North American Vertical Datum of 1988 (NAVD 88)

Figure 5. Structure delineating Yakima River Basin aquifer system, Washington.

The accuracy of the layers depicting depth to the hydrogeologic units primarily is dependent on the methods of unit delineations. The delineations made from a geochemical analysis of a core sample, geologists' lithologic log, or geophysical log are relatively accurate, but vary according to the complexity of the geology. The delineations made from drillers' lithologic logs are the least accurate, particularly in structurally complex areas. About 99 percent of the unit delineations were based on interpretations of available drillers' logs in the study area and less than 1 percent of the delineations were based on interpretations of geochemical, geologists', or geophysical logs. An increased sampling and availability of interpreted geochemical, geologists', and geophysical logs could help to improve and refine the hydrogeologic framework in complex areas and areas of sparse data.

Data layers for each basalt and interbed unit were interpolated to a 30-meter cell size grid to construct a digital hydrogeologic framework for the basin. Data layers for each unit included a digital elevation model (DEM), the simplified surficial geology, previously constructed hydrogeologic unit contour maps (where available), mapped extent of the hydrogeologic unit, and well-log point values of the depth to the top of the individual unit.

In developing the three-dimensional (3D) framework, the original data interpretations were honored as much as possible. Thus, the calculated depth to the top of the unit-cell values and (or) mapped contours for the hydrogeologic units were compared to the original well and (or) mapped contour data then adjusted to more accurately reflect the original interpretations. The areas where the calculated depths are less accurate are in areas with sparse data; where the surficial geology changes abruptly, with structural complexity over short distances; where the well locations are less accurate; and where unit contour intervals were more generalized. However, most discrepancies were reconciled during the 3D framework construction.

Hydrogeologic Framework

This section describes the hydrogeologic framework of the basalt and interbed hydrogeologic units that compose part of the ground-water system in the Yakima River Basin aquifer system. An understanding of the framework is important in determining the occurrence, availability, and movement of ground water within the aquifer system. The ground-water flow system that is composed of the basalt and interbed units is in turn, part of the larger Columbia Plateau regional aquifer system. A correlation chart of the regional generalized stratigraphy and hydrogeologic units is shown in figure 6.

ERA	PERIOD	EPOCH	Sediment Stratigraphy	Basalt Stratigraphy	Hydrogeologic Unit
CENEZOIC	Quaternary	Holocene	Alluvium, alpine glaciation, alluvial fan, dune sand, artificial fill, and peat deposits	Quaternary and Pliocene Basalts	Basin-fill deposits
		Pleistocene	Alluvium, alpine glacial drift, alluvial fan, Palouse Formation, Lakedale Drift, Lookout Mountain Ranch Drift, Hayden Creek Drift, Kittitas Drift, Evans Creek Drift, unknown continental sedimentary deposits, dune sand, glacial Lake Missoula flood deposits		
	Tertiary	Pliocene	Alluvial fan, Ringold Formation, Dalles Formation, Thorpe Gravel, and unknown continental sedimentary deposits		
		Miocene	Ellensburg Formation, Ringold Formation, Dalles Formation, Snipes Mountain deposits, and unknown continental sedimentary deposits	Saddle Mountains Basalt flow members and interbeds	Saddle Mountains unit
				Mabton interbed (Mabton Member of the Ellensburg Formation)	Mabton unit
				Wanapum Basalt flow members and interbeds	Wanapum unit
				Vantage interbed (Vantage Member of the Ellensburg Formation)	Vantage unit
				Grande Ronde Basalt flow members and interbeds	Grande Ronde unit
Older Bedrock					

Figure 6. Correlation chart showing the regional relation between generalized stratigraphy and hydrogeologic units for the Yakima River Basin, Washington.

The hydrogeologic units vary in extent and thickness, and each unit is discussed separately. The hydrogeologic units identified in this report do not necessarily correspond to geologic time-stratigraphic deposits. The ground-water flow system within the Yakima River Basin aquifer system is interconnected with the overlying basin-fill deposits and with the Columbia Plateau regional aquifer system.

Knowledge of the geologic structure that exists within the Yakima River Basin aquifer system (fig. 5) also assisted in mapping of the hydrogeologic units. The structural setting helps to explain the depositional sequences, thickness variations, and segmentation of the ground-water movement or anomalous water-level distributions within the area. For example, a predominantly fine-grained or non-porous unit could be vertically offset and juxtaposed with a coarse-grained or porous unit, thereby truncating the lateral ground-water movement along a fault and also offsetting the water-level distribution on either side of the fault. Although such ground-water flow issues are not addressed in this report, the structural history has provided information for mapping the hydrogeologic units that will assist in the development of numerical ground-water flow models.

Saddle Mountains Hydrogeologic Unit

The Saddle Mountains hydrogeologic unit is the youngest and least extensive of the basalt units. The unit is located in the southeast and south-central part of the Yakima River Basin aquifer system (pl. 1) and encompasses an area of about 2,290 mi^2. Most of the unit area, about 1,800 mi^2, lies beneath the basin fill deposits described in Jones and others (2006). Surficial outcrops of the Saddle Mountains Basalt (SMB) make up about 460 mi^2 of the Saddle Mountains unit and about 30 mi^2 of surficial outcrops of the older Wanapum Basalt (WB) and Grande Ronde Basalt (GRB) are within the mapped unit extent. The outcrops of the SMB are located in the southwest generally south of the Toppenish Ridge near Dry and Satus Creeks, and along the flanks of Horse Heaven Hills Structure, Rattlesnake Hills Structure, Ahtanum Ridge, Yakima Ridge, and the Umtanum Anticline (fig. 5, pl. 1).

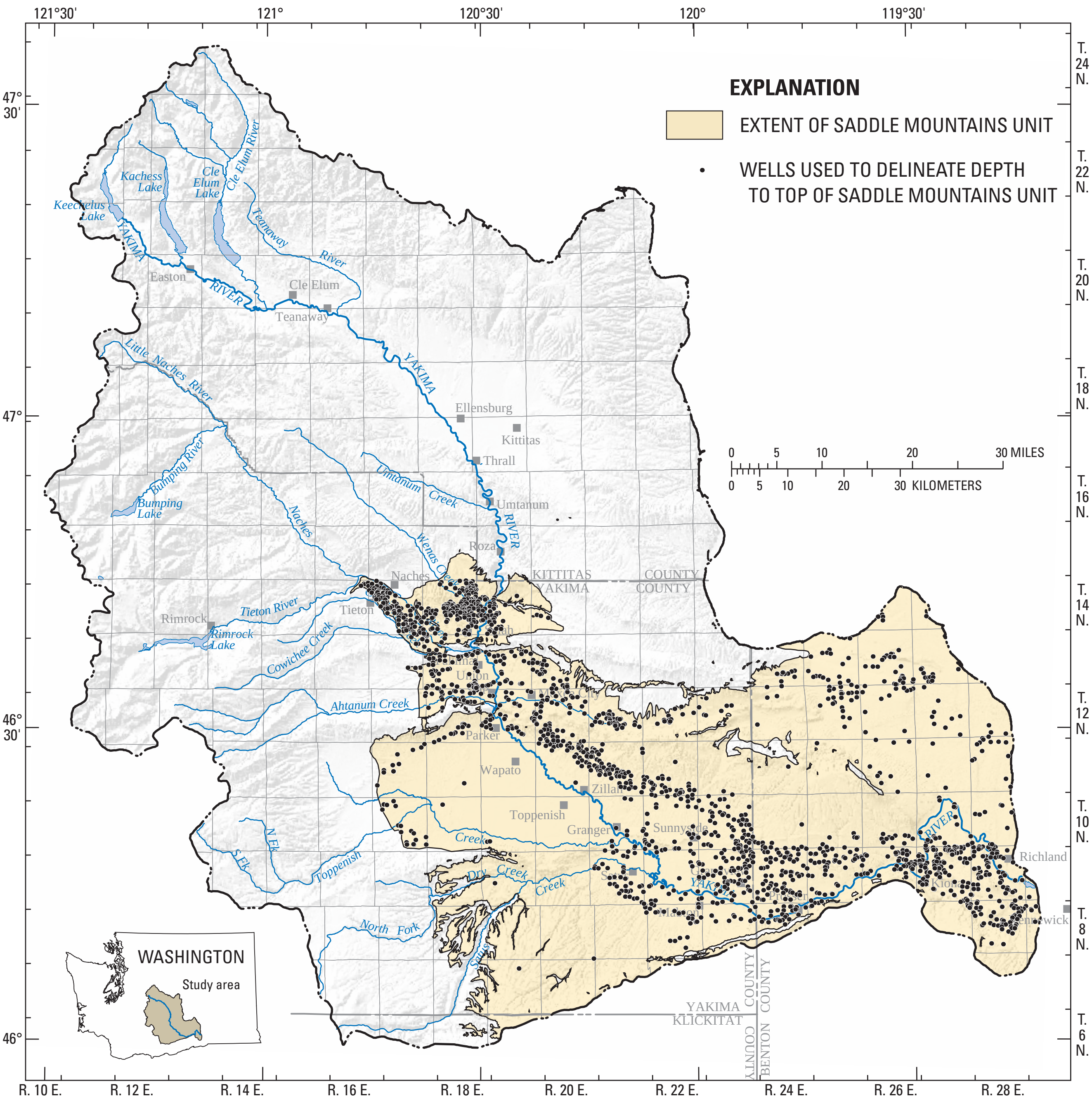
The Saddle Mountains unit predominantly contains the basalt and interbed members associated with the SMB. The SMB is composed of at least 13 named flows and 5 interbed members (Meyers and Price, 1981). The SMB flows' texture and composition differ greatly throughout its extent. The sedimentary interbeds contained within the SMB are common, relatively thick (often 50 ft or greater) and range in composition from clay to sand and gravel (Drost and Whiteman, 1986). The Saddle Mountains unit also may contain some of the younger basalts present in the unit extent due to the inability to delineate between the basalts based on the available well record information and the minimal data available in some areas. This is true particularly in the area near Naches (pl. 1) where Quaternary basalt is mapped at the surface and in places that directly overlie the SMB, but due to a lack of data to effectively separate the basalts they were combined. The hydrogeologic framework could be improved as more detailed data become available at depth and for areas were data are sparse.

The top of the Saddle Mountains unit ranges from a maximum altitude of 4,290 ft where it is exposed at land surface to a depth of 1,840 ft below land surface. The mean and median depths to the top of the Saddle Mountains unit are about 200 ft and 120 ft below land surface, respectively. The highest altitudes of the Saddle Mountains unit are located along the southern boundary of the study area and along the western part of the Horse Heaven Hills Structure where the unit reaches altitudes above 4,000 ft. The unit is at its greatest depth below land surface in the area northwest of the city of Yakima where the depth to the top of the unit exceeds 1,800 ft. Thickness of the Saddle Mountains unit, based on wells that completely penetrated the unit ranged from about 0 to 1,110 ft, with a mean and median thickness of about 550 ft and 560 ft, respectively. The distribution of the well-record information used to delineate the depth to the top of the Saddle Mountains unit is shown in figure 7.

Mabton Hydrogeologic Unit

The Mabton hydrogeologic unit is the sedimentary interbed between the overlying SMB and the WB and is informally called the Mabton Member of the Ellensburg Formation (Drost and Whiteman, 1986). The Mabton unit is located in the southeast and south-central part of the Yakima River Basin (pl. 2) and encompasses an area of about 2,210 mi^2. Most of the unit area, about 2,180 mi^2, lies beneath the Saddle Mountains unit and about 30 mi^2 of the older WB and GRB are within the mapped unit extent (pl. 2). No surficial outcrops of the Mabton unit are present within the study area and the extent is assumed to be within the extent of the Saddle Mountains unit. The Mabton unit might extend beyond the boundary of the Saddle Mountains unit, but it is difficult to delineate between the basin-fill deposits and the Mabton deposits at depth by only using available well-record information.

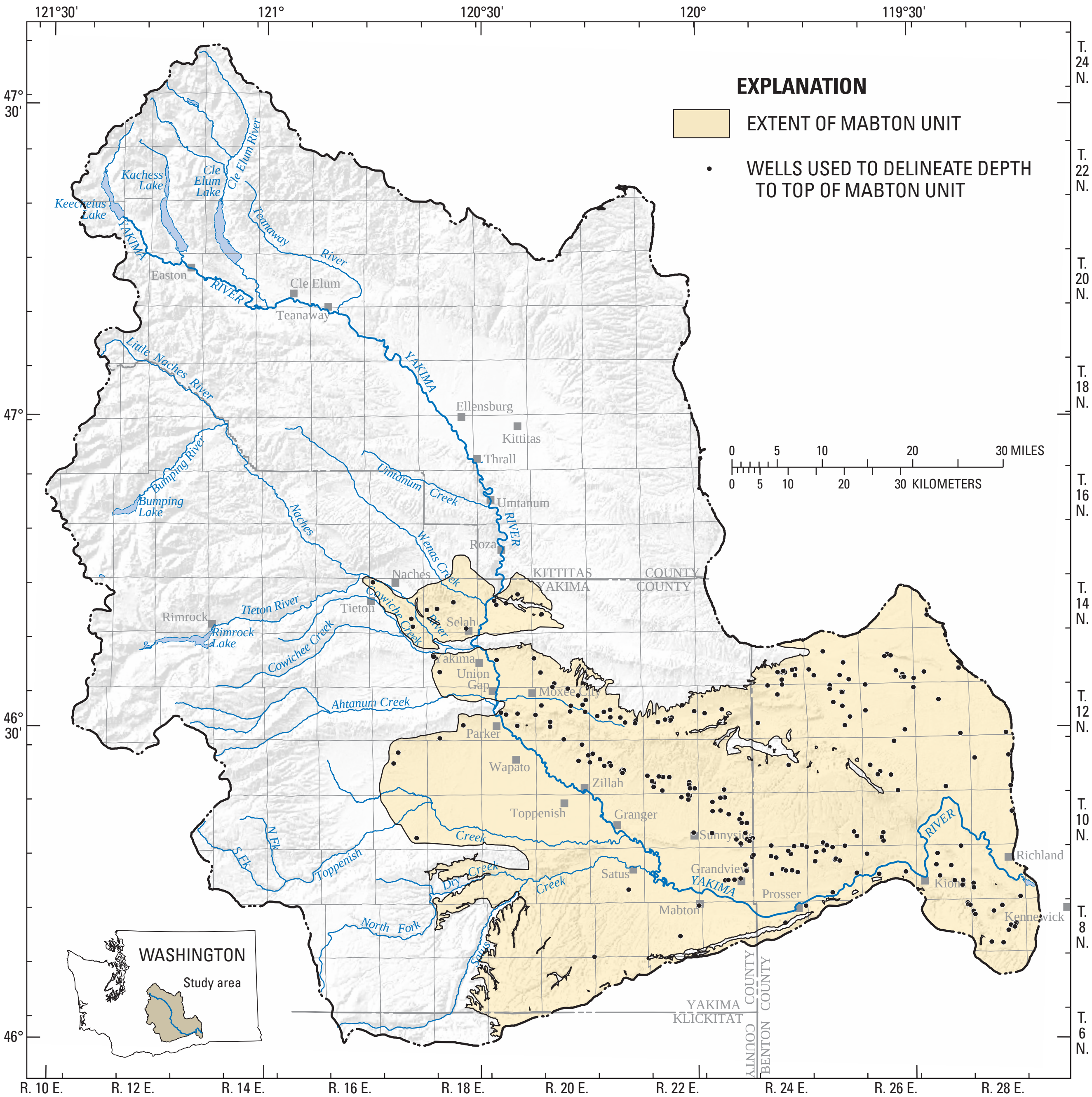
The Mabton unit generally consists of clay, shale, claystone, clay with basalt, clay with sand, and sandstone, but also may contain small amounts of sand and sand-and-gravel, based on the interval interpretations from available well records.



Base from U.S. Geological Survey and (or) Washington Division of Geology and Earth Resources digital data, 1983, 1:100,000
Universal Transverse Mercator projection, Zone 10
Horizontal Datum: North American Datum of 1927 (NAD 27)
Vertical Datum: North American Vertical Datum of 1988 (NAVD 88)

Figure 7. Distribution of wells used to delineate the depth to top of Saddle Mountains unit, Yakima River Basin aquifer system, Washington.

The depth to the top of the Mabton unit ranges from 80 to 2,000 ft below land surface. The mean and median depths are about 730 ft and 640 ft below land surface, respectively. The unit is at its shallowest depth along the southeastern flank of the Yakima ridge near the north end of Rattlesnake Hills Structure (fig. 5, pl. 2). The areas where the unit is at its greatest depth below land surface are in the areas northwest and northeast of Yakima, south of Wapato and north of Toppenish, where the depth to the top of the unit exceeds 1,800 ft. Thickness of the Mabton unit, based on wells that completely penetrate the unit range from about 0 to 250 ft, with a mean and median thickness of about 70 ft. The distribution of the well record information used to delineate the depth to the top of the Mabton unit is shown in figure 8.



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Universal Transverse Mercator projection, Zone 10
Horizontal Datum: North American Datum of 1927 (NAD 27)
Vertical Datum: North American Vertical Datum of 1988 (NAVD 88)

Figure 8. Distribution of wells used to delineate the depth to top of Mabton unit, Yakima River Basin aquifer system, Washington.

Wanapum Hydrogeologic Unit

The Wanapum hydrogeologic unit is located in the northeast, central, south, and southeastern part of the Yakima River Basin aquifer basin (pl. 3) and encompasses an area of about 3,450 mi^2. Most of the unit area (2,760 mi^2) lies beneath the basin-fill deposits, Saddle Mountains unit, or Mabton unit. Surficial outcrops of the WB make up about 660 mi^2 of the Wanapum unit and about 30 mi^2 of the surficial outcrops within the mapped unit extent are older Grande Ronde Basalt. The outcrops of the WB are located predominantly in the northeast, north of and along the Yakima Ridge; and in the southwest, along and south of the Toppenish Ridge. Less continuous WB outcrops occur along the Ahtanum Ridge, Rattlesnake Hills Structure, and Horse Heaven Hills Structure (fig. 5, pl. 3).

The Wanapum unit contains predominantly the basalt and interbed members associated with the WB. The WB is composed of at least six named flows and two interbed members (Meyers and Price, 1981). The WB flows' generally are medium-grained to moderately plagioclase-phyric, olivine bearing, and relatively high in iron and titanium oxides. The clay to sand-and-gravel sedimentary interbeds in the WB are less common than those in the SMB and generally are only a few feet thick (Drost and Whiteman, 1986). But the Wanapum unit also may contain some of the younger basalt, particularly in areas where the available well records occur along the margins of the unit extent and where the younger basalt abuts or overlies the WB.

The top of the Wanapum unit ranges from a maximum altitude of 5,680 ft where it is exposed at land surface to a depth of 2,050 ft below land surface. The mean and median depths to the top of the Wanapum unit are about 420 ft and 260 ft below land surface, respectively. The highest altitudes of the Wanapum unit are located along the southern boundary near Satus Creek, where the unit reaches altitudes above 5,000 ft (fig. 5, pl. 3). The areas where the unit is at its greatest depth below land surface are east of Ellensburg and northwest of Yakima where the depth to the top of the unit exceeds 2,000 ft. Thickness of the Wanapum unit, based on wells that completely penetrated the unit, ranged from about 0 to 1,180 ft, with a mean and median thickness of about 600 ft and 490 ft, respectively. The distribution of the well-record information used to delineate the depth to the top of the Wanapum unit is shown in figure 9.

Vantage Hydrogeologic Unit

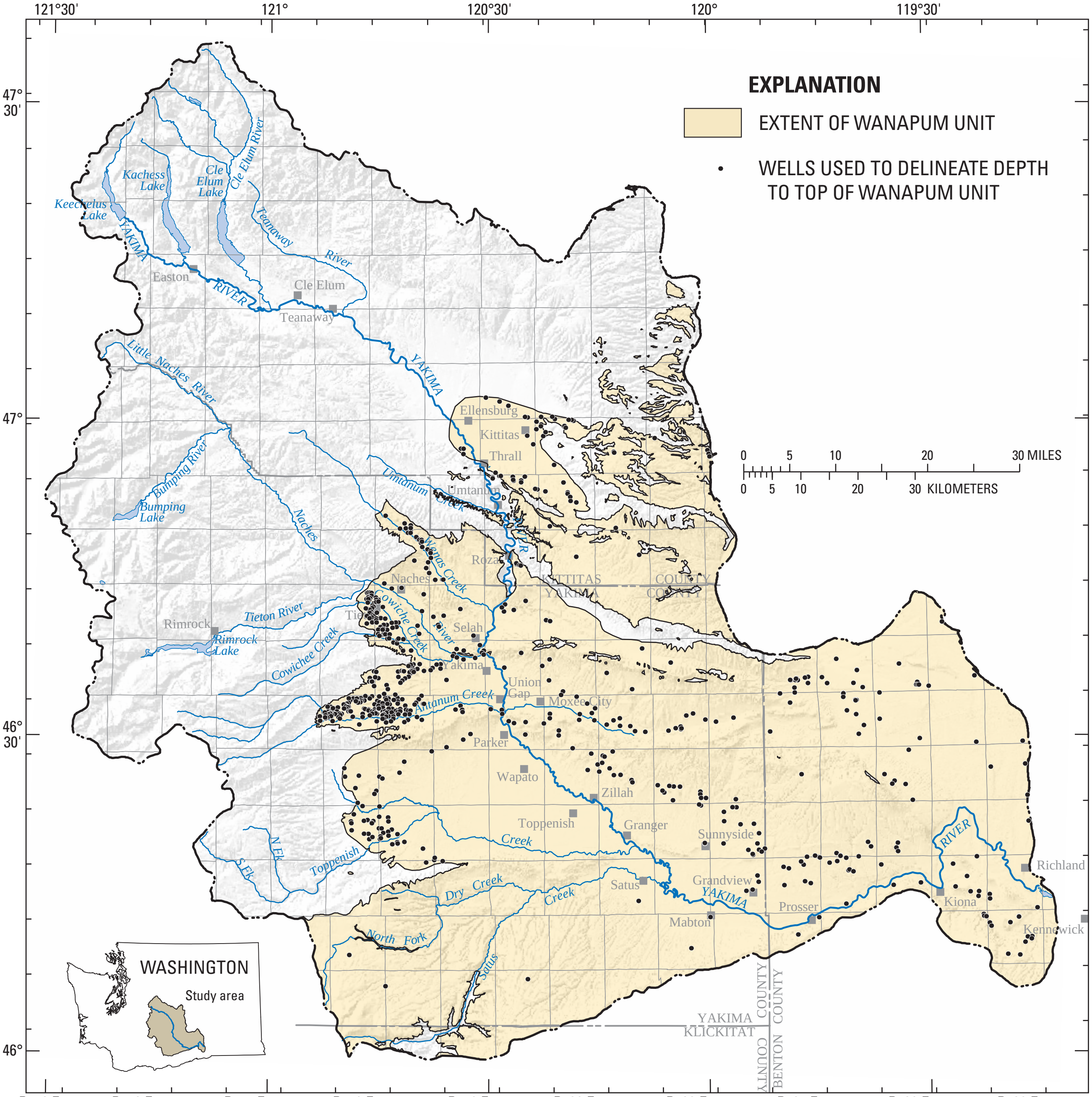
The Vantage hydrogeologic unit is the sedimentary interbed between the overlying WB and the GRB that informally is called the Vantage Member of the Ellensburg Formation (Drost and Whiteman, 1986). The Vantage unit is located in the northeast, central, south, and southeastern part of the Yakima River Basin aquifer system (pl. 4) and encompasses an area of about 3,090 mi^2. Most of the unit area (3,050 mi^2) lies beneath the Wanapum unit and about 40 mi^2 of the older GRB are within the mapped unit extent (pl. 4). No surficial outcrops of this unit within the study area are present and its extent is assumed to be within the extent of the Wanapum unit. The Vantage unit might extend beyond the boundary of the Wanapum unit, but it is difficult to delineate between the basin-fill deposits and the Vantage deposits at depth by only using well-record information.

The Vantage unit consists of clay, shale, sandstone, tuff with claystone, and clay with basalt, but also may contain small amounts of sand and sand-and-gravel. A few well-record interpretations also indicate that the Vantage unit is not present in the southeastern part of the Yakima River Basin aquifer system along the eastern boundary and near the Cold Creek Syncline and Rattlesnake Hills Structure (fig. 5, pl. 4).

The depth to the top of the Vantage unit ranges from 40 to 2,790 ft below land surface. The mean and median depths are about 1,150 ft and 820 ft below land surface, respectively. The unit is at its shallowest depth in the northeastern part of the Vantage unit extent along the eastern boundary, in the area where the WB outcrops at the surface (pls. 3 and 4). The areas where the unit is at its greatest depth are an area north of Toppenish and an area northeast of Rattlesnake Hills Structure, where the depth to the top of the unit exceeds 2,600 ft. Thickness of the Vantage unit, based on wells that completely penetrated the unit, ranged from about 0 to 135 ft, with a mean and median thickness of about 30 ft and 20 ft, respectively. The distribution of the well-record information used to delineate the depth to the top of the Vantage unit is shown in figure 10.

Grande Ronde Hydrogeologic Unit

The Grande Ronde hydrogeologic unit is the oldest and most extensive of the basalt units. It underlies most of the Yakima River Basin aquifer system (pl. 5), except for an area along the western boundary and the northwestern part of the basin where generally older bedrock units outcrop at the surface (fig. 4). The extent of the Grande Ronde unit encompasses about 5,390 mi^2 with most of the unit, 3,790 mi^2, present beneath the basin-fill deposits, Vantage unit, and Wanapum unit. Surficial outcrops of the GRB make up about 1,550 mi^2 of the Grande Ronde unit and about 50 mi^2 of the surficial outcrops within the mapped unit extent are older bedrock deposits. The outcrops of the GRB are located predominantly along the northeastern and western boundary of the unit extent. Less continuous GRB outcrops occur along Yakima Ridge, Rattlesnake Hills Structure, and in the south along Satus Creek (fig. 5, pl. 5).



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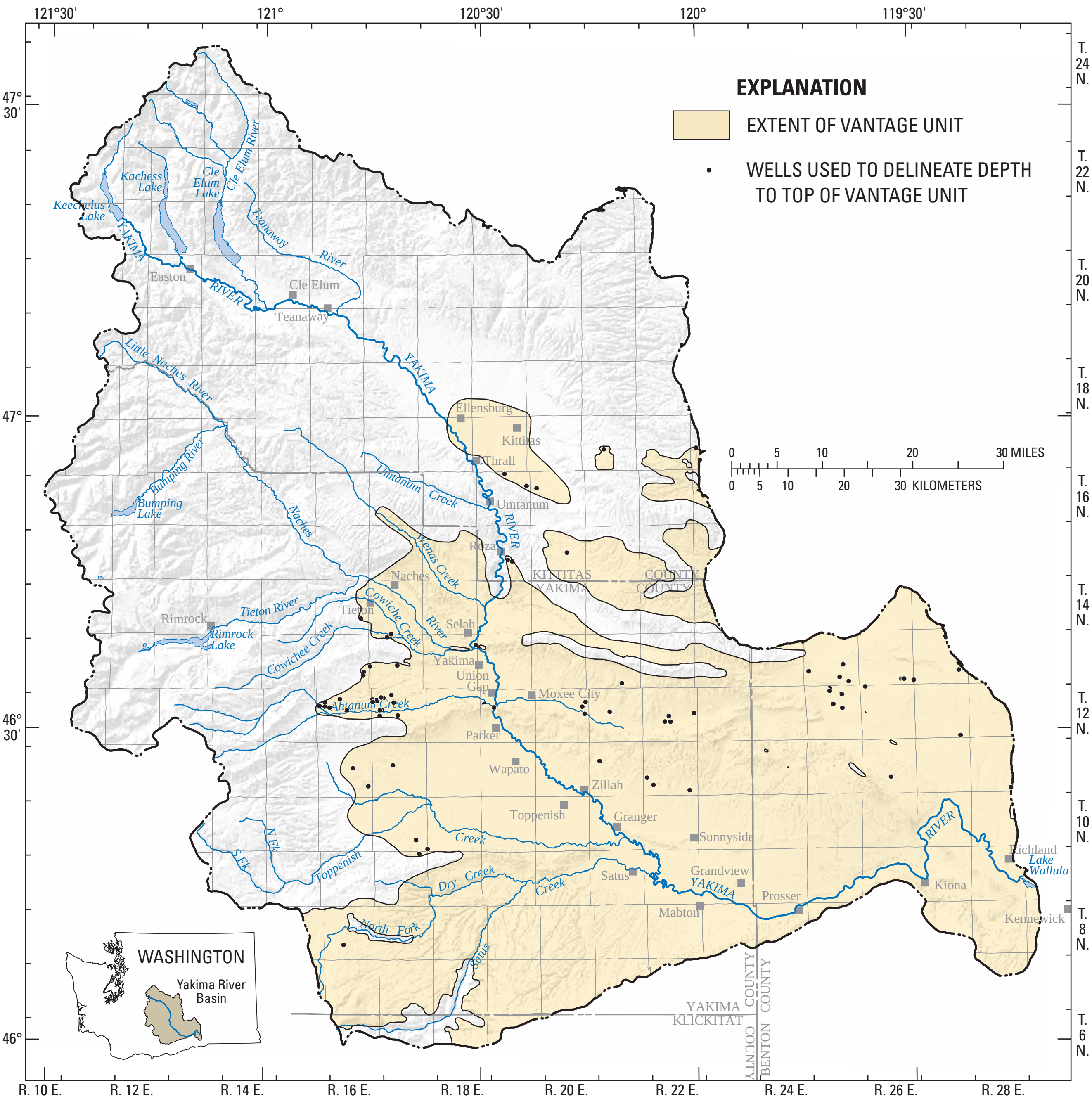
Universal Transverse Mercator projection, Zone 10
Horizontal Datum: North American Datum of 1927 (NAD 27)
Vertical Datum: North American Vertical Datum of 1988 (NAVD 88)

Figure 9. Distribution of wells used to delineate the depth to top of Wanapum unit, Yakima River Basin aquifer system, Washington.



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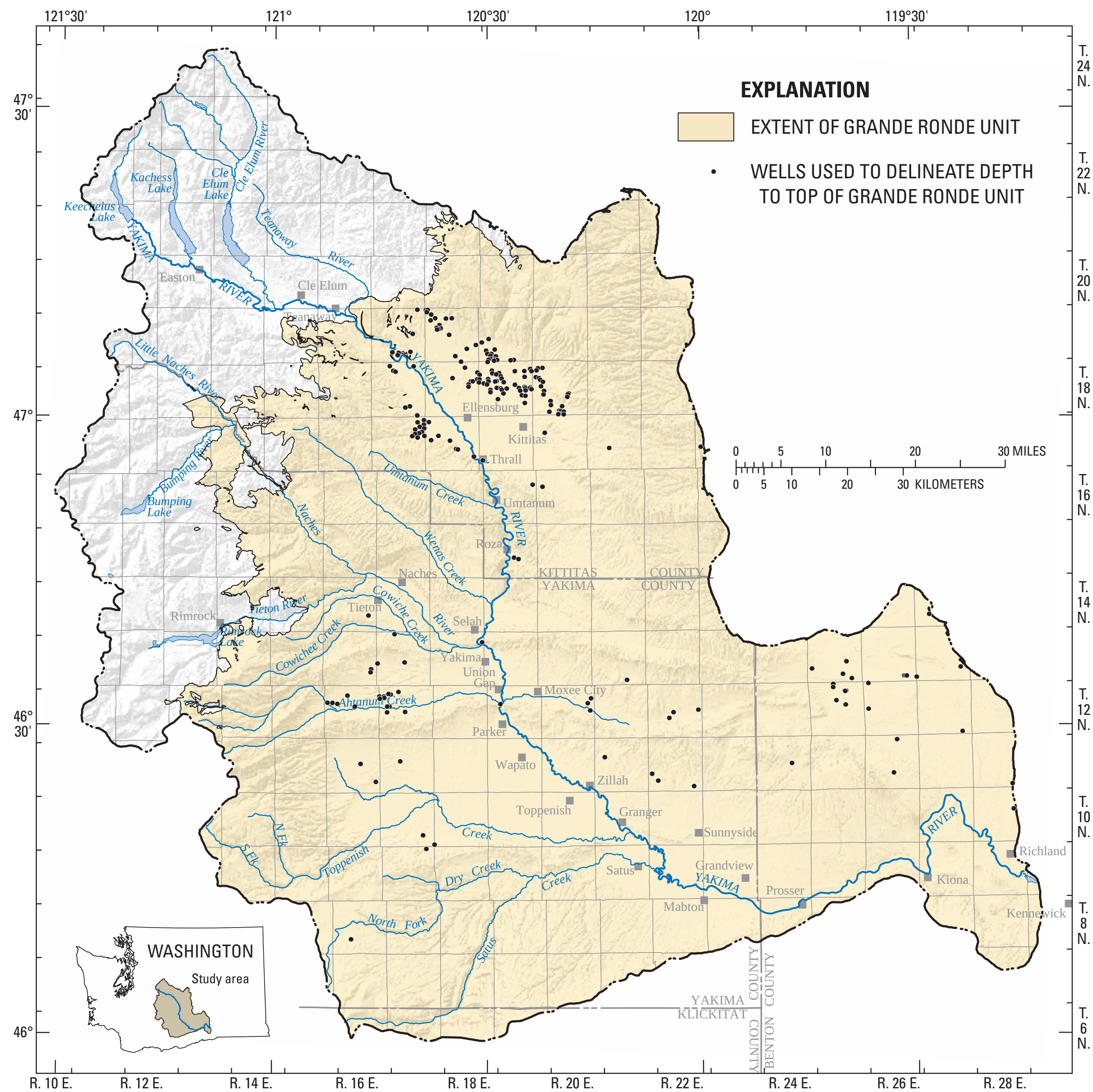
Universal Transverse Mercator projection, Zone 10
Horizontal Datum: North American Datum of 1927 (NAD 27)
Vertical Datum: North American Vertical Datum of 1988 (NAVD 88)

Figure 10. Distribution of wells used to delineate the depth to top of Vantage unit, Yakima River Basin aquifer system, Washington.

The Grande Ronde unit predominantly contains the basalt and interbed members associated with the GRB. The GRB is composed of at least 30 flows and perhaps as many as several hundred individual flows (Meyers and Price, 1981; Drost and Whiteman, 1986). The GRB flows' are aphyric with microphenocrysts of plagioclase and clinopyroxene. Olivine is generally present only in the groundmass, and typically totals less than 0.5 percent of the flow volume (Drost and Whiteman, 1986). Sedimentary interbeds within the GRB generally are rare and where present are only a few feet thick (Meyers and Price, 1981; Drost and Whiteman, 1986). These sedimentary interbeds range in composition from clay to sand-and-gravel.

The top of the Grande Ronde unit ranges from a maximum altitude of 6,900 ft where it is exposed at land surface to a depth of 2,800 ft below land surface. The mean and median depths to the top of the Grande Ronde unit are about 1,300 ft and 980 ft below land surface, respectively. The highest altitudes of the Grande Ronde unit are located along the western boundary near Cowiche Mountain and along the northern boundary on the northern part of the Naneum Ridge Anticline, where the unit reaches altitudes above 6,500 ft. The areas where the unit is at its greatest depth are an area north of Toppenish and an area northeast of Rattlesnake Hills Structure, where the depth to the top of the unit exceeds 2,600 ft (pl. 5). Thickness of the Grande Ronde unit was not determined. The distribution of the well-record information used to delineate the depth to the top of the Grande Ronde unit is shown in figure 11.



Base from U.S. Geological Survey and (or) Washington Division of Geology and Earth Resources digital data, 1983, 1:100,000
Universal Transverse Mercator projection, Zone 10
Horizontal Datum: North American Datum of 1927 (NAD 27)
Vertical Datum: North American Vertical Datum of 1988 (NAVD 88)

Figure 11. Distribution of wells used to delineate the depth to top of Grande Ronde unit, Yakima River Basin aquifer system, Washington.

Summary and Conclusions

The Yakima River Basin aquifer system in south-central Washington encompasses an area of about 6,900 mi^2 including the entire Yakima River Basin and lands to the east extending to the Columbia River. The five hydrogeologic units delineated, from top to bottom, are the Saddle Mountains, Mabton, Wanapum, Vantage, and Grande Ronde. Information for these units was compiled and combined from several data types and sources, which include a simplified geology map, hydrogeologic contour maps from previous studies, and interpretations of about 3,000 well records from previous studies and investigators. This information was used to delineate the extent of and the depth to the top of three basalt and two interbed hydrogeologic units within the study area.

All data and information were converted to digital data layers and entered into a GIS software program in order to construct a 3D digital framework of the unit extents and layers using a gridded 30-meter cell size. Data layers for each basalt and interbed unit include a DEM, simplified surficial-geology map, previously constructed hydrogeologic unit contour maps (where available), mapped extent of the hydrogeologic unit, and well-log point values of the depth to the top of the individual unit. The original data interpretations were honored as much as possible in developing the 3D framework. The calculated depth to the top of the unit-cell values and (or) mapped contours for the hydrogeologic units were compared to the original well and (or) mapped contour data then adjusted to reflect more accurately the original interpretations.

The hydrogeologic framework defines the physical, lithologic, and hydrologic characteristics of the basalt and interbed hydrogeologic units that compose part of the ground-water system in the Yakima River Basin. The hydrogeologic characteristics vary from unit to unit, and the extent and depth-to-top of each hydrogeologic unit is described.

The Saddle Mountains unit is the youngest and least extensive of the basalt units encompassing an area of about 2,290 mi^2. The Saddle Mountains unit ranges in altitude from 4,290 ft where it is exposed at land surface to a depth of 1,840 ft below land surface with most of the unit lying beneath the basin-fill deposits. The hydrogeologic unit consists predominantly of basalt flows and interbed members of the Saddle Mountains Basalt whose flow texture and composition differ greatly throughout its extent.

The Mabton unit is the sedimentary interbed between the Saddle Mountains Basalt and Wanapum Basalt. It encompasses an area of about 2,210 mi^2, and generally is present beneath the Saddle Mountains unit. The depth to the top of this unit ranges from 80 to 2,000 ft below land surface. The hydrogeologic unit generally consists of clay, shale, claystone, clay with basalt, clay with sand, and sandstone, but also may contain small amounts of sand and sand-and-gravel.

The Wanapum unit extends to the north and west beyond the Saddle Mountains unit and encompasses an area of about 3,450 mi^2. The Wanapum unit ranges in altitude from 5,680 ft where it is exposed at land surface to a depth of 2,050 ft below land surface with most of the unit lying beneath the basin-fill deposits, Saddle Mountains unit or Mabton unit. The hydrogeologic unit consists predominantly of basalt flows and interbed members of the Wanapum Basalt. The basalt flows generally are medium-grained to moderately plagioclase-phyric, olivine bearing and relatively high in iron and titanium oxides.

The Vantage unit is the sedimentary interbed between the overlying Wanapum Basalt and Grande Ronde Basalt. It encompasses an area of about 3,090 mi^2 with most of the unit present beneath the Wanapum unit. The depth to the top of this unit ranges from 40 to 2,790 ft below land surface. The hydrogeologic unit generally consists of clay, shale, sandstone, tuff with claystone, and clay with basalt, but also may contain small amounts of sand and sand-and-gravel.

The Grande Ronde unit is the oldest and most extensive of the basalt units encompassing an area of about 5,390 mi^2. The Grande Ronde unit ranges in altitude from 6,900 ft where it is exposed at land surface to a depth of 2,800 ft below land surface with most of the unit lying beneath the basin-fill deposits. The hydrogeologic unit consists predominantly of basalt flows and interbed members of the Grande Ronde Basalt. The basalt flows are aphyric with microphenocrysts of plagioclase and clinopyroxene.

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Bob Crist
Bill Gibbs
Pat Revitzer
Bobbie Jo Richey
Sharon Wahlstrom

For more information concerning the research in this report, contact the
Director, Washington Water Science Center
U.S. Geological Survey, 934 Broadway — Suite 300
Tacoma, Washington 98402
http://wa.water.usgs.gov

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