SUMMARY APPRAISAL OF WATER RESOURCES OF THE UMATILLA INDIAN RESERVATION

By J.B. Gonthier and E.L. Bolke

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ILLUSTRATIONS

[Plate is in pocket]

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
acre	4047.	square meter (m^2)
	Volume	
acre-feet (acre-ft)	1233.	cubic meter (m^3)
	Flow	
gallon per minute (gal/min)	0.0631	liter per second (L/s)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

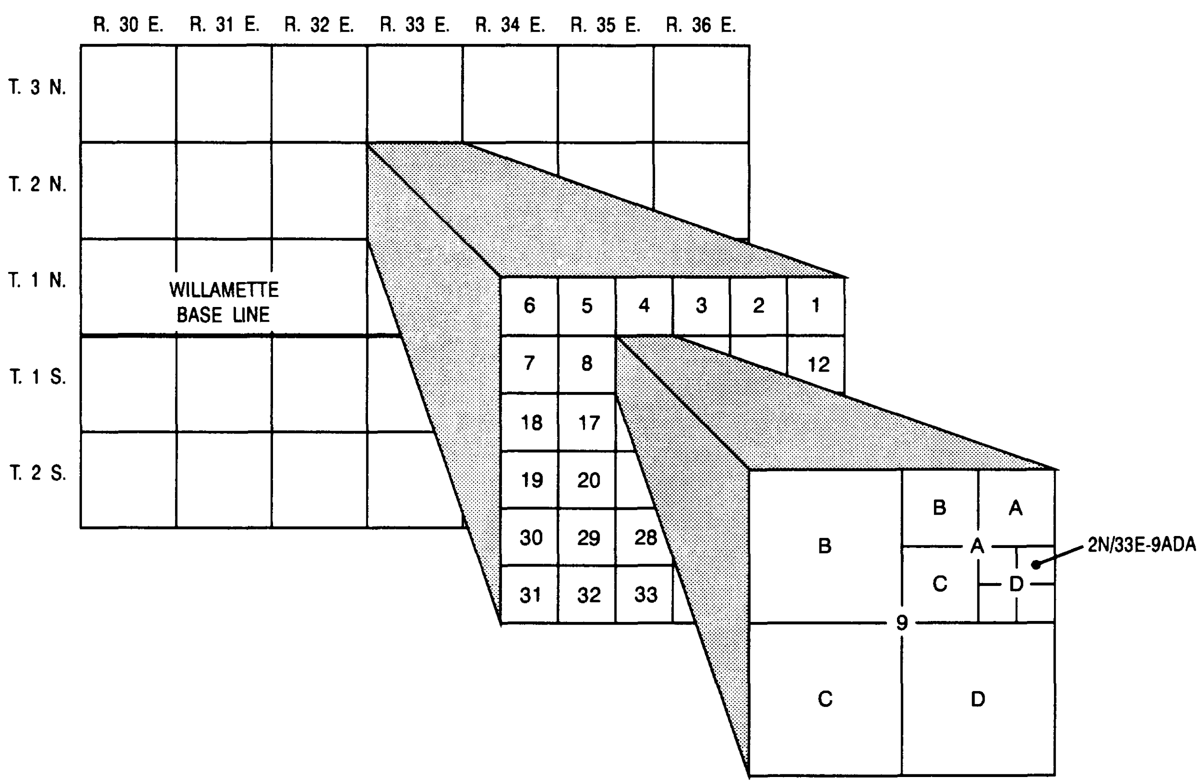
$$°C = 0.555\ (°F-32)$$

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.

DATA-SITE NUMBERING SYSTEMS

Streamflow stations.--Streamflow stations along the main stream are numbered in downstream order, and stations on tributaries are listed between main-stream stations in the same order that the tributaries enter the main stream. Each station has been assigned a unique eight-digit number by the U.S. Geological Survey. Station numbers used in tables in this report are the same as those used in data and water-supply paper reports of the U.S. Geological Survey.

Wells and springs.--The well- and spring-numbering system used in Oregon is based on the rectangular system for subdivision of public land, and each number indicate the location of the well with respect to township, range, and section. In successive order, the numerals represent the township, range, and section. Thus, well 1N/33E-16DDC2 is in township 1 north, range 33 east, section 16. The letters following the section number show the location within the section, the first letter designating the quarter section (160 acres), the second letter the quarter-quarter section (40 acres), and the third letter the quarter-quarter-quarter section (10 acres). For springs, a suffix(es) is added to the number. Where two or more wells are in the same 10-acre subdivision, serial numbers are added after the third letter, as shown below.



SUMMARY APPRAISAL OF WATER RESOURCES OF THE UMATILLA INDIAN RESERVATION, OREGON

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ABSTRACT

This study provides a summary assessment of water resources of the Umatilla Indian Reservation in eastern Oregon. The assessment was made from available data; no new data were collected specifically for the study.

The Umatilla Indian Reservation is underlain by pre-Miocene volcanic rocks, the Columbia River Basalt Group, Quaternary-Tertiary sedimentary rocks and Quaternary alluvium. Sources of water on the reservation are mostly from wells completed in the Columbia River Basalt Group. Of this group, the Wanapum Basalt and the upper hydrogeologic unit of the Grande Ronde Basalt are the most productive units.

The long-term average discharge of streams on and near the reservation has not changed significantly from the long-term averages calculated from earlier studies. Short-term averages are significantly affected by drought conditions such as those during 1977 and 1988.

Observation wells along the Umatilla River Valley indicate no long-term water-level declines in the alluvium and shallow basalt. Water level data outside of the reservation near Adams and near Pendleton indicate that water levels are declining a few feet per year in the deep regional ground-water system as a result of pumpage outside the reservation. The declines are not adequately documented within the reservation boundaries. Average annual ground-water pumpage on the reservation is about 3,350 acre-feet per year.

Results from a previous model study, although not designed specifically for the reservation, but which included part of the reservation, were used to estimate ground-water recharge from precipitation, subsurface inflow and outflow to and from the Wanapum and upper Grande Ronde units, and recharge to and discharge from streams.

Additional study is needed to better define the relation between surface- and ground-water flow, to refine estimates of ground-water recharge, and to more accurately determine the amount of ground water entering and leaving the reservation boundaries as subsurface flow.

INTRODUCTION

The Umatilla Indian Reservation lies east of Pendleton on the west flank of the Blue Mountains in eastern Oregon (fig. 1). The reservation was established by treaty between the United States Government and the Umatilla, Walla Walla, and Cayuse tribes in 1855. In 1885, the Slater Act decreased the reservation area to its present size of 247 square miles (from an original size of 384 square miles). A special act of

Congress in 1939 restored a 22-square mile tract outside the decreased area to tribal control. This tract of land is in the Blue Mountains 7 to 10 miles south of the main reservation (fig. 1). As of 1988, non-Indians own more than half the land within the main reservation boundaries. In 1978, as part of an ongoing effort by the Confederated Tribes of the Umatilla Indian Reservation to increase tribal influence in the management of reservation resources, the Confederated Tribes developed a water code for the reservation, wherein they asserted their ownership and jurisdiction over the waters of the Umatilla Indian Reservation and undertook the responsibility to protect and preserve in perpetuity all waters reserved for the Confederated Tribes of the Umatilla Indian Reservation (Blakley Engineers, Inc., 1978). The Confederated Tribes of Umatilla Indian Reservation are concerned that too little information is available to document their claims for rights to the water resources of the reservation; that ground-water supplies are threatened by declining water levels caused by pumping for irrigation and public supply, both within and outside the reservation boundaries; that streamflow during low-flow periods may be inadequate for sustaining and propagating anadromous fish; and that the relation between ground water and streamflow is poorly known. In 1985, funds were made available by the U.S. Geological Survey to conduct a water resources evaluation of the Umatilla Indian Reservation in order to provide the tribes a current assessment of water resources of the reservation with emphasis on the main or north part of the reservation.

Purpose and Scope

This report provides a summary assessment of the surface- and ground-water resources of the reservation using only available information. Most analyses and interpretations were derived from studies in the basalt of the Columbia Basin or from a previous report on water resources of the Umatilla Indian Reservation (see section on Previous Studies). Water quality on the reservation is not addressed in this report, because the topic was adequately discussed in previous studies and no new data are available to evaluate whether or not substantive changes have occurred.

Previous Studies

The earliest study that was concerned with water resources, soils, geology, or ground water of part or all of the Umatilla Indian Reservation was a report about ground-water resources in Umatilla and Morrow Counties by Wagner in 1949. That report was chiefly a listing of selected well drillers' report data for Umatilla and Morrow Counties. In 1963 a report by the State Water Resources Board (1963) described the water resources, quantified the surface-water resources and summarized the geologic and ground-water data available for the Umatilla Basin at that time. Much of the geologic and ground-water data in that report was from a U.S. Geological Survey Water-Supply Paper describing the geology and ground-water resources of the Umatilla Basin by Hogenson (1964). Gonthier and Harris (1977) described the water resources of the reservation and presented surface-water, ground-water and water-quality data for the streams and aquifers on the reservation. Swanson and others (1981) published geologic reconnaissance maps of most of the Columbia Plateau in Oregon at a scale of 1:250,000. These maps were an

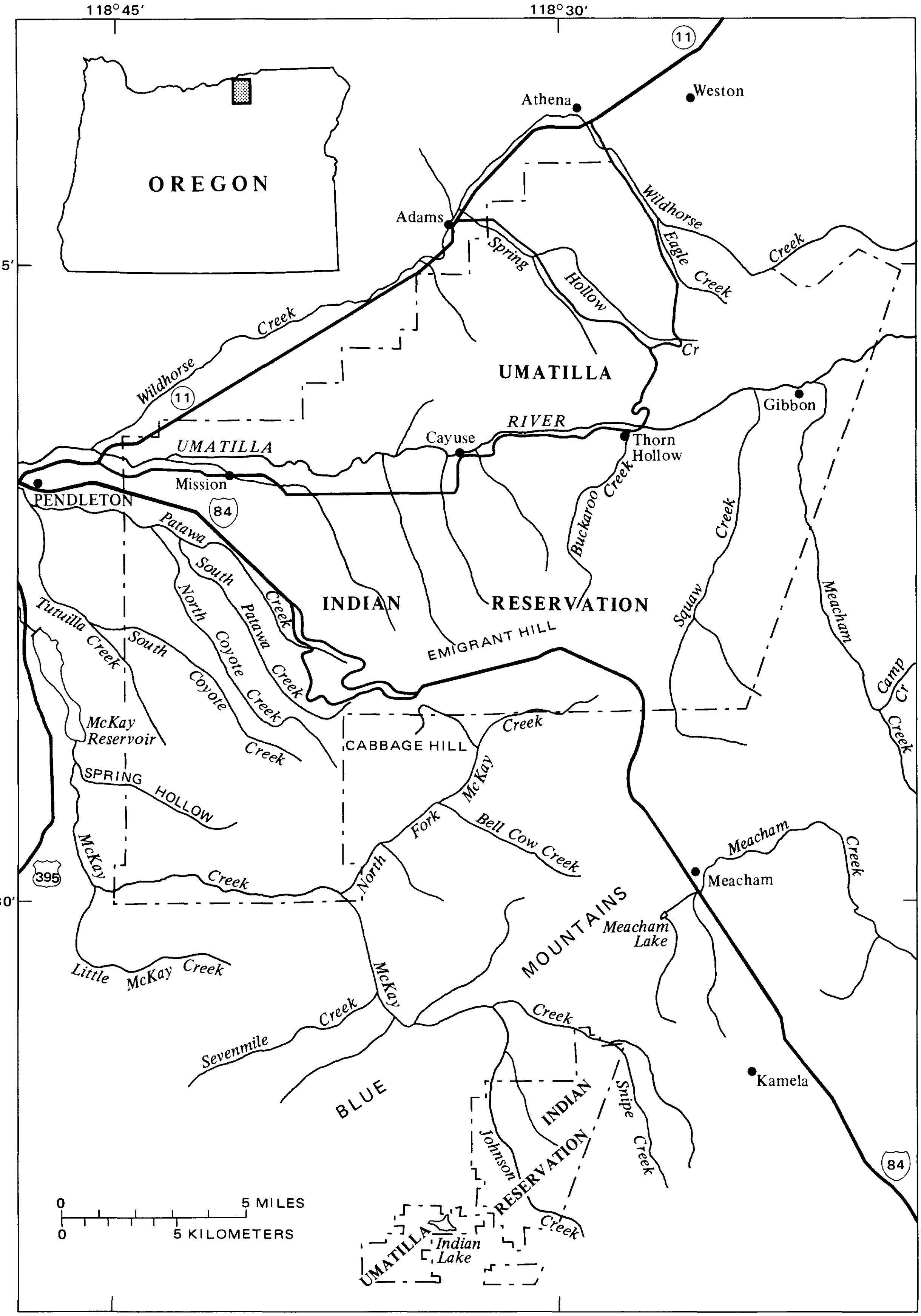


Figure 1.—Location of the study area.

important step in the progression of studies of the region, because for the first time the basalt of the Columbia River Basalt Group in Oregon was subdivided into several distinct formations. This subdivision made it possible to improve earlier evaluations of the hydrology of this important regional aquifer system. A data report was published (Davies-Smith and others, 1983) as part of a study of the Umatilla Plateau in Oregon and the Horse Heaven Hills area in Washington. The area in the vicinity of Hermiston, located about 20-30 miles west of the reservation, was the focus of the study, but the study area was large enough that it included part of the reservation area. A digital computer model of the ground-water flow system was developed and a description of the flow system and modeling results are found in a report by Davies-Smith and others (1988).

In October 1983, the U.S. Geological Survey began a study of the aquifer system underlying the Columbia Plateau in Washington, Oregon, and western Idaho, as part of its Regional Aquifer System Analysis (RASA) Program (Sun, 1986). The specific objectives of the RASA study were to describe the geologic framework of the Columbia Plateau regional aquifer system to determine its geohydrologic characteristics, to analyze the geochemistry and to develop a regional ground-water flow model of the aquifer system (Vaccaro, 1986). Several reports resulting from this study are available (Whiteman, 1986; Drost and others, 1990; Collins, 1987; Gonthier, 1990); other reports will be released in the near future. Each of the Columbia Plateau RASA reports have or will have information or maps that include the Umatilla Indian Reservation.

Maps showing the locations of wells and other data collection sites on the reservation are included in a data report prepared in connection with this study (McCarthy, 1989). The data report also includes compilations of well, water-level, and isotope data for the reservation.

Geography and Climate

The Umatilla Indian Reservation lies east of Pendleton, Oregon. It is crossed by major transcontinental transportation systems, including Interstate Highway 84 and the main line tracks of the Union Pacific Railroad. Access to most of the reservation is by a modest network of State and county secondary roads. The greatest density of residences on the reservation is along the Umatilla River valley, upstream of the west boundary of the reservation for a distance of about 6 miles. There are also small settlements in the valley, upstream at Cayuse, Thorn Hollow, and Gibbon, and on the south part of the reservation in the Patawa Creek area. Elsewhere residences are more widely scattered. The total tribal enrollment was about 1,340 persons in 1986.

The western one-third of the reservation is a gently northwest sloping, slightly dissected plateau consisting of gently rolling hills and plains. It is underlain in part by flat-lying to gently west-sloping basalt and by younger surficial sediments. The eastern one-third lies near the crest of the northeast-trending Blue Mountains. In the reservation area, the Blue Mountains are a deeply dissected uplifted plateau, also underlain by gently northwest-sloping and west-sloping to flat-lying basalt and is commonly referred to as the Blue Mountains uplands. The intervening one-third, the Blue Mountains slope, is underlain by northeast-trending, more steeply northwest-sloping basalt layers and ranges from gently to deeply dissected. The Umatilla River and McKay Creek valleys cross the reservation from east to west and have flat floodplains bounded by steeply sloping valley walls.

The climate of the Umatilla Indian Reservation varies from semiarid at low altitudes to alpine in the Blue Mountains. For the period 1951-80, annual precipitation at Pendleton, at an altitude of about 1,500 feet, averaged about 12.5 inches, and about 33 inches at Meacham, at an altitude of about 4,000 feet. Average monthly temperatures during this period ranged from about 32 degrees in January to about 74 degrees in July at Pendleton, and from about 26 degrees in January to 64 degrees in July at Meacham. Data are from Gonthier and Harris (1977) and from NOAA (National Oceanographic and Atmospheric Administration, 1988).

Acknowledgments

The cooperation of the various officials of the Confederated Tribes of the Umatilla Indian Reservation for supplying information about the reservation and hydrologic data on the reservation is gratefully acknowledged. Special thanks are extended to Aaron Skirvin, Department of National Resources, Confederated Tribes of the Umatilla Indian Reservation, for his assistance and shared knowledge of wells and related hydrologic data on the reservation.

GEOLOGIC SETTING

The geologic map on plate 1 shows the distribution of geologic units and geologic structures on and adjacent to the reservation. It is modified from a series of several larger geologic maps prepared by Swanson and others (1979, 1981) for the Columbia Plateau in Oregon, Washington, and Idaho. Prior to publication of these maps, the geology of the region was only poorly known and understood. Although the maps were compiled and published at a scale of 1:250,000 and represent reconnaissance-level mapping, they are excellent for defining the hydrogeologic framework of the region. Publication of the reconnaissance maps has allowed significant advances of our understanding of the regional geology and hydrogeology of the Columbia Plateau. The geologic sections on plate 1 show the geologic structure, the sequence of flows, and overlying deposits on the reservation; locations of the sections are shown on the geologic map. Because of the vertical exaggeration (times 10), the sections are distorted. Despite this distortion, they show the regional structure reasonably well and are useful aids towards understanding the geology and ground-water hydrology of the area. The sections will be referred to often in the discussions that follow, and were compiled chiefly from the geologic map. The stratigraphic and hydrogeologic chart shown on plate 1 briefly summarizes the stratigraphy, lithology, and hydrogeology of the region on and near the reservation.

Pre-Miocene Volcanic Rocks

The oldest rocks present on the reservation crop out in the valley of McKay Creek and are shown as pre-Miocene volcanic rocks on plate 1. They consist of volcanic flows, breccias, and basaltic andesites, probably equivalent to the Clarno Formation, which crops out more extensively south and southwest of the reservation and in the John Day River basin. A thickness of 100 to 200 feet of these rocks is exposed in the valley of McKay Creek, but the total thickness is not known, nor has it been penetrated by wells on the reservation. The unconformable relation of the pre-Miocene volcanics to younger formations is shown on plate 1. Geologic section D-D' shows that the volcanics outcrop may have been a significant local high in the pre-basalt topography.

Columbia River Basalt Group

Unconformably overlying the pre-Miocene volcanic rocks is a large thickness of basalt that is only locally interbedded with minor amounts of sedimentary materials (rocks). The basalt is part of the Columbia River Basalt Group, whereas the sedimentary rocks, where encountered, are collectively assigned to the Ellensburg Formation. Swanson and others (1979) subdivided the rocks of the Columbia River Basalt Group into five separate formations on the basis of similarities in chemical and mineralogical composition, physical properties, stratigraphic position, and magnetic characteristics. These formations are from oldest to youngest the Imnaha Basalt, the Picture Gorge Basalt, the Grande Ronde Basalt, the Wanapum Basalt, and the Saddle Mountains Basalt. Basalt of the Columbia River Basalt Group was erupted from north- and northwest-trending linear vent systems located on the Columbia Plateau, chiefly in the Blue Mountains east of the reservation in southeastern Washington, northeastern Oregon, and west central Idaho. Extrusion of the basalt lava occurred during the Miocene Epoch between about 16.5 and 6 million years ago (Swanson and others, 1979). Topographic relief in the region prior to eruption of the basalt probably was substantial; therefore early flows filled preexisting valleys and eventually reduced the topographic relief (pl. 1, section D-D'). Later basalt flows were erupted on a relatively smooth flat surface that was gently tilted toward the west. Individual eruptions of basaltic lava were of enormous volume and probably occurred over a period of several days (Swanson and others, 1979). As a result of this mode of deposition, individual flows can be traced and mapped over large areas of the Columbia Plateau, chiefly because of their relatively uniform chemical composition and texture. Volcanism that produced the basalt gradually waned, and the Columbia Plateau was gently and gradually warped by tectonic forces as it was undergoing erosion. As a result, the youngest basalt flows tend to have thicker, more extensive sedimentary interbeds associated with them. Major sedimentary interbeds are abundant and thickest in the central lowland part of the Columbia Plateau. The Columbia Plateau is in reality a large structural basin, the deepest part of which is located near Pasco, Washington.

The internal structure of a typical basalt flow is shown on plate 1, which was compiled and drawn by Swanson and others (1979). The drawing is a composite from observations of flows at many localities across the Columbia Plateau. Most flows can be subdivided without difficulty into three or four distinct parts; a basal colonnade, the entablature, and the upper colonnade and flow top. Commonly the upper colonnade is absent in many flows. The basal colonnade consists of a zone of vertical prismatic columns bounded by cooling joints; the columns are several feet in width and they generally extend one-third to one-half the flow thickness and end rather abruptly at the entablature. The columns either have crude horizontal joints or break along concave upward fractures into brickbat-like pieces. The entablature consists of narrow prismatic fanning joints characterized by hackly fractures. The entablature is overlain by an upper colonnade consisting of blocky columns a few to several feet wide. The upper colonnade grades gradually into the flow top, which is marked by basalt that becomes increasingly vesicular at the top and the top of the flow may be scoriaceous, blocky, and cindery and may be marked by noticeable relief. In each flow, the thicknesses of the individual flow parts may vary widely and change abruptly from place to place.

The oldest unit in the Columbia River Basalt Group, the Imnaha Basalt, does not crop out on the reservation and probably is not present beneath it. The Imnaha Basalt crops out east of the reservation in the valleys of the Imnaha and Snake Rivers, where it consists of coarse-grained grusy-weathering basalt with plagioclase phenocrysts between 0.2 and 1 inch (in.) in length. The Imnaha reaches a thickness of about 1,600 feet (Swanson and others, 1979). However, it probably is not present in Oregon west of the Blue Mountains uplift, and will not be discussed further in this report.

The Picture Gorge Basalt occurs principally in the John Day River basin south and southwest of the reservation and probably does not underlie it at any depth. It consists generally of medium- to coarse-grained basalt lacking phenocrysts. The maximum reported thickness is 5,900 feet at a site where faulting may have caused it to appear very thick. Elsewhere it is believed to be a maximum of about 2,600 feet thick (Swanson and others, 1979). The Picture Gorge Basalt is interlayered with the middle part of the Grande Ronde Basalt locally and therefore is coeval with it.

Basalts cropping out and underlying the reservation collectively are part of the Yakima Basalt Subgroup, which is subdivided into three lithologically distinct formations; from oldest to youngest these are the Grande Ronde, Wanapum, and Saddle Mountains Basalts. Each of these formations in turn consists of a few to several hundred individual flows, some of which are further subdivided into members.

The Grande Ronde Basalt is the most extensive and voluminous of the basalt units and makes up about 95 percent of the total volume of the Columbia River Basalt Group on the Columbia Plateau. The Grande Ronde Basalt contains perhaps as many as a few hundred individual lava flows, consists of fine-grained basalt generally without phenocrysts, and has a chemical composition that is uniform within a relatively narrow range. Because it lacks distinguishing physical characteristics, the only reliable way to subdivide the Grande Ronde Basalt is by field mapping the magnetic polarity and by trace-element chemistry. Mapping of its magnetic polarity enabled Swanson and others (1979) to subdivide the Grande Ronde into four distinct informal magnetostratigraphic units. From oldest to youngest, the informal magnetostratigraphic units in the Grande Ronde Basalt are called the R1, N1, R2, and N2 units, respectively, where R means reversed and N means normal magnetic polarity. On plate 1, R1 corresponds to Tgr1; N1 to Tgn1; R2 to Tgr2; and N2 to Tgn2. These units are distinguished in the field through use of a portable fluxgate magnetometer, and from each other through stratigraphic position and regional mapping. More recently Mangan and others (1986) have shown that these magnetostratigraphic units in the Grande Ronde Basalt also can be identified by trace-element chemistry and relative stratigraphic position. Up to the time of that publication, there had been no method to distinguish between the magnetostratigraphic units in the subsurface by use of either rock cuttings from wells or borings or from drillers' well logs.

The thickness of the Grande Ronde Basalt, in exposures along the Snake River Canyon (not shown) in northwestern Oregon, is about 3,000 feet, but it may be twice that thickness locally in the central part of the Columbia Plateau. There are no wells that fully penetrate the Grande Ronde Basalt on the reservation; therefore its full thickness there has not been determined.

Closest outcrops of the oldest Grande Ronde Basalt magnetostratigraphic unit R1 in the reservation are found in the drainage area of the North Fork of the Umatilla River about 7 miles east of the east reservation boundary near Gibbon. The R1 unit is shown to underlie the reservation at great but uncertain depth in the geologic sections. Because of the lack of actual data, the thickness of the R1 unit shown in most of the sections is uncertain.

The Grande Ronde Basalt magnetostratigraphic unit N1 crops out in the bottom of the canyons of Johnson Creek in the McCoy Tract and the bottom of the canyon at Meacham Creek about one-half mile south of the east reservation boundary. It probably is present beneath all of the reservation except the area near the outcrops of pre-Miocene volcanics on McKay Creek (pl. 1, section D-D'). In most of the sections the N1 unit is shown to be between 600 and about 1,200 feet thick, although verification data are lacking.

The Grande Ronde Basalt magnetostratigraphic unit R2 is exposed on the reservation in the Umatilla River valley, valleys east of Thorn Hollow, and in the McKay Creek valley on the south reservation. Small exposures also are present east of the fault that crosses South Patawa and North Coyote Creeks (pl. 1). The R2 unit underlies all of the reservation at depth elsewhere but is not present at the outcrop of the pre-Miocene volcanic rocks in Mckay Creek valley. Elsewhere the R2 unit is generally overlain by the N2 unit, the youngest of the Grande Ronde magnetostratigraphic units.

The N2 unit is the most widely exposed magnetostratigraphic unit of the Grande Ronde Basalt within the reservation. It is exposed in much of the uplands that make up the east and south parts of the reservation, but the N2 unit is overlain by a few Wanapum Basalt flows on the summits of Cabbage and Emigrant Hills. In the western part of the reservation the N2 unit also is overlain by Wanapum Basalt flows or by Quaternary-Tertiary sedimentary deposits. The N2 unit is exposed in the Umatilla River valley in Pendleton, about 2 miles west of the reservation boundary pl. 1, section C-C').

Within the reservation the two uppermost magnetostratigraphic units of the Grande Ronde Basalt, the R2 and N2 units respectively, each range between 0 and about 1,200 feet thick, and were estimated from the geologic map and topographic maps of the reservation.

Minor amounts of sedimentary rocks are interlayered with flows of the Grande Ronde Basalt on the reservation, but generally are only a few feet thick and are not laterally extensive. Where present, sedimentary rocks generally consist predominantly of fine-grained materials such as clay and silt.

The upper contact of Grande Ronde Basalt is generally marked by the presence of a weathered zone that includes saprolite; at many localities, a sedimentary interbed also is present. The contact at two localities on and near the reservation was examined; at each site it consists of a rusty colored weathered zone about 8 feet thick. The vesicular basalt marking the top of a flow in that zone is deeply weathered, crumbly, and soft. The uppermost 1 to 2 feet of it is a deep red color and may represent a fossil soil zone developed on the surface of the basalt. On the basis of these observations, it is believed that the weathered zone at the top of the Grande Ronde Basalt is not sufficiently distinct to be readily identified in the subsurface by drillers, especially those using rotary-drill machines, because this soft zone will drill much like the soft scoriaceous vesicular basalt commonly found at the tops of individual lava flows. Thin sedimentary interbeds also may be easily missed by rotary drills, because the sedimentary beds are crushed to extremely fine particles and the cuttings are not always easily identified. Thus, the thin weathered zone at the top of the Grande Ronde Basalt may not be easily differentiated from other flow tops when it is penetrated. The approximate altitude of the top of the Grande Ronde in the western part of the reservation is shown in figure 2, where it is generally covered by younger formations. It is based on well data, the geologic map, and on analyses of rock chips at well 2N/33E-9ACA2 (McCarthy, 1989).

The Wanapum Basalt overlies the Grande Ronde Basalt and, in other parts of the Columbia Plateau, can consist of as many as five members--each of which consists of one or more chemically distinct flows. Only the oldest member, the Frenchman Springs Member, is present in the region on or near the reservation. The Frenchman Springs Member consists of up to six individual flows of fine- to medium-grained basalt, both with and without plagioclase phenocrysts (Swanson and others, 1979); many flows have irregularly spaced clots of small plagioclase phenocrysts as much as 50 millimeters (2 inches) across. Sedimentary interbeds tend to be thicker and more extensive in the Wanapum Basalt than in the Grande Ronde Basalt; this may not be true on the reservation, however, because no recognizably extensive interbeds were identified. The Wanapum Basalt underlies most of the western part of the reservation, as well as the summit of Cabbage Hill and its extensions in the Blue Mountains. The geologic map (pl. 1) shows the areas where the Wanapum Basalt crops out and areas where it is overlain by younger basalt formations or sedimentary rocks. In much of the western part of the reservation, the area where most of the residences and most of the irrigable land is present, the Wanapum Basalt is a principal source of water for domestic and stock use, and also supplies significant amounts of water for irrigation. On the reservation, the Wanapum Basalt ranges in thickness from 0 to about 800 feet as indicated from well data; it is thickest beneath the northern part of the reservation. The generalized thickness of the Wanapum Basalt in the western part of the reservation is shown in figure 3. It was compiled from limited well data, from the map showing the top of the Grande Ronde Basalt, and from the 1:250,000 scale topographic map.

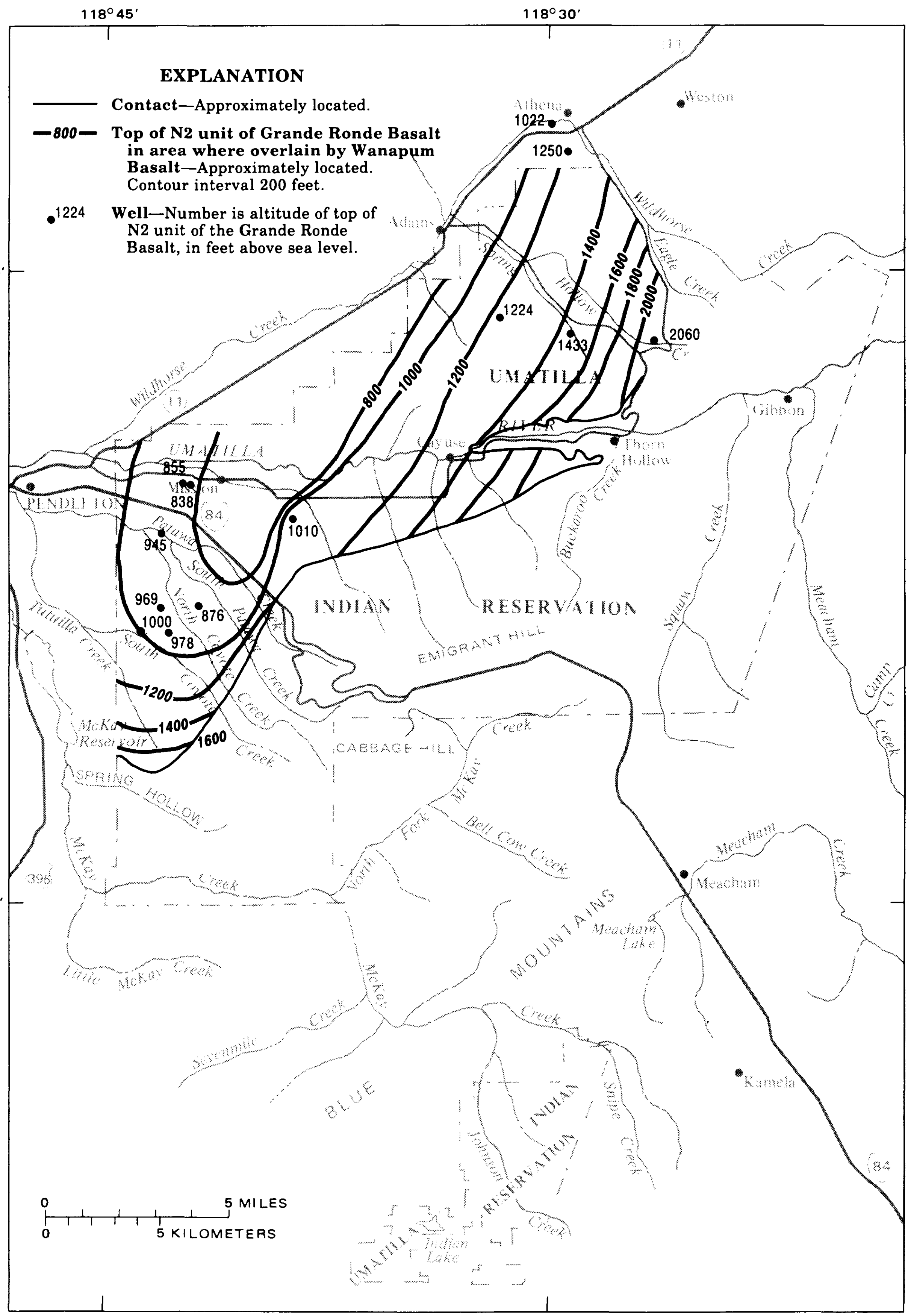


Figure 2.—Altitude of the top of the N2 unit of the Grande Ronde Basalt.

The chemical composition of selected basalt drill cuttings from a 300 foot well (2N/33E-09ACA2) near Mission was determined during this study. Samples from well 2N/33E-09ACA2 were collected by a private drilling contractor for the Confederated Tribes of the Umatilla Indian Reservation, Department of Natural Resources. The samples were submitted to a laboratory operated by Professor Peter Hooper at Washington State University, Pullman, Washington, where they were analyzed using X-ray Fluorescence Techniques. Professor Marvin Beeson of Portland State University interpreted the laboratory data. The chemical data (not included in this report) indicated that samples from depths of 42 and 150 feet were Sentinel Gap flows and the sample at 250 feet was from a Sand Hollow flow. Both the Sentinel Gap and Sand Hollow flows are informal names for basalt flows belonging to the Frenchman Springs Member of the Wanapum Basalt and were first identified in surface outcrops at central Washington localities. At those localities, the Sand Hollow flows form the base of the Wanapum Basalt and they likely represent the basal part of the Wanapum Basalt in the reservation area. From analysis of this data, it was estimated that the base of the Wanapum Basalt or the top of the Grande Ronde Basalt at well 2N/33E-09ACA2 is at an altitude of approximately 750 feet.

In the valley of Spring Hollow Creek in the extreme northwest corner of the reservation, a small outcrop of the Umatilla Member of the Saddle Mountains Basalt is present (pl. 1). The Saddle Mountains Basalt is the youngest formation in the Columbia River Basalt Group. The Umatilla Member has a distinct chemical composition and is a fine-grained and even-grained basalt without phenocrysts. The Umatilla Member apparently is about 100 feet thick near Spring Hollow Creek, but may be as much as 200 feet thick at other nearby locations. On the basis of well-log data, it probably extends only about 1 mile south of Spring Hollow Creek, where it may be absent from the section due to faulting. In other parts of the Columbia Plateau, the base of the Umatilla Member is marked by a widespread sedimentary interbed. The interbed is called the Umatilla-Frenchman Springs interbed and also may be present in the above area. A map of the thickness of the Saddle Mountains Basalt was not constructed for this study because of its limited extent on the reservation, and because of a lesser significance for water-resources development on the reservation than the older and more extensive basalts.

Quaternary and Tertiary Sedimentary Deposits

Overlying the Columbia River Basalt Group locally on the reservation are semiconsolidated to unconsolidated sedimentary deposits consisting of fine- to coarse-grained basaltic sedimentary rocks and windblown loess of Quaternary and Tertiary age. These sedimentary rocks of Pliocene age consist of a heterogeneous mix of clay, silt, sand, and gravels and some undivided thin gravelly alluvial deposits adjacent to present stream channels. The sedimentary deposits generally are veneered by a layer of windblown silt (loess) and have been referred to as fanglomerate, Tertiary sediments, and as the McKay Formation by various authors in other reports. They are thickest beneath the south part of the reservation where as much as 200 feet may be present, but probably are less than 25 feet thick north of the Umatilla River valley. These materials were deposited along the Blue Mountains front by streams similar to Patawa and North and South Coyote Creeks, and possibly by an ancestral Umatilla River issuing from the Blue Mountains.

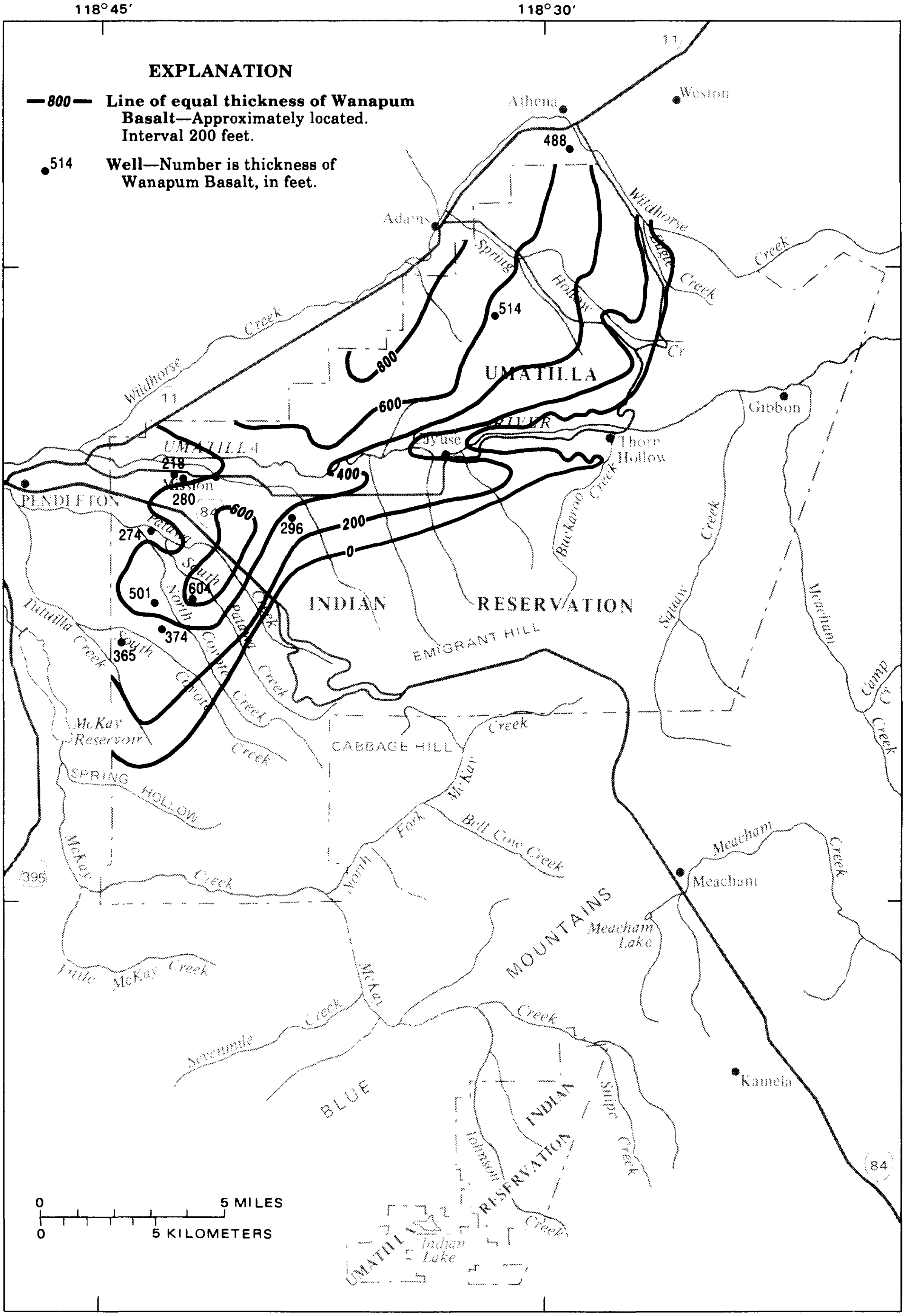


Figure 3.—Thickness of the Wanapum Basalt.

The distribution of the Quaternary and Tertiary sedimentary deposits shown on the geologic map (pl. 1) was modified from Swanson and others (1981). The extent of these deposits is greater than the extent of the nearly equivalent Tertiary deposits mapped during an earlier study of the reservation by Gonthier and Harris (1977); this is especially true for the reservation north of the Umatilla River. Swanson and others (1981) mapped the area south of the Umatilla River as Quaternary and Tertiary gravel and the area north of the river as Quaternary and Tertiary sediment; the chief differences between the two areas, however, are that the gravelly deposits north of the river are overlain by a greater thickness of windblown loess than they are south of the valley. One of the mapping criteria used by Swanson and others (1981) was to map the sediments wherever they were sufficiently thick to obscure the underlying basalt. This criterion led to mapping of a large area north of the Umatilla River valley which is covered by a few to several feet of windblown silt (loess), but is not underlain by the sandy and gravelly sediments that are found on the west edge of the reservation, north and south of the valley.

The windblown silt (loess) ranges from 0 thickness at high elevation areas to possibly as much as 135 feet at one locality; it is thinnest beneath the south reservation, thickens northward, and is absent in summit areas of the Blue Mountains. These windblown deposits are believed to have been formed during the Pleistocene when large areas of the Columbia Plateau along the Columbia River west and northwest of the reservation were periodically inundated by a series of catastrophic floods. Fine-grained sediments deposited by the floods in the flooded regions of the the Columbia Plateau were transported by prevailing winds to the surrounding uplands.

Quaternary Alluviual Deposits

The geologic map (pl. 1) shows the approximate extent of the most significant Quaternary alluvial deposits on the reservation in the Umatilla and McKay Creek valleys. These deposits also are present adjacent to and beneath most streams and creeks; except in areas shown, however, they generally are too thin or their areal extent too small to be shown.

Quaternary alluvium on the reservation generally consists of a poorly sorted mix of river laid bouldery and cobbly basaltic gravels, sands, and silts. Locally, near steep valley walls, it includes colluvium, consisting of a poorly sorted angular basaltic rock debris, granular slope wash and talus that has avalanched from adjacent steep slopes. Minor ash deposits also are included in some localities; in all likelihood, the ash has been carried to the area by westerly winds from volcanic eruptions in the Cascade Range. The clean grayish white ash beds probably were concentrated in localized deposits by storm runoff events that occurred shortly after air currents deposited the ash beds.

Well data indicate that alluvium on the north side of the valley near the active flood plain is thin, probably averaging less than 15 feet. In the south part of the Umatilla Valley, however, data indicate that the alluvial deposits may be thicker and the basalt more deeply eroded than elsewhere. Within this area, several wells are completed in unconsolidated deposits ranging between about 35 and 132 feet in depth overlying the basalt. These deposits are likely to consist mostly of colluvial materials, such as talus and soil debris, that have avalanched or washed down adjacent steep valley walls.

Upstream of the Mission area, the alluvium is reported to be about 20 feet thick, and probably less than 20 feet thick along McKay Creek, Wildhorse Creek, and other streams on the reservation.

Geologic Structure

Major geologic structures present on the reservation include normal and reverse faults, folds, and lineaments. Three normal faults, the Hite fault and two unnamed faults, form the approximate boundaries of an uplifted block of the Blue Mountains south of the Umatilla River which includes both Emigrant Hill and Cabbage Hill (pl. 1). The Hite fault trends north northeast from McKay Creek to Deadman's Hill, to Thorn Hollow and then beyond Wildhorse Creek. Formations on the west side of the fault have been downdropped relative to those on the east. Displacement on the Hite fault is as much as several hundreds of feet on the north, but is almost negligible at its south end. A similar trending, but unnamed set of en echelon normal faults with down-to-the-west displacement are located about 7 miles west of the Hite fault, and are interconnected with the Hite fault by a west northwest trending normal fault just south of Thorn Hollow. The Hite fault forms the contact between the Wanapum Basalt and the N2 units of the Grande Ronde Basalt. Displacement in the pair of en echelon faults on the west appear to range from a few to as much as several hundreds of feet.

Between 1 and 2 miles east of the Hite fault, Swanson and others (1981) mapped a lineament that parallels the full length of the Hite fault. The lineament is mapped as a fault north of the Umatilla River. The lineament symbol on the geologic map (pl. 1) marks the positions of linear topographic features that can be identified and traced on areal photographs. Field mapping of the lineament, however, generally did not indicate displacement or offsetting of geologic units along its length. This suggests that some of the lineaments may be tectonic or master joints along which there has been little or no movement.

The axis of the Agency syncline, an elongated downward bent bowl-like fold, crosses the western side of the reservation in a northeasterly direction along a line that extends from southwest of McKay Reservoir north to near the town of Adams. It was first identified by Hogenson (1964) and at that time was named the Agency syncline. The syncline is a slightly downward bowed flexure of the basalt formations that also plunges gently from the southwest toward the northeast and possibly from the northeast toward the southwest (pl. 1, section E-E'). The syncline is asymmetrical in shape with the east limb dipping more steeply than the west limb. The contour map showing the altitude of the top of the Grande Ronde Basalt (fig. 2) defines the approximate shape of the structure. In all probability, the northern part of the syncline near the north boundary of the reservation is cut by a northwest-southeast trending fault (section E-E'), the trace of which is hidden beneath Quaternary and Tertiary sediments.

Swanson and others (1981) mapped short monoclines in the Blue Mountains; monoclines are flexures of the basalt layers that show either abrupt steepening or flattening of the dip of the basalt layers. Also mapped were a few short, but widely scattered faults that are considered minor structures and will not be discussed.

Because the mapping by Swanson and others (1981) on which this report is largely based was of a reconnaissance nature, it is likely that more geologic structures are present than are actually shown and that these may be identified only when detailed mapping is undertaken.

HYDROLOGY

The sources of water on the Umatilla Indian Reservation are precipitation, streams, and ground water. The boundaries of the reservation do not encompass an entire drainage basin and some precipitation that falls outside the reservation boundaries enters the boundaries as streamflow and ground-water flow. Some precipitation falls directly on the land surface and eventually either becomes surface runoff or recharges the ground-water system underlying the reservation. Water leaves the reservation by streamflow, wells and springs, evapotranspiration, seeps or diffuse seepage, and by subsurface flow. The various aspects of surface- and ground-water resources are discussed in the following sections.

Surface Water

A detailed analysis of the stream system on the Umatilla Indian Reservation was made by Gonthier and Harris (1977), and included data through the 1974 WY (water year) and part of the 1975 WY. The report by Gonthier and Harris (1977) gives a description of streams, locations of gaging stations, low, average, and high-flow analysis, as well as the variability of flow for major streams in the area. In addition to the work by Gonthier and Harris (1977), Friday and Miller (1984) prepared a statistical summary report of streamflow data in Oregon; volume one covers eastern Oregon and includes streams on and near the reservation. The statistical summaries were included for all active and inactive stations having a minimum of 10 years of daily-mean discharge values. The period of record for active stations covered by the Friday and Miller report extended to the end of the 1982 water year.

This report uses data through the 1987 WY to update the reports by Gonthier and Harris (1977), and Friday and Miller (1984) with regard to averages, extremes, and variability of flow for data from active gaging stations on and near the Umatilla Indian Reservation. The locations of active gaging stations are shown in figure 4, and their period of record is given in table 1.

Average Annual Discharge

The average annual discharges of streams listed in table 1 are shown in figure 5, along with the long-term averages for the period of record. Comparison of current (through 1987 WY) long-term average discharges with the long-term averages calculated by Gonthier and Harris (1977) are shown in table 2. The data show only a slight increase inthe long-term averages at all the stations for which data are available.

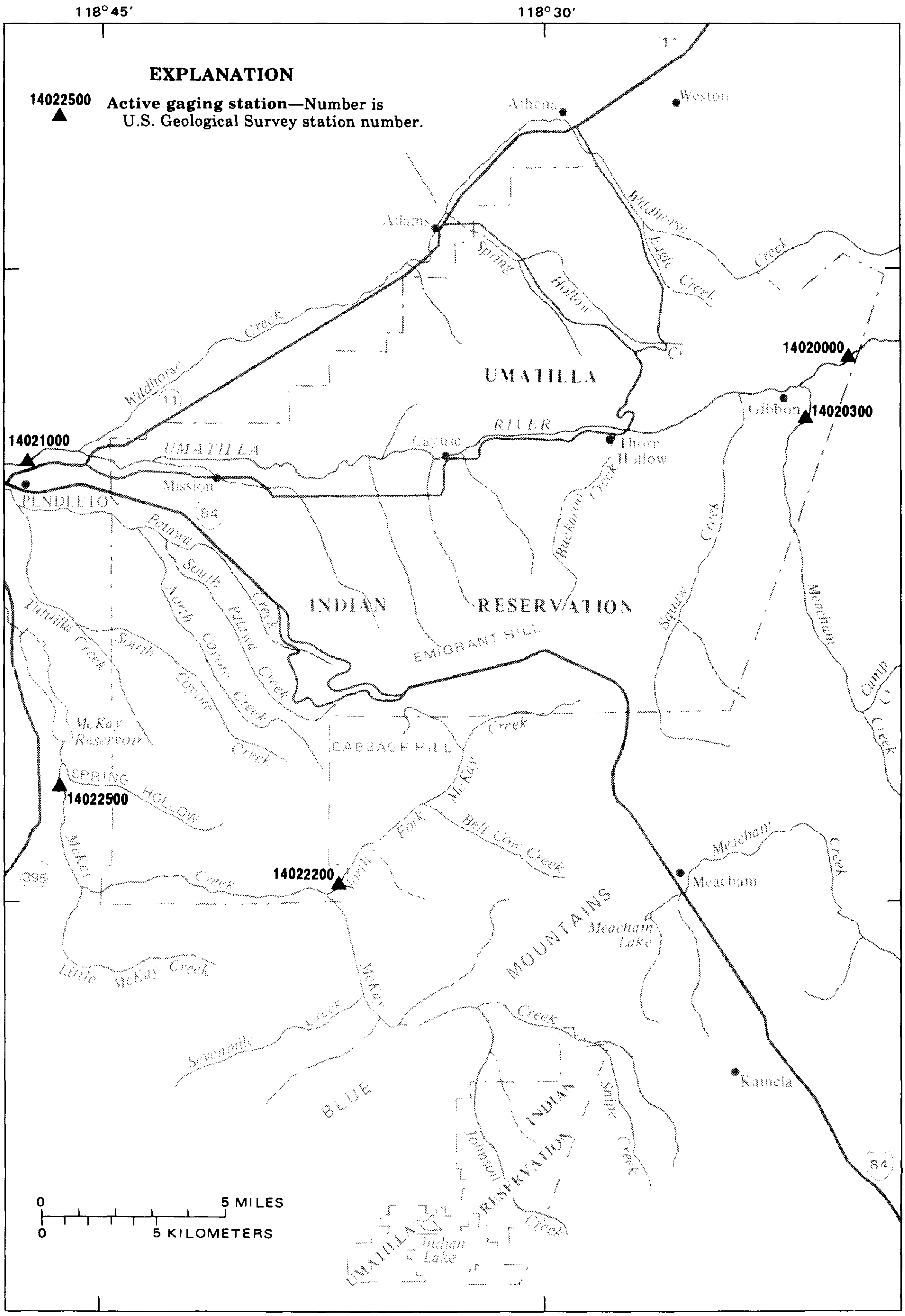


Figure 4.—Location of active streamflow-gaging stations on or near the Umatilla Indian Reservation.

Table 1.--Active streamflow gaging stations on or near the Umatilla Indian Reservation

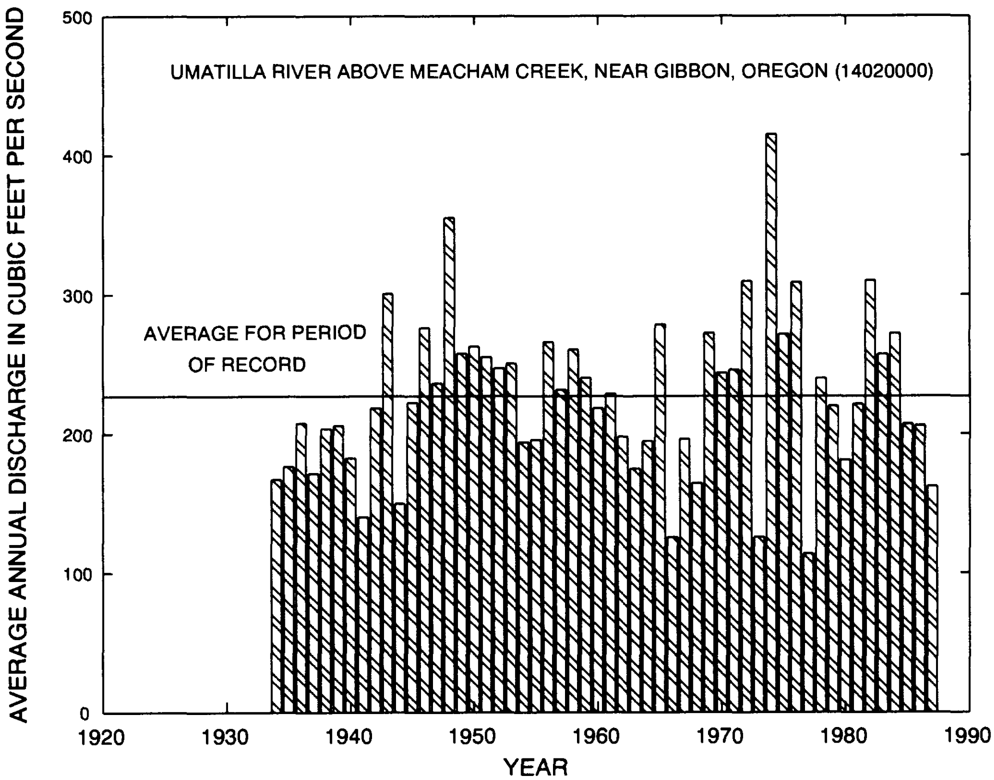
Station number	Station name	Period of record (water years)
14020000	Umatilla River above Meacham Creek, near Gibbon, OR	1934-87
14020300	Meacham Creek at Gibbon, OR	1976-87
14021000	Umatilla River at Pendleton, OR	1935-87
14022200	North Fork McKay Creek near Pilot Rock, OR	1974-87
14022500	McKay Creek near Pilot Rock, OR	1927, 1930-87

Table 2.--Comparison of long-term average discharges used by Gonthier and Harris (1977) to current values (through 1987 water year) for active streamflow-gaging stations on or near the Umatilla Indian Reservation

[ft^3/s = cubic feet per second; -- = no data]

	Gonthier and Harris (1977)		Current (through 1987 water year)	
Station number	Average annual discharge (ft^3/s)	Years of record	Average annual discharge (ft^3/s)	Years of record
14020000	226	41	227	54
14020300	--	--	205	12
14021000	500	40	505	53
14022200	40	1	45	14
14022500	99	46	102	59

The main-stem stations (14020000 and 14021000), for example, show less than 1-percent change from the earlier report. Tributary flow (14022500) shows a slightly higher (3 percent) change over the long term. Because the long-term average discharges at these stations are nearly the same as those calculated in the study by Gonthier and Harris (1977), it can be reasonably assumed that a current estimate of total inflow and outflow from the reservation has not changed substantially from values reported in earlier studies. According to Gonthier and Harris (1977, p. 15), "Estimated average total stream inflow to the main reservation is 540 ft^3/s (cubic feet per second)," and "Estimated average total stream outflow from the main reservation is 600 ft^3/s." The difference, 60 ft^3/s, is the estimated average gain by streams as they flow through the reservation.



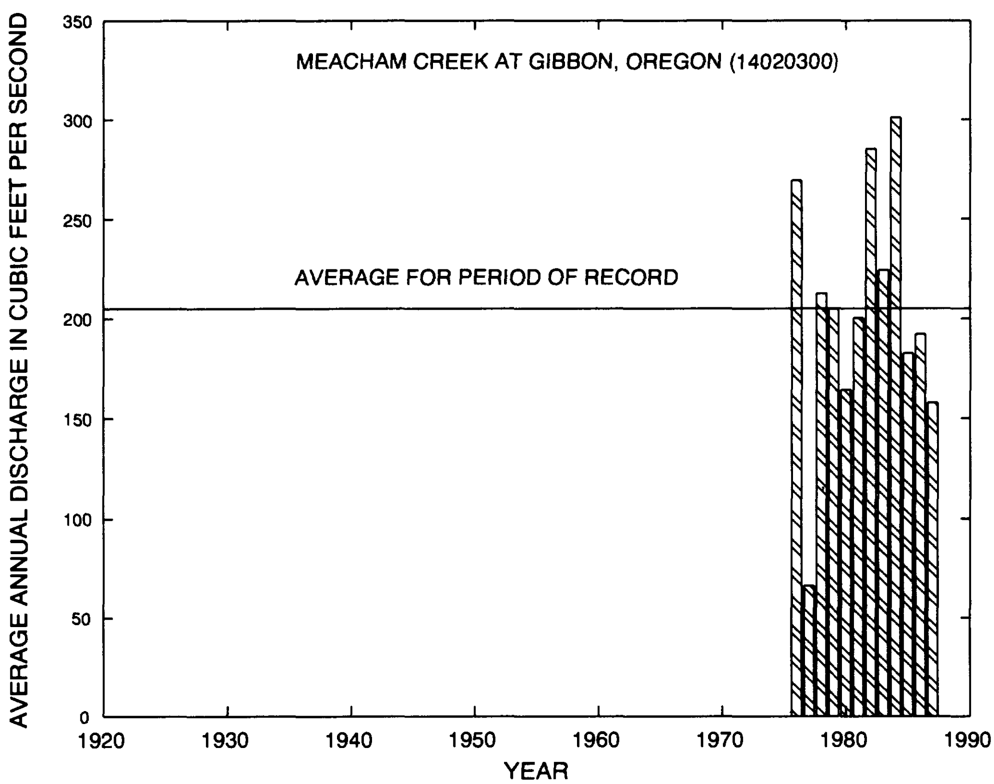


Figure 5.—Average annual discharge at selected streamflow-gaging stations on or near the Umatilla Indian Reservation.

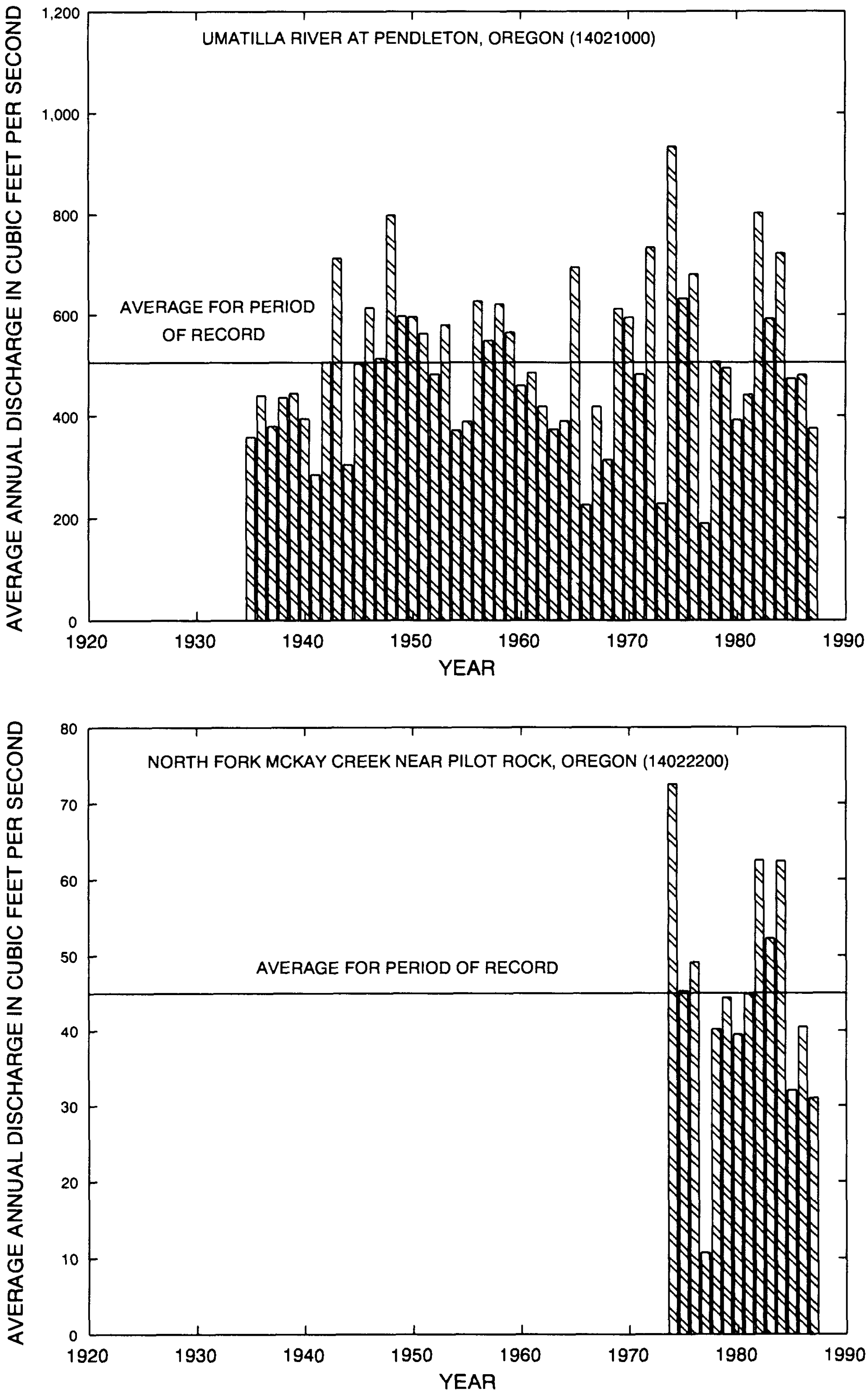


Figure 5.—Average annual discharge at selected streamflow-gaging stations on or near the Umatilla Indian Reservation, continued.

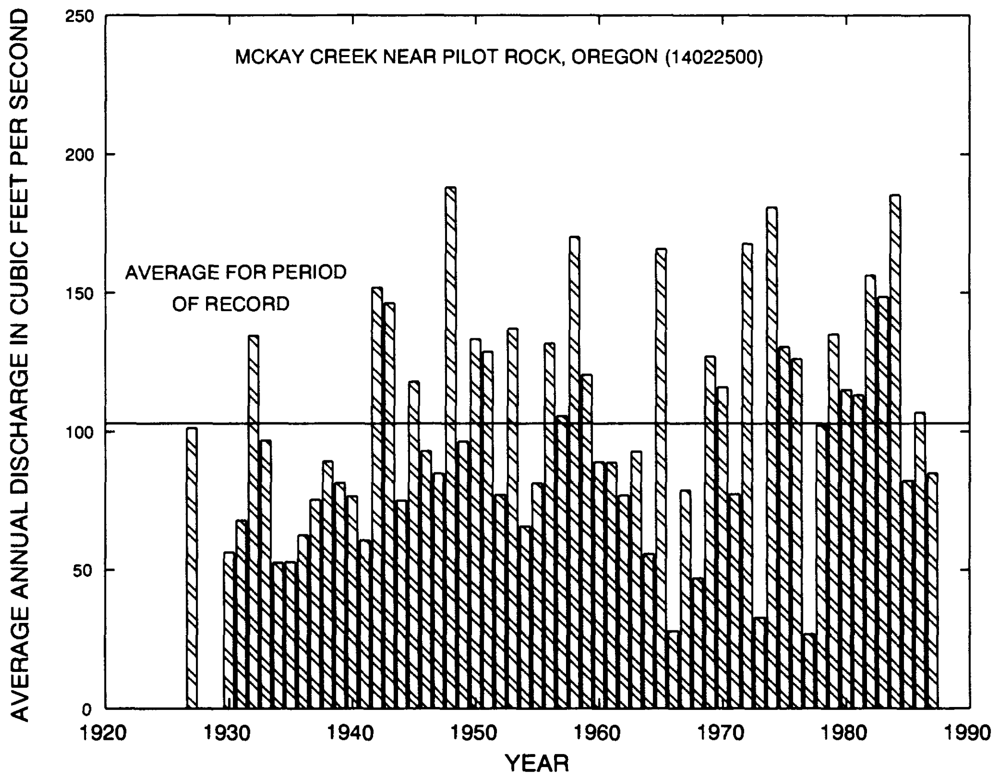


Figure 5.—Average annual discharge at selected streamflow-gaging stations on or near the Umatilla Indian Reservation, continued.

From figure 5, it can be seen that 1977 had the lowest annual average streamflow on record for all five stations. The average annual discharge in 1966 and 1973 was nearly as low as that of 1977, as indicated on three of the five hydrographs for which data are available. Conversely, the highest average annual discharge for three of the four stations for which data are available occurred in 1974. At the fourth station (14022500), discharges for 1948 and 1984 are slightly higher than 1974.

Flow Extremes

For the period from 1975 to 1987, values of previously-observed maximum discharges were exceeded at only one of the five gaging stations listed in table 3. This station was the Umatilla River at Pendleton (14021000), where on February 23, 1986, a peak discharge of 16,200 ft^3/s was recorded. The previous peak for the period of record was 15,500 ft^3/s. The 16,200 ft^3/s peak is equivalent to about the 40-year flood as determined from magnitude and probability data from Friday and Miller (1984, p. 78). The 40-year flood has about a 3-percent chance of occurring each year.

Table 3.--Flow extremes for active streamflow-gaging stations on or near the Umatilla Indian Reservation

[ft³/s = cubic feet per second]

Station number	Peak flow (ft^3/s)	Date	Low flow (ft^3/s)	Date
14020000	5,930	1/25/75	16	11/09/65
14020300	5,750	2/20/82	6.6	8/29/84
14021000	16,200	2/23/86	10	7/13-16/40
14022200	1,980	1/25/75	0.22	1/26/85
14022500	7,400	1/30/65	0	at times

The values of minimum discharge for the period of record for the five stations were not exceeded for the 1975-87 period. The minimum observed discharge at one of the stations (14022500) was zero. This station is affected by many small diversions for irrigation; at times no flow occurs in the stream at this location.

Variability of Flow

In the report by Gonthier and Harris (1977, p. 26), variability of flow was described by presenting flow-duration data of mean daily discharge for selected gaging stations. Part of that data set is reproduced in this report (table 4), along with updated values, through 1987 WY, of the flow-duration data. The flow-duration data show the percentage of time specified flows are equaled or exceeded. For example, for the period 1935-87, the daily mean discharge of the Umatilla River at Pendleton was at least 220 ft^3/s 50 percent of the time and 39 ft^3/s 90 percent of the time.

Comparison of the data between the two periods of record shows that the percentage of time that a specified discharge was equaled or exceeded has not changed significantly even though an additional 13 years of flow-duration data is available. Thus, the duration curves developed by Gonthier and Harris (1977, p. 27) for three gaging stations on or near the reservation remain valid and can be used for further analysis as needed. Those curves were reproduced from the report by Gonthier and Harris (1977) and are shown as figure 6 in this report.

Table 4.--Flow-duration data of mean daily discharge for selected streams on or near the Umatilla Indian Reservation

Station number	Station name	Years of record	Discharge, in cubic feet per second, which was equaled or exceeded for indicated percent of time								
			99	95	90	70	50	30	10	5	1
14020000	Umatilla River above Meacham Creek near Gibbon, Oregon	1934-74	35	--	45	58	120	250	550	--	1,200
		1934-87	--	42	46	58	120	250	550	750	--
14020300	Meacham Creek at Gibbon, Oregon	1976-87	--	9.9	13	21	69	220	570	810	--
14021000	Umatilla River at Pendleton, Oregon	1935-74	22	--	36	67	220	550	1,200	--	3,100
		1935-87	--	32	39	72	220	580	1,300	1,850	--
14022200	North Fork McKay Creek near Pilot Rock, Oregon	1974-87	--	.72	.91	2.3	11	48	130	190	--
14022500	McKay Creek near Pilot Rock, Oregon	1927, 1930-74	0	--	.2	3.2	25	100	290	--	800
		1927, 1930-87	--	0	.2	3.6	26	110	300	440	--

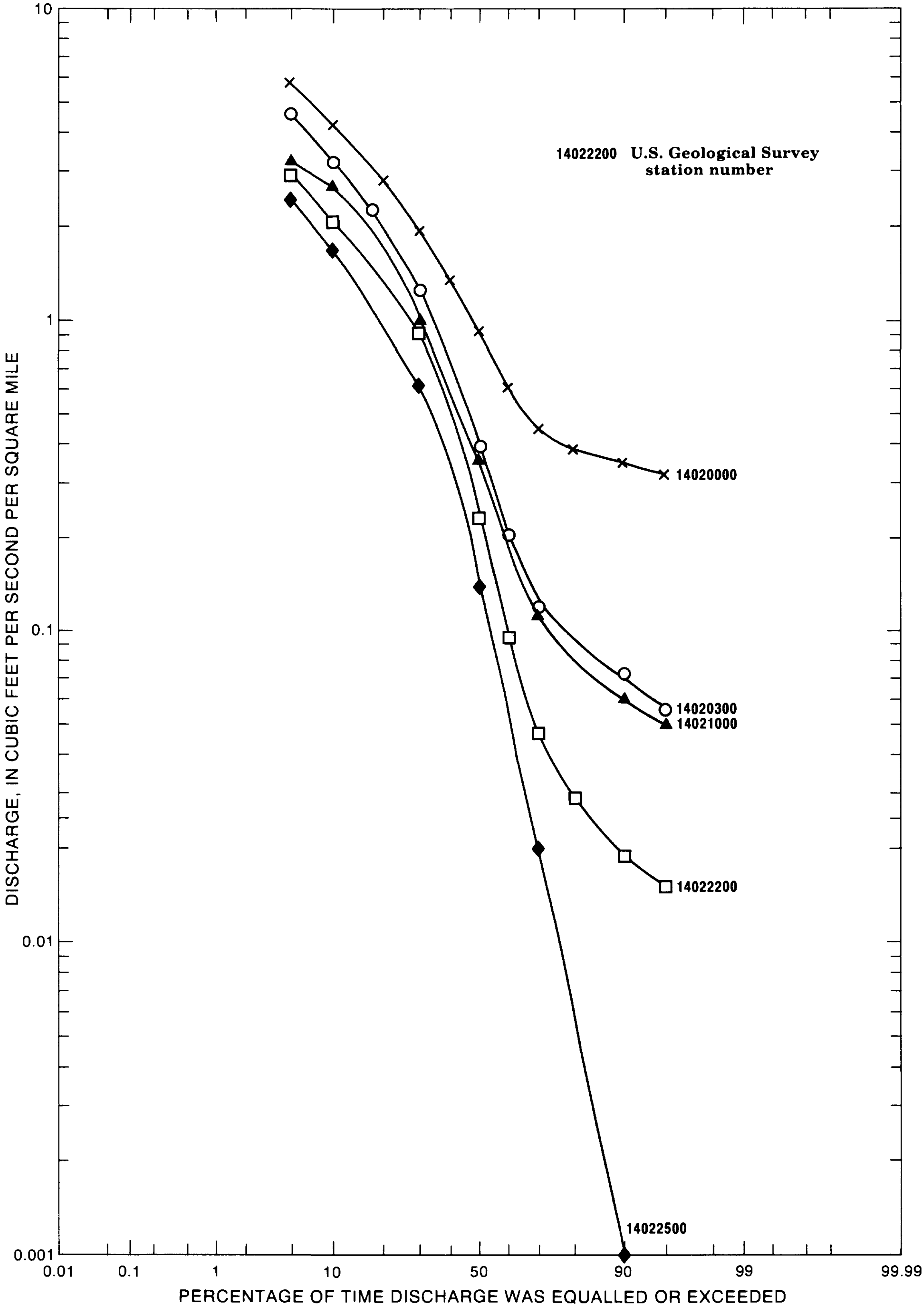


Figure 6.—Duration curves of discharge for selected streams on or near Umatilla Indian Reservation.

Monthly Distribution of Annual Runoff

The monthly distributions of average annual discharge for three long-term gaging stations and two shorter-term stations are shown in figure 7. For all three long-term stations and one shorter-term station, the month of April is the period in which the largest percentage of the average annual runoff occurs, and is due principally to snowmelt. The range of percentage runoff is from 19.6 percent at station 14020000 to 22.8 percent at station 14020300. For station 14022500, runoff for the month of March is nearly as high as April. The period of lowest runoff is August for all stations, and the range is from 0.1 percent at station 14022500 to 1.7 percent at station 14020000. The runoff for the month of September for all five stations is nearly as low as the month of August.

From 1976-87 WY, Streamflow records indicate that the combined July, August, and September mean flows of the Umatilla River above Meacham Creek (14020000) and Meacham Creek at Gibbon (14020300) averaged about 16 ft^3/s more than the flow at the gage on the Umatilla River at Pendleton (14021000). This suggests that a loss of flow occurs in the Umatilla River in July, August, and September on the reservation between these gaging stations. This loss of flow probably is the combined result of several factors previously mentioned by Gonthier and Harris (1977, p. 36),

> "This loss in flow is probably due to several factors, including, (1) direct diversion of streamflow for irrigation and industrial uses; (2) indirect diversion by induced infiltration caused by discharge of water from shallow wells, ponds, and infiltration galleries in the alluvium; (3) direct evaporation of water from the stream surface; and (4) indirect losses due to evapotranspiration of shallow ground water from the alluvium."

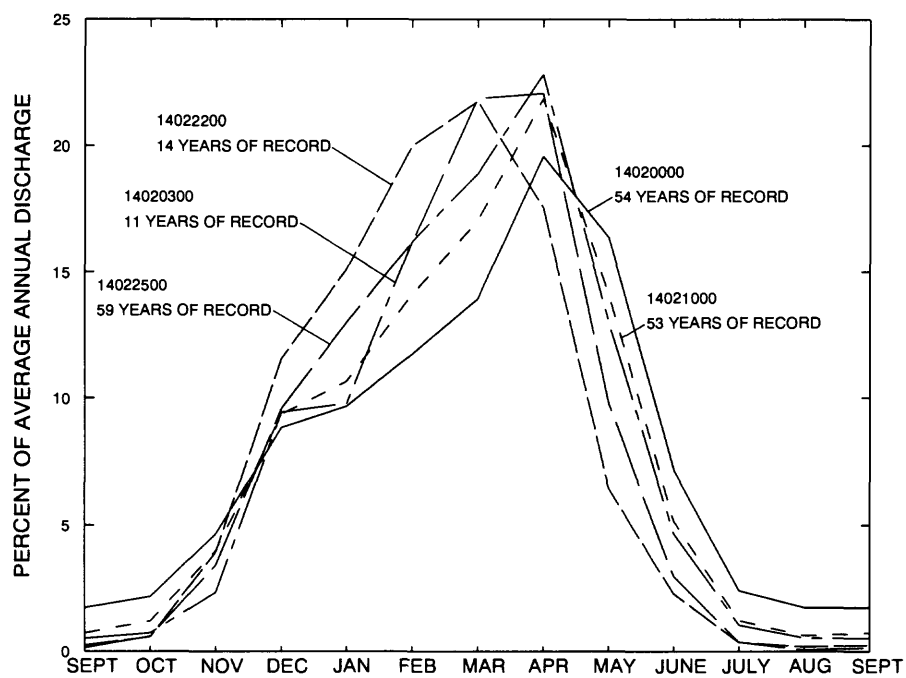


Figure 7.—Monthly percentage of average annual discharge at selected streamflow-gaging stations on or near the Umatilla Indian Reservation.

Additionally, it is likely that some water leaks to aquifers underlying the stream. No attempt has been made to quantify the rate of loss by each process. During periods of high flow, this same reach of the Umatilla River shows a net gain in flow between these stations.

Ground Water

Under natural conditions, recharge percolates to the water table, becomes ground water, moves from the recharge area to springs or as diffuse seepage to surface water, or is evaporated or transpired to the atmosphere. In an earlier report describing the water resources of the reservation, Gonthier and Harris (1977) indicated that in most of the reservation a "zone of perched ground water" of varying thickness was present above a "main zone of saturation." This early concept of the flow system was revised for this report into a concept consisting of shallow to moderately-deep local flow, underlain by deeper regional flow paths. This revision of the early concept is important because it probably describes the system more accurately and recognizes the fact that the system probably is hydraulically connected below the water table. Thus the "zone of perched ground water" referred to in the earlier report is equivalent to the term "local flow system" of this report. The term "main zone of saturation" of the earlier report is conceptually equivalent to the "regional flow system" of this report. The principal difference between the two concepts is that the local and regional flow paths are hydraulically connected, such that changes due, for example, to increased ground-water withdrawals in deep regional flow paths will ultimately impact shallower overlying local flow paths. A system consisting of a "zone of perched ground water" overlying a "main zone of saturation" implies that there is no hydraulic connection between the two zones.

Recharge

Precipitation on the Umatilla Indian Reservation that does not runoff to streams, evaporate, or transpire percolates to the water table as ground-water recharge. Ground-water recharge occurs at most localities, but the quantity of recharge varies accordingly with precipitation quantity, type, and frequency, with soil type, air temperature, land use, slope and altitude, and vegetative cover. Using these factors in conjunction with a method developed by Bauer and Vaccaro (1987) for arid and semiarid environments, the average annual recharge on the reservation was estimated to range from about 0.6 inches in the lowland areas along the west and northwest reservation boundary to more than 3 inches in the uplands east of Thorn Hollow. The distribution of recharge is shown in figure 8.

Flow

Ground-water flow beneath the reservation within the layered basalt and associated sedimentary rock flow system is complex. Because of this complexity each of the principal units in the flow system will be examined separately, beginning with the oldest rocks.

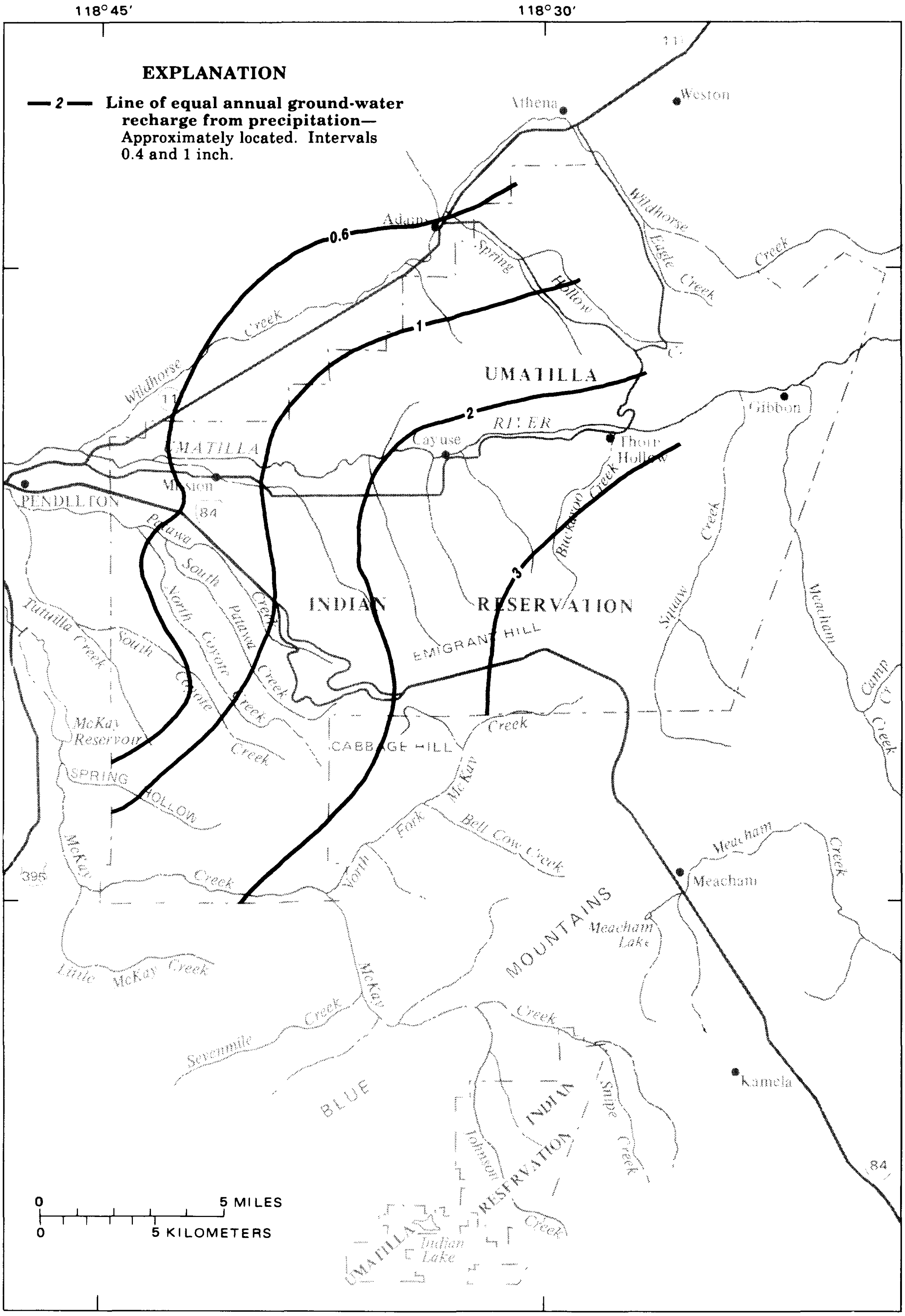


Figure 8.—Distribution of recharge from precipitation on the Umatilla Indian Reservation.

Each of the principal geologic formations discussed earlier in this report are considered to be separate but hydraulically-connected units. For purposes of this report, they are referred to as hydrogeologic units; for example, the Wanapum Basalt (a geologic formation) is the Wanapum hydrogeologic unit or more simply the Wanapum unit (pl. 1). The pre-Miocene volcanic rocks are not considered to be a principal hydrogeologic unit. Areas where each of the hydrogeologic units crop out are shown on plate 1.

Pre-Miocene volcanic rocks

Little is known about the hydrology of the pre-Miocene volcanic rocks in McKay Creek valley. Only two wells are believed to obtain most of their water from these rocks; data from these wells suggest that their water-bearing characteristics are not significantly different from those of the overlying rocks of the Columbia River Basalt Group. Information from outside this area, however, in the John Day Basin, indicates that the pre-Miocene rocks of all types in that area are generally poor water-bearing formations relative to the basalt of the Columbia River Basalt Group. The probable low permeability and topographic position of the pre-Miocene volcanics on the floor of McKay Creek valley tends to impede the westward flow of ground-water in the basalt at that locality. This will be discussed further in the next section.

Grande Ronde Unit

The oldest unit, the R1 magnetostratigraphic unit of the Grande Ronde unit, crops out east of the reservation outside the map area at an altitude generally above 2,600 feet and in the area receiving more than 3 inches of ground-water recharge annually (fig. 8). Beneath the reservation, the unit should be present at great depths everywhere. Ground-water flow in the outcrop area in the R1 unit probably is local in nature; that is, recharge to it is principally from precipitation. Discharge from the R1 unit is principally to springs, canyon wall seepage faces, streams, and to the atmosphere through evapotranspiration in the outcrop area. West of the outcrop area where the R1 unit is covered by younger units, flow in the unit is mostly confined and is regional in nature. Recharge to and discharge from the R1 unit in this area is to and from overlying and underlying units; the amount is determined by head differences between units. No wells on the reservation are sufficiently deep to penetrate this unit.

The low permeability rocks of pre-Miocene volcanics (pl. 1, section D-D') tend to restrict the westward flow of ground water in the R1 and N1 basalt units in that area. It is possible that upward flow from deeper basalt units occurs along or near the contact between the volcanics and the basalt on the upgradient east side of the outcrop.

Outcrop areas for the N1 magnetostratigraphic unit of the Grande Ronde unit are east of the reservation along Meacham Creek and along Johnson Creek in the McCoy Tract. At Meacham and Johnson Creeks, the unit crops out at altitudes above about 2,200 feet. These areas receive more than 3 inches of ground-water recharge annually (fig. 8). Regional confined flow in the N1 unit probably occurs in areas overlain by younger units and where recharge to it, and discharge from it, are through overlying and underlying units. No wells within the reservation are sufficiently deep to penetrate the N1 unit of the Grande Ronde unit.

Outcrop areas underlain by the R2 magnetostratigraphic unit of the Grande Ronde unit on the reservation are along the Umatilla River east of Thorn Hollow, Squaw Creek, and Meacham Creek, as well as McKay Creek. Small outcrops also are present in the valleys of South Patawa and North and South Coyote Creeks. The outcrop areas are all characterized by large local topographic relief. Local flow systems probably occur beneath each topographic high. Recharge is from direct infiltration of precipitation and leakage from overlying units.

Most wells located on the floors of the Umatilla River valley, Squaw Creek and Meacham Creek east of the Hite fault near Thorn Hollow, and east of the fault crossing McKay Creek, are completed in the R2 unit. A few wells east of the fault in the South Patawa, and North and South Coyote Creeks areas also may obtain water from this unit. The existence of many flowing wells in the above areas indicates that these areas are discharge areas for the R2 unit.

The youngest magnetostratigraphic unit, the N2 unit of the Grande Ronde unit crops out in much of the eastern part of the reservation and underlies younger basalt units in much of the western part of the reservation and in the Emigrant Hill and Cabbage Hill areas. Because of erosion, the N2 unit is absent in the valley bottoms of the Umatilla River drainage system upstream of the Hite fault and in much of McKay Creek drainage basin. It also is absent as the result of erosion at three small localities along South Patawa and North and South Coyote Creeks. The N2 unit is deeply eroded in most of its outcrop area and as a result, ground-water flow in much of the N2 unit is unconfined and is part of local flow systems. Annual ground-water recharge to the N2 unit in the outcrop area ranges from about 1 to about 3 inches (fig. 8), most of which is discharged to underlying basalt and to streams in the outcrop area.

In upland areas, water in the N2 unit commonly is first encountered during drilling in rocks within 1 to 200 feet of the land surface. Well yields are extremely erratic and generally small, and water-levels decrease in altitude with increasing well depth. In places, water levels in adjacent shallow and deep wells may differ by as much as several hundreds of feet. These conditions are characteristic of ground-water recharge areas.

Within the upland outcrop areas, the N2 unit is recharged by local precipitation, and where it does not crop out, it is recharged by downward flow from overlying younger basalt. Discharge from the N2 unit is to underlying older basalt flows, to seepage faces in canyon walls, to the atmosphere through evapotranspiration, and to springs and streams in the outcrop areas. Regional confined flow in the N2 units dominates in the western part of the reservation where it is overlain by younger basalt. In that area, discharge is by wells and by leakage to overlying and to underlying units. The uppermost part of the N2 unit also crops out along the Umatilla River in and west of Pendleton. In that area, local flow systems probably have developed in the uppermost part of the unit.

Geologic sections A-A′ through D-D′ (pl. 1) illustrate the lack of continuity of the N2 unit in the east where it crops out and its continuity in the west where it is generally overlain by younger basalt. A generalized water-level map for the N2 unit is shown in figure 9. The water-level contours in figure 9 were reproduced from an earlier set of water-level contour maps of the Columbia Plateau by Whiteman (1986). The contours are generalized because there are few new well data available with which to update the work of Whiteman (1986), and in western part of the reservation most of the water-level information, though sparse, is from wells that are open to both the N2 unit and to the overlying Wanapum unit. As discussed earlier, such wells have composite water levels that commonly mask actual conditions in the hydrogeologic unit of interest. Ground-water flow in the N2 unit is from uplands in the east toward adjacent valleys. Water in the N2 unit discharges to the underlying basalt unit and eventually to springs, seepage faces on canyon walls, and streams. Flow direction varies from southwestward in the area north of the Umatilla River to northwestward in the area south of the Umatilla River.

Wanapum Unit

In the western and most populated part of the reservation, the Wanapum unit either crops out or is covered by only a thin layer of sediments. Most of the wells in this part of the reservation tap this unit for their source of water. Several wells in the Emigrant Hill and Cabbage Hill area also tap the Wanapum unit, but most are sufficiently deep to obtain most of their water from the underlying N2 unit of the Grande Ronde unit. Annual ground-water recharge to the Wanapum unit from direct infiltration of precipitation in areas where it crops out generally ranges from less than 0.6 to about 1 inch (fig. 8). It receives more than these amounts in the Blue Mountains, but that recharge eventually discharges to streams or to the underlying basalt in those areas.

In the western part of the reservation, the upper part of the Wanapum unit has been eroded by the Umatilla River and other streams. In Pendleton, about a mile and a half west of the reservation, the Umatilla River has eroded entirely through the Wanapum unit and has exposed the underlying N2 unit of the Grande Ronde unit. This erosion has disrupted the physical and hydraulic continuity of the Wanapum unit, and consequently, a local flow system has developed in the upper eroded part of the Wanapum unit.

The generalized water levels for the Wanapum unit are shown in figure 10. Water-level contours were reproduced from Whiteman (1986). The area, shown in figure 10, also is one in which water levels in adjacent wells of varying depths commonly have water levels that differ by 200 feet or more. On the reservation north of the Umatilla River where the sediment covering the basalt is thin and not fully saturated, water levels represent the water table. Elsewhere, water levels in the Wanapum unit are above the land surface. Areas where the Wanapum unit crops out in the Blue Mountains have not been contoured because it is believed that only the lowermost Wanapum Basalt layers in that area are saturated and that the top of the saturated zone is actually within the N2 unit of the Grande Ronde unit.

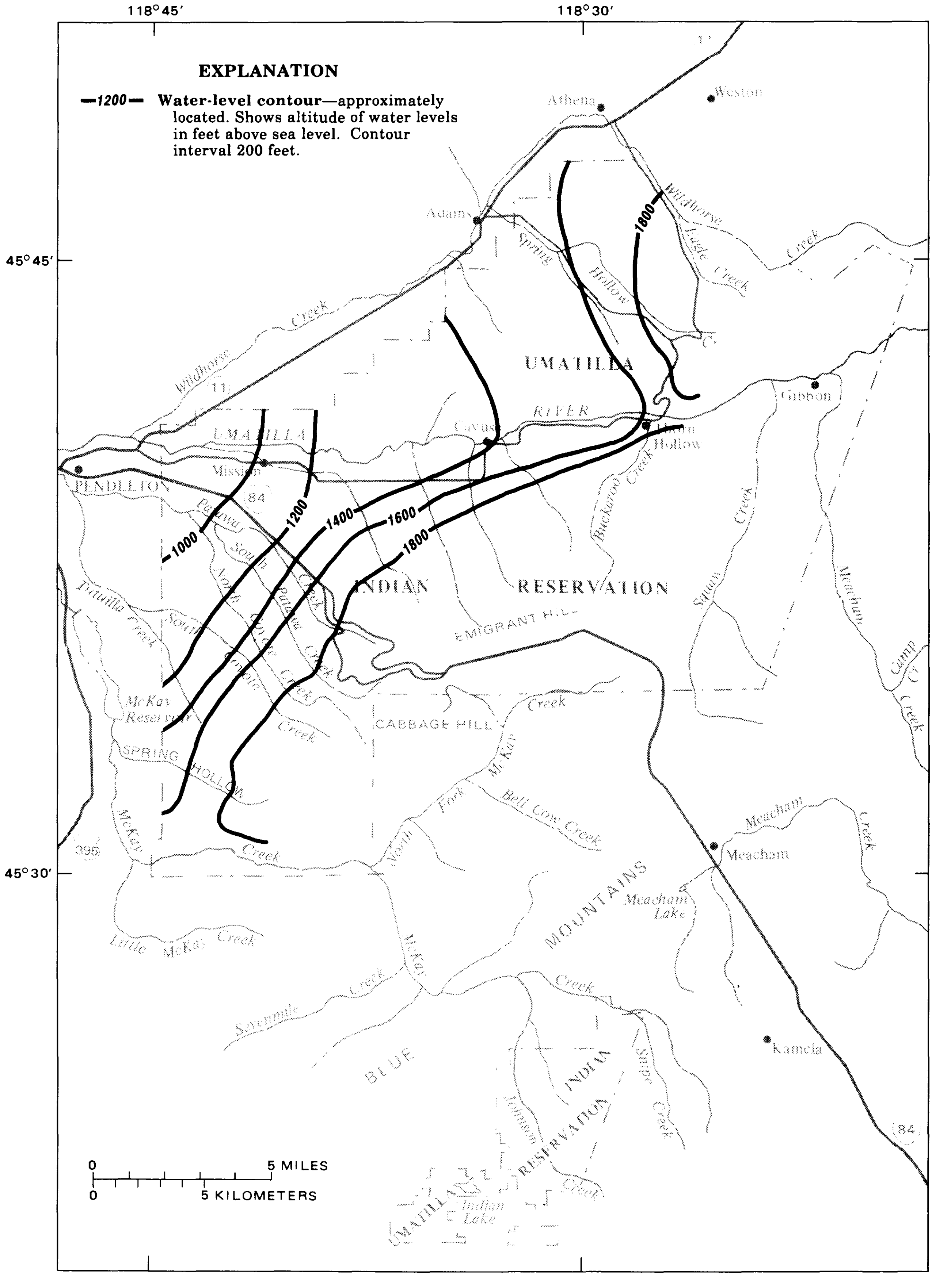


Figure 9.—Generalized ground-water-level contours for the N2 magnetostratigraphic unit of the Grand Ronde unit.

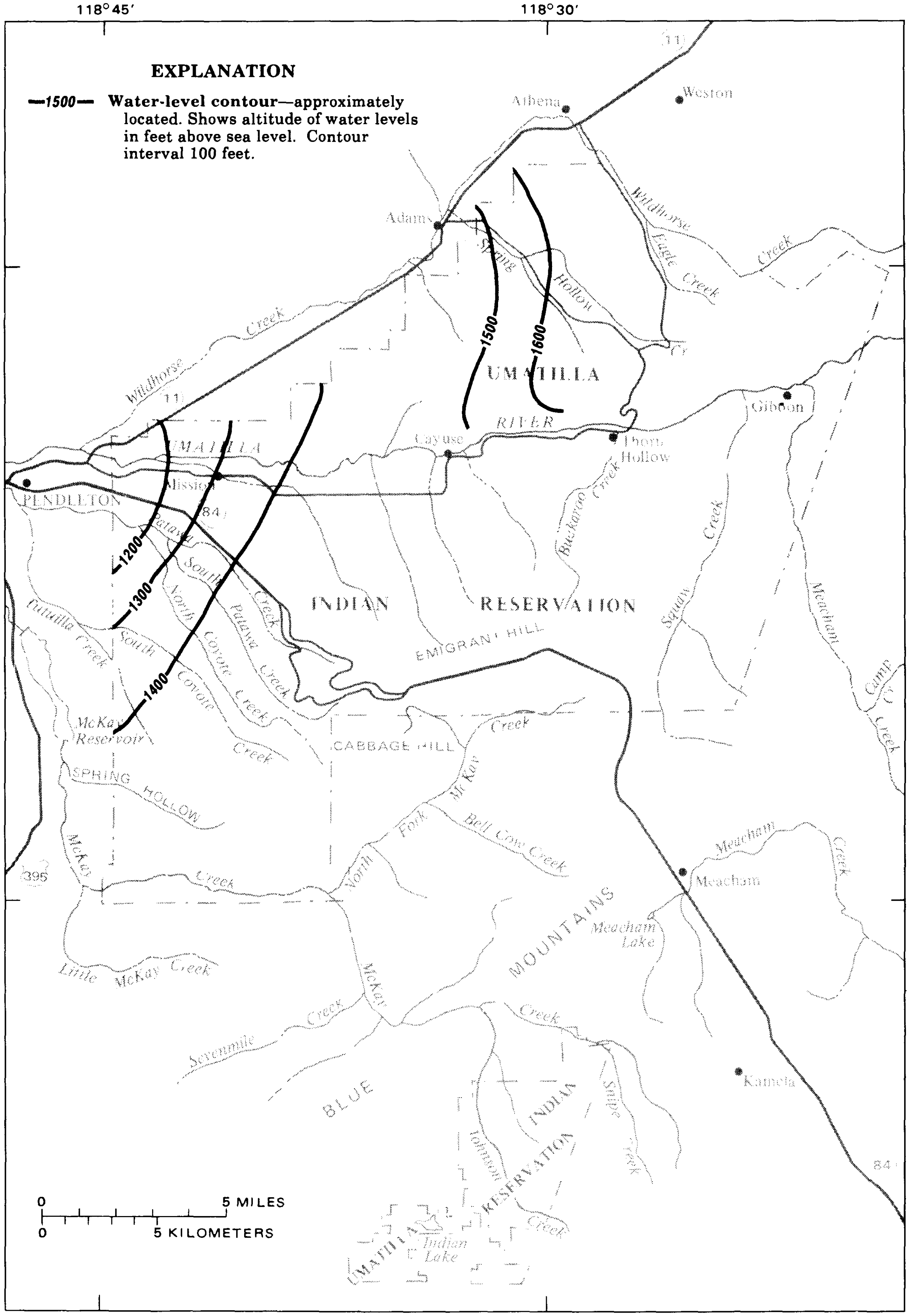


Figure 10—Generalized ground-water-level contours for the Wanapum unit.

The shape of the ground-water surface in the Wanapum unit (fig. 10) generally conforms to the overlying land surface but is more subdued. The map indicates that ground water in the Wanapum unit moves from the uplands towards adjacent lowlands. Flow gradients within the Wanapum unit allow some of the water to move through interconnected fractures and joints in the basalt and through uncased well bores into the underlying units.

If one overlays figure 9, ground-water levels for the N2 unit of the Grande Ronde unit and figure 10, showing ground-water levels in the Wanapum unit, distribution of the differences in hydraulic head between the two can be examined. The differences in hydraulic head between the Wanapum unit and the N2 unit range from 0 near their contact in the uplands to more than 200 feet in the northwest part of the reservation.

The general direction of ground-water flow in the Wanapum unit is west, north of the Umatilla River and to the northwest in areas south of the river.

Quaternary and Tertiary sedimentary deposits

The thickest Quaternary and Tertiary deposits are found on the reservation south of the Umatilla River where they locally may exceed a thickness of 200 feet and are partly saturated. North of the Umatilla River the deposits are much thinner and generally unsaturated. On the south part of the reservation only a few wells, most of them hand dug, have been developed in these deposits and obtain water solely from them. There are, however, several wells in which the casings are perforated opposite the unconsolidated deposits and are uncased in the underlying basalt; thus ground water is obtained from both the unconsolidated deposits and the basalt simultaneously. Recharge to the Quaternary and Tertiary deposits is by direct infiltration of precipitation, by infiltration of streamflow along losing reaches of streams, and by upward flow from the underlying basalt. In the southwestern part of the main reservation and at the edges of the deposits, they are unsaturated and ground water is present only in the underlying basalt. In these areas, precipitation infiltrates through the deposits and eventually recharges the underlying basalt.

On the western part of the reservation, the direction of ground-water flow in the deposits is northwesterly. The reader is referred to Gonthier and Harris (1977, fig. 18, p. 43) because no new water-level data are available for the deposits and general flow directions have changed little from that earlier report. Ground-water from the deposits discharges mostly in the lower reaches of Patawa, South Patawa, and North and South Coyote Creeks.

Flowing wells in the basalt underlying the Quaternary and Tertiary deposits indicate that the potentiometric surface of the basalt (mostly Wanapum Basalt) is above the land surface. This upward flow indicates that water from the basalt discharges to the overlying deposits. The quantity of upward flow from the basalt to the deposits was not determined for this or earlier studies, but probably is small.

Quaternary alluvial deposits

Unconsolidated coarse sand and gravel and boulder beds in the Quaternary alluvial deposits are probably the most permeable type of water-bearing materials present on the reservation. Because these deposits generally are thin and their saturated thickness is small, however, they have not been developed extensively for water supplies. These deposits also may be especially susceptible to water-quality degradation from surface sources because the water table is shallow and the alluvial materials are highly permeable. Ground water is developed through use of large diameter dug wells, shallow dug ponds, or through infiltration galleries. Use of this aquifer as a source of potable water may be declining because of its potential for contamination.

Recharge to the alluvium is by direct infiltration of precipitation, by downward flow from overlying streams during floods and freshets and by upward flow from the underlying basalt. The latter condition is typical along the Umatilla River above the Mission area and along McKay Creek above the west reservation boundary. In these stream reaches, numerous wells within the basalt that probably would flow if they were tightly sealed indicate that ground water in the basalt beneath the alluvium is discharging to the alluvium or directly to streams. The water table in the alluvium is shallow, ranging from a few to about ten feet below the land surface. The flow direction is generally downvalley.

Ground-water Level Fluctuations

Ground-water levels fluctuate in response to natural changes in the rate of recharge and discharge such as those related to climatic events. They also fluctuate artificially in response to manmade stresses such as those caused by pumping ground water or the application of excess irrigation water.

In 1979, the Confederated Tribes of the Umatilla Indian Reservation began installing wells that were designed to be used primarily for the purpose of observing fluctuations of ground-water levels and possibly for obtaining periodic water samples for monitoring ground-water quality. This observation well network presently (1989) consists of eight wells. Six of these wells are shallow and deep pairs located at three separate sites in the valley of the Umatilla River at Mission, Cayuse, and near Thorn Hollow and are referred to as wells 1, 2 and 3 shallow and deep, respectively (fig. 11). Wells 1-shallow (2N/33E-9ADA1), 2-shallow (2N/34E-4DDA2), and 3-shallow (2N/35E-6ACA3) are each completed in Quaternary alluvium and their depths are 25, 13 and 18 feet respectively. Wells 1-deep (2N/33E-9ADA2) and 2-deep (2N/34E-4DDA3) are completed in the Wanapum unit and are 255 and 103 feet deep, respectively. Well 3-deep (2N/35E-6ACA4) is completed in the N2 unit of the Grande Ronde unit and is 52 feet deep. Wells 4 (2N/33E-9ACC3) and 5 (2N/33E-10DBC1) are single wells completed at separate sites in the Mission area in the Wanapum Basalt and are 220 and 180 feet deep, respectively. Water levels for each of these wells have been compiled by the Tribal Department of Natural Resources and are summarized in a report by McCarthy (1989). Several of these wells initially had

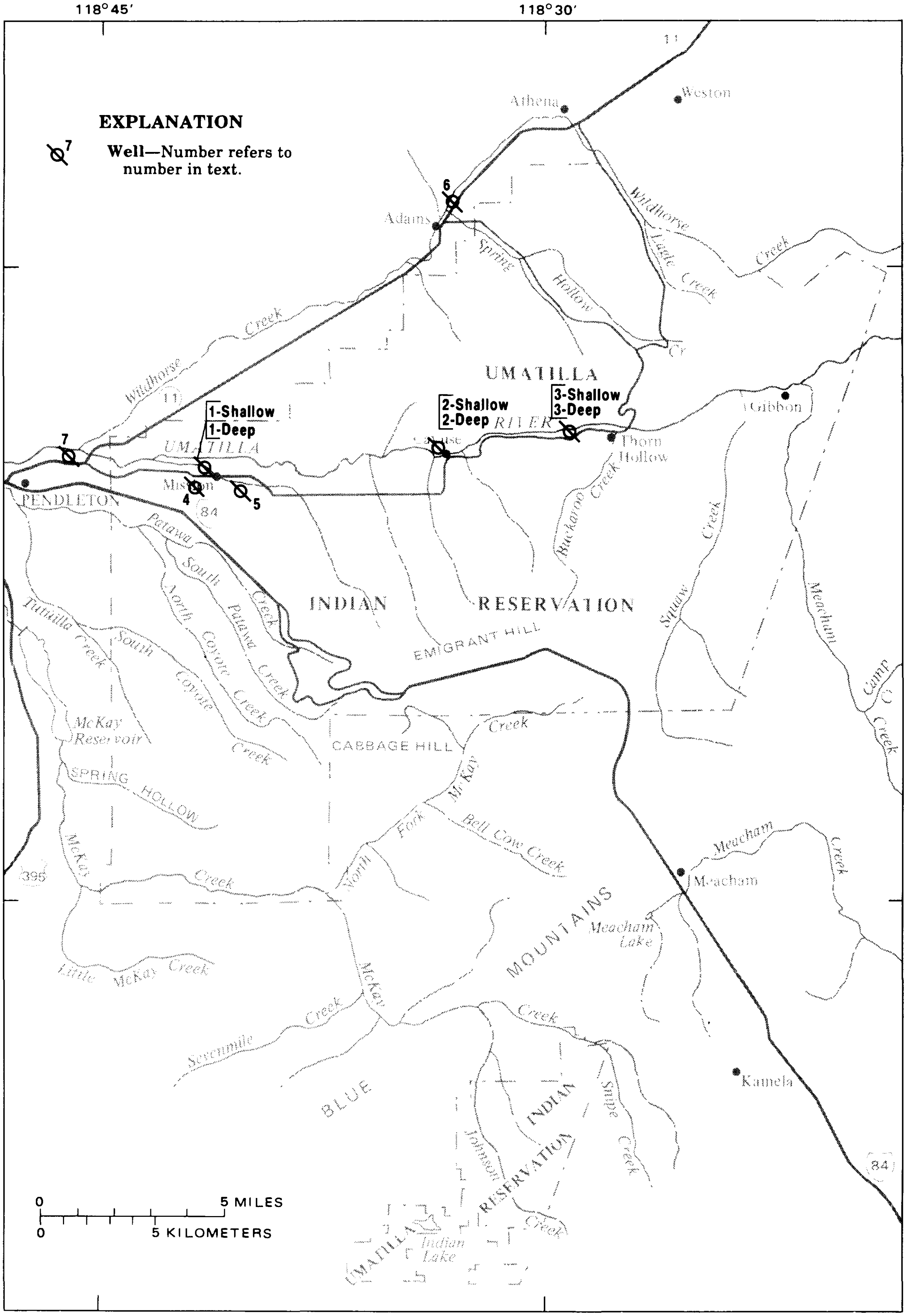


Figure 11.—Location of observation wells.

continuous water-level recorders with analog charts, but the recorders were subsequently removed. Currently, monthly water-level measurements are being made at all observation wells as well as at other non-observation wells at irregular intervals.

The hydrograph of well 1-shallow (2N/33E-9ADA1) is shown in figure 12. Water levels in well 1-shallow fluctuate similarly to those in wells-2 shallow (2N/34E-4DDA2) and 3-shallow (2N/35E-6ACA3), all of which are completed in the alluvium along the Umatilla River. Hydrographs for wells 2- and 3-shallow are not shown because of this similarity. In each well, however, the water levels respond principally to rises and falls in the Umatilla River stage. This can be seen by comparing the average monthly discharge of the Umatilla River at Pendleton (14021000) with the hydrograph of well 1-shallow (fig. 12). Water levels in the alluvium are highest in early spring when snowmelt runoff sustains high flows in the Umatilla River. Low ground-water levels occur in the late summer when streamflow is likewise low.

Hydrographs are shown in figure 13 for wells 2- and 3-deep. Both wells are flowing wells completed in confined aquifers. Well 2-deep (2N/34E-4DDA3) is completed in the lowermost part of the Wanapum unit and is 103 feet deep, whereas well 3-deep (2N/35E-6ACA4) is completed in the N2 unit of the Grand Ronde unit and is 52 feet deep. Well 2-deep shows a slight decline from 1980 to 1987, and well 3-deep shows a slight rise during the same period, neither of which are significant in terms of long-term water-level declines. Well 3-deep shows a seasonal decline and recovery that is probably related to river effect or seasonal recharge to the basalt.

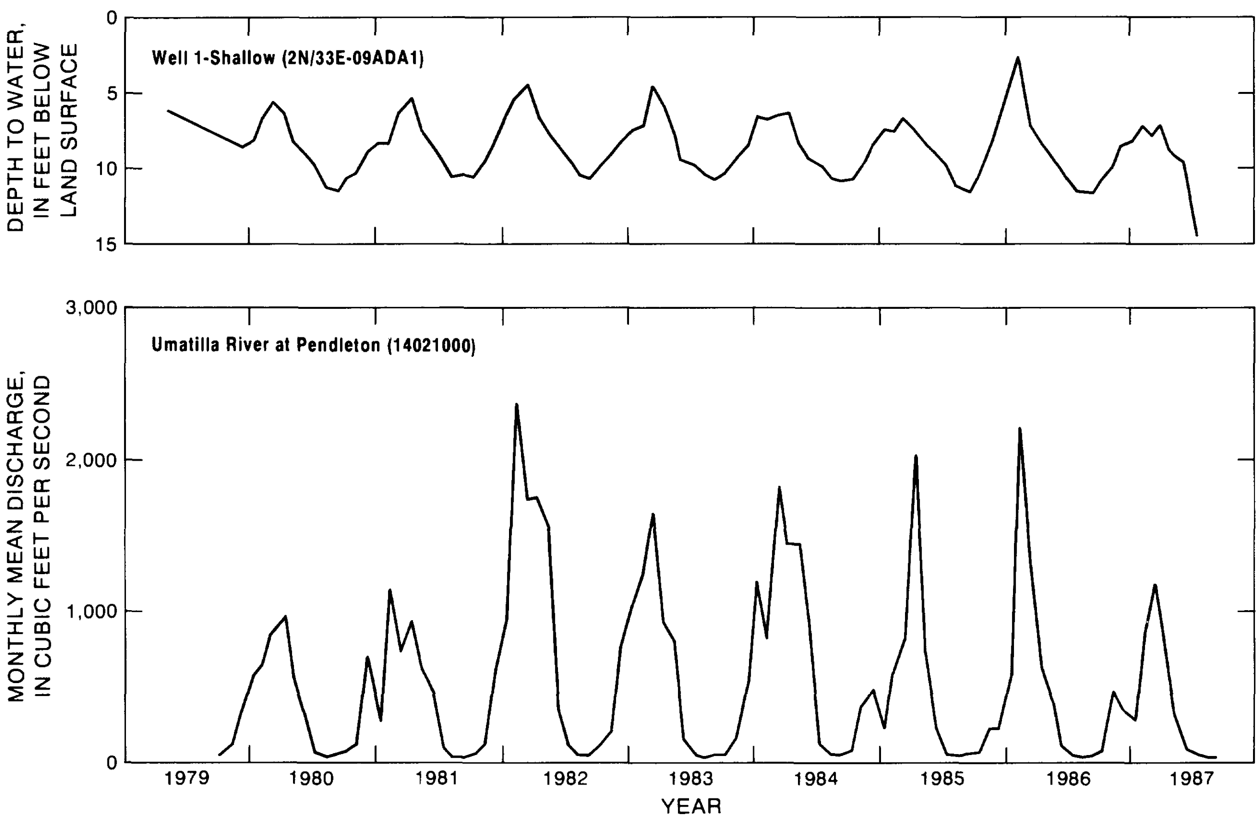


Figure 12.—Water levels in well 1-shallow and monthly mean discharge of Umatilla River at Pendleton, 1979-87.

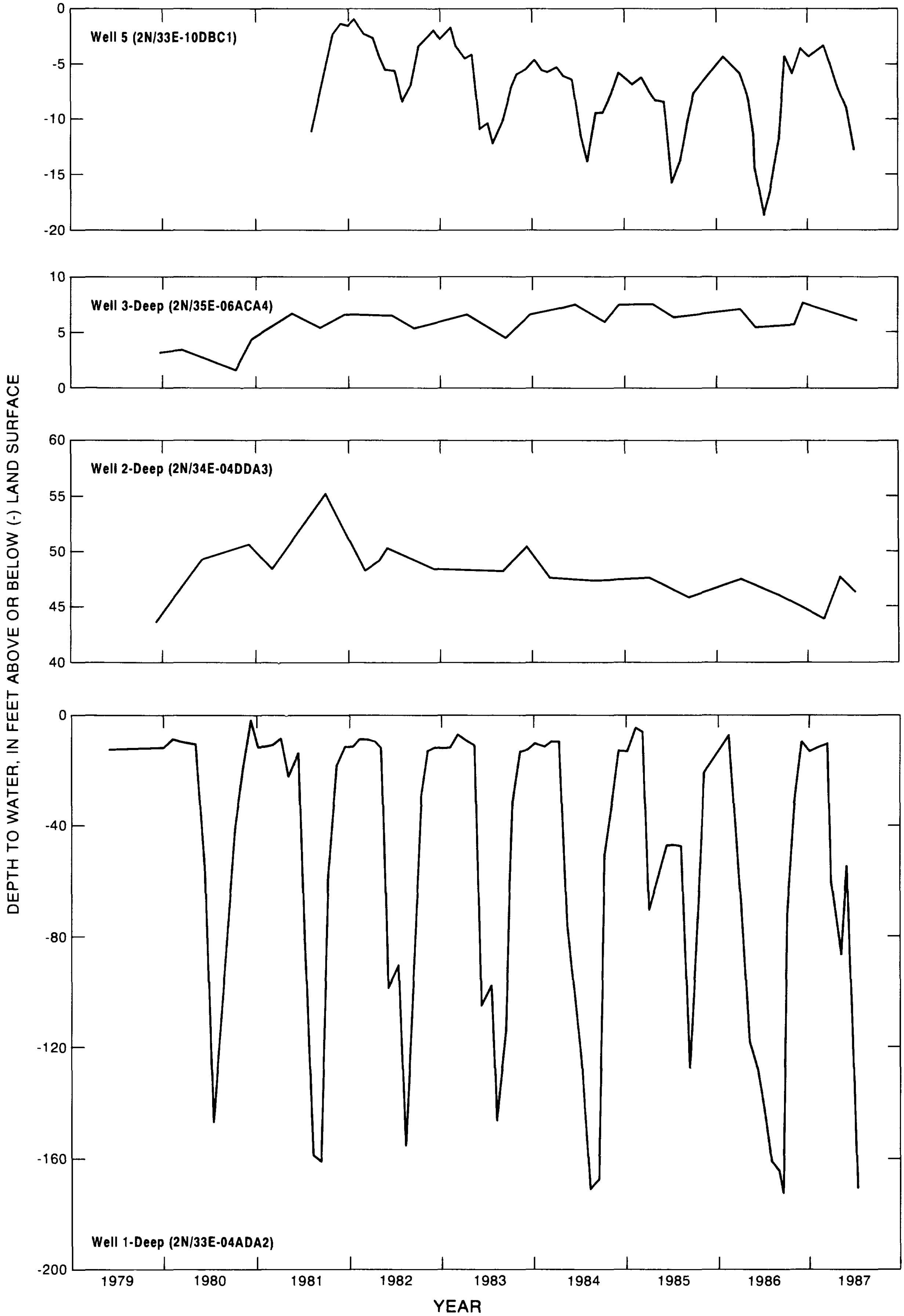


Figure 13.—Water levels in wells 1-deep, 2-deep, 3-deep, and 5, 1979-87.

Hydrographs of well 1-deep (2N/33E-9ADA2) and well 5 (2N/33E-10DBC1) show the seasonal effects of pumping from nearby irrigation wells (fig. 13). The reader is referred to McCarthy (1989) for a description and location of all the wells on the reservation. The water level in well 1-deep declines about 150 feet each summer but recovers after pumping ceases and no long-term decline in water level is apparent. Well 5 shows the same seasonal effect of pumping, but also shows a slight decline in water level from 1981 to 1987.

Long-term fluctuations of water levels are shown in figure 14 for two wells, well 6 (3N/34E-3BAC1) an irrigation well near Adams, Oregon, within three-fourths of a mile of the reservation boundary and well 7 (2N/32E-2CCD1), a public supply well about 1 and one-half miles west of the reservation boundary. The water-level in well 6 shows a decline of about 60 feet from 1965 to 1983. The decline is probably the effect of pumping for irrigation. The water-level recovery in this well between 1980 and 1983 coincides with the economic recession of the 1980's and may indicate reduced irrigation pumpage in the area. In 1972, the well was deepened from 298 to 1,263 feet and is open to both the Wanapum unit and the N2 unit of the Grande Ronde unit.

The hydrograph of well 7 shows a continuous decline in water level from 1970 to 1987. This well is used for public supply and is completed in the Grande Ronde unit. Water levels do not recover on an annual basis because of the constant pumping, and the long-term decline of about 50 feet indicates that recharge is insufficient to supply demand. It is likely that this well has poor hydraulic connection with the Umatilla River, or else its proximity to the river would be effected by changes in river stages. The decline is probably part of a regional water-level decline as discussed in Davies-Smith and others (1988).

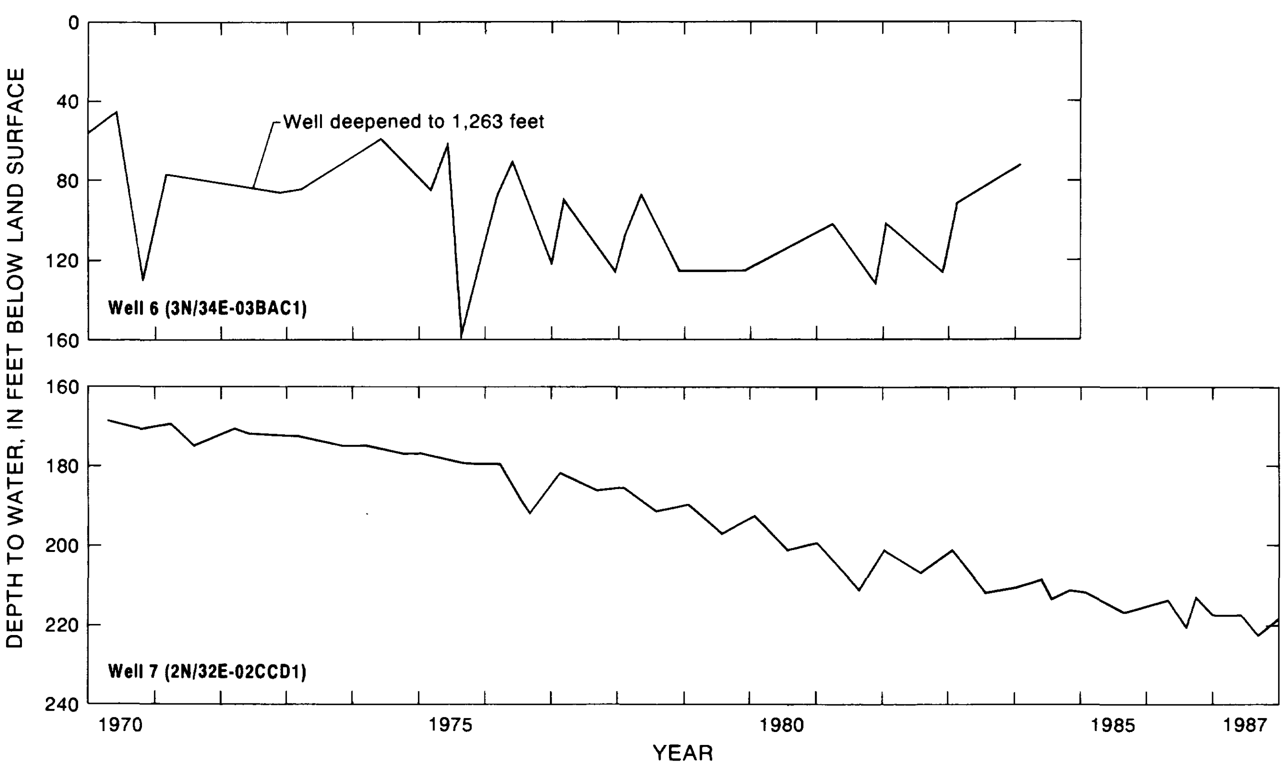


Figure 14.—Water levels in wells 6 and 7, 1970-87.

Most observation wells discussed above are located along the Umatilla River, which is where most of the people on the reservation live. In the Mission area, the water-level data indicate that there is is a local, large seasonal water-level decline occurring in the shallow part of the Wanapum unit that is the result of interference among wells caused by pumping. The deepest wells are completed in both the Quaternary and Tertiary deposits and in the underlying basalt units. Pumpage for irrigation from the basalt units results in lowering of water levels in the basalt units which subsequently decreases water levels in the overlying deposits. This occurs especially during dry seasons when pumpage from the basalt units for irrigation is greatest. Observation wells completed in the Grande Ronde unit to shallow depths near Cayuse and Thorn Hollow indicate no problems due to well interference in the shallow basalt units in those areas. Observation wells near Mission, Cayuse, and Thorn Hollow also indicate no significant water-level decline problems in alluvial deposits in those areas. This is to be expected because there are only a few wells tapping the alluvial deposits in those areas and there is apparent good hydraulic connection with the Umatilla River.

Water-level data from observation wells, outside of but close to the reservation at Pendleton and near Adams, indicate that the ground-water level in the regional flow system in the Columbia River Basalt Group in those areas is declining at the rate of a few feet per year. Similar declines probably are occurring within the reservation caused, in part, by pumpage outside the reservation. These declines are not as yet adequately documented with reliable water-level data collected from wells within the reservation boundaries. In addition, there are local areas within the reservation where irrigation or public-supply pumpage is sufficiently large to warrant periodic measurements in selected pumping wells to document water-level changes.

Ground-water Pumpage and Use

Water-use and pumpage data were compiled by personnel of the Confederated Tribes of the Umatilla Indian Reservation, Department of Natural Resources. The estimated total ground-water withdrawal from aquifers beneath the Umatilla Indian Reservation for 1988 was about 3,350 acre-feet per year. This total is assumed to be an average annual value; however, it varies each year because irrigation use varies with climatic and soil moisture conditions and with type of crops grown. The pumpage estimate is based on metered pumpage at individual wells, on observation of the duration of irrigation pumpage, and on the numbers and sizes of sprinklers in use at each individual withdrawal site. Domestic use was estimated assuming that each household averaged 3.5 persons and each person used 100 gallons per day, each house had 0.2 acre of lawn and garden to water, and 2 feet of water per acre was applied annually. Of the total quantity pumped, about 485 acre-feet or 14 percent is withdrawn for domestic and stock uses, 772 acre-feet, or 23 percent, is for public supply use, 2,088 acre-feet, or 62 percent, is for irrigation use and about 0.5 acre-feet is for industrial and commercial uses.

The total average annual pumpage by Water Management Region on the reservation is listed in table 5, and the location of water management regions within the reservation is shown in figure 15. About 1,910 acre-feet or 57 percent is withdrawn from basalt aquifers beneath the south part of the reservation, 561 acre-feet or 17 percent is withdrawn from basalt within the Mission Basin, and 713 acre-feet or 21 percent of the total is withdrawn from basalt aquifers beneath the north reservation, and 166 acre-feet or 5 percent is withdrawn from the Quaternary alluvium and Quaternary and Tertiary sedimentary deposits.

Table 5.--Average annual ground-water pumpage for 1988 by water management regions, Umatilla Indian Reservation

Water Management Region	Quantity pumped in acre-feet
South reservation	1,910
North reservation	713
Mission Basin	561
Umatilla River valley	102
Blue Mountains	35
McKay Creek	24
Northeast foothills	4
Johnson Creek	1
Total	3,350

Ground-water Budget

Part of the Umatilla Indian Reservation was included in a three-dimensional ground-water model study of the Umatilla Plateau by Davies-Smith and others (1988). The model grid from the study by Davies-Smith and others (1988) and its relation to the boundaries of the reservation are shown in figure 16. The total model study area included about 5,800 square miles, whereas by comparison the Umatilla Indian Reservation includes about 250 square miles or about 4 percent of the model area. The model report described the aquifer system boundaries, the hydrologic properties of the aquifers, the relation between streams and the aquifers, and quantified recharge and discharge to and from the aquifer system of the Umatilla Plateau area. The flow model was constructed and calibrated to help understand the ground-water flow system and to provide a means to predict future effects of ground-water pumping in the model area. The model also was used to calculate discharge to and from major streams in the area, such as the Columbia and Umatilla Rivers. The model study covers the period from 1950 to 1982. A complete discussion of the model, including its construction and calibration is found in the report of Davies-Smith and others (1988).

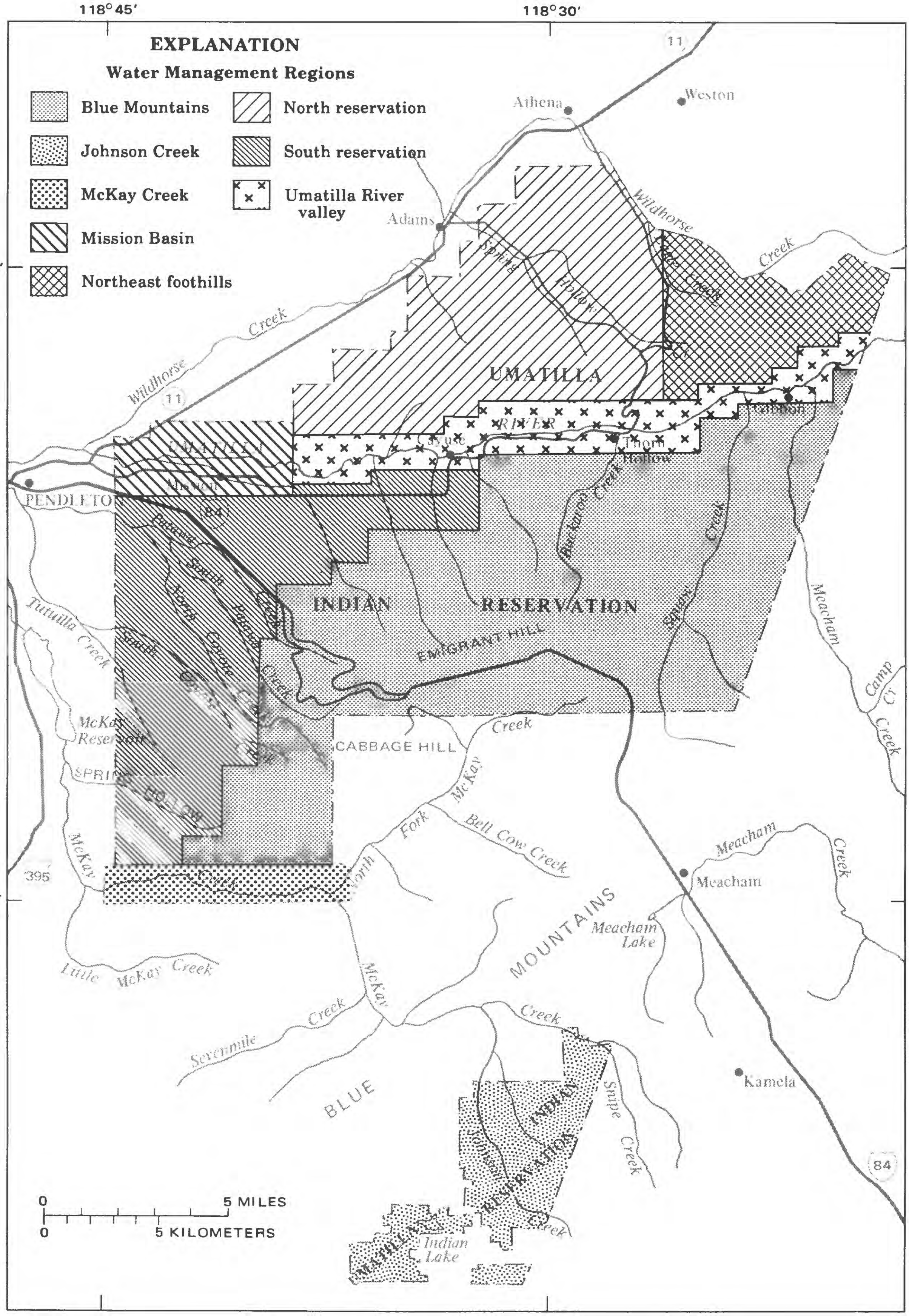


Figure 15.—Water management regions in the Umatilla Indian Reservation.

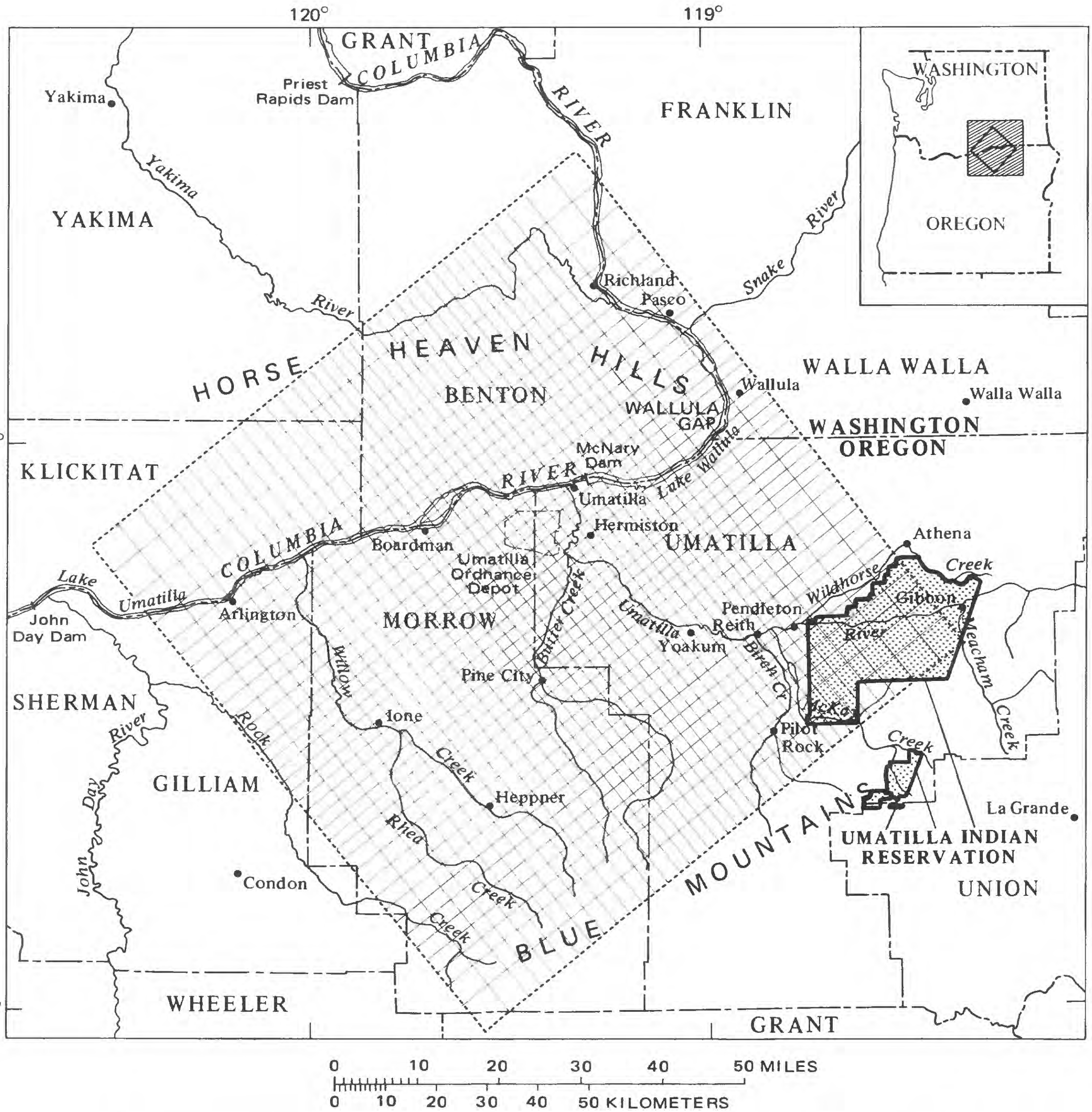


Figure 16.—Relation of the Umatilla Indian Reservation to the grid of the ground-water flow model.

Although the model was not specifically designed to address questions about the ground-water flow system within the Umatilla Indian Reservation, it does nevertheless provide some useful and reasonably reliable information for the reservation area. Each cell within the rectangular model grid (fig. 16) represents a three-dimensional block of a layer within the actual ground-water-flow system. Cell size within the reservation ranges from 3 to 16 square miles. The model has four layers; layers 1 and 2 are approximately equivalent to the Quaternary and Tertiary deposits and the Saddle Mountains unit, respectively, for this study, but were not modeled in the reservation area because these layers in the reservation consist only of small thin partially saturated units. Layers 3 and 4 in the model are approximately equivalent to the Wanapum unit and the N2 unit of the Grande Ronde unit of this study, respectively. Units of the Grande Ronde Basalt older than the N2 unit were not modeled because hydrologic data for the older units are not available. Ground-water flow in these older units therefore was not considered and the bottom of layer 4 was simulated as a no-flow boundary. Each model cell, or block, is composed of six faces (top, bottom, two ends, and two sides) across which water either enters or exits. During a simulation run, the model calculates the hydraulic head distribution in each unit, the gain or loss to streams, and the volume flow rates of water entering, moving through, and leaving each of the six faces of each cell of each layer. In this manner, a ground-water budget was calculated for those cell faces in the model that represent the reservation boundaries and for those nodes in the model that represent the stream-aquifer relation. For equilibrium or steady-state conditions, the ground-water budget was calculated for the modeled part of the reservation and is summarized from model results in table 6. A steady-state analysis assumes that the flow system was as yet undeveloped and that natural ground-water recharge and discharge are in balance.

The model results for steady-state analysis show that ground-water inflow and outflow from the modeled part of the reservation were approximately equal. Recharge to ground water from precipitation averaged about 29,240 acre-feet per year and subsurface flow into the modeled area along the northeast and southeast edges averaged about 13,960 acre-feet per year. Included in this subsurface inflow is an undetermined but significant quantity of ground-water recharge from precipitation that falls outside the modeled area but within the reservation boundaries. A small quantity of ground-water recharge, 800

Table 6.--Ground-water budget from steady-state model analysis (predevelopment conditions, prior to 1950)

Item	Acre-feet per year	Millions of gallons per day
Inflow		
Ground-water recharge from precipitation	29,240	26.1
Recharge from streams	800	.7
Subsurface flow across northeast and southeast model boundaries	13,960	12.5
Total	44,000	39.3
Outflow		
Ground-water discharge to streams	19,980	17.8
Subsurface flow across northwest and southwest model boundaries	24,170	21.6
Total	44,150	39.4

acre-feet per year,also occurs as seepage from streams to ground water in the area modeled. Of these quantities, 19,980 acre-feet per year discharged to the Umatilla River and McKay Creek within the reservation and 24,170 acre-feet per year flowed as ground water out of the area across the modeled areas northwest and southwest boundaries, respectively, which are approximately equivalent to reservation's west boundary. The model indicated that total upward leakage from model layer 4 into model layer 3 was about 1,650 acre-feet per year. The total downward leakage from layer 3 to layer 4 was about 680 acre-feet per year. This budget indicates that on the average about 29,000 acre-feet per year of ground-water recharge originated within the modeled part of the reservation's boundaries. However, most of the water either discharged to streams or flowed across the western boundaries of the reservation and was discharged elsewhere. Since about 1950, development of ground water for irrigation and all other uses in the region has increased significantly both within and outside the reservation, but ground-water development has been substantially greater in the area outside the reservation. The net effect of this development outside reservation boundaries is to increase ground-water gradients toward these developed areas and thereby increase the rate of subsurface flow from within the reservation toward these developments.

During the period 1950-82, ground-water withdrawals increased from zero in 1950 to 2,240 acre-feet per year during 1982 (table 7). The 1982 quantity of pumpage in the model differs from the quantity of pumpage shown in table 5 reported for the water management regions on

Table 7.--Ground-water budget from transient model analysis (volume flow rates for 1982)

Item	Acre-feet per year	Millions of gallons per day
Inflow		
Ground-water recharge from precipitation	29,240	26.1
Recharge from streams	800	.7
Subsurface flow across northeast and southeast model boundaries	14,610	13.0
Water taken from storage	1,120	1.0
Total	45,770	40.8
Outflow		
Ground-water discharge to streams	18,200	16.2
Subsurface flow across northwest and southwest model boundaries	25,430	22.7
Ground-water withdrawal by wells	2,240	2.0
Total	45,870	40.9

the reservation because (1) the quantity in table 5 was estimated for 1988, and (2) pumpage from the Quaternary alluvium and Quaternary-Tertiary deposits and pumpage on the reservation outside the model boundaries was not included in the model analysis. Thus, the model results for 1982 show that the increased pumpage plus that from outside the reservation boundaries resulted in a decrease in ground-water storage during 1982 of about 1,120 acre-feet per year; a decrease in ground-water discharge to streams of about 1,780 acre-feet; and increases in reservation boundary inflow in 1982 of 650 and outflow of 1,260 acre-feet. Recharge from streams remained unchanged during 1982. Discharge from layer 4 to layer 3 decreased by 110 acre-feet and from layer 3 to layer 4 the discharge decreased 200 acre-feet during 1982.

SUMMARY

The long-term average discharge of streams at gaging stations on and near the Umatilla Indian Reservation has not changed significantly from the long-term averages calculated in earlier studies. Whereas short-term discharges are significantly affected by the drought such as during 1977 and 1988.

Basalt flows of the Columbia River Basalt Group are the principal sources of water for wells on the Umatilla Indian Reservation. Observation wells near the Umatilla River indicate no long-term water level declines either in the alluvium or in the shallow basalt hydrogeologic units. Water-level data outside the reservation near Adams and near Pendleton indicate that water levels are declining a few feet per year in the deep regional ground-water system as a result of pumpage outside the reservation. Annual ground-water pumpage on the reservation was about 3,350 acre-feet for 1988.

Results from an earlier model study show that during equilibrium conditions, the reservation receives about 29,240 acre-feet of annual ground-water recharge from precipitation; subsurface flow to the Wanapum and Grande Ronde units is about 13,960 acre-feet per year; and about 800 acre-feet per year recharges these units from streams. Model results show that about 19,980 acre-feet per year discharges from the Wanapum and Grande Ronde units to streams, and about 24,170 acre-feet per year moves across the reservation boundaries as subsurface flow.

Results from the model study show that ground-water withdrawal rates from layers 3 and 4 increased from zero in 1950 to 2,240 acre-feet per year in 1982. This increased pumpage plus increased pumpage from outside the reservation boundaries during 1982 resulted in a decrease in ground-water storage within the modeled part of the reservation of about 1,120 acre-feet; a decrease in ground-water discharge to streams of about 1,780 acre-feet; and increases in reservation boundary inflow of 650 and outflow of 1,260 acre-feet. Recharge to ground water from streams remained unchanged in 1982.

NEED FOR ADDITIONAL WORK

Future work on water resources investigations on the Umatilla Indian Reservation is needed to better define the relation between surface- and ground-water flow; to estimate more accurately the quantity of ground-water recharge from precipitation; and to more accurately estimate the quantity of ground water entering and leaving the reservation boundaries as subsurface flow.

Streamflow data for main-stem gaging stations on the Umatilla River and McKay Creek are mostly adequate, but flow quantities and duration of flow in the numerous small tributaries and ephemeral streams including those to the Umatilla River and McKay Creek are not. Streamflow data, coupled with concurrent water-level measurements in wells completed in the various hydrogeologic units described in previous sections of this report, would help define the hydraulic head relation between the two flow regimes.

Estimates of recharge for the reservation as included in this summary report were previously calculated for use in a larger-scaled study--the model of the Umatilla Plateau. The early work on recharge need to be refined because the earlier work was not designed to specifically address water problems on the reservation. Inaccuracies introduced because of averaging input data over large model nodes in the recharge model would be reduced, and thus the resulting recharge estimates would have greater accuracy locally.

Additional drilling of test wells on the reservation is highly desirable for delineating hydrogeologic units and geologic boundaries. Additionally, information obtained from wells drilled for ongoing municipal, industrial, irrigation, or domestic supplies should continue to be analyzed to help improve or refine the current delineation of thickness and extent of the hydrogeologic units.

The areal distribution of long-term ground-water observations wells is currently limited mostly to the Mission Valley area. Continued operation of the long-term ground-water well observation network, and its expansion to areas other than the Mission Valley area are needed for any future assessment of water resources on the reservation. Measurement of annual pumpage from individual wells is likewise required.

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GLOSSARY

ALLUVIUM--Unconsolidated material which has been transported and deposited by modern rivers and streams. Alluvium generally includes deposits of silt, sand, and gravel in stream valleys and channels, lake beds, and in fans at the mouths of canyons.

ANISOTROPIC--Having physical properties, such as hydraulic conductivity, which vary in different directions.

ANTICLINE--A fold in geological layering which is convex upward, commonly resulting in a ridge with layers sloping away from either side.

BRECCIA--A rock composed of broken angular fragments. Breccias are commonly associated with faults and with the tops and bottoms of lava flows.

COLLUVIUM- Loose, unconsolidated soil or rock debris deposited on the surface over wide areas by sheetwash (runoff not in channels) or by downslope creep.

CONFINED AQUIFER--An aquifer that is overlain by a layer of rock with low hydraulic conductivity that restricts movement of water into and out of the aquifer. The pressure of the water at the top of an confined aquifer is greater than atmospheric. The water level in a well that penetrates a confined-artesian aquifer will rise above the top of the aquifer.

DIFFUSE SEEPAGE--Water that disperses or seeps to or from geologic units in such low quantities that its flow rate cannot easily be measured or estimated.

DURATION CURVE--A graph that shows how often a particular stream discharge is exceeded in a given time.

EN-ECHELON NORMAL FAULTS--Normal faults that are parallel to one another but that are unaligned or offset from each other.

EVAPOTRANSPIRATION--The process by which water is lost from the soil or water surface to the atmosphere by a combination of direct evaporation and transpiration by plants.

GEOLOGIC STRUCTURE--A physical feature in the earth's crust, such as a fold or fault, generally produced by movement of the crust.

GEOLOGIC UNIT--An informal convenient subdivision of geologic materials or deposits. Geologic materials or deposits are typically combined into a geologic unit on the basis of their proximity to each other, some common physical characteristic or common genesis. Geologic units may or may not correspond to formal geologic formations.

GROUND-WATER-FLOW MODEL--A mathematical representation of a ground-water-flow system, generally using a digital computer, which enables the quantitative evaluation of the system.

HYDRAULIC CONDUCTIVITY--The measure of the ability of water to move through a medium. Hydraulic conductivity is defined as the volume of water which will move through a medium in unit time under a unit hydraulic gradient through a unit area at right angles to the flow direction.

HYDROGRAPH--A graph showing the elevation or stage of a surface water body or the water level in a well with respect to time.

IGNEOUS--A term applied to rock such as lava which formed by solidification from a molten state.

INTERBED--A layer of sedimentary rock or other geologic material which occurs between two other layers of rock.

LINEAMENT--A pronounced straight-line feature on a satellite image, aerial photograph or map, commonly indicating a fault, fault zone or other geologic structure.

LOCAL FLOW SYSTEM--A ground water flow system, including recharge and discharge areas, which occurs entirely within a relatively small area and generally involves only relatively shallow ground-water flow and short flow paths. Local flow systems can develop in small drainages of only a few square miles. Compare with regional flow system.

MAGNETIC POLARITY (normal and reverse)--Magnetic polarity refers to the orientation of the north and south magnetic poles in an object. Magnetic polarity in an igneous rock is due to the orientation of the magnetic poles in individual magnetic mineral grains within the rock. This orientation is determined by the orientation of the earth's magnetic field at the time the igneous rock cooled. The earth's magnetic poles have reversed direction periodically throughout geologic time. If the magnetic polarity of a rock is approximately parallel to the present orientation of the earth's magnetic field, the rock is said to have normal magnetic polarity. If the magnetic polarity of a rock is approximately reversed from the present orientation of the earth's magnetic field, the rock is said to have reverse magnetic polarity.

MAGNETOSTRATIGRAPHY--The determination of the sequence and correlation of a series of layered rocks based on their magnetic polarity.

MONOCLINE--A geologic structure where there is an abrupt or noticeable steepening of otherwise nearly horizontal geologic layering.

NORMAL FAULT--A break in the surface of the earth or in a geologic unit along which movement has occurred in response to local tensional stress. Compare with reverse fault.

PLAGIOCLASE PHENOCRYSTS--Relatively large, conspicuous crystals of triclinic feldspars which occur in an otherwise fine-grained crystalline igneous rock. Plagioclase phenocrysts are typically clear or white with a tabular form.

QUATERNARY--The period of geologic time extending from approximately 2 million years ago to the present.

RECHARGE--The quantity of water usually derived from precipitation that percolates from the land surface into the ground-water system. Recharge typically occurs in areas with permeable soils and significant precipitation amounts.

REGIONAL FLOW SYSTEM--A ground-water-flow system, including recharge and discharge areas, which occurs over a large area and which generally involves relatively deep ground-water flow and long flow paths. Regional flow systems may develop over a large area such as an entire major drainage basin or may include multiple basins. Compare with local flow system.

REVERSE FAULT--A break in the surface of the earth or in a geologic unit along which movement has occurred in response to local compressional stress. Compare with normal fault.

SAPROLITE--A mantle of residual clay-rich decomposed rock formed in place by chemical weathering of igneous, sedimentary, and metamorphic rocks.

SEDIMENTARY--A term that describes rock or other material which has been deposited after being transported by water or wind.

SPECIFIC CAPACITY--A term that indicates the performance of a well. The specific capacity of a well is the rate at which water is produced from the well divided by the drawdown in the well at that pumping rate. Specific capacity is typically represented as gallons per minute per foot of drawdown.

SPECIFIC YIELD--The volume of water that will drain by gravity from material when saturated, divided by the total volume of that material.

STEADY STATE--A term used to describe the condition of a ground-water system that is in equilibrium and therefore does not change with time. If a ground water system is in a steady-state condition, the direction and velocity of flow at any point within that system will remain constant in time, and the amount of long-term recharge and discharge remain unchanged as well.

STORAGE--A term used to refer to the space within which water can reside in an aquifer, and also to refer to the volume of water that resides in an aquifer.

STORAGE COEFFICIENT--A term that represents the volume of water an aquifer releases from or takes into storage per unit surface area per unit change in head.

STRUCTURAL BASIN--A topographically low area which has resulted from some structural movement in the earth's crust. Structural basins commonly result from faulting or synclinal folding.

SYNCLINE- A fold in the earth's crust or geological layering which is convex downward, commonly resulting in a linear topographic low with geologic layers sloping toward the center.

TERTIARY--The period of geologic time extending from approximately 63 million to 2 million years before present.

TRANSIENT--A term used to describe the condition of a ground-water system that is not in equilibrium, where the velocity and direction of ground-water flow, as well as the amount of recharge and discharge to and from the system, change with time.

TRANSMISSIVITY--A measure of the ability of an aquifer to transmit water. Transmissivity is defined as the rate at which water moves through a unit width of an aquifer under a unit hydraulic gradient. The transmissivity of an aquifer equals its hydraulic conductivity multiplied by its thickness.

UNCONFINED AQUIFER--An aquifer without any overlying layer of material of low hydraulic conductivity to restrict water movement into or out of the aquifer. The pressure of the water at the top of an unconfined aquifer is atmospheric. The top of the water in an unconfined aquifer is referred to as the water table.

UNCONFORMITY--A break or gap in the geologic record where geologic units are missing from the normal sequence due to erosion or nondeposition.

WATER TABLE--The top of the water surface in an unconfined aquifer. The pressure of the water at the water table is equal to the atmospheric pressure.

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