GROUND-WATER PUMPAGE FROM THE COLUMBIA PLATEAU,

WASHINGTON AND OREGON, 1945 TO 1984

By D. R. Cline and C. A. Collins

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Multiply	by	to obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	4,047	square meter
square mile (mi^2)	2.590	square kilometer
acre-foot (acre-ft)	1,233	cubic meter

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

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ABSTRACT

The study area for determining ground-water pumpage in the Columbia Plateau is located in southeastern Washington and northeastern Oregon. This study is part of the Columbia Plateau Regional Aquifer-System Analysis study and provides estimates of historic ground-water pumpage for selected years from 1945 to 1984. The plateau is underlain by basalt that is divided into three water-yielding units: Grande Ronde, Wanapum, and Saddle Mountains. A fourth water-yielding unit, called overburden and composed of unconsolidated deposits, overlies the basalt in some places and locally yields considerable quantities of water. The major water use on the plateau is irrigation; about 70 percent of the acreage is irrigated with surface water and 30 percent with ground water.

Ground-water pumpage increased from about 56,000 acre-feet in 1945 to about 940,000 acre-feet in 1979, with the greatest increase occurring from 1963 to 1979. In 1984, pumpage was about 828,000 acre-feet, 82 percent of which was in Washington. Economic factors and locally declining water levels contributed to the decreased pumpage from 1979 to 1984.

Pumpage from the basalt was slightly more than 50 percent of the total ground water pumped from the plateau in 1945; this increased to about 75 percent by 1965 and has remained about the same since 1965. The greatest volume of pumpage is derived from the Wanapum unit; in 1984, the Wanapum unit provided 39 percent of the total pumpage. The Grande Ronde unit, which has had an increasing proportion of the water pumped from the plateau, provided 32 percent of the pumpage in 1984.

Nearly all of the pumpage from the overburden unit, which provided 26 percent of the water on the plateau, came from only six counties in Washington and Oregon. Two counties in Washington accounted for 65 percent of the total pumpage from the overburden unit in 1984.

Three subareas in Washington yielded 46 percent of the ground water pumped from the plateau in 1984. Most of the pumpage from one subarea was from basalt; most of the pumpage from the other two subareas came from the overburden.

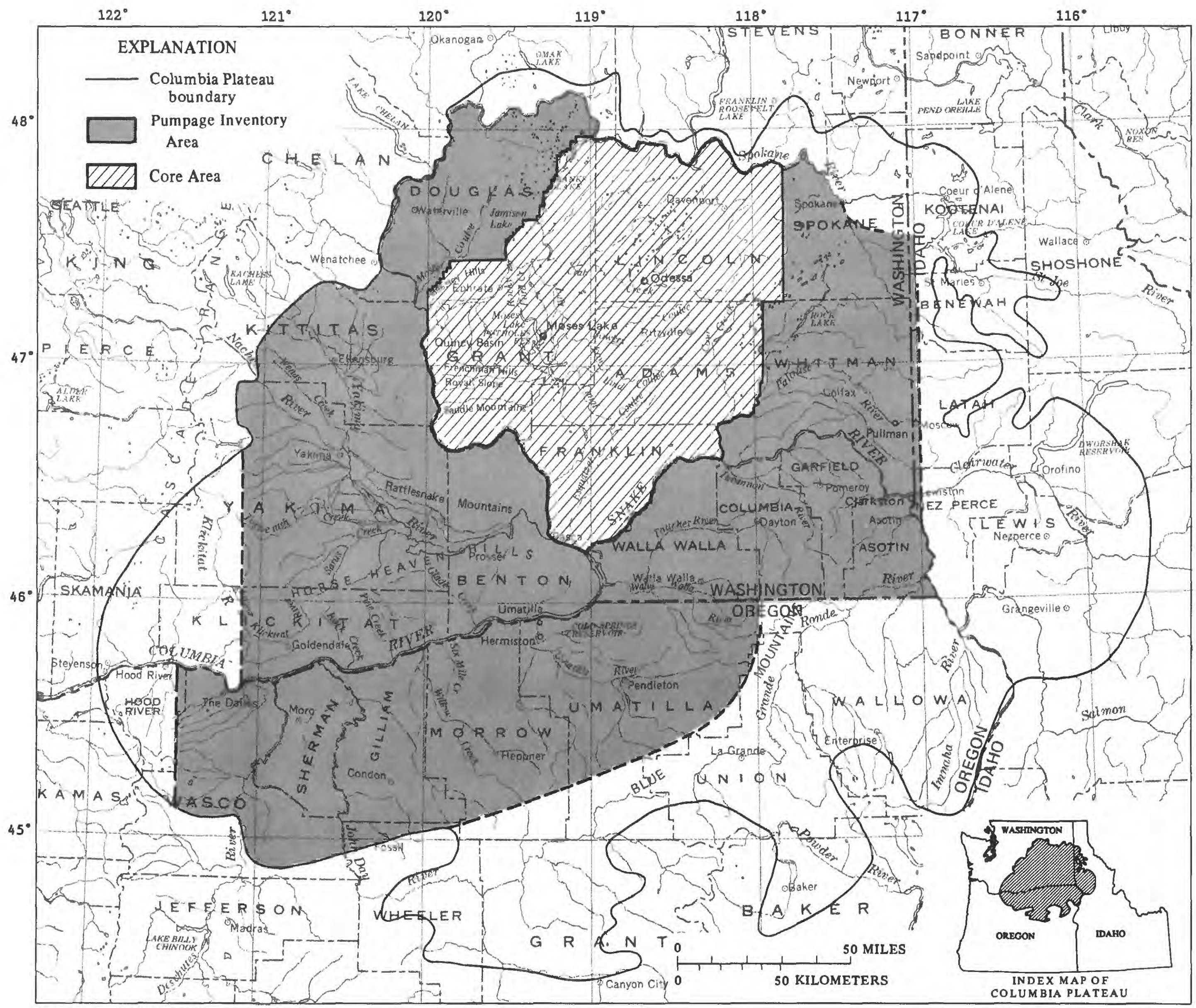
INTRODUCTION

The Columbia Plateau is a major agricultural area located in southeastern Washington, northeastern Oregon, and northwestern Idaho (fig. 1). The Columbia Plateau aquifer system underlies about 50,600 square miles of the Columbia Plateau and consists principally of the Yakima Basalt Subgroup of the Columbia River Basalt Group, all of the intercalated sediments, and water-yielding unconsolidated sediments which locally overlie the basalts. The basalt is the major source of ground water in the plateau, however, in several local areas the overlying unconsolidated sediments are the major source of ground water. The primary use of ground water is for irrigation, but ground water also is used for municipal, industrial, domestic, and stock purposes. More than twice as much acreage is irrigated with surface water as with ground water, mostly in several irrigation district areas on the plateau; surface water also is used for some municipal and industrial supplies. Use of ground water, particularly for irrigation, has resulted in local ground-water-level declines of more than 150 feet.

About 30 percent of the agricultural crops on the plateau are irrigated because much of the area is arid to semiarid (Wukelic and others, 1981). Although most irrigation is supplied by surface water, ground-water pumpage has increased dramatically since the end of World War II in 1945. An inventory of ground-water pumpage began in 1981 as a result of concerns about declining ground-water levels, increasing demand, and changes in the chemical quality of the ground water. The study area for this report is the pumpage inventory area (fig. 1), where nearly all of the pumpage withdrawn from the basalt occurs. Those parts of the plateau that are excluded either are mostly undeveloped, or the basalt is thin and discontinuous. A small quantity of pumpage in Idaho along the eastern border of Washington also is included in this report. The study area covers an area of about 25,000 square miles in Washington and about 8,000 square miles in Oregon. Pumpage data compiled for this study are being used by the Columbia Plateau Regional Aquifer-System Analysis (RASA) study started in 1982.

Purpose and Scope

The major goals of the Columbia Plateau pumpage and RASA projects were to provide information for effective management of the ground-water resources by obtaining data on the geohydrology, use, and geochemistry of the regional aquifer system. The objective of this study was to estimate historical ground-water pumpage in the Columbia Plateau in Washington and Oregon. These estimates help describe the water budget for the pumpage inventory area, and are critical to RASA projects for constructing and calibrating a regional, numerical ground-water flow model of the aquifer system.



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

FIGURE 1.--Columbia Plateau, showing pumpage inventory area, and core area.

The purpose of this report is to provide estimates of the historical rate and distribution of ground-water pumpage from the water-yielding units in the Columbia Plateau for selected years from 1945 to 1984. The 1984 ground-water pumpage data are presented in more detail for the Oregon part of the Columbia Plateau by Collins (1987), and for the Washington part by Cline and Knadle (1991).

Previous Investigations

A number of reports discuss ground-water pumpage on the plateau; representative examples of these reports are those by Hogenson (1964), Garrett (1968), MacNish and others (1973), Luzier and Burt (1974), Gonthier and Harris (1977), Prych (1983), Grady (1983), Cline (1984), Cline and Knadle (1990), Collins (1987), Smoot and Ralston (1987), and Davies-Smith and others (1988). In addition, there have been several recent studies by the U.S. Geological Survey from which pumpage data have been obtained: The Pullman-Moscow area (Lum and others, 1990), the Horse Heaven Hills area (A. J. Hansen, U.S. Geological Survey, written commun., 1985), and the Umatilla basin area (Davies-Smith and others, 1988). Another study, done in conjunction with this study, measured crop water requirements and used Landsat scenes to inventory the core area pumpage (Adams, Franklin, Grant, and Lincoln Counties in Washington (see fig. 1); Van Metre and Seevers, 1991).

Description of the Pumpage Inventory Area

The pumpage inventory area covers most of the Columbia Plateau in southeastern Washington and northeastern Oregon, and is bordered by the Cascade Range on the west, the Columbia and Spokane Rivers on the north, Idaho on the east, and the Blue Mountains on the south (fig. 1). The western part of the study area in Washington is characterized by long, east-west-trending, structurally formed ridges and valleys; most of the ground-water development is in the valleys. The rest of the area generally has a rolling topography, with much of the peripheral parts of the plateau having been cut by streams to form ridges and valleys.

The pumpage inventory area lies within the Columbia River drainage basin, which includes major tributaries such as the Snake, Yakima, Walla Walla, Umatilla, and John Day Rivers. These rivers and their associated tributaries drain the mountainous areas bordering the plateau. The mountains receive an average of 30 to 50 inches of precipitation a year, increasing to more than 100 inches per year in places along the crest of the Cascade Range (U.S. National Oceanic and Atmospheric Administration, 1985). Precipitation is greatest in winter and least in summer. In the lower central part of the plateau, precipitation ranges from 7 to 15 inches a year. The lower precipitation results in an arid environment over much of the plateau, which is characterized by sagebrush and grasslands with few perennial streams. Intermediate elevations are semiarid, with precipitation ranging from 15 to 25 inches, and where vegetation is a mixture of grasslands and forest. Forest lands predominate at higher elevations where precipitation is greatest.

The predominant economic activity on the plateau is agriculture and its associated services. In 1982, 2,270 square miles (about 1,450,000 acres) of croplands were irrigated on the plateau in Washington, and 500 square miles (320,000 acres) in Oregon; about 70 percent of the land is irrigated with surface water and 30 percent with ground water (U.S. Department of Commerce, 1982a,b). The major source of the surface water is the Columbia River, with the Yakima, Walla Walla, and Umatilla Rivers providing the next largest volumes.

Population of the plateau in 1900 was more than 200,000 people (70 percent in Washington; U.S. Department of Commerce, 1900-1980). By 1940, the population had increased to about 500,000 and by 1980 to more than 1 million people (90 percent in Washington).

Acknowledgments

The authors thank the various power companies and many individuals for their permission and assistance in obtaining data. In particular, we thank Douglas Burk and the Grant County Public Utility District, Bonnie Hickman and the Franklin County Public Utility District, Jack Kercheval and Washington Water Power Co., and the staffs of Big Bend Electric Cooperative and Lincoln Electric Cooperative. Thanks also are given to Terry Henderson, Umatilla, Oregon, for his special help with the acoustic flowmeter and pump efficiency testing. Appreciation also is extended to the ground-water staffs of the State of Washington Department of Ecology and the Oregon Water Resources Department, and the staff of the Pendleton Watermaster's Office.

GEOHYDROLOGIC SETTING

Rocks underlying the plateau are primarily the Columbia River Basalt Group of Miocene age, with relatively minor amounts of interbedded sediments and overlying sediments of Miocene to Holocene age. The Columbia River Basalt Group forms a large, complex structural basin containing smaller structural basins that commonly are filled partly with unconsolidated sediments. A fold belt with large east-west-trending anticlinal ridges and intervening broad-to-narrow synclinal valleys is located in the western part of the study area. The rest of the area is underlain by gently southwest-dipping undeformed basalts, except where they rise to form the Blue Mountains. Basalts underlie part of Idaho adjacent to Washington; however, this area has little ground-water pumpage and was excluded from the pumpage inventory except at Moscow, adjacent to Pullman, Wash., and Lewiston, adjacent to Clarkston, Wash. (fig. 1). Beneath the basalts, pre-basalt "basement" rocks form a low-permeability unit that is considered the lower boundary of the regional aquifer system.

Basalt Units

The Columbia River Basalt Group in the pumpage inventory area consists primarily of the Yakima Basalt Subgroup, which, starting with the oldest, consists of the Grande Ronde, Wanapum, and Saddle Mountains Basalts. In this report, the terms Grande Ronde, Wanapum, and Saddle Mountains units are used to define water-yielding units which include any sedimentary interbeds within or underlying the units, except for the Grande Ronde unit, which excludes the basement unit. Pre-Yakima basalts are excluded because they occur only in the southern and southeastern parts of the area where there is little development and generally they are buried deeply. Little is known about them, and probably little ground water is withdrawn from them. Geologic maps of the Grande Ronde, Wanapum, and Saddle Mountains Basalts in Washington (Swanson and others, 1979) were modified by Drost and Whiteman (1986) to show the extent of each basalt unit in Washington. Gonthier (1990) describes the basalts in Oregon, as do Whiteman and others (in press) and Drost and others (1990) for the RASA study area. The general distribution of each unit is shown on the corresponding ground-water pumpage map on the plates at the end of this report.

Along the borders of the plateau, the basalts lap onto Precambrian to lower Tertiary "basement" rocks of mostly volcanic and metamorphic origin. In the central part of the basin near Pasco, Wash., the basalt flows have an estimated composite thickness of about 15,000 feet and overlie older, deeply buried, fine-grained sedimentary rocks. None of the underlying rocks that compose the basement unit yield significant amounts of water.

Individual basalt flows range in thickness from a few inches to more than 200 feet and average about 100 feet. The extrusion and cooling of individual flows under different physical conditions resulted in the formation of permeable zones, such as columnar joints, pillow lavas, and brecciated flow tops. A flow top combined with an overlying lava flow base is called an interflow zone. Interflow zones generally consist of vesicular basalt and clinkers as well as pillow structures and weathered zones, and average about 5 to 10 percent of the total thickness of the basalt units. Most ground water is withdrawn from interflow zones. Wells tapping these zones vary in yield due to variation in thickness, permeability, and areal extent of each interflow zone, as well as the number of zones that are tapped.

The Grande Ronde unit underlies essentially all of the pumpage inventory area (pl. 1). It crops out in places around the margin and along a few deeply incised stream channels in the central part. Its thickness varies from a few feet along the margin, where it pinches out against basement rocks, to more than 10,000 feet in the central part (E. Berkman, Rockwell Hanford, written commun., 1983). The Grande Ronde unit is composed of at least 30 and perhaps as many as several hundred individual basalt flows. Sedimentary interbeds in the Grande Ronde unit are extremely rare and generally are only a few feet thick.

A sedimentary interbed between the Grande Ronde and Wanapum Basalts, where present, is as much as 100 feet thick, averages about 25 feet, and is commonly a good stratigraphic marker bed. This interbed is thin or missing in much of the central part of the area. Water obtained from this interbed is considered as part of the pumpage from the Wanapum unit.

The Wanapum unit underlies most of the study area (pl. 2), and crops out or is covered by a veneer of sediments throughout most of the northern half of the area in Washington. In the southern half of the area in Washington and the northern part of Oregon, the Wanapum unit generally is covered by the Saddle Mountains unit or by sequences of sediments that may reach several hundred feet in thickness. The Wanapum unit averages about 600 feet in thickness, varying from a few feet where it pinches out against exposures of the Grande Ronde unit to more than 1,600 feet in the southwestern part of the area in Washington. The Wanapum unit generally contains about 10 individual basalt flows. Sedimentary interbeds are more common in the Wanapum unit than in the Grande Ronde unit, but they are still relatively rare, and most are only a few feet thick.

A sedimentary interbed between the Wanapum and Saddle Mountains Basalts occurs in the western part of the area. The interbed is as much as 150 feet thick and averages about 50 feet. Water obtained from this interbed is considered as part of the pumpage from the Saddle Mountains unit.

The Saddle Mountains unit underlies the central part of the area and is much less extensive than the Wanapum unit (pl. 3). The Saddle Mountains unit has a maximum thickness of more than 800 feet and averages about 600 feet in Washington, but is much thinner in Oregon. Individual basalt flows in the Saddle Mountains unit vary greatly in texture and composition. Sedimentary interbeds are common and relatively thick, many 50 feet or more; one interbed is areally extensive and hydrologically important in the western part of the area.

Overburden Unit

Unconsolidated sediments, called overburden, comprise a major aquifer in parts of the Columbia Plateau in Washington and Oregon. The term overburden unit is used here to include water-yielding sediments overlying the Columbia River Basalt Group that are 50 feet thick or more; the unit includes Pliocene to Holocene fluvial, glaciofluvial, and volcaniclastic sediments. A windblown silt called loess, which occurs throughout much of the Columbia Plateau, is excluded because it yields little water. Most of the overburden unit occurs in basins underlying the Black Sands, Pasco, Umatilla, and Walla Walla areas, and in the Yakima River valley (fig. 1 and pl. 4). The extent of overburden in Washington is taken from a report by Drost and Whiteman (1986), who included all materials overlying the Columbia River Basalt Group and only generally followed the 50-foot thickness criterion. The areal extent of the overburden in Oregon follows the same general criteria as Washington. Thicknesses can exceed several hundred feet, especially in the Yakima valley and the Pasco area in Washington. Sands and gravels yield the most water of any sediments.

METHODS USED TO DETERMINE GROUND-WATER PUMPAGE

Ground-water pumpage data for large-capacity wells in the Columbia Plateau were estimated by several methods, discussed in detail in reports by Cline and Knadle (1991) and Collins (1987). Electrical-power-consumption data were used for estimating pumpage for wells in the core area in Washington (fig. 1), where most of the pumpage in the plateau occurs (60 percent), and also for some wells in Oregon. Because some data were confidential, particularly power records, pumpage was compiled by quarter-township blocks (9 square miles). Pumpage from power records was calculated and aggregated to quarter-township blocks by the Survey at the power company offices. The period of record for power-consumption data used to estimate pumpage for this study varied; power records were available for some wells in Oregon starting in 1969. In Washington, pumpage was computed from power records as follows:

County	Year started	Year ended	Remarks
Adams	1963	1970	Part of county
	1979	1984	(a)
Franklin	1973	1984	(a)
Grant	1965	1984	
Lincoln	1963	1970	(a)
	1979	1984	

[a] Some wells, many of them municipal, had power records starting in 1982.

Pumpage calculated from power records converts energy used to work done. Pumpage can be computed from the quantity of electricity used by a pump to do the work of lifting water out of a well and distributing it. Pumpage was calculated from power consumption data using the equation:

$$A = \frac{K \times E}{1.024 \times T} \qquad (1)$$

where A = pumpage, in acre-feet of water,
K = kilowatt-hours of electricity used during the year,
E = efficiency of the pumping system, in percent, and
T = total operating head, in feet.

Efficiency is the ratio of water pumped to electricity used. Pumping-system efficiencies were measured for nearly 300 wells, including most of the largest producers. Flow measurements were made with a recently developed acoustic velocity flowmeter that has a tested accuracy of 1 percent under ideal conditions. Test data were compared to pump performance curves where possible to cross check results. For the remaining 1,000 wells that were not tested, an average measured efficiency of 60 percent was used for wells in Grant and Lincoln Counties and 65 percent for wells in Adams and Franklin Counties.

Total operating head is equal to the depth to the pumping water level, plus discharge-line pressure, plus a small calculated friction loss between the pump intake and the point where line pressure is measured. For wells with no line pressure information, an average of 200 feet of head for line pressure was generally assumed. For wells without pumping water levels, old water levels plus drawdown data or water levels in nearby wells were used to estimate pumping water levels. For those wells in Oregon where power records were used to estimate pumpage, it was calculated by using relations developed between inline flowmeters and power consumption. Separate equations were used for wells tapping overburden, and those tapping basalt, which considered total head.

A sample of 50 wells in Washington was used to estimate the accuracy of the pumpage calculated from power records and estimated heads and pump efficiencies. The heads and efficiencies from these wells were measured later, and the pumpage compared. The accuracy of the estimated pumpages ranged from minus 34 percent to plus 86 percent, and was distributed as follows:

Number of wells	Error of estimated pumpage (percent)
16	±0 - 5.0
9	±5.1 - 10.0
6	±10.1 - 15.0
7	±15.1 - 25.0
7	±25.1 - 40.0
1	±40.1 - 50.0
4	±50.1 - 90.0

Of the four wells with errors greater than 50 percent, three had badly worn pumps and were not representative of the condition of most pumps in the study area. The fourth pump had an abnormally large operating head because water was pumped up a high hill. Excluding these four wells, the total estimated pumpage for the 46 wells was 5 percent greater than the measured pumpage. Although the pumpage estimated for an individual well may have a large error, the aggregation of pumpage by quarter-township blocks generally compensates for much of these errors, particularly because most of the wells that pumped large quantities of water had their heads and efficiencies measured. Much of the pumpage in Oregon was obtained from flowmeter data, starting in 1976 in an area southwest of Hermiston and in the entire Umatilla basin by 1980 (fig. 1). Flowmeter and power records were used to estimate about 90 percent of the 1984 Oregon pumpage. The accuracy of inline flowmeters in Oregon may be somewhat better than those in Washington because the State of Oregon inspects the flowmeters annually. Few flowmeters in Washington were found to be operational at the time of the study. Of the flowmeters that were functioning, 36 were checked for flow rate accuracy during the pump efficiency tests. The range of accuracies of the inline flowmeters in Washington is shown in the following table:

Number of wells	Flowmeter error (percent)
14	±0 - 5.0
12	±5.1 - 10.0
8	±10.1 - 15.0
1	±15.1 - 40.0
1	±40.1 - 60.0

If accuracy of flowmeters of the above sample data is representative of most flowmeters in the study area, only about 5 percent of the flowmeters had errors greater than 15 percent.

Pumpage also was estimated by multiplying irrigated acreage by a water-application rate for much of the non-core area in Washington and for the area west of the Umatilla River basin in Oregon. Irrigated acreage was estimated using Landsat images (starting in 1973) and by water-rights data. Application rates varied areally and by crop types, which were divided into low or high water-use crops. Water-application rates for various crops were measured at many sites in the core area of Washington for an allied study started in the late phases of this study by Van Metre and Seevers (U.S. Geological Survey, 1991). A comparison of the water-application rates used in Washington in the two studies is shown in the following table:

Crop category	This study (acre-feet/acre)	Van Metre and Seevers study (acre-feet/acre)
High water use (potatoes, corn, hay, alfalfa, pasture)	2.8	2.9
Low water use (wheat, barley, various vegetables)		
Northern part of area	1.1	1.1
Southern part of area	1.6	1.9

Crop water-use rates outside the core area in Washington are probably similar to those inside. Application rates in Oregon were estimated from areas of known ground-water pumpage and crop type, and are similar to those in Washington. Pumpage estimated by multiplying crop water use times irrigated acreage outside the core area and Umatilla River basin is small and scattered in comparison to the total pumpage.

Other methods used to estimate pumpage, particularly for the non-core area in Washington and for the earlier years of this study, include published reports, unpublished U.S. Geological Survey project data, and field visits. Additionally, population data; water-use and water rights data; inventory of water suppliers; and well data such as use, diameter, depth, yield, pump horsepower, and date drilled, were used to estimate pumpage. Some telephone surveys also were made to obtain water-use information.

Pumpage for each well was assigned to the water-yielding unit tapped by the well. Where a well tapped more than one basalt unit, the pumpage was divided proportionally according to the saturated thickness of each unit open (uncased) to the well.

In a few places in Washington, small volumes of pumpage were omitted because an individual well owner could be identified easily. Also, a small volume of pumpage along the Columbia River in western Grant County was excluded because it was from sand-and-gravel deposits in a bedrock canyon, and was thus assumed to be river water. Pumpage from wells that tapped sand-and-gravel deposits adjacent to the Columbia River outside of the core area was similarly excluded.

Most of the ground-water pumpage in the plateau is in the core area, and in the vicinity of Hermiston, Oreg. Estimated error in calculating the total pumpage from these areas for recent years is less than 10 percent. For the rest of the plateau, the total error is estimated to be less than 30 percent; because this pumpage is a small fraction of the total plateau pumpage, the estimated overall error for the whole plateau is less than 15 percent.

GROUND-WATER PUMPAGE

Ground-water pumpage from wells in the study area is mostly for irrigation (more than 80 percent), with lesser quantities withdrawn for municipal and industrial uses. Much of this irrigation water is distributed by center-pivot sprinkler systems, the remainder by side-roll wheel-line systems. Nearly all large-capacity pumps are electric-powered deep-well turbines. Many wells also have centrifugal booster pumps to help increase flow through the system. Pumping systems range from about 5 to 900 horsepower. Estimates of pumpage from domestic and other small-capacity wells were not made in this study. As mentioned earlier, some pumpage adjacent to the Columbia River was excluded also. The pumpage inventory area excludes parts of several counties; however, excluded areas have little pumpage except for Spokane County, Washington, which has less than 10 percent of its pumpage in the inventory data. Excluded Spokane pumpage is not from basalt or overlying overburden. A small volume of pumpage in Idaho adjacent to Washington is included in this report and amounts to less than 1 percent of the total pumpage.

The core area in Washington (Grant, Adams, Franklin, and Lincoln Counties; fig. 2) had 60 percent of the pumpage on the plateau in 1984 (75 percent of Washington's pumpage), and most of this pumpage occurred in three subareas (pl. 5). Pumpage was largest in the Odessa subarea (fig. 2), which was designated a ground-water management area by the Washington State Department of Ecology because of declining ground-water levels. The second largest pumpage was in the Black Sands subarea in central Grant County, west of Moses Lake (fig. 2). The third subarea with large volumes of ground-water pumpage is that part of the Pasco basin in southern Franklin County which encompasses townships 9, 10, and 11 north (fig. 2).

Three areas in Oregon have been designated "critical ground-water areas" by the Oregon Water Resources Department because of declining water levels in the basalt or overburden units. One of these areas is near The Dalles, and the other two are southwest of Hermiston (fig. 1). These areas also coincide with areas of large quantities of pumpage in Oregon (pl. 5). Other areas with considerable pumpage are the Walla Walla River basin in Washington and Oregon and the Yakima River valley in Washington.

Historical Ground-Water Development

Irrigation of crops using surface water began as early as the 1840's. Starting in the early 1900's, ground water was used for irrigation in a few scattered areas on the Columbia Plateau. Also, a number of the communities within the area began drilling wells for municipal supplies to supplement or replace surface-water sources. Ground-water pumpage was small during this early period, but rapidly expanded in the late 1940's after the Great Depression and World War II.

Population, industry, and especially irrigation increased greatly in the post-war years. The advent of air-rotary drilling techniques made it possible for wells to be drilled much faster in basalt. With changing technology of pump and irrigation equipment, introduction of different crops requiring irrigation, and more municipal and industrial wells being developed, ground-water use expanded greatly, both areally and in volume.

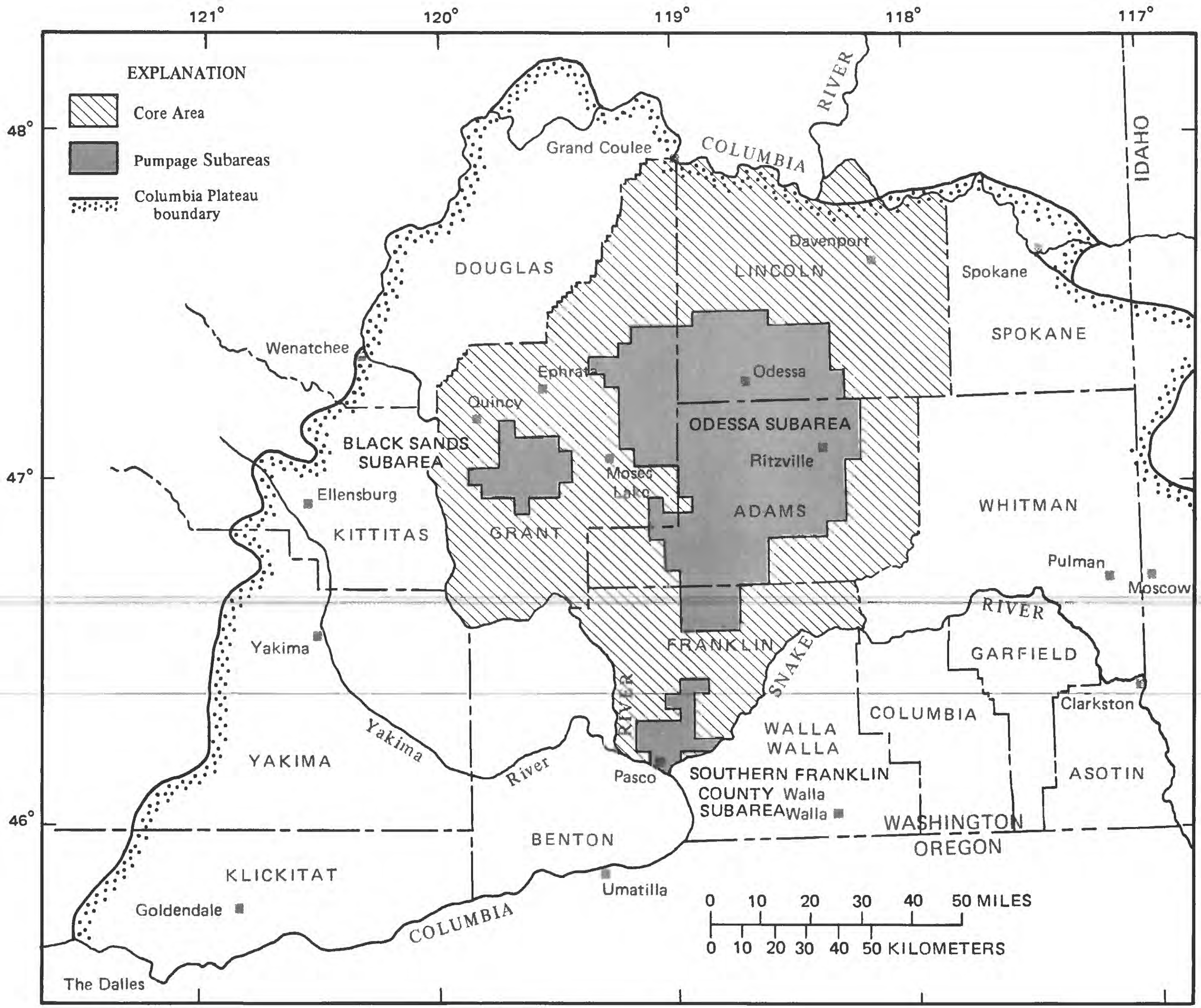


FIGURE 2.--Core area on the Columbia Plateau, showing pumpage subareas.

Changes in pump design have had a major impact on ground-water use in the study area. Centrifugal pumps in shallow dug wells were used as early as the 1920's; however, with development of the deep-well turbine pump, water could be pumped in large quantities from deep wells. This development, along with the change of irrigation practice from flood irrigation to sprinkler-irrigation systems with movable pipe, has greatly increased ground-water use. Sprinklers opened up rolling and higher land to irrigation; much of this land is outside of surface-water-supplied areas. Development of wheel-line and center-pivot irrigation systems has improved water application efficiency while reducing manpower needs. Although some ground-water irrigation has been replaced by surface water as additional irrigation projects have been constructed, ground-water use increased, especially from 1965 to 1979. Starting in the 1960's, large tracts of land were put under ground-water irrigation, and since the early 1970's, water distribution has been mainly with center-pivot systems. Rising electrical-power costs in the late 1970's and early 1980's, along with stable or declining crop prices and declining water levels in some areas, have resulted in ground-water users developing more efficient irrigation practices. Recent use of mist-head sprinklers, often in conjunction with drop pipes that apply the water at crop level, has reduced evaporation losses and soil compaction, thus improving water-application efficiency.

Early use of ground water was mainly for irrigation of hay and pasture. More recently, a greater diversity of crops are being grown with irrigation; the main crops now are potatoes, corn, alfalfa, and wheat. Wheat comprises the most acreage of any crop on the plateau, irrigated or non-irrigated.

Quantities and Distribution, 1945 to 1984

Ground-water pumpage in the inventory area in 1945 was estimated to be 56,000 acre-feet, rose to about 178,000 acre-feet in 1960, and then increased to about 940,000 acre-feet in 1979, when 83 percent of the total was in Washington and 17 percent in Oregon (pl. 5). Pumpage increased most rapidly in Washington from 1963 to 1979 and in Oregon from 1967 to 1979. Pumpage in 1977 and 1979 was probably slightly greater than it otherwise would have been because those were dry years. After 1979, ground-water pumpage stabilized, then declined somewhat, due to higher electricity costs and lower profit margins. By 1983, pumpage had declined to 813,000 acre-feet, mostly because of increased costs of electricity for pumping; also 1983 was a wet year. In 1984, pumpage increased slightly from 1983 and totaled 828,000 acre-feet, 82 percent of which was in Washington.

The distribution and volume of ground-water pumpage on the Columbia Plateau from 1955 to 1984 is shown by quarter-township blocks on plates 1 through 5. These maps, which show pumpage from a quarter-township for each water-yielding unit and also the total pumpage from all units, show the increase of pumpage areally and with time. The years selected, 1955, 1965, 1973, 1979, and 1984, were picked because they best reflect changes with time and include both the maximum and the most recent pumpage. The net change for the period can be seen by comparing the maps on plate 5 (total pumpage) to each other; the difference between the 1955 map and the 1979 map is noticeable; however, the changes from 1979 to 1984 are not as easy to see without careful comparison of the two maps. (See tables 1 and 2 also.)

Changes in pumpage from the four different water-yielding units also are greatest from 1955 to 1979, with generally small changes between 1979 and 1984 (pls. 1-4). Proportionally, the pumpage from the Grande Ronde unit increased the most of any of the units, especially in the Odessa subarea from 1960 to 1968 (table 3). The largest increases on the plateau occurred in the Odessa subarea for both the Grande Ronde and Wanapum units (pls. 1 and 2, table 3). Pumpage from the basalt units on the plateau was just over 50 percent of the total in 1945 and increased to just under 75 percent by 1965 (tables 1 and 2). Since then, this percentage has remained nearly constant. The proportion of the water withdrawn from the basalt each year in Oregon has been a consistent 70 to 80 percent of the total. A breakdown of the pumpage from the units on the plateau for the latest year, 1984, was as follows: Grande Ronde unit, 32 percent (261,000 acre-feet); Wanapum unit, 39 percent (326,000 acre-feet); Saddle Mountains unit, 3 percent (28,000 acre-feet); and overburden, 26 percent (212,000 acre-feet).

Of the water pumped from the basalt in the study area, an increasing proportion came from the Grande Ronde unit. The greatest increase was in Adams County, Washington. With the need for more irrigation water and the subsequent local declines of ground-water levels, many wells were deepened within or into the Grande Ronde unit. In Adams and Lincoln Counties, the proportion of water from the Grande Ronde unit increased considerably, and the Wanapum unit decreased correspondingly. From 1955 to 1984, the pumpage from the Grande Ronde unit in Adams County increased from 17 percent (1,200 acre-feet) of the basalt to 61 percent (81,000 acre-feet), and in Lincoln County from 37 percent (1,300 acre-feet) to 67 percent (33,500 acre-feet) (table 1 and pl. 1). Most of the change occurred between 1965 and 1975. In Umatilla County, Oregon, pumpage from the Grande Ronde unit in 1955 was 32 percent (3,800 acre-feet) of the total basalt pumpage (table 2). By 1984, the pumpage from the Grande Ronde unit was 54 percent (33,100 acre-feet) of the total basalt pumpage.

Pumpage of water from the overburden in the Columbia Plateau was 26 percent (212,000 acre-feet) of the total in 1984. This pumpage was almost entirely from only four counties in Washington (Grant, Franklin, Yakima, and Walla Walla) and two in Oregon (Umatilla and Morrow) (pl. 4). These six counties accounted for 97 percent of the total pumpage from the overburden, and two of these counties, Grant and Franklin, accounted for 65 percent of the total by themselves. The greatest volume of pumpage from any quarter-township block on the plateau, 11,200 acre-feet, came entirely from the overburden in Grant County, Washington, in 1979 (southeast quarter of T.19 N., R.25 E.) (pl. 4).

Much of the ground-water pumpage in 1950 was for municipal uses. Most of the ground water pumped for irrigation in 1950 came from the area around Moses Lake and Quincy in Grant County and in the Walla Walla River basin; the remainder was scattered widely throughout the plateau. Growth in ground-water pumpage since 1950 has been mainly for irrigation within the three subareas of the core area in Washington, and in the vicinity of Hermiston in Oregon (pl. 5). Development in Washington started with the Odessa subarea in the early 1960's. Pumpage in the Odessa subarea, small in 1960, increased rapidly in the late 1960's and again in the mid-1970's (table 3). Pumpage from this subarea accounted for 26 percent (212,500 acre-feet) of the total from the plateau in 1984. Most of the pumpage came from the Wanapum unit until 1975, when the Grande Ronde unit became the major source (table 3, pls. 1 and 2).

By 1979, which was the peak year, pumpage from the Grande Ronde unit accounted for 60 percent of the total from the subarea, and in 1984 it was 63 percent of the total.

Ground-water pumpage in the other two Washington subareas, Black Sands and southern Franklin County, essentially started about 1970. Pumpage increased rapidly in the Black Sands subarea from 1970 to 1973 and from 1975 to 1977, whereas in the southern Franklin County subarea, pumpage increased most rapidly from 1975 to 1977 (tables 4 and 5; see pl. 5 also). Most pumpage in both subareas is from the overburden (pl. 4), although the proportions have changed. Seventy-three percent of the pumpage in the Black Sands subarea was from the overburden in 1973, but this decreased to 55 percent of the total by 1979 (table 4). Since then it has stayed about the same. In southern Franklin County, pumpage from the overburden accounted for nearly all of the total (96 percent) in 1975, but decreased to 82 percent by 1984 (table 5). The greatest annual pumpage occurred in 1979 in the Black Sands subarea (113,000 acre-feet), and in 1982 in southern Franklin County (78,000 acre-feet).

In 1984, pumping from the three above subareas in Washington accounted for most of the pumpage in Washington (56 percent) and nearly half from the plateau (46 percent) (pl. 5). The total from these areas was 384,000 acre-feet.

Pumping of ground water in the Umatilla River basin in Oregon increased rapidly starting about 1950. Most of the pumping in 1950 was in the vicinity of Pendleton and Hermiston, and it expanded northeast of Pendleton and west and southwest of Hermiston (pl. 5). The greatest pumping increase was from 1967 to 1979. Total pumpage decreased from 1982 to 1984.

TABLE 4.--Ground-water pumpage in the Black Sands subarea, Grant County, Washington, 1965 to 1984, in acre-feet

Year	Basalt units: Grande Ronde	Basalt units: Wanapum	Basalt units: Saddle Mountains	Overburden unit	Total
1965	0	300	0	700	1,000
1968	0	550	0	1,360	1,910
1970	300	1,150	0	10,810	12,260
1973	0	13,940	0	37,190	51,130
1975	1,230	24,890	0	40,530	66,650
1977	1,130	37,730	0	57,470	96,330
1979	900	50,200	0	61,580	112,680
1982	970	42,170	0	55,950	99,090
1984	870	42,510	0	52,920	96,300

TABLE 5.--Ground-water pumpage in southern Franklin County subarea, Washington, 1965 to 1984, in acre-feet

Year	Basalt units: Grande Ronde	Basalt units: Wanapum	Basalt units: Saddle Mountains	Overburden unit	Total
1965	0	0	0	200	200
1968	0	0	800	1,550	2,350
1970	0	0	900	2,350	3,250
1973	0	0	1,860	12,160	14,020
1975	0	0	1,600	34,000	35,600
1977	0	1,800	2,300	64,600	68,700
1979	0	3,550	4,150	62,650	70,350
1982	600	7,000	3,000	67,300	77,900
1984	200	10,000	3,000	61,800	75,000

SUMMARY

The Columbia Plateau in eastern Washington and Oregon has become a major producer of agricultural products. In 1982, in this arid to semiarid area, 2,770 square miles of land was irrigated, and about 30 percent of this acreage was irrigated with ground water.

Ground water is pumped from basalt and from the overburden (unconsolidated sediments). The basalt is divided into three water-yielding units, the Grande Ronde, Wanapum, and Saddle Mountains units, with the first two contributing most of the water.

Most of the pumpage was estimated from electrical-power-consumption data using pump efficiencies and total head. A comparison of estimated heads and efficiencies with measurements made later (flow was measured with an acoustic flowmeter) showed that the estimated pumpage was within 20 percent of the measured quantity for 34 of 50 wells. The aggregated pumpage of 46 of 50 wells was within 5 percent of the measured quantity.

Pumpage was determined from inline flowmeters for many wells in Oregon. A check of 36 flowmeters in Washington showed that 26 read within 10 percent of the measured quantity. Nearly all ground water is pumped by electric deep-well turbine pumps, and irrigation is mostly by center-pivot sprinkler systems with the remainder by wheel-line systems. Major crops grown with ground water are wheat, potatoes, corn, and alfalfa.

Pumpage of ground water from the Columbia Plateau in eastern Washington and Oregon has increased greatly since 1945, particularly from 1963 to 1979. Total ground-water pumpage in 1945 was about 56,000 acre-feet, increasing to 940,000 acre-feet by 1979. In 1984, pumpage declined to 828,000 acre-feet due to greater power costs and lower farm profits. Most of the pumpage is in Washington (82 percent in 1984), and most of that is from three subareas: Odessa, Black Sands, and southern Franklin County. In 1960, pumpage was small in the first of these subareas and nearly nonexistent in the other two before 1970. In 1984, pumpage from these three areas amounted to almost half of the total from the Columbia Plateau (46 percent, or 384,000 acre-feet).

Pumpage from the basalt in the Columbia Plateau was just over 50 percent of the total pumpage in 1945, but increased to nearly 75 percent by 1965 and remained approximately at that level through 1984. Most of this increase was in Washington. Of the water pumped from the basalt, an increasing proportion came from the Grande Ronde unit. Most of this increase was in Adams and Lincoln Counties. In 1984, water pumped from the Grande Ronde unit was 32 percent of the total from the plateau, the Wanapum unit 39 percent, and the Saddle Mountains 3 percent.

Pumpage from the overburden amounted to 26 percent of the total from the plateau in 1984, of which 97 percent was from only six counties. Most of this pumpage, 65 percent, was from Grant and Franklin Counties in Washington.

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TABLE 1.--Ground-water pumpage by county and water-yielding unit from the Columbia Plateau, Washington, 1945 to 1984, in acre-feet (a small quantity of pumpage along the border in Idaho also is included)

[AD, Adams; AS, Asotin; BE, Benton; CO, Columbia; DO, Douglas; FR, Franklin; GA, Garfield; GR, Grant; KI, Kittitas; KL, Klickitat; LI, Lincoln; SP, Spokane; WA, Walla Walla; WH, Whitman; YA, Yakima; LA, Latah; NE, Nez Perce.]

Water-yielding unit	WASHINGTON COUNTY															IDAHO COUNTY		
	AD	AS	BE	CO	DO	FR	GA	GR	KI	KL	LI	SP	WA	WH	YA	LA	NE	TOTAL
1945																		
Grande Ronde	150	1,200	0	440	1,110	0	300	1,350	0	0	340	1,000	470	2,550	130	0	--	9,040
Wanapum	400	0	350	0	0	0	0	6,140	0	150	660	1,600	3,130	270	170	400	--	13,270
Saddle Mountains	0	0	930	0	0	0	0	0	0	0	0	0	0	0	1,040	0	--	1,970
Overburden	300	0	0	0	0	210	0	13,840	1,250	0	80	0	1,280	0	6,530	0	--	23,490
TOTAL	850	1,200	1,280	440	1,110	210	300	21,330	1,250	150	1,080	2,600	4,880	2,820	7,870	400	--	47,770
1950																		
Grande Ronde	450	1,700	0	740	1,310	0	300	3,190	0	0	680	1,650	760	3,690	180	0	--	14,650
Wanapum	1,600	0	350	0	0	300	0	14,380	0	300	960	1,850	4,610	340	570	900	--	26,160
Saddle Mountains	50	0	1,200	0	0	300	0	0	0	0	0	0	0	0	1,840	0	--	3,390
Overburden	300	0	0	0	0	550	0	20,440	1,980	0	80	0	3,120	0	12,360	0	--	38,830
TOTAL	2,400	1,700	1,550	740	1,310	1,150	300	38,010	1,980	300	1,720	3,500	8,490	4,030	14,950	900	--	83,030
1955																		
Grande Ronde	1,190	2,200	0	940	1,550	100	300	8,190	0	0	1,340	1,800	860	3,900	180	0	--	22,550
Wanapum	5,840	0	350	0	0	1,400	0	17,910	0	450	2,270	2,030	7,980	1,020	1,300	1,100	--	41,650
Saddle Mountains	50	0	1,400	0	0	400	0	0	0	0	0	0	0	0	2,160	0	--	4,010
Overburden	370	0	0	0	0	1,550	0	21,200	2,380	0	100	0	6,610	0	14,620	0	--	46,830
TOTAL	7,450	2,200	1,750	940	1,550	3,450	300	47,300	2,380	450	3,710	3,830	15,450	4,920	18,260	1,100	--	115,040
1960																		
Grande Ronde	2,120	4,400	0	940	2,000	100	450	9,670	0	0	2,920	2,020	980	4,520	1,060	400	50	31,630
Wanapum	9,730	0	350	0	0	1,800	0	17,450	0	540	4,740	2,220	9,160	1,550	3,380	900	0	51,820
Saddle Mountains	0	0	1,650	0	0	400	0	0	0	0	0	0	0	0	2,840	0	0	4,890
Overburden	170	0	0	0	0	800	0	16,680	2,680	0	100	0	11,670	0	16,110	0	0	48,210
TOTAL	12,020	4,400	2,000	940	2,000	3,100	450	43,800	2,680	540	7,760	4,240	21,810	6,070	23,390	1,300	50	136,550

TABLE 1.--Ground-water pumpage by county and water-yielding unit from the Columbia Plateau, Washington, 1945 to 1984, in acre-feet--continued

[AD, Adams; AS, Asotin; BE, Benton; CO, Columbia; DO, Douglas; FR, Franklin; GA, Garfield; GR, Grant; KI, Kittitas; KL, Klickitat; LI, Lincoln; SP, Spokane; WA, Walla Walla; WH, Whitman; YA, Yakima; LA, Latah; NE, Nez Perce.]

Water-yielding unit	WASHINGTON COUNTY															IDAHO COUNTY		
	AD	AS	BE	CO	DO	FR	GA	GR	KI	KL	LI	SP	WA	WH	YA	LA	NE	TOTAL
1963																		
Grande Ronde	3,830	4,800	0	440	2,050	100	450	8,820	0	0	3,440	2,170	980	4,870	1,750	700	50	34,450
Wanapum	11,650	0	350	0	0	2,110	0	16,900	0	770	5,360	2,220	12,380	1,670	4,980	700	0	59,090
Saddle Mountains	0	0	1,910	0	0	0	0	0	0	0	0	0	0	0	3,420	0	0	5,330
Overburden	180	0	0	0	0	700	0	17,010	2,900	0	240	0	10,270	0	17,110	0	0	48,410
TOTAL	15,660	4,800	2,260	440	2,050	2,910	450	42,730	2,900	770	9,040	4,390	23,630	6,540	27,260	1,400	50	147,280
1965																		
Grande Ronde	8,600	5,400	0	490	2,150	100	450	13,750	0	0	7,840	2,270	1,020	5,240	1,550	1,100	50	50,010
Wanapum	23,200	0	350	0	0	2,540	0	20,350	0	840	9,170	2,250	13,420	1,630	5,950	400	0	80,100
Saddle Mountains	0	0	2,080	0	0	0	0	0	0	0	0	0	0	0	3,900	0	0	5,980
Overburden	100	0	0	0	0	900	0	15,990	3,150	0	590	0	14,220	0	18,000	0	0	52,950
TOTAL	31,900	5,400	2,430	490	2,150	3,540	450	50,090	3,150	840	17,600	4,520	28,660	6,870	29,400	1,500	50	189,040
1968																		
Grande Ronde	17,280	5,500	0	440	2,350	400	500	21,450	0	0	16,790	2,920	1,170	5,700	3,600	2,000	100	80,200
Wanapum	42,010	0	400	0	0	4,080	0	32,970	0	1,240	20,060	2,490	18,210	1,580	8,350	0	0	131,390
Saddle Mountains	0	0	2,500	0	0	800	0	0	0	0	0	0	0	0	5,790	0	0	9,090
Overburden	0	0	0	0	0	2,050	0	18,840	4,300	0	380	0	14,790	0	21,830	0	0	62,190
TOTAL	59,290	5,500	2,900	440	2,350	7,330	500	73,260	4,300	1,240	37,230	5,410	34,170	7,280	39,570	2,000	100	282,870
1970																		
Grande Ronde	18,530	5,500	0	390	2,800	700	600	20,760	0	0	21,450	3,500	1,200	5,920	4,300	2,300	100	88,050
Wanapum	43,730	0	450	0	0	4,050	0	37,500	0	3,580	18,660	2,570	20,470	1,440	9,200	0	0	141,650
Saddle Mountains	0	0	2,960	0	0	900	0	0	0	0	0	0	50	0	7,250	0	0	11,160
Overburden	0	0	0	0	0	2,950	0	27,400	5,410	0	650	0	15,560	0	23,430	0	0	75,400
TOTAL	62,260	5,500	3,410	390	2,800	8,600	600	85,660	5,410	3,580	40,760	6,070	37,280	7,360	44,180	2,300	100	316,260

TABLE 1.--Ground-water pumpage by county and water-yielding unit from the Columbia Plateau, Washington, 1945 to 1984, in acre-feet--continued

[AD, Adams; AS, Asotin; BE, Benton; CO, Columbia; DO, Douglas; FR, Franklin; GA, Garfield; GR, Grant; KI, Kittitas; KL, Klickitat; LI, Lincoln; SP, Spokane; WA, Walla Walla; WH, Whitman; YA, Yakima; LA, Latah; NE, Nez Perce.]

Water-yielding unit	WASHINGTON COUNTY															IDAHO COUNTY		
	AD	AS	BE	CO	DO	FR	GA	GR	KI	KL	LI	SP	WA	WH	YA	LA	NE	TOTAL
1973																		
Grande Ronde	28,450	5,900	0	390	2,850	900	650	23,480	0	1,300	21,570	3,940	1,220	7,000	4,540	2,700	100	104,990
Wanapum	55,640	0	950	0	0	3,490	0	63,430	0	6,130	20,010	2,260	20,320	660	11,140	0	0	184,030
Saddle Mountains	0	0	3,120	0	0	1,860	0	0	0	350	0	0	120	0	7,440	0	0	12,890
Overburden	0	0	0	0	0	13,060	0	55,500	4,450	0	500	0	15,660	0	19,330	0	0	108,500
TOTAL	84,090	5,900	4,070	390	2,850	19,310	650	142,410	4,450	7,780	42,080	6,200	37,320	7,660	42,450	2,700	100	410,410
1975																		
Grande Ronde	53,040	6,300	0	440	2,410	700	700	33,520	0	1,420	32,430	4,210	1,320	6,030	4,600	2,700	100	149,920
Wanapum	55,500	0	1,290	0	0	3,500	0	73,590	0	8,620	23,940	2,120	20,320	1,070	10,880	0	0	200,830
Saddle Mountains	0	0	2,580	0	0	2,000	0	0	0	0	0	0	130	0	7,610	0	0	12,320
Overburden	0	0	0	0	0	35,000	0	58,740	4,000	0	200	0	15,660	0	23,980	0	0	137,580
TOTAL	108,540	6,300	3,870	440	2,410	41,200	700	165,850	4,000	10,040	56,570	6,330	37,430	7,100	47,070	2,700	100	500,650
1977																		
Grande Ronde	86,940	7,300	0	590	3,040	4,400	700	53,010	40	1,420	35,690	4,730	1,290	6,260	4,920	2,800	100	213,230
Wanapum	66,060	0	4,720	0	0	18,000	0	97,770	0	16,740	24,010	2,330	20,320	1,060	14,120	0	0	265,130
Saddle Mountains	0	0	4,330	0	0	3,500	0	0	0	0	0	0	130	0	10,620	0	0	18,580
Overburden	0	0	0	0	0	65,600	0	79,680	4,250	0	40	0	15,660	0	24,380	0	0	189,610
TOTAL	153,000	7,300	9,050	590	3,040	91,500	700	230,460	4,290	18,160	59,740	7,060	37,400	7,320	54,040	2,800	100	686,550
1979																		
Grande Ronde	103,860	6,900	0	590	3,180	5,410	600	60,030	40	1,420	44,680	5,410	1,200	6,910	5,020	3,000	100	248,350
Wanapum	76,430	0	8,250	0	0	20,050	0	115,270	0	29,460	30,930	2,600	20,320	930	16,620	100	0	320,960
Saddle Mountains	60	0	5,520	0	0	5,150	0	0	0	0	0	0	130	0	10,850	0	0	21,710
Overburden	0	0	0	0	0	63,650	0	86,780	4,600	0	40	0	15,660	0	20,910	0	0	191,640
TOTAL	180,350	6,900	13,770	590	3,180	94,260	600	262,080	4,640	30,880	75,650	8,010	37,310	7,840	53,400	3,100	100	782,660

TABLE 1.--Ground-water pumpage by county and water-yielding unit from the Columbia Plateau, Washington, 1945 to 1984, in acre-feet--continued

[AD, Adams; AS, Asotin; BE, Benton; CO, Columbia; DO, Douglas; FR, Franklin; GA, Garfield; GR, Grant; KI, Kittitas; KL, Klickitat; LI, Lincoln; SP, Spokane; WA, Walla Walla; WH, Whitman; YA, Yakima; LA, Latah; NE, Nez Perce.]

Water-yielding unit	WASHINGTON COUNTY															IDAHO COUNTY		
	AD	AS	BE	CO	DO	FR	GA	GR	KI	KL	LI	SP	WA	WH	YA	LA	NE	TOTAL
1982																		
Grande Ronde	94,590	5,300	0	590	2,710	4,700	550	61,650	340	2,200	42,850	7,210	1,110	6,820	5,710	2,900	100	239,330
Wanapum	65,070	0	8,330	0	0	22,950	0	108,780	0	24,440	21,720	3,010	20,320	770	22,190	100	0	297,680
Saddle Mountains	70	0	7,340	0	0	3,800	0	0	0	0	0	0	130	0	12,250	0	0	23,590
Overburden	0	0	0	0	0	68,590	0	80,240	4,800	0	0	0	15,660	0	21,640	0	0	190,930
TOTAL	159,730	5,300	15,670	590	2,710	100,040	550	250,670	5,140	26,640	64,570	10,220	37,220	7,590	61,790	3,000	100	751,530
1983																		
Grande Ronde	74,450	4,900	0	590	2,840	3,600	550	48,810	340	2,200	30,930	7,210	1,070	6,600	5,710	2,900	100	192,800
Wanapum	53,420	0	8,530	0	0	21,920	0	97,130	0	25,320	16,050	3,020	20,420	730	22,320	100	0	268,960
Saddle Mountains	100	0	7,350	0	0	3,200	0	0	0	0	0	0	130	0	12,350	0	0	23,130
Overburden	0	0	0	0	0	60,800	0	78,220	5,100	0	0	0	15,560	0	21,470	0	0	181,150
TOTAL	127,970	4,900	15,880	590	2,840	89,520	550	224,160	5,440	27,520	46,980	10,230	37,180	7,330	61,850	3,000	100	666,040
1984																		
Grande Ronde	81,050	4,400	0	590	2,840	5,810	550	50,610	340	2,200	33,470	7,200	1,070	6,550	5,710	2,900	100	205,390
Wanapum	51,700	0	8,330	0	0	22,940	0	100,360	0	25,320	16,230	3,030	20,420	730	22,320	100	0	271,480
Saddle Mountains	100	0	7,340	0	0	3,800	0	0	0	0	0	0	130	0	12,350	0	0	23,720
Overburden	0	0	0	0	0	62,950	0	74,940	5,100	0	0	0	15,560	0	21,790	0	0	180,340
TOTAL	132,850	4,400	15,670	590	2,840	95,500	550	225,910	5,440	27,520	49,700	10,230	37,180	7,280	62,170	3,000	100	680,930

TABLE 2.--Ground-water pumpage by county and water-yielding unit from the Columbia Plateau, Oregon, 1945 to 1984, in acre-feet

[Due to rounding, totals may not exactly equal the sum of the numbers.]

Water-yielding unit	COUNTY Gilliam	Morrow	Sherman	Umatilla	Wasco	TOTAL
1945						
Grande Ronde	0	320	0	70	60	450
Wanapum	0	0	0	3,410	790	4,200
Saddle Mountains	0	0	0	770	40	810
Overburden	0	0	0	2,410	50	2,460
TOTAL	0	320	0	6,660	940	7,920
1950						
Grande Ronde	0	470	130	780	60	1,440
Wanapum	0	100	0	5,560	2,660	8,320
Saddle Mountains	0	0	0	530	40	570
Overburden	0	280	0	3,530	190	4,000
TOTAL	0	850	130	10,400	2,950	14,330
1955						
Grande Ronde	10	490	130	3,810	550	4,990
Wanapum	20	100	0	7,240	4,670	12,030
Saddle Mountains	0	20	0	900	40	960
Overburden	0	1,180	0	5,320	260	6,760
TOTAL	30	1,790	130	17,270	5,520	24,740
1960						
Grande Ronde	240	2,220	320	8,370	700	11,850
Wanapum	220	1,870	120	9,000	8,170	19,380
Saddle Mountains	0	530	0	1,320	40	1,890
Overburden	0	1,560	0	6,460	260	8,280
TOTAL	460	6,180	440	25,150	9,170	41,400
1965						
Grande Ronde	240	3,020	320	10,390	990	14,960
Wanapum	270	2,060	130	10,940	8,900	22,300
Saddle Mountains	20	670	0	1,450	40	2,180
Overburden	0	2,630	0	8,700	270	11,600
TOTAL	530	8,380	450	31,480	10,200	51,040
1966						
Grande Ronde	290	3,100	260	10,580	990	15,220
Wanapum	270	2,010	130	11,930	9,000	23,340
Saddle Mountains	20	680	0	1,610	40	2,350
Overburden	0	3,720	0	8,660	270	12,650
TOTAL	580	9,510	390	32,780	10,300	53,560

TABLE 2.--Ground-water pumpage by county and water-yielding unit from the Columbia Plateau, Oregon, 1945 to 1984, in acre-feet--continued

[Due to rounding, totals may not exactly equal the sum of the numbers.]

Water-yielding unit	COUNTY					TOTAL
	Gilliam	Morrow	Sherman	Umatilla	Wasco	
1967						
Grande Ronde	550	3,380	260	12,100	990	17,280
Wanapum	270	2,500	130	12,330	9,080	24,310
Saddle Mountains	20	700	0	1,450	40	2,210
Overburden	0	3,820	0	9,170	380	13,370
TOTAL	840	10,400	390	35,050	10,490	57,170
1968						
Grande Ronde	770	5,880	260	14,760	990	22,660
Wanapum	1,090	2,910	120	13,750	9,160	27,030
Saddle Mountains	20	730	0	1,690	40	2,480
Overburden	0	3,420	0	11,890	380	15,690
TOTAL	1,880	12,940	380	42,090	10,570	67,860
1969						
Grande Ronde	1,050	10,620	260	14,810	990	27,730
Wanapum	1,080	4,040	130	13,150	9,030	27,430
Saddle Mountains	20	890	0	1,550	40	2,500
Overburden	0	5,230	0	13,130	380	18,740
TOTAL	2,150	20,780	390	42,640	10,440	76,400
1970						
Grande Ronde	1,800	12,860	330	14,880	1,530	31,400
Wanapum	1,090	6,390	210	13,890	9,220	30,800
Saddle Mountains	20	890	0	1,740	40	2,690
Overburden	0	7,670	0	14,910	400	22,980
TOTAL	2,910	27,810	540	45,420	11,190	87,870
1971						
Grande Ronde	2,230	15,510	330	15,590	1,530	35,190
Wanapum	1,090	7,330	220	13,900	9,780	32,320
Saddle Mountains	20	970	0	1,630	40	2,660
Overburden	0	12,240	0	13,540	400	26,180
TOTAL	3,340	36,050	550	44,660	11,750	96,350
1972						
Grande Ronde	2,650	15,930	330	16,050	1,540	36,500
Wanapum	1,110	7,640	220	14,230	9,570	32,770
Saddle Mountains	20	1,060	0	1,730	40	2,850
Overburden	0	13,600	0	14,700	400	28,700
TOTAL	3,780	38,230	550	46,710	11,550	100,820

TABLE 2.--Ground-water pumpage by county and water-yielding unit from the Columbia Plateau, Oregon, 1945 to 1984, in acre-feet--continued

[Due to rounding, totals may not exactly equal the sum of the numbers.]

Water-yielding unit	COUNTY Gilliam	Morrow	Sherman	Umatilla	Wasco	TOTAL
1973						
Grande Ronde	2,370	16,680	330	15,610	1,540	36,530
Wanapum	1,060	7,910	210	14,530	8,890	32,600
Saddle Mountains	20	1,090	0	1,720	40	2,870
Overburden	0	13,390	0	14,280	400	28,070
TOTAL	3,450	39,070	540	46,140	10,870	100,070
1974						
Grande Ronde	2,320	17,550	400	16,230	1,540	38,040
Wanapum	1,750	7,980	210	14,560	9,500	34,000
Saddle Mountains	20	1,240	0	1,760	40	3,060
Overburden	0	13,620	0	14,830	400	28,850
TOTAL	4,090	40,380	610	47,380	11,480	103,950
1975						
Grande Ronde	2,790	17,830	250	22,460	1,540	44,870
Wanapum	2,000	9,210	620	16,570	9,800	38,200
Saddle Mountains	20	1,560	0	1,930	40	3,550
Overburden	0	14,110	0	16,450	400	30,960
TOTAL	4,810	42,710	870	57,410	11,780	117,580
1976						
Grande Ronde	3,400	18,650	710	26,060	1,540	50,360
Wanapum	1,900	9,380	810	18,950	9,850	40,890
Saddle Mountains	20	1,650	0	1,880	40	3,590
Overburden	0	13,740	0	16,570	400	30,720
TOTAL	5,320	43,420	1,520	63,460	11,840	125,560
1977						
Grande Ronde	3,660	22,180	930	30,470	1,540	58,780
Wanapum	2,030	10,720	820	21,440	9,670	44,680
Saddle Mountains	20	1,870	0	2,100	40	4,030
Overburden	0	13,850	0	16,680	400	30,930
TOTAL	5,710	48,620	1,750	70,690	11,650	138,420
1978						
Grande Ronde	2,940	21,030	950	32,530	1,680	59,130
Wanapum	2,040	9,100	900	27,970	10,600	50,610
Saddle Mountains	20	1,440	0	2,090	50	3,600
Overburden	0	14,230	0	16,320	510	31,060
TOTAL	5,000	45,800	1,850	78,910	12,840	144,400

TABLE 2.--Ground-water pumpage by county and water-yielding unit from the Columbia Plateau, Oregon, 1945 to 1984, in acre-feet--continued

[Due to rounding, totals may not exactly equal the sum of the numbers.]

Water-yielding unit	COUNTY Gilliam	Morrow	Sherman	Umatilla	Wasco	TOTAL
1979						
Grande Ronde	3,220	19,990	1,130	36,780	1,700	62,820
Wanapum	2,750	9,970	1,040	30,870	12,380	57,010
Saddle Mountains	20	1,800	0	2,380	50	4,250
Overburden	0	14,780	0	17,730	520	33,030
TOTAL	5,990	46,540	2,170	87,760	14,650	157,110
1980						
Grande Ronde	2,970	22,520	1,120	38,000	1,710	66,320
Wanapum	4,180	8,400	1,040	29,480	13,650	56,750
Saddle Mountains	20	1,680	0	2,290	310	4,300
Overburden	0	13,820	0	17,310	550	31,680
TOTAL	7,170	46,420	2,160	87,080	16,220	159,050
1981						
Grande Ronde	4,420	22,280	1,200	33,780	1,750	63,430
Wanapum	5,080	9,730	1,040	28,890	13,480	58,220
Saddle Mountains	80	1,700	0	2,360	300	4,450
Overburden	0	15,570	0	17,890	590	34,050
TOTAL	9,580	49,280	2,240	82,920	16,120	160,140
1982						
Grande Ronde	4,560	19,970	1,200	33,050	1,710	60,490
Wanapum	5,230	8,820	1,040	29,670	13,350	58,110
Saddle Mountains	80	1,500	0	2,380	300	4,260
Overburden	0	14,510	0	17,280	590	32,380
TOTAL	9,870	44,800	2,240	82,380	15,950	155,240
1983						
Grande Ronde	4,360	15,220	1,170	32,860	2,320	55,930
Wanapum	5,040	8,380	1,030	26,330	14,200	54,980
Saddle Mountains	100	2,160	0	2,210	310	4,780
Overburden	0	14,320	0	16,670	580	31,570
TOTAL	9,500	40,080	2,200	78,070	17,410	147,260
1984						
Grande Ronde	3,690	15,330	1,300	33,130	2,350	55,800
Wanapum	4,770	9,620	910	26,210	13,480	54,990
Saddle Mountains	90	1,920	0	2,350	310	4,670
Overburden	0	14,610	0	16,690	580	31,880
TOTAL	8,550	41,480	2,210	78,380	16,720	147,340

TABLE 3.--Ground-water pumpage in the Odessa subarea, Washington, 1945 to 1984, in acre-feet

Year	County	Basalt units: Grande Ronde	Basalt units: Wanapum	Basalt units: Saddle Mountains	Over-burden unit	Total
1945	Adams	150	300	0	0	450
	Grant	50	60	0	100	210
	Lincoln	150	50	0	80	280
		350	410	0	180	940
1950	Adams	450	890	0	0	1,340
	Franklin	0	300	0	0	300
	Grant	350	1,360	0	350	2,060
	Lincoln	340	160	0	80	580
		1,140	2,710	0	430	4,280
1955	Adams	1,140	3,680	0	50	4,870
	Franklin	100	1,400	0	0	1,500
	Grant	1,940	2,510	0	1,070	5,520
	Lincoln	830	880	0	100	1,810
		4,010	8,470	0	1,220	13,700
1960	Adams	1,980	5,920	0	50	7,950
	Franklin	100	1,800	0	0	1,900
	Grant	2,150	2,590	0	1,340	6,080
	Lincoln	1,430	2,400	0	100	3,930
		5,660	12,710	0	1,490	19,860
1963	Adams	3,650	7,260	0	60	10,970
	Franklin	100	2,110	0	0	2,210
	Grant	2,500	2,440	0	1,360	6,300
	Lincoln	1,860	2,520	0	160	4,540
		8,110	14,330	0	1,580	24,020
1965	Adams	8,080	17,210	0	0	25,290
	Franklin	100	2,540	0	0	2,640
	Grant	4,420	4,090	0	1,490	10,000
	Lincoln	5,710	4,970	0	590	11,270
		18,310	28,810	0	2,080	49,200
1968	Adams	16,220	33,110	0	0	49,330
	Franklin	400	3,680	0	0	4,080
	Grant	10,610	15,900	0	2,450	28,960
	Lincoln	12,890	11,920	0	260	25,070
		40,120	64,610	0	2,710	107,440
1970	Adams	16,480	34,190	0	0	50,670
	Franklin	700	3,450	0	0	4,150
	Grant	9,030	15,420	0	2,110	26,560
	Lincoln	15,840	9,360	0	550	25,750
		42,050	62,420	0	2,660	107,130

TABLE 3.--Ground-water pumpage in the Odessa subarea, Washington, 1945 to 1984, in acre-feet--continued

Year	County	Basalt units: Grande Ronde	Basalt units: Wanapum	Basalt units: Saddle Mountains	Overburden unit	Total
1973	Adams	26,330	46,840	0	0	73,170
	Franklin	900	2,870	0	0	3,770
	Grant	10,280	19,750	0	2,400	32,430
	Lincoln	15,560	8,770	0	400	24,730
		53,070	78,230	0	2,800	134,100
1975	Adams	49,560	46,360	0	0	95,920
	Franklin	700	2,400	0	0	3,100
	Grant	17,910	18,520	0	1,150	37,580
	Lincoln	25,070	11,230	0	0	36,300
		93,240	78,510	0	1,150	172,900
1977	Adams	79,780	54,930	0	0	134,710
	Franklin	4,400	9,250	0	0	13,650
	Grant	33,410	25,520	0	1,860	60,790
	Lincoln	27,560	12,380	0	0	39,940
		145,150	102,080	0	1,860	249,090
1979	Adams	99,290	62,910	0	0	162,200
	Franklin	4,870	10,800	0	0	15,670
	Grant	35,700	23,160	0	940	59,800
	Lincoln	33,170	15,700	0	0	48,870
		173,030	112,570	0	940	286,540
1982	Adams	89,640	54,360	0	0	144,000
	Franklin	3,900	9,600	0	0	13,500
	Grant	35,200	22,140	0	360	57,700
	Lincoln	31,380	11,060	0	0	42,440
		160,120	97,160	0	360	257,640
1983	Adams	70,130	44,460	0	0	114,590
	Franklin	3,000	8,400	0	0	11,400
	Grant	26,730	17,720	0	310	44,760
	Lincoln	24,190	8,910	0	0	33,100
		124,050	79,490	0	310	203,850
1984	Adams	78,590	42,920	0	0	121,510
	Franklin	3,970	8,730	0	0	12,700
	Grant	26,350	17,970	0	370	44,690
	Lincoln	24,940	8,650	0	0	33,590
		133,850	78,270	0	370	212,490