ESTIMATED AVERAGE ANNUAL GROUND-WATER PUMPAGE IN THE PORTLAND BASIN, OREGON AND WASHINGTON 1987-88

By C.A. Collins and T.M. Broad

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[Plates are 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	4,047.	square meter (m^2)
	Volume	
acre-foot (acre-ft)	1,233.	cubic meter (m^3)
	Flow	
gallon per minute (gal/min)	0.06309	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.

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ABSTRACT

Data for ground-water pumpage by major water-use category were obtained during an inventory of selected wells in 1987-88 in the Portland Basin of Oregon and Washington. Data-collection techniques were defined and estimates of ground-water pumpage were made for the three major categories of use: public supply, industrial, and irrigation.

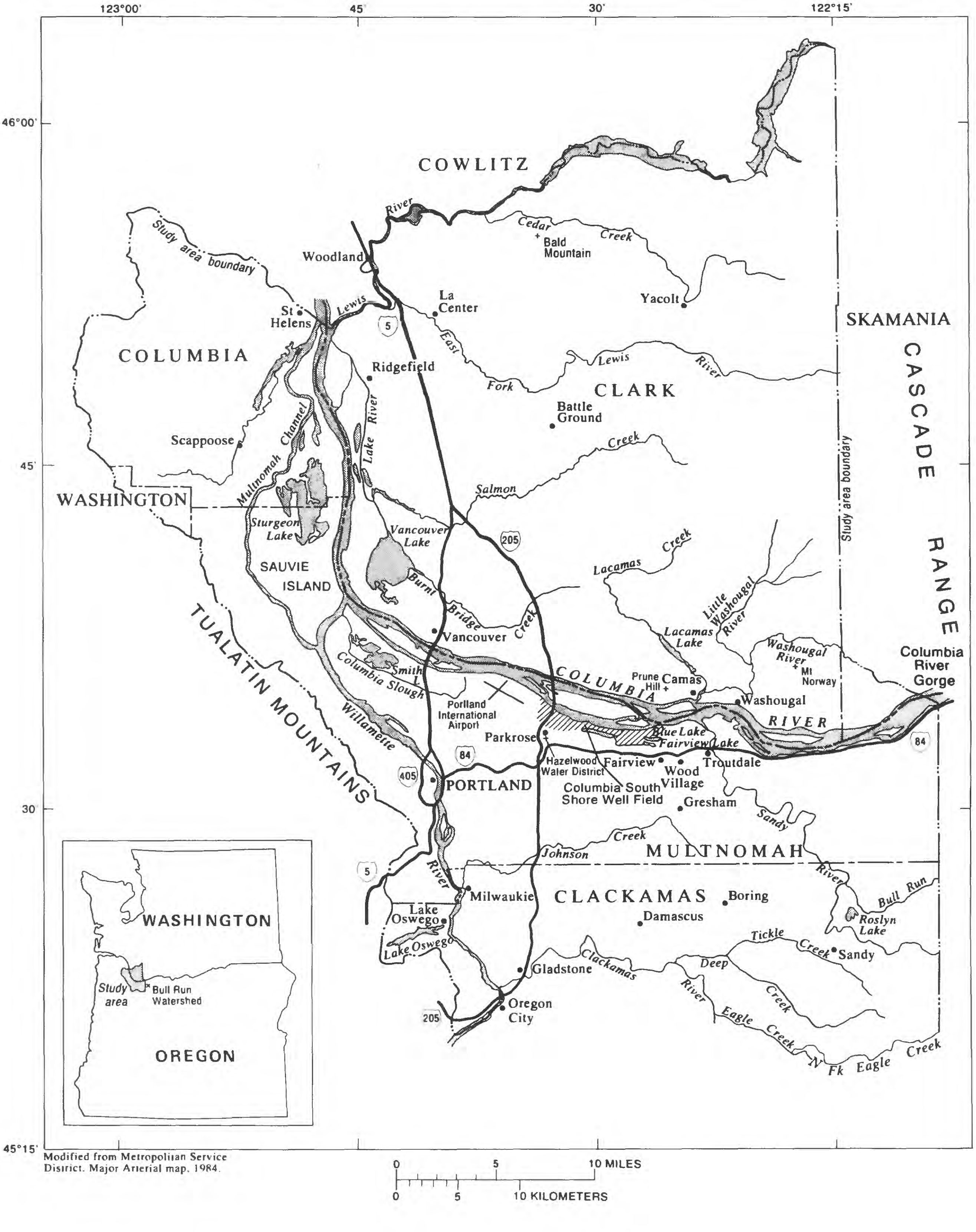
The Portland Basin is a structural basin filled with sedimentary rocks of Pliocene to Holocene age, which are the primary source of ground water. Situated within the Portland Basin is a large metropolitan area with a rapidly expanding suburban area and several large industries that use significant quantities of ground water. The estimated total average annual ground-water pumpage for 1987-88 was about 127,800 acre-feet. Of this quantity, about 50 percent was pumped for industrial use, about 40 percent for public supply, and about 10 percent for irrigation. Domestic use is a small part of the total pumpage and is not included.

INTRODUCTION

In 1987, the U.S. Geological Survey, in cooperation with the Oregon Water Resources Department, the City of Portland Bureau of Water Works, and the Intergovernmental Resource Center, began a study of the ground-water system in the Portland Basin (fig. 1). As an integral part of that study, data for ground-water pumpage were collected in 1987-88 to define the spatial distribution and amounts of withdrawal for the major water-use categories. The three major ground-water-use categories are public supply, industrial, and irrigation.

A large metropolitan area with a rapidly expanding suburban area is located within the Portland Basin. Although the City of Portland and several surrounding communities use the surface-water resources of the Bull Run Watershed east of Portland, many residents use the ground-water resources of the Portland Basin. Increasingly, ground-water sources also are being used to supplement surface-water sources during periods of low streamflow.

Industries that produce wood products and primary metals use large quantities of water in their processes, most of which is supplied from ground-water sources. Although agriculture does not provide a large percentage of the Portland basin total economy, several areas have large blocks of agricultural land that locally requires significant quantities of ground water for irrigation. Over the past several decades, a large number of nurseries that grow deciduous and coniferous shrubs and trees have developed. The nurseries are irrigated almost exclusively with ground water.



Modified from Metropolitan Service District. Major Arterial map. 1984.

Figure 1. Location of the Portland Basin study area.

Description of Study Area

The Portland Basin study area is located in northwestern Oregon and southwestern Washington. Parts of Clackamas, Columbia, Washington, and Multnomah Counties in Oregon are contained within this area. Part of Skamania County and all of Clark County in Washington are also within the study area. The study area is bounded by the eastern border of Clark County and a north-south line about 10 miles east of the Sandy River that intersects and follows Eagle Creek, a tributary to the Clackamas River. The area is bounded by the Clackamas River on the south, the Tualatin Mountains on the west, and the Lewis River on the north; the basin covers 1,310 square miles (fig. 1). The Portland Basin study area and the Portland Basin are synonymous in this report.

The Columbia River, the largest river in the study area, enters from the east and exits near the northwest corner. The Willamette River enters near the southwest corner of the area and joins the Columbia River. Other major streams in the basin are the Lewis, Washougal, and Sandy Rivers.

The central part of the basin contains a large area of flat or gently rolling lowlands. A few low hills are found on these lowlands. Foothills form the periphery of the basin. Altitudes within the study area range from less than 10 feet near the Columbia River to more than 3,000 feet near the eastern boundary of Clark County.

Two large cities, Portland and Vancouver, and several smaller towns and communities are located within the basin (fig. 1). The population of the study area is about 1,000,000 persons (State of Oregon, 1990). The combined urban area of Portland and Vancouver and the surrounding suburban areas account for a large part of the floor of the basin. That part of the basin outside the urban-suburban area is primarily rural agricultural or forest lands.

The climate in the basin is humid marine, where the period from fall through spring is generally cool and wet and summers are warm and dry. Average temperatures for the Portland area range from about 39 °F (degrees Fahrenheit) for January to about 68 °F for July. Annual precipitation averages about 37 inches per year at the Portland International Airport; almost 90 percent of this amount falls between October 1 and May 31. Total precipitation at this station for 1987 was 29.9 inches, and for 1988, 31.7 inches (U. S. National Oceanographic and Atmospheric Administration, 1990). Average annual rainfall in the Tualatin Mountains on the west side of the study area is about 45 inches per year and is about 80 inches per year near the east boundary of the study area.

Purpose and Scope

This report presents information on the quantity and distribution of ground-water pumpage from the Portland Basin for major uses during 1987-88. Data for the major ground-water uses (public supply, industrial, and irrigation) were collected during a field inventory of selected wells within the study area. Additional data were collected from other governmental agencies, various private companies, and individuals. These data, along with the techniques of estimating ground-water pumpage in areas where minimal data were available, will be described.

Previous Studies in the Portland Basin

A comprehensive study of ground-water pumpage has not been done for the entire Portland Basin; however, data for ground-water pumpage were collected in parts of the area as early as 1928 (Piper, 1942). The geology and ground-water resources of Clark County, with estimates of ground-water pumpage, were analyzed by Mundorff (1964). Estimates of ground-water pumpage were also part of a study of eastern Multnomah County (Hogenson and Foxworthy, 1965) and northern Clackamas County (Leonard and Collins, 1983). Use of ground water for heating and cooling at commercial buildings in downtown Portland was studied by Brown (1963).

Acknowledgments

Ground-water pumpage data were obtained from many municipal and private water purveyors, industrial and commercial sources, and private well owners. Several of the cooperating governmental agencies also supplied ground-water-use information. The WDOE (Washington Department of Ecology) and OWRD (Oregon Water Resources Department) provided important information on ground-water rights for their respective state. The cooperation of these individuals and groups is gratefully acknowledged.

Hydrogeology

The Portland metropolitan area is in the geologic, structural basin referred to as the Portland Basin. Older rocks of Eocene to Miocene age form the basin and crop out around the margins. Sedimentary rocks of Pliocene to Holocene age fill this structural basin and are the primary source of ground water in the basin.

Within the basin, eight hydrogeologic units (aquifers and confining units) have been mapped as part of the Portland Basin ground-water study. From youngest to oldest, these units are: unconsolidated sedimentary unit; Troutdale gravel unit; confining unit 1; Troutdale sandstone unit; confining unit 2; sand and gravel unit; and the older rocks unit. The eighth unit is an undifferentiated fine-grained unit that is equivalent to a combination of the two confining units where the Troutdale sandstone unit and the sand and gravel unit are not present. The sedimentary hydrogeologic units that occur in the central part of the basin are described in detail by Hartford and McFarland (1989).

Most ground water in the basin is obtained from the unconsolidated sedimentary unit and the Troutdale gravel unit. These units include Holocene to Pleistocene alluvium, glaciofluvial flood and terrace deposits, and gravels of the uppermost part of the Troutdale Formation.

Older sedimentary units, including the Troutdale sandstone and sand and gravel units, are areally less extensive than the younger sedimentary units and are confined by confining units 1 and 2 throughout most of the basin. These units are within the Troutdale Formation and the Sandy River Mudstone as described by Trimble (1963). Near the western side of the basin, the older sedimentary units below confining unit 1 pinch out and are represented by the undifferentiated fine-grained unit (R.D. Swanson, Intergovernmental Resource Center, written commun., 1990).

The older rocks unit includes the Columbia River Basalt Group, Skamania Volcanics, basalts of Waverly Heights (Beeson and others, 1989), Goble Volcanics, Scappoose, Pittsburg Bluff, and Rhododendron Formations. The most extensive of these are the Columbia River Basalt Group, which underlie much of the basin, and the Skamania Volcanics, which underlie much of Clark County. The older rocks units are generally less permeable than units in the basin-fill sediments, although the Columbia River Basalt Group yields adequate ground water for commercial uses in downtown Portland and irrigation and municipal use in the southeastern part of the basin.

DATA COLLECTION TECHNIQUES FOR WATER-USE SITES

Selection of Sites

Data such as location, owner, well depth, date drilled, well yield, and use for about 15,500 wells drilled within the basin was collected during the initial part of the study. Criteria were then developed to select a number of representative pumpage sites (one well or a group of wells) that were consistent with the scope of the project. Initial criteria for the selection of sites were: areal distribution, hydrogeologic significance, and use. Fifteen hundred wells were selected for further data collection; of these, about 900 wells were field located during the study, and about 600 had been located in previous or concurrent studies. Information on construction and hydraulic characteristics for these 1,500 wells is described in a report by McCarthy and Anderson (1990). Additional criteria used for site selection included water-rights information, as related to well capacity and irrigated area. Water rights for 1,100 wells in Clark County and 750 wells in the three Oregon counties were evaluated. Only wells with withdrawal rates of 50 gallons per minute or more were selected. Irrigation wells were selected if the irrigated area was 10 acres or larger.

Sites used only for domestic purposes were excluded because the total volume of ground water pumped from domestic wells in the basin is small. Although there were about 14,000 domestic wells in the basin, it is estimated that their combined ground-water pumpage is less than 3 percent of the total ground water pumped.

From the above selection process, about 700 wells were used for collection of pumpage data. Information for wells abandoned or unused provided documentation for historical pumpage estimates. Data for closely-spaced wells were aggregated to a single site. Of the 700 wells used, data were collected during 1987-88 for about 500 pumping sites.

Methods

Data for ground-water pumpage were collected for the three major water-use categories in the basin: public supply, industrial, and irrigation. Many of the preliminary data for these categories were collected at the time of initial field inventory. Typical data collected at this time included: location, water level, pump type and horsepower, electrical power meter reading, information about the water distribution system, and crop type and acreage if the site was used for irrigation. This preliminary information, coupled with flowmeter readings, sewage records, water rights, irrigation practices, and climatic data, was used to determine pumpage for about 500 wells in the data set.

Public Supply

Public-supply pumpage data were available from most of the water purveyors. Pumpage data for 150 sites were recorded using in-line totalizing flowmeters. Current, as well as historic pumpage data, were obtained for these wells, usually on a monthly basis. Public-supply data are considered to be the most complete and most accurate of all data collected for this study because the flow meters are read frequently (often daily) and are kept in good mechanical condition.

Industrial

Industrial water-use data, which includes commercial use, were collected for about 90 industrial wells in the study area. Because historical data are not available for many of these wells, estimates of pumpage were made for only 1987-88. The larger industrial water users generally use totalizing flowmeters to record their ground-water pumpage. The meters are read and maintained frequently, and are a good source of data. Other industrial users maintain their water-use records by multiplying the hours of operation by the pump capacity of the well. Another source of data for industrial use of ground water are records collected by the City of Portland Sewer Department. These records show the quantity of water that is spilled to the sewer after being withdrawn for the heating and cooling of commercial buildings. The sewer record method assumes no consumptive use of water in the process; both the hours of operation and sewer record method provide fair to good estimates of use. Smaller industrial water users are less likely to know the quantity of water used. Information from field inventory, telephone interviews, and water rights were combined to give pumpage estimates for these users. The quality of the estimates from smaller industrial users is rated poor to fair when compared with data collected from wells equipped with flowmeters.

Irrigation

Irrigation water-use data include water applied to agricultural crops in addition to livestock watering and dairy washing. These data were the most difficult to collect for the study because few existing ground-water use data are available, and few irrigators know how much water they use. Irrigation water-use was estimated for about 260 sites for 1987-88 by evaluating water-rights information and data collected during field visits. The location of wells, along with information about the types of crops grown and the irrigation practices applied, were used with orthophoto maps and water-rights information to estimate the irrigated acres in the basin. Climatic data for eight stations in the basin were then applied to the FAO (Food and Agricultural Organization) Blaney-Criddle formula to calculate the quantity of water required to grow the crop in a particular locale. A general application efficiency based on the type of irrigation system used was then added to the crop water requirement to determine water use per acre for a given crop. This quantity was then multiplied by the crop acreage to estimate water use for a given well. These estimates were compared with electrical power consumption records (obtained from field visits) to refine the estimates and were rated as fair to good where power consumption data were available. The estimates were rated poor to fair when power data were not available. These relative ratings were based on comparisons with wells equipped with flowmeters.

Estimates of water-use for nursery crops were especially difficult. Several different methods are used for growing and irrigating a variety of nursery stock in the study area. Some stock are grown in the ground, whereas other stock are grown in containers; some nurseries recycle their water, others do not. Consequently, the actual water need for a particular type of nursery stock is highly variable. Estimates of water use for nurseries were improved by collecting information on type of stock, irrigation practices, and electrical power consumption records for selected nurseries in the basin. Estimates of use by nurseries has the widest range of accuracy, and was rated from good to poor, as compared with data from wells equipped with flowmeters.

In the past, ground-water pumpage for irrigation has been calculated using electrical power consumption records and a locally adjusted factor to convert power consumed into water pumped. Due to restrictions on the release of electrical power data for individuals by the local electrical utility companies, however, power consumption was calculated only from electric meter readings collected from wells located in the field.

GROUND-WATER PUMPAGE

Ground-water pumpage was estimated for all major users within the basin. The total average annual ground-water pumpage for the 1987-88 period was about 127,800 acre-ft. Of this quantity, about 50 percent was pumped for industrial use, about 40 percent for public supply, and about 10 percent for irrigation. Water pumped for domestic use is only a small part of the total pumpage and is not included. Areal distribution of average annual total ground-water pumpage for 1987-88 is shown on plate 1.

Pumpage was aggregated according to a coordinate system that will be used in a subsequent ground-water model. The coordinate system uses rows and columns to form a grid network as shown on plate 1. Each grid cell is 3,000 feet on a side. Pumpage was aggregated for all wells within a grid cell; for instance, a grid cell may contain pumpage from one or several wells. The cells are identified by row and column numbers beginning in the upper left corner of the grid. Average annual ground-water pumpage by major water-use category (public supply, industrial, and irrigation) and hydrogeologic unit is shown in table 1. Average annual ground-water pumpage (total, public supply, industrial, and irrigation) by model row and column are shown in table 2 (at back of report).

Table 1.--Average annual pumpage by hydrogeologic unit for public supply, industrial, and irrigation, 1987-88

[US = unconsolidated sedimentary unit, TG = Troutdale gravel unit, C1 = confining unit 1, TS = Troutdale sandstone unit, C2 = confining unit 2, UF = undifferentiated fine-grained unit, SG = sand and gravel unit, OR = older rocks]

	Average annual pumpage in acre-feet							
	Hydrogeologic unit							
Use	US	TG	C1	TS	C2	UF	SG	OR
Public supply	18,600	21,000	280	2,500	90	2,400	4,800	530
Industrial	50,700	6,500	30	3,200	60	430	2,200	1,300
Irrigation	2,200	5,500	600	3,500	300	270	500	260
Total	71,500	33,000	910	9,200	450	3,100	7,500	2,090

Several areas in the basin had large withdrawals of ground water in 1987-88. The largest withdrawal, about 25,000 acre-ft, was by an industrial user located near the Columbia River. The largest withdrawals for public-supply use were by the City of Vancouver and the Clark County PUD (Public Utility District) utilizing a number of sites between the Columbia River and Salmon Creek; and the City of Portland, whose well field along the Columbia River was activated for a period during the fall of 1987. An area west of the Sandy River and north and east of Boring and Damascus contains a large nursery industry that relies heavily on ground water for irrigation.

Public Supply

For use in this report, public supply pumpage is ground water that is withdrawn by public and private water suppliers and delivered to groups of users. Included in this category are self-supplied housing developments and mobile home parks. Generally, five or more units supplied from one water system was the minimum size used in this study for a public-supply designation. Systems with fewer units were considered as domestic use and were not included in the pumpage estimates. In addition to domestic uses, public suppliers may provide water for commercial and industrial uses.

Average annual pumpage for 1987-88 was about 50,400 acre-ft for the 150 public-supply sites in the study area. Annual pumpage ranged from about 23,000 acre-ft for the City of Vancouver to about 1 acre-ft for several of the small suppliers. About 75 percent of the public-supply wells pumped more than 15 acre-ft per year. Areal distribution of average annual ground-water public-supply pumpage for 1987-88 is shown on plate 2. For distribution of public-supply pumpage by hydrogeologic unit and model row and column, see tables 1 and 2 (at back of report).

As expected, the largest systems that serve the most residents have the largest number of wells in their systems. The City of Vancouver has about 30 wells, the City of Portland about 20 wells, and the Clark County PUD about 20 active wells in their systems. Some of the medium-sized water systems may have 8 to 10 wells and some of the smaller suppliers have 1 or 2 wells.

In Clark County, nearly all drinking water is supplied from ground water. The communities of Vancouver, Washougal, Battleground, Ridgefield, LaCenter, and Yacolt use ground water as their sole source of drinking water. Several water districts, such as the Clark County PUD and Meadow Glade Water District which is southwest of Battleground, use only ground water. The City of Camas relies on surface water as a primary supply, but uses a well field for supplemental and emergency use. The remaining parts of the county are supplied by small, privately-owned systems or individual domestic wells.

On the Oregon side of the Columbia River, much of Multnomah County is served by surface water. This water comes from the City of Portland's Bull Run Reservoir system in the Cascade Range, about 40 miles east of the city. This system serves much of the metropolitan area, including Gresham. Several water districts between Portland and Gresham that historically have pumped ground water have recently (since 1985) been annexed by either city and now rely on Bull Run water. However, two districts in this area, Rockwood and Gilbert, supply a mixture of ground water and purchased surface water from the City of Portland. One district in northern Clackamas County, serves a mixture of Clackamas River water and ground water to its customers. Two communities in Columbia County, Scappoose and St. Helens, use surface water almost exclusively, but do have wells as a backup supply.

Ground water is the only water source for some Oregon communities in the study area. In eastern Multnomah County, Troutdale, Wood Village, and Fairview rely solely on ground water. In northern Clackamas County, Boring, Damascus, and Milwaukie all rely on wells. The area between Scappoose and St. Helens, in Columbia County, serves customers only from wells.

The City of Portland has developed a well field near the Columbia River east of the Portland International Airport as a backup for its Bull Run supply. Twenty-two wells in this field yield water from several of the hydrogeologic units that fill the basin. During 1987, excessive declines in the city's reservoir system forced the activation of the well field from early September to early December. Pumpage from the well field, during this period, ranged from less than 20 Mgal/d (million gallons per day), or about 61 acre-ft per day, to more than 90 Mgal/d (276 acre-ft per day).

Industrial

Industrial water use for this report is defined as ground water withdrawn by an industry for uses such as fabrication, processing, washing, and cooling, and includes such industries as aluminum, chemical and related products, and paper and related products. In addition, water used for space heating and (or) cooling is included in this category, as is water withdrawn for commercial uses such as restaurants.

Estimates of industrial use of ground water were made for about 90 wells in the four-county area for the period 1987-88. The average annual industrial pumpage was about 64,500 acre-ft. Nearly 70 percent of the ground water pumped for industrial use in the basin is pumped at four sites in Clark County (pl. 3), with the largest single user withdrawing an annual average of 25,000 acre-ft. These sites, involved in either paper processing or aluminum smelting, are all located near the Columbia River in alluvial materials. The next largest industrial use of ground water is for the heating and cooling of buildings, primarily in downtown Portland. Areal distribution of average annual ground-water pumpage for industrial use for 1987-88 is shown on plate 3. For distribution of industrial pumpage by hydrogeologic unit and model row and column, see tables 1 and 2 (at back of report).

Other large water-using industries in the basin are supplied from surface water. Most of the small industrial users purchase water from public-supply facilities.

Irrigation

For this study, irrigation water use is defined as the application of water on lands to assist in the growing of crops and pastures or to maintain vegetative growth in recreational lands, such as parks and golf courses. Water used for other agricultural purposes, such as livestock watering or dairy operations also are included in this category.

Irrigation-water-rights files indicate that nearly 500 sites have irrigation rights for about 26,000 acres of land in the basin. Some of these rights, however, are more than 40 years old and have been abandoned due to land-use changes in the area. Others are for small plots of land or low yielding wells. The 260 sites examined have water rights to withdraw at least 50 gallons per minute and to irrigate a minimum of 10 acres. Water users with water rights to irrigate less than 10 acres account for less than 8 percent of the total irrigation-water-rights acreage.

Data indicate that in the Portland Basin, the volumes of water actually withdrawn and the amount of acreage actually irrigated are less than the amount granted in a water right. Oregon ground-water rights allow about 2.5 feet of water per acre to be applied for most standard agricultural crops, but few irrigators in the study area use that much on their crops. The amount of water allotted for nurseries is an exception; some growers may use as much as 5 feet per acre for container nursery stock. Because water-rights information tends to overestimate water use, locally collected data were used in conjunction with water rights to estimate water use. Field data were available for most irrigation sites and included pump type and horsepower, information on the irrigation system, and electric meter readings, and for some sites, information on crop type and acreage. Data collected on field outlines and crop type were also utilized, as were aerial photographs taken during a reconnaissance flight over the basin, in June, 1987.

Estimates of ground-water use for irrigation were made for about 260 wells in the basin for 1987-88. Average annual pumpage for 1987-88 was estimated to be about 13,000 acre-ft. This water was applied to about 10,000 acres of land in the basin. The largest single user of ground water for irrigation is a nursery that used slightly more than 1,000 acre-ft per year. Approximately 40 percent of the irrigation sites used 30 or more acre-ft per year. Areal distribution of average annual ground-water pumpage for irrigation for 1987-88 is shown on plate 4. For distribution of irrigation pumpage by hydrogeologic unit and model row and column, see table 1 and 2 (at back of report).

The largest use of ground water for irrigation in the basin is the nursery industry. Most of the nurseries are located in eastern Multnomah and northern Clackamas Counties, west of the Sandy River. Several of the larger nurseries occupy between 500 and 1,000 acres, and nearly all nurseries irrigate with ground water. Many plants are grown in the ground, but a fairly large percentage are grown in containers. Several types of irrigation systems are used by the nurseries. These range from drip systems to the more conventional impact head sprinkler systems.

The second largest use of ground water for irrigation is for golf courses and cemeteries. Although the basin has a moist climate, about 2 feet of water per acre is used from late spring through fall to maintain these facilities.

Basic agricultural crops grown in the basin are hay and pasture, alfalfa, berries, corn, and vegetable row crops. Ground water is applied to these crops using a variety of irrigation equipment that includes drip, as well as hand moved and solid set sprinkler lines, and big gun and side roll sprinklers.

The remaining part of ground-water pumpage included in the irrigation water-use category is for dairy operations and livestock rearing. Much of the dairy operation water goes to holding ponds where, after settling, it is used to irrigate fields for forage.

ESTIMATION OF HISTORIC PUMPAGE

Long-term records of ground-water pumpage are not available for the Portland Basin. Several of the earlier ground-water reports show estimates of pumpage for parts of the basin.

In the Multnomah and Clackamas County area Hogenson and Foxworthy (1965) and Brown (1963), estimated that users in the three major water-use categories annually pumped about 49,000 acre-ft of ground water during 1958 and 1960. Average annual estimates of ground-water pumpage for the two county area for 1987-88 is about 38,000 acre-ft. Ground-water withdrawals for public supply increased from the earlier estimates, while ground-water used for irrigation declined for the period from 1958-60 to 1987-88. The decline in irrigation pumpage is attributed to a rapid expansion in suburban housing and commercial development; land that was previously irrigated is now used for other purposes. In addition, several of the larger industrial water users are no longer in operation.

A similar situation exists in Clark County. Total ground-water pumpage was estimated by Mundorff (1964) to be about 106,000 acre-ft for 1950. The average annual ground-water pumpage for Clark County for 1987-88 was estimated to be about 89,000 acre-ft. Public-supplied ground water showed a three-fold increase, while industrial pumpage declined by about 35 percent.

Comparable pumpage data were not available for Columbia County. However, an increase in population and an increase in irrigated agriculture indicate that the ground-water use in this area has increased over the past several decades.

DATA ANALYSIS--ESTIMATION OF ERROR

Information from public-water suppliers is considered the most complete and accurate water-use data available in the study area. Nearly all data were recorded from totalizing flowmeters. Although these devices have some error, it is considered small. Information from sites equipped with flowmeters is the most accurate available and is the standard against which other data are compared.

The accuracy of flowmeter data was verified by Collins (1987) where the volume of water pumped for irrigation, as determined by flowmeter data, was related to electrical power consumed. Collins (1987) checked selected flowmeters against an acoustic velocity meter and generally found the flowmeters to be accurate even though many were not serviced regularly. Meters generally checked within ±5 percent of an acoustic meter, which has an accuracy of about ±1 percent.

During 1987-88, most of the flowmeters checked were installed on public-supply wells and were in good mechanical condition. For the few systems that were not equipped with flowmeters, annual pumpage was estimated by multiplying the number of served living units, such as homes and mobile homes, by a factor of 110,000 gallons per year per living unit. The estimate of 110,000 gallons per year per service was derived in the following manner. A U.S. Geological Survey/Oregon Water Resources Department survey of Oregon public-water suppliers in 1984 estimated that domestic per capita use for portions of the Portland Basin was 117 gallons per day. Census information for the Portland area indicates that the average number of persons per household is 2.6. Multiplying the domestic per capita use value by the average number of persons per household value gives a daily water use per household. This daily value, multiplied by 365, gives an annual water use of approximately 110,000 gallons per household.

Ground-water data collected from industrial and commercial sources vary in accuracy based on measurement method. Large industrial users record their pumpage with totalizing flowmeters or by system operation timers. Several large users check their systems' capacity regularly to monitor volume pumped. The volume of water pumped by heating and cooling wells in downtown Portland is metered at the discharge point and is estimated to be accurate within 5 to 10 percent as compared with data from wells equipped with flowmeters. The volume for smaller industrial users was estimated generally by pump capacity and operating hours. While the accuracy of these estimates may vary, the total volume pumped by these industrial users is small in relation to the total ground water withdrawn.

The estimates of ground-water pumped for irrigation are the least accurate, and are based on water-application rates for the major crop types. Few data exist to document water needs of agricultural crops in the area, so the FAO modified Blaney-Criddle formula was used. This formula estimates crop water requirements based on air temperature, precipitation, and hours of daylight during the active growing season of the crop. These estimates appear to be slightly high in this area, when compared with information gathered from local water users and from the agriculture extension service (Dr. Richard Cuenca, Oregon State University, Department of Agricultural Engineering, written commun., 1989). These differences may be due to local relative humidity. To correct for this over-estimation, the crop-water requirements were reduced slightly. Determining whether a water right was active or inactive was difficult for some locations. A water right was assumed to be inactive unless definite confirmation could be obtained from field observations, county extension agents, or personal contacts. Error in the estimates for this category may be ± 50 percent as compared to estimates of pumpage from wells equipped with flowmeters.

SUMMARY

Data for ground-water pumpage were collected and compiled for three major water-use categories in the Portland Basin in 1987-88. The three major uses are public supply, industrial, and irrigation. The data are distributed or delineated areally by use and collectively by hydrogeologic unit and use.

Few ground-water pumpage data were available prior to this study, so techniques were developed to estimate pumpage for the three major water-use categories. The total average annual pumpage for 1987-88 for all uses in the basin was about 127,800 acre-ft. About 50 percent of this pumpage was for industrial use, about 40 percent was for public-supply, and about 10 percent was for irrigation use.

The accuracy of ground-water pumpage data collected from public suppliers is considered to be ± 5 percent. Generally, data were recorded by totalizing flowmeters which are kept in good mechanical condition and read regularly. Ground water pumped for public supply was about 50,400 acre-ft per year for 1987-88. Due to the large volume of ground water pumped and lower precision of reporting, data supplied by large industrial users were less accurate than public supply data. Smaller industrial ground-water users rarely kept water-use records. Their use was estimated by pump or system capacity plus hours of operation, and is only a small percentage of the total ground-water withdrawals for the basin. Industrial ground-water pumpage averaged about 64,500 acre-ft for 1987-88. Irrigation ground-water pumpage data were the least accurate and were estimated from crop acreage and a water-application rate adjusted for the local major crop groups and climatic conditions. Ground-water pumpage for irrigation averaged about 13,000 acre-ft for 1987-88. Although irrigation pumpage accounts for only about 10 percent of the total ground water withdrawn, it is a large percentage of the ground-water withdrawn in the southeastern basin area near Boring and Damascus.

An area near the Columbia in Clark County has the largest ground-water pumpage in the basin. The most heavily pumped area for public supply is north and east of Vancouver, and the most heavily pumped area for irrigation is southeast of Gresham.

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SUPPLEMENTAL DATA

Table 2.--Average annual ground-water pumpage by model row and column for total, public supply, industrial, and irrigation, 1987-88

[Totals may not agree because of rounding. Model row and column refers to cell position on plates 1-4]

Model		Average annual ground-water pumpage in acre-feet			
Row	Column	Total	Public supply	Industrial	Irrigation
7	13	160	160	0	0
8	12	39	39	0	0
8	14	11	11	0	0
9	12	84	84	0	0
10	12	56	56	0	0
10	15	17	17	0	0
10	36	20	0	0	20
11	27	4	0	0	4
12	31	99	99	0	0
14	22	24	24	0	0
15	22	250	250	0	0
17	8	37	0	26	11
18	7	6	6	0	0
18	23	3	0	0	3
18	33	21	0	0	21
19	27	76	0	0	76
20	19	35	0	0	35
20	23	11	0	0	11
20	24	16	0	0	16
20	27	4	3	0	1
22	20	2	0	0	2
22	29	31	0	0	31
23	24	1	0	1	0
23	29	3	0	0	3
23	36	9	9	0	0
24	18	9	0	0	9
24	19	5	0	0	5
24	21	6	0	0	6
24	24	12	0	0	12
24	38	140	140	0	0
25	19	20	0	0	20
25	27	37	0	0	37
25	39	27	0	0	27
26	6	430	0	0	430
26	21	190	190	0	0
27	15	250	0	0	250
27	20	15	0	0	15
27	24	13	0	0	13
27	30	62	0	0	62
27	31	16	0	0	16
27	35	510	340	0	170
28	20	47	0	0	47

Table 2.--Average annual ground-water pumpage by model row and column for total, public supply, industrial, and irrigation, 1987-88--Continued

Model		Average annual ground-water pumpage in acre-feet			
Row	Column	Total	Public supply	Industrial	Irrigation
28	30	300	300	0	0
28	34	87	87	0	0
28	42	3	0	0	3
29	6	210	0	0	210
29	18	20	0	0	20
29	21	560	560	0	0
29	25	2	0	0	2
29	31	5	0	0	5
29	32	12	12	0	0
30	14	6	0	0	6
30	22	450	450	0	0
30	33	87	0	0	87
31	10	370	0	0	370
31	18	160	160	0	0
31	19	26	0	26	0
31	23	1,200	1,200	0	0
31	26	19	0	0	19
31	29	13	0	0	13
31	30	16	0	0	16
32	19	3	0	0	3
32	21	230	230	0	0
32	24	170	170	0	0
32	29	3	0	3	0
32	32	34	34	0	0
33	6	61	0	61	0
33	13	5,300	0	5,300	0
33	17	62	0	0	62
33	21	20	20	0	0
33	24	530	530	0	0
33	28	17	0	0	17
33	30	16	0	0	16
33	32	5	0	0	5
33	33	23	0	0	23
33	37	19	0	0	19
33	39	13	0	0	13
34	8	270	0	270	0
34	16	120	0	0	120
34	20	1,200	1,200	0	0
34	21	550	530	0	18
34	30	110	0	0	110
34	33	3	0	0	3
34	34	21	0	0	21
35	15	3	0	0	3
35	23	88	0	88	0
35	27	4	0	0	4

Table 2.--Average annual ground-water pumpage by model row and column for total, public supply, industrial, and irrigation, 1987-88--Continued

Model		Average annual ground-water pumpage in acre-feet			
Row	Column	Total	Public supply	Industrial	Irrigation
35	31	420	410	0	8
35	38	1	0	0	1
36	18	1,500	1,500	0	0
36	23	5	0	0	5
36	24	1,300	1,300	0	0
36	25	39	0	0	39
36	27	2	0	0	2
36	31	1	0	0	1
36	32	2	0	0	2
37	15	13,300	0	13,300	0
37	18	12	0	0	12
37	21	1	0	0	1
37	29	3	0	0	3
37	38	13	13	0	0
38	13	5	0	5	0
38	15	3,300	0	3,300	0
38	16	3,900	0	3,900	0
38	18	89	0	0	89
38	19	5,500	5,500	0	0
38	20	3	0	0	3
38	27	9	0	0	9
38	28	21	21	0	0
38	35	4	0	0	4
39	11	1,600	0	1,600	0
39	13	2,000	0	2,000	0
39	15	1,700	1,700	0	0
39	17	54	0	0	54
39	20	1	0	0	1
39	25	21	0	0	21
39	27	2,100	2,100	3	25
39	30	2	0	0	2
39	32	33	0	0	33
39	33	43	0	0	43
40	11	810	0	810	0
40	12	970	0	750	220
40	18	6	0	0	6
40	23	960	930	0	38
40	24	200	0	0	200
40	27	470	0	470	4
40	28	49	0	0	49
40	34	38	0	0	38
41	7	3	0	3	0
41	8	480	0	480	0
41	12	160	0	160	0
41	14	120	0	0	120

Table 2.--Average annual ground-water pumpage by model row and column for total, public supply, industrial, and irrigation, 1987-88--Continued

Model		Average annual ground-water pumpage in acre-feet			
Row	Column	Total	Public supply	Industrial	Irrigation
41	19	6,000	6,000	0	0
41	21	110	0	0	110
41	26	6	6	0	0
41	30	47	0	0	47
41	35	9	0	0	9
42	9	84	0	0	84
42	13	140	0	140	0
42	15	43	35	8	0
42	16	150	0	0	150
42	24	1	0	0	1
42	25	1,000	1,000	0	0
42	27	18	18	0	0
42	29	5,100	5,100	0	0
42	33	12	0	0	12
43	14	10	0	0	10
43	16	99	0	0	99
43	25	62	0	0	62
43	26	1	0	0	1
43	27	7	0	0	7
43	28	14	0	0	14
44	14	47	0	47	0
44	16	42	0	0	42
44	26	17	0	0	17
44	30	16	0	0	16
45	17	11	0	0	11
45	26	14	0	0	14
45	30	180	0	180	0
46	9	14	0	14	0
46	27	12	0	0	12
46	29	25	25	0	0
46	30	22	0	22	0
46	37	8	0	0	8
47	24	230	0	230	0
47	28	3	3	0	0
47	30	670	17	660	0
47	31	18	0	0	18
48	11	81	0	81	0
48	20	9	0	9	0
48	26	20	0	0	20
49	9	83	0	83	0
49	10	430	0	430	0
49	11	220	0	220	0
49	28	33	33	0	0
50	9	560	0	560	0
50	12	140	0	140	0

Table 2.--Average annual ground-water pumpage by model row and column for total, public supply, industrial, and irrigation, 1987-88--Continued

Model		Average annual ground-water pumpage in acre-feet			
Row	Column	Total	Public supply	Industrial	Irrigation
50	22	73	15	58	0
50	23	41	41	0	0
51	10	58	0	58	0
51	11	64	0	64	0
51	12	5	0	5	0
51	15	10	0	0	10
51	17	31	0	0	31
51	18	280	0	0	280
51	24	570	570	0	0
51	34	1	1	0	0
52	13	100	0	100	0
52	24	270	270	0	0
52	25	930	930	0	0
53	12	47	0	0	47
53	22	41	0	0	41
53	24	460	460	0	0
53	25	570	570	0	0
53	26	1,100	1,100	0	0
53	27	100	100	0	0
53	38	3	0	0	3
54	20	270	270	0	0
54	22	140	140	0	0
54	23	82	82	0	0
54	27	330	330	0	0
54	28	240	240	0	0
54	34	25,200	0	25,200	0
54	35	250	250	0	0
54	41	2	0	0	2
55	19	8	0	0	8
55	21	160	18	0	140
55	22	340	0	0	340
55	26	340	280	0	55
55	28	780	780	0	0
55	29	1,300	1,300	0	30
55	30	1,100	1,100	0	0
55	35	80	80	0	0
55	36	1,700	1,700	0	0
55	37	3	0	0	3
56	18	68	0	68	0
56	20	32	0	0	32
56	26	2	0	0	2
56	27	67	24	20	23
56	28	19	19	0	0
56	29	130	15	0	110

Table 2.--Average annual ground-water pumpage by model row and column for total, public supply, industrial, and irrigation, 1987-88--Continued

Model		Average annual ground-water pumpage in acre-feet			
Row	Column	Total	Public supply	Industrial	Irrigation
56	30	15	15	0	0
56	38	410	410	0	0
57	12	1	0	1	0
57	23	4	0	0	4
57	27	14	0	0	14
57	29	300	300	0	0
57	30	110	0	10	98
57	32	1,500	0	1,500	0
57	33	1,100	0	1,100	0
57	39	49	0	0	49
58	11	210	0	210	0
58	23	41	41	0	0
58	29	5	0	0	5
58	30	130	130	0	0
58	38	4	0	4	0
59	9	300	300	0	0
59	10	1,400	1,400	0	0
59	12	5	5	0	0
59	20	460	460	0	0
59	25	130	0	130	0
59	27	24	24	0	0
59	28	5	0	5	0
59	30	100	100	0	0
59	32	240	240	0	0
60	9	450	450	0	0
60	14	12	12	0	0
60	22	7	0	0	7
60	25	6	0	6	0
60	30	350	350	0	0
60	31	160	150	0	3
60	32	16	0	0	16
61	10	770	290	480	0
61	12	4	0	4	0
61	15	210	0	0	210
61	16	200	0	0	200
61	25	26	0	0	26
61	27	19	0	19	0
61	29	150	0	0	150
61	30	67	0	0	67
62	10	630	630	0	0
62	11	85	0	0	85
62	26	25	0	3	22
62	32	350	350	0	0
63	10	11	0	0	11
63	13	75	0	0	75

Table 2.--Average annual ground-water pumpage by model row and column for total, public supply, industrial, and irrigation, 1987-88--Continued

Model		Average annual ground-water pumpage in acre-feet			
Row	Column	Total	Public supply	Industrial	Irrigation
63	14	40	0	0	40
63	19	16	16	0	0
63	22	87	0	0	87
63	31	32	0	0	32
64	6	4	4	0	0
64	22	34	0	0	34
64	29	16	0	0	16
64	30	6	0	6	0
65	7	24	0	24	0
65	14	78	78	0	0
65	27	36	0	0	36
65	33	30	0	0	30
66	10	70	70	0	0
66	15	89	0	0	89
66	19	220	0	0	220
66	22	4	4	0	0
66	26	270	0	0	270
66	29	23	0	0	23
66	30	110	0	0	110
66	31	21	0	0	21
66	32	28	0	0	28
67	8	15	0	0	15
67	12	21	0	0	21
67	18	230	200	0	24
67	21	46	46	0	0
67	25	15	15	0	0
67	29	80	0	0	80
67	30	140	0	0	140
67	33	48	0	0	48
68	14	6	0	6	0
68	15	46	46	0	0
68	17	52	0	0	52
68	18	41	0	0	41
68	22	38	38	0	0
68	23	12	12	0	0
68	24	330	0	0	330
68	25	47	0	0	47
68	28	160	0	0	160
68	31	3	0	0	3
68	32	25	0	0	25
68	33	87	0	0	87
68	35	110	0	0	110
69	16	28	28	0	0
69	17	17	0	0	17
69	19	68	0	0	68

Table 2.--Average annual ground-water pumpage by model row and column for total, public supply, industrial, and irrigation, 1987-88--Continued

Model		Average annual ground-water pumpage in acre-feet			
Row	Column	Total	Public supply	Industrial	Irrigation
69	27	36	36	0	0
69	28	22	0	0	22
69	32	2	0	0	2
69	33	7	0	7	0
69	35	230	0	0	230
70	16	13	13	0	0
70	22	72	72	0	0
70	25	46	0	0	46
70	28	66	4	0	62
70	29	110	0	0	110
70	30	13	0	0	13
70	31	200	0	0	200
70	33	210	0	0	210
71	21	400	400	0	0
71	22	120	0	0	120
71	23	14	0	0	14
71	26	110	0	0	110
71	28	140	0	0	140
71	32	57	0	0	57
71	33	190	0	0	190
71	34	200	0	0	200
72	26	200	200	0	0
72	28	14	0	0	14
72	32	53	0	0	53
72	33	160	0	0	160
72	34	290	0	0	290
73	25	47	0	0	47
73	27	480	0	0	480
73	28	170	0	0	170
73	34	34	34	0	0
74	28	160	0	0	160
74	31	540	0	0	540
74	35	190	0	0	190
75	31	32	0	0	32
75	32	25	25	0	0
75	34	36	0	0	36
76	33	72	0	0	72
76	34	36	0	0	36
77	33	120	0	0	120
78	28	40	0	0	40
78	33	11	0	0	11
79	27	47	47	0	0
TOTAL		127,800	50,400	64,500	13,000

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