

## Introduction

### Background and Study Objectives

The Willamette Basin ([fig. 1](#)) is home to about two-thirds of the residents of Oregon and has one of the fastest growing populations in the State. Census figures indicate 2.4 million people lived in the Willamette Basin, an increase of 0.4 million, or 20 percent, since 1990 (U.S. Census Bureau, 2003). The Willamette Basin is also a major agricultural area, accounting for over 50 percent of Oregon's crop sales (Oregon Agricultural Statistics Service, 2001). Rapid population growth and the need for irrigation have increased the demand for water within the basin. The principal sources of water available to meet these demands are streams, reservoirs, and ground water.

The Oregon Water Resources Department (OWRD) allocates surface and ground water with a permit system based on the doctrine of prior appropriation. Because of competing demands for municipal, industrial, irrigation, and instream (pollution abatement and fish habitat) uses, many streams in the basin are administratively closed to additional appropriation in the summer, when demand is high and streamflow is low. Ground water is the only readily available resource to satisfy new demands in many areas. Various factors limit the capacity of the ground-water system to meet these demands including (1) potential depletion of streamflow by ground-water withdrawals, (2) large seasonal and long-term declines in ground-water levels, (3) low-permeability aquifers that are suitable for low-demand uses only, and (4) natural water-quality problems that affect human health.

Prior to this study, the information and tools to quantify these limiting factors were inadequate. To address this deficiency, the U.S. Geological Survey (USGS) and the OWRD began a cooperative study in 1996. The main objectives of this study were to assess the regional ground-water system and to develop quantitative tools that can be used to support water-resources management decisions. This report is one in a series that presents the results of the study.

Previous publications from the study have documented the distribution of arsenic in ground water (Hinkle and Polette, 1999), compiled water levels, ground-water chemistry, and geophysical logs (Orzol and others, 2000), described the origin, extent and thickness of permeable sediments in the flood-

plain of the major tributaries of the basin (O'Connor and others 2001), estimated ground-water recharge and the exchange of water between aquifers and streams (Lee and Risley, 2002), and estimated ground-water discharge to streams using heat as a tracer (Conlon and others, 2003).

Piper (1942) completed the earliest comprehensive study of hydrogeology in the Willamette Basin, and laid the foundation for subsequent investigations, which include qualitative water-supply assessments by Brown (1963), Hogenson and Foxworthy (1965), Hart and Newcomb (1965), Price (1967a, 1967b), Foxworthy (1970), Hampton (1972), Frank (1973, 1974, 1976), Frank and Collins (1978), Gonthier (1983), and Leonard and Collins (1983). Much of this earlier work was synthesized by McFarland (1983) into a larger framework that defined and described the regional aquifer units of western Oregon.

In the late 1980s, an investigation was conducted by the U.S. Geological Survey to quantify ground-water resources of the Portland Basin. Results were published in reports that describe the geologic framework (Swanson and others, 1993), ground-water pumpage (Collins and Broad, 1993), ground-water recharge (Snyder and others, 1994), and ground-water flow system (McFarland and Morgan, 1996) in the basin. In addition, a numerical model was constructed to simulate ground-water flow (Morgan and McFarland, 1996).

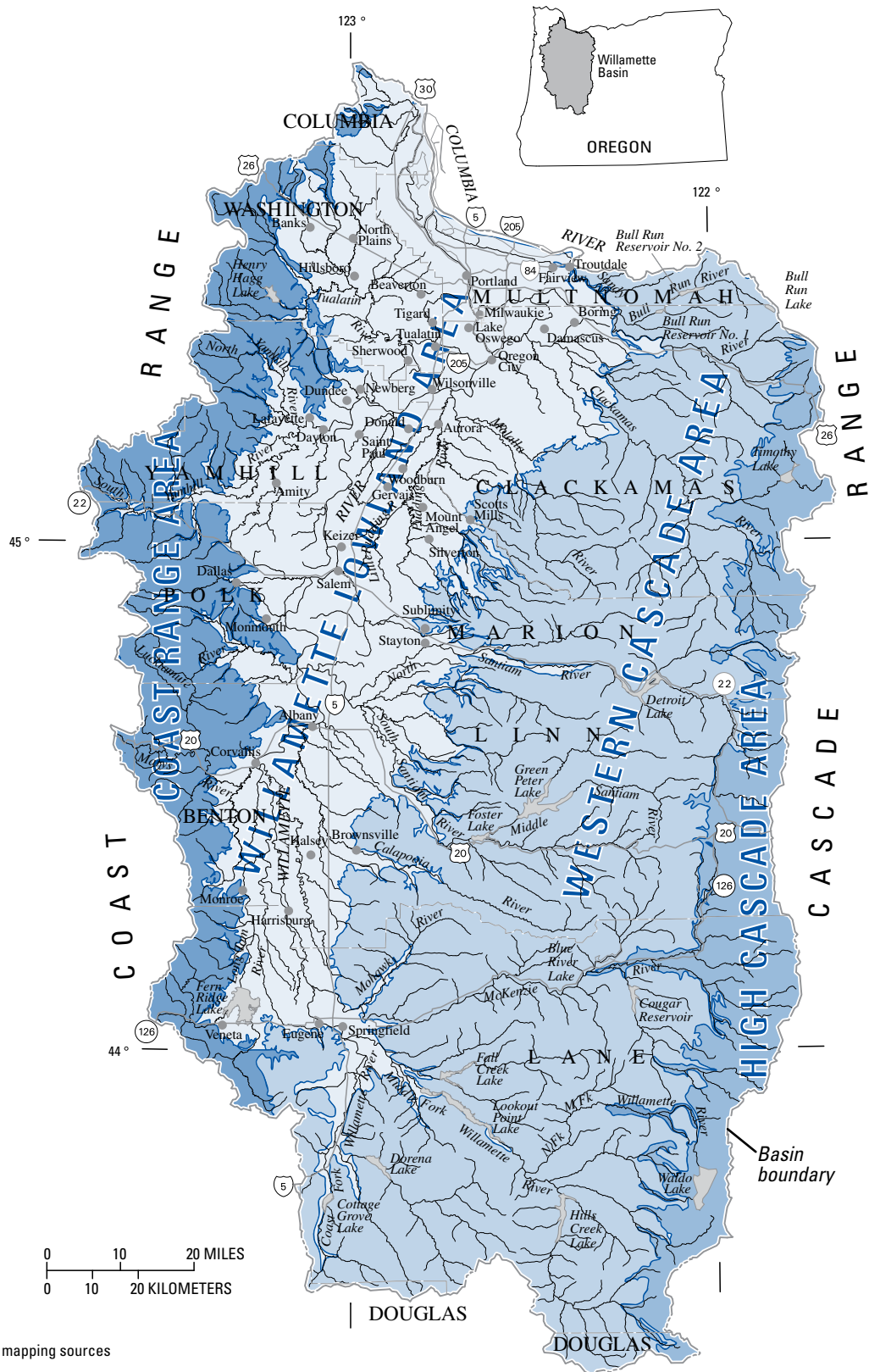
A synthesis of the hydrogeology of the Willamette lowland was conducted in the early 1990s as part of the Regional Aquifer-System Analysis (RASA) program of the U.S. Geological Survey (Vacarro, 1992). The main products are an extensive bibliography of the hydrogeology of the Willamette Basin (Morgan and Weatherby, 1992), a comprehensive description of the geologic framework (Gannett and Caldwell, 1998) and a description of regional hydrogeologic units (Woodward and others, 1998).

### Purpose and Scope

The purpose of this report is to provide a conceptual framework of the ground-water flow system in the Willamette Basin that will help resource managers evaluate the impacts of ground-water-management decisions. The report integrates information from previous studies and data collected during the current study.

The study was divided into a regional phase to understand the ground-water flow and ground-water budget for the entire Willamette Basin and a focused phase to evaluate temporal changes in the ground-water flow in the central Willamette Basin ([pl. 1](#)). Although the study covered the entire Willamette Basin, the scarcity of well data in the Coast and Cascade Ranges limited the scope of a detailed analysis to the Willamette lowland.

Regional scale data, including ground-water levels, geophysical logs, stream seepage (gains and losses), and ground-



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**Figure 1.** Location of Willamette Basin, Oregon and major geographic and cultural features.

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water chemistry, were collected from 1996 to 2003, with an emphasis on the period between 1996 and 1997. Focused data collection in the central Willamette Basin between 1998 and 2003 included ground-water levels, stream seepage, aquifer tests, and water temperature of streams and ground water.

### Study Area

The study area ([fig. 1](#)) includes the Willamette and Sandy River drainage basins in northwestern Oregon. The combined drainage area of the two basins is referred to as the Willamette Basin in this report. The study area encompasses about 12,000 square miles between the crests of the Coast Range on the west and the Cascade Range on the east. It is bounded on the south by the convergence of the Coast and Cascade Ranges and on the north by the Columbia River.

The Clackamas, North and South Santiam, McKenzie, and Middle Fork Willamette Rivers are the major tributaries to the Willamette River. These large streams drain the Cascade Range. Smaller streams in the Cascade and Coast Ranges also flow into the Willamette River, which flows through the lowland to the Columbia River at the northern edge of the study area.

The Willamette Basin is bordered on the west by the deeply incised Coast Range, where elevations range from 1,000 to 4,000 ft (feet). The east side of the basin is bounded by the Cascade Range, which includes the older, more weathered and deeply incised Western Cascade area, where elevations range from 1,000 to 6,000 ft, and the younger High Cascade area, where elevations range from 4,000 ft near mountain passes to 10,000 ft at the summit of volcanic peaks along the crest of the range. Between the Coast and Cascade Ranges is a lowland, approximately 120 mi (miles) long and 20 mi wide, where most of the population, industry, and agriculture occurs. Elevations within the lowland plain are near sea level at Portland and gently increase to about 400 ft near Eugene. Uplands of bedrock that reach elevations of 1,500 ft divide the lowland into the Portland, Tualatin, central Willamette, Stayton, and southern Willamette Basins ([pl. 1](#)).

The Willamette Basin is characterized by cool, wet winters and warm, dry summers. Precipitation, mostly from winter storms moving eastward from the Pacific Ocean, varies with elevation. Mean annual precipitation ([fig. 2](#)) ranges from 40 to 130 in (inches) (mostly rain) in the Coast Range, approximately 40 in (rain) in the lowland, 50 to 100 in (mostly rain) in the Western Cascade area, and up to 130 in (rain and snow) at crest of the Cascade Range. Heavy snowfall occurs in winter in the Cascade Range, resulting in permanent snowfields and glaciers on the highest peaks. About 80 percent of the annual precipitation falls from October through March, but less than 5 percent falls in July and August (Wentz and others, 1998). Precipitation at Salem was above average for water years 1995–99 and 2002, average for 2003, and below average from 2000–2001. An especially dry water year was 2001, when precipitation was approximately 50 percent of average.

Mean monthly temperatures in the lowland range from 39 degrees F (Fahrenheit) in January to 68 degrees F in August. In the Coast Range and Western Cascade area, mean monthly temperatures range from 37 degrees F in January to 64 degrees F in August. The mean monthly temperature in the High Cascade area is 28 degrees F in January and 57 degrees F in August.

Approximately 70 percent of the Willamette Basin is forested, including most of the Coast and Cascade Ranges (Pacific Northwest Ecosystem Research Consortium, 2002). Agricultural land encompasses 20 percent of the study area and is generally restricted to the lowland. The remaining land is urban, covered grasslands, water, or snow. Major population centers are the metropolitan areas of Portland, Salem-Keizer, Corvallis, and Eugene-Springfield. Of these communities, Springfield and Keizer rely solely on ground water. Salem, Portland, and some suburban Portland communities use ground water to supplement surface-water supplies during summer. Many smaller communities rely on ground water.

Agricultural crops in the Willamette Basin account for 62 percent of Oregon's total crop sales and include grass seed, wheat, hay, oats, clover and vetch seed, sweet corn, filberts, snap peas, mint, berries, hops, vineyards, and nursery stock. Historically, crops, such as wheat, that do not require irrigation were cultivated in the lowland. As markets and technology evolved, high-value crops that require irrigation became more common. Because surface-water irrigation is limited to fields adjacent to streams, much of the lowland is irrigated with ground water. Irrigation with ground water is increasing adjacent to many smaller streams because of low streamflow and poor surface-water quality in the summer. Irrigation canals are not widely used, except in the Stayton Basin.

### Approach

The ground-water flow system in the Willamette Basin was characterized by (1) reviewing existing geologic and hydrologic reports, (2) locating wells for geologic and ground-water level information, (3) compiling and collecting water-level information to evaluate ground-water flow directions and water-level trends, and (4) collecting other hydrologic data to evaluate recharge, ground-water flow paths, and exchanges between surface and ground waters. This report addresses these elements and supports the data needs for the development of computer models to simulate the ground-water flow system.

Data for approximately 6,000 wells located in previous studies and as part of this study were compiled (Orzol and others, 2000). A subset of about 1,200 wells provided information on subsurface geology, water chemistry, and ground-water levels. Subsurface geology was interpreted from geophysical logs collected in 16 wells, ground-water age was estimated in 21 wells using chlorofluorocarbons, and water levels were measured in 687 wells. Wells referred to in this report are

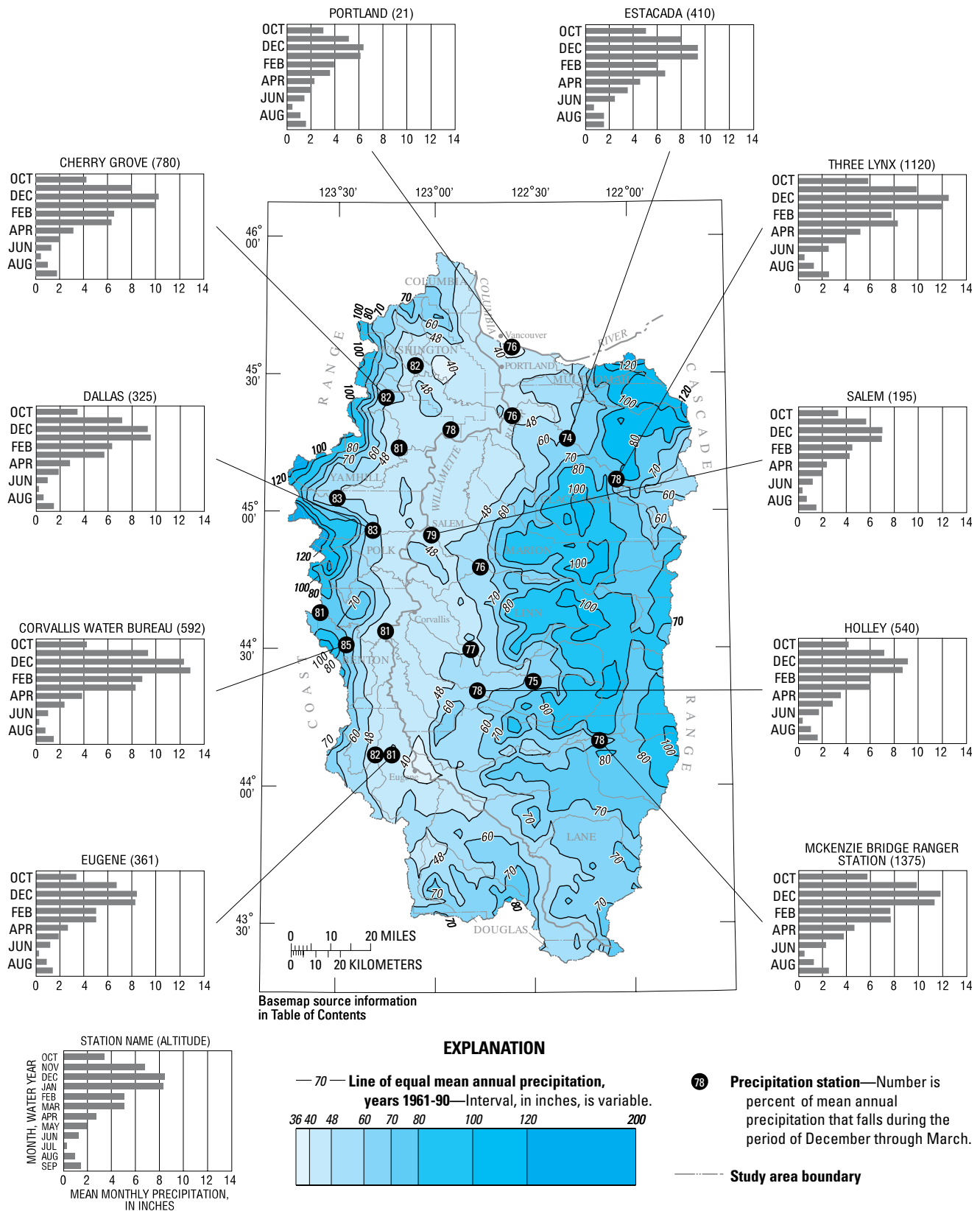


Figure 2. Mean annual and mean monthly precipitation, Willamette Basin, Oregon (modified from Woodward and others, 1998).

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listed by location in Appendix A and correlated to USGS and OWRD identifiers.

Several observation-well networks were established during the study to evaluate the ground-water flow system. During a 2-week period in November 1996, water levels were measured in approximately 470 wells to construct ground-water level maps and to infer horizontal and vertical ground-water flow directions. To understand the temporal dynamics of the flow system, water levels were collected every 2 hours in 48 unused wells equipped with data loggers. An additional 12 wells were instrumented with data loggers for shorter periods to measure responses to aquifer tests and other short-term hydrologic stresses. A second network of 118 wells, measured bimonthly over periods ranging from 1 to 6 years, was established to supplement the continuous-recorder network. In addition to these wells, the OWRD maintains a network of about 51 long-term observation wells that are generally measured 4 times per year. Historic water levels, with periods of record ranging from 1 to 70 years, are also available for several hundred inactive observation wells that were measured by the USGS or by OWRD between 1928 and 2000. Water-level data for most of these wells were published by Orzol and others (2000). Several aquifer tests conducted during the study were analyzed to estimate hydraulic properties of aquifers and confining units.

To evaluate the impacts of ground-water pumping on smaller streams, detailed information was collected at a site near Mount Angel, Oregon, adjacent to the Pudding River. This information is summarized by Iverson (2002).

The components of the hydrologic budget include recharge, evapotranspiration, ground-water withdrawals, and discharge to streams. Recharge from precipitation and evapotranspiration from the unsaturated zone were estimated with watershed models (Lee and Risley, 2002). Evapotranspiration from the water table was estimated in the southern Willamette Basin where the water table is near land surface. Ground-water withdrawals for public use were based on measurements or estimates reported to OWRD. Industrial water use was estimated from water right records at OWRD. Irrigation withdrawals were estimated using LANDSAT images, crop-water-use estimates, and ground-water right information from OWRD. Recharge from surface water and ground-water discharge to surface water were estimated from seepage measurements (Lee and Risley, 2002), seepage meters and heat-tracing methods (Conlon and others, 2003).

### Acknowledgments

The authors wish to thank the hundreds of landowners who allowed access to their wells. We especially acknowledge Charles Eder and Ron Johnson for granting permission to install piezometers on their land and six other landowners for allowing piezometers to be installed in streams adjacent to their land. The City of Mount Angel and Paul Kirsch generously allowed us to perform aquifer tests on their wells. Drill-

ers, especially Steve Schneider of Schneider Equipment and Floyd Sippel of Sippel Well Drilling, are acknowledged for collecting drill cuttings and providing opportunities to obtain geophysical logs from water wells. Lastly, several individuals, notably Marvin Beeson and Terry Tolan, helped shape our interpretation of the hydrogeology by generously sharing their time and expertise. The passion for understanding the geology of the Columbia River Basalt Group demonstrated by Marvin Beeson, who passed away in 2004, will be missed.