Environmental Setting of the Willamette Basin, Oregon

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water resource agencies and by many academic institutions. These organizations are collecting water quality data for a host of purposes that include: compliance with permits and water supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water supply facilities; and research on factors that affect water quality. An additional need for water quality information is to provide a basis on which regional and national level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of about 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the study units and more than two-thirds of the people served by public water supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
acre-feet (acre-ft)	1,233	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton (short)	0.9072	metric ton (t)

Temperature in degrees Fahrenheit (°F) as follows:

$$°F = 1.8\ (°C) + 32$$

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, called Mean Sea Level of 1929.

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By Mark A. Uhrich *and* Dennis A. Wentz

ABSTRACT

The Willamette Basin, Oregon, is one of more than 50 large river basins and aquifer systems (referred to as study units) across the United States where the status and trends of water quality and the factors controlling water quality are being studied by the National Water-Quality Assessment Program of the U.S. Geological Survey. The 12,000-square-mile Willamette Basin Study Unit consists of the Willamette and Sandy River Basins, which are tributary to the Columbia River. The Willamette River is the 13th largest in the conterminous United States in terms of discharge and is the largest of all major United States rivers in terms of discharge per square mile of drainage area. The environmental setting of a study unit includes all natural and human related, land based factors that have the potential to influence the physical, chemical, and/or biological quality of its surface and ground water resources. For the Willamette Basin, these include primarily ecoregions, hydrogeology, climate, hydrology, land use/land cover, and crop types.

INTRODUCTION

In 1991, the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) began studies to document status and trends of water quality in more than 50 large river basins and aquifer systems (referred to as study units) across the United States and to explain the natural and human factors that affect the quality of these surface and ground water systems (Leahy and Thompson, 1994). A primary goal of the studies is to provide information that is useful to national, State, and local policy makers and planners for managing water resources.

The main objective of NAWQA investigations in the Willamette Basin Study Unit in Oregon (fig. 1) (hereafter called the Willamette Basin) has been to evaluate effects of agricultural and urban land use on surface and ground water quality. Implications regarding nutrients and pesticides from these land uses, and their effects on water quality, are discussed in detail in Anderson and others (1996, 1997), Hinkle (1997), Rinella and Janet (1998), and Wentz and others (1998). Water quality effects resulting from timber harvesting in the Willamette Basin have not been addressed by the NAWQA Program.

Purpose and Scope

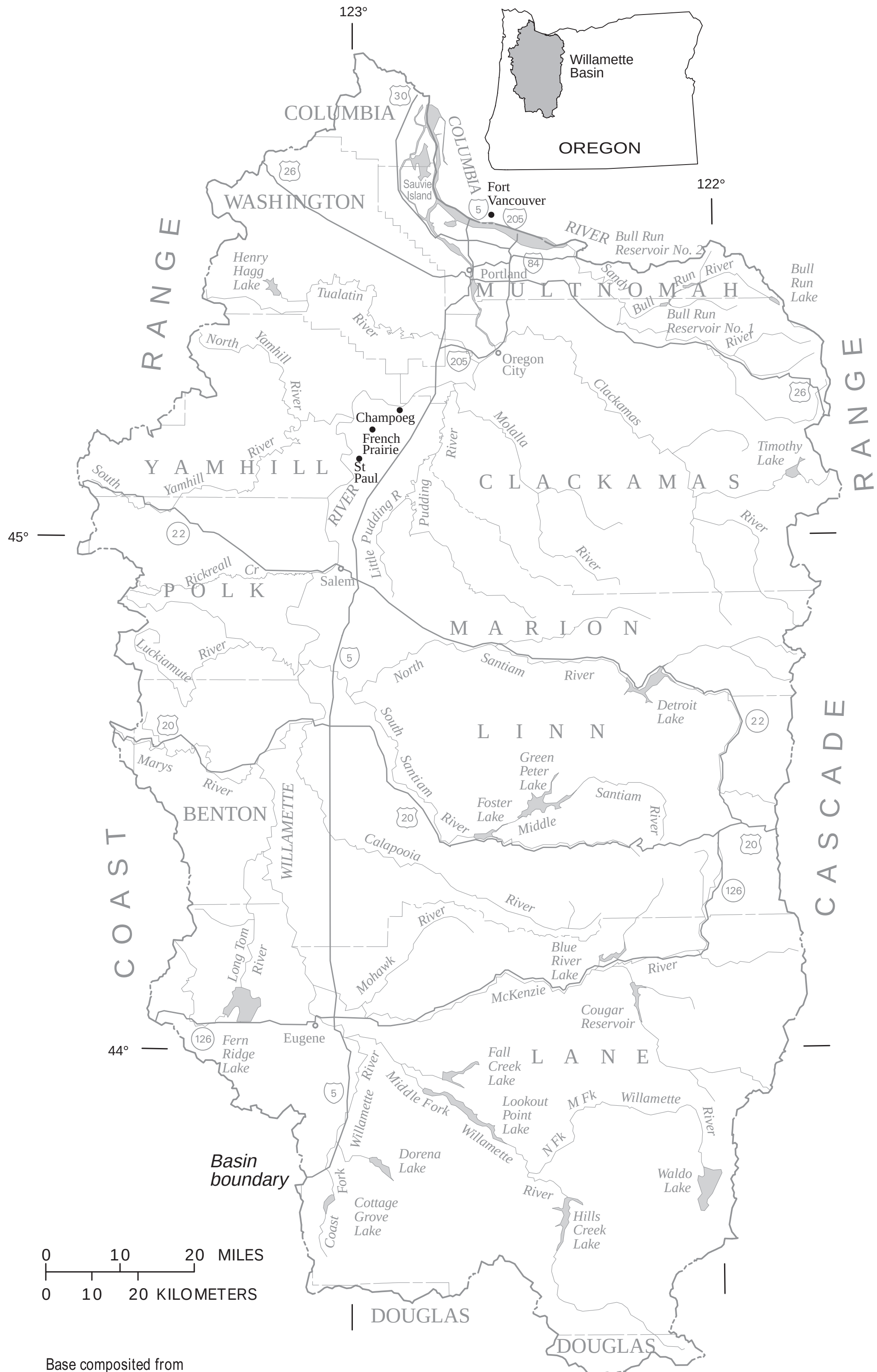
This report describes the history and development of the Willamette Basin and some of the important environmental factors that may affect water quality in the basin. It also briefly summarizes hydrologic conditions during 1993–95, the high intensity period of data collection for the Willamette Basin NAWQA.

Acknowledgments

The authors thank Rob Baskin and Frank Voss for providing technical reviews of an earlier version of this report. Their reviews contributed importantly to the overall quality of the report.

BASIN HISTORY

The discussion of settlement of the Willamette Basin is based on information in Corning (1973), O'Donnell (1993), and Warren and Ishikawa (1993). Historical information on development of agriculture in



Base composited from
USGS digital line graphs and other digital information.
Universal Transverse Mercator projection, Zone 10
1927 North American Datum

Figure 1. Location and features of the Willamette Basin, Oregon.

the Willamette Valley is summarized from Bowen (1978).

Settlement

The Columbia River, which forms the northern boundary of much of Oregon, was explored by British Captain Robert Gray in 1792 and became the main route for the initial exploration and settlement of the Willamette Basin by non-Native Americans. The first overland route to the basin was established by Meriweather Lewis, secretary to president Thomas Jefferson, and Lewis's army comrade, William Clark. Leaving St. Louis in the spring of 1804, the Lewis and Clark Expedition arrived some 19 months later at the mouth of the Columbia River, where they overwintered. They left their winter camp in March 1806 and returned to St. Louis in September, having documented a route for the future settlement of the Oregon Territory and the Willamette Basin.

In 1825, Dr. John McLoughlin (known as the father of Oregon) and a group of Hudson Bay Company fur trappers established an early trading post at Fort Vancouver on the north side of the Columbia River near the mouth of the Willamette River. In 1829, McLoughlin allowed French Canadians to establish farms along the Willamette River near present-day St. Paul, midway between Portland and Salem. Thus began the first settlement of Oregon by non-Native Americans. Between 1840 and 1860, about 53,000 people started the journey west to Oregon via the 2,000-mile Oregon Trail.

Many of the early settlements, including Portland, Eugene, and Salem, were established on the banks of the Willamette River to take advantage of the transportation opportunities that the river afforded for both people and goods. With the introduction of steamboats in the 1840s and the opening of the navigation locks around Willamette Falls at Oregon City in 1873, the Willamette River took on an even greater importance to the growth and prosperity of the basin.

Agricultural Development

The Oregon frontier economy began to develop soon after the great migration of the mid-1800s, and agriculture became a key component of the area's prosperity. Swine were some of the first animals brought in by the early settlers. The Hudson Bay Company settlement at Fort Vancouver imported long-horned cattle from California and created a ranching business in the early Willamette Valley. However, because of their spirited nature and lack of milk production, the long-horned cattle gradually were replaced with Durham breeds of beef and dairy cattle. American sheep from the eastern United States were introduced around 1847 and became plentiful along the Yamhill and Tualatin Rivers.

In addition to livestock, crops helped to support the early economy of the Willamette Valley. Wheat, the most important crop, fed the frontier people, helped to bolster local industries, and provided a basis for foreign trade. The first recorded harvest (in 1847) totaled approximately 150,000 bushels, mostly grown near Champoeg, about 20 miles north of Salem. The harvest increased to over 208,000 bushels in 1850. Nearly 56,000 bushels of oats were grown that same year, mostly near French Prairie, about 5 miles south of Champoeg.

Vegetables also were an important component of the early farm economy. Potatoes were grown over much the Willamette Valley, but, due to spoilage, few were transported long distances. The largest potato farm was located in the Clackamas River Basin, with other large farms near the Columbia River and Sauvie Island. The family garden, though not beneficial for income, helped stave off hunger and balance the diet of the pioneers. Legumes, such as peas and beans, were grown at French Prairie, as were cabbage, lettuce, squash, turnips, carrots, onions, rutabagas, parsnips, tomatoes, and melons.

The first fruit orchards probably were started at French Prairie by French Canadian settlers during the late 1820s, with apples, pears, and peaches most common, and all grown from seed. Early Oregon farmers, used to harsh eastern winters, were slow to develop orchards because they felt colder temperatures were needed to propagate the trees. Farmers that did venture into orchard farming believed the many rodents of the Willamette Valley would decimate the small budding trees, so seedlings were started on oxbow islands of the Willamette River, where rodent numbers were less.

The Willamette Valley developed distinct regions of agriculture in the mid-1800s. In the northern low-lying areas near the Columbia River and Sauvie Island, perishable produce, including vegetables, potatoes, and dairy products, were the mainstays. Large commercial gardens were started there and near population centers, such as Oregon City and Portland. In the prairies between Champoeg and Salem, wheat, oats, and other grains were cultivated for commercial use.

French Prairie became the center for grain production and export, with a secondary emphasis on beef cattle and swine. In areas east of the Pudding River and south to the Santiam River, farms were smaller and less established, with harvests mixed among grain, livestock, and potatoes. The Tualatin Valley shared production equally between crops and livestock. To the south near the Yamhill River, livestock herds became prevalent. Farther south, between Rickreall Creek and the Marys River, swine were predominant. To the far south, past the Luckiamute River, dairy products led the rural economy.

Presently, agriculture is the chief industry in Oregon. During 1992–93, the Willamette Basin accounted for more than 50 percent of Oregon's gross farm sales; these were derived from more than 200 agricultural commodities (Oregon Agricultural Statistics Service, 1993; Clark, November 1994; John Burt, Oregon State University Extension, oral commun., 1997). In 1992, Oregon lead the United States in production of grass seed, Christmas trees, blackberries, boysenberries, loganberries, black raspberries, hazelnuts (filberts), and peppermint, and was second in production of red raspberries, hops, prunes and plums, sweet cherries, snap beans, and onions (Oregon Agricultural Statistics Service, 1993; Thompson, November 9, 1994). Except for cherries and onions, most of this production came from the Willamette Basin.

Timber Production

Oregon has led the nation in timber production since 1938, with most timber coming from the Willamette Basin. Timber harvest in the basin (fig. 2) totaled 128,700 million board feet (mbf) for 1947–95, averaging 2,630 mbf per year. The peak harvest was 3,340 mbf in 1952, and the lowest recorded harvest was 1,460 mbf in 1994 (Bourhill, 1947–1995).

Mining

Mining also has played an important role in the development of the Willamette Basin. Extraction of complex sulfide ores from various locations in the Cascade Range from 1880 to 1947 yielded more than 1.3 million pounds of gold, silver, copper, lead and zinc, including about 133,000 ounces of gold and silver (Callaghan and Buddington, 1938; Oregon Department of Geology and Mineral Industries, 1951). Mining of cinnabar from one of Oregon's largest mercury mines, south of Eugene, peaked during World War II (Brooks and Baily, 1969), but the site is now abandoned.

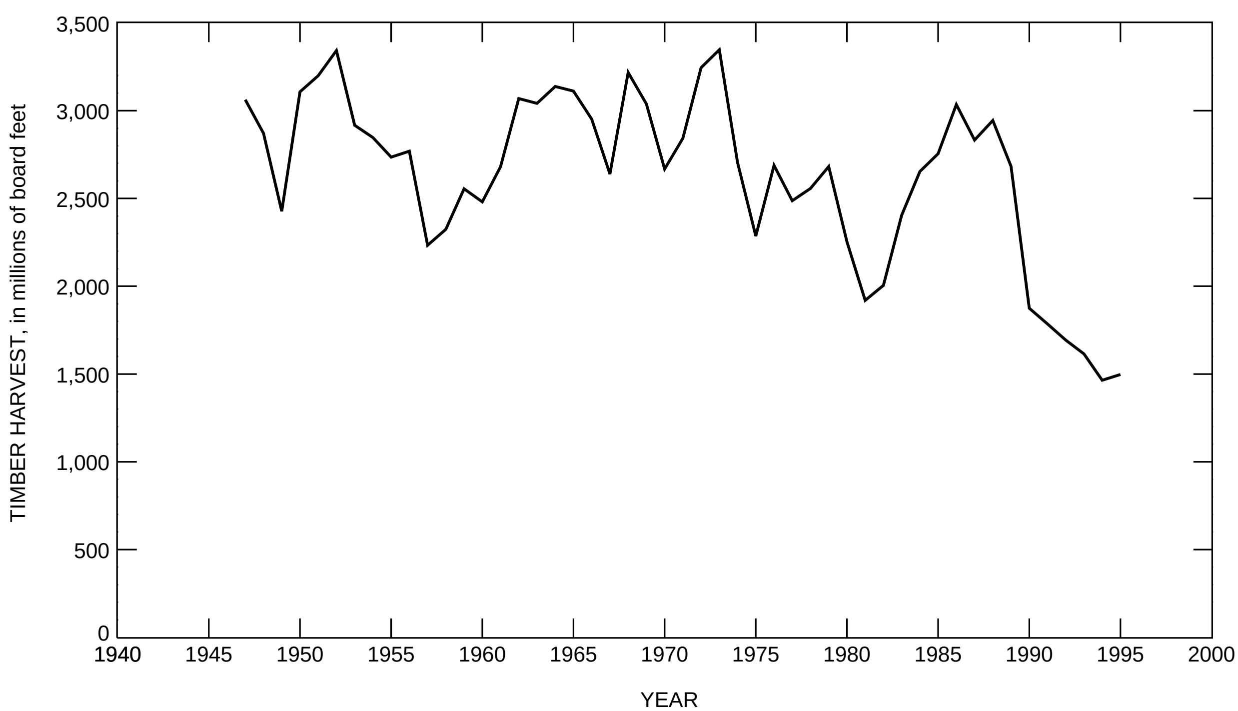


Figure 2. Timber harvest in the Willamette Basin (data from Bourhill, 1947–1995).

In 1993, gold was the only metal mined in the basin, and production was less than 100 ounces; however, mining of aggregate resources, such as sand, gravel, and crushed rock, totaled 28 million tons (3 million tons from waterways) (Whelan, 1994). Total mineral production in the basin in 1993 was valued at over $127 million, or 53 percent of the State's total mineral production. The sand and gravel portion alone was valued at more than $90 million (Whelan, 1994).

Population Growth

Population in the Willamette Basin has grown steadily since the mid-1800s (fig. 3). Between 1890 and 1930, the population of Multnomah, Washington, and Clackamas Counties, which include most of the Portland metropolitan area, increased by 236 percent. The population of Multnomah County alone rose by 352 percent (Bureau of Municipal Research and Service, 1958; Abbott, 1996).

According to the U.S. Bureau of the Census, nearly 2 million people, or about 70 percent of Oregon's population, lived in the Willamette Basin in 1990; this represents a 20 percent increase since 1980. In 1992, 1.1 million people, (37 percent of Oregon's population), resided in 14 of the 16 largest cities in Oregon, all within the Willamette Basin (Center for Population Research and Census, 1992).

The basin population for 1995 increased by over 205,000 from 1990, almost twice the national average (Center for Population Research and Census, 1996). The greatest percentage increase for Oregon over the last 15 years has been in the Willamette Basin, particularly in the State's three largest metropolitan areas—Portland, Eugene, and Salem.

PHYSICAL SETTING

The Willamette Basin NAWQA Study Unit is composed of the Willamette and Sandy River Basins (fig. 1). The Willamette River has a channel length of 309 miles (Kammerer, 1990), a drainage area of 11,500 square miles, and is tributary to the Columbia River. With an average annual flow at Portland of 31,700 cubic feet per second for 1972–92 (Hubbard and others, 1993), the Willamette River is 13th largest in terms of discharge and has more runoff per square mile of drainage area than any other large river in the conterminous United States (Kammerer, 1990). Flow of the river is controlled by 13 major tributary reservoirs with a com-

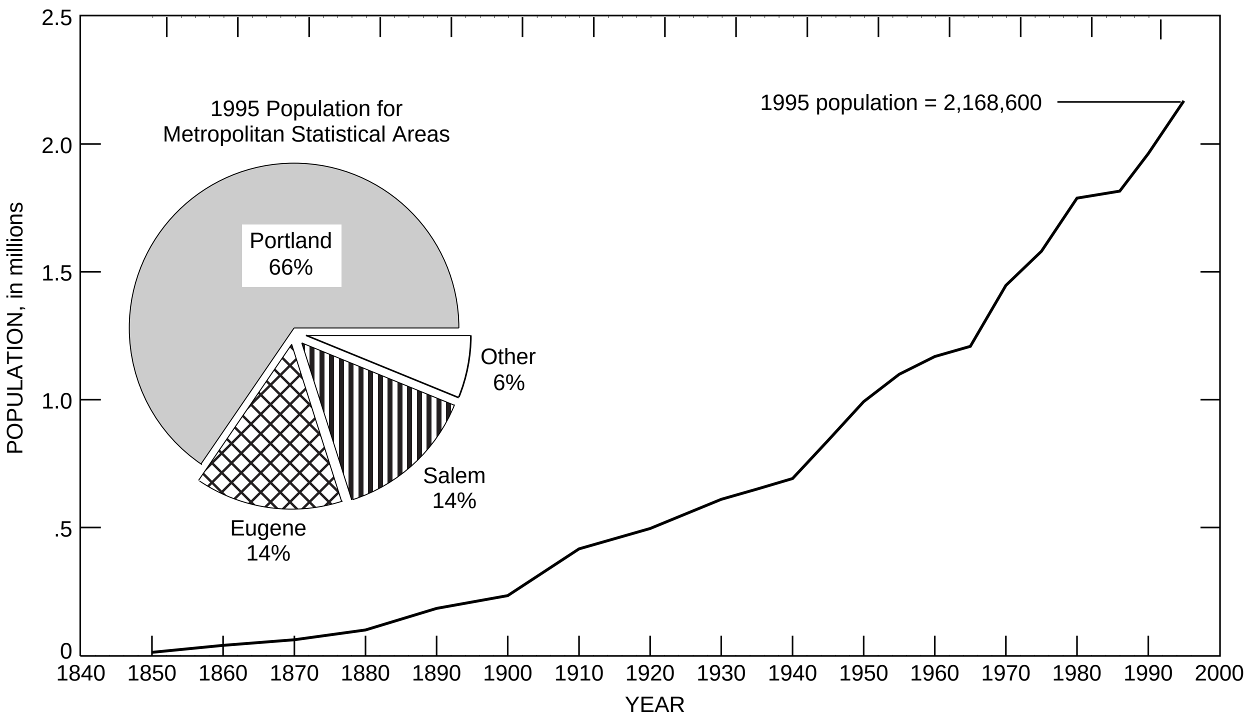


Figure 3. Population of the Willamette Basin. (Data are from Bureau of Municipal Research and Service [1958] and Abbott [1996]. Population estimates are based on county totals and include significant areas of Benton and Lane Counties that lie outside the Willamette Basin. For each of these counties, the total population living outside the basin, but included in the above estimates, is less than 5 percent of the county population.)

bined usable storage capacity of approximately 1.88 million acre-feet (Shearman, 1976). The reservoirs are operated for flood protection, power generation, navigation, irrigation, recreation, domestic water supply, fish and wildlife conservation, and pollution abatement.

The Sandy River, with a drainage area of about 500 square miles, also is tributary to the Columbia River. Bull Run (in the Sandy River Basin) provides much of Portland's drinking water through a series of three water supply reservoirs totaling 44,600 acre-feet of usable storage capacity (Snyder and Brownell, 1996).

Ecoregions

The Willamette Basin includes five ecoregions—Coastal Mountains, Willamette Valley Plains, Willamette Valley Foothills, Western Cascades, and High Cascades (Clarke and others, 1991) (fig. 4). Ecoregions are spatially homogenous areas based on physical and landscape features, including physiography, climate, soils, land use, natural vegetation, and biotic communities.

The Coastal Mountains (8 percent of the basin) form the western boundary of the Willamette Basin; they are generally 1,500–2,000 feet in elevation, with peaks higher than 3,000 feet. The Coastal Mountains are extensively dissected by streams, with a typical density of 2–3 miles of perennial streams per square mile (Omernick and Gallant, 1986).

The Western and High Cascades account for 44 and 6 percent of the basin area, respectively, and border the basin to the east. These mountains are generally 5,000–6,000 feet in elevation, with a few peaks greater than 10,000 feet, and have stream densities of 1.5–2 miles of perennial streams per square mile (Omernick and Gallant, 1986).

The Willamette Valley Plains, which comprise 22 percent of the basin, are nearly level to low sloping floodplains, ranging from 100 to 300 feet in elevation. The Willamette Valley Foothills, at 20 percent of the basin area, surround the plains. Slopes are steeper in the foothills than in the plains, and elevations average 1,000 feet in the north to over 2,000 feet in the central and southern basin.

A greater percentage of perennial streams occur in the northern Willamette Basin, whereas intermittent streams are more prevalent in the southern basin (Omernick and Gallant, 1986). Artificial stream channelization has been particularly extensive in the southern basin, where the Willamette River channel length has been reduced by about 50 percent compared to historic conditions (Benner and Sedell, 1997).

Figure 4. Ecoregions of the Willamette Basin (modified from Clarke and others, 1991).

Hydrogeology

The Willamette Basin includes six principle hydrogeologic units (fig. 5): marine volcanic and sedimentary rocks of the Coast Range; alluvial deposits;

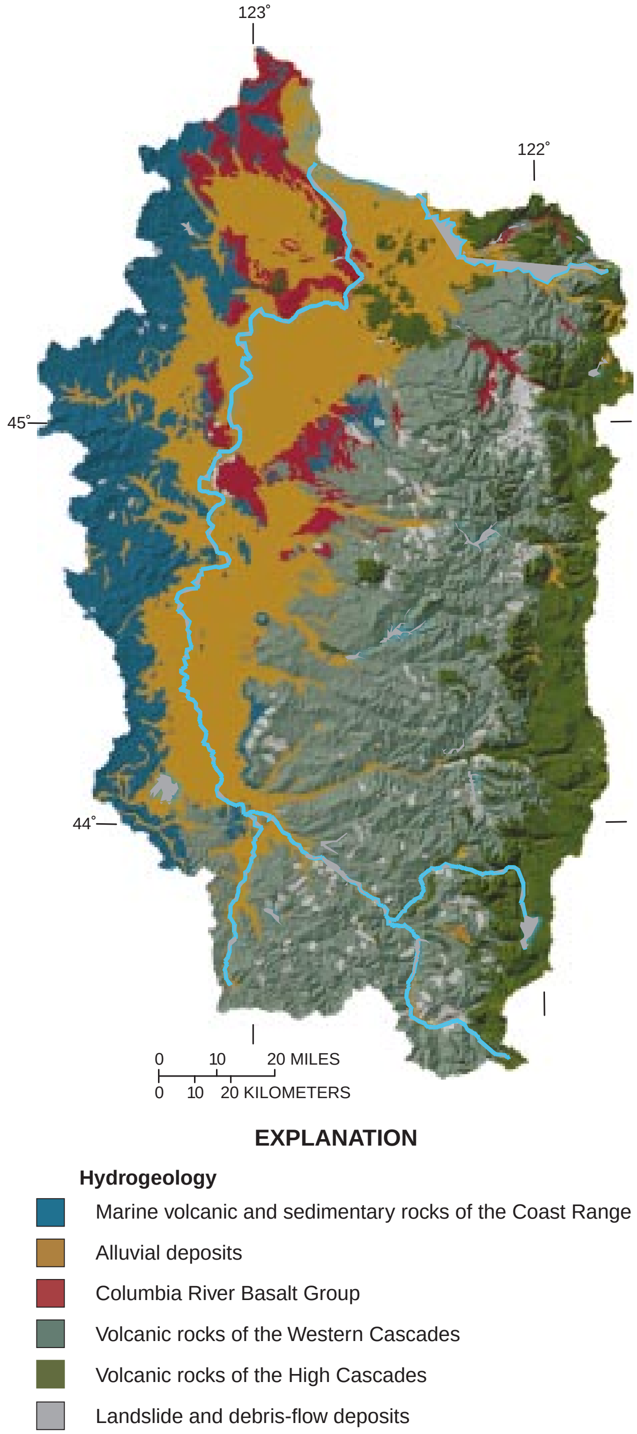


Figure 5. Hydrogeology of the Willamette Basin (modified from Walker and MacLeod, 1991).

Columbia River Basalt Group; volcanic rocks of the Western Cascades; volcanic rocks of the High Cascades; and landslide and debris-flow deposits (Walker and MacLeod, 1991).

The alluvial deposits, which are composed of a heterogeneous mixture of unconsolidated and semi-consolidated clay, silt, sand, and gravel, represent the most important aquifer in the Willamette Basin with respect to water use. Most surficial deposits in the Willamette Valley are included in this highly productive aquifer, and the water table usually is within a few feet to a few tens of feet of the land surface (Woodward and others, 1998). Ground water supplies in the Willamette Valley are taken principally from the alluvial sands and gravels beneath terraces and bottomlands adjacent the Willamette River. Although 1990 public supply withdrawals for the basin were only 12 percent from ground water (36 million gallons per day), most of the ground water used for public supply is withdrawn from the alluvial aquifer (Broad and Collins, 1996).

Climate and Hydrology

The proximity of the Willamette Basin to the Pacific Ocean and its exposure to prevailing westerly winds combine to produce a modified maritime temperature regime characterized by cool, wet winters and warm, dry summers. About 75 percent of the annual precipitation falls from October through March, and less than 5 percent falls in July and August (fig. 6). Most precipitation falls as snow above about the 5,000-foot level of the Cascades (Stan Fox, Natural Resources Conservation Service, written commun., 1996); however, the Coast Range and Willamette Valley receive relatively little snow. Mean monthly air temperatures in the valley range from 3–5^{o}C during January to 17–20^{o}C during August.

Although annual precipitation averaged 62 inches in the Willamette Basin during 1961–90, topography strongly influenced its distribution. Yearly amounts ranged from 40–50 inches in the valley to as much as 200 inches near the crests of the Coast and Cascade Ranges (fig. 7).

Streamflow in the Willamette Basin strongly reflects the distribution of precipitation. About 60–85 percent of runoff typically occurs from October through March, and less than 10 percent occurs during July and August (fig. 6). Because of the greater proportion of precipitation falling as snow, runoff from Cascade streams extends farther into spring than runoff from Coast Range streams. Annual mean discharge per unit drainage area during the 1961–90 water years typically was greater for Cascade Range basins than for Coast Range basins (fig. 8).

Annual mean discharge of the Willamette River for the 1961–90 water years increased from a median value of 4,050 cubic feet per second at Jasper (near Eugene) to 33,000 cubic feet per second at Portland

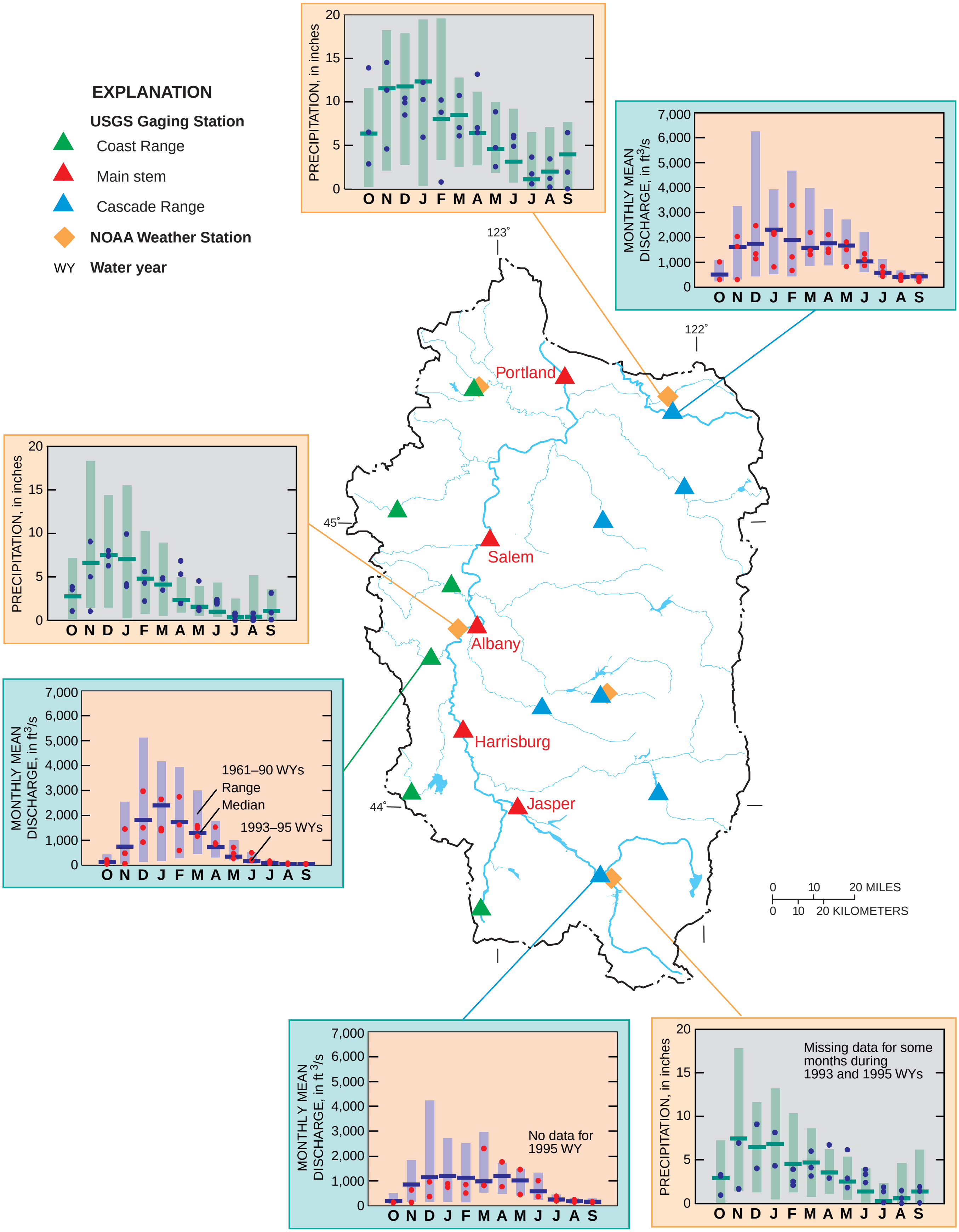


Figure 6. Precipitation and streamflow for the 1993–95 water years compared with the recorded range of conditions for the 1961–90 water years. (Site locations are for data presented in figs. 8 and 9.)

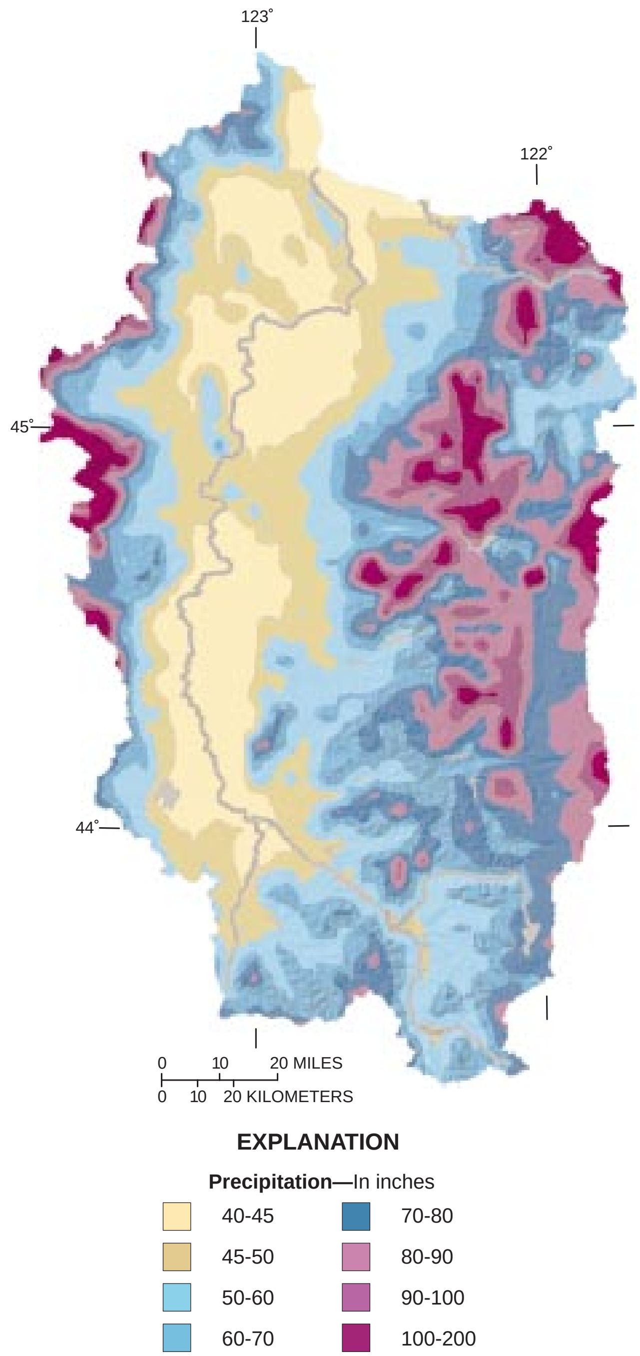


Figure 7. Mean annual precipitation in the Willamette Basin 1961–90 (data from Chris Daley, Oregon Climate Service).

(fig. 9). The total range of annual mean discharge also increased downstream because of (1) natural differences in timing of storm events from contributing subbasins, and (2) regulation of streamflows by tributary reservoirs.

Hydrologic Conditions during 1993–95

Hydrologic conditions during the high intensity period of data collection (1993–95 water years) of the

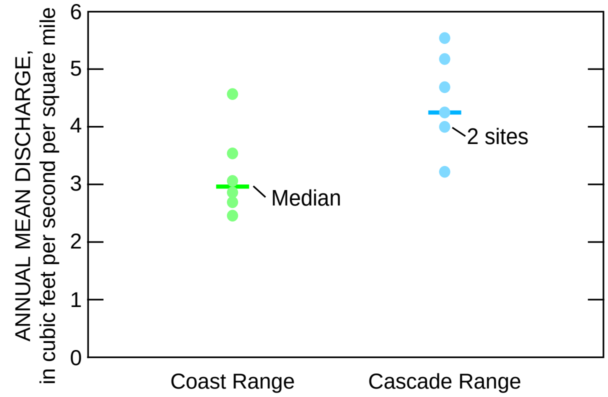


Figure 8. Streamflow per unit drainage area for Coast Range and Cascade Range basins during 1961–90. (See figure 6 for site locations.)

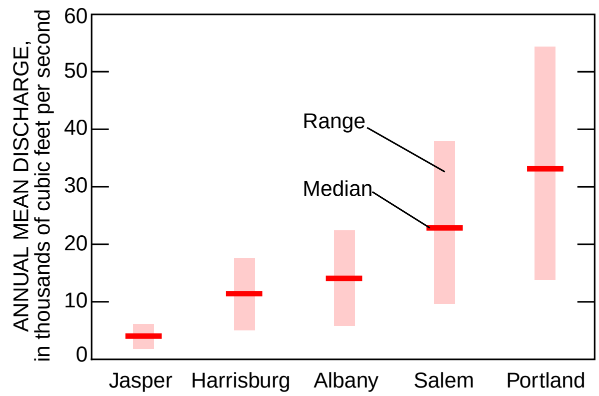


Figure 9. Annual mean discharge for the main stem Willamette River during 1961–90. (See figure 6 for site locations.)

Willamette Basin NAWQA were quite variable. Based on precipitation data from five National Oceanic and Atmospheric Administration (NOAA) sites (fig. 6), the 1993 water year was about normal (5 percent below the 1961–90 water year average). However, the 1994 water year was a drought year (32 percent below average), and the 1995 water year was relatively wet (18 percent above average).

Within any given water year, monthly conditions sometimes differed considerably from long-term average monthly conditions. For example, during the 1993 water year, February precipitation and streamflow were considerably below normal (generally the lowest February data points on fig. 6); however, precipitation and streamflow for April and May were well above normal (highest April and May values), particularly in the southern Willamette Basin.

LAND USE AND LAND COVER

Land use is defined as activity occurring on the land, whereas land cover is a visual description of the land. As an example, the land cover of an area may be categorized as forest; however, the forest may be used in many ways, including timber production, recreation, or wilderness camping. Land use changes are typically due to human intervention and have considerable potential for impacting water quality of associated rivers and aquifers.

Most land use/land cover data are derived by using computer software to interpret satellite or other remotely sensed imagery. For the Willamette Basin, two land use/land cover maps have been created using this approach.

1970s Land Use

A land use map of the United States was created using late 1970s high altitude aerial photographs acquired from the National Aeronautics and Space Administration and from the National High-Altitude Photography program (NHAP). The photographs are the basis for the Geographic Information Retrieval and Analysis System (GIRAS) developed by the U.S. Geological Survey (Mitchell and others, 1977). Typically, photographs were taken at scales less than 1:60,000, and land use information from these photographs was transferred to 1:250,000 topographic base maps. The final product was digitized at a scale of 1:250,000. Resolution of the GIRAS land use data is about 10 acres for urban land and water and about 40 acres for other categories. A land use classification system was developed by Anderson and others (1976) to categorize the GIRAS data; it provides multiple levels of detail for landscape classification (table 1).

Level I GIRAS land use categories (fig. 10) subdivide the Willamette Basin into areas that are similar in spatial extent to ecoregions (fig. 4) and hydrogeology (fig. 5). Most of the forested land is in the Coastal Mountains and Western and High Cascades ecoregions and their associated hydrogeologic units, whereas the Willamette Valley ecoregion is almost entirely agricultural land that overlies the alluvial aquifer. Forested land (70 percent of the basin) is the dominant land use, followed, in turn, by agricultural and urban land (22 and 5 percent, respectively) (U.S. Geological Survey, 1990). The ‘other’ category on figure 10 is a combination of rangeland, barren land, tundra, wetland, and perennial snow and ice.

The original Willamette Basin GIRAS land use map was updated using U.S. Bureau of Census 1990 population data (Hitt, 1994). Census blocks were overlaid on land use to assess changes in population density. Areas with 1,000 or more people per square mile were reclassified as residential, an Anderson Level II subcategory of urban land (table 1). This revision increased the area depicted as urban by about 110 square miles, or from 5.3 to 6.2 percent of the basin (fig. 11).

Paper maps showing irrigated and nonirrigated areas (Oregon Water Resources Department, 1979, 1980, 1981) also were digitized and added to the original GIRAS map. The paper maps of irrigated and nonirrigated areas had been constructed by interpreting 1972–80 high-altitude color infrared photographs at a scale of 1:130,000. Landsat imagery taken during the summers of 1978–80 at a scale of 1:1,000,000 was used to update the high-altitude photographs. The final product was published as three separate paper maps in polyconic projection at scales ranging from 1:260,000 to 1:212,000. The irrigated area (fig. 11) comprises 5 percent of the total basin or about one-fourth of the GIRAS agricultural land; the remaining 17 percent of the GIRAS agricultural land was assumed to be nonirrigated.

1990s Land Cover

A land cover map of the Willamette Basin (fig. 12) was created from Landsat Thematic Mapper (TM) data collected during June and August of 1992 and (or) 1993 as part of a joint effort between the NAWQA Program and the Earth Resources Observation Systems (EROS) Data Center in Sioux Falls, South Dakota (Paul Seevers, U.S. Geological Survey, written commun., 1996). (An ARC GRID file of this map is available at http://oregon.usgs.gov/projs_dir/pn366/landuse.html.) To construct the map, digital images were captured by sensors that record data in seven bands of the electromagnetic spectrum. Image classification software was used to combine information from three of these bands. Each pixel of the resulting digital data covers about 0.2 acre (10,000 square feet). The software identified areas of similar vegetation or land cover (table 2) and produced a digital map of the aggregated areas (fig. 12). Map information was compared with known vegetation/cover types based on field observations. The selection of vegetation/land cover classes was, to some extent, dictated by the needs of the NAWQA Program, which has emphasized effects of agricultural and urban activities on water quality.

To cover the entire Willamette Basin, eight TM scenes were combined to form a mosaic. Separate mosaics were produced for June and August because of

Table 1. Description of land use/land cover categories used in the Geographic Information Retrieval and Analysis System (GIRAS) (Anderson and others, 1976; U.S. Geological Survey, 1990)

LEVEL I	Land Use Type	LEVEL II	Land Use Type
1	Urban or Built-up Land	11	Residential
		12	Commercial
		13	Industrial
		14	Transportation, Communications, and Utilities
		15	Industrial and Commercial Complexes
		16	Mixed Urban or Built-up Land
		17	Other Urban or Built-up Land
2	Agricultural Land	21	Cropland and Pasture
		22	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
		23	Confined Feeding Operations
		24	Other Agricultural Land
3	Rangeland	31	Herbaceous Rangeland
		32	Shrub and Brush Rangeland
		33	Mixed Rangeland
4	Forested Land	41	Deciduous Forest Land
		42	Evergreen Forest Land
		43	Mixed Forest Land
5	Water	51	Stream and Canals
		52	Lakes
		53	Reservoirs
		54	Bays and Estuaries
6	Wetland	61	Forested Wetland
		62	Nonforested Wetland
7	Barren Land	71	Dry Salt Flats
		72	Beaches
		73	Sandy Areas other than Beaches
		74	Bare Exposed Rock
		75	Strip Mines, Quarries, and Gravel Pits
		76	Transitional Areas
		77	Mixed Barren Land
8	Tundra	81	Shrub and Brush Tundra
		82	Herbaceous Tundra
		83	Bare Ground
		84	Wet Tundra
		85	Mixed Tundra
9	Perennial Snow and Ice	91	Perennial Snowfields
		92	Glaciers

changes in growing cycles and cropping patterns occurring between these months. If an area was depicted by the TM imagery as bare ground in June, and the same area was observed as vegetated in August, then it was assumed this area was irrigated cropland. Urban areas, as defined by the 1990 U.S. Bureau of Census data (Hitt, 1994), were applied as a mask to delineate that portion of the imagery that represents urban land.

Land Use and Land Cover Comparisons

It would be useful to be able to ascribe differences between GIRAS data (figs. 10 and 11) and TM data (fig. 12) solely to actual land use/land cover changes between the late 1970s and the early 1990s. Unfortunately, dissimilarities in the procedures used to generate the two classifications can produce artifacts that influence the land use/land cover designation for a

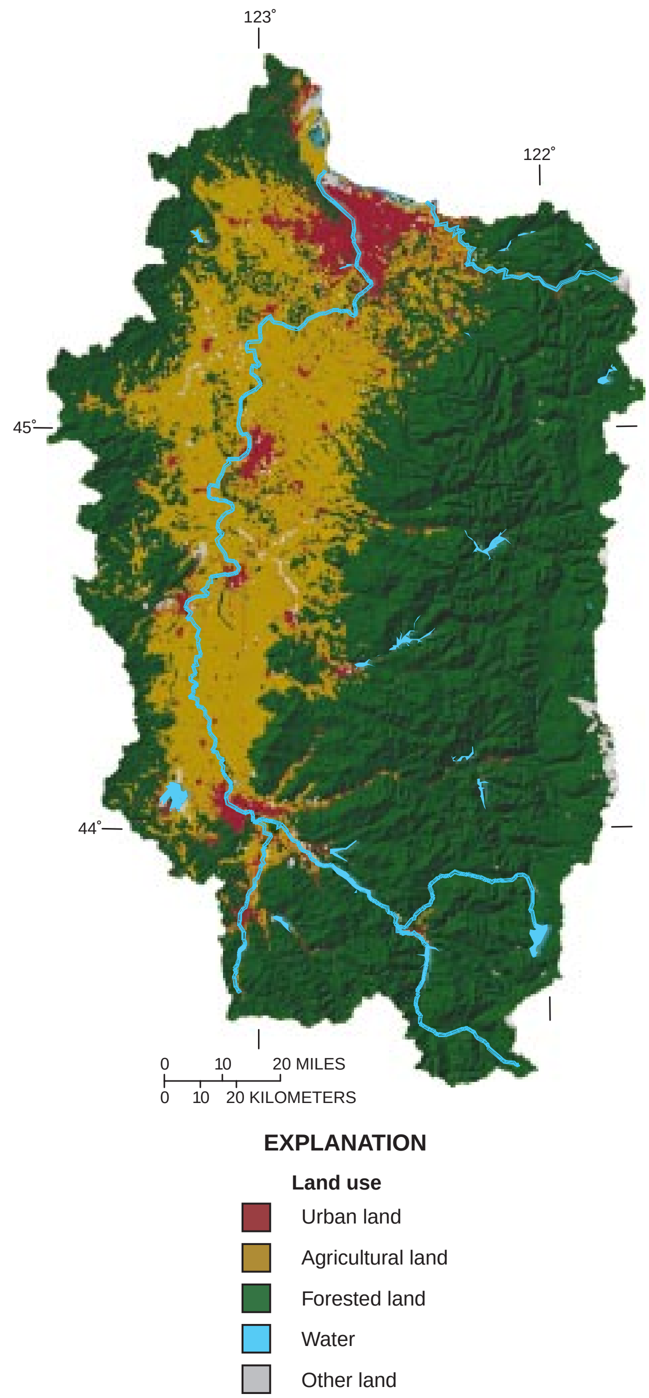


Figure 10. Land use in the Willamette Basin in the late 1970s (modified from U.S. Geological Survey, 1990).

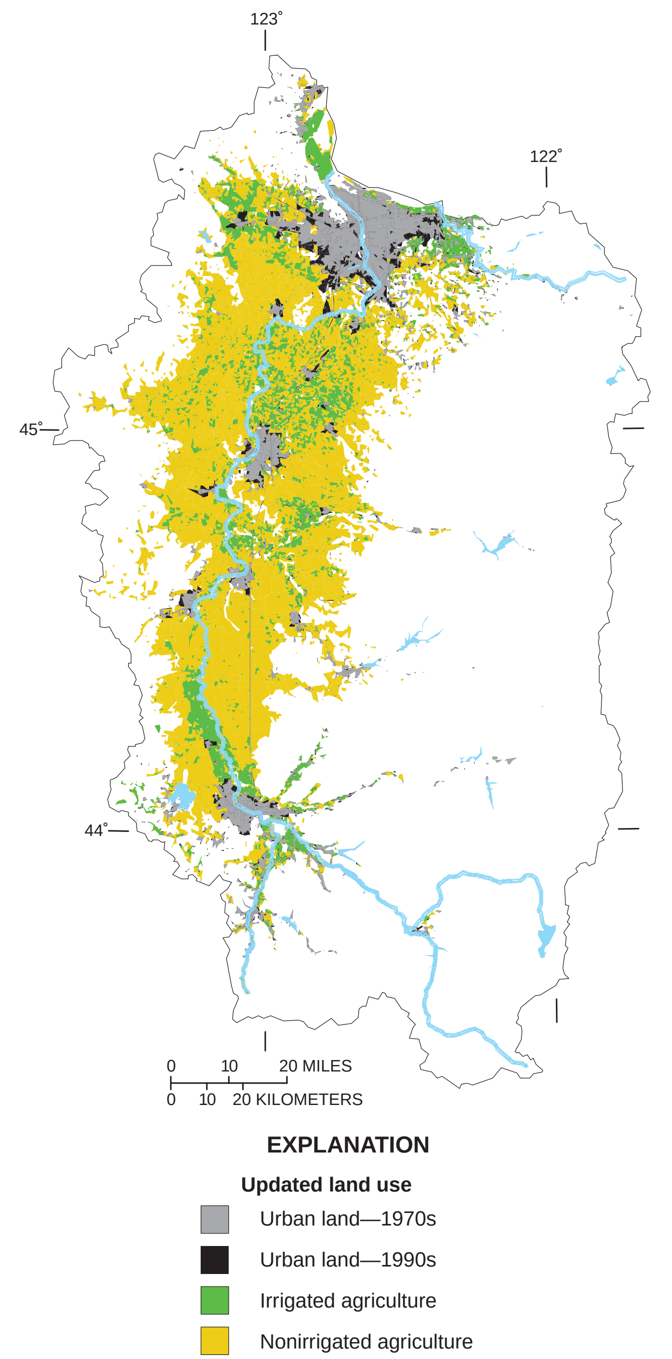


Figure 11. Updated urban and irrigation land use in the Willamette Basin (after Oregon Water Resources Department, 1979, 1980, 1981; Hitt, 1994).

given area. Such artifacts result from differences in coverage type (vector vs. raster), scale, and classification scheme. However, it is still informative to compare the two data sets. To facilitate the comparisons, common categories were developed by reassigning some TM land cover data to equivalent GIRAS categories.

As mentioned previously, the areas categorized as urban are the same for both GIRAS land use and TM land cover. Water and irrigated cropland descriptions were similar for the two data sets; thus, these TM categories were not changed. Mature and regrowth forest TM categories were combined to provide a better match to the forested category of the GIRAS data. The TM grass fields and small grains category was assumed to be the same as the GIRAS nonirrigated agriculture. The TM categories, nonforested upland and native valley vegetation, were not

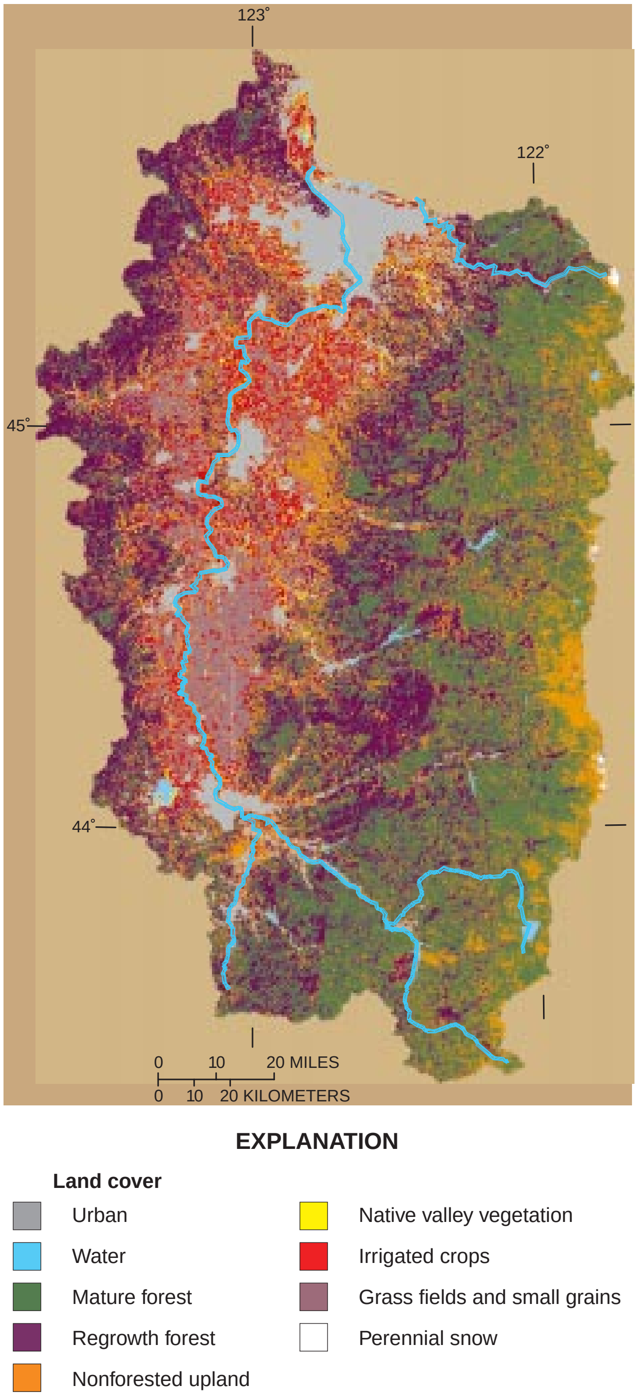


Figure 12. Land cover in the Willamette Basin in the early 1990s (modified from Paul Seevers, U.S. Geological Survey, written commun., 1996).

altered or combined into other categories, as they represent new and unique landscape features that could not be grouped into equivalent GIRAS Anderson level categories. TM water and perennial snow categories were combined and designated "other."

Some obvious differences exist between the GIRAS land use and TM land cover categories (table 3). For example, TM data indicate that the sum of the Willamette and Sandy River Basins is 60 percent forested and 17 percent agricultural, whereas the corresponding GIRAS percentages are 70 and 22. Irrigated agriculture by the TM classification is 8 percent, and nonirrigated agriculture is 9 percent; however, GIRAS percentages are 5 and 17, respectively.

In general, TM irrigated agriculture percentages are higher than comparable GIRAS percentages, whereas TM nonirrigated agriculture percentages are lower than the corresponding GIRAS percentages. TM forest percentages usually are lower than GIRAS forest percentages, with many GIRAS forested areas exceeding the TM forested areas by 10 percent or more. The TM nonforested upland category, which is part of the GIRAS forested category, probably accounts for much of this difference.

The Washington Department of Natural Resources and Oregon Department of Forestry, in conjunction with Pacific Meridian Resources, Portland, Oregon, have classified forest types for western Oregon and Washington using 1988 Landsat TM images. A map depicting three forest seral stages, other forested land, nonforested land, and water was produced. Image processing software, field reconnaissance, aerial photography at several scales, forest inventory data, and review of maps by professionals familiar with the local terrain were used for accuracy assessment. The raster data were converted to polygons with a minimum size of 5 acres (Schriever and Birch, 1995). Assessment of the data for the Willamette National Forest indicated approximately 90 percent accuracy when the remotely sensed data were compared to ground truth data and aerial photography (Teply and Green, 1991; Green and others, 1993).

Figure 13 illustrates the percentages of forest growth types in the Willamette Basin derived from the above study. According to Kevin Birch (Oregon Department of Forestry, written commun., 1996), "late growth" trees typically are large Douglas firs, older than 80–100 years, with total crown closure and diameters greater than 21 inches at breast height (dbh). "Mid-growth" trees are conifers that have achieved crown closure, but are smaller in diameter than late growth trees (usually less than 21 inches dbh and from 20–30 to 80–100 years in age). "Early growth" trees are conifers with less than 70 percent crown closure and aged from 5–10 to 20–30 years. The "other forest" category represents recently harvested stands with trees too young to be detected using aerial imagery and with vegetation dominated by brush and hardwoods.

The following table compares the 1992–93 TM land cover data with the 1988 succession stage data for

Table 2. Description of land cover categories used in the 1992–93 Thematic Mapper (TM) classification system (Paul Seevers, U.S. Geological Survey, written commun., 1996) (See text for explanation.)

Land Cover	Description
Urban	Area of urban development. Defined by a combination of GIRAS and 1990 Census of Population data. Represents a population density of 1,000 or more persons per square mile.
Water	Open water. Streams may show intermittent open water if widths are smaller than the spatial resolution of the satellite data (about 100 feet).
Mature Forest	Represented by the darkest shades of green in the spectral mosaic.
Regrowth Forest	Forested areas with open spaces and trees of smaller size than mature forest. Identified by green areas in the spectral mosaic that were lighter than those for mature forest.
Nonforested Upland	Spectral class without a green vegetation signature. Distinguished from valley areas by elevation and slope differences. Includes recent clearcuts, open grassland, nonforested alpine areas, and barren land.
Native Valley Vegetation	Vegetation in valley areas; distinctively different from agricultural activities. Represents areas with a natural water source throughout the growing season. Includes wetlands and riparian vegetation associated with streams.
Irrigated Crops	Defined as fields that were bare ground (nonvegetated) in June and vegetated in August.
Grass fields and Small Grains	Primarily grass seed fields of the valley floor. Also includes hay fields, pastures, and small grains.
Perennial Snow	Snow in the August image at the peaks of the Cascade Range.

the Western and High Cascades ecoregions. The percentages for the two forest categories are nearly identical between data sets, whereas the nonforested and “other” categories show obvious discrepancies. The discrepancies may have resulted in part because the focus of the land cover classification was on both forested and agricultural areas, whereas the succession stage studies emphasized forested areas only.

Land Cover (1992–93 Landsat data)	Percent	Succession Stages (1988 Landsat data)	Percent
Mature Forest	54	Late and Mid Seral	55
Regrowth Forest	29	Early Seral	30
Nonforested Upland	15	Nonforest	5
Other Land Cover	2	Other Forest	10

AGRICULTURAL COMMODITIES

Agricultural commodity data, primarily for 1992, are discussed in this section; data for 1980 or 1982 and for 1987 are presented for comparison. Data for these years were selected to match, as closely as possible, the periods for which GIRAS land use (late 1970s) and TM land cover (1992–93) were available. The agricultural data were derived primarily from the 1992 Census of Agricultural report (U.S. Department of Commerce, 1993) and Agriculture and Fisheries Statistics reports for Oregon (Oregon Agricultural Statistics Service, 1981, 1988, 1993; Korn, 1996b). These publications use slightly different crop categories and reporting methods; thus, the data are not always entirely consistent, depending upon which references provided the source material.

Thirteen counties—Benton, Clackamas, Columbia, Douglas, Lane, Lincoln, Linn, Marion, Multnomah, Polk, Tillamook, Washington, and Yamhill—lie completely or partly within the Willamette Basin (fig. 1). However, less than 2 percent each of Douglas, Lincoln, and Tillamook Counties fall within the basin; thus, data for these counties are not included in this report. Data for Columbia County also are not included because its drainage contributes only to a bypass channel from the lower Willamette River to the Columbia River, and this channel was not considered in studies conducted as part of the Willamette Basin NAWQA.

Gross farm sales for the nine primary Willamette Basin counties was $1.1 billion for all crops in 1992; 49 percent of this was derived from specialty crops, such as nursery plants and christmas trees.These gross farm sales represent more than a 75 percent increase from 1987 (Miles, 1988, 1994).

Agricultural commodities in the Willamette Basin are among the most diverse found anywhere in the United States. They have been grouped into eight general categories, with annual estimates of harvested acres presented in table 4 for 1980, 1987, and 1992 (U.S.

Table 3. GIRAS land use and TM land cover comparisons for subbasins sampled as part of water column, bed sediment, tissue, and (or) ecological studies in the Willamette Basin during 1992–95
[listed approximately from north to south; CF; Coast Fork; Mt., Mount; R, River; St., Saint]

Basin	Area (square miles)	Urban	Nonirrigated agriculture		Irrigated agriculture		Forest		Non-forested upland	Native valley vegeta-tion	Other	
		GIRAS/TM	GIRAS	TM	GIRAS	TM	GIRAS	TM	TM	TM	GIRAS	TM
Sum of Willamette and Sandy R Basins	12,000	6	17	9	5	8	70	60	14	2	2	1
Sandy River near Troutdale	484	2	1		2		93	84	12		2	2
Beaver Creek near Troutdale	14	67	3	4	27	15	3	3	9	2		
Fir Creek near Brightwood	6						100	94	6			
Willamette River at Portland	11,200	6	18	9	5	8	69	60	14	2	2	1
Johnson Creek at Milwaukee	49	67	3	4	20	12	10	6	9	2		
Johnson Creek at Hogan Road near Gresham	13	27	7	7	53	22	13	14	26	4		
Clackamas River at Oregon City	941	3	6	1	2	2	88	73	19	1	2	1
Tualatin River at West Linn	709	17	24	11	12	13	47	45	10	4		
Fanno Creek at Durham	31	92	2	1		1	5	2	2	1	1	1
Beaverton Creek at Beaverton	7	98					2	1	1			
Gales Creek near Glenwood	7						100	99	1			
Gribble Creek near Canby	10	9	68	35	21	51	2			5		
Senecal Creek at Donald Road	11	8	69	42	20	44	3			5		1
Pudding River at Aurora	480	5	42	20	16	23	37	33	15	4		
Bear Creek at Barlow-Monitor Road	20	12	71	38	15	41	2		2	7		
Zollner Creek near Mt. Angel	15	1	38	34	61	54		2	5	4		
Little Pudding River near Rambler Drive	41	22	58	35	17	33	3	1	4	5		
Pudding River near Mt. Angel	203	3	40	12	7	9	50	47	26	3		
Little Abiqua Creek near Scotts Mills	10		4				96	93	7			
Pudding River at Kaufman Road	25	1	84	28	6	15	9	7	44	5		
Pudding River Tributary at Cascade Highway	5	3	90	15	4	7	3	11	63	1		
McKay Reservoir near St. Paul	20		60	50	37	44	2			6	1	
Skookum Lake near Newberg	3		48	47	52	43				9		1
Willamette River at Newberg	8,320	4	17	10	4	7	73	63	14	1	2	1
Yamhill River at Dayton	771	2	33	18	6	12	58	53	12	3	1	
Palmer Creek at Dayton	36	1	62	27	24	40	10	12	13	7	3	
Rickreall Creek near Rickreall	82	5	38	20	4	12	52	47	15	1	1	
Luckiamute River near Suver	237	1	18	8	3	7	78	67	14	3		
Soap Creek near Corvallis	10		6	1		2	94	85	11	1		
Santiam River at Jefferson	1,780	2	9	4	2	4	86	73	15	1	1	1
Cedar Creek near Elkhorn	9						100	90	10			
Middle Fourth Lake near Albany	26	14	81	57	3	24	2	1	2	2		
Calapooia River at Albany	370	3	45	34	2	9	50	42	11	1		
Marys River at Corvallis	151	2	9	1		2	87	79	14	1	2	1
Muddy Creek near Peoria	146	2	67	54	4	11	27	20	11	2		
Muddy Creek at Nixon Road	47	2	51	44	9	12	37	26	14	2	1	
Muddy Creek at Weatherford Lane	31	3	32	25	7	10	57	40	21	1	1	
Little Muddy Creek at Nixon Road	60	1	60	44	2	8	37	30	16	1		
Willamette River near Corvallis	2,630	5	8	5	5	4	80	71	13	1	2	1
Long Tom River at Bundy Bridge	403	10	24	9	6	10	56	52	14	2	4	3
Long Tom River at Monroe	394	10	24	8	5	9	57	53	15	2	4	3
Ferguson Creek at Territorial Highway	21		20	7	3	7	77	74	10	2		
Ferguson Creek at Ferguson Road	6				1		99	96	4			
Bear Creek at Territorial Highway	27	1	28	8	2	10	69	64	15	2		
Amazon Creek near Eugene	24	65	16	3		8	19	14	10			
A-3 Channel at Wallis and 5th Street at Eugene	3	90	10	2		7				1		
McKenzie River near Coburg	1,340	1	1		1	1	94	76	20		3	2
Mack Creek near Blue River	2						100	97	3			
Mill Race Pond at Springfield	5	66	6	5	12	12	11	6	8	3	5	
Dorena Lake near Cottage Grove	265	1					98	92	6		1	1
CF Willamette R below Cottage Grove Dam	106	2	1				96	87	10		1	1
Cottage Grove Lake near Cottage Grove	106	1	1				96	87	10		2	1
CF Willamette River at London	71	1	1		1		97	91	8			
Dennis Creek below Black Butte Mine	1						95	68	32		5	
Garoutte Creek near Cottage Grove	6						100	84	15			1

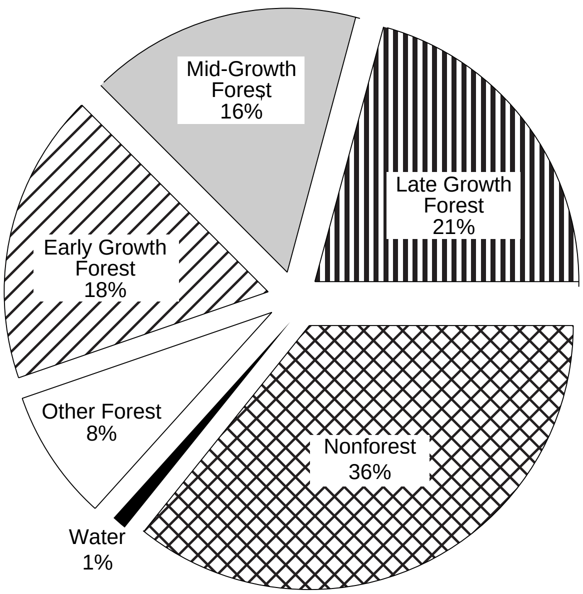


Figure 13. Land cover in the Willamette Basin in 1988 (data from Green and others, 1993).

Department of Commerce, 1993). Figure 14 shows 1992 percentages of major crop types for five of the eight general crop categories given in table 4.

During 1992, approximately 415,000 acres of grass and legume seeds, 210,000 acres of hay and silage, and 165,000 acres of grains (mostly wheat and oats) were harvested in the Willamette Basin (Miles, 1994; Oregon Agricultural Statistics Service, 1993). In addition, nearly 90,000 acres of major vegetables (mostly sweet corn, snap beans, and green peas) were sent to market. The Willamette Basin provides 98 percent of the Nation's hazelnuts, 80–90 percent of its caneberries (blackberries and raspberries), and 27 percent of its peppermint. Other crops grown in important amounts include hops, sugar beet and flower seed, cherries, wine grapes, prunes and plums, strawberries, blueberries, and nursery stock.

Value added to agricultural commodities by further processing and shipment to suppliers also has contributed significantly to Willamette Basin agricultural sales. Vegetables account for the largest increase in value added to all agricultural commodities. Beets and squash have the highest percent value added, with increases greater than 500 percent. Field crops, such as mint and hops, show the lowest percent increases, with less than 10 percent value added (Miles and Cornelius, 1994).

Nurseries recently have become the major agricultural commodity in Oregon and in the Willamette Basin, and their economic value has grown significantly since 1982 (fig. 15). Oregon was ranked third nationally in nursery production in 1992 (U.S. Department of Commerce, 1993), with sales in the Willamette Basin surpassing $320 million (Oregon Agricultural Statistics Service, 1993). This production represented 93 percent of Oregon's total nursery production and 11 percent of the State's agricultural production. In 1995, nurseries surpassed cattle to become Oregon's number one farming commodity, with more than $380 million in gross

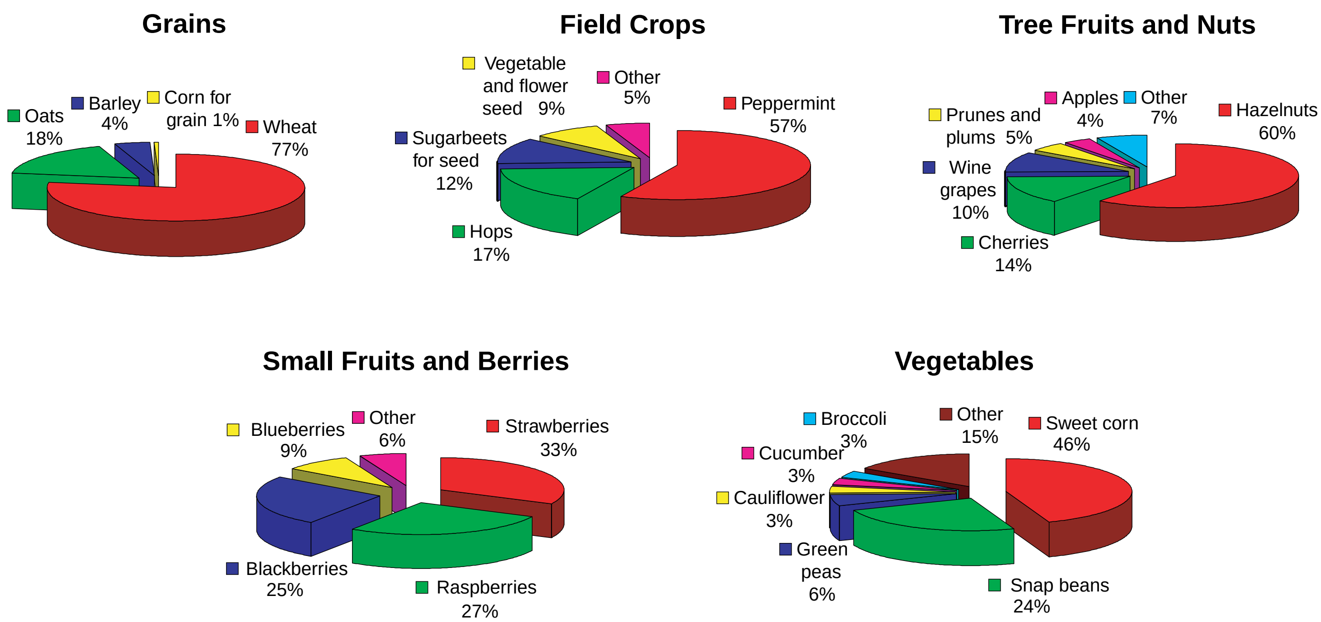


Figure 14. Percentage of harvested acres for selected major crops in the Willamette Basin during 1992 (data from U.S. Department of Commerce, 1993).

Table 4. Harvested acres for common crops in the Willamette Basin during 1980, 1987, 1992 (Economic Information Office, Agricultural and Resource Economics, Oregon State University, unpub. data, 1999).

Crop	1980	1987	1992
Grass and legume seeds	316,000	373,000	397,000
Hays and silage	181,000	210,000	197,000
Grains	312,000	212,000	165,000
Field crops	34,700	34,600	46,100
Tree fruits and nuts	38,400	40,000	42,900
Small fruits and berries	13,800	19,300	18,300
Vegetables	79,900	83,500	90,000
Nurseries and Christmas trees	1,770	4,730	6,420
TOTAL ACRES	977,570	977,130	962,720

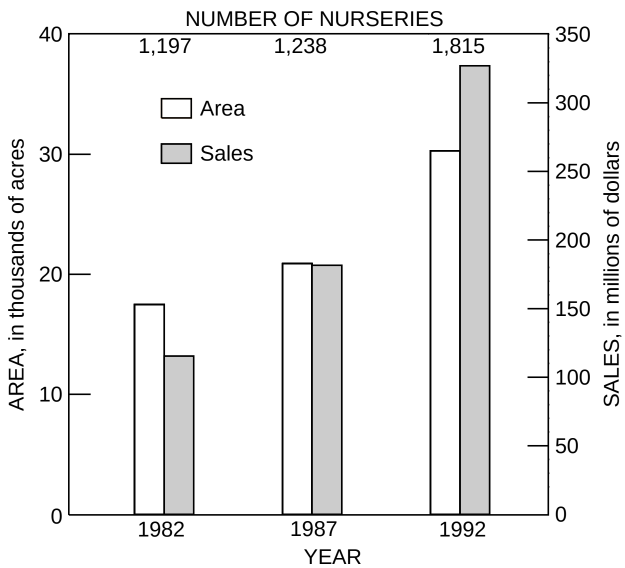


Figure 15. Importance of nurseries in the Willamette Basin (data from Oregon Agricultural Statistics Service, 1981, 1988, 1993).

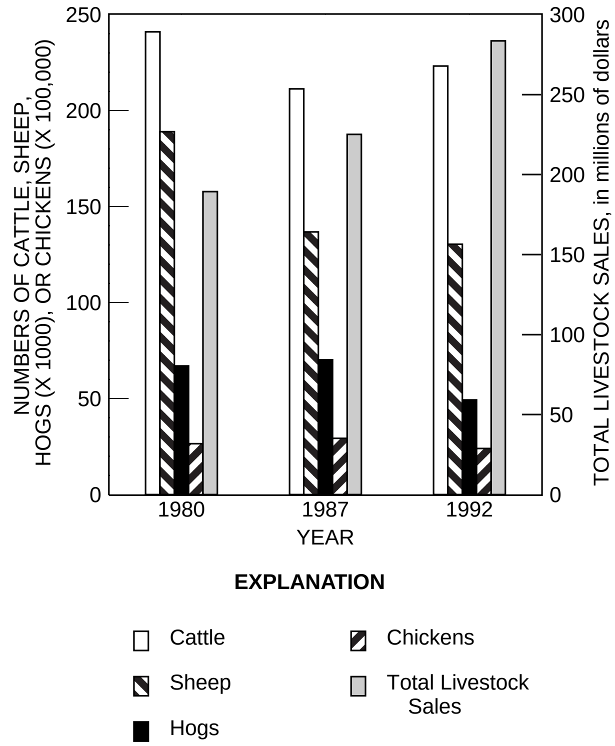


Figure 16. Livestock production in the Willamette Basin (data from Oregon Agricultural Statistics Service, 1981, 1988, 1993).

sales from nursery stock grown in the Willamette Basin (Korn, 1996a, 1996b; Leeson, September 29, 1995).

Numbers of cattle, hogs, and chickens raised in the Willamette Basin remained fairly stable from 1980 to 1992, although the numbers of sheep declined somewhat during that period (fig. 16). Cattle and dairy products represent the largest percentage of total livestock sales at 56 percent, followed by egg and poultry products at 36 percent. Animal products represented 21 percent of the 1992 total gross farm sales for the basin, with total livestock sales increasing by 50 percent from 1980 to 1992 (Oregon Agricultural Statistics Service, 1981, 1988, 1993; Miles, 1982, 1988, 1994).

SUMMARY

Urbanization, agricultural activities, and timber harvesting have been integral to the development of Oregon's economy. Settlement of the Willamette Basin began in the early 1800s, and the population has risen steadily since that time. In 1990, 2 million people (70 percent of Oregon's population) lived in the basin, with more than 90 percent of the basin population residing in the metropolitan areas of Portland, Eugene, and Salem. Agriculture was introduced in the Willamette Basin during the mid-1800s, and today agriculture is Oregon's primary industry. During 1992–93, the Willamette Basin accounted for more than one-half of Oregon's gross farm sales. Oregon has led the Nation in timber production since 1938, with most of this production originating in the Willamette Basin. Metal and aggregate mining have played small, though important, roles in the basin's economy throughout its history.

The environmental setting of the Willamette Basin has largely controlled its economic development. The basin is mostly forested (60–70 percent, depending on the data source). Forested areas are located primarily in the Coastal and Cascade mountains, which border the western and eastern sides of the basin, respectively. These areas receive up to 200 inches of precipitation per year and provide a solid base for timber production.

Agricultural land, which comprises 17–22 percent of the basin, is found predominantly in the low lying Willamette Valley between the Coastal and Cascade mountains. Here, temperatures are mild, and precipitation is adequate (40–50 inches per year, depending on location) for growing a variety of crops. Grass seed traditionally has been the primary crop in terms of acreage, but nurseries have become the largest crop in terms of sales. In addition, a large variety of specialty crops are grown, including hazelnuts, caneberries, peppermint, hops, wine grapes, and flower seed. Livestock provides about one-fifth of the basin's gross farm sales.

The Willamette River—13th largest in the United States in terms of discharge—provided ample streamflow for transportation of goods and people during early settlement of the Willamette Basin, and most of the major cities were founded on the banks of the river to take advantage of these opportunities. Much of the present urban land (6 percent of the basin) is still found in close proximity to the river.

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