Hydrologic Budget

The processes that affect ground-water supply in the Willamette Basin include recharge by infiltration of precipitation and applied irrigation water, the exchange of water between surface- and ground-water systems, and discharge by evapotranspiration and wells. Each of these processes is discussed below in an attempt to quantify the amount of ground water entering and leaving the ground-water system.

Recharge from Precipitation and Applied Irrigation Water

Infiltration of precipitation into the ground-water system is the main source of recharge in the Willamette Basin. Locally, recharge also occurs by infiltration of irrigation water, stormwater through subsurface gravel galleries (drywells), and surface water. This section discusses recharge from these sources, except from streams, which is discussed in a separate section on surface- and ground-water interactions.

In previous studies, recharge was estimated in the Portland Basin using a water-balance model, referred to as the Deep Percolation Model or DPM (Bauer and Vaccaro, 1987), which incorporated infiltration of runoff from drywells and onsite waste disposal (Snyder and others, 1994), and in the Willamette lowland using estimates from previous reports, the DPM, and correlation between the percent of precipitation recharged and surficial geology (Woodward and others, 1998). Neither of these studies provides a rigorous, consistent estimate of recharge over the entire Willamette Basin.

For this study, recharge estimates were based on watershed modeling using the Precipitation-Runoff Modeling System (PRMS) (Leavesley and others, 1983), except in the Portland Basin, where recharge was based on estimates by Snyder and others (1994). The PRMS models simulated surface-water conditions on a daily basis and average annual recharge values were estimated for the 1995 and 1996 water years, a wetter than average period that corresponds to the period when synoptic water levels and annual water-use information were collected in the basin. Monthly recharge in the central Willamette Basin was simulated for the 1999 and 2000 water years, a period of average precipitation when continuous water levels and monthly water-use information were collected. PRMS was modified to incorporate infiltration of irrigation water. Details of the application of PRMS models in the Willamette Basin may be found in Lee and Risley (2002). The following discussion focuses on the area simulated by the watershed models, which includes the drainage area upstream of Portland.

The simulated average annual recharge for the 1995-96 period (fig. 12) in the Willamette Basin closely corresponds to observed precipitation patterns (fig. 2). Recharge ranged from 7 in/yr (inches per year) in the lowland areas, where precipitation is less than 55 in/yr, to more than 40 in/yr in areas in the Coast and Cascade Ranges, where precipitation is more than 100 in/yr. The average recharge for the basin for the period was 22 in/yr. For comparison, this rate of recharge is equivalent to 18,000 ft^3/s (cubic feet per second), or approximately the average annual flow of the Willamette River at Salem. In the lowland, average annual recharge was 16 in/yr. Generally, recharge is greater in the higher elevations where precipitation is greater. As a percent of precipitation, recharge varied little, from a low of 27 percent of precipitation recharging the lowland to a high of 31 percent in the Coast Range.

Simulated recharge estimates were generally proportional to precipitation. Recharge estimates were higher than expected in the Coast Range and Western Cascade area where precipitation is high but steep slopes and low permeability bedrock promote runoff and reduce infiltration. PRMS overestimates recharge in these areas because once water infiltrates past the soil zone in the model, it is assumed to be recharge. In the Coast Range and Western Cascade area, however, water probably infiltrates to a shallow depth before discharging to streams within these regions. From a regional perspective, this infiltration is not recharge but shallow flow in the soil zone. High rates of recharge are reasonable in the High Cascade unit because of permeable material at the surface, high precipitation rates, and an undeveloped stream network (Ingebritsen and others, 1992). Most recharge in the Coast Range, Western, and High Cascade areas eventually discharges to streams within those regions and is unavailable as ground-water inflow to the lowland. Consequently, recharge to the lowland area occurs locally and is the source of water for most ground-water resources in the lowland.

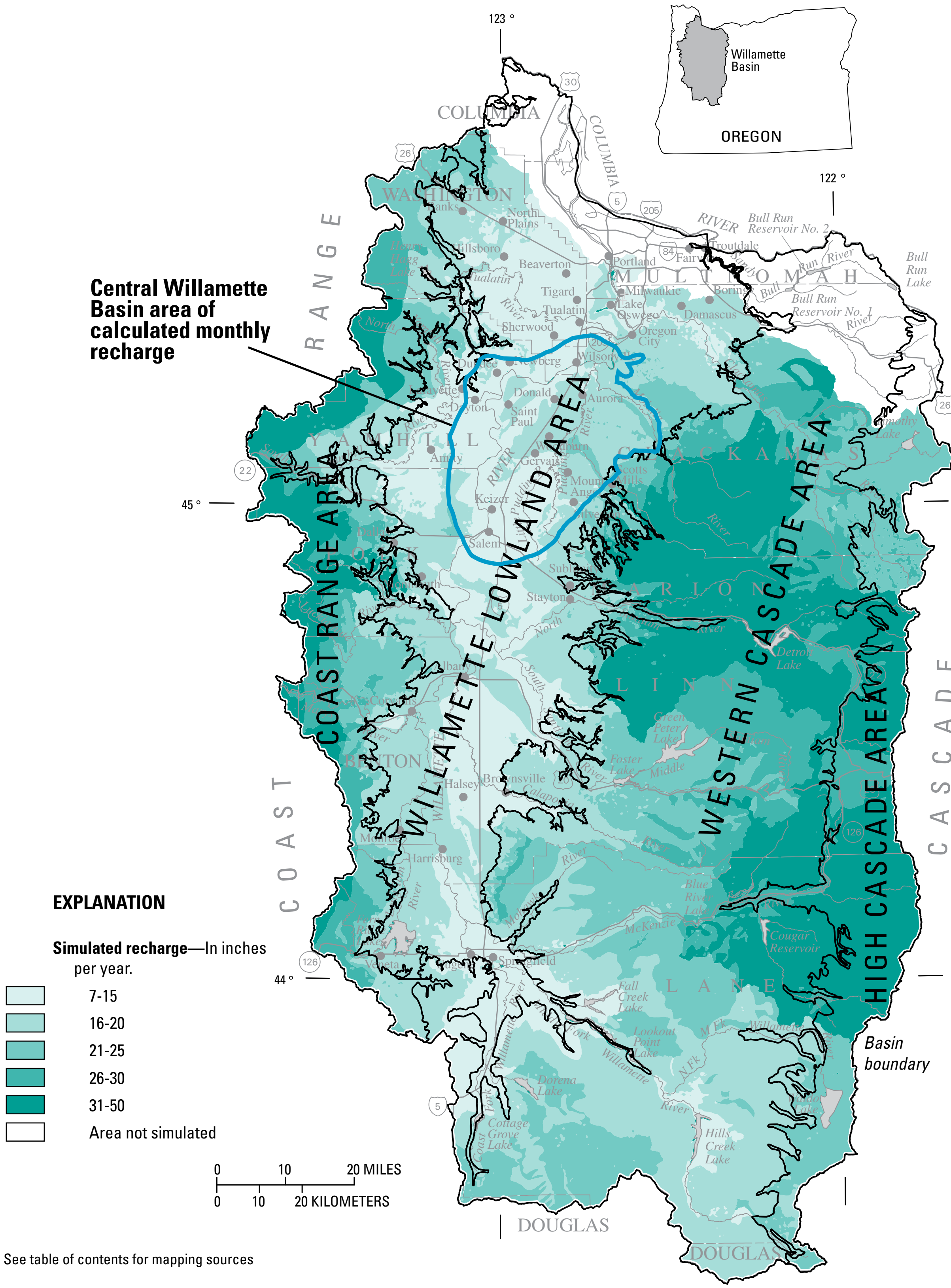


Figure 12. Simulated annual recharge, Willamette Basin, Oregon, 1995–96.

In the lowland area, simulated recharge is low because precipitation is less than in the mountain ranges. Recharge in lowland areas, where the permeable upper and middle sedimentary units are at the surface, is expected to be greater than in lowland areas underlain by less permeable units of the Willamette silt and the lower sedimentary units. The relatively young age of ground water in areas underlain by the upper sedimentary unit (Appendix B) suggests that the ability of water to infiltrate and recharge the ground-water system is greater than in areas underlain by the less permeable Willamette silt unit.

Recharge into the Willamette silt unit may be facilitated by ponding of precipitation on the flat surface of the unit. Although the low permeability of the unit inhibits recharge relative to more permeable units, standing water is available for recharge during much of the wet winter months. For the purpose of analysis, recharge simulated by PRMS will be used to compare components of the ground-water budget with the understanding that recharge may be overestimated in the Coast Range and Western Cascade area.

Recharge varies seasonally because of the large seasonal variation in precipitation. This variation (fig. 13) is shown for the central Willamette Basin (fig. 12) for water year 2000. Fall precipitation replenished soil moisture in the unsaturated zone. By November, soil moisture capacity was exceeded and recharge occurred. Although precipitation declined from November to December, recharge continued to increase because soil moisture was at capacity and precipitation was available for recharge and runoff. Recharge declined in February and March with decreasing precipitation. By April, evapotranspiration and runoff had consumed any additional precipitation, resulting in no recharge. An increase in precipitation in May resulted in a small amount of recharge. After May 2000, evapotranspiration and runoff consumed the modest amount of precipitation and soil moisture. A reduction in evapotranspiration occurred in July and August as soil moisture was depleted. Consequently, recharge was greatest in the wet, winter months and declined to zero in the dry, summer months, when evapotranspiration is large and precipitation is low.

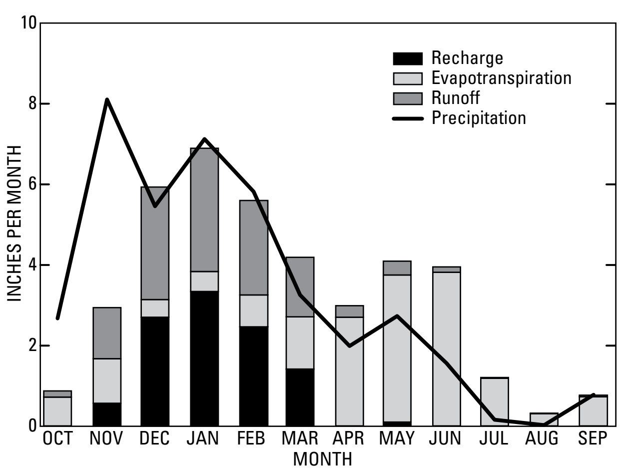


Figure 13. Simulated monthly water budget for water year 2000, central Willamette Basin, Oregon.

Interaction between Surface and Ground Water

Water exchanges, or seepage, occur between the ground-water system and surface-water bodies, such as streams. When the elevation of the stream is above the water table, a downward hydraulic gradient exists and stream water can seep downward to the underlying ground-water system, resulting in a losing stream. Conversely, the elevation of the water table may be above the elevation of the stream, resulting in ground-water seepage upward into the stream, resulting in a gaining stream. Losing streams provide recharge to the ground-water flow system, and ground-water discharge to gaining streams provides an important component of streamflow.

Regionally, streams in the High Cascade area show evidence that ground-water discharge to streams contributes a large proportion to streamflow (Ingebritsen and others, 1992, 1994; Woodward and others, 1998; Gannett and others, 2001; Lee and Risley, 2002; Tague and Grant, 2004). For these ground-water dominated streams, such as the Clackamas River at Big Bottom (USGS site number 14208000), the relatively constant ground-water discharge sustains summer flows and results in seasonal variation in streamflow of less than 50 percent of mean annual flow (fig. 14). Baseflow, which is a measure of the contribution of ground water to streamflow, is estimated to be more than 80 percent of streamflow for streams draining the High Cascade area (Lee and Risley, 2002). Because of the ability of the permeable High Cascade unit to absorb and store water, streams that originate in the High Cascade area provide a large portion of the summer flow to the Willamette River in the lowland (Woodward and others, 1998).

For runoff dominated streams of the Western Cascade area, lowland and Coast Range, such as the Little North Santiam, Molalla, and Luckiamute Rivers, streamflow is flashy, summer flows are small, and the seasonal variation is greater than 100 percent of mean annual streamflow (fig. 14). Baseflow as a percent of streamflow is 50 to 80 percent, considerably less than in streams draining the High Cascade area (Lee and Risley, 2002). Streams in the Coast Range and the Western Cascade area have high precipitation and snowfall, but drain older geologic areas with low permeability and more deeply incised streams resulting in a higher proportion of precipitation becoming surface runoff.

The remaining discussion of the interaction of surface and ground waters is focused in the lowland, where ground-water development is widespread. In the lowland, ground water discharges to streams but its contribution to annual streamflow is relatively small. During the rainy winters, both runoff and ground-water discharge contribute to streamflow. In the dry summers, ground water is the main component of streamflow and discharges at a low rate to streams. As ground-water levels decline during summer, ground-water discharge

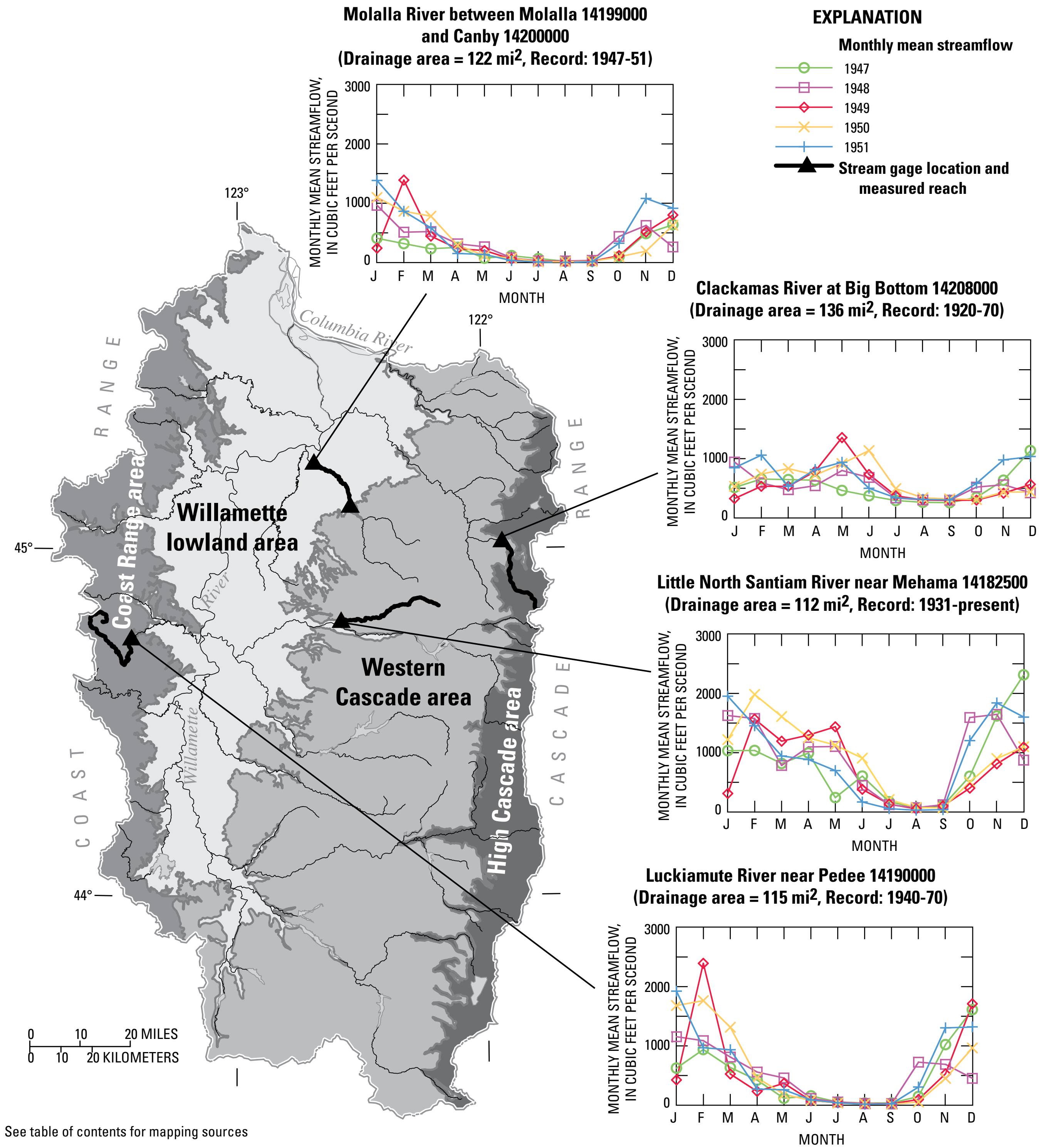


Figure 14. Mean monthly flow of streams of similar drainage area for period when measurements available for all sites, Willamette Basin, Oregon.

to streams decreases. Several methods were used to evaluate the interaction of ground and surface waters and how these exchanges are affected by the permeability of the material underlying the streams, such as the permeable upper and middle sedimentary units and the less permeable Willamette silt unit.

In the lowland, seepage runs, where seepage is calculated from the difference in streamflow at two points along a stream reach (Riggs, 1972), indicated that seepage was small relative to streamflow. In many instances, the calculated seepage was less than the uncertainty in the measurement (5 percent). Seepage was calculated for individual reaches and summed over adjacent reaches (Appendix C) to determine if seepage was greater than measurement uncertainty at different scales. Seepage values are shown in figures 15 and 16 at the scale where seepage is greater than measurement uncertainty. Where seepage is less than measurement uncertainty along individual reaches and cumulatively over many reaches, the entire length of the measured stream is shown without seepage values.

Seepage runs were conducted during low (summer and fall) and high (spring) flow conditions (Lee and Risley, 2002, and Appendix C). Streams gained in most reaches where seepage was greater than the measurement uncertainty and stream diversions were quantified (fig. 15 and 16). During low flows, the smaller streams that flow in a northwesterly direction along the eastern edge of the central Willamette Basin (Butte, Abiqua, and Drift Creeks) lost water in the upstream reaches and gained water in the downstream reaches (fig. 15); however, irrigation withdrawals from these streams were not quantified and could account for the apparent stream losses. The alternating gains and losses in the South Santiam (Appendix C) and Willamette Rivers (fig. 15, Appendix C), although less than the uncertainty in some of the measurements, may indicate shallow flow along short flow paths between the stream and the gravels of the streambed and adjacent floodplain (Laenen and Risley; 1997, Woodward and others, 1998; Hinkle and others, 2001; Laenen and Bencala, 2001; Fernald and others, 2001).

Gaining reaches throughout the lowland are consistent with the shape of shallow water-level contours (pl. 1). Most water-level contours bend upstream as they cross streams within the lowland indicating gaining stream reaches. The upstream bend of the contour is gentle across the broad, shallow floodplains of the Willamette River and major tributaries which are underlain by permeable upper sedimentary unit. The bend of the water-level contours is sharp across the deep narrow floodplains of the smaller streams underlain by less permeable Willamette silt unit, especially in the central Willamette Basin.

Gaining reaches were confirmed by comparing water levels in wells near streams to stream stage. Upward hydraulic gradients confirmed gaining reaches in streams flowing over the upper sedimentary unit (well 12S/05W-02AAA near Corvallis) and the Willamette silt unit (wells 04S/02W-01CDD01 and 05S/01W-28CCD02) (pl. 1).

Water levels in shallow wells near large streams (wells 11S/05W-35DDD and 06S/03W-04ACD) track stream stage, indicating a good hydraulic connection between the stream and the underlying upper sedimentary unit. Stream water is easily stored in the permeable bank during extremely high flows and ground water readily discharges to these regional discharge areas during most of the year.

The rate of ground-water discharge to streams flowing on the Willamette silt unit at six sites was estimated with seepage meters and by simulating one-dimensional heat transport (Conlon and others, 2003). Seepage meters estimate seepage by measuring the change in volume of water entering or leaving a bag connected to an open-ended steel drum pushed into the streambed (Lee and Cherry, 1978). Seepage is estimated with heat transport modeling by simulating the vertical flow beneath a stream necessary to match simulated to observed streambed temperature gradients (Niswonger and Prudic, 2003). The gains were small, ranged over two orders of magnitude, and provide a constraint of the ground-water discharge to streams flowing over the Willamette silt unit (table 3).

The small gains to streams flowing on the Willamette silt unit are due to the poor hydraulic connection between the streams and the underlying ground-water system. This poor connection is a result of the low hydraulic conductivity of the Willamette silt unit. The vertical hydraulic conductivity was estimated using heat transport modeling and ranged from 0.04 to 0.7 ft per day (table 3), which probably represent maximum values. Most ground-water discharge to these streams occurs from the Willamette silt unit and is small relative to streamflow (Iverson, 2002). Upward flow from the middle sedimentary unit is limited by the low vertical hydraulic conductivity of the overlying Willamette silt unit. Similarly, where pumping locally from the middle sedimentary unit lowers ground-water levels below the stream stage, losses of stream water to the ground-water flow system are expected to be small. The ground-water discharge per unit area in streams underlain by the less permeable Willamette silt unit is small (table 3) relative to gains in streams that flow over the permeable upper sedimentary unit.

Quantifying ground-water discharge to streams and stream losses to the ground-water system in the Willamette Basin is difficult. For large streams with permeable streambeds, large gains are expected; however the calculated gains and losses are generally less than seepage run measurement uncertainty because of large flows and flow regulation. For smaller streams with less permeable streambeds consisting of the Willamette silt unit, gains are smaller than the measurement uncertainty, despite the low flow of these streams. Regional ground-water discharge to streams will be estimated as the residual of an annual regional water balance in the section Budget Summary.

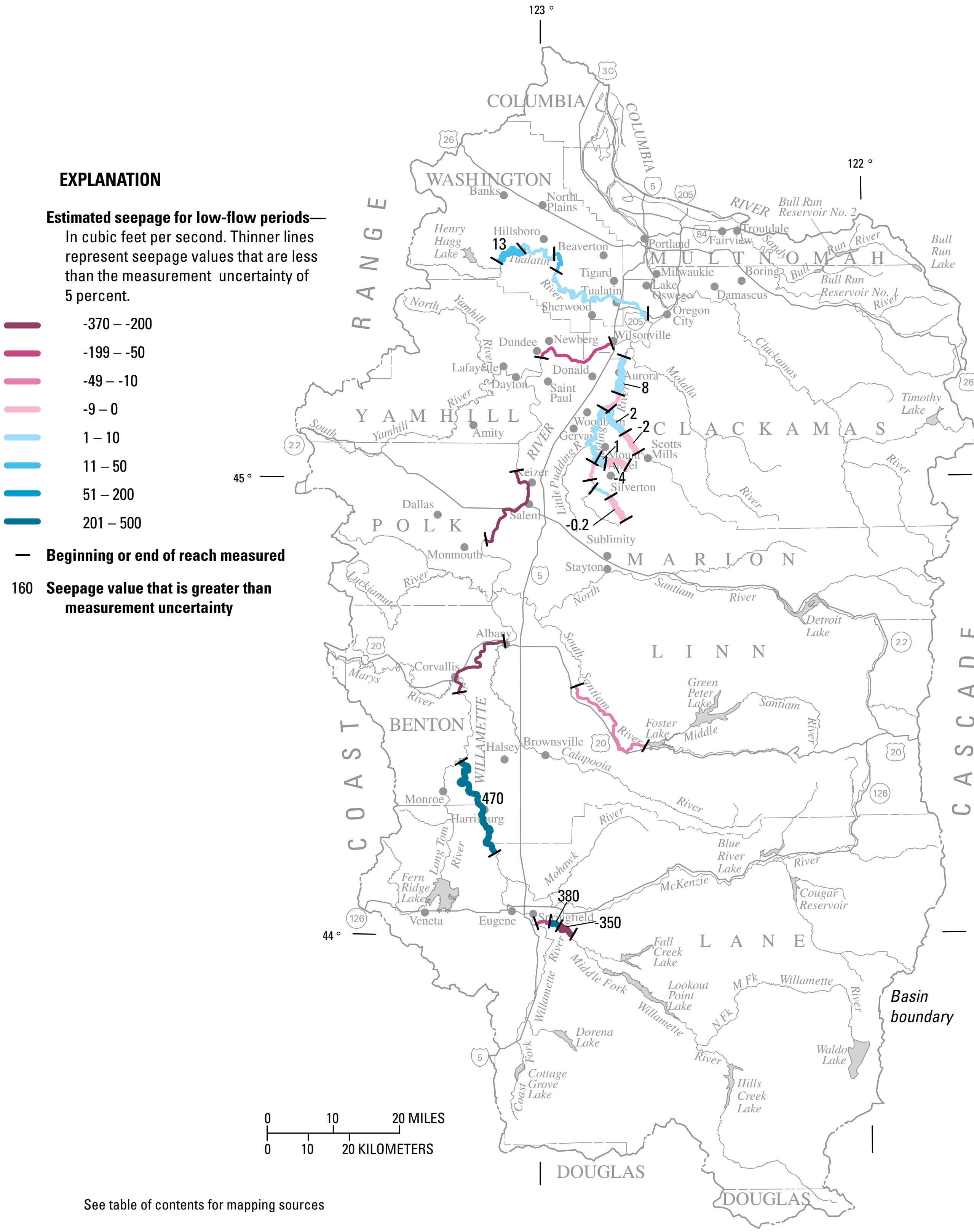


Figure 15. Estimated seepage for selected streams during low flow periods, summer and fall 1993, 1996, and 2000, Willamette Basin, Oregon.

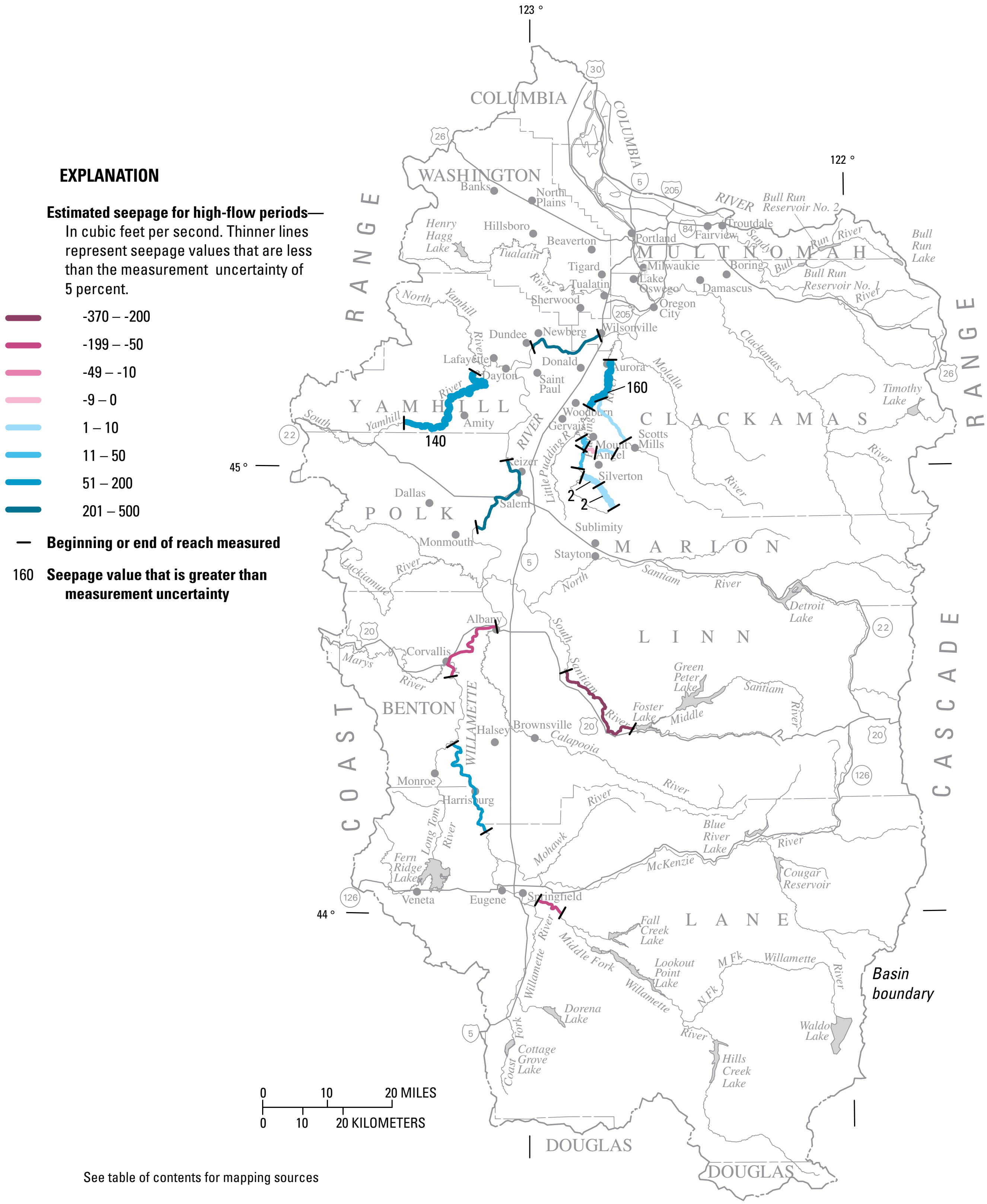


Figure 16. Estimated seepage for selected streams during high flow periods, spring 1996 and 2000, Willamette Basin, Oregon.

Table 3. Selected stream gains and losses in the Willamette Basin, Oregon.

[RM, river mile; WSU, Willamette silt unit; USU, upper sedimentary unit; ft, feet; d, day; Kv, vertical hydraulic conductivity, MF, Middle Fork. Unit gain is calculated by dividing volumetric gain by area over which gain occurs. For seepage runs, the area is the estimated width times the distance between river miles. For seepage meters, the area is the area of the seepage meter drum]

Stream	From RM	To RM	Date	Streambed material	Seepage run unit gain (+) or loss (-) (ft/d)	Seepage meter unit gain (ft/d)	Heat tracing unit gain (ft/d)	Heat tracing Kv (ft/d)	Estimated river width (ft)
Case Creek	at 0.1	na	August 2000	WSU	na	0.003	0.10	0.67	--
Little Pudding River	at 9.0	na	August 2000	WSU	na	0.001	0.02	na	--
Upper Pudding River	at 48.5	na	August 2000	WSU	na	0.006	0.01	0.33	--
Zollner Creek	at 1.0	na	August 2000	WSU	na	0.249	0.01	0.04	--
Lower Pudding River	at 22.5	na	August 2000	WSU	na	0.001	0.17	0.25	--
Butte Creek	at 2.5	na	August 2000	WSU	na	0.004	0.15	na	--
Butte Creek	5.9	1	9/12/2000	WSU	0.15	na	na	na	20
Pudding River	17.5	8.1	9/21-22/2000	WSU	0.29	na	na	na	50
MF Willamette River	195	192.8	7/23/1996	USU	-26.03	na	na	na	200
MF Willamette River	192.8	190.5	7/23/1996	USU	27.14	na	na	na	200
MF Willamette River	169.6	149.6	7/24/1996	USU	3.85	na	na	na	200
Johnson Creek*	3.2	2.2	7/21-22/2000	USU	0.53	na	na	na	50
Crystal Springs Creek*	1.8	0	8/7/2000	USU	4.87	na	na	na	20

* Gains in Johnson and Crystal Springs Creeks result from spring flow over distances shorter than the reach between discharge measurements. Consequently, seepage run unit gain is a minimum value.

Evapotranspiration

Evapotranspiration occurs from the unsaturated zone as water percolates to the water table and from the saturated zone when the water table is within the rooting depth of plants. Evapotranspiration from the unsaturated zone is accounted for in the watershed model PRMS and is discussed in Lee and Risley (2002). Evapotranspiration from the saturated zone is estimated where the water table is within 10 ft of the land surface between April and September.

Of the approximately 5,000 wells considered in this report, 10 percent of the wells had water levels less than 10 ft below land surface. In the central Willamette, Tualatin, and Portland Basins, shallow water levels are limited to the small area containing the floodplains of streams and are assumed to be insignificant. The assumption that evapotranspiration is negligible in these areas is based on a limited data set of wells that are generally completed below the Willamette silt unit in the upper and middle sedimentary units. In the southern Willamette Basin, shallow water levels suggest evapotranspiration is possible from an area of about 1,100 mi^2 (square miles).

The maximum amount of water that could be consumed by evapotranspiration from the saturated zone annually is estimated based on potential evapotranspiration computed by the PRMS watershed models. Lee and Risley (2002) estimated the potential evapotranspiration possible if an unlimited amount of water were available, and the actual evapotranspiration, which reflects the availability of moisture in the unsaturated zone to satisfy potential evapotranspiration. The residual evapotranspiration is the remaining amount of potential evaporation possible from the saturated zone that is not satisfied by actual evapotranspiration at land surface.

The average annual rate of residual evapotranspiration for 1995–96 in the 1,100 mi^2 area in the southern Willamette Basin is 28 in/yr (inches per year). Actual evapotranspiration is less than 28 in/yr because there are no long-term water-level declines as would be expected if the actual evapotranspiration rate in the saturated zone exceeded the recharge rate of 16 in/yr. Actual evapotranspiration from the saturated zone is probably less than the recharge rate of 16 in/yr. For purposes of the water budget, evapotranspiration from the saturated zone is assumed to be 50 percent of the recharge rate in the lowland, or 8 in/yr. Assuming this rate, annual evapotranspiration from the water saturated zone is equivalent to 630 ft^3/s, or 460,000 acre-ft/yr (acre-feet per year). This estimate represents an upper bound on evapotranspiration because (1) the water table is not at or near the land surface, but at some depth below the land surface, (2) plants grown in the area, such as turf grass and grass for grass seed, may have shallow roots that do not extend to the water table, and (3) not all areas within the 1,100 mi^2 area have shallow water levels.

Well Discharge

Most ground-water use in the Willamette Basin falls into four categories: public supply, irrigation, industrial, and domestic. Public supply includes all water distributed by public water utilities within utility boundaries, including water used for drinking, industrial, commercial, and irrigation purposes. Public supply use includes municipal water use. Irrigation use is predominantly rural agricultural crop irrigation but also includes nursery irrigation and some irrigation of golf courses and parks that is not supplied by water utility wells. Industrial use includes ground water pumped from non-public supply wells for manufacturing, food processing, and other industrial or commercial processes. Domestic use refers to pumpage from private domestic wells.

Ground-water withdrawal estimates were made for irrigation, public supply, and industrial use and are described below. Withdrawals were estimated for each hydrogeologic unit and summarized by basin. Annual pumpage for the entire basin was estimated for water years 1995 and 1996. Monthly withdrawals were estimated for the central Willamette Basin for water years 1999 and 2000. Estimates for domestic use were not made because the consumptive portion of domestic use was assumed to be small and because domestic use is assumed to be a small fraction of the regional water budget. Collins and Broad (1996) estimated that about 40 acre-ft/yr (0.6 ft^3/s) of water was pumped for domestic use in the entire Willamette lowland (including Clark County, Washington) in 1990. Consumptive domestic use may, however, be a large component of the local water budget in areas of dense rural residential development, even when land parcels are small, if landowners collectively irrigate substantial areas of lawns, gardens, and pastures. This is more likely to be the case where rural domestic development occurs in upland areas underlain by the Columbia River basalt and basement confining units.

Methods

Estimates of ground-water withdrawals for public supply are based on annual reports of monthly water-use that public-water purveyors submit to the OWRD for each permitted well. Missing data were obtained directly from water suppliers, extrapolated from the reports of previous years with an adjustment for population growth, or estimated from population data.

Industrial water use was estimated using water right data from the OWRD and data from periodic surveys of water-use by the U.S. Geological Survey (Broad and Collins, 1996; Collins and Broad, 1996). Estimates were based on permitted water rates, waste-discharge permits, and supplemental information from interviews with facility operators.

Estimates of ground-water withdrawals for irrigation were based on water right information and satellite imagery because irrigation water use is not reported. Water rights specify a maximum allowable use but do not provide a good indication of actual use in any given year. Crop rotation patterns, changes in land use or ownership, economic considerations, and other factors affect actual water use in any given year or area. Because of these factors, irrigation pumpage was estimated using 1992 LANDSAT satellite images by the following procedure: (1) Land cover by crop type was classified using spectral data from LANDSAT thematic mapper images. (2) Lands irrigated with ground water were determined using water right records. (3) Irrigation water needs were estimated by multiplying these acreages by crop water requirements minus any precipitation that fell during the irrigation season. Where ground water is used to supplement surface-water rights, ground-water withdrawals were assumed to annually account for 50 percent of irrigation water needs on lands. (4) Withdrawals from wells were calculated by dividing irrigation water needs by the irrigation efficiency which was assumed to be 0.75 (King and others, 1978) for the entire basin. Pumpage was assigned to hydrogeologic units based on completion intervals from well logs or based on the hydrogeologic units underlying the well location if a well log was not identified for the water right. Monthly withdrawals were estimated in the central Willamette Basin for 1999 and 2000 by distributing crop water requirements over the growing season for each crop type based on evapotranspiration and precipitation.

Many factors introduce uncertainty into estimates of irrigation water use in the Willamette Basin. For example, many of the crops grown in the basin have similar spectral properties in satellite imagery, but may have substantially different water needs. Small fields, many less than 20 acres in size, and variable crop types increase the difficulty of producing a coherent land-cover classification. In addition, different irrigation methods can result in substantially different amounts of applied water, even for the same crop. This is an important consideration in assessing the water use of the expanding nursery industry where irrigation methods range from hand-line sprinklers, to low-pressure overhead sprinklers, to drip irrigation systems. To assess these factors, extensive field inspections during 1999 were used to evaluate uncertainties in irrigation water-use estimates. The results indicate that irrigated croplands can generally be distinguished from nonirrigated croplands with a high degree of confidence. However, extensive field inspections are necessary to refine land cover classifications to a crop-specific level and to evaluate the impact of varying irrigation methods.

More refined estimates of irrigation water use were made in the central Willamette Basin during 1999 and 2000 by using three sets of LANDSAT images over the irrigation season and by conducting periodic field inspections to verify crop types and irrigation practices. In addition, unlike most other areas in the Willamette Basin, up-to-date digital water right maps were available for the entire central Willamette Basin and well logs were identified for most water rights in the area. Because of these factors, estimated withdrawals in 1999 for the central basin were presumed to be more accurate than those determined during the 1995–96 regional analysis. Estimates made in 1999 were about 60 percent of those made in 1995–96. Because county crop production summaries indicated little change in crop acreages between these time periods, this proportion was assumed to be caused by systematic overestimation of irrigated acreages due to uncertainty in the classification of 1992 satellite imagery in the basinwide estimate. The proportion was also assumed to be typical of the entire Willamette Basin and was used to adjust the basinwide irrigation water use for the 1995–96 period.

Annual Ground-Water Withdrawals in the Willamette Basin in 1995 and 1996

Annual ground-water withdrawals in the Willamette Basin for 1995 and 1996 are summarized in table 4 by category of use, hydrogeologic unit, and drainage basin. Most ground water is withdrawn from permeable units in the lowland (fig. 17). Total pumpage was about 300,000 acre-ft, the equivalent of a mean annual pumping rate of about 400 ft^3/s. This represents 10 percent of annual recharge in the lowland. For comparison, this is equal to about 1 percent of the average annual flow of the Willamette River at Portland (33,400 ft^3/s) and about 32 percent of the average annual flow of the Pudding River at Aurora (1,250 ft^3/s). Of the total withdrawals, 81 percent was pumped for irrigation, 14 percent for public supply, and 5 percent for industrial use. These proportions are typical of all areas except the Portland Basin, which had a smaller proportion of irrigation use (40 percent) and larger proportions of public supply (37 percent) and industrial (24 percent) use, a distribution that is consistent with a larger fraction of urbanized area in the Portland Basin.

About 48 percent of all ground-water withdrawals occurred in the central Willamette Basin, 39 percent in the southern Willamette Basin, 9 percent in the Portland Basin, and 5 percent in the Tualatin Basin. Most pumpage in the central and southern basins was for irrigation, which in these two areas accounted for 74 percent of the total ground-water use in the entire Willamette Basin. Lower pumpage in the Portland Basin reflects the smaller area available for irrigation in the basin and a greater reliance on surface water for public supplies. Pumpage in the Tualatin Basin is limited by the lack of productive aquifers.

Most ground water in the Willamette Basin was withdrawn from basin-fill sediments (86 percent) with lesser amounts pumped from the Columbia River basalt (11 percent) and basement confining units (3 percent). Within the basin-fill sediments, the largest fraction of pumpage was from the middle sedimentary unit with a slightly smaller fraction from the upper sedimentary unit and a much smaller fraction from the lower sedimentary unit.

About 73 percent of all pumpage in the Willamette Basin is from the upper and middle sedimentary unit, most of which is used for irrigation in the central and southern basins. More water is drawn from the middle sedimentary unit in the central Willamette Basin, where wells are widely distributed and thick

Table 4. Mean annual ground-water use in the Willamette Basin, Oregon, 1995–96.

[USU, upper sedimentary unit; MSU, middle sedimentary unit; LSU, lower sedimentary unit; CRB, Columbia River basalt unit; BCU, basement confining unit]

Willamette Basin ground-water withdrawals							
	Withdrawals by category		Withdrawals by category and hydrogeologic unit				
Willamette Basin	Pumpage by category (acre-feet)	Percent of Willamette Basin	USU (acre-feet)	MSU (acre-feet)	LSU (acre-feet)	CRB (acre-feet)	BCU (acre-feet)
Irrigation	241,100	81.0%	79,700	104,000	25,900	24,400	7,000
Public supply	42,700	14.4%	9,200	14,900	10,400	6,600	1,600
Industrial	13,700	4.6%	1,500	7,100	3,600	1,300	200
Total	297,500		90,400	126,000	39,900	32,300	8,800
Percent		100.0%	30.4%	42.4%	13.4%	10.9%	3.0%

Ground-water withdrawals by region							
	Withdrawals by category		Withdrawals by category and hydrogeologic unit				
Portland Basin Region	Pumpage by category (acre-feet)	Percent of Subbasin	USU (acre-feet)	MSU (acre-feet)	LSU (acre-feet)	CRB (acre-feet)	BCU (acre-feet)
Irrigation	10,200	39.7%	4,100	5,500	70	500	10
Public supply	9,400	36.6%	30	6,300	2,700	300	0
Industrial	6,100	23.7%	800	3,800	900	600	0
Total	25,700		4,930	15,600	3,670	1,400	10
Percent of subbasin		100.0%	19.2%	60.7%	14.3%	5.4%	0.0%
Tualatin Basin							
Irrigation	11,900	84.2%	0	0	4,700	6,900	300
Public supply	2,000	13.9%	0	0	0	2,000	0
Industrial	300	1.9%	0	0	200	100	0
Total	14,200		0	0	4,900	9,000	300
Percent of subbasin		100.0%	0.0%	0.0%	34.5%	63.4%	2.1%
Central Willamette Region							
Irrigation	123,000	86.1%	16,600	69,400	20,200	14,400	2,500
Public supply	14,300	10.0%	600	2,800	6,700	4,100	4
Industrial	5,600	3.9%	500	2,600	1,900	700	0
Total	142,900		17,700	74,800	28,800	19,100	2,504
Percent of subbasin		100.0%	12.4%	52.3%	20.2%	13.4%	1.8%

Table 4. Mean annual ground-water use in the Willamette Basin, Oregon, 1995–96—Continued.

[USU, upper sedimentary unit; MSU, middle sedimentary unit; LSU, lower sedimentary unit; CRB, Columbia River basalt unit; BCU, basement confining unit]

	Ground-water withdrawals by region						
	Withdrawals by category		Withdrawals by category and hydrogeologic unit				
Southern Willamette Region	Pumpage by category (acre-feet)	Percent of Subbasin	USU (acre-feet)	MSU (acre-feet)	LSU (acre-feet)	CRB (acre-feet)	BCU (acre-feet)
Irrigation	96,000	83.6%	59,000	29,100	900	2,700	4,200
Public supply	17,100	14.9%	8,600	5,700	1,000	300	1,600
Industrial	1,700	1.5%	200	600	600	0	200
Total	114,800		67,800	35,400	2,500	3,000	6,000
Percent of subbasin		100.0%	59.1%	30.8%	2.2%	2.6%	5.2%

coarse-grained alluvial fan deposits underlie broad areas of the valley floor, compared to thin strips of younger floodplain sediments, which are restricted to narrow floodplains (figs. 4 and 7). A greater proportion of pumpage is from the upper sedimentary unit in the southern Willamette Basin, where wells are concentrated in the Willamette River floodplain.

Only 13 percent of all ground-water withdrawals are from the lower sedimentary unit, and most of these withdrawals occur in the central Willamette Basin, where permeable lenses of sand are common in the upper part of the unit. Almost 90 percent of all pumpage from the Columbia River basalt unit occurs in the Tualatin and central Willamette Basins, mostly for irrigation use. In the central Willamette Basin, most of these withdrawals occur at the eastern margin of the valley floor, where the basin-fill sediments are thin.

The proportion of pumping from each hydrogeologic unit varies considerably between basins because of variations in the geology of each basin. For example, the lack of thick coarse-grained sediments in the Tualatin Basin (figs. 4 and 7) accounts for the small proportion of pumpage from the basin-fill sediments (35 percent) and the large proportion of pumpage from the Columbia River basalt unit (63 percent). Similarly, the absence of the Columbia River basalt unit in most of the southern Willamette Basin results in a small contribution to pumpage from the unit.

Over 10,000 wells irrigate about 240,000 acres of land based on valid primary ground-water rights in the Willamette Basin. However, a significant fraction of these lands are not irrigated in any given year because of crop rotation patterns. About 241,000 acre-ft of ground water was pumped for irrigation use in 1995, 91 percent of which was withdrawn from the central and southern Willamette Basins (table 4). A comparison of estimated pumpage for 1990 (Collins and Broad, 1996) indicates that irrigation withdrawals increased by 32 percent in the southern basin, 12 percent in the central basin, and 170 percent in the Tualatin Basin. A comparison for the Portland Basin was not made because the 1990 report included parts of Clark County, Washington.

Most large cities in the Willamette Basin, including Portland, Salem, Albany, Corvallis, and Eugene, rely principally on surface water for their public water supplies. Many of these cities are located adjacent to major streams that have additional water available for future demands; however, most will increase their reliance on ground-water supplies in the future. For example, the Portland Water Bureau has developed a large well field to supplement surface water in the summer when municipal demands are high and serve as an emergency backup supply. Similarly, Eugene is developing well fields to meet some of their growing water demand. Many smaller cities in the Willamette Basin are largely, or wholly, dependent upon ground water. Most of these cities are adjacent to smaller streams that have a limited capacity to meet future demands. In many cases, ground-water sources are the only available short-term option for meeting future water demands.

In 1995 and 1996, about 42,700 acre-ft of ground water were withdrawn for public supplies in the Willamette Basin from 182 wells serving 51 community water systems (table 4, fig. 17c). Withdrawals were greatest in the southern (17,100 acre-ft) and central (14,300 acre-ft) Willamette Basins and least in the Portland (9,400 acre-ft) and Tualatin (2,000 acre-ft) Basins.

In the Portland and Tualatin Basins, surface water from Bull Run reservoirs supplies most of the municipal needs of the City of Portland and many of its suburbs. Other communities in the Portland Basin rely completely or partially on ground-water sources. Major ground-water users include the cities of Milwaukie, Troutdale, and Fairview, and the Damascus Water District. Most ground water in the basin is pumped from basin-fill sediments, except in Damascus, where some ground water is withdrawn from the Columbia River basalt unit. In the Tualatin Basin, where the basin-fill sediments are predominantly fine grained, all publicly supplied ground water is withdrawn from the Columbia River basalt unit. Major users include the cities of Sherwood, Tigard, North Plains, and Banks, and the Rivergrove Water District near Lake Oswego.

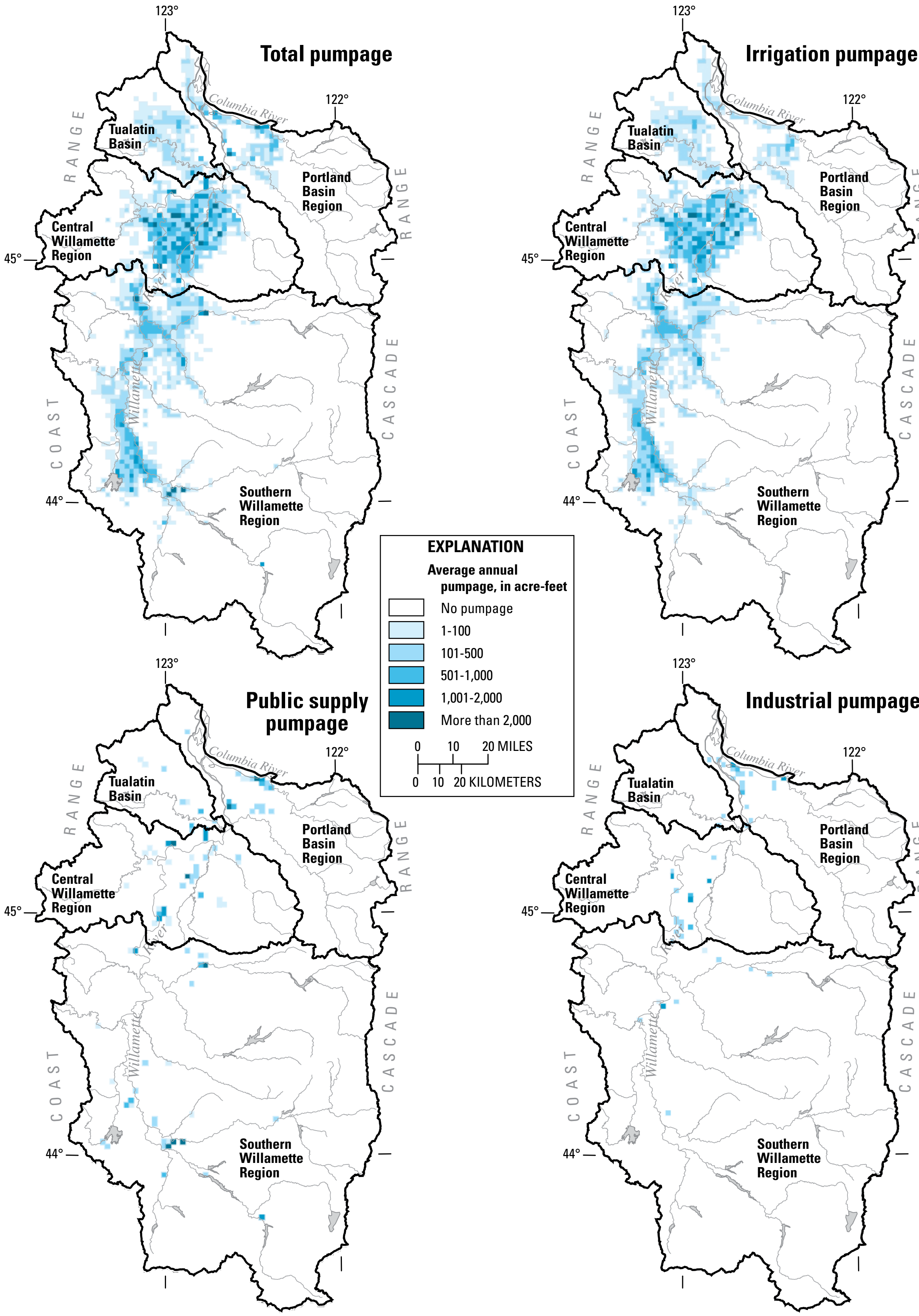


Figure 17. Mean annual ground-water use, 1995–96, Willamette Basin, Oregon.

Except for Salem, most cities in the central Willamette Basin use ground water as their principal source of water. About two-thirds of these withdrawals are from basin-fill sediments and one-third from the Columbia River basalt unit. Major users include Keizer, Wilsonville, Newberg, Woodburn, and Salem. The Cities of Wilsonville, Mount Angel, Dayton, Lafayette, and Scotts Mills withdraw ground water from the Columbia River basalt unit. Because of long-term water-level declines, the City of Wilsonville discontinued withdrawals from the Columbia River basalt unit in 2002 and began using water from the Willamette River as its main source, retaining wells completed in the Columbia River basalt unit as a backup supply.

The Springfield Water Utility Board is the largest ground water user in the southern Willamette Basin. Ground water is also used by Harrisburg, Monroe, Brownsville, Halsey, Veneta, and many other small cities. Almost 90 percent of this pumpage is from the basin-fill sediments.

Industrial withdrawals of ground-water in 1995 totaled about 13,700 acre-ft, about 5 percent of the total ground-water use in the basin. Most of this use occurred at scattered localities in the Portland and central Willamette Basins for food processing, metals, and forest products industries.

Monthly Ground-Water Withdrawals in the Central Willamette Basin in 2000

Annual ground-water withdrawals provide a general gauge for evaluating the impacts of wells on hydrologic systems. However, pumpage impacts can vary greatly within a year if seasonal withdrawals are variable. To assess this variability, monthly ground-water withdrawals were estimated for the central Willamette Basin for the year 1999 (fig. 18). The annual water use of the central Willamette region (table 4) differs from the sum of the monthly water use (fig. 18) because the area of the central Willamette region (fig. 17) differs from the area of the central Willamette Basin (fig. 12). Total ground-water pumpage for the year 1999 was estimated to be about 135,200 acre-ft. About 88 percent of the total was used for irrigation between the months of May and October, 10 percent for public supply, and 2 percent for industrial use. Withdrawals were greatest in the summer and least in the winter. All uses increased during the summer but changes in irrigation use were greatest. The average monthly withdrawal for the year was about 11,300 acre-ft per month. However, from November through April, typical withdrawals were about 900 acre-ft per month mostly for public supply and industrial uses. In contrast, withdrawals in July were about 42,000 acre-ft. Thus, peak withdrawals in July are about 4 times the annual mean monthly withdrawal and about 45 times the typical monthly withdrawal in winter months.

A perspective for comparing seasonal ground-water withdrawals to surface-water flows in the central Willamette Basin can be gained by comparing the monthly equivalents of continuous ground-water pumping rates, in cubic feet per second, to mean monthly streamflows in the Willamette River at Salem and the Pudding River at Aurora (table 5). In the winter months, ground-water withdrawals are equivalent to less than 1 percent of mean monthly flow in the Pudding River and less than 0.1 percent of mean monthly flow in the Willamette River. In July, however, the ground-water withdrawals are equivalent to about 460 percent of the mean July flow in the Pudding River and about 10 percent of mean July flow in the Willamette River. Although mean annual ground-water pumpage is relatively small compared to mean annual streamflow in the Willamette and the Pudding Rivers, ground-water pumpage in the summer is equivalent to a much larger fraction of summer flows in these streams.

Budget Summary

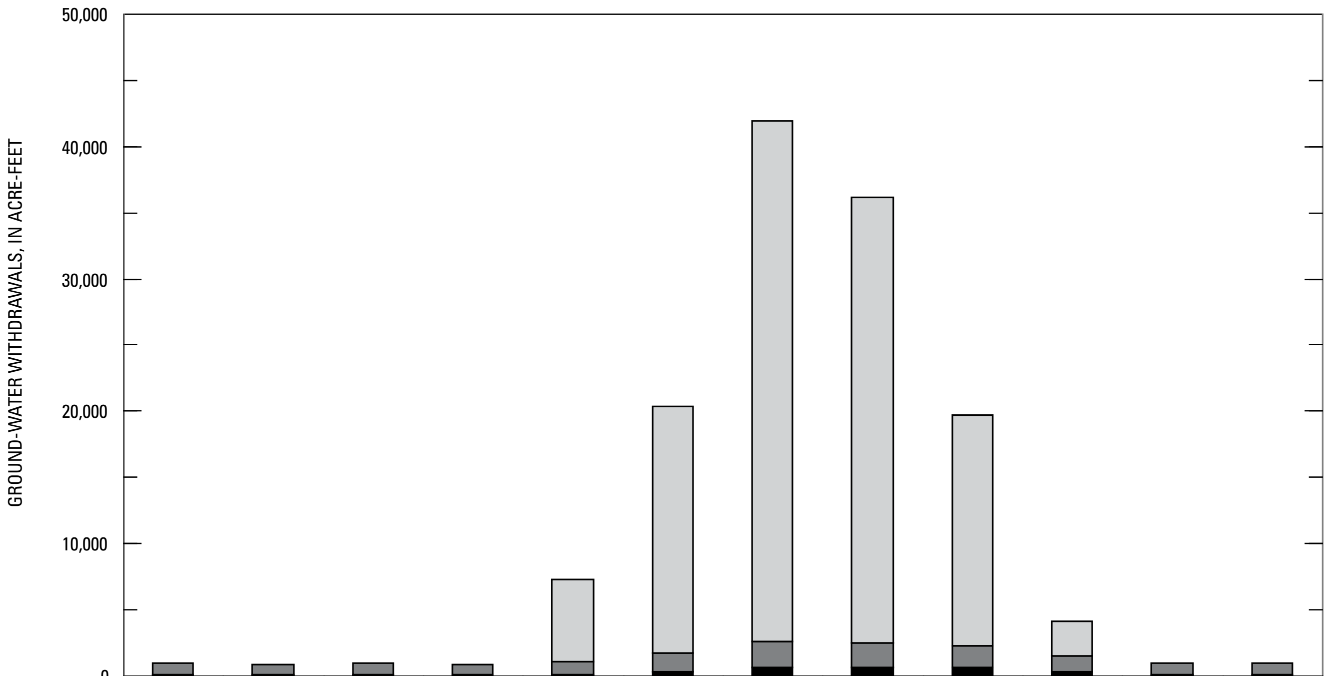
In the previous sections, the components of the hydrologic and ground-water budgets of the Willamette Basin were described and estimated. Although all these quantities are estimated and contain uncertainties, they may be used to estimate a hydrologic and ground-water budget for the Willamette Basin. The following analysis is limited to 1995–96 values for the area within the Willamette Basin modeled using PRMS, which is the area upstream of the Willamette River stream gage at Portland. The area does not include parts of the Portland Basin, including the Sandy River drainage area.

The hydrologic budget, in this report, quantifies how precipitation is divided between recharge to the ground-water system, evapotranspiration from the unsaturated zone, and runoff to streams. The ground-water budget estimates how recharge is divided between evapotranspiration from the saturated zone and discharge to streams and wells. Ground-water inflow to and outflow from the ground-water system are not quantified in the budget. The budgets are computed for three different scales: the Willamette Basin, the lowland portion of the Willamette Basin, and the central Willamette Basin, where ground-water withdrawals are greatest.

Less than one-third (28 percent) of precipitation infiltrates into the subsurface as recharge (table 6). Basinwide, most precipitation is returned to streams as runoff. Within the lowland (fig. 1), where agriculture and warmer temperatures occur, losses to evapotranspiration above the water table are greater than runoff or recharge.

The ground-water budget is poorly constrained because of large uncertainties in evapotranspiration from the water table, seepage to streams, and unquantified subsurface inflows and outflows. Evapotranspiration from the water table is assumed to be 8 in/yr, or approximately half of the lowland recharge rate. Because it was not possible to quantify seepage to streams, it was estimated as the residual of the budget and, therefore, depends on the accuracy of the other components.

In the Willamette Basin, most recharge is returned to streams as ground-water discharge to streams. Ground-water



	Jan 99	Feb 99	Mar 99	Apr 99	May 99	Jun 99	Jul 99	Aug 99	Sep 99	Oct 99	Nov 99	Dec 99
TOTAL	950	850	930	910	7,320	20,390	41,980	36,140	19,690	4,150	940	960
☐ Irrigation	0	0	0	0	6,240	18,640	39,390	33,620	17,450	2,650	0	0
▩ Public supply	890	790	870	830	990	1,460	1,920	1,820	1,620	1,130	860	890
■ Industry	60	60	60	80	90	290	670	700	620	370	80	70

Figure 18. Monthly ground-water use by category, 1999, central Willamette Basin, Oregon.

Table 5. Mean monthly pumping and streamflow in the central Willamette Basin, Oregon.

[ft^3/s, cubic feet per second]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Ground-water pumpage, in ft^3/s	16	14	16	15	123	343	705	607	331	70	16	16	186
Willamette River flow at Salem (14191000), in ft^3/s (1909–2002)	46,460	40,310	31,920	26,370	20,600	13,950	7,320	5,789	7,129	10,990	28,249	43,140	23,300
Pudding River flow at Aurora (14202000), in ft^3/s (1928–1997)	2,764	2,747	2,111	1,548	880	420	152	70	92	345	1,456	2,482	1,252

Table 6. Hydrologic and ground-water budgets in the Willamette Basin, Oregon, 1995–96.

[M acre-fy/yr, millon acre-feet per year; mi², square mile]

	Hydrologic budget					
	Precipitation = Recharge + Evapotranspiration + Runoff					
	Willamette Basin[1] (11,111 mi² area)		Lowland (3,394 mi² area)		Central Willamette Basin (683 mi² area)	
	M acre-ft/yr	Percent of precipitation	M acre-ft/yr	Percent of precipitation	M acre-ft/yr	Percent of precipitation
Precipitation	46.63		10.77		2.09	
Recharge	13.22	28.4%	2.86	26.6%	0.56	26.9%
Evapotranspiration[2]	14.38	30.8%	4.16	38.6%	0.86	41.1%
Runoff	19.03	40.8%	3.75	34.8%	0.67	32.0%

	Ground-water budget					
	Recharge = Evapotranspiration + Well discharge + Stream seepage (storage change assumed negligible)					
	Willamette Basin[1]		Lowland		Central Willamette Basin	
	M acre-ft/yr	Percent of recharge	M acre-ft/yr	Percent of Recharge	M acre-ft/yr	Percent of Recharge
Recharge	13.22		2.86		0.56	
Evapotranspiration[3]	0.46	3.4%	0.46	15.9%	0.00	0.0%
Well discharge	0.28	2.1%	0.28	9.8%	0.14	25.0%
Stream seepage	12.49	94.4%	2.13	74.3%	0.42	75.0%

[1]Upstream of Portland stream gage.

[2]Evapotranspiration from land surface and unsaturated zone simulated with PRMS.

[3]Evapotranspiration from water table (saturated zone) estimated in southern Willamette Basin to be 8 in/yr.

withdrawals by wells are small, only 2 percent of total basinwide recharge. The basinwide budget does not reflect ground-water availability within the lowland because (1) recharge in the Cascade and Coast Ranges discharges to streams within those areas and is not available as ground water in the lowland, and (2) ground-water withdrawals and evapotranspiration are concentrated in the lowland.

Assuming no subsurface inflow to or outflow from the lowland, ground-water seepage to streams accounts for 74 percent of the recharge entering the lowland. Evapotranspiration losses from the water table represent 16 percent of lowland recharge. Ground-water withdrawals within the lowland account for 10 percent of lowland recharge. In the central Willamette Basin, ground-water withdrawals are approximately 25 percent of local recharge, and ground-water discharge to streams accounts for 75 percent of recharge, assuming no subsurface inflow or outflow and no evapotranspiration from the water table in this area.

Ground-water discharge to streams is approximate and calculated as a residual of the ground-water budget. Based on limited data described previously, ground-water discharge to streams occurs throughout the basin, but is expected to be greater to streams in the High Cascade area and the streams flowing over the upper and middle sedimentary units in the lowland than to streams underlain by the low permeability basement confining unit, lower sedimentary unit, and Willamette silt unit.