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Prepared in cooperation with Blaine County, City of Hailey, City of Ketchum, The Nature Conservancy, City of Sun Valley, Sun Valley Water and Sewer District, Blaine Soil Conservation District, City of Bellevue, and Citizens for Smart Growth

Ground-Water Budgets for the Wood River Valley Aquifer System, South-Central Idaho, 1995–2004

Hailey, Idaho, July 4, 1913

Hailey, Idaho, August 22, 2008

Scientific Investigations Report 2009–5016

U.S. Department of the Interior
U.S. Geological Survey

Cover: Top: Panoramic photograph of Hailey, Idaho, looking southeast from Carbonate Mountain, 1913. (Photograph taken by James. A. Allen, Pyro Studio, July 4, 1913; from the Library of Congress Panoramic Photograph Collection.)
Bottom: Panoramic photograph of Hailey, Idaho, looking southeast from Carbonate Mountain, 2008. (Photograph taken by James. R. Bartolino, U.S. Geological Survey, August 22, 2008.)

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U.S. Department of the Interior
U.S. Geological Survey

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KEN SALAZAR, Secretary

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
square foot (ft^2)	0.09290	square meter (m^2)
	Volume	
gallon (gal)	0.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8.

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Ground-Water Budgets for the Wood River Valley Aquifer System, South-Central Idaho, 1995–2004

By James R. Bartolino

Abstract

The Wood River Valley contains most of the population of Blaine County and the cities of Sun Valley, Ketchum, Hailey, and Bellevue. This mountain valley is underlain by the alluvial Wood River Valley aquifer system which consists of a single unconfined aquifer that underlies the entire valley, an underlying confined aquifer that is present only in the southernmost valley, and the confining unit that separates them. The entire population of the area depends on ground water for domestic supply, either from domestic or municipal-supply wells, and rapid population growth since the 1970s has caused concern about the long-term sustainability of the ground-water resource. To help address these concerns this report describes a ground-water budget developed for the Wood River Valley aquifer system for three selected time periods: average conditions for the 10-year period 1995–2004, and the single years of 1995 and 2001. The 10-year period 1995–2004 represents a range of conditions in the recent past for which measured data exist. Water years 1995 and 2001 represent the wettest and driest years, respectively, within the 10-year period based on precipitation at the Ketchum Ranger Station.

Recharge or inflow to the Wood River Valley aquifer system occurs through seven main sources (from largest to smallest): infiltration from tributary canyons, streamflow loss from the Big Wood River, areal recharge from precipitation and applied irrigation water, seepage from canals and recharge pits, leakage from municipal pipes, percolation from septic systems, and subsurface inflow beneath the Big Wood River in the northern end of the valley. Total estimated mean annual inflow or recharge to the aquifer system for 1995–2004 is 270,000 acre-ft/yr (370 ft^3/s). Total recharge for the wet year 1995 and the dry year 2001 is estimated to be 270,000 acre-ft/yr (370 ft^3/s) and 220,000 acre-ft/yr (300 ft^3/s), respectively.

Discharge or outflow from the Wood River Valley aquifer system occurs through five main sources (from largest to smallest): Silver Creek streamflow gain, ground-water pumpage, Big Wood River streamflow gain, direct evapotranspiration from riparian vegetation, and subsurface outflow (treated separately). Total estimated mean 1995–2004 annual outflow or discharge from the aquifer system is 250,000 acre-ft/yr (350 ft^3/s). Estimated total discharge is 240,000 acre-ft/yr (330 ft^3/s) for both the wet year 1995 and the dry year 2001.

The budget residual is the difference between estimated ground-water inflow and outflow and encompasses subsurface outflow, ground-water storage change, and budget error. For 1995–2004, mean annual inflow exceeded outflow by 20,000 acre-ft/yr (28 ft^3/s); for the wet year 1995, mean annual inflow exceeded outflow by 30,000 acre-ft/yr (41 ft^3/s); for the dry year 2001, mean annual outflow exceeded inflow by 20,000 acre-ft/yr (28 ft^3/s). These values represent 8, 13, and 8 percent, respectively, of total outflows for the same periods. It is difficult to differentiate the relative contributions of the three residual components, although the estimated fluctuations between the wet and dry year budgets likely are primarily caused by changes in ground-water storage.

The individual components in the wet and dry year ground-water budgets responded in a consistent manner to changes in precipitation and temperature. Although the ground-water budgets for the three periods indicated that ground-water storage is replenished in wet years, statistical analyses by Skinner and others (2007) suggest that such replenishment is not complete and over the long term more water is removed from storage than is replaced. In other words, despite restoration of water to ground-water storage in wet years, changes have occurred in either recharge and (or) discharge to cause ground-water storage to decline over time. Such changes may include, but are not limited to: lining or abandoning canals and ditches, conversion of surface-water irrigation rights to ground-water rights, changes in location of diversion points, changes in irrigation method and efficiency, increased consumptive use by evaporation or evapotranspiration, and long- or short-term climatic change.

Estimates were made of evapotranspiration (consumptive use), simulated irrigation, and deep percolation for a 1-acre parcel for each of 14 land-use classifications in the Wood River Valley. The mean evapotranspiration rate for urban land uses generally is less than for agricultural land uses,

mean simulated irrigation for urban land uses is less than for agricultural uses, and the volume of deep percolation (recharge) tends to be larger for urban land uses. Most urban land uses in the Wood River Valley generally are estimated to have slightly less consumptive water use than agricultural uses. However, many other factors influence the ultimate effects of the conversion of agricultural land to urban uses and may have greater effects on the aquifer system by the redistribution or reduction of recharge.

Introduction

Blaine County in south-central Idaho experienced a 40-percent population growth—from 13,000 to more than 20,000 people—from 1990 to 2000. Between April 1, 2000, and July 1, 2005, the county population increased by about 11.5 percent (U.S. Census Bureau, 2007). In addition to permanent residents, thousands of people annually visit Blaine County for winter and summer recreation. Most population growth and recreational use is in the northernmost part of the county in the Wood River Valley. The entire population of the valley depends on ground water for domestic supply, either from privately owned or municipal-supply wells; surface water is used for recreation and irrigation.

Water managers and private landowners are increasingly concerned about the effects of population growth on ground-water and surface-water supplies in the area, particularly the sustainability of ground-water resources and the effects of wastewater disposal on ground-water and surface-water quality. Development in recent years has been moving into tributary canyons of the Wood River Valley, and residents in some canyon areas have reported declining ground-water levels. It is uncertain whether these declining water levels are caused by pumping that has accompanied increased development or are a response to several years of drought conditions. In June 2005, Blaine County Commissioners approved an interim moratorium on selected development activities while the effects of growth, including those on water resources, were evaluated.

Although several studies and the resulting technical reports have addressed specific water-related issues or aspects in selected areas of the Wood River Valley, a current, comprehensive evaluation of water resources in the valley is needed to address concerns about the effects of current development and the potential effects of continued growth and development. In 2005, the U.S. Geological Survey (USGS), in cooperation with several local government agencies and organizations[1], completed a compilation and review of existing information and data on the hydrology of the Wood River Valley, identified gaps in information about water resources, and proposed a work plan with priorities for data collection and interpretation to fill these gaps. The objectives of the overall work plan for the USGS study are: (1) to provide data and interpretations about the water resources of the Wood River Valley to enable county and local governments to make informed decisions about those resources, and (2) to identify any additional water-resources data collection or studies needed to support decision makers. The first phase of the work plan, compilation of ground-water level maps for partial-development and 2006 conditions, the change between them, and an analysis of hydrologic trends in the ground- and surface-water systems was completed in 2007 (Skinner and others, 2007). The development of a ground-water budget described in this report is the next phase of the 2005 work plan.

Purpose and Scope

This report describes the development of ground-water budgets for the Wood River Valley aquifer system for the 10-year period 1995–2004, as well as for a wet year (1995), and a dry year (2001) within that period. The report also includes discussions of the issue of the sustainability of the ground-water resource in the study area, how the findings of the current study can be applied, and offers suggestions for future data collection aimed at reducing uncertainties in the ground-water budget.

Previous Work

A description of previous work on the hydrology of the Wood River Valley area related to ground-water level maps and surface-water flows is available in Skinner and others (2007). Previously published studies that developed water budgets for all or part of the Wood River Valley are shown in table 1 along with the study area and budget years addressed. Because the water budgets developed for these studies differ in study area extent, time period, manner in which budget components were combined, and whether they address combined surface- and ground-water or exclusively ground-water systems, they are not directly comparable.

[1] Cooperating organizations and local government agencies in Idaho include: Blaine County, City of Hailey, City of Ketchum, The Nature Conservancy, City of Sun Valley, Sun Valley Water and Sewer District, Blaine Soil Conservation District, City of Bellevue, and Citizens for Smart Growth.

Table 1. Water budgets of the Wood River Valley, south-central Idaho, from previous studies.

[SW, surface water; GW, ground water; –, not specified or period of record]

Reference	Study area	System	Budget years
Smith, 1959	South of Hailey	SW/GW	1940-54
Castelin and Chapman, 1972	South of Hailey	SW/GW	–
Brockway and Grover, 1978	South of Bellevue	GW	1975-76
Luttrell and Brockway, 1984	North Fork to Glendale Road	SW/GW	1983-84
Brockway and Kahlown, 1994	South of Hailey	GW	1993
Frenzel, 1989	North of Glendale Road	SW/GW	1940-79
Wetzstein and others, 1999	South of Hailey	GW	1993-94

Description of Study Area

The Wood River Valley of south-central Idaho extends from Galena Summit (north of the study area) southward to the Picabo and Timmerman Hills (fig. 1). The valley can be separated into upper and lower parts along an east-west line immediately south of Bellevue: the upper valley is narrow, broadening downstream to a maximum width of 2 mi and the lower valley opens into a triangular alluvial fan (the Bellevue fan) about 9 mi across at its southern end. The study area of this report is the part of the Wood River Valley aquifer system that extends from the northernmost USGS stream-gaging station on the Big Wood River, Big Wood River near Ketchum (13135500), at the Sawtooth National Forest boundary, southward to the Timmerman Hills. This area is identical to that studied by Skinner and others (2007) and comprises about 86 mi^2.

The Wood River Valley has a relatively flat bottom, and land-surface altitudes range from about 6,000 ft at the northern boundary of the study area to about 4,800 ft at the southern boundary. A number of tributary canyons intersect the valley, the largest of which are those of North Fork Big Wood River, Warm Springs Creek, Trail Creek, East Fork Big Wood River, Deer Creek, and Croy Creek. The main valley and the tributary canyons have steep sides and are surrounded by highlands with peaks that reach altitudes of more than 11,000 ft.

In addition to their different physiographic characteristics, the upper and lower valleys also differ in land use. The upper Wood River Valley is more developed and contains the incorporated communities of Sun Valley, Ketchum, Hailey, and Bellevue. Land use in the upper valley is predominantly residential with many large homes situated on landscaped acreage. The lower Wood River Valley is dominated by farms and ranches (irrigated by ground water and diverted surface water), and contains the small communities of Gannett and Picabo. Although some of the tributary canyons in the upper valley, such as Trail Creek and Warm Springs Creek, have supported development for more than 50 years, more recent development has expanded into the valley's other tributary canyons. Three wastewater-treatment plants in the study area discharge to the Big Wood River, but many homes rely on septic systems for wastewater disposal.

Most of the Wood River Valley is drained by the Big Wood River or its tributaries, except for the southeastern part of the Bellevue fan, which is drained by Silver Creek, a tributary to the Little Wood River. Although several of the tributary canyons to the Big Wood River have perennial streams, most streams flow only in response to precipitation or snowmelt. A more complete description of the study area, including climate, is available in Skinner and others (2007).

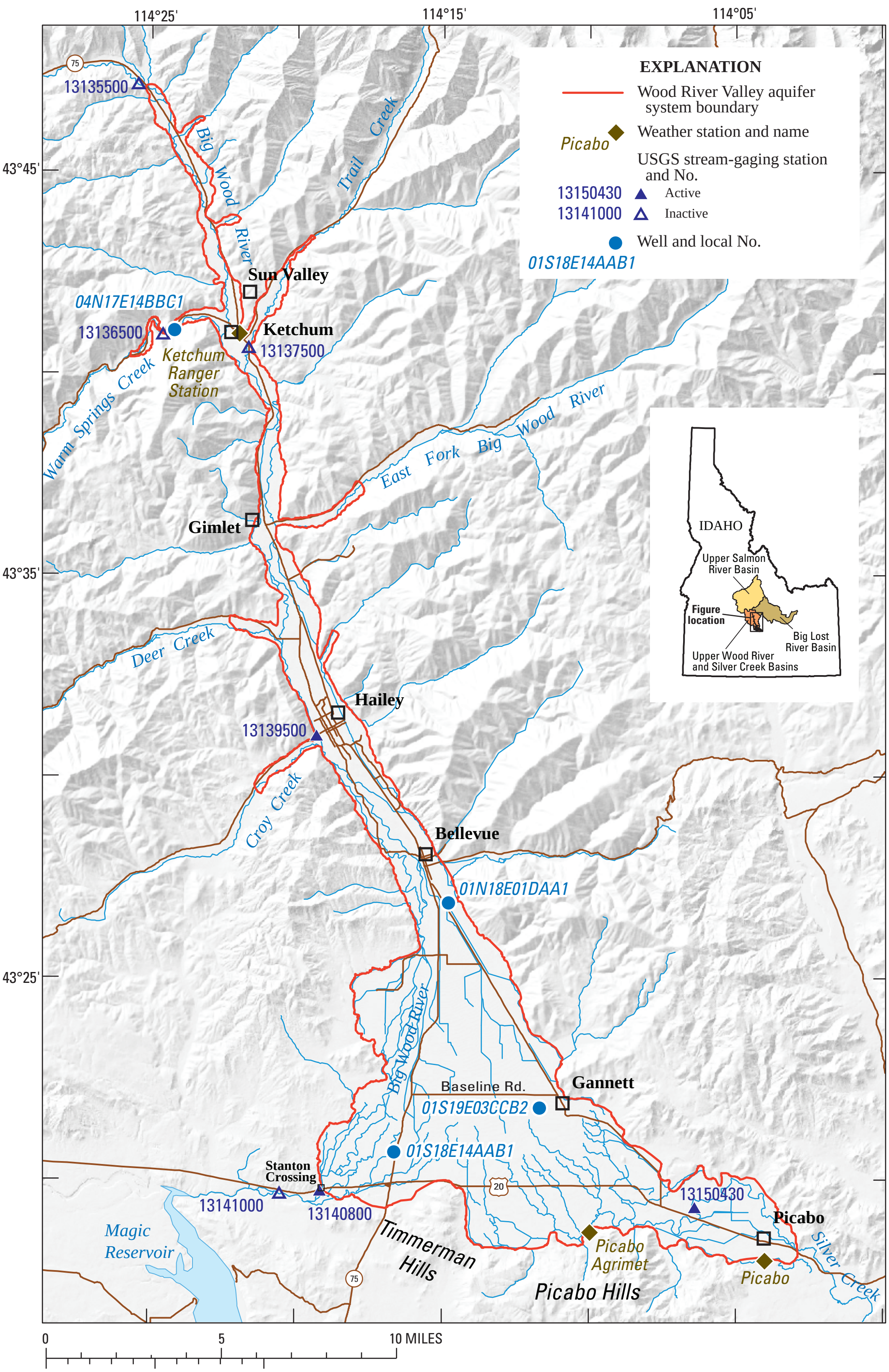

Figure 1. Locations of communities, selected active and inactive U.S. Geological Survey stream-gaging stations, and selected weather stations, Wood River Valley, south-central Idaho.

Hydrogeologic Setting and Framework

The Wood River Valley lies within the Northern Rocky Mountain physiographic province (Fenneman, 1931). Bedrock highlands of Precambrian metamorphic, Mesozoic sedimentary, and Tertiary intrusive and volcanic rocks surround the valley. The valley is filled with interbedded, Quaternary lacustrine, fluvial, and proglacial sediments deposited during late-Pleistocene glaciation. In the southern portion of the Bellevue fan, Quaternary basalts are interbedded with these sediments. Sediments underlying the valley floor in the southern part of the Wood River Valley were largely deposited as the alluvial Bellevue fan with the Big Wood River continually shifting and depositing sediment across its surface. Episodic volcanic activity disrupted the surface-water drainage pattern; after one such eruption created a lava dam, a lake formed over the Bellevue fan, and fine-grained lacustrine sediments were deposited. After the dam was breached, deposition of alluvial sediments continued until post-glacial climate change caused the Big Wood River to incise about 30 ft, resulting in its present-day appearance. However, glaciofluvial sediments deposited in the tributary canyons have been largely unaffected by the Holocene climate; thus they preserve their Pleistocene form. Schmidt (1962) provides a detailed discussion of the depositional history of the sediments that constitute the aquifer system.

Ground Water

Following the usage of Skinner and others (2007), the term Wood River Valley aquifer system is used here to refer to the single unconfined aquifer that underlies the entire valley, an underlying confined aquifer that is present only to the south of Baseline Road, and the confining unit separating the two aquifers. The aquifer system primarily consists of the Quaternary sediments of the Wood River Valley. Because the aquifer system is sufficiently productive at shallow depths, few wells in the main valley have been drilled to bedrock. Geologic sections drawn by Moreland (1977) suggest that the thickness of alluvium approaches 500 ft in places, but unconsolidated sediment in most of the study area is much thinner. In the vicinity of Ketchum, bedrock is at a depth of approximately 100 ft. On the basis of a surficial geophysical survey across the Big Wood River canyon approximately at its confluence with the North Fork Big Wood River, Castelin and Winner (1975) concluded that bedrock there was at a depth of 22–32 ft. Thickness of the unconsolidated sediment in the tributary canyons may be as little as 30 ft in the Warm Springs Creek drainage (Castelin and Winner, 1975). Schmidt (1962, p. 66) noted that “The thickness of the valley-bottom deposits averages about 8 feet where tested by drilling on lower Rock, Reed, and Brock Creeks.”

The lower confined aquifer is separated from the overlying unconfined aquifer by fine-grained lacustrine deposits below approximately 150 ft (Moreland, 1977). This confining unit thickens towards the south and, generally, as land-surface elevation decreases in the same direction, the potentiometric surface rises above land surface and wells have the ability to flow under artesian pressure.

Depth to ground water in the upper valley is commonly less than 10 ft, increasing to approximately 90 ft southward. Water levels in wells completed in the unconfined aquifer in the lower valley range from less than 10 ft to approximately 150 ft, whereas wells completed in the confined aquifer are under artesian pressure and flow where the potentiometric surface is above land surface.

Surface Water

Most of the Wood River Valley is drained by the Big Wood River or its tributaries, except for the southeastern portion of the Bellevue fan, which is drained by Silver Creek, a tributary to the Little Wood River. The Big Wood and Little Wood Rivers meet near Gooding, approximately 35 mi southwest of the study area, where they become the Malad River, a tributary to the Snake River. The Big Wood River originates near Galena Summit, approximately 20 mi northwest of Ketchum, and it gains flow from a number of perennial and ephemeral tributaries as it meanders across the narrow upper valley. At Bellevue the channel follows the western side of the Bellevue fan (though flow through most of this reach is ephemeral), finally exiting the valley at the Big Wood River at Stanton Crossing near Bellevue gaging station (13140800). Fed by springs and seeps, Silver Creek and its tributaries originate on the Bellevue fan and flow out of the valley at Picabo. Most of the streams in the tributary canyons to the Big Wood River are ephemeral and flow only in response to precipitation or snowmelt; however, North Fork Big Wood River, Warm Springs Creek, Trail Creek, East Fork Big Wood River, Deer Creek, and Croy Creek typically flow into the Big Wood River year-round. Streams in some of the tributary canyons are perennial in their upper reaches, and some of this water likely infiltrates directly into the aquifer system or reaches the Big Wood River by subsurface flow through streambed gravels. Most of the Wood River Valley was under irrigation by 1900 (Jones, 1952), and a well-developed network of irrigation canals and drains exists throughout the study area. The diversions and return flows between the irrigation system and the Big Wood River, as well as the exchange of water between the canals, drains, and streams and the underlying unconfined aquifer complicate the interpretation of streamflow measurements.

Ground-Water Budgets

A number of water budgets for all or part of the Wood River Valley aquifer system have been developed in previous studies (table 1). Ground-water budgets for the system for three periods that were developed in the current study are described in detail below and are summarized in table 2 and figure 2.

Three water budgets were developed: one to represent average conditions for the 10-year period 1995–2004, and two others for the single years 1995 and 2001. (Unless otherwise noted, years in this report denote water years: October 1–September 30.) The period 1995–2004 was selected to represent a range of conditions in the recent past for which measured data were available. Water years 1995 and 2001 were selected because they were the wettest and driest years, respectively, within the 10-year period, based on precipitation at the Ketchum Ranger Station National Weather Service weather station (Western Regional Climate Center, 2008). Total monthly precipitation at the Ketchum Ranger Station and Picabo National Weather Service weather stations is shown in figure 3. (The Picabo weather station is included because data from this station is used for analysis of areal recharge from precipitation and applied irrigation.)

Table 2. Estimated ground-water budgets for the Wood River Valley aquifer system, south-central Idaho, for average conditions 1995–2004, 1995, and 2001.

[See "Ground-Water Budget" section for information on significant figures and rounding. **Abbreviations:** acre-ft/yr, acre-foot per year, ft^3/s, cubic foot per second]

Budget component	Ground-water rate (acre-ft/yr) 1995–2004	1995	2001	Ground-water rate (ft^3/s) 1995–2004	1995	2001
Inflow (recharge)						
Tributary canyon recharge	170,000	170,000	140,000	230	230	190
Big Wood River streamflow loss, Hailey-Stanton Crossing	65,000	60,000	52,000	90	83	72
Areal recharge from precipitation and irrigation	20,000	30,000	10,000	28	41	14
Canal seepage loss and recharge pits	8,900	9,800	8,200	12	14	11
Municipal pipe leakage	2,300	1,800	2,400	3.2	2.5	3.3
Septic system percolation	1,400	1,400	1,400	1.9	1.9	1.9
Subsurface inflow	1,300	1,300	1,300	1.8	1.8	1.8
Outflow (discharge)						
Silver Creek streamflow gain	102,000	112,000	87,600	141	155	121
Pumpage:	110,000	89,000	110,000	150	120	150
Irrigation	55,000	42,000	60,000	76	58	83
Self-supplied domestic and subdivisions	42,000	39,000	43,000	58	54	59
Municipal	8,900	7,700	9,900	12	11	14
Big Wood River streamflow gain, Ketchum-Hailey	25,000	23,000	20,000	34	32	27
Direct evapotranspiration from riparian vegetation	18,000	16,000	21,000	25	22	29
Total inflow (recharge):	270,000	270,000	220,000	370	370	300
Total outflow (discharge):	250,000	240,000	240,000	350	330	330
Difference (residual):	20,000	30,000	[1]-20,000	28	41	[1]-28

[1]The negative residual indicates that discharge is greater than recharge.

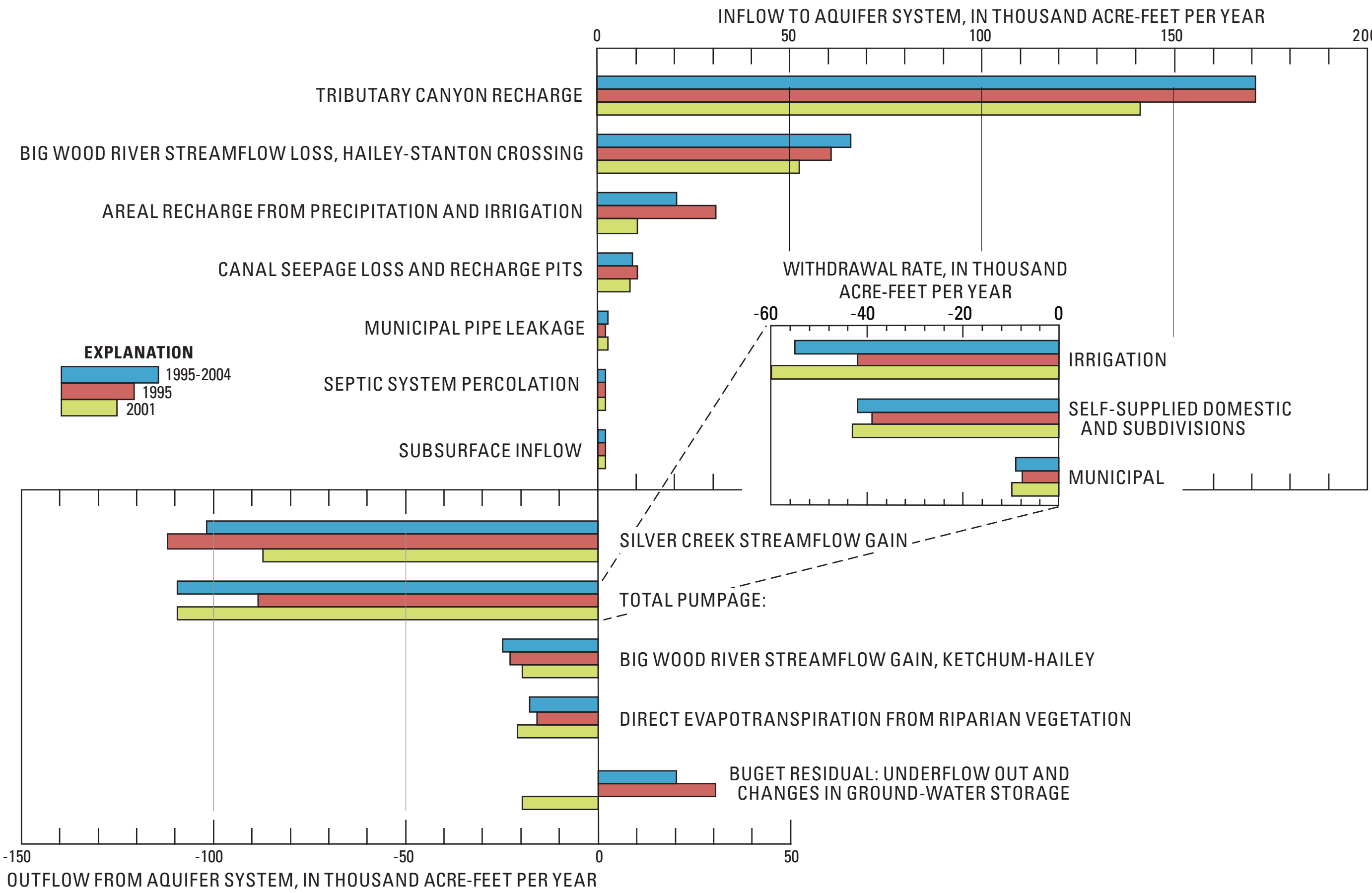

Figure 2. Estimated ground-water budget components for the Wood River Valley aquifer system, south-central Idaho, for average conditions 1995–2004, 1995, and 2001.

To allow easy comparison between the values of the different budget components, flow rates associated with the inflow and outflow budget components in this report are reported in acre-feet per year and in cubic feet per second. Because some budget components were originally estimated in units of cubic feet per second and others in acre-feet per year, in the text, the original units are shown first and the corresponding converted units are shown in parentheses. For values originally estimated as cubic feet per second, measured values are reported in acre-feet per year to three significant figures and calculated values are reported in cubic feet per second to two significant figures; the converted values of acre-feet per year maintain this precision. Following standard practice, estimated values maintain the significant figures of the least precise number used in the calculation. In table 2, the acre-feet per year values were used to determine total inflows, outflows, and differences and were rounded to two significant figures. These values were then converted to cubic feet per second and rounded to two significant figures (because of rounding errors, summing the total inflows, outflows, and differences in the cubic foot per second columns may not equal the totals shown). Also, because instantaneous or mean monthly flow rates originally reported in cubic feet per second (such as surface-water diversions) were converted to mean annual values, care must be taken to determine over what time period flow rates were averaged.

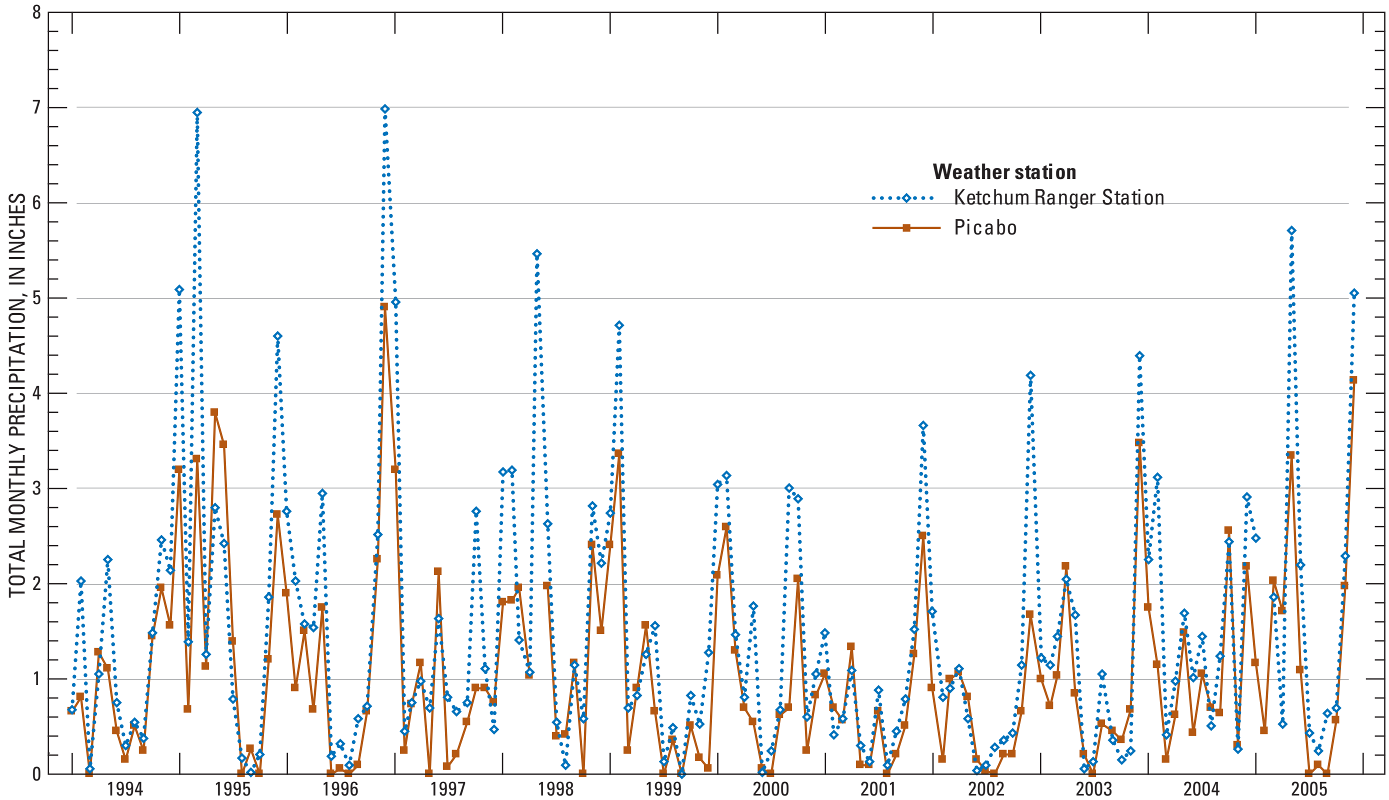

Figure 3. Total monthly precipitation at the Ketchum Ranger Station and Picabo National Weather Service weather stations, south-central Idaho, calendar years 1994–2005.

Inflows

Recharge or inflow of water to the Wood River Valley aquifer system originates from seven main sources: infiltration from tributary canyons, streamflow loss from the Big Wood River, deep percolation of precipitation and excess irrigation water, seepage from canals and recharge pits, subsurface inflow beneath the Big Wood River in the northern end of the valley, leakage from municipal pipes, and percolation from septic systems. Total estimated mean annual inflow or recharge to the aquifer system for 1995–2004 is 270,000 acre-ft/yr (370 ft^3/s) (table 2). Total estimated recharge for the wet year 1995 is 270,000 acre-ft/yr (370 ft^3/s) and for the dry year 2001, 220,000 acre-ft/yr (300 ft^3/s) (table 2).

Recharge from Tributary Canyons

Runoff from the highlands and tributary canyons surrounding the Wood River Valley contributes recharge to the aquifer system. Because the sediments of the valley floor are highly permeable and the flow of some tributaries, such as Indian Creek, has been modified or diverted by development, only the largest tributaries are perennial and contribute flow directly to the Big Wood River throughout the year. It is assumed that streamflow from most of these tributary basins infiltrates to the aquifer system once drainage debouches onto the valley floor. Because streamflow records are available for very few of these tributaries, a geographic-information system (GIS) based technique is used to estimate basin yield and recharge to the aquifer system from 28 of the tributaries.

Method and Assumptions

The USGS StreamStats Web application (Ries and others, 2004) is used to derive estimates of discharge from tributary canyons to the Wood River Valley. StreamStats applies the regional regression equations developed by the USGS (Hortness and Berenbrock, 2001) to estimate selected discharge parameters for ungaged basins in Idaho that are unaffected by regulation structures and (or) diversions. (The entire study area lies within Hortness and Berenbrock's streamflow region 5.) These equations, which were developed on the basis of discharge data from long-term gaging stations in the area, relate the discharge to various physical and climatic characteristics of the drainage basin. These calculated discharge values were then used to estimate recharge to the Wood River Valley aquifer system. A similar approach was used by Hortness (2007) to estimate tributary recharge to the Spokane Valley-Rathdrum Prairie aquifer.

The median monthly streamflows for May and June calculated by StreamStats and based on measured discharge at the USGS gaging station Big Wood River at Hailey (13139500) are approximately an order of magnitude greater than the median monthly flows for the winter months. Furthermore, because surface-water diversions during the irrigation season—typically from May through September—affect flow, and because flow from many tributaries reaches the river only during spring runoff, the median monthly streamflows for November through April were used to estimate recharge to the aquifer system and were adjusted as described in the following paragraph. Irrigation diversion records are kept for April through September; however, diversions may continue into October or November. Diversion volumes for April often are minimal or nonexistent.

Hortness and Berenbrock (2001) presented standard errors of estimate for the regression equation for each of their regions; for region 5 the mean standard error of estimate for monthly median flow (Q_{50}) for November through April is +51 to -34 percent. Because some of the basin characteristics for nearly all of the 28 tributary basins for which recharge is estimated were outside of the range of values used to develop the regression equations for region 5, the calculated monthly median flows may be unreliable. To address this concern, monthly median flow calculated from data collected at the Big Wood River at Hailey gaging station for the three time periods is compared to the StreamStats-estimated value thus: For each budget period the ratio of median monthly streamflow for November through April to the mean of the StreamStats-estimated median monthly streamflow for November through April is computed—89 percent for the 1995–2004 period, 90 percent for 1995, and 74 percent for 2001. The StreamStats-estimated value for each of the 28 tributary streams is then multiplied by this ratio.

In assigning values to recharge contributed to the Wood River Valley aquifer system by streams in the tributary canyons, several primary assumptions were made that introduce a moderate degree of uncertainty. It is assumed that no appreciable underflow enters the aquifer system from the tributary canyons and that all streamflow that infiltrates to the aquifer system does so downstream of the estimation point. Exceptions are flow from six tributary canyons: North Fork Big Wood River, Warm Springs Creek, Trail Creek, East Fork Big Wood River, Deer Creek, and Croy Creek, because they typically flow into the Big Wood River year round; for these tributary streams it is assumed that combined recharge and underflow is equal to 50 percent of the adjusted StreamStats-estimated streamflow. Hortness and Berenbrock (2001) noted that the regression equations used in the StreamStats calculations are unreliable for sites where streamflow is affected by upstream diversions and (or) regulation structures or by appreciable spring inflows. Because most tributary canyons to the Big Wood River are relatively undeveloped and yield relatively low amounts of streamflow, it is assumed that diversions and regulations are negligible compared with other components of the ground-water budget; the use of the November–April period also minimizes the effects of such diversions and regulations. Inflow from springs in the tributary canyons may occur but such flow is difficult to quantify, and discharge values may be larger than those estimated by the StreamStats regression equations; this particularly holds true for the tributary basins in the Timmerman and Picabo Hills. Therefore, recharge is estimated only for the largest tributary canyons. Slopes that drain directly to the valley floor, tributary basins less than 1 mi^2, and small tributary streams that drain directly to the Big Wood River (such as Fox Creek) were not included in these recharge estimates.

Results

A total of 28 tributary streams with a combined basin area of 560 mi^2 are assumed to contribute appreciable recharge to the Wood River Valley aquifer system (fig. 4; table 3). Total mean annual recharge from these tributary streams for the period 1995–2004 is estimated as 230 ft^3/s (170,000 acre-ft/yr), which represents 63 percent of the total annual inflow of 370 ft^3/s (270,000 acre-ft/yr) (fig. 2; tables 2 and 3). Tributary canyon recharge for the wet year 1995 is calculated as 230 ft^3/s (170,000 acre-ft/yr), and for the dry year 2001, 190 ft^3/s (140,000 acre-ft/yr) (fig. 2; tables 2 and 3).

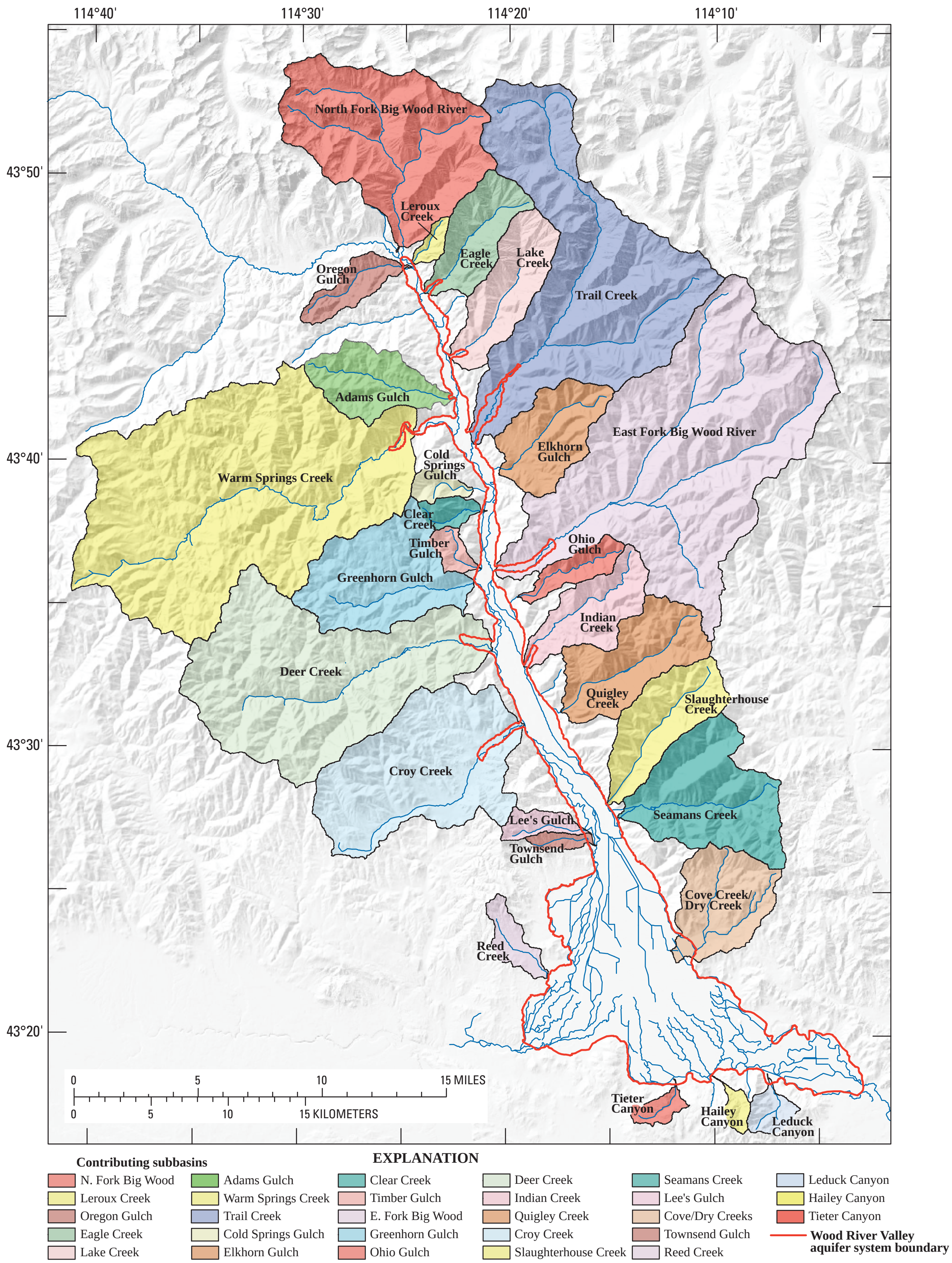

Figure 4. Location of 28 basins adjacent to the Wood River Valley, south-central Idaho, for which mean annual discharge is estimated.

Table 3. Estimated recharge to the Wood River Valley aquifer system from 28 selected tributary basins to the Big Wood River, south-central Idaho, 1995-2004, 1995, and 2001.

[Locations of tributary basins shown in figure 4. Percentages shown in parenthesis indicate the percentage by which StreamStats values were adjusted based on measured streamflow at the Hailey gaging station. Values shown in bold are for six major tributaries with significant surface-water flow and are reduced by 50 percent to approximate underflow; see text for explanation. **Abbreviations: Nov, November; Apr, April;** Q_{50}, median daily streamflow; mi², square mile; ft³/s, cubic foot per second; acre-ft/yr, acre-foot per year]

Tributary	Drainage area (mi²)	StreamStats estimated mean Nov–Apr Q_{50}		Adjusted Q_{50} (percentage of StreamStats estimated Nov–Apr Q_{50})					
				1995–2004 (89 percent)		1995 (90 percent)		2001 (74 percent)	
		(ft³/s)	(acre-ft/yr)	(ft³/s)	(acre-ft/yr)	(ft³/s)	(acre-ft/yr)	(ft³/s)	(acre-ft/yr)
North Fork Big Wood River	40	34	25,000	**15**	**11,000**	**15**	**11,000**	**12**	**8,700**
Leroux Creek	1.5	1.3	940	1.2	870	1.2	870	1.0	700
Oregon Gulch	5.1	2.5	1,800	2.2	1,600	2.3	1,700	1.9	1,400
Eagle Creek	11	9.3	6,700	8.2	5,900	8.3	6,000	6.8	4,900
Lake Creek	13	9.5	6,900	8.5	6,200	8.6	6,200	7.1	5,100
Adams Gulch	11	6.2	4,500	5.5	4,000	5.5	4,000	4.6	3,300
Warm Springs Creek	94	40	29,000	**18**	**13,000**	**18**	**13,000**	**15**	**11,000**
Trail Creek	64	40	29,000	**18**	**13,000**	**18**	**13,000**	**15**	**11,000**
Cold Springs Gulch	13	1.9	1,400	1.7	1,200	1.7	1,200	1.4	1,000
Elkhorn Gulch	2.2	8.1	5,900	7.2	5,200	7.3	5,300	6.0	4,300
Clear Creek	2.3	1.8	1,300	1.6	1,200	1.6	1,200	1.3	940
Timber Gulch	2.2	1.9	1,400	1.7	1,200	1.7	1,200	1.4	10,000
East Fork Big Wood River	86	45	33,000	**20**	**14,000**	**20**	**14,000**	**17**	**12,000**
Greenhorn Gulch	22	13	9,400	11	7,900	11	8,000	9.3	6,700
Ohio Gulch	4.3	3.7	2,700	3.3	2,400	3.4	2,500	2.8	2,000
Deer Creek	57	28	20,000	**13**	**9,400**	**13**	**9,400**	**11**	**8,000**
Indian Creek	11	7.2	5,200	6.4	4,600	6.5	4,700	5.3	3,800
Quigley Creek	17	11	8,000	9.8	7,000	10	7,200	8.2	5,900
Croy Creek	37	20	14,000	**8.8**	**6,400**	**8.9**	**6,400**	**7.3**	**5,300**
Slaughterhouse Creek	14	9.3	6,700	8.3	6,000	8.4	6,100	6.9	5,000
Seamans Creek	23	15	11,000	14	10,000	14	10,000	11	800
Lee's Gulch	2.8	2.2	1,600	1.9	1,400	1.9	14,000	1.6	1,200
Dry Creek and Cove Creek	14	10	7,200	9.3	6,700	9.4	6,800	7.8	5,600
Townsend Gulch	1.5	3.9	2,800	3.5	2,500	3.5	2,500	2.9	2,100
Reed Creek	3.6	12	8,700	11	8,000	11	8,000	9.2	6,700
Hailey Canyon	1.4	10	7,200	8.9	6,400	9.0	6,500	7.4	5,400
Leduck Canyon	2.7	2.5	1,800	2.2	1,600	2.2	1,600	1.8	1,300
Tieter Canyon	1.9	10	7,200	8.9	6,400	9.0	6,500	7.4	5,400
Total	560	360	260,000	230	170,000	230	170,000	190	140,000

The volume of recharge from tributary canyons estimated in this report is the largest source of recharge to the aquifer system and is more than double the estimated recharge for the next largest recharge source, streamflow loss between the Big Wood River between Hailey and near Bellevue gaging stations. The area of the aquifer system is 86 mi^2, which is 15 percent of the contributing area of the 28 tributary basins (560 mi^2). For comparison, the percentage of areal recharge to tributary recharge ranges from 7 to 18 percent. Although the comparison of values in this report with previous ground-water budgets is problematic for reasons detailed in the "Previous Work" section, two previous budgets can be compared to parts of the current work. Smith (1959) addressed only the area of the Wood River Valley from Hailey south and estimated the recharge from Quigley, Slaughterhouse, and Seamans Creeks plus "all other local tributaries" to be 38,500 acre-ft/yr. In the current study, summing the mean 1995–2004 tributary recharge for Quigley Creek and all tributaries south (fig. 4, table 3) yielded 48,000 acre-ft/yr (not including the Timmerman or Picabo Hills). A similar comparison may be made from Wetzstein and others (1999) who estimated tributary recharge from Warm Springs Creek, Trail Creek, East Fork Big Wood River, and Deer Creek to total 57,400 acre-ft/yr; the comparable 1995–2004 value in this study is 49,400 acre-ft/yr. As noted earlier, a moderate degree of uncertainty attends the estimates reported here and those of previous authors' work.

Areal Recharge from Precipitation and Applied Irrigation

Areal recharge to the Wood River Valley aquifer system originates from two sources—precipitation and applied irrigation water that passes through the root zone as deep percolation. Recharge from precipitation can be further separated into direct infiltration from permeable surfaces and indirect infiltration of runoff from impervious cover in urban areas.

Method and Assumptions

Areal recharge to the Wood River Valley aquifer system is estimated by a two-step process. First, the area of each land-use/land-cover type overlying the aquifer system is calculated using a GIS coverage of the 2001 National Land Cover Database (2001 NLCD) (Multi-Resolution Land Characteristics Consortium, 2003; Homer and others, 2007). Second, ground-water recharge is estimated for each land-use/land-cover type by applying values of deep percolation from Allen and Robison (2007a, 2007b) described in the following paragraphs. Of the 17 land-cover classes delineated for the conterminous United States in the 2001 NLCD, 15 were identified in the Wood River Valley. These 15 land covers then were matched to 10 of Allen and Robison's (2007a, 2007b) land covers and four degrees of impervious cover delineated in this report (the cottonwood cover of Allen and Robison [2007a, 2007b] is used for two 2001 NLCD land-cover classes). Descriptions, areas, and recharge rates for each of the land-cover classes identified in the Wood River Valley are shown in table 4. All "Cultivated crop" area from the 2001 NLCD is assigned to the "Alfalfa - less frequent cuttings" land cover. The 2002 Census of Agriculture (U.S. Department of Agriculture, 2004) data for all of Blaine County show alfalfa as grown on 106 farms covering 19,000 acres. Other crops include small grain and other tame hay (25 farms), barley (23 farms), haylage, sileage, and greenchop (7 farms), oats (4 farms), wheat (3 farms), wild hay (2 farms), and corn, sunflower, triticale, and wheatgrass seed (1 farm each). (The census does not indicate acreages for many of these crop types.)

Allen and Robison (2007a) used the American Society of Civil Engineers (ASCE) standardized Penman-Monteith reference equation to compute evapotranspiration and net irrigation water requirements on a daily, monthly, and annual basis for 123 weather and Agrimet stations throughout Idaho. Rather than publish extensive series of static values they created the "ETIdaho" web site that allows the user to enter various land covers/crop types for a given station and time period and select whether results are to be displayed on an annual, monthly, or daily basis (Allen and Robison, 2007b). The daily time series for a given land cover and weather station returns eight series of values calculated by the ETIdaho site, including various types of evapotranspiration, simulated irrigation, estimated runoff, and deep percolation below the root zone.

Of the 123 weather stations addressed by Allen and Robison (2007a, 2007b), four are in or near the study area: Galena, Hailey Ranger Station, Picabo, and the Picabo Agrimet station. Of these four stations, only the two stations with periods of record coinciding with the 1995–2004 period are used: Picabo and the Picabo Agrimet station (fig. 1).

Bartolino (2007) reported that calculations of evapotranspiration using mean monthly and annual meteorological data tend to underestimate recharge; therefore, evapotranspiration and deep percolation should be calculated on a daily basis and then summed for the period of interest (such as sub-annual recharge periods for a ground-water flow model or the annual and decadal periods of the ground-water budgets described in this report). Consequently, daily time series for 1995–2004 were retrieved from the ETIdaho site for 10 land cover types and the Picabo and the Picabo Agrimet stations. For each land cover type daily values for these two weather stations were averaged and then summed to determine recharge for each of the three periods.

Table 4. Areal extent, deep percolation rate, and calculated areal recharge from precipitation and applied irrigation for 2001 National Land Cover Database land-cover classes in the Wood River Valley, south-central Idaho, 1995–2004, 1995, and 2001.

[Data from Allen and Robison, 2007a, 2007b and Multi-Resolution Land Characteristics Consortium, 2003. **Abbreviations:** NLCD, National Land Cover Database; ET, evapotranspiration; in/yr, inch per year; acre-ft/yr, acre-foot per year; ft^3/s, cubic foot per second; –, none or not applicable]

2001 NLCD land cover class	Definition	Area (acres)	Allen and Robison (2007a, b) ET Idaho land class	Deep percolation rate (in/yr)			Recharge volume (acre-ft/yr)			Recharge volume (ft^3/s)		
				1995–2004	1995	2001	1995–2004	1995	2001	1995–2004	1995	2001
Open water	All areas of open water, generally with less than 25 percent cover of vegetation or soil.	84	Open water–shallow systems (ponds, streams)	–	–	–	–	–	–	–	–	–
Perennial ice/ snow	All areas characterized by a perennial cover of ice and (or) snow, generally greater than 25 percent of total cover.	1.1	–	–	–	–	–	–	–	–	–	–
Developed, open space	Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.	3,405	80 percent Grass–Turf (lawns)–Irrigated, 20 percent impervious cover	8.29	12.65	5.35	2,353	3,590	1,519	3.3	5.0	2.1
Developed, low intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20–49 percent of total cover. These areas most commonly include single-family housing units.	4,356	51 percent Grass–Turf (lawns)–Irrigated, 49 percent impervious cover	9.04	14.53	5.75	3,281	5,273	2,086	4.5	7.3	2.9
Developed, medium intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50–79 percent of the total cover. These areas most commonly include single-family housing units.	846	21 percent Grass–Turf (lawns)–Irrigated, 79 percent impervious cover	9.81	16.46	6.15	691.8	1,161	433.8	1.0	1.6	.6
Developed, high intensity	Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total cover.	106	100 percent impervious cover	10.35	17.82	6.44	91.4	157.4	56.9	.1	.2	.1

Table 4. Areal extent, deep percolation rate, and calculated areal recharge from precipitation and applied irrigation for 2001 National Land Cover Database land-cover classes in the Wood River Valley, south-central Idaho, 1995–2004, 1995, and 2001.—Continued

[Data from Allen and Robison, 2007a, 2007b and Multi-Resolution Land Characteristics Consortium, 2003. **Abbreviations:** NLCD, National Land Cover Database; ET, evapotranspiration; in/yr, inch per year; acre-ft/yr, acre-foot per year; ft³/s, cubic foot per second; –, none or not applicable]

2001 NLCD land cover class	Definition	Area (acres)	Allen and Robison (2007a, b) ET Idaho land class	Deep percolation rate (in/yr)			Recharge volume (acre-ft/yr)			Recharge volume (ft^3/s)		
				1995–2004	1995	2001	1995–2004	1995	2001	1995–2004	1995	2001
Barren land (rock/soil/clay)	Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15 percent of total cover.	34	Bare Soil	5.04	9.60	1.29	14.4	27.3	3.7	0.0	0.0	0.0
Deciduous forest	Areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.	5.8	Cottonwoods	.14	.26	0.00	.1	.1	.0	.0	.0	.0
Evergreen forest	Areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.	951	Willows	.24	.50	0.00	18.8	39.6	.2	.0	.1	.0
Shrub/scrub	Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.	8,698	Sage Brush	3.10	6.66	0.01	2,247	4,826	7.1	3.1	6.7	.0
Grasslands/herbaceous	Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.	8,257	Range grasses–early short season	.16	.30	0.00	111.3	205.9	.0	.2	.3	.0

Table 4. Areal extent, deep percolation rate, and calculated areal recharge from precipitation and applied irrigation for 2001 National Land Cover Database land-cover classes in the Wood River Valley, south-central Idaho, 1995–2004, 1995, and 2001.—Continued

[Data from Allen and Robison, 2007a, 2007b and Multi-Resolution Land Characteristics Consortium, 2003. **Abbreviations:** NLCD, National Land Cover Database; ET, evapotranspiration; in/yr, inch per year; acre-ft/yr, acre-foot per year; ft^3/s, cubic foot per second; –, none or not applicable]

2001 NLCD land cover class	Definition	Area (acres)	Allen and Robison (2007a, b) ET Idaho land class	Deep percolation rate (in/yr)			Recharge volume (acre-ft/yr)			Recharge volume (ft^3/s)		
				1995–2004	1995	2001	1995–2004	1995	2001	1995–2004	1995	2001
Pasture/hay	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.	9,095	Grass Pasture–high management	7.26	11.44	4.35	5,505	8,673	3,296	7.6	12.0	4.6
Cultivated crops	Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.	12,123	Alfalfa–less frequent cuttings	5.15	5.38	2.79	5,207	5,433	2,814	7.2	7.5	3.9
Woody wetlands	Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	3,974	Cottonwoods	.14	.26	.00	46.7	86.1	.0	.1	.1	.0
Emergent herbaceous wetlands	Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	3,033	Wetlands–narrow stands	.02	.17	.00	4.4	42.3	.0	.0	.1	.0
Total		54,900					20,000	30,000	10,000	28	41	14

The methodology used by Allen and Robison (2007a, 2007b) assumes that sufficient water is applied by a combination of precipitation and irrigation to each crop type to avoid plant stress; therefore, the simulated irrigation varies in response to changes in evapotranspiration due to meteorological conditions. Consequently, the areal recharge values used in this water budget incorporate that assumption, but the actual amount of irrigation water applied on a given parcel of land may be greater or less. For all irrigated plots in the valley, the actual mean application rate is probably near the simulated application rate calculated by Allen and Robison (2007a, 2007b). This approach negates the need to differentiate lands irrigated by surface-water diversions from those irrigated by ground water. Recharge from seepage through canals and recharge pits are accounted for separately (see the section of this report entitled "Seepage from Canals and Recharge Pits"). This water budget also does not differentiate cultivated land irrigated by subirrigation because it is difficult to identify and is probably relatively minor: Brockway and Kahlown, (1994) reported that only 5 percent of the irrigated area on the Bellevue fan used subirrigation.

The 2001 NLCD includes four "Development" land-cover classes, in which percentages of impervious cover range from less than 20 percent to 100 percent of the land surface (table 4). Precipitation that falls on an impervious surface does not infiltrate directly; rather, it either evaporates or runs off to an infiltration basin, dry well, or to an adjacent permeable surface. A ground-water flow model of the Spokane Valley-Rathdrum Prairie aquifer developed by Hsieh and others (2007) assumed that 15 percent of the total precipitation that fell on impermeable surfaces was lost to evapotranspiration and that the remaining 85 percent recharged the ground-water system. Because of similarities between the Wood River Valley aquifer system and the Spokane Valley-Rathdrum Prairie aquifer, including soil permeability, aquifer material, and Köppen climate type, this ratio is used in the current work. For each of the four 2001 NLCD "Development" land-cover classes in the study area, the 85-percent (of precipitation) deep-percolation value is applied to the maximum percentage of the range given for impervious cover and Allen and Robison's (2007a, 2007b) "Grass - Turf (lawns) – Irrigated" value is applied to the remaining area.

Results

Total estimated mean annual areal recharge from precipitation and applied irrigation for 1995–2004 to the aquifer system from permeable and impermeable surfaces is 20,000 acre-ft/yr (28 ft^3/s), which represents 7 percent of the total inflow of 270,000 acre-ft/yr (370 ft^3/s) (fig. 2; tables 2 and 4). By comparison, areal recharge totals for the wet year 1995 and dry year 2001 are 30,000 acre-ft/yr (41 ft^3/s) and 10,000 acre-ft/yr (14 ft^3/s), respectively (fig. 2; tables 2 and 4).

Seepage from Canals and Recharge Pits

Surface water is diverted for irrigation at many locations in the Wood River Valley; Brockaway and Kahlown (1994) identified more than 90 diversion sites. Although nearly all of this diverted water is used for irrigation, some is lost to seepage from canals, is diverted to recharge pits, or is returned to a stream. Applied irrigation water is either lost to evapotranspiration or infiltrates through the root zone and becomes recharge (as described in the "Areal Recharge from Precipitation and Applied Irrigation" section above). The separate components of ground-water recharge from canal seepage and diversion to recharge pits are accounted for in this section.

Method and Assumptions

Previous studies have recognized that seepage from irrigation canals in the Wood River Valley contributes recharge to the aquifer system, but have not explicitly quantified the volume of this recharged water. Brockway and Grover (1978) made a series of seepage measurements in some of these canals, and although seepage rates for specific reaches were identified, no total volumes were given. In the ground-water flow model described in Wetzstein and others (1999), canal seepage was treated separately only for the approximately 1.5-mi reach between the District Canal diversion in Bellevue and the point where it divides into three laterals; no rate or volume was given.

Numerous small surface-water diversions occur in the Wood River Valley, most of which are ungaged, though Water District 37 maintains records of measured diversions for their canals during the irrigation season (April through September) (Water District 37 and 37-M, 1995–2004). Some ungaged diversions may continue past the growing season into October or November; for example, Skinner and others (2007) reported a diversion of 35 ft^3/s into the District Canal on October 24, 2006. In the Wood River Valley, seven canals carry most of the surface water diverted for irrigation: Hiawatha (Canal No. 22), Cove (Canal No. 33), District (Canal No. 45), Bannon (Canal No. 49), Glendale (Canal No. 50), Baseline (Canal No. 55-C), and Black's Ditch (Canal No. 61) (Kevin Lakey, Watermaster, Water District 37 and 37M, oral commun., October 14, 2008) (fig. 5; table 5). For this study canal seepage is estimated only for these seven canals.

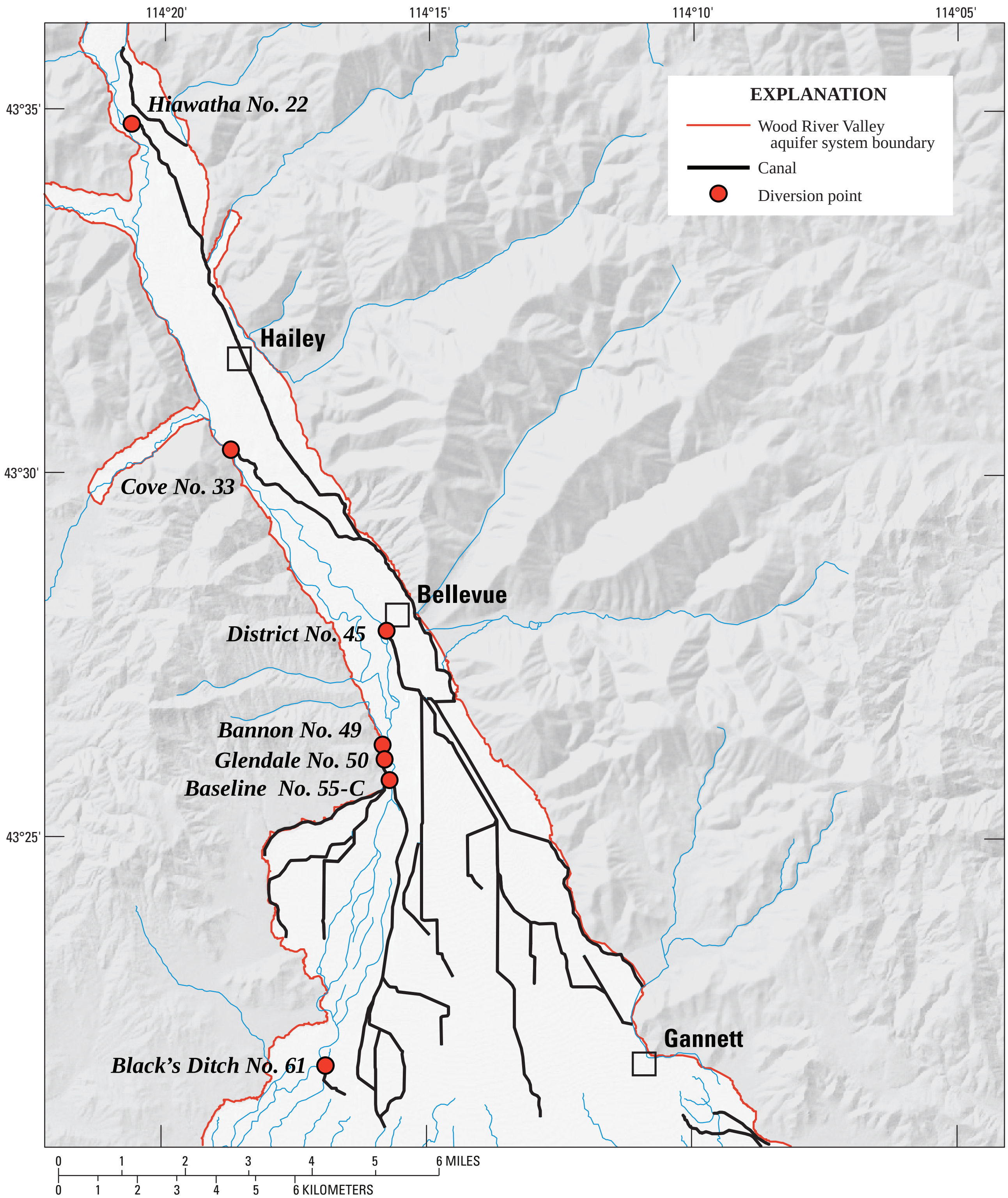

Figure 5. Locations of seven selected canals in the Wood River Valley, south-central Idaho, for which canal seepage is estimated.

Table 5. Annual diversions for seven canals and estimates of recharge from canal seepage and recharge pits, Wood River Valley, south-central Idaho, 1995–2004, 1995, and 2001.

[Diversion data from District 37 and 37-M (1995–2004); seepage loss from Brockway and Grover (1978); recharge pit diversions from Brockaway and Kahlown (1994). **Abbreviations:** acre-ft/yr, acre-foot per year; ft^3/s, cubic foot per second]

Canal name	Canal No.	Seepage loss as a percentage of total flow	Annual diversion						Canal seepage					
			1995–2004		1995		2001		1995–2004		1995		2001	
			(acre-ft/yr)	(ft^3/s)	(acre-ft/yr)	(ft^3/s)	(acre-ft/yr)	(ft^3/s)	(acre-ft/yr)	(ft^3/s)	(acre-ft/yr)	(ft^3/s)	(acre-ft/yr)	(ft^3/s)
Hiawatha	22	12	8,000	11	11,000	15	6,100	8.4	960	1.3	1,300	1.8	730	1.0
Cove	33	12	2,500	3.5	1,200	1.7	3,200	4.4	300	0.41	140	0.02	380	0.52
District	45	12	37,000	51	40,000	55	37,000	51	4,400	6.1	4,800	6.6	4,400	6.1
Bannon	49	12	870	1.2	1,200	1.7	720	1.0	100	0.14	140	0.02	86	0.12
Glendale	50	1.0	6,100	8.4	4,500	6.2	5,700	7.9	61	0.084	45	0.062	57	0.079
Baseline	55-C	7.0	15,000	21	17,000	23	9,600	13	1,000	1.4	1,200	1.7	670	0.93
Black's Ditch	61	12	8,000	11	8,100	11	6,300	8.7	960	1.3	970	1.3	760	1.0
Total			78,000	110	83,000	110	69,000	95	7,800	11	8,600	12	7,100	10
Recharge pit recharge									1,100	1.5	1,200	1.7	1,100	1.5
Total canal seepage and recharge pits									8,900	12	9,800	14	8,200	11

During the 1975 and 1976 irrigation seasons, Brockway and Grover (1978) made 16 pairs of discharge measurements in order to estimate canal seepage along nine canal reaches on the Bellevue fan. Their estimates of seepage ranged from 49 percent of flow on the east leg of the District Canal to 1 percent of flow on the lower reach of the Glendale Canal. For application to their ground-water flow model they varied the canal seepage rate with the percentage of maximum flow measured in the canal; these adjusted rates ranged from 20 to 100 percent of the calculated seepage. Because the standard error of a discharge measurement is 3–6 percent for most measurements and can range from 2 percent under ideal conditions to 20 percent under poor conditions (Sauer and Myer, 1992), many of the canal seepage rates calculated on the basis of discharge measurements by Brockway and Grover are inherently somewhat uncertain.

Canal seepage rates used in this study may be compared to those used in the ground-water flow model of the Eastern Snake Plain Aquifer (ESPA) by Cosgrove and others (2006) who explicitly represented irrigation-conveyance losses for five canal systems as a percentage of diversion volume, as described by Contor (2004). These five canals, one near Blackfoot, and the other four near Twin Falls, are larger than those in the Wood River Valley, although most of their lengths are underlain by sediment with similar hydraulic properties. The ESPA model simulated canal seepage as 5–50 percent of diversion volume. These values for the ESPA are very similar to seepage values measured by Brockway and Grover (1978) for the Wood River Valley.

For this report, Brockway and Grover's (1978) estimates of canal seepage (as a percentage of flow) are averaged for the District, Glendale, and Baseline Canals, resulting in seepages of 12, 1, and 7 percent of flows, respectively. Brockway and Grover did not measure discharge or calculate seepage on the Hiawatha, Cove, Bannon, and Black's Ditch Canals; therefore, the seepage value of 12 percent of flow calculated for the District Canal is used for these four canals. Thus, the reported diversion volumes for the seven canals are used to estimate total canal seepage.

Brockaway and Kahlown (1994) used data from landowners and Water District 37 to estimate ground-water recharge of 1,400 acre-ft in 1993 via seepage from five recharge pits fed by the District Canal into the Wood River Valley aquifer system. This estimate represents 3 percent of the total diversion for the District Canal in 1993 as reported by District 37. This 3 percent "multiplier" is applied to reported District canal diversions for the period 1995–2004, and for the individual years 1995 and 2001, to estimate seepage from the recharge pits to the aquifer system.

Results

Total estimated mean annual recharge to the aquifer system from canal seepage for 1995–2004 is 7,800 acre-ft/yr (11 ft^3/s). For the wet year 1995 and dry year 2001, estimated recharge is 8,600 acre-ft/yr (12 ft^3/s) and 7,100 acre-ft/yr (10 ft^3/s), respectively (table 5). Total estimated mean annual recharge from recharge pits for 1995–2004 is 1,100 acre-ft/yr (1.5 ft^3/s), and 1,200 acre-ft/yr (1.7 ft^3/s) and 1,100 acre-ft/yr (1.5 ft^3/s) for the wet and dry years of 1995 and 2001, respectively (table 5).

Total estimated mean annual recharge from the combined seepage from canals and recharge pits for 1995–2004 to the aquifer system is 8,900 acre-ft/yr (12 ft^3/s) representing

3 percent of the total inflow of 270,000 acre-ft/yr (370 ft^3/s) (fig. 2; tables 2 and 5). By comparison, estimated recharge for the wet year 1995 is 9,800 acre-ft/yr (14 ft^3/s) and 8,200 acre-ft/yr (11 ft^3/s) for the dry year 2001 (fig. 2; tables 2 and 5).

Leakage from Municipal Pipes

Most municipal supply systems lose some amount of water as determined by the difference between the total amount of water produced and the sum of all metered uses; this is referred to as unaccounted for water. Among the causes for such discrepancies are system leaks, inaccurate customer or master meters, underestimation of water consumed by non-metered or public uses, and accounting errors (Kenny, 2000). Non-metered public uses can include street cleaning, flushing of water-supply lines, maintaining public pools, and irrigation of parks and other public space. In the budget of the Wood River Valley aquifer system developed for this study, water lost to system leaks is assumed to recharge the aquifer system and is considered an inflow component.

Method and Assumptions

Wyatt (2000) reported that in the United States municipalities strive to keep unaccounted for water in the range from 10 to 12 percent, but a value of 40 percent or greater is typical. Kenny (2000) used data for 1997 from 596 public-water suppliers in Kansas to determine that unaccounted for water ranged from less than 3 percent to greater than 65 percent of the water put into the system; the mean value was 15 percent. Without a detailed system audit it is difficult to determine what percentage of these losses can be attributed to each of the potential components of unaccounted for water described in the preceding section. Garcia-Fresca and Sharp (2003) and Sharp and Garcia-Fresca (2003) reported that worldwide, leakage from water mains ranges from 5 percent to greater than 60 percent of the conveyance, and that cities with the most efficient water-main repair and replacement programs typically have a 10 percent loss. These reports also indicated that leakage from sewer systems is probably a similar percentage. For the purpose of the current ground-water budget, it is assumed that 15 percent of the municipal production of public water supplies in Sun Valley, Ketchum, Hailey, and Bellevue (including springs) is unaccounted for water that is lost to leakage and therefore becomes recharge to the aquifer system.

Ground-water withdrawals (pumpage) for municipal supply in the Wood River Valley are described in more detail in the "Ground-Water Withdrawals (Pumpage)" section below. However, the estimated total mean annual municipal production (including that from springs, which is not included as pumpage) for Sun Valley, Ketchum, Hailey, and Bellevue for 1995–2004 is 15,500 acre-ft/yr (21.4 ft^3/s); for the wet year 1995 estimated production is 12,300 acre-ft/yr (17.0 ft^3/s), and for the dry year 2001 it is 16,300 acre-ft/yr (21.1 ft^3/s).

Results

Estimated 1995–2004 mean annual recharge (inflow) to the aquifer system contributed by municipal water-system leakage is 2,300 acre-ft/yr (3.2 ft^3/s), which represents less than 1 percent of the total inflow of 270,000 acre-ft /yr (370 ft^3/s) (fig. 2; table 2). Estimated recharge from municipal water-system leakage for the wet year 1995 is 1,800 acre-ft/yr (2.5 ft^3/s) and 2,400 acre-ft/yr (3.3 ft^3/s) for the dry year 2001 (fig. 2; table 2).

Percolation from Septic Systems

Much of the study area is not served by municipal sewage systems and wastewater treatment plants. Residents in these unserved areas rely on onsite wastewater-disposal systems such as septic tanks and leach fields, and typically draw their water supply from a domestic well. A large percentage of the water discharged to these systems infiltrates through the root zone and becomes recharge to the aquifer system; this is particularly true in the Wood River Valley because for several months each year snow cover or frozen soils limit evapotranspiration. Although estimates of the amount of percolation from septic systems vary, for a ground-water flow model of the Spokane Valley-Rathdrum Prairie aquifer Hsieh and others (2007) simulated 95 percent of indoor water use infiltrated to the underlying aquifer system through septic systems (similarities between the two aquifer systems are discussed in the "Areal Recharge from Precipitation and Applied Irrigation" section above).

Method and Assumptions

Mean per capita indoor water use is determined for Sun Valley, Ketchum, and Hailey by assuming that all water supplied for domestic use (reported as a percentage by each city) between October and April is for indoor use. The estimated mean per capita indoor usage rate is 462 gallons per day (gal/d) for 1995–2004, 468 gal/d for 1995, and 453 gal/d for 2001. Multiplying this indoor per capita use by the 2000 census mean household size of 2.4 persons for Blaine County (U.S. Census Bureau, 2007), yields a per household indoor use. By assuming that approximately 1,200 domestic wells are completed in the Wood River Valley aquifer system and that each well serves one household, indoor water use supplied by domestic wells is determined (the values used in this estimate are described in more detail in the "Self-Supplied Domestic and Subdivision Pumpage" section below). Two additional assumptions are used to estimate recharge to the Wood River Valley aquifer system from septic system percolation: (1) that each household served by a domestic well utilizes an onsite septic system, and (2) that the estimated 95 percent of the water supplied by domestic wells and used indoors is returned to the aquifer system through deep percolation. Because these estimates of septic system percolation utilize per capita use, which is calculated by calendar year, these estimates should be considered calendar year estimates.

Results

Total estimated 1995–2004, 1995, and 2001 mean annual recharge to the aquifer system from septic system percolation is 1,400 acre-ft/yr (1.9 ft^3/s) representing less than 1 percent of the total inflow of 270,000 acre-ft/yr (370 ft^3/s) (fig. 2; table 2).

Subsurface Inflow

An unknown quantity of water enters the Wood River Valley aquifer system as underflow beneath the channel of the Big Wood River at the upper end of the study area. Most water budgets of the study area have not addressed underflow, focusing instead on the valley downstream of Hailey. Smith (1960) estimated that underflow at the Big Wood River near Ketchum gaging station (13135500) was greater than 10 percent of the basin yield (that is, the total amount of water that leaves a basin either as surface or subsurface flow). Because underflow cannot be measured directly, this study makes an indirect estimate using Darcy's law; however, little is known about the subsurface in this area and a great deal of uncertainty attends this estimate.

Method and Assumptions

To calculate a flow rate Darcy's law requires values for hydraulic gradient and hydraulic conductivity. The computed hydraulic gradient between two wells measured October 23, 2006 (wells 78 and 81 in Skinner and others [2007]) is 0.011. Because no aquifer test results are available in the area upstream of Ketchum, the mean value of hydraulic conductivity for five wells (225 ft/d) in the Wood River Valley (Frenzel, 1989) is used. This value then must be multiplied by the cross-sectional area of the aquifer system to determine a flow rate. The IDWR well information database includes 40 drillers' logs for wells in T.5 N., T. 17 E., sec. 10 (Idaho Department of Water Resources, 2008) near the inflow area. An examination of these logs suggests that the mean saturated thickness of the Wood River Valley aquifer system in the inflow area is 50 ft. The aquifer system width is estimated to be 800 ft, which is the width of the Wood River alluvium and youngest gravel terrace deposits as shown on the surficial geologic map of Breckenridge and Othberg (2006) at its narrowest point at the confluence of the Big Wood and North Fork Big Wood Rivers. The cross sectional shape is assumed to be one-half of an elliptical cross section, resulting in an area of 62,800 ft^2. Because the Big Wood River is perennial in this reach, the estimated value of underflow is assumed to be constant for the 1995–2004 period.

Results

Total mean annual subsurface inflow to the aquifer system at the gaging station near Ketchum is estimated to be 1,300 acre-ft/yr (1.8 ft^3/s) for all periods, representing less than 1 percent of the total 1995–2004 mean inflow of 270,000 acre-ft/yr (370 ft^3/s) (fig. 2; table 2). Although there is a high degree of uncertainty about this estimate, the quantity of water is a small proportion of the total estimated inflows, thus any error is probably relatively insignificant.

Streamflow Gains and Losses

The ground-water budget developed in this report is for the Wood River Valley aquifer system as a whole; consequently, gains and losses in flow were calculated for the three stream reaches defined by USGS gaging stations shown on figure 1: the Big Wood River between Ketchum and Hailey, the Big Wood River between Hailey and Stanton Crossing, and Silver Creek above Sportsman Access. Of these three reaches, only the Big Wood River below Hailey is a losing reach so that it contributes recharge to the aquifer system; the other two are gaining reaches that receive discharge or outflow from the aquifer system.

Method and Assumptions

The northernmost USGS gaging station on the Big Wood River is designated Big Wood River near Ketchum (13135500), where flow data were recorded from June 1948 through September 1971. The gaging station Big Wood River at Hailey (13139500) has been operated continuously since 1915. The gaging station Big Wood River at Stanton Crossing near Bellevue (13140800) replaced the Big Wood River near Bellevue gaging station (13141000) in 1996; however, the data for the two gaging stations "are not equivalent because of inflow between sites" (Brennan and others, 2005). (The locations of the two gaging stations are near Stanton Crossing and approximately 1 mile apart. Henceforth, the location of the two gages is referred to as Stanton Crossing, and the gaging stations are referred to as the Stanton Crossing gaging station and near Bellevue gaging station.) The gaging station Silver Creek at Sportsman Access (13150430) has been operated since 1974 and replaced the Silver Creek at Highway 20 near Picabo gaging station (13150500), operated between 1920 and 1962. (Other discontinued gaging stations in the study area are described in Skinner and others [2007].) Because these gaging stations have been operated over different (and not coincident) periods, an analysis of streamflow gains and losses must necessarily involve compromises; thus streamflow gains and losses on the Big Wood River calculated for the period 1948–71 are assumed to be representative of the years 1995–2004, the period being considered in this study. Streamflow gain along Silver Creek is calculated on the basis of data from the Silver Creek at Sportsman Access gaging station for 1995–2004.

Numerous diversions from the Big Wood River for irrigation complicate the analysis of streamflow gain and loss; to minimize the effect of these diversions, only monthly mean streamflows for November through April are used in the analysis. Monthly mean streamflows at the upstream and downstream gaging stations are compared, inflows from tributaries and wastewater treatment plants (WWTPs) subtracted, and the mean of the resulting differences is taken as the mean streamflow gain or loss over the reach (table 6).

The monthly mean November–April streamflow for the 1948–71 and 1995–2004 periods at the Hailey gaging station are nearly identical: 236 and 238 ft^3/s, respectively. In order to maintain the ratio between the relative gains and losses on the Big Wood River, data for the same time period (1948–71) and method used for the Ketchum-Hailey reach is applied to estimate streamflow loss between the stations below Hailey and near Bellevue.

Diversions for irrigation, discharge from wastewater treatment plants, and inflow from tributary streams must be accounted for in order to estimate gains and losses of flow in the Big Wood River. The choice of the November-April time period virtually eliminates the effects of irrigation diversions; however, flow from WWTPs and from some tributaries must be considered. Mean November–April WWTP discharge for 1995–2004 is compiled for the Ketchum WWTP (which includes Ketchum and Sun Valley) (Patrick McMahon, Sun Valley Water and Sewer District, written commun., September 18, 2008; U.S. Environmental Protection Agency, 2008). Monthly mean November-April WWTP discharge for 1997 and 2002 is compiled for Hailey from USEPA records (U.S. Environmental Protection Agency, 2008). Approximately 0.45 ft^3/s (330 acre-ft/yr) of wastewater from Bellevue is routed to a land-spreading facility south of the

Table 6. Monthly mean November to April streamflow and streamflow gain and loss for selected U.S. Geological Survey gaging stations in the Wood River Valley, south-central Idaho, water years 1948–71, 1995–2004, 1995, and 2001.

[Percentages shown in parentheses indicate the percentage by which 1948–71 values were adjusted based on measured streamflow at the Hailey gaging station. **Abbreviations**: USGS, U.S. Geological Survey; WWTP, wastewater treatment plant; ft^3/s, cubic foot per second; –, no data or not applicable]

USGS gaging station No.	Gaging station or inflow name	Period of record (water years)	1948–71		Measured mean November–March flow (ft^3/s)			Reach gain (-) or loss (+) (ft^3/s)		
			Mean November–April flow, (ft^3/s)	Reach gain (-) or loss (+) (ft^3/s)	1995–2004	1995	2001	1995–2004 (100 percent)	1995 (93 percent)	2001 (81 percent)
13135500	Big Wood River near Ketchum	1948–72	69	–	–	–	–	–	–	–
–	North Fork Big Wood River[1]		31	–	–	–	–	–	–	–
–	WWTP discharge[2]		2.5	–	–	–	–	–	–	–
–	Warm Springs Creek[1]		42	–	–	–	–	–	–	–
–	Trail Creek[1]		29	–	–	–	–	–	–	–
–	East Fork Big Wood River[1]		25	–	–	–	–	–	–	–
–	Deer Creek[1]		9.5							
13139500	Big Wood River at Hailey	1889, 1915–present	236	-34	238	222	192	-34	-32	-27
–	Croy Creek[1]		8.9	–	–	–	–	–	–	–
–	WWTP discharge[3]		.37	–	–	–	–	–	–	–
13141000	Big Wood River near Bellevue	1911–96	156	90	–	–	–	90	83	72
13150430	Silver Creek at Sportsman Access near Picabo	1974–present	–	–	141	155	121	-141	-155	-121

[1] Mean of previous streamflow measurements, see table 7.

[2] November–April mean for Ketchum, 1997 and 2002.

[3] November–April mean for Hailey, 1997 and 2002.

city that uses a combination of infiltration trenches and crop irrigation for disposal to the WWTP (Connolly and others, 2003). The potential recharge volume is relatively small, especially considering that some of this water is lost to evapotranspiration. Therefore, recharge contribution from the Bellevue WWTP is not considered in the budget developed here. Similarly, November-April discharge for 2002-03 from the Meadows RV Park WWTP, south of Ketchum, was approximately 0.06 ft^3/s (40 acre-ft/yr) to the Big Wood River; this negligible flow is not used in the gain and loss estimates (U.S. Environmental Protection Agency, 2008). Combined mean November-April discharge for the Ketchum WWTP is 2.5 ft^3/s (1,800 acre-ft/yr) and 0.37 ft^3/s (260 acre-ft/yr) for the treatment plant at Hailey.

As discussed in the "Recharge from Tributary Canyons" section above, six tributary streams were assumed to contribute flow directly to the Big Wood River between the gaging stations near Ketchum and near Bellevue: North Fork Big Wood River, Warm Springs Creek, Trail Creek, East Fork Big Wood River, Deer Creek, and Croy Creek (tables 6 and 7). A limited number of discharge measurements of these six streams have been made for previous studies, primarily during irrigation season, and these measurements were averaged for each tributary to approximate their mean flow into the Big Wood River (tables 6 and 7). These tributary flows were then subtracted from Big Wood River flows to calculate gains and losses.

Table 7. Streamflow discharge measurements of six tributary streams to the Big Wood River by previous authors, Wood River Valley, south-central Idaho.

[**Abbreviations:** ft^3/s, cubic foot per second; –, not applicable]

Tributary	Monthly mean, Trail Creek at Ketchum gaging station (13137500)		Castelin and Winner (1975)		Luttrell and Brockway (1984)		Frenzel (1989)		Skinner and others (2007)		Mean discharge for all measurements
	Month	ft^3/s	Date	ft^3/s	Date	ft^3/s	Date	ft^3/s	Date	ft^3/s	ft^3/s
Reach: Big Wood River near Ketchum gaging station (13135500)											
North Fork Big Wood River	–	–	09-14-72	39	–	–	–	–	–	–	31
	–	–	04-09-73	19	–	–	–	–	–	–	–
	–	–	07-10-73	36	–	–	–	–	–	–	–
	–	–	09-18-73	32	–	–	–	–	–	–	–
	–	–	12-19-73	28	–	–	–	–	–	–	–
Warm Springs Creek	–	–	09-14-72	48	09-13-83	60	–	–	10-25-06	39	42
	–	–	04-09-73	48	03-13-84	51	–	–	–	–	–
	–	–	07-10-73	57	–	–	–	–	–	–	–
	–	–	09-18-73	27	–	–	–	–	–	–	–
	–	–	12-19-73	25	–	–	–	–	–	–	–
	–	–	02-06-74	22	–	–	–	–	–	–	–
Trail Creek	08-20	7.4	09-14-72	11	09-13-83	31	08-01-86	26	10-25-06	23	29
	09-20	7.4	07-10-73	10	03-13-84	33	–	–	–	–	–
	07-21	100	09-18-73	6.6	–	–	–	–	–	–	–
	08-21	23	–	–	–	–	–	–	–	–	–
East Fork Big Wood River	–	–	09-14-72	26	09-13-83	37	08-01-86	43	10-26-06	20	25
	–	–	04-09-73	17	03-13-84	24	–	–	–	–	–
	–	–	07-10-73	27	–	–	–	–	–	–	–
	–	–	09-18-73	6.6	–	–	–	–	–	–	–
Deer Creek	–	–	–	–	09-13-83	6.0	–	–	–	–	9.5
	–	–	–	–	03-14-84	13	–	–	–	–	–
Reach: Big Wood River at Hailey gaging station (13139500)											
Croy Creek	–	–	–	–	09-14-83	13	08-01-86	4.8	–	–	8.9

A USGS gaging station, Warm Springs Creek at Guyer Hot Springs (13136500), was operated between December 1940 and March 1959; the mean discharge for the period of record is 85 ft^3/s. This value is significantly larger than any of the values of measured discharge shown in table 7. Jones (1952) reported that a pipeline from Guyer Hot Springs carried water to Bald Mountain Resort but he did not measure the flow; however, Anderson and Bideganeta (1985) reported that a flow rate of 2.2 ft^3/s entered this pipeline. Although this pipeline existed in the 1930s and was operated through approximately 1988, the diversion amount is relatively small compared to total streamflow. The probable reason for the difference in measured flows at this gaging station and streamflow measurements made near the confluence of Warm Springs Creek and the Big Wood River is that Warm Springs Creek is a losing reach over the intervening 2 mi. Thus, the record from the Guyer Hot Springs station is not a good indication of flow at the mouth of Warm Springs Creek and is not used in the analysis.

To estimate streamflow loss of the Big Wood River for the wet (1995) and dry (2001) years, the monthly mean flow for November–April during the period 1995–2004 at the gaging station at Hailey is compared to the November–April mean flows for 1995 and 2001 at the same gaging station. November–April mean streamflow at the gaging station at Hailey is 238 ft^3/s for 1995–2004, 222 ft^3/s in 1995, and 192 ft^3/s in 2001; thus the 1995 and 2001 mean annual streamflows were 93 and 81 percent, respectively, of the 1995–2004 November–April mean streamflow. These percentages were multiplied by the calculated 1948–71 gains and losses to estimate the 1995 and 2001 gains and losses (table 6).

Most of the flow of Silver Creek is contributed by springs and seeps and it is assumed that no irrigation return flow or overland runoff to the creek during November–April affects streamflow. Thus the entire flow at the gaging station Silver Creek at Sportsman Access (13150430) is attributed to ground-water discharge from the Wood River Valley aquifer system. Because the Silver Creek at Sportsman Access gaging station is about 3 mi above the aquifer system boundary defined by Skinner and others (2007), some streamflow gain along Silver Creek may be unaccounted for although measurements made during the irrigation season by Moreland (1977) suggest that this quantity is small relative to the total ground-water budget.

It should be noted that although net streamflow gains and losses are calculated for two reaches of the Big Wood River (those between Ketchum and Hailey and between Hailey and approximately Stanton Crossing) and the reach of Silver Creek above Sportsman Access, on a local scale each of these large reaches has smaller gaining and losing reaches. Examples are the Big Wood River below Bellevue, which typically is dry near Glendale Road during some parts of the year but regains flow near Stanton Crossing, and gaining and losing reaches on Silver Creek (Moreland, 1977). Because the ground-water budget developed in this study is for the entire Wood River Valley aquifer system, identification of these smaller individual reaches is not significant to the overall budget.

Some uncertainty attends the estimates of streamflow gains and losses. There is intrinsic uncertainty associated with the measurement (Sauer and Myer, 1992) and computation of streamflow and computed discharge. Other factors leading to uncertainty are the assumptions that mean November-April rates of streamflow gain and loss are constant throughout the year, that the rates of streamflow from tributary canyons are quantified correctly, that all major inflows and diversions are accounted for, and that flow conditions during 1948–71 represent flow conditions during 1995–2004.

Results

Total estimated 1995–2004 mean streamflow loss (recharge to the aquifer system) from the reach of the Big Wood River between the Hailey and the near Bellevue gaging stations (Hailey-Stanton Crossing) is 90 ft^3/s (65,000 acre-ft/yr) representing 24 percent of the total inflow of 370 ft^3/s (270,000 acre-ft/yr) (fig. 2; tables 2 and 6). Estimated streamflow losses for the wet year of 1995 and dry year of 2001 are 83 ft^3/s (60,000 acre-ft/yr) and 72 ft^3/s (52,000 acre-ft/yr), respectively (fig. 2; tables 2 and 6).

Total estimated 1995–2004 mean streamflow gain (discharge from the aquifer system) into the reach of the Big Wood River between the near Ketchum and the Hailey gaging stations (Ketchum-Hailey) is 34 ft^3/s (25,000 acre-ft/yr) representing 10 percent of the total outflow of 350 ft^3/s (250,000 acre-ft/yr) (fig. 2; tables 2 and 6). Estimated streamflow gains for the 1995 wet year and 2001 dry year are 32 ft^3/s (23,000 acre-ft/yr) and 27 ft^3/s (20,000 acre-ft/yr), respectively (fig. 2; tables 2 and 6).

Total estimated 1995–2004 mean streamflow gain (discharge from the aquifer system) into Silver Creek above the Sportsman Access gaging station is 141 ft^3/s (102,000 acre-ft/yr) (representing 41 percent of the total outflow of 350 ft^3/s (250,000 acre-ft/yr) (fig. 2; tables 2 and 6). Estimated streamflow gains for the 1995 wet and 2001 dry years are 155 ft^3/s (112,000 acre-ft/yr) and 121 ft^3/s (87,600 acre-ft/yr), respectively (tables 2 and 6).

Outflows

Discharge, or the outflow of water from the Wood River Valley aquifer system occurs through five main sources (from largest to smallest): Silver Creek streamflow gain, pumpage, Big Wood River streamflow gain, direct evapotranspiration from riparian vegetation, and subsurface outflow (treated separately). The total estimated mean annual outflow from the aquifer system is 250,000 acre-ft/yr (350 ft^3/s) (fig. 2; table 2). Total estimated outflow for the wet and dry years of 1995 and 2001 is 240,000 acre-ft/yr (330 ft^3/s) (fig. 2; table 2).

Ground-Water Withdrawals (Pumpage)

In the Wood River Valley, water withdrawn from wells is used primarily for irrigation, self-supplied domestic and subdivision, and municipal uses. Domestic wells with additional water-use categories listed in the IDWR database (for example, domestic and irrigation, or domestic and stock) are treated solely as domestic wells in the current analysis. As in earlier studies, stock use is considered negligible compared to other uses but for wells with multiple uses reported in the water right stock use may be included as part of the domestic or irrigation use. Self-supplied industrial and commercial uses are considered negligible and are not included in other water-use categories. Because the per capita use calculations are from annual census data, all reported or estimated pumpage volumes in this section are by calendar year.

Method and Assumptions

Irrigation Pumpage

The number of irrigation wells in the Wood River Valley and associated pumping volumes are difficult to ascertain. Information on self-supplied domestic, subdivision, and irrigation wells is compiled from IDWR water-rights databases. IDWR currently (2008) is adjudicating water-rights in the Wood River Valley, and until the adjudication is completed, records on wells and diversions are somewhat contradictory or incomplete. Wetzstein and others (1999) noted similar problems in their hydrologic evaluation of the Big Wood River and Silver Creek watersheds. Consequently, there is a large degree of uncertainty associated with the estimates of the number of irrigation, domestic, and subdivision wells, and their corresponding pumpage volumes.

To estimate irrigation pumpage, IDWR databases were used to determine ground-water irrigation water rights on the basis of decreed, statutory claim, or licensed beneficial use for lands overlying the Wood River Valley aquifer system. A total of 603 wells were identified in the database. Obvious duplicate records were culled (records indicating a well that has more than one permitted use, such as a well permitted for both domestic and irrigation uses), which left a total of 468 irrigation wells distributed throughout the study area. Maximum annual diversion volumes associated with the water rights were then summed for all wells to estimate annual pumpage from irrigation wells. This maximum diversion volume is assumed to represent the 1995–2004 mean annual irrigation pumpage. Values for the wet and dry years were determined by dividing the 1995 and 2001 mean simulated irrigation value for “Grass pasture-high management” for the Picabo and Picabo Agrimet stations (1.79 and 2.57 ft/yr, respectively) by the mean 1995–2004 rate (2.32 ft/year) (Allen and Robison, 2007a, 2007b). (The “Grass pasture-high management” class is used because it represents the mean value of the main three classes served by irrigation water: Alfalfa - less frequent cuttings,” “Grass pasture-high management,” and “Grass - Turf (lawns) – Irrigated.”) The resulting ratios of 77 and 111 percent, for 1995 and 2001, respectively, were then multiplied by the maximum diversion volume representing the 1995–2004 mean annual irrigation pumpage. (Additional detail regarding the work of Allen and Robison (2007a, 2007b) is described in the “Areal Recharge from Precipitation and Applied Irrigation” section above.)

Self-Supplied Domestic and Subdivision Pumpage

As with irrigation pumpage, once IDWR completes the water-rights adjudication of the Wood River Valley, domestic and subdivision pumpage will be known with more confidence. Until then, the estimates for the number of domestic and subdivision wells, and the corresponding pumpage volumes, are made with assumptions that introduce a large degree of uncertainty into the estimated values.

IDWR records indicate that there are approximately 1,200 self-supplied domestic wells completed in the Wood River Valley aquifer system distributed throughout the study area. Several approaches were considered to estimate the pumpage volume from these wells involving various combinations of population estimates, per capita water use, and water rights. The approach used here involves several steps: (1) each domestic well is assumed to serve one household; (2) each household contains 2.4 persons (the average household size for Blaine County from the 2000 census [U.S. Census Bureau, 2007]); and (3) per capita use for domestic wells is equivalent to the mean per capita use of Sun Valley, Ketchum, and Hailey.

Mean per capita water use is determined using data from Sun Valley, Ketchum, and Hailey. First all residential water deliveries, reported as a percentage of total production, including spring flows are summed for each city. (These percentages are 85, 75, and 95 percent for Sun Valley, Ketchum, and Hailey, respectively [M.A. Maupin, U.S. Geological Survey, written commun., May 21, 2008].) This total is then divided by the total population of the three municipalities as determined from U.S. Census Bureau estimates and the 2000 census (U.S. Census Bureau Population Division, 2000; 2006). The resulting mean per capita use is 767, 735 and 791 gal/d for 1995–2004, 1995 (wet year) and 2001 (dry year), respectively. By comparison, public-supply data from the 2000 water-use compilation of Hutson and others (2004) indicates that mean per capita water use is 179 and 263 gal/d for the USA and Idaho, respectively. The National mean is much smaller than either the Idaho or Wood River Valley mean because of generally lower irrigation requirements due to increased precipitation east of the 100th meridian. Undoubtedly, part of the reason for the large per capita use calculated for the Wood River Valley is that significant numbers of visitors and non-resident homeowners are unaccounted for by census and population estimates. The 2000 census data indicate that of the 2,340 housing units in Sun Valley, 68 percent are "Vacant housing units for seasonal, recreational, or occasional use" (U.S. Census Bureau, 2008a). For Ketchum, Hailey, and Bellevue the corresponding percentages are 38, 2.4, and 2.5 percent, respectively (U.S. Census Bureau, 2008b, 2008c, 2008d).

There are 57 wells completed in the Wood River Valley aquifer system that supply subdivisions, mobile-home parks, or small communities distributed throughout the study area. Because these wells are seldom metered and the determination of the number and size of households are unknown, pumpage is estimated as the permitted water right.

Municipal Pumpage

Municipal monthly pumpage volumes were provided by Sun Valley (9 wells), Ketchum (6 wells), Hailey (4 wells, 1 spring), and Bellevue (2 wells, 3 springs). Calendar years are used rather than water years in analysis and reporting of municipal water use. For Bellevue, only 2005–07 pumpage volumes were reported, thus the 3-year mean of these volumes is used for the 1995–2004, 1995, and 2001 estimates.

Both Hailey and Bellevue derive much of their municipal supply from springs outside the aquifer system (more than 40 and 90 percent, respectively), thus this water is not included as a ground-water withdrawal. Ultimately the municipal water is discharged to the Big Wood River as treated wastewater, is lost to consumptive use, or returns to the aquifer system through deep percolation and consequently is accounted for as areal recharge or WWTP discharge.

Results

The estimated mean annual (1995–2004) total ground-water pumpage for irrigation is 55,000 acre-ft/yr (76 ft^3/s). Estimated irrigation pumpage is 42,000 acre-ft/yr (58 ft^3/s) and 60,000 acre-ft/yr (83 ft^3/s) for 1995 (wet year) and 2001 (dry year), respectively. The most recently published estimate of ground-water withdrawals in the Wood River Valley was 51,500 acre-ft/yr for the aquifer system from Hailey southward (Brockway and Kahlown, 1994), placing it within the irrigation pumpage estimates in this report.

Estimated mean annual 1995–2004 combined self-supplied domestic and subdivision pumpage from 1,200 domestic and 57 subdivision wells is 42,000 acre-ft/yr (58 ft^3/s). Estimated pumpage is 39,000 acre-ft/yr (54 ft^3/s) for the wet year 1995 and 43,000 acre-ft/yr (59 ft^3/s) for the dry year 2001.

Total estimated mean annual 1995–2004 municipal pumpage from 21 wells in Sun Valley, Ketchum, Hailey, and Bellevue is 8,900 acre-ft/yr (12 ft^3/s). Estimated municipal pumpage is 7,700 acre-ft/yr (11 ft^3/s) for the wet year 1995 and 9,900 acre-ft/yr (14 ft^3/s) for the dry year 2001.

Total estimated 1995–2004 mean annual pumpage from irrigation, combined self-supplied domestic and subdivision, and municipal uses is 110,000 acre-ft/yr (150 ft^3/s) representing 44 percent of the total outflow of 250,000 acre-ft/yr (350 ft^3/s) (fig. 2; table 2). Total estimated pumpage is 89,000 acre-ft/yr (120 ft^3/s) for the wet year 1995 and 110,000 acre-ft/yr (150 ft^3/s) for the dry year 2001 (fig. 2; table 2).

Direct Evapotranspiration from Riparian Vegetation

Direct evapotranspiration (ET) from ground water occurs as phreatophytes, plants whose root systems extend to the water table, draw their water supply directly from ground water. In the Wood River Valley, as in much of the western United States, these plants are primarily cottonwood and willow that grow along streams and irrigation canals, but also include perennial vegetation in wetland areas.

Method and Assumptions

The 2001 NLCD separates the deciduous vegetation (cottonwood and willow) along streams and irrigation canals from the perennial wetland vegetation into two land-cover classes: woody wetlands and emergent herbaceous wetlands. These two land-cover classes correspond to the Allen and Robison (2007a, 2007b) land classes of cottonwoods and wetlands-narrow stands, respectively (table 4). A third class, deciduous forest, is considered to be largely cottonwood in the Wood River Valley and is thus considered in estimating direct ET in the water budget analysis described here. Because wetlands are commonly narrow and discontinuous, the total vegetated area of the two land classes determined on the basis of the 2001 NLCD classification, 7,013 acres, may underestimate actual wetland area. It is assumed that the source of all the water used by these plants is shallow ground water that is part of the Wood River Valley aquifer system.

Results

Total estimated mean annual discharge (outflow) for 1995–2004 by direct evapotranspiration is 18,000 acre-ft/yr (25 ft^3/s) representing 7 percent of the total outflow of 250,000 acre-ft/yr (350 ft^3/s) (fig. 2; table 2). Estimated discharge is 16,000 acre-ft/yr (22 ft^3/s) and 21,000 acre-ft/yr (29 ft^3/s) for 1995 (wet year) and 2001 (dry year), respectively (fig. 2; table 2).

Budget Residuals: Subsurface Outflow and Changes in Ground-Water Storage

Two ground-water budget components, subsurface outflow and changes in ground-water storage, cannot be measured directly. Because independent estimates of these components are highly uncertain they are estimated as part of the difference (or residual) between estimated inflows to and outflows from the Wood River Valley aquifer system for the three periods of interest. For 1995–2004, estimated mean annual inflow exceeds outflow by 20,000 acre-ft/yr (28 ft^3/s) and 30,000 acre-ft/yr (41 ft^3/s) for 1995–2004 and 1995 (wet year), respectively; for the dry year 2001, estimated mean annual outflow exceeds inflow by 20,000 acre-ft/yr (28 ft^3/s) (fig. 2, table 2). These estimated residuals represent 8, 13, and 8 percent, respectively, of total estimated outflows for the same periods.

Subsurface Outflow

Because of the large uncertainty associated with the estimate of subsurface outflow from an aquifer, this component is commonly included as part of the residual in order to balance ground-water budgets or to calibrate ground-water flow models. Previous studies support the conclusion by Smith (1959) that subsurface outflow from the Wood River Valley aquifer system in the vicinity of Stanton Crossing is “relatively small” based on such evidence as water-level gradients and subsurface geology. There is more ambiguity, however, in estimates of subsurface outflow in the Picabo area, which range from 11,800 acre-ft/yr (Brockway and Kahlown, 1994) to 38,000 acre-ft/yr (Smith, 1959). These estimates of outflow were made by first estimating aquifer system properties and then applying the Darcy equation, but as noted in the “Subsurface Inflow” section above, such estimates require several assumptions and are thus subject to a large degree of uncertainty. Garabedian (1992) and Cosgrove and others (2006) made estimates of tributary underflow beneath Silver Creek into the Eastern Snake River Plain aquifer system for separate ground-water flow models of that aquifer system (53,000 and 47,000 acre-ft/yr, respectively).

Although transmissivity of the geologic materials that constitute the Wood River Valley aquifer system can be determined using a single inconclusive aquifer test (performed on a well 3 mi southeast of Picabo by Smith [1959]), and the hydraulic gradient can be measured, an estimate must still be made of the thickness and width of the hydrogeologic units, as well as their hydraulic connection with the Eastern Snake River Plain aquifer system. Because of the uncertainties in these estimates the ground-water budget documented in this report assumes the subsurface outflow from the Wood River Valley aquifer system near Stanton Crossing is zero and the subsurface outflow in the Picabo area is part of the residual between the estimated inflow and outflow.

Changes in Ground-Water Storage

Under natural conditions, recharge to an aquifer over the long term is approximately balanced by discharge from the aquifer—inflows approximate outflows and there is negligible change in the amount of water stored in the system. However, short-term climatic variations, and for developed aquifers, subsequent land-use changes and (or) changes in ground-water use, tip this balance and water may be taken into or released from storage in the aquifer. The source of water for withdrawals (or pumpage) is either increased recharge, decreased discharge, removal of water from storage, or some combination of the three. A decrease in ground-water storage results in water-level declines. Thus water levels decline if the rate of recharge to the aquifer is less than discharge from the aquifer.

Skinner and others’ (2007) map of ground-water level changes for the entire aquifer system from partial-development conditions (242 wells) to October 2006 (98 wells) shows areas of increased and decreased water levels that indicate changes in ground-water storage. Although ground-water level maps are useful for defining areas where ground-water storage is occurring, and whether such changes are increasing or decreasing, they are not appropriate for quantifying such changes. Other methods for quantifying changes in ground-water storage are equally problematic (although an appropriate ground-water flow model can make such estimates). Consequently, for the current ground-water budget, no separate attempt is made to quantify changes in ground-water storage.

Probable Magnitude and Significance of Subsurface Outflow and Changes in Ground-Water Storage

The relative contributions of underflow, ground-water storage change, and budget error to the respective residuals are difficult to differentiate.

Ground-water levels for various periods consistently indicate that subsurface flow out of the Wood River Valley aquifer system in the Picabo area flows into the Eastern Snake Plain aquifer system. This rate may be constant (as is assumed for the subsurface inflow beneath the gaging station near Ketchum) or may be somewhat responsive to precipitation (as with recharge from tributary canyons). However, if the underflow rate is assumed to be constant, that no changes in ground-water storage occurred over the long term as represented by the 10-year 1995–2004 mean, and that errors are negligible, subsurface outflow is equivalent to the budget residual estimated for this period, about 20,000 acre-ft/yr. If this 20,000 acre-ft/yr is assumed to be relatively constant, during the wet year 1995, 10,000 acre-ft was added to ground-water storage in the Wood River Valley aquifer system and during the dry year 2001, 40,000 acre-ft was withdrawn from ground-water storage. Assuming an aquifer system area of 86 mi^2 and a specific yield of 25 percent, a 40,000 acre-ft decrease in ground-water storage represents a water-level decline of approximately 3 ft over the entire unconfined aquifer of the Wood River Valley aquifer system. Such a decline would not be uniformly distributed as these changes in ground-water storage in the Wood River Valley quickly result in changes in streamflows.

Ground-Water Budget Errors and Uncertainty

The development of any water budget inherently involves a certain level of complexity, and even the most detailed studies of aquifer systems contain some uncertainty arising "from natural variability in hydrology, geology, climate, and land use and inaccuracies in the techniques used to collect and interpret data" (Healy and others, 2007, p. 46). Much of the uncertainty in the ground-water budget presented in this report is a result of the fact that many of the components of the budget cannot be measured directly and uncertainty may be introduced by incomplete data and (or) simplifying assumptions. Even the components that can be measured, such as streamflow gains and losses, have some uncertainty because of measurement standard error and temporal and spatial variations. The current report explains in detail the methods and assumptions used to estimate each water-budget component and describes the associated uncertainties.

Additional data collection likely can reduce the uncertainty in some components (such as pumpage and tributary recharge) although uncertainties in other components (such as subsurface outflow) likely will be more difficult to reduce. A ground-water flow model that incorporates parameter estimation can help quantify the uncertainties and refine estimates of the budget components.

Sustainability of the Ground-Water Resource

Stakeholders in the Wood River Valley—municipalities, public-water suppliers, land-and water-use planners and managers, and residents—have expressed concern about whether an increasing population and its demands on ground-water are "sustainable." To address this question, the concept of ground-water sustainability is examined in the context of the ground-water budget for the Wood River Valley aquifer system. Ground-water sustainability has been defined in different ways, and the concept has evolved over time.

Sustainability and Safe Yield

The concept of "sustainable ground-water development" has its origin in the older term "safe yield," which was first used in the early 20th century. The definition of safe yield evolved in the hydrologic literature to that of Todd (1959): "the amount of water which can be withdrawn from [a ground-water basin] annually without producing an undesired result." Others have refined this concept to include socioeconomic factors as well as purely hydrologic ones. Still others have recommended dropping the term completely because it is too nebulous or because it oversimplifies how aquifers function. Perhaps the principal misconception (even among hydrologists) is that safe yield equals the average annual rate of natural recharge.

The idea of sustainable development, developed in the early 1980s, was applied to ground-water systems, which led to the concept of "sustainable ground-water development." As with safe yield, the definition is somewhat ambiguous and subjective: "development and use of ground water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences." (Alley and others, 1999, p. 2).

Although some critics argue that any ground-water withdrawal will have adverse effects over some period of time and reject the concepts of safe yield or sustainability, the concepts remain useful if for no other reason than to promote a long-term view of how ground-water resources will be developed and managed. As aquifers are developed, "as with other natural resources, society must weigh the benefits against the consequences of such use." (Bartolino and Cunningham, 2003, p. 1).

Much of this discussion is taken from Alley and others (1999) and Alley and Leake (2004). The latter paper describes the development of the concepts of safe yield and sustainability and how they relate to each other. The reader desiring more information is referred to this paper and its list of references.

How a Water Budget Can Be Used to Determine Sustainability

The key to ground-water sustainability is to develop tools that water managers can use to evaluate probable effects of withdrawals. One such tool is a hydrologic ground-water budget—an accounting of the inflow to, outflow from, and storage in a ground-water system. Its purpose is to quantify these components and improve understanding of their relations and interactions However, as with most tools, the application of a ground-water budget has limitations and it is important to understand these limitations.

As an aquifer system is developed the ultimate source of water for withdrawals (or pumpage) is either increased recharge, decreased discharge, removal of water from storage, or some combination of the three. In the absence of artificial recharge, ground-water withdrawals can induce additional recharge by such mechanisms or processes as increased infiltration of wastewater, infiltration of runoff from impervious surfaces such as roads, parking lots, or home sites (driveways and roofs), or increased infiltration from lakes or streams as a result of declining water levels. Natural discharge is reduced by pumping or otherwise intercepting water that formerly discharged at springs and gaining stream reaches. A decrease in ground-water storage results in water-level declines. However, as water levels decline, a new equilibrium may be reached as stream reaches are converted from gaining to losing, as springs and seeps stop flowing, or as riparian vegetation dies off. Consequently, in a dynamic system, the volume of recharge—whether under predevelopment or development conditions—cannot be used alone to determine sustainability without considering the effects of declining water levels and reduced discharge.

In the Wood River Valley, the intimate connection of the surface-water and ground-water systems suggests that changes in ground-water storage will affect recharge and discharge relatively quickly. This is consistent with the declining water levels and reduced baseflow described in Skinner and others (2007), and indicates that ground-water discharge has increased relative to recharge as development of the aquifer system has proceeded. This may be due to the reasons discussed in the previous paragraph and (or) because long-term drought and the effects of global climate change (such as earlier snowpack runoff seen in basins throughout the Western United States [Stewart and others, 2005]) have altered the amount of recharge.

Currently (2008), the only possible sources for increases in ground-water recharge are streams and irrigation canals (resulting in decreased streamflows, at least in some reaches). Most natural discharge from the ground-water system is to the Big Wood River, Silver Creek, and their tributaries, thus a decrease in discharge would also result in decreased streamflows. A reduction of ground water in storage would result in water-level declines. The situation is further complicated by such factors as variations in climate and how much ground-water pumpage is used consumptively and where the remainder is returned to the system.

If it is assumed that at some point, further reduction in streamflow would be unacceptable, a ground-water budget can be used to roughly determine the amount of sustainable development. However, such an estimate will have a degree of uncertainty as discussed in the “Ground-Water Budget Errors and Uncertainty” section above.

Although a ground-water budget can indicate an approximate value of sustainable pumpage for the entire aquifer system, the budget cannot be used to predict site-specific effects or predict the effect of pumping from a given well on either the ground-water or surface-water system A detailed ground-water flow model could be used to make such forecasts, but the model would be based on the ground-water budget estimates and include many of the same limiting assumptions used to formulate the budget.

Short and Long Term Behavior of the Wood River Valley Aquifer System

The individual components in the wet (1995) and dry (2001) year ground-water budgets responded in a consistent manner. The estimated inflow components that depend directly on precipitation and temperature— tributary canyon and areal recharge— increased during 1995 and decreased during 2001. The corresponding estimated outflow component, direct riparian evapotranspiration, behaved in the opposite manner as expected. The estimated outflow component that depends indirectly on precipitation and temperature, pumpage, decreased during 1995 and increased during 2001. The estimated inflow attributed to leakage from municipal pipes is proportional to the municipal pumpage and is similar for both years. Budget components related to streamflow, streamflow gain and loss and canal seepage, increased during 1995 and decreased during 2001. Percolation from septic systems remained constant because indoor water use is constant based on the assumptions made in its determination. The estimated means of the budget components for 1995–2004 generally were within the estimated values for 1995 and 2001.

Ground-water storage is fairly responsive to annual climatic fluctuations. Water is removed from storage in dry years and replaced (at least in part) during wet years with changes reflected in streamflow and ground-water levels.

For the period of record, Skinner and others (2007) analyzed stream discharges for three stream gaging stations and water levels in three wells in the Wood River Valley and concluded that there were indications of long-term declines in ground-water storage. Among their conclusions were that the Big Wood River near Bellevue gaging station (13141000) showed statistically significant decreases in 7- and 30-day low flow and December, January, and February mean monthly discharge from 1911 to 1996. The Silver Creek at Sportsman Access gaging station (13150430) showed statistically significant decreasing trends in annual and mean monthly discharge for July through February and April from 1975 to 2005. Their analysis of water levels in three wells in the Wood River Valley with at least 50 years of measurements (1950-2006) determined statistically significant downward trends in water levels in all three wells.

Although the ground-water budgets for the three periods indicate that ground-water storage is replenished in wet years, the statistical analyses of the long-term record evaluated by Skinner and others (2007) suggest that such replenishment is incomplete and more water is removed from storage than is replaced. Despite restoration of water to ground-water storage in wet years, changes have occurred in either recharge and (or) discharge that caused ground-water storage to decline over time. Such changes may include, but are not limited to, the lining or abandonment of canals and ditches, conversion of surface-water irrigation rights to ground-water rights, changes in the location of diversion points, changes in irrigation method and efficiency, increased consumptive use by evaporation or evapotranspiration, and long- or short-term climatic change.

Effects of Urbanization

In the Wood River Valley, as in many areas of the American West, there is concern about the conversion of agricultural land to urban uses and its effect on the hydrologic system. The scientific literature contains a range of possible effects but they tend to be location specific. Such variation is due to the complex interplay between changes in consumptive use of water due to irrigation of different vegetation types, recharge due to the amount and location of impervious cover, the source of the water, conversion from septic systems to sewers, development density, and other factors. Worldwide, urbanization has increased ground-water recharge primarily due to municipal water-system and sewer leakage and direct infiltration of urban irrigation water (Garcia-Fresca and Sharp, 2003; Sharp and Garcia-Fresca, 2003). For the Wood River Valley Wetzstein and others (1999) (summarized by Brown [2000]) concluded that changes in water use due to urbanization were small, but the resulting parcel size determined whether more or less water is used.

For this study, estimates of evapotranspiration (consumptive use), simulated irrigation, and deep percolation were made for a 1-acre parcel for 14 land-use classifications using methods described in the "Areal Recharge" section above. (An additional land-use classification, developed—80 percent turf, is included for comparison, perennial ice/snow is excluded, and Allen and Robison's [2007a, 2007b] cottonwood class is used twice, but is shown only once in table 8.) Table 8 shows the resulting evapotranspiration, irrigation, and deep percolation for the resulting 14 land-use classifications grouped into three categories: agricultural, urban, and undeveloped. The results of this analysis indicate that the two agricultural land-use classifications have a slightly larger consumptive-use rate than that of the largest rate for urban land use, the 100-percent turf class. However, the mean evapotranspiration rate for urban land use is less than for agricultural land use. The two agricultural land-use classifications require similar amounts of simulated irrigation to the 100-percent turf class, although the mean for urban land use is less than for agricultural use. Deep percolation (recharge) tends to be larger for urban land use. However, many other factors influence the ultimate effects of the conversion of agricultural land to urban uses. Values shown in table 8 are estimates, and were made using data from Allen and Robison (2007a, 2007b) and methods described in this report. Consequently, the embedded assumptions described in the "Areal Recharge from Precipitation and Applied Irrigation" section may not apply to all situations in the Wood River Valley.

Although the comparison of consumptive use is important to analyses of sustainability the effect of development on the distribution of recharge is at least as relevant. Diversions from the Big Wood River into the District Canal at Bellevue remove water that would have recharged the aquifer system along the channel of the river and distributes it onto the Bellevue fan. Although some of this water is lost to evapotranspiration, much of it recharges the aquifer system by percolation of applied irrigation water through the root zone, canal seepage, and infiltration from recharge pits. That water which infiltrates east of the ground-water divide described by Skinner and others (2007) and other investigators ultimately discharges to Silver Creek or is lost through underflow near Picabo. As other studies (for example Brown, 2000) have noted, any reduction of this surface-water diversion and subsequent recharge would likely result in reduced discharge to Silver Creek but increased flow in the Big Wood River.

Table 8. Evapotranspiration (consumptive use), simulated irrigation, and deep percolation for 14 land-cover classes in the Wood River Valley, south-central Idaho, 1995–2004, 1995, and 2001.

[Values from Allen and Robison, 2007a, 2007b; Multi-Resolution Land Characteristics Consortium, 2003. **Abbreviations**: acre-ft/yr, acre-foot per year; –, none or not applicable; <, less than]

Land-use classification	Evapotranspiration (acre-ft/yr)			Simulated irrigation (acre-ft/yr)			Deep percolation (acre-ft/yr)		
	1995–2004	1995	2001	1995–2004	1995	2001	1995–2004	1995	2001
Agricultural									
Alfalfa - less frequent cuttings	3.2	3.1	3.5	2.3	1.5	1.5	0.4	0.4	0.2
Grass pasture - high management	3.0	2.9	3.1	2.3	1.8	2.6	.6	1.0	.4
Urban									
Developed, open space (100 percent turf)	2.8	2.8	3.0	2.3	1.8	2.6	0.6	0.9	0.4
Developed, open space (80 percent turf)	2.3	2.3	2.4	1.8	1.5	2.1	.7	1.1	.4
Developed, medium intensity (51 percent turf)	1.5	1.5	1.5	1.2	.9	1.3	.8	1.2	.5
Developed, low intensity (21 percent turf)	.6	.6	.6	.5	.4	.5	.8	1.4	.5
Developed, high intensity (0 percent turf)	.2	.3	.1	–	–	–	.9	1.5	.5
Undeveloped									
Wetlands–narrow stands	2.7	3.0	3.6	–	–	–	<0.01	0.01	<0.01
Cottonwoods	2.7	2.9	2.8	–	–	–	.01	.02	<.01
Willows	2.7	2.8	2.8	–	–	–	.02	.04	<.01
Open water	2.6	2.4	2.7	–	–	–	--	--	--
Sage brush	.9	1.5	.6	–	–	–	.3	.6	<.01
Range grasses–early short season	.8	1.2	.6	–	–	–	.01	.02	<.01
Barren land (rock/soil/clay)	.7	1.1	.6	–	–	–	.4	<.01	.1
Precipitation (acre-ft/yr)	1.0	1.7	0.6	1.0	1.7	0.6	1.0	1.7	0.6

Suggestions for Future Study and Additional Data Collection

As noted in the “Ground-Water Budget Errors and Uncertainty” section above, even the most detailed water budgets contain some uncertainty arising from variability in various components of the hydrologic system, inherent errors in the collection and interpretation of data, and the necessary assumptions used to quantify some budget components. Additional data and information can help reduce uncertainty associated with some ground-water budget components though it will never be completely eliminated. Additional data and information that could be used to reduce such uncertainty fall into three broad classes: hydrogeologic framework development, ground- and surface-water measurements, and water use.

Data collection efforts that would provide the information needed to improve the understanding of the hydrogeologic framework of the Wood River Valley aquifer system would include data that document the depth of alluvial fill in tributary canyons and the nature of their hydraulic connection with the main valley, the extent to which underlying consolidated rocks serve as a source of water to wells in the tributary canyons and the nature of their hydraulic properties, and the cross-sectional area and hydraulic properties of the unconfined aquifer above Ketchum. These data would improve estimates of ground-water recharge contributed by tributary canyons and the extent of water-bearing rocks in them, and improve the estimate of subsurface inflow from the Wood River Valley north of Ketchum. (Of the 1995–2004 mean annual inflow into the aquifer system, 63 percent is from tributary canyons and less than 1 percent is from subsurface inflow beneath the Big Wood River channel near Ketchum.) Among the efforts that could provide such information is a detailed analysis of drillers’ logs coupled with surficial geophysical investigations. Both of these efforts are components of the hydrogeologic framework development phase of the proposed USGS workplan for the Wood River Valley described in the “Introduction” chapter above. If the hydrogeologic framework reveals that underlying consolidated rocks in the tributary canyons are a potentially significant source of water, their hydraulic connection to the Wood River Valley aquifer system and their suitability as a water source could be established by water-quality analyses made as part of the water-quality phase of the workplan.

Basic data collection in the form of ground-water level and streamflow measurements would significantly improve estimates of streamflow gains and losses of the Big Wood

River and Silver Creek as well as provide an indication of the significance of changes in ground-water storage. (Of the 1995–2004 mean annual inflow into the aquifer system, 24 percent is streamflow loss from the Big Wood River; and streamflow gains into the Big Wood River and Silver Creek are 11 and 44 percent of the outflow from the aquifer system, respectively.) Reactivation of the gaging station Big Wood River near Ketchum (13135500) would provide important data needed for the determination of ground-water/surface-water interaction between the Big Wood River and the aquifer system upstream of Hailey. Monthly measurements of streamflow in the six main tributary canyons (North Fork Big Wood River, Warm Springs Creek, Trail Creek, East Fork Big Wood River, Deer Creek, and Croy Creek) would improve estimates of streamflow gains and losses in the tributary canyons and the Big Wood River, and improve estimates of recharge to the aquifer system from those canyons. Similarly, monthly streamflow measurements at points along the Big Wood River would better define the location and magnitude of gaining and losing reaches. Another data gap is the character of the Big Wood River channel and the nature of streamflow gains and losses in the reach downstream of Bellevue. Such data would also be useful in managing the Wood River Legacy Project—an attempt to restore streamflow in the Big Wood River and Silver Creek (Idaho Rivers United, 2008). Ground-water data collection in the form of regular water-level measurements in the well network established by Skinner and others (2007) would help establish the magnitude and location of changes in ground-water storage and contribute to the understanding of how the aquifer system responds to climatic conditions and future development. In order to document temporal variability in ground-water levels, the entire network should be measured on an annual or biannual schedule, a smaller subset on a quarterly or monthly basis, and several wells should be instrumented with continuous water-level recorders. Another reason for broadening the scope of basic hydrologic data collection in the Wood River Valley is presented by Milly and others (2008), who argue that although water management throughout the developed world relies on the assumption that “natural systems fluctuate within an unchanging envelope of variability,” observable changes in the hydrologic cycle are rendering this assumption invalid. Among their conclusions is that stochastic modeling will be increasingly important for water management in the future. Such modeling will require long-term, high-quality hydrologic data series. In addition, the continuity of data (a lengthy historic record) from individual locations (such as streamflow-gaging stations and wells) becomes increasingly important.

A final category of additional data collection may be broadly characterized as water use, and includes information on both ground-water pumpage and surface-water diversions. (Of the 1995–2004 mean annual outflow from the aquifer system, 42 percent is ground-water pumpage.) Although municipal pumpage is known with a high degree of certainty, the number of self-supplied domestic and irrigation wells is uncertain, as is the volume and timing of irrigation and subdivision pumpage. The location, timing, and amount of all but the largest surface-water diversions are largely unknown. No detailed maps are available of the irrigation-water distribution network including locations and altitudes. The IDWR adjudication of water rights in the Wood River Valley will provide much of these data, but further compilation and refinement of data and limited field surveys also may be necessary.

Summary and Conclusions

The Wood River Valley contains most of the population of Blaine County and the cities of Sun Valley, Ketchum, Hailey, and Bellevue. This mountain valley is underlain by the alluvial Wood River Valley aquifer system which consists of a single unconfined aquifer that underlies the entire valley, an underlying confined aquifer that is present only in the southernmost valley, and the confining unit that separates them. The entire population of the area depends on ground water for domestic supply, either from domestic or municipal-supply wells, and rapid population growth since the 1970s has caused concern about the long-term sustainability of the ground-water resource. To help address these concerns this report describes a ground-water budget developed for the Wood River Valley aquifer system for three time periods: average conditions for the 10-year period 1995–2004, and the single years of 1995 and 2001. The 10-year period 1995–2004 is selected because it represents a range of conditions in the recent past for which measured data existed. Water years 1995 and 2001 were selected because they represent the wettest and driest years, respectively, within the 10-year period based on precipitation at the Ketchum Ranger Station.

Recharge or inflow to the Wood River Valley aquifer system occurs through seven main sources (from largest to smallest): infiltration from tributary canyons, streamflow loss from the Big Wood River, areal recharge from precipitation and applied irrigation water, seepage from canals and recharge pits, leakage from municipal pipes, percolation from septic systems, and subsurface inflow beneath the Big Wood River in the northern end of the valley. Total estimated mean annual inflow or recharge to the aquifer system for 1995–2004 is 270,000 acre-ft/yr (370 ft^3/s). Total recharge for the wet year 1995 and the dry year 2001 is estimated to be 270,000 acre-ft/yr (370 ft^3/s) and 220,000 acre-ft/yr (300 ft^3/s), respectively.

Discharge or outflow from the Wood River Valley aquifer system occurs through five main sources (from largest to smallest): Silver Creek streamflow gain, ground-water pumpage, Big Wood River streamflow gain, direct evapotranspiration from riparian vegetation, and subsurface outflow (treated separately). Total estimated mean 1995–2004 annual outflow or discharge from the aquifer system is 250,000 acre-ft/yr (350 ft^3/s). Estimated total discharge is 240,000 acre-ft/yr (330 ft^3/s) for both the wet year 1995 and the dry year 2001.

The difference between estimated ground-water inflow and outflow is the budget residual and encompasses subsurface outflow, ground-water storage change, and budget error. For 1995–2004, estimated mean annual inflow exceeds outflow by 20,000 acre-ft/yr (28 ft^3/s); for the wet year 1995, estimated mean annual inflow exceeds outflow by 30,000 acre-ft/yr (41 ft^3/s); and, for the dry year 2001, estimated mean annual outflow exceeds inflow by 20,000 acre-ft/yr (28 ft^3/s). These values represent 8, 13, and 8 percent, respectively, of total estimated outflows for the same periods. It is difficult to differentiate the relative contributions of the three residual components, although the estimated fluctuations between the wet and dry year budgets likely are primarily caused by changes in ground-water storage.

Although any water budget contains some uncertainty, most of the uncertainty in the ground-water budget presented in this report is attributable to incomplete data, simplifying assumptions, and the fact that several of the components cannot be measured directly. The current report explains in detail the methods and assumptions used to determine each water-budget component and qualifies the uncertainty associated with each. Although additional data collection can reduce the uncertainty in some components, others likely will remain highly uncertain. A ground-water flow model using parameter estimation techniques can improve estimates of these uncertain components and quantify uncertainty.

The individual components in the wet and dry year ground-water budgets responded in a consistent manner to annual changes in precipitation and temperature. Although the ground-water budgets for the three periods indicated that ground-water storage is replenished in wet years, statistical analyses by Skinner and others (2007) suggest that such replenishment is not complete and over the long term more water is removed from storage than replaced. In other words, despite restoration of water to ground-water storage in wet years, changes have occurred in either recharge and (or) discharge to cause ground-water storage to decline over time. Such changes may include, but are not limited to: lining or abandoning canals and ditches, conversion of surface-water irrigation rights to ground-water rights, changes in location of diversion points, changes in irrigation method and efficiency, increased consumptive use by evaporation or evapotranspiration, and long- or short-term climatic change. The concepts of safe yield and sustainability, although somewhat nebulous and controversial, are useful to foster a longer-term view of how ground-water resources will be developed and managed. As aquifer systems are developed, as with other natural resources, there are associated benefits and consequences that confront stakeholders of the resource. The ground-water budget described in this report can be used to gain an understanding of the relative magnitude of various inflow and outflow components as well as effects of climate variability on the aquifer system. The ground-water budget can be used by stakeholders to evaluate various ground-water development strategies within the context of sustainable development.

Estimates were made of evapotranspiration (consumptive use), simulated irrigation, and deep percolation for a 1-acre parcel for each of 14 land-use classifications in the Wood River Valley. The estimated mean evapotranspiration rate for urban land use generally is less than for agricultural land use, mean simulated irrigation for urban land use is less than for agricultural use, and the estimated volume of deep percolation (recharge) tends to be larger for urban land use. Most urban land uses in the Wood River Valley generally consume slightly less water than agricultural uses. However, many other factors influence the ultimate effects of the conversion of agricultural land to urban uses and may have greater effects on the aquifer system by the redistribution or reduction of recharge.

Additional data collection can help reduce uncertainty associated with some ground-water budget components though it will never be completely eliminated. Possible data collection efforts to reduce uncertainty fall into three broad classes: hydrogeologic framework development, ground- and surface-water measurements, and water use. Especially important is the collection of basic data such as ground-water level and streamflow measurements. Not only would these data enable significant improvement in estimates of certain ground-water budget components, they would contribute to a better understanding of how the aquifer system responds to climate and how that response can guide water management in the future.

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