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Surface-Water/Ground-Water Interaction along Reaches of the Snake River and Henrys Fork, Idaho

Scientific Investigations Report 2004–5115

Version 1.0

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

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By Jon E. Hortness, U.S. Geological Survey, and Peter Vidmar, Idaho Power Company

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Conversion Factors, Datums, and Water Year Definition

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter (m^3)
cubic foot per second (ft^3/s)	.02832	cubic meter per second (m^3/s)
inch (in.)	2.54	centimeter (cm)
inch per year (in/yr)	2.54	centimeter per year (cm/yr)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

Sea level: In this report, “sea level” refers to the North American Vertical Datum of 1988 (NAVD of 1988)—a vertical control datum established by the minimum-constraint adjustment of Canadian-Mexican-United States leveling observations and held fixed at Father Point/Rimouski, Quebec, Canada.

Water year: In U.S. Geological Survey reports, a water year is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which it ends; thus, the water year ending September 30, 2001, is called the “2001 water year.”

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Surface-Water/Ground-Water Interaction along Reaches of the Snake River and Henrys Fork, Idaho

By Jon E. Hortness and Peter Vidmar

ABSTRACT

Declining water levels in the eastern Snake River Plain aquifer and decreases in spring discharges from the aquifer to the Snake River have spurred studies to improve understanding of the surface-water/ground-water interaction on the plain. This study was done to estimate streamflow gains and losses along specific reaches of the Snake River and Henrys Fork and to compare changes in gain and loss estimates to changes in ground-water levels over time. Data collected during this study will be used to enhance the conceptual model of the hydrologic system and to refine computer models of ground-water flow and surface-water/ground-water interactions.

Estimates of streamflow gains and losses along specific subreaches of the Snake River and Henrys Fork, based on the results of five seepage studies completed during 2001–02, varied greatly across the study area, ranging from a loss estimate of 606 ft^3/s in a subreach of the upper Snake River near Heise to a gain estimate of 3,450 ft^3/s in a subreach of the Snake River that includes Thousand Springs. Some variations over time also were apparent in specific subreaches. Surface spring flow accounted for much of the inflow to subreaches having large gain estimates. Several subreaches alternately gained and lost streamflow during the study.

Changes in estimates of streamflow gains and losses along some of the subreaches were compared with changes in water levels, measured at three different times during 2001–02, in adjacent wells. In some instances, a strong relation between changes in estimates of gains or losses and changes in ground-water levels was apparent.

INTRODUCTION

Declining water levels in the eastern Snake River Plain (ESRP) aquifer and decreases in spring discharges from the aquifer to the Snake River have raised concerns about the sustainability of water resources in the ESRP. These trends are believed to be the result partly of (1) improvements in the efficiency of irrigation practices that began in the early 1970s that have decreased recharge to the aquifer from irrigated lands, and (2) increases in ground-water withdrawals for irrigation and public supply that began about the same time. The effects of these changes in water use have resulted in competition between surface-water and ground-water users for the water supplies on the plain.

In 1999, the Snake River Plain Hydrologic Modeling Committee developed a general strategy to refine and enhance the conceptual and computer models of the ESRP hydrologic system. The strategy includes modeling and data-collection programs that will be implemented through a partnership of the Idaho Department of Water Resources (IDWR), the Idaho Water Resources Research Institute, the Bureau of Reclamation (BOR), the U.S. Geological Survey (USGS), Idaho Power Company (IPCo), and the University of Idaho. The first phase of the strategy focuses on (1) enhancing existing flow models using advanced computer programs, (2) collecting and evaluating data to improve the conceptual model of critical components of the system such as the aquifer/river boundary, and (3) evaluating new developments in aquifer/river simulation models and their potential application to the ESRP. The results of the first phase will help guide more detailed data-collection programs in subsequent phases.

Purpose and Scope

This report presents data and results from a study performed during 2001–02 to estimate streamflow gains and losses along reaches of the Snake River and Henrys Fork and to compare changes in seasonal and long-term gains or losses with changes in water levels in nearby wells. Information gathered during this study will be combined with the results from other studies to enhance the conceptual model of the hydrologic system and to refine surface-water/ground-water computer flow models of the ESRP.

Seepage studies of three separate reaches of the Snake River and Henrys Fork (fig. 1) were designed and conducted during 2001–02. These reaches were (1) the Snake River from the gaging station at Minidoka downstream to the gaging station at King Hill (lower reach); (2) the Snake River from the gaging station near Shelley downstream to the gaging station near Minidoka (middle reach); and (3) the Henrys Fork from the gaging station near Ashton downstream to the mouth, near Lorenzo, and the Snake River from the gaging station near Heise downstream to the gaging station near Shelley (upper

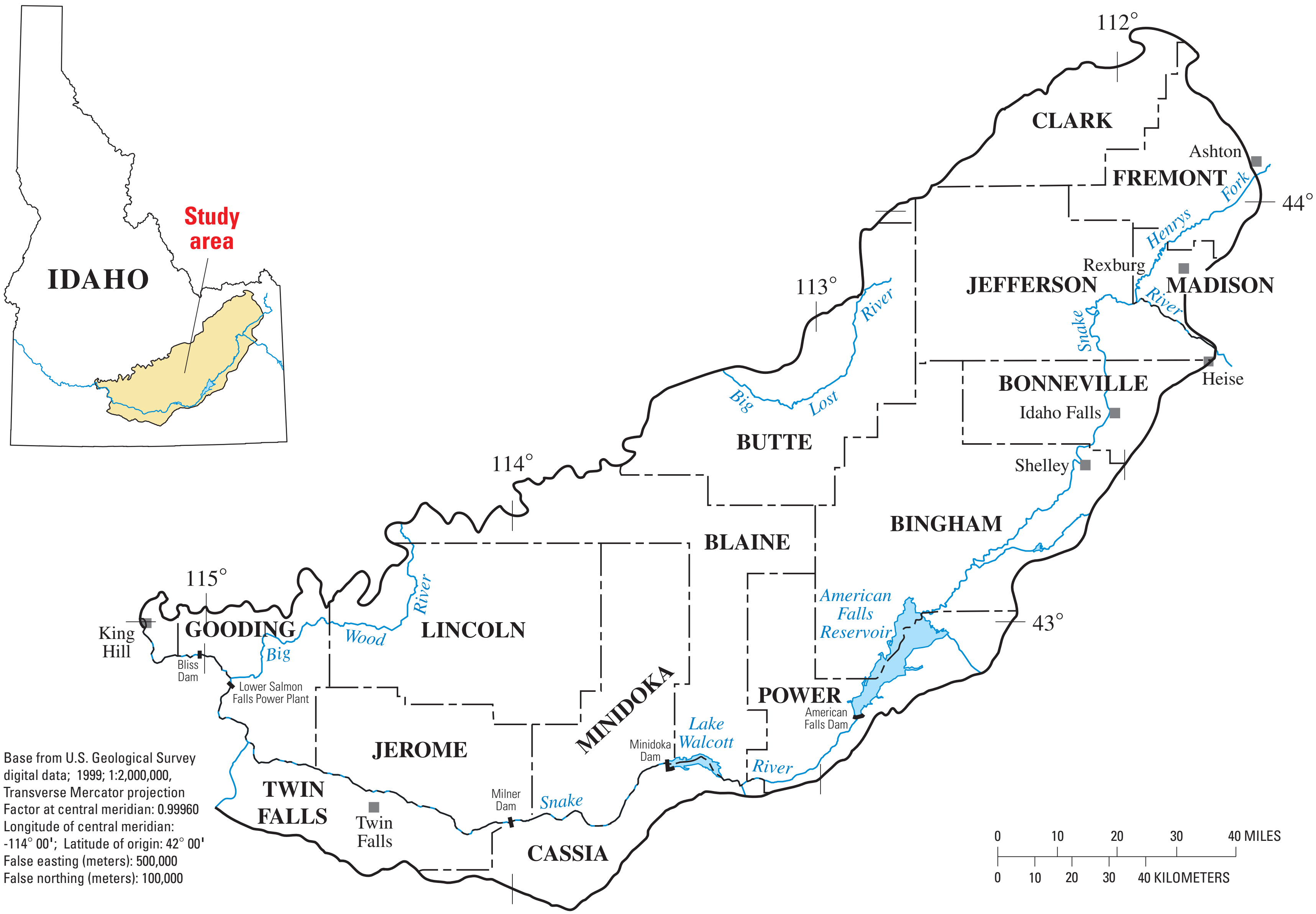

Figure 1. Location of study area, eastern Snake River Plain, southeastern Idaho.

reach). Data collected in each reach included discharges at USGS and/or IPCo gaging stations, discharges at several intermediate sites between gaging stations measured using acoustic Doppler current profilers (ADCPs), and measured and/or estimated discharges at several miscellaneous inflow (mostly tributaries) and outflow (irrigation canals) sites. Locations of the intermediate sites were determined by (1) availability of a good measurement section, (2) accessibility by road or boat, and (3) river distance to adjacent measurement sites.

Water levels in 1,350 wells located on or near the ESRP were measured at three different times during 2001–02. Wells selected for water-level measurements consisted of wells that were part of the USGS Regional Aquifer-System Analysis (RASA) network in 1980, private wells in the Rexburg area, current USGS observation wells, Idaho National Engineering and Environmental Laboratory (INEEL) project wells, BOR network wells, and IDWR network wells.

Description of Study Area

The study area is made up of the area commonly referred to as the eastern Snake River Plain (ESRP). The ESRP covers an area approximately 200 mi long and 60 mi wide across south-central and southeastern Idaho (fig. 1) and constitutes about 30 percent of the upper Snake River Basin (area upstream from King Hill, Idaho). The climate of the plain is semiarid; average precipitation ranges from about 8 to 14 in/yr. The range in summer and winter temperatures is large, and most of the precipitation occurs as rainfall during the summer months. Snow accumulation, if any, during the winter months is typically only a few inches, with the exception of the northeastern part of the plain, where accumulations may be higher. In general, the precipitation is not adequate to support crops without the use of irrigation. Sources of irrigation water include streamflow from mountains adjacent to the plain, irrigation reservoirs, and the underlying aquifer.

The underlying aquifer consists of a thick sequence of basaltic rocks interconnected with occasional unconsolidated sedimentary deposits. Sediments overlie the basalts in most areas. The geologic makeup of the aquifer allows for extremely high ground-water transmissivity rates and for the storage and yield of large volumes of water (Kjelstrom, 1995).

Ground-water generally flows toward the southwest, and most aquifer recharge occurs in the northern and eastern parts of the plain. Additional recharge occurs in other parts of the plain where streams from adjacent mountain ranges flow onto the plain and lose all of their flow to the aquifer (Kjelstrom, 1988).

The Snake River itself originates in the high mountains of Wyoming near the southern border of Yellowstone National Park. Much of the river within the study area is entrenched in canyons as deep as 700 ft. The river is highly regulated by numerous dams that were constructed primarily for agricultural and power-generation purposes. Mean annual inflow to the ESRP during 1934–80 was about 10.2 million acre-ft (14,000 ft^3/s) (Kjelstrom, 1988).

Gravity-flow and pumped diversions are predominant across the study area. In 1980, total gravity-flow and pumped diversions from the Snake River and its tributaries were almost 8.8 million acre-ft (Goodell, 1988). Gravity-flow diversions occur mainly in the upper part of the study area and pumped diversions occur mainly in the lower part of the study area. Streamflow in the Snake River during the months of April through August is significantly affected by these irrigation diversions and, to a lesser extent, by the return of irrigation water that is not consumed. It is possible for return flows to make up a majority of the water in parts of the Snake River during drought years (Maupin, 1995).

PREVIOUS INVESTIGATIONS

Many early investigations of water resources in the ESRP were related to development of the system for irrigation uses. Newell (1928, 1929) analyzed the general characteristics of water resources in the American Falls area. Stearns and others (1938) presented a water budget for the Snake River Basin upstream from Weiser. Mundorff and others (1964) estimated recharge to the ground-water system from tributary drainage basins and irrigated areas. A report by Norvitch and others (1969) includes a discussion on possible changes in the hydrologic systems of the Snake River Plain resulting from increased use of ground water for irrigation.

More recent studies by the USGS and BOR specifically evaluated the interaction between the ground-water and surface-water systems. Thomas (1969) and Kjelstrom (1992, 1995) analyzed spring discharges to the Snake River between Milner Dam and King Hill. Kjelstrom (1988) also studied gains and losses in reservoirs on the Snake River between Blackfoot and Milner. The RASA report by Kjelstrom (1995), which presents information on streamflow gains and losses in the Snake River and ground-water budgets, includes the most comprehensive collection of gain and loss data for the Snake River before that presented in this report.

METHODS FOR ESTIMATING GAINS AND LOSSES

All gain and loss calculations performed during this study were based on the basic conservation of mass equation,

$$Q_{in} +/- \Delta S = Q_{out}, \qquad (1)$$

where Q_{in} is the discharge into a specific subreach; ΔS is the change in storage within the subreach; and Q_{out} is the discharge out of the subreach. For the purpose of this report, a subreach is defined as a section of the river bounded upstream and downstream by sites where discharge data were collected.

For any specific subreach of the study area, the basic equation can be rearranged as

$$Q = -(Q_{u/s} + Q_{inflow} - Q_{outflow} + \Delta S - Q_{d/s}), \qquad (2)$$

where Q is the gain (positive result) or loss (negative result) estimate; $Q_{u/s}$ is the measured discharge in the river at the upstream end of the subreach; Q_{inflow} is the total estimated inflow to the subreach from tributaries and irrigation-return drains; $Q_{outflow}$ is the total estimated outflow from the subreach to irrigation canals; ΔS is the estimated change in storage within the subreach; and $Q_{d/s}$ is the measured discharge in the river at the downstream end of the subreach.

Performing the seepage studies during the nonirrigation season allowed for the removal of the $Q_{outflow}$ term for most subreaches. Coordinating steady releases from the dams and powerplants located within the study area virtually negated the ΔS term in most cases. Thus, the form of the equation most often used in the final gain and loss calculations was

$$Q = -(Q_{u/s} + Q_{inflow} - Q_{d/s}). \qquad (3)$$

Values for the $Q_{u/s}$ and $Q_{d/s}$ terms were obtained from either gaging-station data or instantaneous acoustic Doppler measurements. If gaging-station data were used, the actual value typically was an instantaneous value (not a daily mean) based on the estimated traveltime downstream to the next measurement site. For one specific subreach where unsteady releases from a powerplant resulted in unsteady discharges, 30-day average discharges at adjacent gaging stations were used to obtain a gain or loss estimate for that time period. Values for the Q_{inflow} term were obtained from a combination of daily mean discharges (where gaging-station data were available), current-meter measurements, and estimates made from visual observations. Values for the $Q_{outflow}$ term were obtained from a combination of daily mean discharges from irrigation-district records and current-meter measurements.

Because water levels in some of the reservoirs located within the study area were changing during the seepage studies, ΔS values for specific time periods were estimated by analyzing reservoir-storage data. The estimated ΔS then was transformed to an average flow rate for the seepage-study time period. It is important to note that, although this method for estimating the ΔS of a reservoir was based on the best available data, any gain/loss estimates calculated using a ΔS value other than zero could be subject to larger errors than other gain/loss estimates.

DATA ACCURACY AND LIMITATIONS

As discussed previously, several different sources of discharge data were used in the calculation of gain/loss estimates. Data sources included long-term gaging-station records, acoustic Doppler measurements, current-meter measurements, irrigation-district records, and visual inspections. Because of the variety of methods used in obtaining the data, the accuracy could be quite variable.

Long-term Gaging Stations

Streamflow data from long-term gaging stations operated by either the USGS or IPCo were used during this study. The accuracy of data from long-term gaging stations depends primarily on (1) the stability of the stage-discharge relation, (2) the frequency of actual discharge measurements, and (3) the accuracy of individual stage and discharge measurements (Kennedy, 1983). Streamflow data are published with an indicator of the accuracy of the data at each specific gaging station. An “excellent” rating indicates that about 95 percent of the daily mean discharges are within 5 percent of true; a “good” rating, within 10 percent; and a “fair” rating, within 15 percent. Records that do not meet the criteria are rated “poor.” Most gaging-station data used to calculate estimates of gains and losses during this study were rated “good.” Instances where this was not the case are discussed where appropriate. Although a “good” rating indicates an accuracy of at least plus or minus 10 percent, in many cases the accuracy is believed to be much better. Because a stage-discharge relation is essentially an estimate of the true value based on a sample population, the relation for a site with a very stable control section (low variability) and a large number of actual discharge measurements (large sample size) likely will have a very high degree of accuracy.

Acoustic Doppler Measurements

The use of acoustic Doppler instrumentation specifically designed to measure river discharges allows discharges to be measured at locations previously very difficult or impossible to measure. However, limitations in the application of this instrumentation include the inability to measure water velocities in all areas of a specific cross section, which could contribute to the overall error of a measurement.

Unmeasured Areas

Acoustic Doppler instruments cannot measure water velocities in all areas of a river cross section (Morlock, 1996). These unmeasured areas (top, bottom, left edge, and right edge) are illustrated in figure 2. The depth of the unmeasured top section is a function of the transducer depth (distance the transducer extends into the water) and the blanking distance (time lag between when the sensor sends a signal and when it is ready to receive the return echoes of that signal). Part of the flow near the bed of the river channel cannot be measured

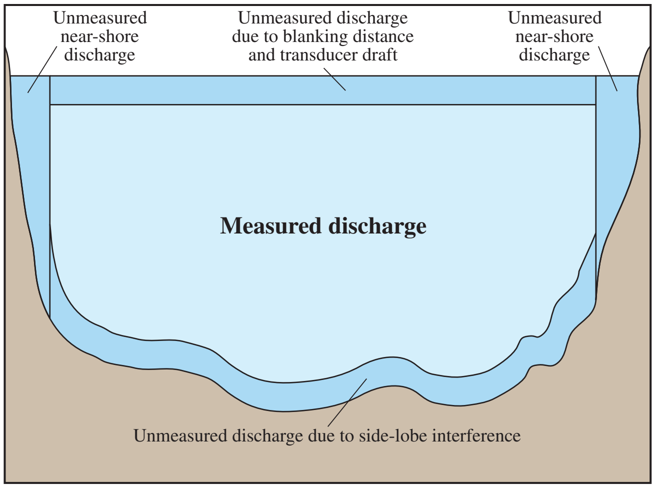

Figure 2. Typical river cross section and areas where water velocities cannot be measured using acoustic doppler instruments.

because of side-lobe interference (physical characteristic of the acoustic beam where the side lobe reflects off of the bottom before the main beam, which ultimately interferes with the reception of the remaining velocity data) (Simpson, 2001). Discharges in these top and bottom unmeasured sections are estimated using either a power-law or a constant method, depending on the velocity characteristics at the section.

Part of the flow at each edge of a cross section also cannot be measured because of minimum operational depth requirements and beam interference along vertical or nearly vertical edges. Beam interference can occur along vertical walls in much the same manner as described previously with regard to the river bottom. Edge discharges are estimated using an interpolation method based on the last recorded water velocities and depths, the distance to the edge of water, and the general shape of the unmeasured section (triangular or vertical).

Error

Two types of error occur during acoustic Doppler discharge measurements: random error and systematic error (or bias) (Simpson, 2001). Random error can be attributed to the accuracy of the instrumentation with regard to pulse length, transmit frequency, signal-to-noise ratio, and beam angle. Channel and flow characteristics can greatly affect the magnitude of random error. The effects of random error can be minimized by averaging several individual measurements.

Systematic error, or bias, can be separated into two parts: instrument-caused and operator-caused. Instrument-caused systematic errors relate to the operation of the instrument and the physical properties of the acoustic signal. Most of these errors are thought by manufacturers to be small and insignificant (Simpson, 2001). The operator-caused systematic errors listed below can be monitored easily and rectified; however, failure to do so can significantly affect the accuracy of discharge measurements. Possible errors include

- inaccurate measurement of transducer depth,
- consistent overestimation or underestimation of distance-to-edge values,
- inaccurate characterization of edge shapes, and
- failure to recognize a “moving bed” situation.

It can be very difficult to identify or quantify systematic error from a measurement summary; thus, it is critical to ensure that these inaccuracies are avoided. More detailed information on random and systematic errors resulting from the use of acoustic Doppler instruments is presented in a report by Simpson (2001).

The final assessment of the discharge measurement is based on a qualitative judgment of measuring conditions and a quantitative evaluation of the individual measurements (Lipscomb, 1995). The coefficient of variation (COV) is a useful statistic for making the quantitative assessment of the measurement. The coefficient of variation is equal to the standard deviation of a set of individual measurements made at a site divided by the mean of those measurements. Results of these calculations are illustrated in tables 1 and 2 for different numbers of individual measurements.

USGS policy requires that, if the COV of the first four individual measurements at a site is greater than 0.05, four more individual measurements must be made (Lipscomb, 1995). The final discharge value is then the average of all eight measurements. During this study, IPCo followed similar procedures and, in some cases, made more than eight individual measurements at a single site. Commonly, when more than four individual measurements were made at a site, the COV still was greater than 0.05. Large COVs can indicate variability

Table 1. Results of mean, standard deviation, and coefficient-of-variation calculations for a set of eight acoustic Doppler measurements of discharge at a site

Measurements	Discharge, in cubic feet per second
Measurement #1	1,325
Measurement #2	1,115
Measurement #3	1,297
Measurement #4	1,182
Measurement #5	1,261
Measurement #6	1,291
Measurement #7	1,086
Measurement #8	1,347
Mean	1,238
Standard deviation	98
Coefficient of variation	0.08

Table 2. Results of mean, standard deviation, and coefficient-of-variation calculations for a set of four acoustic Doppler measurements of discharge at a site.

Measurements	Discharge, in cubic feet per second
Measurement #1	932
Measurement #2	927
Measurement #3	911
Measurement #4	951
Mean	930
Standard deviation	16
Coefficient of variation	0.02

of flow at the time of the measurements and/or the presence of random error effects discussed earlier. It is important to note, however, that the COV is not a direct indicator of the overall accuracy of the measurement; qualitative judgment also is used to assess the measurement quality.

Current-Meter Measurements

When applicable, inflows to and outflows from the Snake River were measured using standard current meters. Possible sources of error in a current-meter discharge measurement are (Sauer and Meyer, 1992)

- errors in measurement of the cross-sectional area,
- errors in measurement of the mean stream velocity,
- errors in computation procedures, and
- general systematic errors, such as changes in stage, boundary effects, ice, obstructions, wind, incorrect equipment, incorrect techniques, poor distribution of measurement verticals, carelessness, and other factors.

The final assessment of a current-meter measurement is based commonly on a qualitative judgment of measuring conditions and equipment condition at the time of the measurement (Sauer and Meyer, 1992). An “excellent” rating indicates that the hydrographer felt that the measurement was within 2 percent of true; a “good” rating, within 5 percent; a “fair” rating, within 8 percent; and a “poor” rating, over 8 percent (Rantz and others, 1982). During this study, most inflows and outflows measured using current meters were relatively small (one to two orders of magnitude) compared with the overall discharge in the main channel. Thus, even large errors in the current-meter measurements likely had little or no effect on the final gain/loss estimates.

Irrigation-District Records

Daily mean discharge data were available for many of the irrigation canals used to divert water from the Snake River. Methods and equipment used to obtain this data varied greatly by site. As a result, the accuracy of these data also could vary greatly. However, since most of the irrigation canals were not in service during the spring and fall study periods, any errors in the irrigation-discharge data would have had little or no effect on the final gain/loss estimates for these seasons. Most of the canals were in service during the summer 2002 study period, and large errors in irrigation-discharge records could have had some effect on the final estimates for specific subreaches. To help reduce the possibility of error, current meters were used, when possible, to measure discharge in some of the irrigation canals.

Visual Inspections

Because of the large number of inflow sites along the study area, it was not feasible to make actual discharge measurements at all of the sites. Therefore, many sites were visually inspected and an estimate of discharge was recorded. Since the discharges at most of these inflow sites were very small (one to three orders of magnitude) compared with the discharges in the main channel, even large errors in the estimated discharges likely had no significant effect on the final gain/loss estimates.

STREAMFLOW GAINS AND LOSSES

The study area was divided into three reaches primarily to improve the efficiency of the data-collection efforts and data analyses. Gains and losses in the lower (Snake River near Minidoka to Snake River at King Hill gaging stations) and middle (Snake River near Shelley to Snake River near Minidoka gaging stations) reaches were documented five times beginning in March 2001 and ending in November 2002. Gains and losses in the upper reach (Henrys Fork near Ashton gaging station to the mouth, near Lorenzo, and Snake River near Heise to near Shelley gaging stations) were documented four times beginning in November 2001 and ending in November 2002.

Because of the error inherent in each of the data-collection methods used, relatively small estimates of gains or losses for many subreaches were statistically insignificant and should be treated as “zero change” estimates. In this report, a threshold of 5 percent of the average of the upstream and downstream discharge values was used to identify statistically significant gains or losses. For example, the loss estimate for a reach with upstream and downstream discharge values of 1,200 ft^3/s and 1,000 ft^3/s, respectively, would be considered significant because 200 ft^3/s is approximately 18.2 percent of the average, 1,100 ft^3/s, of the upstream and downstream discharge values. Conversely, the estimated loss for a reach with upstream and downstream discharge values of 500 ft^3/s and 480 ft^3/s, respectively, would not be significant because the estimated loss of 20 ft^3/s is approximately 4.1 percent of 490 ft^3/s and, thus, believed to be within the range of probable measurement error.

It is important to note that gain/loss estimates that included change-in-storage calculations, even if the estimates were determined to be statistically significant, could still contain larger errors than estimates that did not include change-in-storage calculations. Gain and loss estimates for the summer of 2002 were calculated on the basis of estimates of irrigation returns that had limited accuracy and main-channel discharge and irrigation-withdrawal values that were significantly larger than those during the spring and fall studies. As a result, the errors associated with these gain/loss estimates likely are larger than those associated with estimates for other time periods.

Lower Reach (Snake River near Minidoka to Snake River at King Hill)

Data collected during each of the seepage studies of the lower reach included discharge data from seven long-term gaging stations, acoustic Doppler discharge measurements from an additional 13 intermediate sites (fig. 3), and discharge data, obtained using current meters or by visual inspection, from numerous tributaries and irrigation-return drains. A summary of these data is presented in Appendix A.

It was assumed that the inflow values obtained for each subreach during each of the spring and fall seepage studies represented most, if not all, of the actual inflows occurring at the time of the study. Many irrigation-return drains were active during the summer of 2002. For this period, it was assumed that the inflow values that were obtained represented about 90 percent of the actual inflows occurring at that time.

Three structures (Milner Dam, Lower Salmon Falls Power Plant, and Bliss Dam; fig. 1) are located within this reach. Unsteady releases from these structures and unsteady storage conditions upstream from these structures complicated the analyses in some instances and could have affected the final gain/loss estimates.

The gain/loss estimates for the subreach between the Snake River near Minidoka and Snake River at Milner gaging stations (L1 and L4) showed that there were slight gains during 2001. By the fall of 2002, this subreach had begun to lose a significant amount of streamflow (table 3). The gain/loss estimate for the spring of 2002 was essentially zero, and the estimate for the summer of 2002 was not statistically significant, likely because of the larger measurement errors associated with higher flows. Kjelstrom (1995) reported that, although this subreach lost streamflow during much of water years 1979 and 1980, historically it has been a gaining subreach.

Estimates of gains for the subreach between the Snake River at Milner and Snake River near Kimberly gaging stations (L4 and L6) ranged from 220 ft^3/s in the spring of 2002 to 330 ft^3/s in the summer of 2002; the average gain for this subreach during the study period was about 278 ft^3/s (table 3). This average gain estimate compared well with Kjelstrom's (1995) average gain estimate of approximately 210,000 acre-ft (294 ft^3/s) during water year 1980.

Estimates of gains for the subreach between the Snake River near Kimberly and Snake River near Buhl gaging stations (L6 and L10) ranged from 918 ft^3/s in the spring of 2001 to 1,150 ft^3/s in the fall of 2001; the average gain was about 1,030 ft^3/s (table 3). The average gain estimate was about 16 percent smaller than the average gain estimate by Kjelstrom (1995) of 1,230 ft^3/s (880,000 acre-ft) during water year 1980.

Gain estimates for the subreach between the Snake River near Buhl and Snake River below Lower Salmon Falls near Hagerman (L10 and L16) gaging stations ranged from 2,700 ft^3/s during the summer of 2002 to 3,450 ft^3/s during the spring of 2001; the average gain was about 3,100 ft^3/s (table 3). This subreach receives significant inflows from a few large springs and several smaller springs located in the area. In general, the gain/loss estimates for this subreach were relatively consistent for the entire study period. Kjelstrom (1995) determined the gain in this subreach during water year 1980 to be approximately 2,650,000 acre-ft (3,710 ft^3/s), about 95 percent from the north side of the river. That estimate was about 19.7 percent larger than the estimate from this study.

Unsteady releases from dams and powerplants and resulting changes in reservoir storage likely affected the measurements and resulting gain/loss estimates during some of the seepage studies of the subreaches between the Snake River below Lower Salmon Falls near Hagerman and the Snake River below Bliss Dam near Bliss gaging stations (L16 and L18) and between the Snake River below Bliss Dam and the

Table 3. Summary of streamflow gain and loss estimates for the lower reach of the Snake River, between the near Minidoka and at King Hill gaging stations, Idaho

[See figure 3 for locations of subreaches; ft^3/s, cubic feet per second; values in **boldface** are statistically significant]

Subreach	Estimates of gains or (losses), in ft^3/s				
	Spring 2001	Fall 2001	Spring 2002	Summer 2002	Fall 2002
L1 to L4	**44**	**40**	(5)	(110)	**(238)**
L4 to L6	**248**	**277**	**220**	**330**	**315**
L6 to L10	**918**	**1,150**	**994**	**1,100**	**986**
L10 to L16	**3,450**	**3,310**	**3,050**	**2,700**	**2,970**
L16 to L18	(104)	62	260	136	**377**
L18 to L20	200	(65)	(10)	**437**	(195)

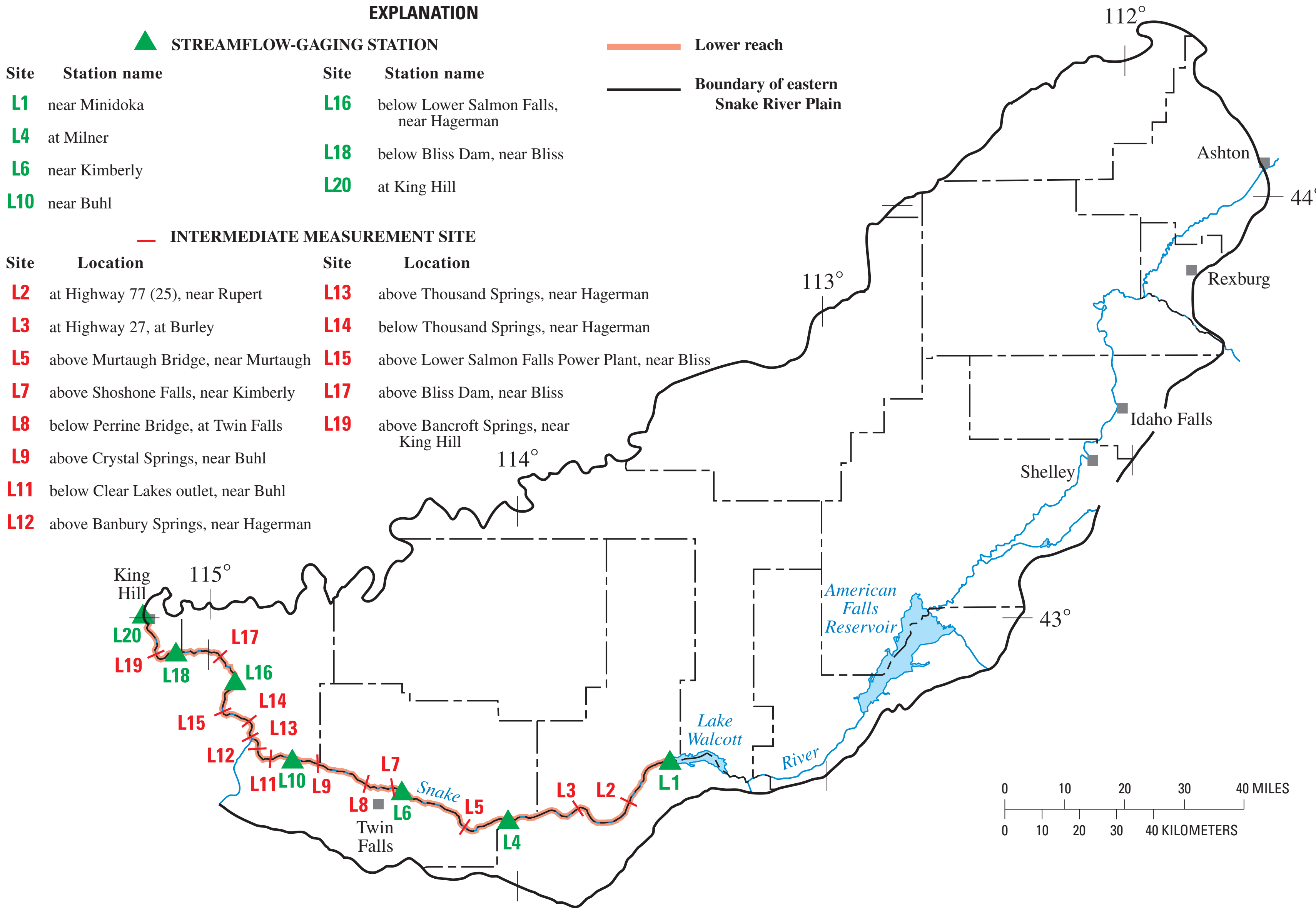

Figure 3. Locations of sites along the lower reach of the Snake River, southeastern Idaho, where streamflow was measured.

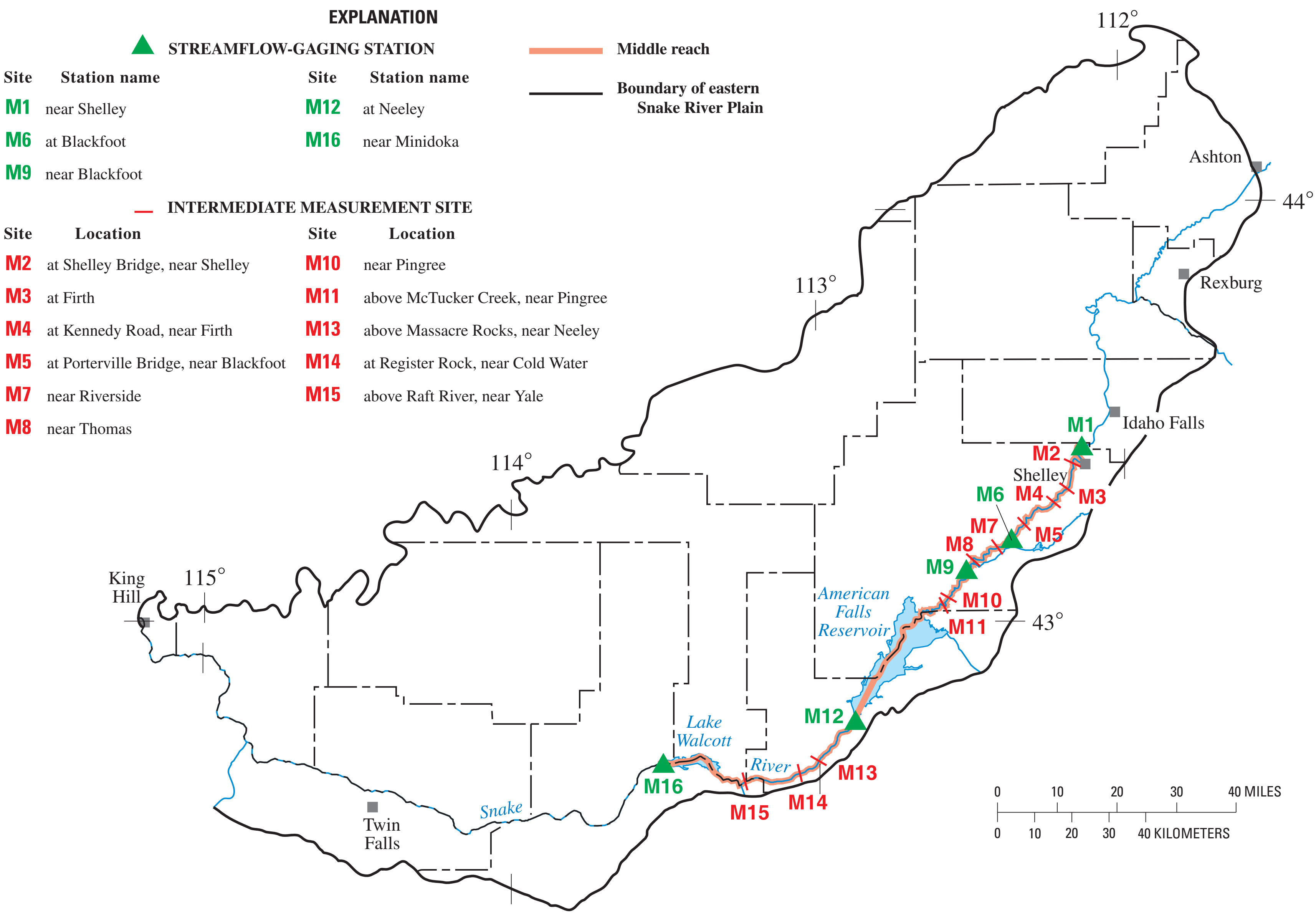

Figure 4. Locations of sites along the middle reach of the Snake River, southeastern Idaho, where streamflow was measured.

Table 4. Summary of streamflow gain and loss estimates for the middle reach of the Snake River, between the near Shelley and near Minidoka gaging stations, Idaho

[See figure 4 for locations of subreaches; ft^3/s, cubic feet per second; values in **boldface** are statistically significant]

Subreach	Estimates of gains or (losses), in ft^3/s				
	Spring 2001	Fall 2001	Spring 2002	Summer 2002	Fall 2002
M1 to M6	**(470)**	**(435)**	**(310)**	**(555)**	[1]**(480)**
M6 to M9	[2]**(309)**	**(219)**	**(330)**	**(398)**	**(269)**
M9 to M12	**1,940**	**2,060**	**1,690**	**1,130**	**2,680**
M12 to M16	(121)	[3]**114**	**1,080**	87	[4]**125**

[1] An estimate of a gain between sites M2 and M3 was significant.
[2] An estimate of a gain between sites M8 and M9 was significant.
[3] An estimate of a loss between sites M14 and M15 was significant.
[4] An estimate of a loss between sites M13 and M14 was significant.

Snake River at King Hill gaging stations (L18 and L20). Gain/loss estimates throughout these subreaches were variable, and only two estimates were statistically significant (Appendix A). Regardless, even the statistically significant estimates (table 3) were significantly smaller than Kjelstrom's (1995) estimated gain for the overall subreach (L16 to L20) of 1,020,000 acre-ft (1,430 ft^3/s) during water year 1980.

Middle Reach (Snake River near Shelley to Snake River near Minidoka)

Data collected during each of the seepage studies of the middle reach included discharge data from five long-term gaging stations, acoustic Doppler discharge measurements from an additional 11 intermediate sites (fig. 4), and discharge data, obtained using current meters or by visual inspection, from numerous tributaries and irrigation-return drains. A summary of these data is presented in Appendix B.

It was assumed that the inflow values obtained for each subreach during each of the spring and fall seepage studies represented most, if not all, of the actual inflows occurring at the time of the study. Many of the irrigation-return drains were active during the summer of 2002. For this period, it was assumed that the inflow values that were obtained represented about 90 percent of the actual inflows occurring at that time.

Unsteady releases from two structures (American Falls Dam and Minidoka Dam; fig. 1) and unsteady storage conditions upstream from these structures complicated the analyses in some instances and could have affected the final gain/loss estimates. Also, unsteady releases from two small hydrogeneration facilities located on the Snake River near Idaho Falls affected streamflows during some of the seepage studies.

The subreach between the Snake River near Shelley and Snake River at Blackfoot gaging stations (M1 and M6) lost streamflow during each of the five seepage studies. Although the gain/loss estimates for this subreach were relatively consistent, ranging from a loss of 310 ft^3/s during the spring of 2002 to a loss of 555 ft^3/s during the summer of 2002 (table 4), the gain/loss estimates for the intermediate subreaches were quite variable and did include one statistically significant gain during the fall of 2002 (Appendix B). Kjelstrom (1995) noted that this subreach alternately gains and loses streamflow depending on changes in adjacent ground-water levels, which are affected by irrigation withdrawals. This could explain some of the variability in the gain/loss estimates. Variability in the summer of 2002 also could be partially a result of larger magnitude errors associated with larger discharge values.

The subreach between the Snake River at Blackfoot and Snake River near Blackfoot gaging stations (M6 and M9) also lost streamflow during each of the five seepage studies. Estimates for this subreach were relatively consistent, ranging from a loss of 219 ft^3/s during the fall of 2001 to a loss of 398 ft^3/s during the summer of 2002 (table 4). All but two of the estimates for the intermediate subreaches showed losses; however, all of these estimates were still somewhat variable (Appendix B). Kjelstrom (1995) noted that spring discharges, which are controlled by ground-water levels, often decrease the net loss of streamflow in this subreach.

Kjelstrom (1995) noted that the overall subreach between the Snake River near Shelley and Snake River near Blackfoot gaging stations (M1 and M9) lost an estimated 200,000 acre-ft per year (280 ft^3/s) from 1915 to 1927. Data from 1932 through 1980 showed losses that were variable, ranging from around 100,000 to 400,000 acre-ft per year (140 ft^3/s to 560 ft^3/s), and very responsive to adjacent ground-water levels. The average loss for this overall subreach during the five seepage studies was approximately 760 ft^3/s (table 4).

The subreach between the Snake River near Blackfoot and Snake River at Neeley gaging stations (M9 and M12) includes several springs in addition to American Falls Reservoir and historically has gained streamflow. The average gain for this subreach during the five seepage studies was about 1,900 ft^3/s, but gains varied from 1,130 ft^3/s during the summer of 2002 to 2,680 ft^3/s during the fall of 2002 (table 4). Again, this large variability could result partly from difficulties in accurately estimating changes in storage in the reservoir. Because of the size of the reservoir, even small errors in estimating changes in storage could have significant effects on the final gain/loss estimates. Gain/loss estimates for the intermediate subreaches, in some cases, were quite variable (Appendix B). Annual gains within this subreach from 1912 to 1980 were relatively stable and averaged about 1,800,000 acre-ft per year (2,540 ft^3/s) (Kjelstrom, 1995). That estimate is about 33 percent larger than the estimate from this study.

The subreach between the Snake River at Neeley and Snake River near Minidoka gaging stations (M12 and M16) also includes several springs and a reservoir, Lake Walcott. Kjelstrom (1995) noted that this subreach alternately gains and loses streamflow, but that annual gains almost always have exceeded losses. Variability in gain/loss estimates for this subreach is reflected in the estimates for the intermediate

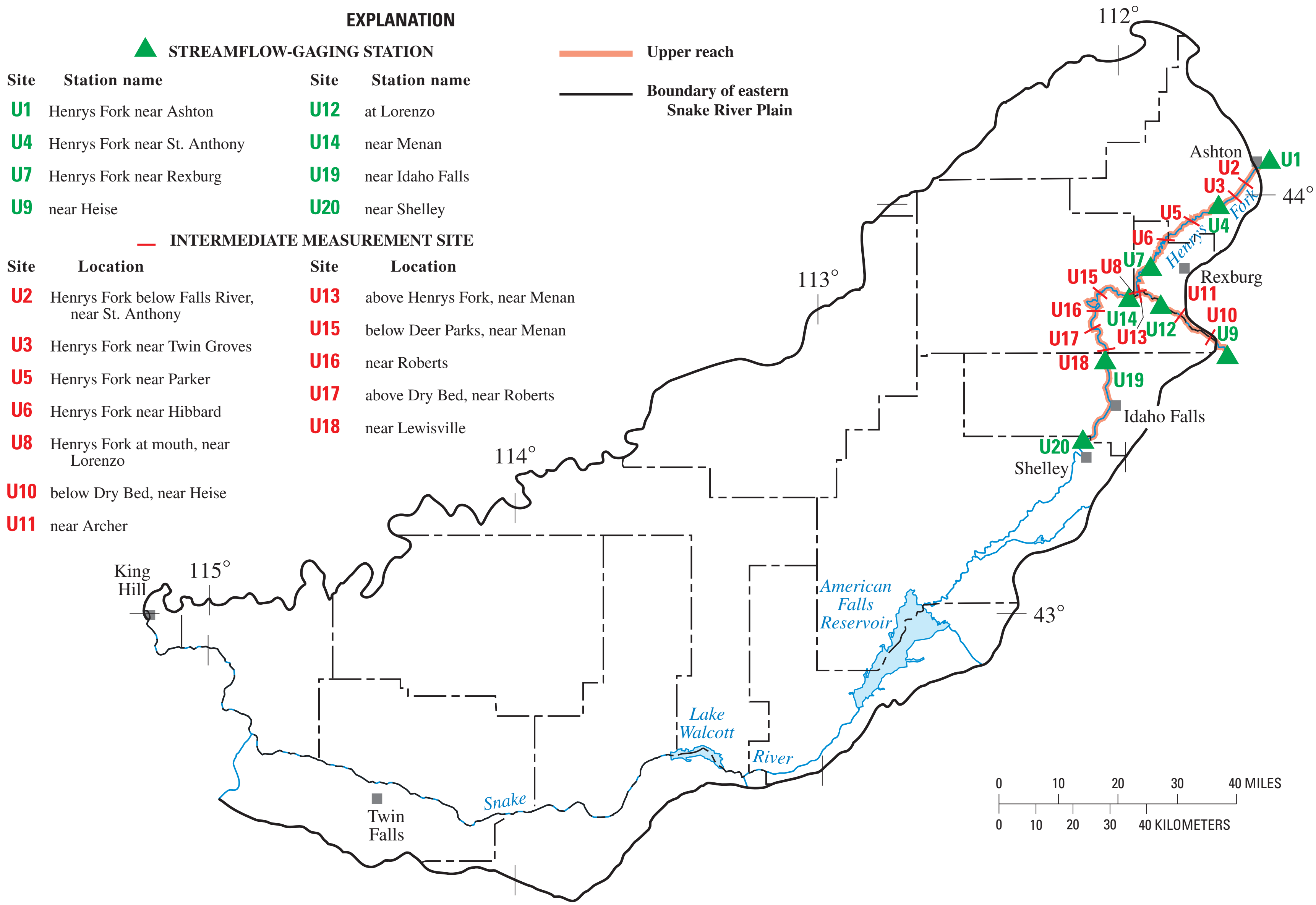

Figure 5. Locations of sites along the upper reach of the Snake River and along the Henrys Fork, southeastern Idaho, where streamflow was measured.

subreaches. Some of the variability, especially the estimate for the spring of 2002, could have been the result of difficulties in accurately estimating changes in storage in Lake Walcott. Excluding the spring 2002 value, statistically significant estimates averaged a gain of 120 ft^3/s (table 4). Kjelstrom (1995) estimated a gain of approximately 200,000 acre-ft (280 ft^3/s) in this subreach during water year 1980. He also noted losses that averaged about 15,000 acre-ft per month (252 ft^3/s) during June, July, and August of 1979.

Upper Reach (Henrys Fork near Ashton to Henrys Fork at mouth, near Lorenzo / Snake River near Heise to Snake River near Shelley)

Data collected during each of the seepage studies of the upper reach included discharge data from eight long-term gaging stations, acoustic Doppler discharge measurements from an additional 12 intermediate sites (fig. 5), and discharge data, obtained using current meters or by visual inspection, from numerous tributaries and irrigation-return drains. A summary of these data is presented in Appendix C.

It was assumed that the total inflow values determined for each subreach during each of the spring and fall seepage studies represented most, if not all, of the actual inflows occurring at the time of the study. Many of the irrigation-return drains were active during the summer of 2002. For this period, it was assumed that the total inflow values represented about 90 percent of the actual inflows occurring at that time.

Unsteady releases from two small hydrogeneration facilities located on the Snake River near Idaho Falls affected streamflows during some of the seepage studies. In an effort to reduce the effects of the variable releases from these facilities, 30-day average daily mean discharges were used to calculate the gain/loss estimates in the subreach between the near Idaho Falls and near Shelley gaging stations (U19 and U20). Although the use of average values could have reduced some of the variability in the gain/loss estimates, this method did not account for variability in inflows or outflows within the subreach and could have resulted in estimates with larger levels of error. In addition, the Snake River channel upstream from the confluence with the Henrys Fork is very active, and braided channels and bypass flows are common.

The subreach between the Henrys Fork near Ashton and Henrys Fork near St. Anthony gaging stations (U1 and U4) generally gained streamflow during the four seepage studies. Gain/loss estimates ranged from essentially no gain during the spring of 2002 to a gain of about 235 ft^3/s during the summer of 2002 (table 5). Most estimates for the intermediate subreaches within this subreach were gains; however, a statistically significant loss between sites U1 and U2 occurred in the fall of 2002 (Appendix C).

The subreach between the Henrys Fork near St. Anthony and Henrys Fork near Rexburg gaging stations (U4 and U7) generally lost streamflow during the four seepage studies; however, two statistically significant gains between sites U4 and U5 were calculated during the study (Appendix C). Loss estimates ranged from 71 ft^3/s during the spring of 2002 to 188 ft^3/s during the fall of 2001 (table 5). The average loss estimate for this subreach during the entire study period was about 121 ft^3/s.

The subreach between the Snake River near Heise and Snake River at Lorenzo gaging stations (U9 and U12) lost streamflow during three of the four seepage studies. Estimates for intermediate subreaches were losses or essentially no gain except that for one subreach: a statistically significant gain between sites U11 and U12 was calculated during the summer of 2002 (Appendix C), resulting in a near zero loss estimate for the subreach. Excluding results for the summer of 2002, overall subreach estimates ranged from a loss of 393 ft^3/s during the fall of 2001 to a loss of 606 ft^3/s during the spring of 2002. The average loss estimate for this subreach, excluding the summer of 2002, was about 474 ft^3/s (table 5). Kjelstrom (1995) noted that this reach is very responsive to adjacent ground-water levels and often alternates between gaining and losing streamflow during any given year. During water years 1979 and 1980, estimates ranged from a loss of about 590 ft^3/s to a gain of about 750 ft^3/s (Kjelstrom, 1995).

Because of the difficult measuring conditions at the Snake River site (U13) immediately upstream from the confluence with the Henrys Fork, no gain/loss estimates for the intermediate subreaches within the subreach between the Snake River at Lorenzo and Snake River near Menan gaging stations (U12 and U14) were calculated. In addition, because discharge was not measured at site U8 during the fall of

Table 5. Summary of streamflow gain and loss estimates for the upper reach of the Henrys Fork and Snake River, between the near Ashton gaging station and the mouth, near Lorenzo, and the near Heise and near Shelley gaging stations, Idaho

[See figure 5 for locations of subreaches; ft^3/s, cubic feet per second; values in **boldface** are statistically significant]

Subreach	Estimates of gains or (losses), in ft^3/s			
	Fall 2001	Spring 2002	Summer 2002	Fall 2002
U1 to U4	**76**	3	**235**	[1] **210**
U4 to U7	**(188)**	[2] **(71)**	[2] **(101)**	**(122)**
U9 to U12	**(393)**	**(606)**	[3] (8)	**(424)**
U12 to U14	[4] **319**	**428**	[4] 228	**517**
U14 to U19	**(142)**	**(352)**	[5] (300)	[6] 4
U19 to U20	30	**(205)**	(6)	**(149)**

[1] An estimate of a loss between sites U1 and U2 was significant.
[2] An estimate of a gain between sites U4 and U5 was significant.
[3] An estimate of a gain between sites L11 and L12 was significant.
[4] Includes any gains or losses within the subreach between the Henrys Fork near Rexburg gaging station and Henrys Fork at the mouth, near Lorenzo.
[5] An estimate of a loss between sites U14 and U15 was significant.
[6] An estimate of a loss between sites U14 and U15 and an estimate of a gain between sites U17 and U18 were significant.

2001 or the summer of 2002, the estimates for this subreach included gains or losses within the Henrys Fork subreach from the Henrys Fork near Rexburg gaging station downstream to the mouth, near Lorenzo (U7 and U8). Estimates for the spring and fall of 2002, which can be attributed solely to streamflow gains and losses in the Snake River subreach (U12 to U14), showed a relatively consistent gain that ranged from 428 ft^3/s during the spring of 2002 to 517 ft^3/s during the fall of 2002. The average gain during these two seepage studies was about 472 ft^3/s (table 5).

Estimates for the subreach between the Snake River near Menan and Snake River near Idaho Falls gaging stations (U14 and U19) were somewhat variable during the four seepage studies. The estimates ranged from essentially no change during the fall of 2002 to a loss of 352 ft^3/s during the spring of 2002 (table 5). Most estimates for the intermediate subreaches within this subreach were not statistically significant; however, significant losses between sites U14 and U15 were calculated during three of the four seepage studies (Appendix C). The only statistically significant gain occurred between sites U17 and U18 during the fall of 2002. In contrast, Kjelstrom (1995) described this reach as one that gains streamflow during most years and in which gains increase during the irrigation season. He also noted a direct relationship between monthly gains and nearby ground-water levels.

As previously discussed, because of the probability of unsteady discharges from two hydrogeneration facilities located downstream from Idaho Falls, 30-day average discharge values were used to calculate gain/loss estimates within the subreach between the Snake River near Idaho Falls and Snake River near Shelley gaging stations (U19 and U20). For the same reason, no intermediate acoustic Doppler measurements were obtained within this subreach. For comparison, loss estimates calculated for the subreach between sites U4 and U7 using 30-day average discharges averaged about 110 ft^3/s; loss estimates calculated for the same subreach using the acoustic Doppler discharge measurements and gaging-station data averaged about 121 ft^3/s. Estimates for the Snake River near Idaho Falls to the Snake River near Shelley subreach based on the 30-day average discharge values ranged from essentially no change during the fall of 2001 and the summer of 2002 to a loss of 205 ft^3/s during the spring of 2002 (table 5). Kjelstrom (1995) noted somewhat similar results for water years 1979 and 1980: his estimates ranged from very small gains to losses exceeding 1,000 ft^3/s, depending on adjacent ground-water levels.

COMPARISONS OF GROUND-WATER LEVELS WITH STREAMFLOW GAINS AND LOSSES

Water levels in 1,350 wells located on and adjacent to the ESRP (fig. 6) were measured during three separate mass measurement efforts. Of the 1,350 wells, 825 either were the same wells included in the 1980 RASA study (Lindholm, 1996) or were suitable replacements (i.e. similar location and depth). The remaining wells were private wells in the Rexburg area, current USGS observation wells operated in cooperation with the State of Idaho, INEEL project wells, BOR network wells, and IDWR network wells. Water levels were measured before the 2001 irrigation season (beginning in mid-March 2001), following the 2001 irrigation season (beginning in mid-October 2001), and before the 2002 irrigation season (beginning in late March 2002). Water levels in the wells, with the exception of some in the Rexburg area, were measured within a 3-week time period during each of the three efforts. Those in the Rexburg area were measured only during the final two measurement efforts. Water-level data obtained during these measurement efforts are available in volume 1 of the water year 2002 annual data report for Idaho (Brennan and others, 2003) and in the USGS National Water Information System database. Where possible, data from selected wells were analyzed and compared to streamflow gain/loss estimates for adjacent subreaches.

Lower Reach (Snake River near Minidoka to Snake River at King Hill)

The data for well 9S-25E-23DBA1 (well no. 1; fig. 6), which is adjacent to the subreach between the Snake River near Minidoka and Snake River at Milner gaging stations (L1 and L4), showed a decrease in water levels of approximately 10 ft between 1980 and 2002. An apparent relation between water levels in this well and estimates of gains and losses within this subreach can be seen in the plot in figure 7. The statistically significant estimates of gains for this subreach during the spring and fall of 2001 were consistent with Kjelstrom's (1995) findings that this subreach historically gains streamflow. The estimated loss during the fall of 2002 was consistent with Kjelstrom's (1995) observation that this subreach may lose streamflow following a general lowering of ground-water levels.

Long-term data for well 10S-20E-27BCC1 (fig. 6) adjacent to the subreach between the Snake River at Milner and Snake River near Kimberly gaging stations (L4 and L6) showed a decrease in water levels of about 8 ft during the study period. As discussed previously, estimates of gains within this subreach were very consistent and also very similar to estimates of gains determined by Kjelstrom (1995). The consistency of estimated gains and ground-water-level decreases indicated that there was no relation between the estimated gains and changes in ground-water levels.

As discussed previously, the average gain estimate for the subreach from the Snake River near Kimberly to Snake River near Buhl gaging stations (L6 and L10) was about 16 percent smaller than that calculated for water year 1980. Head in an artesian well (9S-16E-20ADD1; fig. 6) on the south side of the Snake River near Twin Falls decreased by more than 30 ft

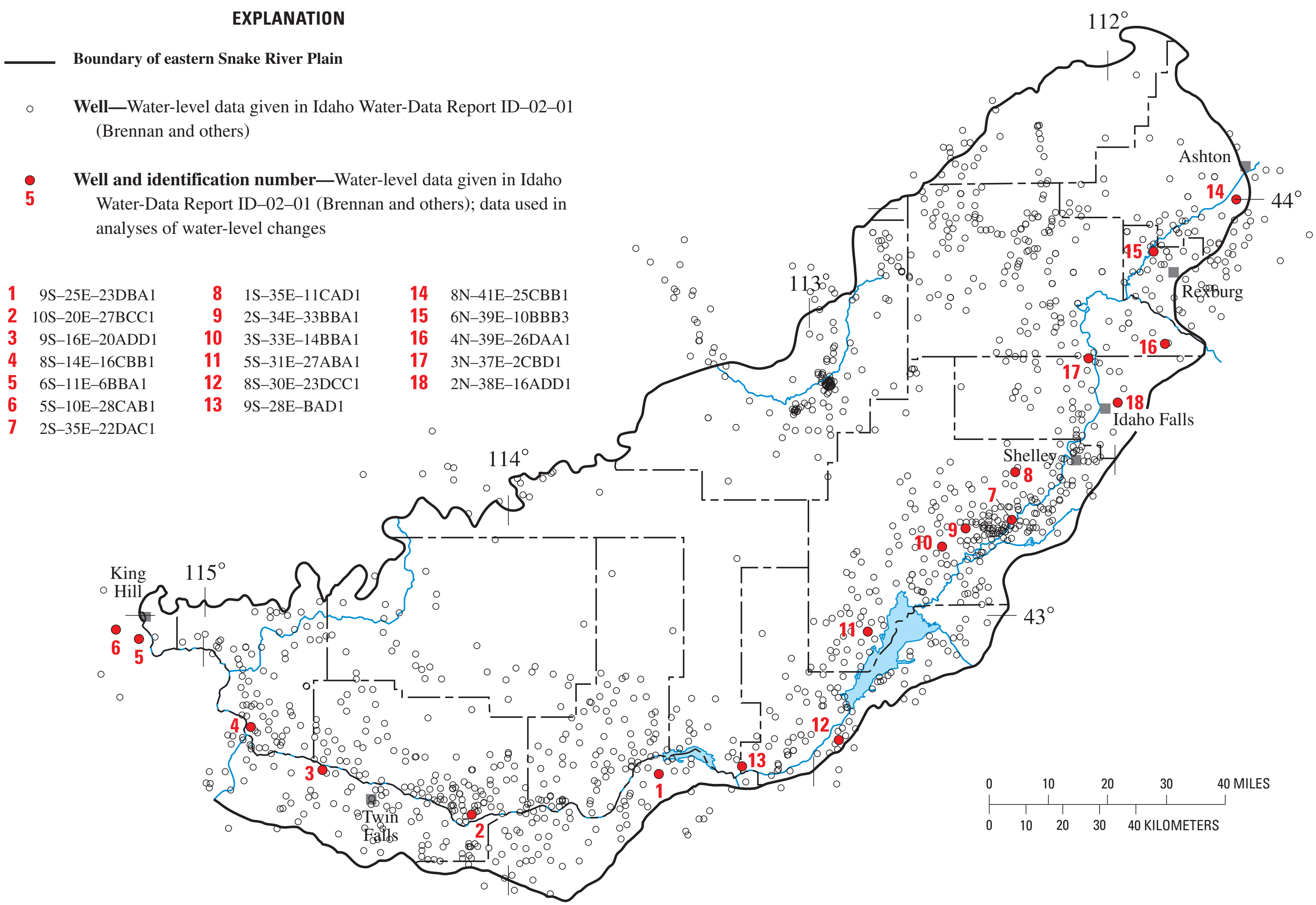

Figure 6. Locations of wells on and near the eastern Snake River Plain, southeastern Idaho, where water levels were measured during water years 2002-03.

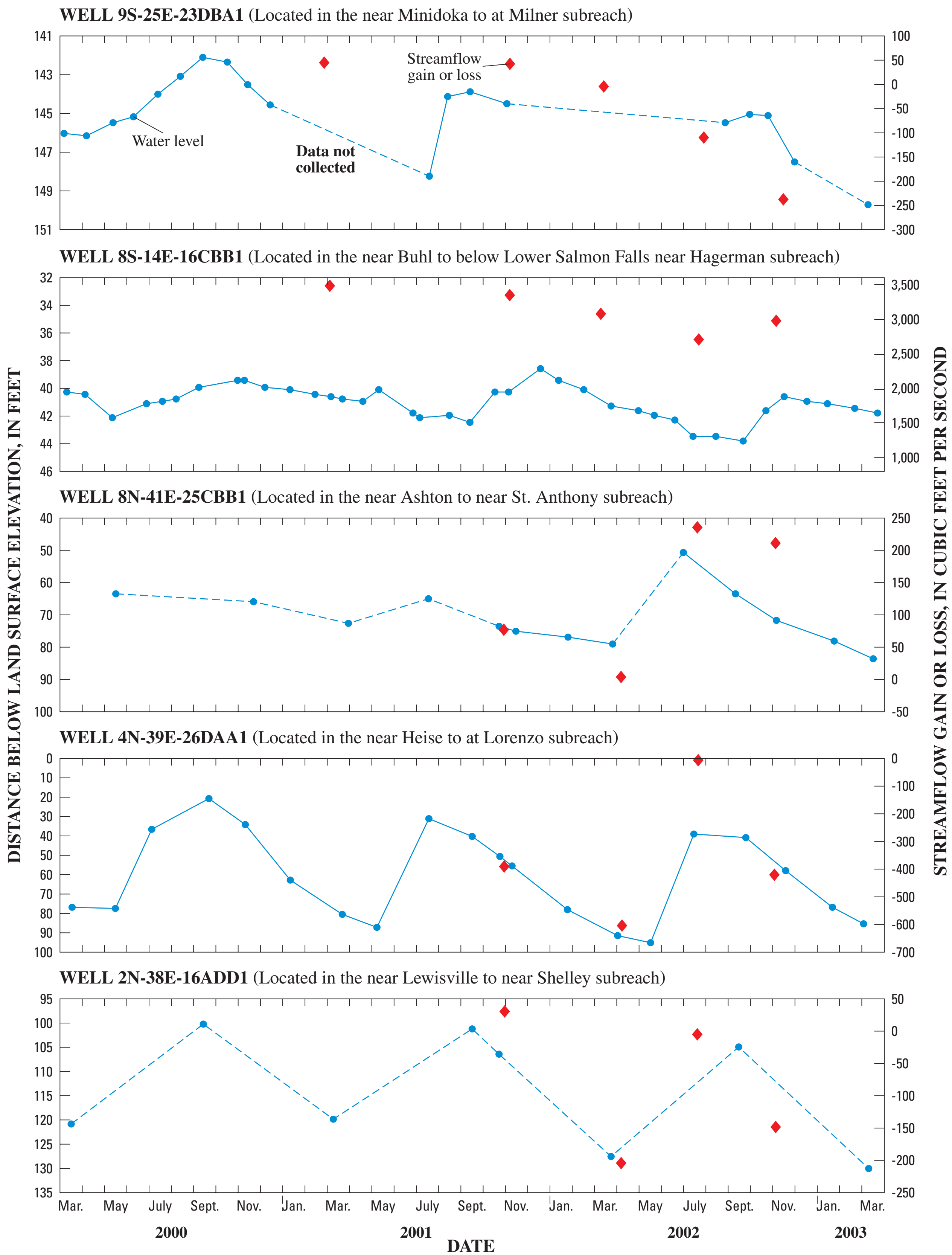

Figure 7. Water levels in selected wells during water years 2000–03 and estimates of gains and losses in selected subreaches of the Snake River and Henrys Fork, southeastern Idaho, spring 2001 to fall 2002.

between 1984 and 2002. The decrease in estimated gains from Kjelstrom's (1995) estimates to the results from this study for this subreach could be related to the relatively large decreases in water levels between 1980 and 2002.

The average gain estimate for the subreach between the Snake River near Buhl and the Snake River below Lower Salmon Falls near Hagerman gaging stations (L10 and L16) was about 19.7 percent smaller than that calculated for water year 1980. A relation between water levels in well 8S-14E-16CBB1 (fig. 6), adjacent to this subreach, and spring discharges from the north side of the river was noted by Kjelstrom (1995). The water-level decrease in this well of approximately 2 ft between 1980 and 2002 could be related to the decrease in gains during that time period. Water levels during water years 2000–03 and gain/loss estimates from the seepage studies are presented in figure 7. Although short-term water-level variations were relatively small, these variations could be related to changes in gain estimates within this subreach during the five seepage studies.

A comparison of the average estimate of gains for 1980 (Kjelstrom, 1995) for the subreach between the Snake River below Lower Salmon Falls near Hagerman and the Snake River at King Hill gaging stations (L16 and L20) and the average estimate of gains for this study showed an apparent decrease in gains since 1980. Data for well 6S-11E-6BBA1 (fig. 6), which is adjacent to this subreach, showed a decrease in water levels of nearly 10 ft between 1980 and 2002. Data for another well (5S-10E-28CAB1; fig. 6), located about 5 mi downstream from the King Hill gaging station, also showed significant decreases in water levels. Between 1980 and 2002, this well changed from an artesian well with a head of approximately 5 ft to a well with water levels about 5 to 7 ft below land surface.

Middle Reach (Snake River near Shelley to Snake River near Minidoka)

Water levels in two wells (2S-35E-22DAC1 and 1S-35E-11CAD1; fig. 6) located adjacent to the subreach between the Snake River near Shelley and the Snake River-Blackfoot gaging stations (M1 and M6) decreased about 9 to 15 ft between the mid-1980s and 2002. The estimates between intermediate sites within this subreach were somewhat vari able; however, there were insufficient data available to determine if there was a relation between these variations and the variations in water levels in the selected wells.

Estimates of losses between intermediate sites within the subreach between the Snake River at Blackfoot and the Snake River near Blackfoot gaging stations (M6 and M9) were somewhat variable, but these variations did not seem to be related to the relatively small changes in water levels recorded during the study. Water levels in selected wells (2S-34E-33BBA1 and 3S-33E-14BBA1; fig. 6) located adjacent to this subreach decreased about 3 to 5 ft between 1980 and 2002 and varied about 1 to 3 ft during the study. The decrease in ground-water levels along the overall subreach between the Snake River near Shelley and the Snake River near Blackfoot gaging stations (M1 and M9), however, could partially explain the increase in losses within this subreach from about 560 ft^3/s estimated in 1980 (Kjelstrom, 1995) to about 750 ft^3/s estimated during this study.

Gains and losses within the subreach between the Snake River near Blackfoot and the Snake River at Neeley gaging stations (M9 and M12) likely are affected by American Falls Reservoir. Mundorff (1967) related water levels in well 5S-31E-27ABA1 (fig. 6) with monthly ground-water discharge to American Falls Reservoir. He also noted that gains are affected by the stage of the reservoir. As the reservoir stage declines, water is released from bank storage; as stage rises, water is added to storage. Kjelstrom (1995) showed a distinct relation between ground-water levels in well 5S-31E-27ABA1 and flows in Danielson Creek, a major spring inflow in the area. Although no distinct relation between changes in estimates of gains within this subreach and changes in ground-water levels during 2001 and 2002 was apparent, the long-term decline in water levels in well 5S-31E-27ABA1 of over 5 ft between 1980 and 2002 could explain the apparent decrease in gains since 1980. The average gain estimate for this subreach during the seepage studies was about 1,900 ft^3/s; the estimate determined by Kjelstrom (1995) for water years 1912 through 1980 was about 2,540 ft^3/s.

Long-term data for two wells (8S-30E-23DCC1 and 9S-28E-18BAD1) located adjacent to the subreach between the Snake River at Neeley and the Snake River near Minidoka gaging stations (M12 and M16) were quite variable but showed net decreases in ground-water levels of about 3 to 8 ft between 1980 and 2002. As discussed previously, this subreach historically has alternated between gaining and losing streamflow. The variable ground-water levels could partially explain the historical changes between gaining and losing. However, statistically significant gains within this subreach during the study were quite variable and did not seem to be related to water levels in adjacent wells.

Upper Reach (Henrys Fork near Ashton to Henrys Fork at mouth, near Lorenzo / Snake River near Heise to Snake River near Shelley)

Water levels in well 8N-41E-25CBB1 (fig. 6), located adjacent to the subreach between the Henrys Fork near Ashton and the Henrys Fork near St. Anthony gaging stations (U1 and U4), were quite variable during water years 2001 and 2002 and appear to relate to estimated gains during the same time period (fig. 7). During this time, the difference between the maximum and minimum water levels was more than 30 ft. The estimate of essentially no gain during the spring of 2002 corresponded to lower ground-water levels, and the estimate of a gain of 235 ft^3/s during the summer of 2002 corresponded to the highest recorded ground-water level during water years

2001 to 2003. Kjelstrom (1995) noted that ground-water levels along this subreach seem to be very responsive to surface recharge from irrigation, which, in turn, can affect the rate of gain or loss.

The subreach between the Henrys Fork near St. Anthony and Henrys Fork near Rexburg gaging stations (U4 and U7) generally lost streamflow during the seepage studies. The losses ranged from 71 ft^3/s to 188 ft^3/s. Water levels in well 6N-39E-10BBB3 (fig. 6), located adjacent to this subreach, decreased approximately 8 ft during water years 2001 and 2002; however, no relation between changes in ground-water levels and changes in gain/loss estimates was apparent.

Estimates of losses in the subreach between the Snake River near Heise and the Snake River at Lorenzo gaging stations (U9 and U12) were somewhat variable during the seepage studies. Water levels in well 4N-39E-26DAA1 (fig. 6), located adjacent to this subreach, also were somewhat variable. The relation between changes in water levels in this well and changes in gain/loss estimates was strong, with the exception of that for the summer of 2002 (fig. 7). This well is completed in the alluvial deposits along the river, which could explain the strong relation. Gain/loss estimates for the summer of 2002 could have been affected by larger errors associated with measuring larger summer discharges and summer outflow estimates. Kjelstrom (1995) also noted a relation between gains and losses and water levels in wells adjacent to this subreach. He attributed the rise in ground-water levels and subsequent increase in streamflow gains during 1980 to surface recharge from irrigation. Timing of the increased gains during 2001 and 2002 (fig. 7) suggests that surface recharge from irrigation was likely also the source of increases during this period.

No relation between ground-water levels and estimates of gains in the subreach from the Snake River at Lorenzo to the Snake River near Menan gaging stations (U12 and U14) was apparent. Two possible reasons could be that few wells are located adjacent to the reach and, as discussed previously, the estimates of gains for two of the seepage studies included any gains or losses within the Henrys Fork subreach from near Rexburg to the mouth.

Few wells were usable for comparisons along the subreach from the Snake River near Menan to the Snake River near Idaho Falls gaging stations (U14 and U19). Increases and decreases in water levels in the only well located near the river, 3N-37E-2CBD1 (fig. 6), were consistent with increases and decreases in surface recharge from irrigation; however, no relation between the ground-water levels and the estimates of gains and losses based on the limited water-level data was apparent within the subreach.

A relation between water levels in well 2N-38E-16ADD1 (fig. 6) and gain/loss estimates between the near Lewisville site and the Snake River near Shelley gaging station (U18 and U20) was noted by Kjelstrom (1995). A similar relation was found during 2001 and 2002 between water levels in the same well and estimates of gains and losses between the Snake River near Idaho Falls and the Snake River near Shelley gaging stations (U19 and U20; fig. 7). The statistically insignificant estimates during the fall of 2001 and the summer of 2002 corresponded to higher ground-water levels, and the estimates of losses for the spring and fall of 2002 corresponded to lower ground-water levels.

SUMMARY

Declining water levels in the eastern Snake River Plain (ESRP) aquifer and decreases in spring discharges from the aquifer to the Snake River have raised concerns about the sustainability of water resources in the ESRP. To address this question, the Snake River Plain Hydrologic Modeling Committee developed a general strategy to refine and enhance the conceptual and computer models of the ESRP hydrologic system. Because of the need for improved and additional information concerning surface-water/ground-water interactions along specific reaches of the Snake River and Henrys Fork included in these models, the U.S. Geological Survey (USGS), in cooperation with the Idaho Department of Water Resources (IDWR) and Idaho Power Company (IPCo), designed and conducted seepage studies in three separate reaches of the Snake River and Henrys Fork in southeastern Idaho. Data collected in each reach included discharges at USGS and(or) IPCo, discharges at several intermediate sites between gaging stations measured using acoustic Doppler current profilers (ADCPs), and measured and(or) estimated discharges at several miscellaneous inflow (mostly tributaries) and outflow (irrigation canals) sites. Estimates of streamflow gains and losses in specific subreaches of the Snake River then were calculated.

Gain/loss estimates varied greatly within and between the selected study reaches. Surface spring flow was present in many of the subreaches for which large estimates of gains were calculated, most notably the reach that includes Thousand Springs. Both gain and loss estimates were calculated for some subreaches depending on the time of the study. The overall magnitude of the gains was about 5 times larger than that of the losses. Unsteady releases from dams and powerplants and changes in reservoir and channel storages probably contributed a large component of the error in several of the calculated gain/loss estimates.

In addition to estimates of streamflow gains and losses, water levels in 1,350 wells across the study area were measured at three different times during the study period. Relations between gain/loss estimates in each subreach and ground-water levels in wells located adjacent to each subreach were analyzed. In some instances, general relations between changes in gain/loss estimates and changes in ground-water levels were apparent.

A comparison of streamflow and water-level data from the 1980 Regional Aquifer-System Analysis study (Kjelstrom, 1995) with data from the 2001 to 2002 study period indicated that long-term changes in gain/loss estimates likely were related to long-term changes in ground-water levels. Gain

estimates for three of the subreaches located within the lower study reach (L6 to L10, L10 to L16, and L16 to L20) were more than 15 percent smaller than the estimates determined by Kjelstrom (1995). The gain estimate for the subreach that includes American Falls Reservoir (M9 to M12) was about 33 percent smaller than that determined by Kjelstrom (1995). The gain/loss estimates for the subreach of the Snake River immediately downstream from the confluence with the Henrys Fork (U14 to U19) ranged from no change to statistically significant losses. In contrast, Kjelstrom (1995) noted that this historically had been a gaining reach.

REFERENCES CITED

Brennan, T.S., Lehmann, A.K., Campbell, A.M., O'Dell, I., and Beattie, S.E., 2003, Water resources data – Idaho, water year 2002, volume 1: U.S. Geological Survey Water Data Report ID–02–1, 419 p.

Goodell, S.A., 1988, Water use on the Snake River Plain, Idaho and eastern Oregon: U.S. Geological Survey Professional Paper 1408–E, 51 p.

Kennedy, E.J., 1983, Computation of continuous records of streamflow: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A13, 53 p.

Kjelstrom, L.C., 1988, Estimates of gains and losses for reservoirs on the Snake River from Blackfoot to Milner, Idaho, for selected periods, 1912 to 1983: U.S. Geological Survey Water-Resources Investigations Report 87–4063, 62 p.

Kjelstrom, L.C., 1992, Assessment of spring discharge to the Snake River, Milner Dam to King Hill, Idaho: U.S. Geological Survey Open-File Report 92–147 (Water Fact Sheet), [2] p.

Kjelstrom, L.C., 1995, Methods to estimate annual mean spring discharge to the Snake River between Milner Dam and King Hill, Idaho: U.S. Geological Survey Water-Resources Investigations Report 95–4055, 9 p.

Kjelstrom, L.C., 1995, Streamflow gains and losses in the Snake River and ground-water budgets for the Snake River Plain, Idaho and eastern Oregon: U.S. Geological Survey Professional Paper 1408–C, 47 p.

Lindholm, G.F., 1996, Summary of the Snake River Plain Regional Aquifer-System Analysis in Idaho and eastern Oregon: U.S. Geological Survey Professional Paper 1408–A, 59 p.

Lipscomb, S.W., 1995, Quality assurance plan for discharge measurements using broadband acoustic Doppler current profilers: U.S. Geological Survey Open-File Report 95–701, 7 p.

Maupin, M.A., 1995, Water-quality assessment of the upper Snake River Basin, Idaho and western Wyoming—environmental setting, 1980–92: U.S. Geological Survey Water-Resources Investigations Report 94–4221, 35 p.

Morlock, S.E., 1996, Evaluation of acoustic Doppler current profiler measurements of river discharge: U.S. Geological Survey Water-Resources Investigations Report 95–4218, 37 p.

Mundorff, M.J., 1967, Ground water in the vicinity of American Falls Reservoir, Idaho: U.S. Geological Survey Water-Supply Paper 1846, 58 p.

Mundorff, M.J., Crosthwaite, E.G., and Kilburn, Chabot, 1964, Ground water for irrigation in the Snake River basin in Idaho: U.S. Geological Survey Water-Supply Paper 1654, 224 p.

Newell, T.R., 1928, Segregation of water resources, American Falls basin and reservoir: Idaho Falls, Report to Water District No. 36, 127 p.

Newell, T.R., 1929, Segregation of water resources, American Falls basin and reservoir: Idaho Falls, Report to Water District No. 36, 144 p.

Norvitch, R.F., Thomas, C.A., and Madison, R.J., 1969, Artificial recharge to the Snake Plain aquifer, an evaluation of potential and effect: Idaho Department of Reclamation, Water Information Bulletin no. 12, 59 p.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow: U.S. Geological Survey Water-Supply Paper 2175, 2 v., 631 p.

Sauer, V.B., and Meyer, R.W., 1992, Determination of error in individual discharge measurements: U.S. Geological Survey Open-File Report 92–144, 21 p.

Simpson, M.R., 2001, Discharge measurements using a broadband acoustic Doppler current profiler: U.S. Geological Survey Open-File Report 01–1, 123 p.

Stearns, H.T., Crandall, Lynn, and Steward, W.G., 1938, Geology and ground-water resources of the Snake River Plain in southeastern Idaho: U.S. Geological Survey Water-Supply Paper 774, 268 p.

Thomas C.A., 1969, Inflow to Snake River between Milner and King Hill, Idaho, 1968: Idaho Department of Reclamation, Water Information Bulletin no. 9, 39 p.

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