ESTIMATES OF GAINS AND LOSSES FOR RESERVOIRS ON THE SNAKE RIVER FROM BLACKFOOT TO MILNER, IDAHO, FOR SELECTED PERIODS, 1912 TO 1983

By L.C. Kjelstrom

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CONVERSION FACTORS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, conversion factors are listed below:

Multiply inch-pound unit	By	To obtain metric unit
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.40	millimeter
megawatt-hour (MWh)	3,600,000,000	joule
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

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ABSTRACT

Croplands in the semiarid central part of the Snake River Plain are dependent on the availability of irrigation water, most of which comes from the Snake River. Allocation of irrigation water from the river requires that gains and losses be determined for American Falls Reservoir, Lake Walcott, and Milner Lake.

From 1912 to 1983, average ungaged inflow to American Falls Reservoir, determined from monthly water budgets, was 2,690 cubic feet per second. About 94 percent of this inflow was spring discharge and ground-water seepage; the remainder was from small tributaries and irrigation-return flow. Ungaged inflow estimated from water budgets for various periods correlated favorably with measured discharge of two springs and water levels in two wells. Discharge of Spring Creek was a better indicator of ungaged inflow than ground-water levels. Therefore, correlation with Spring Creek discharge was used in estimating ungaged inflow to American Falls Reservoir in 1983. Daily water-budget calculations of ungaged inflow to American Falls Reservoir are less variable when storage changes are determined by using three stage-recording stations rather than one. Water budgets do not indicate large amounts of leakage from American Falls Reservoir, but small amounts of leakage are indicated because flow in downstream springs increased about 25 percent after reservoir storage began in 1926.

Water budgets for Lake Walcott and Milner Lake show average annual net gains (1951-83) to Lake Walcott and Milner Lake of 245 and 290 cubic feet per second. These amounts are verified by (1) monthly water budgets when discharge in the Snake River is low, and (2) measured and estimated sources of inflow. Gains and losses estimated from daily water budgets are variable, owing to inadequate determination of (1) changes in reservoir storage, (2) streamflow, (3) lake-surface precipitation, and (4) lake-surface evaporation. Backwater effects are accounted for in the process used to determine storage in Milner Lake.

INTRODUCTION

The economy of the semiarid Snake River Plain, southern Idaho, relies heavily on irrigated agriculture. American Falls Reservoir, Lake Walcott, and Milner Lake (fig. 1) supply irrigation water to the central area of the plain. Diversions are made to fulfill established water rights on natural streamflow (without regulation or diversion) and reservoir storage. To determine the amount to be diverted, which depends on the amount available, water managers use water budgets to compute gains to and losses from the Snake River between U.S. Geological Survey gaging stations near Blackfoot and at Neeley (above and below American Falls Reservoir), at Neeley and near Minidoka (above and below Lake Walcott), and near Minidoka and near Milner (above and below Milner Lake).

During the 1983 irrigation season (April-October), diversions from American Falls Reservoir, Lake Walcott, and Milner Lake were about 42,900, 694,500, and 2,597,300 acre-ft. This water is used to irrigate about 600,000 acres (Water District 01, 1981).

The daily gain or loss in each reservoir is presently (1983) computed by the Snake River watermaster by use of a water budget, where:

gain or loss = measured outflow (to river and canals) − measured inflow ± storage changes + evaporation from the reservoir

Differences between discharges of the river at gaging stations upstream and downstream from each reservoir (adjusted for change in storage, diversions, and evaporation) are considered to constitute the net gain or loss for each reservoir. Gains include ungaged discharge from springs and small tributaries, ground-water seepage, irrigation-return flow, and precipitation on the reservoirs. Losses include percolation to ground water and bank storage.

Gain and loss values determined by water budgets include an error component composed of discharge-measurement errors, change-in-storage errors, and undefined interactions between ground and surface water. Inaccuracies may be reduced by collection of additional data. Where additional data collection is not possible or where the quality of the data is not likely to reduce inaccuracies, gains and losses in the reservoirs may be more accurately defined by re-examining available data and the relations that exist between ground water and surface water.

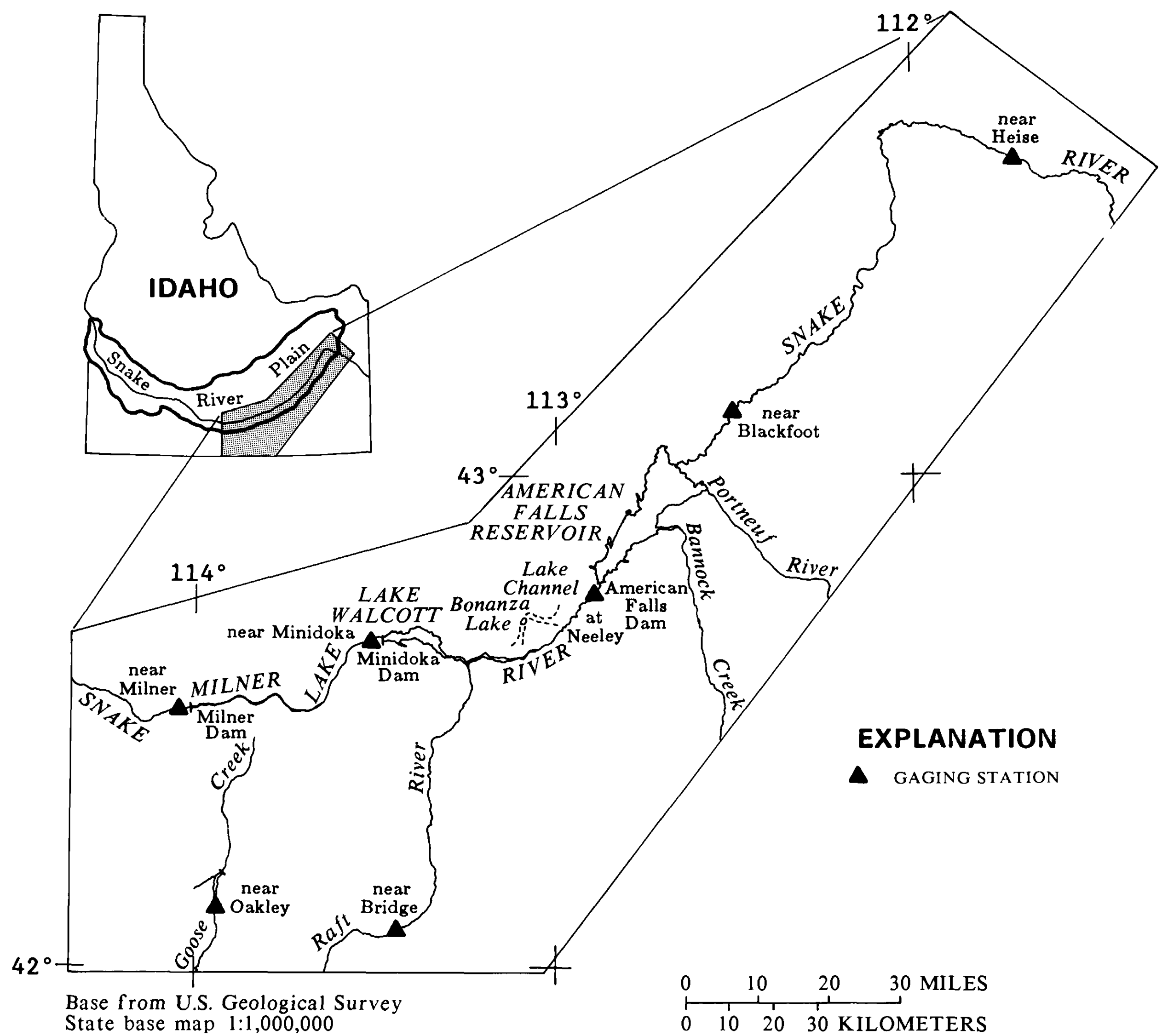

Figure 1.--Study area.

Purpose and Scope

The purpose of this report was to present results of a study to: (1) Determine, by use of water budgets, gains and losses for three Snake River reservoirs between Blackfoot and Milner; (2) account for budget errors; and (3) suggest ways to reduce or eliminate those errors. The major study effort was focused on the river reach between the gages near Blackfoot and at Neeley, which includes American Falls Reservoir. This was done because of the size of the reservoir and the effect that unmeasured ground-water inflow appears to have on the water budget. Analyses of gains and losses determined from water budgets were made by using available data and data collected for this study.

This study was made in cooperation with Idaho Water District 01 during water years 1983 and 1984. The objective of the study was to provide information for the management of irrigation diversions, reservoir storage, and flow in the Snake River.

The scope of the study included (1) collecting water-stage data at three sites in American Falls Reservoir, two sites in Milner Lake, and one site in Bonanza Lake (a landlocked lake) from November 1982 to September 1983; (2) computing daily change in storage by using the three stage gages in American Falls Reservoir; (3) operating a discharge-measurement station on Spring Creek at Sheepskin Road near Fort Hall from August 1980 through September 1983; (4) measuring water levels in 10 wells from November 1982 through September 1983 (3 wells were equipped with continuous recorders and 7 were measured monthly); and (5) developing a storage-capacity table for Milner Lake that considers backwater conditions.

Existing data used in the study included discharge records for four sites on the Snake River and one site on the Portneuf River, stage records from gages near the dams of all three reservoirs, diversion data, and records from five recording precipitation stations and from one pan-evaporation station.

Well-Numbering System

The well-numbering system (fig. 2) used by the U.S. Geological Survey in Idaho indicates the location of wells within the official rectangular subdivision of the public lands, with reference to the Boise base line and Meridian. For example, well 5S-31E-27ABA1 is in the NE¼NW¼NE¼, sec. 27, T. 5 S., R. 31 E. The first two segments of the number designate the township (5S) and range (31E). The third

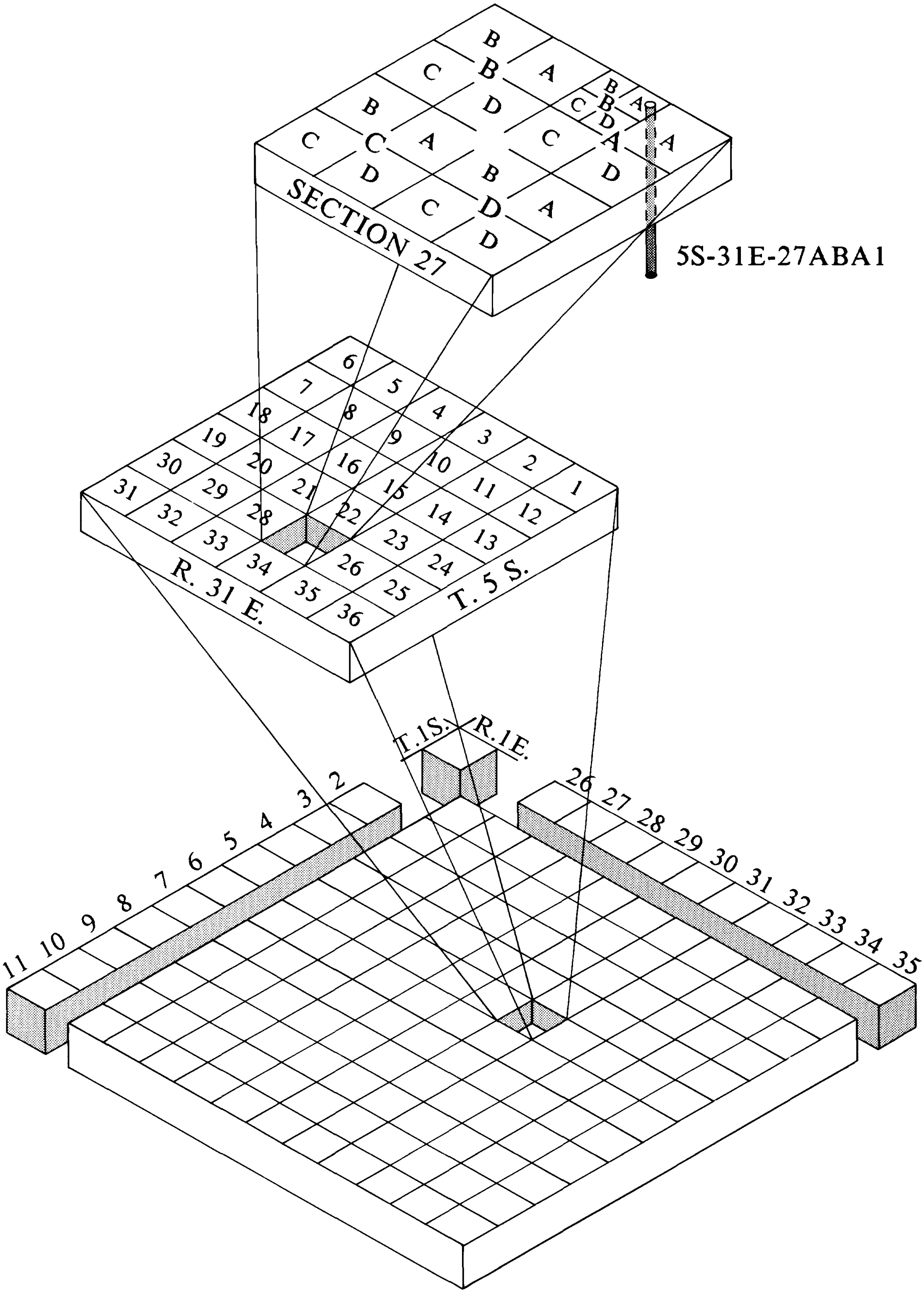

Figure 2.--Well-numbering system.

segment gives the section number (27); three letters (ABA), which indicate the ¼ section (A, 160-acre tract), ¼-¼ section (B, 40-acre tract), ¼-¼-¼ section (A, 10-acre tract); and sequence number of the well (1) within the tract, if available. Quarter sections are lettered A, B, C, and D in counterclockwise order from the northeast quarter of each section. Within the quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. The sequence number indicates it was the first well inventoried in that tract.

Gaging-Station Numbering System

Each continuous- and partial-record gaging station in Idaho has been assigned a number in accordance with the permanent numbering system used by the U.S. Geological Survey. Numbers are assigned in downstream order along the main stream, and stations on tributaries between main-stream stations are numbered in the order they enter the main stream. A similar order is followed on other ranks of tributaries. The complete eight-digit number, such as 13075500, which is used for the station "Portneuf River at Pocatello," includes the part "13," indicating that the Portneuf River is in the Snake River basin, plus a six-digit number.

Acknowledgments

The cooperation and technical contributions of the following individuals and groups are greatly appreciated. Mr. A. C. Robertson and Mr. R. Sutter of the Idaho Department of Water Resources provided technical advice and tabulated data. The Shoshone-Bannock Tribal Council and other landowners allowed access to gaging stations and wells, which greatly facilitated the study. The U.S. Bureau of Reclamation cooperated in obtaining recorded-stage data on the reservoirs. Mr. Jerry Eggleston of CH2M Hill Engineering furnished cross-sectional data for Milner Lake.

PREVIOUS WORK

Reports by Newell (1928, 1929) and Mundorff (1967) provide detailed discussion and quantitative analysis of ungaged ground- and surface-water inflow to American Falls Reservoir. Inflow to Lake Walcott is discussed in detail in reports by Meisler (1958) and Mundorff and others (1964).

After American Falls Dam was completed and reservoir storage began in 1926, irrigation water was allotted by the watermaster. To differentiate natural flow to the reach from reservoir storage, Newell (1928, 1929) measured flow of 27 tributaries--largely discharge from springs--to American Falls Reservoir during the irrigation seasons of 1927 and 1928. Combined discharge of the 27 sites was used as an index of total ungaged inflow (obtained by water-budget analysis) and the following relation was determined:

$$I = 840 + 1.33\ Qm \qquad (1)$$

where

I = ungaged inflow, in cubic feet per second,
840 = discharge from less variable sources, and
Qm = total discharge at 27 measuring sites, in cubic feet per second.

Ungaged inflow to the reservoir was estimated by the watermaster using this relation during each succeeding irrigation season from 1932 to 1977. Since 1977, ungaged inflow has been computed as the residual of daily water budgets or the remainder after subtraction of measured surface inflow (largely from springs) from measured outflow with adjustments for storage change and evaporation.

Newell (1928, 1929) measured water levels in wells, estimated reservoir evaporation from pan-evaporation data, and determined bank storage and reservoir-seepage losses for American Falls Reservoir. Profiles he constructed from water-level data showed that the water table in the shallow aquifer generally sloped toward the reservoir except at the southwestern end of the reservoir, where ground-water levels were generally below those of the reservoir water surface.

Mundorff (1967) studied the effects on ground-water levels and spring discharges that would result from raising the height of American Falls Dam 15 ft. He estimated that ground-water discharge from springs in the early 1900's was about 1.2 to 1.4 million acre-ft/yr, but that seepage losses from the reservoir, built in 1926, were negligible because fine-grained deposits that crop out along the shore and extend to depths of 50 to 100 ft form an effective seal beneath the reservoir.

Meisler (1958) investigated the area north and west of American Falls Dam to determine the direction of ground-water movement and the relation of the regional ground-water system to the Snake River. He concluded that ground-water movement in the Bonanza Lake area is generally southwestward to the Snake River or westward toward the Snake Plain aquifer and that ground water in the Bonanza Lake area may be perched above relatively impermeable strata, perhaps lakebeds of the Raft Formation (Meisler, 1958, p. 18, 19).

Stearns and others (1938, p. 137-142) concluded that recharge to springs discharging to American Falls Reservoir is mostly underflow from the Snake River far upstream. Ground-water underflow from the Portneuf River valley and precipitation on lava beds north of the Snake River were suggested as other sources of recharge. After American Falls Reservoir was filled in 1926, Stearns and others (1938, p. 154) observed a rise in the level of Bonanza Lake, southwest of American Falls Dam. They concluded that this rise, along with the hydraulic gradient determined from water-level measurements in wells, indicated leakage from the reservoir moves southwestward and affects stage of Bonanza Lake and discharge of several springs on the north side of Lake Walcott.

Crosthwaite (1974, p. 17) suggested that hydraulic gradients in alluvium and basalt overlying the Raft Formation in the general area of Lake Channel slope southward. His data from a resistivity profile and an exploratory well (8S-29E-34CBC1) indicated that basalt of the Snake River Group is generally above the regional water table from the vicinity of Bonanza Lake southward to the Snake River. Water moving southwestward through basalt east and northeast of Lake Channel is perched above the Raft Formation.

GEOHYDROLOGIC SETTING

Basaltic rocks with lesser amounts of intercalated, unconsolidated sedimentary rocks compose the Snake River Plain aquifer system. Permeable zones between adjacent lava flows result in high aquifer transmissivities.

Fine-grained sediments, exposed south of and underlying American Falls Reservoir, grade into sand and gravel layers interbedded with basalt west of the reservoir. Large springs have developed at the upper end of the reservoir where tributaries have cut downward through fine-grained sediments into gravels.

Lake Channel, southwest of American Falls Dam, is an abandoned channel of the Snake River that is partially filled with basalt flows and fine sediments. Bonanza Lake and several other spring-fed ponds are located in Lake Channel. From Bonanza Lake to the Snake River, loess and alluvium overlie basalt flows and fine sediments.

Lakebeds of the Pleistocene Raft Formation along the south side of American Falls Reservoir and upper Lake Walcott probably extend north of the river under basalt flows. Basalt flows with interbedded sediments extend westward and downstream on both sides of the Snake River from Lake Channel on the north and Raft River on the south. In some areas north of Milner Lake, alluvial deposits overlie the basalts and interbedded sediments.

Water-table gradients west and north of American Falls Reservoir are toward the reservoir from a ground-water divide (Mundorff, 1967, p. 15) approximately parallel to the Aberdeen-Springfield High Line Canal (fig. 3). Because the relatively impervious Raft Formation along the western shore of the reservoir restricts ground-water movement, the water table is generally above reservoir high-water stages. Comparison of historical and recent water-table contour maps (Garabedian, 1986, pl. 1) shows the configuration of the water table has remained relatively unchanged since 1928. Seasonal fluctuations of the water table are caused by irrigation practices and differ depending on the local effects of recharge from surface-water irrigation or discharge from pumpage (Young and Norvitch, 1984, p. 5-7).

Mundorff (1967, p. 30) showed a correlation between water levels in well 5S-31E-27ABA1 (fig. 3) and monthly ground-water discharge to American Falls Reservoir estimated from water-budget analysis. When water levels are high, estimated ground-water discharge to American Falls Reservoir tends to be high, and when water levels are low, estimated ground-water discharge tends to be low.

GAINS AND LOSSES COMPUTED FROM WATER BUDGETS

Gains and losses in American Falls Reservoir, Lake Walcott, and Milner Lake were computed from annual, monthly, and daily water budgets. Specific methods and data used to compute the water budgets are discussed in following sections. Annual water budgets were used to indicate overall trends in gains and losses and to determine annual averages; monthly water budgets were used to compare gains and losses with a selected range of discharge-measurement accuracy and to determine monthly averages; daily water budgets were used to show errors in determining short-term changes in reservoir storage, precipitation, and evaporation.

Sources of gains to and losses from each reservoir were quantified on the basis of available data. Gains determined by water-budget analysis were compared with estimations of ungaged inflow. Losses estimated by water budgets were compared with water-level changes and water levels in relation to reservoir stage. Benefits of additional data collection to determine gains and losses are discussed in the following sections.

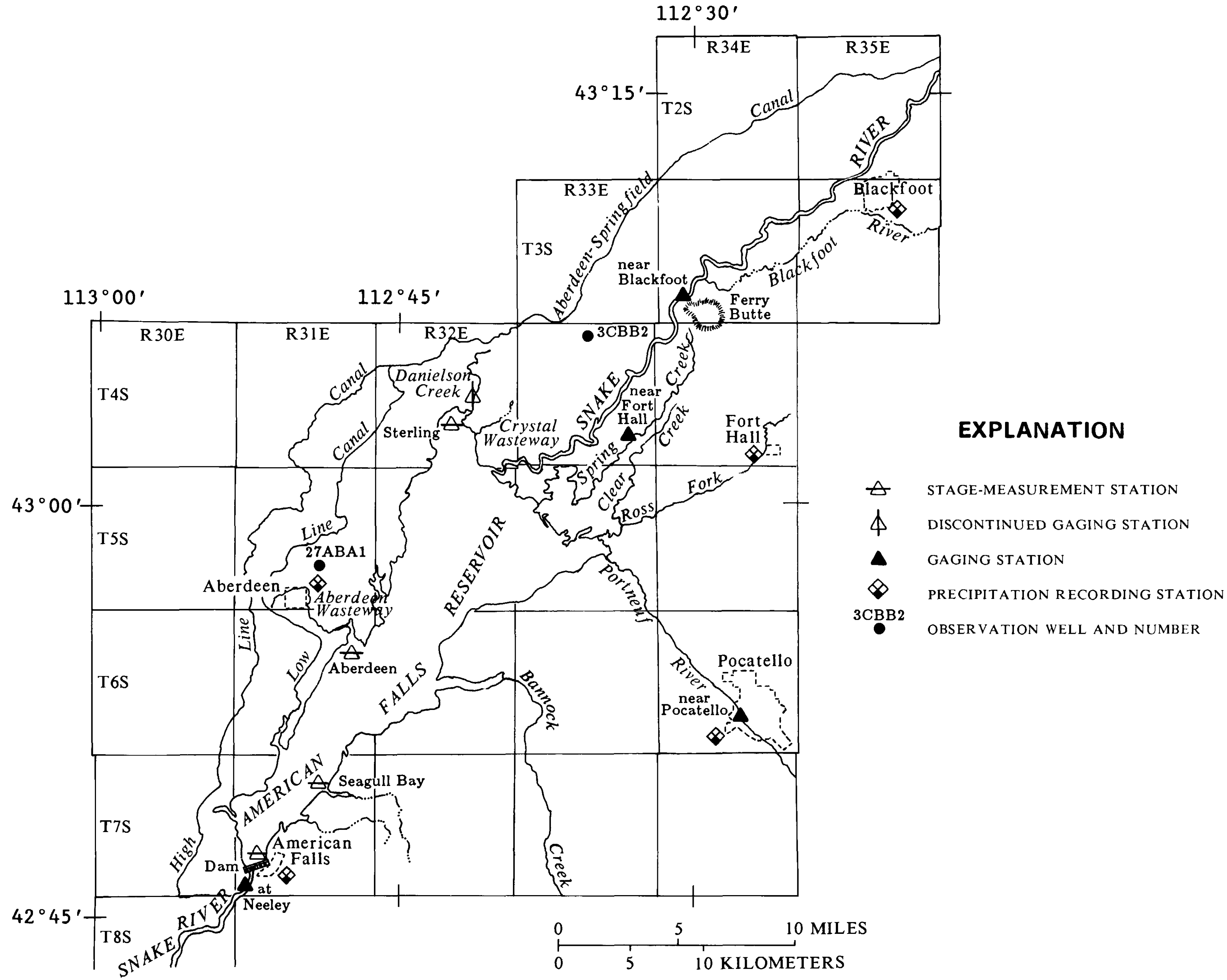

Figure 3.--Data-collection sites near American Falls Reservoir.

American Falls Reservoir

American Falls Reservoir, when at a maximum operating elevation of 4,354.5 ft above sea level, has a surface area of nearly 60,000 acres. Usable reservoir storage is about 1.7 million acre-ft between normal operating elevations 4,295.7 and 4,354.5 ft. American Falls Dam was completed in 1926 and reconstructed in 1977. Stored water from American Falls Reservoir is restored in Lake Walcott and Milner Lake where it is diverted for irrigation. Storage space in American Falls Reservoir can also be used for flood control. A powerplant at the dam generates about 340,000 MWh annually (Heitz and others, 1980, p. 130).

Gain to American Falls Reservoir was determined for this study as:

$$\text{Gain} = Q_N + D + E \pm SC - Q_B - Q_P - R \qquad (2)$$

where

Q_N = discharge of the Snake River at Neeley,

D = discharge diverted for irrigation,

E = evaporation from American Falls Reservoir,

SC = change in reservoir storage,

Q_B = discharge of the Snake River near Blackfoot,

Q_P = discharge of the Portneuf River at Pocatello, and

R = precipitation on reservoir water-surface area.

This computed gain represents the sum of the unmeasured ground- and surface-water inflow and hereafter is referred to as ungaged inflow. Ungaged inflow (gain) includes discharge from springs and small tributaries, ground-water seepage, and irrigation-return flow. Inflow from these sources accounts for nearly 35 percent of total inflow to American Falls Reservoir (table 1). The remaining 65 percent is measured discharge in the Snake River near Blackfoot and Portneuf River near Pocatello (fig. 3).

Inflow to the reservoir from precipitation was estimated by using daily mean rainfall data from weather stations at Aberdeen, American Falls, Pocatello, and Blackfoot (National Oceanic and Atmospheric Administration, 1983). On the basis of a gage density equivalent to 250 mi^2 per gage, Winter (1981, p. 87) showed that by using these data, errors up to 60 percent can be introduced. A rectangular area that includes American Falls Reservoir and the above four weather stations covers about 400 mi^2; within that rectangle, gage density is about one per 100 mi^2. However,

Table 1.--Ungaged surface-water inflow to American Falls Reservoir, 1980

[Site locations shown on figure 7]

Site No.	Source	Average inflow (cubic feet per second)
1	Crystal Wasteway [1]	37.0
2	Sterling Wasteway [1]	14.6
3	Coburn Wasteway [1]	5.4
4	Aberdeen Wasteway [1]	28.8
5	Pocatello Creek [2]	4.7
6	Fort Hall Main Canal waste [3]	3.2
7	Ross Fork [1]	60.6
8	Dubois lateral waste [3]	1.1
9	Tyhee lateral waste [3]	2.7
10	Church lateral waste [3]	3.8
11	Gibson drain [3]	2.8
12	Bannock Creek [1]	48.2
13	Tarter drain [1]	6.1
14	Schiltz drain [1]	3.6
15	Tributary to Seagull Bay [1]	.3
16	Sunbeam Creek [1]	1.5
17	Cedar Creek [1]	.4
	Total	224.8

[1] Average of bimonthly measurements made in 1980.

[2] Estimate from regional regression equation (Kjelstrom, 1986).

[3] Data from U.S. Bureau of Reclamation gages in 1980.

increasing gage density would not result in appreciably improved accuracies because mathematical methods used to calculate areal averages differ by as much as 18 percent (Winter, 1981, p. 86), and instrument errors and errors caused by placement of gages would remain.

Precipitation on the reservoir equals about 0.5 percent of the total average annual inflow. Most rain falls during only a few days each year; however, on those particular days, rainfall can have a significant impact on water budgets. For instance, 1 in. of rain falling on the water surface of the reservoir in 24 hours is equivalent to an inflow of about 3,200 acre-ft, or 1,600 ft^3/s. Daily inflow to the reservoir from precipitation for 5 months in 1983 is shown in fig. 4. On 13 days between May and September 1983, daily inflow from precipitation on American Falls Reservoir was greater than 400 ft^3/s.

Outflow from American Falls Reservoir consists of discharges of the Snake River at Neeley, two irrigation diversions, and evaporation from the reservoir. In 1983, discharge of the Snake River at Neeley ranged from 91 percent of daily outflow from the reservoir in the summer to nearly 100 percent in the winter. The average flow at Neeley is 7,260 ft^3/s and in 1983, flows ranged from 832 to 30,700 ft^3/s. Average flow for water year 1983 was 11,740 ft^3/s. An average of 175 ft^3/s was diverted for irrigation for about 120 days between May and September 1983.

Reservoir evaporation was estimated using pan data collected at the University of Idaho's Aberdeen Experiment Station (National Oceanic and Atmospheric Administration, 1983). A coefficient of 0.70 was used to convert pan evaporation to reservoir evaporation. Rates of evaporation are variable (fig. 5), and daily estimates of evaporation may introduce significant errors in daily water budgets. These errors probably would remain relatively high, even with additional data collection and use of more sophisticated estimation techniques.

Average annual evaporation from American Falls Reservoir from 1946 to 1958 was about 38 in. (Meyers, 1962, p. 94), or 180,000 acre-ft. Total evaporation from April to October 1983 was nearly 34 in. (160,000 acre-ft), or about 90 percent of average annual evaporation for the period 1946-58.

Ungaged Inflow

Annual mean ground-water discharge, which accounts for about 94 percent of the average annual ungaged inflow to American Falls Reservoir, has been relatively steady from

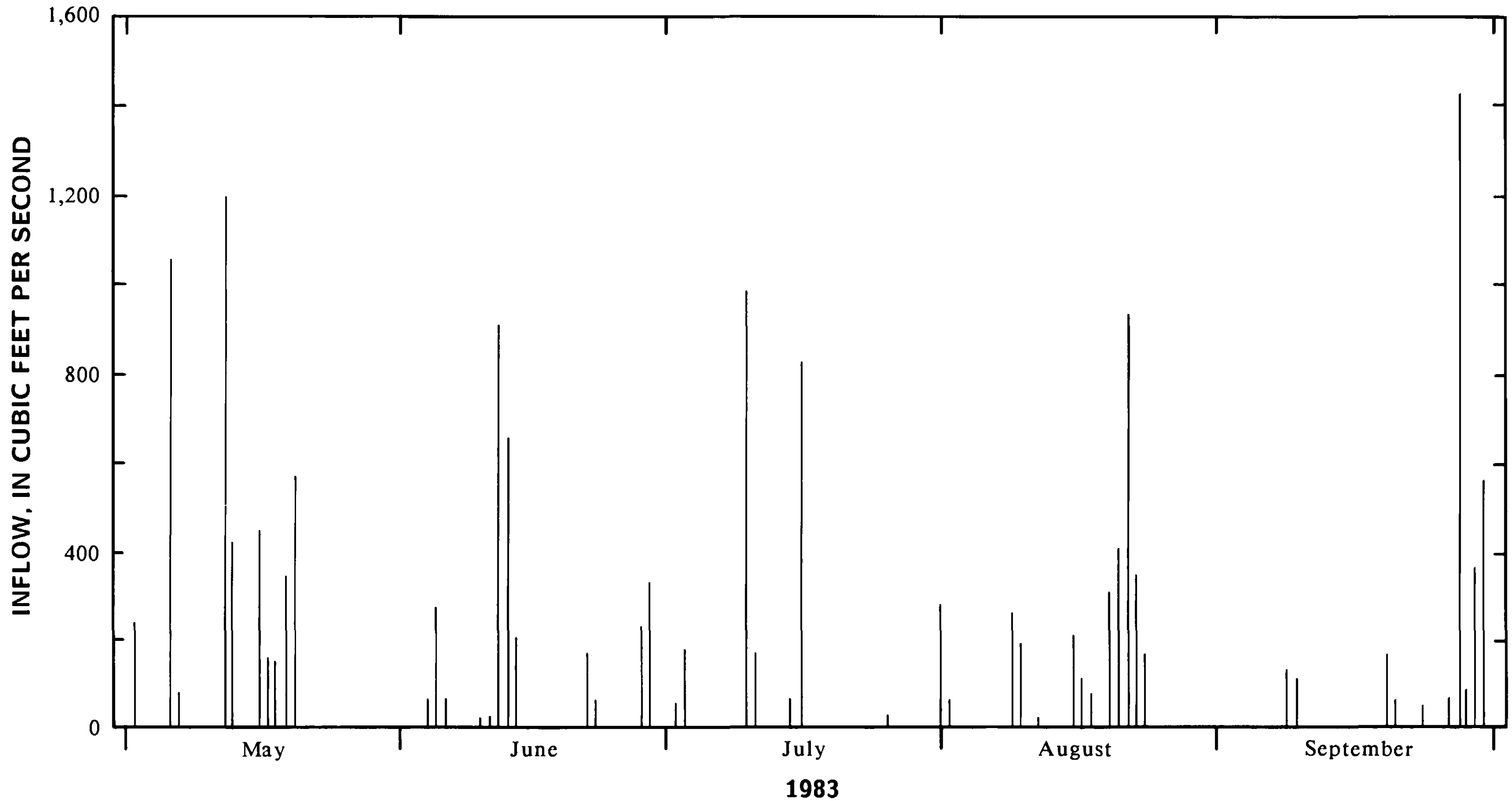

Figure 4.--Daily inflow from direct precipitation on American Falls Reservoir.

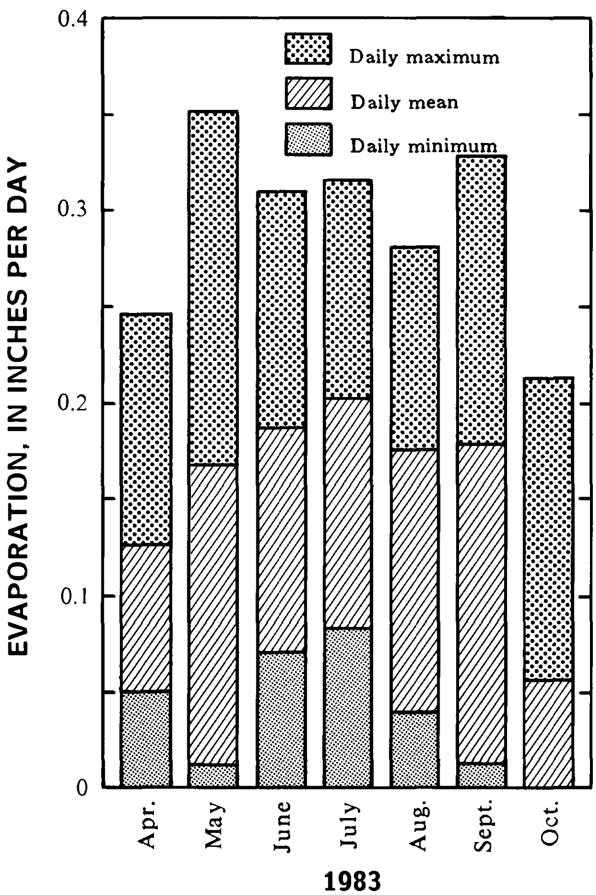

Figure 5.--Daily rates of evaporation from American Falls Reservoir.

1912 to 1983 (fig. 6). Water-budget analysis indicates that average annual ungaged inflow to American Falls Reservoir from 1912 to 1983 was about 2,690 ft^3/s. On the basis of miscellaneous discharge measurements and water yield estimates from 1934 to 1980 (Kjelstrom, 1986), surface-water inflow from small tributary streams and irrigation-return flow account for an average annual discharge of about 150 ft^3/s. The ratio of annual to average annual discharge of the Portneuf River was used to vary the average annual discharge from small tributaries for each year. The percentage of diverted irrigation water that returned to the reservoir each year was assumed to be equivalent to the percentage obtained from measurements made in 1980.

The sources and relative volumes of ungaged surface-water inflow to American Falls Reservoir (fig. 7) are given in table 1. The higher-than-average (1912-83) total discharge may be attributed to above-normal precipitation, base or ground-water flow being included at several of the sources, and estimation errors. In addition, Spring and Clear Creeks, although primarily fed by springs, collect some runoff from adjacent areas.

Mean monthly ungaged inflow was determined from water budgets for the period 1951-82; averages and corresponding standard deviations for each month are given in table 2. An examination of differences between monthly ungaged inflow for the period 1951-82, when most surface-water irrigated land had been developed, and for the period 1912-25 (also determined by water-budget analysis), prior to construction of American Falls Dam (fig. 8), shows that the post-dam and post-irrigation development inflow is greater from June to January and less from March to May than pre-dam and pre-irrigation development inflow. No climatological change is indicated when nearly similar periods (1912-25 and 1962-80) of mean monthly flows of the Snake River near Heise adjusted for upstream storage are compared (Kjelstrom, 1986). The increase may be attributed to seasonal rises in ground-water levels owing to irrigation and additional water released from bank storage. The decrease may be attributed to loss of water to bank storage when the reservoir stage is rising.

For water year 1983, monthly mean ungaged inflows range from 2,330 to 3,260 ft^3/s (table 3). The annual mean ungaged inflow for water year 1983 is about 2,800 ft^3/s. Annual mean surface-water inflow, based on discharge from the Portneuf River and upstream diversions, was estimated as 176 ft^3/s. Ground-water discharge was assumed to be the residual, or about 2,620 ft^3/s.

Ground-water discharge, primarily from springs, is associated closely with the regional ground-water system and, as would be expected, ground-water levels correlate

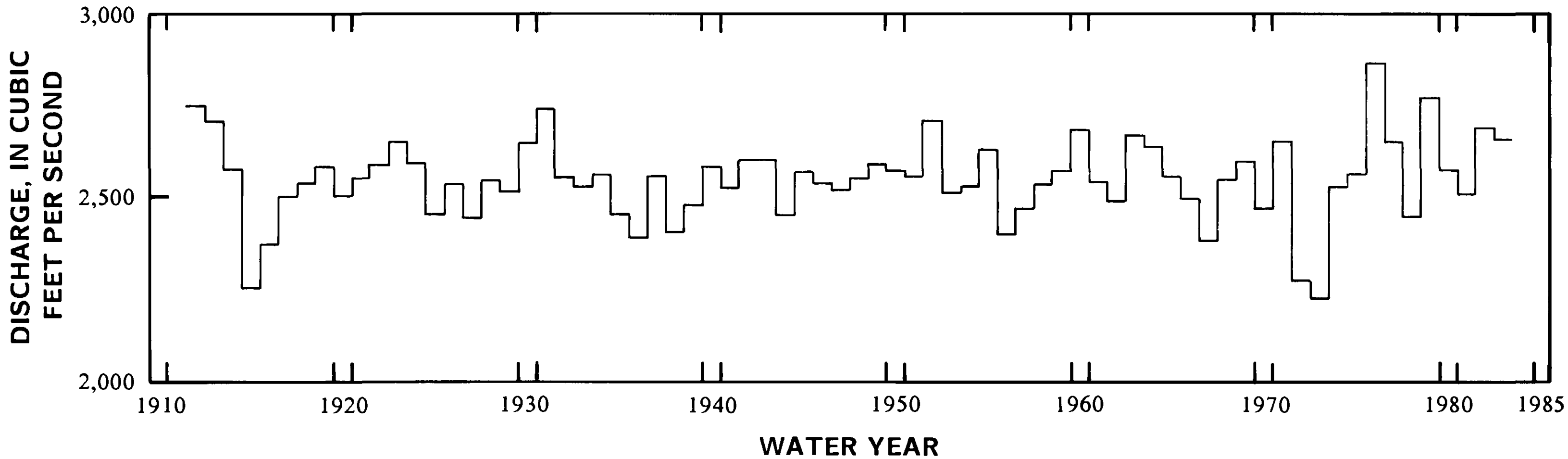

Figure 6.--Annual mean ground-water discharge to American Falls Reservoir, 1912-83.

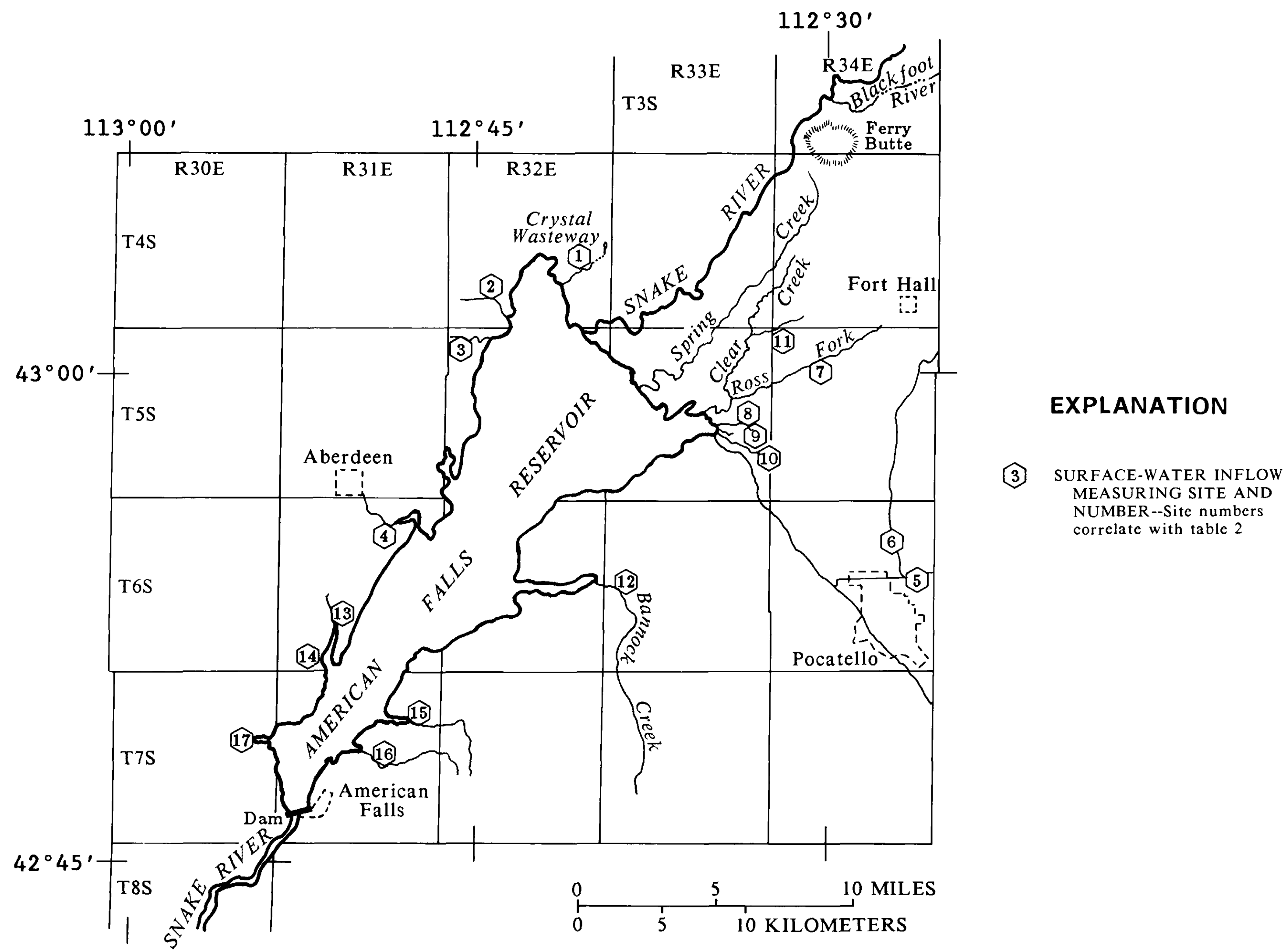

Figure 7.--Ungaged surface-water inflow sources to American Falls Reservoir.

Table 2.--Average monthly ungaged inflow to American Falls Reservoir and corresponding standard deviations, 1951-82

Month	Average monthly ungaged inflow (cubic feet per second)	Standard deviation (cubic feet per second)	Standard deviation (percent of mean)
October	2,920	180	6.2
November	2,750	180	6.5
December	2,610	210	8.0
January	2,600	180	6.9
February	2,570	270	10.5
March	2,520	260	10.3
April	2,430	380	15.6
May	2,490	310	12.4
June	2,790	340	12.2
July	2,930	320	10.9
August	3,050	180	5.9
September	2,890	220	7.6

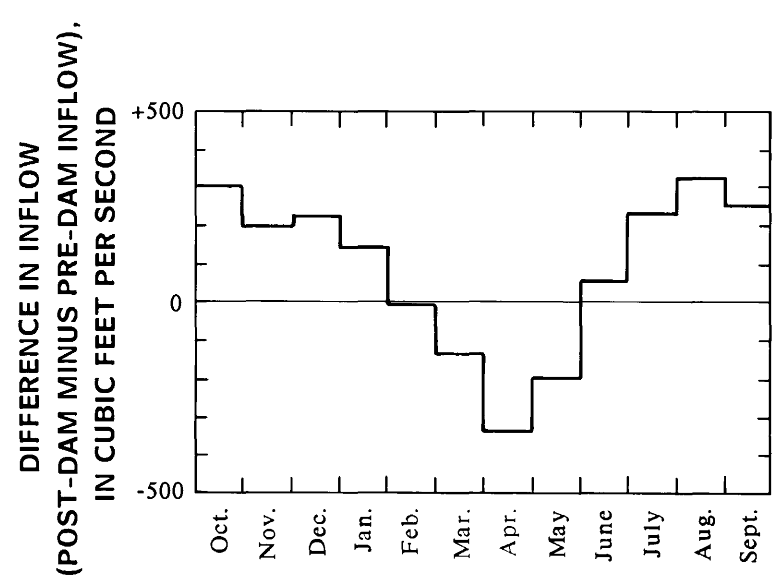

Figure 8.--Differences between average monthly ungaged inflow to the Snake River between Blackfoot and Neeley before (1912-25) and after (1951-82) construction of American Falls Dam.

Table 3.--Monthly and annual water budgets for water year 1983 used to determine ungaged inflow to American Falls Reservoir

Month	Monthly mean discharge (cubic feet per second)							
	Snake River at Neeley (+) Q_N	Diversions for irrigation (+) D	Evaporation from reservoir (+) E	Change in storage (+ or -) SC	Snake River near Blackfoot (-) Q_B	Portneuf River at Pocatello (-) Q_P	Precipitation on reservoir (-) R	Ungaged inflow (residual)
October	6,938	0	150	+2,090	5,919	340	70	2,850
November	9,644	0	80	-300	6,026	336	100	2,960
December	10,320	0	50	-1,120	5,943	314	110	2,870
January	9,600	0	40	+390	6,700	377	30	2,920
February	7,249	0	60	+1,440	5,272	410	70	3,000
March	4,655	0	110	+4,820	5,936	756	150	2,740
April	11,210	0	290	+1,070	9,058	875	30	2,610
May	22,330	16	410	-30	18,440	1,513	150	2,620
June	22,810	206	450	+190	19,150	1,142	100	3,260
July	16,210	245	490	-1,340	12,830	363	80	2,330
August	10,420	110	410	-3,200	4,641	290	100	2,710
September	9,253	112	380	-3,820	2,760	338	100	2,730
Annual	11,740	58	240	+12	8,576	588	90	2,800

with spring discharge to American Falls Reservoir. Table 4 shows sources and amounts of ground-water recharge that may supply springs. For 1983, recharge was balanced with discharge by seepage of irrigation water on land upstream from American Falls Reservoir. Prior to irrigation on the Snake River Plain, recharge that supplied springs in the Blackfoot to Neeley reach was primarily from upstream channel losses in the Snake River. Tributary underflow to and precipitation on the land being recharged by irrigation water are assumed to have supplied about the same amounts both before and after irrigation and are based on 1934-80 averages of water yield and precipitation (Kjelstrom, 1986). Water-budget analysis shows that average annual losses from the Snake River between Heise and Blackfoot from 1912 to 1922 were 750,000 acre-ft. A water-budget analysis for 1974-80 shows losses of 280,000 acre-ft. The decrease in losses can be attributed to less flow in the Snake River as a result of increased upstream diversions and, possibly, high water tables where the river is hydraulically connected with ground water. From the early 1890's to the late 1950's, when most of the surface-water irrigated land was developed, the regional water table rose about 60 to 70 ft (Mundorff and others, 1964, p. 162), and ground-water discharge as spring flow to the Snake River from Blackfoot to Neeley nearly doubled (table 2).

From this general correspondence between rises in the water table and increases in spring flow, it is reasonable to expect that water levels in particular wells could be related to spring flow. Well 5S-31E-27ABA1 (fig. 3) is drilled in basalt of the Snake River Group to a depth of 50 ft. Mundorff (1967) showed that hydrographs of water levels in this well correlated with discharge hydrographs for nearby springs. To determine the current degree of correlation, mid-month water levels in well 5S-31E-27ABA1 from May 1952 to September 1982 were regressed with monthly mean ungaged inflows. After the months with missing data were eliminated, 346 months were available for regression analysis. The RMSE (root mean square error) determined by using the regression was 290 ft^3/s, which is about 10 percent of the average annual ungaged inflow of 2,740 ft^3/s. The RMSE is the standard deviation of the distribution (assumed normal) of residuals about the regression line. Residuals are the difference between ungaged inflows determined by water budget and those determined by the regression.

Storage changes in American Falls Reservoir also may be a source of error in the water budget. While the dam was being reconstructed in 1977 and the reservoir was empty, the reservoir basin was resurveyed and a new capacity table was developed (U.S. Bureau of Reclamation, 1979). To determine errors owing to storage change on regression residuals, water budgets that determined ungaged inflow were recomputed

Table 4.--Sources and amounts of ground-water recharge supplying water for spring discharge

Sources of ground-water recharge	Relative amounts of recharge (millions of acre-feet)	
	1983	Prior to irrigation
Irrigation losses	1.4	0
Snake River losses	.3	.8
Tributary underflow	.1	.1
Precipitation	.1	.1
Total or ground-water discharge	1.9	1.0

using the new capacity table for the 20 months with the largest residuals. The resulting regression equation reduced the RMSE from 290 to 260 ft^3/s. From this analysis, it appears that the original reservoir capacity table may account for a small part of the error.

Although errors in determining change in reservoir contents for monthly water budgets appear to be small, possible errors in daily water budgets can be large. An error of only 0.01 ft of reservoir stage results in a difference in estimated ungaged inflow of 250 to 500 ft^3/s, depending on the water-surface area of the reservoir. However, errors in defining reservoir stage that are due to wind or wave effects (and lag times) are evened out by using longer periods of record or monthly water budgets.

An evaluation of the discharge records may be made by analysis of differences between estimates of ungaged inflow determined by a water budget and those determined by regressions based on ground-water levels. About 94 percent of the differences are less than 5 percent of the combined Snake River discharges near Blackfoot and at Neeley (fig. 9). Combined discharge more closely represents actual flow through the reservoir system than inflow or outflow. Although inflow is high in the spring, outflow may be small while the reservoir is being filled. In late summer, inflow may be small because of upstream diversions and outflow may be large because of releases for downstream diversions.

Discharge records are considered excellent if about 95 percent of the daily mean discharges are within 5 percent of the true discharge. Although monthly mean discharges would be more accurate than daily mean discharges because of the smoothing effect of the longer period, the distribution of differences appears to be nearly within the error range of excellent discharge records. The relatively low discharge-measurement errors may be attributed to the basalt channel of the Snake River that provides stable controls for the stage-discharge relation.

Regression estimates of ungaged inflow may avoid the large variations in water-budget estimates that could be attributed to discharge-measurement errors and that are not representative of the relatively steady inflow from 1912 to 1983, mostly from ground water. In addition, other independent variables may be used in the regression. Miscellaneous measurements of Spring Creek discharge from 1926 to 1978 (U.S. Geological Survey, 1968-78; Decker and others, 1970), averaging about 20 percent of the ungaged inflow to the reservoir (most of which is spring discharge), correlate well with ungaged inflow computed by Newell's formula (C.A. Thomas, U.S. Geological Survey, oral commun., 1980). A

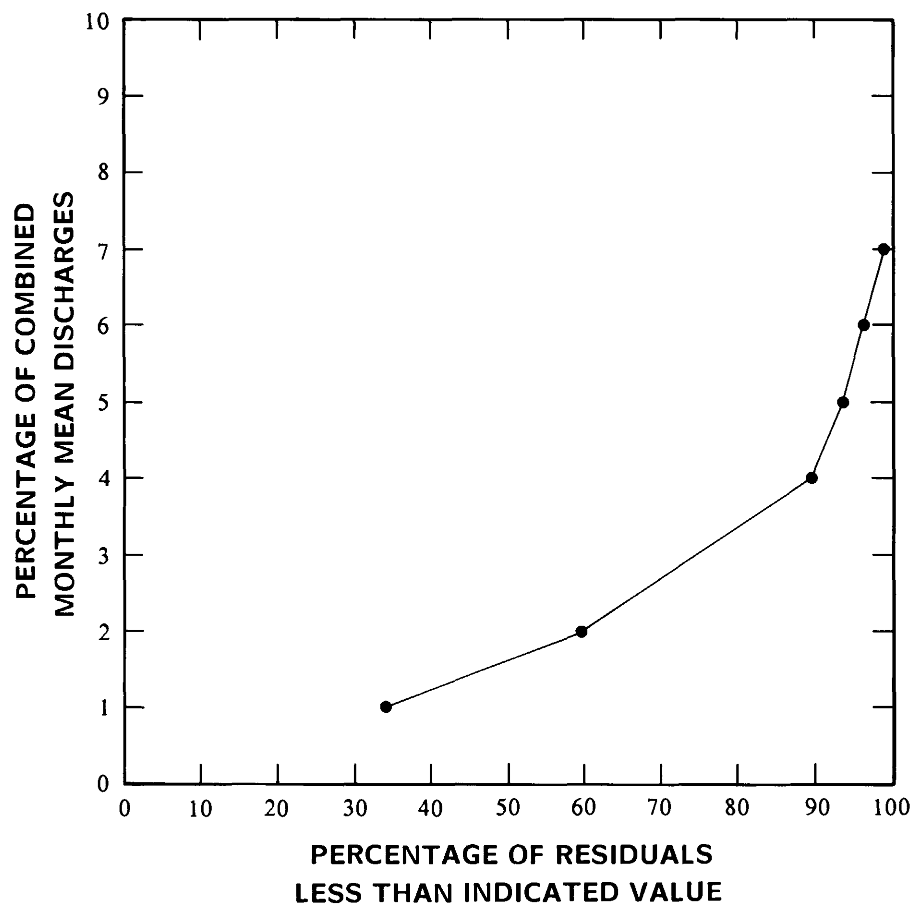

Figure 9.--Frequency curve for regression residuals of ungaged inflow to American Falls Reservoir as a percentage of combined monthly discharge of the Snake River at Blackfoot and at Neeley, 1952-82.

gaging station was established in August 1980 on Spring Creek at Sheepskin Road near Fort Hall, about 5 mi upstream from the miscellaneous measurement site used from 1926 to 1978. The station was established there to avoid backwater conditions from the reservoir. Flow past the gaging station averages about 15 percent of the ungaged inflow to American Falls Reservoir. On the basis of several sets of discharge measurements, ground-water inflow between the two sites ranges from 90 to 120 ft^3/s.

Monthly mean discharges of Spring Creek from August 1980 to September 1982 were regressed with monthly ungaged inflow. Mid-month water levels in well 5S-31E-27ABA1 also were regressed with ungaged inflow for the same period. The RMSE's were 332 ft^3/s for ungaged inflow estimated from discharge in Spring Creek and 294 ft^3/s estimated from water levels in the well.

Regression of ungaged inflow with discharge in Danielson Creek (fig. 3) for 14 months from August 1980 to September 1981 resulted in an RMSE of 322 ft^3/s. When both Danielson Creek (spring fed) and Spring Creek discharges were used as independent variables, the RMSE was reduced to 264 ft^3/s. The gaging station on Danielson Creek was discontinued in 1981 so was not used in further regression analysis.

Discharge records for the Snake River near Blackfoot and at Neeley were reanalyzed for 12 of the 26 months from August 1980 to September 1982 when residuals from Spring Creek discharge or ground-water level regressions exceeded the RMSE. Changes in shift adjustments applied to the stage/discharge relation during 5 months at Neeley and 1 month near Blackfoot resulted in increases or decreases of 1 to 3 percent in monthly mean discharges. Ungaged inflow was recomputed using the revised discharge records at Blackfoot and Neeley. These ungaged inflows were related to Spring Creek discharge by:

$$Q = 2{,}140 + 6.90\,(Qs) \qquad (3)$$

where

Q = ungaged inflow to American Falls Reservoir, in cubic feet per second; and
Qs = Spring Creek discharge, in cubic feet per second minus 250 ft^3/s (for easier computation of the regression equation).

The equation that resulted from regressing with the revised ungaged inflow on mid-month water levels of well 5S-31E-27ABA1 is:

$$Q = 2{,}130 + 55.8\,(L) \qquad (4)$$

where

Q = ungaged inflow to American Falls Reservoir, in cubic feet per second; and
L = water-surface elevation, in feet above sea level, minus 4,370 ft (for easier computation of the regression equation).

The RMSE was 196 ft^3/s. Multiple regression of both Spring Creek discharge and water levels in well 5S-31E-27ABA1 as independent variables did not decrease the RMSE.

Another possible variable for regression with ungaged inflow is water level in well 4S-33E-3CBB2, located about 7 mi north of the reservoir and completed in basalt of the Snake River Group. Water levels in the well were recorded continuously from 1959 to 1969 and were measured periodically during 1970-77. A recorder was reinstalled in January 1978. Water levels from 1978 to 1982 were lower than during 1959-69 (probably as a result of a drought in 1977), with fewer seasonal fluctuations than during the 1959-69 period.

The equation that resulted from regressing mid-month water levels of well 4S-33E-3CBB2 with ungaged inflow is:

$$Q = 1,230 + 164\ (L) \qquad (5)$$

where

Q = ungaged inflow to American Falls Reservoir, in cubic feet per second; and
L = water-surface elevation, in feet above sea level, minus 4,440 ft (for easier computation of the regression equation).

The RMSE of a regression with ungaged inflow into American Falls Reservoir for the period August 1980 to September 1982 was 185 ft^3/s.

Equations (3), (4), and (5) were used to estimate monthly mean ungaged inflow for the period October 1982 to October 1983. Results of both Spring Creek and well 5S-31E-27ABA1 regression equations were satisfactory in that the difference between regression equation estimates and the ungaged inflow as compiled by water budgets was generally less than 2 percent of the combined monthly discharges of the Snake River near Blackfoot and at Neeley (fig. 10).

Water levels in well 4S-33E-3CBB2 were less satisfactory than the other regression variables because water levels in 1983-84 tended to be higher than 1978-82 levels.

Lag times between water-level changes in wells and discharge peaks in Spring Creek were determined by comparing well and discharge hydrographs. Maximum water levels in

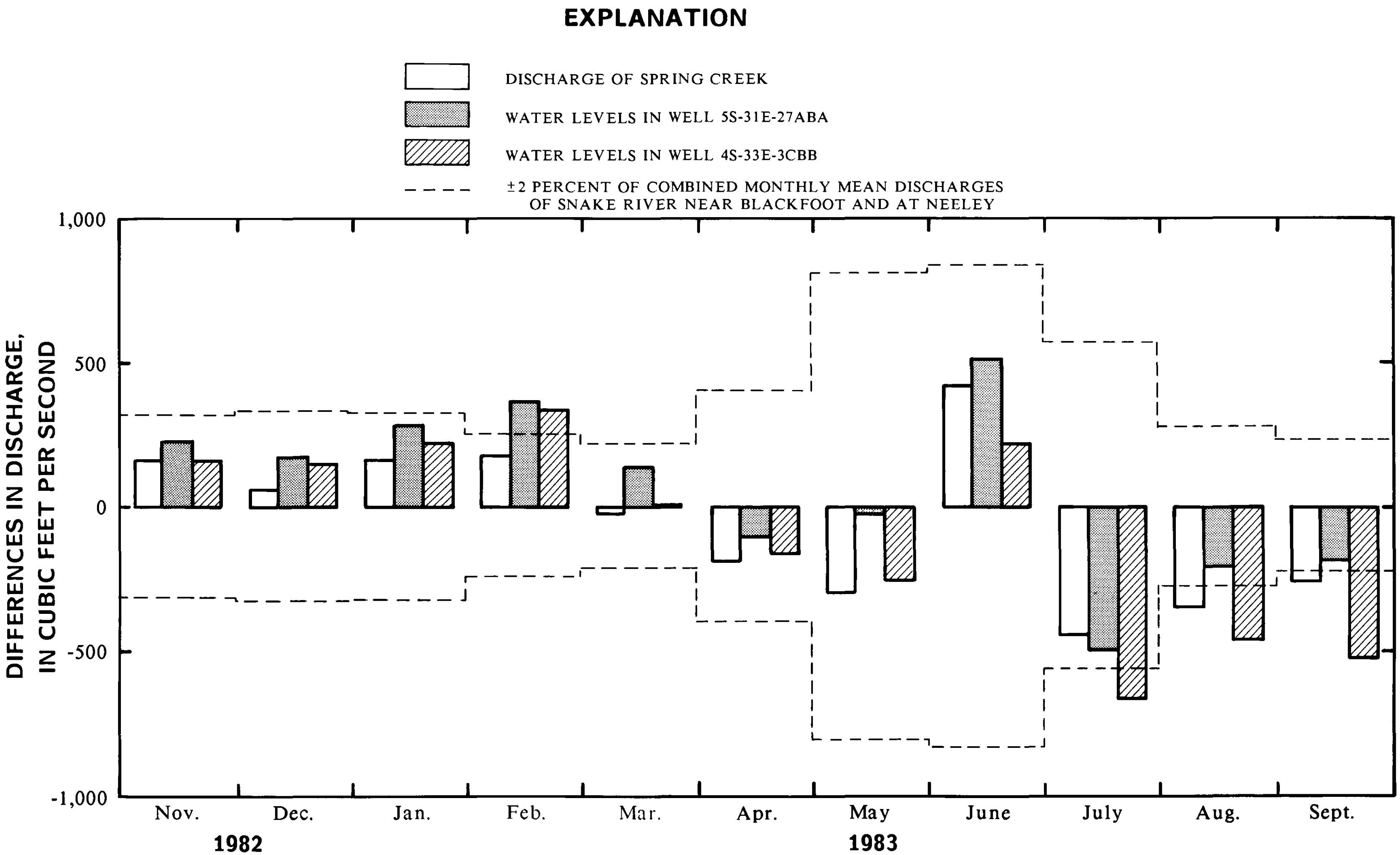

Figure 10.--Differences between three regression equation estimates of monthly mean ungaged inflow to American Falls Reservoir and ungaged inflow as compiled by water budgets.

well 5S-31E-27ABA1 seemed to lag peaks in Spring Creek by an average of about 9 days. Water levels in well 4S-33E-3CBB2 seemed to peak at nearly the same time as Spring Creek discharge.

The regression relations for Spring Creek were developed using monthly data but also can be used to calculate daily inflow, although some additional error is introduced. As previously determined, ground-water discharge is about 94 percent of the average ungaged inflow to American Falls Reservoir, and daily changes in ground-water discharge are probably small. Most of the change in daily ungaged inflow (and the source of additional error) is due to runoff from precipitation and irrigation-return flow that is much more variable than the monthly averages used to develop the regression equations. Figure 11 shows that increases in daily discharge of Spring Creek above base flow generally correspond to precipitation recorded at nearby weather stations. Increases in discharge do not always correspond to precipitation at recording stations because rainstorms are scattered geographically.

Use of Spring Creek daily discharge as the independent variable in the regression equation would account for some of the regression error introduced by computing daily ungaged inflows with an equation developed from monthly data. Further reduction in daily variances could be made by measuring flow in the larger ungaged tributaries (Bannock Creek and Ross Fork) and drains (Crystal and Aberdeen Wasteways).

Reservoir Storage

Errors in determining reservoir storage change can be introduced by (1) insufficient or poor stage data for the reservoir, and (2) an inaccurate reservoir-capacity table. The first is likely to have the greater effect in computation of daily water budgets because 0.01 ft in stage will cause a change larger than the RMSE. To more accurately define the stage of American Falls Reservoir, three additional gages were installed in November 1982: at Sterling in the northernmost part of the reservoir, along the western shore near Aberdeen, and along the eastern shore in Seagull Bay (fig. 3). The area-capacity table (U.S. Bureau of Reclamation, 1979) was used to determine storage. To determine change in storage, average daily change in stage of all gages was multipled by the average surface area obtained from the area-capacity table.

Two daily water budgets were compared for determination of ungaged inflow. For one water budget, the change in reservoir storage was determined using only data from the gage at American Falls. For the other, change in storage

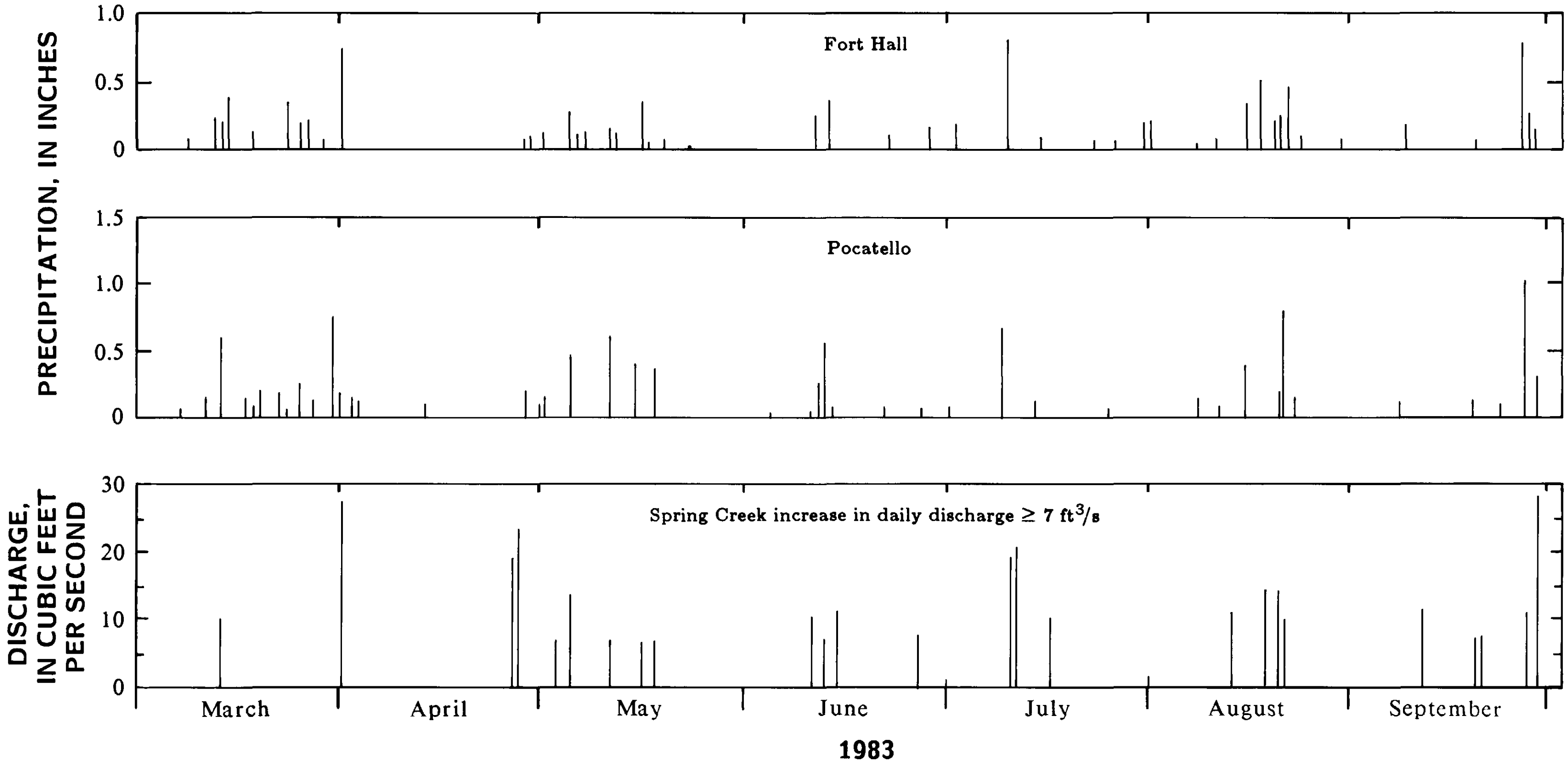

Figure 11.--Increases in daily discharge of Spring Creek above base flow and recorded precipitation at Fort Hall and Pocatello, March 1 to September 30, 1983.

was determined using the best combination of data from the three additional gages. A comparison of standard errors of gains computed using various combinations of the four reservoir stage gages is shown in table 5. The greatest decrease in standard error was achieved using data from the gages at Sterling, Aberdeen, and American Falls. Gains or losses in the water budget determined using data from these gages were compared with estimated ungaged inflow computed from the Spring Creek regression equation for the period March to September 1983 (fig. 12).

Standard errors of the daily estimates for each month from March through September are shown in figure 13. Greatest decreases in standard error resulting from use of the three gages were in September when stage in the reservoir was rapidly decreasing. Although stage also was decreasing in August, little decrease in standard error was evident. High winds in mid-August may have caused fluctuations in the recorded stage, particularly at the Sterling gage.

Reservoir Leakage

Leakage from American Falls Reservoir contributes some spring discharge to the Snake River between Neeley and Minidoka (Mundorff, 1967, p. 38). Spring discharge increased after storage began in the reservoir. Although water levels in wells at the southwestern end of American Falls Reservoir (fig. 14) increase from February to May when stage in the reservoir increases (fig. 15), the lack of correlation between ground-water levels and reservoir stage at other times may indicate that leakage is small.

Water levels in well 7S-30E-14DCC1 along the west side of American Falls Reservoir indicate a locally perched aquifer that is recharged by percolation of irrigation water. Water levels in the well increase from May to September and decline thereafter. Water levels in wells 7S-30E-15AAA1 and 7S-30E-28BBC1, west of the Aberdeen-Springfield Canal, increase from February to May and decrease from May to July. Water-level trends in wells 7S-30E-13DCA1, 7S-30E-24DDC1, and 7S-30E-26DDD1 near the southwestern end of the reservoir were like those in wells 7S-30E-15AAA1 and 7S-30E-28BBC1. Water levels in wells along Lake Channel and stage in Bonanza Lake also follow the same pattern (fig. 16). The rise seems to diminish downgradient from the reservoir. Declines in water levels probably are accelerated by ground-water pumping for irrigation. On the basis of water levels in wells near the reservoir, the effect of recharge from reservoir leakage on water levels is masked by the effect of ground-water pumpage. Increases and decreases in leakage owing to alternating high and low reservoir stages are not apparent.

Table 5.--Comparison of standard errors of gains computed from combinations of reservoir stage gages (April 15 to September 15, 1983)

[x, stage gages used in the computation]

Sterling	Aberdeen	Seagull Bay	American Falls	Standard error (cubic feet per second)	Percentage decrease in standard error using multiple gages
			x	1,231	
x	x	x	x	809	34
x			x	908	26
x	x		x	781	37
x		x	x	924	25
x	x	x		848	31

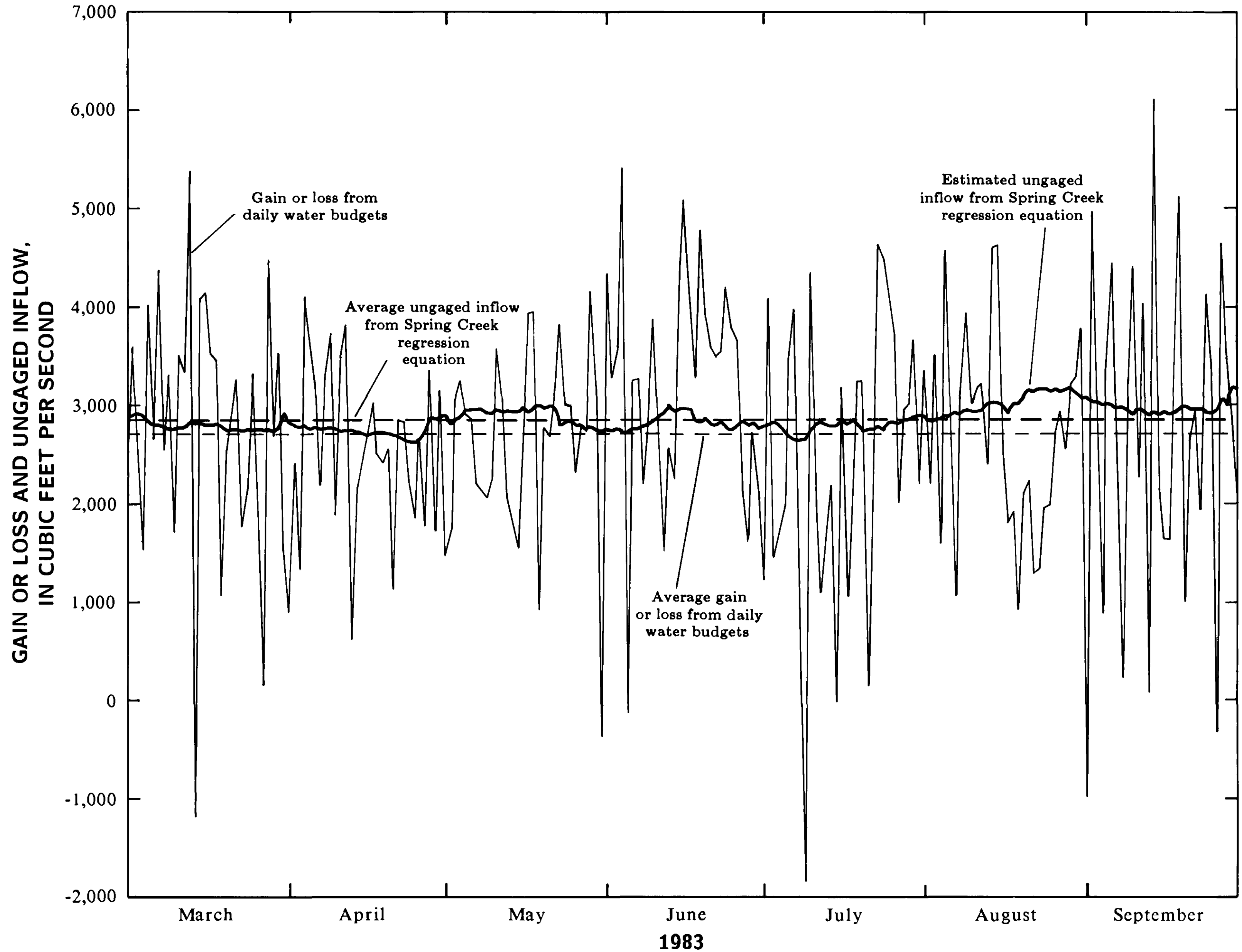

Figure 12.--Comparison between water-budget gain or loss and estimated ungaged inflow to American Falls Reservoir based on Spring Creek discharge, March 1 to September 30, 1983.

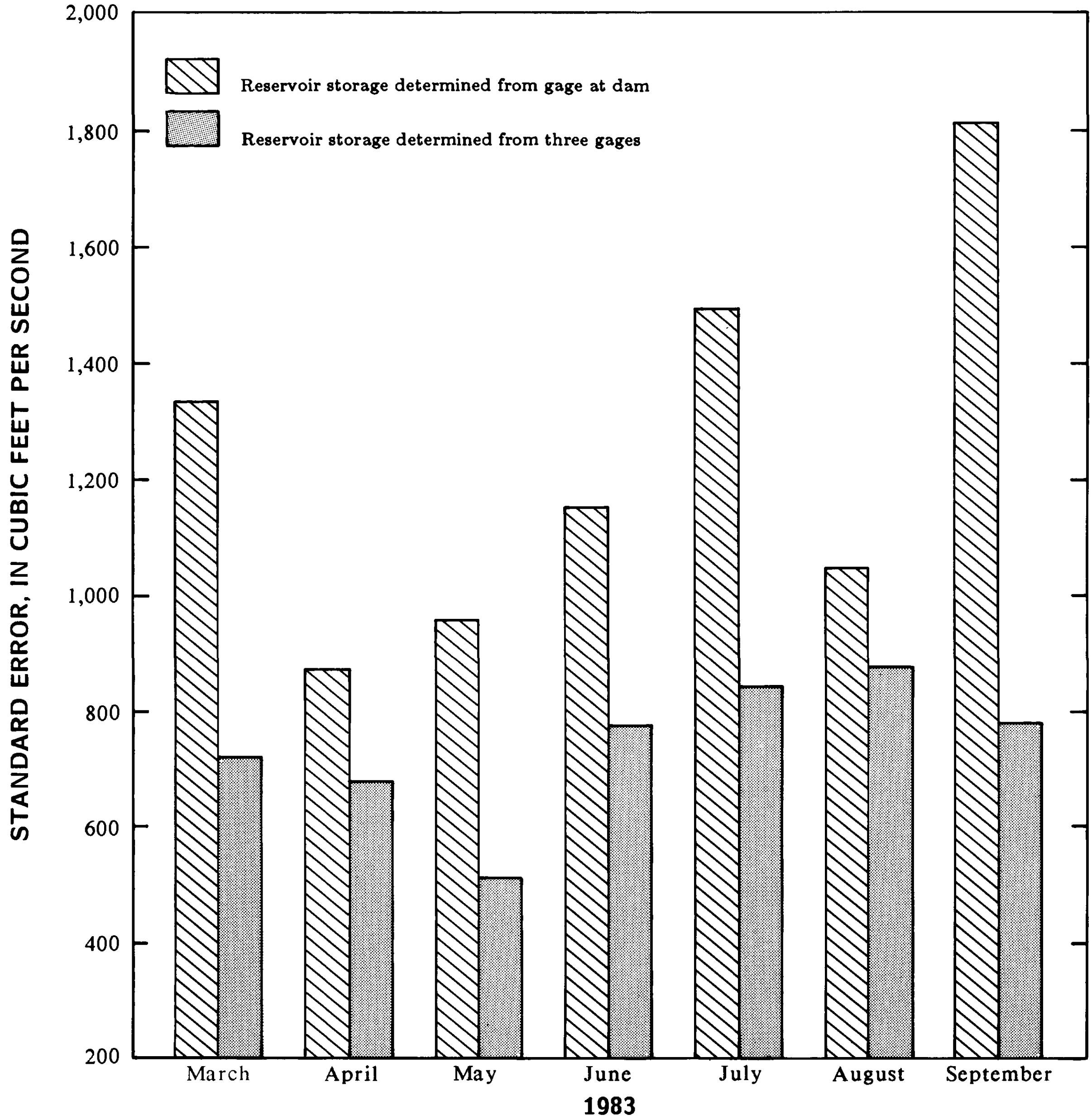

Figure 13.--Standard errors of two daily water-budget estimates of ungaged inflow to American Falls Reservoir from estimates derived from regression equations that relate ungaged inflow to Spring Creek discharge.

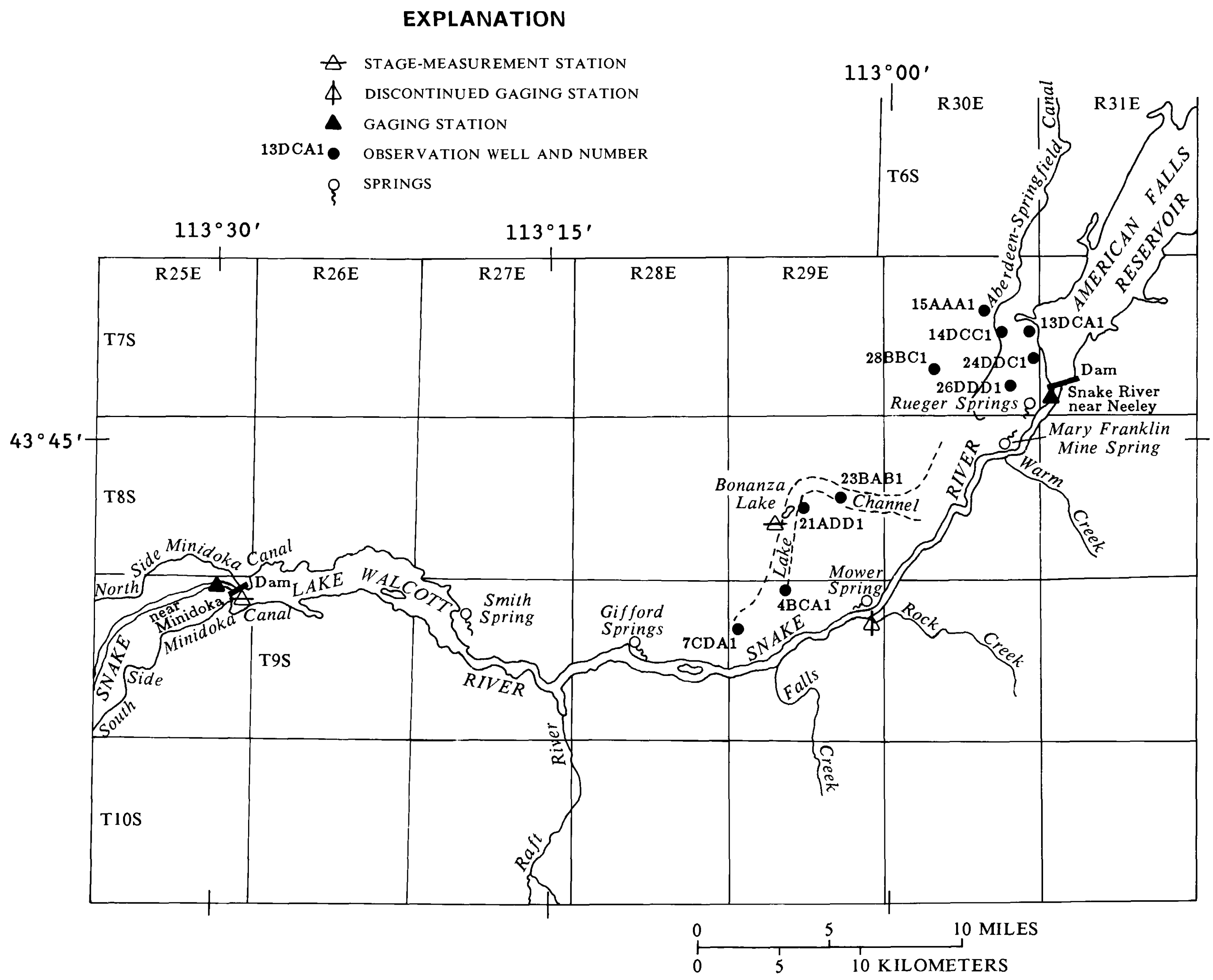

Figure 14.--Lake Walcott reach of the Snake River.

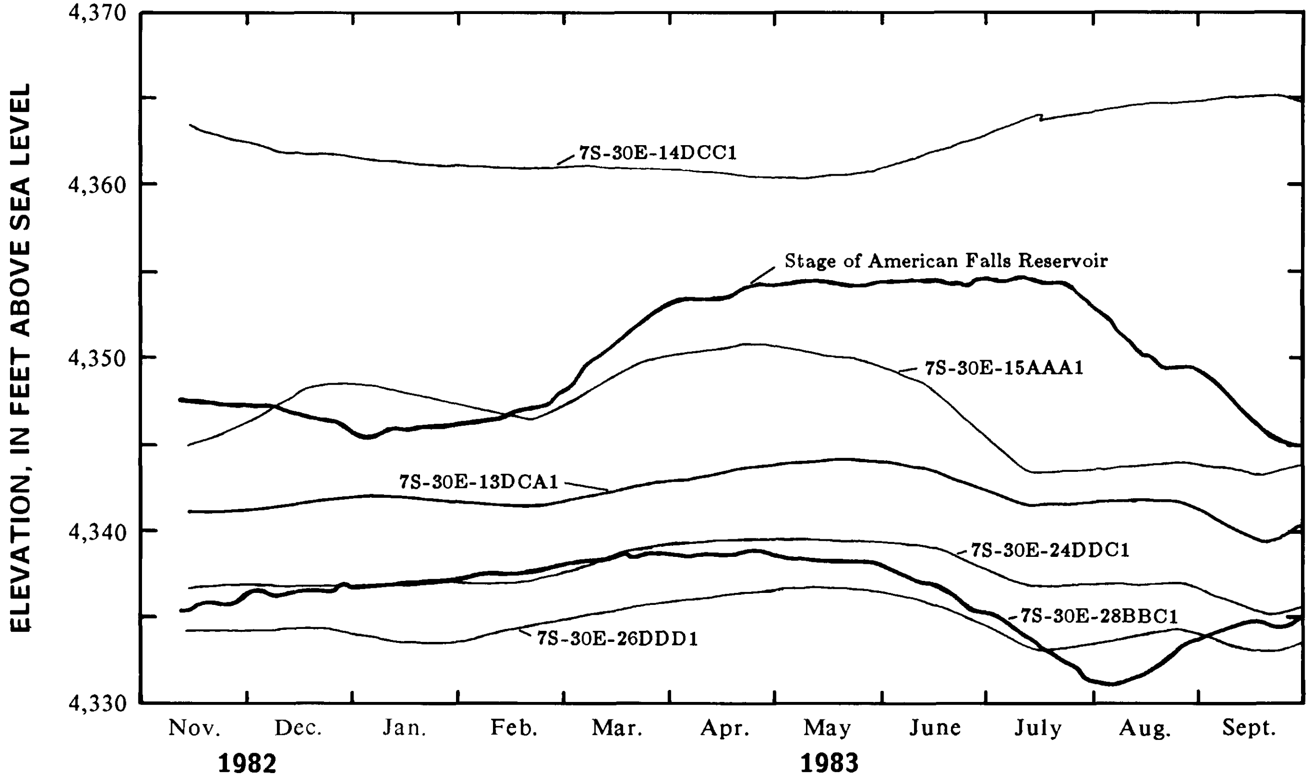

Figure 15.--Stage of American Falls Reservoir and elevation of water levels in downgradient wells.

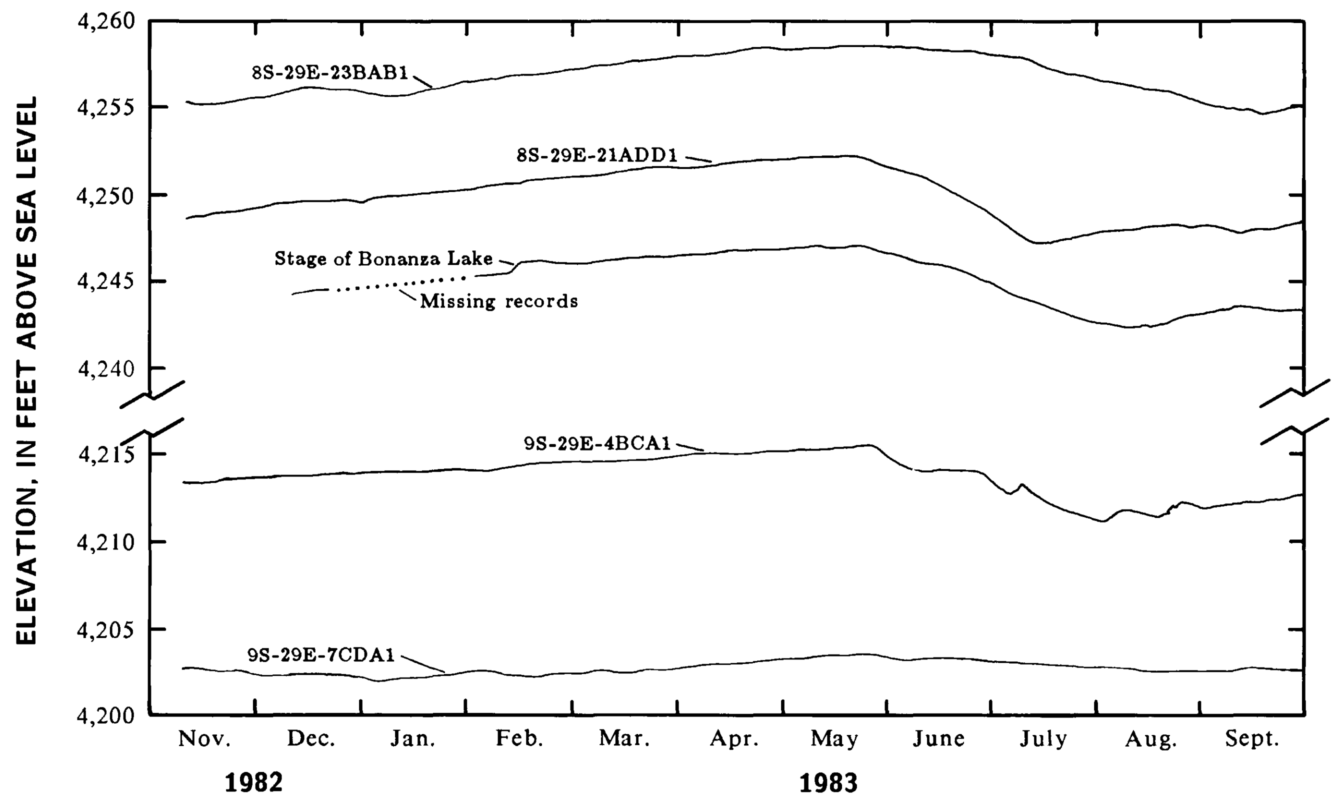

Figure 16.--Stage of Bonanza Lake and water levels in nearby wells.

Lake Walcott

Minidoka Dam, completed in 1909 to divert water for irrigation projects both north and south of the Snake River, is about 40 mi downstream from American Falls Dam. Backwater from Lake Walcott, behind Minidoka Dam, may extend about 33 mi upstream. Lake Walcott has a usable storage capacity of 107,000 acre-ft between elevations 4,236 and 4,246 ft. A powerplant at the dam generates about 90,000 MWh annually (Heitz and others, 1980, p. 130). Discharge through the powerplant and spillways is inflow to Milner Lake.

Water budgets were prepared for the reach of the Snake River from Neeley to Minidoka. Inflow to the reach is discharge of the Snake River at Neeley; outflow from the reach is discharge of the Snake River near Minidoka plus diversions to the North Side and South Side Minidoka Canals. Gains or losses in the reach are the difference between inflow and outflow adjusted for precipitation, storage change, and evaporation in Lake Walcott.

Average annual gain from 1951 to 1983, determined using the water budgets, was 245 ft^3/s. Figure 17 shows the 5-year moving average (four previous years plus current year) gain in the reach from 1953 to 1983, compared with cumulative departures from mean discharge of Goose Creek near Oakley (fig. 1). From this comparison, it appears that the high gain from 1970 to 1983 is related to high runoff from tributaries. Goose Creek discharge is assumed to represent surface-water runoff from tributaries to the Snake River between Neeley and Minidoka.

Inflow between Neeley and Minidoka gages from the north side of the river is entirely from springs and ground-water seepage. Gifford Springs (fig. 13) is the largest group of these springs. Stearns and others (1938, p. 153) estimated Gifford Springs discharged 25 to 35 ft^3/s prior to irrigation of the Aberdeen-Springfield tract in about 1900. Backwater from normal water levels in Lake Walcott has prevented further discharge measurements of these and several other springs. Discharges of Rueger and Mary Franklin Mine Springs increased about 70 and 55 percent, respectively, after storage in American Falls Reservoir began in 1926. The average of eight discharge measurements of Rueger Springs in 1925-26 was 11.8 ft^3/s, and the average of three discharge measurements in 1928 was 19.9 ft^3/s (Stearns and others, 1938, p. 151). The average of 25 discharge determinations of Mary Franklin Mine Springs in 1925-26 was 5.8 ft^3/s, and the average of 12 determinations in 1928 was 9.0 ft^3/s (Stearns and others, 1938, p. 153). Mundorff (1967, p. 40) estimated that spring discharge and

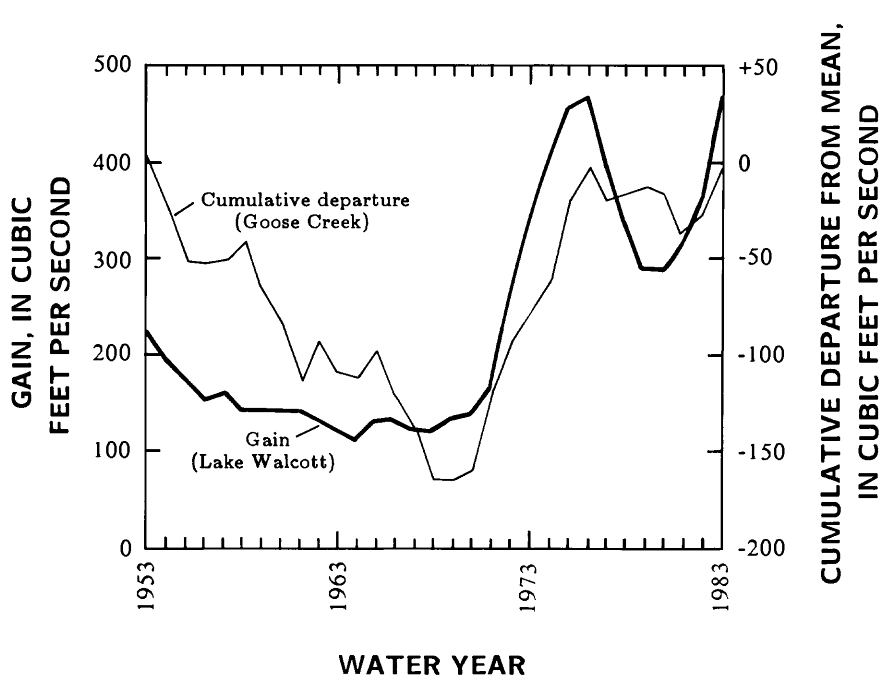

Figure 17.--Comparison between 5-year moving average gain to Lake Walcott and cumulative departures from mean discharges of Goose Creek near Oakley, 1953-83.

seepage to the Snake River were 80 to 100 ft^3/s before construction of American Falls Dam and that the average discharge increased 15 to 20 ft^3/s after construction. For the Neeley gaging station, 30 ft^3/s are added to each discharge measurement to make them compatible with historical measurements made at an older site below the springs. Therefore, actual net spring discharge to the reach is about 65 to 90 ft^3/s (95 to 120 ft^3/s minus 30 ft^3/s).

Inflow between Neeley and Minidoka gages from the south side of the river is largely from Rock Creek basin (fig. 13). Williams and Young (1982, p. 20) estimated the average surface-water flow from Rock Creek to the Snake River was 16,500 acre-ft/yr, or 23 ft^3/s. They also estimated that 51,000 acre-ft/yr, or 70 ft^3/s, moves as underflow from the basin to the Snake River (p. 38). Rock Creek near American Falls discharged 85 percent of its annual flow from November to April in water years 1979 and 1980. Mean discharges for these 2 years are 27.4 and 39.8 ft^3/s. Maximum daily mean discharges are 1,760 ft^3/s for the November through March period and 173 ft^3/s for the April through October period. Mean discharges are 126 ft^3/s for November through March and 13 ft^3/s for April through October. Streamflow in other tributaries, including tributaries to the lower part of the Raft River, generally exhibits seasonal trends similar to trends for Rock Creek, and little or no flow enters the Snake River in the summer. Yield from Warm Creek, Falls Creek, and other tributaries (a total drainage area of about 60 mi^2) is estimated to be equal to the rate of yield from Rock Creek basin, or 0.29 $(ft^3/s)/mi$. Discharge from the upper Raft River basin is high April through June, but part of this discharge does not reach the Snake River because of diversions and seepage. The average annual surface-water flow reaching the Snake River is about 10 ft^3/s. Ground-water outflow from the Raft River basin averages 80,000 acre-ft/yr, or 110 ft^3/s (Walker and others, 1970, p. 112). Nace (1961, p. 103) indicated that at least some of the ground water does not discharge to the Snake River but passes beneath it. Water-table contour maps for the area indicate that most of the ground-water movement is westward. As a result of pumpage for irrigation, water-level declines in the Raft River basin from 1971 to 1982 (Young and Norvitch, 1984, p. 11) have reduced the hydraulic gradient, and ground-water underflow to the Snake River from the Raft River basin is probably much less at present than the 80,000 acre-ft estimated by Walker and others (1970).

Table 6 lists sources of inflow to Lake Walcott and their likely contributions. The north-side springs and seeps are assumed to be at the high end of the estimated range in discharge. The sum of north-side spring discharge and south-side surface- and ground-water inflow is equal to

Table 6.--Inflow to Lake Walcott, 1951-83

Sources of inflow	Average annual discharge (cubic feet per second)
North-side springs and seepage	90
Rock Creek basin:	
Surface water	23
Ground water	70
Water yield from small tributary basins	42
Raft River basin:	
Surface water	10
Ground water (residual)	10
Total (set equal to average gain)	245

the gain determined by water-budget analysis (245 ft^3/s) when ground-water inflow from the Raft River basin is 10 ft^3/s. Because part of the ground-water outflow from the Raft River basin is to the west and to the north under the Snake River, additional inflow is likely to be small and, consequently, leakage from the reservoir would be small. Stearns and others (1938, p. 197) reported that seepage losses from Lake Walcott in the first 52 months of its existence were about 1.4 million acre-ft, or an average flow of 450 ft^3/s. Stearns also reported that, in the following 52 months, the losses averaged 140 ft^3/s. Present losses appear to be much less than 140 ft^3/s. The decrease in losses can be attributed to sediment sealing the bottom of Lake Walcott.

Discharge-measurement errors of a few percent can influence whether water-budget calculations show a gain or loss in the Neeley to Minidoka reach. Five percent of the average flow of the Snake River at Neeley (7,256 ft^3/s) is 360 ft^3/s compared to the average gain of 245 ft^3/s. To obtain a more accurate estimate of gains to the reach, monthly mean discharge data from 33 months during the period 1935-82 when combined inflow and outflow averaged less than 2,000 ft^3/s were used in water budgets to determine gain. The 33 months selected were all in the nonirrigation season from November to March. The combined inflow and outflow of less than 2,000 ft^3/s was selected because residuals would be a larger percentage of the total. Mean gain to Lake Walcott for the 33 months was 203 ft^3/s; the standard deviation was 92 ft^3/s (fig. 18). Although only the period November to March was included in the analysis, the mean gain also should be representative of that from April to October because high tributary flows in April and May would be balanced by low flows in July, August, and September.

For the data examined, the smallest gain was 51 ft^3/s in November 1961, and the largest gain was 511 ft^3/s in January 1980. This large gain was verified by the monthly mean discharge for Rock Creek near American Falls, which was 153 ft^3/s.

Leakage from Lake Walcott would average 40 to 50 ft^3/s if 203 ft^3/s is assumed to be the average gain. This amount of leakage seems reasonable, given the leakages that occurred in the first several years of storage.

Improvements in the water-budget analysis could be made by additional data collection. Ground-water discharge could be quantified by measuring discharge in the Snake River when reservoir stage and river discharge were low. Miscellaneous discharge measurements from other sources of surface-water runoff could be correlated with the discharge record of Rock Creek.

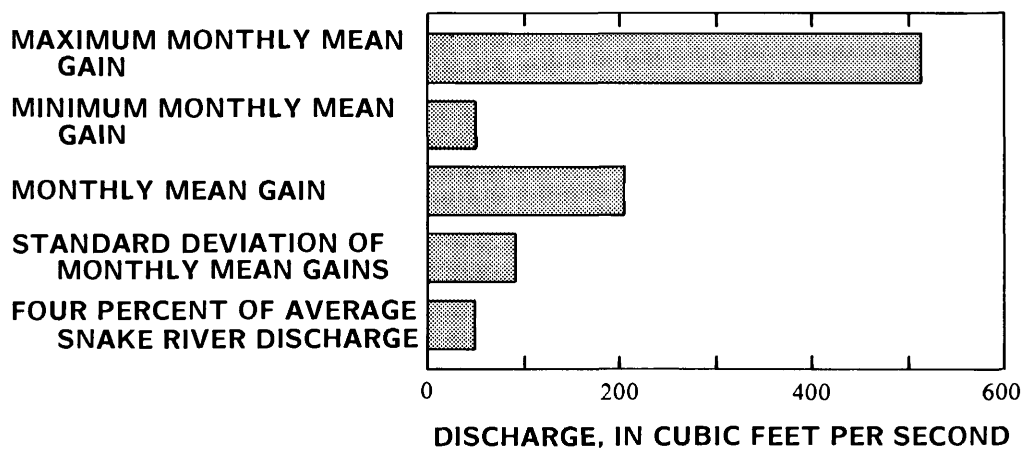

Figure 18.--Statistical summary of gains to Lake Walcott during low flow in the Snake River, 1935-82.

Milner Lake

Milner Dam, completed in 1905, was one of the first dams on the Snake River. Most diversion works and canals were completed by 1910. Water is diverted from headgates at the dam and is pumped from Milner Lake to irrigate downstream land on both sides of the Snake River. Above the dam, most of Milner Lake is confined in a narrow, 34.5-mi long canyon. Because of the long canyon, reservoir elevation varies throughout the reach. Consequently, a step-backwater analysis was used to develop a reservoir-capacity table.

Water budgets were calculated for the reach of the Snake River from Minidoka to Milner (fig. 19) by assuming ungaged inflow to be the difference between inflow and outflow and adjusting for the change in reservoir storage. Inflow is discharge of the Snake River near Minidoka; outflow is discharge of the Snake River near Milner plus several diversions. During parts of August and September 1983, most of the Snake River discharge was diverted (fig. 20). In some years, leakage from the dam constitutes the only flow past the gaging station near Milner during parts of August and September.

Neither precipitation on nor evaporation from Milner Lake are included in the water budget because of the narrowness of the reach and its relatively small surface area. Instead, gains from precipitation and losses from evaporation are included as part of the net gain or loss in the reach.

Gain and Loss Analysis

Gains and losses in the reach are small relative to the amount of water flowing through the Milner Lake reach, so that discharge-measurement errors of a few percent are likely to be larger than the actual gain or loss much of the time. However, discharge-measurement errors may balance out when averages are computed for longer time periods. Mean monthly gains and losses in Milner Lake for water years 1975-83 were determined from water budgets (contents in Milner Lake have been determined only since 1975). Results indicate that highest gains were in September and October (more than 400 ft^3/s) and that losses of about 100 ft^3/s may have occurred in May (fig. 21).

Standard deviations are generally near ± 4 percent of the monthly mean discharge of the Snake River near Minidoka (fig. 22) and probably represent discharge-measurement errors rather than actual variations in gain or loss.

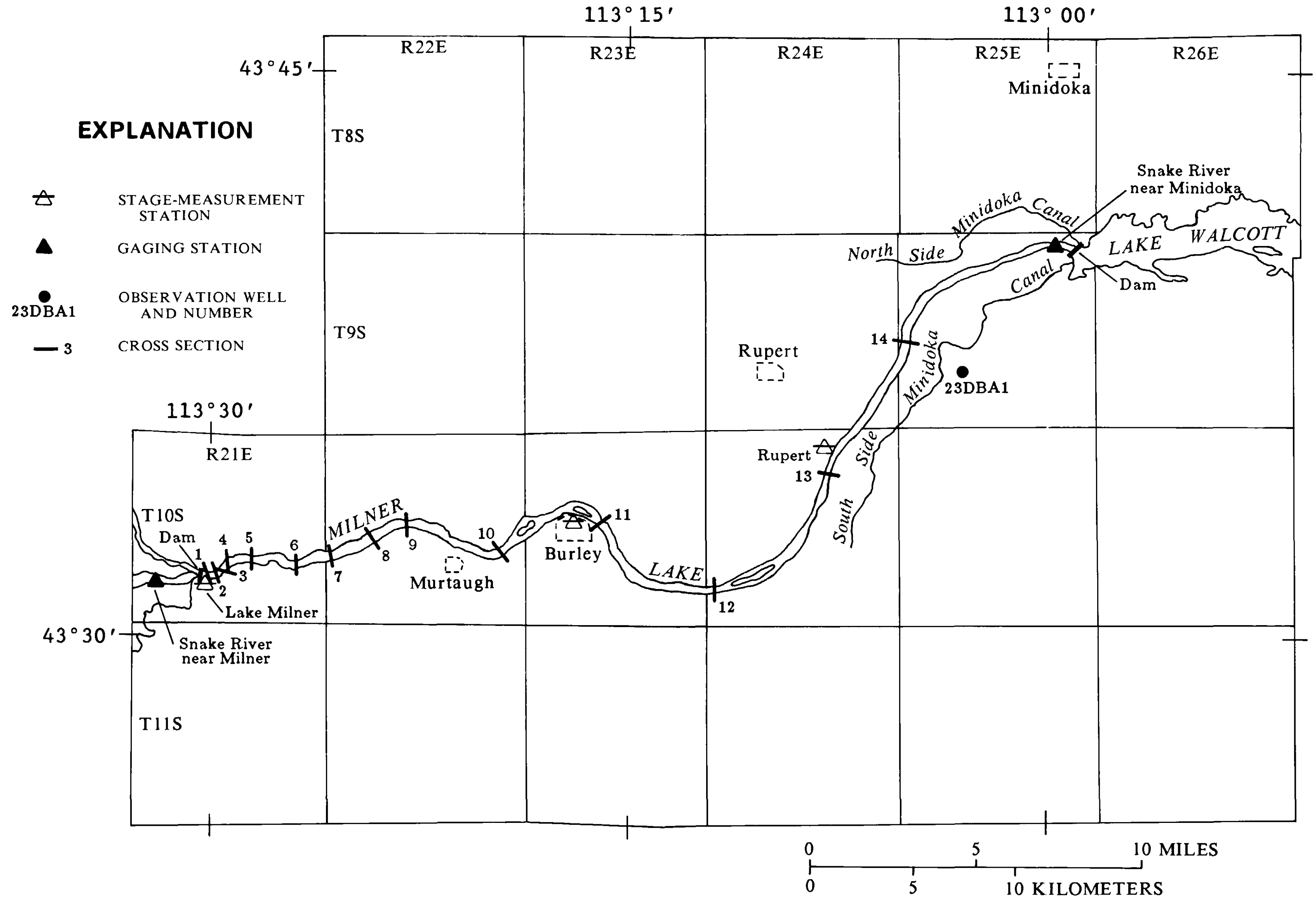

Figure 19.--Milner Lake reach of the Snake River.

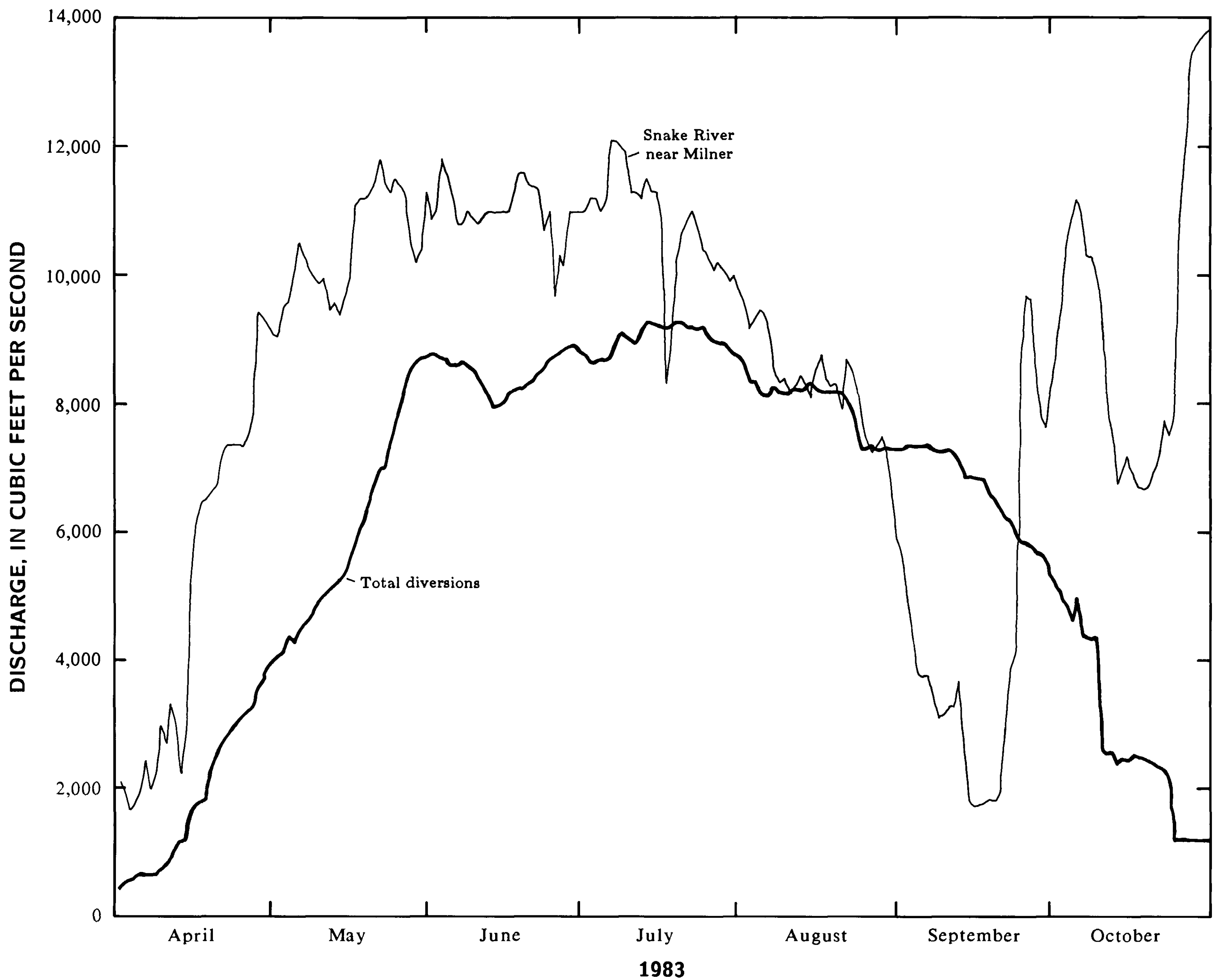

Figure 20.--Outflow from Milner Lake.

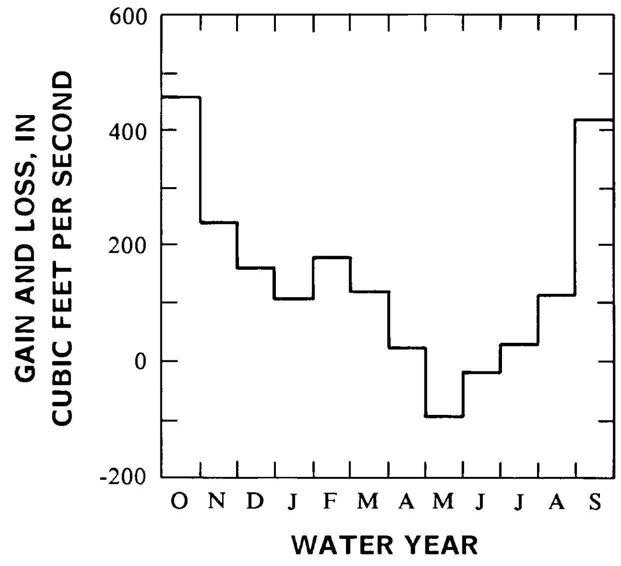

Figure 21.--Mean monthly gains and losses in Milner Lake reach, 1975-83.

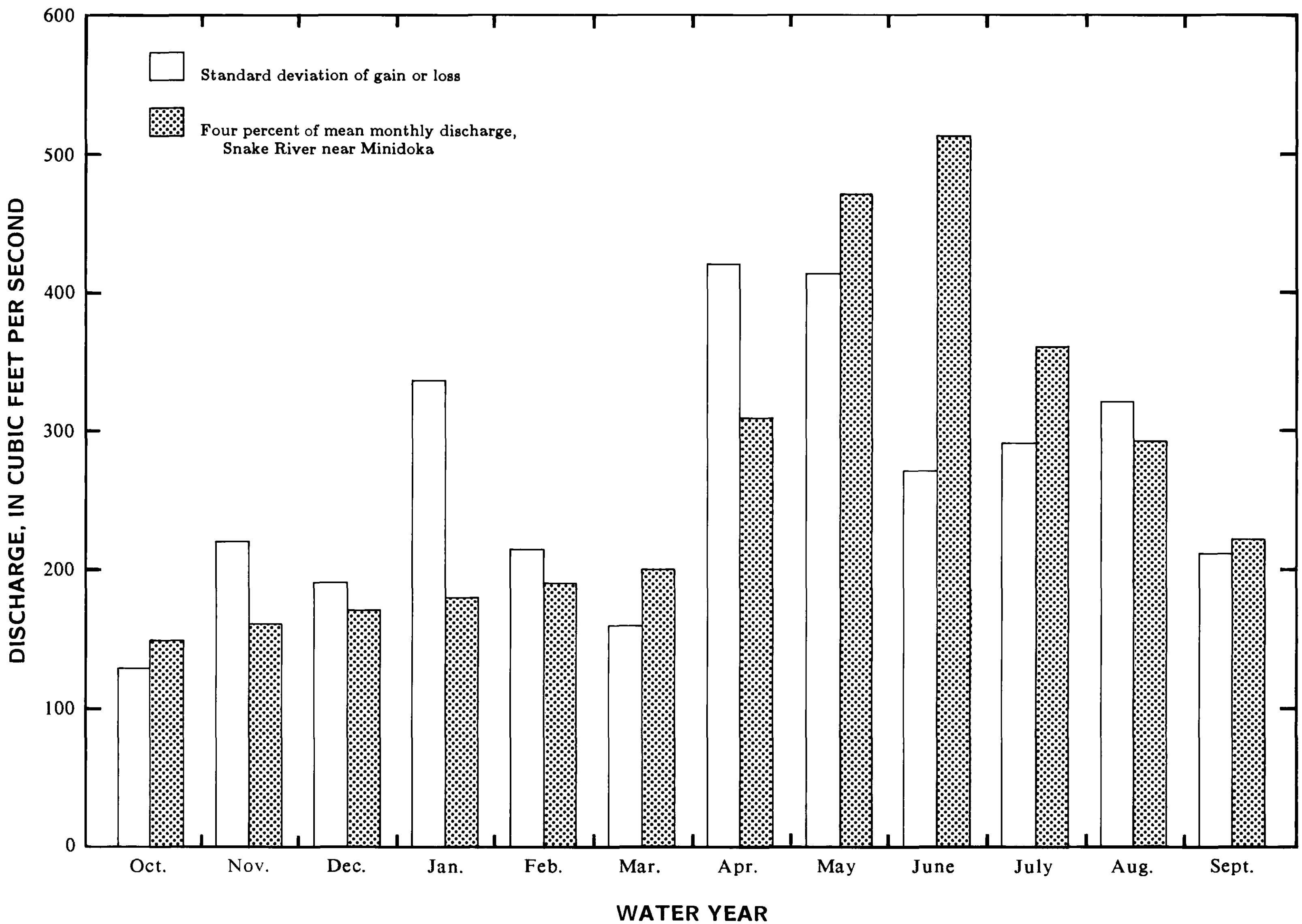

Figure 22.--Standard deviations of gains or losses in Milner Lake and possible discharge-measurement errors in mean monthly discharge, 1975-83.

Total surface-water inflow to the Snake River between Minidoka and Milner was measured seven times between March 1980 and March 1981 (table 7).

Most gains are from irrigation-return flow, but snowmelt and rainstorm runoff can produce flows of several hundred cubic feet per second for short periods. Measured surface-water inflow during the 1980 irrigation season was greater than the average gain from 1975 to 1983. Average gain or loss computed from a few years of data could be highly inaccurate as an estimate of short-term values.

Although surface-water inflow provides most of the gain from Minidoka to Milner, water levels in well 9S-25E-23DBA1, south of the Snake River at the upper end of Milner Lake, indicate that the hydraulic gradient is toward Milner Lake. Seepage from ground water then would contribute to gains in the reach, at least when ground-water levels are highest near the end of the irrigation season (fig. 23). Most of the time, however, ground-water levels on both the north and south sides of the Snake River are at a lower elevation than the lake level, and there may be some net losses to ground water.

The average annual gain in Milner Lake from 1951 to 1983 was 290 ft^3/s. Figure 24 shows the 5-year moving average of annual mean gain in Milner Lake and water levels in well 9S-25E-23DBA1. Since 1976, gain in the reach has declined. This may be due to about a 10-percent decrease in diversions from the Snake River since 1975 and the use of sprinkler irrigation systems, which are generally more efficient than flood irrigation. Water levels in well 9S-25E-23DBA1 also have declined, which would be anticipated with reduced gains in Milner Lake.

Monthly mean water-budget gains or losses were determined for 14 months from 1977 to 1982 (fig. 25) when discharge in the Snake River was low. Four percent of the monthly mean discharge in the Snake River near Minidoka is shown as a reliability indicator; however, water-budget errors could be greater. Standard deviation of daily gain or loss is another reliability indicator. It is apparent that even for low flows, daily gains and losses determined by water budgets are highly inaccurate. From the seemingly more reliable months, average gain during the nonirrigation season probably would range from 100 to 200 ft^3/s. The large gain for February 1982 may be attributed to peak discharges at gaging stations on Raft River, Goose Creek, and Rock Creek on February 16.

Table 7.--Surface-water inflow to the Snake River between Minidoka and Milner

Date	Surface-water inflow (cubic feet per second)
3-26-80	20
5-22-80	235
7-22-80	268
9-16-80	563
11- 5-80	75
1-22-81	6
3-10-81	14

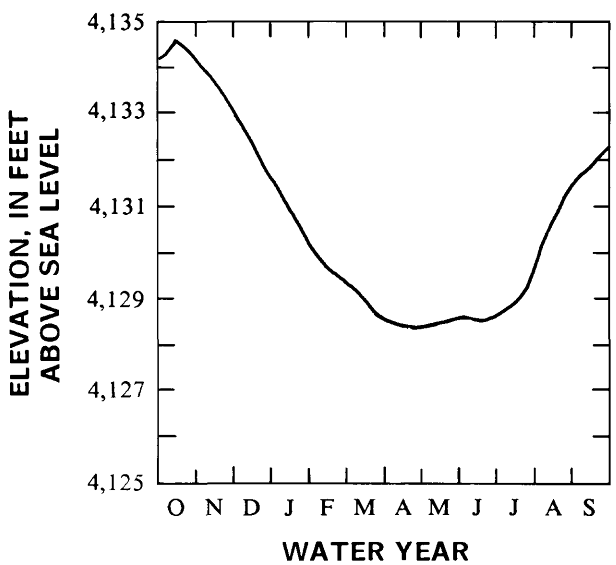

Figure 23.--Water levels in well 9S-25E-23DBA1, water year 1983.

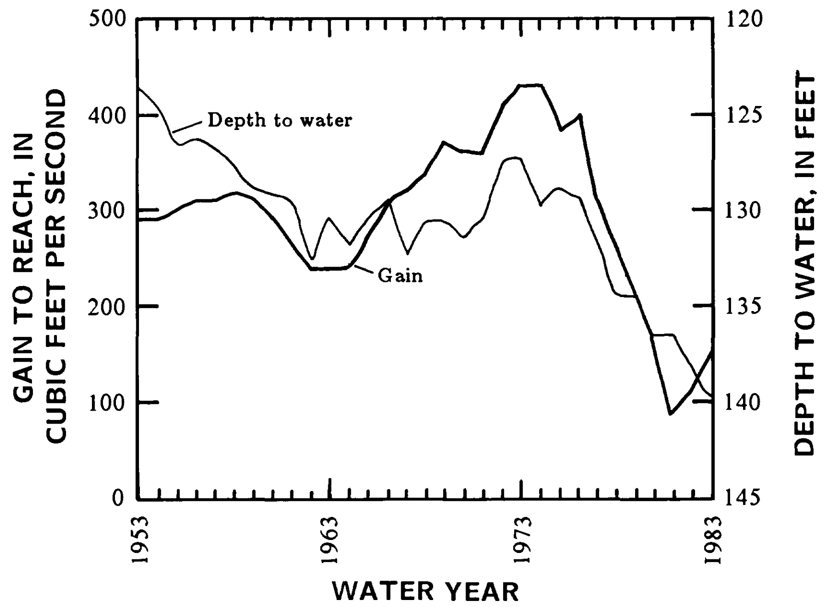

Figure 24.--Five-year moving average of annual mean gain in Milner Lake and water levels in well 9S-25E-23DBA1.

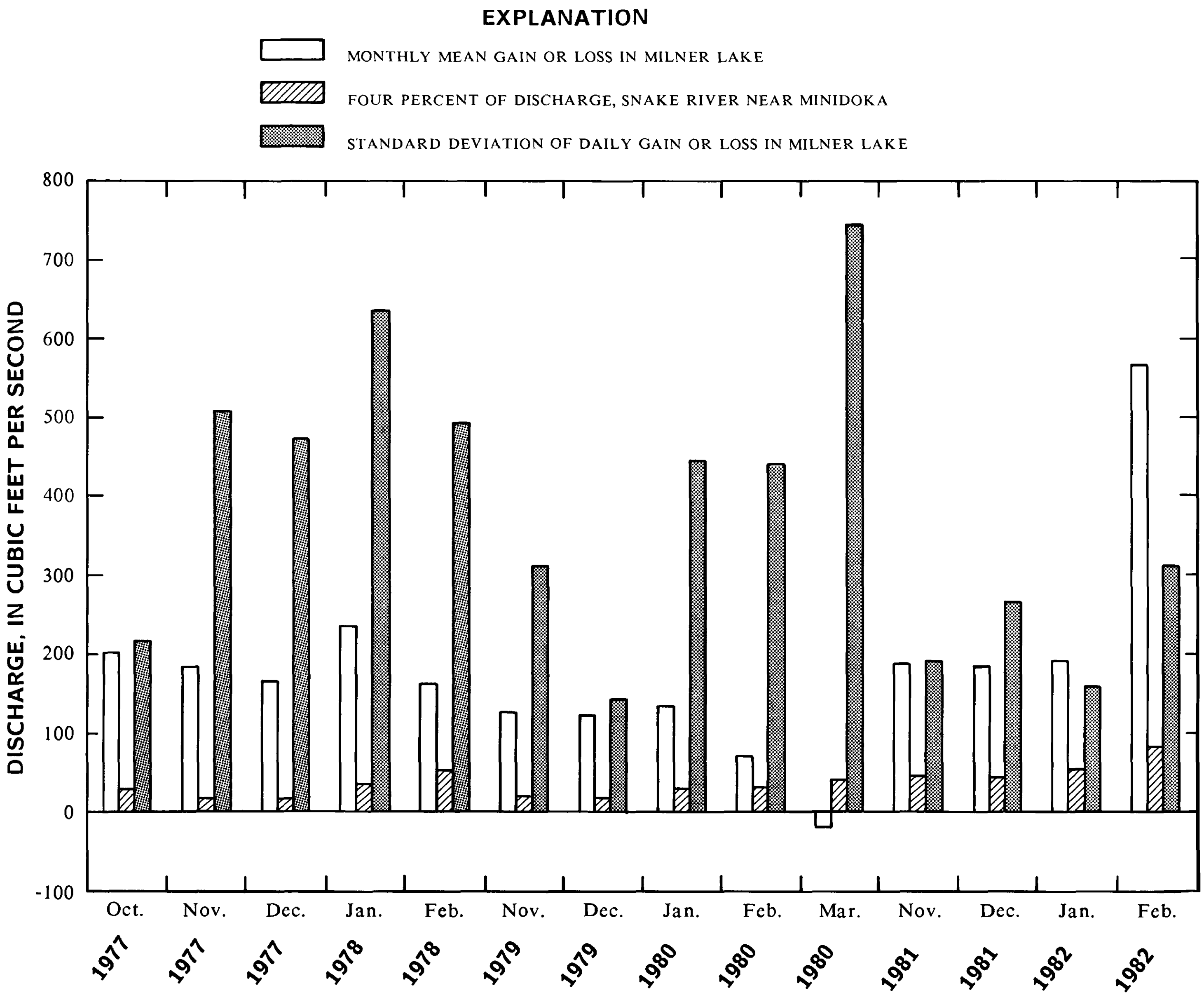

Figure 25.--Monthly mean gain or loss in Milner Lake for selected months, 1977-82.

Reservoir Storage

In 1974, a storage-capacity table was developed for Milner Lake that considered both stage at the dam and discharge at the upper end of the reach near Minidoka. However, discrepancies in water-budget calculations during this study made it apparent that a better definition of the backwater curve and cross-sectional area of canyon was required. Data obtained during 1983 and 1984 better defined the capacity table for Milner Lake. Additional reservoir stage measurements were obtained at Burley and near Rupert (fig. 19). Data for 14 cross sections in Milner Lake and 1 cross section at the measurement site near Minidoka (fig. 19), reservoir stage at the dam and near Rupert and Burley, and discharge of the Snake River near Minidoka were used to redefine backwater curves for a range of reservoir stages and discharges. The U.S. Geological Survey step-backwater computer program, E 341 (Shearman, 1976), was used to determine water-surface elevation at each of the 15 cross sections. Water-surface elevations for the Burley and Rupert gaging sites were compared with interpolated elevations from the computed backwater curve elevations at cross sections 11-12 and 13-14, respectively (fig. 19).

To obtain a proper fit of the backwater curve, roughness coefficients ("n" values) were adjusted until water-surface elevations were within a few hundredths of a foot of the recorded stages at Burley, near Rupert, and near Minidoka. Roughness coefficients normally vary inversely with discharge and, in the upper subreaches, n values ranged from 0.029 to 0.023 in the main channel at discharges from 6,000 to 16,000 ft^3/s. In the lower subreaches, n values ranged from 0.016 to 0.020 at these same discharges. The low n values are attributed to water flowing through the reservoir, where boundary friction is reduced.

Water-surface profiles in Milner Lake for a constant reservoir elevation of 4,134 ft at Milner and two discharges are shown in figure 26. Profiles for a constant inflow of 9,000 ft^3/s and two reservoir elevations at Milner are shown in figure 27.

The new storage-capacity table for Milner Lake developed from corresponding surface areas and profiles is given in table 8. Backwater curves were determined and capacities were computed for each 1,000 ft^3/s of discharge of the Snake River near Minidoka (below 1,000 ft^3/s, 100 ft^3/s increments were used) and each 1-ft change in stage of Milner Lake at the dam. For all other combinations of discharge and stage, storage can be interpolated between values given in the table.

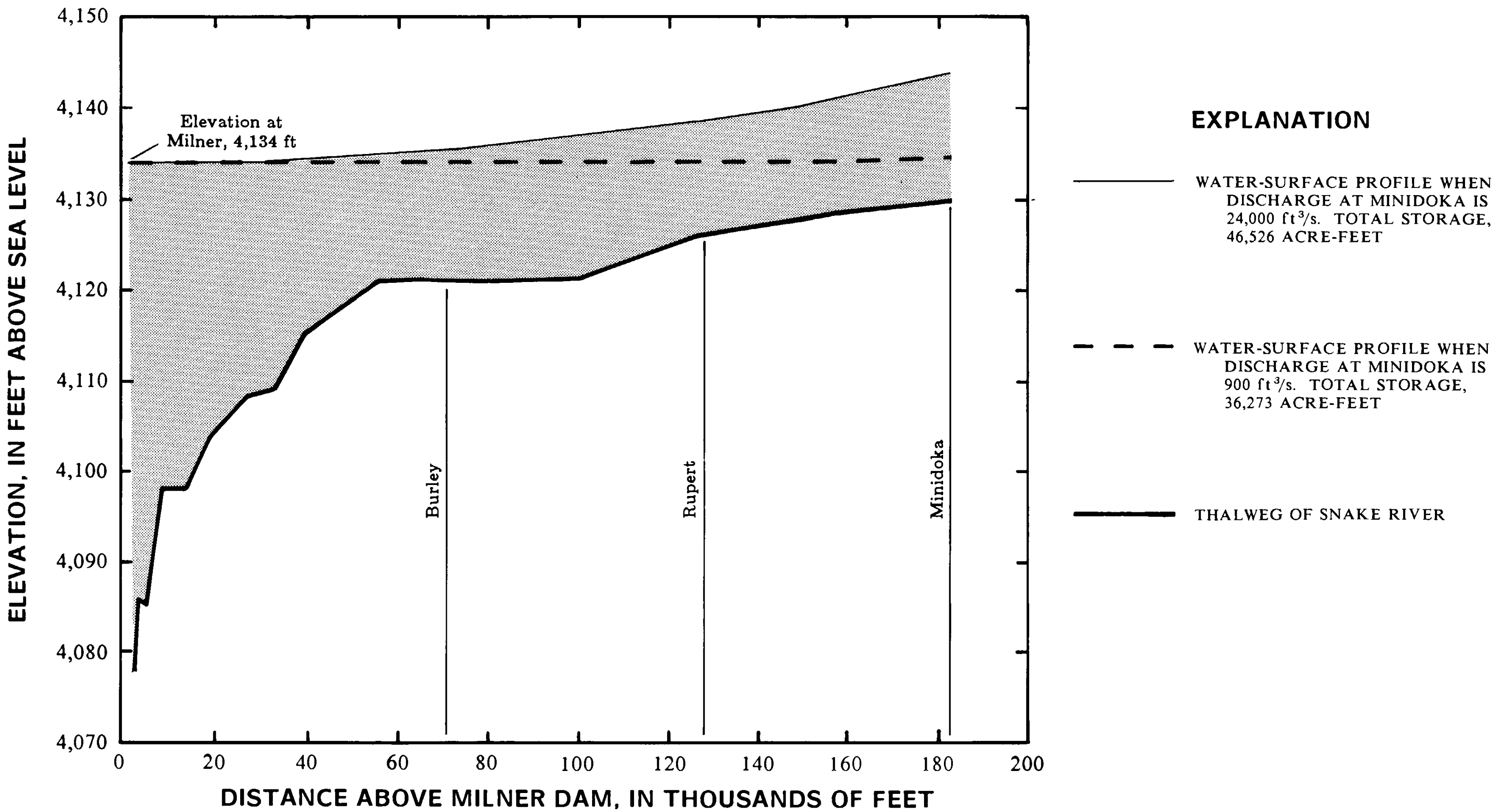

Figure 26.--Water-surface profiles in Milner Lake for a constant reservoir elevation at Milner and two discharges.

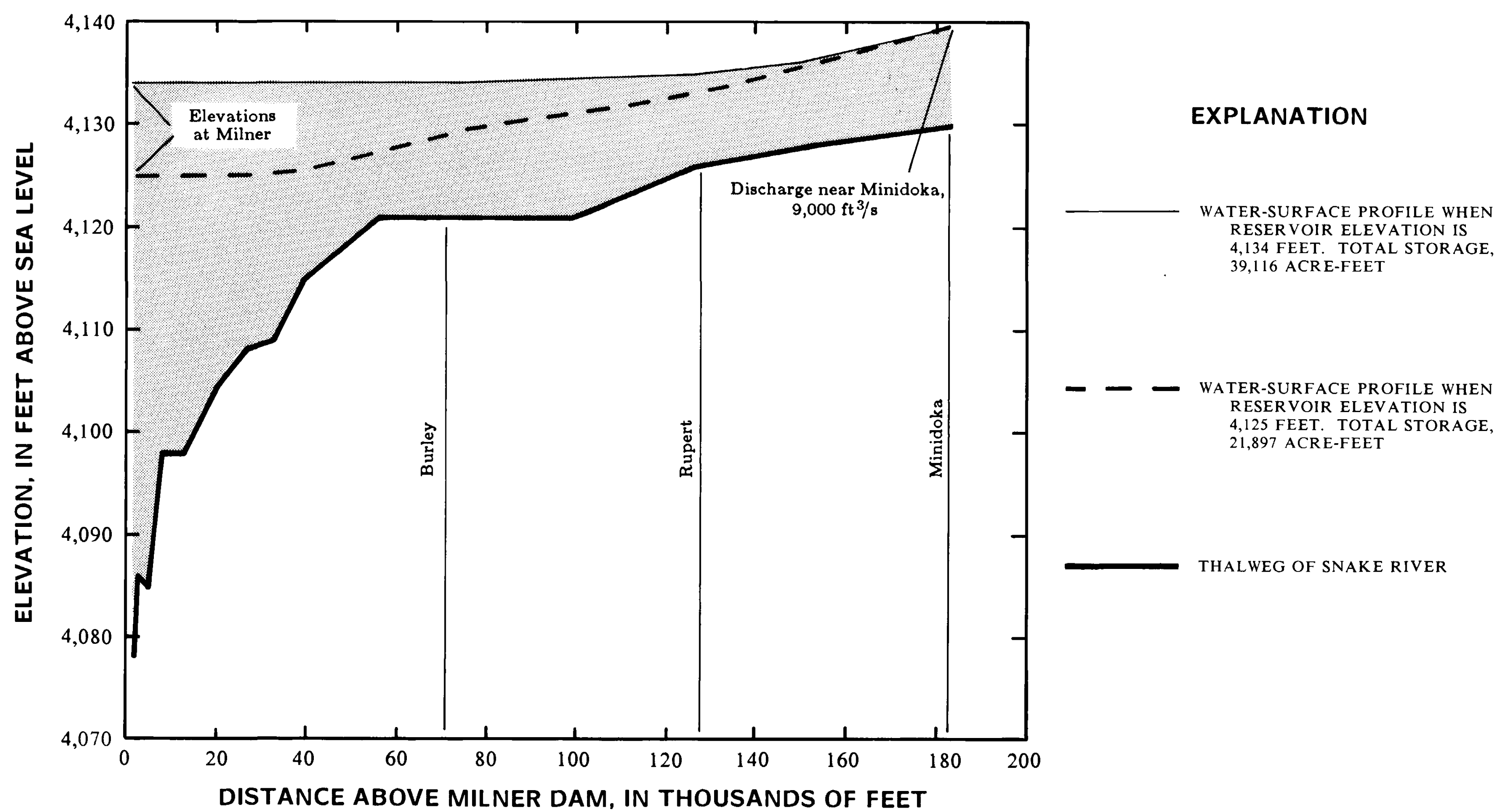

Figure 27.--Water-surface profiles in Milner Lake for a constant inflow and two reservoir elevations at Milner.

Table 8.--Storage capacity table for Milner Lake
[Storage capacity in acre-feet]

Discharge of Snake River near Minidoka (cubic feet per second)	Gage height of Milner Lake at the dam (datum 4,122.5 feet above sea level)										
	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5
500	11,222	12,921	14,380	15,995	17,873	20,102	22,706	25,636	28,861	32,392	36,130
600	11,444	13,140	14,577	16,195	18,063	20,276	22,837	25,739	38,949	32,443	36,161
700	11,660	13,358	14,789	16,383	18,266	20,436	22,967	25,841	29,205	32,494	36,169
800	11,882	13,571	14,981	16,563	18,444	20,590	23,110	25,942	29,103	32,567	36,234
900	12,091	13,781	15,178	16,758	18,603	10,757	23,238	26,041	29,181	32,626	36,273
1,000	12,297	13,989	15,359	16,935	18,763	20,903	23,363	26,165	29,260	32,694	36,312
2,000	14,081	25,608	16,831	18,282	20,046	22,094	24,441	27,061	30,036	33,168	36,778
3,000	15,635	16,370	17,523	18,961	20,640	22,631	24,928	27,511	30,379	33,589	37,004
4,000	17,032	17,264	18,373	19,735	21,349	23,259	25,496	28,015	30,852	33,930	37,316
5,000	17,644	18,320	19,320	20,679	22,182	24,048	26,201	28,621	31,394	34,431	37,671
6,000	17,833	18,463	19,489	20,845	22,338	24,196	26,344	28,758	31,517	34,543	37,764
7,000	18,490	19,350	20,356	21,652	23,104	24,873	26,956	29,306	32,107	34,975	38,154
8,000	20,037	20,841	21,957	23,076	24,440	26,091	28,004	30,289	32,885	35,673	38,739
9,000	20,975	21,897	22,794	23,883	25,205	26,822	28,726	30,924	323,447	36,110	39,116
10,000	22,721	23,456	24,335	20,353	26,604	28,140	29,963	32,069	34,348	36,985	39,870
11,000	23,669	24,400	25,249	26,232	27,461	28,902	30,640	32,651	34,983	37,510	40,341
12,000	24,590	25,752	26,576	27,530	28,673	29,281	30,997	33,007	35,299	37,798	40,827
13,000	24,853	26,098	26,910	27,858	28,992	29,970	31,666	33,630	35,872	38,435	41,001
14,000	25,667	26,434	27,235	28,185	29,303	30,688	32,326	34,250	36,413	38,909	41,491
15,000	26,449	27,700	28,483	29,391	30,479	31,098	32,967	34,845	37,001	39,418	42,275
16,000	27,204	27,932	28,722	29,634	30,697	32,023	33,613	36,011	37,564	39,935	42,754
17,000	27,552	29,242	29,988	30,864	31,916	32,696	34,238	36,036	38,106	40,431	43,226
18,000	28,680	29,402	30,160	31,042	32,080	33,374	34,854	36,626	38,669	40,933	43,714
19,000	29,409	30,040	30,774	31,633	32,649	33m983	35,463	37,190	39,185	41,426	44,177
20,000	30,103	30,748	31,467	32,318	33,309	34,604	36,061	37,762	39,735	41,921	44,651
21,000	31,843	32,035	32,723	33,546	34,522	35,710	37,107	38,738	40,632	42,760	45,129
22,000	32,093	32,712	33,405	34,211	35,157	36,333	37,730	39,320	41,164	43,273	45,589
23,000	32,777	33,380	34,062	34,857	35,794	36,943	38,311	39,885	41,741	43,779	46,063
24,000	33,441	34,717	35,372	36,110	37,046	37,567	38,880	40,465	42,264	44,308	46,526
25,000	34,790	35,370	36,010	36,775	37,667	38,767	40,072	42,557	43,333	45,252	46,732
26,000	35,448	36,014	36,657	37,407	38,307	39,386	40,658	42,149	43,856	46,077	48,196
27,000	36,120	36,645	37,285	38,043	38,928	39,997	41,245	42,715	44,390	46,579	48,684
28,000	36,724	37,268	37,915	38,640	39,541	40,594	41,799	43,248	45,285	47,112	49,177
29,000	37,340	37,881	38,509	39,259	40,142	41,167	42,423	44,152	45,797	47,627	49,675
30,000	37,963	38,897	39,491	40,252	41,100	42,137	43,351	44,726	46,300	48,197	50,155

SUMMARY

Agriculture is the most important industry on the Snake River Plain and, because of a semiarid climate, its success relies on irrigation. Determinations of gains and losses for American Falls Reservoir, Lake Walcott, and Milner Lake on the Snake River are necessary to allocate water for irrigation on the basis of established water rights. Gains and losses estimated from daily water budgets are variable, owing to inadequate determination of (1) changes in reservoir storage, (2) streamflow, (3) lake-surface precipitation, and (4) lake-surface evaporation.

The combined discharge of the Snake River near Blackfoot and the Portneuf River at Pocatello accounts for about 65 percent of the inflow to American Falls Reservoir. The remainder is spring discharge, ground-water seepage, small-tributary streamflow, irrigation-return flow, and precipitation on the reservoir. Precipitation, which is estimated from nearby recording stations, contributes about 0.5 percent of the average inflow. Outflow is measured in the Snake River at Neeley and at two diversions. Evaporation from the reservoir is estimated from pan data. Neither precipitation nor evaporation can be estimated with much reliability, but both can have a significant effect on a daily water budget. Average annual ungaged inflow to American Falls Reservoir from spring discharge, ground-water seepage, small tributaries, and irrigation-return flow from 1912 to 1983 was 2,690 ft^3/s. About 94 percent of the ungaged inflow, or 2,540 ft^3/s, is the average ground-water discharge (springs and seepage). Seasonal fluctuations of ungaged inflow seem to have increased after storage in American Falls Reservoir began in 1926. Bank storage in the reservoir and increased seasonal fluctuations in ground-water levels as a result of irrigation are probable causes.

Ungaged inflow to American Falls Reservoir generally can be estimated more accurately by correlation with ground-water levels in wells or measured spring discharge than by water budgets based on discharge measurements alone. However, analysis indicates that the discharge of Spring Creek, the largest ungaged tributary to the reservoir, is a better indicator of ungaged inflow than ground-water levels. Most of the flow in Spring Creek, like most of the ungaged inflow, comes from springs. However, flow in Spring Creek also includes occasional runoff from precipitation that is not readily represented by water levels in wells.

Leakage from American Falls Reservoir is small, as indicated by water levels in wells downstream from the reservoir and water budgets for the Snake River between

Neeley and Minidoka. Although water levels in wells at the southwestern end of American Falls Reservoir and along Lake Channel increase from February to May when stage in the reservoir increases, it cannot be shown that the changes are due to reservoir leakage. Declines in water levels in wells from May to September probably are accelerated by ground-water pumping for irrigation. The continued high reservoir stage during this period seems to have no effect on these declines.

Spring discharge to the Snake River between Neeley and Minidoka increased by about 25 percent, or about 15 to 20 ft^3/s, after storage began in American Falls Reservoir in 1926. Water budgets generally were balanced when 65 to 90 ft^3/s of spring discharge was assumed. Verification of spring discharge could be made by measuring the Snake River below the springs when stage in Lake Walcott is low and river flow is low.

Annual gains to Lake Walcott from 1951 to 1983, determined using annual water budgets, averaged 245 ft^3/s. The tendency for higher gains in the latter part of the 1951-83 period appears to be associated with high runoff from tributaries. An average of 203 ft^3/s was determined by a water-budget analysis of 33 months when Snake River discharge was low and normal discharge-measurement errors would not have significant effect. The total of estimates of discharge from springs and seeps along the north side of the Snake River and upper Lake Walcott and streamflow and underflow from tributary drainage basins south of the River and lake is nearly equal to the 1951-83 average. However, leakage from the lower part of the reservoir would be about 40 to 50 ft^3/s using the 33-month average gain of 203 ft^3/s.

Water budgets are not reliable for estimating gains and losses in Milner Lake because discharge-measurement errors are likely to be larger than the gains and losses. Annual gains in Milner Lake from 1951 to 1983, determined using water-budget analysis, averaged 290 ft^3/s. Gains to Milner Lake are mostly from irrigation-return flow and are highest in September and October. The declines in gains since 1976 may be due to decreased diversions and increased use of sprinkler-irrigation systems.

Milner Lake generally is confined to the narrow Snake River canyon, and water levels along the reservoir vary because of backwater. The backwater curve has been defined for combinations of stage at the dam and discharge of the Snake River near Minidoka. A step-backwater computer program was used to determine water-surface elevations at 15 cross sections. Roughness coefficients were adjusted until surface-water elevations of the backwater curve matched recorded elevations at Burley, near Rupert, and near Minidoka. This information was used to prepare a table of storage for various combinations of inflow discharge and gage height at the dam.

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